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WATER | WASTE | ENERGY

Placing the risk of thermal mobilization into perspective

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Some facts

3rd largest oil reserve in the world

170.2 billion barrels proven *(99% in oil sands)*

Majority inaccessible from surface

127 operating oil sands projects as of Jan 2013 *(includes 7 mines)*

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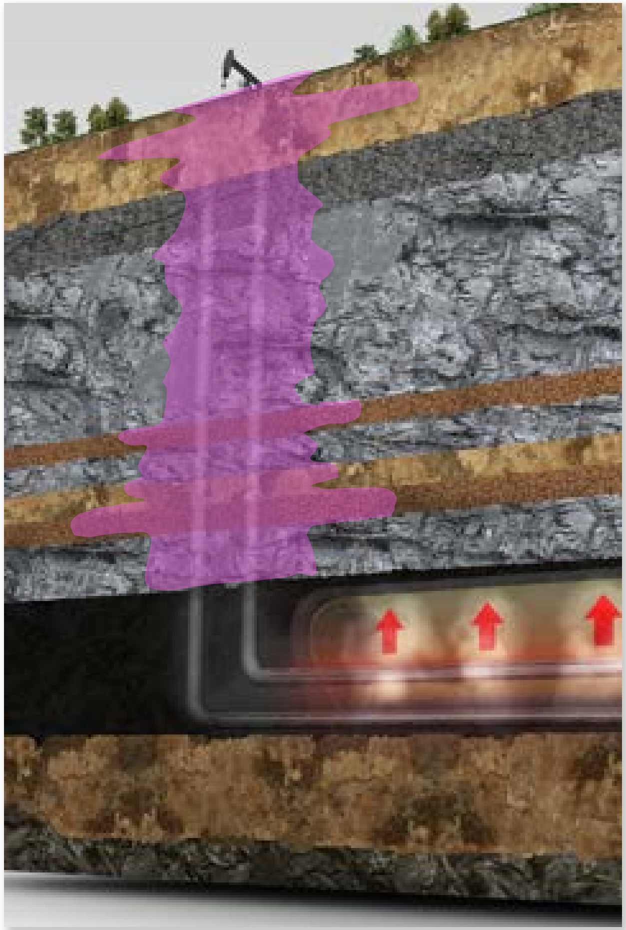
The issue

Temperature has a significant control on the physical and chemical environment

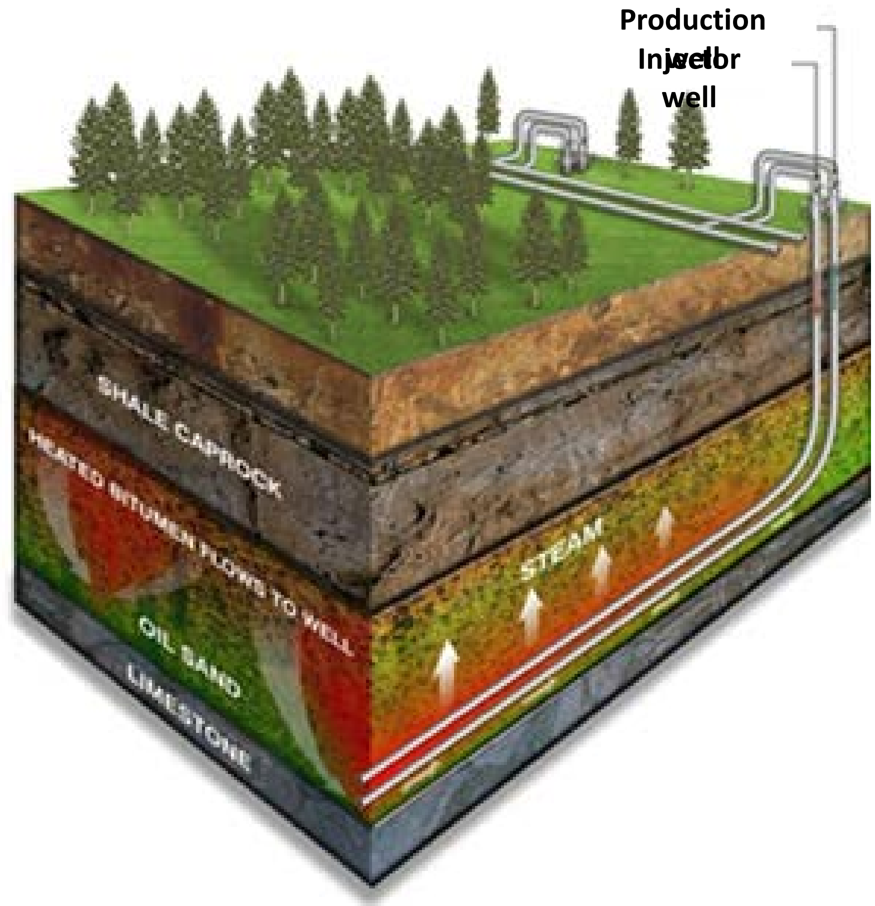
Conductive heating of fresh water aquifers around thermal in situ wells alters local groundwater conditions



The challenge

Most of the bitumen in the oil sands deposits will require thermal in situ recovery

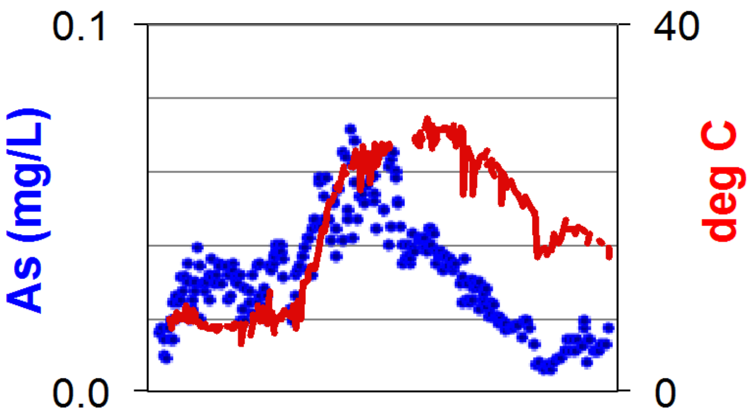
Concern has been mounting regarding potential for cumulative effects from thermal mobilization



Observations to date

- Constituents released:
  - *all major cations, Si, Al, As, B, Mo, Sb, Zn, organic acids, phenols, trace volatile hydrocarbons*
  - *increased microbial activity facilitating release (IRBs and SRBs)*

- Releases at temperatures as low as 30°C
  - *E.g., Arsenic up to 350 μg/L (i.e., well in excess of the drinking water guideline of 10 μg/L)*



