Controls on the evolution of stable isotopes of oil sands mine site waters

University of Saskatchewan

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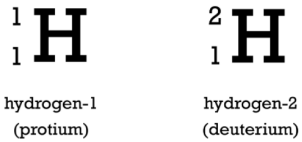
Overview

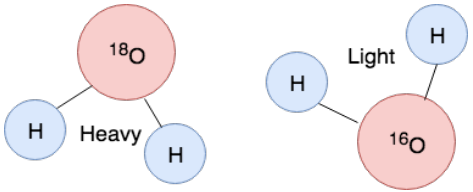
- Isotope Theory
- Traditional isotope tracer method for lake water balance
- Isotopic signatures of mine site waters
- Isotope mass balance and E/I ratios
- Isotope mass balance predictive model

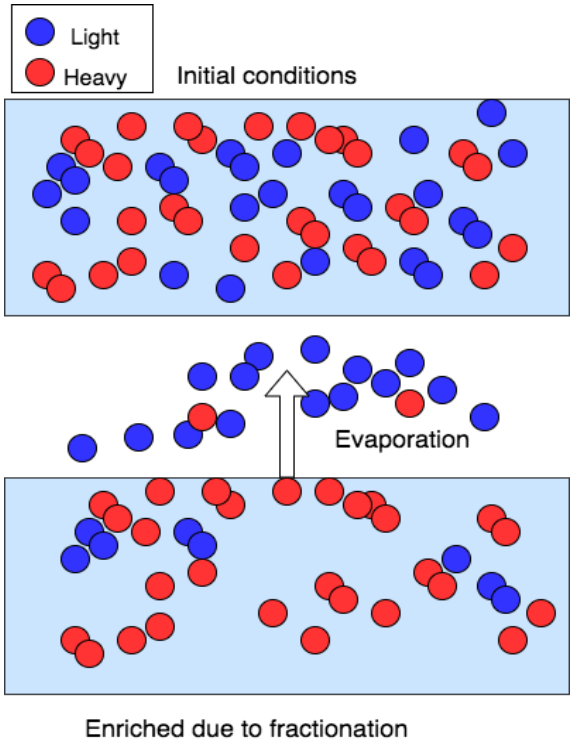
Isotope theory

Isotopes = atoms of the same element that have a different numbers of neutrons

- ^{18}O and ^{2}H are constituent part of natural water molecules—they *are* the water molecule
- Applied naturally during precipitation events
- Mixing and fractionating processes will alter concentration of water
- 'Light' molecules will preferentially evaporate resulting in enrichment due to fractionation

