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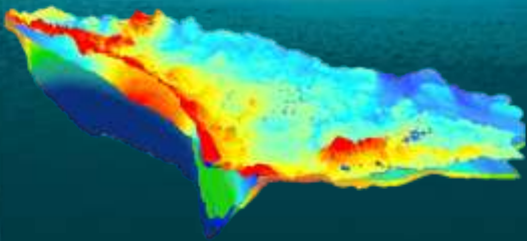
Numerical Modelling in Support of the Provincial Groundwater Inventory Program



Amandeep Singh
ERCB - Alberta Geological Survey
Environmental Modelling Workshop
March 14, 2013

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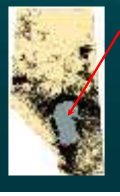
Objectives & Background

Provincial Groundwater Inventory Program (*PGIP*)

- MOU with Alberta Environment & Water
- Evaluates fresh groundwater (above Base of GW Protection)
- Evaluate quantity, quality, and thresholds between sustainable/ unsustainable use of groundwater resources through use of numerical flow models



Edmonton-Calgary Corridor (ECC)

- 1st study area
- ~50 000 km^2
- Dense population
- Rapid growth
- Based on 10 drainage basins
- Data-rich subsurface (both water well & oil and gas data)

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Outline / Numerical Model Workflow

- Establish the **PURPOSE** of the model.
- Develop a **CONCEPTUAL MODEL** of the system.
  - Gather data
- **GOVERNING EQUATION** and **COMPUTER CODE**
- **DESIGN**
- **CALIBRATION**
  - Conduct a **CALIBRATION SENSITIVITY ANALYSIS**
  - Determine how the model responds to uncertainty in parameter values.
- **VALIDATE** the model
- **PRESENT RESULTS** of model and model design
- **POSTAUDIT**

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Regional Geomodel (SARGS)

- Southern Alberta Regional Groundwater Simulation (SARGS)
  - Develop ~420 000 km^2 Steady State numerical model (Top of Colorado Group to Surface)
- Why is SARGS so big?
  - Sound, geologically-based boundary conditions (exception of US border: General Head Boundary)
  - Western Boundary : Deformation Belt
  - Eastern Boundary : Belly River Zero Edge & Pierre Shale in Saskatchewan
  - Basal Boundary : Top of Lea Park/Colorado Group
  - Effects of boundary conditions well removed from boundaries of management-scale models (local-scale models to be developed)

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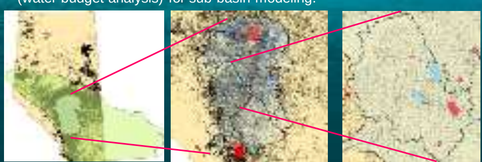
Modelling Objective

SARGS – Objective is to provide a reliable set of boundary conditions (water budget analysis) for sub-basin modeling.



SARGS ECC Sub-basin

ALL MODELS ARE WRONG BUT SOME ARE USEFUL!!!

- **Provides regional context for management scale**
- **Allows for use of Local Grid Refinement Package (LGR) in ModFlow**
- **Reduces influence of BC's on management-scale model**
- **Accounts for groundwater flux between sub-basins**

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Concept of Hydrostatic Pressure

$$h = z + \psi$$

Hydraulic head Elevation head Pressure head

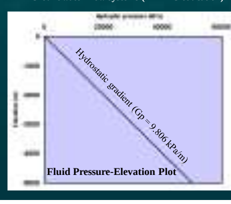
$$\psi = \frac{P}{\rho g}$$

Formation fluid pressure

Density of fluid × Gravitational constant

$$h = z + \frac{P}{\rho g}$$

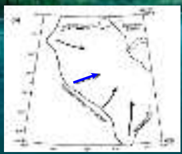
Groundwater flow systems (** MAC education)

