Groundwater Inventory Update

Dan Palombi, Brian Smerdon, Kevin Parks

Alberta Energy Regulator – Alberta Geological Survey

Watertech Symposium, 7 April 2016 – Regulatory Update Session

Refresher: Provincial Groundwater Inventory Program and CCA Pyramid Model

PGIP Program Objectives:

Phase I: Define the natural system; quantification of the geological framework and analytical models for hydrogeological regime (conceptual model design)

- *Fox Creek Area project (Smerdon et al., this morning)*
- *Calgary-Lethbridge Corridor project (Liggett and Atkinson, this morning)*

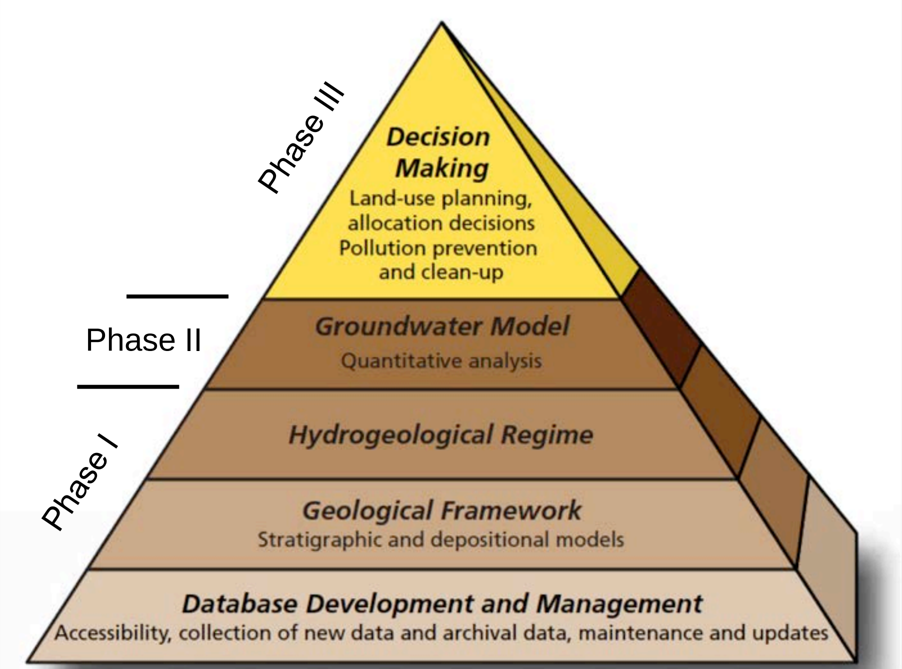
Phase II: Regional and sub-basin scale groundwater modelling

- Southern Alberta Regional Groundwater Simulation
- Groundwater Modelling in the Sylvan Lake Sub-Basin
    - *ags.aer.ca: New Website*

Phase III: Water resource decision-support tools for management, regulation, and policy assurance

- ***Focus of this presentation***

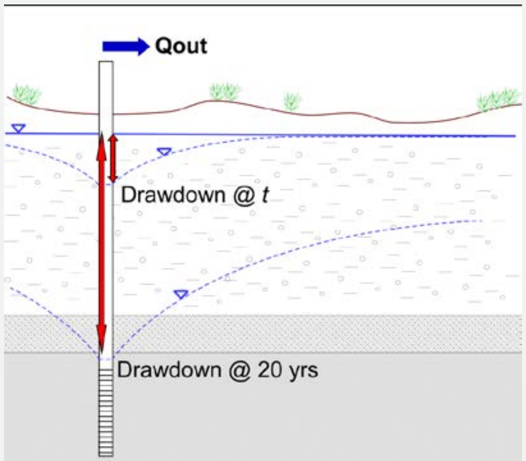
Science Requirements for Groundwater Sustainability

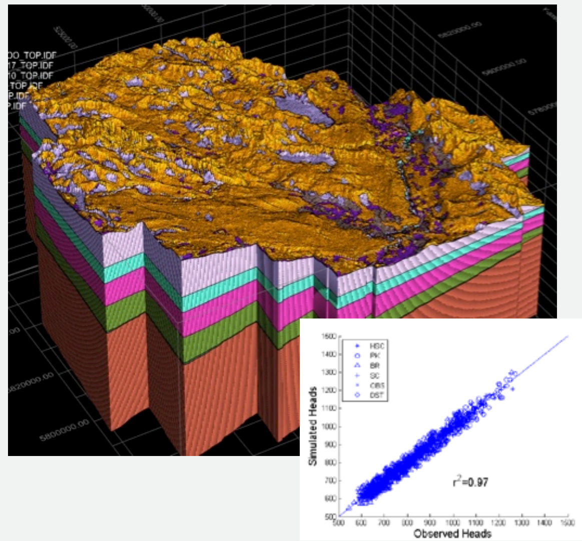


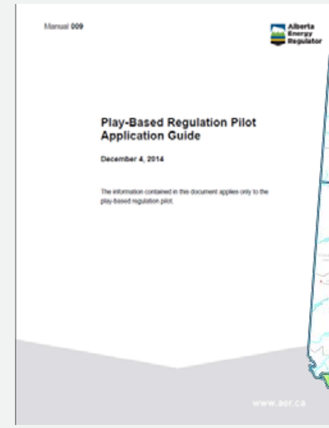
Canadian Council of Academies, 2009

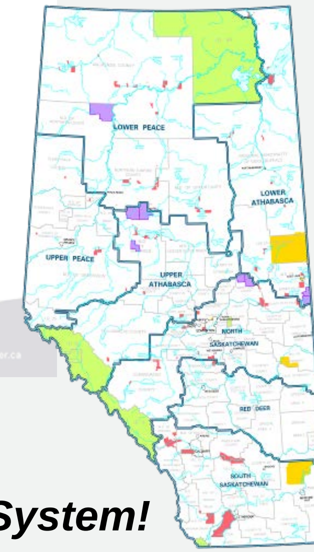
Present and Future States: What's Our Target for Cumulative Effects Management?

Present State → ***Desired Future State***





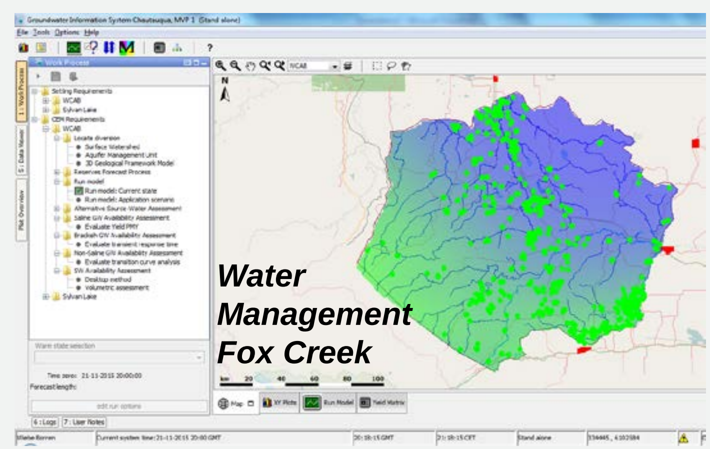




Requires an Information System!

Q_{20} : 20 year safe yield

- Well-based concept (drawdown vs. time)
- Does not quantify cumulative effects (multiple wells)
- Does not address the ultimate source or sustainability of pumping



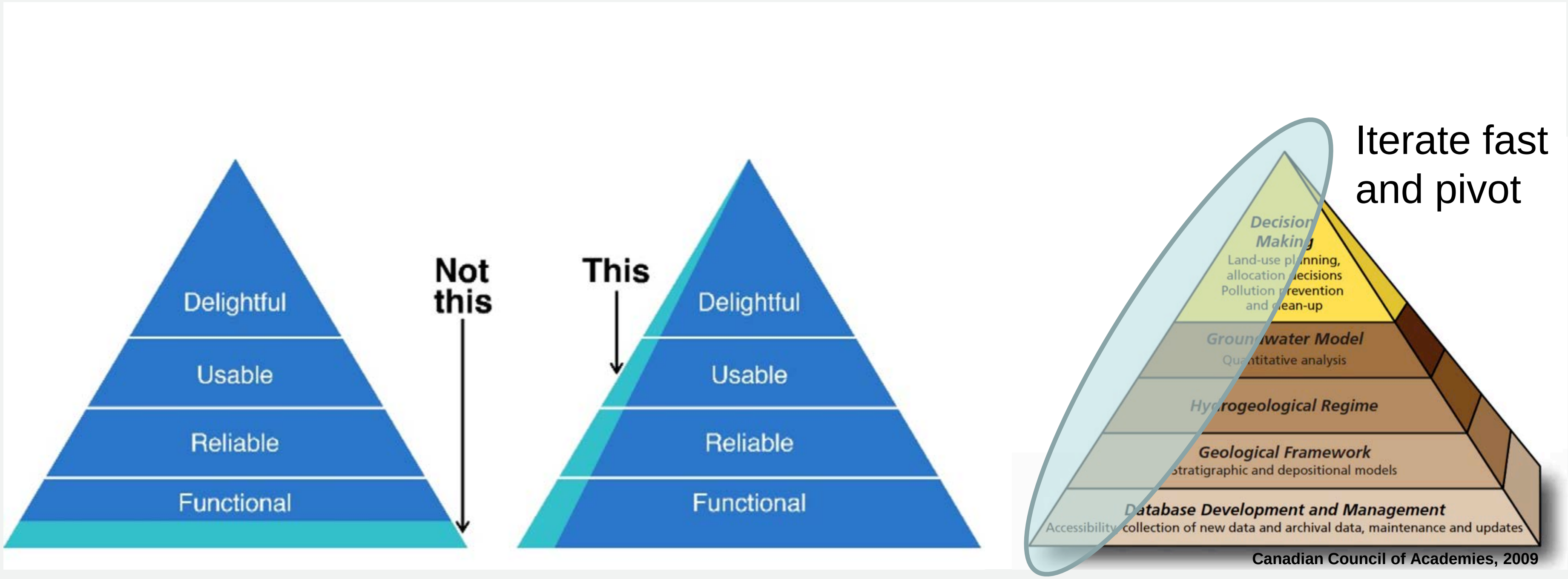
Phase 3 Project Goals and Objectives

- Have an information system that provides high quality, consistent information about groundwater resources and their management to support decision making
- Deliver results of groundwater models to regulators and consultants in ways that are fit for purpose
- Develop social and technology platform needed for developing, sharing, and continuously improving groundwater models among specialists in government, consulting, energy industry, etc.
- *Prepare a functional and conceptual technical design*
- *Develop a working prototype in the Fox Creek area*

