Characterizing a Diesel Contaminated Fractured Rock Aquifer

Development of a Nutrient Flushing Remediation Technique

KOMEX

Environment Canada Environnement Canada

Authors & Collaborators

Presenting Authors

- **Michael Brown & Stefan Humphries**

Komex International

- **D. Thomson, B. Reiter, J. Armstrong, etc.**

Universities of Calgary & Alberta

- **K. McLeish (Ph.D.)**
- **Dr. K. Biggar, Dr. J. Foght, K. Cross (M.Sc.)**

Environment Canada

- **P. Bacchus**

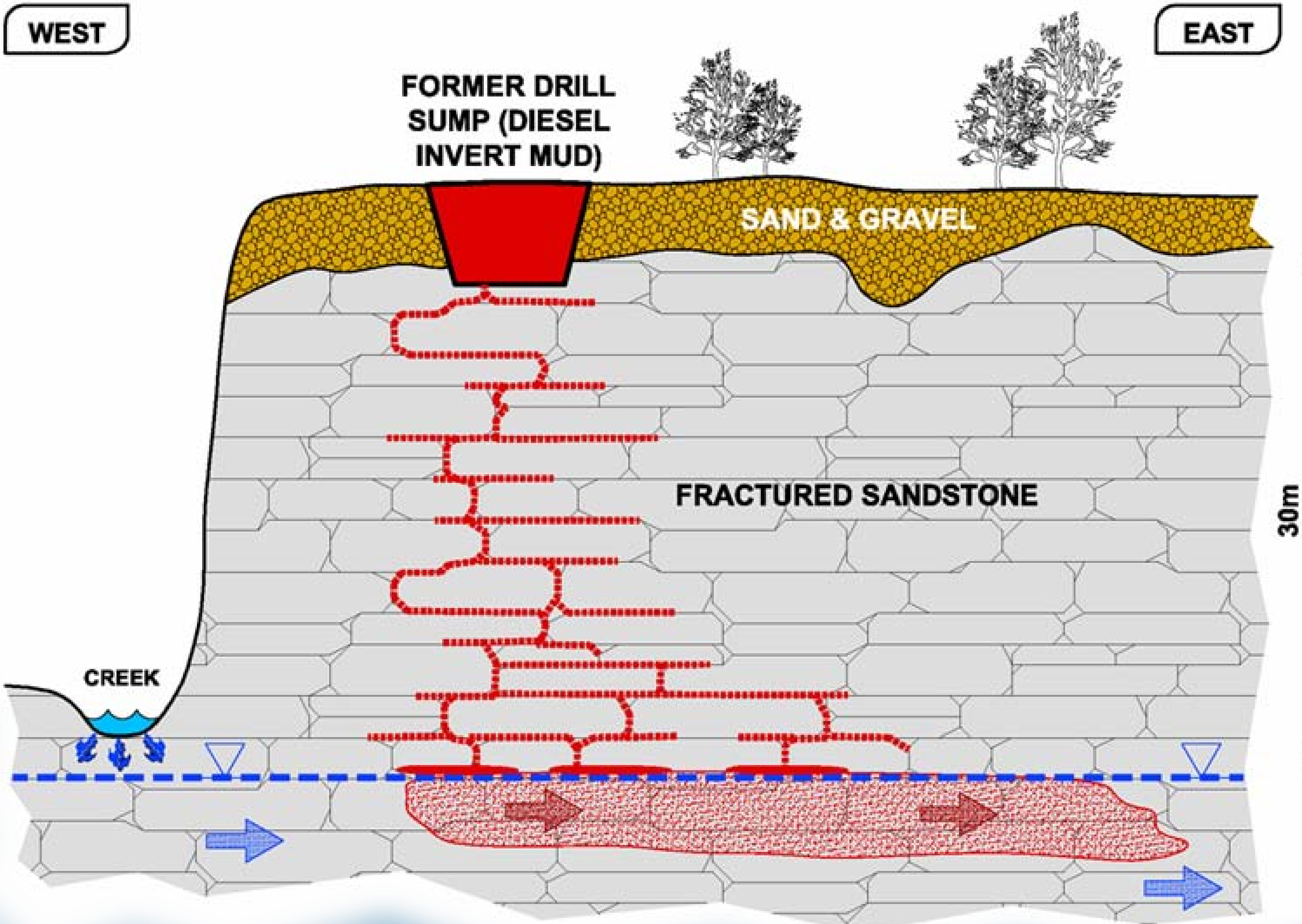
Site History

- 1982 - gas well drilled, diesel invert mud buried in sump
- 1996 - diesel impact in groundwater, excavate drilling sump
- 1996 to 2005 – site characterization, remedial pilot tests

