Attenuation of Contaminants in Groundwater Impacted by Surface Mining of Oil Sands, Alberta, Canada

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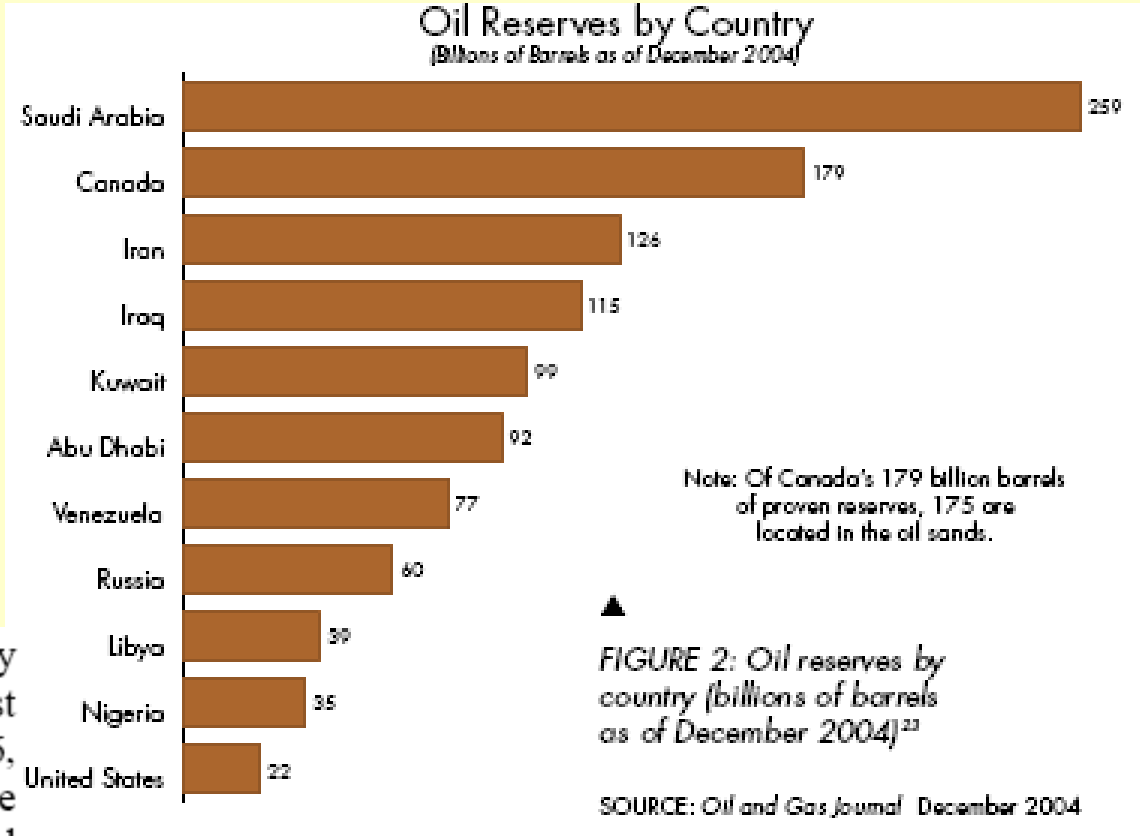
Canada's Oil

- Canada's proven reserves now 179 billion barrels (mainly oil sands)



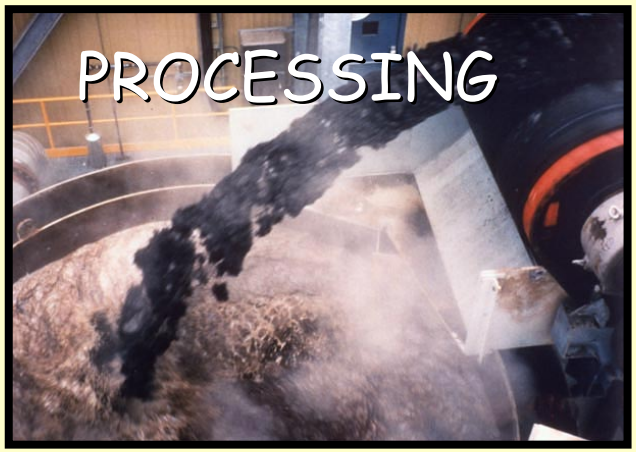
The United States with a refining capacity of over 17 million b/d is Canada's largest market for crude oil exports and, in 2006, Canada was the largest exporter of crude oil supplying almost 12 percent of United States requirements, ahead of both Mexico and Saudi Arabia. In 2006, Canada exported almost 1.6 million b/d and the

Alberta's Oil Sands

- Oil sands production from surface mining and in situ steam-assisted gravity drainage (SAGD)
  - 2005: mining – 552,000 b/d
    in situ – 438,000 b/d
- Canadian total crude production: 2,000,000 b/d

