

# **Research on bioremediation of petroleum hydrocarbons in groundwater in cold climates: Limitations or opportunities?**

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# Acronyms:

**CORONA** = Consortium for Research on Natural Attenuation

**EC** = Environment Canada

**INAC** = Indian & Northern Affairs Canada

**NWRI** = National Water Research Institute

**NWT** = Northwest Territories

**PERD** = federal Program for Energy Research and Development

**U of A** = University of Alberta

**WCSB** = Western Canada Sedimentary Basin



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# Acronyms:

**LNAPL** = light nonaqueous phase liquid

**MNA** = monitored natural attenuation

**PHCs** = petroleum hydrocarbons

**VFAs** = volatile fatty acids (acetate, butyrate, propionate)



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# Acknowledgments

Main funding: PERD, EC, INAC

Coordination with CORONA at Alberta sites (2002-2004)

Collaboration with University of Calgary (isotope and microbial analyses)



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# Acknowledgments

## Field assistance:

John Voralek, Charles Talbot, Ross Neureuther (NWRI)  
Ron Breadmore, Rob Duschene (INAC)  
Kim McLeish (Komex International Ltd.)  
Patricia Coyne (NWT Dept. Transportation)

## Laboratory analyses:

Renu Grewal, Susan Brown, Helena Steer (NWRI)  
Maxxam Analytics (Alberta sites)  
Jela Burkas (U of A)



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# Topics covered

- ↗ Background information
- ↗ Study #1 - Sulfate reduction / WCSB
  - ↗ NWRI and Komex
- ↗ Study #2: Northern spills
  - ↗ NWRI and U of A



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# Bioremediation of PHCs: Trends since early 1990s

- ↗ Rapid global expansion of applications
  - ↗ Thousands in Canada
- ↗ Has become a “preferred” approach
  - ↗ Active and passive technologies
  - ↗ in-situ and ex-situ



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# Bioremediation of PHCs in groundwater at “warm” sites:

- ↗ Various electron acceptors linked to anaerobic microbial degradation of PHCs in groundwater
  - ↗  $O_2$ ,  $Fe^{3+}$ ,  $Mn^{3+,4+}$ , sulfate, nitrate
- ↗ Strains of microorganisms, consortia
- ↗ Enhanced in-situ bioremediation
- ↗ Intrinsic bioremediation (MNA)



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# Review: Bioremediation of PHCs in soil/groundwater at cold climate sites (NWRI and U of A, 2005)

- ↗ List of successful **soil** applications growing
- ↗ Biopiles and landfarms most common
- ↗ Often used for fuel spills
- ↗ Cold climate is generally not a major deterrent; documented biodegradation at < 10°C in a number of sites, lab studies
- ↗ **groundwater** research/applications rare



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# Gap in knowledge about bioremediation of PHCs in groundwater

- ↗ How applicable at colder sites?
  - ↗ upstream oil and gas sites in WCSB
  - ↗ Arctic Canada / permafrost
  - ↗ fractured rock settings



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# **Study #1: Role of sulfate reduction in PHC plumes in groundwater, WCSB (NWRI & Komex)**

2002-05



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Groundwater in WCSB:  
Temperatures  $\sim$  5-10°C  
Sulfate concentrations often  
 $>1,000 \text{ mg/L}$   
= most abundant potential  
electron acceptor



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# “D” Site, Alberta

PHC-contaminated  
profile



Reference  
profile



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Typical existing  
well at this site

Injection  
well



Sediment  
samples

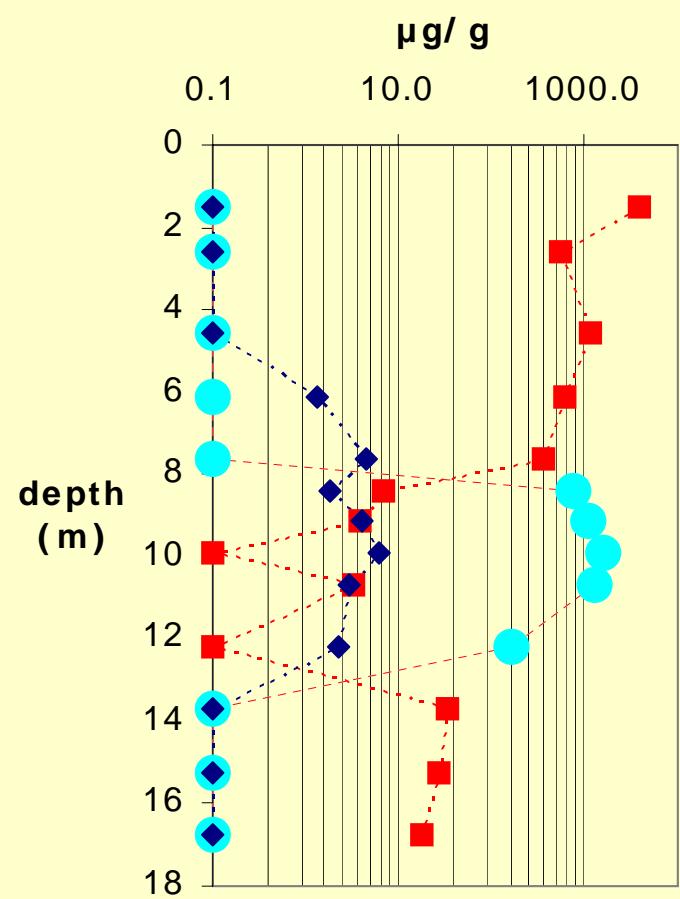
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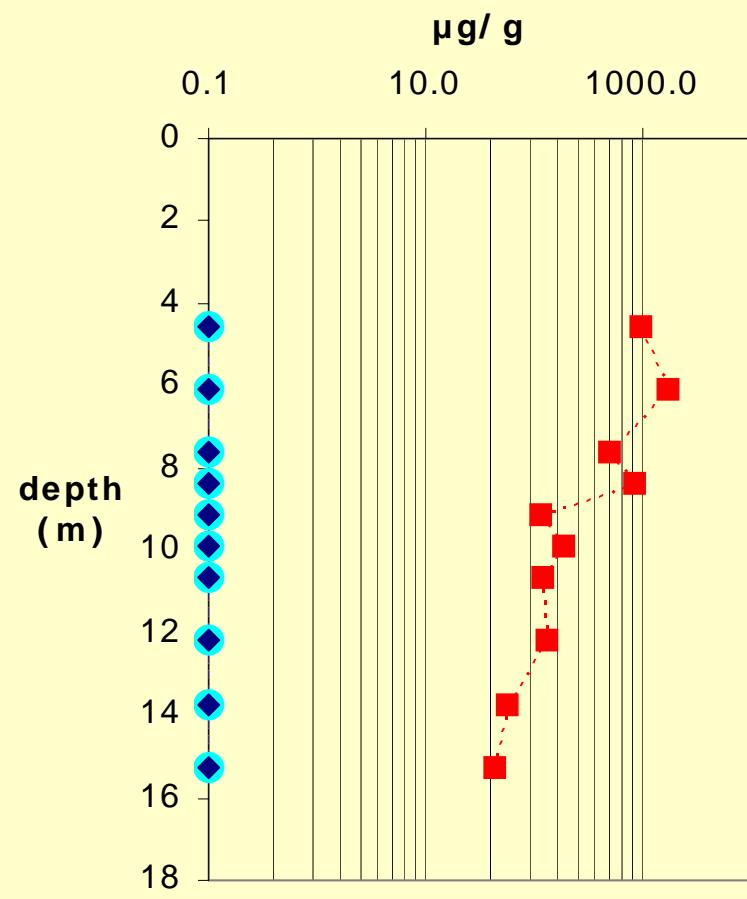
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# Contaminated profile



