Water supply issues in unconfined bedrock aquifers in the Ft. McMurray area

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Presentation Outline

1. Unconfined bedrock aquifers – geologic setting and conceptual model overview

2. Gas effect on Neutron Logs – A primer/review and how this can help characterize partially saturated aquifers

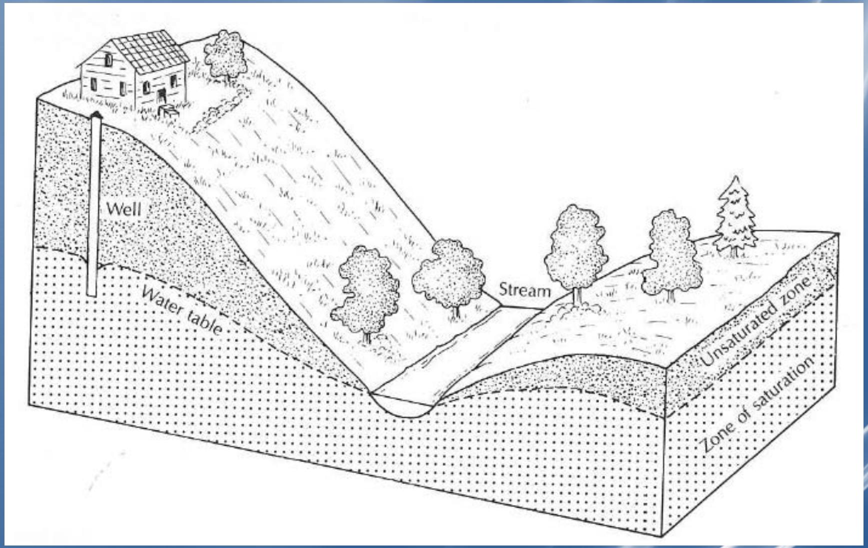
3. Where do we see this occurring in Alberta?

4. Case study: Viking Aquifer in the Birch Mountains area

Unconfined Aquifers

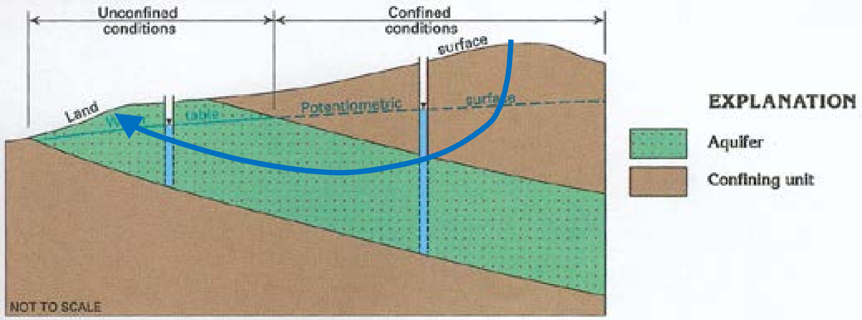
An aquifer "close to land surface, with continuous layers of materials of higher instrinsic permeability extending from the land surface to the base of the aquifer"

Fetter 2001



From Fetter 2001

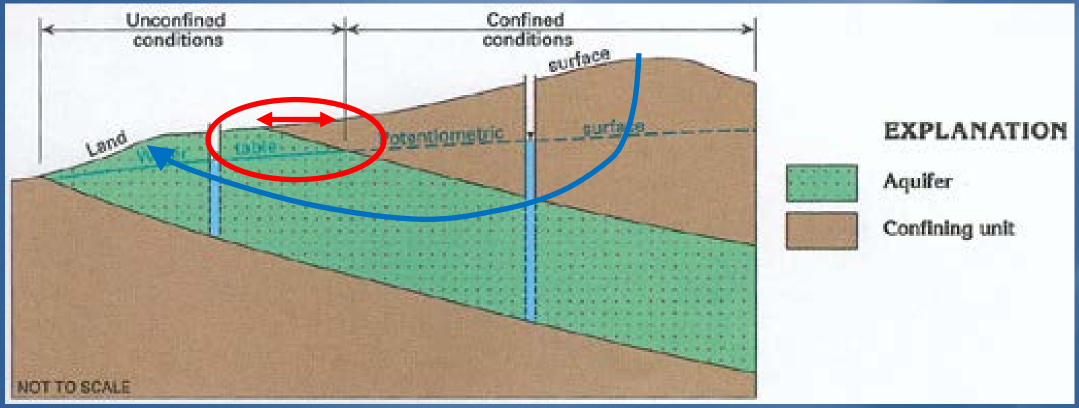
Confined (Saturated) vs. Unconfined (Partially Saturated) conditions can occur within the same aquifer in certain hydrogeologic settings



Conceptual drawing from Groundwater Atlas of the United States based on the Denver Basin (Robson and Banta 1995)

Unconfined Aquifers

What conditions can give rise to this hydrogeologic setting?



Robson and Banta 1995

- Continuous, permeable aquifers confined above and below
- Variable topography
- Outcropping/subcropping allowing effective discharge

Result is unsaturated conditions at the outcrop edge, relatively flat pressure gradient within the aquifer. Unsaturated conditions can extend back into the "confined" portion of the aquifer; ~20 km in Viking Aquifer in NE Alberta

How can we characterize these settings?

- For shallow aquifers, water wells and piezometers can provide a good picture
- Deeper bedrock aquifers that are not currently exploited; may have some sporadic pressure data (drill stem tests, some water level measurements)

’→ **Neutron porosity logs can record the air/water interface in partially saturated aquifers**

Neutron Porosity Logs

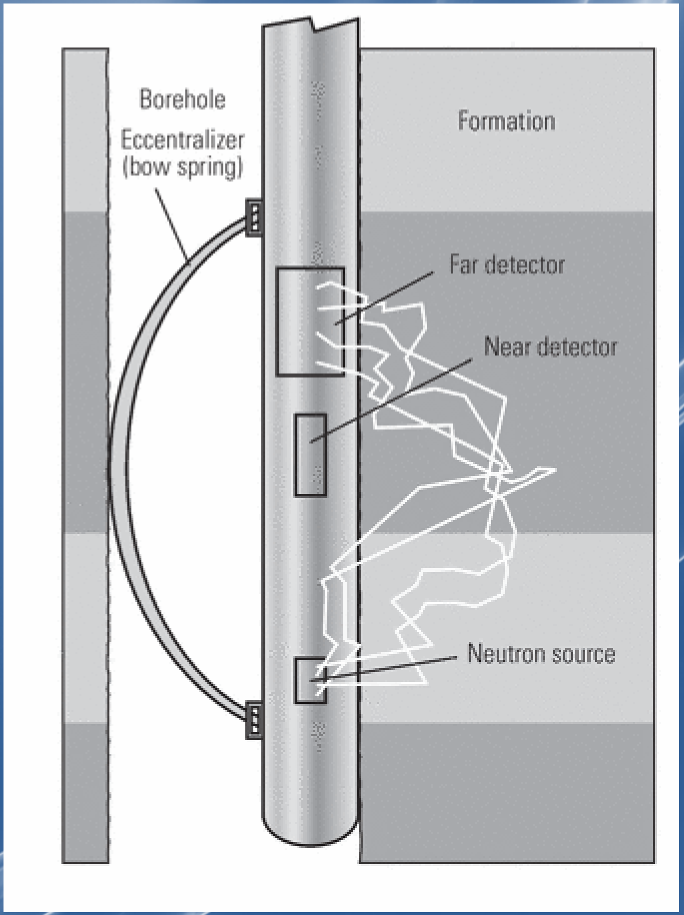
High energy neutrons emitted from a radioactive source

Neutrons collide with the nuclei of atoms in formation materials and lose energy based on relative mass; greatest energy losses occur when collision is with object of equal mass

Hydrogen, u = 1.008/Neutron, u = 1.009

Slowed neutrons are captured. Detector measures return of neutrons. Porosity is calculated from this response.

