Active In-Situ Petroleum Hydrocarbon Remediation in Discontinuous Permafrost –

Practical Experience and Lessons Learned

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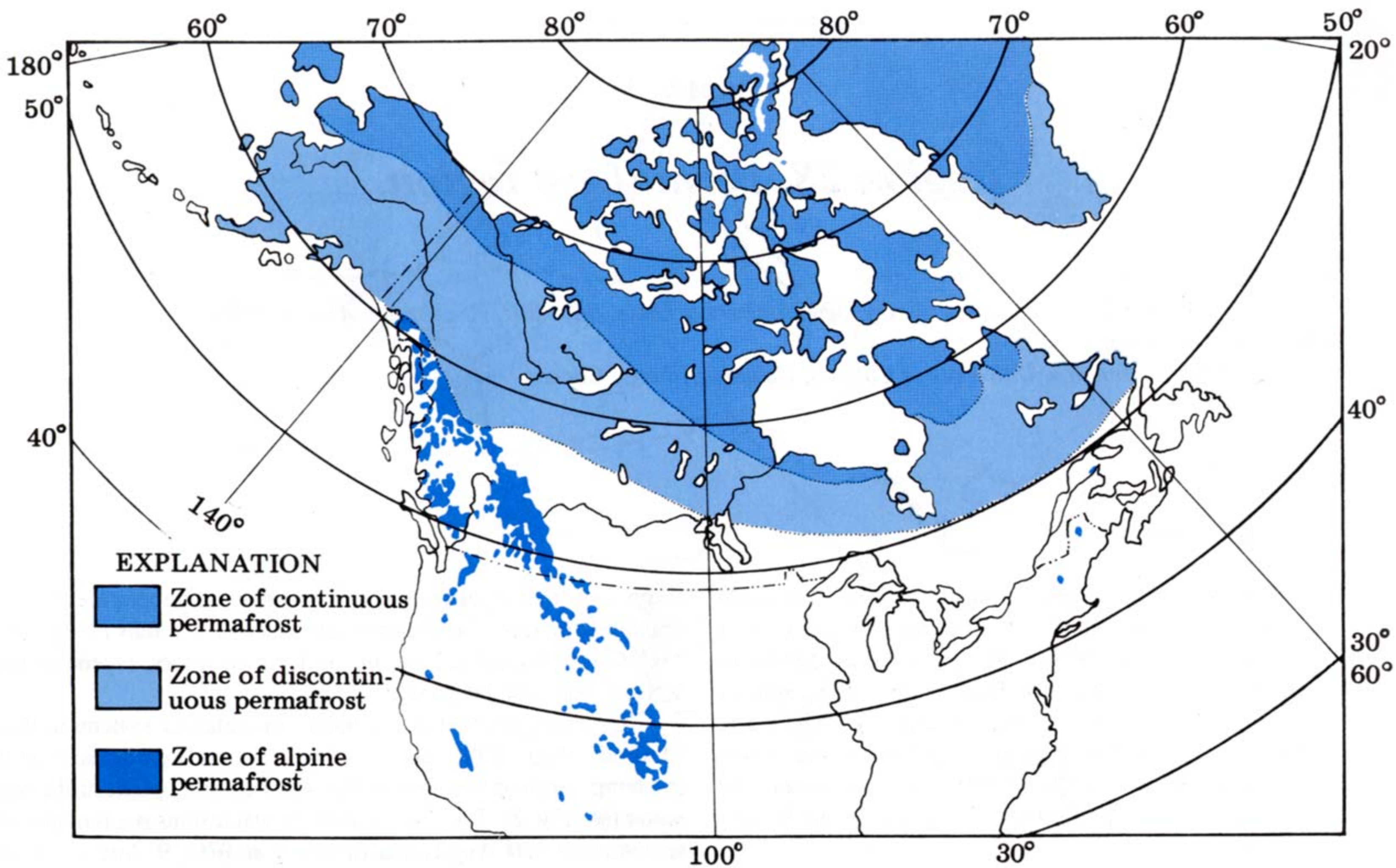
Presentation Overview

- Permafrost Background
- Site Characterization Phase
- Conceptual Site Model
- Remedial Options Analysis
- Permeability Enhancement
- Full Scale Remediation System
- Challenges and Optimization (Lessons Learned)

Permafrost in North America



Source: Sloan & van Everdingen, 1988. Region 28, Permafrost region. *In:* Hydrogeology: Geology of North America, GSA.