## Reference profile

----- ■ ----- Sulfate-S

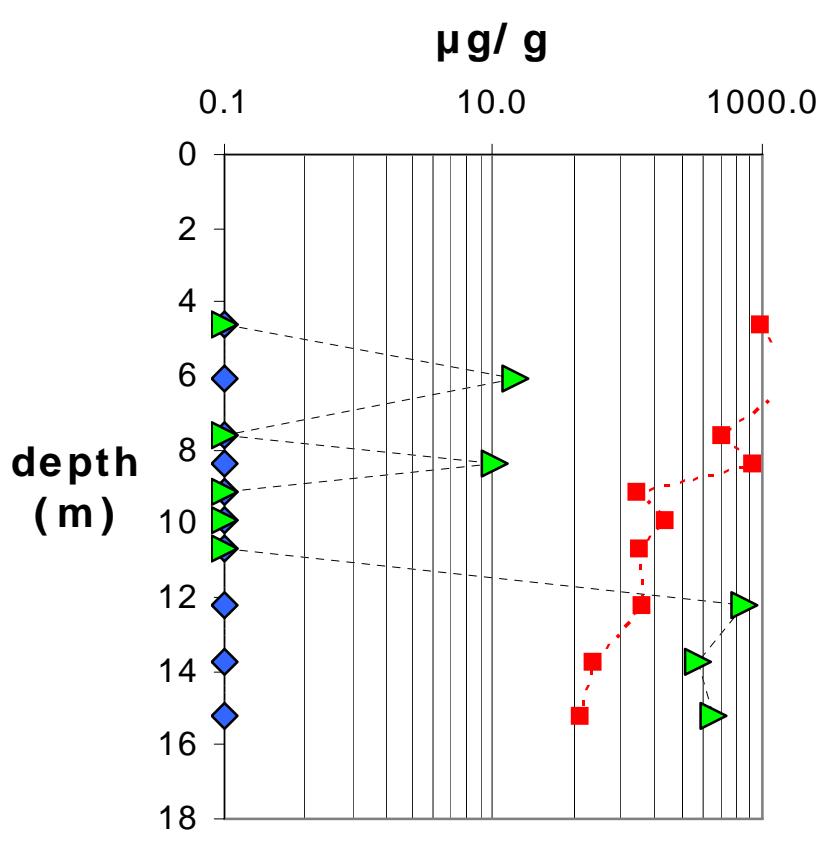
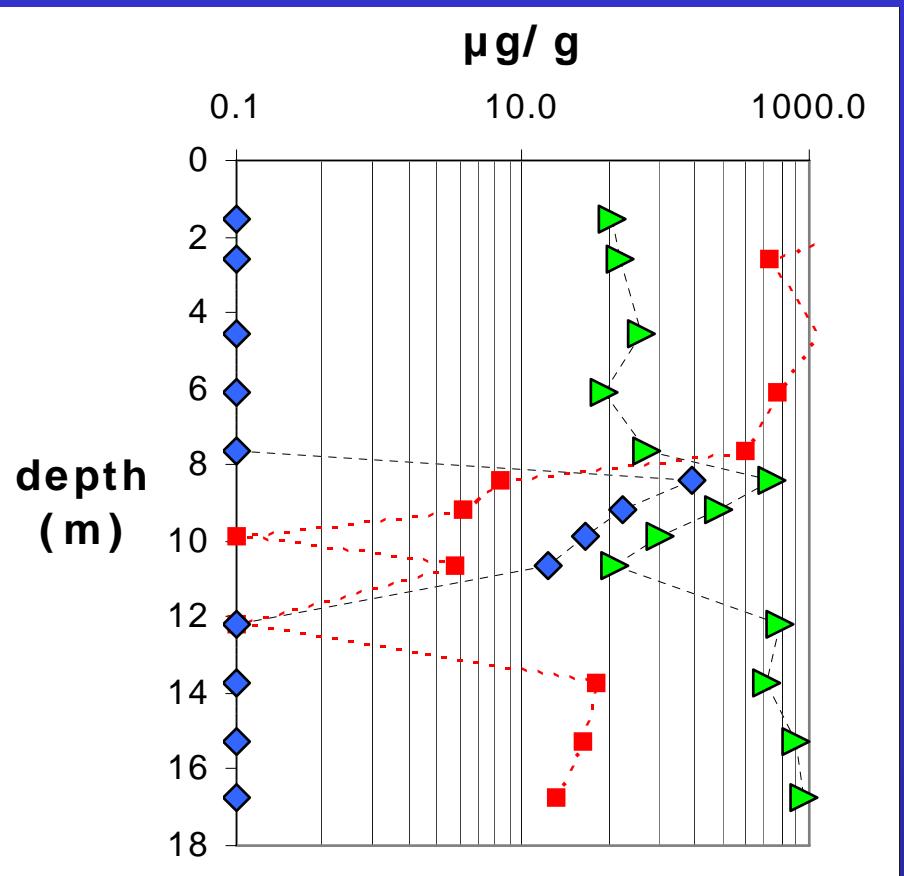
acetate C