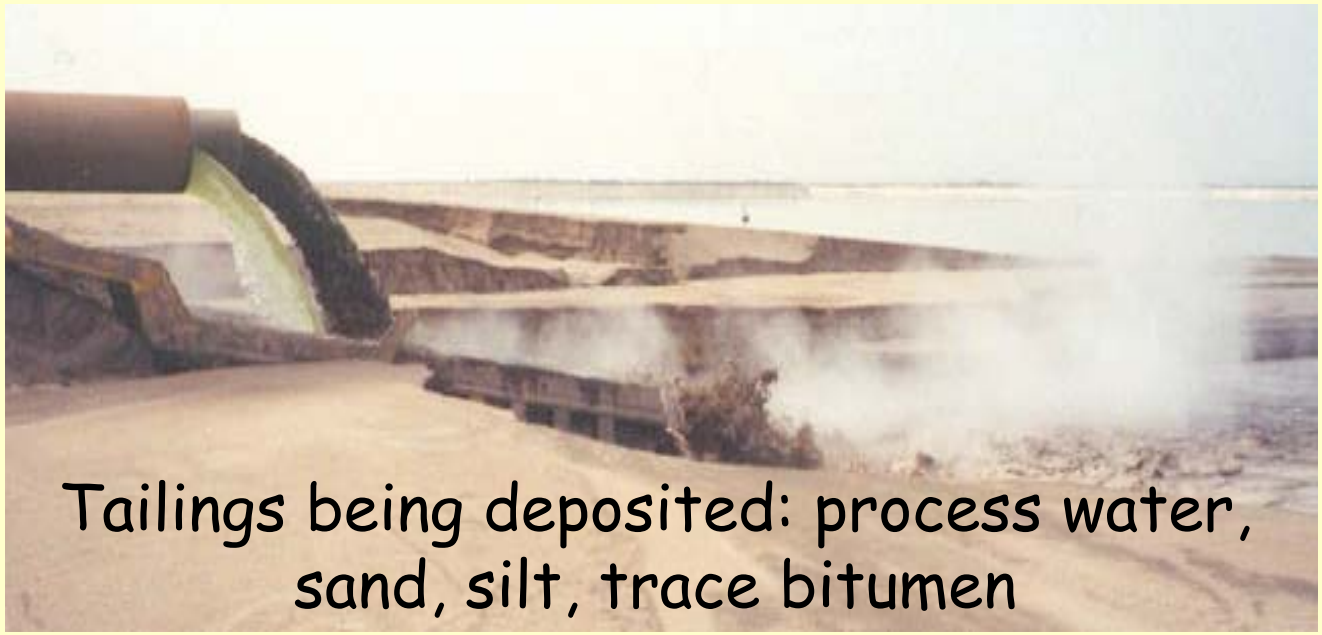
Oil Sands Mining & Processing

- Current production: 90,000 m^3/d upgraded oil
- Each m^3 of oil requires 2 – 5 m^3 of water
- > 95% of water for extraction is recycled
- 10^6 m^3 of tailings generated annually



Oil Sands Mining & Processing

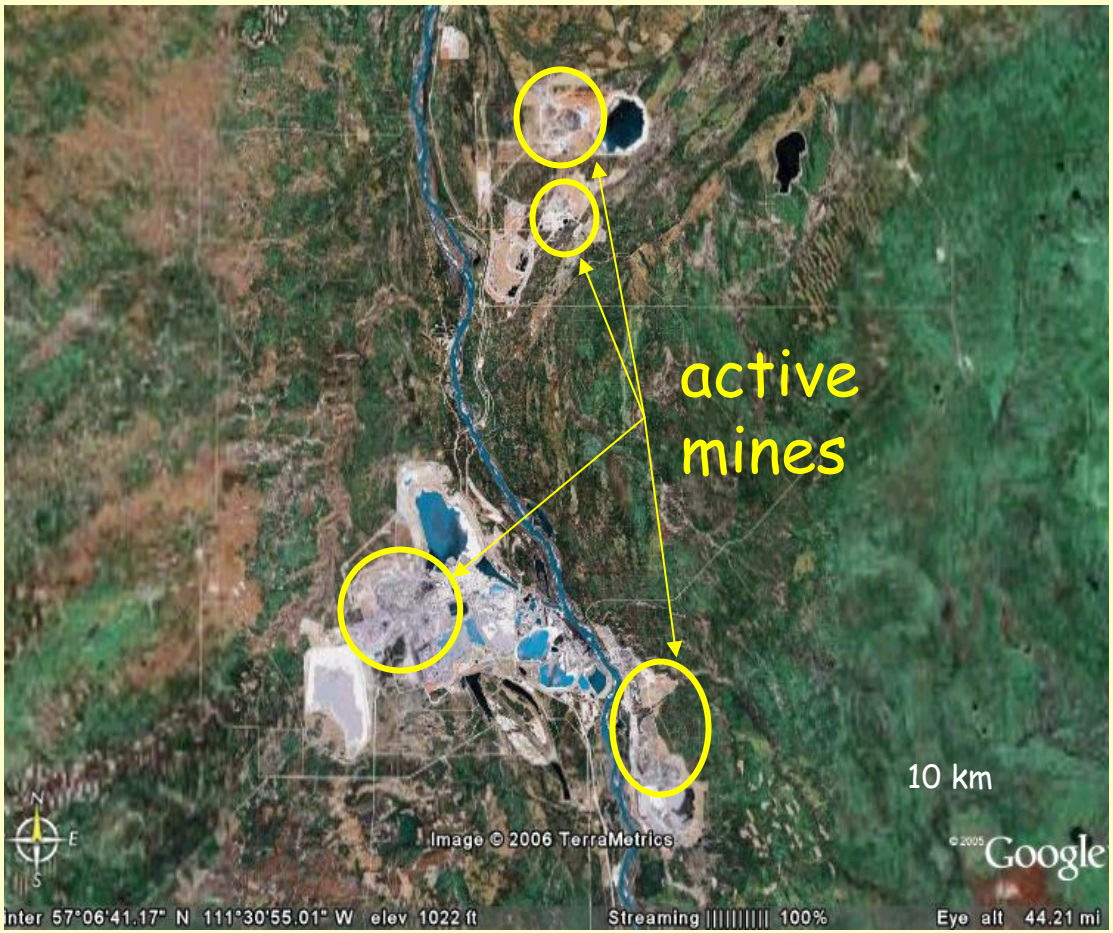
- Previous tailings would likely remain fluid for > 500 years; new technologies being employed to generate more rapid consolidation