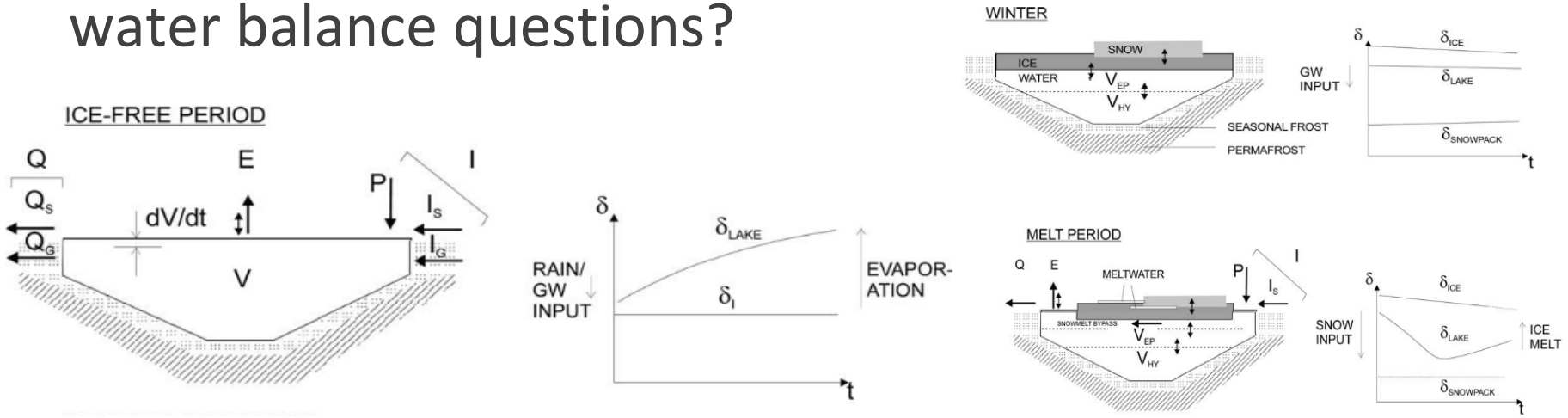






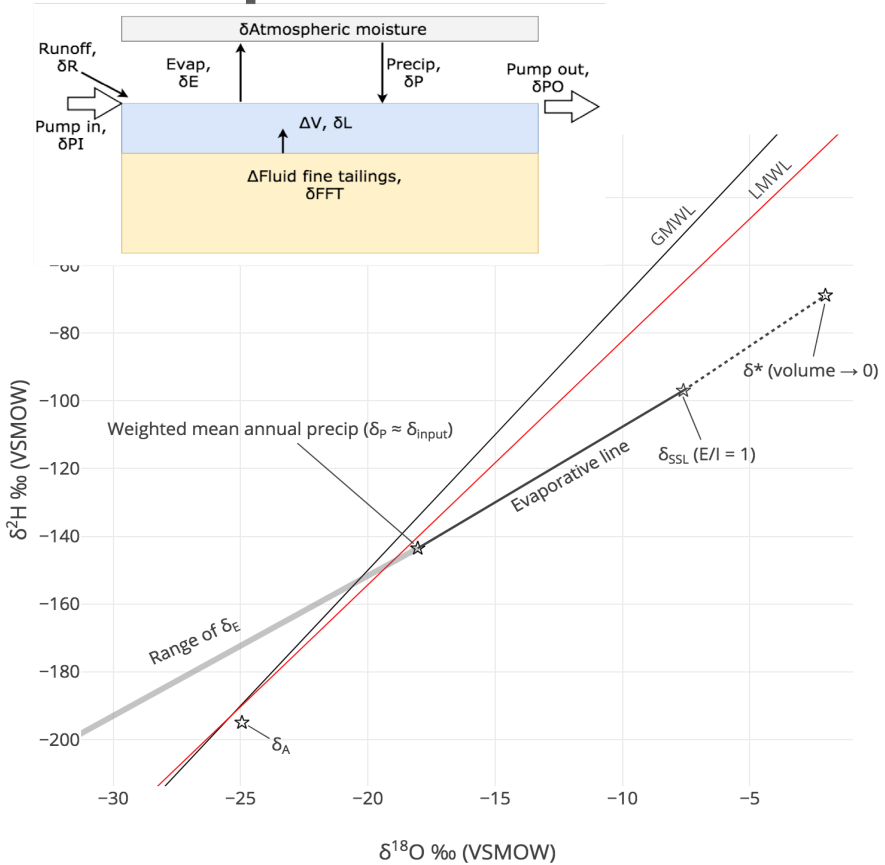
Study

- Can isotope tracer methodology developed for natural systems be applied to an engineered system to answer water balance questions?



Reproduced from Gibson, J. (2002). Short-term evaporation and water budget comparisons in shallow Arctic lakes using non-steady isotope mass balance. *Journal of Hydrology, 264*(1), 242-261.

Isotope framework



Isotope mass balance

$$V\frac{d\delta_L}{dt} + \delta_L\frac{dV}{dt} = I\delta_I - Q\delta_Q - E\delta_E$$

Assume steady state 'throughflow' scenario

$$I\delta_I = Q\delta_Q + E\delta_E$$

+

$$\delta_E = \left[\frac{((\delta_L - \varepsilon^*)/\alpha^* - h\delta_A - \varepsilon_k)}{(1 - h + \frac{\varepsilon_k}{1000})}\right]$$

Isotopic comp. of atmospheric water vapour

Equilibrium separation (function of temp)

Kinetic separation (function of humidity)

=

$$\frac{E}{I} = \left[\frac{(\delta_L - \delta_I)}{(\delta^* - \delta_L)\cdot m}\right]$$