Site Characterization

Some Potential Sources:

- Fire Training Area
- Multiple Above Ground Storage Tanks

Phase II ESA:

- More than 60 piezometers
- More than 150 soil sampling locations
- Hydrocarbon delineation in soil & groundwater complete
- Permafrost characterization – drilling and geophysics

Remediation Planning:

- Options analysis
- Three seasons of pilot testing
- Gradual scale up & optimize design

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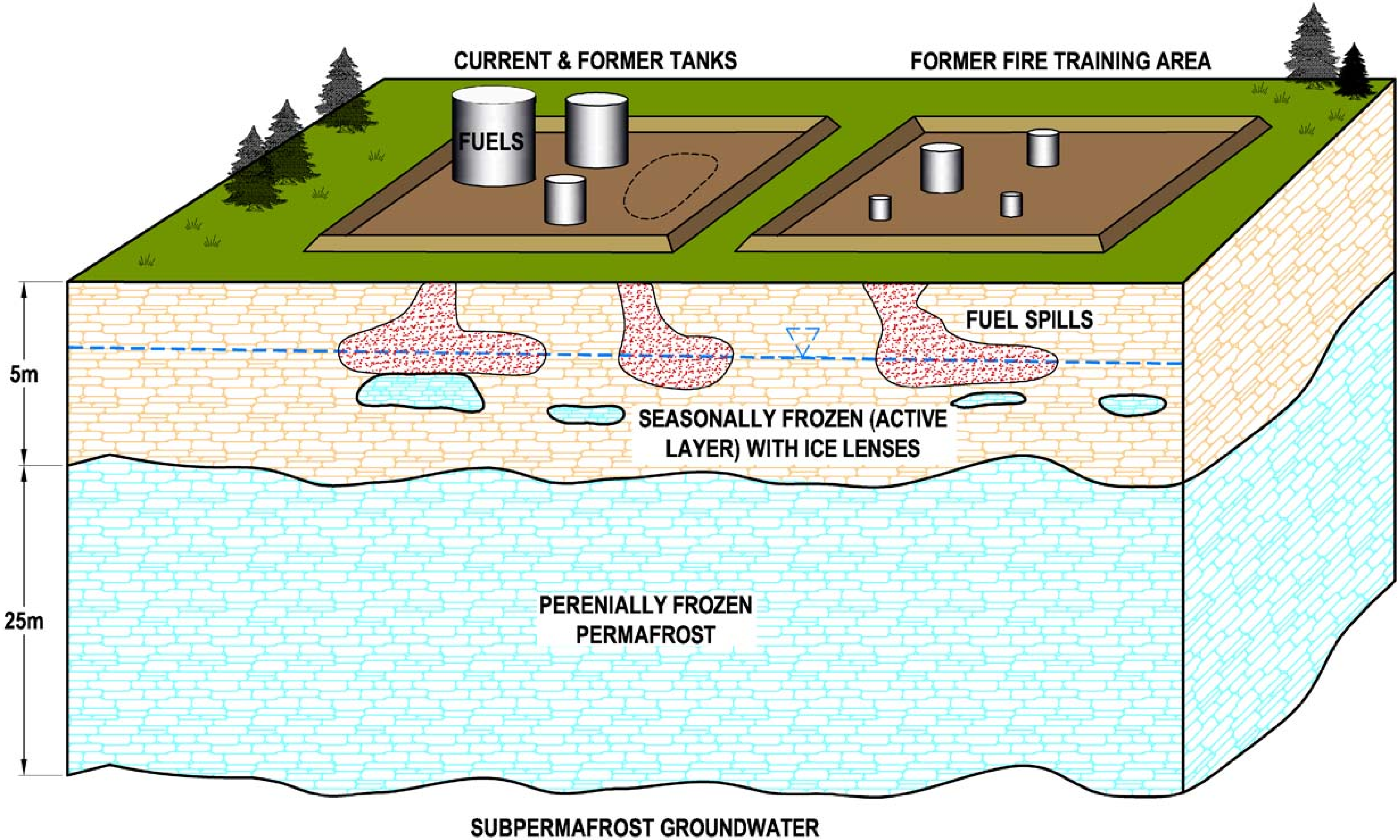
Conceptual Model



