Remediation of LNAPL Contaminated Fractured Bedrock Using a Bioreactor Study in Southern Alberta

Jennifer Arnold, M.Sc., Geol.I.T., BIT, CEPIT

October 16, 2008

Chris Mathies, Tony Gregov, Al Jobson, Craig Langford

One Team. Infinite Solutions

Stantec

Outline

Site Location
Background

Previous Environmental Activities

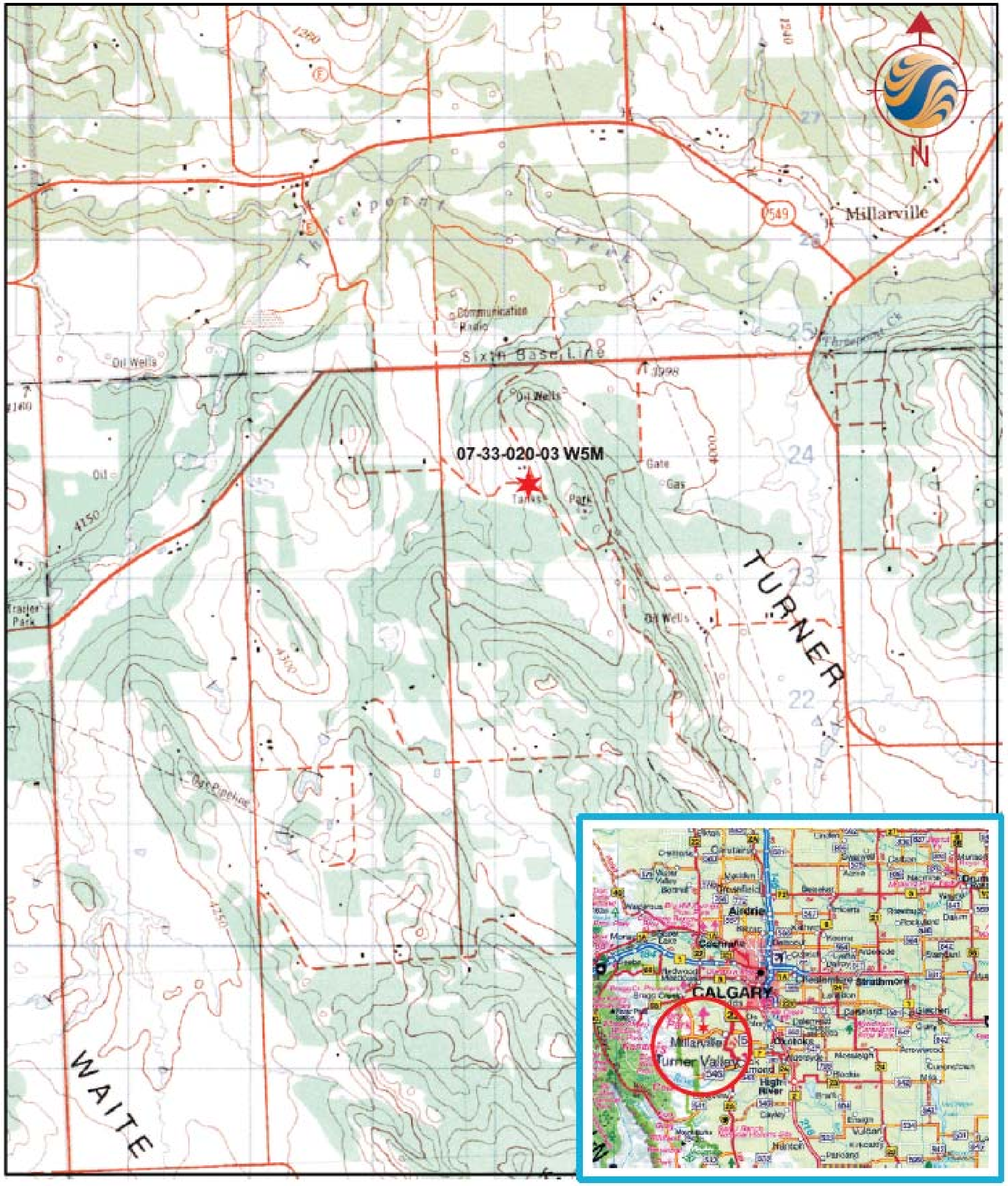
Objective

Bioreactor Study
Nutrient Amendment Study
N_2O Activity Study

Conclusions and Limitations

Site Location

Site is located southwest of Calgary



Site Plan

Surrounded by Forested and Agricultural Area