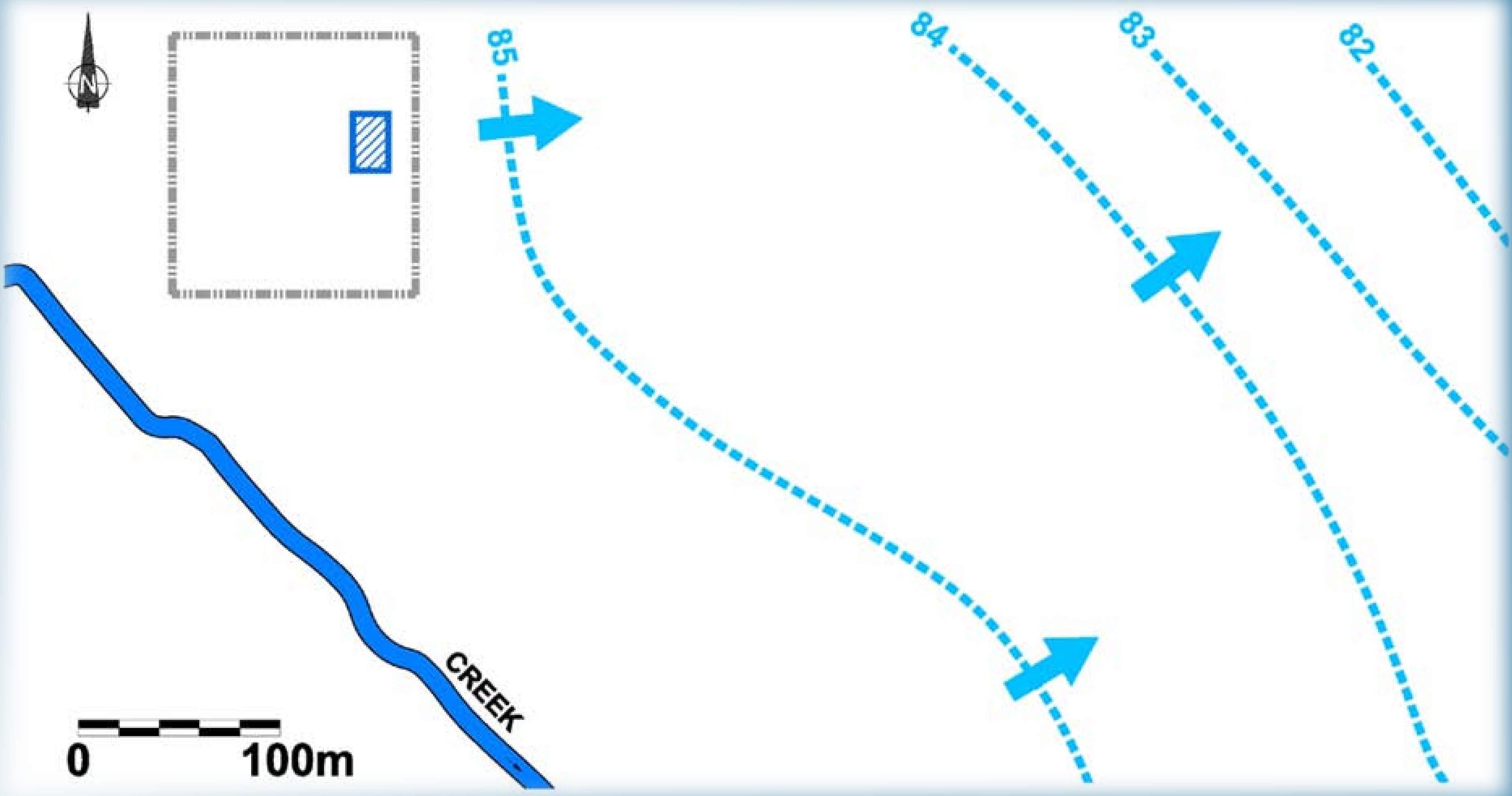
Monitoring Locations

- Monitoring & Characterization:
  - 50+ piezometers
  - 4 angled coreholes
  - 11 vertical coreholes
  - 12 nutrient flush pilot coreholes
  - Cross-gradient springs
  - Residential sampling in area (Domestic Use Aquifer)
  - 9 years of groundwater monitoring data (chemistry, fluid levels, pilot testing, etc.)

