Thermal Effects and Quaternary Hydrogeology: Making Good Decisions in a Complex Geologic Setting

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Abstract and Introduction

Heat propagates from thermal wellbores to surrounding sediments and has been found to mobilize certain constituents bound to minerals into an aqueous phase (i.e. Bonte 2013, Fennell 2008). The thermally mobilized constituents are of concern when there is potential for them to impact domestic use aquifers (DUA's). The AER is in the process of finalizing regulations for groundwater monitoring and risk management with respect to thermal effects. In the Alberta in-situ oil sands area, almost all DUA's of concern are within the Quaternary drift package. The drift package can comprise more than 200 m of the uppermost stratigraphy in some areas. Characterization of the Quaternary drift in terms of hydrostratigraphy (aquifers vs. aquitards) and aquifer properties (thickness, extent, permeability, connectivity) is paramount to understand how heat and solutes migrate. This characterization(s) is achieved through a multidisciplinary approach with a team of Quaternary geologists, hydrogeologists and groundwater modelers and helps to predict the magnitude and extent of thermal related effects. The methods used to characterize the Quaternary system and the thermal effects assessment methods applied to this characterization are discussed in this presentation.

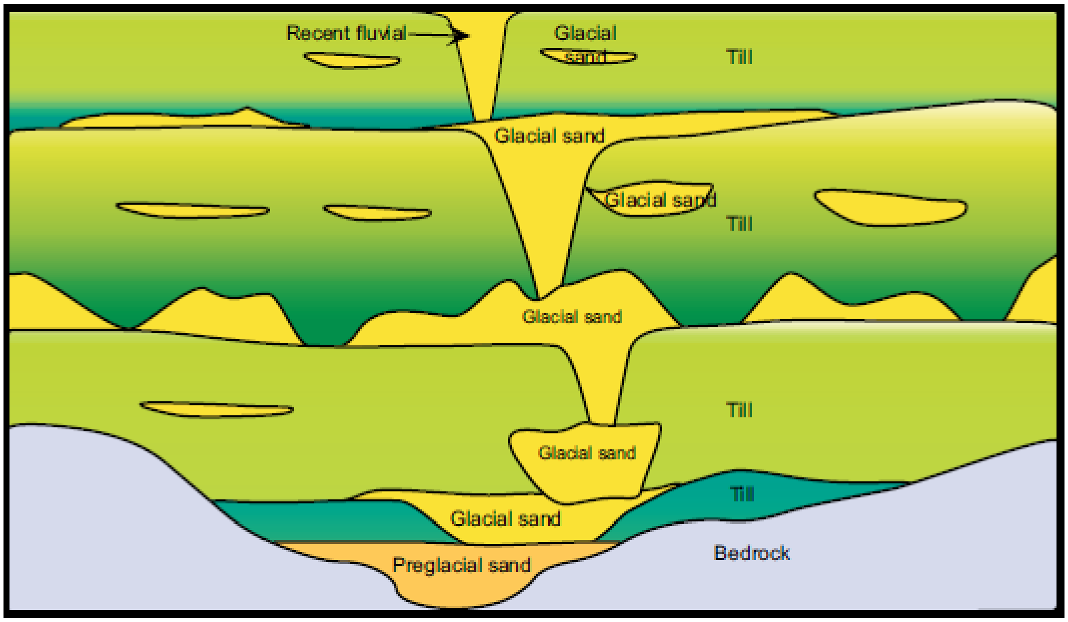
Background

The Quaternary drift interval in northeast Alberta was deposited during repeated glacial cycles of the Laurentide Ice Sheet. This included some deposition during interglacial periods. Regionally correlatable till sheets record periods of full glaciation while inter-till sand and gravel packages form aquifers of various geometries that mostly represent glaciofluvial deposition during advance and retreat of the Laurentide Ice Sheet. These sand and gravel packages can also include sediments deposited underneath the ice sheet. The stratigraphy can be complex, due in part to glaciofluvial processes that have eroded into and through underlying till sheets. These incisions can result in potential interconnections between sand and gravel layers and sand lenses deposited at different stratigraphic levels (i.e. a labyrinth type stratigraphy, Andriashek 2003; see figure below). During ice-sheet advance, glaciotectonic thrusting has further complicated the underlying stratigraphy.