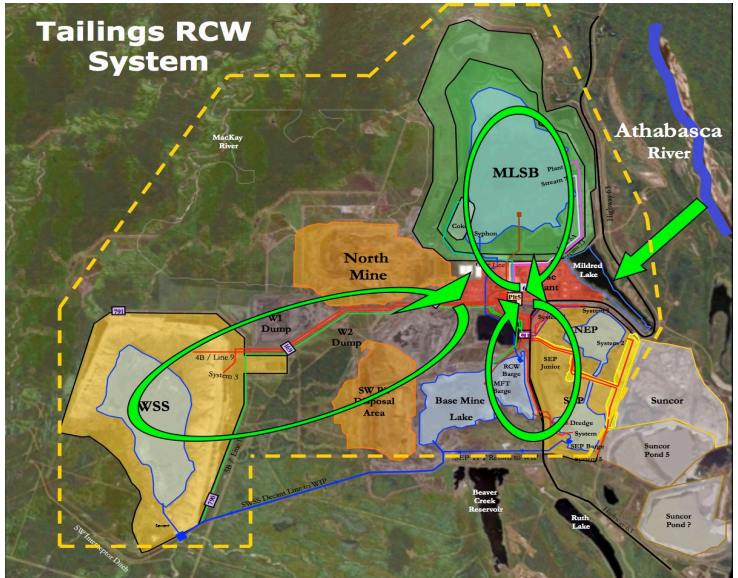
Limiting isotopic enrichment

Assume 'well-mixed' conditions ($\delta_Q = \delta_L$)

Enrichment slope (function of humidity and temp)

Oil sands water usage

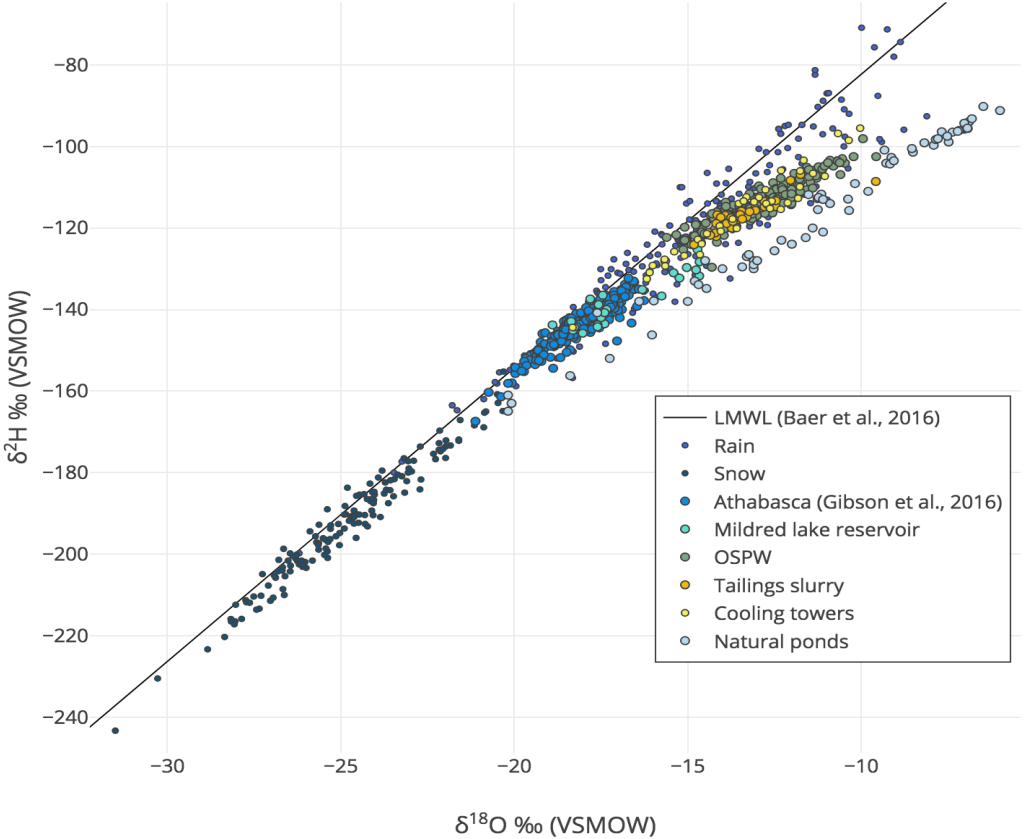
- Syncrude Canada Ltd (SCL), located in Northern Alberta oil sands region, is one of the world's largest producers of synthetic crude oil
- 2.5 m^3 of fresh water is required for production of 1 m^3 of synthetic crude oil
- Annually SCL uses ~160 million m^3 of water in extraction, transport, and upgrading processes for bitumen recovery