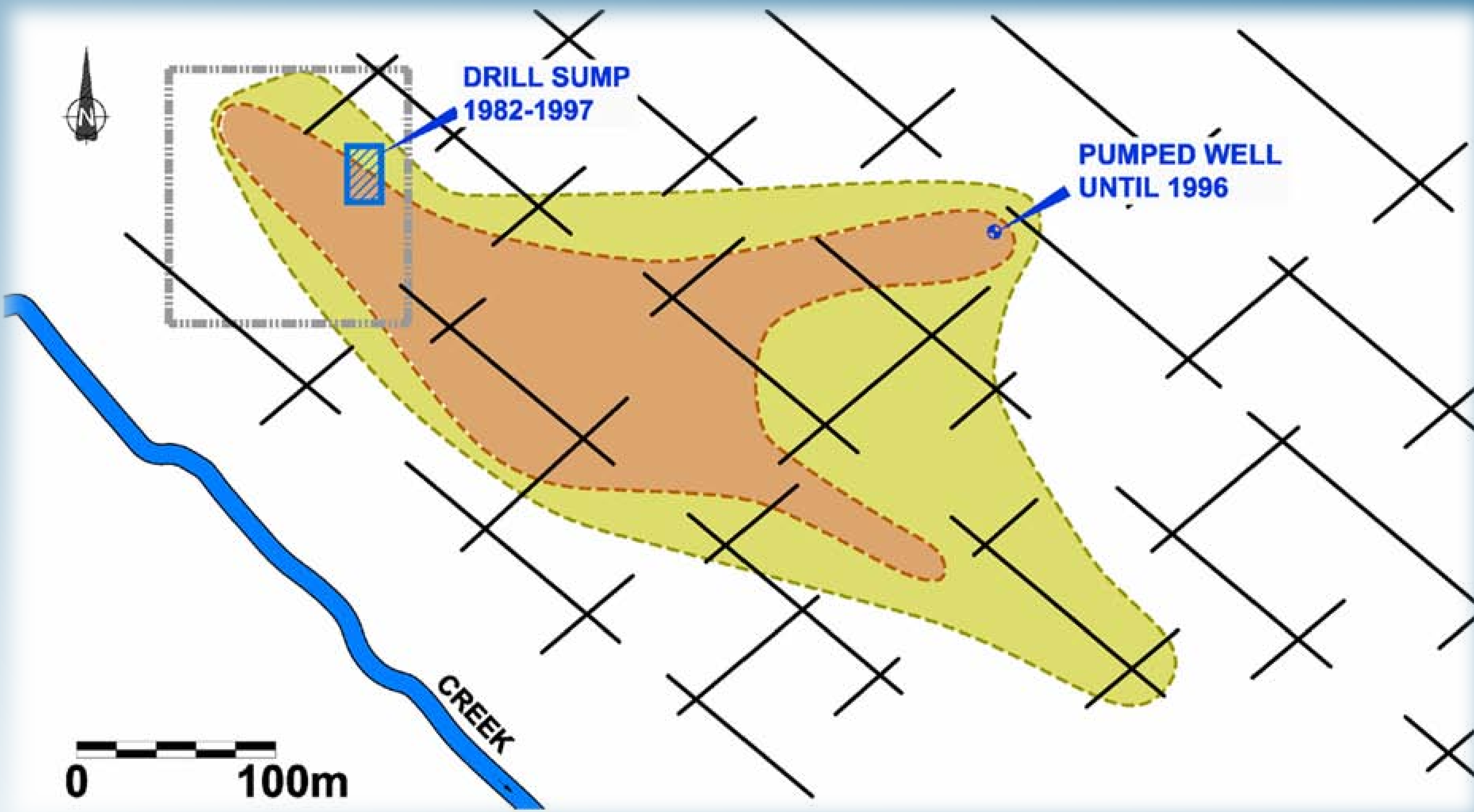
Conceptual Hydrogeology



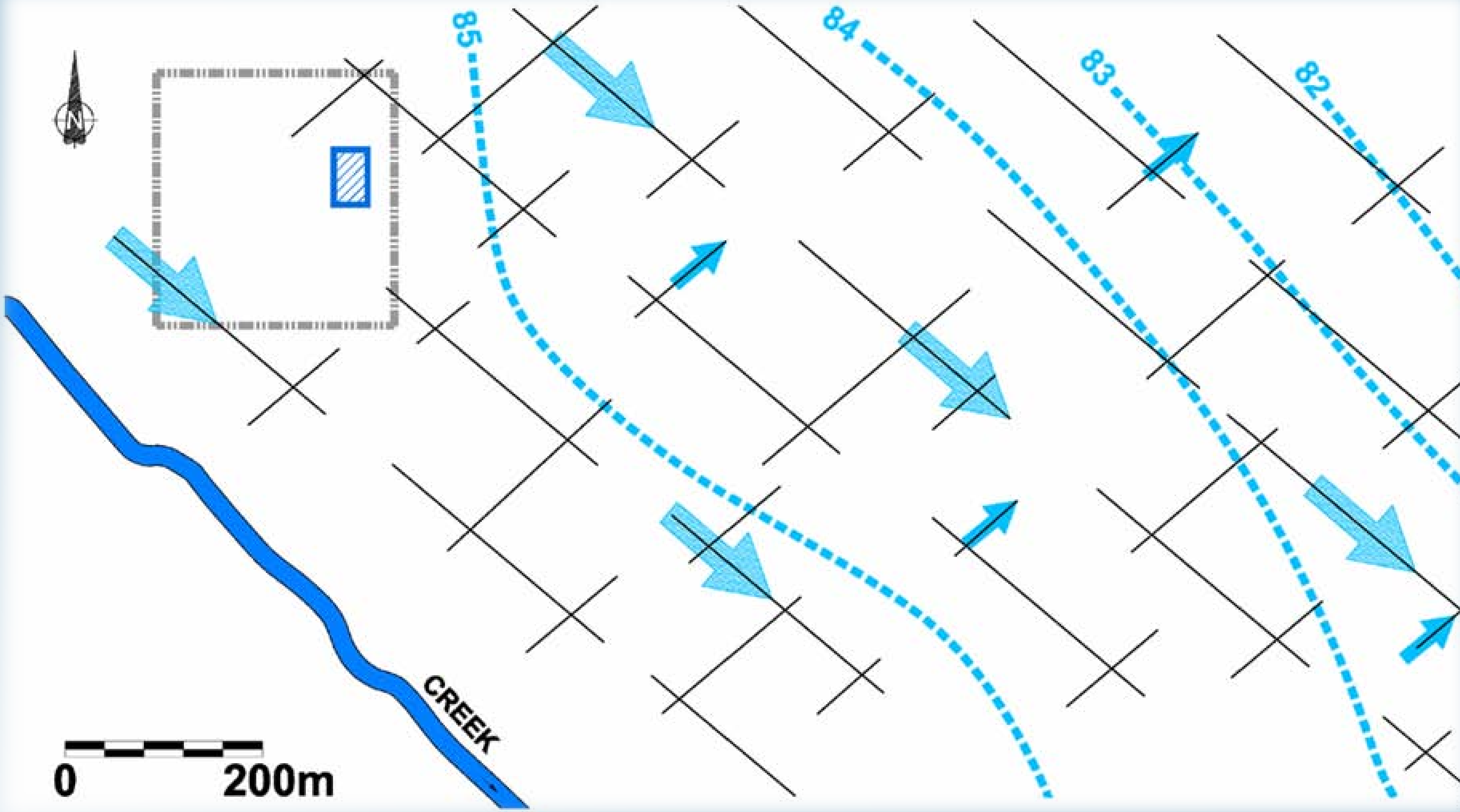
Groundwater Surface – Apparent Flow to Northeast



