Alberta Energy Regulator

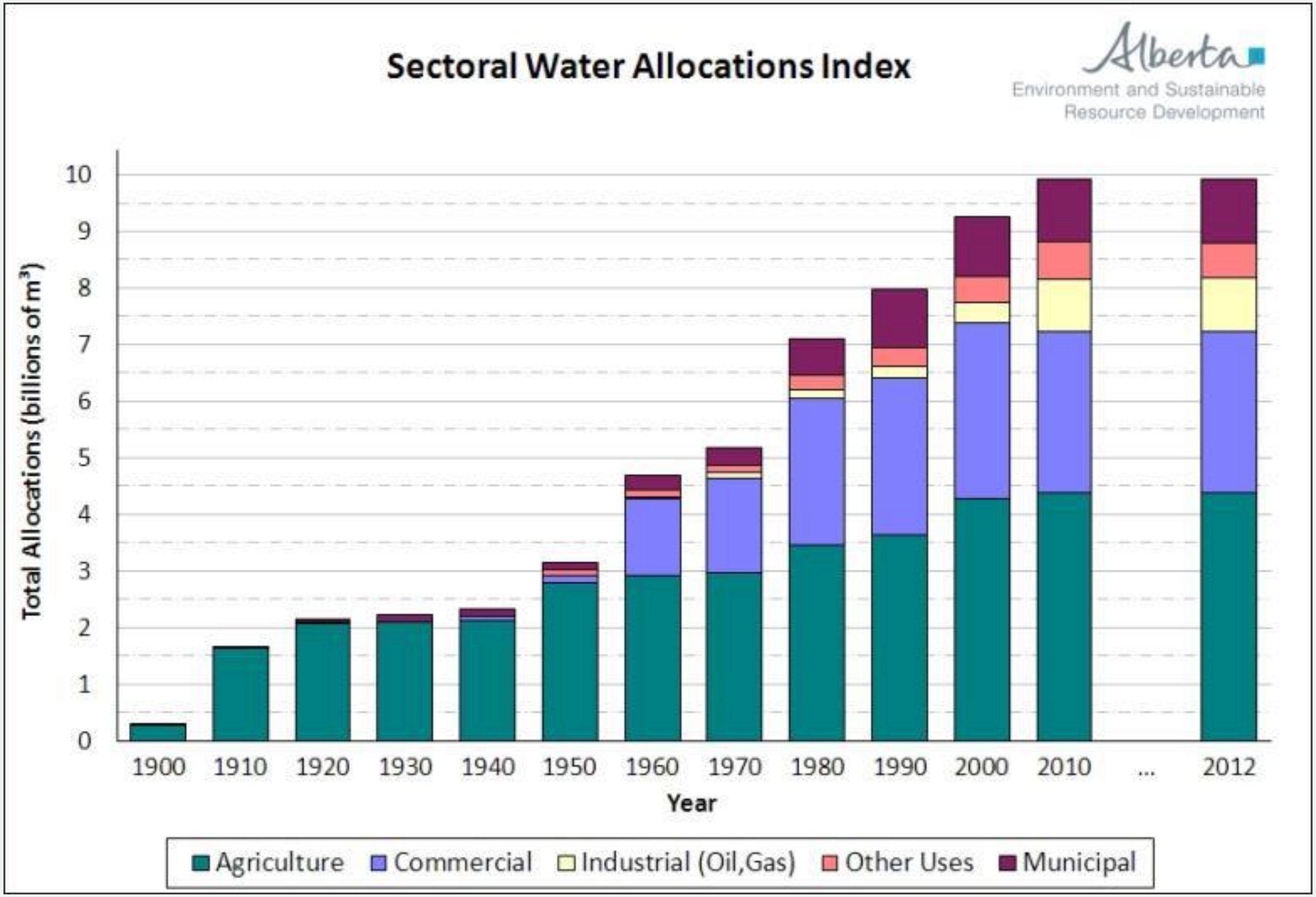
AGS ALBERTA GEOLOGICAL SURVEY

Transitioning to an Enhanced Groundwater Management Framework in Alberta

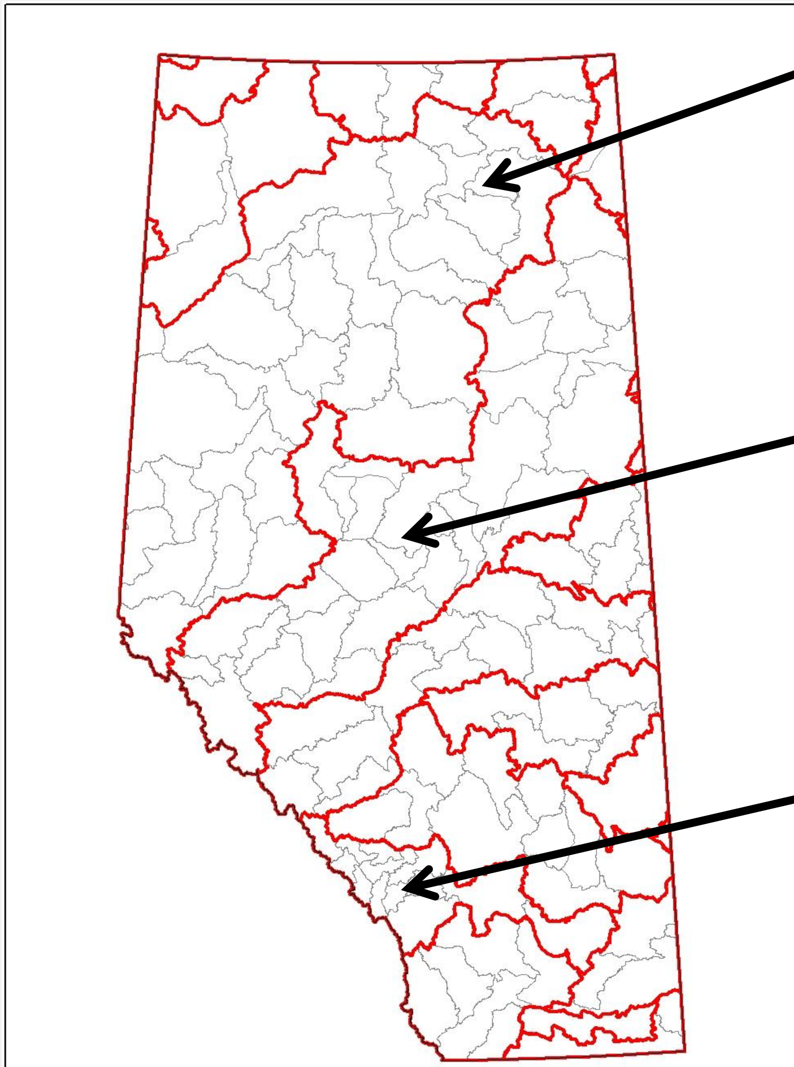
Dan Palombi

Alberta Geological Survey

Alberta Water Demand



Water Use in Major River Basins



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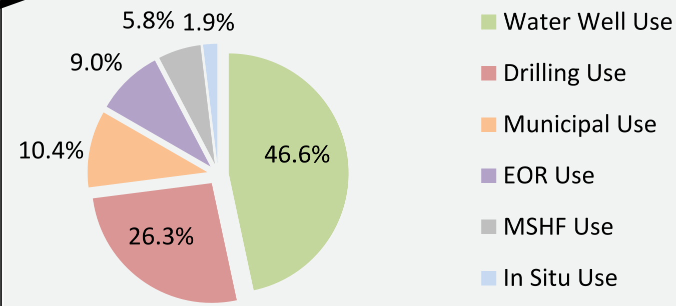
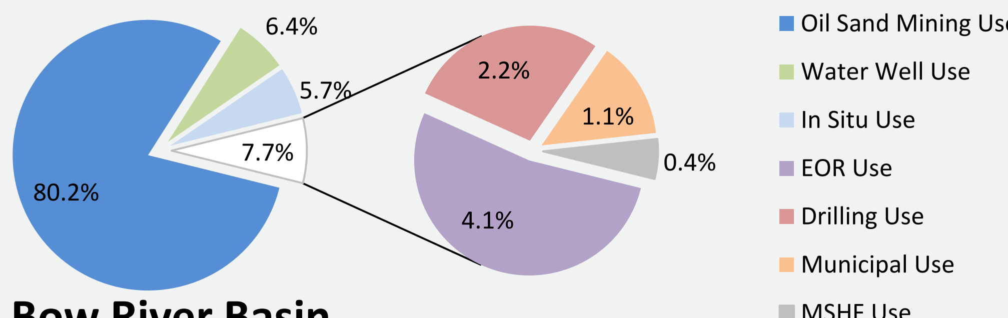
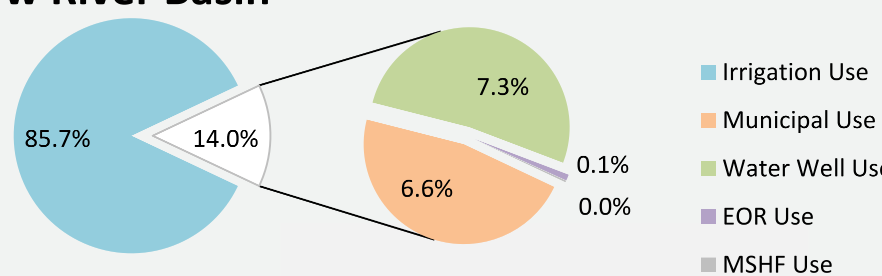
Peace River Basin



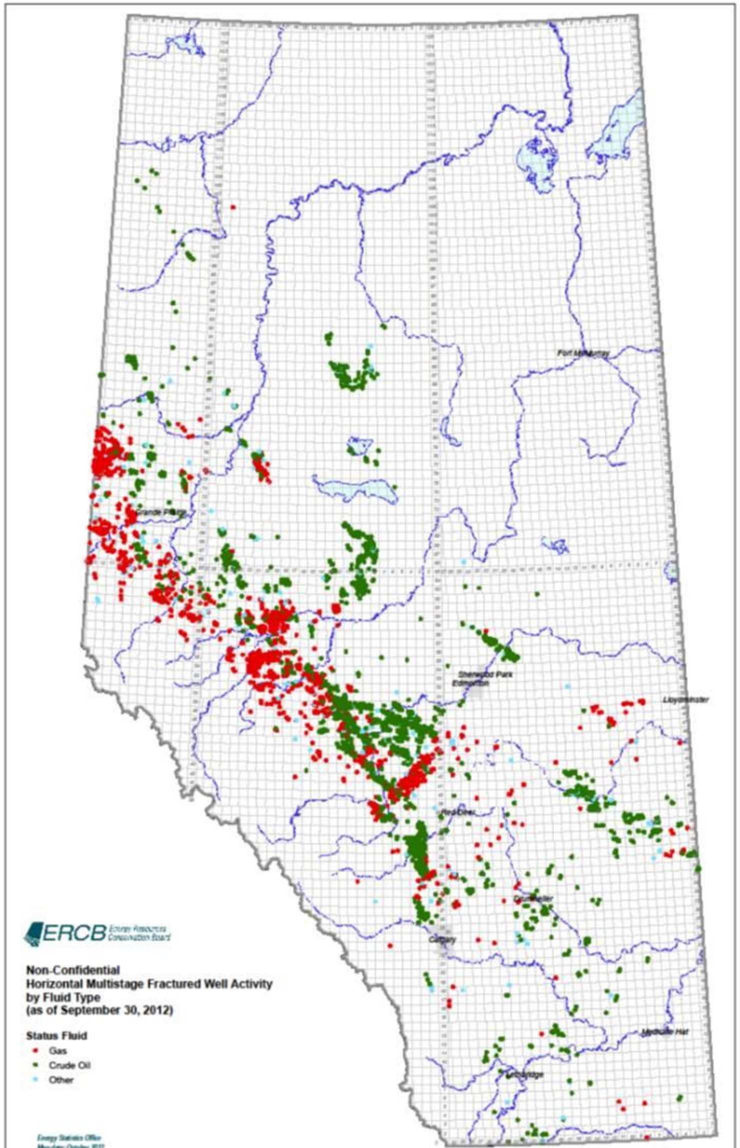
Athabasca River Basin