Several Domestic Use wells near the site

Datum: NAD 83
Projection: UTM Zone 11

1:2,500

Meters
0 15 30 60

Background
Land Use

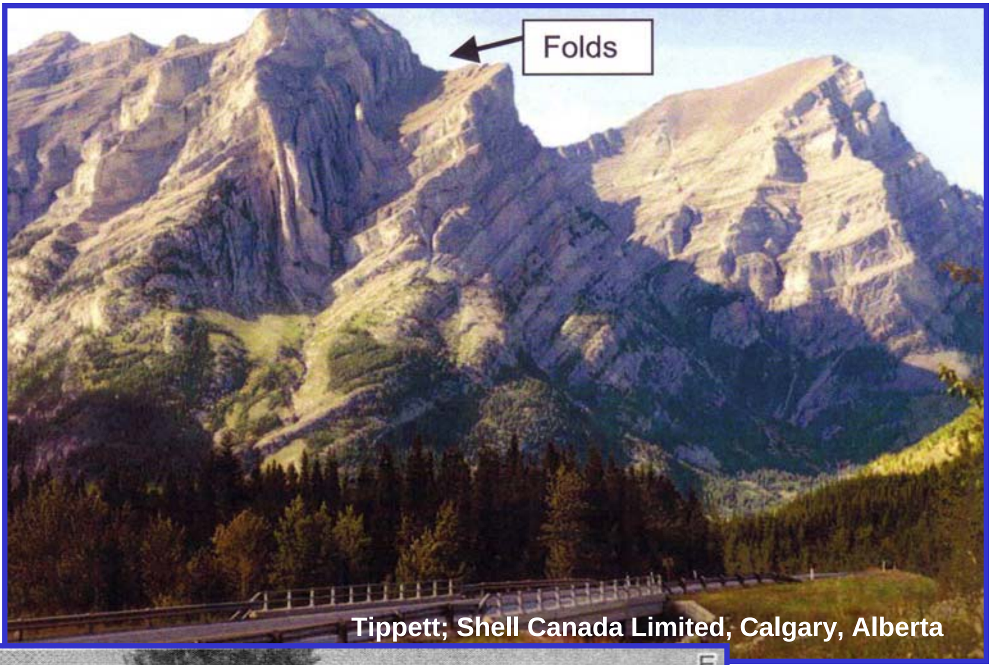
- Former oilfield 'landfill' bone-yard
- Operation from 1951
- Closed in 1985
- Total of 5 unlined landfill cells
- Impacted with Light Non-Aqueous Phase Liquids (LNAPL)

Background
Contaminants

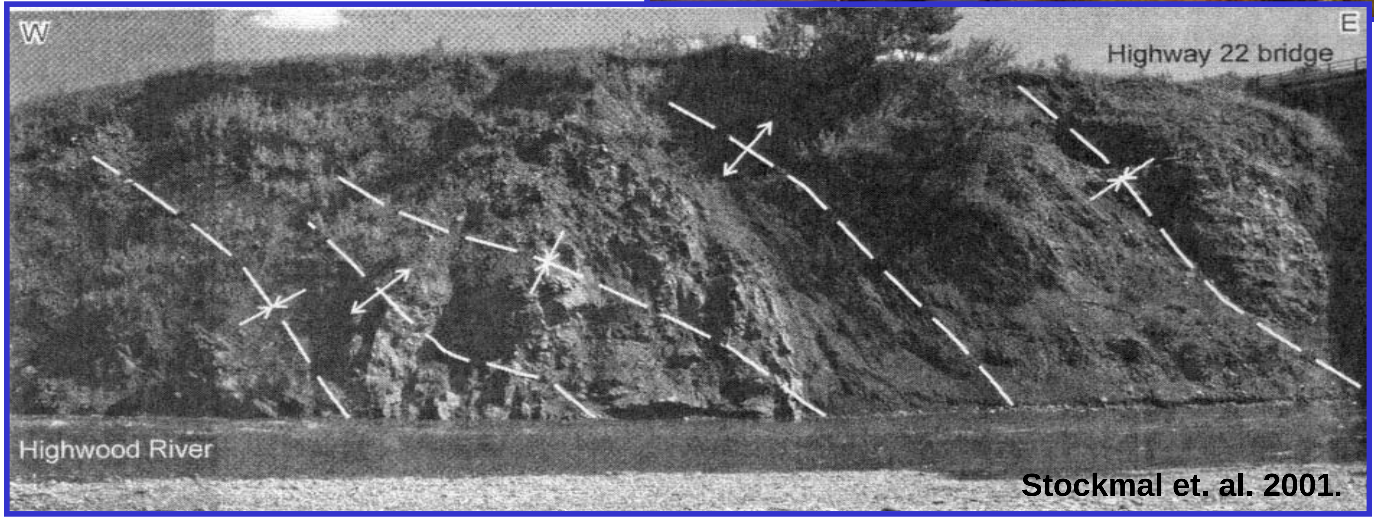
- LNAPL and Chloride contaminants of concern
- LNAPL characterized as refined lubricant oil
- 2 phases of LNAPL; free phase and emulsified