Project Design and Approach: *Lean Startup*

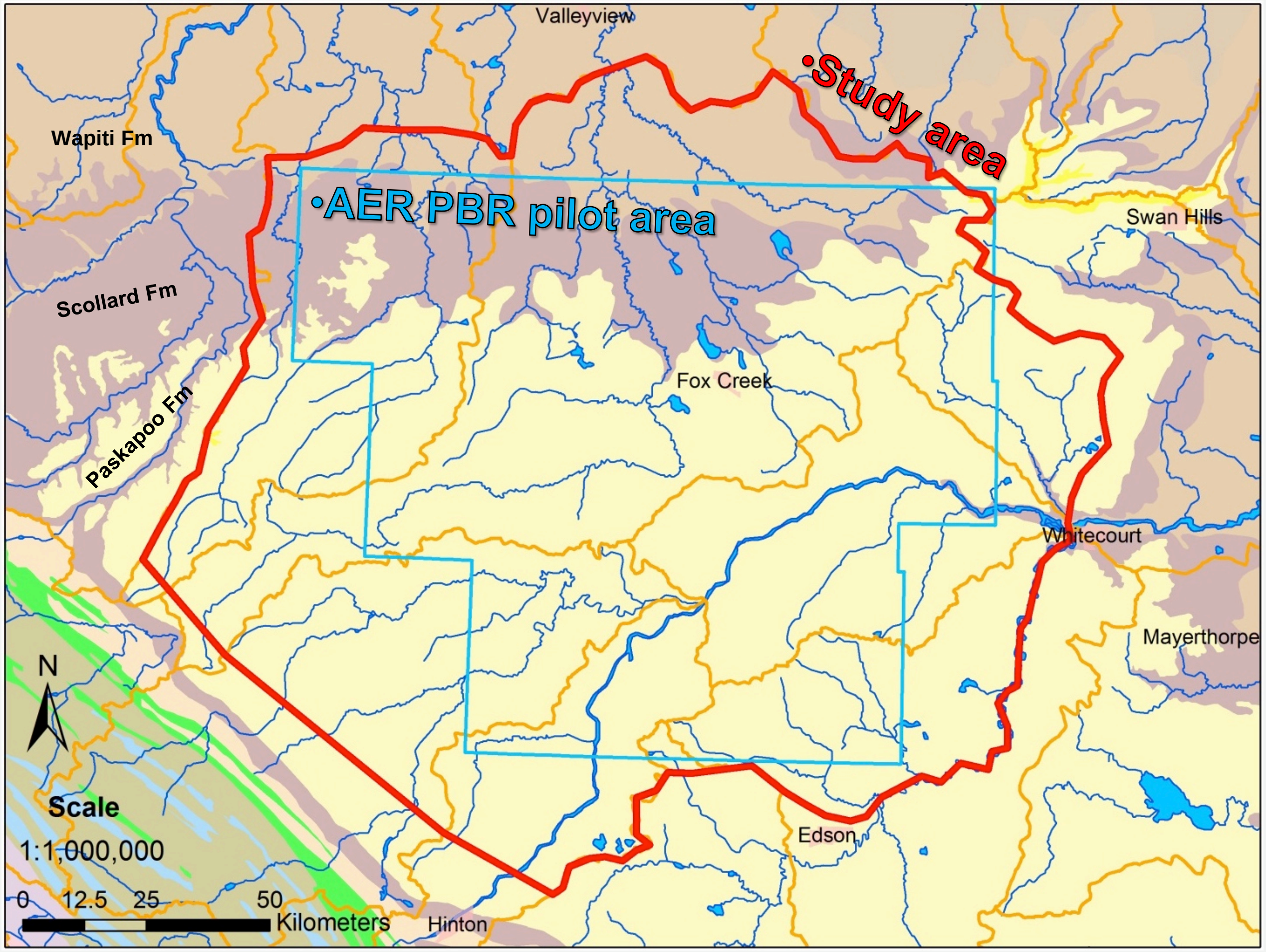
- Conduct a rapid assessment of groundwater availability in the Fox Creek area
- Design working prototype information system that contains key components to test with regulators and community of practice
- Produce Minimum Viable Product (MVP)
    1. Groundwater Yield Matrix: setting limits and thresholds
    2. Prototype Groundwater Information System: balancing energy development with environmental and social impacts

What is an MVP?



Canadian Council of Academies, 2009

Fox Creek Study Area

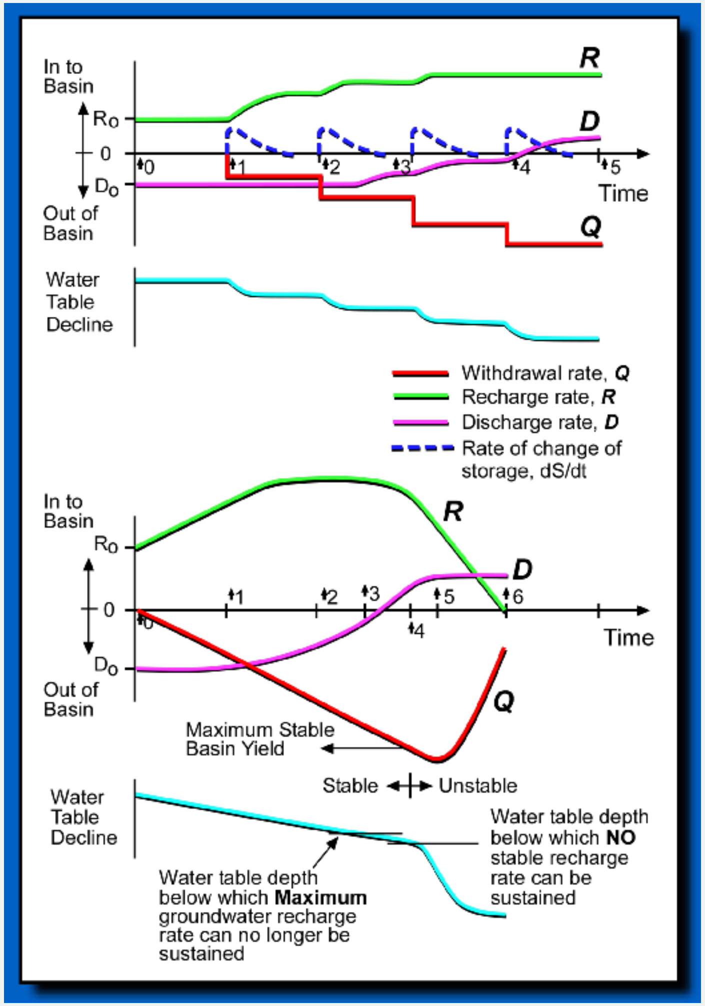


- Encompasses AER PBR pilot area
- Spans Peace and Athabasca basins
- Defined by sub-basin drainage
- Bounded by deformation belt
- 22,000 km^2

Alberta Energy Regulator

AGS ALBERTA GEOLOGICAL SURVEY

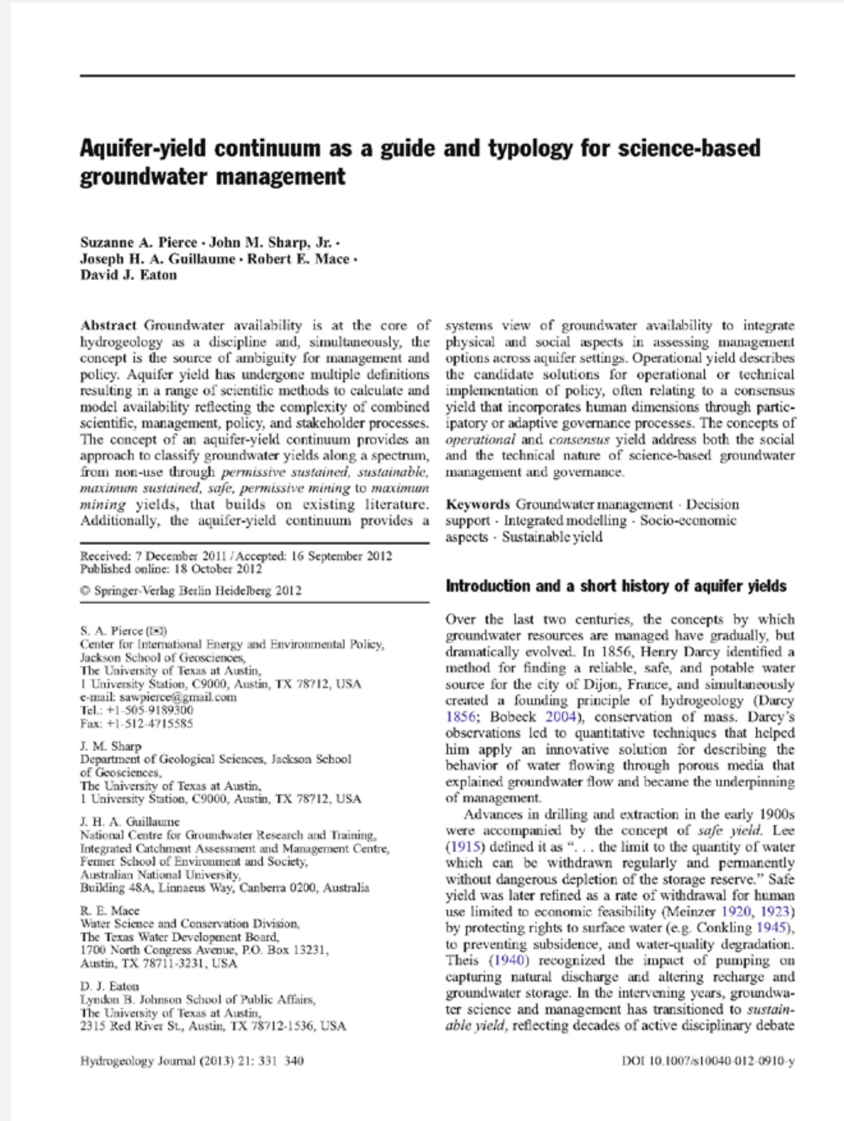
Groundwater Inventory & Capacity Assessment



