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# Groundwater Supply Management vs. Petroleum Reservoir Management

*Alexander Haluszka, M.Sc., P.Geol*
*William Wilmot, P.Geol.*
*Gordon MacMillan, P.Geol.*
*Matrix Solutions Inc.*

## Summary

Groundwater supply management involves many similar aspects to petroleum reservoir management, but some key differences are important to emphasize. To ensure the long term sustainability of large scale industrial withdrawals, groundwater needs to be assessed as an integrated system including adjacent aquifers, aquitards, and surface water bodies in the vicinity of the withdrawal aquifer. An effective management strategy begins by having a solid understanding of the regional and local geology in the context of a hydrostratigraphic framework. Regional mapping of aquifers and aquitards from oil and gas industry datasets, including downhole geophysical logs (either cased or not), can form the basis of this framework. For groundwater supply problems not concerned about contaminant fate and transport, the scale of the mapping can be relatively coarse and over large geographic areas. Especially for confined aquifers, which are the typical type of oil and gas industrial use aquifer in Alberta, drawdown from source wells can propagate 10's of kilometers within months of initiating pumping. In this case it is important to capture large scale stratigraphic trends, regional outcrop and subcrop areas and potential hydraulic connections to other aquifers or surface water features. Having a conceptual model for the aquifer depositional environment is important but at this scale it is not as important to have detailed facies reconstructions built from core or petrophysical interpretations. Transmissivity (hydrogeology equivalent of kh) is an important parameter to predict aquifer behaviour. Bulk permeability estimates from well tests including DST's or more ideally multi-day production tests are more useful for predicting longer term aquifer sustainiability than core analysis, which is well-scale and may not account for secondary permeability. Similar tools to reservoir engineers, including analytical and finite element/finite difference numerical models, are used to assess pumping test results and predict aquifer behaviour. For groundwater numerical models assessing confined aquifer groundwater supply problems, model domains are large, contain multiple stratigraphic units, and often a representation of surface topography and surface water features. 3D geomodeling and GIS software are useful tools to organize and synthesize regional geologic datasets, digital surface topography models, and surface water networks for these types of problems. Ultimately, scale is the biggest difference between groundwater and reservoir management problems but datasets and workflows are very similar between hydrogeologists and petroleum geologists/reservoir engineers so there are many opportunities for collaboration and shared learning.

## Introduction

Groundwater supply management involves many similar aspects to petroleum reservoir management, but some key differences are important to emphasize. We will look at some potential workflows and methods, utilizing some examples from Alberta, for assessing some key aspects of effective groundwater management including aquifer deliverability, cumulative effects,regulatory constraints, and groundwater-surface water interaction. Through this discussion we will illustrate what we view as some key differences to consider compared to typical petroleum geology and reservoir engineering methods.

## Theory and Methods

Due to the desire to avoid direct groundwater-surface water interaction and minimize conflict with domestic useage, most of the aquifers currently being used or considerd for large scale oil and gas industrial groundwater supply (SAGD, hydraulic fracturing) are confined aquifers, such as the Haynes Member of the Paskapoo Formation in West-Central Alberta, or Mannville Group aquifers in Northeastern Alberta. The definition of a confined aquifer is one in which an aquitard is present above the aquifer and the total hydraulic head (reservoir pressure) is above the aquifer top. For confined, freshwater aquifers (containing water <4000 mg/L TDS), according the Alberta *Water Act*, the water level may not be drawn down below the aquifer top during pumping, so water is never removed from storage (aquifer pore space) when pumping. Instead, it is released from aquifer and water compressibility. In this case, calculating a volume of "water in place" is not a meaningful measurement to characterize the potential deliverability or sustainability of an aquifer or gain any insight as to potential impacts to other users or receptors. Below, a review of standard hydrogeological approaches that are more applicable to confined aquifers in Alberta are discussed.

