Non-saline Surface Water and **Groundwater Use** for Hydraulic Fracturing in an Area of Duvernay and Montney Exploration and Development, West-Central Alberta

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Fundamental Questions

- Are the effects of current groundwater allocation acceptable?
- If current allocation is acceptable, will the effects of additional groundwater allocation be acceptable?
- How is acceptable defined?
Groundwater Yield

OUTLINE OF GROUND-WATER HYDROLOGY, WITH DEFINITIONS.

By Oscar E. Meinzer.

INTRODUCTION.

FACTS, CONCEPTS, DEFINITIONS, AND TERMS.

The facts or truths on which ground-water hydrology or any other branch of science is based are immutable, but they are not fully known—indeed, they are known in only small fragments.

The concepts of a science are based on the facts or truths that are known or believed to exist. The more fully and accurately the facts of the science are known the more definite and satisfactory are its concepts. Without the complete facts a concept must (1) remain more or less indefinite, (2) be hypothetical, or (3) rest on a fictitious basis. Both hypothetical and fictitious concepts involve assumption of facts that are not known to exist, but they are very different in that one recognizes the lack of knowledge and the other does not.

For most concepts the facts are not fully known, but the absence of knowledge does not make it necessary to adopt a fictitious basis. A poor scientist or careless thinker, in the desire to make his concepts definite and complete, is willing to assume as a fact something which he believes is probably true but which has not been conclusively proved. A true scientist, on the other hand, thinks so clearly that he is able to differentiate between what is known to be a fact and what is only probable or hypothetical. Inherently, incomplete knowledge does not necessitate erroneous concepts.

A definition is the expression of a concept by means of language. It should include all that is involved in the concept but nothing more. Obviously there are two kinds of pitfalls for the man who writes definitions—his concepts may be incorrect or hazy, or his command of language may not be adequate to enable him to express even satisfactory concepts accurately and completely. More often than
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 institutional processes. The concept of an aquifer-yield continuum provides an approach to classify groundwater yields along a spectrum, from non-use through part-time sustained, sustainable, maximum sustained, safe, permitted mixing to maximum existing 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 common yield that incorporates human dimensions through participatory or adaptive governance processes. The concept of operational and common yield address both the social and the technical nature of science-based groundwater management and governance.

Keywords Groundwater management - Decision support - Integrated modeling - Socio-economic aspects

Introduction and a short history of aquifer yields

Over the last two centuries, the concepts by which groundwater resources are managed have gradually, but progressively, evolved. The scientific method for finding a reliable, safe, and potable water source for the city of Denver, Colorado, and simultaneously created a founding principle of hydrogeology (Darcy 1856; Darcy 1856), observations of water flow 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 1932) defined it as “... the limit to the quantity of water which can be withdrawn regularly and permanently without dangerous depletion of the storage reservoir.” Safe yield was later refined as a rate of withdrawal for human use limited to economic feasibility (Mortenson 1950, 1952) by protecting rights to surface water (e.g., Conkling 1843) to prevent subsidence, and water-quality degradation. Then (1948) 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.
Diagram of Yield Concepts

- Quantity of extractable groundwater
- Recharge rates and storage conditions
  - Water quality
  - Discharge rates and environmental flows
- Legal constraints
- Economic feasibility
  - Inter-generational equity

After Pierce et al. (2013)
Groundwater Yield

“... consideration of the present and future costs and benefits may lead to ... mining groundwater, perhaps even to depletion ... [or they] may reflect the need for complete conservation. Most often, the optimal groundwater development lies somewhere between these extremes.” (Freeze and Cherry, 1979)

“... aquifer yields can be viewed through the lens of an adjustable continuum. By [using] the concept of a continuum ... a framing device for describing the selection of an aquifer yield emerges.” (Pierce et al. 2013)
Aquifer Yield Continuum

Groundwater dependent ecosystems will be stressed within natural variations experienced but essentially intact. No observable or statistically significant effects on groundwater-fed streams, wetlands, springs.

Groundwater-fed streams, wetlands, springs are constant at minimal tolerable level with notable stress on groundwater-dependent ecosystems. (Tolerable changes in subsidence, change in head, change in chemistry, change in baseflow)

Baseflow goes to zero resulting in all groundwater-fed streams, wetlands, and springs drying up net of return flow, but water table levels stay constant.

All discharge is captured, experience continuously falling water levels everywhere in aquifer. Possible land subsidence. Possible partial dewatering of aquifer. Loss of bequest volume.

Partial to complete dewatering of aquifer. Major land subsidence, fissures, collapse, seismiscity, leading to permanent loss of aquifer for all uses.