Tailings being deposited: process water, sand, silt, trace bitumen

Alberta's Oil Sands Mining Area

- Surface mineable deposits cover 2,800 km^2
- Currently over 60 km^2 of tailings ponds

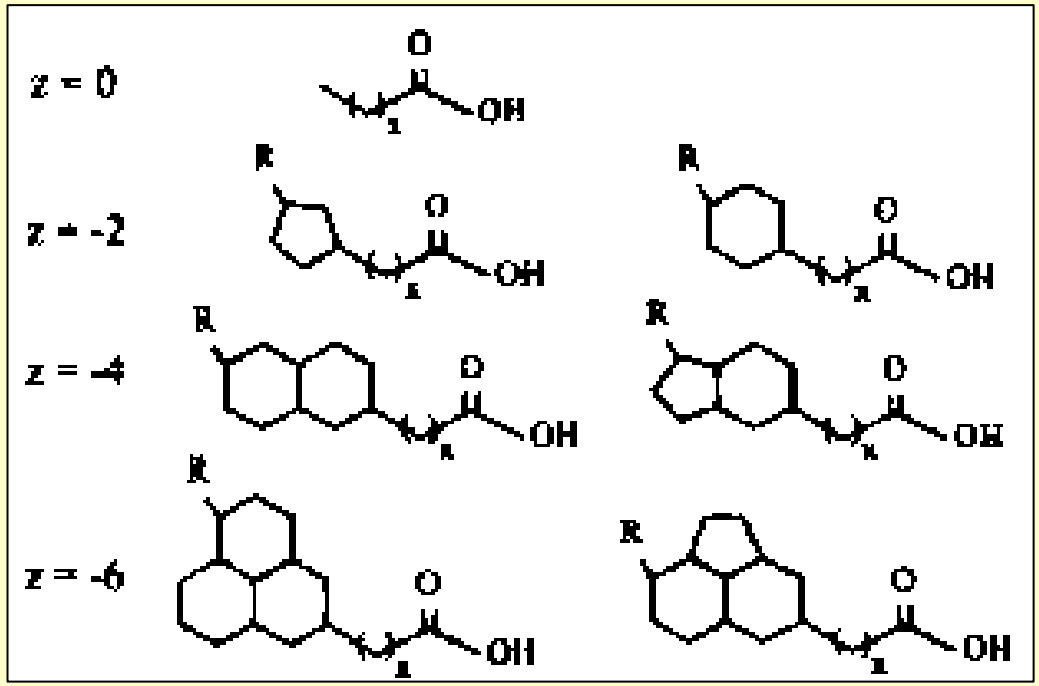


Groundwater Issues

- The Challenge: tailings fluids are toxic to aquatic organisms
- Naphthenic Acids (NAs) are the major toxicants
  - NAs are constituents of oil sand;
  - a few mg/L are often observed in surrounding surface waters, un-impacted by process water

Groundwater Issues

- Naphthenic Acids (NAs): the major toxicant
  - A complex mixture of acyclic and aliphatic carboxylic acids, with the general chemical formula $C_nH_{2n+z}O_2$, where n refers to the number of carbon atoms and z to the hydrogen atom deficiency caused by ring formation.