- Basin yield concept (1970's…not new…)
- Response to stress
- Develop intrinsic breakpoints for system
- Yield → *Safe? Optimal? Sustainable?*

Aquifer-yield Continuum:
Basis for AGS Groundwater Yield Matrix

- An initial application of the paper by *Pierce et al. 2013*
- We need to quantify groundwater availability in rapid manner to understand potential development risks and current state of use versus availability
- "Give me a single number" with associated uncertainty and risk
  - Performance metrics



Aquifer-yield continuum as a guide and typology for science-based groundwater management

Suzanne A. Pierce · John M. Sharp, Jr. · Joseph H. A. Guillaume · Robert E. Mace · David J. Eaton

Abstract Groundwater availability is at the core of hydrogeology as a discipline and, simultaneously, the concept is the source of ambiguity for management and policy. Aquifer yield has undergone multiple definitions resulting in a range of scientific methods to calculate and model availability reflecting the complexity of combined scientific, management, policy, and stakeholder processes. The concept of an aquifer-yield continuum provides an approach to classify groundwater yields along a spectrum, from non-use through *permissive sustained, sustainable, maximum sustained, safe, permissive mining* to *maximum mining* yields, that builds on existing literature. Additionally, the aquifer-yield continuum provides a systems view of groundwater availability to integrate physical and social aspects in assessing management options across aquifer settings. Operational yield describes the candidate solutions for operational or technical implementation of policy, often relating to a consensus yield that incorporates human dimensions through participatory or adaptive governance processes. The concepts of *operational* and *consensus* yield address both the social and the technical nature of science-based groundwater management and governance.

Keywords Groundwater management · Decision support · Integrated modelling · Socio-economic aspects · Sustainable yield

Received: 7 December 2011 / Accepted: 16 September 2012
Published online: 18 October 2012

S. A. Pierce (✉)
Center for International Energy and Environmental Policy,
Jackson School of Geosciences,
The University of Texas at Austin,
1 University Station, C9000, Austin, TX 78712, USA
e-mail: sawpierce@gmail.com
Tel.: +1-505-9189300
Fax: +1-512-4715585

J. M. Sharp
Department of Geological Sciences, Jackson School of Geosciences,
The University of Texas at Austin,
1 University Station, C9000, Austin, TX 78712, USA

J. H. A. Guillaume
National Centre for Groundwater Research and Training,
Integrated Catchment Assessment and Management Centre,
Fenner School of Environment and Society,
Australian National University,
Building 48A, Linnaeus Way, Canberra 0200, Australia

R. E. Mace
Water Science and Conservation Division,
The Texas Water Development Board,
1700 North Congress Avenue, P.O. Box 13231,
Austin, TX 78711-3231, USA

D. J. Eaton
Lyndon B. Johnson School of Public Affairs,
The University of Texas at Austin,
2315 Red River St., Austin, TX 78712-1536, USA

Introduction and a short history of aquifer yields

Over the last two centuries, the concepts by which groundwater resources are managed have gradually, but dramatically evolved. In 1856, Henry Darcy identified a method for finding a reliable, safe, and potable water source for the city of Dijon, France, and simultaneously created a founding principle of hydrogeology (Darcy 1856; Bobeck 2004), conservation of mass. Darcy's observations led to quantitative techniques that helped him apply an innovative solution for describing the behavior of water flowing through porous media that explained groundwater flow and became the underpinning of management.

Advances in drilling and extraction in the early 1900s were accompanied by the concept of *safe yield*. Lee (1915) defined it as "... the limit to the quantity of water which can be withdrawn regularly and permanently without dangerous depletion of the storage reserve." Safe yield was later refined as a rate of withdrawal for human use limited to economic feasibility (Meinzer 1920, 1923) by protecting rights to surface water (e.g. Conkling 1945), to preventing subsidence, and water-quality degradation. Theis (1940) recognized the impact of pumping on capturing natural discharge and altering recharge and groundwater storage. In the intervening years, groundwater science and management has transitioned to *sustainable yield*, reflecting decades of active disciplinary debate

DOI 10.1007/s10040-012-0910-y

Aquifer-yield Continuum

- Yield → *Safe? Optimal? Sustainable?*
- Continuum attempts to define gradation of impact (i.e., volumetric bounds & break points)

Permissive Sustained Yield	Maximum Sustained Yield	Safe Yield	Permissive Mining Yield	Maximum Mining Yield
$P=R_p-D_{psy}$	$P=R_p-D_p$	$P=R_p$	$P = V_0-V_{min}+R_p-D_{min}$	$P=V_0+R_p$

P = human induced discharge

R_p = recharge modified by pumping

D_p = discharge modified by pumping

D_{psy} = discharge permissible sustained yield discharge

D_{min} = mining permisisble discharge

V_0 = initial volume of aquifer

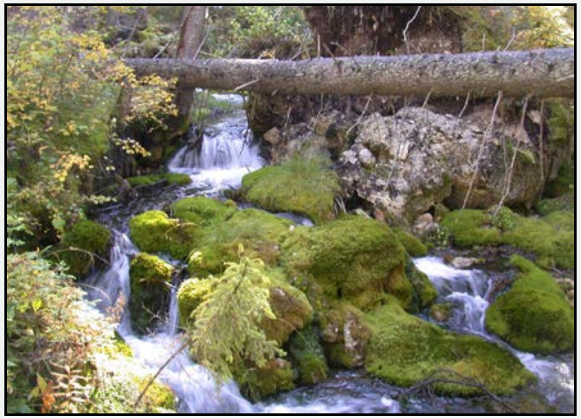
V_{min} = permissible volume decrease when mining

