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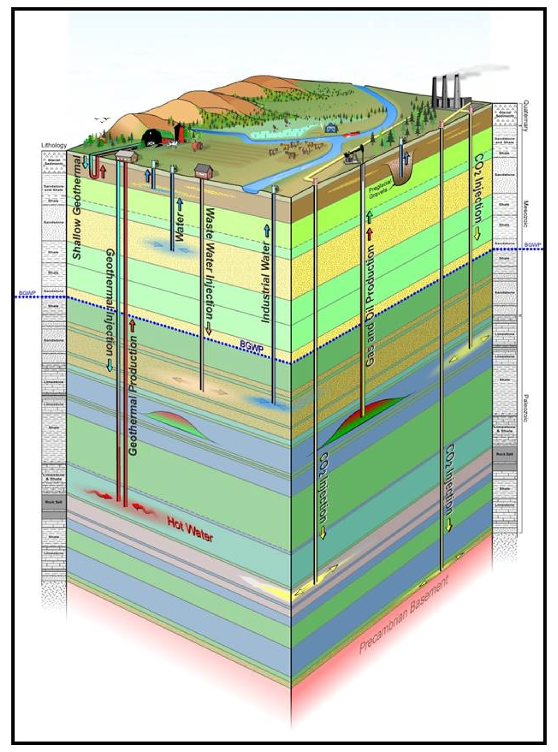
Advancing Methods for Hydrogeological Characterization of Deep Aquifers in Sedimentary Basins

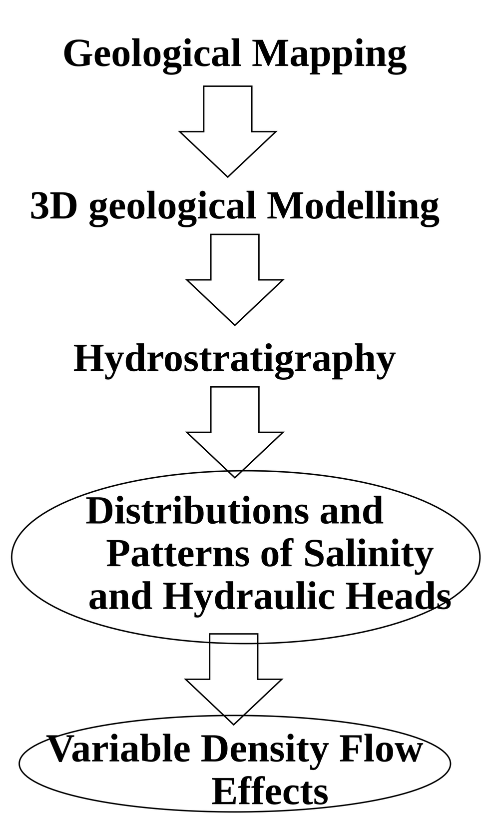
Alberta Energy Regulator

AGS ALBERTA GEOLOGICAL SURVEY

Introduction

The Alberta Geological Survey's (AGS) Groundwater Program is focused on identifying, characterizing and quantifying Alberta's groundwater resources. Characterization and mapping of deep groundwater resources is becoming increasingly important as the Government of Alberta implements its Water Conservation Policy seeking to minimize freshwater use.





Workflow for hydrogeological characterization of deep aquifers

Two methodologies are presented in this work.

1. Improving the data quality for pressure measurements in deeper (> 4000 mg/l) units used for mapping hydraulic heads. Drill stem testing (DST) or pressure-transient testing is an oil and gas exploration procedure to determine the fluids present and the rates at which they can be produced from a formation. The focus here is to identify the DST's pressure measurements influenced by nearby production/ injection.
2. The Water Driving Force (WDF) methodology to takes into account the density variations in hydraulic head mapping for deeper aquifers. This study implements a vectorial analysis to account for density variations which are often neglected in conventional analysis.