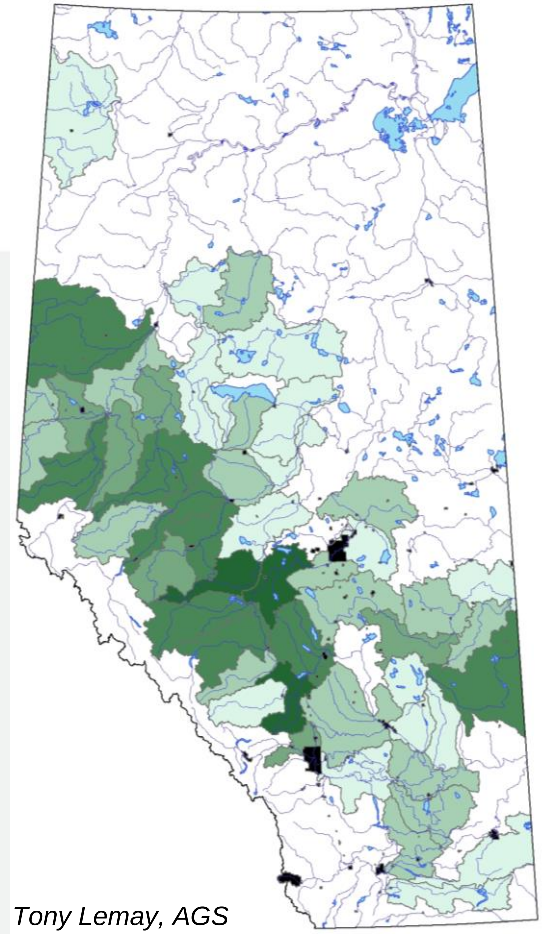
Bow River Basin



Hydraulic Fracturing in Alberta



- Only oil and gas wells with multi-stage hydraulic fracturing since 2008 (left)
- Red dots show locations where drilling targets natural gas including deep shale formations in the Montney and Duvernay play areas
- Green dots show locations where drilling targets crude oil from conventional sandstone and carbonate formations



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- Above: Sub-basin water use for multiple-stage hydraulic fracturing (2013)

