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Regional hydrogeological mapping of saline and non-saline groundwater resources in the Belly River Group of the Alberta Basin

Introduction

The inventory of saline groundwater resources is becoming increasingly important as the Government of Alberta implements its Water Conservation Policy to reduce freshwater use in the energy sector and identify alternate sources of water. The groundwater program at the Alberta Geological Survey (AGS) is undertaking hydrogeological mapping to quantify the distribution and chemical composition of regional saline and non-saline aquifers. This work is part of a tiered approach for sustainable groundwater management (Figure 1). Figure 2 displays total water allocation across all sectors. It identifies increase of approximately 1 billion m^3 of water allocaton every decade. Figure 3 shows the increasing trend of using saline water for oilfield injection in Alberta over the last decade.

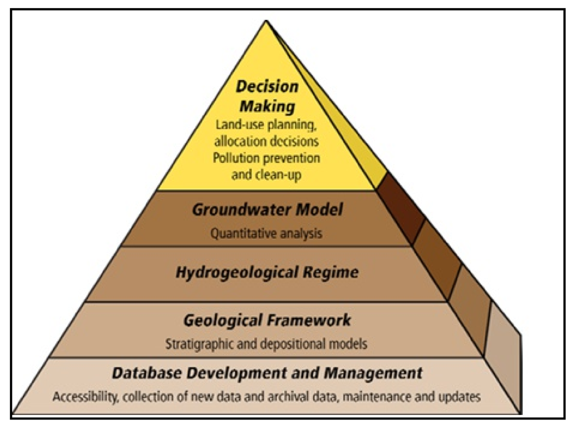


Fig 1. Science requirements for groundwater sustainability (Council of Canadian Academics, 2009)

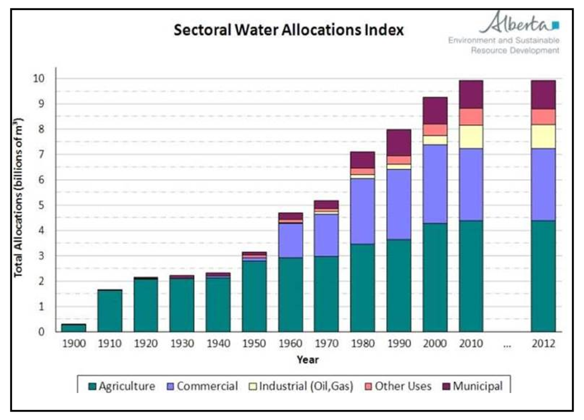


Fig 2. Alberta Water Allocation

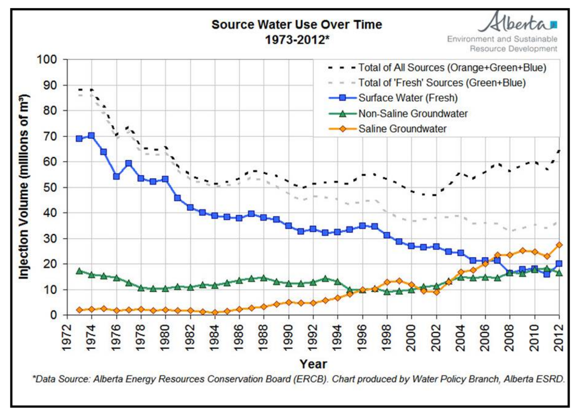


Fig 3. Source water use over time

Why Belly River Aquifer Mapping?

- Regional aquifer containing non-saline and saline groundwater
- Important water source for domestic users
- Target aquifer for alternative water source in unconventional oil and gas development
- One of the youngest (upper Cretaceous-aged) economically important hydrocarbon producing zones in Alberta

Study Objective

Given the various groundwater uses on the Belly River aquifer, and the fact that the aquifer contains saline and non-saline groundwater, it is important to map regional groundwater flow, salinity, and where relevant, density-corrected flow directions to assess current and future development opportunities for this aquifer.
Our current study is focused on mapping:

- salinity
- hydraulic head
- density-corrected flow directions

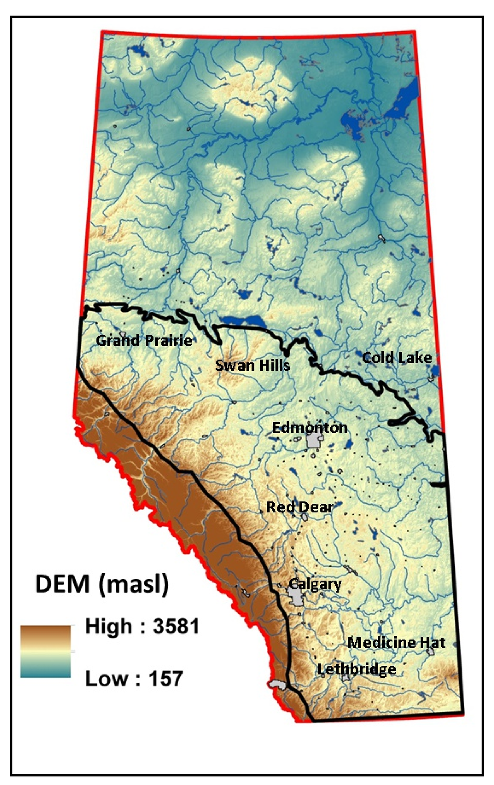


Fig 4. Study area with hydrography, major cities and Digital Elevation Model (DEM)

Geologic Setting

The Belly River Group comprises a westward-thickening, nonmarine to shallow marine clastic succession of Campanian-age. It has a maximum thickness of about 1300 metres in the west, and progressively thins toward its erosional extent in the east.

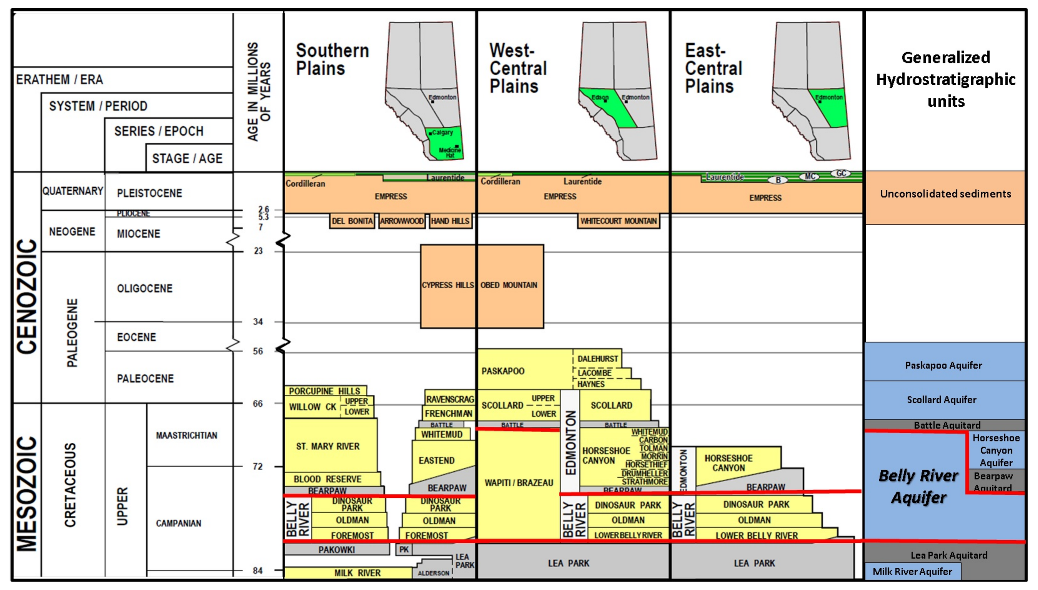


Fig 5. Alberta Table of Formations with generalized hydrostratigraphy (AGS, 2015)

In the southern plains, and partially in the west and east-central plains, the Belly River Group is overlain by the north-westward-thinning marine shales of the Bearpaw Formation, which underlies the Horseshoe Canyon or St. Mary River formations. In parts of the plains where the Bearpaw Formation is absent, the Belly River Group and the overlying Horseshoe Canyon Formation are not distinguishable from one another and are stratigraphically known as the Wapiti Formation. In southern Alberta, the Belly River Group has been subdivided stratigraphically into the Foremost, Oldman and Dinosaur Park formations, which have similar hydraulic properties on a regional scale and are grouped together (Figure 5). For the same reason, we have grouped the Belly River strata and its lateral equivalents into one regional aquifer unit forming the Belly River Aquifer (Figures 6 & 7).

