AGU 2014
H53B-0853

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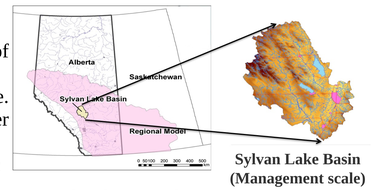
Application of Response Surface Based Calibration Methods for Regional Hydrogeological Modelling in the Western Canada Sedimentary Basin

Introduction

A regional scale numerical groundwater flow model was developed in the Western Canada Sedimentary Basin (WCSB), comprising parts of Alberta, Saskatchewan and British Columbia. This study was conducted as part of the Alberta Geological Survey's (part of the Alberta Energy Regulator) groundwater program. AGS's groundwater program is set to evaluate quantity, quality, and thresholds between sustainable/ unsustainable uses of groundwater resources. The objectives of the numerical model developed in this study are:

- Verify and establish conceptual model of regional hydro-geology in WCSB.
- Provide realistic boundary conditions (i.e. water budget analysis) for groundwater management models (basin scale).
- **Nested Scale Approach**- Provide hydrologic framework for development of independent management models to ensure hydraulic continuity.

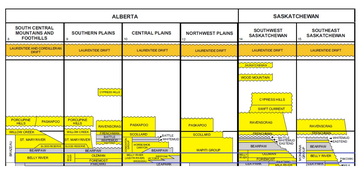
Study area within Western Canada Sedimentary Basin (WCSB)



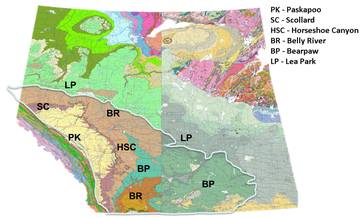
Nested Scale approach

Sylvan Lake Basin (Management scale)

Geologic Setting



Stratigraphy of the Western Canada Sedimentary Basin



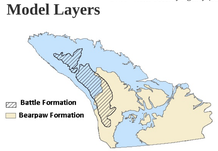
Bedrock Subcrop Map

Hydrostratigraphic architecture

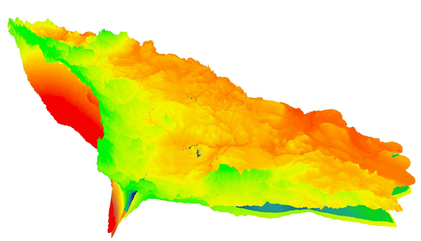
Hydrostatigraphic Layers	Hydraulic Property	Source	Model Layer Number
Recent	Variable	AER\AGS	1
Paskapoo	Aquifer		2
Scollard	Aquifer	AER\AGS	3
Battle	Confining	AER\AGS	4
Horseshoe Canyon	Aquifer		5
Bearpaw	Confining	Hamblin(GSC) picks\AGS\Sask. (WSA) \Outcrops	6
Belly River	Aquifer	AER\AGS\WSA	7
Lea Park (Top of Colorado Group)	Confining	AER\AGS\WSA	

*SWA - Water Security Agency (Saskatchewan)

Model Layers



Distribution of regional confining units

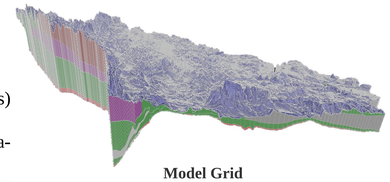


Model Domain

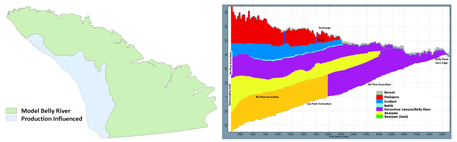
Numerical Model

- USGS MODFLOW used for simulation
- Domain: 610 x 1000 x 8 (approx. 3x106 active cells)
- Present grid size (approx.): 1.1 (km) x 1.1 (km)
- No flow along Brazeau-Waptiti thrust (Canadian Rockies) belt (western edge).
- Generalized Head Boundaries (GHB) along the Canada-USA international border.
- No flow boundary in the north and east along the Belly River Formation zero edge.
- Extents of the model accounts for the presence of sub-hydrostatic conditions and the hydrocarbon production taking place in the basin.
  - The sub-hydrostatic regions are considered hydraulically disconnected from the normal hydrostatic regions, hence no-flow boundary is imposed across the boundary.
  - The sub-hydrostatic regions were identified using Bachu (2002) and production zone map for the Belly River Formation

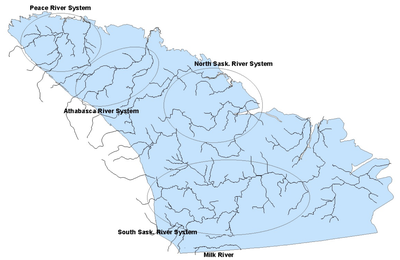
ESR 2002-04, Hydrogeology and Stress Regime of the Upper Cretaceous-Tertiary Coal-Bearing Strata in Alberta Bachu, S.; Michael, K., 2002.