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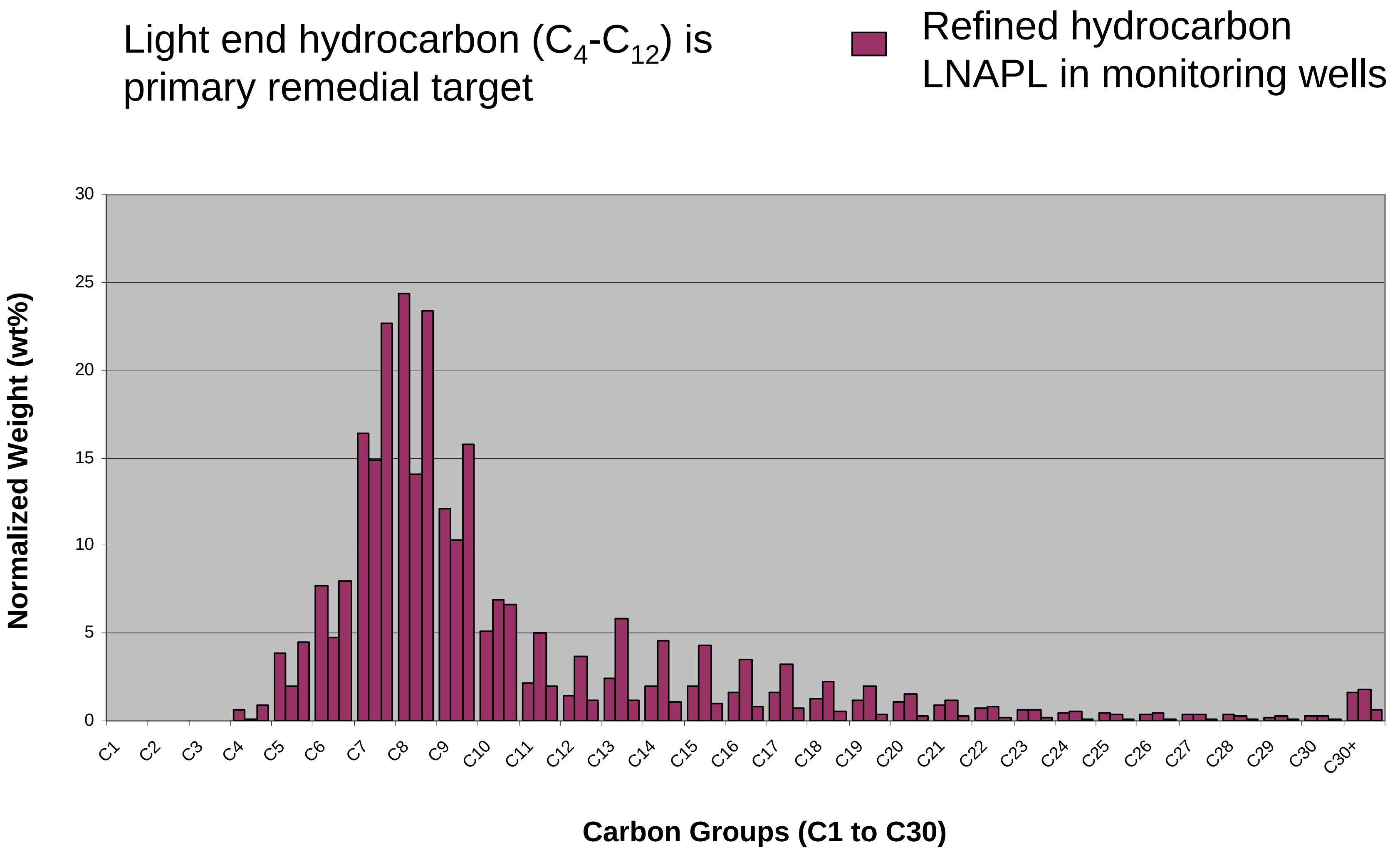
Remediation Options 1

Technique	Description / Applicability
Impacted soil	▸ Approx. 100,000 m3 overlying permafrost ▸ Dominantly light-end hydrocarbon (F1-F2)
Excavate & landfill	▸ Transport costs to nearest landfill are prohibitive (more than 700 km) ▸ Excavations will tend to degrade permafrost ▸ Suitable backfill not readily available
Excavate & biocell	▸ PHC-F1, F2, limited F3 treatable ▸ Biocell treatment takes 1 to 2 seasons ▸ 4-month season, rainfall & frost slow progress ▸ Limited current capacity, but expansion planned