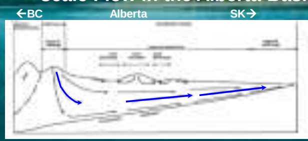


i.e. h remaining constant, P∝1/z

Under normal (hydrostatic) conditions, hydrostatic pressure increases by 9.8 kPa for every meter increase in depth

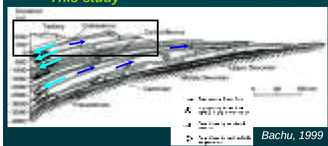
Existing knowledge of Basin-scale Flow in the Alberta Basin





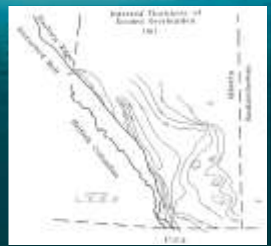
Hitchon, 1984

This study



Bachu, 1999

Sub-Hydrostatic Regime in SW Alberta

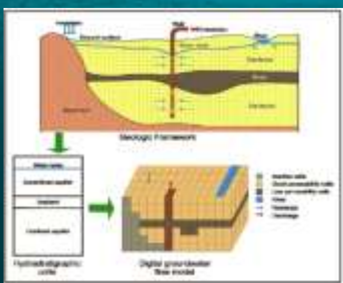


Distribution of freshwater hydraulic heads in the Horseshoe Canyon aquifer (Bachu and Underschulz, 1995)

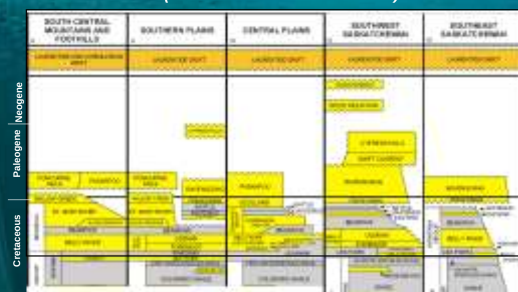
Bustin, 1991

Net unloading effect (combination of erosional and glacial processes) has been interpreted as the main mechanism for the sub-hydrostatic regime

Building Conceptual Model



Stratigraphy of the Western Canada Sedimentary Basin *(Alberta and SE Saskatchewan)*



conceptual model contd.

SARGS Model Layers

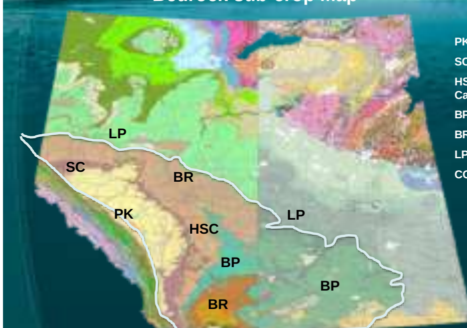
Hydrostratigraphic Layers	Hydraulic Property	Source
Recent	Depends	ERCB/AGS
Paskapoo	Aquifer	
Scollard	Aquifer	ERCB/AGS
Battle	Confining	ERCB/AGS
Horseshoe Canyon	Aquifer	
Bearpaw	Confining	Hamblin (GSC) picks / AGS/ Saskatchewan Data / Outcrops
Belly River*	Aquifer	ERCB/AGS & SWA
Lea Park (Top of Colorado Group)	Confining	ERCB/AGS & SWA

***For modeling purposes*

- *Belly River and Horseshoe Canyon have same spatial extent hydraulic properties.*
- *Paskapoo and Scollard have same spatial extent*
- **Belly River divided into to two sub-layers Belly River and Basal Belly River*

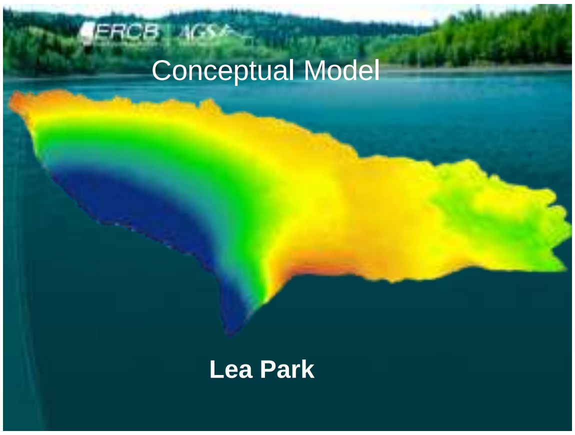
conceptual model contd.