Dissolved Hydrocarbon: Extractable HC in C_{11} to C_{27} Range

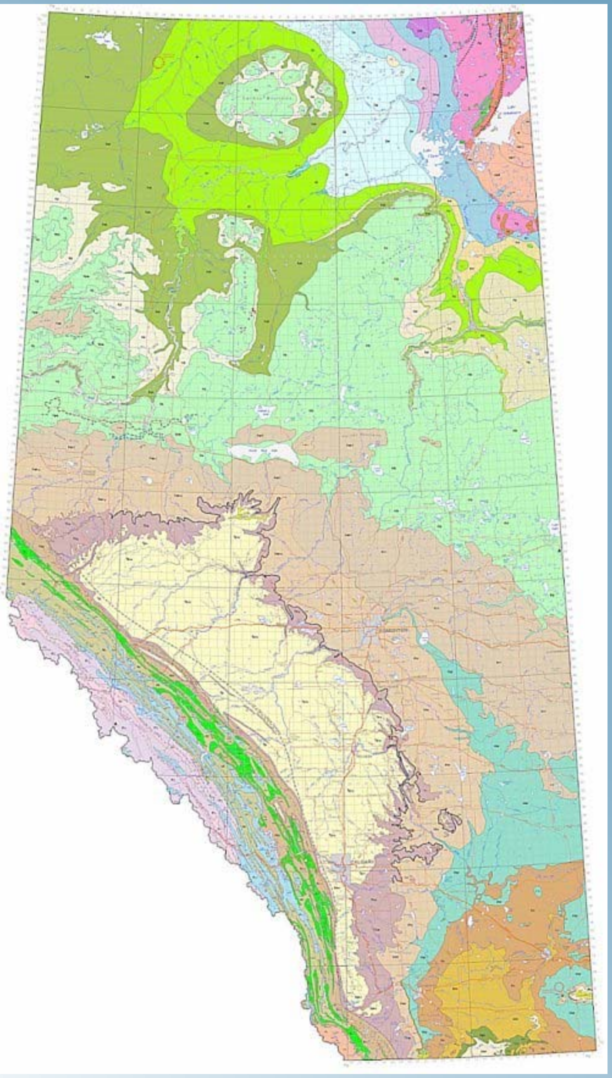


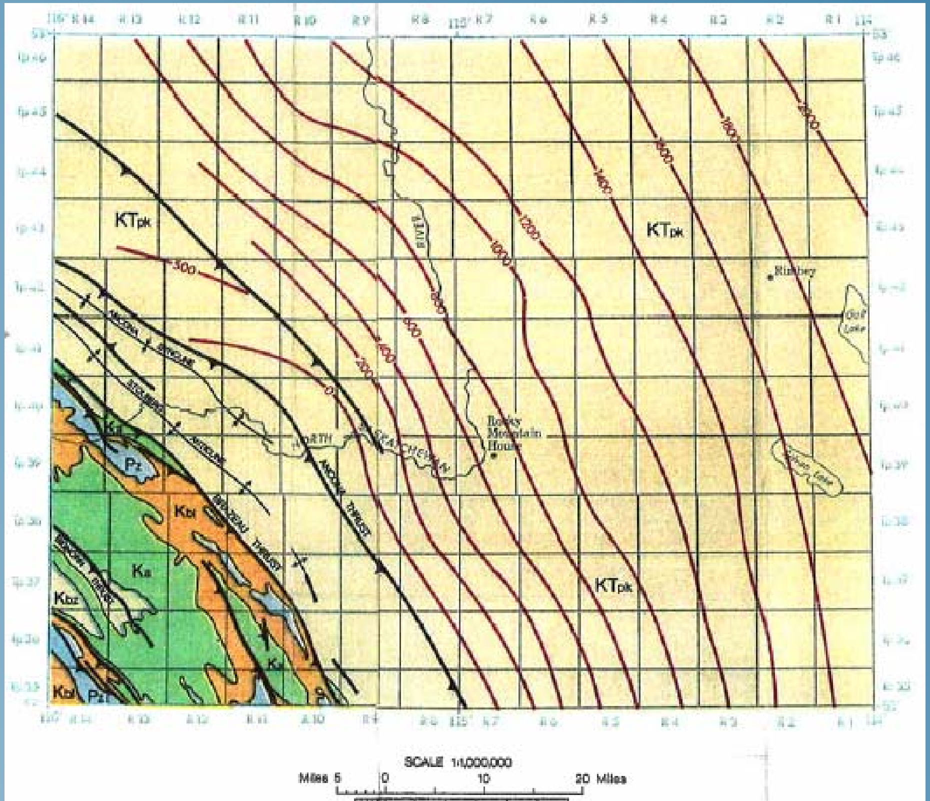
Fracture Control – Transport Mainly to Southeast



Regional Background

- **East of Rockies**
  - **Within main cordilleran “Disturbed Belt”**
- **Paskapoo Fm.**
  - **Sandstone/ siltstone/ mudstone/ coal**



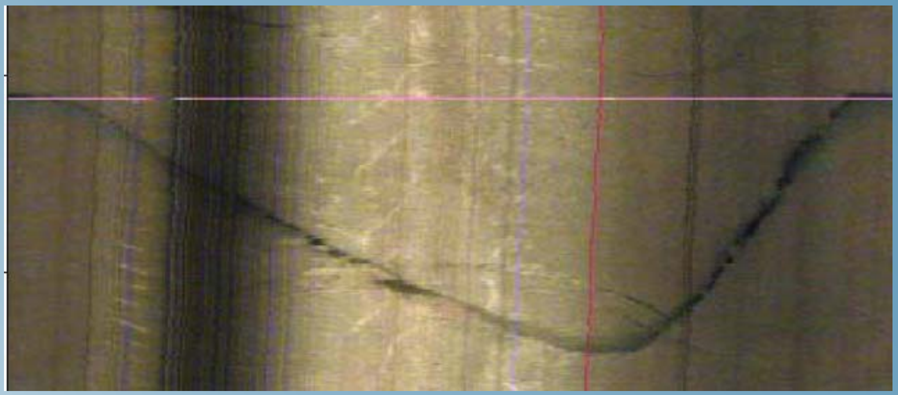


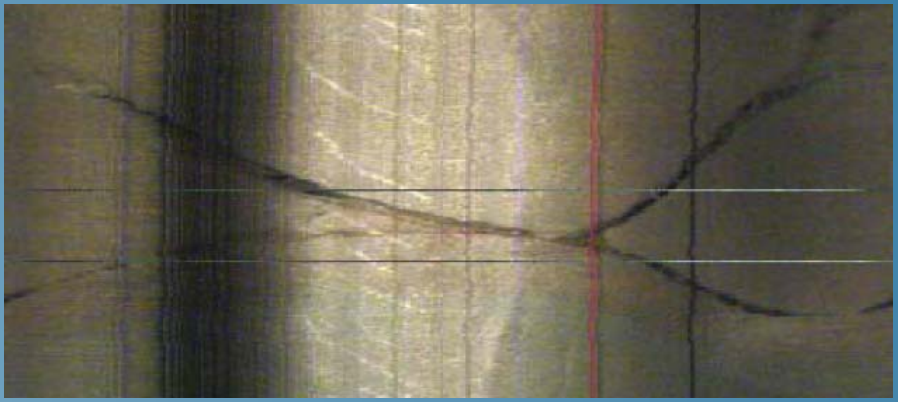
Fracture Characterization Methods

- Bedrock cores (vertical, angled)
- Borehole digital camera (BIPS)
- Outcrop structural mapping
- Hydraulic testing (pump tests)
- Flow model simulations
- Conservative tracer tests

