Evaluating Historical Well Data for Characterizing Regional Scale Aquifer Potential

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Summary

The Geological Survey of Canada (GSC) is establishing a framework for characterizing regional scale aquifer potential. This is a data intensive task that requires a large amount of data from multiple sources. One key component in the project is the hydrogeologic characterization of mapped geologic units that currently host aquifers. The Groundwater Information Center (GIC) Groundwater Data from Alberta Environment is one data source that has extensive coverage across the province of Alberta and can be used for the project. The GIC data provides borehole and historical hydrogeologic data that is here evaluated to determine its suitability for characterizing regional scale aquifer potential. Findings show that historical hydrogeologic data associated with lithology data from boreholes grouped into two broad geology classes and three well completion types can successfully be used to distinguish distinct hydrogeologic properties for geologic units mapped at four different scales.

Introduction

Assigning hydrogeologic properties to mapped geologic units requires spatial coincidence of boreholes (groundwater well locations that have the associated hydrogeologic data) and the polygons that define geologic units at various scales of generalization. Spatial statistics tools available in ArcGIS allow for exploratory data analysis (EDA) that is used to identify spatial patterns and/or processes that reflect or affect the occurrence of groundwater wells. Results of the spatial EDA indicate that the distribution of GIC borehole postings provide representative coverage of the mapped geologic data. The GIC data contains three broad data types (Wozniak 2009) including: Geology data represented by lithology recorded from drilling logs; Groundwater Production data represented by well construction information, water levels, and pumping test results; and Groundwater Composition data represented by results from chemical analysis of water samples taken from groundwater wells.

The GIC Geology data is first classified as either surficial materials or bedrock. The well construction data in conjunction with the classified lithology identifies completion intervals designated as SRF and BDR, for the respective surficial and bedrock classes, as well as those that span the surficial/bedrock contact (SRF_BDR). The distribution of SRF well completions and geostatistical modeling of the surficial material thickness, established by division of the lithology into two classes, show good spatial coincidence with paleochannel thalwegs (Pawlowicz et al., 2007) indicating the lithology data is well classified and also has potential for identifying the occurrence of buried valley features in certain parts of the province. Water levels from the three well completion types are compared as are aggregated values of hydraulic conductivity approximated from pumping tests, major-ion concentrations, and water types.

GIS overlay analysis provides the means to aggregate values from the point data using the surficial geology of GSC Map 1880A (Fulton, 1996), AGS DIG 2007-0012 (Shetsen, I. 2002a), AGS DIG 2007-0018 (Shetsen, I. 2002b), AGS DIG 2004-0034 (Edwards and Budney 2007); and the bedrock geology of GSC Map 1860A (Wheeler et al. 1998) and AGS DIG 2004-0033 (Hamilton et al., 1999).

Evaluation of Groundwater Production Data

Static water levels measured prior to pumping tests can be used to determine total head *h* ($h = \psi + z$ where ψ = *pressure head* and z = *elevation head*) which represents the potential for groundwater to flow to or from a location. Head values from multiple locations interpolated over an area can map the water table for unconfined conditions or a potentiometric surface in confined conditions to provide a sense of where local or regional groundwater flow occurs. The correlation between depth to static water level and well depth (or depth to *z*) is also an indicator of groundwater recharge or discharge in an area (Freeze and Cherry, 1979) and has been used to infer downward-directed flow over the Paskapoo Fm (Grasby et al., 2008). Correlation values for the GIC data across the province are weak but show a tendency toward downward-directed flow, more so in the SRF and BDR completion zones than for measurements taken at SRF_BDR wells completed across the surficial/bedrock contact.

During EDA of the water level data a relationship between pressure head (ψ) and depth to the measurement point (*z*) was noted. The R^2 values for the relationships in the three completion types range from 0.58 in BDR completions to 0.72 in SRF completions. More importantly the slope of the regression equation for the SRF and SRF_BDR completions tend closer toward a 1:1 correspondence (0.65 and 0.66 respectively) than the slope for the BDR completions which is noticeably less (0.59) suggesting that ψ makes a greater contribution to *h* at or above the surficial/bedrock contact than below this contact. The two types of relationships described are both interpreted as indicating a hydraulic conductivity (K) contrast between the defined surficial and bedrock classes and point to the possibility that the contact between the two lithology classes has an influence on regional groundwater flow.

It has long been recognized that it is possible to approximate Transmissivity (T) from specific capacity (SC) (Theis, 1964; Driscoll, 1986; Batu, 1998) and the method has been tested using both field and synthetic data (Razack and Huntley, 1991; Meier et al., 1999). Transmissivity values were determined for pumping tests conducted in the Paskapoo Fm (Chen et al., 2007) and the relationship between these T values and the corresponding SC values are evaluated. Previous work indicates the relationship between T and SC is better recognized after a ln transformation of both T and SC (Razack and Huntley, 1991) and the regression for the Paskapoo lnT and lnSC data produces an R^2 of 0.80 using data from 1021 pumping tests. Based on this strong correspondence between T and SC 32,457 pumping test results were used to approximate T from SC across the province. K values allow for better universal comparison and are backed out from the T values using well completion interval lengths as a surrogate for aquifer thickness.

