Mapping groundwater conditions of deep saline formations in West-Central Alberta

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Alberta Energy Regulator

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ALBERTA GEOLOGICAL SURVEY

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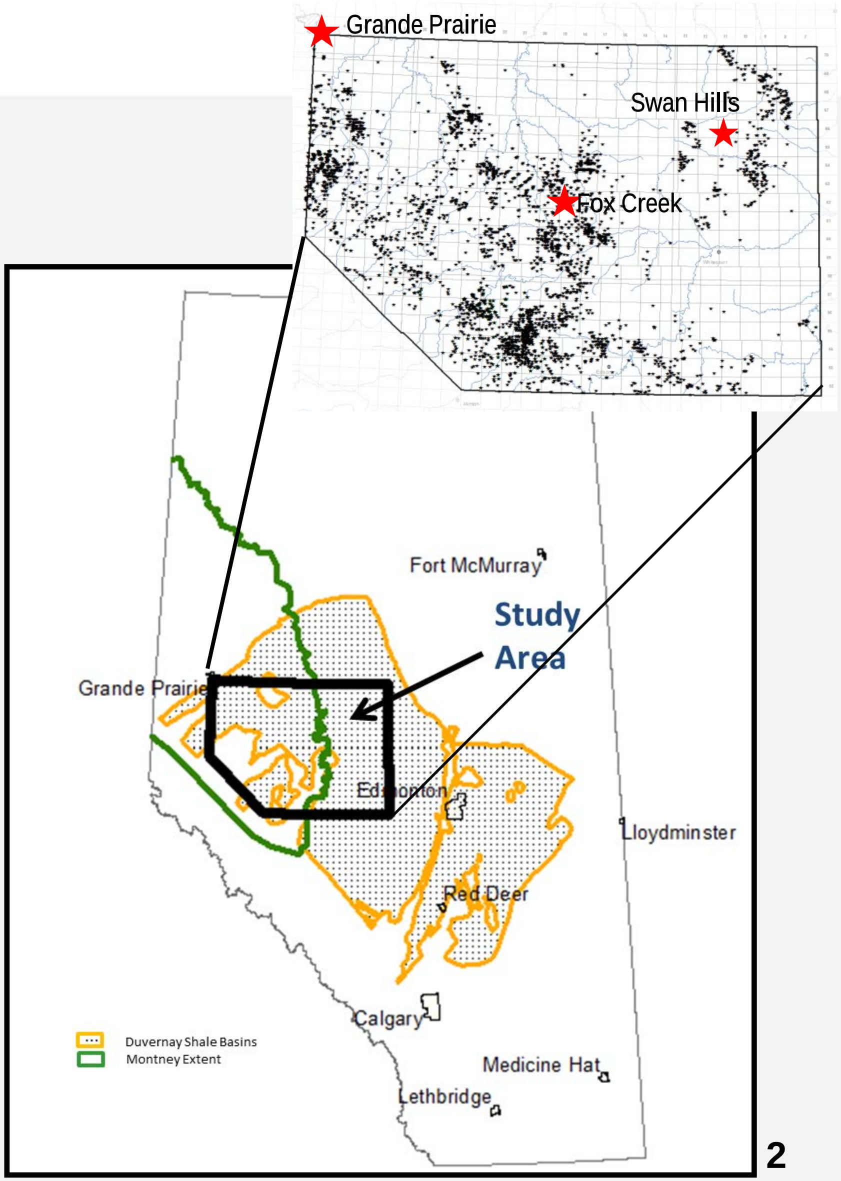
Area of Interest

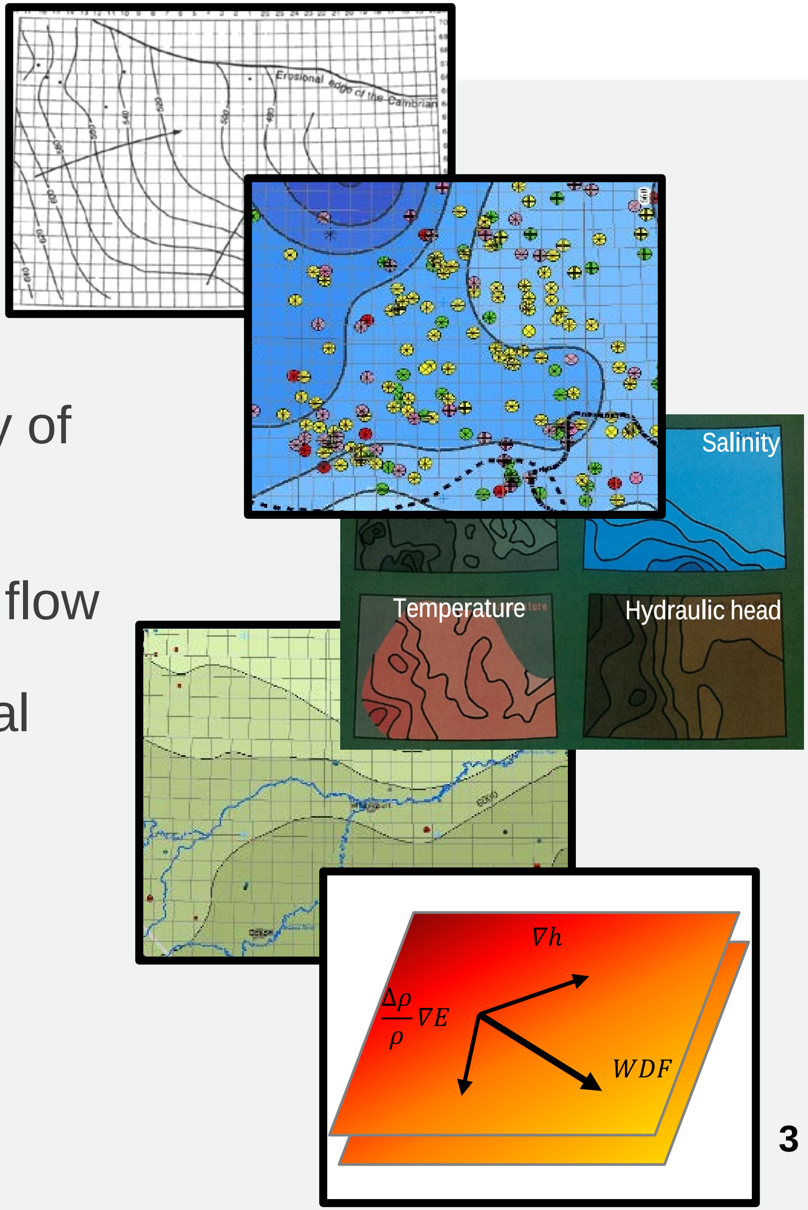
- Area centered on the Town of Fox Creek (42,840 km^2)
- Area of active industry development
- Unconventional resource plays in Duvernay and Montney formations
- Increasing water demand for hydraulic fracturing



Project Purpose

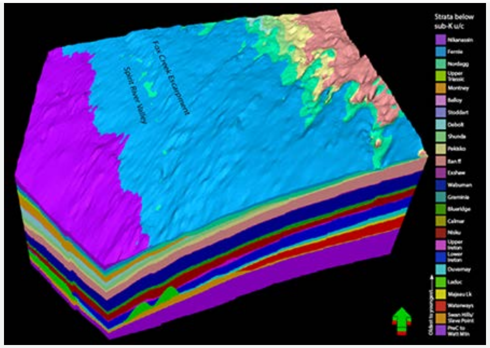
To understand:

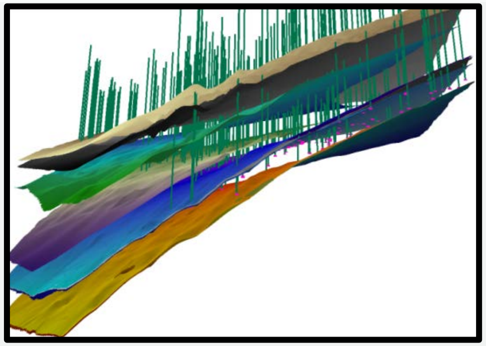
- Basin-scale flow systems (determine direction and rate of movement)
- Characterize formation water chemistry of deeper saline formations
- Variable density effect on groundwater flow
- Potential for water sources and disposal zones (flow-back, produced fluids)
- Inform government, regulator, industry

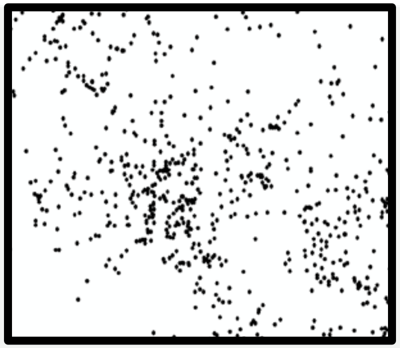


Hydrogeological Mapping Workflow

Data Sources


3D Geological Framework grids by AGS


Data allocation


Data analyses and culling

Products

Hydraulic Head Map

- Representative formation pressures
- DSTs recovering water
- Mechanically successful DST (stable or near stable pressure)
- Identify production/injection influenced pressures using CII (goal depending)

Salinity Map

- Samples representative of formation water
- DST recovering enough water (>100 m)
- Samples with no indication of contamination
- Preferably bottomhole samples, at reservoir pressure and temperature

Water Driving Force (WDF) Map

- Neglecting density variations within a formation may result in misinterpretation of both groundwater flow direction and magnitude
- WDF map identifies regions where density could change the inferred magnitude and direction of flow

Implementing CII and WDF

Focus on two aspects:

- The influence of hydrocarbon production and injection on pressure measurements used to map hydraulic heads
- The effect of variable density groundwater on understanding the magnitude and direction of flow in saline aquifers

Two methodologies used:

- Cumulative Interference Index (CII)
- Water Driving Force (WDF)

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Research paper

An efficient approach for characterizing basin-scale hydrodynamics

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A R T I C L E I N F O

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Hydrodynamics

A B S T R A C T

As the upstream oil and gas sector continues to use more groundwater resources for their operations, a comprehensive understanding of formation fluids at the sedimentary basin scale is required to inventory and manage available groundwater resources. Basin-scale fluid flow is often simplified to only assess pre-development groundwater conditions without understanding how large-scale hydrocarbon development might be changing regional flow patterns. This study focuses on two aspects of hydrogeological mapping for characterizing basin-scale hydrodynamics: (1) assessing the influence of hydrocarbon production and injection on pressure measurements used to map hydraulic heads and infer groundwater conditions; and (2) determining the effects of variable density groundwater on understanding the magnitude and direction of flow primarily in saline formation water aquifers. Drillstem Tests (DST's) are transient pressure tests that are used to infer regional groundwater flow, but they can be strongly affected when the sample location is located within the vicinity of a hydrocarbon production or injection well. To identify production and injection influences this study implements a Cumulative Interference Index (CII) methodology. This implementation can be used to map pre-development groundwater flow conditions and evaluate regional changes or effects due to historical oil and gas activity. Density effects are often neglected and can have considerable effect on groundwater flow in cases where aquifers contain dense brines, are inclined and sloping, or possess weaker hydraulic gradients than the buoyancy force potential. This study implements 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. Two case studies are presented to demonstrate the effectiveness of these methodologies at evaluating basin-scale hydrodynamics.

1. Introduction

The importance of groundwater resources in many sedimentary basins is ever increasing with the onset and expansion of water-intensive hydrocarbon production technologies e.g. Steam Assisted Gravity Drainage, hydraulic fracturing, etc. Geoscience agencies continue to focus on evaluating the distribution, occurrence, and availability of groundwater resources at the basin scale and hydrogeological mapping plays a major role in this assessment.

Many basin-scale hydrogeological investigations aim to assess the pre-development state of groundwater flow i.e. the natural conditions (Hitchon, 1969a,b; Bachu and Underschultz, 1993). Typically data points that either appear anomalous or unexplainable in comparison to the overall direction of flow are not considered important in understanding the phenomenon related to regional groundwater flow. This brings into question an important aspect of basin-scale mapping which is the procedure taken for differentiating high and low quality data given the abundance of issues related to acquiring representative formation pressures information, such as those determined from Drillstem Tests (DST's). Resolving poor quality data from that which could appear abnormal but related to production or injection operations can get significantly more challenging for mature hydrocarbon-rich sedimentary basins with hundreds of thousands of pressure measurements.

One of the persistent challenges in saline groundwater studies is the treatment of density variations in aquifers containing variable salinity formation water especially when evaluating the aquifer across its entire extent (Bachu, 1995). Formation water density can have considerable effect on predicting groundwater flow especially in the sedimentary basins with significant density variations. A

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Cumulative Interference Index (CII)

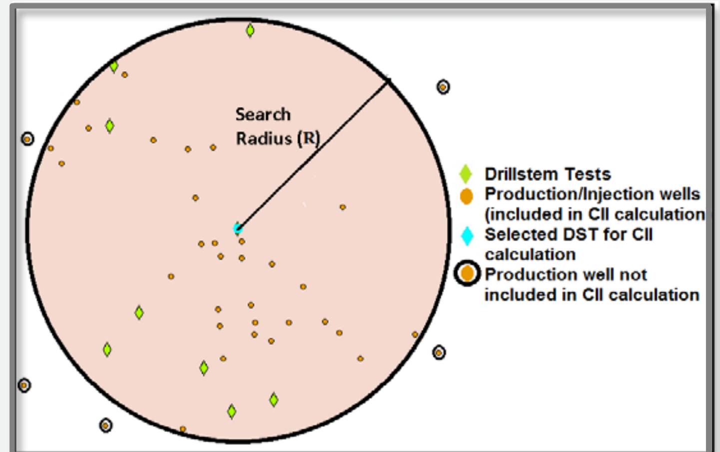
Assessing Production and Injection Effects

Goal: To identify DST pressures that are potentially affected by nearby Production/Injection activities

Assumption: Production Influenced Drawdown (PID) is directly proportional to an interference index defined as $\mathbf{I = t / r^2}$
(analogous to water-well testing principles)

t - length of time (years) since production/injection

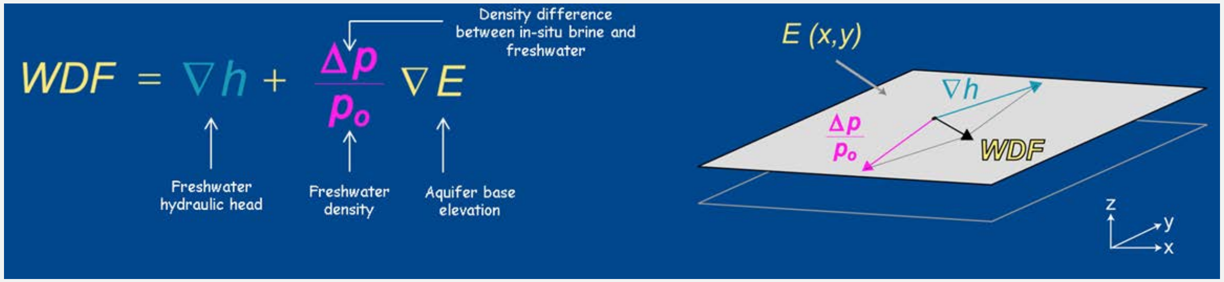
r - radial distance between production/injection wells and the DST where pressure was measured

