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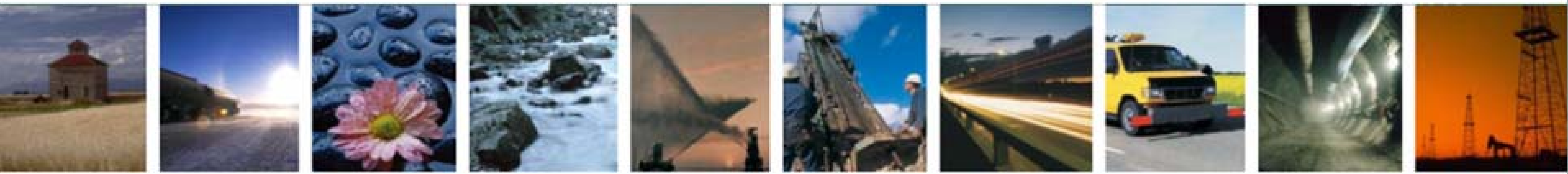

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Technical And Economic Feasibility Of Soil Flushing With Non-Ionic Surfactant To Remediate Gas Well Condensate

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Presentation Outline

- Part I, Candidate Site – high volume source, geology, infrastructure, environmental mitigation, remediation
- Part II, Technical Feasibility – surfactants 101, bench-scale tests and field trial (initial findings)
- Part III, Economic Feasibility – addressing risk and cost, regulatory framework, economic comparison
- Summary and Conclusions

Part I, Candidate Site - High Volume Source

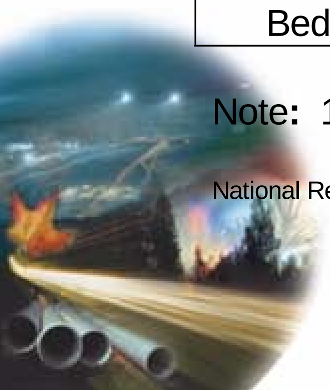
Part I, Candidate Site - Geology

Ranking for Groundwater Remediation Difficulty

Host Media	Mobile Dissolved (Degrades/ Volatilizes)	Mobile Dissolved	Strongly Sorbed, Dissolved (Degrades/ Volatilizes)	Strongly Sorbed, Dissolved	Separate Phase LNAPL	Separate Phase DNAPL
• Homogeneous Single Layer	1	1 - 2	2	2 – 3	2 - 3	3
• Homogeneous Multiple Layers	1	1 - 2	2	2 – 3	2 - 3	3
• Heterogeneous Single Layer	2	2	3	3	3	4
• Heterogeneous Multiple Layers	2	2	3	3	3	4
• Fractured Bedrock	3	3	3	3	4	4