Background
Geology

- Foothills of the Rocky Mountains
- Passive continental margin
- Thin-skinned thrust-and-fold belt mechanics
- North-east of the Longview Deformation



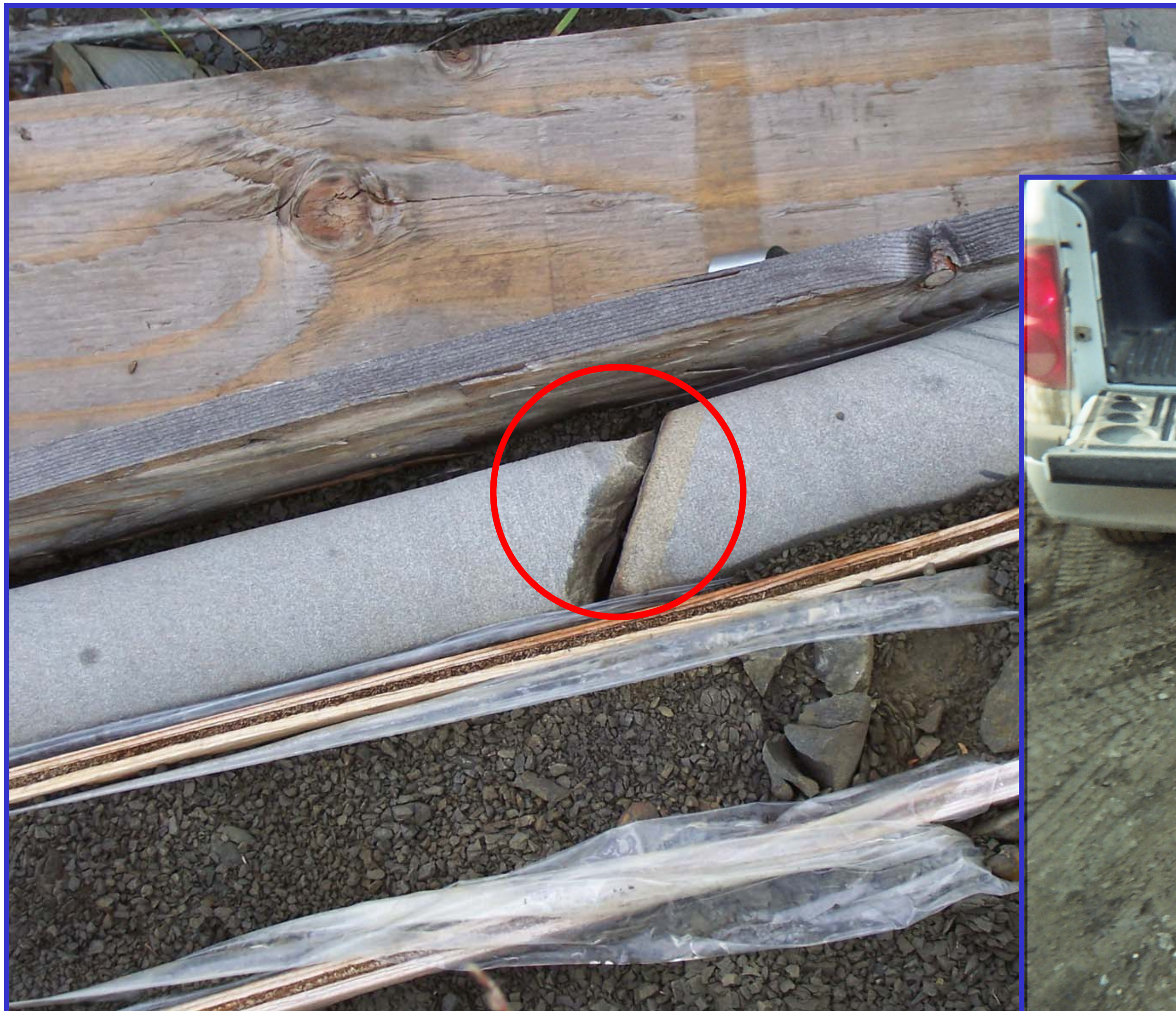
Tippett; Shell Canada Limited, Calgary, Alberta



Stockmal et. al. 2001.