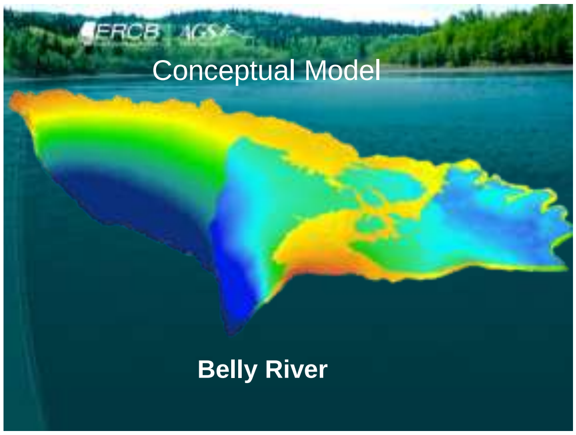
Bedrock sub-crop Map

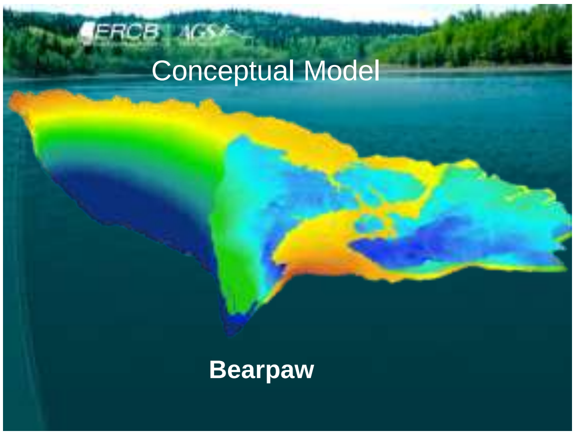


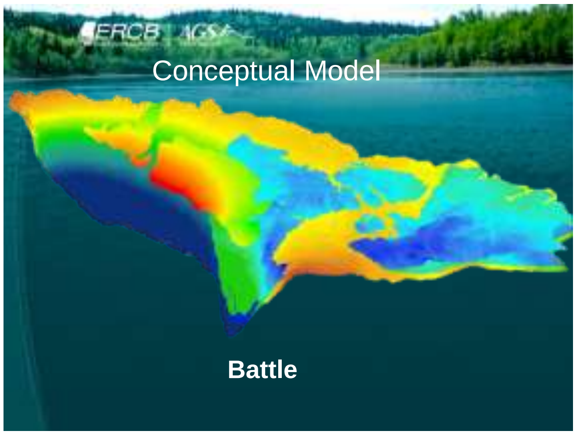
PK: Paskapoo
SC: Scollard
HSC: Horseshoe Canyon
BP: Bearpaw
BR: Belly River
LP: Lea Park
COL: Colorado

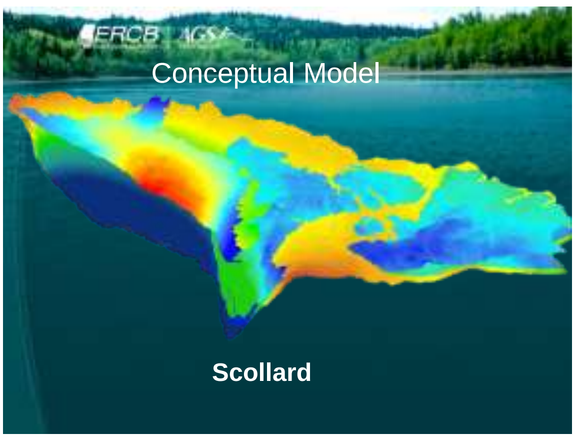
conceptual model contd.