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Effects on groundwater flow

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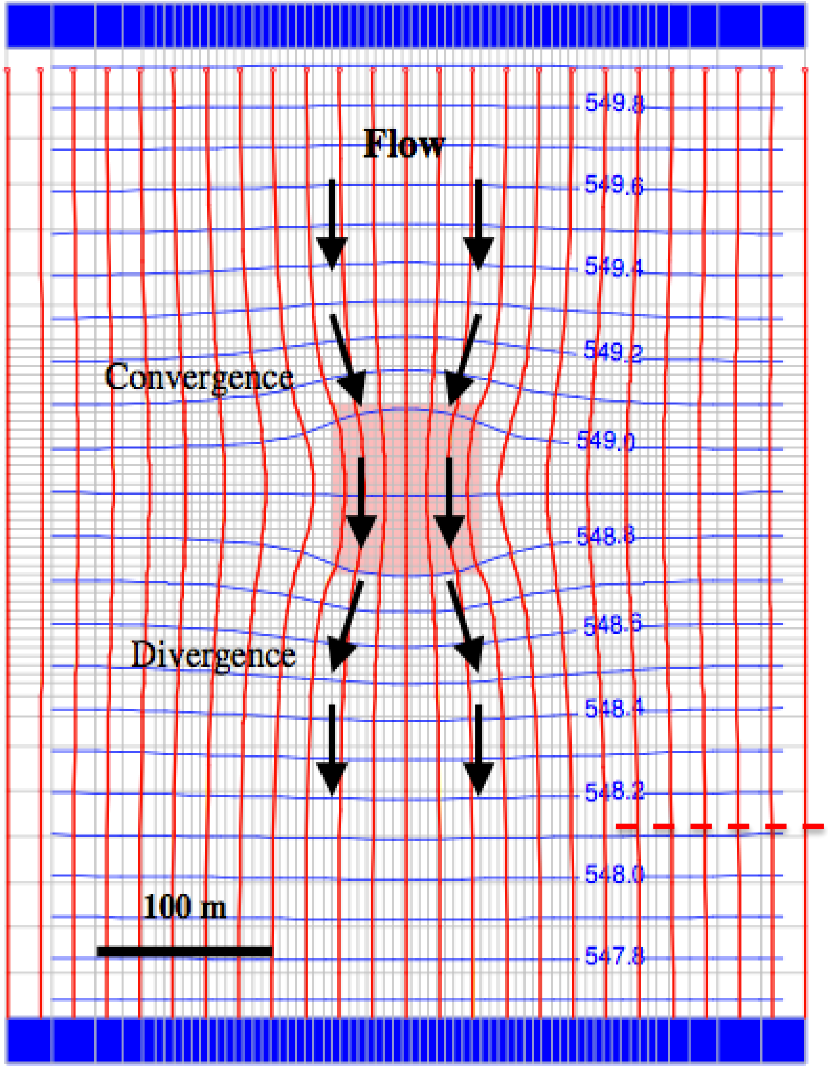
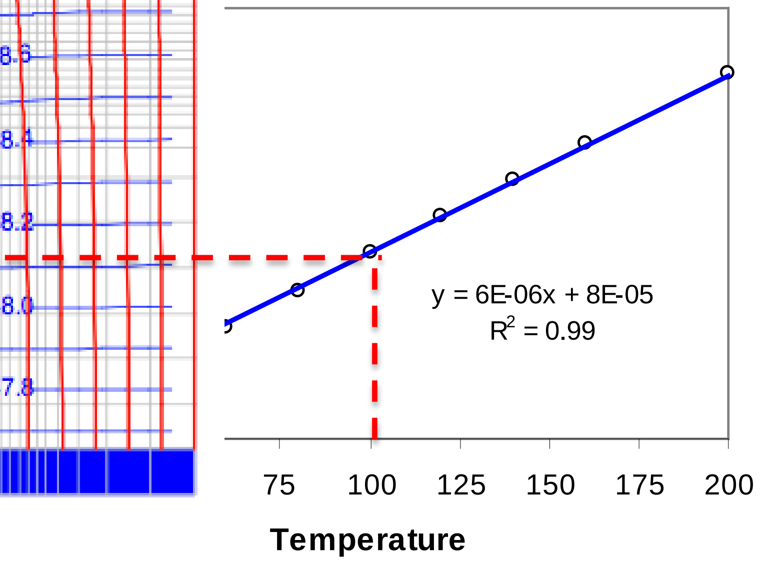


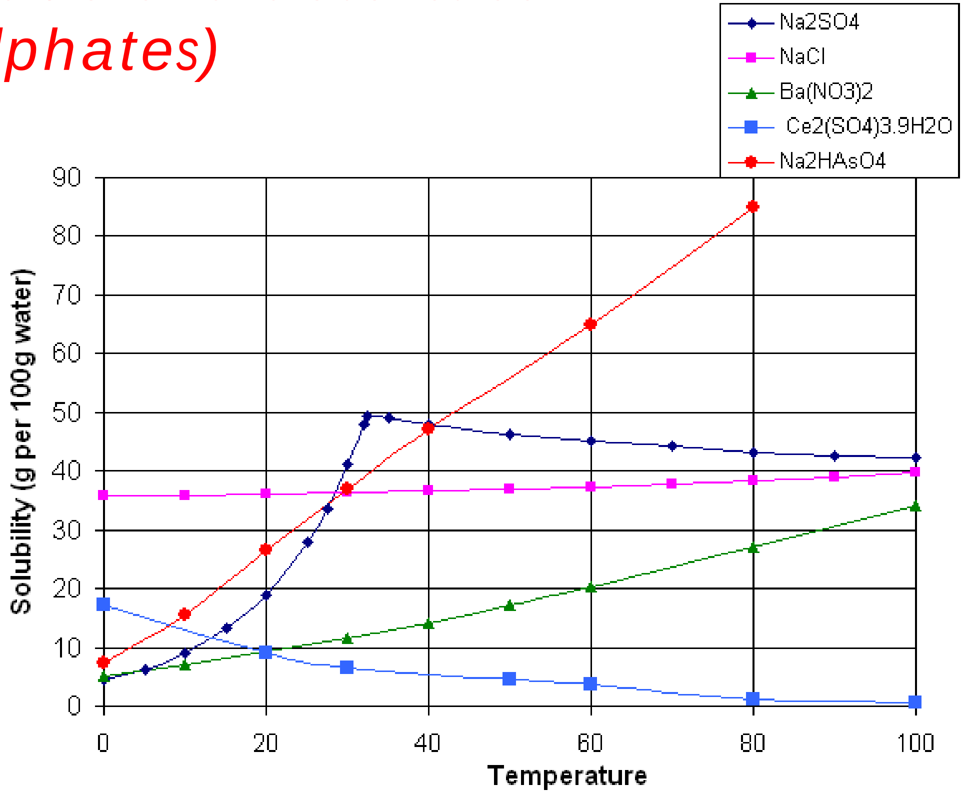


Effects on mineral solubility

- The solubility of most minerals increases at elevated temperatures
  - *endothermic vs. exothermic*
  - *some display retrograde characteristics (e.g. carbonates, sulphates)*

van't Hoff equation:

$$\ln\left(\frac{K_2}{K_1}\right) = -\frac{\Delta H^\circ}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$



