Three-Dimensional Groundwater Flow Modelling in the Quaternary Succession Near Cold Lake in East-Central Alberta

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Outline

1. Introduction
2. Geology and Hydrostratigraphy
3. Numerical Model Setup & Calibration
4. Some Modelling Results
5. Conclusions
1. Introduction

- Groundwater from the Quaternary succession is an important source of water for domestic and industrial use in the Cold Lake – Beaver River (CLBR) drainage basin.

- Growing demands on groundwater by expanding thermal in-situ heavy oil extraction projects in the basin, coupled with an extended period of drought, has increased the need for a regional groundwater numerical model to help assess groundwater flow and manage its use in the basin.
Digital Elevation Model w/ Lake Bathymetries

High 700m to 860masl

600m

Low 435masl

Cold Lake
Cold Lake Bathymetry

High 700m to 860masl

Marie Lake

Cold Lake

Low 435masl
2. Geology and Hydrostratigraphy
Bedrock Topography and Buried Valleys

- High 630m+
- 500m
- Low 390 masl
Cross-section of Quaternary Strata Superposed on 3-D model of Bedrock Surface
Conceptual Hydrogeological Model
‘Stair-stepped’, labyrinth connection of aquifers
3. Model Setup & Calibration
Setup of Modflow Grid

- True layer approach
- Finite differences
- ~ 185,000 active cells
Top Layer Boundary Conditions

+ River node

Constant-head node (Lakes)
3D Representation of Surface Topography and Stratigraphy
Computed Hydraulic Heads (vs. observations) in the Empress I
Steady-state Calibration

- Grand Centre
- Sand River
- Marie Creek
- Ethel Lake

Computed hydraulic heads (m)

Observed static water level (m)

\[ \pm 10 \, \text{m} \]

\[ \pm 20 \, \text{m} \]
Parameter Sensitivities w.r.t. Observations

Composite Scaled Sensitivity (-)

Parameters

Grand, Sand, Marie, Ethel, Bonny, Muriel, Emp3, Emp1
Transient Calibration
2 long-term pump tests (15 years)
4. Modelling Results
Computed Hydraulic Heads in the Grand Centre Fm.
## Water Balance

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recharge</td>
<td>232404</td>
</tr>
<tr>
<td>Recharge (mm/year)</td>
<td>7.1</td>
</tr>
<tr>
<td>Lakes (In)</td>
<td>30718</td>
</tr>
<tr>
<td>Lakes (Out)</td>
<td>-87143</td>
</tr>
<tr>
<td>Beaver River (+ Amisk)</td>
<td>-110983</td>
</tr>
<tr>
<td>Sand River</td>
<td>-13734</td>
</tr>
<tr>
<td>Kehiwin River</td>
<td>-18845</td>
</tr>
<tr>
<td>Other drainage</td>
<td>-29764</td>
</tr>
<tr>
<td>Intra-basin flow</td>
<td>-4061</td>
</tr>
<tr>
<td>Pumping</td>
<td>0</td>
</tr>
<tr>
<td>Total In</td>
<td>263122</td>
</tr>
<tr>
<td>Total Out</td>
<td>-264530</td>
</tr>
<tr>
<td>Water balance (error)</td>
<td>-1408</td>
</tr>
<tr>
<td>Water balance (% error)</td>
<td>-0.54</td>
</tr>
</tbody>
</table>

*Values are in m³/day*
Compensation of Produced Water by Induced Infiltration from Surface Water

- Change in storage
- Decreased leakage to lakes
- Decreased leakage to rivers
- Induced recharge
Grand Centre (Layer 2)
Basin Contributions to Licensed Pumping

- Increased surface recharge: 67%
- Increased recharge from lakes: 5%
- Decreased surface discharge: 9%
- Decreased discharge to lakes: 11%
- Decreased baseflow to rivers: 8%
Basin Response to Licensed Pumping

- Increased surface recharge: +8%
- Decreased surface discharge: -4%
- Decreased discharge to lakes: -1%
- Increased recharge from lakes: +9%
- Decreased baseflow to rivers: -8%
5. Conclusions

- A proper **geological characterization** of the subsurface, and the adequate representation of fluid sources and sinks are essential for developing a well-calibrated numerical model.
- A key component was the incorporation of **lake-bottom bathymetry** to map aquifer outcrops on the bottoms of lakes.
- The model is very sensitive to hydraulic properties of till aquitards, for which little measured data exist and "**non-uniqueness**" is a concern.
Conclusions (cont.)

- Transient calibration using long-term pump test data is important to determine hydraulic properties; especially those of aquifers.
- The regional numerical flow model is useful to answer general questions on regional water balances, groundwater - surface water interactions, and to assess the impact of existing and new pumping scenarios.
- The model has to be refined to obtain realistic quantitative results on a local-scale.
- Groundwater and surface water should be managed as a single resource.