Non-saline Surface Water and Groundwater Use for Hydraulic Fracturing in an Area of Duvernay and Montney Exploration and Development, West-Central Alberta

Alberta Energy Regulator

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ALBERTA GEOLOGICAL SURVEY

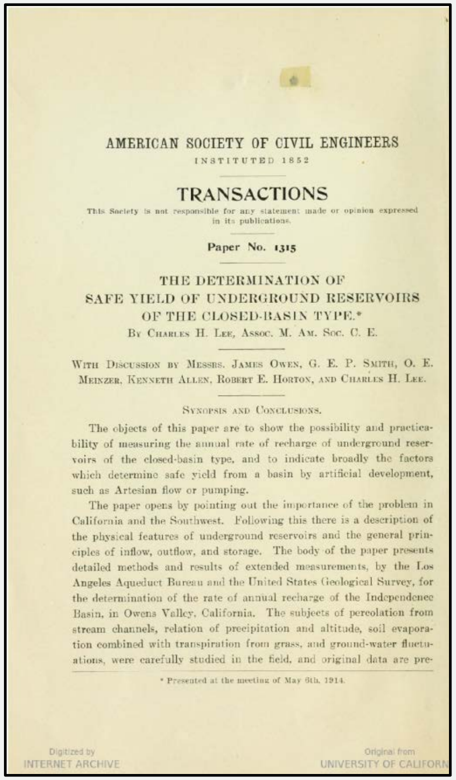
Tony Lemay

May 15, 2017

Fundamental Questions

- Are the effects of current groundwater allocation acceptable?
- If current allocation is acceptable, will the effects of additional groundwater allocation be acceptable?
- How is acceptable defined?

Groundwater Yield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Paper No. 1315

THE DETERMINATION OF SAFE YIELD OF UNDERGROUND RESERVOIRS OF THE CLOSED-BASIN TYPE.*

By Charles H. Lee, Assoc. M. Am. Soc. C. E.

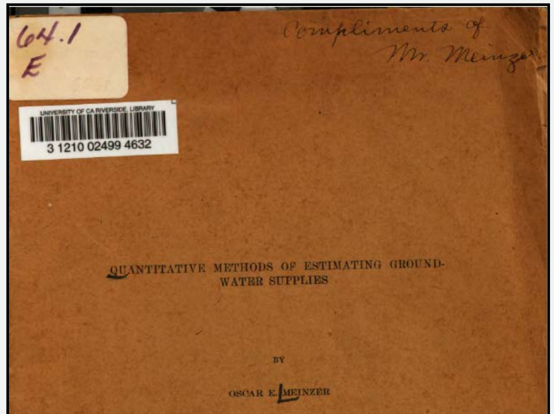
With Discussion by Messrs. James Owen, G. E. P. Smith, O. E. Meinzer, Kenneth Allen, Robert E. Horton, and Charles H. Lee.

Synopsis and Conclusions.

The objects of this paper are to show the possibility and practicability of measuring the annual rate of recharge of underground reservoirs of the closed-basin type, and to indicate broadly the factors which determine safe yield from a basin by artificial development, such as Artesian flow or pumping.

The paper opens by pointing out the importance of the problem in California and the Southwest. Following this there is a description of the physical features of underground reservoirs and the general principles of inflow, outflow, and storage. The body of the paper presents detailed methods and results of extended measurements, by the Los Angeles Aqueduct Bureau and the United States Geological Survey, for the determination of the rate of annual recharge of the Independence Basin, in Owens Valley, California. The subjects of percolation from stream channels, relation of precipitation and altitude, soil evaporation combined with transpiration from grass, and ground-water fluctuations, were carefully studied in the field, and original data are pre-

* Presented at the meeting of May 6th, 1914.

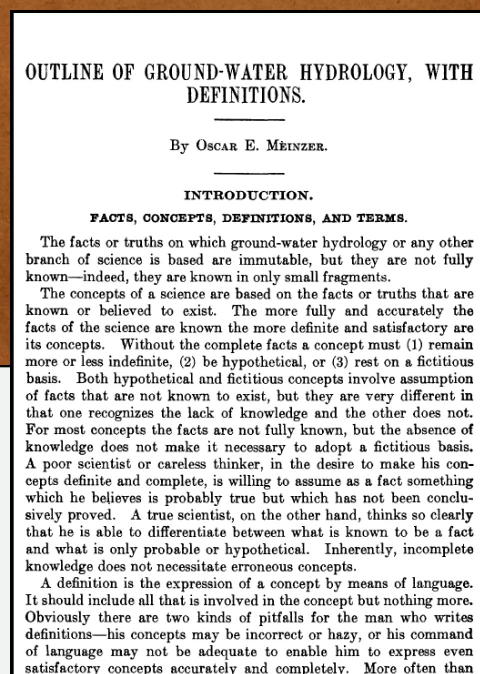


Compliments of Mr. Meinzer

QUANTITATIVE METHODS OF ESTIMATING GROUND-WATER SUPPLIES

BY

OSCAR E. MEINZER


OUTLINE OF GROUND-WATER HYDROLOGY, WITH DEFINITIONS.

By Oscar E. Meinzer.

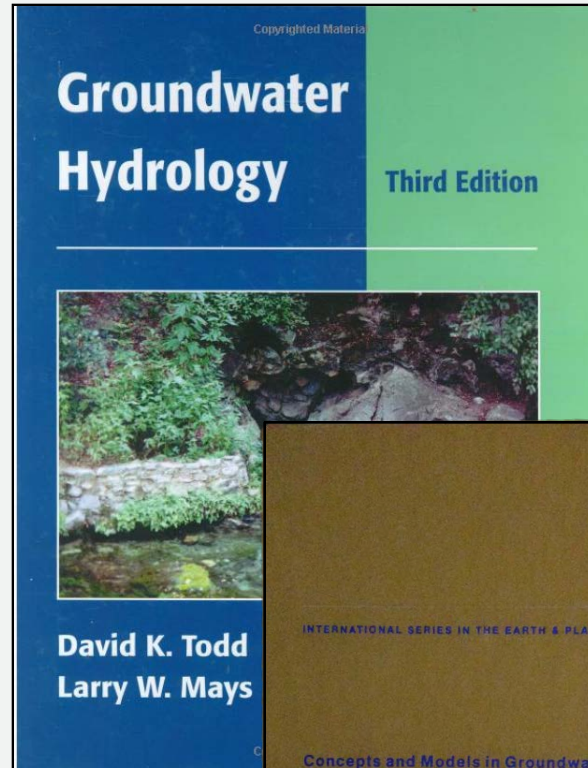
INTRODUCTION.