## C6-C10 hydrocarbons

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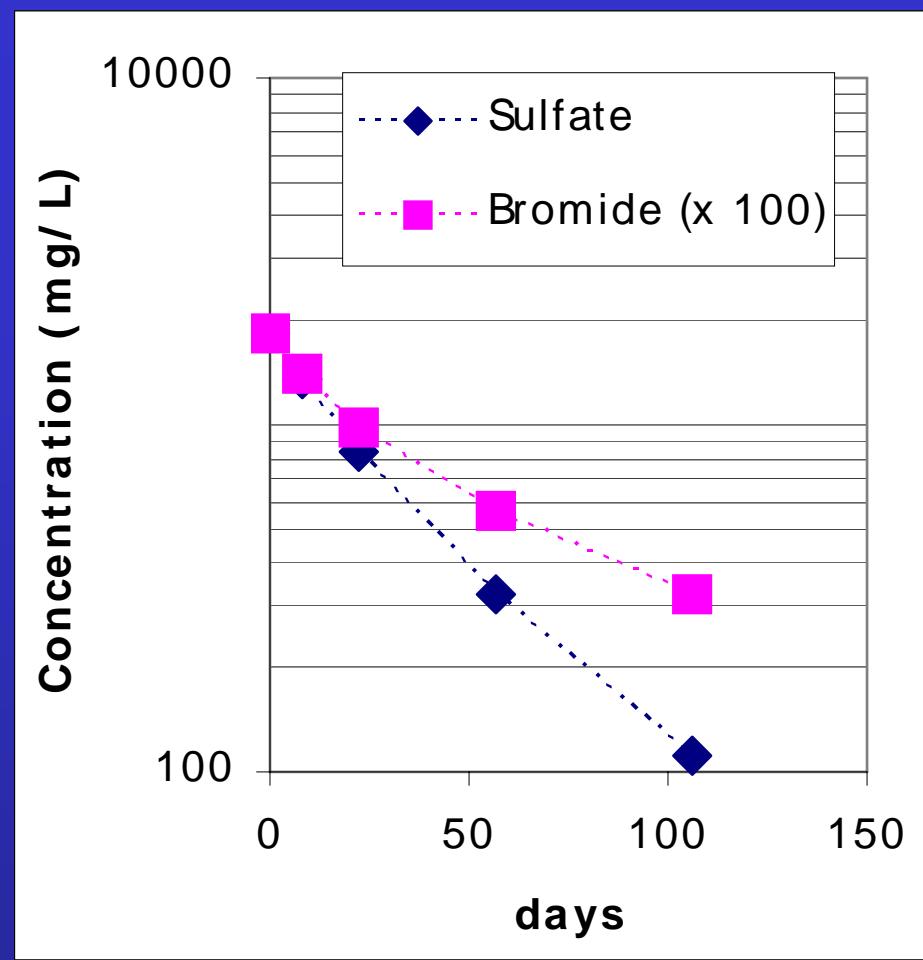


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- Sulfate-S
- ◆ Acid Vol. S
- ▲ Cr- Red. S





Overall sulfate reduction  
rate ~ 5 mg/L per day



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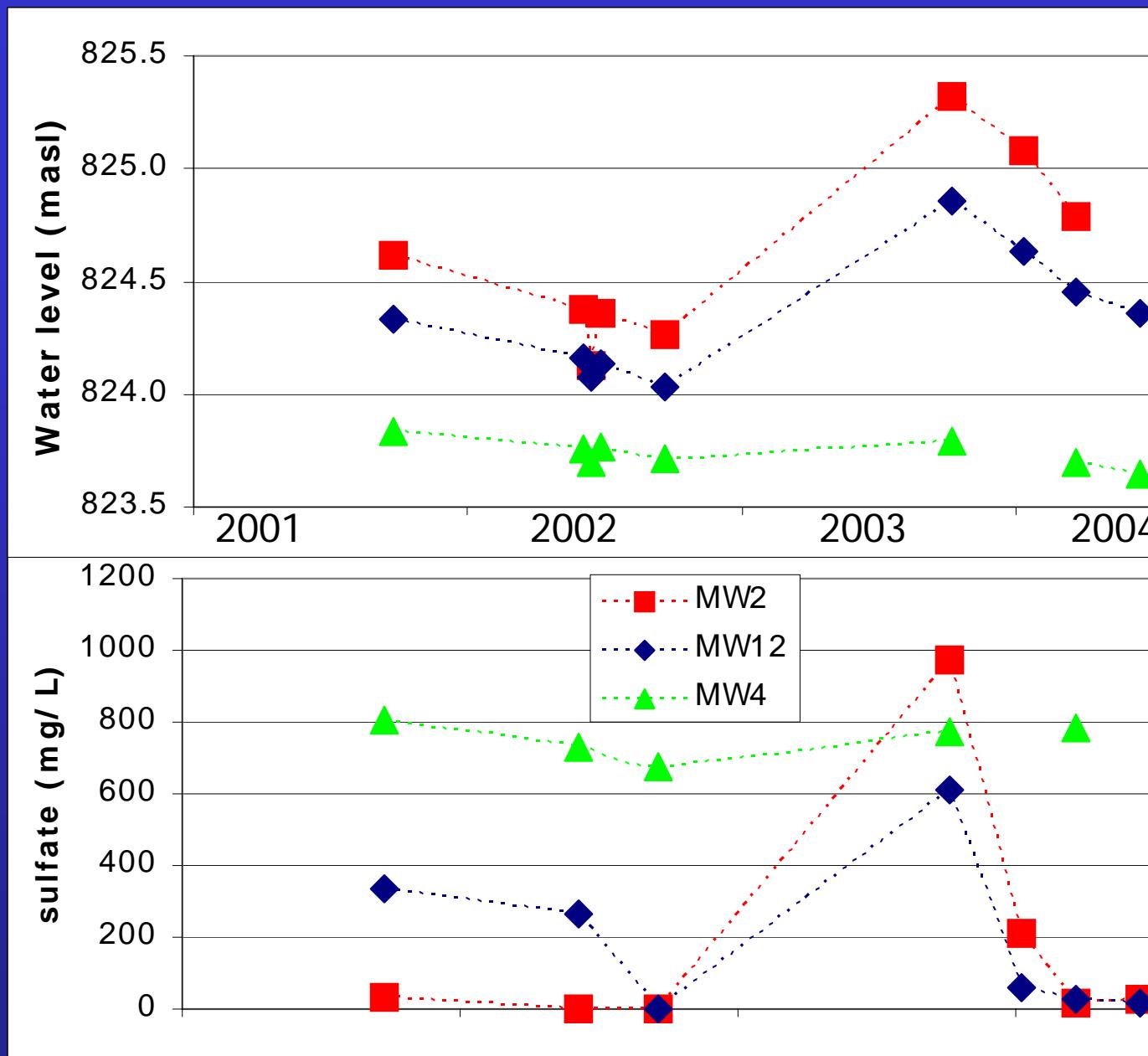