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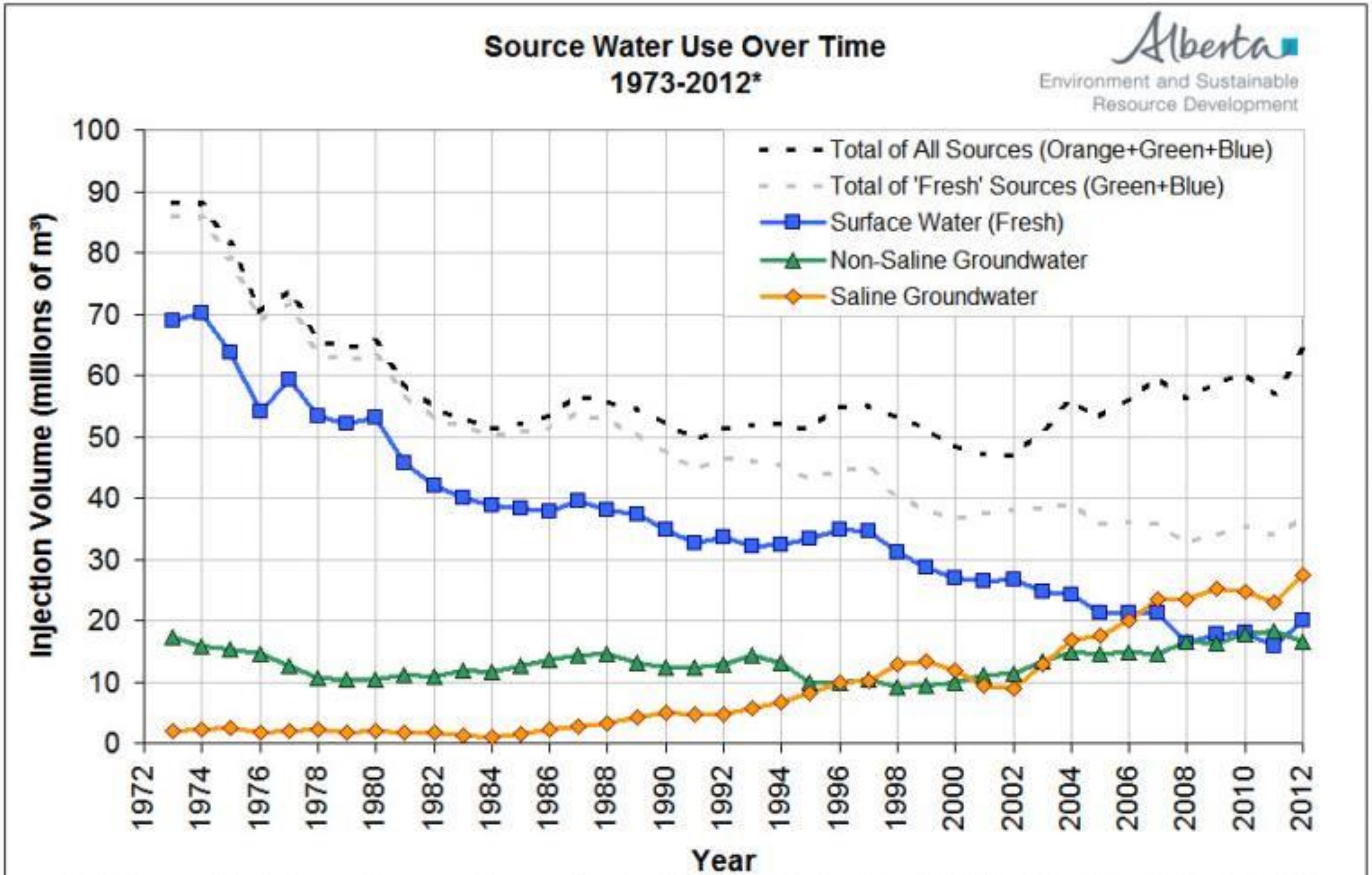
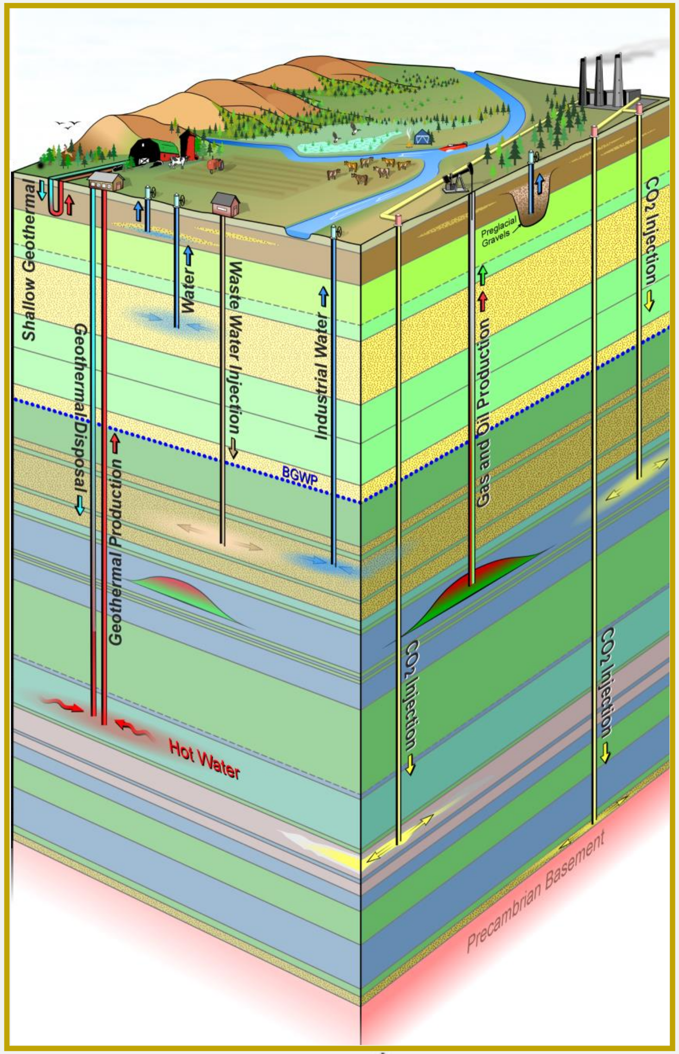
Conservation: Oilfield Injection



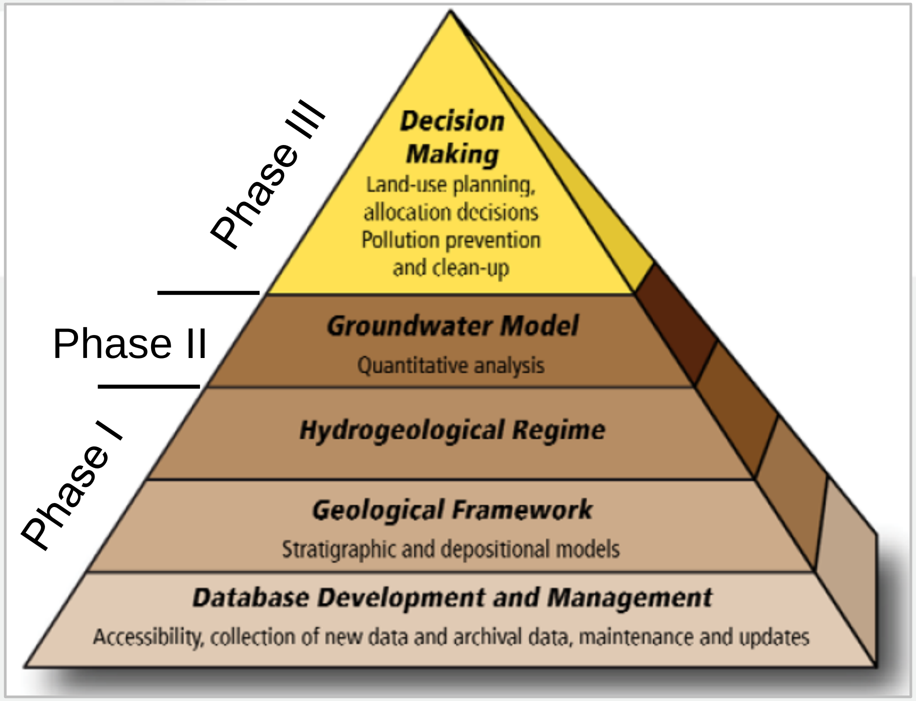
*Data Source: Alberta Energy Resources Conservation Board (ERCB). Chart produced by Water Policy Branch, Alberta ESRD.