Groundwater Issues

- Groundwater is not used for drinking water supply, so aquatic receptors are the focus of concern. Groundwater is a pathway.
- Does (or will) discharge of process-affected groundwater cause significant impacts to aquatic/benthic communities?
- Is aquatic toxicity attenuated by biotransformation during groundwater transport?

Groundwater Issues

- Seepage of tailings water
  - more likely from sand dyke construction than from ponds
  - most seepage is collected and returned to pond
  - current plumes are not affecting aquatic systems (TID is "grandfathered")
  - groundwater may also be a significant pathway in the reclaimed landscape

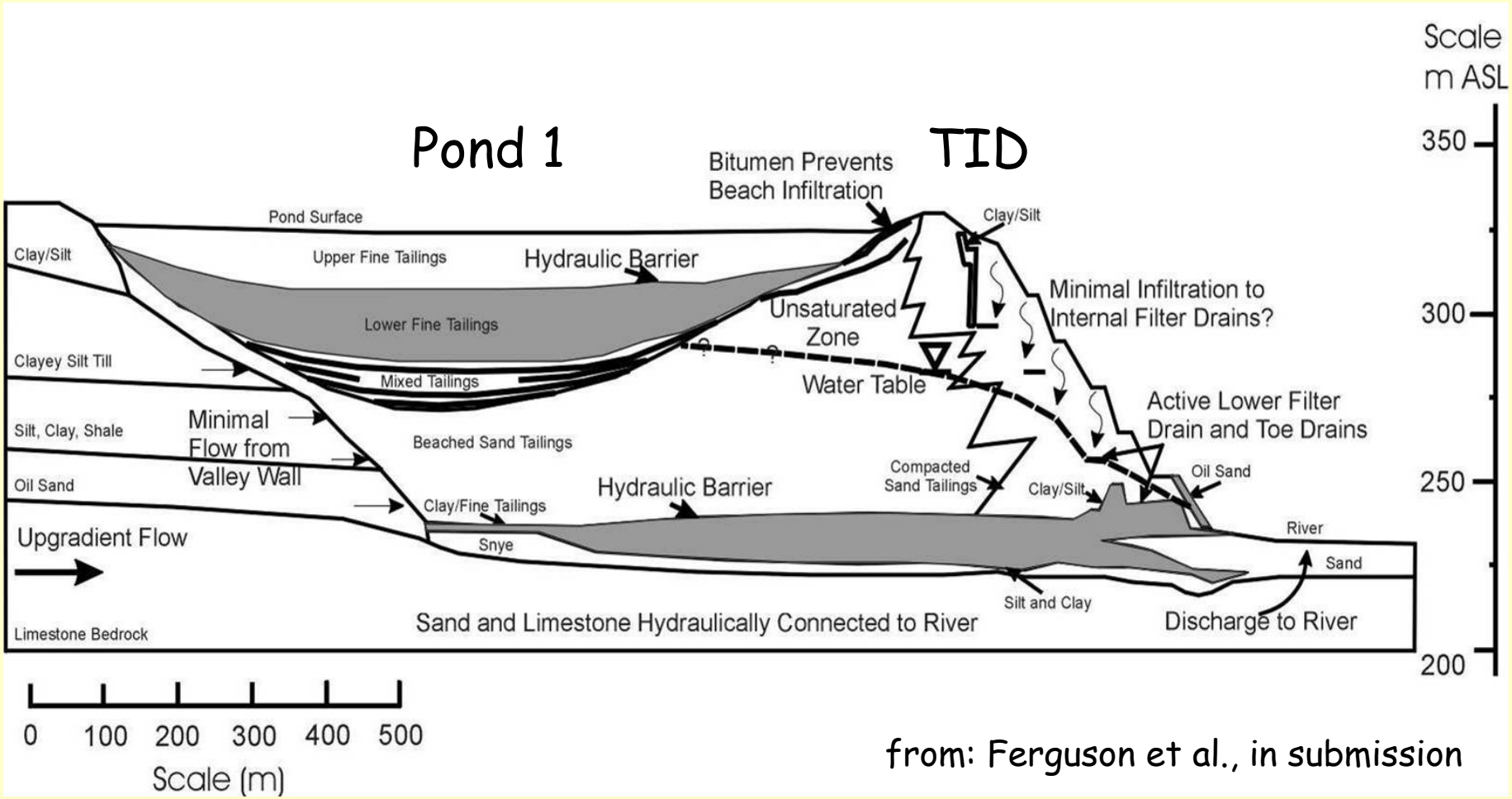
Seepage from Tar Island Dyke

- Initial tailings pond, begun in early 1960's
- Current pond is perched, as fines and tar line the pond
- Seepage to Athabasca River is acknowledged
- No impacts to the aquatic ecosystem have been found
- Ongoing seepage should decline, even without reclamation of the pond