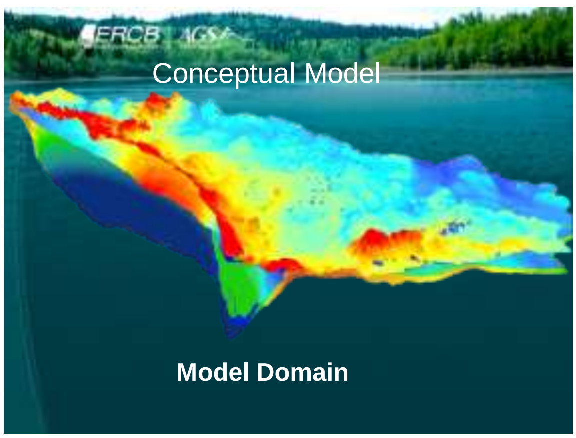

Conceptual Model
Lea Park


Conceptual Model
Belly River


Conceptual Model
Bearpaw


Conceptual Model
Battle


Conceptual Model
Scollard


Conceptual Model
Model Domain

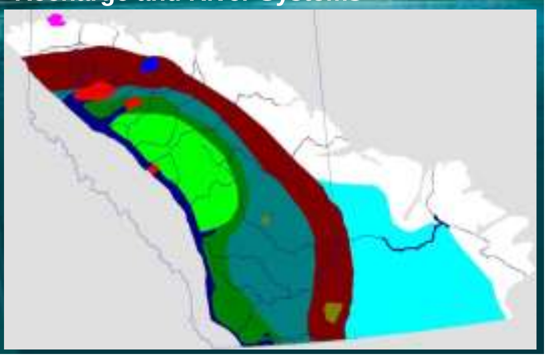
NUMERICAL MODEL

- Model domain : 610 X 1000 X 8 (approx. 3 x 10^6 active cells)
- Present grid size (approx) : 1250 (m) X 1250 (m)

Numerical Model (contd.)

- Pseudo Underpressuring
  - Generalized Head Boundary at the bottom (Lea Park)
  - The size of above mentioned underpressured zone based on DST measurements and earlier work
  - Drillstem test (DST) measurements are error prone hence a rigorous data culling procedure was undertaken that included identifying samples affected by production-induced drawdown
- Major River Systems (along with major tributaries)
  - North Saskatchewan River
  - South Saskatchewan River
  - Peace River
  - Athabasca River
- Recharge is implemented as a combination of precipitation, ET, etc.