Note: 1 = least difficult, 4 = most difficult

National Research Council

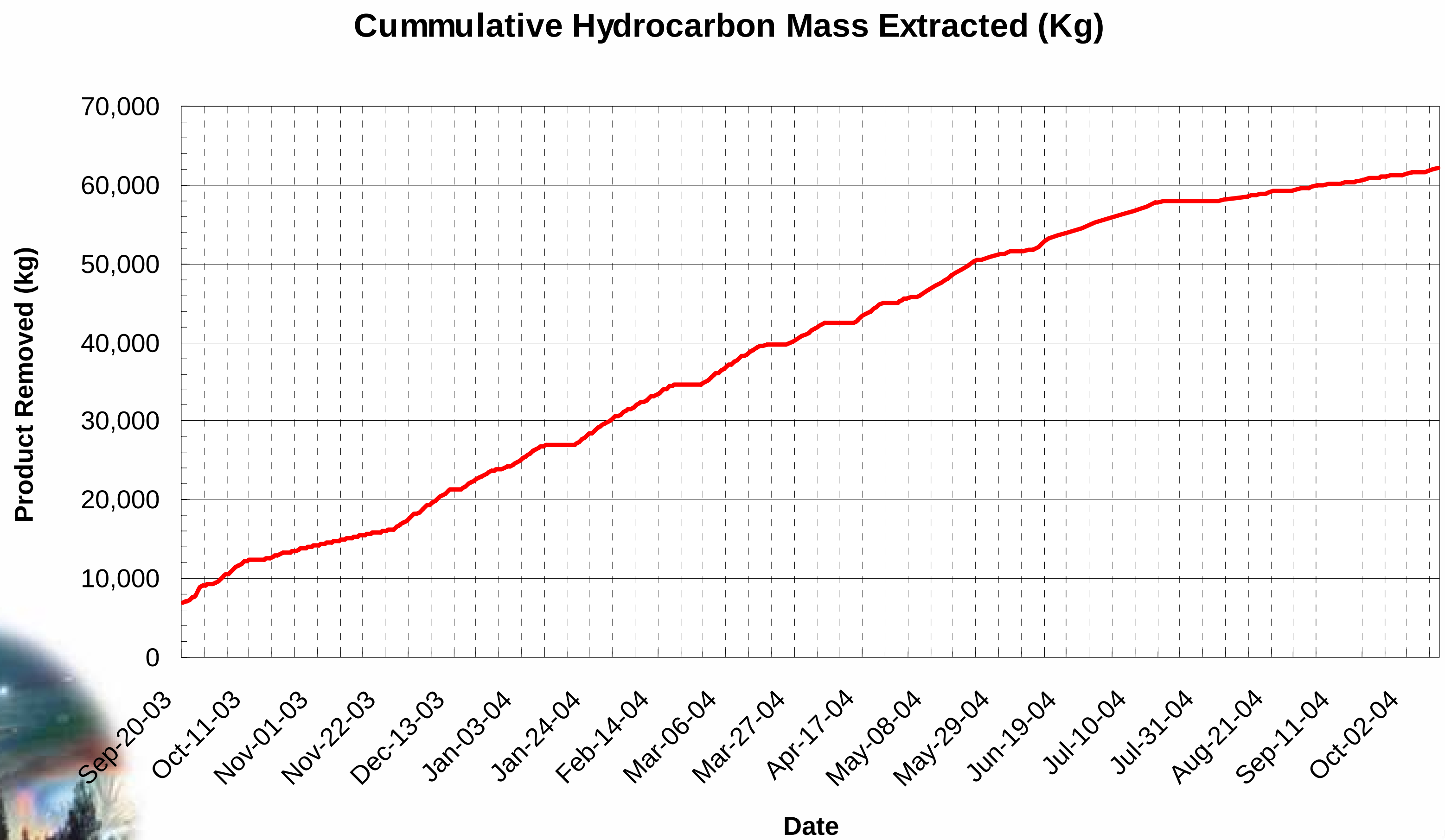


Part I, Candidate Site – Infrastructure

Part I, Candidate Site - Mitigation

Part I, Candidate Site - Remediation

Part I, Candidate Site – Remediation Progress



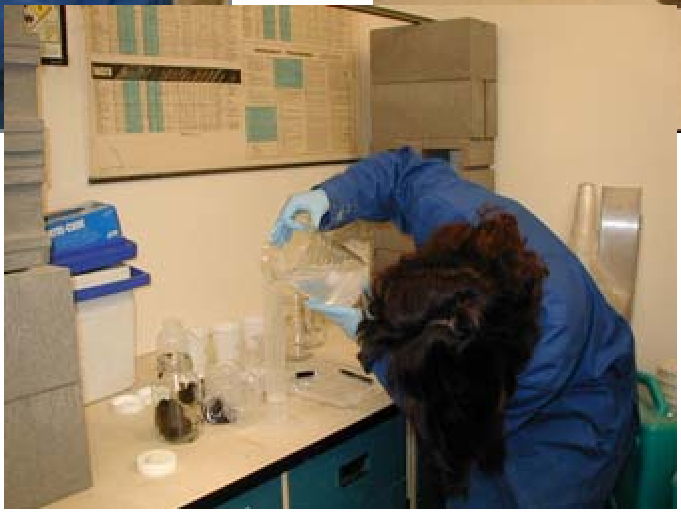
Part II, Technical Feasibility - Surfactants 101