In most subsurface settings, formation hydrogen content is the key factor. More hydrogen ~ higher porosity.

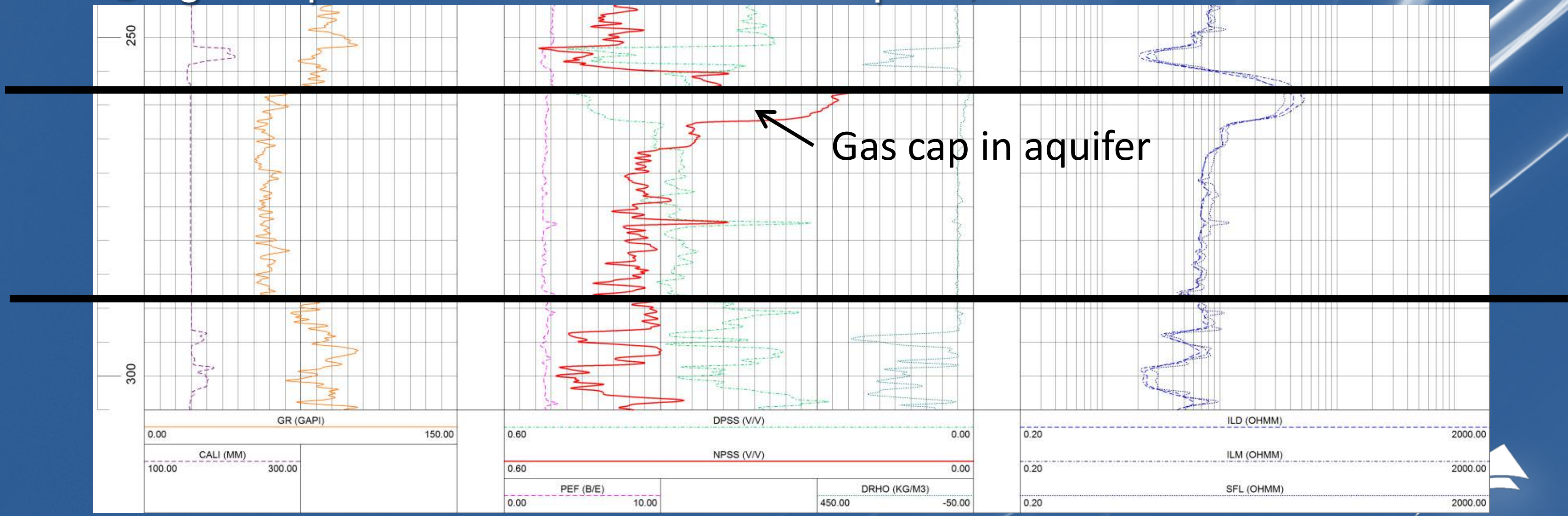


From Ellis and Singer, 2007

Neutron Porosity Logs

- Gas effect on neutron logs: liquid hydrocarbons and water have higher hydrogen density than gases
- Therefore, neutron porosity reads low in gas

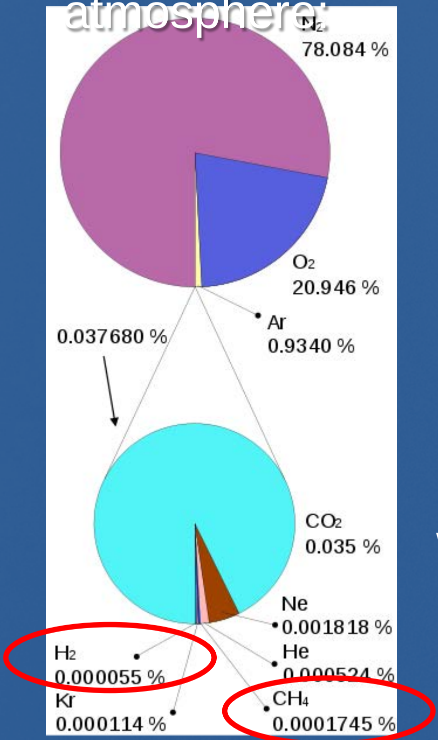
Natural gas cap in the Middle Clearwater Aquifer, SAOS:



Neutron Porosity Logs

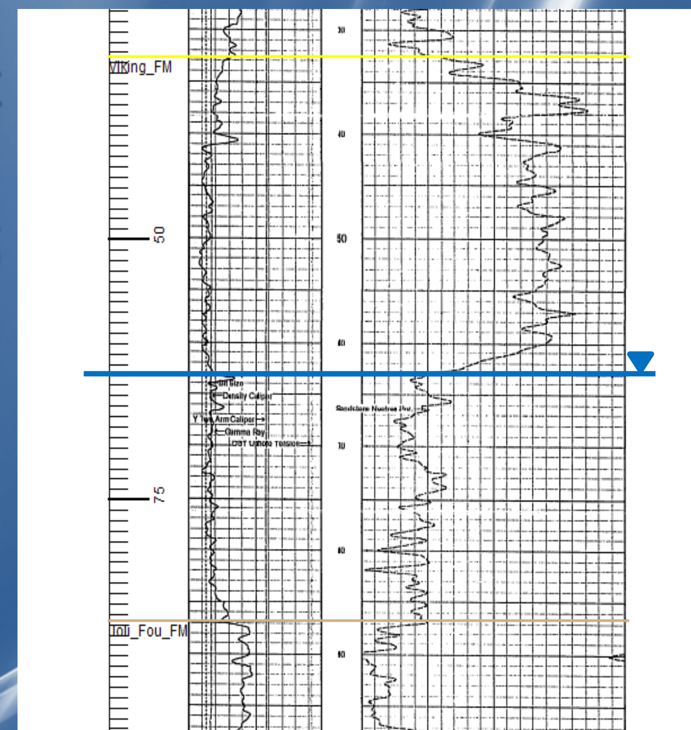
Same principles apply to partially air saturated aquifers:

Composition of atmosphere:



Lower pressure and less hydrogen = greater effect

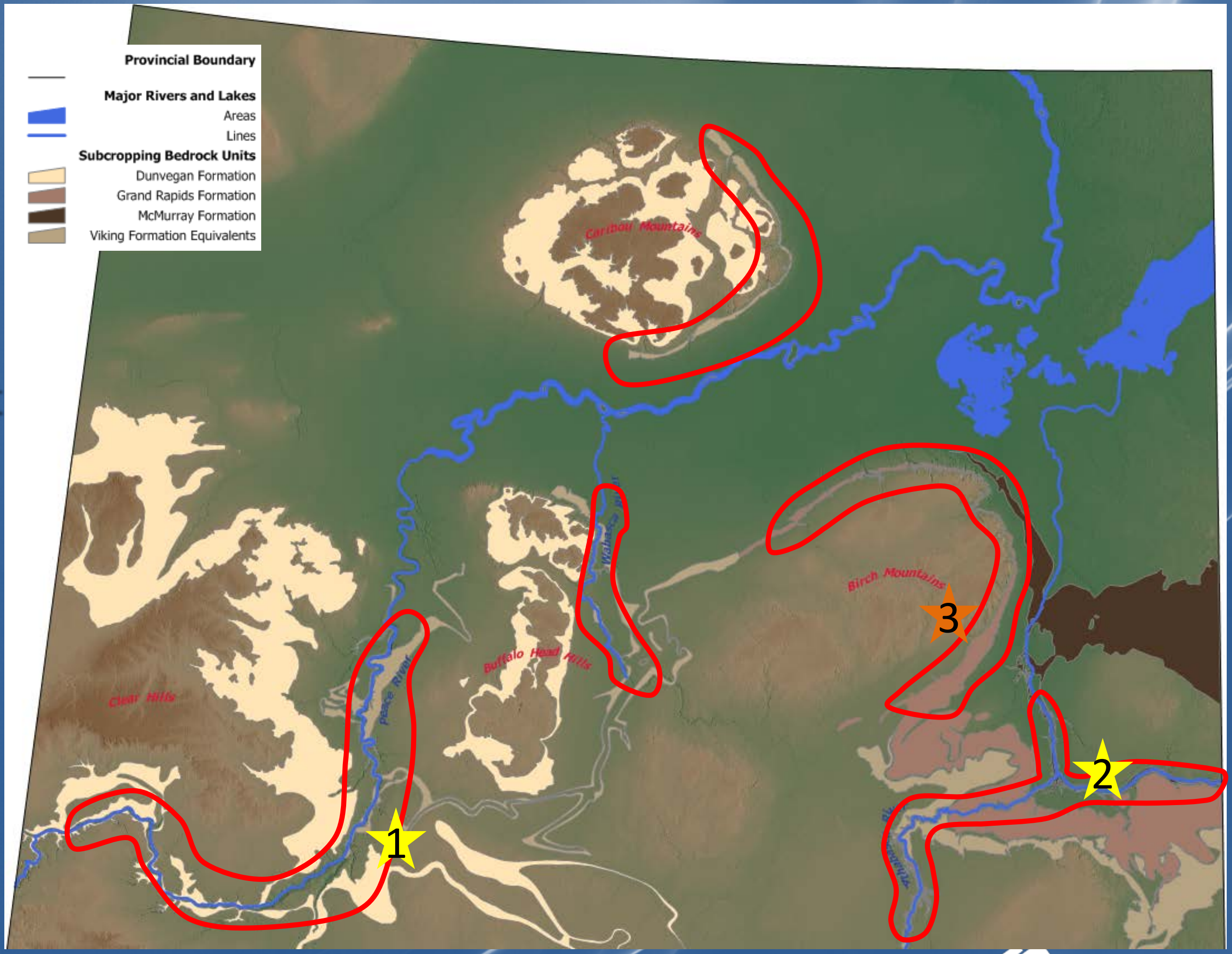
Can read through casing; along with gamma ray logs now required to be run through surface casing in all oil and gas wells (AER directive 43)



Where to expect these settings in Alberta?

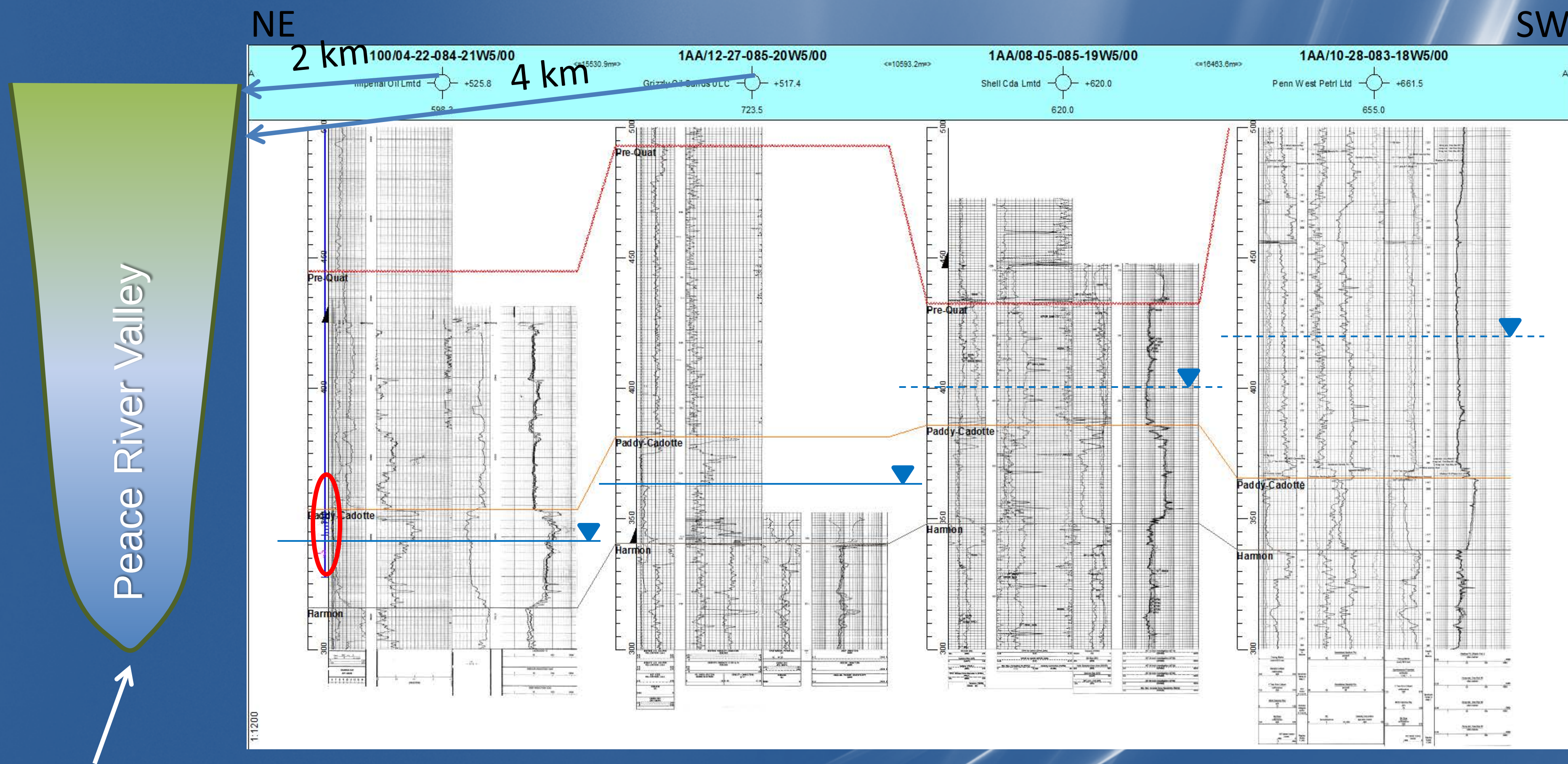
Geologic/geographic factors that result in contiguous aquifers with high K values that locally outcrop:

- Marine siliclastic depositional environment
- Less burial diagenesis and cementation = high total porosity? (30%+ in cretaceous units in NE Alberta)
- Topographic variability; river valleys and highlands