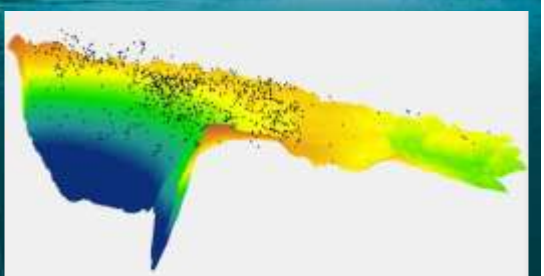
Recharge and River Systems



Calibration

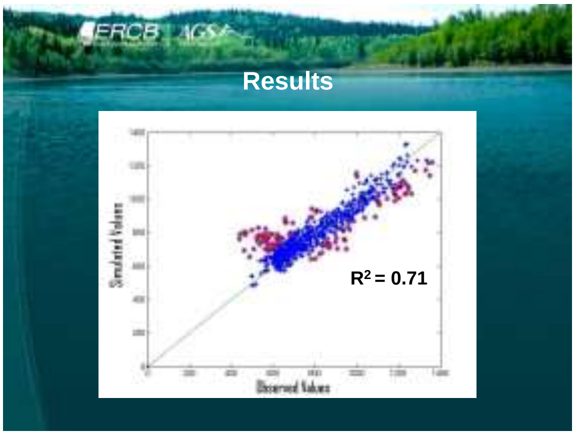
- Automated Calibration
  - Dynamically Dimensioned Search (DDS[1])
- Calibration targets
  - ESRD Observation wells
  - Water wells
  - DST measurements (cleaned for production influence)
  - Calibration Targets (820)
    - Drift = 61
    - Paskapoo = 241
    - Scollard = 68
    - Belly River / Horseshoe Canyon = 450 (200 DSTs)
- Initial hydraulic parameters estimated from aquifer test results
  - [1]Tolson, B. A., and C. A. Shoemaker (2007, WRR), Dynamically dimensioned search algorithm for computationally efficient watershed model calibration

Calibration



Results

- Quality of results / uncertainty
  - Plot of simulated head vs. observed head
  - Error plot
  - Spatial distribution of errors
- Hydraulic head maps
  - Paskapoo
  - Scollard
  - Belly River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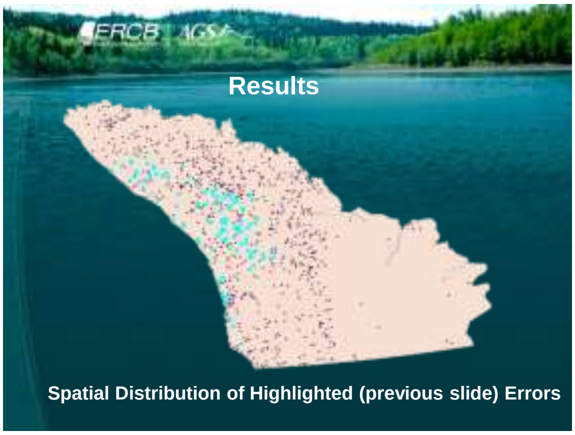
Results
$R^2 = 0.71$
Simulated Values
Observed Values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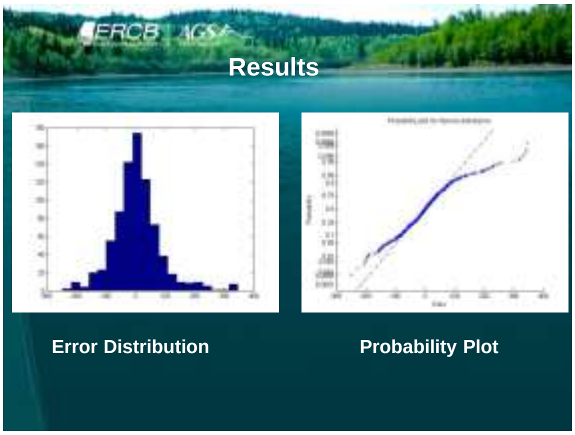
Results
Spatial Distribution of Highlighted (previous slide) Errors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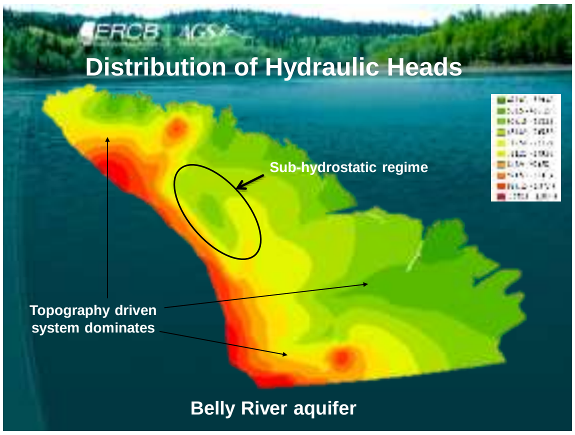
Results
Error Distribution
Probability Plot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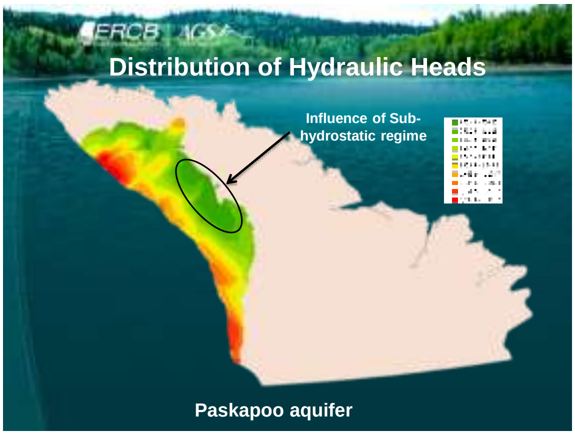
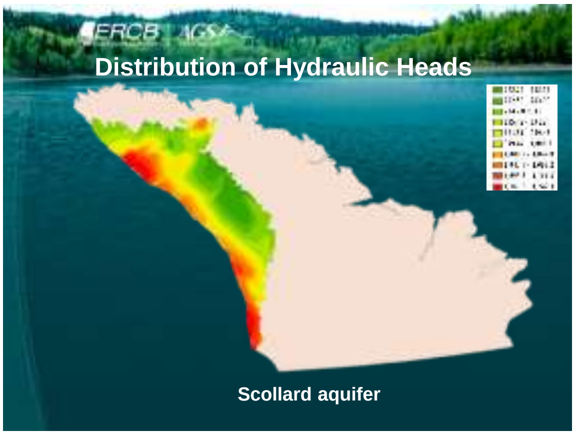
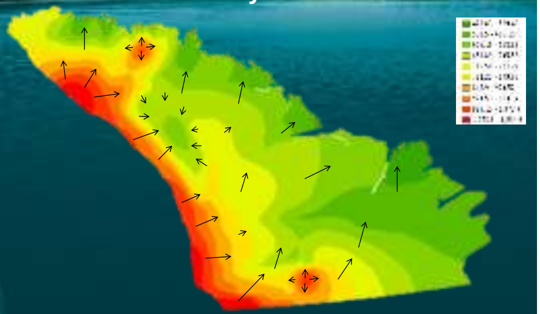
Distribution of Hydraulic Heads
Sub-hydrostatic regime
Topography driven
system dominates
Belly River aquifer