- Surfactant adsorbs to soil-water interface and reduces interfacial tension, typically halves water tension
- Current study used non-ionic surfactant (Ivey-sol), biodegradable, effective at very low concentrations (<< LC_{50}) therefore non-toxic and significantly less than critical micelle concentration (CMC)
- Surfactant hydrophilic group does not dissociate (alcohol, phenol, ester, amide)

Part II, Technical Feasibility - Surfactant Bench-scale

- Best case aqueous desorption is evaluated:
  - maximized soil contact: soil and surfactant in jars, shake and analyse soil and decanted liquids
  - controls required: soil and water control
  - no consideration of ‘washed’ pore volumes, therefore may not scale-up to field situation with groundwater flowing in intergranular pore spaces
- Can quantify desorption in terms of: total hydrocarbons, broad range or selective range?

Part II, Technical Feasibility - Surfactant Bench-scale



Part II, Technical Feasibility - Surfactant Bench-scale

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SOIL		Disturbed Soil Sample	Method Control	Trial 1	Trial 2	Trial 3	Surfactant 3% vol
Benzene	mg/kg	0.01	<0.02	<0.03	<0.2	<0.2	
Toluene	mg/kg	0.08	0.12	<0.05	<0.3	<0.3	
Ethylbenzene	mg/kg	<0.02	<0.03	<0.05	<0.3	<0.3	
Xylenes	mg/kg	0.60	0.91	0.40	0.5	<0.3	
F1 (C_6-C_{10})	mg/kg	25	10	9	<20	<20	
F2(C_{10}-C_{16})	mg/kg	19	10	26	57	59	
F3(C_{16}-C_{34})	mg/kg	380	620	620	790	960	
F4(C_{34}-C_{50})	mg/kg	230	360	300	380	520	
WATER							
Oil and Grease	mg/L	-	80	-	17	200	130

Part II, Technical Feasibility - Surfactant Field Trial

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Part II, Technical Feasibility - Surfactant Field Trial

- Inter-well (injection and recovery) test of actual geology and injection with local groundwater (ideally)
- Short flow path (5.1 m) for short duration (2.5 hour) repeatable tests for successive desorption
- Recovery tracking with groundwater tracer
- Injection stock solutions formulated, 3 - 4 orders magnitude dilution anticipated

Part II, Technical Feasibility - Surfactant Field Trial

- Alberta Code of Practice For Hydrologic Tracing Analysis, applicable to surface water, no guidelines for groundwater tracers in Alberta
- Used sodium bromide tracer, highly soluble, conservative tracer, foreign to freshwater, acceptable to most regulators (USEPA: low acute oral toxicity), no TDG issues
- AENV requested post-test compliance with GCDWQ, clean-up of all injectants required

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Part II, Technical Feasibility - Surfactant Field Trial