### Part 1 – Hydrogeology Jargon and Simplifying Assumptions

Groundwater flow equations used in hydrogeology, like reservoir engineering, are based off principles developed by Henri Darcy. However, hydrogeology and reservoir engineering have developed in parallel and use different terminology and jargon. Kawecki (2000) presented a useful table identifying typical oilfield terminology and units vs typical ground water equivalencies. For this presentation, the terms that will be discussed include:

| Hydrogeology Term | Typical Units (metric) | Oilfield Term | Typical Units (metric) |
|---|---|---|---|
| Hydraulic conductivity (K) | m/sec | Water-mobility ($k/\mu_{water}$) | md/cp |
| Transmissivity (T) | $m^2$/sec | Mobility thickness product | md·m/cp |
| Available head ($H_a$) | m | Reservoir pressure | kPa |

k=intrinsic permeability (md)
μ=dynamic viscosity (cp)

Transmissivity is the product of aquifer thickness (b) x hydraulic conductivity (K). It can be related to intrinsic permeability by an empirical relationship developed by Jacob (1950):

$$\mathbf{k = K(\mu/\rho g)}$$

Where k is the intrinsic permeability in $m^2$ ($1x10^{15}$ md), K is the hydraulic conductivity in m/sec, μ is the dynamic viscosity of the fluid in kg/(m·s), ρ is the density of the fluid in kg/$m^3$ and g is the acceleration due to gravity in m/$s^2$.

Therefore, any standard oilfield method for obtaining a permeability estimate (i.e. analysis of pressure buildup from DST's or swabbing programs, porosity/permeability relationships from core analysis) can be utilized to estimate hydraulic conductivity and used along with available head to estimate deliverability. This can be a useful screening tool prior to undertaking an expensive groundwater drilling and testing field program.

### Part 2 – Estimating Confined Aquifer Deliverability Through Analytical Methods

Analytical methods are useful in order to get an estimate of aquifer deliverability but not aquifer cumulative effects or groundwater-surfacewater interactions.

A simple empirical relationship developed to estimate long term aquifer deliverability was developed by Farvolden (1959) for a confined aquifer and utilizes the available head and the expected transmissivity:

$$\mathbf{Q_{20} = (0.68 \times T \times H_a) \times 0.7}$$

Where $Q_{20}$= 20 year sustainable yield and 0.7 is a safety factor. Available head is measured from the aquifer top to the top of the water column. This method is useful for a first approximation of potential aquifer deliverability, with the aquifer thickness interpreted from logs and the hydraulic conductivity estimate can either be obtained from analysis of pressure transient data, core analysis or literature. However, this method does not take into account aquifer heterogeneity or boundaries and assumes an infinite acting homogeneous confined aquifer. It also does not take into account competitive drawdown from adjacent wells if the $H_a$ used is the initial aquifer pressure.

Because drawdown in confined aquifers propagates laterally over large distances, when dealing with competitive usage or multi-well networks the long term deliverability of a single well can be strongly affected by cumulative effects. MacMillan (2009) developed a method to extend analytical approaches based on the Theis (1935) equation to compute efficiency of multi-well networks. This approach is still bound by the simplifying assumptions of an infinite acting homogeneous confined aquifer. For multi-well networks the per-well deliverability vs. competitive drawdown and full deliverability of the network must be optimized with an eye on costs (minimize number of wells and well spacing). An example of applying this approach to the Haynes Aquifer will be discussed below.

**Part 3 – Evaluating Long Term Sustainability and Environmental Effects With Groundwater Flow Models**

Analytical approaches do not consider aquifer complexities and regional boundaries. Especially for confined aqufiers, large scale stratigraphic trends, regional outcrops and subcrops and potential hydraulic connections to other aquifers or surface water features play an important role in influencing long term deliverability of aquifers and the environmental effects to the hydrologic system. In this case, building a numerical model of groundwater flow that incorporates these features is warranted.

The first step of building a groundwater flow model is developing a conceptual model, which consists of an understanding of the hydrostratigraphy (aquifers vs. aquitards) and boundary conditions (often where aquifers outcrop, subcrop, or pinch out). This starts with regional scale mapping appropriate to the scale of the problem, often on the 10's of km of scale up to 100's of km scale for confined aquifers that are highly utilized such as the Lower Grand Rapids Aquifer in Northeastern Alberta. Depending on the hydrogeologic system, the scale of the mapping can be relatively coarse and over large geographic areas.