Background
Geology

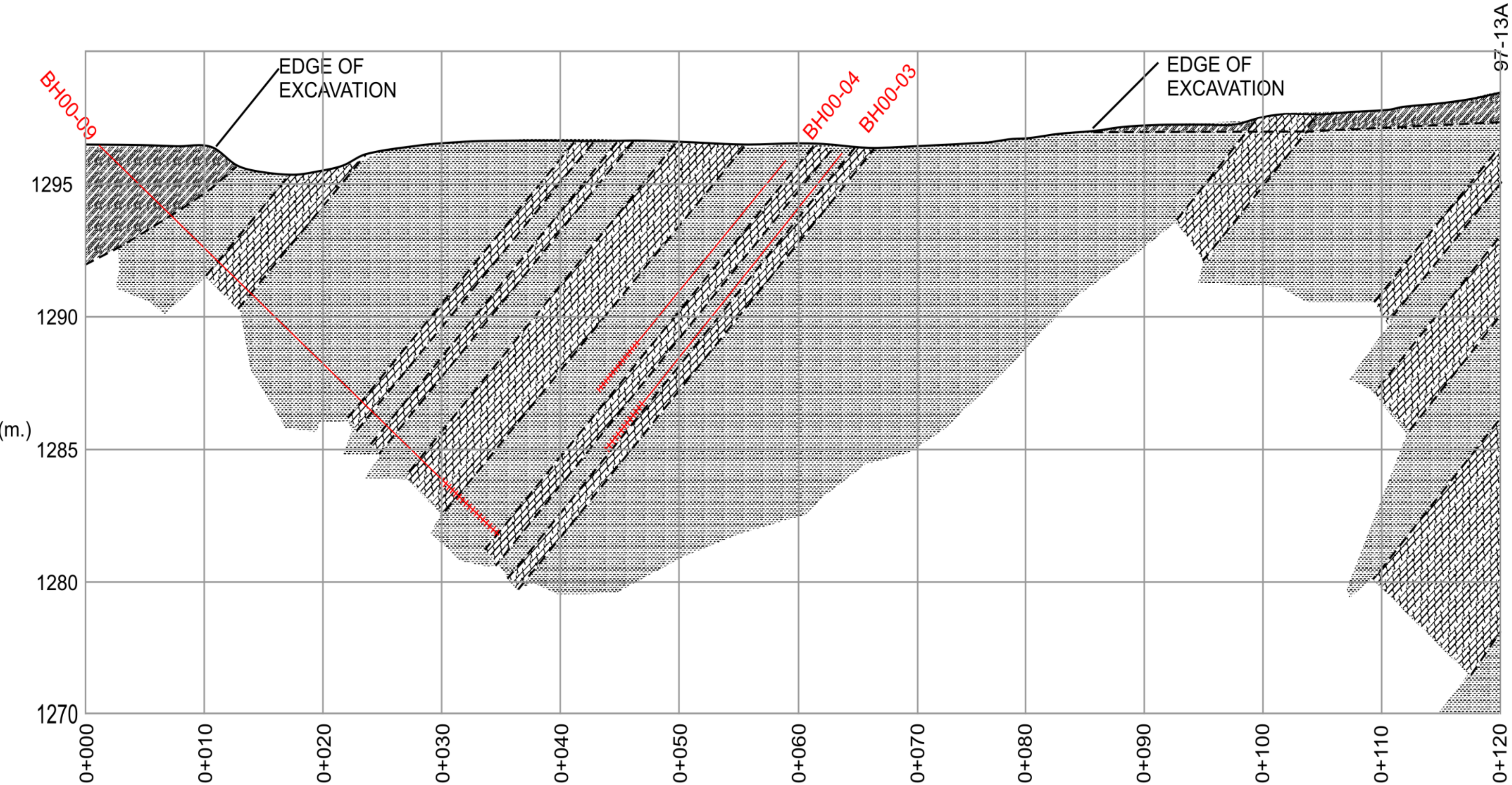
- Shale, sandstone and siltstones
- Interbedded mudstones and minor coal
- Competent to highly fractured