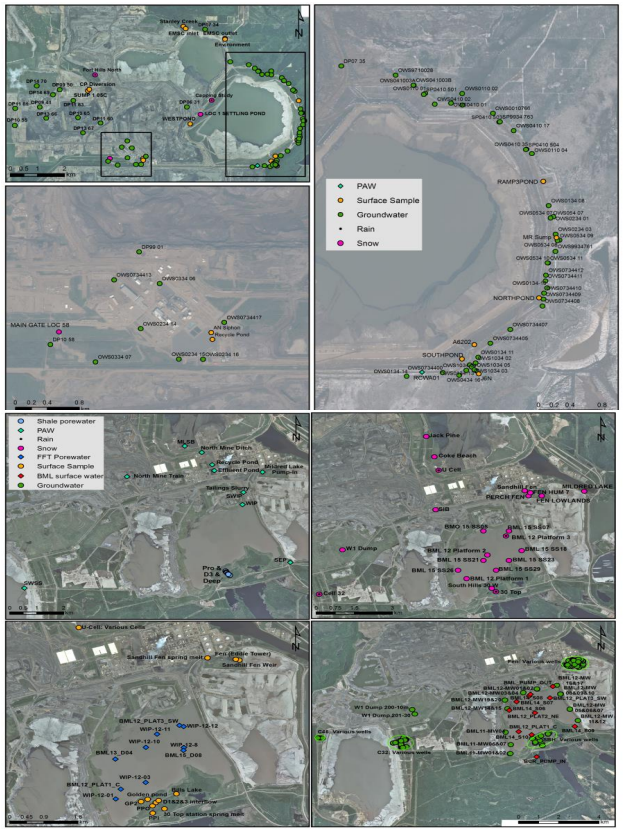


Recycle water circuit

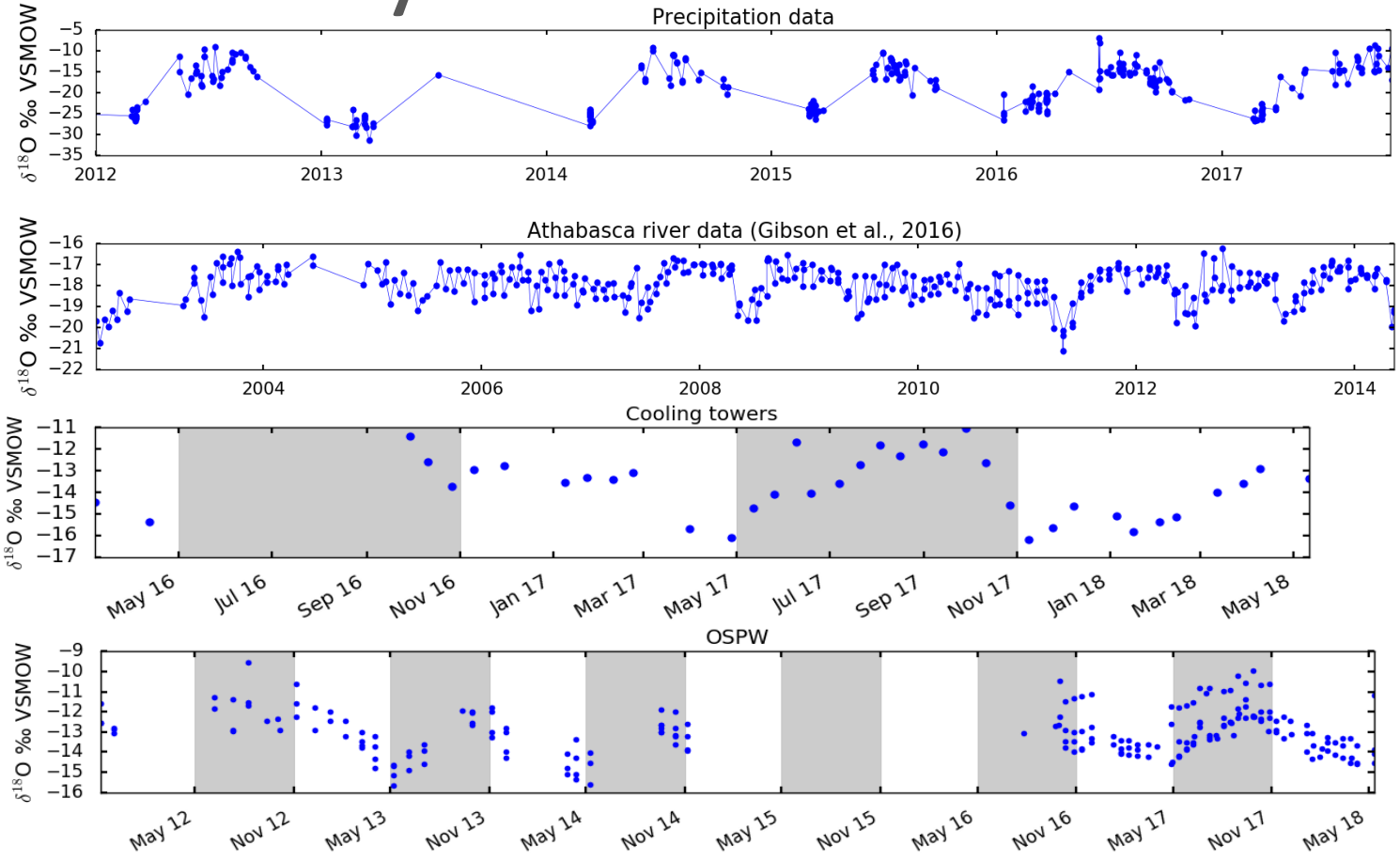
- 40 million m^3 is 'raw' or freshwater diverted from Athabasca river
- Remaining water is provided from the recycling of oil sands process-affected water (OSPW)
- Focus of this study is OSPW and recycle water circuit (tailings ponds)