Bedrock Coring – Fracture and Oxidation Halo

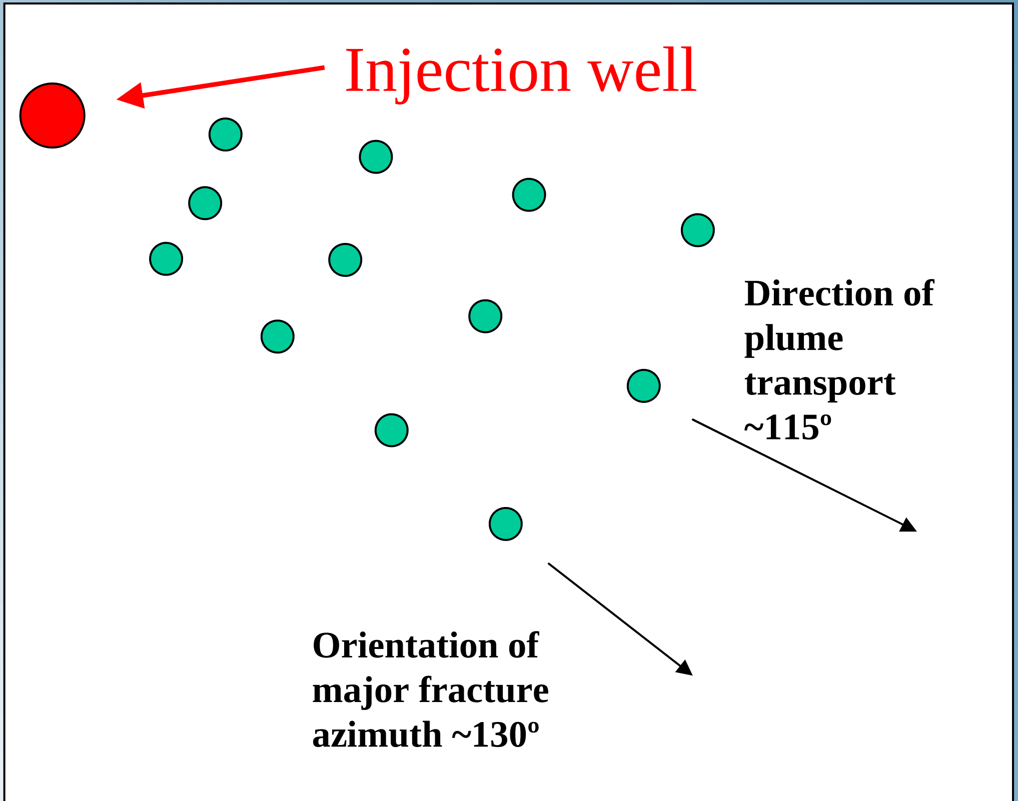
Borehole Digital Camera (BIPS)





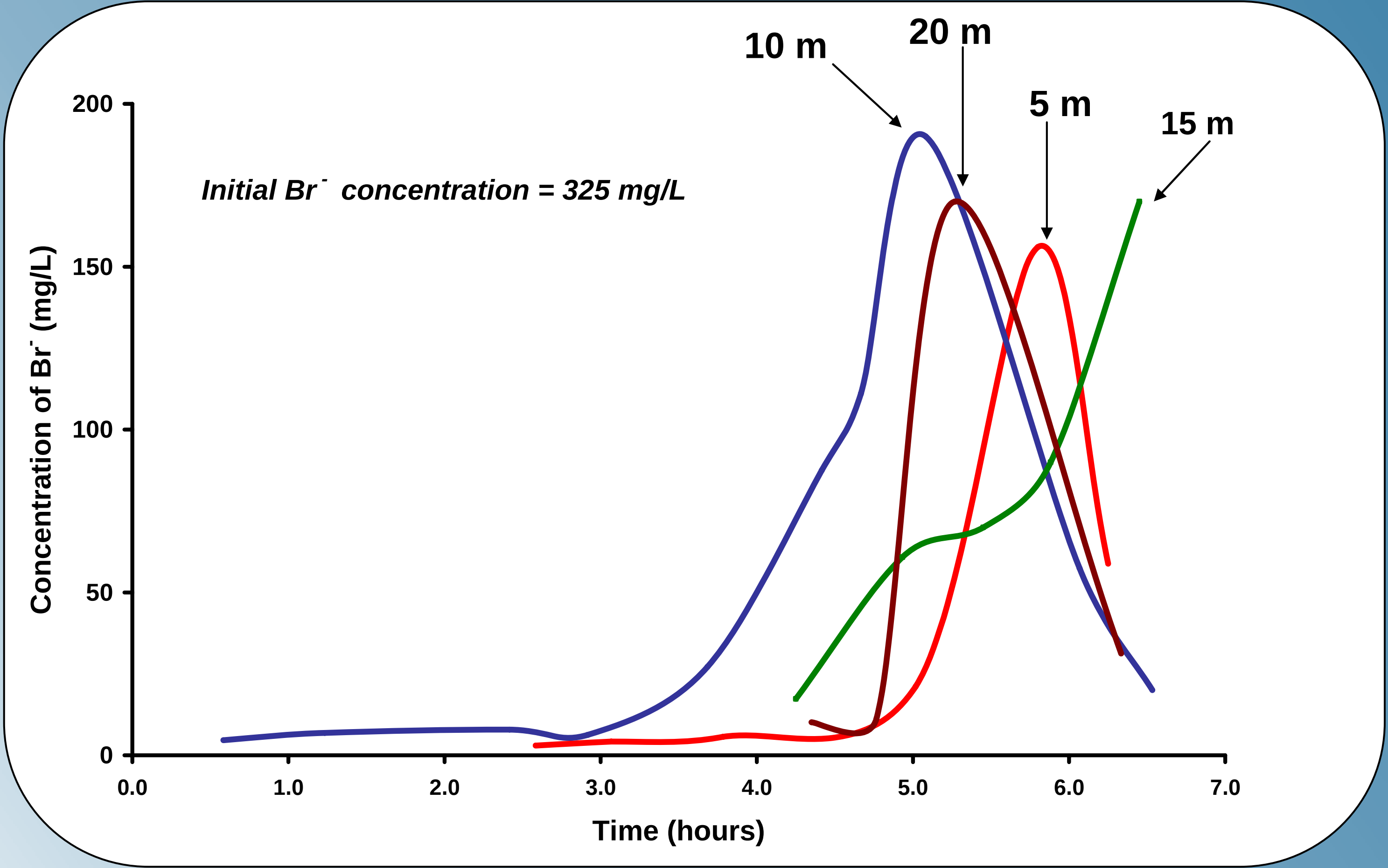
Tracer & Nutrient Test Area

- 12 closely spaced coreholes
- Oriented along major fracture azimuth and resulting GW flow



Conservative Tracer Test

- Define solute transport & fracture interconnection



Site Characterization Summary

- Complex fractured environment
  - Unexpected distribution of free phase and dissolved hydrocarbon plumes
- Number of methods used to characterize
  - Conceptual model improvement
- Impacts on remediation of site:
  - Conceptual model must be optimized to consider effective remedial options