Seepage from Tar Island Dyke

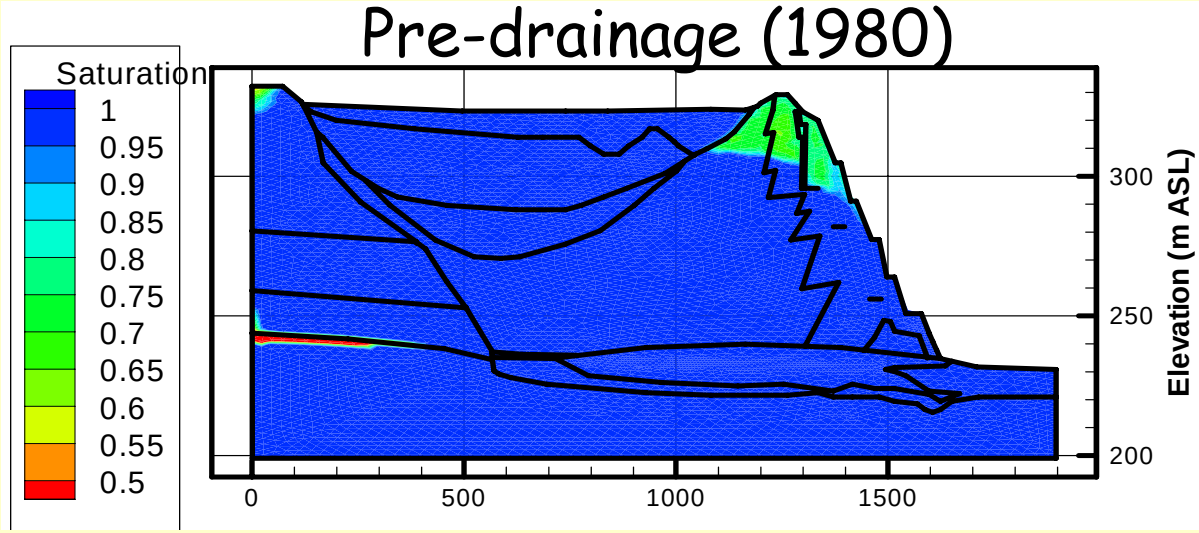
Seepage from Tar Island Dyke

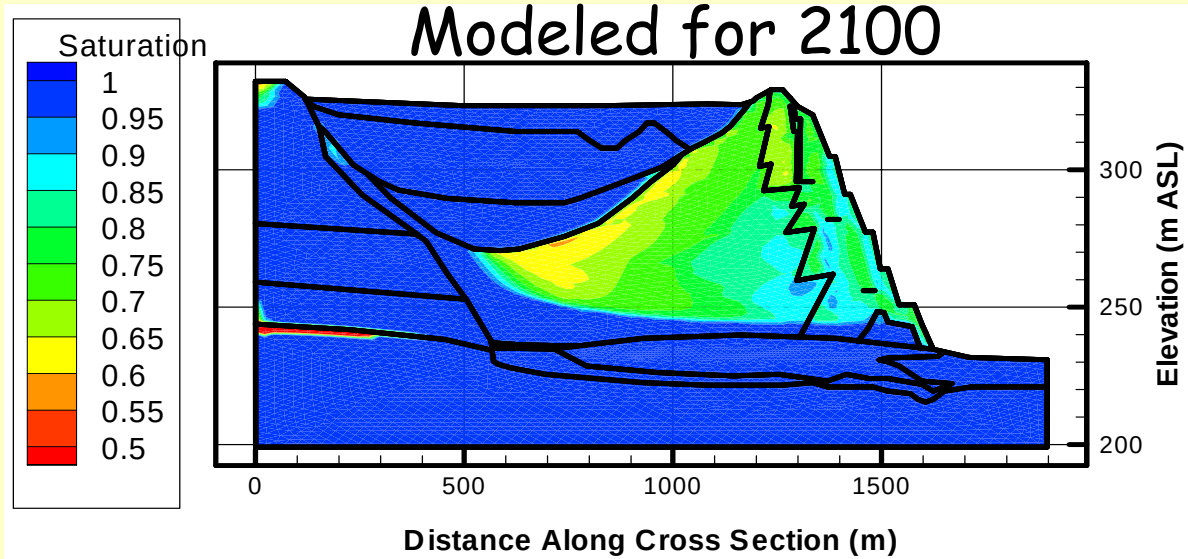
- Conceptual model



from: Ferguson et al., in submission