ERCB AGS
Distribution of Hydraulic Heads
Influence of Sub-
hydrostatic regime
Paskapoo aquifer

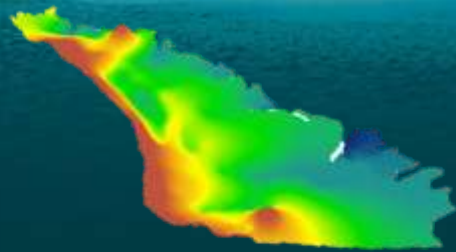

ERCB AGS
Distribution of Hydraulic Heads
Scollard aquifer

Distribution of Hydraulic Heads



Belly River aquifer

Distribution of Hydraulic Heads



Belly River aquifer

Summary

- Developed regional numerical model to provide a reliable set of boundary conditions (water budget analysis) for sub-basin modelling.
- The nested approach for sub-basin models ensures continuity at a variety of scales.
- Results show that topography-driven, local- to intermediate-scale flow systems dominate in the upper hydrostratigraphic units (i.e. Quaternary, Paskapoo, Scollard) but are influenced (relatively small) by sub-hydrostatic conditions in deeper units.
- Flow paths in the Horseshoe Canyon Formation and Belly River Group hydrostratigraphic units are controlled by regional scale topography-driven flow systems and sub-hydrostatic pressure regimes.

Acknowledgments

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• Colleagues in the Groundwater section, and Bedrock and Quaternary geology sections at the AGS

Alberta Environment and Sustainable Resource Development

Water Security Agency

Thank You