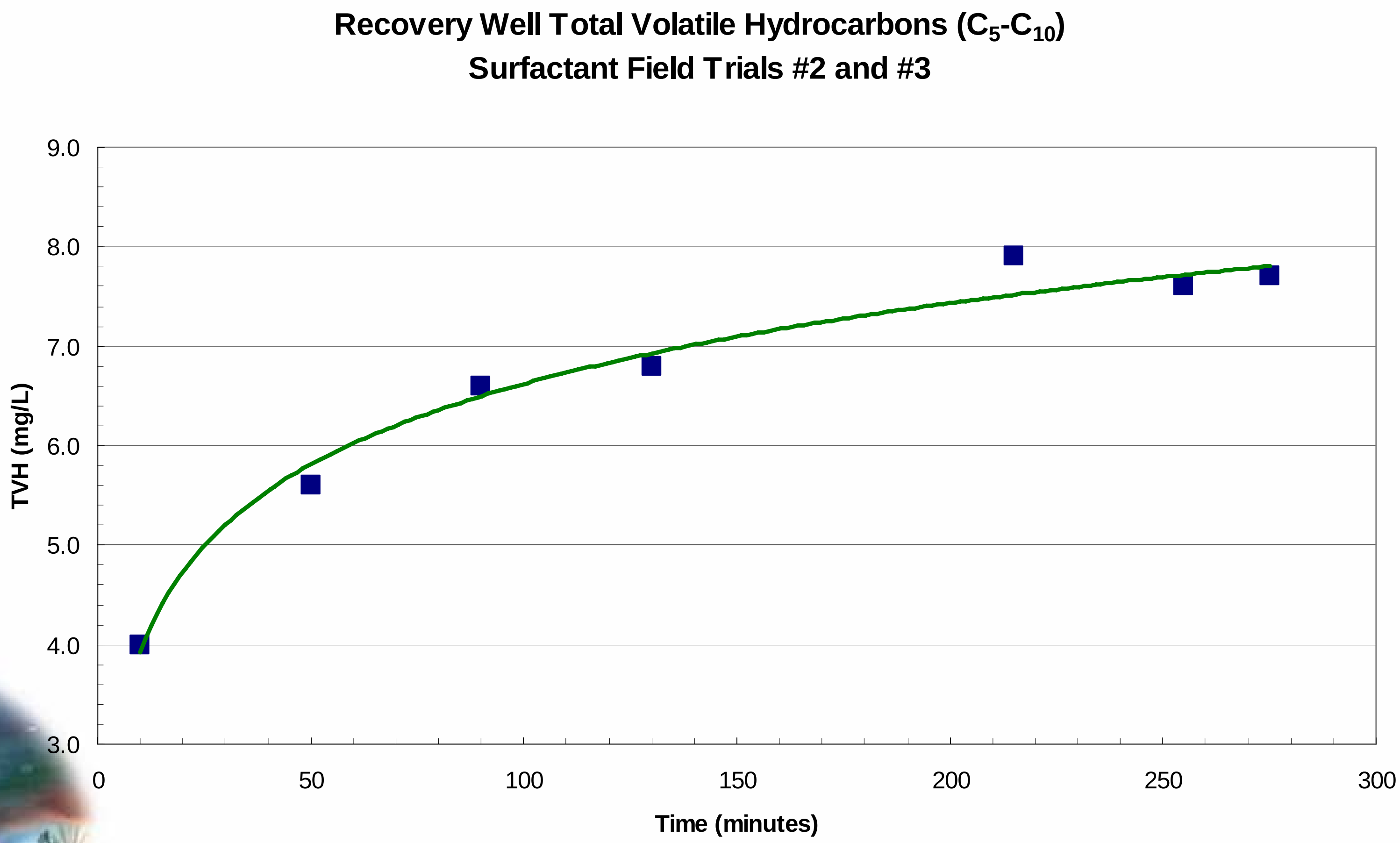
Part II, Technical Feasibility - Surfactant Field Trial

Four 100 L stock solutions sequentially injected:

- Trial 1 – creek water and tracer (918 mg/L)
- Trial 2 – creek water, surfactant (1.5% v/v) and tracer (833 mg/L)
- Trial 3 – creek water, surfactant (1.5% v/v) and tracer (745 mg/L)
- Trial 4 – creek water, surfactant (1.5% v/v) and tracer (1,370 mg/L)