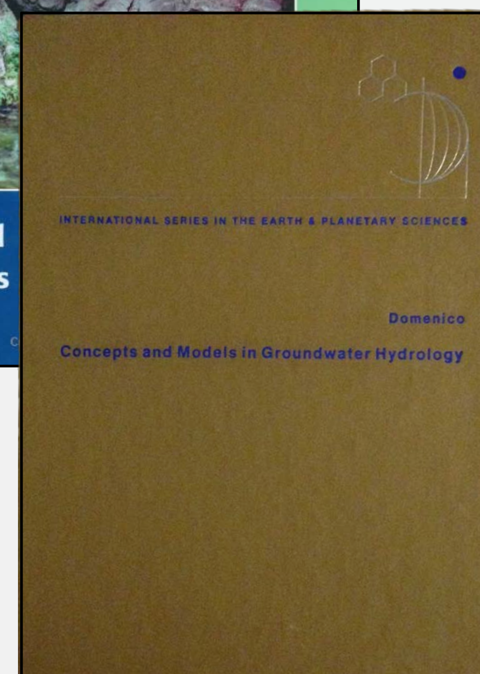
FACTS, CONCEPTS, DEFINITIONS, AND TERMS.

The facts or truths on which ground-water hydrology or any other branch of science is based are immutable, but they are not fully known—indeed, they are known in only small fragments.

The concepts of a science are based on the facts or truths that are known or believed to exist. The more fully and accurately the facts of the science are known the more definite and satisfactory are its concepts. Without the complete facts a concept must (1) remain more or less indefinite, (2) be hypothetical, or (3) rest on a fictitious basis. Both hypothetical and fictitious concepts involve assumption of facts that are not known to exist, but they are very different in that one recognizes the lack of knowledge and the other does not. For most concepts the facts are not fully known, but the absence of knowledge does not make it necessary to adopt a fictitious basis. A poor scientist or careless thinker, in the desire to make his concepts definite and complete, is willing to assume as a fact something which he believes is probably true but which has not been conclusively proved. A true scientist, on the other hand, thinks so clearly that he is able to differentiate between what is known to be a fact and what is only probable or hypothetical. Inherently, incomplete knowledge does not necessitate erroneous concepts.

A definition is the expression of a concept by means of language. It should include all that is involved in the concept but nothing more. Obviously there are two kinds of pitfalls for the man who writes definitions—his concepts may be incorrect or hazy, or his command of language may not be adequate to enable him to express even satisfactory concepts accurately and completely. More often than





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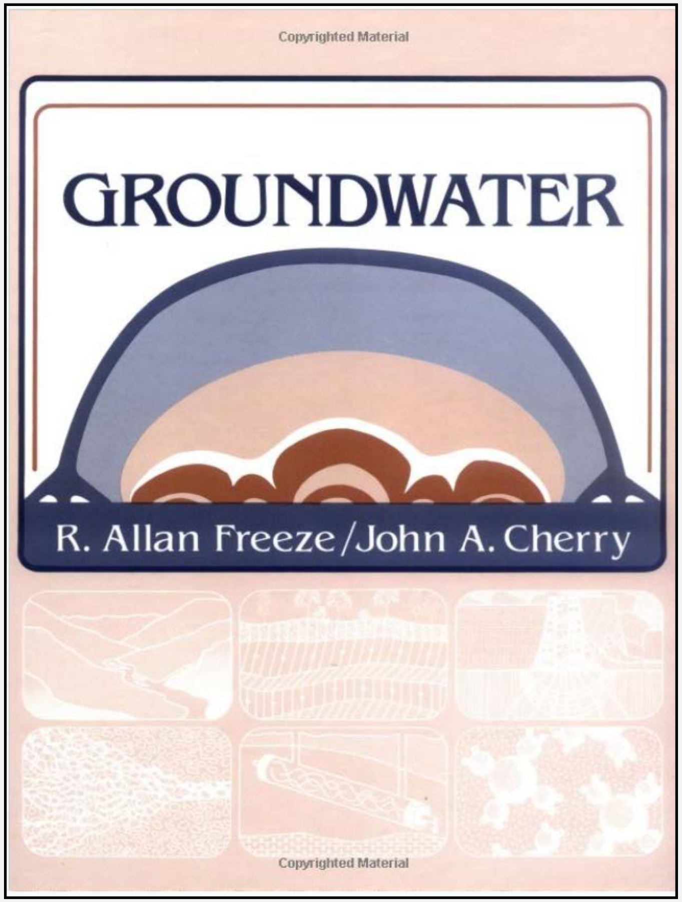
Groundwater Yield



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

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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

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Diagram of Yield Concepts

Yield

- Quantity of extractable groundwater

Aquifer performance

- Recharge rates and storage conditions
- Water quality
- Discharge rates and environmental flows

Aquifer governance

- Legal constraints

- Economic feasibility
- Inter-generational equity

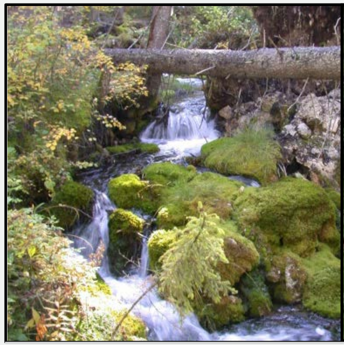
After Pierce et al. (2013)

Groundwater Yield

"… *consideration of the present and future* ***costs and benefits may lead to … mining groundwater****, perhaps* ***even to depletion*** *… [or they] may reflect the need for* ***complete conservation****. Most often, the optimal groundwater development lies somewhere between these extremes*." (Freeze and Cherry, 1979)

"… *aquifer yields can be viewed through the lens of an* ***adjustable continuum****. By [using] the concept of a continuum … a framing device for describing the* ***selection of an aquifer yield emerges***." (Pierce et al. 2013)

Aquifer Yield Continuum



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.