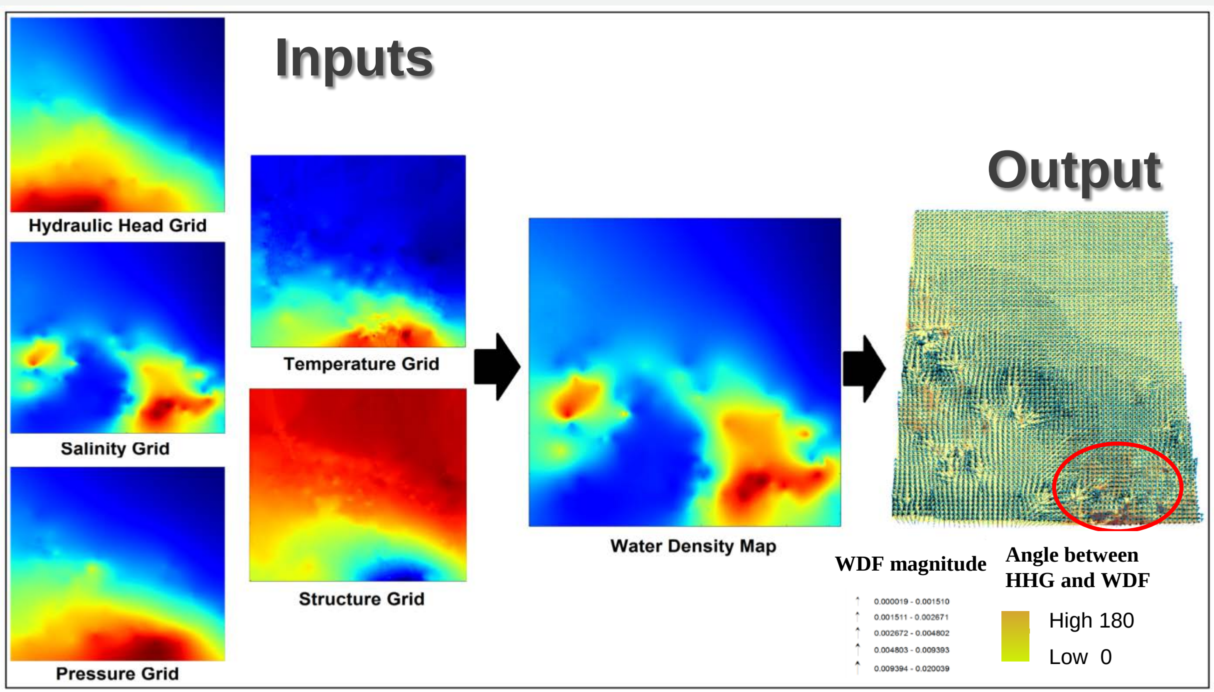


Cumulative Interference Index (CII) search radius (R) in relation to neighboring DST's and production or injection wells

The **CII index** for a particular DST is the cumulative sum of interference indices (log of $\upsilon\Sigma t/r^2$) for hydrocarbon wells in the surrounding region

Water Driving Force (WDF) Methodology





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The concept of WDF

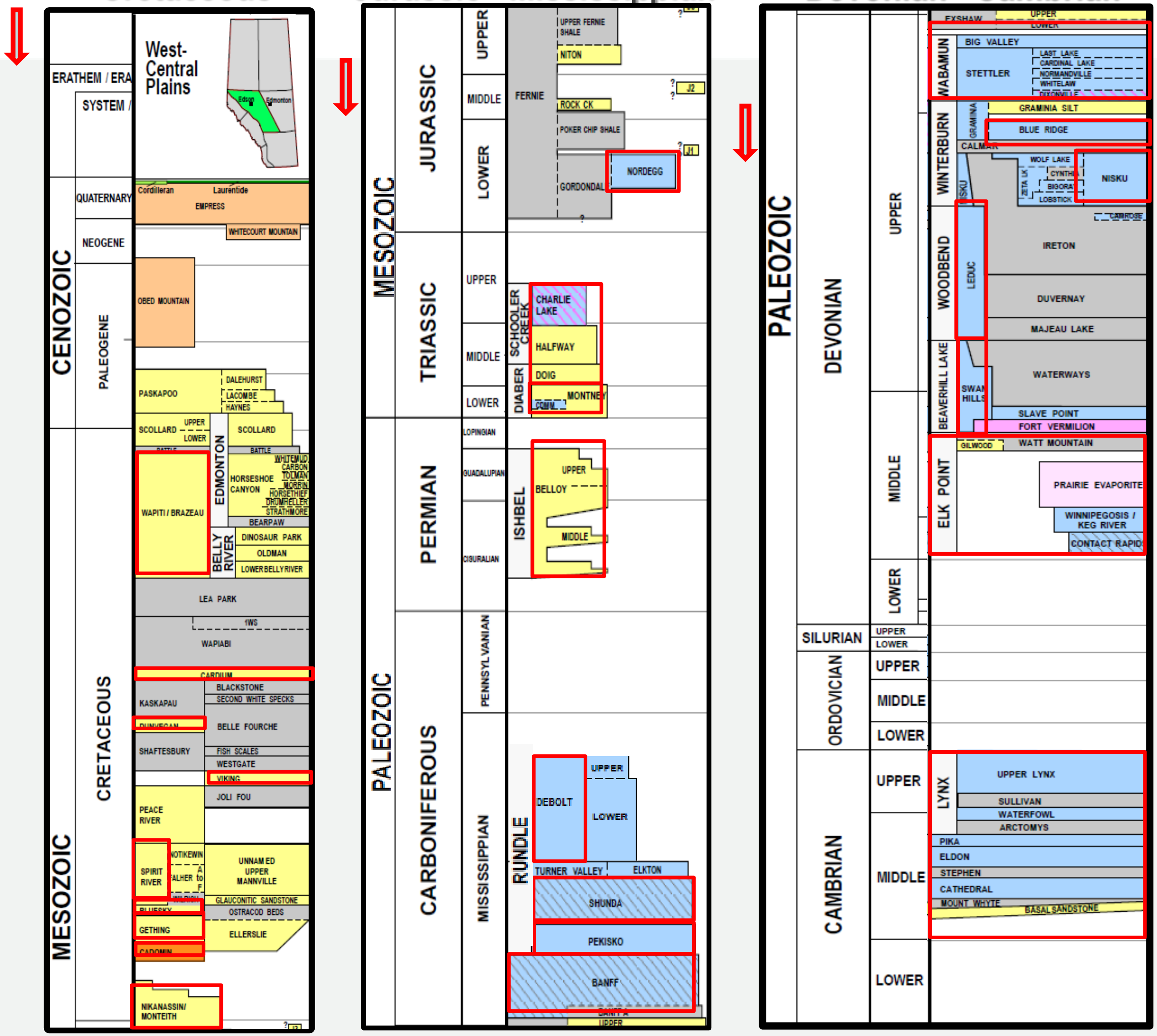
- Force due to potential gradient
- Force due to buoyancy
- WDF is the net driving force on the formation water at a particular point

WDF implementation using python script

In situ brine density is calculated as a function of pressure, temperature and total dissolved solids (TDS) using Chierici (1994) equation of state.