Program Objectives

Fresh and saline water focus



www.ags.gov.ab.ca



Council of Canadian Academics, 2009

3 Phases of the Program

I. Characterize the natural system: groundwater regime, aquifer maps, reports, and data sets

II. Understand dynamics of groundwater systems: numerical models

III. Develop decision-support tools for resource management, regulation, and policy development

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Recent Advancements in Mapping Deep Regional Aquifers

1. Analytical method to examine the influence of production and injection operations on well-test analyses (e.g., Drill Stem Tests)
   - Use for mapping natural and production-affected hydraulic head distributions for regional aquifers
2. Analytical method to account for variable density flow effects using the Water Driving Force (WDF) method
   - Employ vector analysis to identify flow directions in regions where density-driven flow is important and can change the inferred magnitude and direction of flow

1. Examining the Influence of Production and Injection

- Cumulative Inference Index (CII) methodology can be implemented to identify production influences

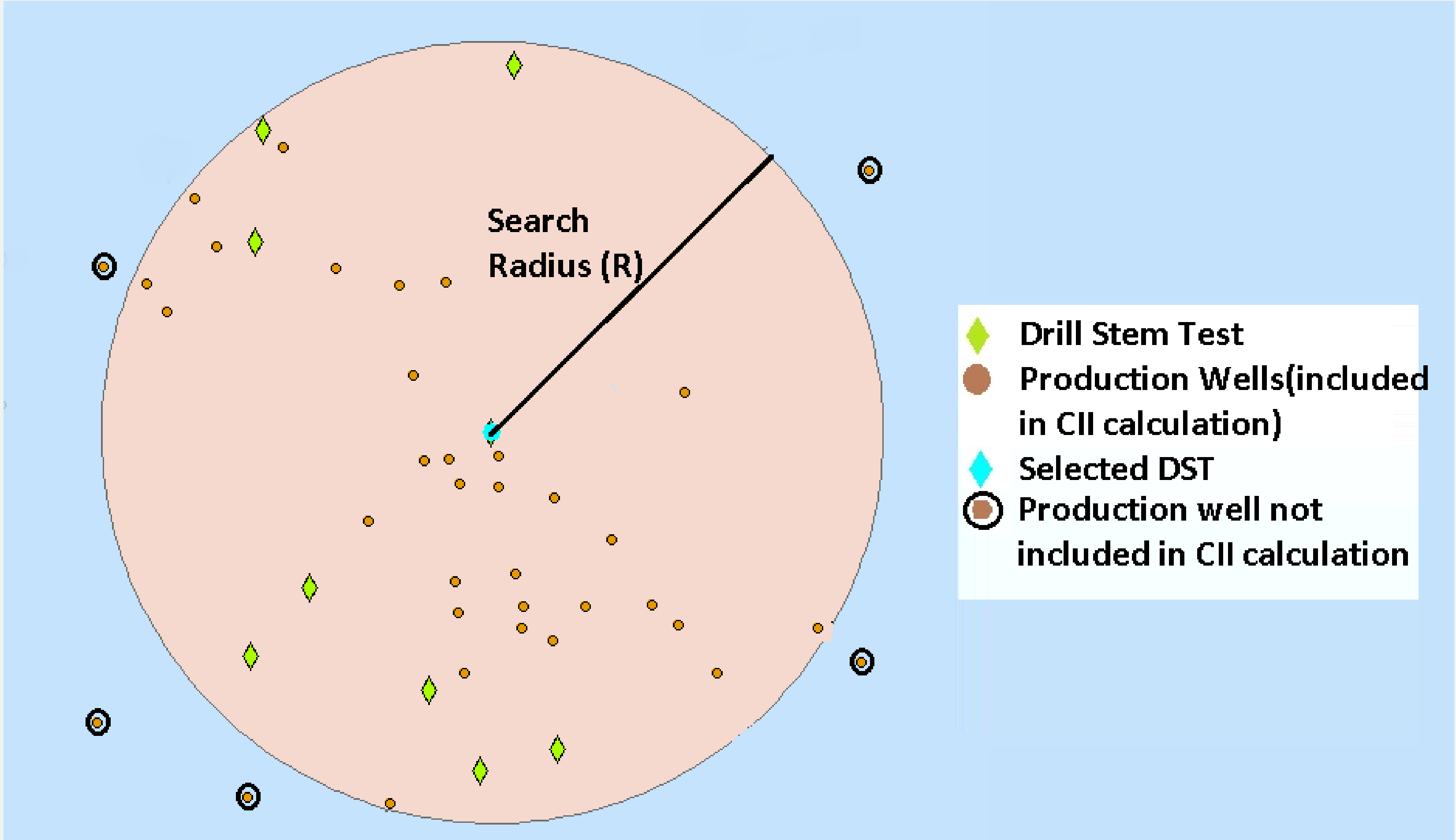
- The methodology assumes that production influences are analogous to **water-well testing principles;** meaning the effect is directly proportional to an inference index, log (t/r^2)**

  - "t" is the length of time since production and r is distance (radial proximity) between a production well and the well where pressure was measured (e.g., DST)

- The CII index for a particular DST is the cumulative sum of inference indices for pumping/injection wells in the surrounding region

** Bruin and Hudson (1961), Tóth and Corbett (1986)

Depiction of CII Methodology



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CII Required Data and Output

- Input
  - DST test location and date
  - Production well locations along with production start/end dates
  - Search Radius
- Output
  - Cumulative inference index (CII)
  - Distance to the nearest well
  - Number of wells within the radius (R)
  - Longest production duration among the wells within the search radius

CII Code Results

CILC

```
#include<stdio.h>
#include<stdlib.h>
#include<math.h>
#include<time.h>
#include<string.h>

#define R 6371
#define TO_RAD (3.1415926536 / 180)

int
{
  ch
  lo
  in
  fl
  in
  sy
  pr
  pr
  pr
  pr
  pr
  pr
  pr
  sc
```

D:\working folder\Dan\C-code\cii.exe

```
This Code Calculates CII
Code developed by Amandeep Singh and Dan Palombi
------------------------------------------------------------
Production data file name- prodata.txt
Refer readme.txt for input/output details
------------------------------------------------------------
Enter Production data file name with extension
prodata.txt
Enter DST da
dstdata.txt
Enter Search
10
Enter Output
out.txt
Reading Prod
Production d
Reading DST
DST record l
Enter to exi
```