Carbon Group Distribution

Light end hydrocarbon (C_4-C_{12}) is primary remedial target



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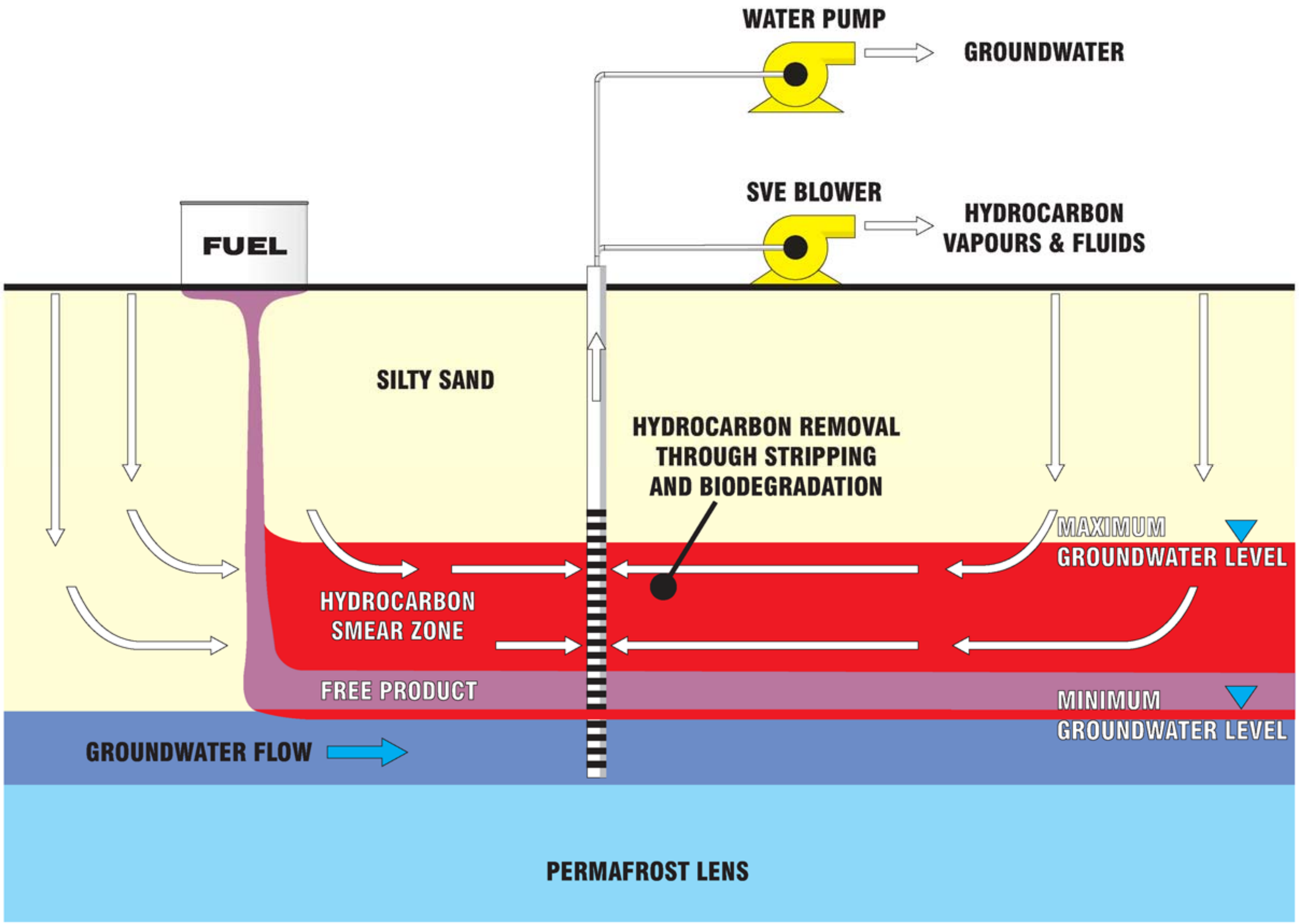
Remediation Options 2

Technique	Description / Applicability
Soil Vapour Extraction (SVE)	▸ Volatile contaminants only ▸ Above water table only ▸ Requires good permeability (fine sand to gravel) ▸ Promotes aerobic biodegradation
Dual Phase Extraction (DPE)	▸ Recovers fluids by pump, vapours by vacuum line ▸ Applies to both volatile and non-volatile NAPL ▸ Can work in tighter permeability soils ▸ Promotes aerobic biodegradation

Remediation Strategy – SVE & DPE



Full Scale DPE Remediation

DPE Strategy

- Shallow water table perched on permafrost
- Pumping lowers shallow water table
- High vacuum removes vapours
- Hydraulic and pore pressure gradients encourage LNAPL flow to trench
- Airflow also enhances natural biodegradation

- Pilot testing completed 2001
- Full-scale system commissioned October 2004
- Currently 30 trenches installed