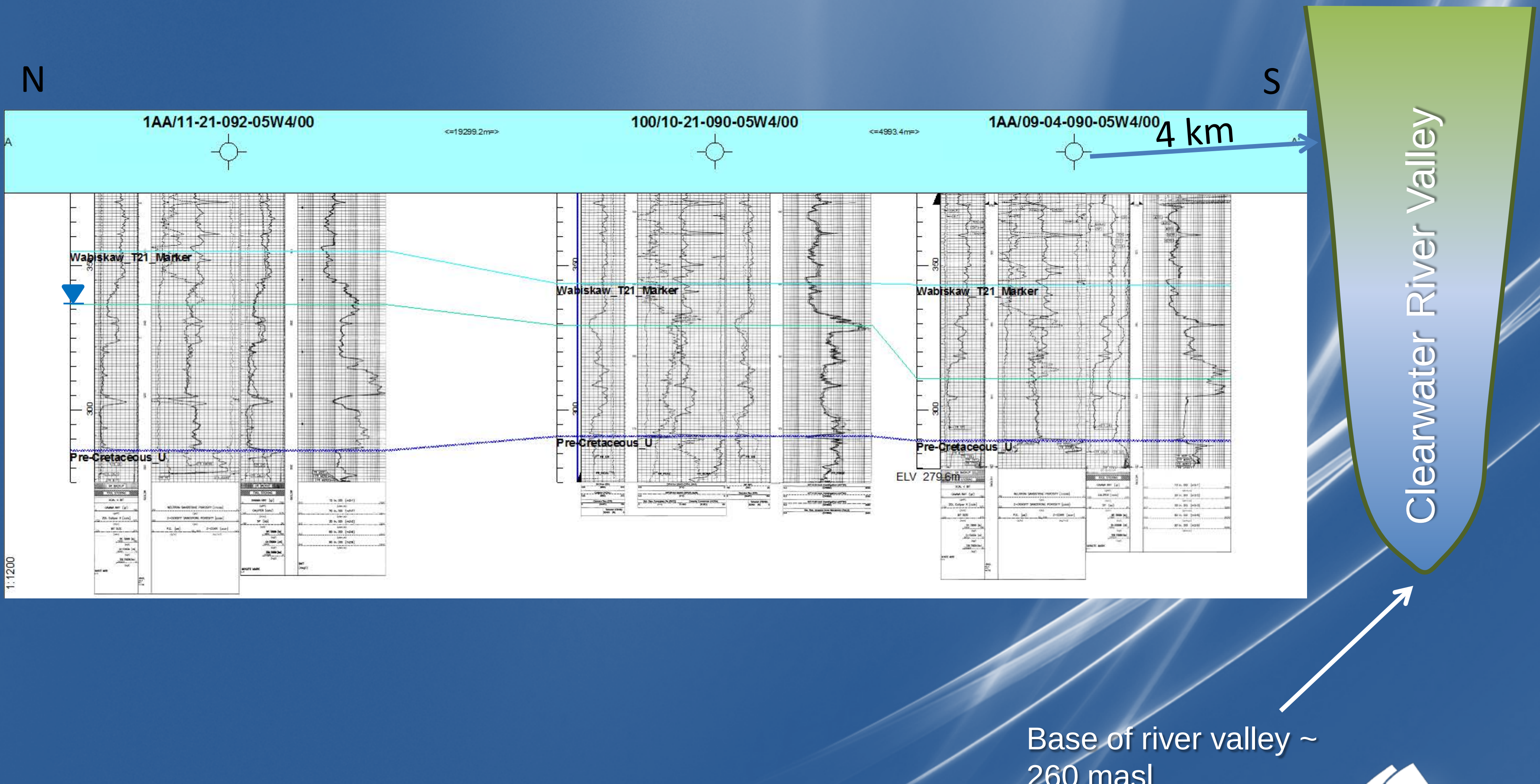
Unit subcrop data from AGS (Prior et al 2013)

1. Peace River /Paddy Cadotte Aquifer – Peace River Valley



Base of river valley ~ 300 masl

2. McMurray Aquifer– Clearwater River Valley



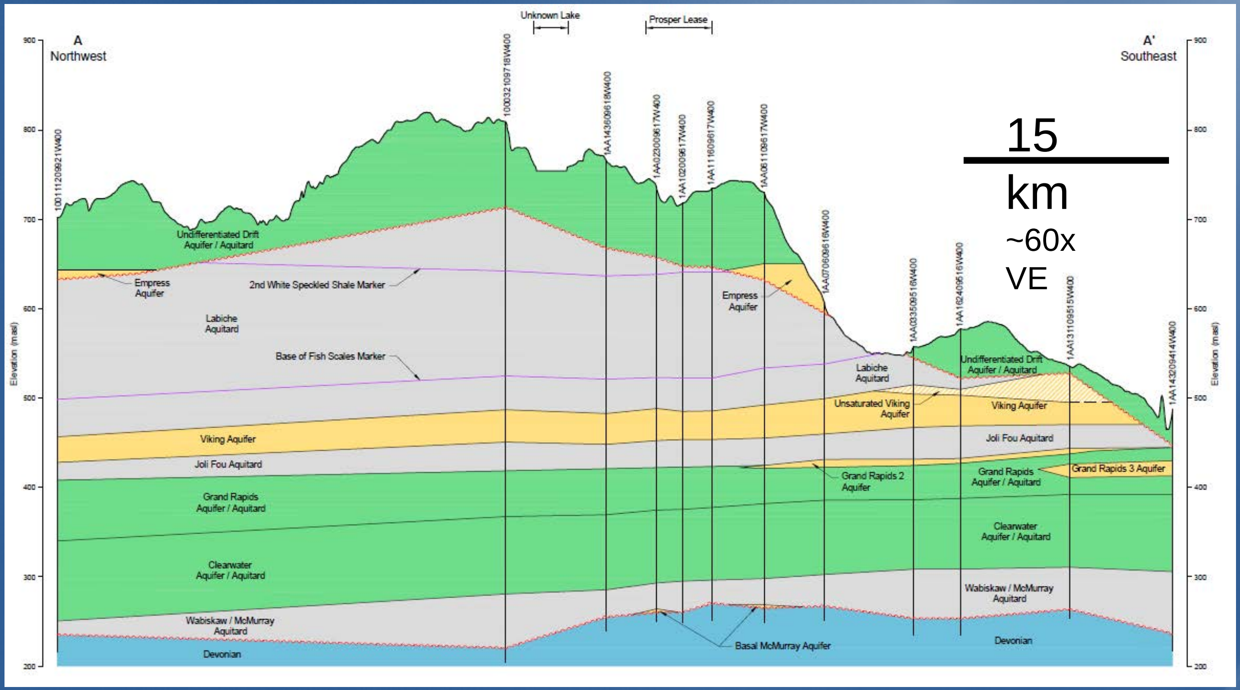
3.Viking Aquifer– Birch Mountains

Background:

- Active development area for in-situ SAGD projects
- Matrix completed an application for a 10,000 BPD project for Prosper Petroleum in fall 2013
- Water requirements of ~940 m^3/day during steady state operations