Features of groundwater supply modelling for confined aquifers that are different from reservoir models include:

- Large model domains
- Not sensitive to local heterogenieties in the aquifer/reservoir
- Sensitive to aquifer boundary conditions (lateral and vertical)
- Vertical propagation of pressure is often of interest
- Aquitard geometry is important

Because of the regional scale and multiple units, geomodeling can form a useful part of the geologic reconstruction workflow. It allows integration of multiple datasets of differeing scales and honours a 3D representation of all hydrostratigraphic surfaces, including aquitards separating key aqufiers. It also allows for iterations of geologic conceptualizations and the application of geostatistical approachs in a separate platform from the groundwater flow model. Scripts have been developed to transfer hydrostratigraphic surfaces from geomodeling platforms, such as GOCAD®, directly to groundwater flow modelling software such as FEFLOW®.

## Examples

### Case 1 – Haynes Aquifer in Central Alberta

The Haynes Aquifer comprises stacked fluvial channel sandstones in the lower part of the Paskapoo Formation. It is a relatively tight, well cemented, freshwater bearing, confined aquifer with average porosity near 15% and hydraulic conductivity on the order of $10^{-7}$ to $10^{-5}$ m/s. The aquifer's high thicknesses (up to 100's of meters) and low utilization make it an attractive target for hydraulic fracturing water supply. It is a confined aquifer and is relatively deeply buried but can outcrop in river valleys in some areas, such as the Red Deer River east of the city of Red Deer near the type section defined by Demchuk and Hills (1991). We now have several regional geologic characterization studies for scoping regional aquifer potential (e.g. Lyster and Andriashek 2012). Based on regional studies, local gross and net isopach mapping can be completed and permeability estimates obtained from drill stem test or pumping test data. When in a location where not expecting significant groundwater-surface water interaction, well network requirements can be estimated using analytical approaches based on ranges of thickness obtained from local isopach mapping. Because the aquifer has relatively low hydraulic conductivity, large multi-well networks will likely be required to meet the demands for hydraulic fracturing. Going forward, to better understand the long term deliverability and sustainability of the Haynes Aquifer, field testing, gathering long term pumping data, and developing regional scale groundwater models will be the most useful approaches as opposed to detailed core based sedimentology or petrographic studies.

### Case 2 – Lower Grand Rapids Aquifer in Northeastern Alberta

The Lower Grand Rapids Aquifer comprises amalgamated marine deposited sand bodies in the Upper Mannville Group in Northeastern Alberta. It is saline to non-saline and has been utilized by approximately 20 SAGD projects spread throughout the Athabasca Oil Sand play area and is planned to be utilized by other operators for future projects. It is poorly cemented and porosity is in excess of 30%, that can be associated with high hydraulic conductivity where sands are clean and well developed (typically 1 to 3 x $10^{-5}$ m/s). It is confined by overlying shales that in some places can be breached by Quaternary and Neogene buried channel incisions. These channel incisions create pathways for drawdown to propagate vertically through the Quaternary aquifer system to shallower aquifers and surface water. The aquifer also outcrops along the edges and within the Athabasca River valley and other regional surface water features. In this context, assessing drawdown and environmental impacts using groundwater numerical models is required to predict long term sustainability of the aquifer due to the regional aquifer boundaries, competitive usage and potential environmental effects.

## Conclusions

Because most oil and gas industrial water supply aquifers targeted in Alberta are confined, it is important to remember that water is not removed from porosity during pumping and this is enforced by the provincial *Water Act* for freshwater aquifers. Therefore in this case, petroleum reservoir approaches that focus on draining fluids from pore space are not useful tools to apply to groundwater management. Drawdown propagation in confined aquifers can be over large distances and affected by regional aquifer boundaries on the 10's of kilometers in scale. For groundwater supply problems it is more important to characterize large scale hydrostratigraphic relationships and conceptualize how these may affect long term sustainability and relate to cumulative environmental effects in the hydrologic system. Like petroleum reservoir management, geologic mapping, analytical methods, geomodelling and flow modelling are useful tools for aquifer management but consideration must be given to the different scale of the problem.

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