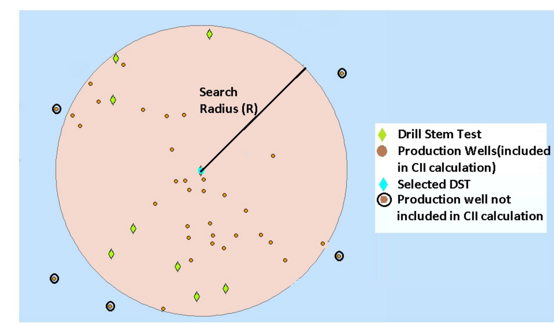
Assessing Production and Injection Effects

- DST results are directly influenced by test conditions as well as the hydrogeological conditions in the vicinity of test.
- Even for good quality tests, there are still a number of issues in measuring formation pressures such as presence of production/ injection wells in the vicinity, inaccuracies in the position of the gauges, gas/hydrocarbons, or fluid variations.
- DST measurements must be reviewed and culled carefully in order to determine the best estimate of the formation pressure. Cumulative Interference Index (CII) methodology can be implemented to identify the production /injection influences.
- The CII methodology assumes that for production influences, in analogy to water-well testing principles (Bruin and Hudson, 1961; Tóth and Corbett, 1986) the effect is directly proportional to an inference index, $\log(t/r^2)$. Here 't' is the length of time, in years, since production started before the pressure measurement and 'r' is distance between the production wells and the well where the pressure was measured.
- The CII index for a particular DST is the cumulative sum of interference indices for pumping/injection wells in the surrounding region.

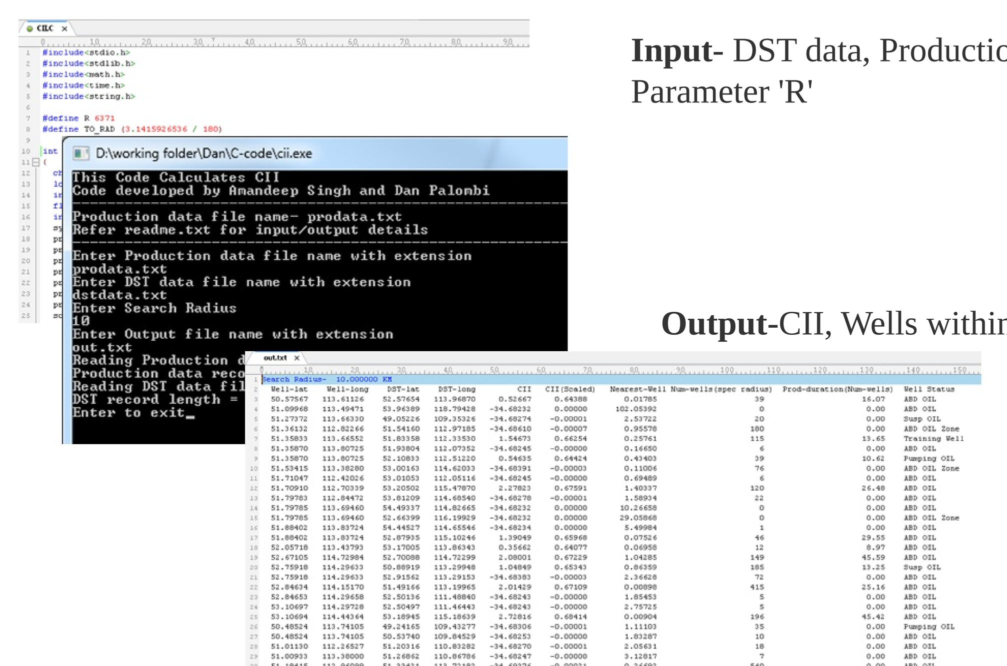
Cumulative Interference Index (CII)

C-code was developed for implementing the CII methodology (A.I. Alkalali, and B.J. Rostron, 2003).

- Methodology implemented uses a parameter "R", the search radius from DST location within which the production wells are included in CII calculation.
- CII value of zero indicates no production effect (i.e. no wells within the search radius before the test) and the value of 1 indicates DST at the production location.