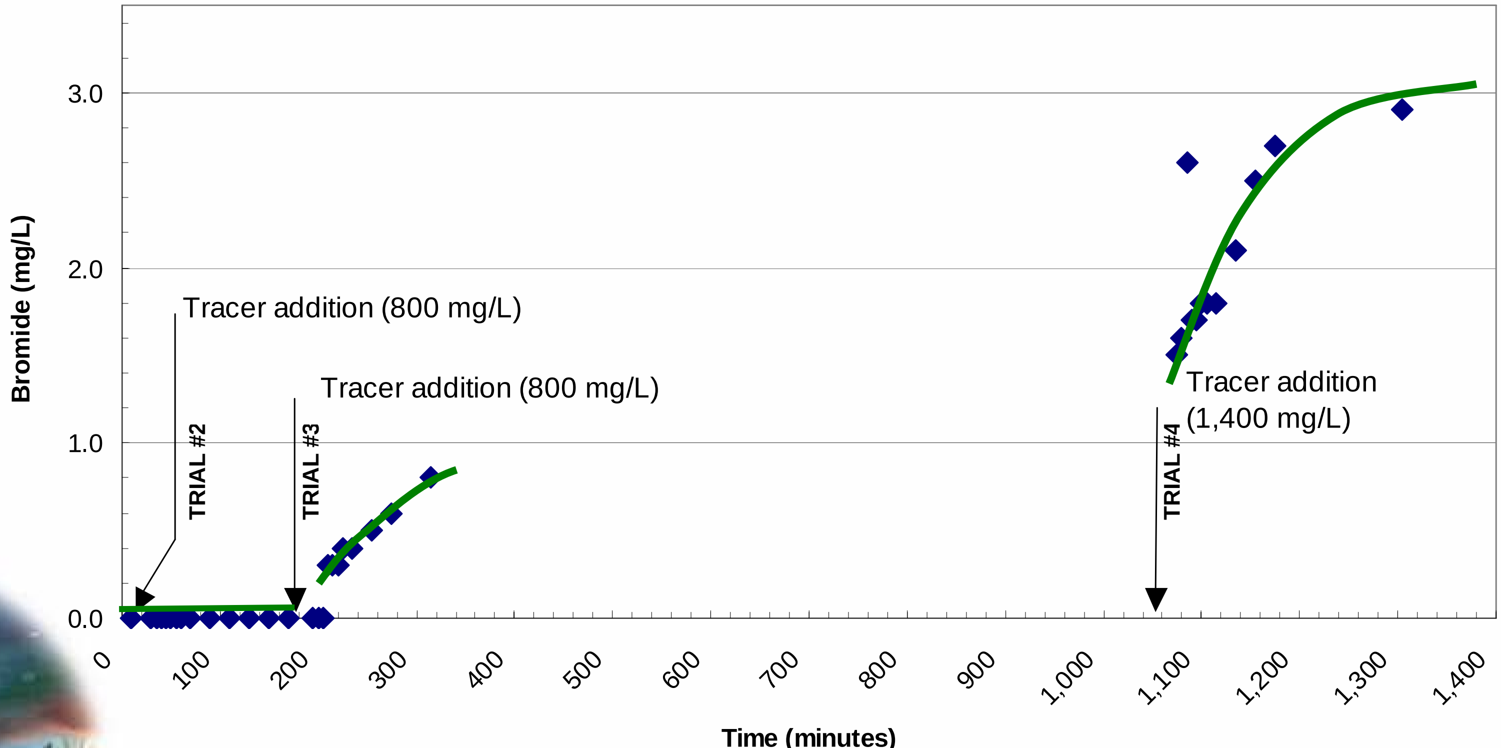
Part II, Technical Feasibility - Surfactant Field Trial

Part II, Technical Feasibility - Field Trial Results



Part II, Technical Feasibility - Field Trial Results

Recovery Well Bromide Concentrations versus Time
Surfactant Field Trials #2, #3 and #4