Hydrocarbon staining along fractures

Highly fractured throughout bedrock

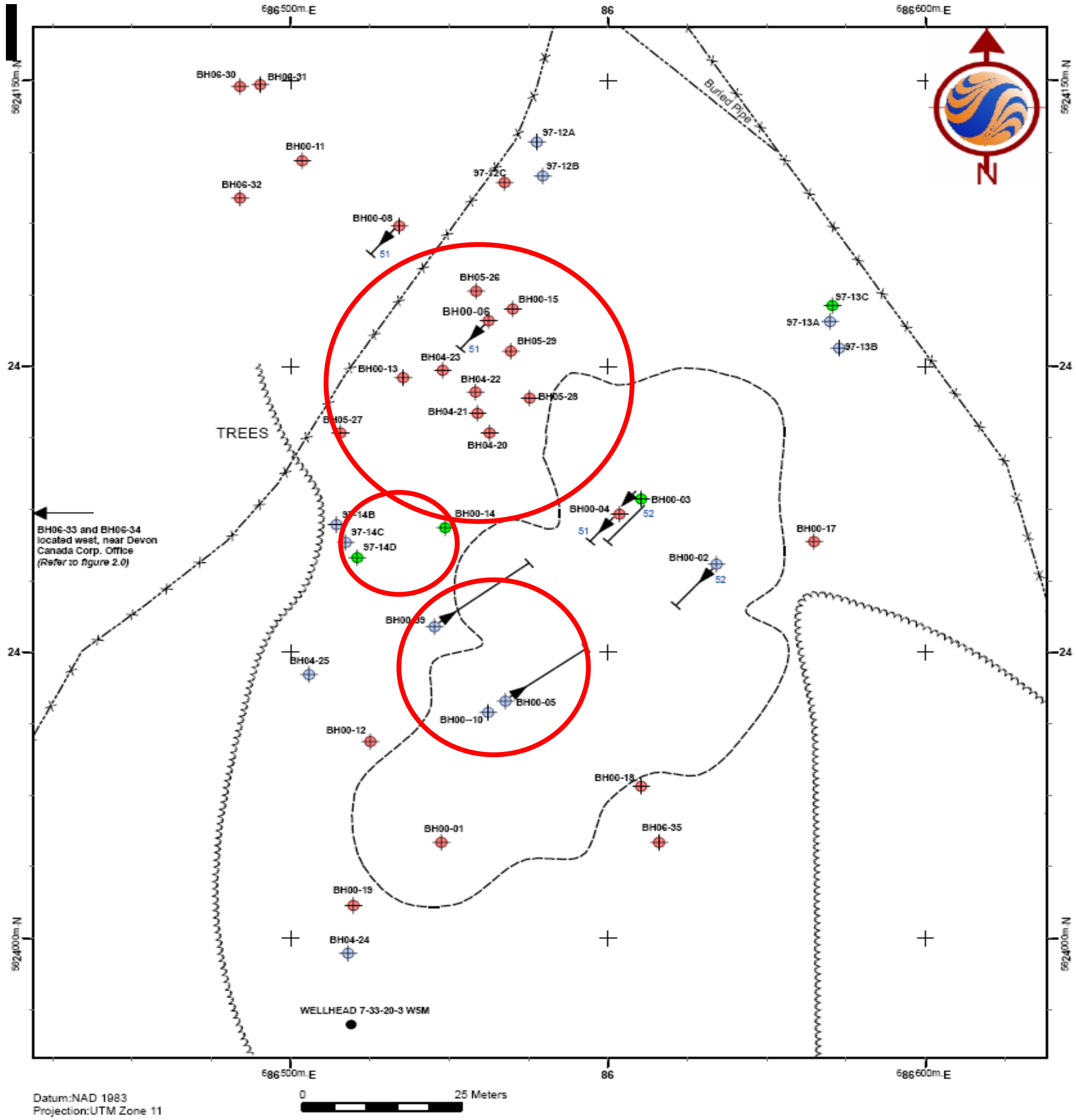
Background
Geology



CROSS SECTION B-B'
N.T.S.

Stantec

Monitoring Well Locations



Previous Environmental Activities

- Excavation
- Groundwater monitoring
- Dual phase vacuum extraction

Previous Environmental Activities

- Dual phase vacuum extraction (DPVE) pilot study conducted in 2002
- Full scale operations conducted in 2003 and 2005
- DPVE system removed in 2005

Previous Environment Activities
DPVE System performance

Recovery Rates	2002 DPVE	2003 DPVE	2005 DPVE
LPH recovery rate (L/hr)	0	<0.1	0
Dissolved phase recovery rate (L/hr)	0.088	<0.1	0.01
Vapour phase recovery rate (L/hr)	4.0	0.5	0.3
Estimated biological phase recovery rate (L/hr)	7.0	0.5	1.5
Total hydrocarbon recovery rate (L/hr)	1.9	1.8	1.8
Fluid recovery rate (L/hr)	34	120	439
Recovered Volumes	**2002 DPVE**	**2003 DPVE**	**2005 DPVE**
LPH (L)	0	25	0
Dissolved phase (L)	1	10	6
Vapour phase (L)	153	1,417	140
Estimated biological phase (L)	329	694	895
Total hydrocarbons (L)	483	2,146	1,041
Fluids (L)	11,000	148,500	242,000

Why a Bioreactor?