Permissive Sustained Yield (PSY)

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)

Maximum Sustained Yield (MSY)

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.

Sustained Yield (SY)

All discharge is captured, experience continuously falling water levels everywhere in aquifer. Possible land subsidence. Possible partial dewatering of aquifer. Loss of bequest volume.

Permissive Mining Yield (PMY)

Partial to complete dewatering of aquifer. Major land subsidence, fissures, collapse, seismscity, leading to permanent loss of aquifer for all uses.

Maximum Mining Yield (MMY)

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Aquifer Yield Continuum
(after Pierce et al. 2013)

- Permissive Sustained Yield (PSY)

  $P = R_P - D_{PSY}$

- Maximum Sustained Yield (MSY)

  $P = R_P - D_P$

- Safe Yield (SY)

  $P = R_P$

- Permissive Mining Yield (PMY)

  $P = V_o – V_{min} + R_P – D_{min}$

- Maximum Mining Yield (MMY)

  $P = V_o + R_P$

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P	= Discharge from pumping
R_P	= Recharge due to pumping
D_{PSY}	= Discharge required to maintain PSY conditions
D_P	= Discharge to maintain MSY conditions
V_o	= Original volume of water in place
V_{min}	= Minimum volume of water remaining under PMY

Aquifer Yield Continuum - Modified

- Permissive Sustained Yield (PSY)

  $P = fD_{PSY} \times R$, where $fD_{PSY}=0.1$ and R from hydrographs analyses

- Maximum Sustained Yield (MSY)

  $P = fD_P \times R$, where $fD_P = 0.5$

- Safe Yield (SY)

  $P = R$

- Permissive Mining Yield (PMY)

  $P = V_o \times fV_{min} + R$, where $fV_{min} = 0.01$, and $V_o = V_{aq} \times n$ estimate

- Maximum Mining Yield (MMY)

  $P = V_o + R$

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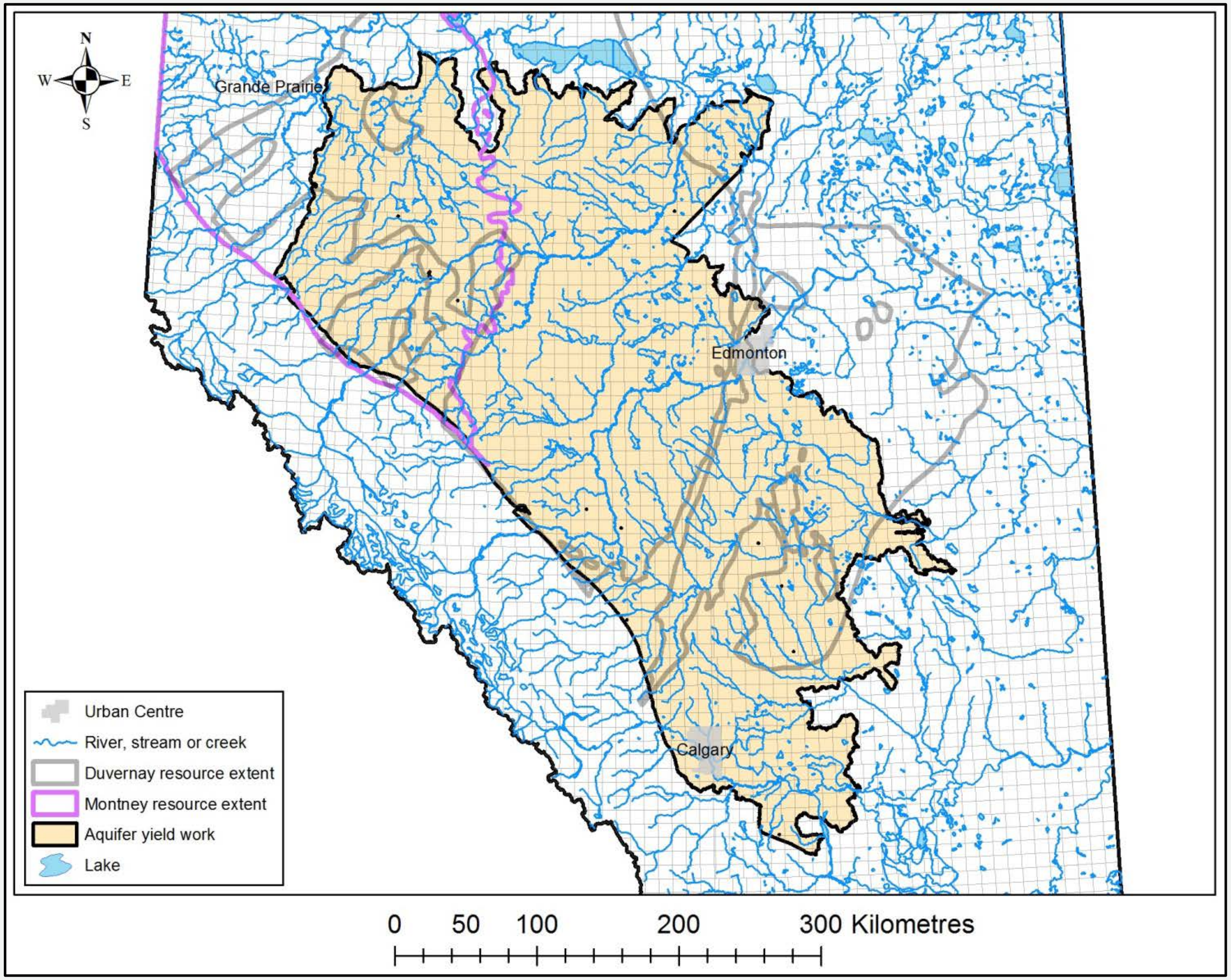
Aquifer Yield Matrix

Aquifer	PSY (m^3/yr)	MSY (m^3/yr)	SY (m^3/yr)	PMY (m^3)	MMY (m^3)
Aquifer 1	$V1_{PSY}$	$V1_{MSY}$	$V1_{SY}$	$V1_{PMY}$	$V1_{MMY}$
Aquifer 2	$V2_{PSY}$	$V2_{MSY}$	$V2_{SY}$	$V2_{PMY}$	$V2_{MMY}$
Aquifer 3	$V3_{PSY}$	$V3_{MSY}$	$V3_{SY}$	$V3_{PMY}$	$V3_{MMY}$
Aquifer 4	$V4_{PSY}$	$V4_{SY}$	$V4_{SY}$	$V4_{PMY}$	$V4_{MMY}$

