Refresher: Provincial Groundwater Inventory Program and CCA Pyramid Model

PGIP Program Objectives:

**Phase I:** Define the natural system; quantification of the geological framework and analytical models for hydrogeological regime (conceptual model design)
- Fox Creek Area project (Smerdon et al., this morning)
- Calgary-Lethbridge Corridor project (Liggett and Atkinson, this morning)

**Phase II:** Regional and sub-basin scale groundwater modelling
- Southern Alberta Regional Groundwater Simulation
- Groundwater Modelling in the Sylvan Lake Sub-Basin
  - [ags.aer.ca: New Website](http://ags.aer.ca)

**Phase III:** Water resource decision-support tools for management, regulation, and policy assurance
- *Focus of this presentation*
Present and Future States: What’s Our Target for Cumulative Effects Management?

**Present State**

- \( Q_{20} \): 20 year safe yield
- Well-based concept (drawdown vs. time)
- Does not quantify cumulative effects (multiple wells)
- Does not address the ultimate source or sustainability of pumping

**Desired Future State**

Requires an Information System!

**Fox Creek**

Water Management
Phase 3 Project Goals and Objectives

- Have an information system that provides high quality, consistent information about groundwater resources and their management to support decision making.

- Deliver results of groundwater models to regulators and consultants in ways that are fit for purpose.

- Develop social and technology platform needed for developing, sharing, and continuously improving groundwater models among specialists in government, consulting, energy industry, etc.

- Prepare a functional and conceptual technical design.

- Develop a working prototype in the Fox Creek area.
Project Design and Approach: 
**Lean Startup**

- Conduct a rapid assessment of groundwater availability in the Fox Creek area
- Design working prototype information system that contains key components to test with regulators and community of practice
- Produce Minimum Viable Product (MVP)
  1. Groundwater Yield Matrix: setting limits and thresholds
  2. Prototype Groundwater Information System: balancing energy development with environmental and social impacts
What is an MVP?

Iterate fast and pivot

Delightful
Usable
Reliable
Functional

Not this

This

Not this

This

Iterate fast and pivot

Canadian Council of Academies, 2009
Fox Creek Study Area

- Encompasses AER PBR pilot area
- Spans Peace and Athabasca basins
- Defined by sub-basin drainage
- Bounded by deformation belt
- 22,000 km²
Groundwater Inventory & Capacity Assessment

- Basin yield concept (1970’s…not new…)
- Response to stress
- Develop intrinsic breakpoints for system
- Yield → Safe? Optimal? Sustainable?
Aquifer-yield Continuum: Basis for AGS Groundwater Yield Matrix

An initial application of the paper by Pierce et al. 2013

We need to quantify groundwater availability in rapid manner to understand potential development risks and current state of use versus availability

“Give me a single number” with associated uncertainty and risk

Performance metrics

Aquifer-yield continuum as a guide and typology for science-based groundwater management


Abstract Groundwater availability is at the core of hydrogeology as a discipline and, simultaneously, the concept is the source of ambiguity for management and policy. Aquifer yield has undergone multiple definitions resulting in a range of scientific methods to calculate and model availability reflecting the complexity of combined scientific, management, policy, and stakeholder processes. The concept of an aquifer-yield continuum provides an approach to classify groundwater yields along a spectrum from non-extractive sustainable, extractable, intermediate sustainable, safe, permitted mining to maximum mining yields, that builds on existing literature. Additionally, the aquifer-yield continuum provides a systems view of groundwater availability to integrate physical and social aspects in assessing management options across aquifer settings. Operational yield describes the candidate solutions for operational or technical implementation of policy, often relating to a consensus yield that incorporates human dimensions through participatory or adaptive governance processes. The concepts of operational and consensus yield address both the social and the technical nature of science-based groundwater management and governance.

Keywords Groundwater management - Decision support - model-based - Socio-economic aspects - Sustainable yield

Introduction and a short history of aquifer yields

Over the last two centuries, the concepts by which groundwater resources are managed have gradually, but dramatically evolved. In 1856, Henry Darcy identified a method for finding a reliable, safe, and potable water source for the city of Dijon, France, and simultaneously created a feasibility principle of hydrogeology (Darcy 1856; Holbeck 2004). Conservation of mass, Darcy’s observations led to quantitative techniques that helped him apply an innovation solution for describing the behavior of water flowing through porous media that explained groundwater flow and became the underpinning of management.