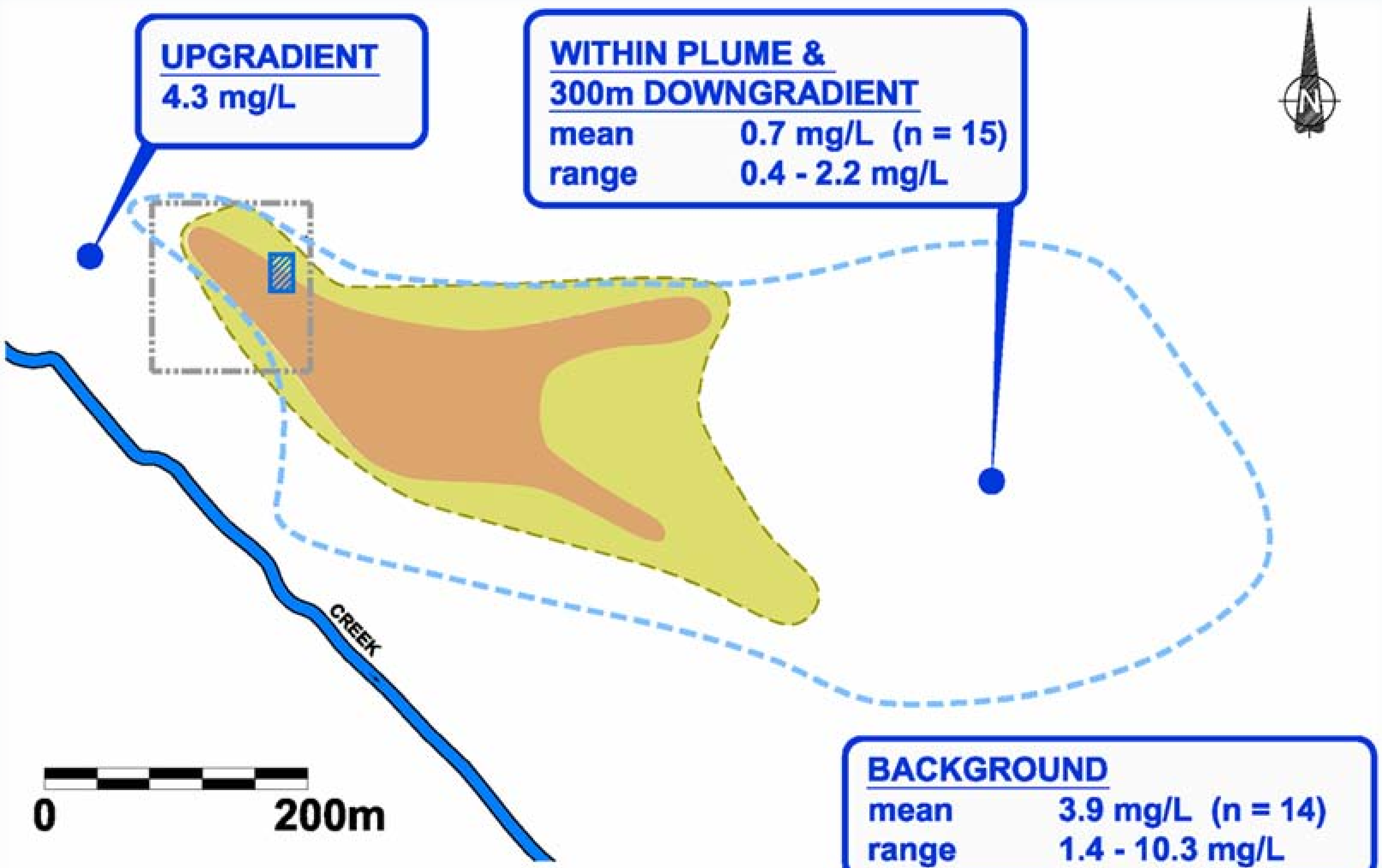
Remedial Options ??

- Physical HC removal limited by:
  - Depth of impacts
  - Complex fractured media
  - Discontinuous distribution of free phase HC
  - Low-volatility of contaminant
- Chemical evidence of natural attenuation
- Stable plume size
- In-situ treatment most promising option
- Enhance natural HC biodegradation rate