Effect on reaction rates

- Increased temperature causes atoms or molecules of the reactants to move more quickly
  - *more frequent collisions with greater energy*
  - *higher concentrations = more collisions*

Arrhenius equation:

$$k = Ae^{-Ea/RT} \quad \text{or}$$

$$\ln k = -\frac{E_a}{RT} + \ln A$$

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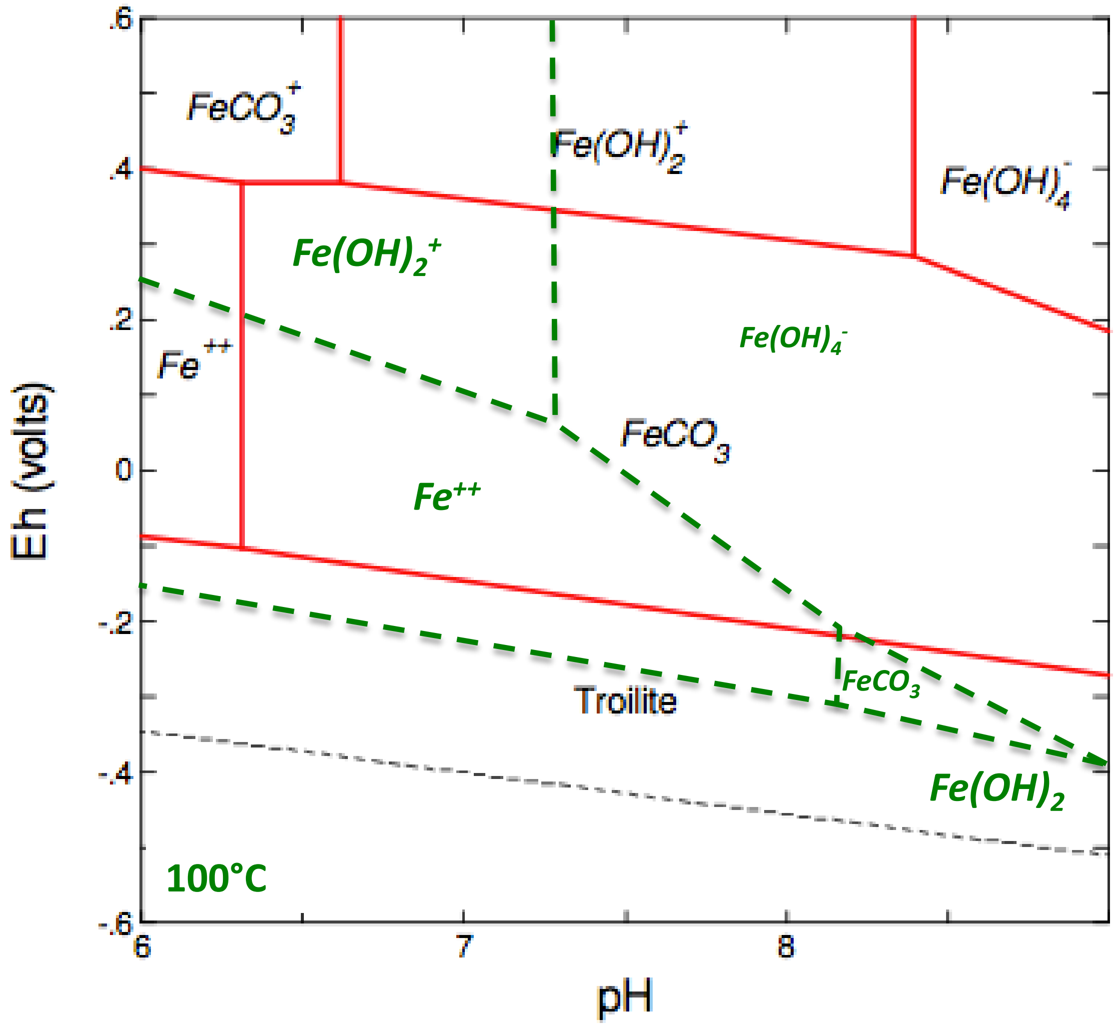
Effect on redox conditons



Change in stability fields can lead to constituent release

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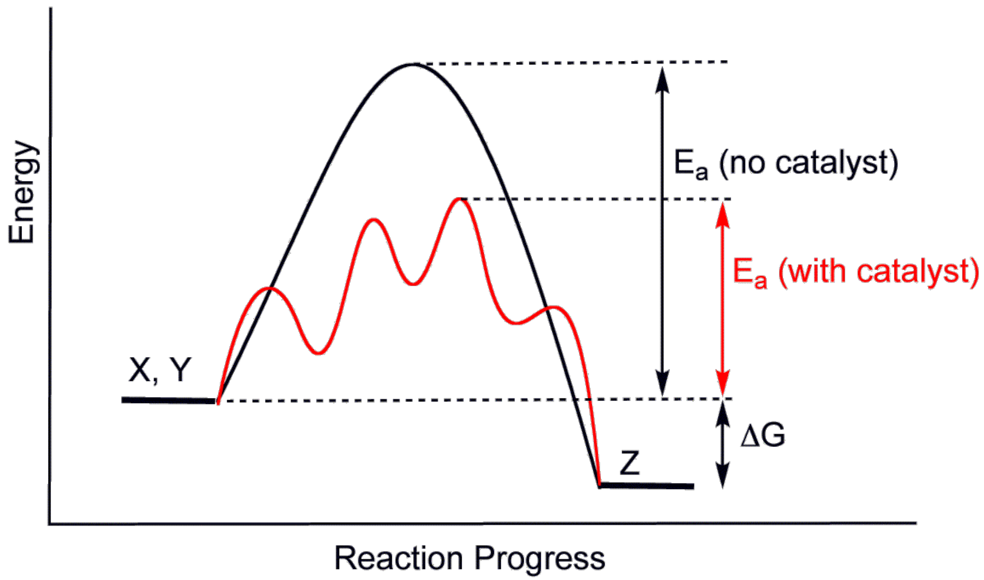
Other important factors