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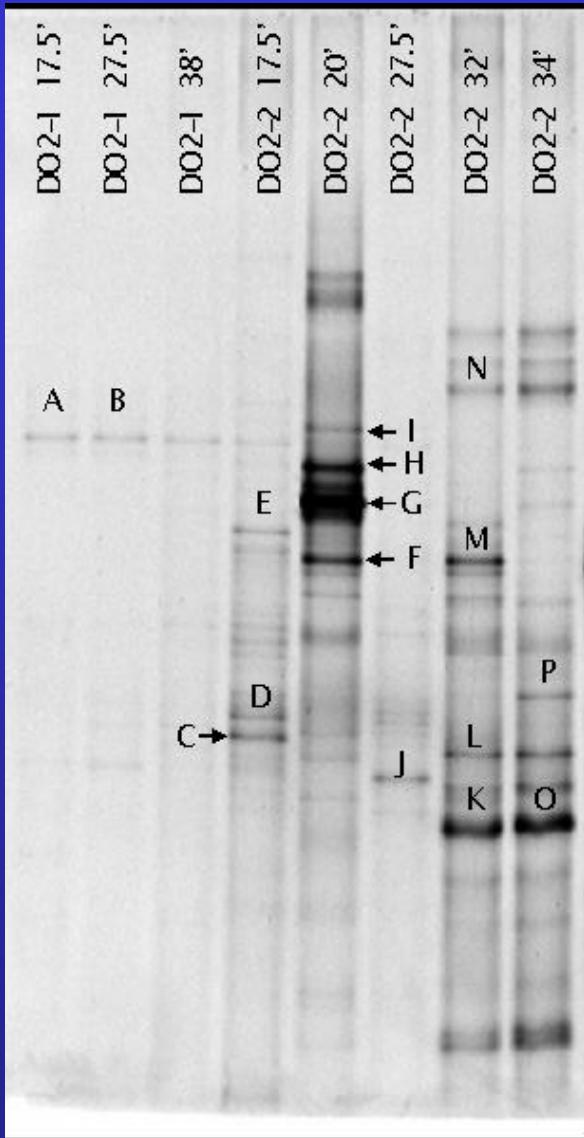




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40%



## Extraction / Analysis of DNA from Sediment Samples

- DGGE profiles of eubacterial 16S rDNA fragments
- Indicated sulfate reducing bacteria (*Desulfosporosinus spp.*) and other anaerobes (e.g. *Geobacter*)



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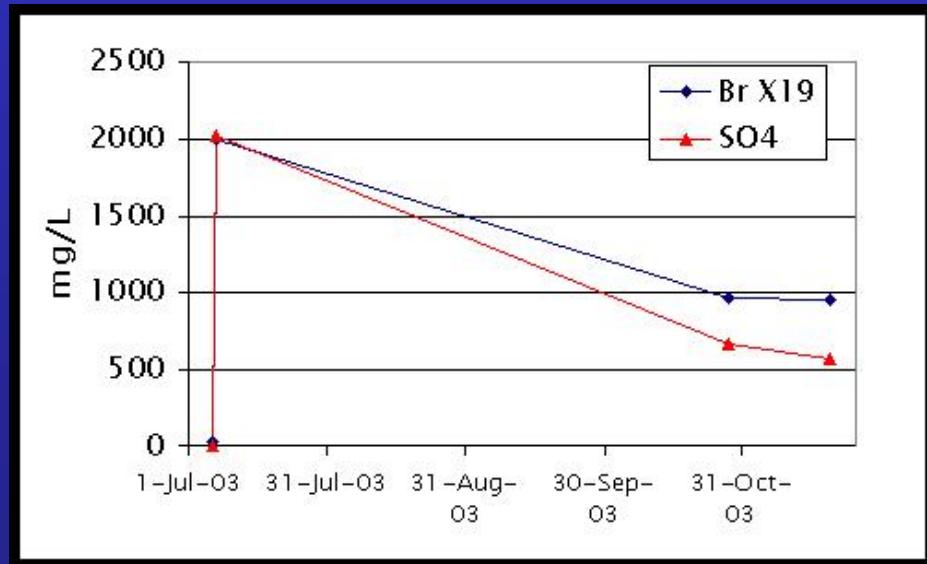




# "E" Site, Alberta

## Injection test

### July-November, 2003



inferred sulfate  
reduction rate:  
~5 mg/L per day



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# Conclusions: Study #1

- ↗ Significant rate of sulfate reduction in PHC plumes in groundwater in WCSB
- ↗ Low temperatures (5-10°C) don't impede in-situ bioremediation
- ↗ Cold-adapted bacteria present
- ↗ Seasonal infiltration of sulfate to water table important
- ↗ Promise for active/passive bioremediation approaches

Journal publications in submission/prep.



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# **Study #2: Fate of petroleum spills, northern environments (NWRI & U of A) 2004-2008**

**Unique, pioneering study of fate & behaviour of  
PHCs in groundwater at spill sites in Arctic  
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- fractured rock, permafrost
- terrace deposits, Mackenzie pipeline route



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Base Map: INAC



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# Spill investigation: Colomac mine

Fate/transport/degradation of PHCs in “active” layer  
(seasonal thaw), fractured rock above permafrost



Photo: I. Holubec Consulting Inc.



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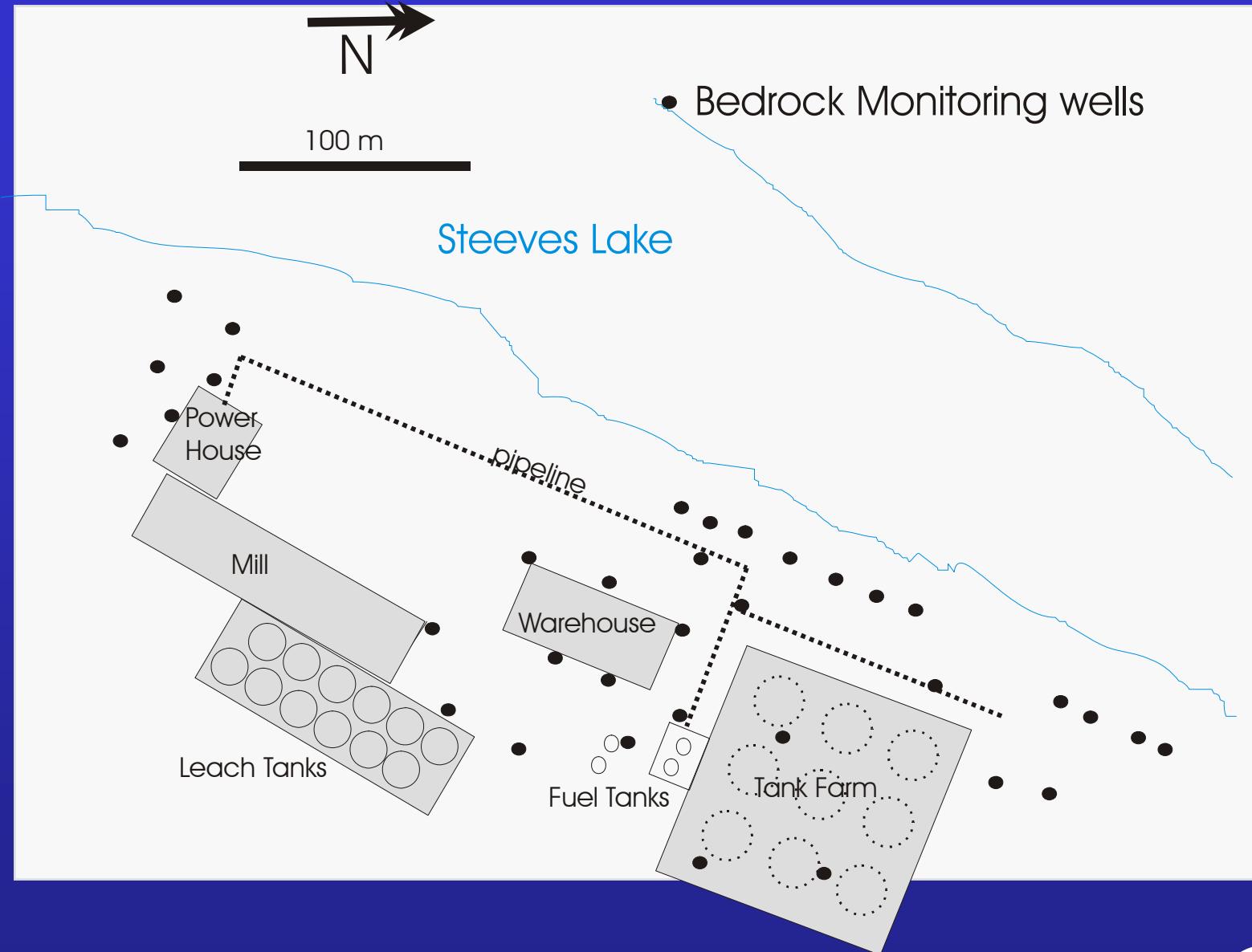
- Address large gaps in understanding of behavior/fate of petroleum spills in fractured rock/permafrost setting.