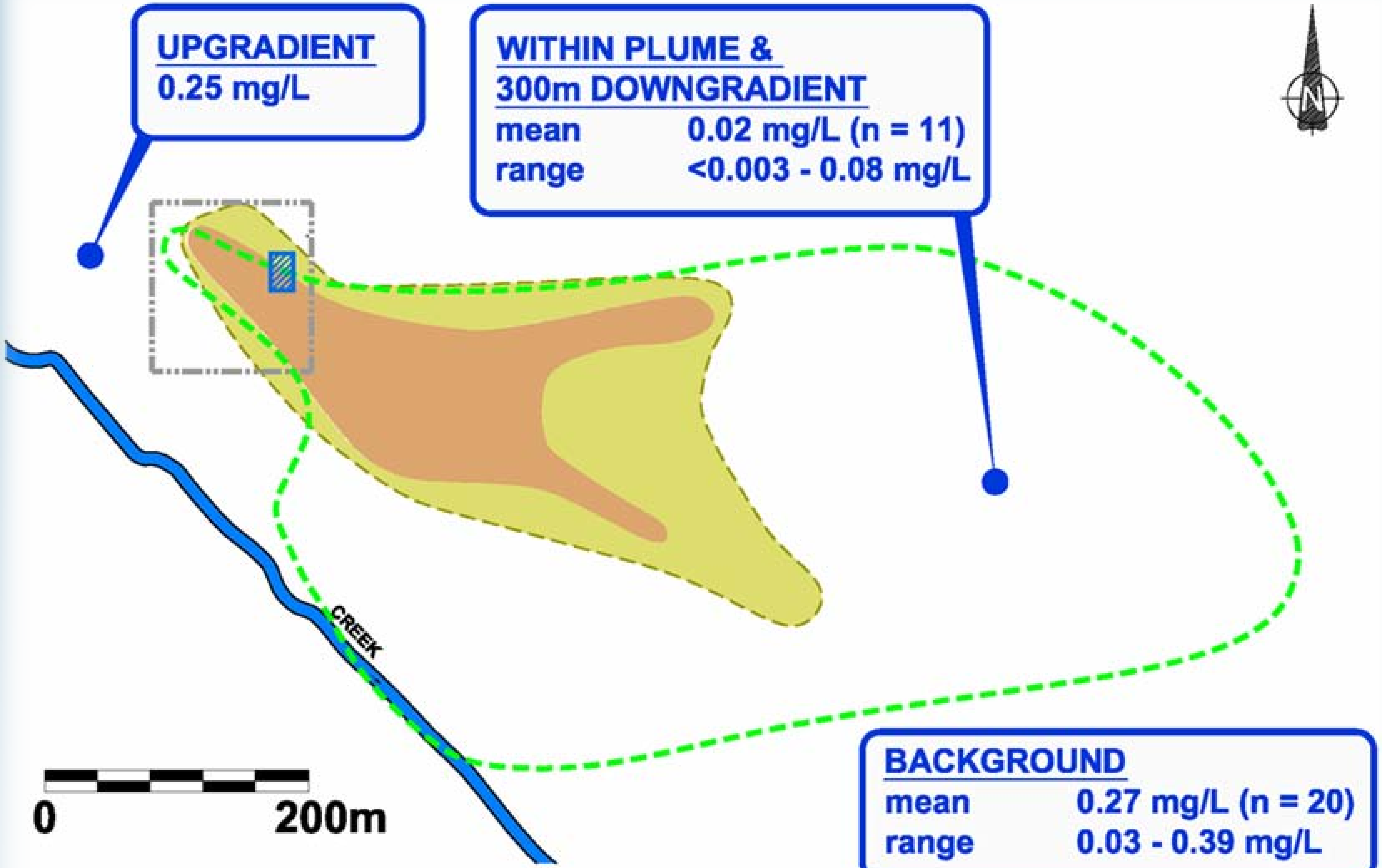
MNA Focused Sampling

- **Extra sampling at 10 select wells for details specifically important to biodegradation & MNA**
- **Key geochemical/microbiological indicators**
  - **TEH (C_{11}-C_{60}), Dissolved oxygen, NO_3, NH_4, PO_4, SO_4, Fe, Mn**
- **Bacterial**
  - **Denitrifiers, sulphate-reducing, iron-reducing, HC-degraders**
- **Dissolved gas diffusion sampling**
  - **CO_2 & CH_4 degradation by-products**

MNA Indicators – Dissolved Oxygen



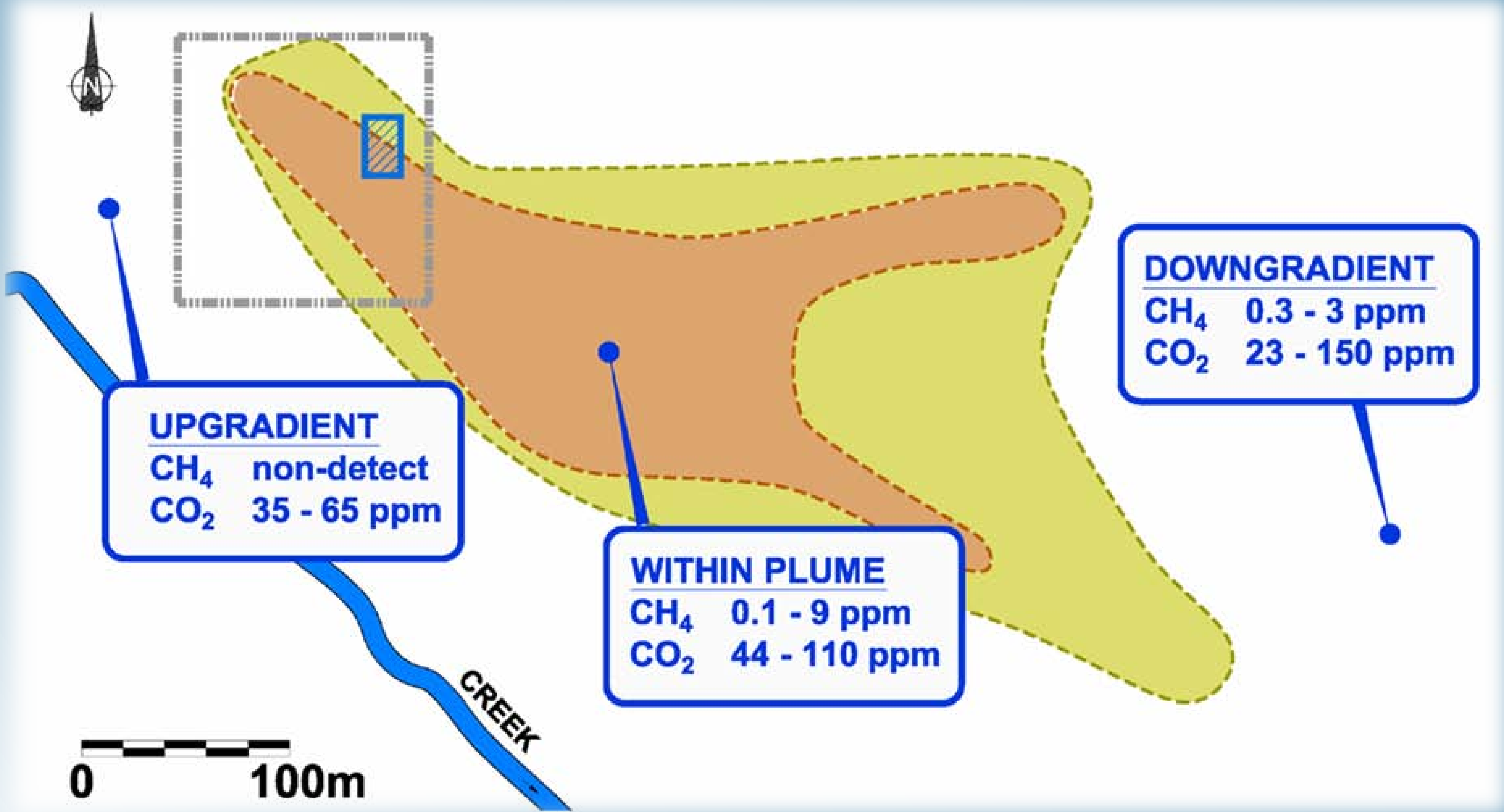
MNA Indicators – Dissolved Nitrate



Dissolved Gas Sampling

- Dissolved gases are produced/consumed in most biogeochemical reactions
  - Reliable data needed to confirm biodegradation and produce robust mass balance calculations
  - Regulators look for decrease in contaminant concentrations, plus evidence of degradation
    - dissolved gases direct evidence of degradation
    - production of CO_2 and CH_4

MNA Indicators – Dissolved Gases



Results: Dissolved Gases

- **Total dissolved gas pressure**
  - **High bioactivity within the plume**
  - **Low bioactivity downgradient of plume**