Isotopically ‘finger printing’ site waters

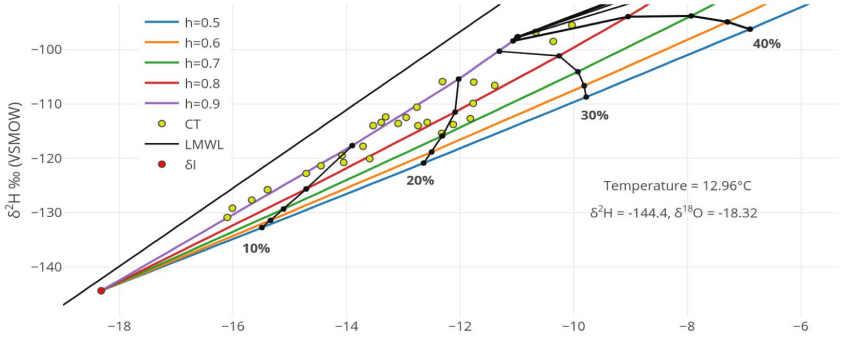


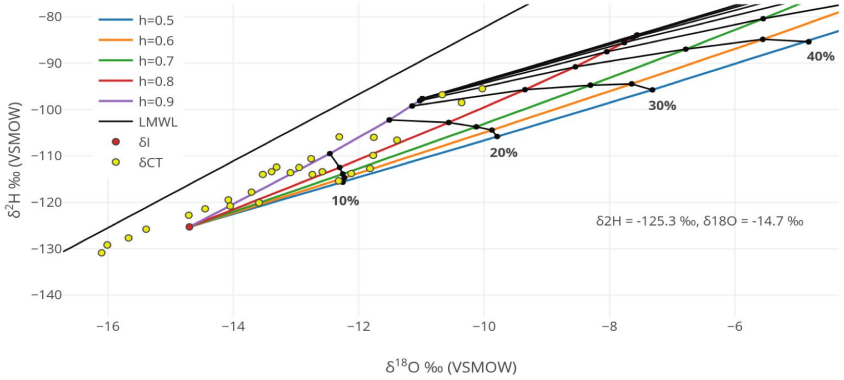


Seasonality

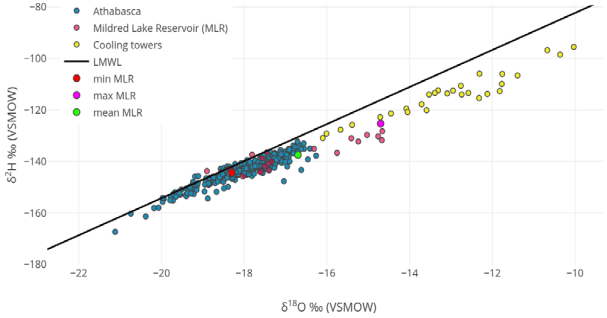


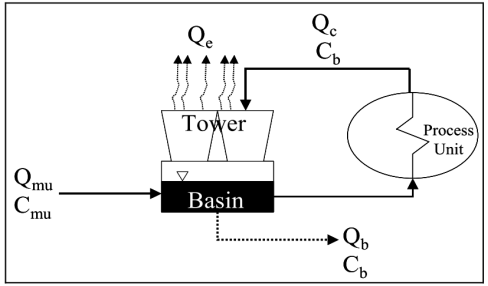