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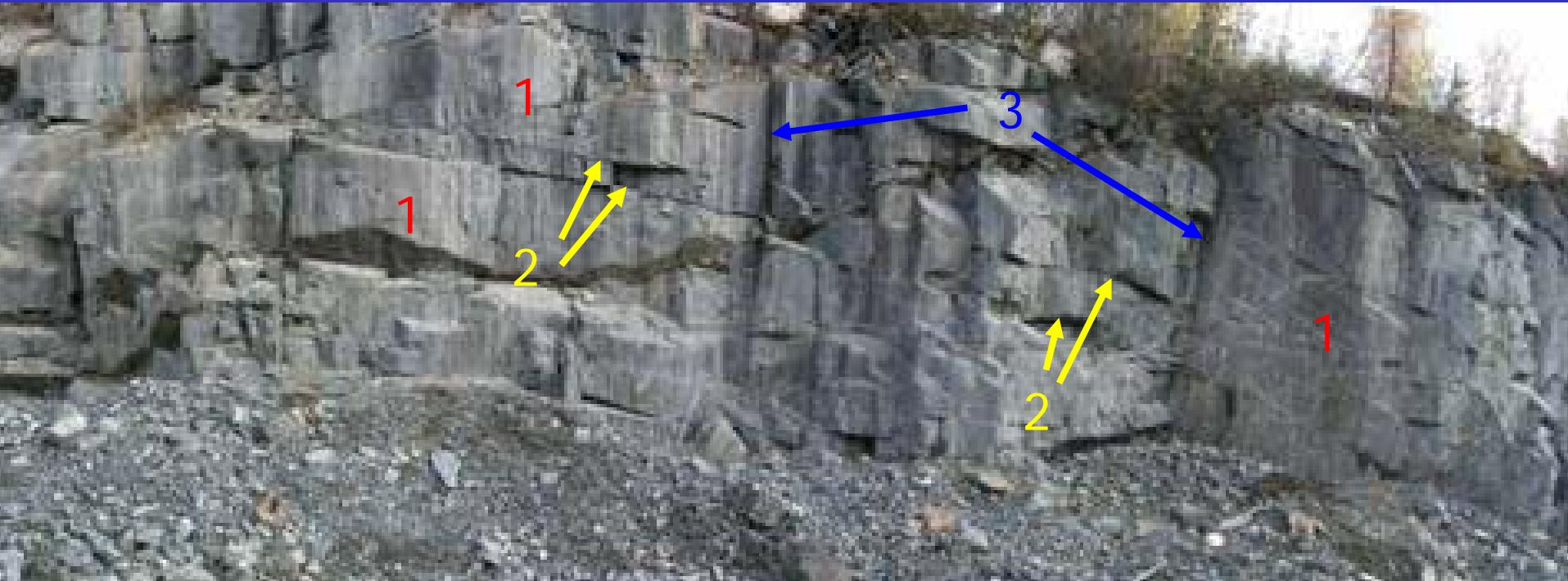


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# Bedrock: metamorphosed sediments

- meta-greywacke, meta-argillite



## 3 main sets of fractures

1. Sub-vertical, parallel to foliation, includes “slaty cleavage”
2. Sub-horizontal

Sub-vertical, ~ normal to 1,2



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Hydraulic testing, August 2005