$D_{min} > D_{psy} > D_p$

Alberta Energy Regulator

AGS ALBERTA GEOLOGICAL SURVEY

Hydrologic Limits: Yield Matrix



Permissive Sustained Yield

Maximum Sustained Yield

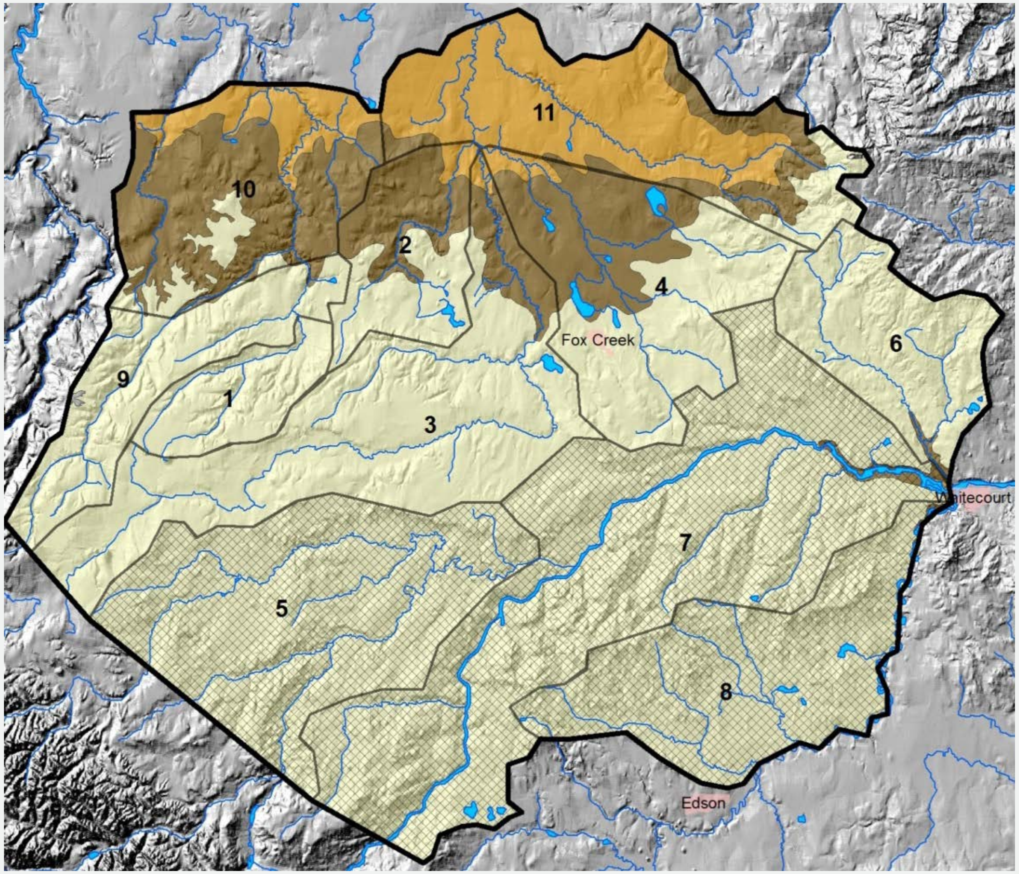
Safe Yield

Permissive Mining Yield

Maximum Mining Yield

Non-saline Aquifer Yield Methodology

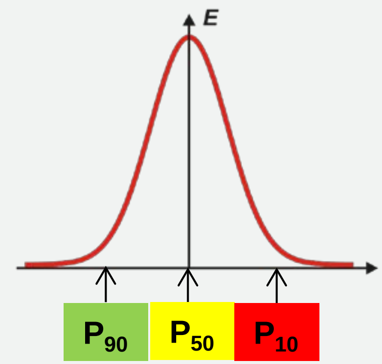
- Partition study area into sub-basins

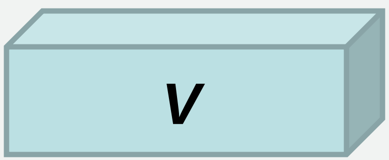


- 1 to 9 represent surficial deposits, Paskapoo-Scollard
- 10 & 11 represent Wapiti
- 12 represents non-saline Wapiti beneath Paskapoo-Scollard
- 13 (hatched pattern) represents saline Wapiti beneath Paskapoo-Scollard

Non-saline Aquifer Yield Methodology

- Estimate recharge from Environment Canada gauges (Q25, Mean, Q75), correcting for % coverage





- Estimate volume associated with each sub-basin

- Assume porosity:
  - 5, 10, 20% for Paskapoo & Scollard formations
  - 3, 9, 12% for Wapiti Formation

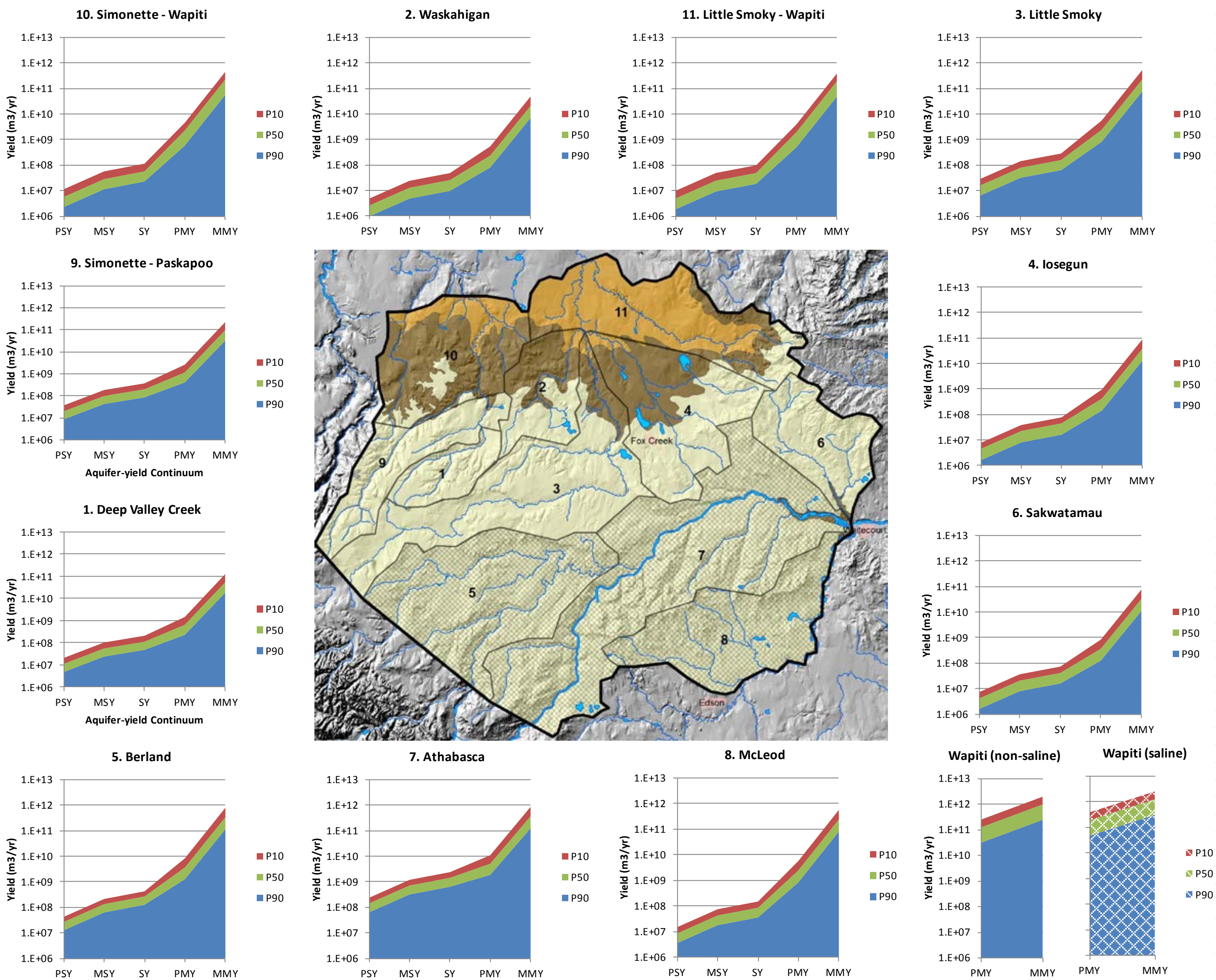
Non-saline Aquifer Yield Methodology

- Calculate yield:
  - Using ‘fractions’ of recharge to approximate Dpsy (10% of R) and Dp (50% of R) for sustained yield
  - Using ‘fraction’ of aquifer volume for permissive mining (1%)

Permissive Sustained Yield	Maximum Sustained Yield	Safe Yield	Permissive Mining Yield	Maximum Mining Yield
$P=R_p-D_{psy}$	$P=R_p-D_p$	$P=R_p$	$P = V_0-V_{min}+R_p-D_{min}$	$P=V_0+R_p$