Seepage from Tar Island Dyke





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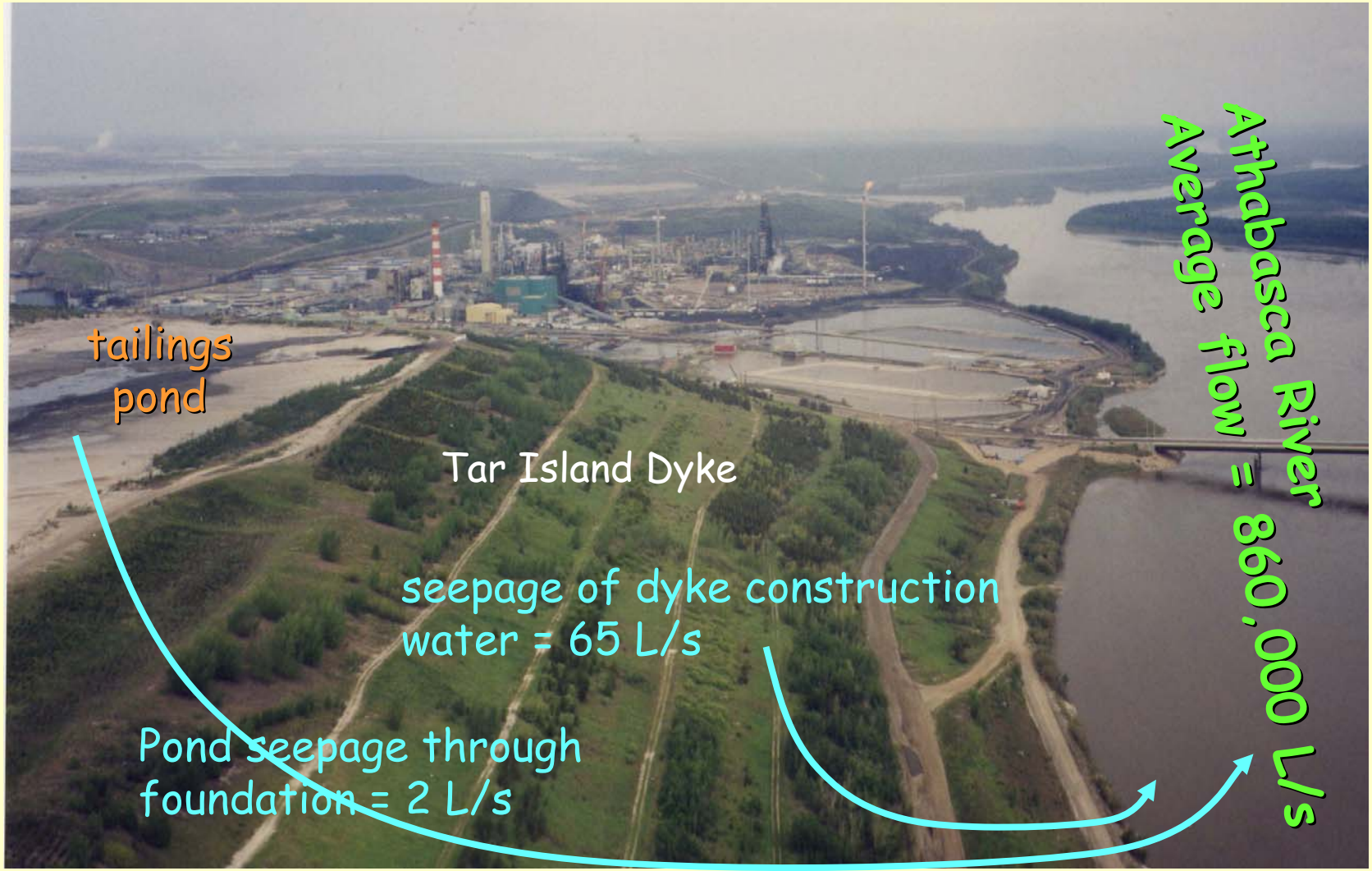
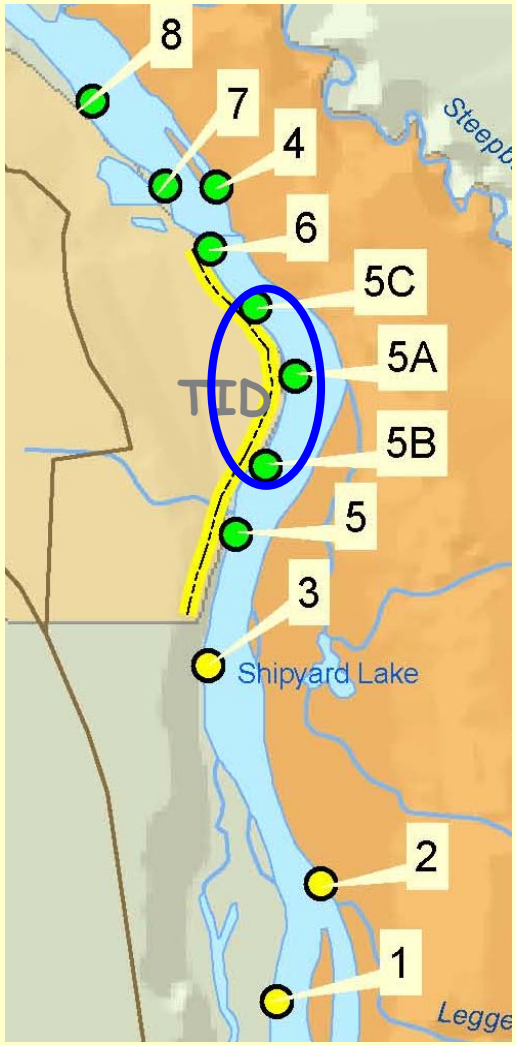