- Operates seasonally when ground not frozen
- About 100 days per year

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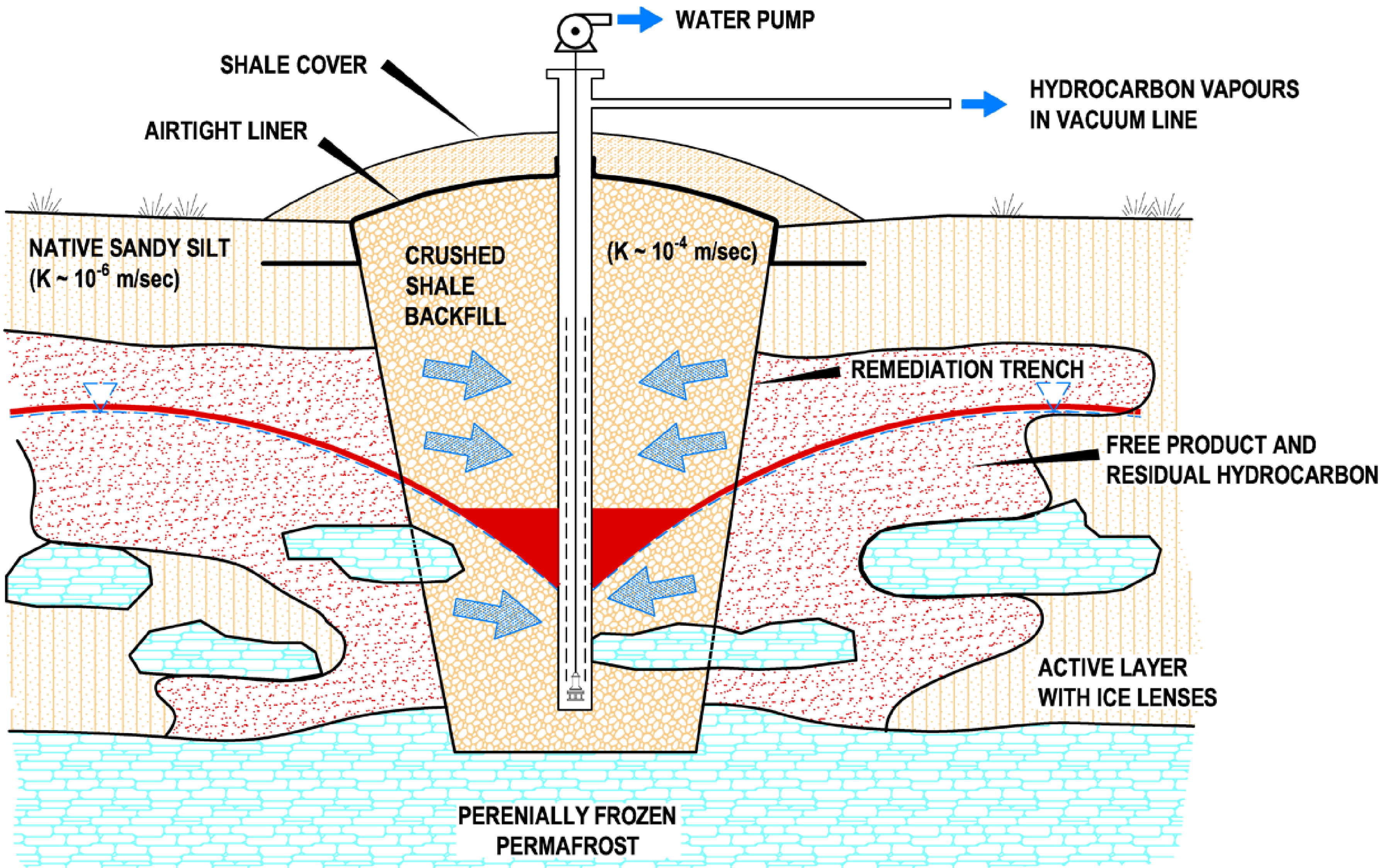
Enhancing Limited Permeability

Technique	Description / Applicability
Trenches vs. Wells	▸ Effectiveness of in-situ remediation depends on permeability – it's dominant control on both vapour and fluid transport ▸ Typically will flush out more permeable strata ▸ Diffusion of contaminants from low-K to high-K zones controls remedial timeframe ▸ Low-K zones can remain largely untreated ▸ Permeable trenches are linear high-K features that focus gradients, and intercept discrete permeable pathways where migration occurs ▸ Trenches can be more effective than large numbers of vertical wells