- Surface area of the participating minerals plays an important role
  - *the more surface contact between reactants, the higher the rate of reaction*
  - *sand will behave very differently compared to silts and clays*

- Degree of mineral crystallinity will affect constituent release
  - *amorphous versus well structured*

Other important factors

- The presence of a catalyst will influence the reaction rate *(i.e., a substance that speeds up the rate of a chemical reaction without being used up in the reaction itself)*
  - *when is present reaction(s) can proceed with less energy input*
  - *E.g., enzymes produced by microbes; certain metals*



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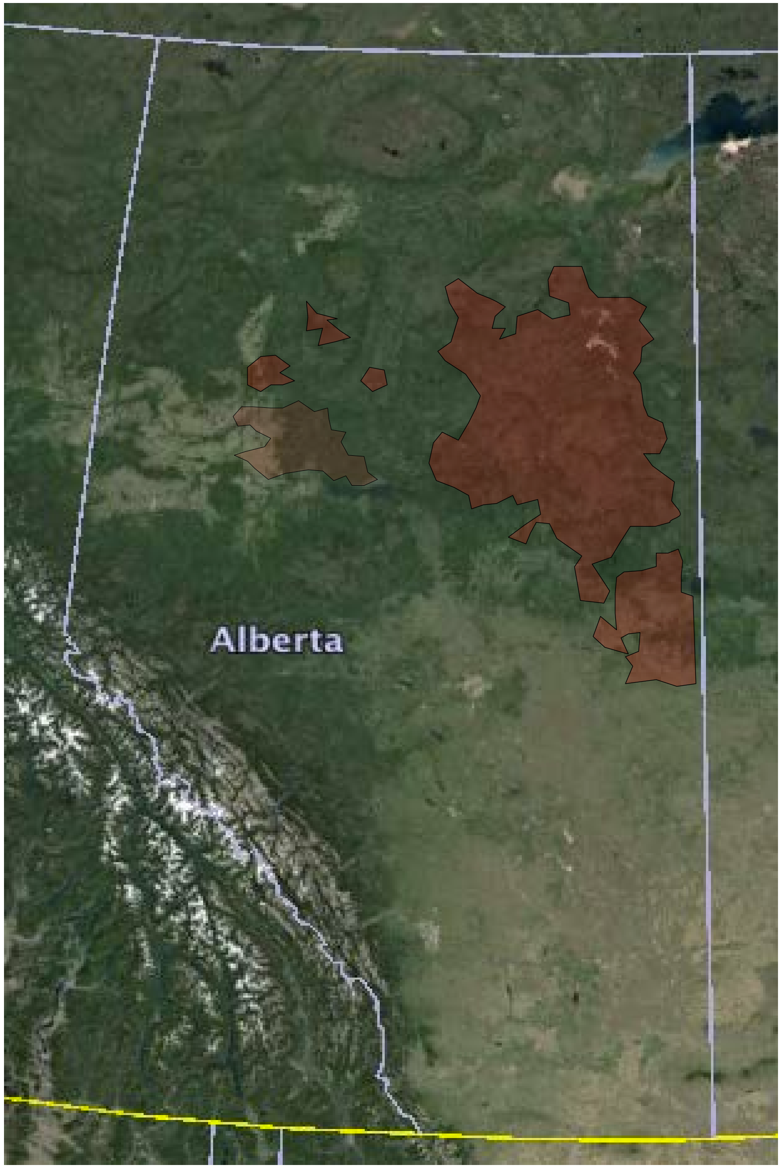
The reality

The majority of thermal in situ projects are (and will be) located in remote areas of the province

Lower risk profile for human receptors



The reality

Not all parts of the province, or aquifers beneath, have the same conditions that will favour thermal mobilization

The risk of thermal mobilization needs to be understood before any action can be taken to mitigate (if necessary)

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Sources

Not all sources are the same

Are the constituents "in" the mineral or "on" the mineral *(it makes a makes a big difference)*

Reactions	Typical range of Ea values (kcal/mol)		
Physical adsorption	2	to	6
Aqueous diffusion	<5		
Mineral dissolution or ppt	8	to	36
Mineral dissolution via surface rxn control	10	to	20
Ion exchange	>20		
Isotopic exchange in solution	18	to	48
Solid-state diffusion in minerals at low T	20	to	120
Cellular and life-related reactions	5	to	20

To date, values of 2 to 12 kcal/mol identified

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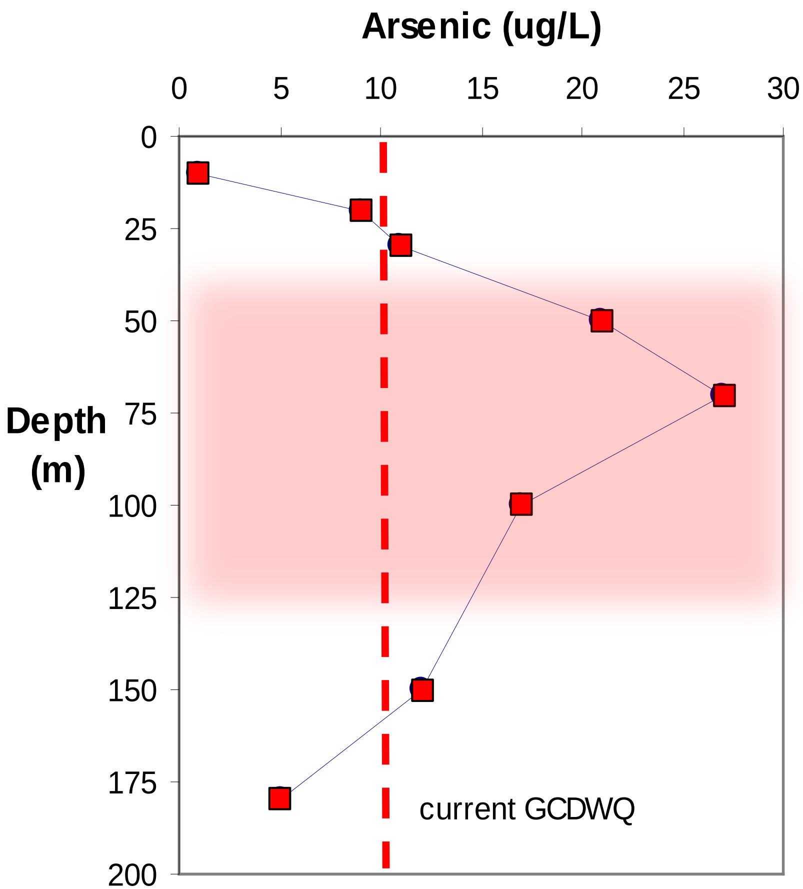
Not all geochemical conditions are the same