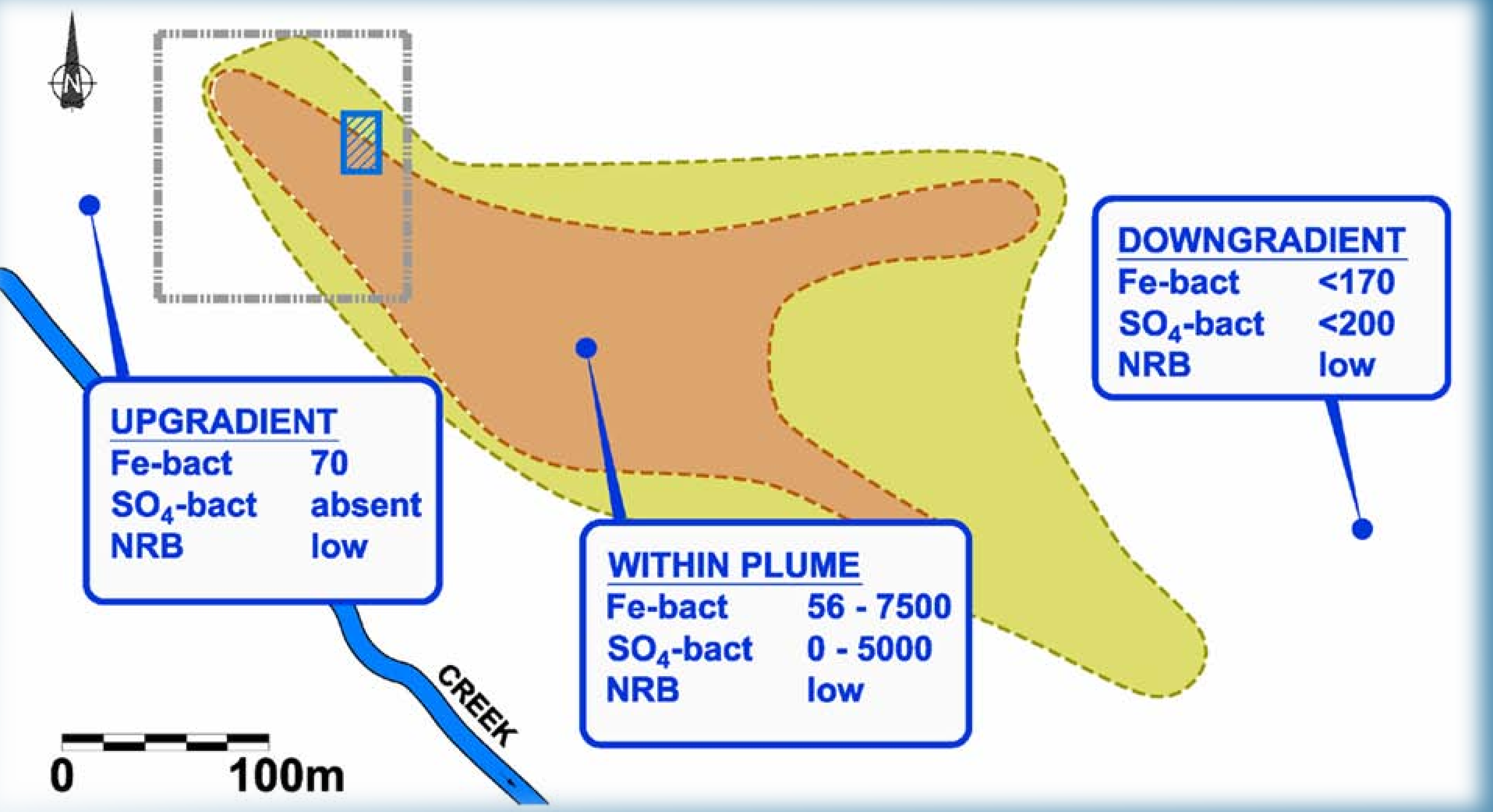
- **Dissolved gas concentrations**

  CH_4
    - **Non-detect upgradient, present in plume and downgradient**

  CO_2
    - **Typically higher values within plume and downgradient**

  N_2O
    - **Generally non-detect in all areas (background <0.5 mg/L nitrate, denitrification may be relatively minor pathway under natural aquifer conditions)**

Bacterial Populations (CFU/mL)



Field Data Summary

- Background dissolved gas testing indicates presence of a bioactive zone within the plume

- High counts of Fe-reducing bacteria within the plume and at the periphery
  - ↑ microbiological activity within plume

- High to very high levels of Fe, Mn, and low levels of NO_3 within the plume

- Stable plume size over time

Can We Accelerate the Biodegradation ?

- Natural biodegradation confirmed in field

- Laboratory bench scale amendments
  - Experiments at University of Alberta
  - Cross, Biggar et al. (J. Env. Eng. manuscript)

Lab Scale Microcosms

- **Anaerobic TEH Degradation**

Microcosm	Temperature (deg C)	Estimated Half-Life (yrs)
No amendment	10	3.8
Sulphate amended	10	3.2
Nitrate amended	10	1.9
Nutrient mix amended	10	1.2

Nutrient Amendment Proposal

Parameter	Target (mg/L)	Drinking Water Guideline (mg/L)
Nitrate (NO3 as N)	8	10
Sulphate (SO4)	200	500
Phosphate (PO4 as P)	3	- -
Ammonium (NH4)	10	- -
Potassium (K)	30	- -
Chloride (Cl)	20	250

Nutrient Flush – Planning Steps

Permission from AENV

- Several conditions related to input values to DUA
- Hydraulic controls to ensure no uncontrolled migration (*i.e.,* forced gradient best)

Tracer & pilot testing

- Confirm flowpaths & velocity by conservative tracer
- Ensure quality control of nutrient solution

  (*i.e.,* impurities in commercial fertilizers)

Full Scale Remedial Design

- Pumping ensures hydraulic control of plume
- Modelled estimate 13 wells & 2 infiltration galleries
- Treatment train
  - Remove HC & amend with NO_3, SO_4, micronutrients
- Forced gradient nutrient circulation for in-situ treatment of dissolved phase HC
- Free product skimming near pumped wells

Conclusions

- Fractured rock sites require extensive characterization (standard & unconventional)
- Detailed hydrogeological model is key
- Difficult conditions (non-volatile HC, fractures, domestic use aquifer) require innovation
- Nutrient amendments a promising alternative for in-situ treatment

Authors & Collaborators

Presenting Authors

- Michael Brown & Stefan Humphries

Komex International

- D. Thomson, B. Reiter, J. Armstrong, etc.

Universities of Calgary & Alberta

- K. McLeish (Ph.D.)
- Dr. K. Biggar, Dr. J. Foght, K. Cross (M.Sc.)

Environment Canada

- P. Bacchus