out.txt

Search Radius- 10.000000 KM

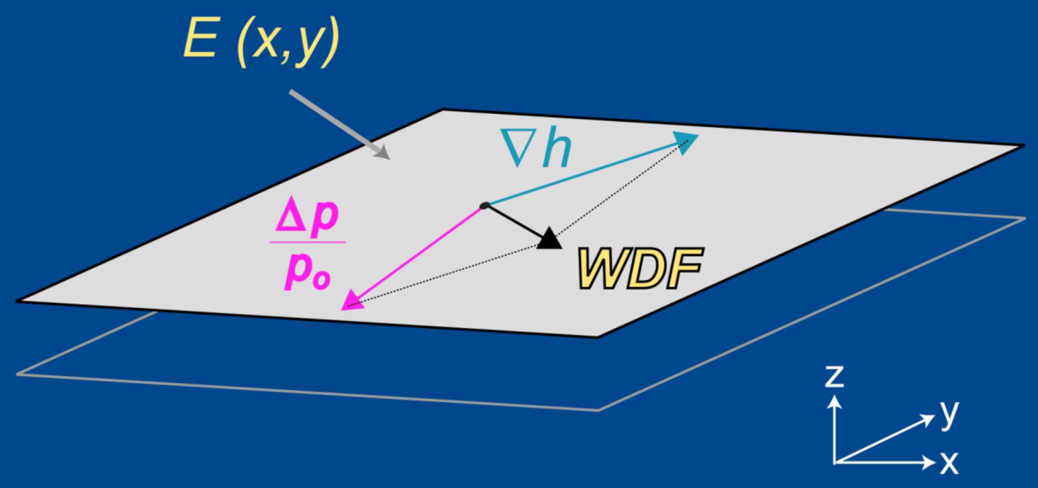
Well-lat	Well-long	DST-lat	DST-long	CII	CII(Scaled)	Nearest-Well	Num-wells(spec radius)	Prod-duration(Num-wells)	Well Status
50.57567	113.61126	52.57654	113.96870	0.52667	0.64388	0.01785	39	16.07	ABD OIL
51.09968	113.49471	53.96389	118.79428	-34.68232	0.00000	102.05392	0	0.00	ABD OIL
51.27372	113.66330	49.05226	109.35326	-34.68274	-0.00001	2.53722	20	0.00	Susp OIL
51.36132	112.82266	51.54160	112.97185	-34.68610	-0.00007	0.95578	180	0.00	ABD OIL Zone
51.35833	113.66552	51.83358	112.33530	1.54673	0.66254	0.25761	115	13.65	Training Well
51.35870	113.80725	51.93804	112.07352	-34.68245	-0.00000	0.16650	6	0.00	ABD OIL
51.35870	113.80725	52.10833	112.51220	0.54635	0.64424	0.43403	39	10.62	Pumping OIL
51.53415	113.38280	53.00163	114.62033	-34.68391	-0.00003	0.11006	76	0.00	ABD OIL Zone
51.71047	112.42026	53.01053	112.05116	-34.68245	-0.00000	0.69489	6	0.00	ABD OIL
51.70910	112.70339	53.20502	115.47870	2.27823	0.67591	1.40337	120	26.48	ABD OIL
51.79783	112.84472	53.81209	114.68540	-34.68278	-0.00001	1.58934	22	0.00	ABD OIL
51.79785	113.69460	54.49337	114.82665	-34.68232	0.00000	10.26658	0	0.00	ABD OIL
51.79785	113.69460	52.66399	116.19929	-34.68232	0.00000	29.05868	0	0.00	ABD OIL Zone
51.88402	113.83724	54.44527	114.65546	-34.68234	0.00000	5.49984	1	0.00	ABD OIL
51.88402	113.83724	52.87935	115.10246	1.39049	0.65968	0.07526	46	29.55	ABD OIL
52.05718	113.43793	53.17005	113.86343	0.35662	0.64077	0.06958	12	8.97	ABD OIL
52.67105	114.72984	52.70088	114.72299	2.08001	0.67229	1.04285	149	45.59	ABD OIL
52.75918	114.29633	50.88919	113.29948	1.04849	0.65343	0.86359	185	13.25	Susp OIL
52.75918	114.29633	52.91562	113.29153	-34.68383	-0.00003	2.36628	72	0.00	ABD OIL
52.84634	114.15170	51.49166	113.19965	2.01429	0.67109	0.00898	415	25.16	ABD OIL
52.84653	114.29658	52.50136	111.48840	-34.68243	-0.00000	1.85453	5	0.00	ABD OIL
53.10697	114.29728	52.50497	111.46443	-34.68243	-0.00000	2.75725	5	0.00	ABD OIL
53.10694	114.44364	53.18945	115.18639	2.72816	0.68414	0.00904	196	45.42	ABD OIL
50.48524	113.74105	49.24165	109.43277	-34.68306	-0.00001	1.11103	35	0.00	Pumping OIL
50.48524	113.74105	50.53740	109.84529	-34.68253	-0.00000	1.83287	10	0.00	ABD OIL
51.01130	112.26527	51.20316	110.83282	-34.68270	-0.00001	2.05631	18	0.00	ABD OIL
51.00933	113.38000	51.26862	110.86786	-34.68247	-0.00000	3.12817	7	0.00	ABD OIL
51.18415	112.96099	51.33421	113.72182	-34.69376	-0.00021	0.26692	540	0.00	ABD OIL
51.18415	112.96099	51.42155	110.43494	-34.68291	-0.00001	2.83148	28	0.00	ABD OIL
51.18415	112.96099	51.42516	110.80991	-34.68278	-0.00001	1.97272	22	0.00	ABD OIL
51.35886	112.98357	51.43601	111.30786	-34.68237	0.00000	1.84853	2	0.00	Pumping OIL

2. Variable Density Effects: Water Driving Force Vector Fields

Water Driving Force (WDF) is a function of:

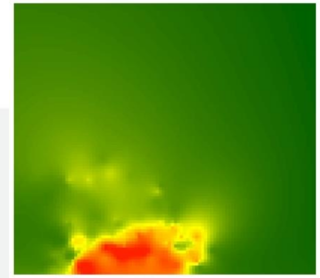
- Pressure-related driving force
- Relative density
- Aquifer structural gradient

$$WDF = \nabla h + \frac{\Delta p}{p_o} \nabla E$$

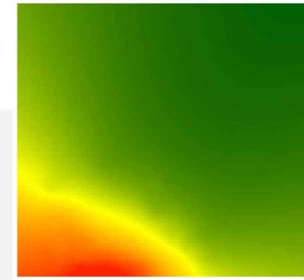


Implementing the WDF

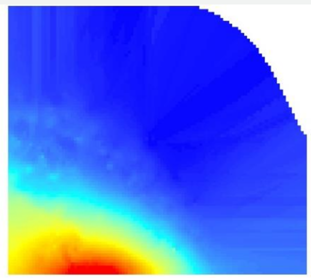
Salinity



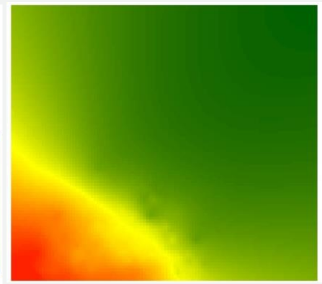
Pressure



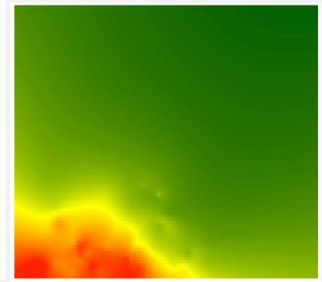
- Input grids of:
  - Structure top of underlying aquifer
  - Hydraulic head
  - Temperature
  - Salinity
  - Pressure