Advances in drilling and extraction in the early 1900s were accompanied by the concept of safe yield. Lee (1913) defined it as “…, the limit of the quantity of water which can be withdrawn regularly and permanently without dangerous depletion of the storage reserve.” Safe yield was later refined as a rate of withdrawal for human use limited to economic feasibility (Kuzmin 1920, 1923) by protecting rights to surface water (e.g. Guiling 1945), to promoting subsurface, and water-quality degradation. Thirls (1960) recognized the impact of pumping on capturing natural discharge and altering recharge and groundwater storage. In the intervening years, groundwater science and management has transitioned to sustainable yield, reflecting decades of active disciplinary debate.
Aquifer-yield Continuum

» Yield → Safe? Optimal? Sustainable?

» Continuum attempts to define gradation of impact (i.e., volumetric bounds & break points)

<table>
<thead>
<tr>
<th>Permissive Sustained Yield</th>
<th>Maximum Sustained Yield</th>
<th>Safe Yield</th>
<th>Permissive Mining Yield</th>
<th>Maximum Mining Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>P = R_p - D_{psy}</td>
<td>P = R_p - D_p</td>
<td>P = R_p</td>
<td>P = V_0 - V_{min} + R_p - D_{min}</td>
<td>P = V_0 + R_p</td>
</tr>
</tbody>
</table>

P = human induced discharge  
R_p = recharge modified by pumping  
D_p = discharge modified by pumping  
D_{psy} = discharge permissible sustained yield discharge  
D_{min} = mining permissible discharge  
V_0 = initial volume of aquifer  
V_{min} = permissible volume decrease when mining  
D_{min} > D_{psy} > D_p
Hydrologic Limits: Yield Matrix

Permissive Sustained Yield  Maximum Sustained Yield  Safe Yield

Permissive Mining Yield  Maximum Mining Yield
Non-saline Aquifer Yield Methodology

Partition study area into sub-basins

- 1 to 9 represent surficial deposits, Paskapoo-Scollard
- 10 & 11 represent Wapiti
- 12 represents non-saline Wapiti beneath Paskapoo-Scollard
- 13 (hatched pattern) represents saline Wapiti beneath Paskapoo-Scollard
Non-saline Aquifer Yield Methodology

- Estimate recharge from Environment Canada gauges (Q25, Mean, Q75), correcting for % coverage

- Estimate volume associated with each sub-basin

- Assume porosity:
  - 5, 10, 20% for Paskapoo & Scollard formations
  - 3, 9, 12% for Wapiti Formation
Non-saline Aquifer Yield Methodology

- Calculate yield:
  - Using ‘fractions’ of recharge to approximate Dpsy (10% of R) and Dp (50% of R) for sustained yield
  - Using ‘fraction’ of aquifer volume for permissive mining (1%)

- Summarize graphically

<table>
<thead>
<tr>
<th>Permissive Sustained Yield</th>
<th>Maximum Sustained Yield</th>
<th>Safe Yield</th>
<th>Permissive Mining Yield</th>
<th>Maximum Mining Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P = R_p - D_{psy}$</td>
<td>$P = R_p - D_p$</td>
<td>$P = R_p$</td>
<td>$P = V_0 - V_{min} + R_p - D_{min}$</td>
<td>$P = V_0 + R_p$</td>
</tr>
</tbody>
</table>

Alberta Energy Regulator

AGS
ALBERTA GEOLOGICAL SURVEY
Summary of Aquifer Yield Estimates
Prototype of Fox Creek Area Groundwater Yield Limits & Thresholds

Qualitative Description

Quantitative Estimate
Forecasting the Duvernay Play’s Water Future: Key Components for Regulating Energy and Water
Forecasting the Duvernay Play’s Water Future: Key Components for Regulating Energy and Water
Duvernay Water Demand: D-059

Kaybob Duvernay Total Water Volume per Well

<table>
<thead>
<tr>
<th>2013/2014</th>
<th>Best fit</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>P99</td>
<td>6,277</td>
<td></td>
</tr>
<tr>
<td>P90</td>
<td>11,417</td>
<td></td>
</tr>
<tr>
<td>P60</td>
<td>23,781</td>
<td></td>
</tr>
<tr>
<td>P10</td>
<td>49,533</td>
<td></td>
</tr>
<tr>
<td>P1</td>
<td>90,069</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2015</th>
<th>Best fit</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>P99</td>
<td>10,516</td>
<td></td>
</tr>
<tr>
<td>P90</td>
<td>18,704</td>
<td></td>
</tr>
<tr>
<td>P60</td>
<td>37,902</td>
<td></td>
</tr>
<tr>
<td>P10</td>
<td>76,805</td>
<td></td>
</tr>
<tr>
<td>P1</td>
<td>138,602</td>
<td></td>
</tr>
</tbody>
</table>