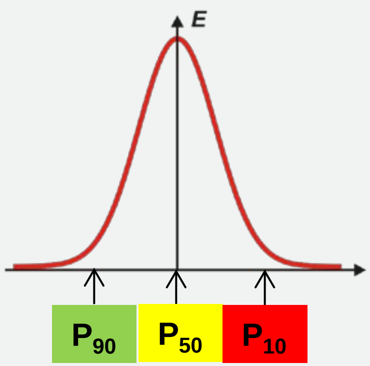
- Summarize graphically

Summary of Aquifer Yield Estimates



Prototype of Fox Creek Area Groundwater Yield Limits & Thresholds

Qualitative Description



Quantitative Estimate

Alberta Energy Regulator | AGS ALBERTA GEOLOGICAL SURVEY

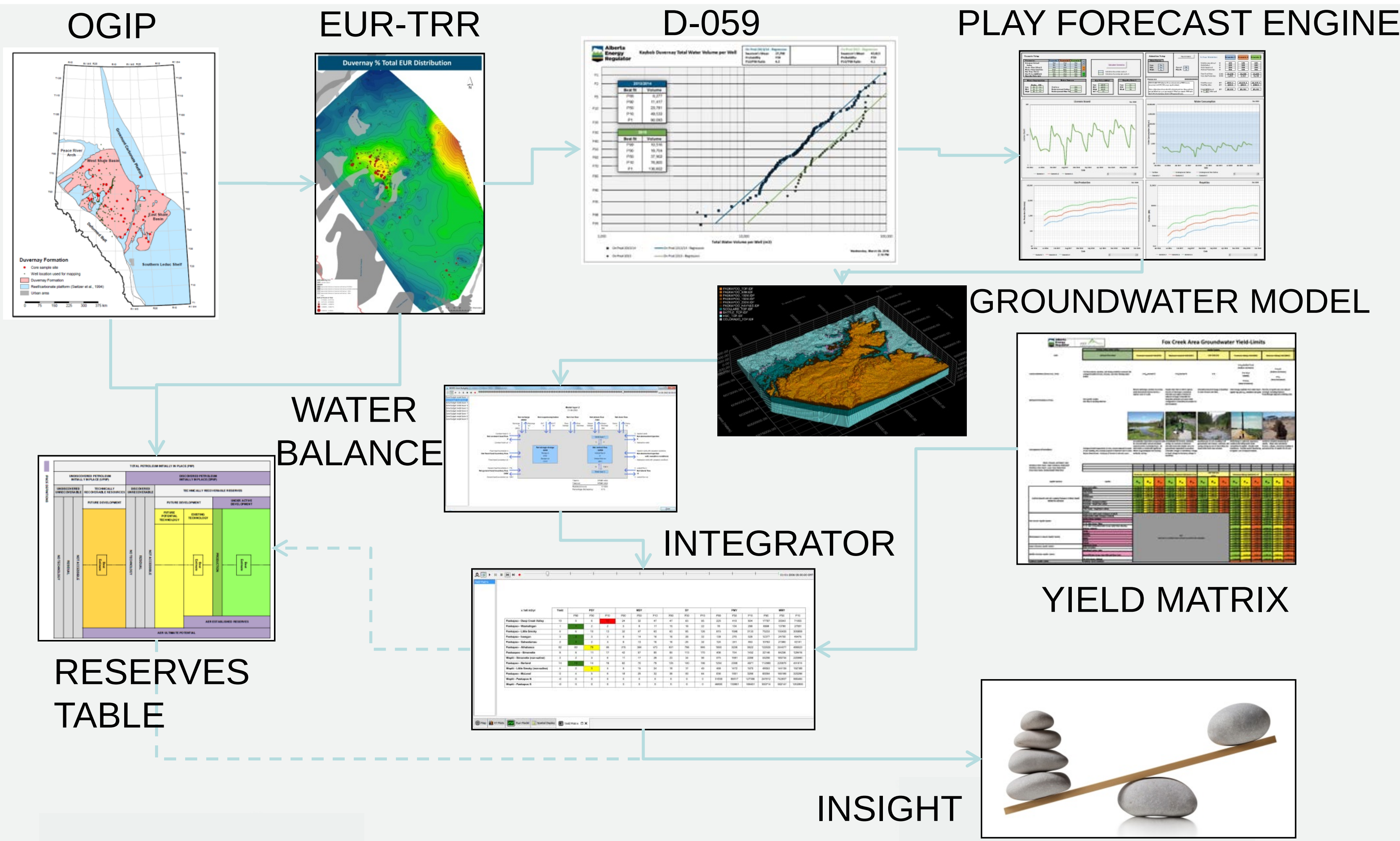
Fox Creek Area Groundwater Yield-Limits

	Flowing Surface Water Bodies	Aquifer Systems				
Limit	Instream Flow Need	Permissive Sustained Yield (PSY)	Maximum Sustained Yield (MSY)	Safe Yield (SY)	Permissive Mining Yield (PMY)	Maximum Mining Yield (MMY)
Formal Definitions (Pierce et al., 2013)	The flow volume, duration, and timing needed to maintain the ecological health of rivers, streams, and other flowing water bodies.	$P=D_{sw}fraction*R$	$P=D_r fraction*R$	P=R	$P=V_{ss}fraction*V_c+R$ [shallow sub-basins] $P=0.7H_eA$ [Wapiti] $P=0.7V_c$ [deep formations]	$P=V_c+R$ [shallow sub-basins] $P=V_c$ [deep formations]
Method of Estimation or Proxy	Site-specific studies. AEP Alberta Desktop Method	Natural hydrologic variation at surface water boundaries intersected by a capture zone of a well.	Steady-state limit at which capture fraction of discharge is maximum tolerable and capture fraction of induced recharge is tolerable for drainable wetlands and water-table configuration is tolerable/recoverable for phreatophytes.	Estimated annual recharge or baseflow to main streams and lakes.	Total storage available from static head > aquifer top plus D_{sss}-modified safe yield.	Porosity of aquifer plus any induced recharge, including leakance from/through adjacent confining units.
						
Consequences of Exceedance	Ecological health impairment of river, stream impaired to point of non-viability, non-recovery at point of diversion and to some degree downstream. Drying up of stream in extreme cases.	Groundwater dependent ecosystems will be stressed within natural variations experienced but essentially intact. No observable or statistically significant effects on groundwater-fed streams, wetlands, springs.	Groundwater-fed streams, wetlands, springs are constant at minimual tolerable level with notable stress on groundwater-dependent ecosystems. (Tolerable changes in subsidence, change in head, change in chemistry, change in baseflow)	Baseflow goes to zero resulting in all groundwater-fed streams, wetlands, and springs drying up net of return flow, but water table levels stay constant.	All discharge is captured, experience continuously falling water levels everywhere in aquifer. Possible land subsidence. Possible partial dewatering of aquifer. Loss of bequest volume.	Partial to complete dewatering of aquifer. Major land subsidence, fissures, collapse, seismicity, leading to permanent loss of aquifer for all uses.

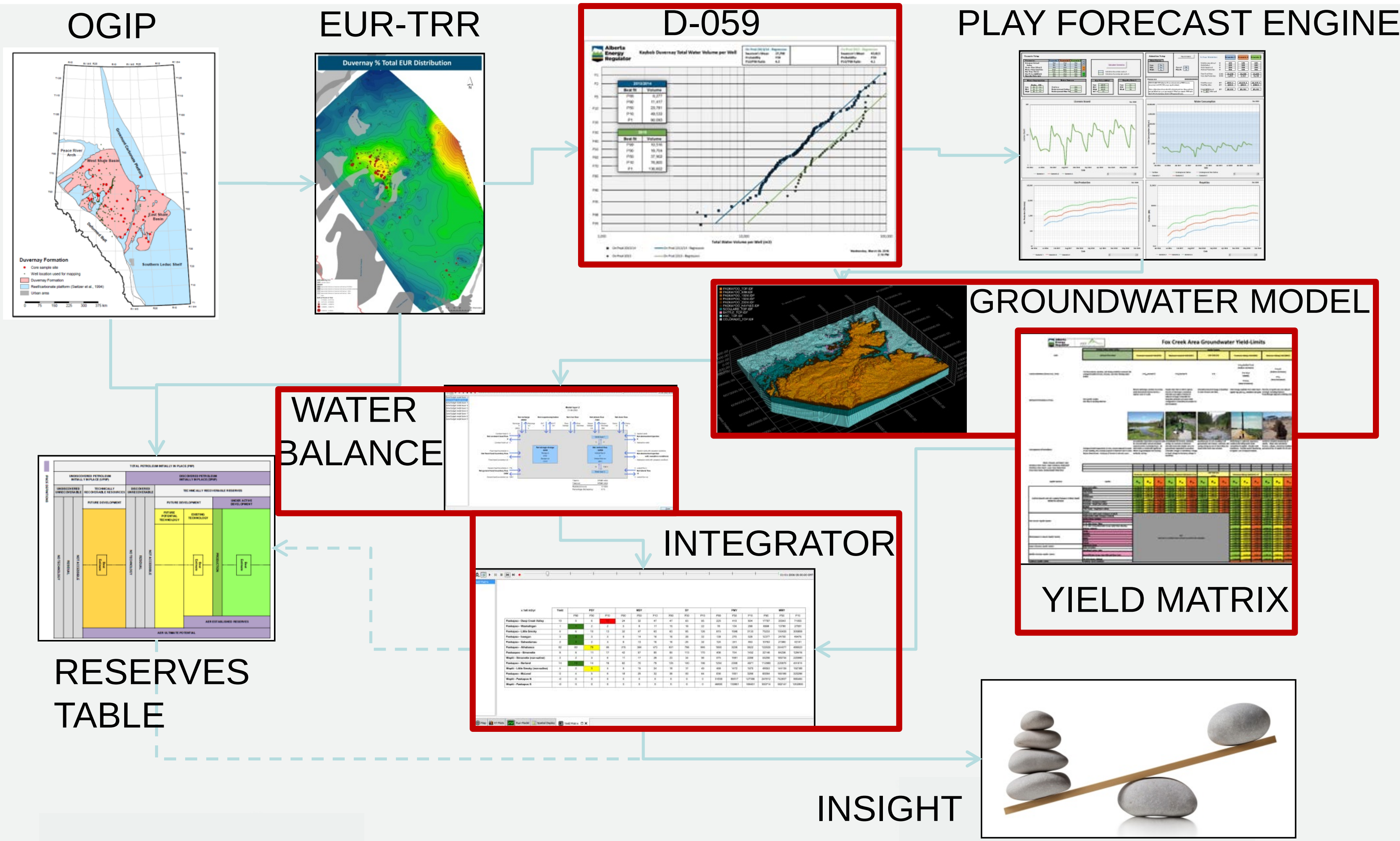
Rivers, Streams, and Major Lakes																
Athabasca River Basin: Upper Athabasca Watershed																
Athabasca River Basin: Lesser Slave Watershed																
Peace River Basin: Smoky/Wapiti Watershed																