Cooling tower effects

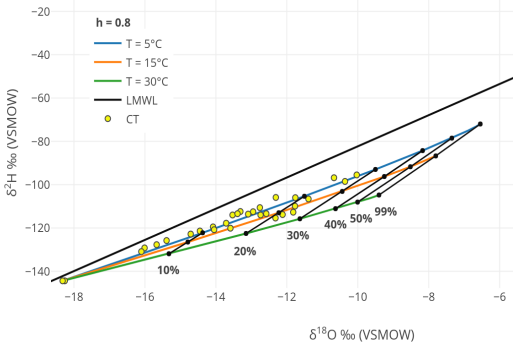




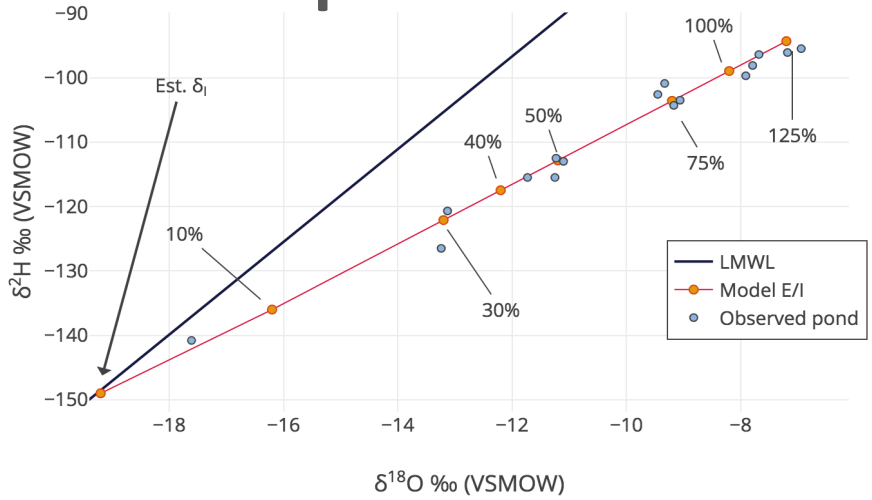
Ave. fraction remaining = 0.67

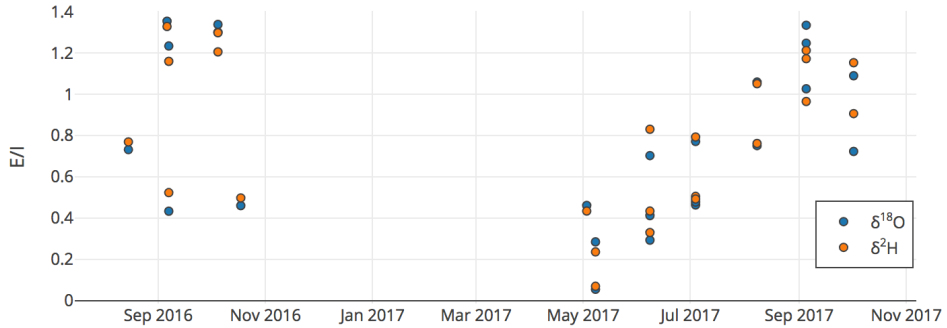


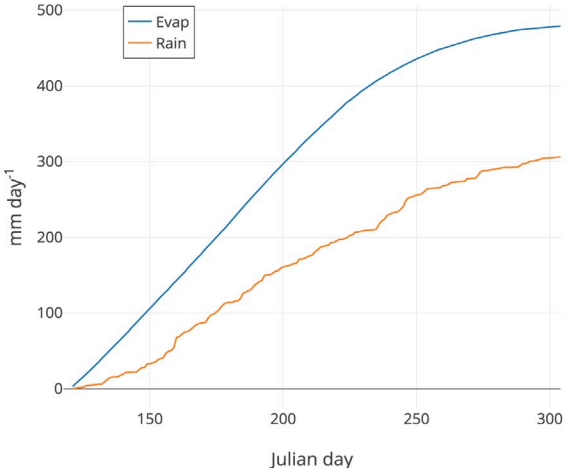




Natural ponds test