Bacteria have the ability to reach into bedrock fracture networks having access to impacts where vacuum driven systems cannot

Bacteria have the capability to breakdown hydrocarbons to some extent

Flexible system design with a relatively small ecological footprint

Objective

Reduce LNAPL and dissolved hydrocarbon impacts on the site using indigenous microbes

Innovative approach with little to no ecological footprint

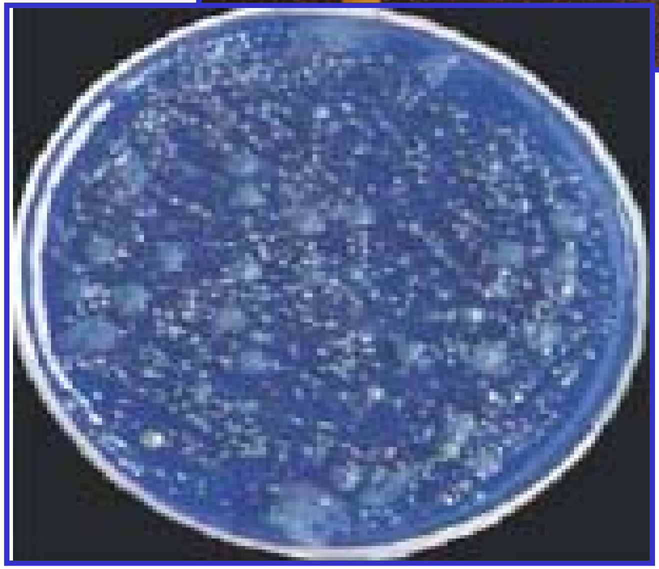
Optimize the existing bioreactor system

Bioreactor Study
System Design

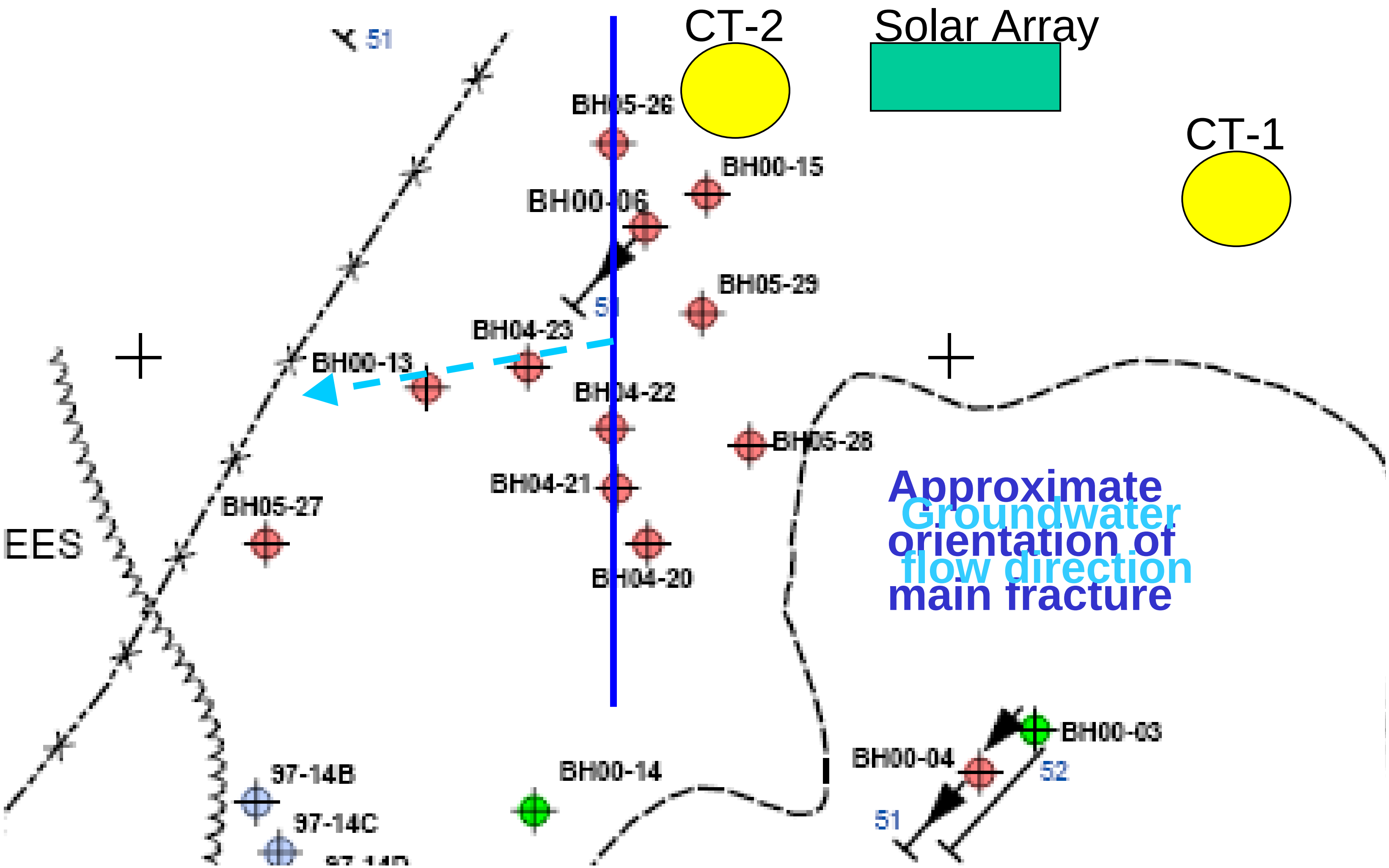
- Implemented in 2005
- 2 - 10,000 L Tanks
- Solar power