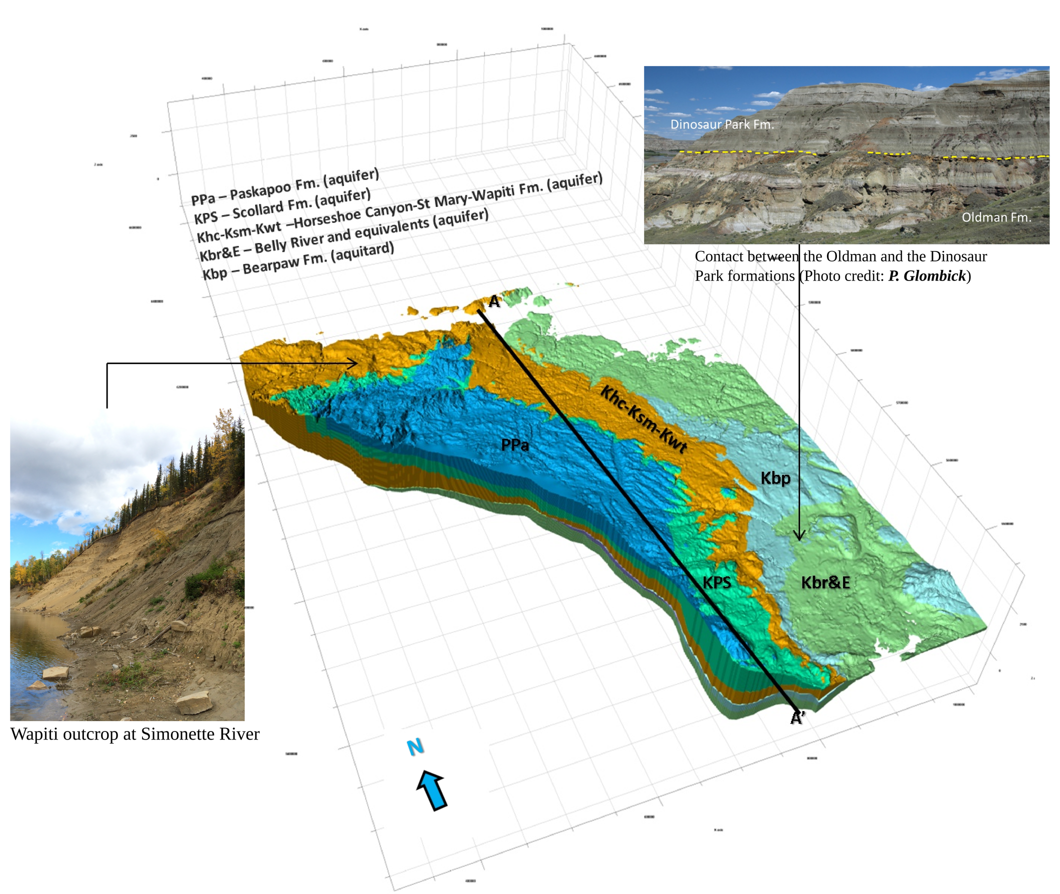


Fig 6. Extract from AGS 3D Geological Framework (*Courtesy K. MacCormack, AGS*)