AGS Yield Matrix Work to Date



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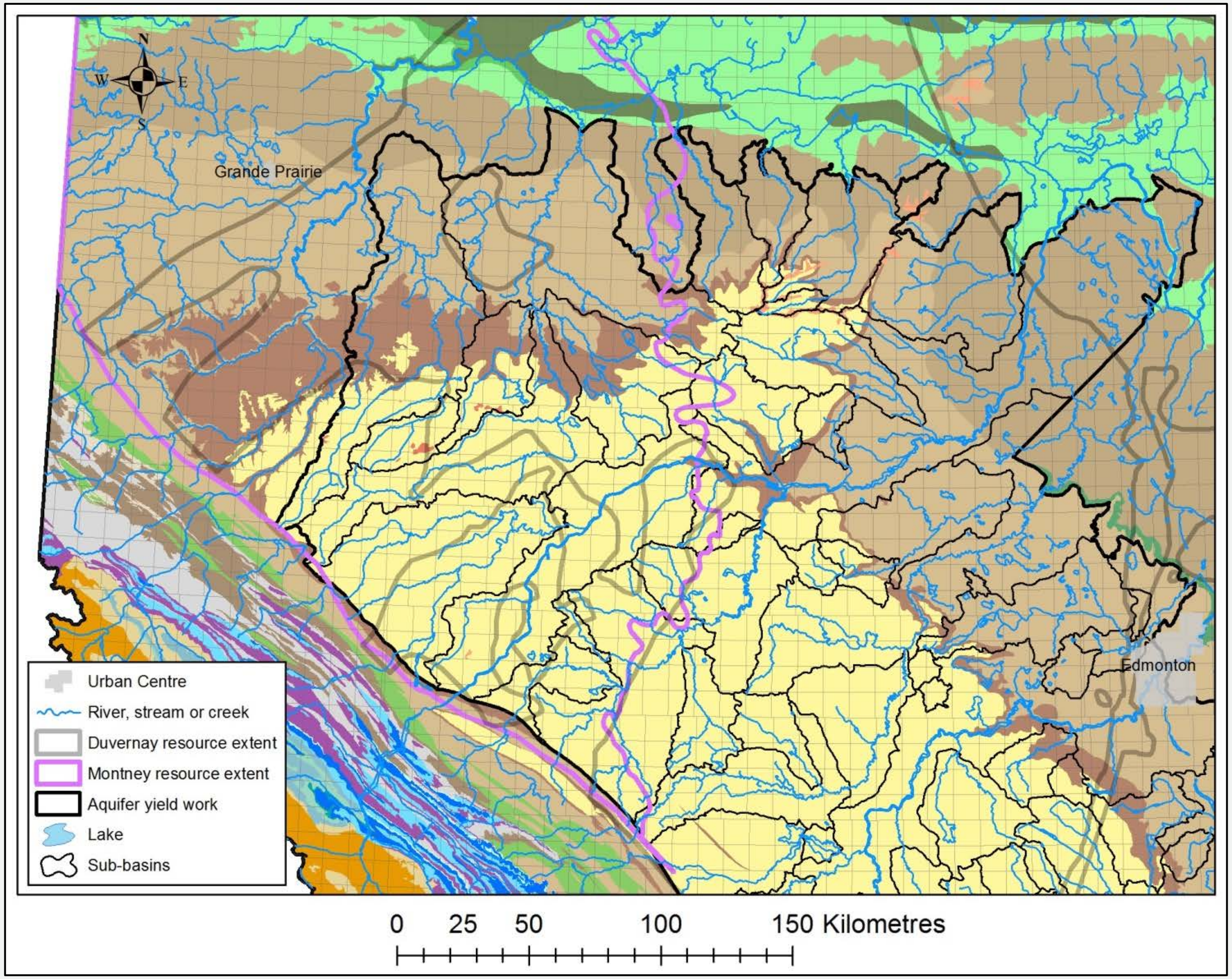
Upcoming AGS Open File Report: Klassen and Smerdon (2017)

Area of Interest



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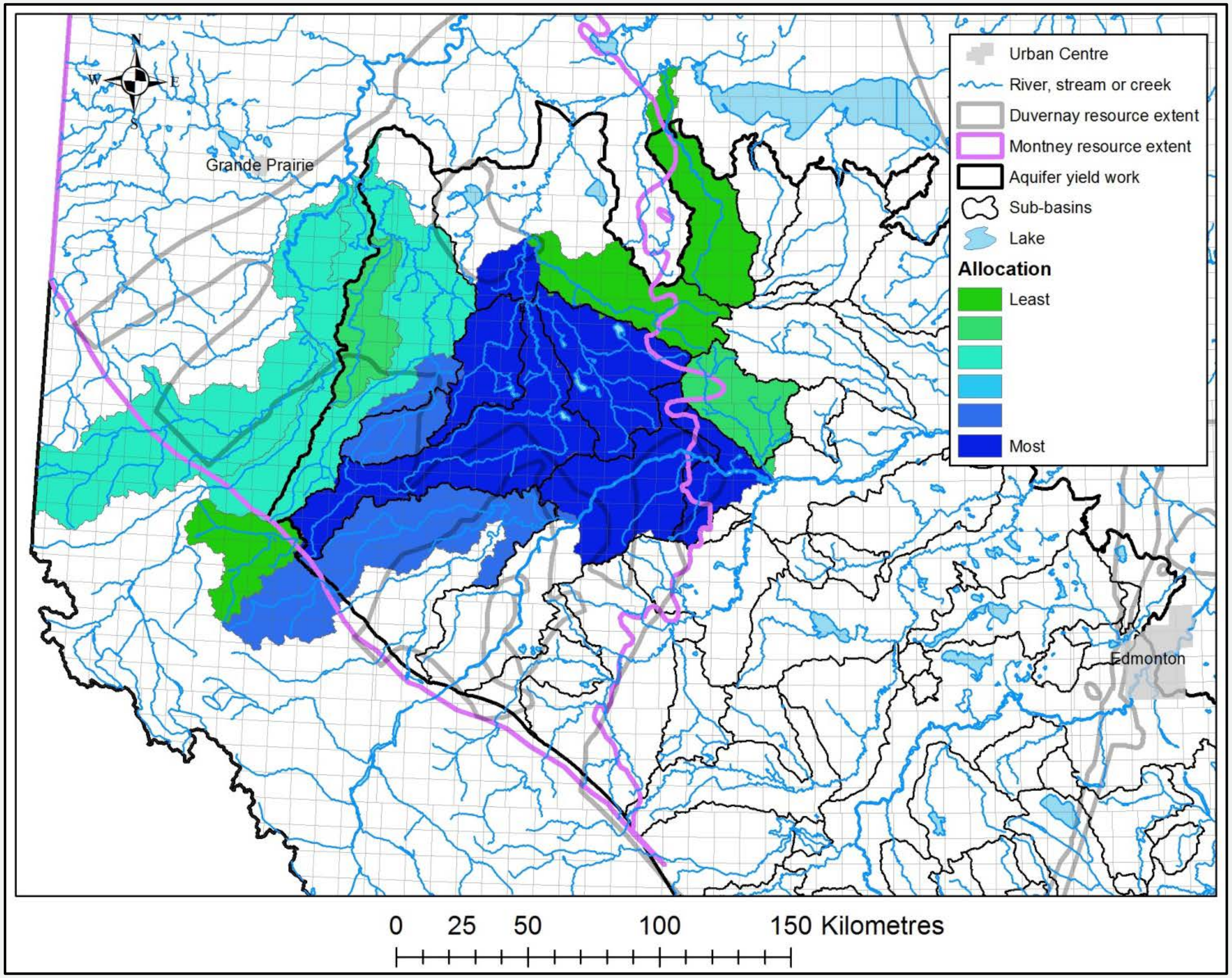
Allocations in the Paskapoo Fm