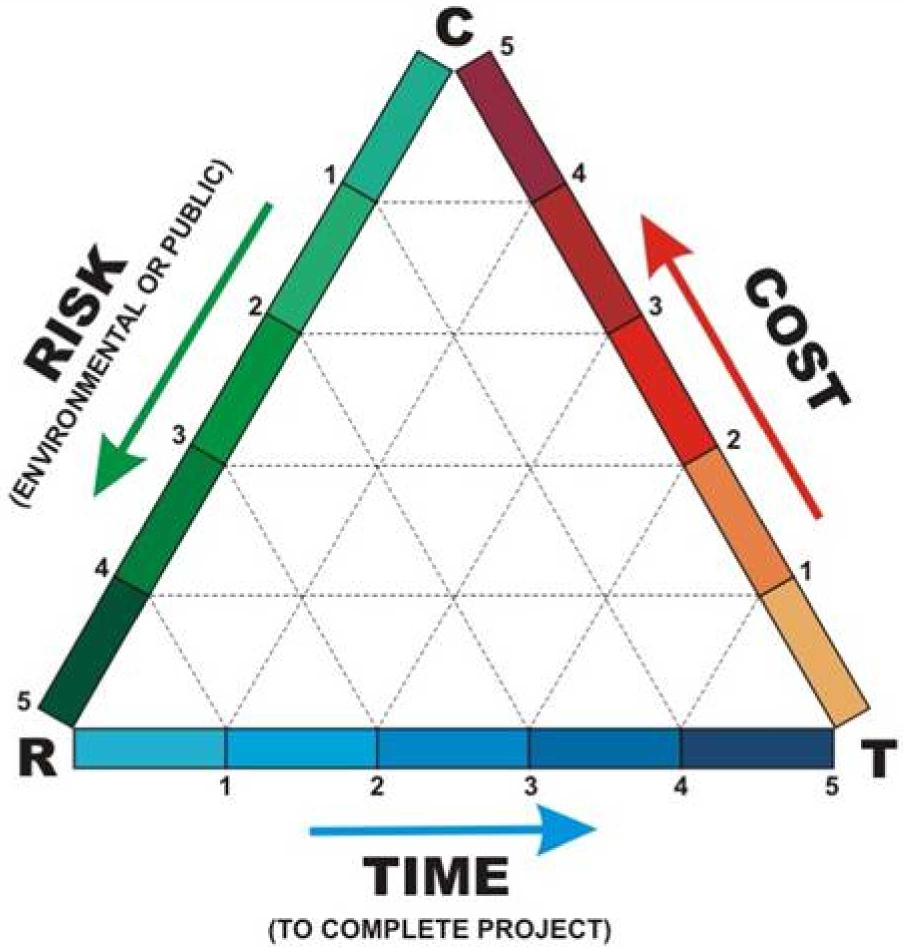


Part II, Technical Feasibility – Post Field Trial

Part III, Economic Feasibility - Regulatory Framework

- Bench-scale and field trial initial findings, first technical evaluation
- High volume hydrocarbon source + complex site => protracted time for remediation (reasons: advective transport and diffusion into soil matrix over time)
- Challenge - find more expeditious site closure remediation for O&G sector without increasing risks