Data Interpretation and Use

Fortunately, the complex Quaternary drift interval has proved mappable by integrating data commonly available to industry. These data include:

- Cased-hole geophysical well logs
- Airborne geophysics
- Seismic data
- LiDAR



Complex Quaternary drift interval and it's effect on unit connectivity: Depiction of a "labyrinth" type stratigraphy in Quaternary sediments in notheast Alberta illustrating the potential interconnectedness of aquifers units (Figure 51, Andriashek 2003)

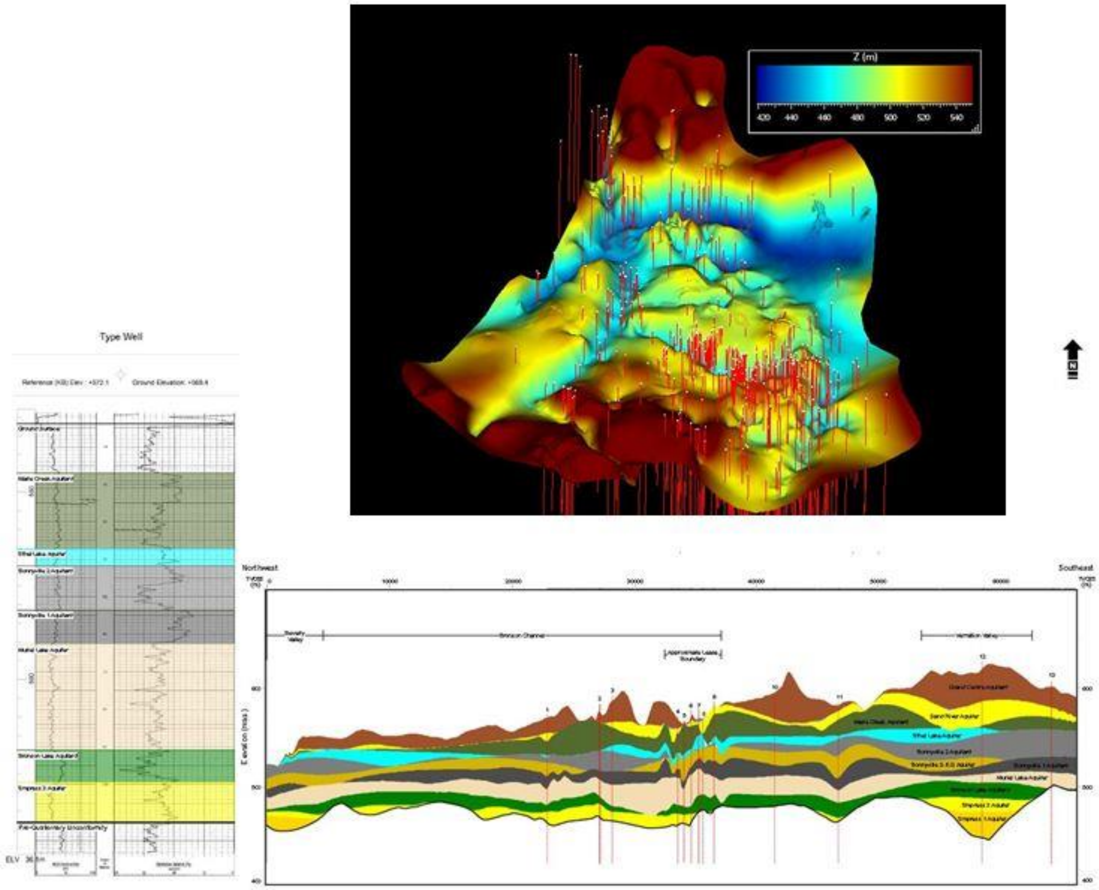
Cased-hole geophysical well logs, which include gamma ray and neutron porosity logs, are used to differentiate sand from till. Airborne geophysics is used to constrain the lateral extents of units by differentiating conductive from non-conductive materials at various depth slices. Seismic data is used to map the Quaternary base with a focus on buried channels and valleys. It is also used to interpret the stratigraphy within the Quaternary and glaciotectonized zones. LiDAR data is used to map surficial geology materials in detail to identify more permeable sediments that may be important to groundwater-surface water interaction.