Remediation Trench for DPE



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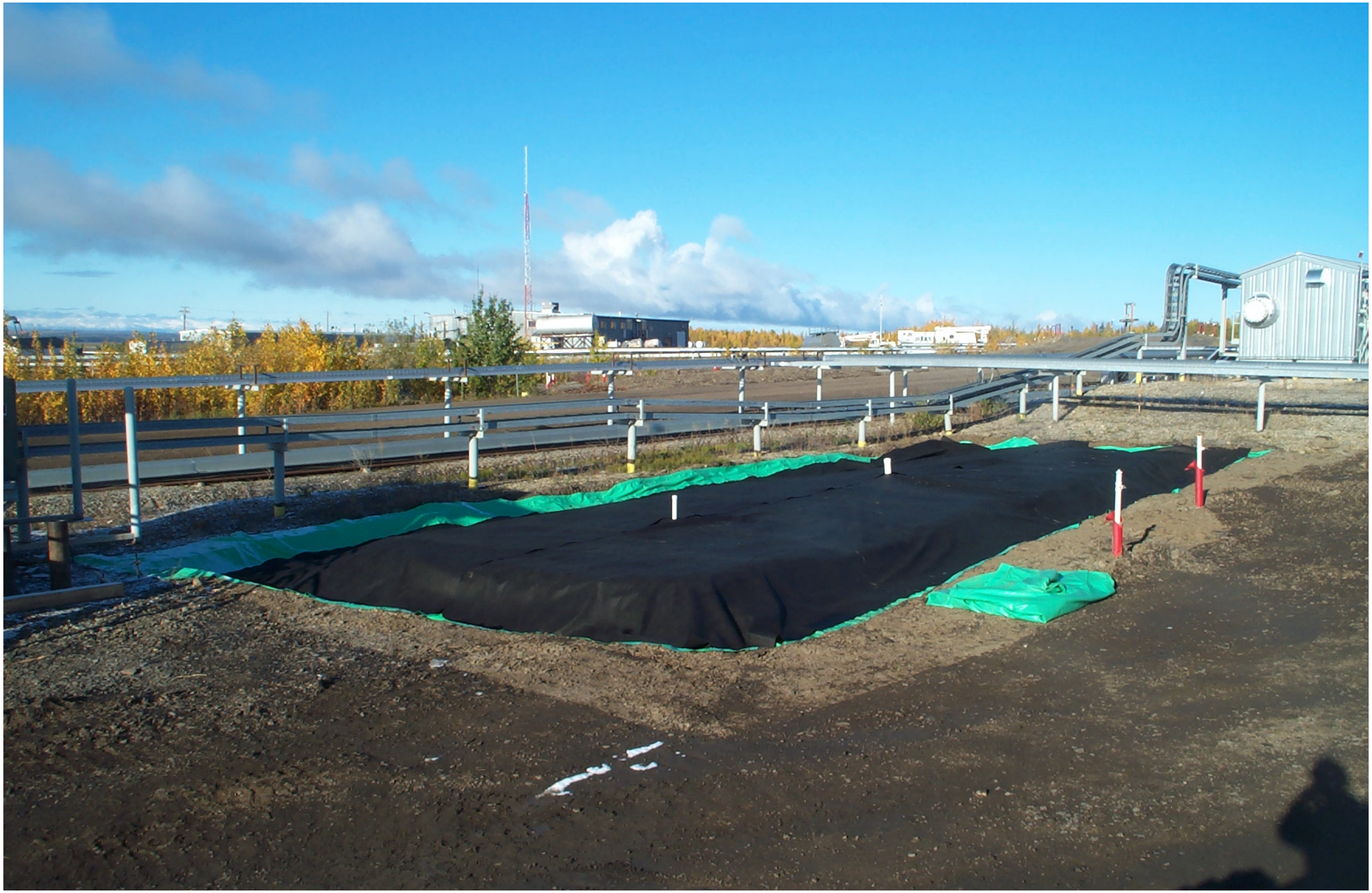
Remediation Trench Installation



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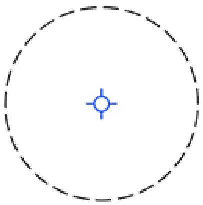
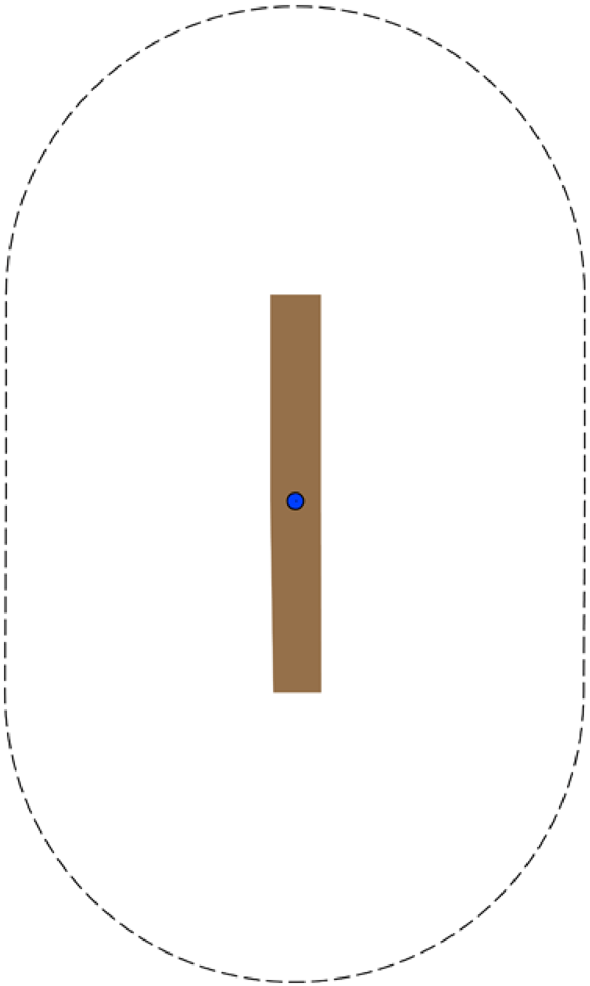
Radius of Influence