<table>
<thead>
<tr>
<th>Permissive Sustained Yield (PSY)</th>
<th>Maximum Sustained Yield (MSY)</th>
<th>Sustained Yield (SY)</th>
<th>Permissive Mining Yield (PMY)</th>
<th>Maximum Mining Yield (MMY)</th>
</tr>
</thead>
</table>
Aquifer Yield Continuum
(after Pierce et al. 2013)

» Permissive Sustained Yield (PSY)
  \[ P = R_P - D_{PSY} \]

» Maximum Sustained Yield (MSY)
  \[ P = R_P - D_P \]

» Safe Yield (SY)
  \[ P = R_P \]

» Permissive Mining Yield (PMY)
  \[ P = V_o - V_{min} + R_P - D_{min} \]

» Maximum Mining Yield (MMY)
  \[ P = V_o + R_P \]

\[ P \] = Discharge from pumping
\[ R_P \] = Recharge due to pumping
\[ D_{PSY} \] = Discharge required to maintain PSY conditions
\[ D_P \] = Discharge to maintain MSY conditions
\[ V_o \] = Original volume of water in place
\[ V_{min} \] = Minimum volume of water remaining under PMY
Aquifer Yield Continuum - Modified

- **Permissive Sustained Yield (PSY)**
  \[ P = fD_{PSY} \times R \text{, where } fD_{PSY} = 0.1 \text{ and } R \text{ from hydrographs analyses} \]

- **Maximum Sustained Yield (MSY)**
  \[ P = fD_p \times R \text{, where } fD_p = 0.5 \]

- **Safe Yield (SY)**
  \[ P = R \]

- **Permissive Mining Yield (PMY)**
  \[ P = V_o \times fV_{min} + R \text{, where } fV_{min} = 0.01 \text{, and } V_o = V_{aq} \times n \text{ estimate} \]

- **Maximum Mining Yield (MMY)**
  \[ P = V_o + R \]
## Aquifer Yield Matrix

<table>
<thead>
<tr>
<th>Aquifer</th>
<th>PSY (m³/yr)</th>
<th>MSY (m³/yr)</th>
<th>SY (m³/yr)</th>
<th>PMY (m³)</th>
<th>MMY (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquifer 1</td>
<td>V₁&lt;sub&gt;PSY&lt;/sub&gt;</td>
<td>V₁&lt;sub&gt;MSY&lt;/sub&gt;</td>
<td>V₁&lt;sub&gt;SY&lt;/sub&gt;</td>
<td>V₁&lt;sub&gt;PMY&lt;/sub&gt;</td>
<td>V₁&lt;sub&gt;MMY&lt;/sub&gt;</td>
</tr>
<tr>
<td>Aquifer 2</td>
<td>V₂&lt;sub&gt;PSY&lt;/sub&gt;</td>
<td>V₂&lt;sub&gt;MSY&lt;/sub&gt;</td>
<td>V₂&lt;sub&gt;SY&lt;/sub&gt;</td>
<td>V₂&lt;sub&gt;PMY&lt;/sub&gt;</td>
<td>V₂&lt;sub&gt;MMY&lt;/sub&gt;</td>
</tr>
<tr>
<td>Aquifer 3</td>
<td>V₃&lt;sub&gt;PSY&lt;/sub&gt;</td>
<td>V₃&lt;sub&gt;MSY&lt;/sub&gt;</td>
<td>V₃&lt;sub&gt;SY&lt;/sub&gt;</td>
<td>V₃&lt;sub&gt;PMY&lt;/sub&gt;</td>
<td>V₃&lt;sub&gt;MMY&lt;/sub&gt;</td>
</tr>
<tr>
<td>Aquifer 4</td>
<td>V₄&lt;sub&gt;PSY&lt;/sub&gt;</td>
<td>V₄&lt;sub&gt;SY&lt;/sub&gt;</td>
<td>V₄&lt;sub&gt;SY&lt;/sub&gt;</td>
<td>V₄&lt;sub&gt;PMY&lt;/sub&gt;</td>
<td>V₄&lt;sub&gt;MMY&lt;/sub&gt;</td>
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AGS Yield Matrix Work to Date

Area of Interest
Allocations in the Paskapoo Fm
Percentage of PSY
All Paskapoo Fm Allocations

[Map showing distribution of PSY allocations across different regions with color-coded areas indicating percentage allocations.]

AGS
Area of Interest for Additional Analysis

Source of Duvernay prospectivity is AER’s Duvernay Reserves and Resources Report
PSY Aquifer Yield Volumes by Sub-Basin

- Iosegun ~ 8% of total PSY volume from all three sub-basins
- Upper Little Smoky ~ 86% of total PSY volume from all three sub-basins
- Waskahigan ~ 5% of total PSY volume from all three sub-basins
Groundwater Diversion, Hydraulic Fracturing - Iosegun River

57% used in Duvernay Fm. development
43% available for other uses
Groundwater Diversion, Hydraulic Fracturing – Upper Little Smoky R.
Groundwater Diversion, Hydraulic Fracturing – Waskahigan River

Waskahigan PSY Volume

- 65% used in the Duvernay Fm.
- 7% used in the Montney Fm.
- 18% available for other uses
Conclusions

» The Aquifer Yield Matrix approach provides a means to understand current allocations of groundwater in the context of the potential repercussions of those allocations.

» Total current allocations might be exceeding some of the thresholds between yield categories.

» Sourcing for hydraulic fracturing contributes to total diversions, but it does not exceed the first aquifer yield threshold on its own.
Thank you