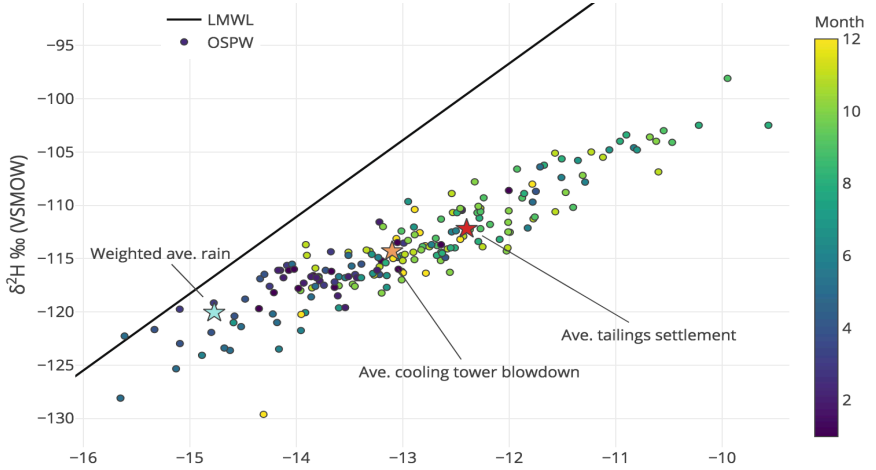


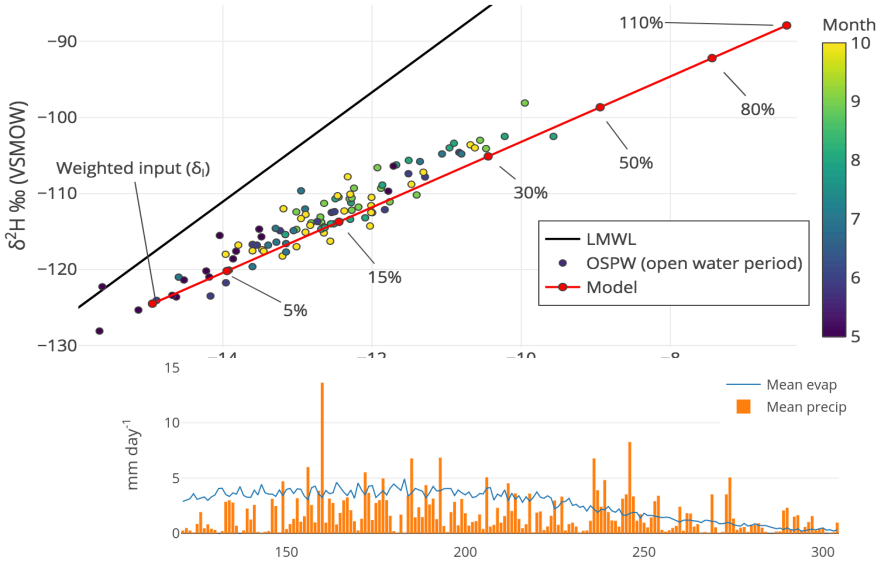
Quick napkin math…

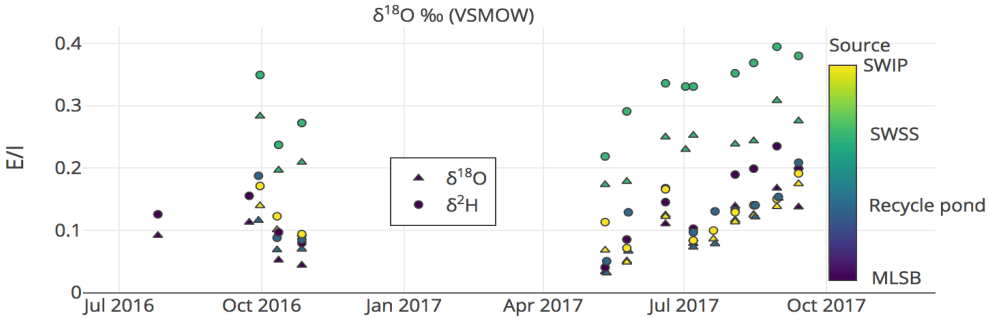
Input = Rain + Snow + Runoff
Rain = 300 mm
SWE = ~50 mm
Runoff = 0.2 x 350 mm