Part III, Economic Feasibility - CRT Triangle



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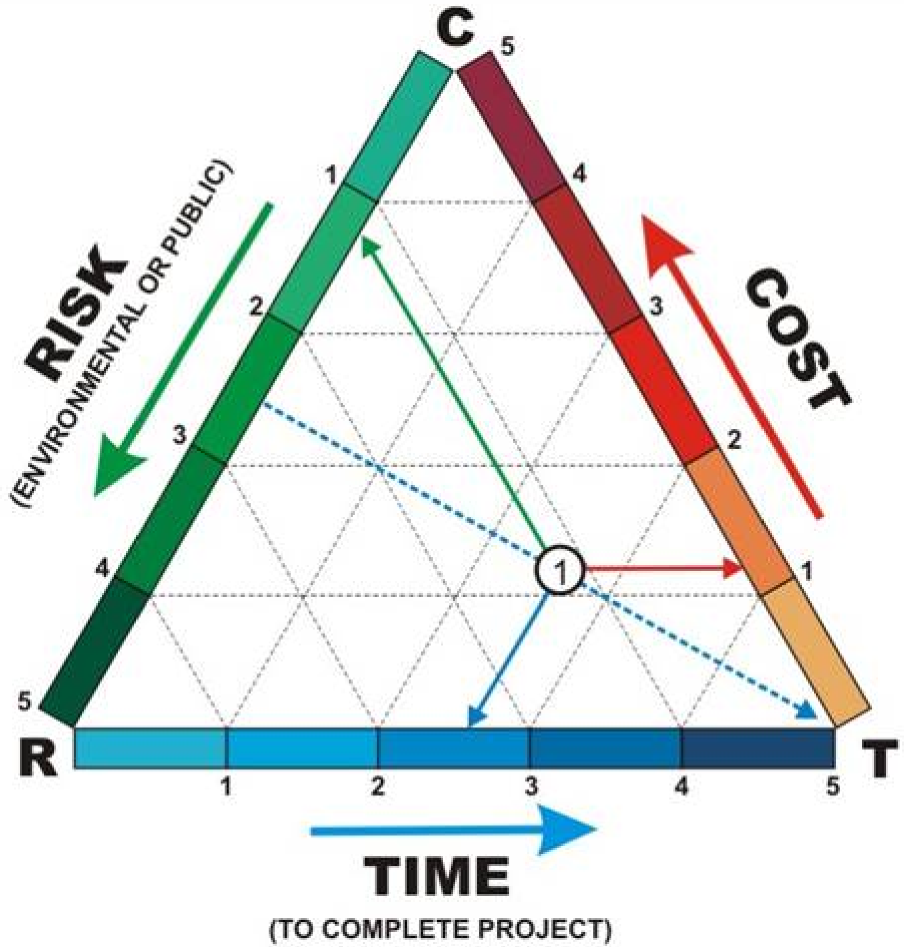

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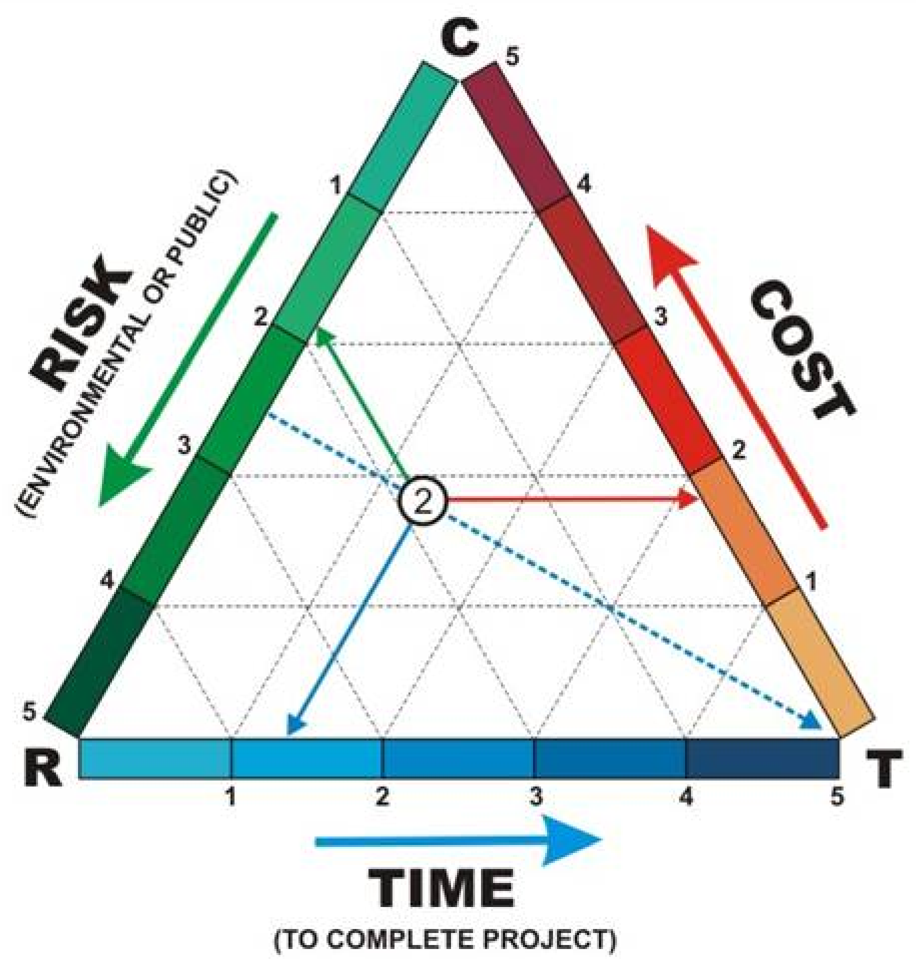