Reactions	Eh (V)
$O_2(g) + 4H^+ + 4e^- = 2H_2O$	0.816
$NO_3^- + 6H^+ + 5e^- = ½ N_2(g) + 3H_2O$	0.713
MnO_2 (pyrolusite) $+ 4H^+ + 2e^- = Mn^{2+} + 2H_2O$	0.544
$NO_3^- + 2H^+ + 6e^- = NO_2^- + H_2O$	0.431
$NO_2^- + 8H^+ + 6e^- = NH_4^+ + 2H_2O$	0.340
$Fe(OH)_3 + 3H^+ + e^- = Fe^{2+} + 3H_2O$	0.014
$SO_4^{2-} + 10H^+ + 8e^- = H_2S(aq) + 4H_2O$	-0.217
$HCO_3^- + 9H^+ + 8e^- = CH_4(aq) + 3H_2O$	-0.260

§ After Langmuir (1997)

Major players



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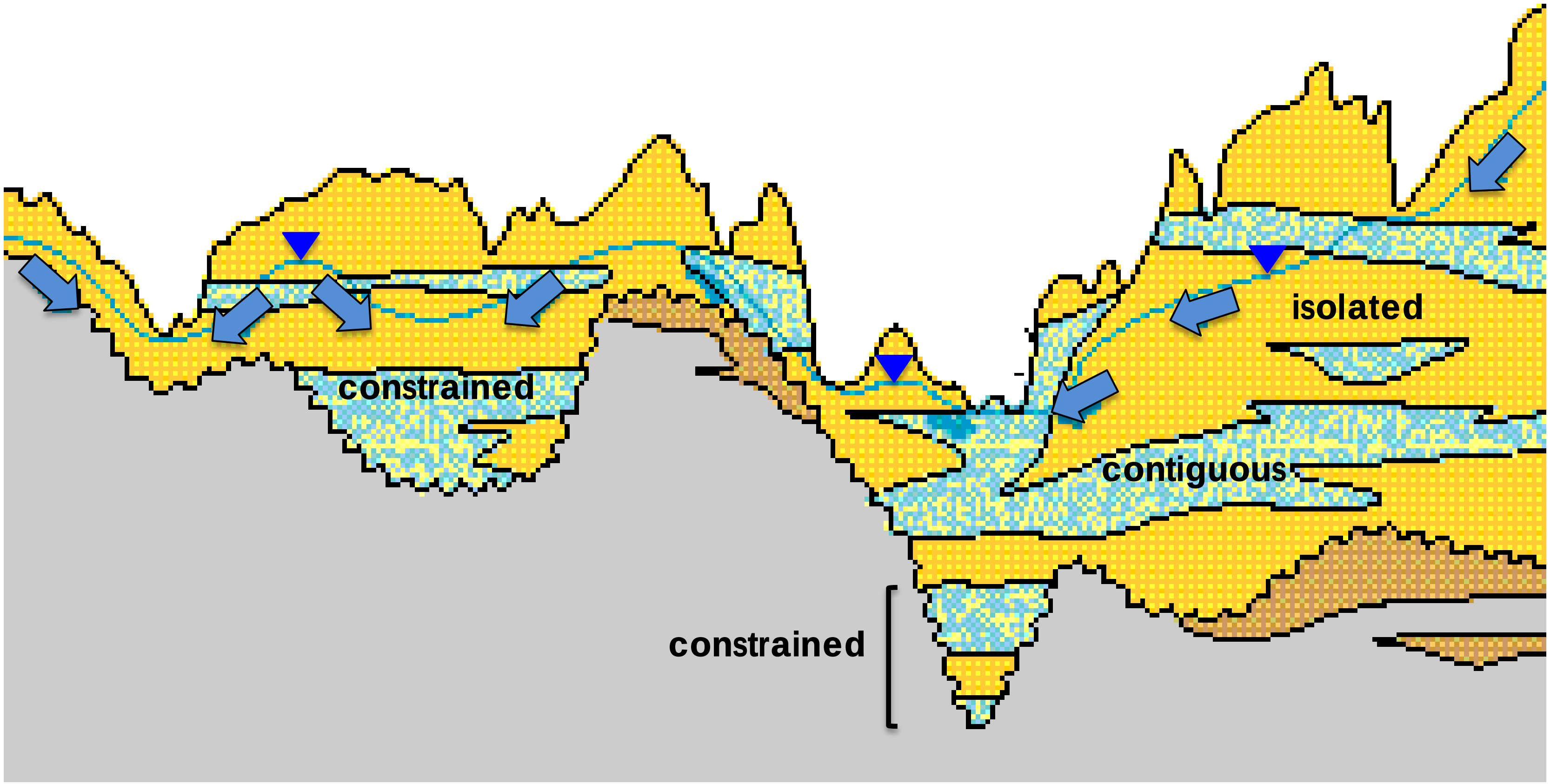
Pathways