CII methodology



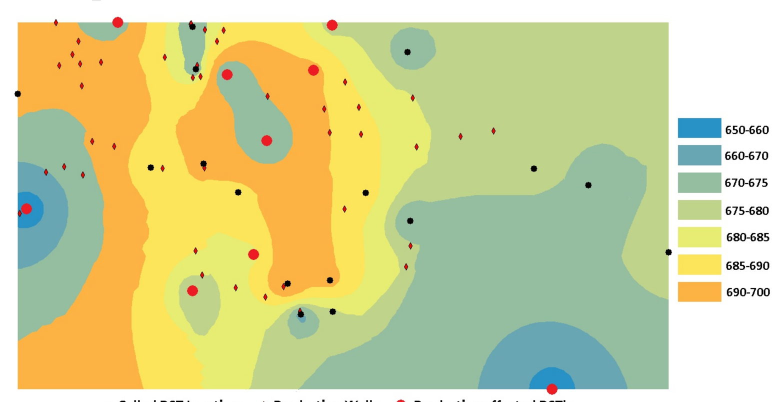
Input- DST data, Production well data, Parameter 'R'

Output-CII, Wells within 'R'

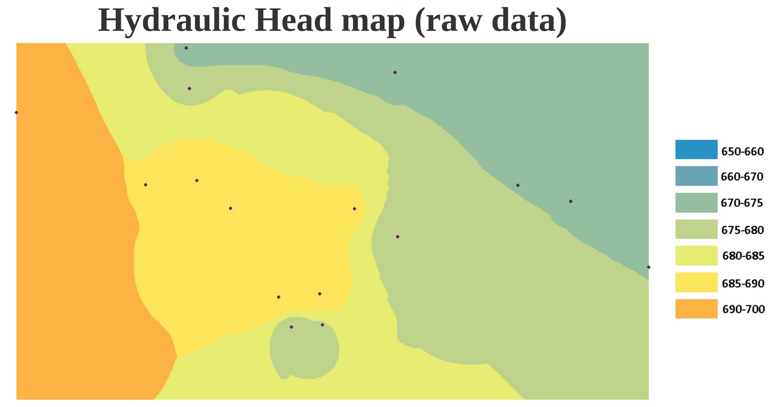
CII Implementation

Case Study

- A case study for the area spanning across 4 Alberta township (032-8-W-4 to 032-10-W-4) is presented within eastern Alberta.
- Figures to the right show the head map from the raw data set and the head map from the culled data set, illustrating the differences and need to cull the DST dataset for quality and production influences.



Hydraulic Head map (raw data)



Hydraulic Head map (culled data using CII)

Variable Density Flow Effects

Regional groundwater flow in majority of sedimentary basins around the world has traditionally been studied using:

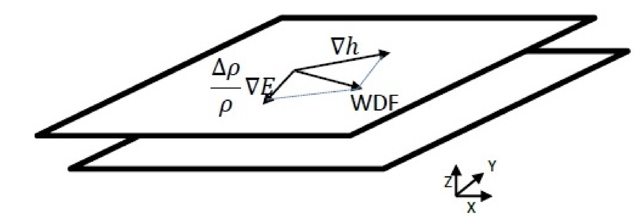
- Freshwater hydraulic heads.
- Pressure-depth plots.

These methods assume that the density variations within the formation are negligible. However in practice the density driven flow can be important in aquifers with dense brines, large dip, or small hydraulic gradient. This study implements a Water Driving Force (WDF) approach (i.e. a vectorial analysis to identify flow directions in regions where density-driven flow is important and can change the inferred magnitude and direction of flow).

Water Driving Force (WDF)

Based on Hubbert's (1940) and Davies (1987) work the "Water Driving Force" can be defined as