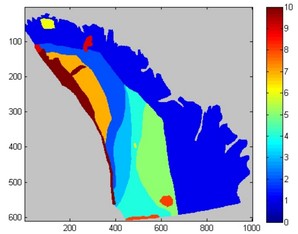
Model Grid



Belly River Formation Extent and Boundary Conditions



Implemented river network

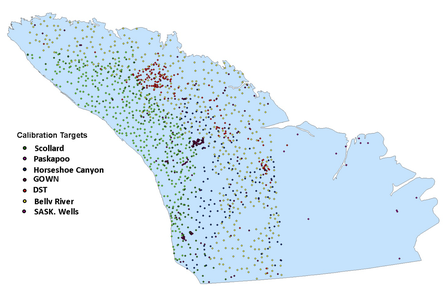


Recharge zones for calibration (based on elevation and amount of precipitation)

Calibration

- Calibration Targets
  - o Groundwater Observation Well Network (GOWN) - Monitoring wells maintained by Alberta Environmental Monitoring, Evaluation and Reporting Agency (AEMERA).
  - o Water wells (WW) from ESRD database.
  - o Drill Stem Tests (DST) - Transient pressure tests usually performed during hydrocarbon exploration.
- Distribution of calibration targets
  - o Paskapoo model layer (300 WW and 32 GOWN).
  - o Scollard model layer (240 WW and 40 GOWN).
  - o Horseshoe Canyon model layer (150 WW and 30 GOWN).
  - o Belly River model layer (450 WW, 88 GOWN and 160 DST's).
- Numerical model calibrated for minimizing the Sum of Square Errors (SSE), differences between measured and simulated groundwater levels.
- Automated calibration using Response Surface based Method (Romel. R. and Shoemaker C. A.)
  - o Mathematical model (such as Radial Basis (RBF)) used as a surrogate for the optimization objective to guide the search.
  - o Surrogate is fit to the objective function values (SSE's) from prior generations.

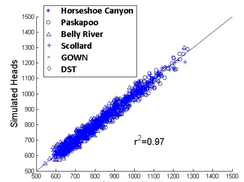
R.G.Regis, and C. A. Shoemaker (2005, Journal of Global optimization), Constrained global optimization of expensive black box functions using radial basis functions



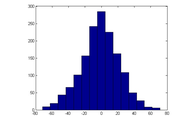
Calibration targets

Results

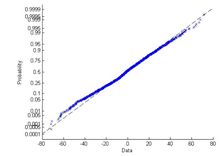
Model Validation



Cross Validation plot

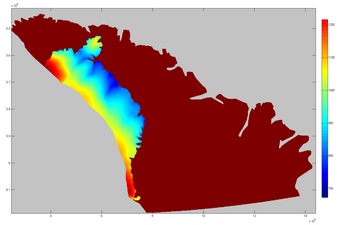


Histogram for Error distribution (difference between simulated and observed heads)

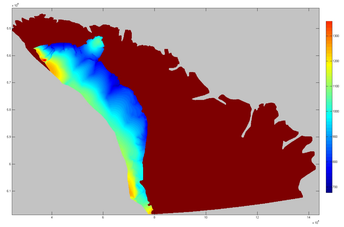


Probability plot for Errors

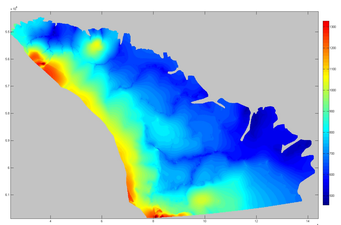
Maps of Simulated Hydraulic Head



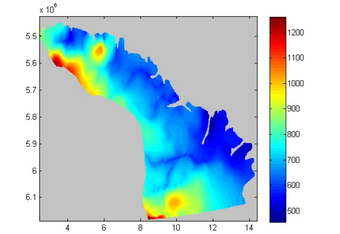
Paskapoo model layer



Scollard model layer



Horseshoe Canyon model layer



Belly River model layer

Discussion and Conclusion

- Developed regional numerical model to provide a reliable set of boundary conditions (water budget analysis) for nested-scale modelling.
- The application of nested scale approach for sub-basin models ensures continuity at a variety of scales for future numerical modelling.
- In this study the sub-hydrostatic zones are considered as hydraulically disconnected from the normal hydrostatic regions.
- Results show that topography driven, local to intermediate scale flow systems dominate in all hydro-stratigraphic units.
- Future work focuses on application of nested scale approach for Sylvan Lake Basin in collaboration with Deltares to develop management scale numerical model using the boundary conditions from the regional model.

Acknowledgements

Government of Alberta

Deltares Enabling Delta Life

Water Security Agency

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