WCAB – Formations Mapped

Cretaceous | Jurassic - Mississippian | Devonian - Cambrian



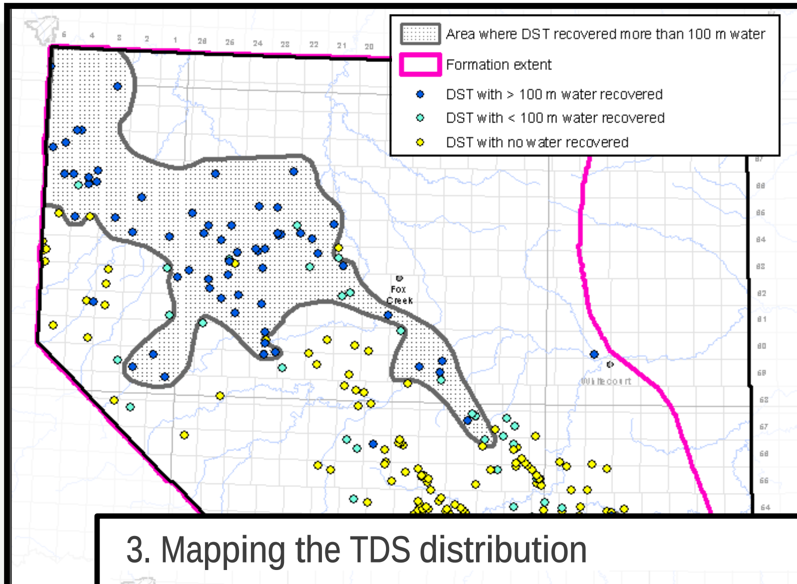
- 24 formations mapped
- Non-Saline to TDS over 250 000 mg/L
- 500 > deep > 3500 m

Modified from Alberta Table of Formation, AGS 2015

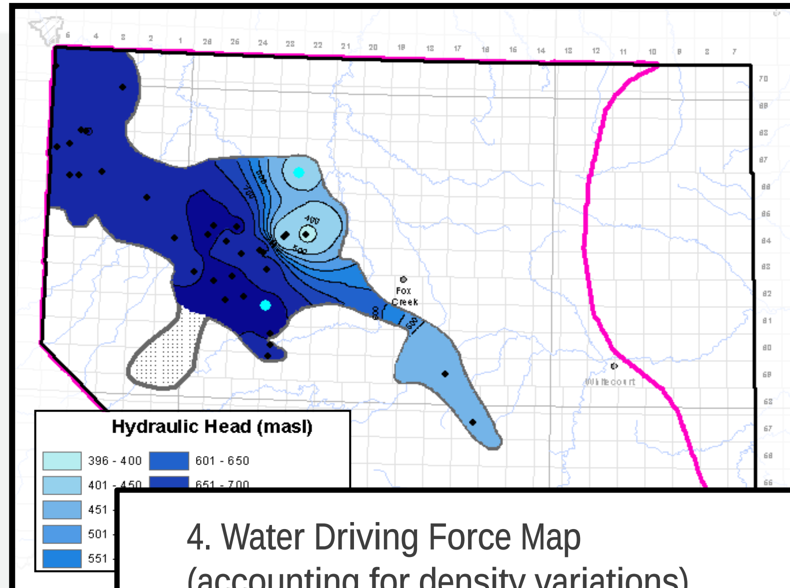
Mapping Approach

Example: Cardium Formation

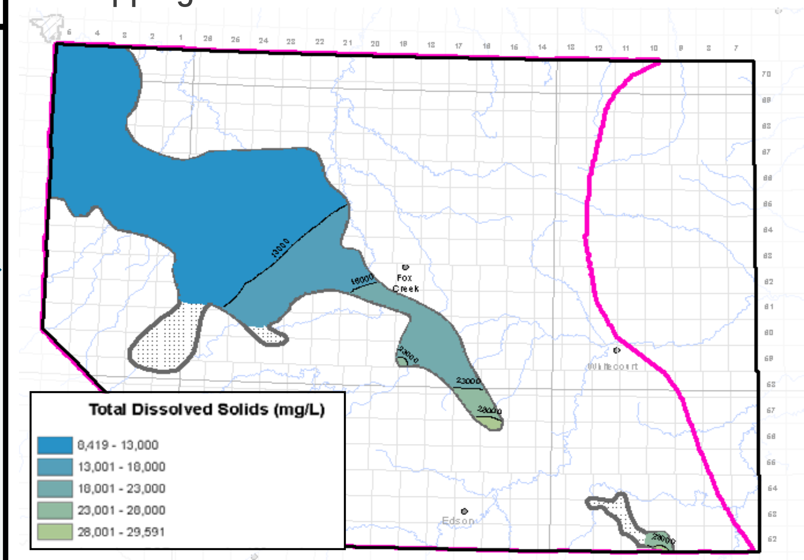
1. Delineation of area with sufficient water recovery



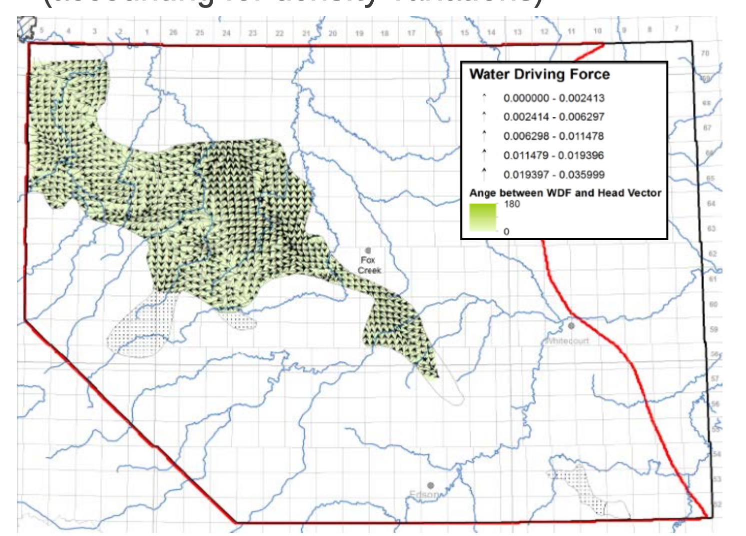
2. Hydraulic head mapping and CII (prod/inj effects)



3. Mapping the TDS distribution

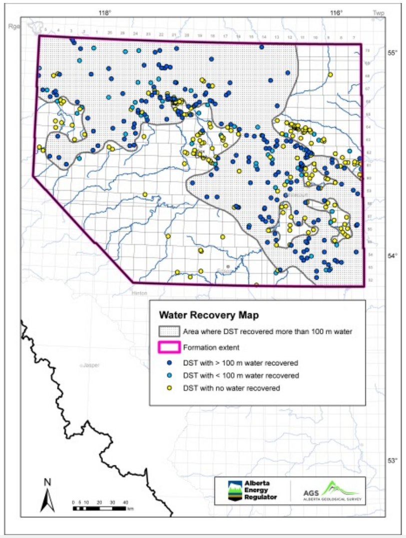


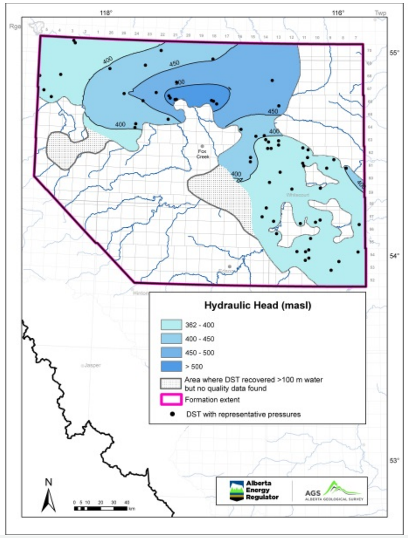
4. Water Driving Force Map
(accounting for density variations)