Not all pathways are the same



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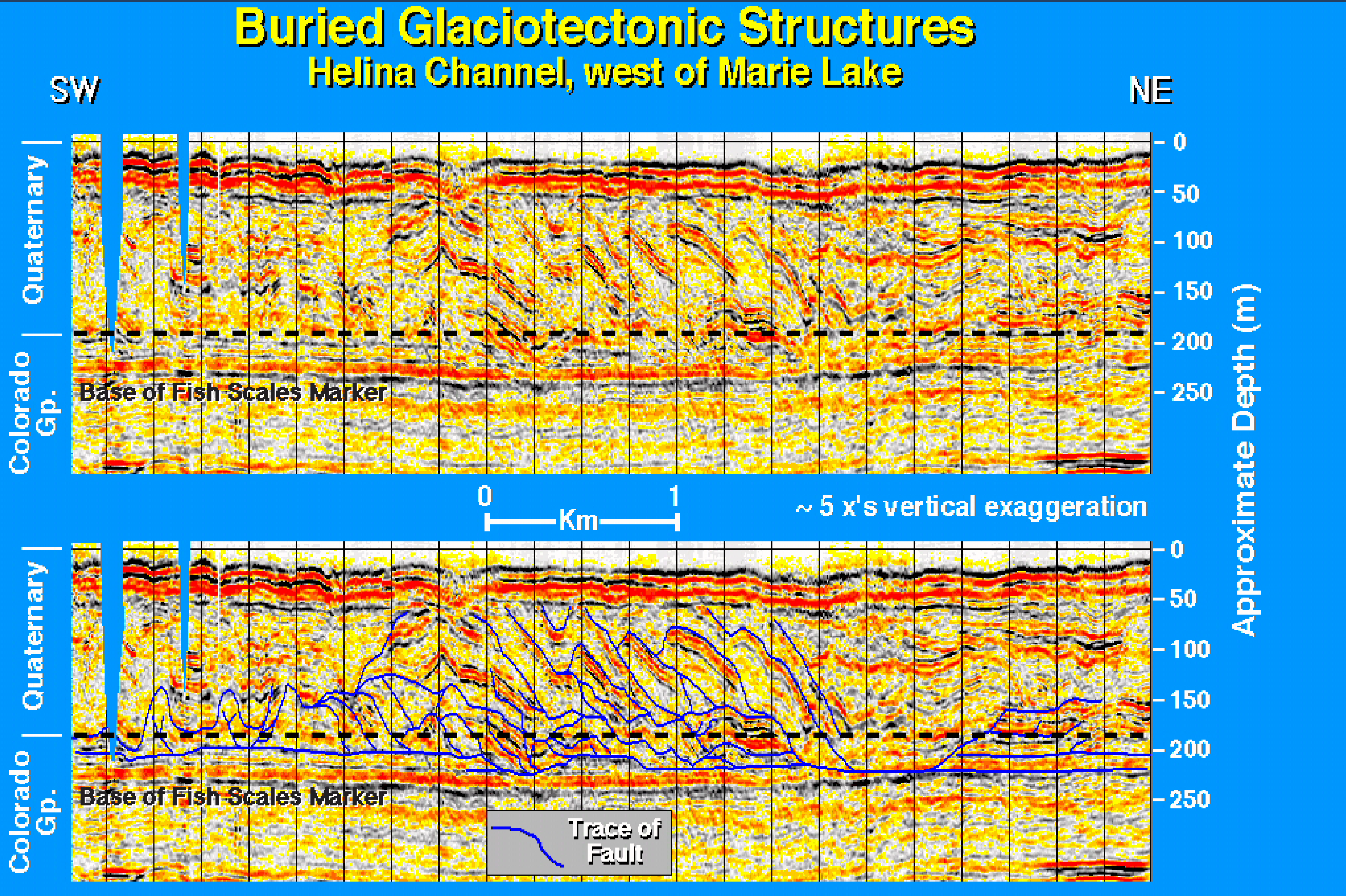
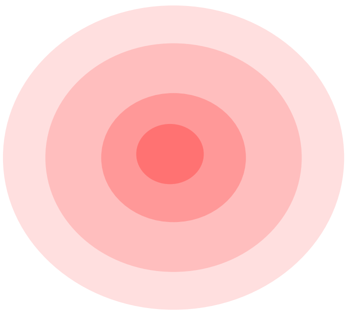
…and they can be significantly influenced



Not all rates of groundwater movement are the same

Conduction dominated

(slow groundwater movement)



Advection dominated

(faster groundwater movement)

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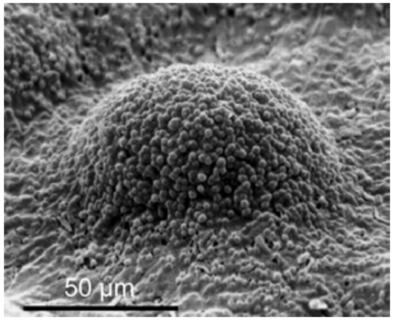
Things also happen along the way