3.Viking Aquifer– Birch Mountains

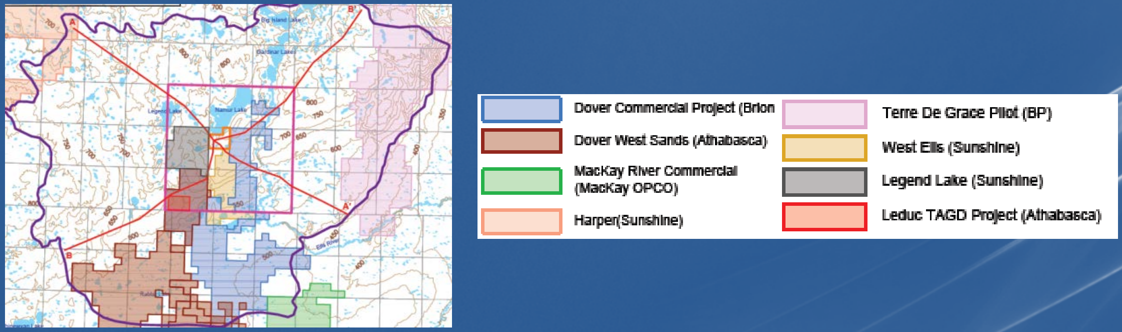
Regional Hydrostratigraphy:



Viking – 900-1200 TDS mg/L

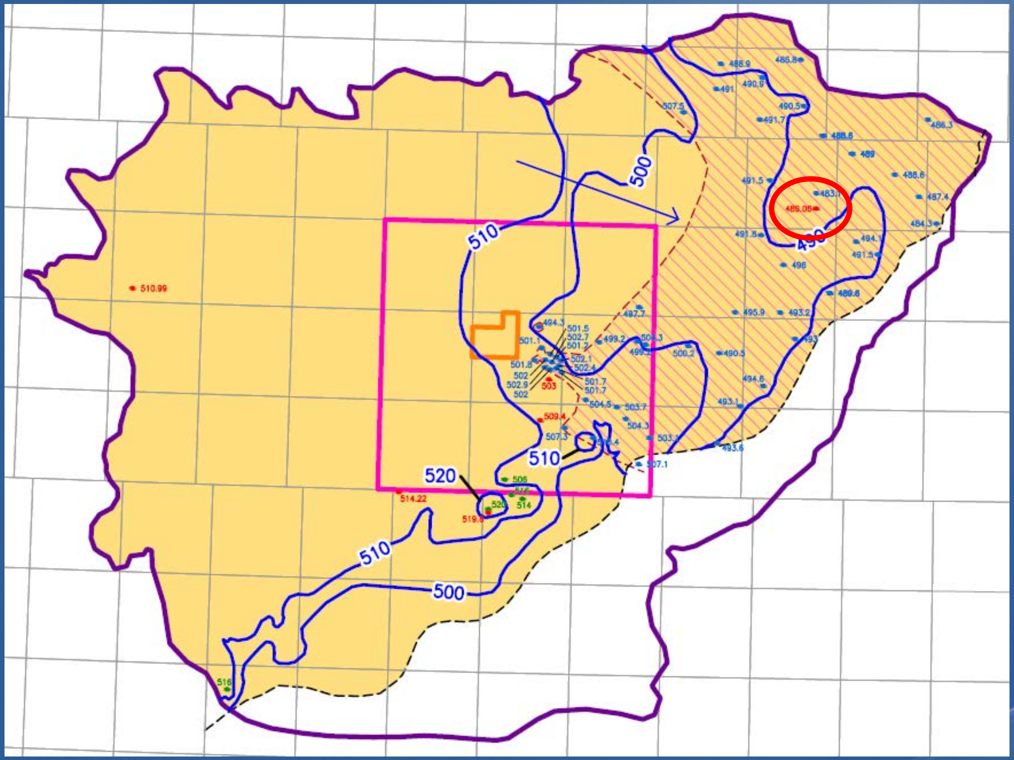
Grand Rapids - 1000-1500 TDS mg/L

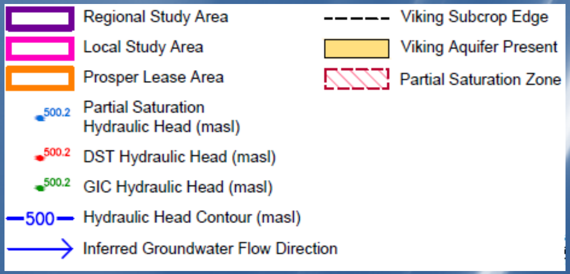
Basal McMurray – 2000 – 8000 TDS mg/L



3.Viking Aquifer– Birch Mountains

Hydraulic Head Mapping:

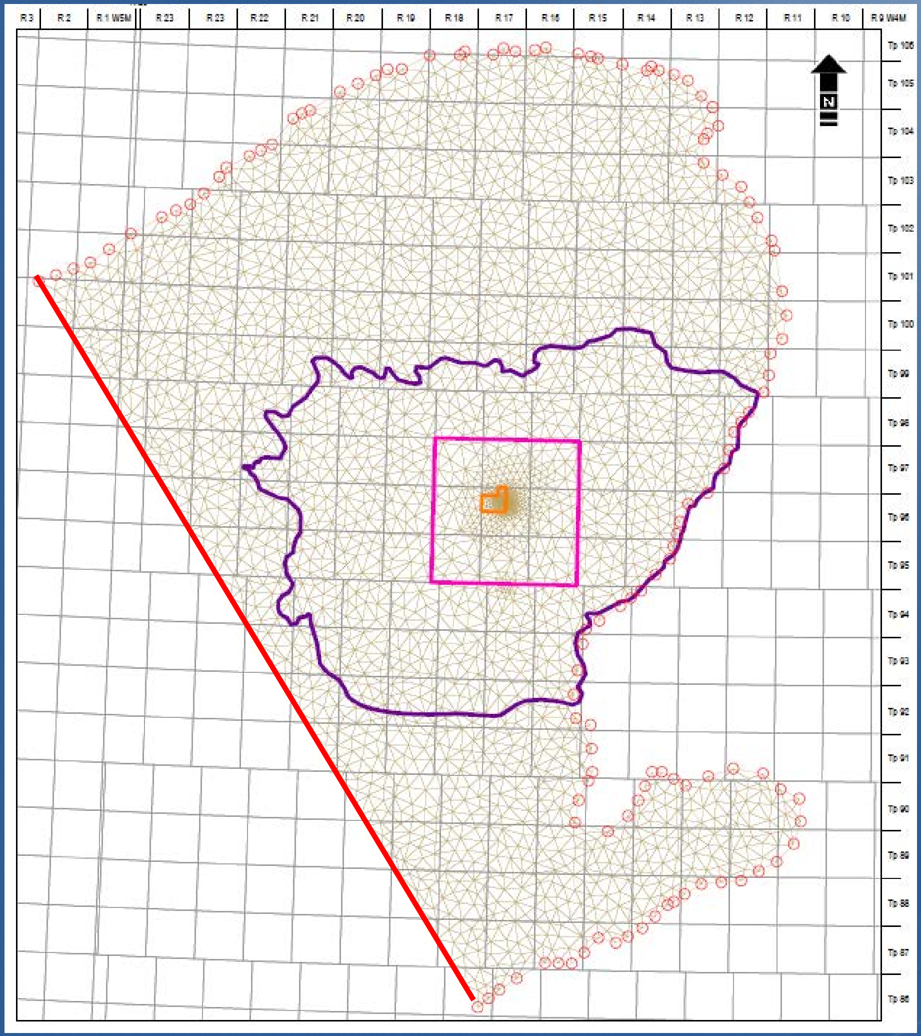




- 6 drill stem tests
- 5 measured water levels
- 60 values from partial saturation response on neutron logs **(85% of head estimates)**