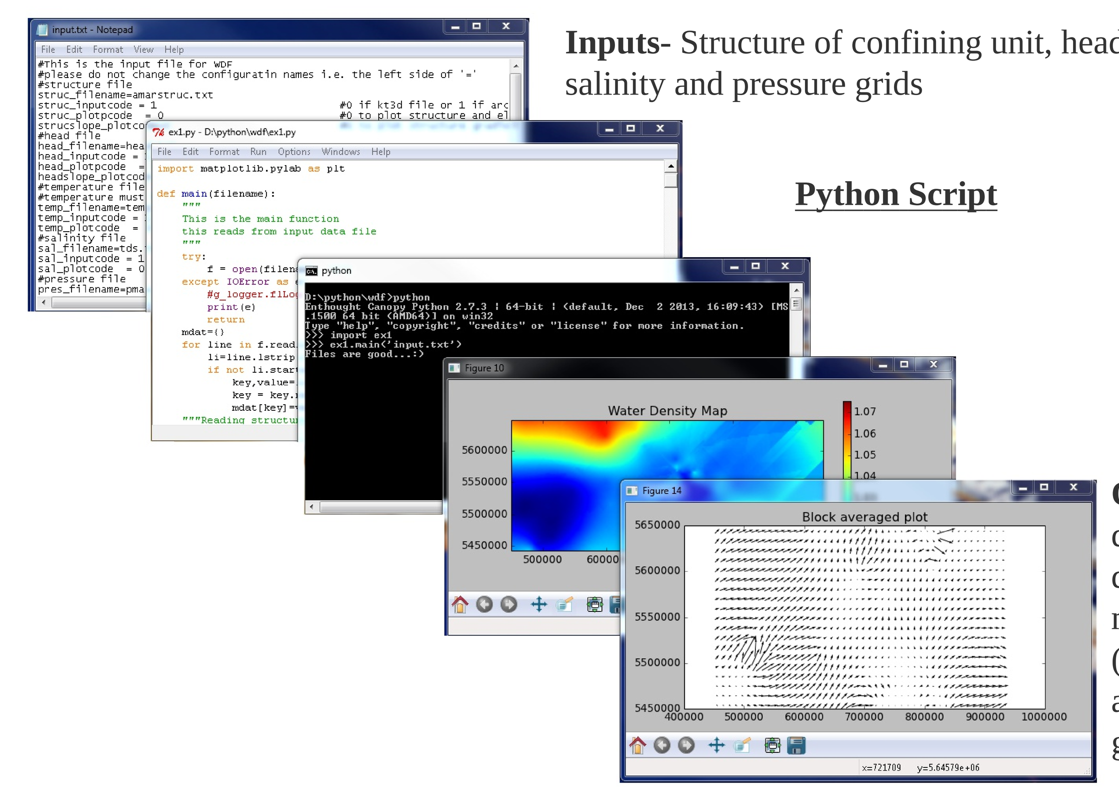
$$\mathbf{WDF} = \nabla \mathbf{h} + \frac{\Delta\rho}{\rho_0}\Delta \mathbf{E} \qquad (1)$$



where, h is the freshwater hydraulic head, Δρ is the density difference between in-situ brine and freshwater, ρ is the density of freshwater, and E is the elevation of the aquifer base.

- In equation (1), the first term represents the force due to potential gradient whereas the second term represents the force due to buoyancy.
- The equation represents the addition of two vectorial terms, which gives the net driving force on the formation water at a particular point.
- In situ brine density is calculated as a function of pressure, temperature and total dissolved solids (TDS) using Chierici (1994) equation of state.

WDF implementation



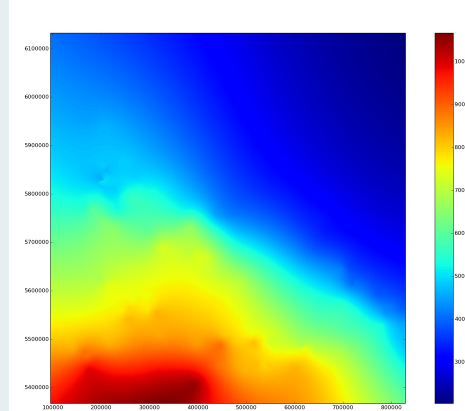
Inputs- Structure of confining unit, head, temperature, salinity and pressure grids