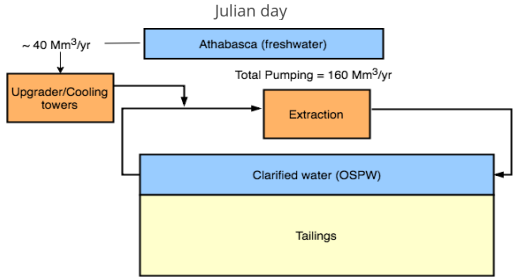
E = Input (411mm) x E/I (1.2) = 493mm

Recycle water circuit E/I ratios

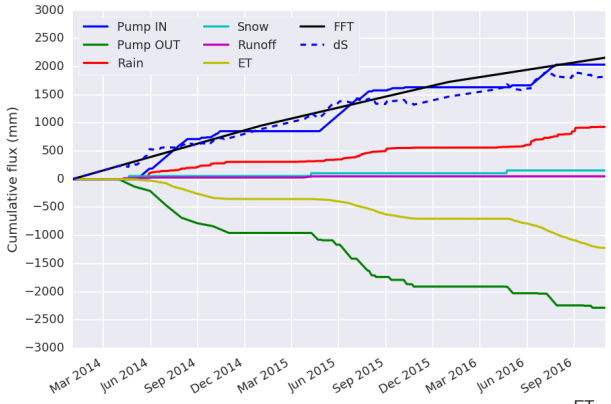


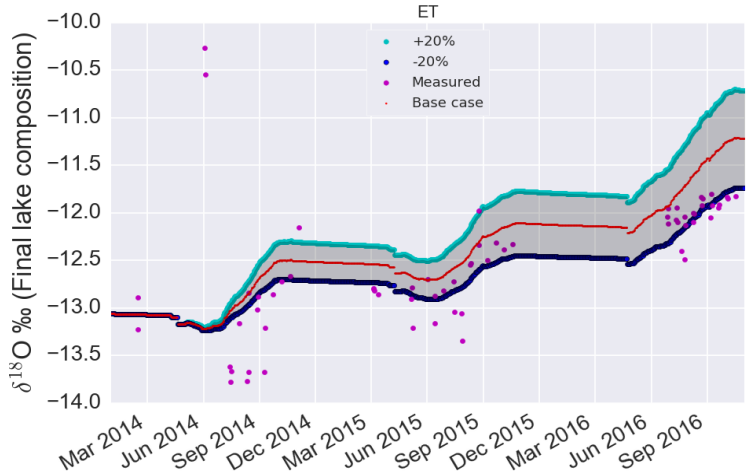


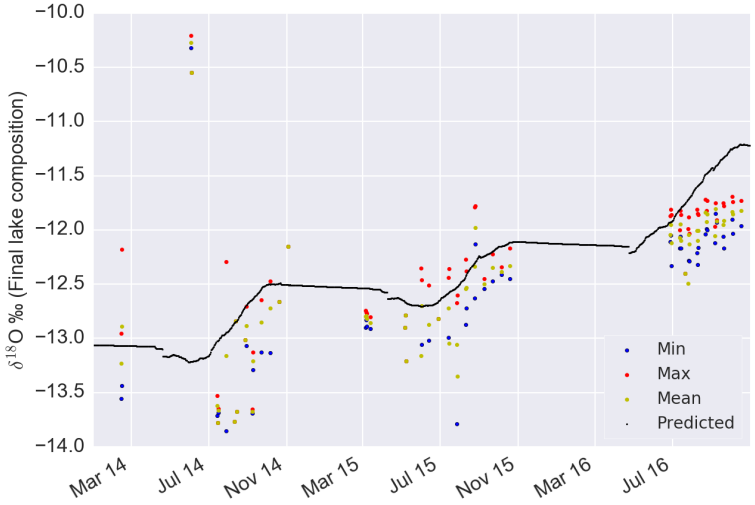




Base Mine Lake predictive model







Isotope Mass Balance

$$V\frac{d\delta_L}{dt} + \delta_L\frac{dV}{dt} = I\delta_I - Q\delta_Q - E\delta_E$$

$$\downarrow$$

$$\delta_{L_f} = \left(\delta_{L_i}\cdot V_i + I\delta_I - O\delta_O - E\delta_E\right)\frac{1}{V_f}$$

Key findings

- Adapting isotope tracing theory to engineered system
  a) Better quantify evaporative signals from mining process
     - Cooling tower enrichment
     - Open water evaporation from tailings ponds is not the only contributor to enrichment
  b) Mixing processes from tailings settlement and blowdown could outweigh open water evaporative enrichment for modelling
  c) High pumping rates = low residence time in recycle water circuit
     - Need to adapt time scale to observe evaporative enrichment
  d) Bitumen mats may inhibit evaporation/affect fractionation
     - Eddy covariance over predicting evaporation at Base Mine Lake

THANK YOU

Syncrude
Teck
Imperial
SUNCOR ENERGY
Canadian Natural