DPE radius of influence:

vertical well - 4 m
trench & well – 12 m





1 trench treats same area as 12 wells

0 5 10m
SCALE 1 : 250

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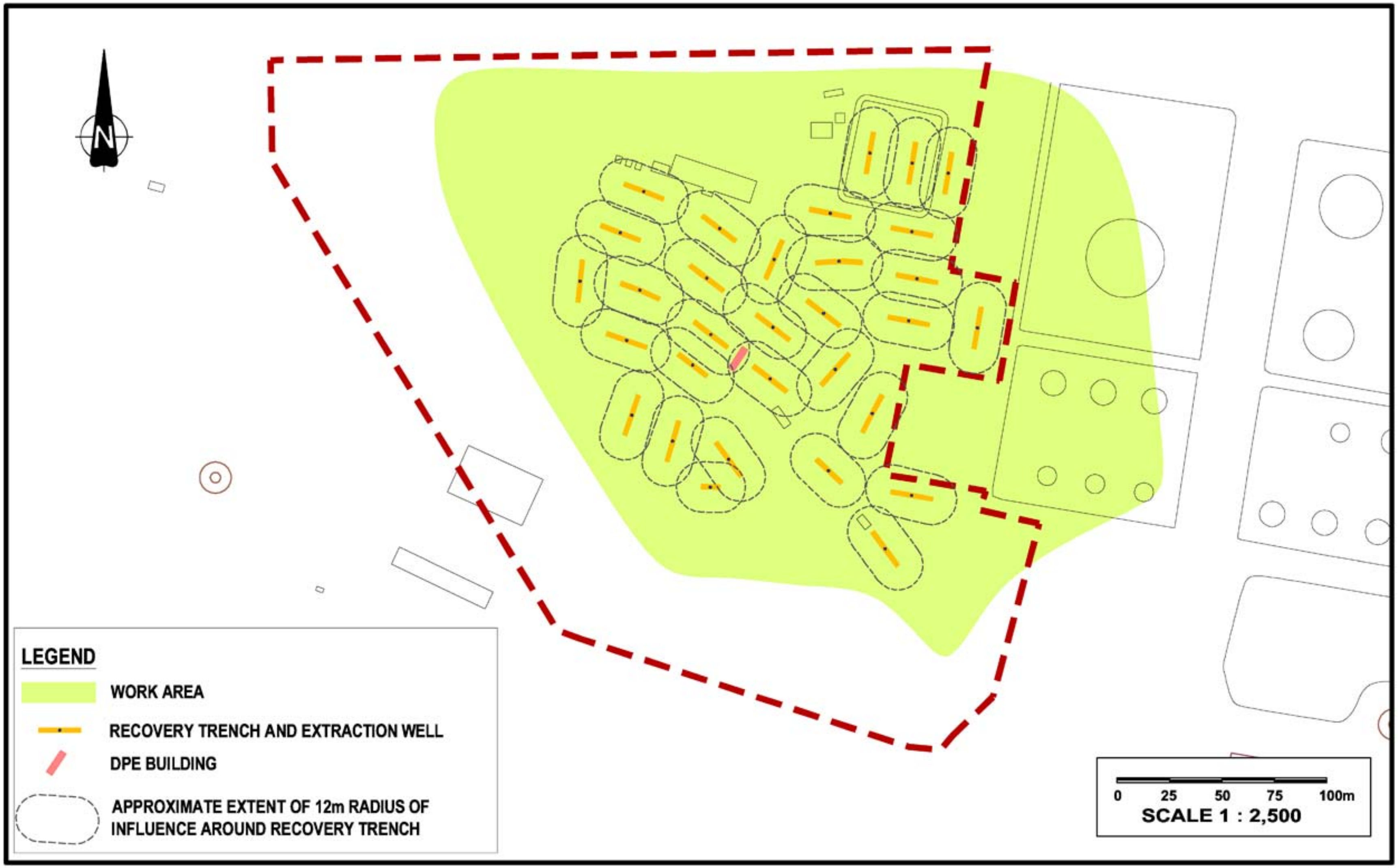
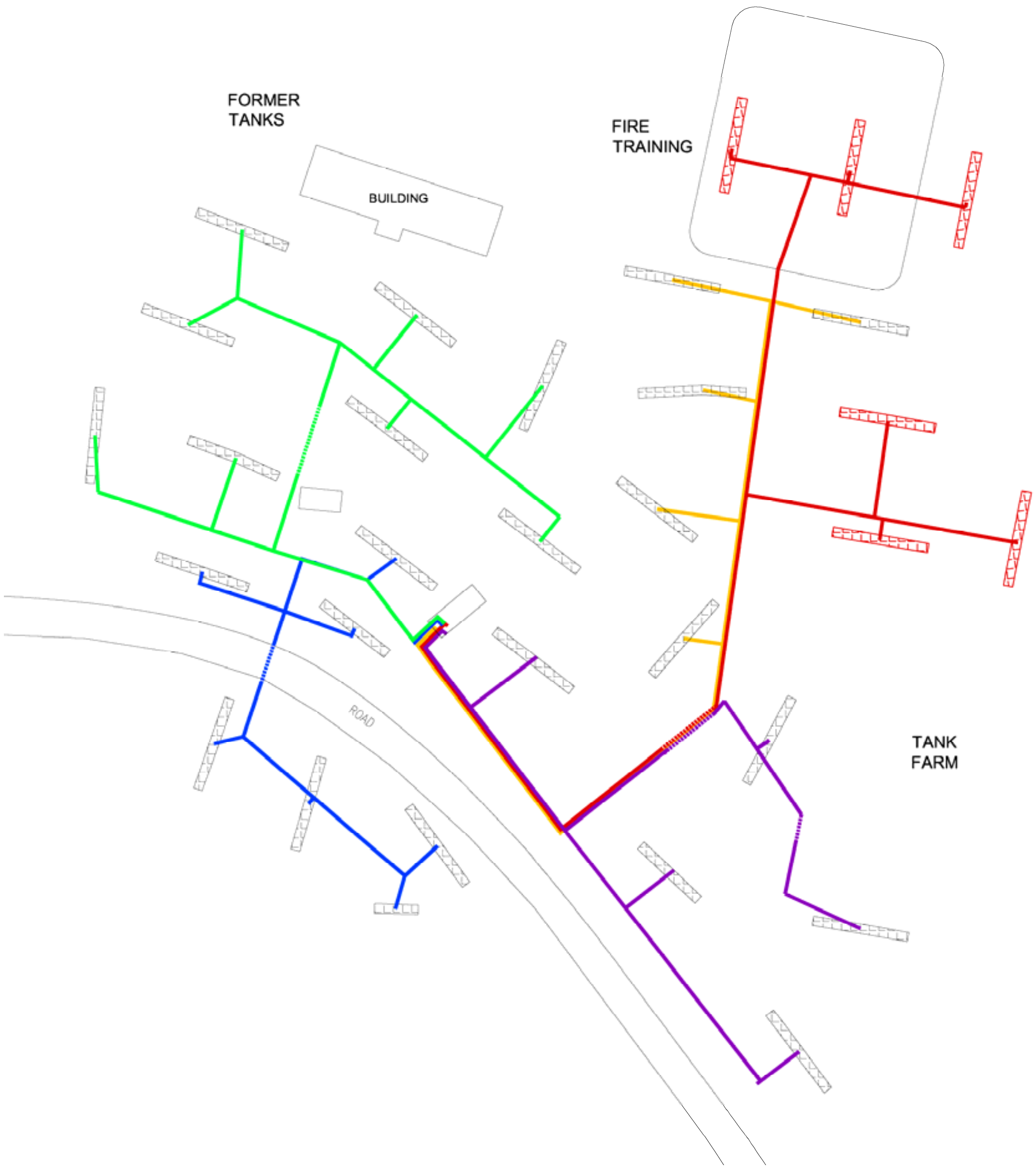
Trench Potential Radius of Influence