Python Script

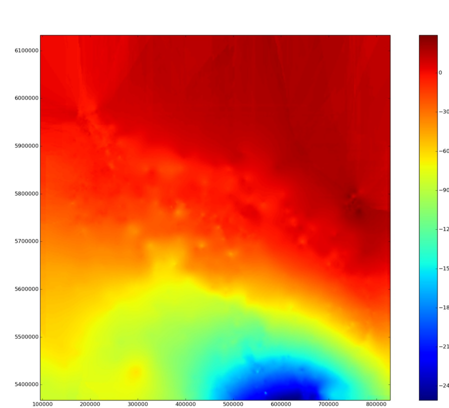
Outputs -Water density map, WDF direction/magnitude map, Aspect difference (WDF - strucure slope and WDF- head gradient)

Case Study

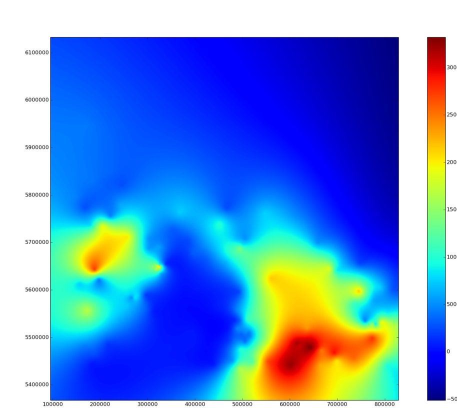
- A case study is presented for the illustration of WDF implementation. The aquifer presented is the Duperow aquifer from the Williston Basin.The aquifer has a maximum thickness of 150m and is composed of limestones/dolostones alongwith layers of sandstones, siltstones and shale belonging to the Upper-Devonian system.