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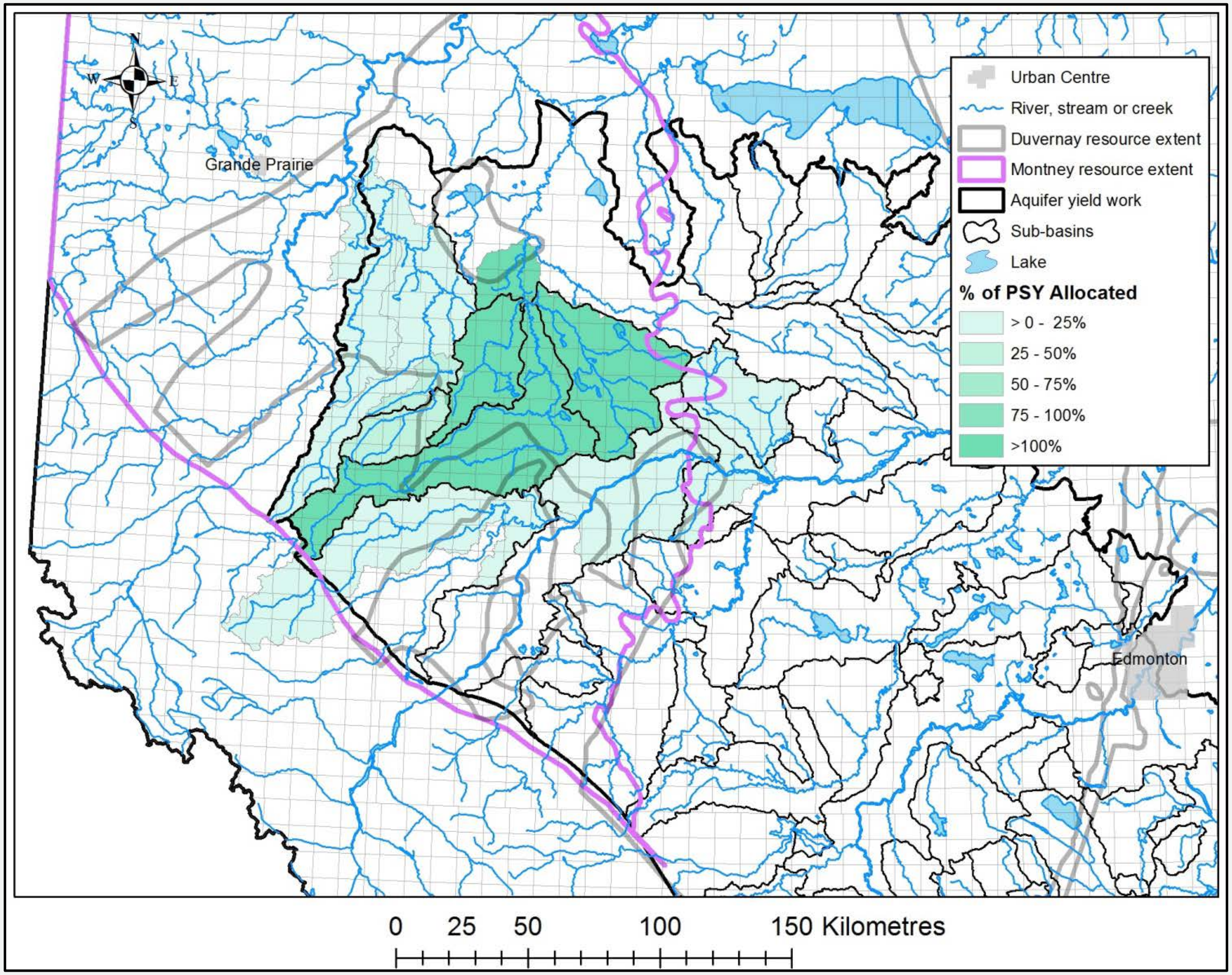
Percentage of PSY
All Paskapoo Fm Allocations