Structure



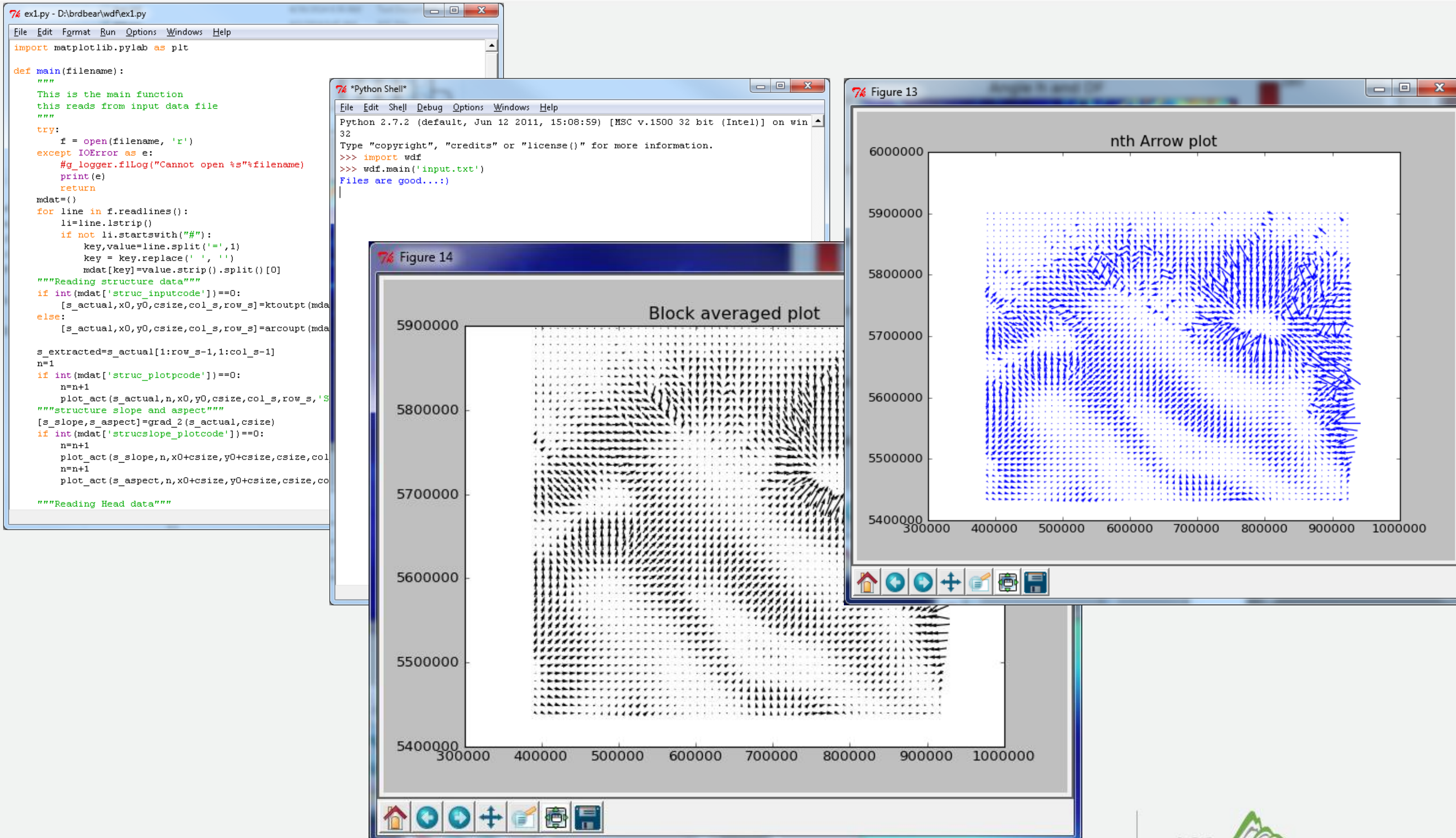
Head



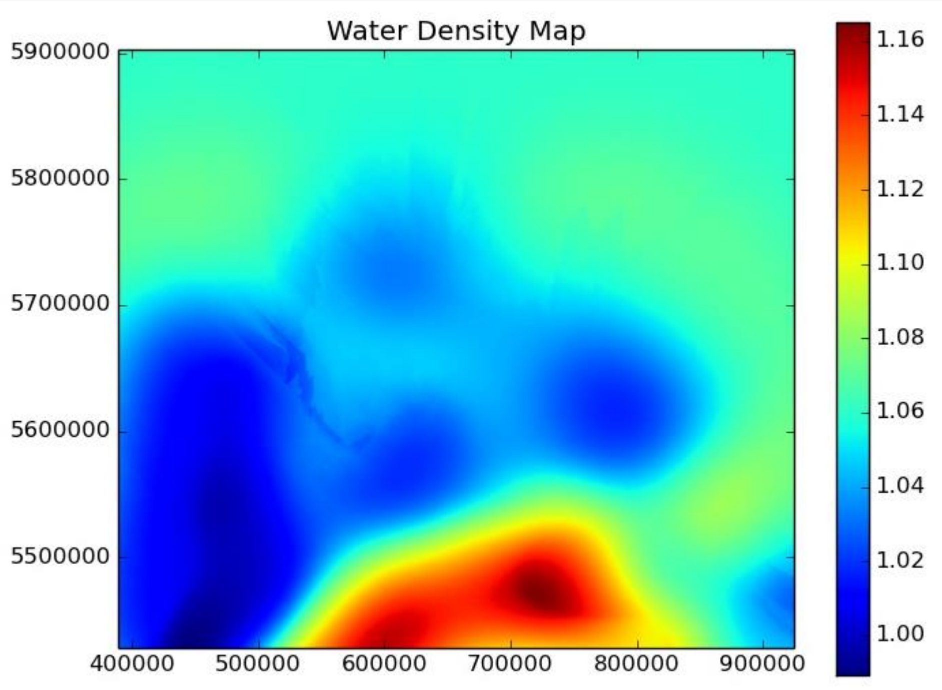
Temperature

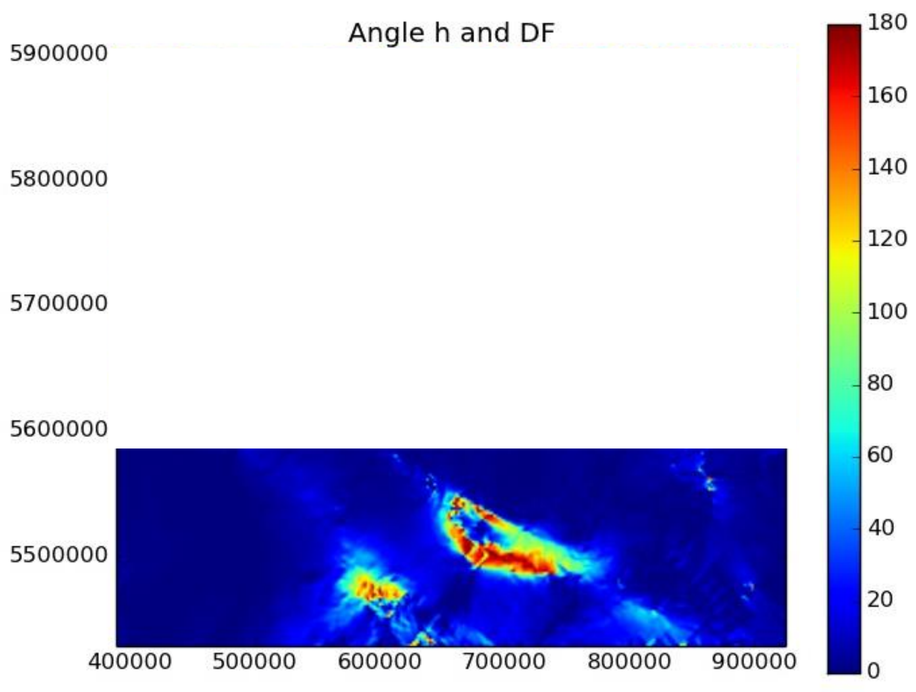
- Output
  - Water driving force (resultant and magnitude)
- Methodology
  - Water density calculated from temperature, salinity and pressure grids (Chierici, 1994, equation of state)
  - Resultant WDF calculated using the equation of previous slide
  - Methodology implemented in Python and ArcMap is used for visualization