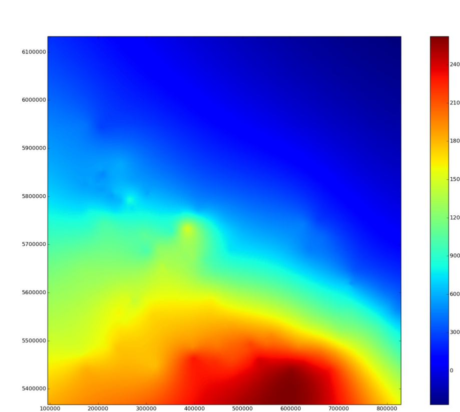
Hydraulic Head map



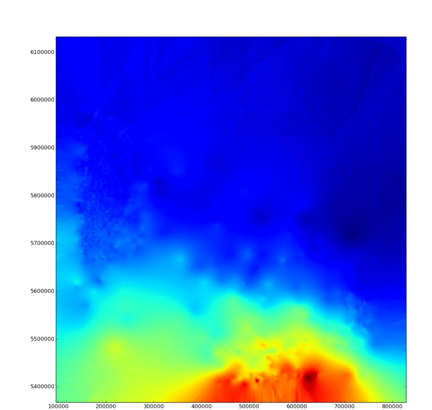
Structure map



Salinity map



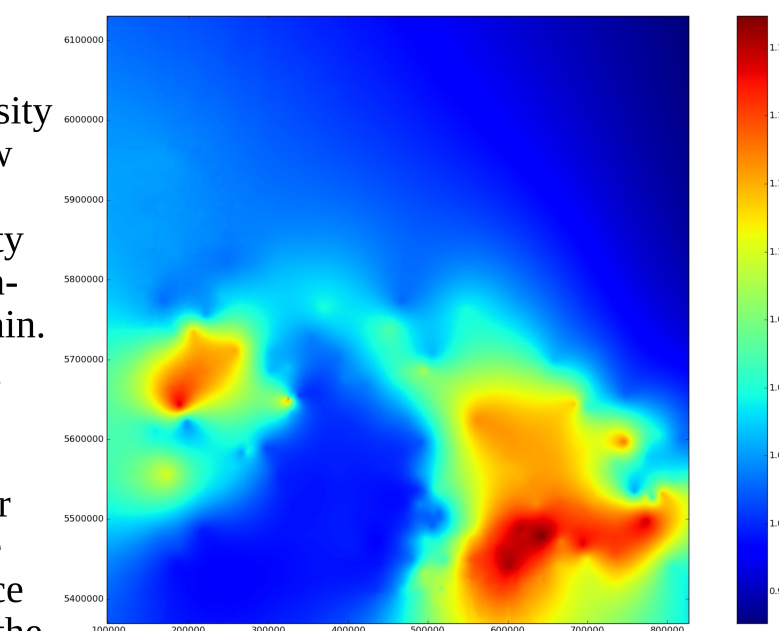
Pressure map



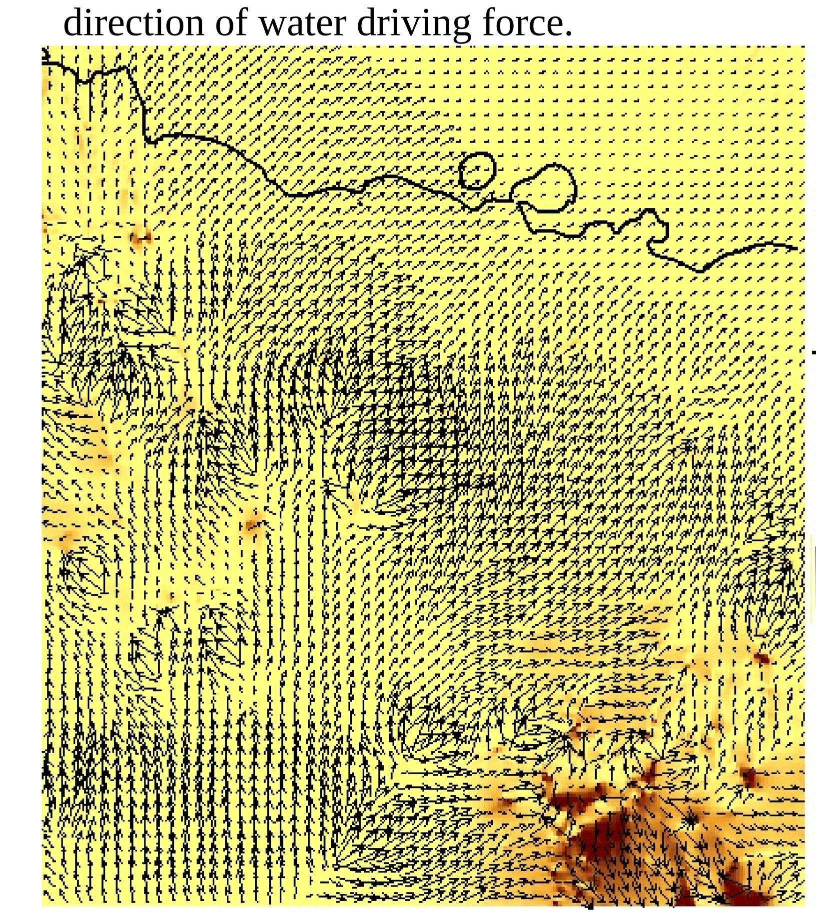
Temperature map

Results

- Figure to the right shows the water density map for the Duperow aquifer. The map shows that the density is higher in the south-east part of the domain.
- Figure below shows the vector map for WDF and the angle between WDF vector and head vector. The arrows show the force acting on water and the colour demonstrates the WDF angle with respect to the head vector. The figure demonstrates that the WDF method can help identify the regions where density driven flow should be taken into consideration and the approximate direction of water driving force.



Water density map (kg/l)



Water driving force magnitude and direction

Conclusion

- As industry in Alberta moves to utilize more saline water, a more comprehensive understanding of deep groundwater will be required to manage and allocate water resources in the province. Current work focuses on developing existing methodologies to map regional groundwater flow across large areas in a mature sedimentary basin.
- CII methodology provides the user a tool to identify and cull out potentially erroneous production influenced pressure measurements, in order to map distributions of hydraulic head unaffected by production influences. The methodology can also be used to map present-day (after production) hydraulic head distribution.
- The WDF methodology assists in identifying the regions of an aquifer where density driven flow needs to be taken into account. The methodology implements a vectorial analysis to identify flow directions in these regions where density can change the inferred magnitude and direction of flow.

Acknowledgements

Government of Alberta

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