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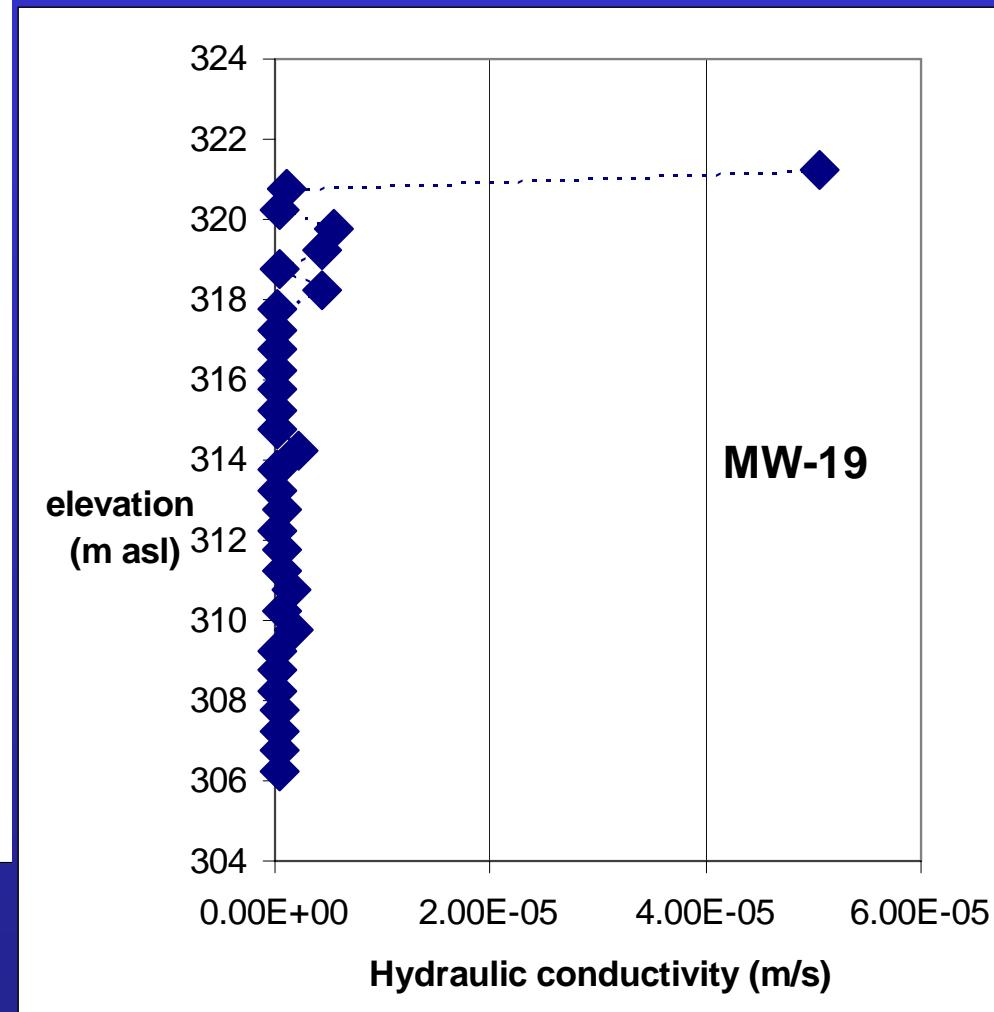
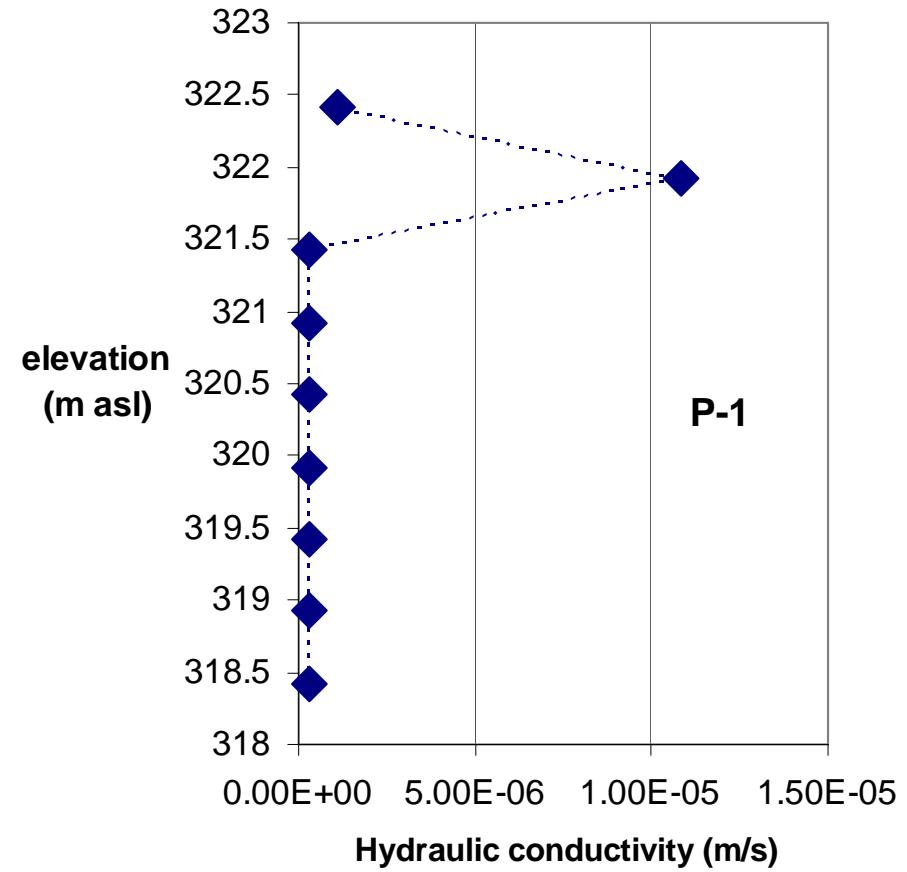


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# Preliminary hydraulic test results:



# Preliminary sampling results: Aug/05

- Typical groundwater temperatures: 1-4°C
- Wide hydrocarbon distribution (LNAPL, dissolved)
- VFAs present (propionate, butyrate)
- Elevated iron, manganese, low O<sub>2</sub> (most < 0.5 mg/L)