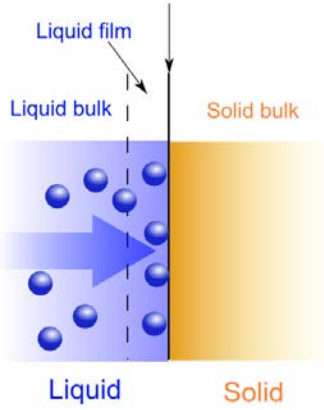
Hydrodynamic dispersion ***(↓C₀)***

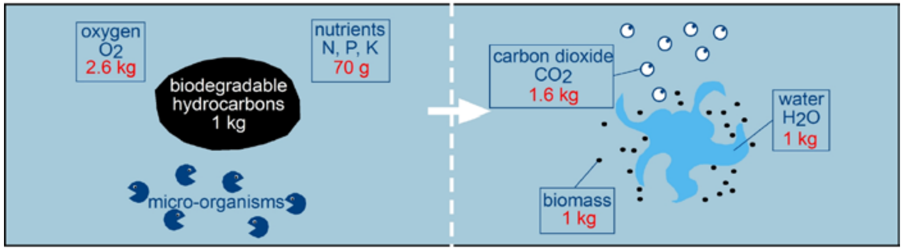
Mineral precipitation

Biodegradation

Sorption







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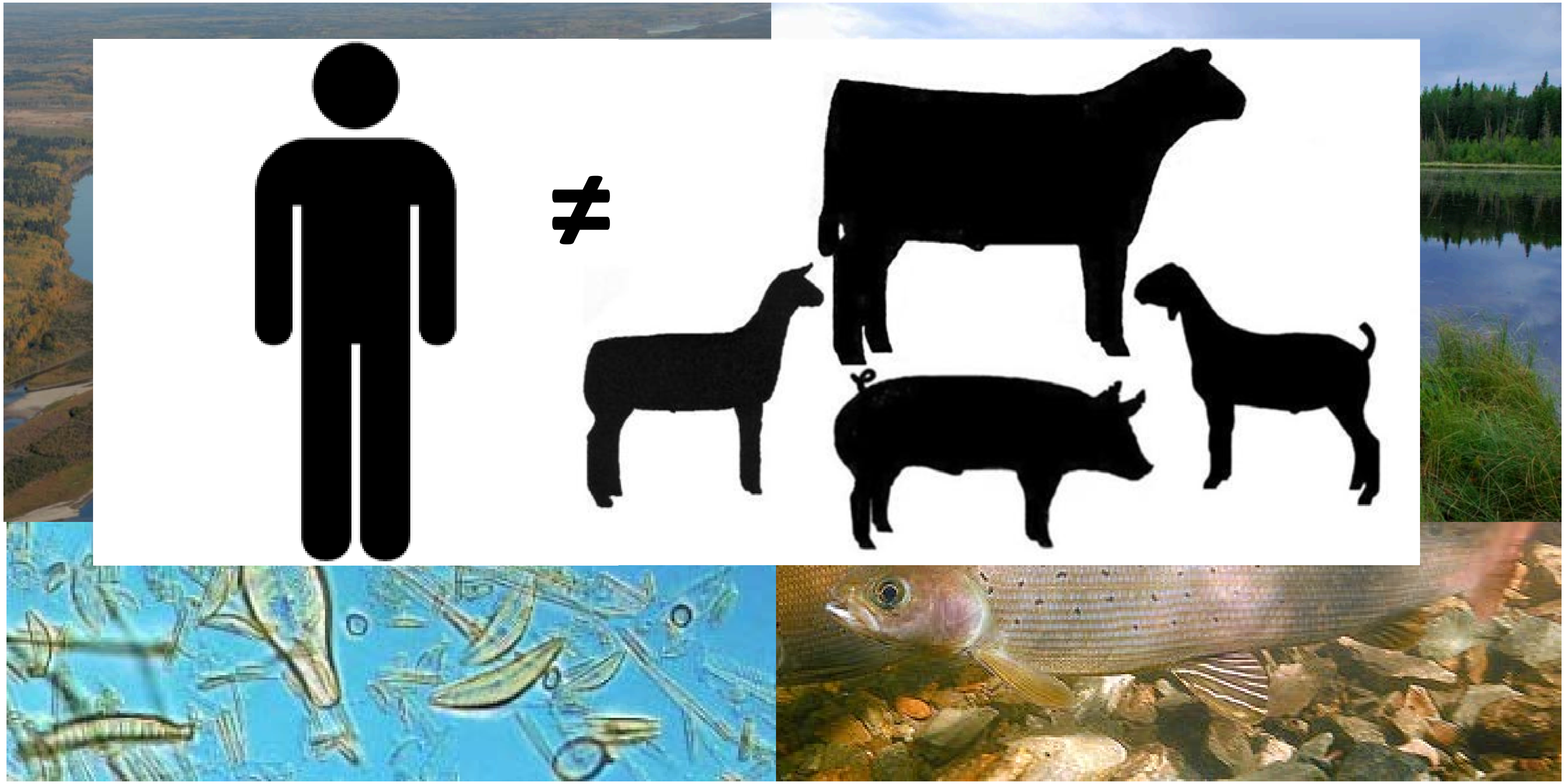
Receptors

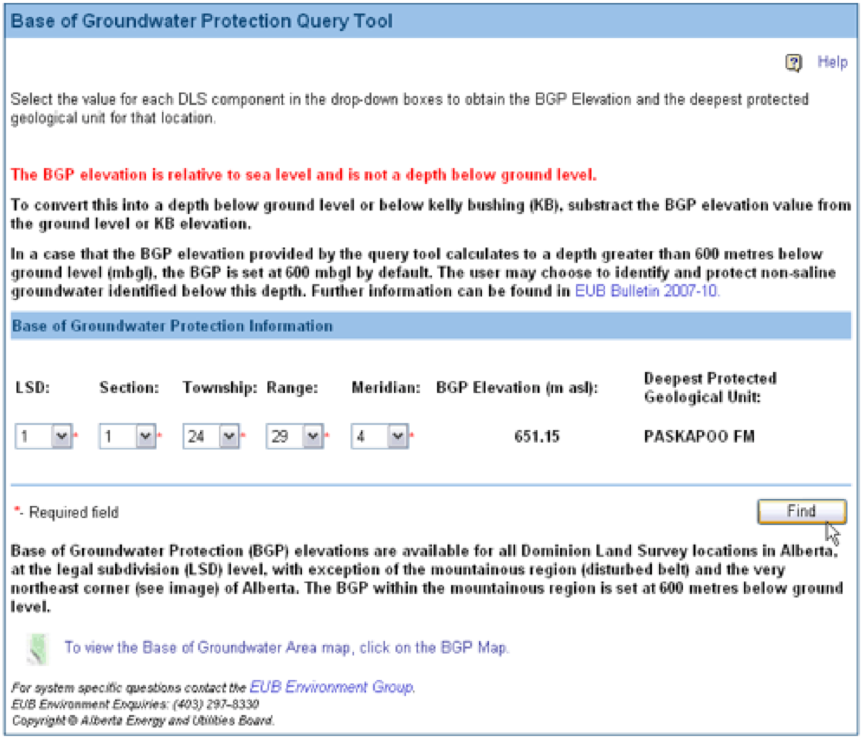
Not all receptors are the same



They need to be present

They need to be relevant

- Vast majority of water wells are completed within 150m of surface *(costs & logistics for going deeper too constraining)*
- Deeper formations are isolated from surface receptors and domestic wells *(chances of impact are low)*
- Risk is significantly different for shallow versus deep non-saline intervals *(should they be treated differently?)*