Seepage from Tar Island Dyke



- Groundwater under/adjacent to TID

  NAs: 1 - 60 mg/L (PA water > 40 mg/L)

  NH_4^+: 0.4 – 4.7 mg N/L (PA water > 10 mg N/L)

  - River sediment pore water

    NAs: ~ bkgd, except 9 mg/L @ 5A

    NH_4^+: > CCME (1 -2 mg N/L) @ 5, 5C, 6

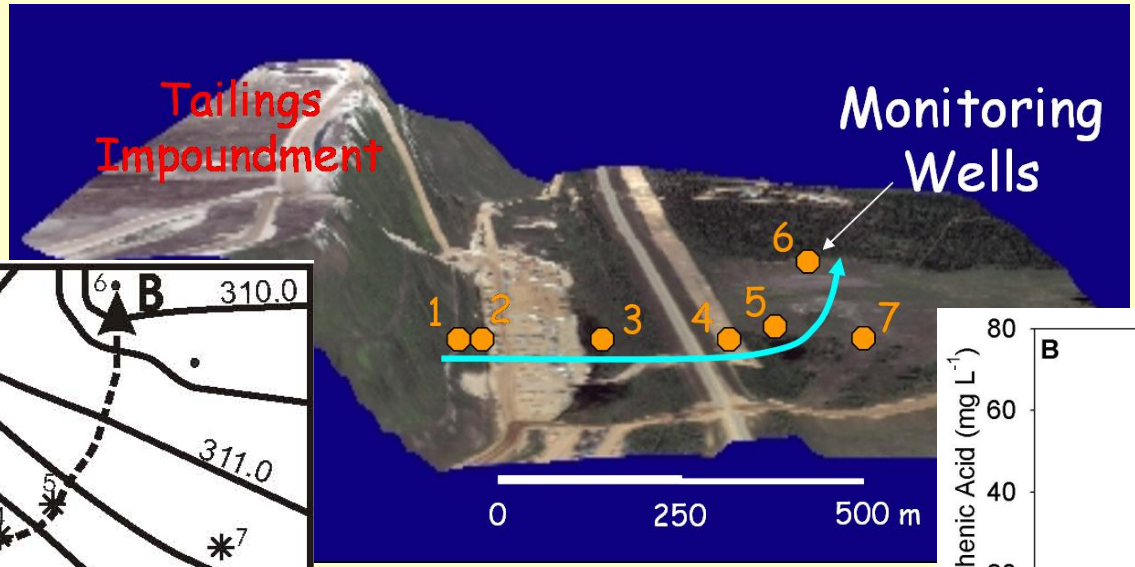
  - Benthic invertebrate community

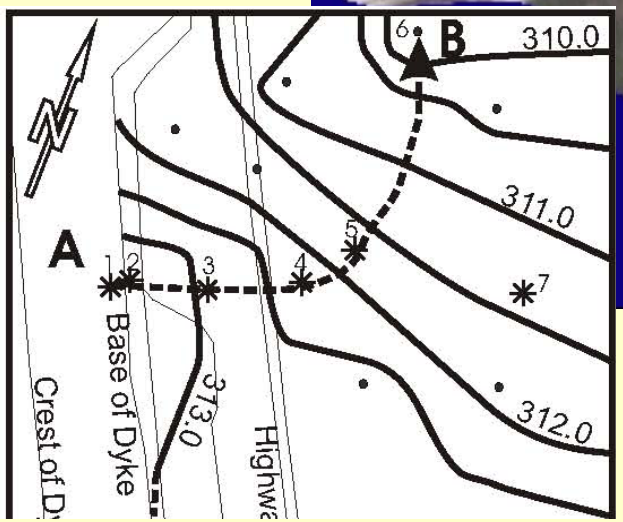
    Larval chironomid midges & tolerant oligochaete worms dominate.