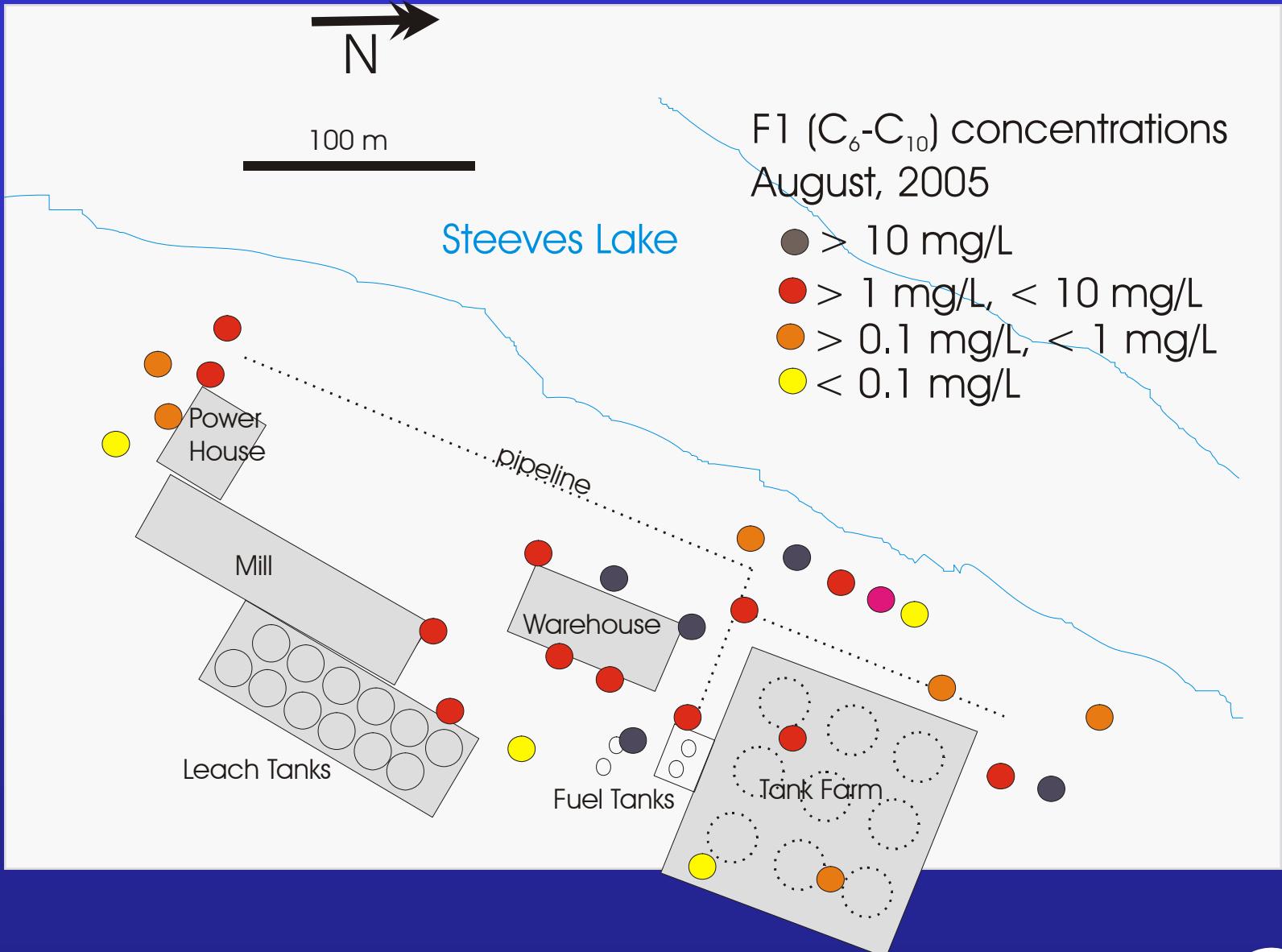
near neutral pH



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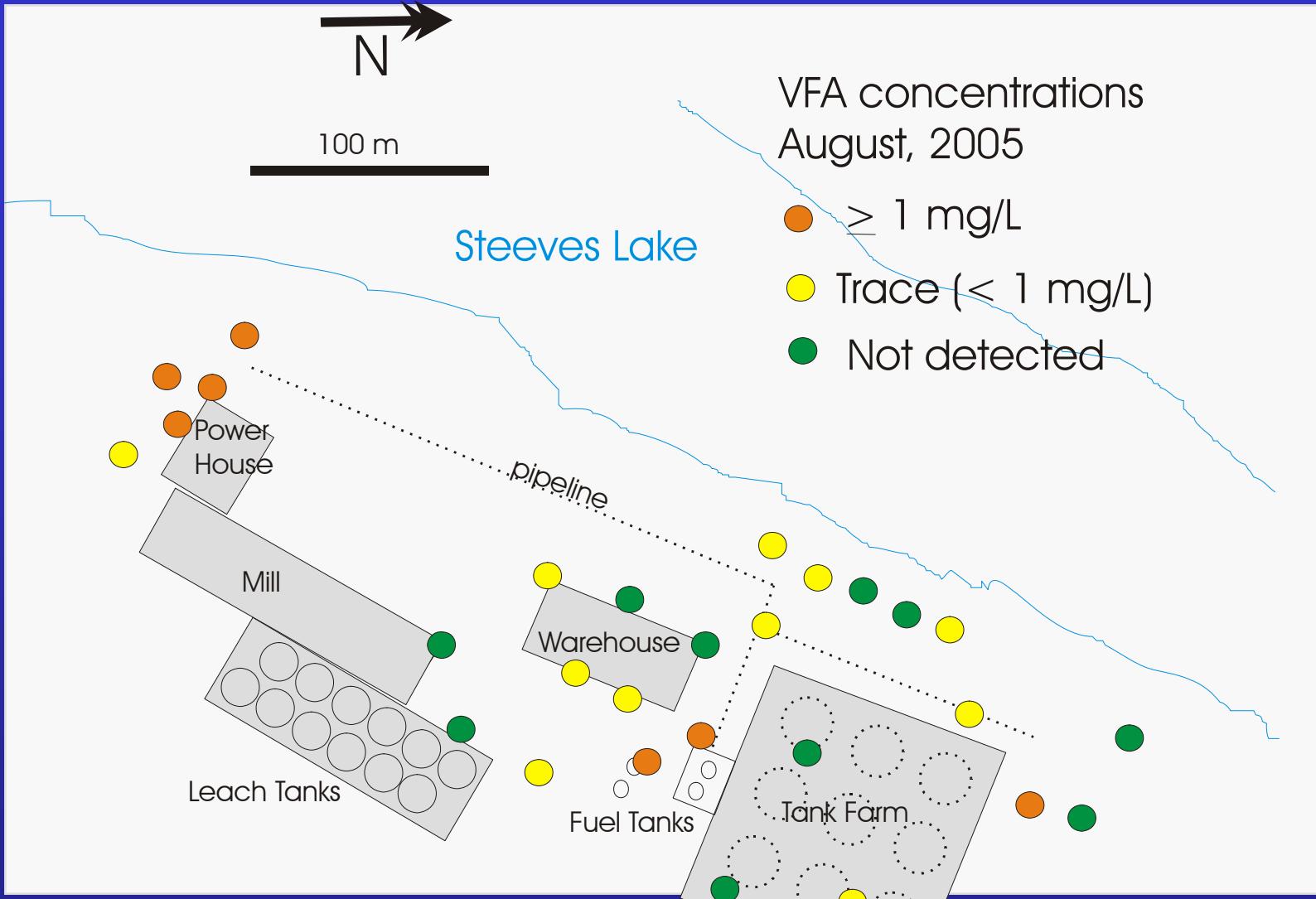