		Permissive Sustained Yield (PSY) m^3/yr			Maximum Sustained Yield (MSY) m^3/yr			Safe Yield (SY) m^3/yr			Permissive Mining Yield (PMY) m^3			Maximum Mining Yield (MMY) m^3		
Aquifer Systems	Aquifer	P_{90}	P_{50}	P_{10}	P_{90}	P_{50}	P_{10}	P_{90}	P_{50}	P_{10}	P_{90}	P_{50}	P_{10}	P_{90}	P_{50}	P_{10}
Surficial deposits and sub-cropping Paskapoo-Scollard, Wapiti divided by sub-basin	Deep Creek Valley	4.73E+06	6.31E+06	9.47E+06	2.37E+07	3.16E+07	4.73E+07	4.73E+07	6.31E+07	9.47E+07	2.25E+08	4.18E+08	8.04E+08	1.78E+10	3.55E+10	7.11E+10
	Waskahigan	9.47E+05	1.58E+06	2.21E+06	4.73E+06	7.89E+06	1.10E+07	9.47E+06	1.58E+07	2.21E+07	7.84E+07	1.54E+08	2.98E+08	6.90E+09	1.38E+10	2.76E+10
	Little Smoky	6.31E+06	9.47E+06	1.26E+07	3.16E+07	4.73E+07	6.31E+07	6.31E+07	9.47E+07	1.26E+08	8.15E+08	1.60E+09	3.13E+09	7.52E+10	1.50E+11	3.01E+11
	Iosegun	1.58E+06	2.84E+06	3.16E+06	7.89E+06	1.42E+07	1.58E+07	1.58E+07	2.84E+07	3.16E+07	1.39E+08	2.76E+08	5.26E+08	1.24E+10	2.48E+10	4.95E+10
	Saleswatamau	1.58E+06	2.52E+06	3.16E+06	7.89E+06	1.26E+07	1.58E+07	1.58E+07	2.52E+07	3.16E+07	1.24E+08	2.41E+08	4.63E+08	1.08E+10	2.16E+10	4.31E+10
	Athabasca	6.31E+07	7.89E+07	9.47E+07	3.16E+08	3.94E+08	4.73E+08	6.31E+08	7.89E+08	9.47E+08	1.85E+09	3.23E+09	5.82E+09	1.23E+11	2.45E+11	4.89E+11
	Simonette - Paskapoo-Scollard	8.50E+06	1.13E+07	1.70E+07	4.25E+07	5.66E+07	8.50E+07	8.50E+07	1.13E+08	1.70E+08	4.06E+08	7.55E+08	1.45E+09	3.21E+10	6.42E+10	1.28E+11
	Simonette - Wapiti (non-saline)	2.26E+06	3.39E+06	5.65E+06	1.13E+07	1.70E+07	2.83E+07	2.26E+07	3.39E+07	5.65E+07	5.75E+08	1.69E+09	2.27E+09	5.53E+10	1.66E+11	2.21E+11
	Berland	1.25E+07	1.41E+07	1.56E+07	6.25E+07	7.03E+07	7.81E+07	1.25E+08	1.41E+08	1.56E+08	1.25E+09	2.40E+09	4.67E+09	1.13E+11	2.26E+11	4.52E+11
	Little Smoky - Wapiti (non-saline)	1.84E+06	3.06E+06	4.90E+06	9.18E+06	1.53E+07	2.45E+07	1.84E+07	3.06E+07	4.90E+07	4.99E+08	1.47E+09	1.97E+09	4.81E+10	1.44E+11	1.92E+11
	McLeod	3.56E+06	4.98E+06	6.40E+06	1.78E+07	2.49E+07	3.20E+07	3.56E+07	4.98E+07	6.40E+07	8.36E+08	1.65E+09	3.27E+09	8.01E+10	1.60E+11	3.20E+11
Post Jurassic Aquifer System	Wapiti (non-saline under Paskapoo-Scollard)	N/A Recharge to confined saline systems assumed to be negligible									3.18E+10	9.55E+10	1.27E+11	2.48E+11	7.43E+11	9.90E+11
	Wapiti (saline under Paskapoo-Scollard)										4.66E+10	1.40E+11	1.86E+11	3.01E+11	9.02E+11	1.20E+12
	Smoky Group: Cardium										6.47E+10	1.26E+11	1.88E+11	9.25E+10	1.79E+11	2.61E+11
	Dunvegan										5.39E+09	1.12E+10	2.17E+10	7.70E+09	1.59E+10	3.10E+10
	Ft. St. John Group: Viking										6.69E+09	1.65E+10	2.66E+10	9.56E+09	2.36E+10	3.80E+10
	Ft. St. John Group/Mannville Group: Spirit River, Bluesky, Gething, Cadomin										4.83E+10	1.33E+11	2.45E+11	6.89E+10	1.90E+11	3.49E+11
Mississippian to Jurassic Aquifer System	Fernie										5.25E+09	1.47E+10	2.54E+10	7.50E+09	2.10E+10	3.63E+10
	Nordegg										1.52E+10	5.30E+10	8.59E+10	2.17E+10	7.57E+10	1.23E+11
	Montney										3.24E+10	8.03E+10	1.19E+11	4.63E+10	1.15E+11	1.69E+11
	Belloy										4.49E+09	1.41E+10	2.18E+10	6.41E+09	2.02E+10	3.11E+10
	Debolt										1.45E+10	7.11E+10	1.38E+11	2.08E+10	1.02E+11	1.97E+11
	Pekisko										1.69E+10	5.11E+10	1.09E+11	2.42E+10	7.31E+10	1.55E+11
Upper Devonian Aquifer System	Wabamun Group										3.42E+10	1.05E+11	2.82E+11	4.89E+10	1.50E+11	4.03E+11
	Nisku Formation										2.73E+10	8.36E+10	1.88E+11	3.90E+10	1.19E+11	2.68E+11
Middle Devonian Aquifer System	Woodbend Group: Leduc										9.13E+09	2.79E+10	5.96E+10	1.30E+10	3.99E+10	8.52E+10
	Beaverhill Lake Group: Swan Hills and Slave Point										1.21E+10	4.13E+10	9.80E+10	1.74E+10	5.90E+10	1.40E+11
	Elk Point Group: Gilwood										7.02E+08	2.53E+09	6.83E+09	1.00E+09	3.61E+09	9.76E+09
Cambrian Aquifer System	Cambrian: Basal Sandstone															

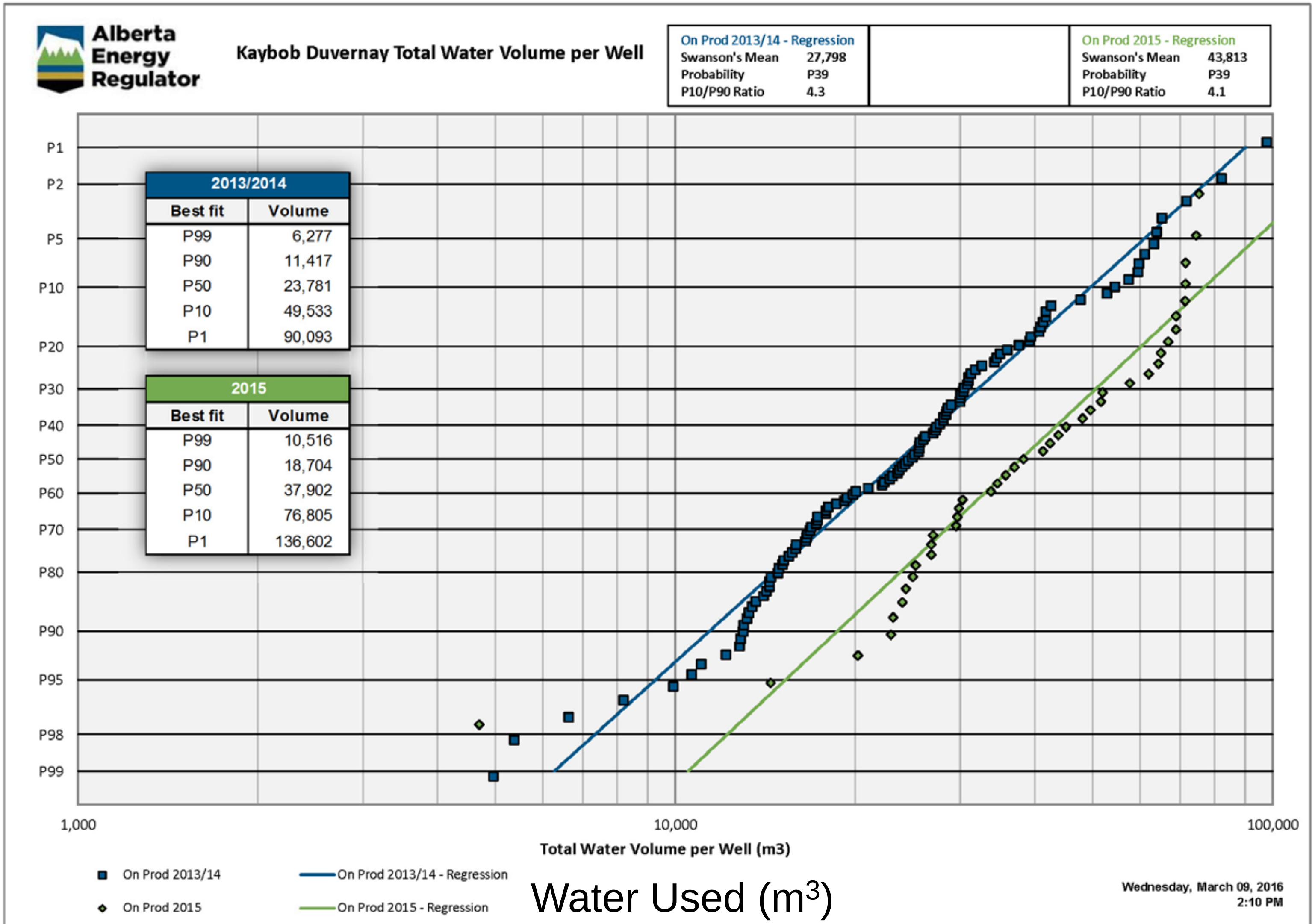
Forecasting the Duvernay Play's Water Future: Key Components for Regulating Energy and Water



Forecasting the Duvernay Play's Water Future: Key Components for Regulating Energy and Water