Geomodeling

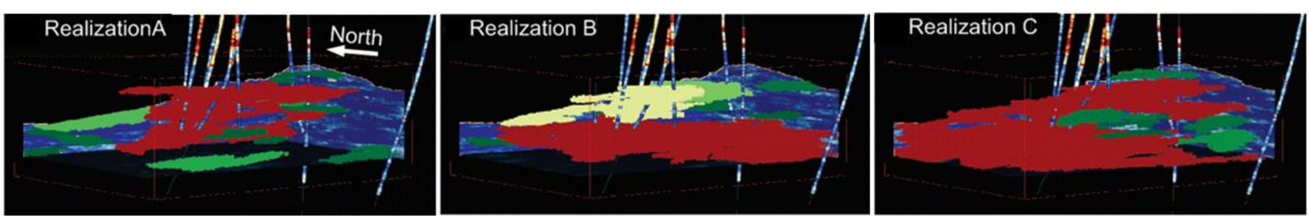
Geomodels are constructed to produce the most realistic understanding of the relevant geology by integrating a variety of data and aligning interpretations with regional geologic knowledge. Guided by an understanding of the geologic processes that formed the various aquifer and aquitard units, data control points are used to produce more realistic geologic features and geobodies including: channels, terraces, lacustrine deposits, and erosive glaciofluvial deposits. This effort results in a 3D geomodel of the Quaternary interval that highlights the local and regional distribution of key hydrostratigraphic units. The hydrostratigraphic unit distribution provides an understanding of the potential interaction between hydrostratigraphic units, specifically aquifers, to potential receptors like DUA's. Additionally, the 3D gemodel can be used to highlight the potential hydraulic connection between aquifers at depth and surface water features such as water bodies, water courses and wetlands.

Geostatistical Modeling

A geostatistical modeling approach can be used to generate multiple realizations (scenarios) of geologic unit distributions within the Quaternary package, as an alternative to the deterministic geomodel. The best case and worst case scenarios can be used to estimate the minimum and maximum likelihood of aquifer connectivity (i.e. potential for thermal migration) and to highlight the most representative scenario.



Quaternary geology reconstruction using cased-hole geophysical well logs (left) that are used to build unit distributions as cross sections (lower right), and 3D representations of major stratigraphic surfaces (top).