Example of WDF – Python Code and Resultant Maps



Example of WDF – Resultant Maps

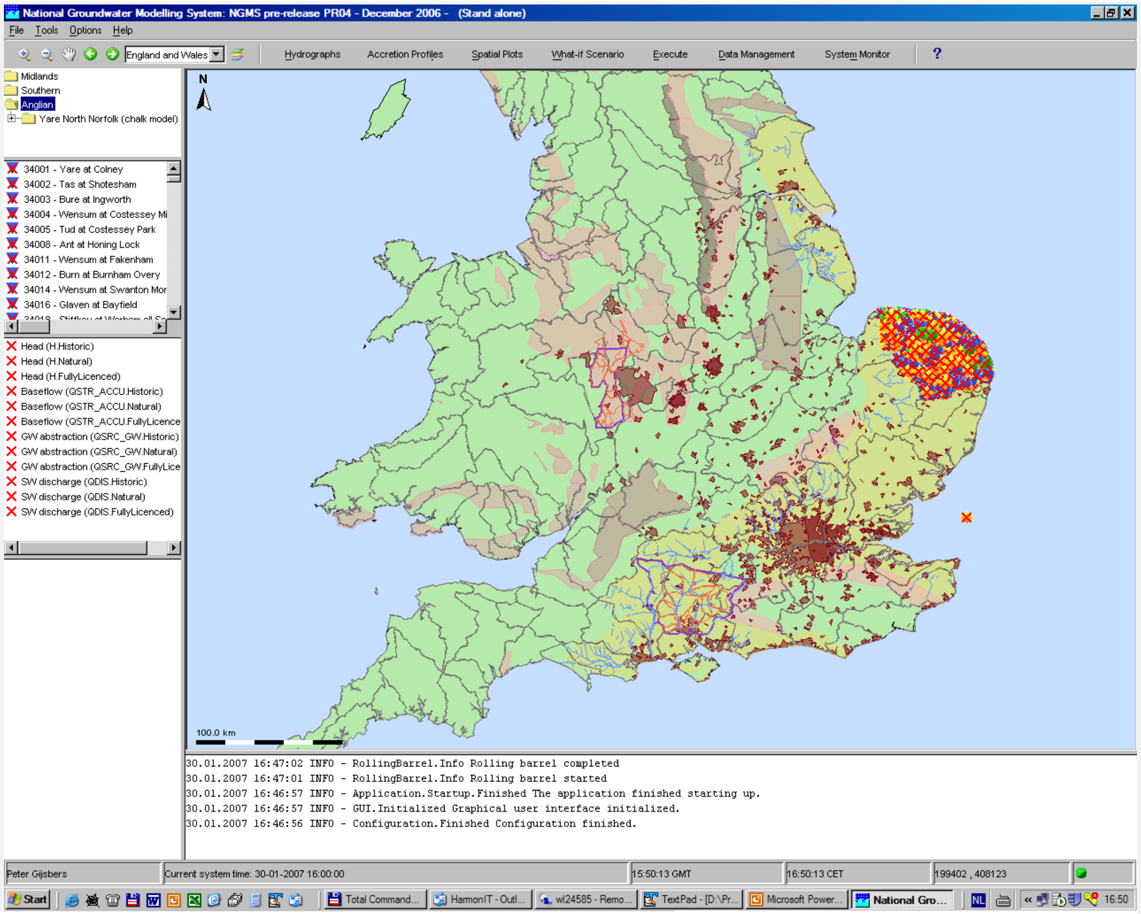




AGS Regulatory Enhancement Targets for Non-Saline Groundwater Management

- Assist regulator(s) of the *Water Act* using groundwater mapping and numerical models to enhance authorization process:
  - Evaluate groundwater authorizations
  - Support a change from well by well (Q20) evaluations to cumulative impact based assessments
  - Generate regional models to assess water-balance, drawdown, and yield forecasting
  - Enable scenario modelling to evaluate future groundwater developments

What Have Other Jurisdictions Done For Cumulative Effects?



National Groundwater Modelling System (NGMS) in United Kingdom

Environment Agency

Capabilities includes:

1. Reference situation
   - Historic (calibration)
   - Natural (zero extractions)
   - Recent (actual)
   - Fully licensed
2. Scenarios (impacts of change)
   - Groundwater extractions
   - Surface water extractions and discharges
   - Climate change (rainfall)
3. Output of Interest
   - Absolute values and differences in:
     - Surface water flows
     - Hydraulic heads
     - Water budgets

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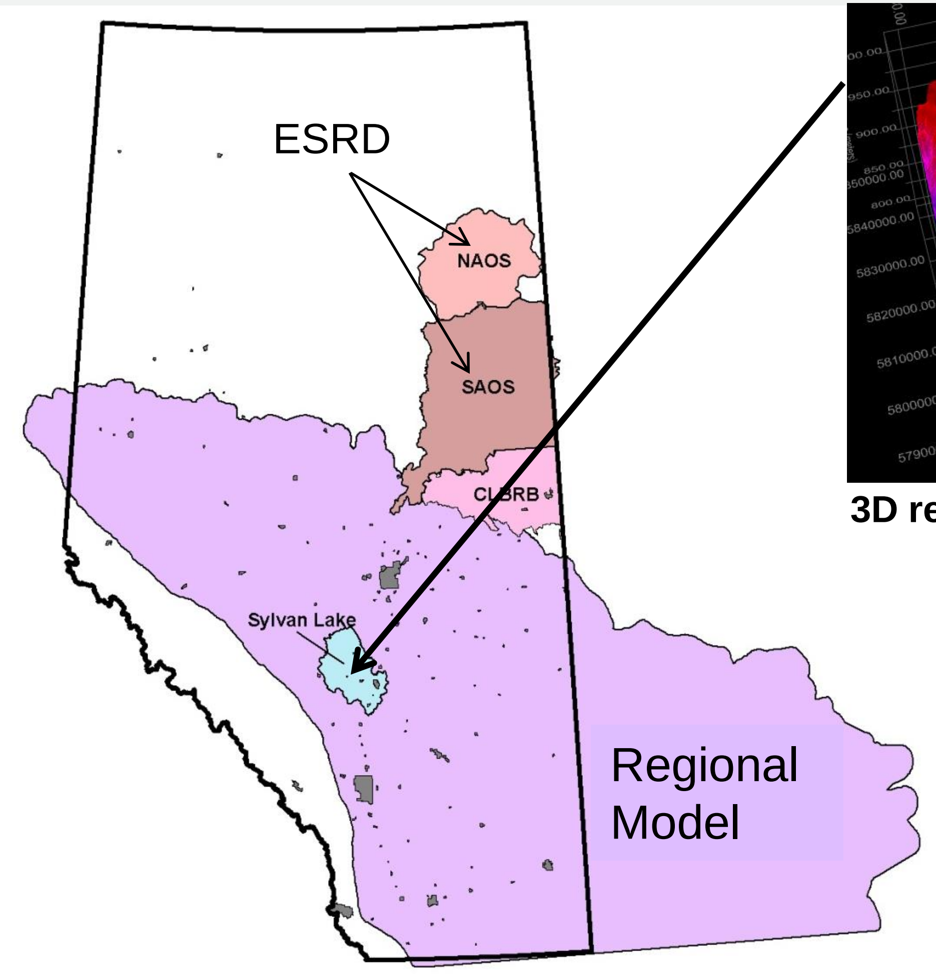
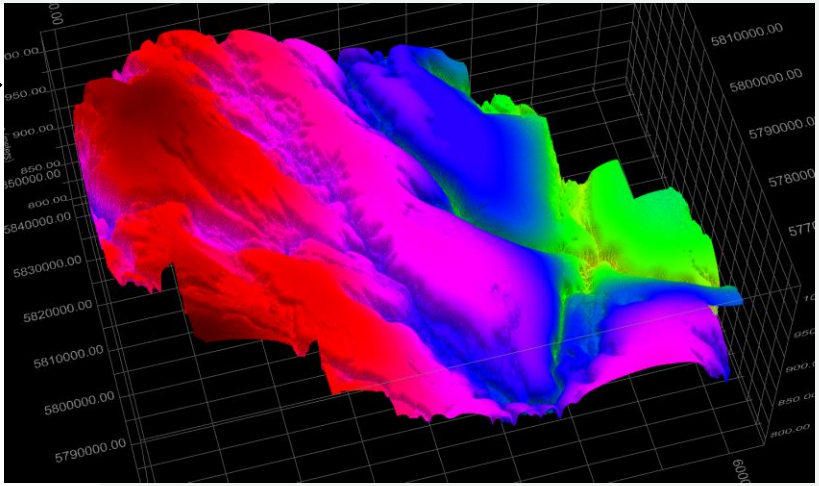
Regional Groundwater Flow Models – Taking a Nested-Scale Approach



