Groundwater modelling study for sustainable water management in Town of High River

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Outline

- Site Location
- Objectives
- Hydrogeological Conceptual Model
- Data Sources
- Groundwater Model Structure
- Hydraulic Parameters/Boundary Conditions
- Model Calibration (steady-state and transient)
- Scenario Simulations
- Conclusions
Site Location

LEGEND
- Montrose Stormwater Pond
- Town of High River
- Town Wells
Objectives

- Support a sustainable water management plan for the Town;
- Determine sustainable yield of the well field in the aquifers underlying and abutting the Town;
- Assessment of surface water/groundwater interactions from current and (proposed future) wells;
- Quantitatively predict/estimate effects of pumping by different sectors, under different climatic scenarios;
- Identify additional data needs.
Data Sources

- 1,637 wells records selected from the well database (ESRD)
- Surficial and consolidated geological maps (AGS);
- Regional scale geological and hydrogeological studies (ARC);
- Hydrogeological investigation reports commissioned by the Town of High River;
- Base map (IHS Accumap 2011);
- Digital elevation model (CCG);
- Surface water monitoring (WSC); and
- Town well field operational data (Town of High River);
What is a hydrogeological conceptual model?
- Defines the structure of the system;
- Defines the hydraulic properties and flow mechanisms;
- Defines the water inputs and outputs;
Hydrogeological Conceptual Model
Limitations and Assumptions

- Model provides a simplified representation of the real system
- Hydraulic parameters were averaged over zones of relatively uniform characteristics
- Quick recovery rates in pumping wells consistent with fairly direct hydraulic communication with the river
Code Selection

- Three-Dimensional groundwater model
  - Simulate flow & yield in main aquifers
  - Predict effects of natural (climatic change) & artificial (pumping) stresses

- **FEFLOW® 6.0**
  - Finite element flow and transport code (WASY, Gmbh)
  - Flexibility in gridding
  - Groundwater density, and coupled solute transport and heat
Model Structure

- Model construction
  - Model domain 840 km²;
  - Six layer model;
  - Element size (horizontal) 30 m² to 0.1 km²; and,
  - Denser finite element mesh near town.

<table>
<thead>
<tr>
<th>Lithological Unit</th>
<th>Aquifer/Aquitard</th>
<th>Model Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surficial Deposit</td>
<td>Aquitard</td>
<td>1</td>
</tr>
<tr>
<td>Sand and Gravel</td>
<td>Aquifer</td>
<td>2 and 3</td>
</tr>
<tr>
<td>Confining Unit 1</td>
<td>Aquitard</td>
<td>4</td>
</tr>
<tr>
<td>Confining Unit 2</td>
<td>Aquitard</td>
<td>5</td>
</tr>
<tr>
<td>Interbedded Sandstone</td>
<td>Aquifer</td>
<td>6</td>
</tr>
</tbody>
</table>

Town of High River
Hydraulic Conductivity Distribution

- Sand and Gravel Aquifer
Boundary Conditions

- Sand and Gravel Aquifer

**Legend:**
- Lakes and Rivers
- Numerical Model Boundary
- Urban Boundaries
  - Dirichlet (Type 1) Boundary
  - Cauchy (Type 3) Boundary
Model Calibration

- **Steady State Calibration**
  - 39 groundwater levels in the sand and gravel aquifer, and 94 groundwater levels in the sandstone aquifer
  - For pre-pumping conditions, oldest data used as calibration targets
Model Calibration

- Steady State Calibration
  - Regional hydraulic head distribution in the **sand and gravel** unit
Model Calibration

- **Steady State Calibration**
  - Regional hydraulic head distribution in the **sandstone aquifer**
Transient Calibration

• Focus on representing aquifers’ response to pumping around Town
• Simulated vs. to observed responses in 12 town wells
Calibrated Hydraulic Parameters

- Hydraulic conductivity and recharge rate

<table>
<thead>
<tr>
<th>Lithological Unit</th>
<th>Horizontal hydraulic conductivity ([K_{xy}]) (m/s)</th>
<th>Vertical hydraulic conductivity ([K_z]) (m/s)</th>
<th>Recharge (mm/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surficial Deposit (above sand and gravel)</td>
<td>1.0x10^-6 to 1.5x10^-5</td>
<td>1.0x10^-7 to 2.0x10^-4</td>
<td>4 to 40</td>
</tr>
<tr>
<td>Surficial Deposit (clay and till)</td>
<td>1.0x10^-7</td>
<td>1.0x10^-8</td>
<td>less than 1</td>
</tr>
<tr>
<td>Sand and Gravel</td>
<td>1.0x10^-7 to 2.0x10^-3</td>
<td>5.0x10^-7 to 2.0x10^-3</td>
<td>-</td>
</tr>
<tr>
<td>Confining Unit 1</td>
<td>1.0x10^-9 to 1.0x10^-7</td>
<td>1.0x10^-10 to 1.0x10^-8</td>
<td>-</td>
</tr>
<tr>
<td>Confining Unit 2</td>
<td>1.0x10^-9 to 1.0x10^-7</td>
<td>1.0x10^-10 to 1.0x10^-8</td>
<td>-</td>
</tr>
<tr>
<td>Interbedded Sandstone</td>
<td>5.0x10^-6</td>
<td>5.0x10^-7</td>
<td>-</td>
</tr>
</tbody>
</table>