Bioreactor Study
Concept

- Extract groundwater containing indigenous microbes
- Amplify indigenous cultures in aboveground storage tanks by the addition of macronutrients
- Hydrocarbon impacts are the carbon source
- Inject amplified cultures back to formation via gravity injection



Bioreactor Study



Bioreactor Study

System Design

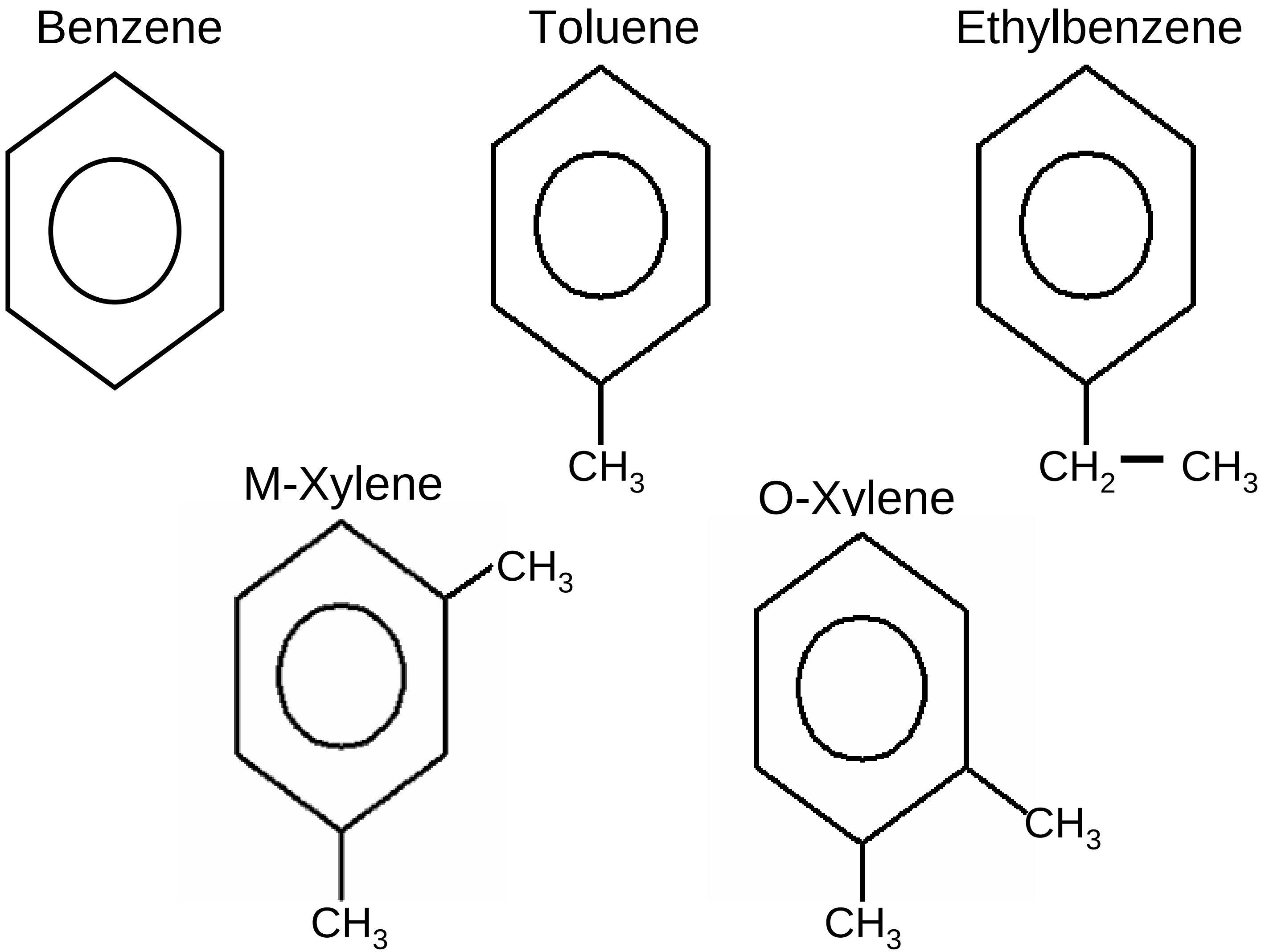
Bioreactor Study

Design

Bioreactor Study
Results