Sylvan Lake Management Model

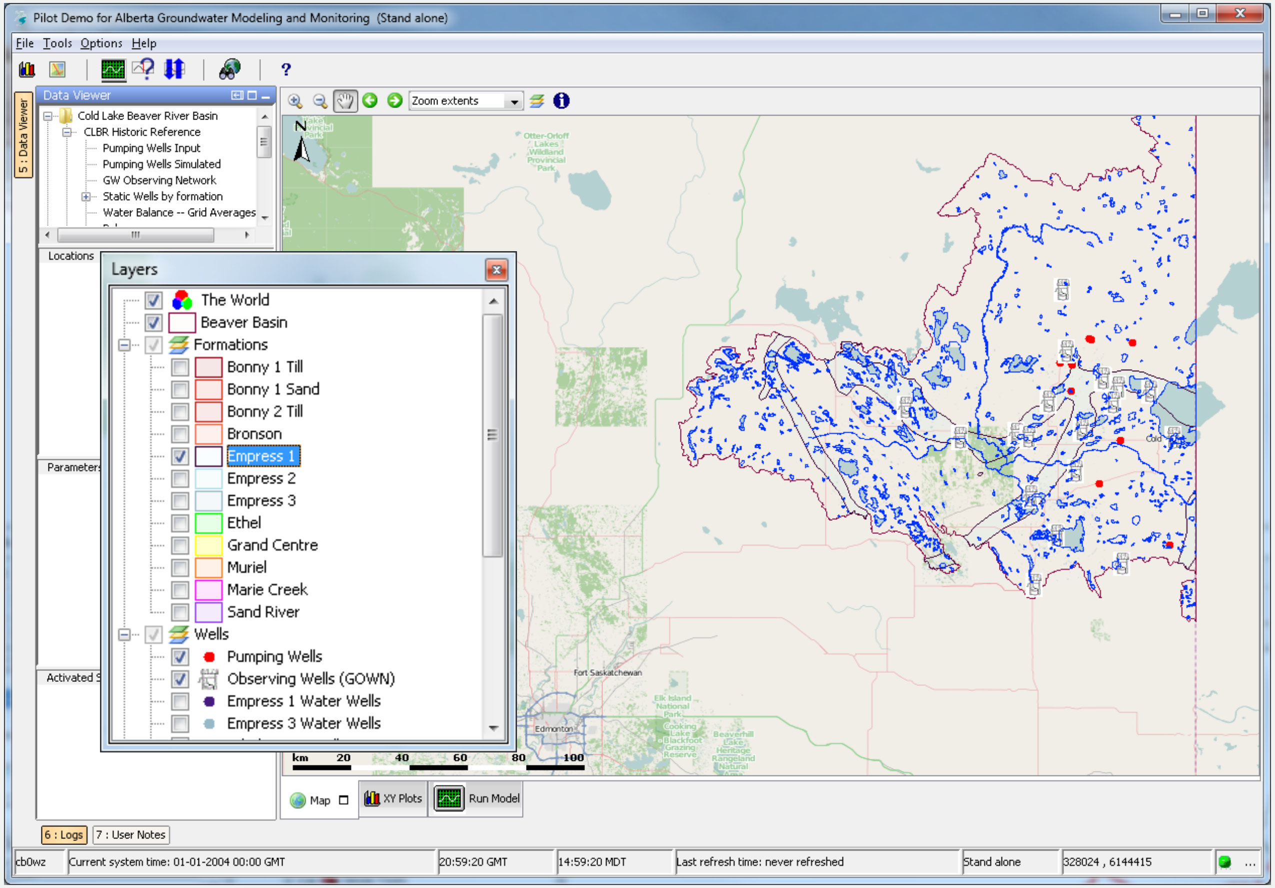


3D representation of hydraulic heads (above)

- Local-scale groundwater management model "nested" within a regional groundwater model
- "Nested" predominantly refers to numerical boundary conditions (heads and fluxes)

More details in Paper No. 282-6

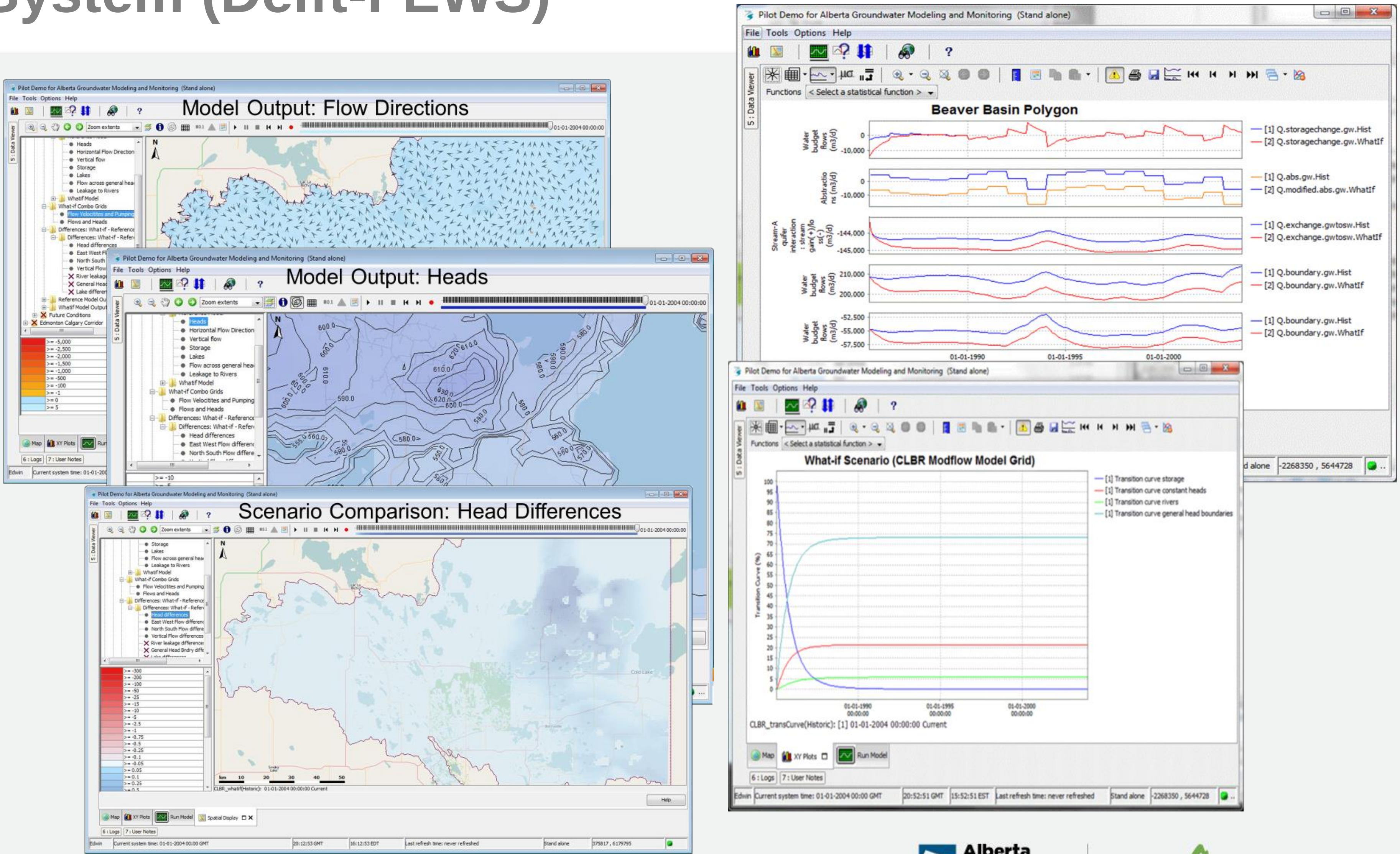
Integration of Numerical Model In Delft-FEWS (Forecasting, Evaluation & Warning System)



About Delft-FEWS:

- The software is free
- Any model can be linked to FEWS
- New displays can be added to the user interface
- Wide variety of data can be imported, displayed and used in the models
- New data can be added anytime
- Output can be automatically formatted and posted to a web server

Groundwater Model Displays in an Operational System (Delft-FEWS)



Summary

- Continued energy resource development is relying upon available water resources overprinted on existing water use across multiple sectors.
- Characterization of deep groundwater resources is becoming increasingly important as the Government of Alberta implements its Water Conservation Policy seeking to minimize freshwater use.
- As industry moves to utilize more saline water, a more comprehensive understanding of deep groundwater will be required to manage and allocate water resources in Alberta.
- Comprehensive strategies for water resource management are being evaluated and regulatory decision-support systems underpinned by numerical models have emerged as a potential path forward.
- We are seeking a scientific linkage between regulators, model developers, policy makers, and local stakeholders in order to devise an enhanced groundwater management framework focused on understanding cumulative effects of development.

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