The arithmetic means of aggregated K values for material types in the sand and gravel deposits data (Edwards and Budney 2007) are close to published values whereas geometric means are on the low end. The converse is true for the bedrock units where aggregated arithmetic means are on the high end for known geology and the geometric means are in the range of what is expected. The relative differences between approximated K values for the different material types are logically consistent. Gravels have higher values than sands, eolian and fluvial deposits have higher values than glacial and till deposits, surficial materials have higher values than bedrock, and Tertiary bedrock which is likely less diagenetically altered and has been closer to ground surface during its history has higher K values than Cretaceous bedrock. The latter indicates that differences between K values for 25 of the formations in the AGS bedrock data (Hamilton et al., 1999) can also be used to characterize regional scale aquifer potential.

Evaluation of Groundwater Composition Data

Concentrations of major-ions (Ca^{2+}, Mg^{2+}, Na^+, HCO_3^-, SO_4^{2-}, Cl^-) are also evaluated for the three well completion types. In the GIC data there are 4,175 SRF, 1959 SRF_BDR, and 20,128 BDR samples available, but the number of analysis that provide measured concentrations vary for each of the ions in the respective completion zones. Histograms of the concentration distributions for most ions are highly skewed so median values are considered representative values for comparison. Based on the available analysis results for Ca^{2+} and Mg^{2+}, higher concentrations for these two ions occur in SRF completions and their concentrations successively decline in the SRF_BDR and BDR completion zones. Na^+ concentration on the other hand successively increases through the SRF (96 mg/L) to BDR (320 mg/L) sequence as do the HCO_3^- concentrations. SO_4^{2-} increases between the SRF (164 mg/L) and SRF_BDR (191 mg/L) completion zones with a marked decrease in the BDR (120 mg/L) completion zone. Cl^- remains relatively unchanged between the three completion zones and Total Dissolved Solids (TDS) follow a similar pattern to that of SO_4^{2-}.

A data quality check was done to ensure there was consistent calculation of HCO_3^- which is assumed to be calculated from Total Alkalinity (TA) recorded as $CaCO_3$ in the GIC data. The charge balance between the major cations and anions was also evaluated. Samples with analysis results for HCO_3^- that fell outside a range of 1.21-1.23 for the 1.22 factor commonly used to convert TA as $CaCO_3$ to HCO_3^- were eliminated as were analysis results where the charge balance error was >±5%. The culled data was further reduced to samples where analysis values for all of the six major-ions were included and resulted in 2377 SRF, 848 SRF_BDR, and 5860 BDR samples. Although the values are slightly different between the total and culled data sets, the same trends seen in the total data set are observed in the culled set. Na^+ increases through the SRF (97 mg/L) to BDR (272 mg/L) sequence and SO_4^{2-} increases between the SRF (174 mg/L) and SRF_BDR (245 mg/L) completion zones with a marked decrease in the BDR (152 mg/L) completion zone. The higher Na^+ levels in the BDR completion zone may be a result of Ca+/Na^+ cation exchange affected by the presence of albite (Grasby et al., 2010). The occurrence of water types reflects the same trends with a corresponding dominance of Na-HCO_3 water types in the BDR completion zone.

The work of Grasby et al., (2010) using a high quality data set collected from the Paskapoo Fm proposes that a zone of SO_4^{2-} dominated water, introduced by flow of groundwater through sediments deposited during the Laurentide glaciation, is moving downward through that system as recharge is added. The authors also refer to earlier work that suggests the SO_4^{2-} zone is preceded by a zone of low SO_4^{2-} water that entered the system prior to this last glaciation. The GIC data presents a similar sequence with the SO_4^{2-} zone concentrated in the SRF_BDR completion zone at a median depth of about 36 m. The corroboration of findings using two independent data sources provides an indication that the GIC Groundwater Composition data is also suitable for characterizing regional scale aquifer potential.

Conclusions

Findings of this work indicate that the historical GIC data is of reasonable quality and quantity and has a spatial distribution that will allow for regional characterization of aquifer potential across Alberta, but establishing the suitability of the data is only the first step. The scale of geologic map units that best represent aquifer systems must be established and methods for aggregating the hydrogeologic data must be refined to ensure proper characterization of the geologic units. Methods for differentiating the representative values of geologic units must also be evaluated and GIS Weights of Evidence methods may offer a solution for future work.

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