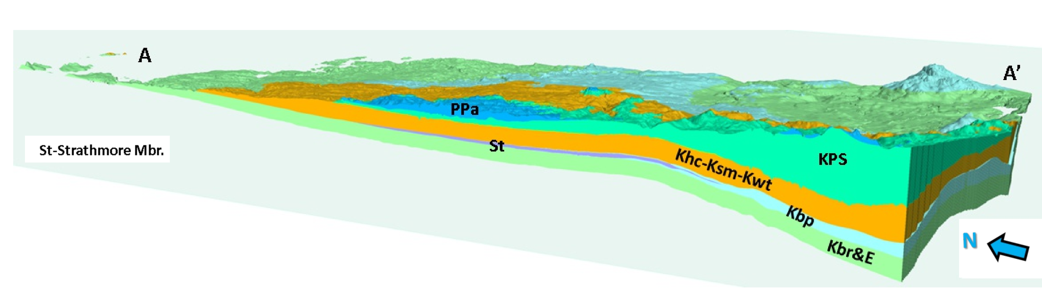


Fig 7. Cross-section A-A'

Data Sources and Methodology

Data from two sources were analysed (Figure 8):

1. Alberta Water Well Information Database (AWWID), to evaluate hydraulic heads and chemical analyses, and
2. Drill stem tests (DST) and production data, to obtain pressure data

DSTs were subjected to screening criteria to ensure that only representative pressures were used to calculate hydraulic heads. A method called the Cumulative Interference Index (CII), (e.g. Tóth and Corbet, 1986) was also used to examine the influence of production and injection on the pressure recorded during the DST (Figure 9). Chemistry data was also subjected to screening criteria to identify potential contamination of formation water by drilling fluids such as acid water, corrosion inhibitors, mud filtrates, and alcohols (modified after Hitchon 1996).

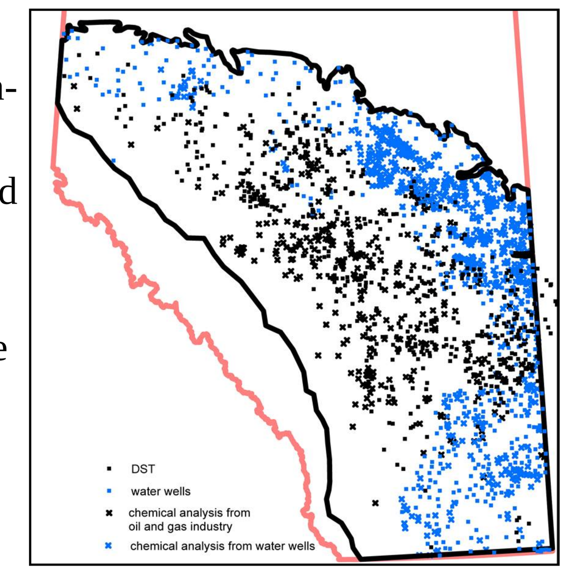


Fig 8. Spatial distribution of data sources

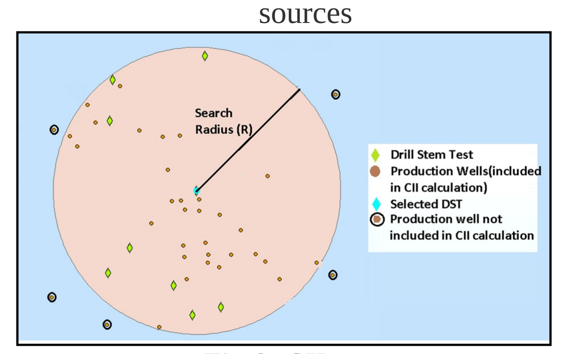


Fig 9. CII concept

Considering Density Effects and Implementing the Water Driving Force (WDF)

- Formation water density variations (buoyancy) can affect the magnitude and direction of formation water flow, particularly in aquifers with dense brines, large dip or small hydraulic gradient.
- Traditional use of freshwater or reference formation water densities for calculation hydraulic head assumes negligible density variations within the aquifer.
- Neglecting density variations can result in misinterpretation of both groundwater flow direction and magnitude.
- Figure 10 introduces the concept of WDF, used to create a python script (Figure 11) to evaluate potential areas of density-dependent flow.
- In situ brine density is calculated as a function of pressure, temperature and total dissolved solids (TDS) using the Chierici (1994) equation.