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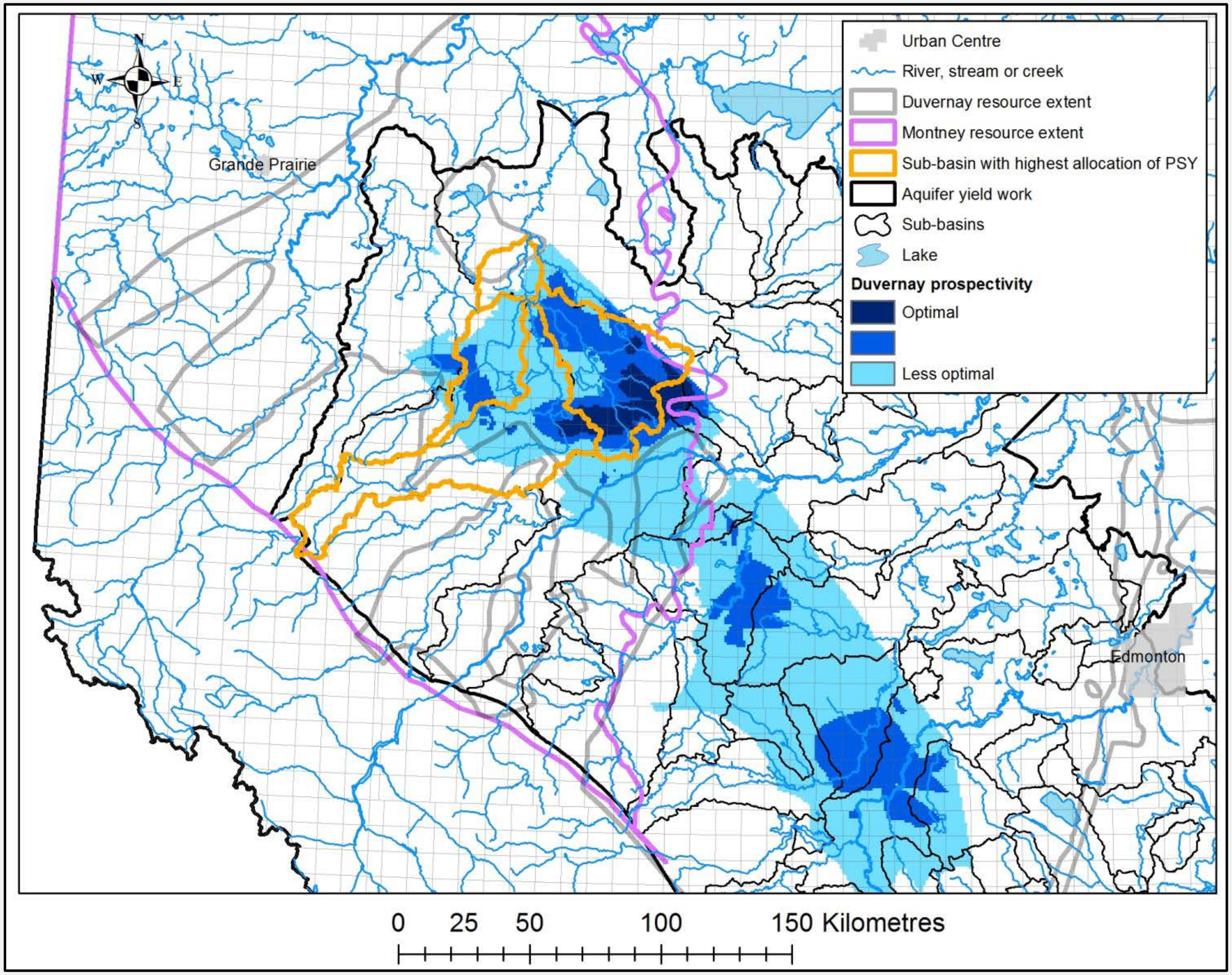
Area of Interest for Additional Analysis



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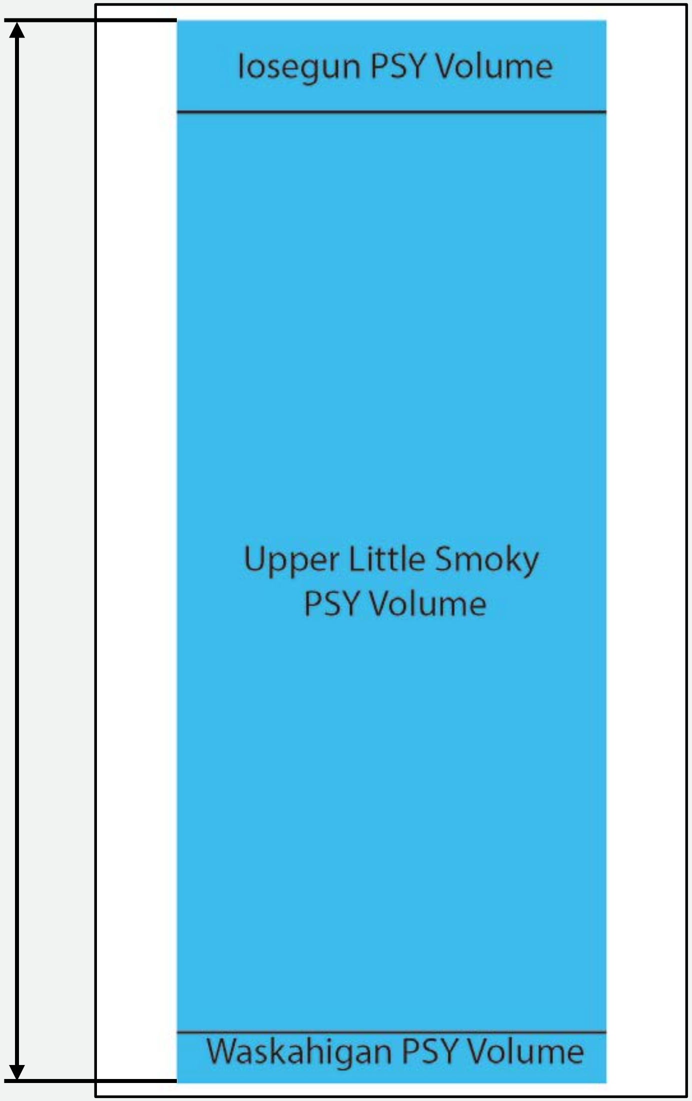
Source of Duvernay prospectivity is AER's Duvernay Reserves and Resources Report