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Part III, Economic Feasibility – Extra Risk & Cost

- Risk (environmental) – AENV Tier 2 O&G site-specific assessment involving: off-site receptor(s) evaluation, on-site groundwater and soil quality criteria back-calculation for receptor(s) protection
- Risk (technology) – reduce at bench and field scales
- Cost – controlled by selecting BAT(EA), significant time saving potential of chemo-remediation processes versus assisted bioremediation

Part III, Economic Comparison – Options

- Area: 4,400 m^2 and 0.3 m vertically => 1,320 m^3 (2,640 kg at 2 T/m^3 bulk density)
- Constraints: infrastructure cannot be shut-down or moved
- Soil at residual hydrocarbon saturation
  - bioremediation – biosparging
  - chemical oxidation – e.g., RegenOx™ products
  - surfactant – injection
  - status quo – multi-phase extraction

Part III, Economic Feasibility – One Year Costs

Preliminary:

- Biosparging - $15k/mth ($180,000), includes rental
- RegenOx™ products - $45k materials plus $35k delivery system ($80,000)
- Surfactant - $40k materials plus $35k delivery system ($75,000)
- Status quo - multi-phase extraction – $20k/mth ($240,000), includes rental

Summary and Conclusions

- Applicability – geologically coarse materials (thin capillary fringe), conductive (K > 10^{-5} to 10^{-6} m/s), topographically-assisted groundwater gradients (natural conveyor belt)
- Bench tests and field trials for site suitability
- Economics – surfactants comparable at least to in-situ oxidation, attractive based on $/m^3 but technology risk must be addressed (not fully emerged technology)
- Regulatory – GCDWQ compliance, recovery of <u>all injectants</u>, not just desorbed hydrocarbons

Further Studies and the Future

- Bench-scale range of soil sizes and natural organics
- Column tests to evaluate pore volume exchanges (number of applications) and maximum induced groundwater gradients for efficient surfactant flushing
- Longer field trials for breakthrough curves and mass balance assessments, tracer pump-back tests for effective porosity, etc.
- Surfactant evaluation emerging alongside the technology in Alberta, within 1-2 years evaluation may become standardized, hopefully more to report at RemTech 2006

Thank You

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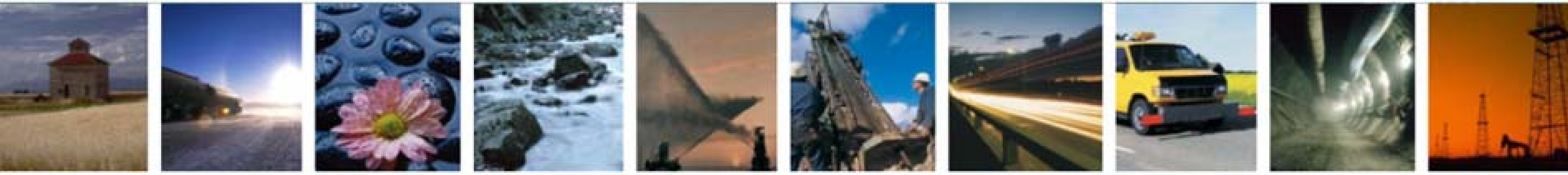

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