Fluid & Vapour Gathering System



- 30 trenches
- 7 fluid headers
- 4 vapour headers

DPE Remediation Facility

Hydrocarbon Mass Removal

	Days SVE or DPE Operational	Groundwater Pumped (m^3)	HC Mass Removal (kg)	HC Liquid Equivalent Barrels
2004	33	400	2,911	23
2005	51	553	7,313	59
2006	35	1,480	1,926	15
2007	112	1,043	7,856	63
2008	94	489	2,964	24
2009	78	1,941	2,674	21
2010 (up to 15-Oct-10)	95	2,800	27,580	221
TOTAL	**498 days**	**8,700 m^3**	**53,200 kg**	**470 barrels**

Based on LNAPL density of 770 kg/m3

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Challenges and Lessons Learned 1

Challenges	Lessons Learned and Solutions
Seasonal operation	▸Active layer is seasonal, not much to gain by designing to operate beyond May-October
Permafrost encroachment into trenches	▸Difficult to predict, spatially variable ▸About 30% of trenches require more operator attention ▸Well screen or pump intake in trenches may freeze off ▸Vaporization of hydrocarbon encourages freezing ▸Priority locations optimized with solar water heater ▸Take advantage of long summer daylight ▸Solar heating also enhances volatilization rate (water temperature raised 10°C)

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Solar Water Heater Prototype

Challenges and Lessons Learned 2

Challenges	Lessons Learned and Solutions
Flammable vapours	▸ Design avoids electrical equipment near DPE wellheads ▸ Solution was pneumatic pumps, limited heat trace
Downhole pump freezing over time	▸ Downhole pump freezing (submersible pneumatics) – water near 0^oC and volatile HC cools further ▸ Solved with above-ground diaphragm pumps ▸ Easier to service and diagnose problems
Variable performance & balancing flows	▸ Variable water flows between wells depending on local ice lenses and silt/sand permeability ▸ Customize operation with multiple headers ▸ Limiting flow rates to match well yield ▸ Optimizing use of instrument air

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Conclusions

- Complex Environment and Logistics
- Understanding Conceptual Model is Key
- Take Time to Properly Characterize
- Multiple Pilot Tests May be Necessary
- Expect Challenges as Full Scale System is Optimized
- Be Innovative – Use Site Conditions to Advantage