Swanson's Mean

<table>
<thead>
<tr>
<th>On Prod 2013/14 - Regression</th>
<th>Swanson's Mean</th>
<th>Probability</th>
<th>P10/P90 Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>27,798</td>
<td>43,813</td>
<td>P99</td>
<td>4.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>On Prod 2015 - Regression</th>
<th>Swanson's Mean</th>
<th>Probability</th>
<th>P10/P90 Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>P99</td>
<td>4.1</td>
</tr>
</tbody>
</table>
Groundwater Modelling: Start Simple for MVP

AGS Table of Formations, 2015
Integrator: Deltares FEWS Technology

Work Process

Data Viewer

Map Display

XY Plots

Yield Matrix

Spatial Display
Groundwater Model Outputs for Decision Making in FEWS

- Display model results for various runs and compare baseline and reference conditions to scenarios (right: hydraulic heads)
- Adding wells and well fields to assess effects of proposed or forecasted development

- Modelled baseflow from groundwater model compared to long-term surface water flows (left)
- Implementation of “traffic light” concept allows for uncertainty and risk to be evaluated as part of the work flow
### Cumulative Effects Assessment

#### Table

<table>
<thead>
<tr>
<th>Yield</th>
<th>PSY</th>
<th>MSY</th>
<th>SY</th>
<th>PMY</th>
<th>MMY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paskapoo - Deep Creek Valley</td>
<td>16</td>
<td>2</td>
<td>24</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Paskapoo - Waskesihgan</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>Paskapoo - Little Smoky</td>
<td>4</td>
<td>6</td>
<td>10</td>
<td>13</td>
<td>32</td>
</tr>
<tr>
<td>Paskapoo - Lesagean</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>Paskapoo - Balkantamou</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Paskapoo - Athabasca</td>
<td>6</td>
<td>63</td>
<td>63</td>
<td>95</td>
<td>315</td>
</tr>
<tr>
<td>Paskapoo - Simonette</td>
<td>8</td>
<td>6</td>
<td>11</td>
<td>17</td>
<td>43</td>
</tr>
<tr>
<td>Wapiti - Simonet (non-estuarine)</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>Paskapoo - Berland</td>
<td>14</td>
<td>14</td>
<td>10</td>
<td>62</td>
<td>70</td>
</tr>
<tr>
<td>Wapiti - Little Smoky (non-estuarine)</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Paskapoo - McLeod</td>
<td>0</td>
<td>4</td>
<td>5</td>
<td>8</td>
<td>18</td>
</tr>
<tr>
<td>Wapiti - Paskapoo N</td>
<td>-6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wapiti - Paskapoo S</td>
<td>-6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Summary:
Aquifer Yield Matrix

- Offers robust approach to assess current state of groundwater resources (i.e., allocation/use vs. availability)
- Delivers results to regulators that is fit for purpose (effective and efficient for decision making under *Alberta’s Water Act*).
- Provides knowledge about alternate water sources (e.g., low quality non-saline and saline resources).
- Continuous improvement as geological and hydrological knowledge is gained will be required.
- Ability to update yield-matrix results using numerical model accounting for drawdown from adjacent units.
Summary:
Prototype Groundwater Information System

- An operational/information system such as FEWS offers the ability to forecast anticipated water demand and evaluate cumulative effects.
- FEWS provides an opportunity to develop, share, and continuously improve groundwater models amongst specialists in Alberta.
- This prototype demonstrated the possibility of using this configuration for testing regulatory strategies and balancing energy development with desired environmental outcomes.
- The lean-startup approach proved useful for AER-AGS innovation through fast and relatively inexpensive iterations of testing this work with regulators, water-policy managers, and stakeholders.
Acknowledgments

Jim Jenkins, Stefan Walter, Sean Stricker

Project Team: Wiebe Borren, Peter Vermeulen, Sheila Ball, Edwin Welles, Hans van Duijne

Steve Wallace, Aaron Petty