3.Viking Aquifer– Birch Mountains

Model construction for impact assessment:



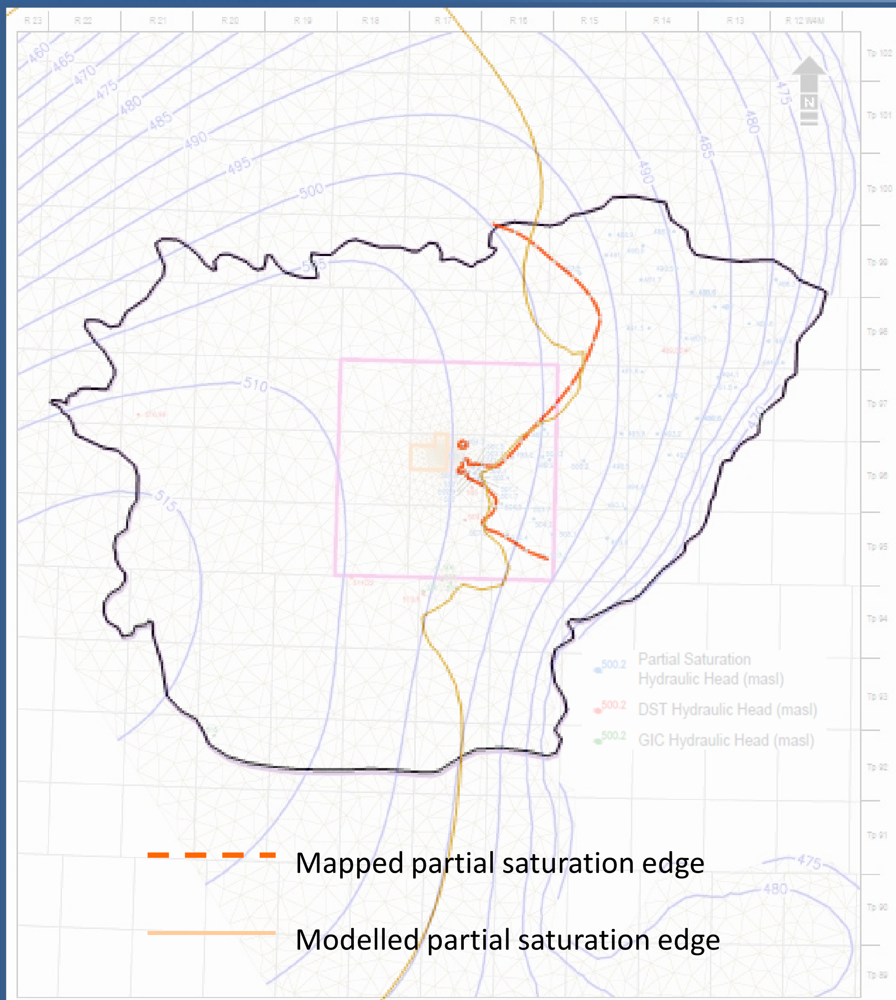
- Simple, one layer finite element model (FEFLOW) using structure top and base of the Viking aquifer
- 17,000 km^2 model domain

Boundaries:

- Transfer boundary along subcrop edge
- No-flow along SW boundary
- Specified flux boundaries at top and no flow at base
- K value of 1.9×10^{-5} m/s assigned to aquifer based on 3 publicly available well tests

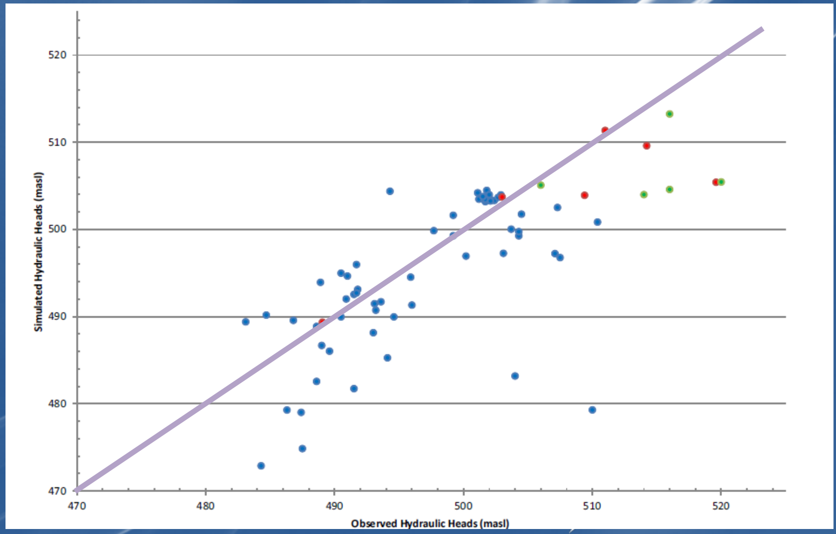
3.Viking Aquifer– Birch Mountains

Model calibration:



- Manually adjusted the recharge rate and the transfer rate at subcrop edge:

Parameter	Initial Estimate	Calibrated Value
Recharge	1 mm/year	0.3775 mm/year
Transfer Rate	3×10^{-8} 1/s	2.74×10^{-9} 1/s
Hydraulic Conductivity	1.91×10^{-5} m/s	1.91×10^{-5} m/s
Specific Storage	0.0001 1/m	0.0001 1/m
Specific Yield	0.2	0.2

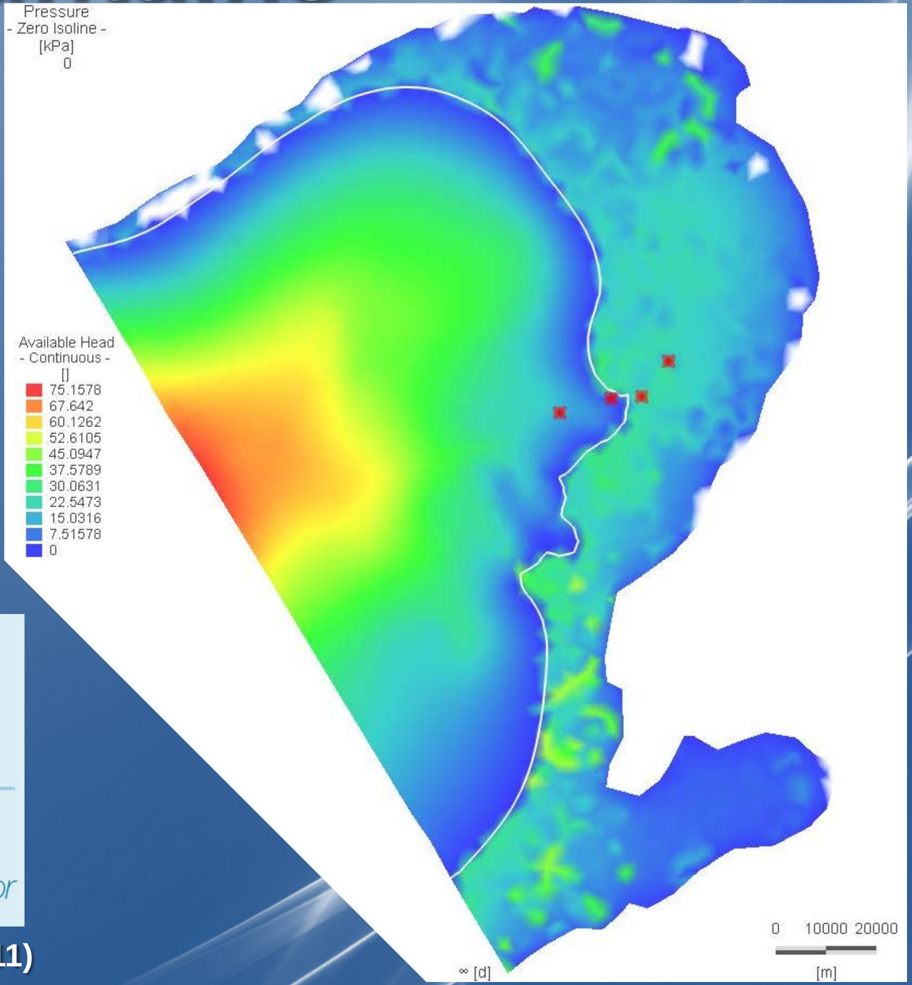


3.Viking Aquifer– Birch Mountains

Available head

The available head (Ha) for a confined aquifer is the distance between the non-pumping water level and the top of the aquifer.