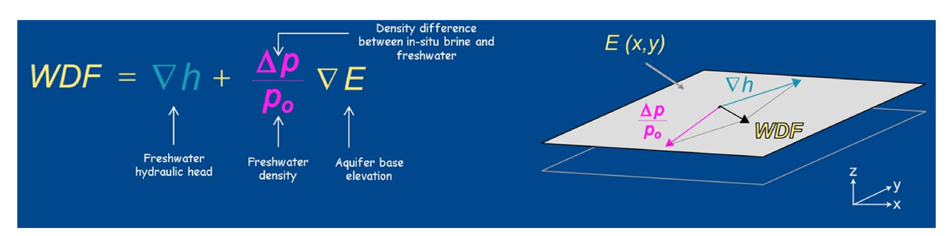
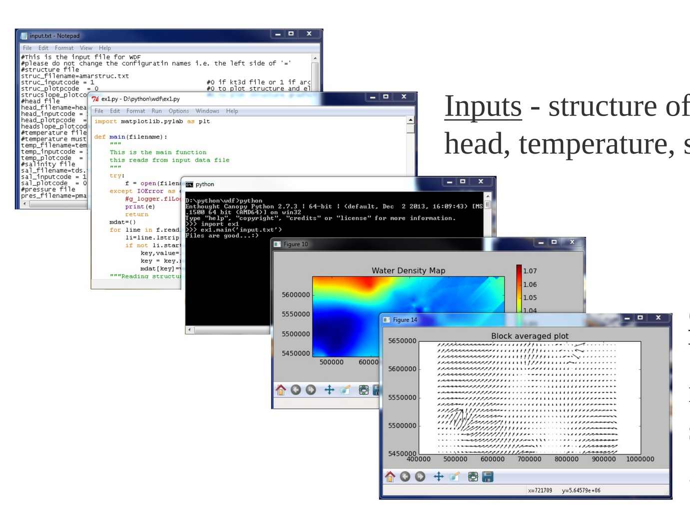


Fig 10. WDF equation modified after Davies, 1987



Inputs - structure of confining unit, hydraulic head, temperature, salinity and pressure grids

Outputs - water density map, WDF direction/magnitude map, aspect difference (WDF structure slope and WDF head gradient)

Fig 11. WDF implementation using python script

Results-Belly River Aquifer Maps

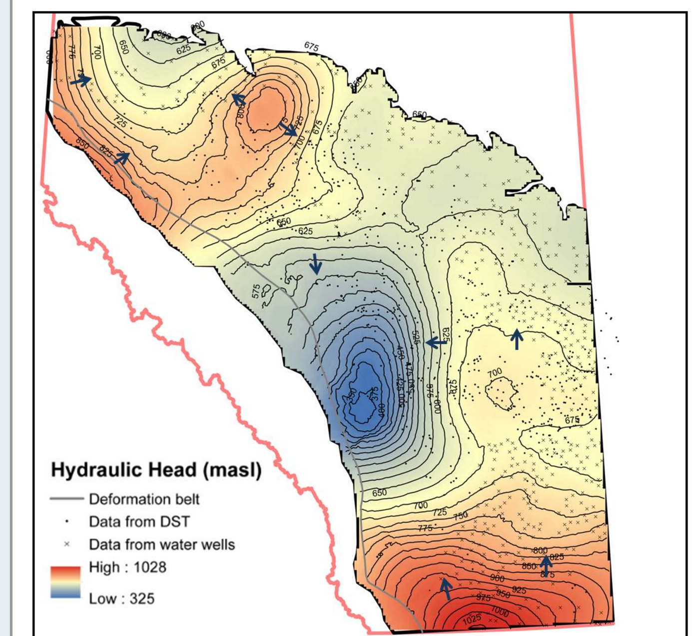


Fig 12. Hydraulic head map

- Distribution of hydraulic heads indicates mainly topography-driven flow in the northwest, northeast, and south. Hydraulic heads in the west-central part of the basin indicate groundwater flow reversal, where hydraulic heads drop by approximately 250 m toward the deformation belt over a 70-km distance (Figure 12).The high salinity and the west-southwestward decrease in hydraulic head in this region indicates flow driven by erosional rebound (Bachu and Michael, 2002).