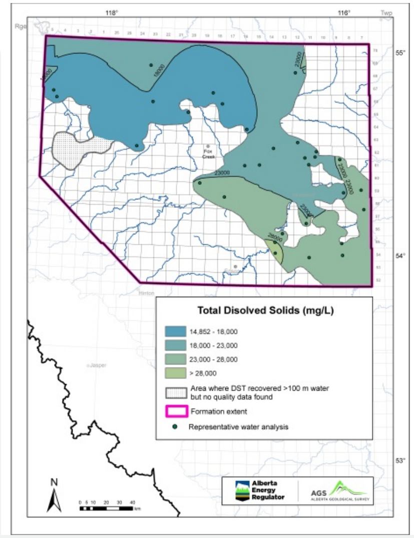


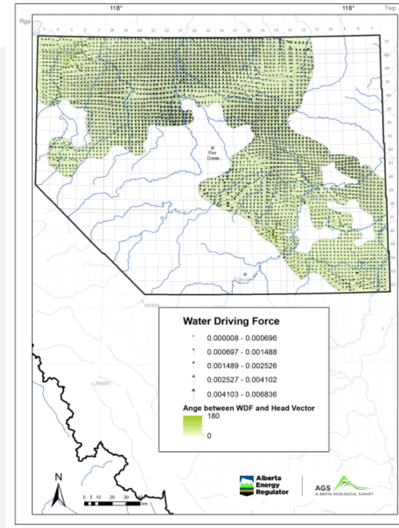
Map Series Examples

Viking Formation

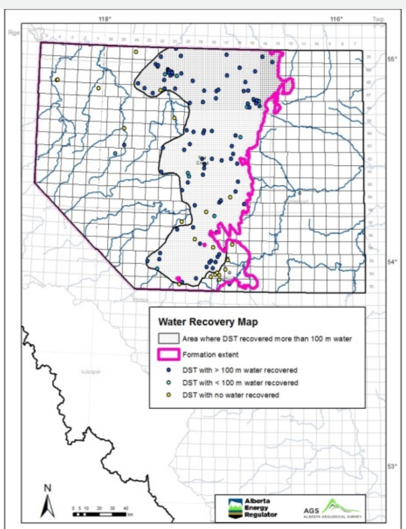


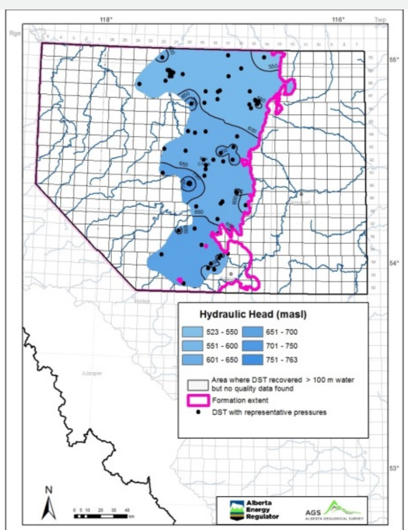


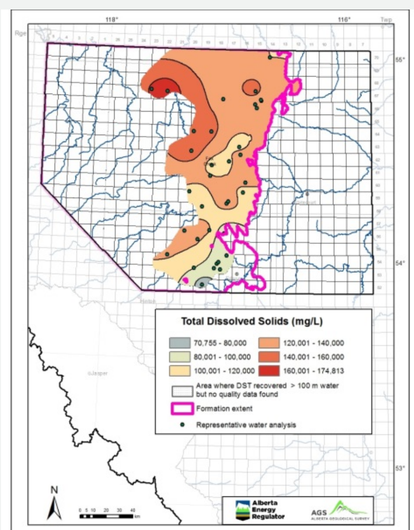


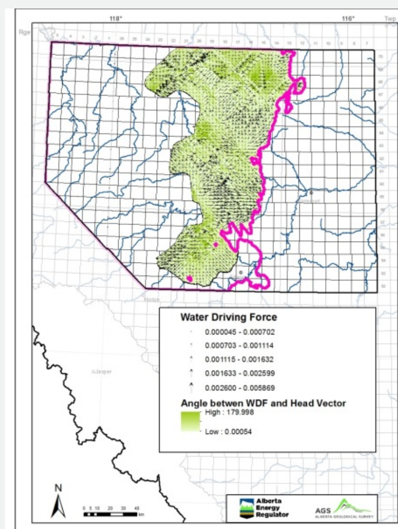


Debolt Formation

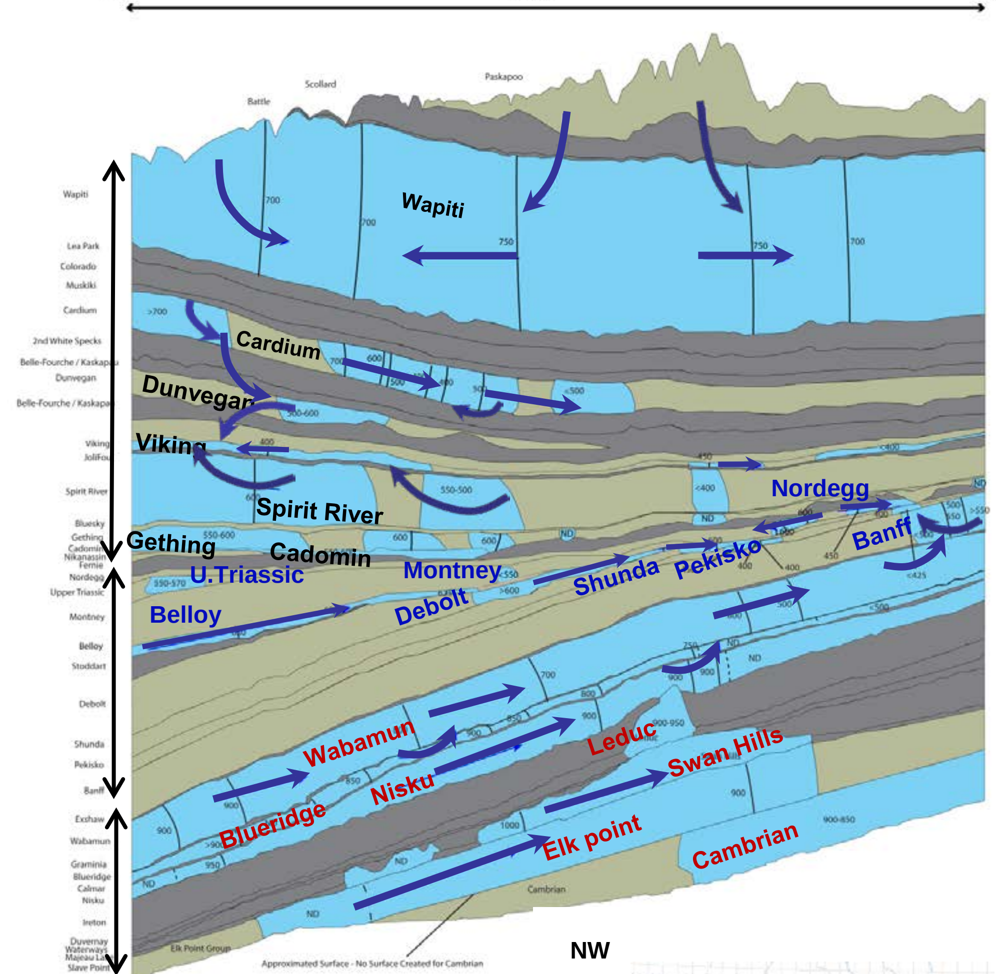








Hydraulic Head



Mapped formations - areas with water recoveries >100 m

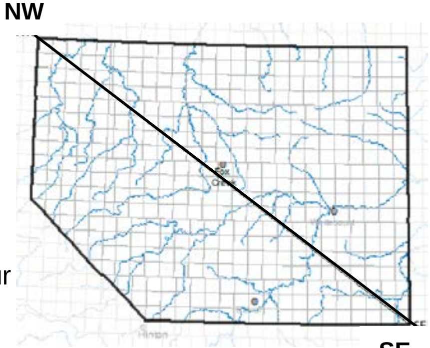
Mapped formations - areas with water recoveries < 100 m