For unconfined aquifers, the available head (Ha) is two-thirds of the initial saturated thickness of the aquifer.



Modified Moell Method (Maathuis and van der Kamp)

$$Q_{20} = \frac{0.7 \times Q \times H_a}{S_{100\,min} + (S_{20\,yrs} - S_{100\,min})_{Theor}}$$

from Alberta Guide to Groundwater Authorization (2011)

3.Viking Aquifer– Birch Mountains

Case Study:

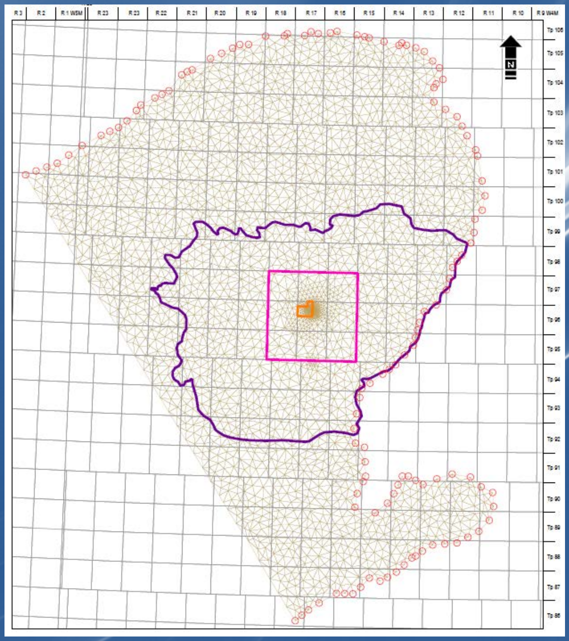
Assess four theoretical production well cases with different placements in relation to unconfined area

Modified Moell Method (Maathuis and van der Kamp)

$$Q_{20} = \frac{0.7 \times Q \times H_a}{S_{100\,min} + (S_{20\,yrs} - S_{100\,min})_{Theor}}$$

from Alberta Guide to Groundwater Authorization (2011)

Parameters to assess will be theoretical well yields (Q20) and change in aquifer discharge at the subcrop edge



Assumptions:

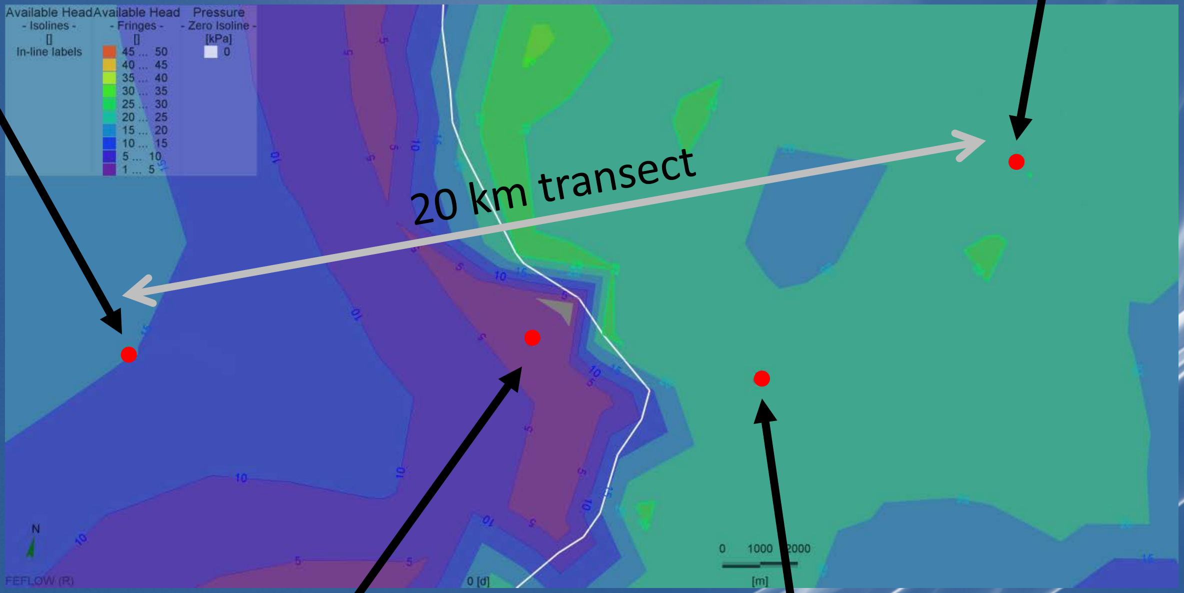
- S_{100min} from Theis (1935) with a 70% efficient well

3.Viking Aquifer– Birch Mountains

Q20 Calculations

240 m³/day – 15 m available head, confined

520 m³/day – 21 m available head, unconfined



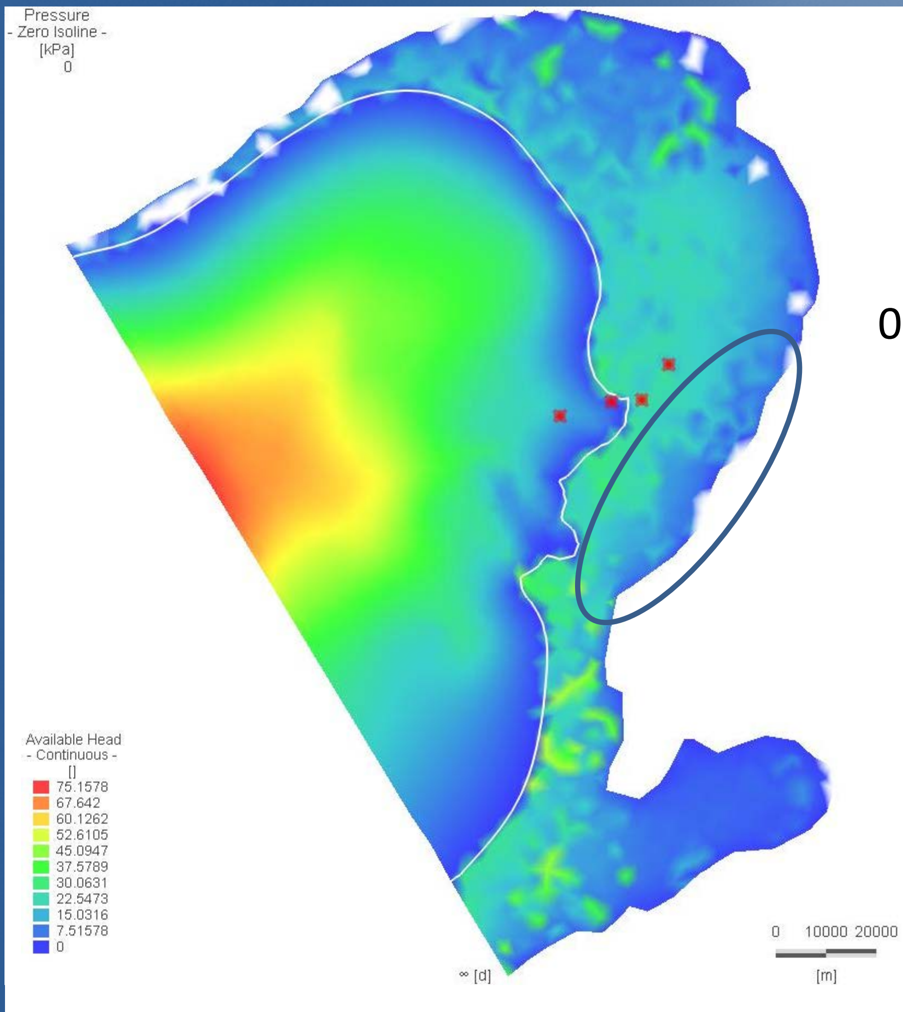
33 m³/day – 2 m available head, confined