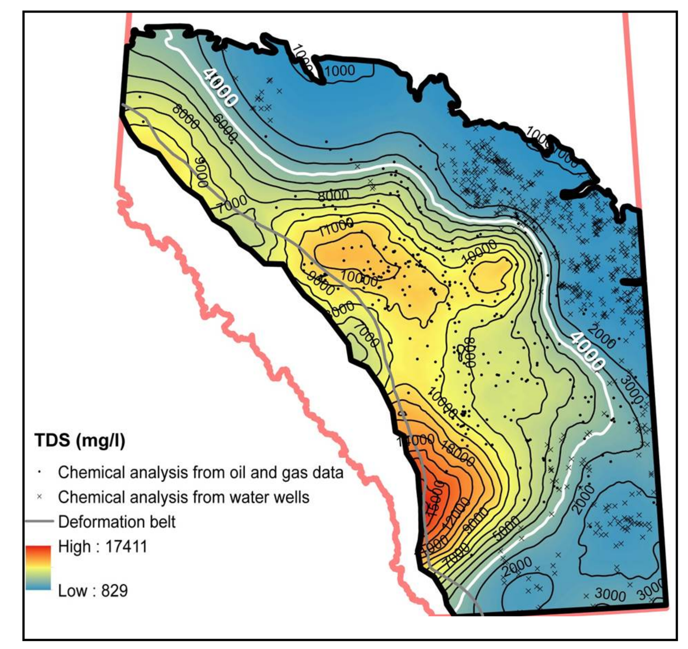


Fig 13. Salinity map

- Salinity varies from non-saline (fresh) in the eastern part of the aquifer to saline toward the deformation belt. The white contour on Figure 13 marks the interpolated 4000 mg/l isoconcentration line that distinguishes saline and non-saline groundwater in Alberta. Salinity generally increases in the direction of groundwater flow except in the northwest where it increases in the direction opposite of groundwater flow (Figure 13).

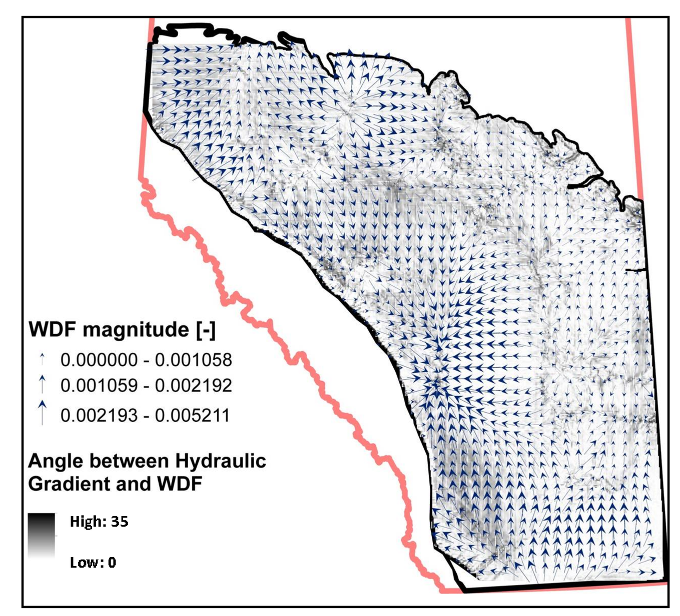


Fig 14. Water driving force (WDF) map

- The WDF vector map (Figure 14) shows the flow directions and gradients in the regions where density could change the inferred magnitude and direction of flow. The small angle between the WDF vector and hydraulic gradient vector (< 35 degrees) indicates no significant effect of buoyancy on the groundwater flow direction, as a result of the dominant hydraulic gradient over the density gradient.

Summary

1. Non-saline and saline groundwater zones in Belly River Aquifer have been identified and mapped using water wells and industry data.
2. Implementation of WDF methodology did not identify areas where density can significantly change the inferred magnitude and direction of groundwater flow.
3. Three new regional-scale aquifer maps have been produced, providing regional insights to the distribution, composition and availability of groundwater in the Belly River Aquifer.
4. Belly River Aquifer maps to be published and available on AGS website (ags.gov.ab.ca) early 2016.

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