PSY Aquifer Yield Volumes by Sub-Basin

Total PSY volume all 3 sub-basins



- Iosegun ~ 8% of total PSY volume from all three sub-basins
- Upper Little Smoky ~ 86% of total PSY volume from all three sub-basins
- Waskahigan ~ 5% of total PSY volume from all three sub-basins

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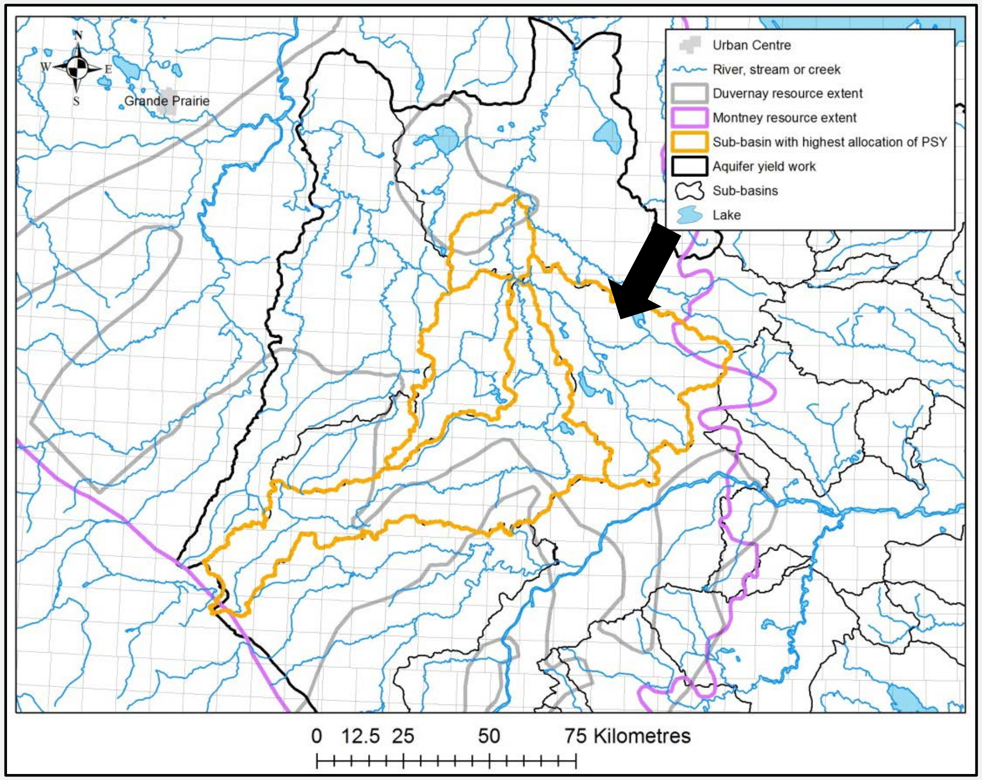
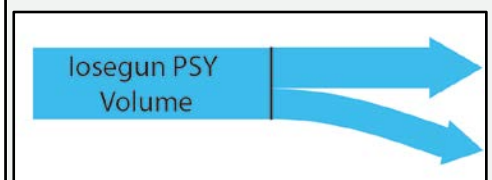
Groundwater Diversion, Hydraulic Fracturing - Iosegun River





57% used in Duvernay Fm. development

43% available for other uses

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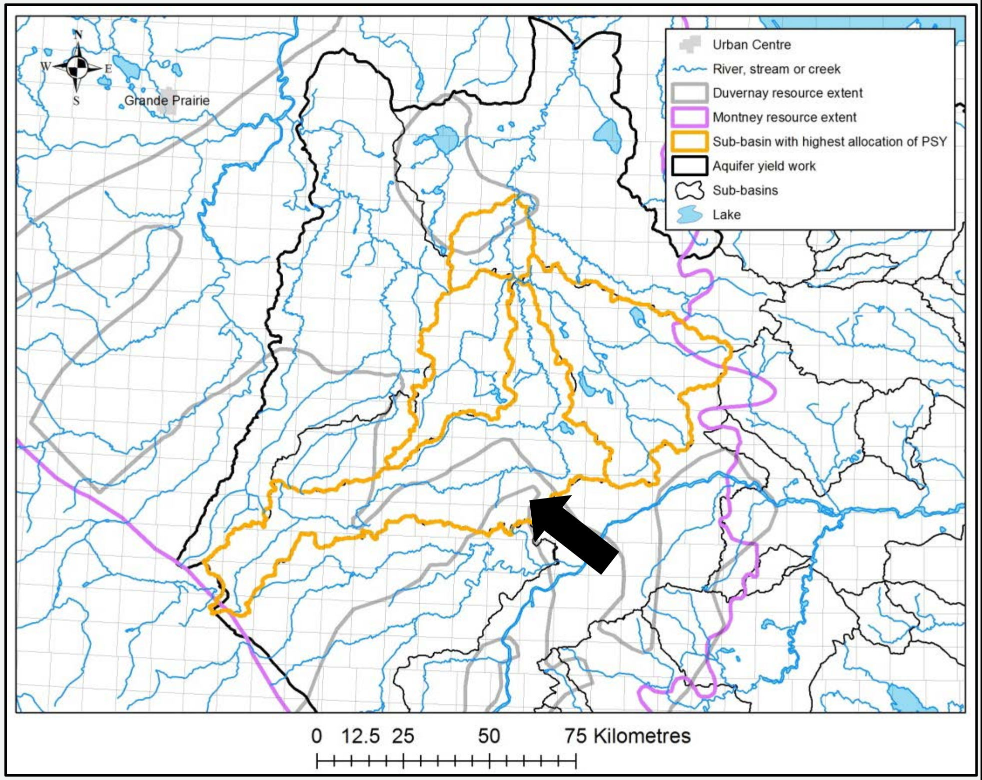
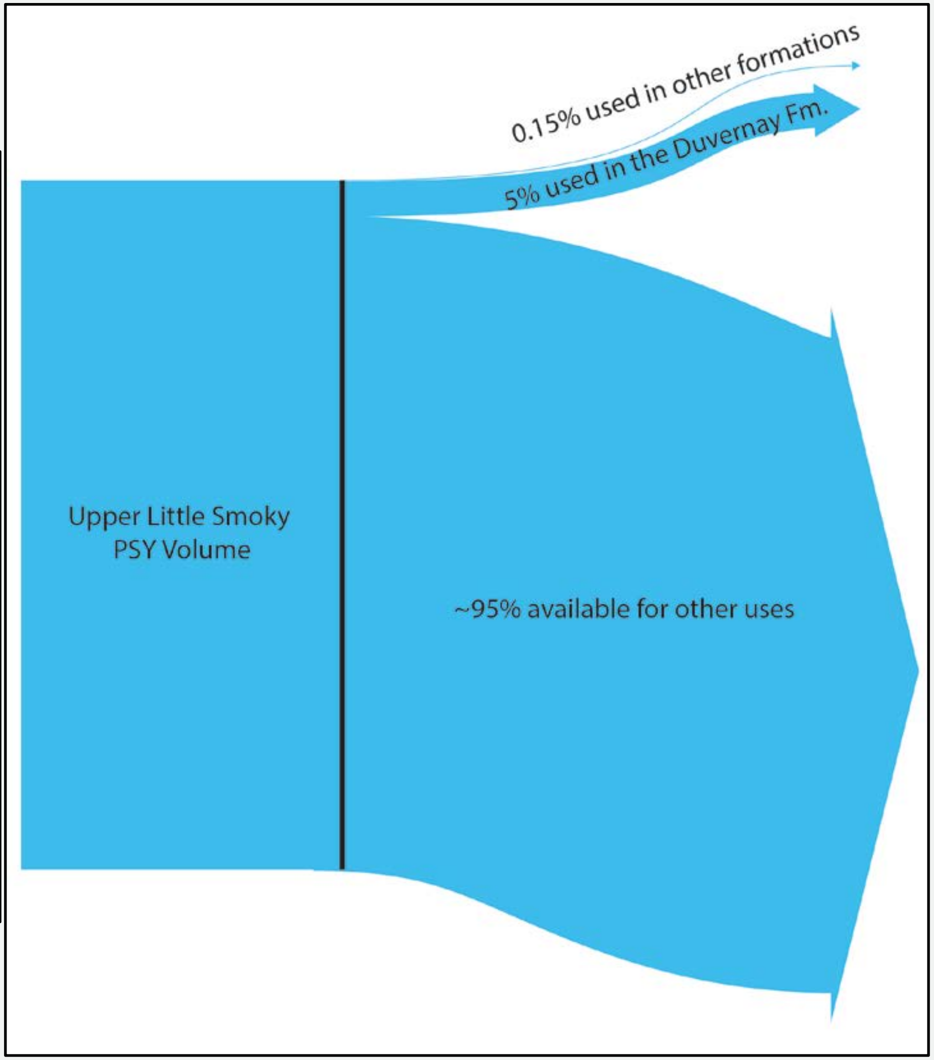
Groundwater Diversion, Hydraulic Fracturing – Upper Little Smoky R.