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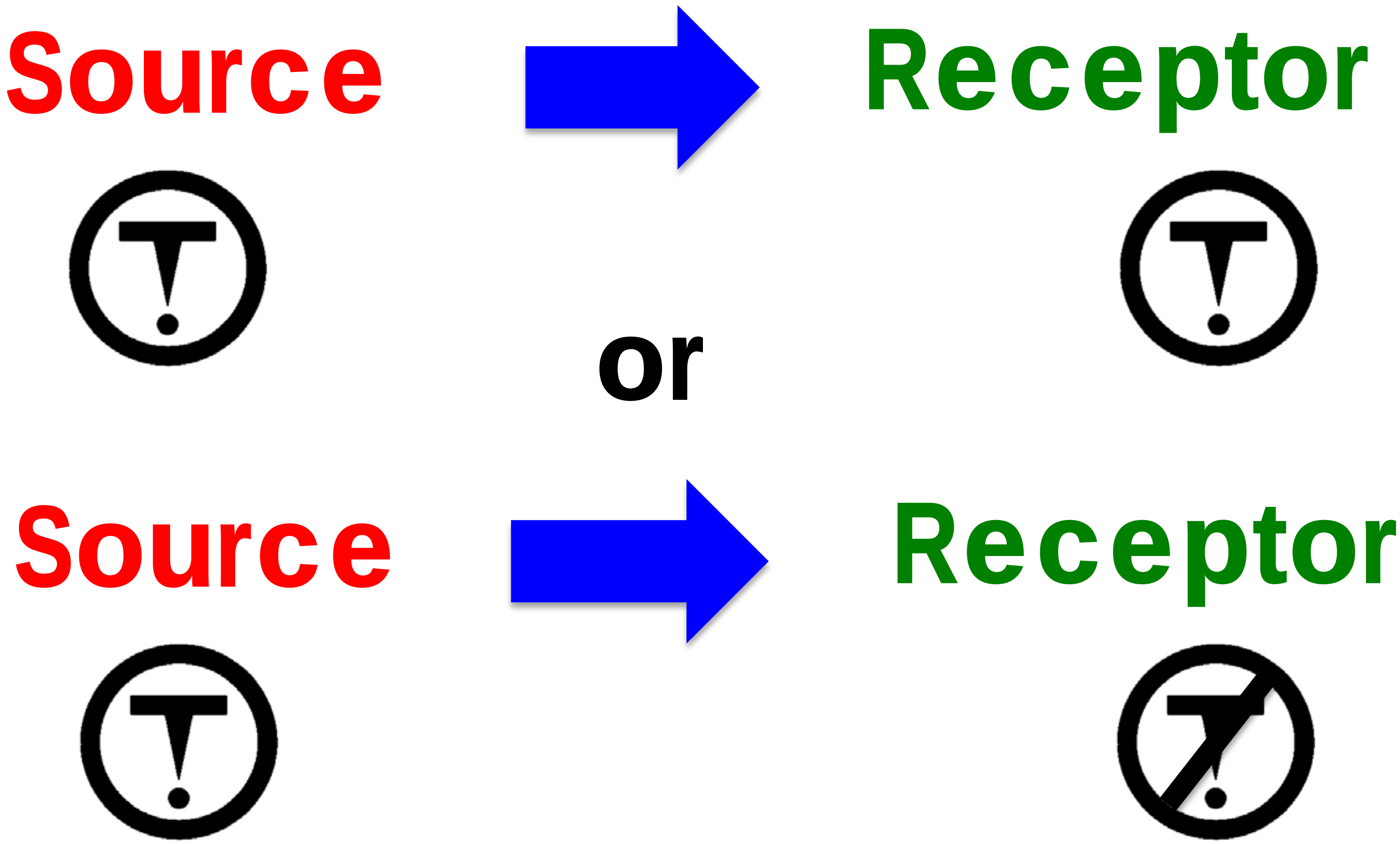
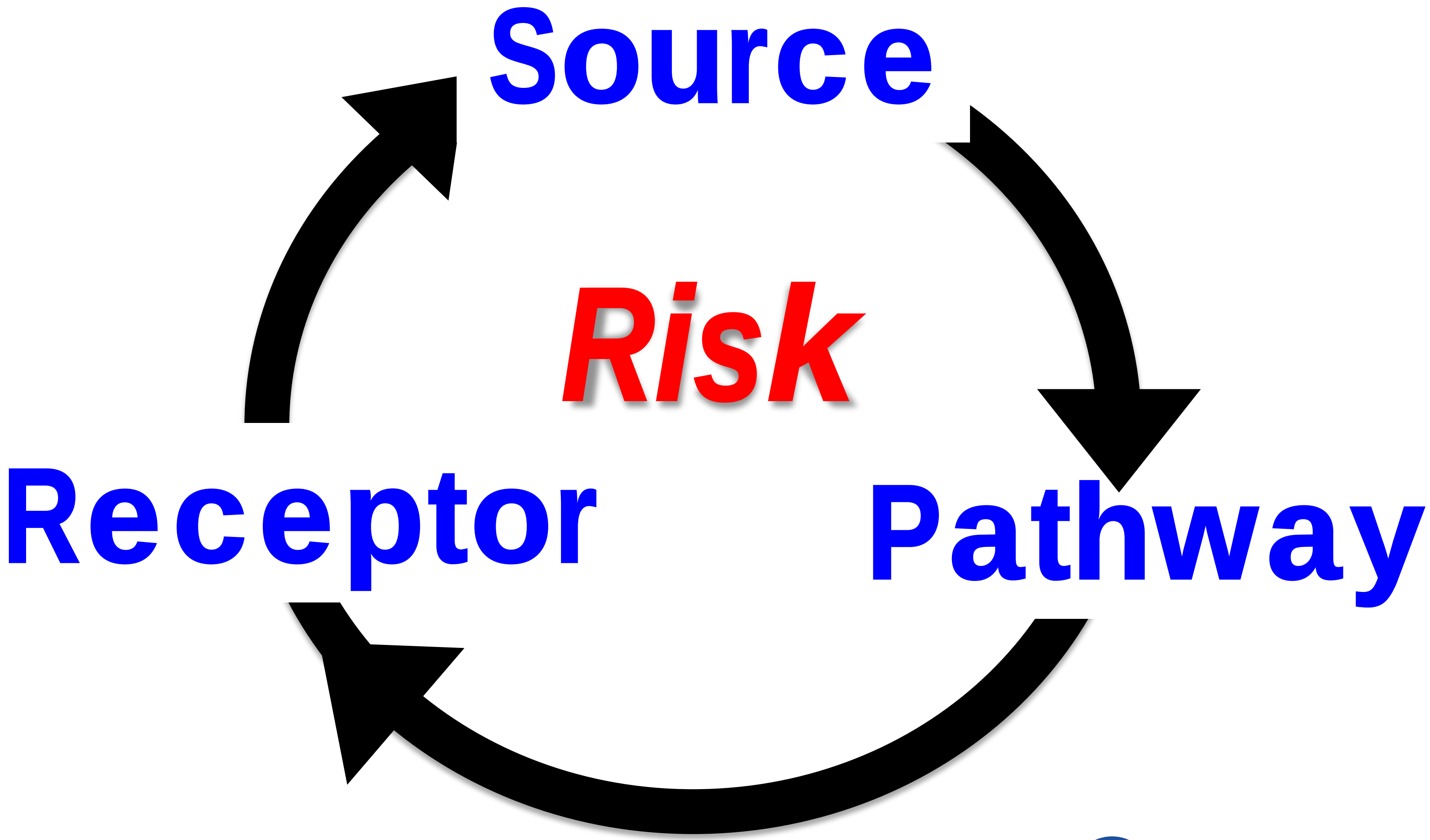
They need to be sensitive



So…in the end you need all of this



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Final thoughts

1. The risk of thermal mobilization is real, but relative based on:
   - *location*
   - *sediment types*
   - *groundwater conditions (flow, geochemical state)*

Final thoughts

2. A concern with thermal mobilization does not automatically equate to an issue, because you need:

   - *mobile source*
   - *open and active pathway*
   - *sensitive receptor*

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Final thoughts

3. One should take a measured response to ensure:

   - *effective and relevant monitoring*
   - *timely detection of change (and why)*
   - *proper framing and communication of risk*

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So…do you know your risk profile?

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