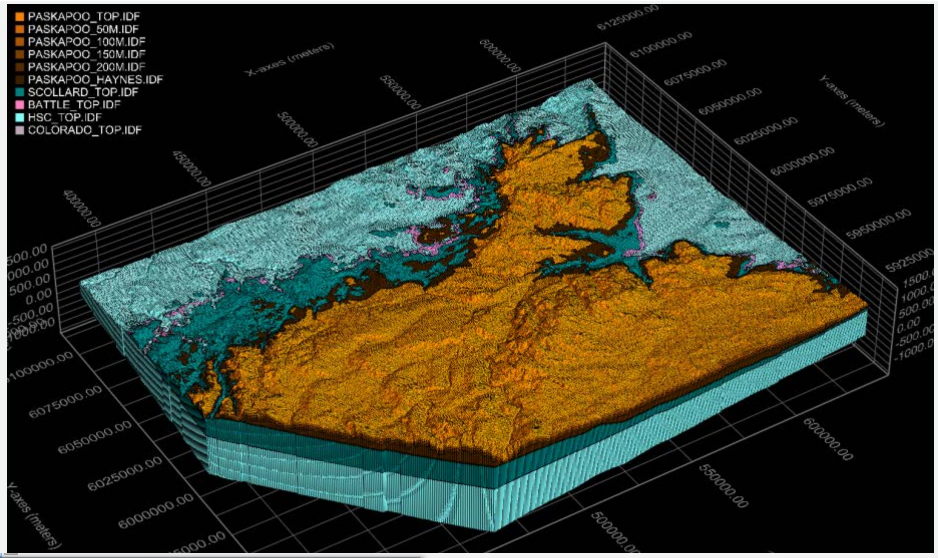
Duvernay Water Demand: D-059

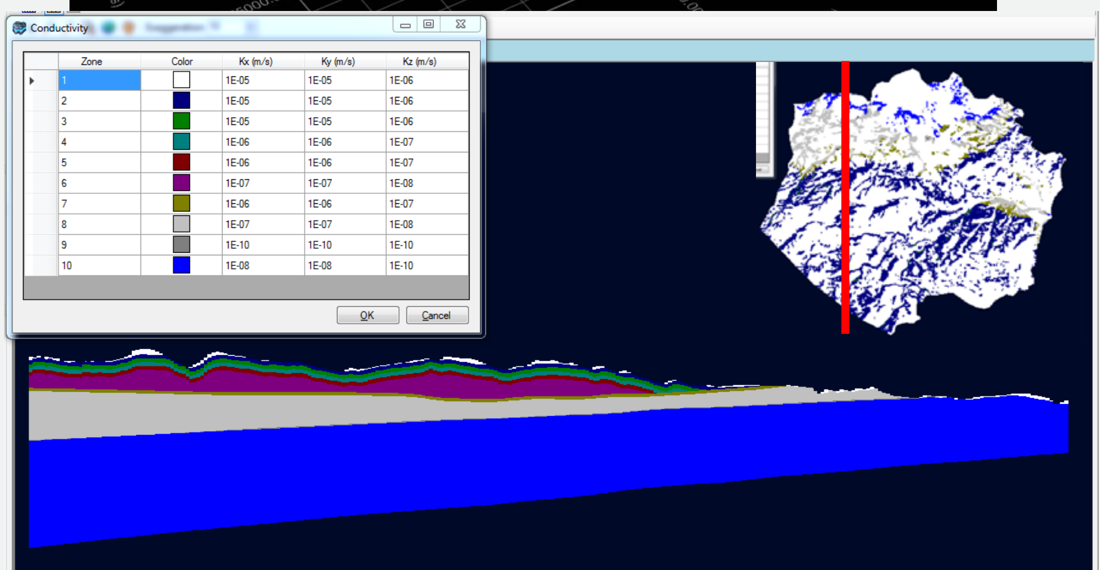


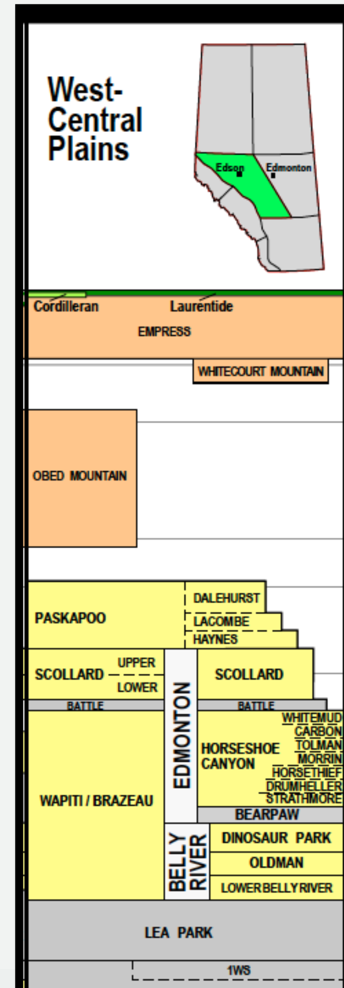
2013/2014	
Best fit	Volume
P99	6,277
P90	11,417
P50	23,781
P10	49,533
P1	90,093