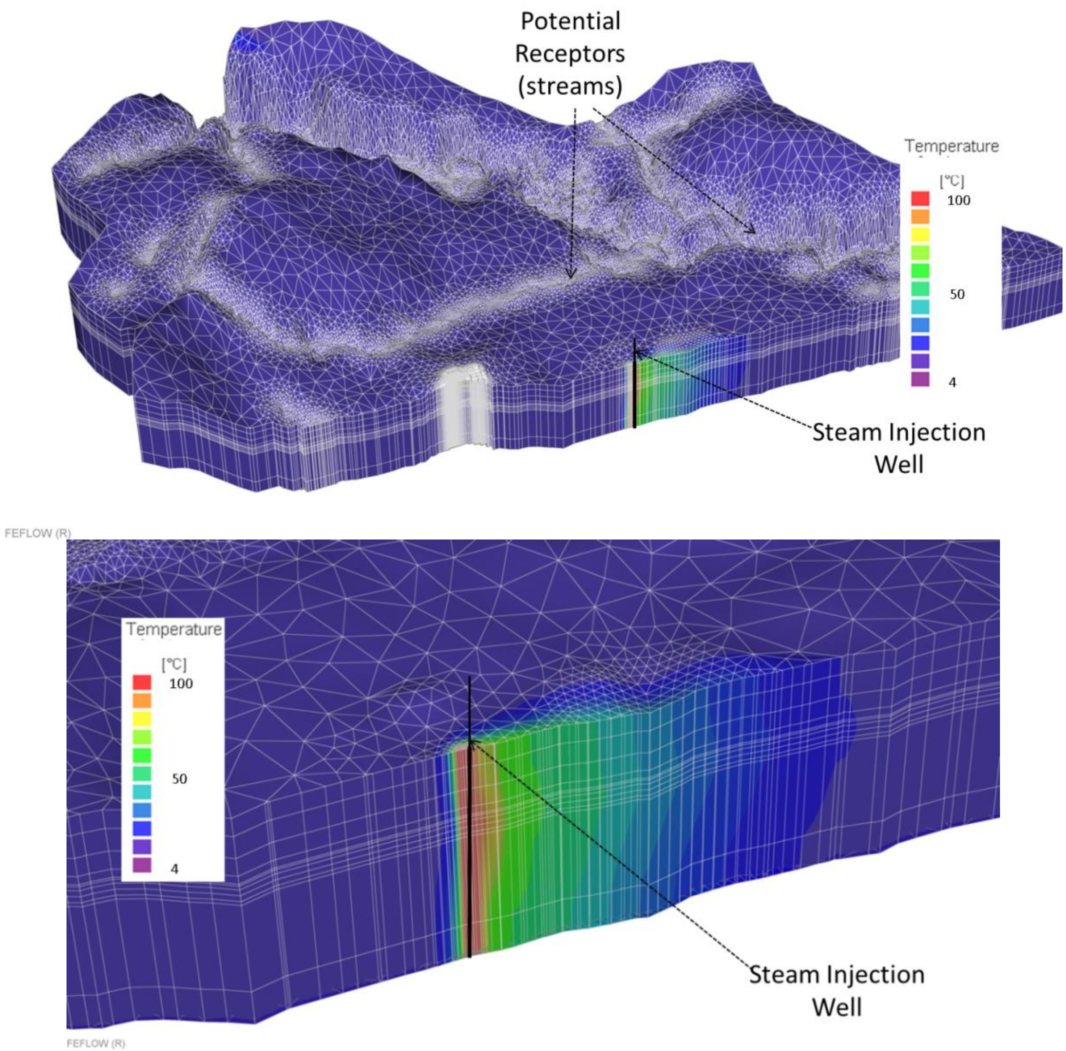


3D view of porous and connected geobodies (green, yellow and red bodies) computed on realizations of porosity A, B and C showing the variation in connectivity depending on the realization.
Figure modified from Claprood et al 2014.

Thermal Modeling

Geomodeling and geostatistical analysis provide estimates of potential unit connectivity, unit depth and overlying/underlying lithologies which are put in context for Project specific receptors (i.e. DUA's, surface water features where Quaternary aquifers may outcrop and discharge etc.). Thermal modeling should consider the influence of aquifer thickness, heat loss to overlying and underlying units, heat loss to ground surface, groundwater velocity and heat migration across the wellbore on thermal plume migration

(Matrix 2014). The predictions from thermal modeling provide the information required to make educated Project specific recommendations for thermal monitoring programs. Specifically, to frame potential effects in a manner that empowers operators with the knowledge necessary to best manage potential risks to their Project specific receptors.



Model of a themral plume from the vertical portion of a SAGD wellbore within 3D finte element groundwater model built in Feflow. Groundwater model was based on site specific subsurface geological and hydrogeological characterization and surface topography.

Conclusions

In complex Quaternary geologic settings, an understanding of the depositional environment combined with a multi-disciplinary approach of integrating geomodeling, geostatistics and hydrogeology can be used to effectively to frame risks to groundwater and surface water receptors from thermal effects. This context helps stakeholders make more effective and efficient decisions related to their monitoring networks and assess whether further monitoring or mitigative measures should be considered.

References

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