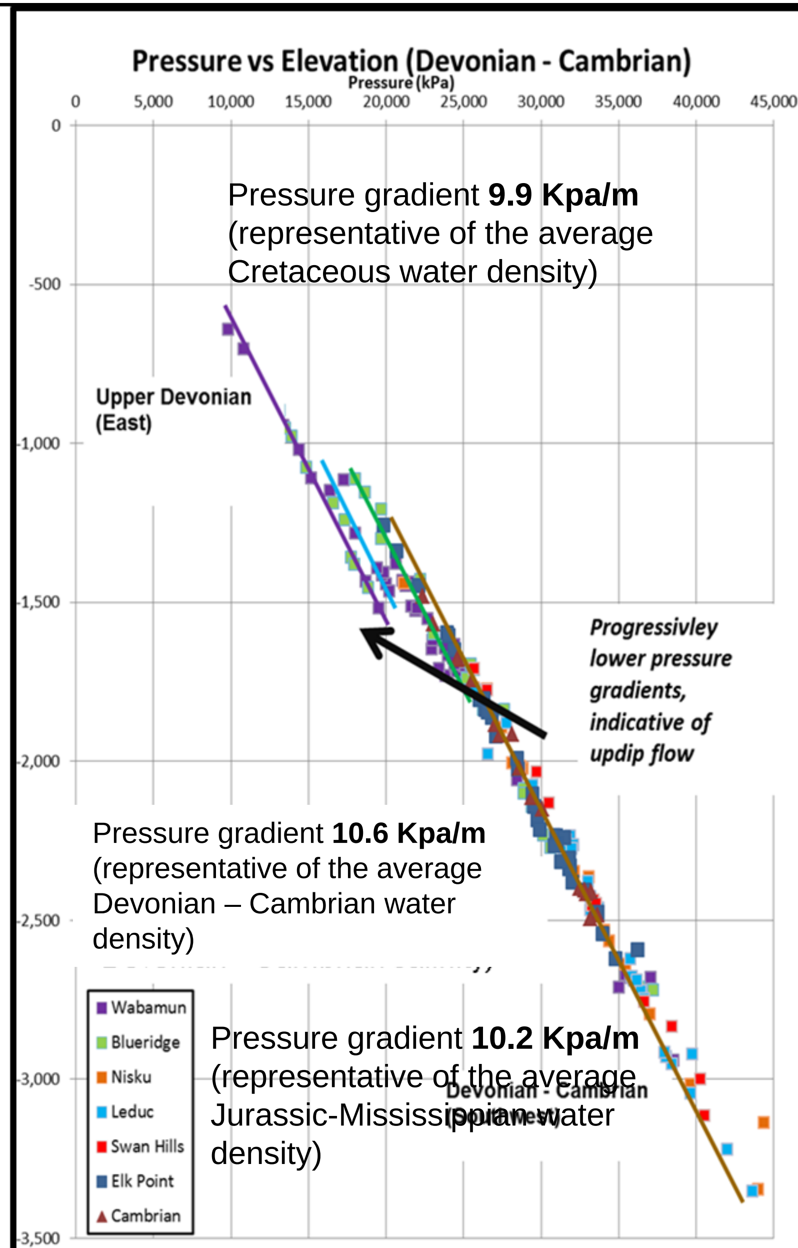
Formations not mapped

Approximate potentiometric contour

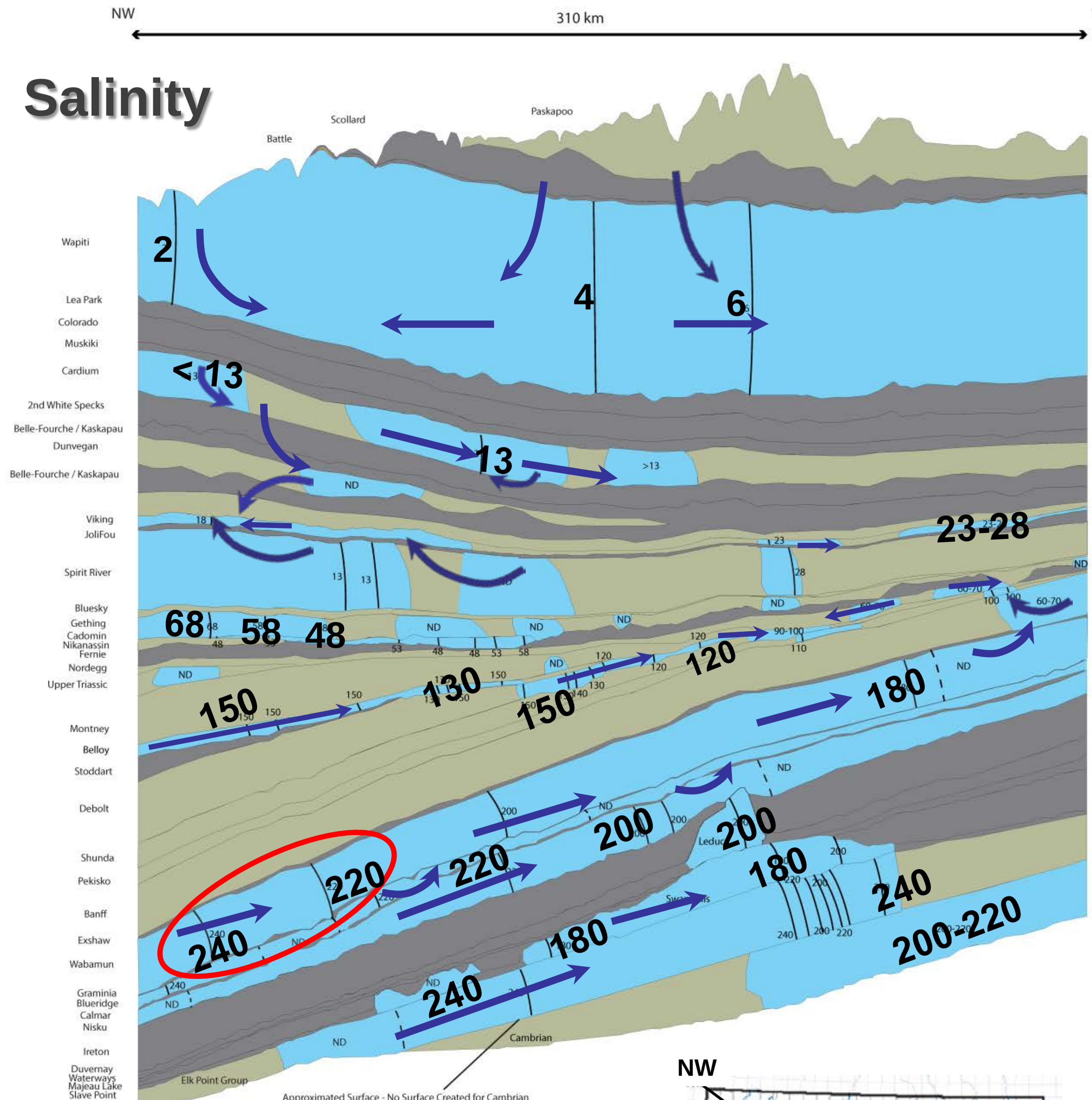
Flow direction

ND – No data, not mapped VE=80x





Salinity



Mapped formations - areas with water recoveries >100 m

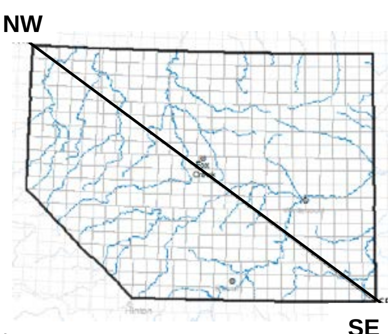
Mapped formations - areas with water recoveries < 100 m

Formations not mapped

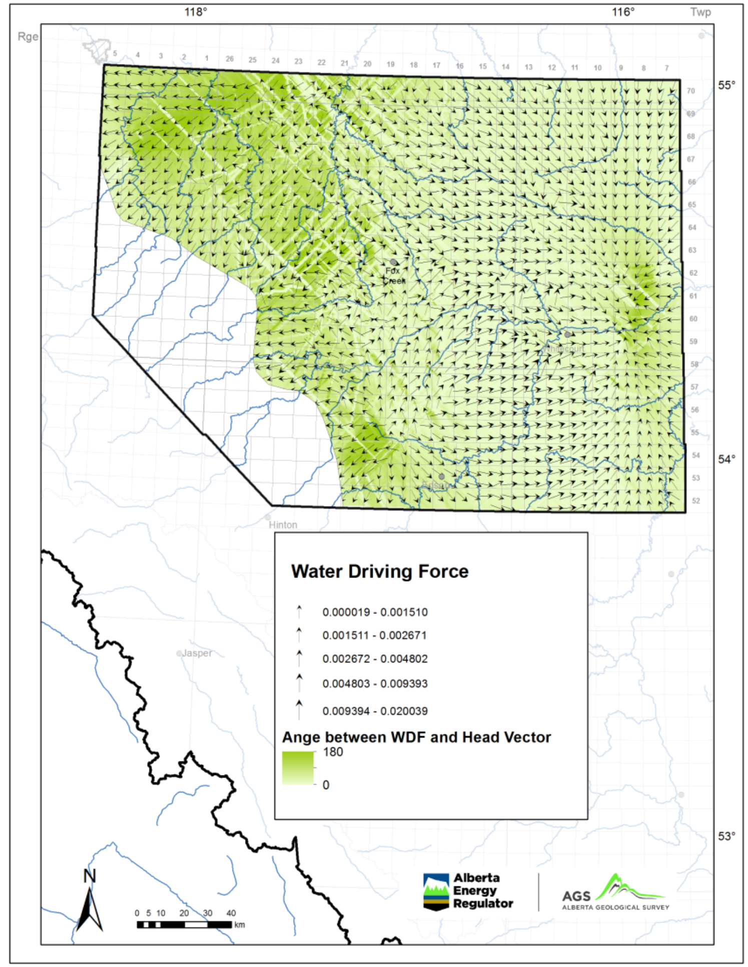
Approximate TDS contour (g/L)