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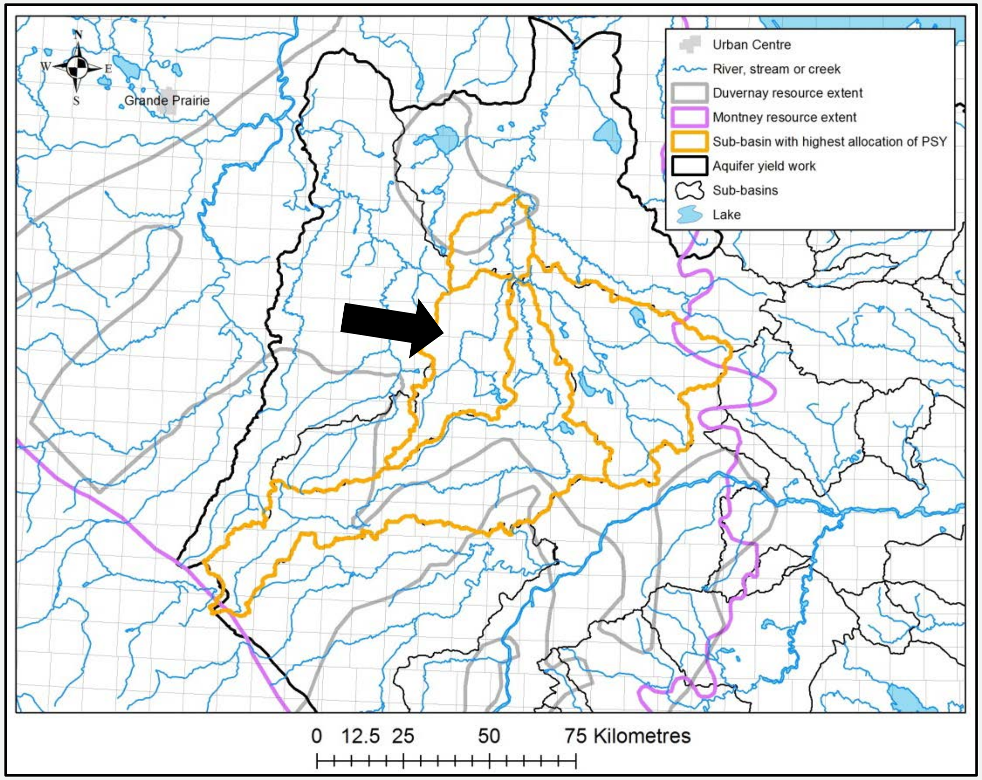
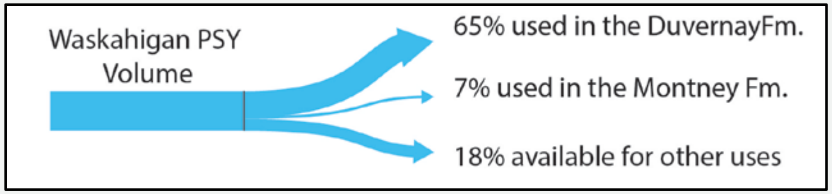
Groundwater Diversion, Hydraulic Fracturing – Waskahigan River





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Conclusions

- The Aquifer Yield Matrix approach provides a means to understand current allocations of groundwater in the context of the potential repercussions of those allocations
- Total current allocations might be exceeding some of the thresholds between yield categories
- Sourcing for hydraulic fracturing contributes to total diversions, but it does not exceed the first aquifer yield threshold on its own

Questions

Thank you