2015	
Best fit	Volume
P99	10,516
P90	18,704
P50	37,902
P10	76,805
P1	136,602

Groundwater Modelling: Start Simple for MVP

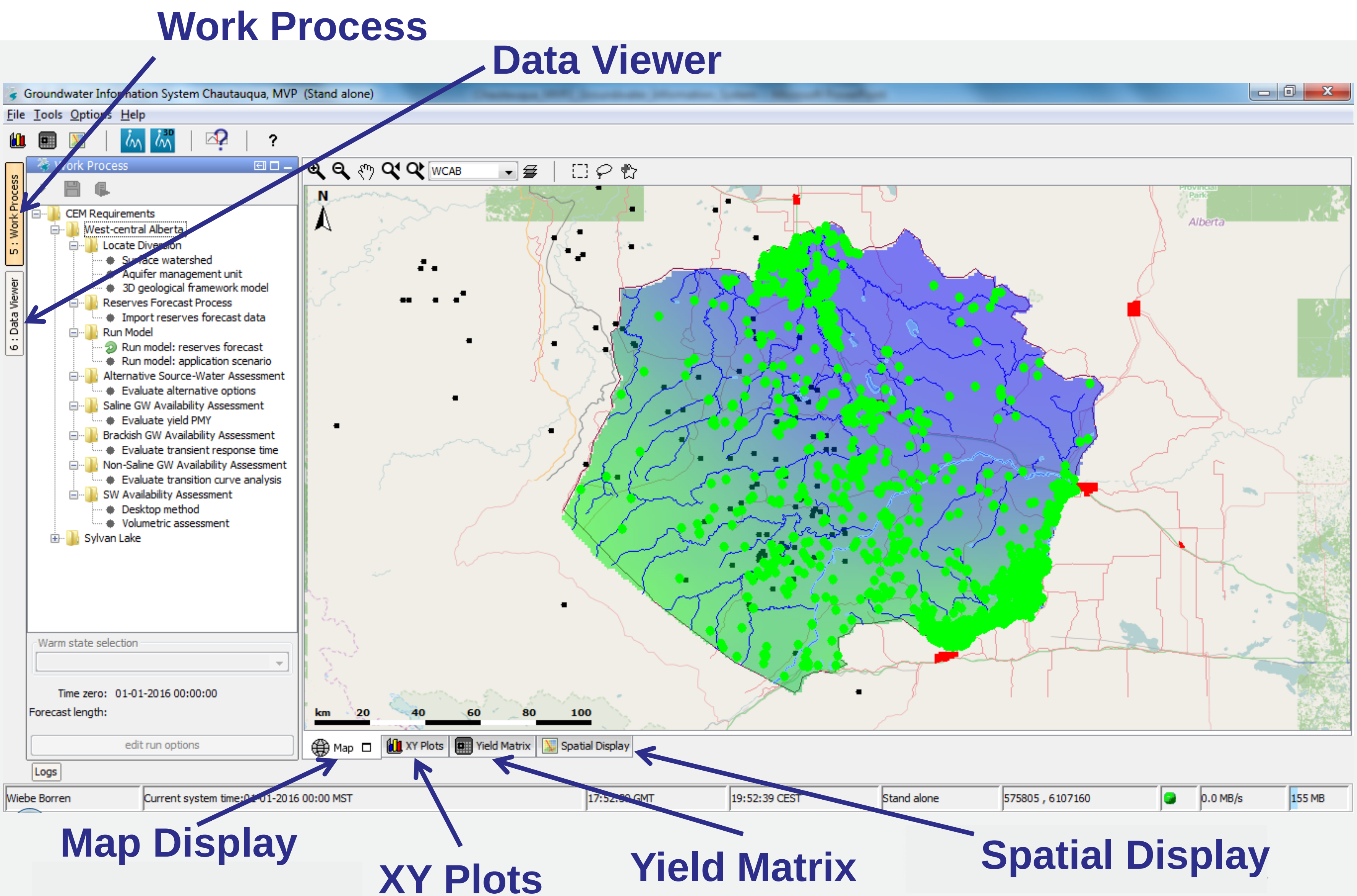






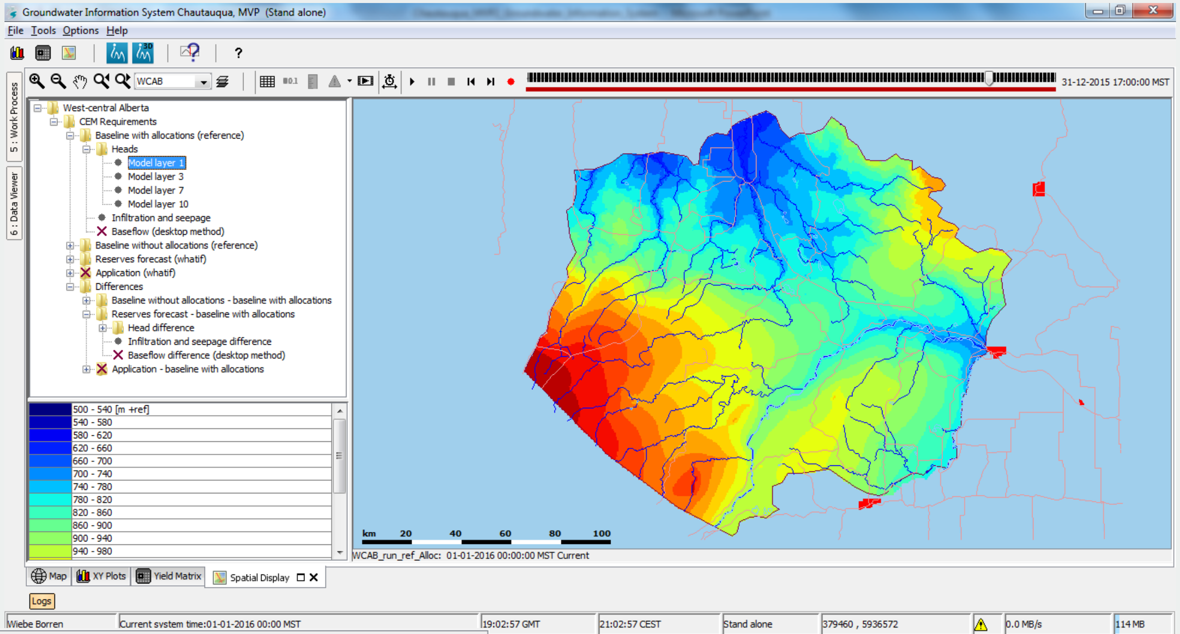
AGS Table of Formations, 2015

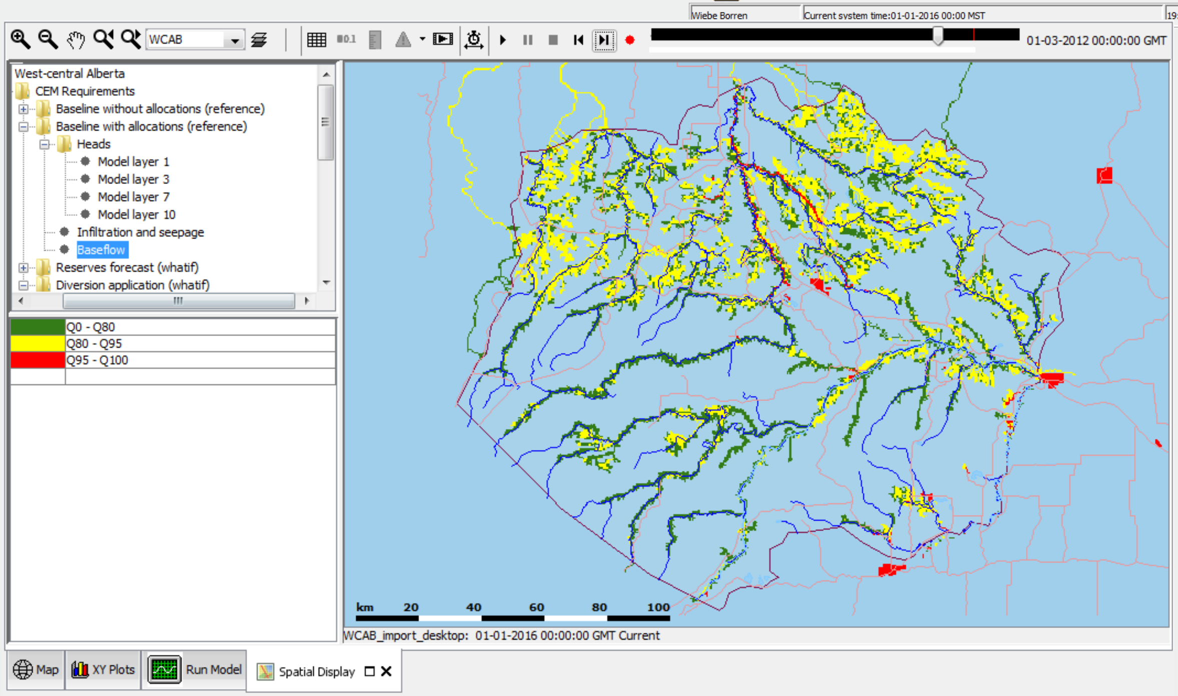
Integrator: Deltares FEWS Technology



Groundwater Model Outputs for Decision Making in FEWS

- Display model results for various runs and compare baseline and reference conditions to scenarios (right: hydraulic heads)
- Adding wells and well fields to assess effects of proposed or forecasted development

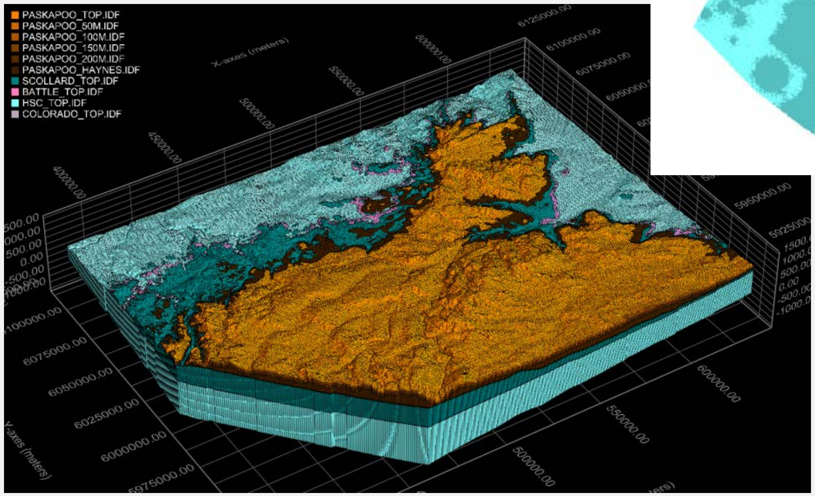


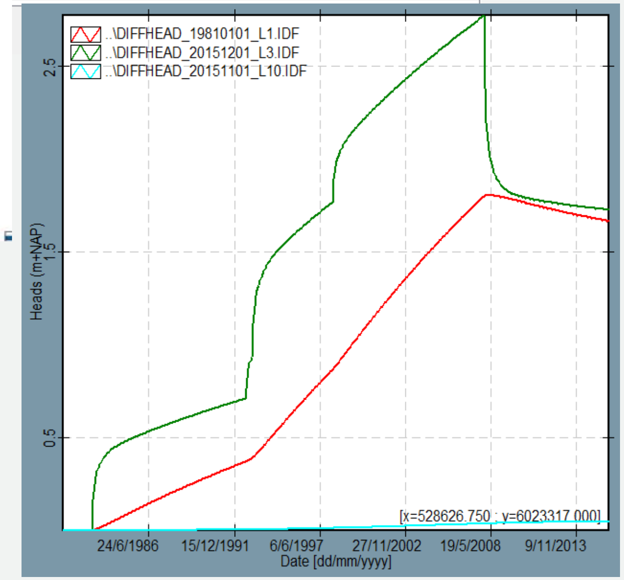


- Modelled baseflow from groundwater model compared to long-term surface water flows (left)
- Implementation of “traffic light” concept allows for uncertainty and risk to be evaluated as part of the work flow

Cumulative Effects Assessment

x 1e6 m3/yr	Yield	PSY			MSY			SY			PMY			MMY		
		P90	P50	P10	P90	P50	P10	P90	P50	P10	P90	P50	P10	P90	P50	P10
Paskapoo - Deep Creek Valley	10	5	6	10	24	32	47	47	63	95	225	418	804	17787	35543	71055
Paskapoo - Waskahigan	1	1	2	2	5	8	11	10	16	22	78	154	298	6899	13795	27581
Paskapoo - Little Smoky	4	6	10	13	32	47	63	63	95	126	815	1598	3133	75233	150435	300808
Paskapoo - Iosegun	3	2	3	3	8	14	16	16	28	32	139	276	526	12377	24750	49476
Paskapoo - Sakwatamau	2	2	2	3	8	13	16	16	25	32	124	241	463	10793	21580	43141
Paskapoo - Athabasca	82	63	79	95	315	394	473	631	788	946	1850	3226	5822	122525	244577	488523
Paskaapoo - Simonette	8	8	11	17	42	57	85	85	113	170	406	754	1452	32146	64236	128416
Wapiti - Simonette (non-saline)	2	2	3	6	11	17	28	23	34	56	575	1691	2266	55256	165734	220990
Paskapoo - Berland	14	12	14	16	62	70	78	125	140	156	1254	2398	4671	112989	225870	451614
Wapiti - Little Smoky (non-saline)	4	2	3	5	9	15	24	18	31	49	499	1472	1970	48053	144135	192188
Paskapoo - McLeod	0	4	5	6	18	25	32	36	50	64	836	1651	3266	80094	160166	320296
Wapiti - Paskapoo N	-0	0	0	0	0	0	0	0	0	0	31839	95517	127356	247612	742837	990450
Wapiti - Paskapoo S	-0	0	0	0	0	0	0	0	0	0	46600	139801	186401	300714	902141	1202855





Summary: Aquifer Yield Matrix

- Offers robust approach to assess current state of groundwater resources (i.e., allocation/use vs. availability)
- Delivers results to regulators that is fit for purpose (effective and efficient for decision making under *Alberta's Water Act*)
- Provides knowledge about alternate water sources (e.g., low quality non-saline and saline resources)
- Continuous improvement as geological and hydrological knowledge is gained will be required
- Ability to update yield-matrix results using numerical model accounting for drawdown from adjacent units

Summary:
Prototype Groundwater Information System

- An operational/information system such as FEWS offers the ability to forecast anticipated water demand and evaluate cumulative effects
- FEWS provides an opportunity to develop, share, and continuously improve groundwater models amongst specialists in Alberta
- This prototype demonstrated the possibility of using this configuration for testing regulatory strategies and balancing energy development with desired environmental outcomes
- The lean-startup approach proved useful for AER-AGS innovation through fast and relatively inexpensive iterations of testing this work with regulators, water-policy managers, and stakeholders

Acknowledgments

Alberta Energy Regulator

Jim Jenkins, Stefan Walter, Sean Stricker

Deltares

Project Team: Wiebe Borren, Peter Vermeulen, Sheila Ball, Edwin Welles, Hans van Duijne

Alberta Government

Steve Wallace, Aaron Petty