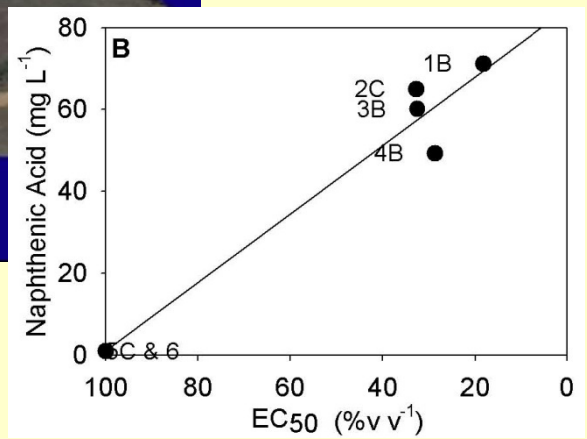
    Similar density, richness, diversity to upstream communities

NAs at a Different Site

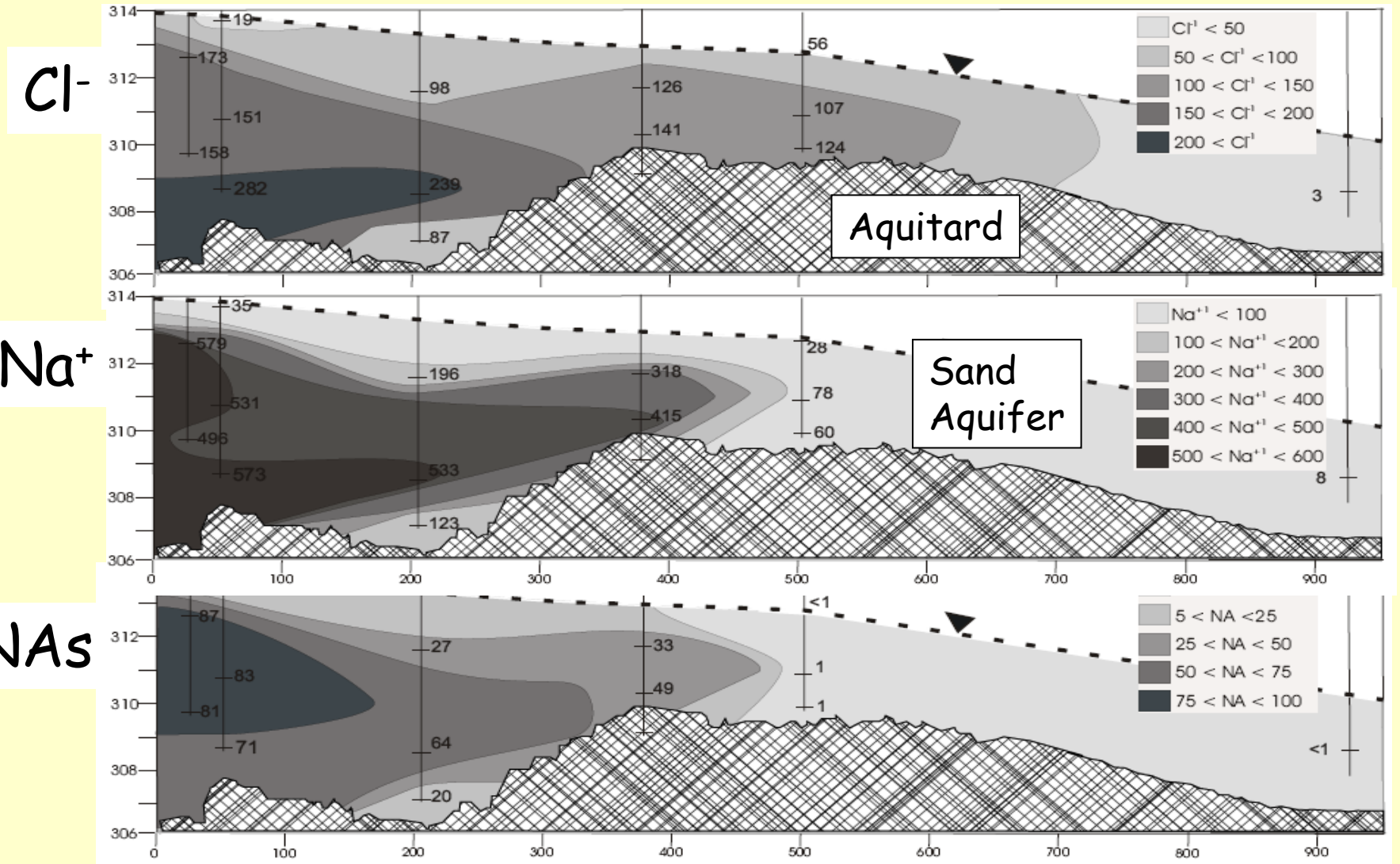
- Shallow sand aquifer adjacent to a tailings pond – process-affected water has escaped seepage collection







NAs in a Shallow Sand Aquifer



IPEC November, 2007

NAs in a Shallow Sand Aquifer

- Natural attenuation of Naphthenic Acids:
  - Mobile (perhaps some retardation, as Na^+)
  - Persistent under mildly anoxic aquifer conditions
  - Little attenuation capacity evident

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- Will the seepage of process-affected water become a major problem?
  - improved tailings processing should minimize future tailings pond needs
  - On the other hand, new mines are encountering more shallow sand and so potential for impacts remains
- Ongoing research:
  - controlled release NAs studies underway
  - lab studies of NA biodegradation (U of Alberta)
  - ISCO lab and field trials planned

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- Research Support