Flow direction

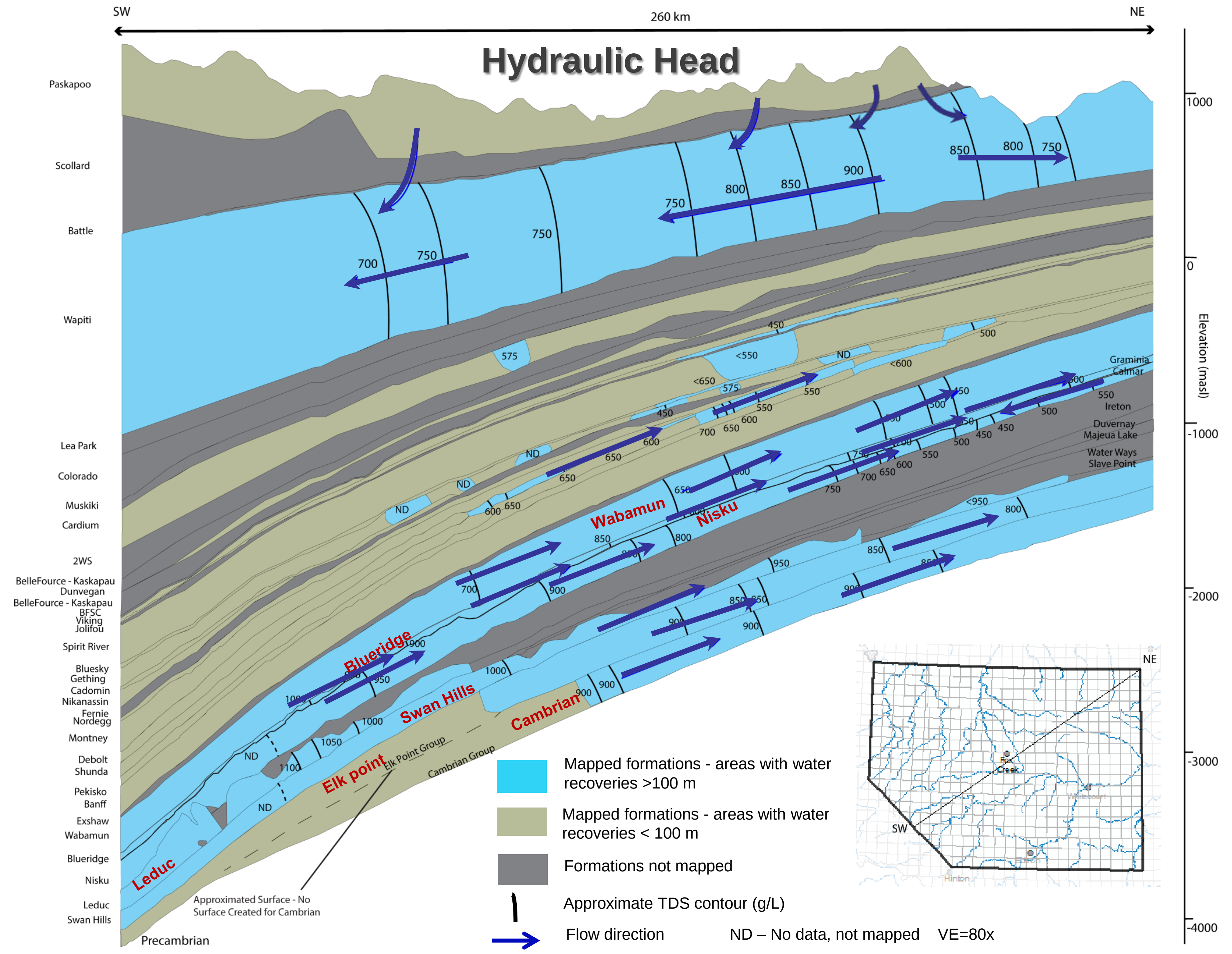
ND – No data, not mapped VE=80x

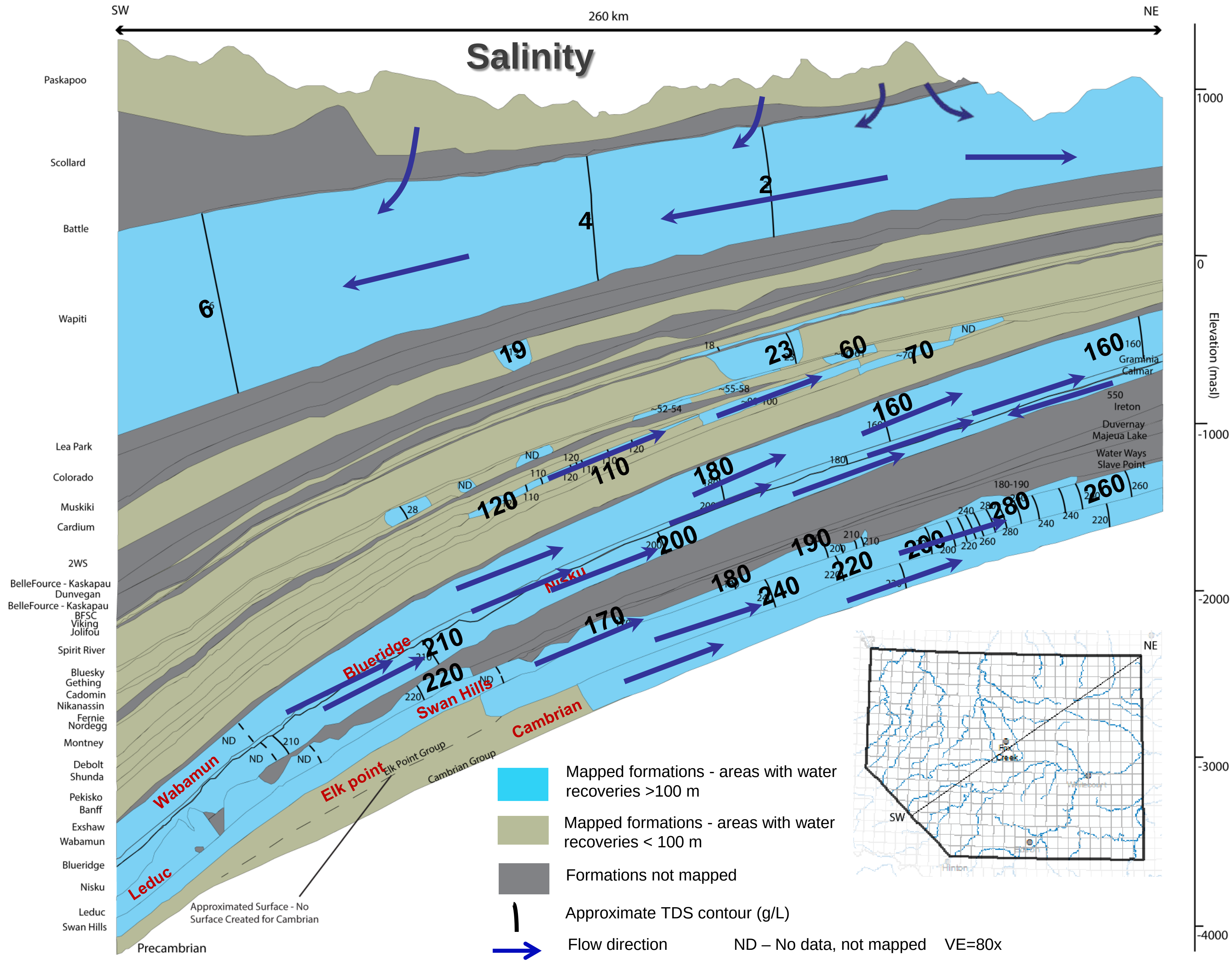


Wabamun Formation (WDF)



The large angle between the WDF vector and hydraulic gradient vector indicates significant effect of buoyancy on the groundwater flow direction, as a result of the dominant density gradient over the hydraulic gradient


Hydraulic Head
SW
260 km
NE
Paskapoo
Scollard
Battle
Wapiti
Lea Park
Colorado
Muskiki
Cardium
2WS
BelleFource - Kaskapau
Dunvegan
BelleFource - Kaskapau
BFSC
Viking
Jolifou
Spirit River
Bluesky
Gething
Cadomin
Nikanassin
Fernie
Nordegg
Montney
Debolt
Shunda
Pekisko
Banff
Exshaw
Wabamun
Blueridge
Nisku
Leduc
Swan Hills
Precambrian
Graminia
Calmar
Ireton
Duvernay
Majeua Lake
Water Ways
Slave Point
Elevation (masl)
1000
0
-1000
-2000
-3000
-4000
Wabamun
Nisku
Blueridge
Swan Hills
Cambrian
Elk point
Leduc
Elk Point Group
Cambrian Group
Approximated Surface - No Surface Created for Cambrian
Mapped formations - areas with water recoveries >100 m
Mapped formations - areas with water recoveries < 100 m
Formations not mapped
Approximate TDS contour (g/L)
Flow direction
ND – No data, not mapped
VE=80x
NE
SW


SW
260 km
NE
Salinity
Paskapoo
Scollard
Battle
Wapiti
Lea Park
Colorado
Muskiki
Cardium
2WS
BelleFource - Kaskapau
Dunvegan
BelleFource - Kaskapau
BFSC
Viking
Jolifou
Spirit River
Bluesky
Gething