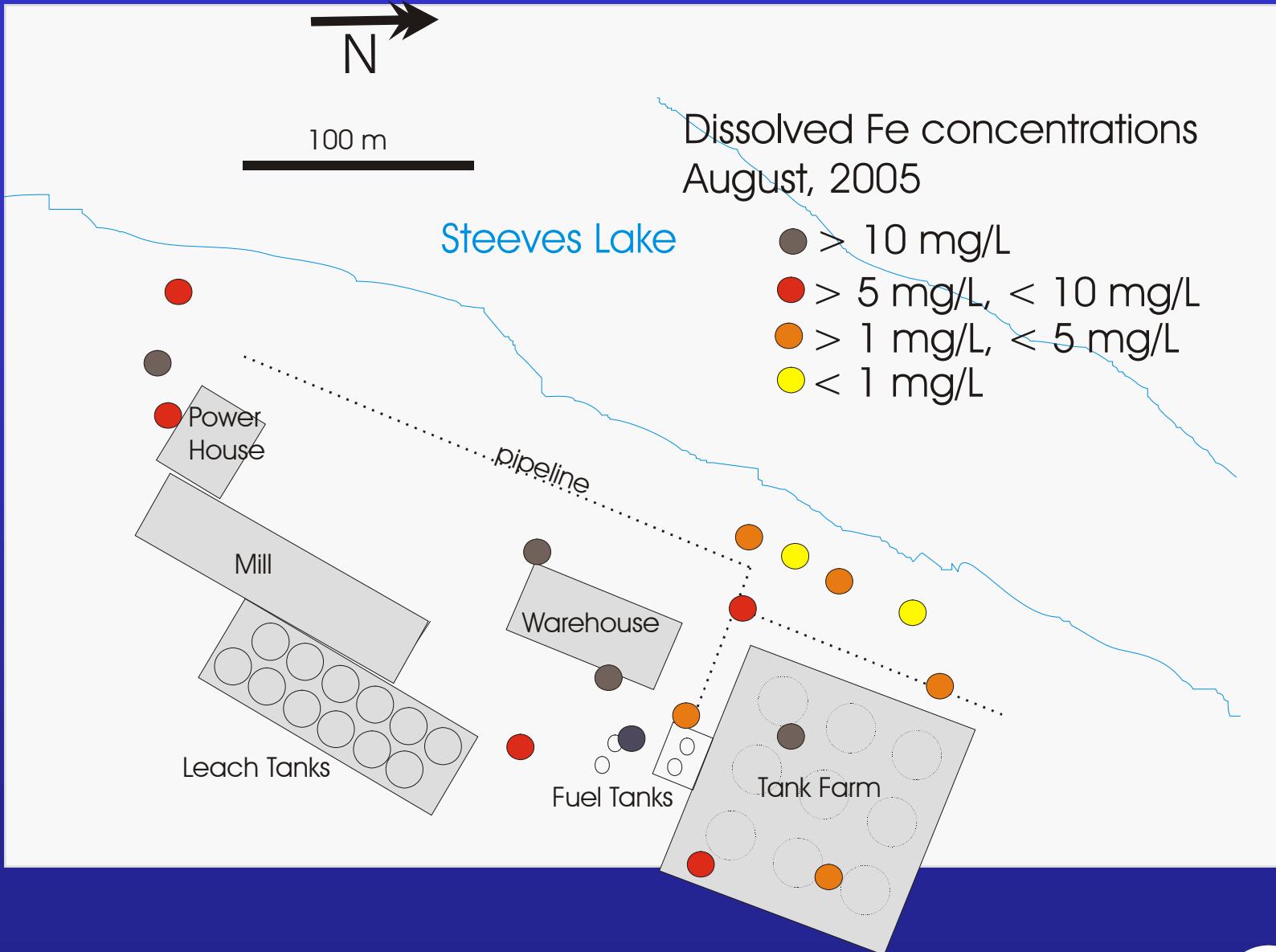


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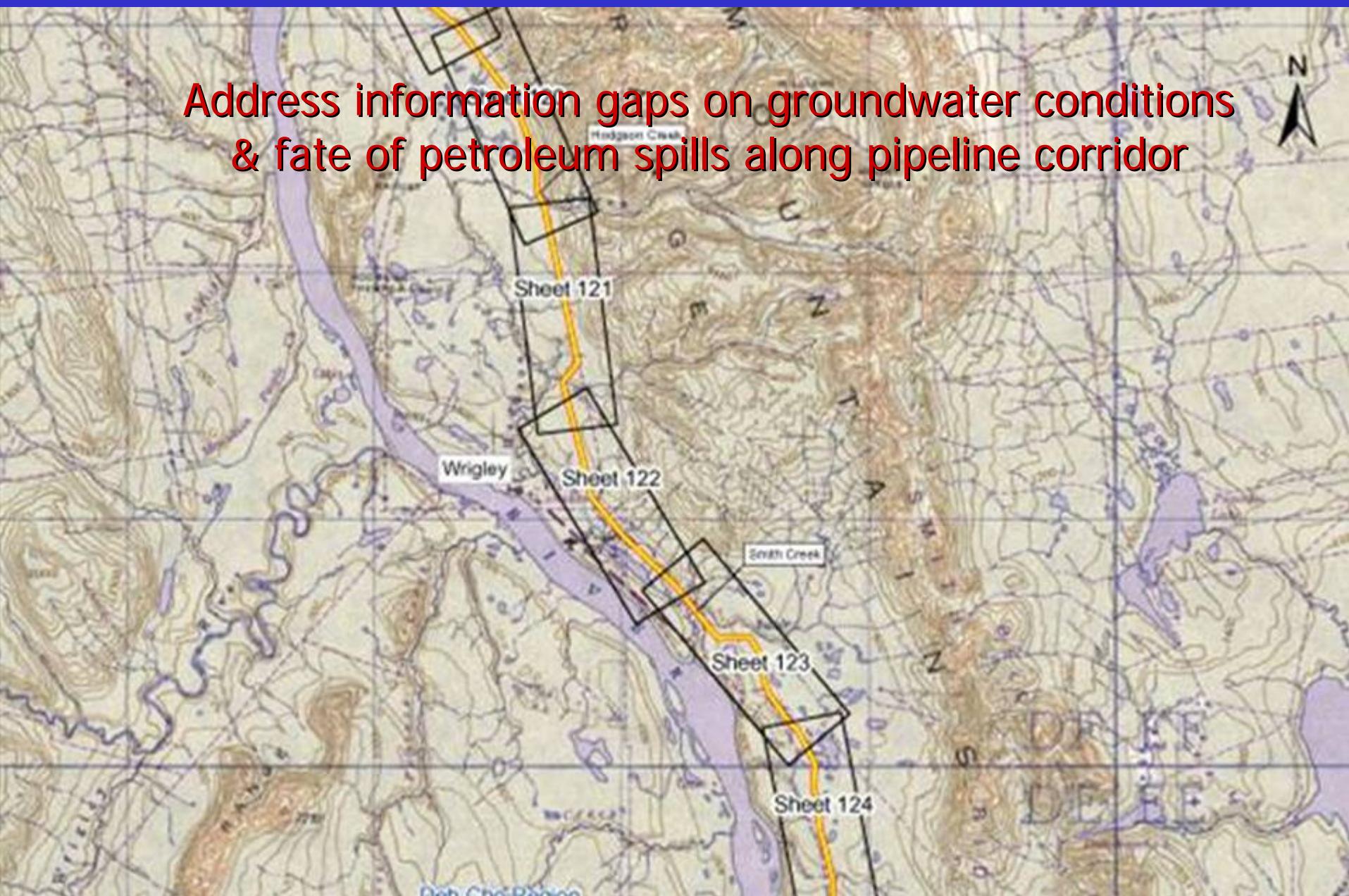






# Spill investigation: Wrigley airport

Address information gaps on groundwater conditions  
& fate of petroleum spills along pipeline corridor





1948



Airport established in 1942 to service US Army's Canol pipeline

Taken over by Canadian govt. in mid-40's

Currently managed by NWT Dept. Transportation



1957

Photo Source: NWT Archives



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## Terrain:

- On terrace of sandy silt along Mackenzie R.
- Underlain by thick sand and gravel unit
- Forest, muskeg, hot springs in area

## Groundwater:

- Community water supply
- deep, unfrozen year-round, at ~ 0-5°C



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Initial drilling program:  
October, 2005

Preliminary results:

- “channelized” flow in sand & gravel above clay
- PHC contamination



# Anticipated Research Outputs

1. Updated conceptual models
  - LNAPL & dissolved PHCs, fractured rocks with permafrost
  - dissolved plumes in groundwater, pipeline corridor
2. Evaluation of in-situ bioremediation potential
  - Appropriate for PHC in groundwater in north?
  - MNA feasible?



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