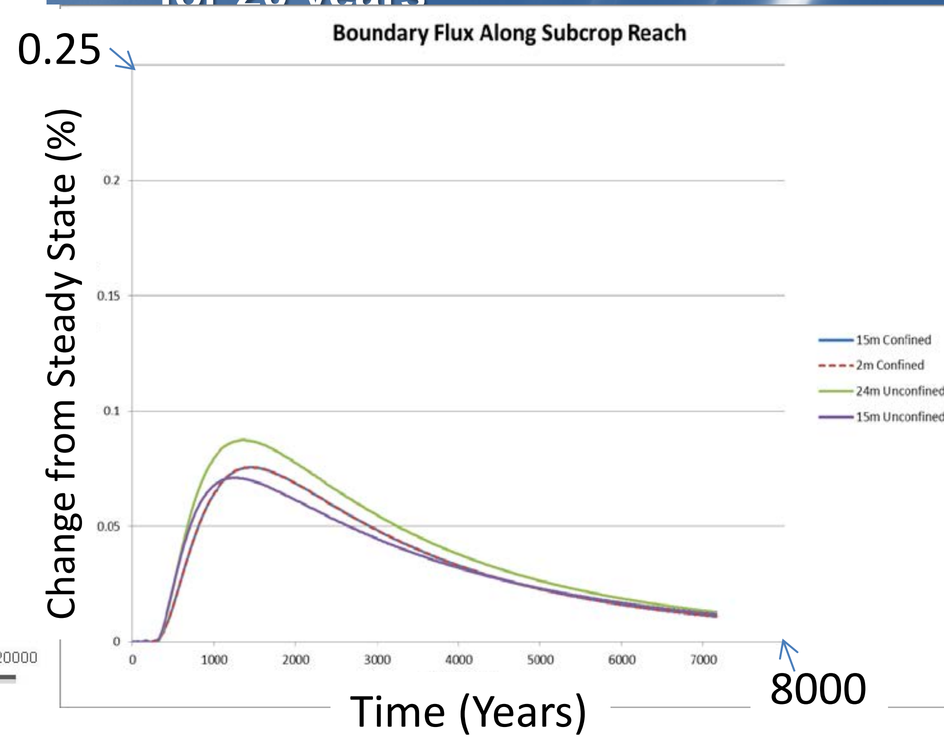
565 m³/day – 24 m available head, unconfined

3.Viking Aquifer– Birch Mountains

Surface Water Capture

- **Examine the change in flux along a reach of the transfer boundary as a % change from steady state**
- **Pumping rate of 1000 m^3/day for 20 years**

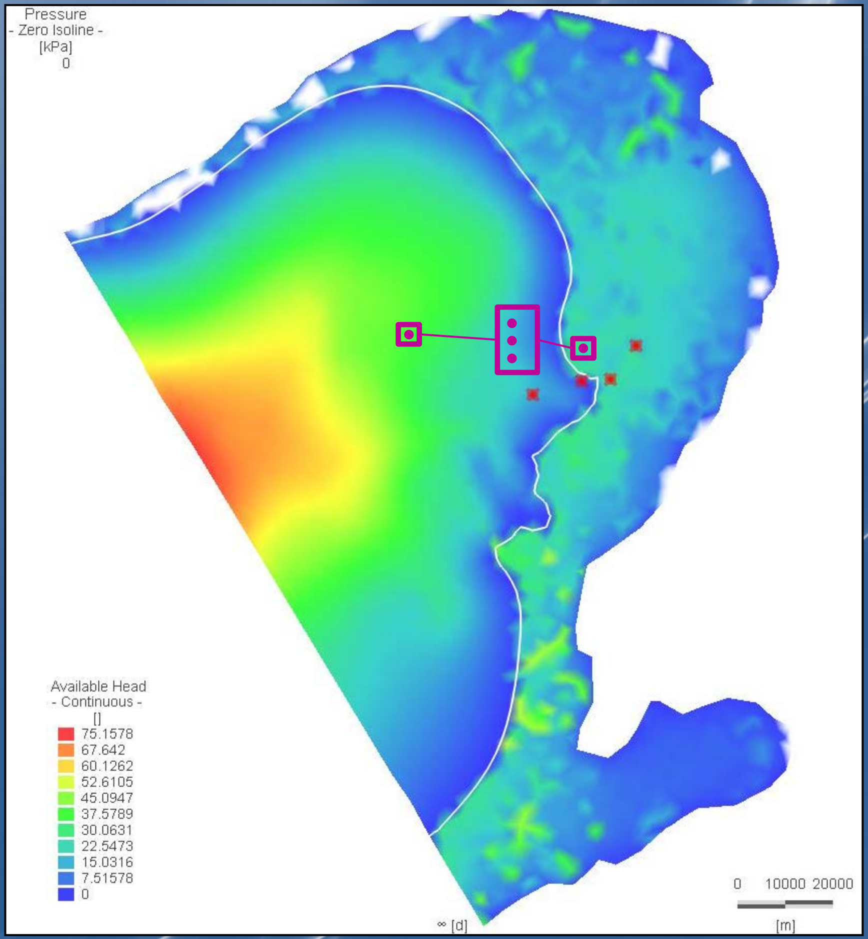




Concluding Comments

What does this mean for projects?

- **Projects located in confined portion of the aquifer with low available head may have to expand footprint to have more "optimally" placed source wells or drill more wells locally**
- **Increased footprint = higher costs, more surface disturbance and potential surface impacts**
- **Impacts to surface water are similar regardless of footprint**



Concluding Comments

- Bedrock aquifers typically thought of as confined can have unconfined conditions in certain settings
- These settings may be relatively common in Northeastern Alberta
- Water level data may be obtained in these settings by examining neutron logs through surface casing for gas effect in context with a solid conceptual model
- Regulating water use from non-saline aquifers in these settings based on available head and drawdown may not be the best approach
- Changes in discharge at subcrop edges due to groundwater withdrawal in aquifers with unconfined conditions are small and attenuated over large temporal scales

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