Cadomin
Nikanassin
Fernie
Nordegg
Montney
Debolt
Shunda
Pekisko
Banff
Exshaw
Wabamun
Blueridge
Nisku
Leduc
Swan Hills
Precambrian
Graminia
Calmar
Ireton
Duvernay
Majeua Lake
Water Ways
Slave Point
Wabamun
Blueridge
Nisku
Swan Hills
Elk point
Cambrian
Leduc
Elk Point Group
Cambrian Group
Approximated Surface - No Surface Created for Cambrian
Elevation (masl)
1000
0
-1000
-2000
-3000
-4000
Mapped formations - areas with water recoveries >100 m
Mapped formations - areas with water recoveries < 100 m
Formations not mapped
Approximate TDS contour (g/L)
Flow direction
ND – No data, not mapped
VE=80x

Key Messages

- Results show a good correlation with previous mapping studies (e.g. Michael and Bachu, 2001; 2002)
- New techniques help better understand the potential of deep saline aquifers
  - Analysis of cumulative interference (production and injection) identifies potential influence of modern activities compared to natural conditions
  - WDF provides flow system context for potential source and disposal zones
- Saline groundwater resources are a key component of Alberta Environment and Parks Water Conservation Policy
  - Deeper saline sources may help reduce non-saline water use in the energy sector by identifying alternative sources of water
- A technical report and associated digital products will be published on the AGS website throughout 2017

? Questions

Thank you