- Specific storage value of 1x10^-4 m^-1 and a effective porosity of 0.2 were assumed for the entire model domain.
Groundwater Drawdown

- 2009 / 2010 simulated groundwater drawdown in sand and gravel aquifer
  - Simulated using operational data
  - Groundwater drawdown is less than 3 m.
Contribution of Various Components

- Source of water withdrawn by Town wells
  - Simulated for 2010 using operational data.
Scenarios

- Simulation period from 2010 to 2040 (30 years)
- Scenarios with various pumping rates and number of wells
  - 12 well scenarios - Scenario 1 (4.9 Mm³/y)
    - Scenario 2 (7.2 Mm³/y)
  - 15 well scenarios - Scenario 3 (4.9 Mm³/y)
    - Scenario 4 (7.2 Mm³/y)
River Contribution on Pumping

- Predicted river contribution with increased withdrawals.

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4.6 Mm³/year</td>
<td>4.9 Mm³/year</td>
<td>7.2 Mm³/year</td>
<td>4.9 Mm³/year</td>
<td>7.2 Mm³/year</td>
</tr>
<tr>
<td>Withdrawal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% GW originating</td>
<td>70</td>
<td>84</td>
<td>84</td>
<td>78</td>
<td>82</td>
</tr>
<tr>
<td>from river</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of minimum</td>
<td>16</td>
<td>20</td>
<td>30</td>
<td>19</td>
<td>29</td>
</tr>
<tr>
<td>monthly river flow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Groundwater Drawdown (end of 2040)

12 well scenarios

Scenario 1

Scenario 2

**LEGEND:**
- Lakes and Rivers
- Urban Boundaries

150 Mm³

220 Mm³
Groundwater Drawdown (end of 2040)

- 15 well scenarios

**Scenario 3**
- 150 Mm$^3$

**Scenario 4**
- 220 Mm$^3$
Predictions – Climate Change

- **Shifts in Climate**

  Simulated climate change scenarios indicate relatively low impact on the groundwater system if river flow is still maintained.

<table>
<thead>
<tr>
<th></th>
<th>Upstream GW Inflow (m3/d)</th>
<th>Rivers and Lakes (m3/d)</th>
<th>Recharge (m3/d)</th>
<th>Pumping (m3/d)</th>
<th>Imbalance (m3/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steady Run (before pumping)</td>
<td>Inflow 8,887.6</td>
<td>45,933.2</td>
<td>2,081.7</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Outflow -4,311.1</td>
<td>-52,535.9</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Net flow 4,576.5</td>
<td>-6,602.6</td>
<td>2,081.7</td>
<td>0.0</td>
<td>55.5</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.8</td>
</tr>
<tr>
<td>Steady Run (Regional Wells)</td>
<td>Inflow 10,556.0</td>
<td>122,411.3</td>
<td>2,081.7</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Outflow -3,733.1</td>
<td>-30,479.2</td>
<td>0.0</td>
<td>-100,838.0</td>
<td>-1.3</td>
</tr>
<tr>
<td></td>
<td>Net flow 6,822.9</td>
<td>91,932.1</td>
<td>2,081.7</td>
<td>-100,838.0</td>
<td>-1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0</td>
</tr>
<tr>
<td>Transient Run (Climate Change)</td>
<td>Inflow 3,513.0</td>
<td>123,575.0</td>
<td>2,082.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Outflow -</td>
<td>-28,544.0</td>
<td>0.0</td>
<td>-100,799.0</td>
<td>-173.0</td>
</tr>
<tr>
<td></td>
<td>Net flow 3,513.0</td>
<td>95,031.0</td>
<td>2,082.0</td>
<td>-100,799.0</td>
<td>-173.0</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.2</td>
</tr>
</tbody>
</table>
Conclusions

- Current groundwater use has no major impact on the groundwater system.
- 70% of produced water originates from surface water.
- With continuous pumping for the next 30 years, river contribution over 80%.
- Flow from the river to the aquifer equals 30% of monthly minimum river flow when pumping rate of 7.2 Mm³/y was simulated.
- Climate change scenario has relatively low impact on the groundwater system.

*Assuming that river contribution to groundwater remains constant*