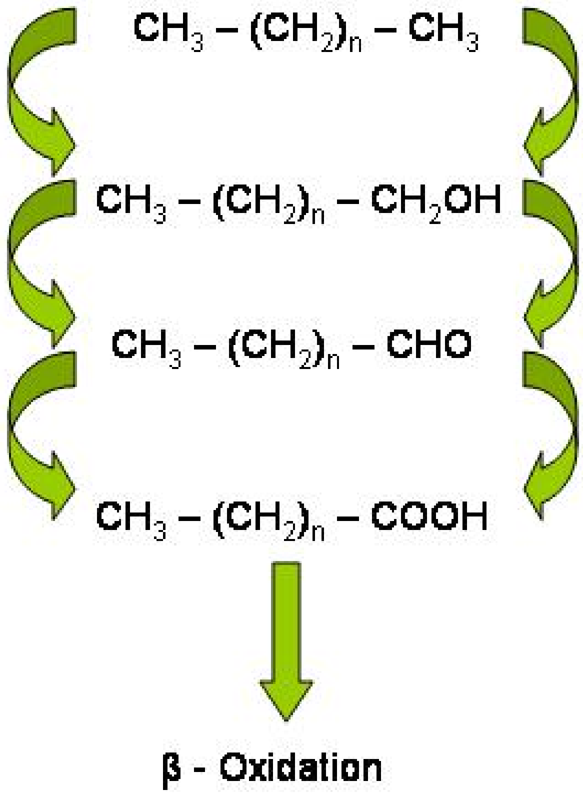
	Initial		After Incubation	
	CT1	**CT2**	**CT1**	**CT2**
Benzene	**0.0111**	**0.0136**	<0.00050	<0.00050
Toluene	<0.00050	<0.00050	<0.00050	<0.00050
Ethylbenzene	<0.00050	<0.00050	<0.00050	<0.00050
Xylenes	0.00383	0.00501	<0.00050	<0.00050
F1-BTEX	<0.1	<0.1	<0.1	<0.1
F2(C10-C16)	**1.9**	0.83	**2.3**	**8.4**

Bioreactor Study

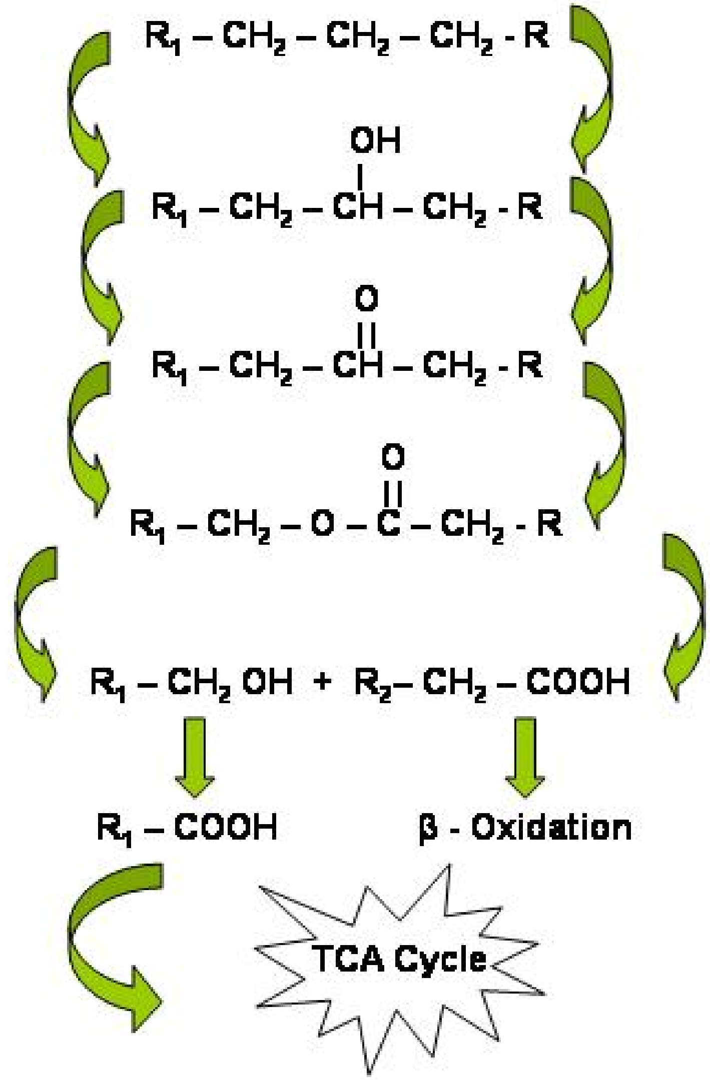


Bioreactor Study

H



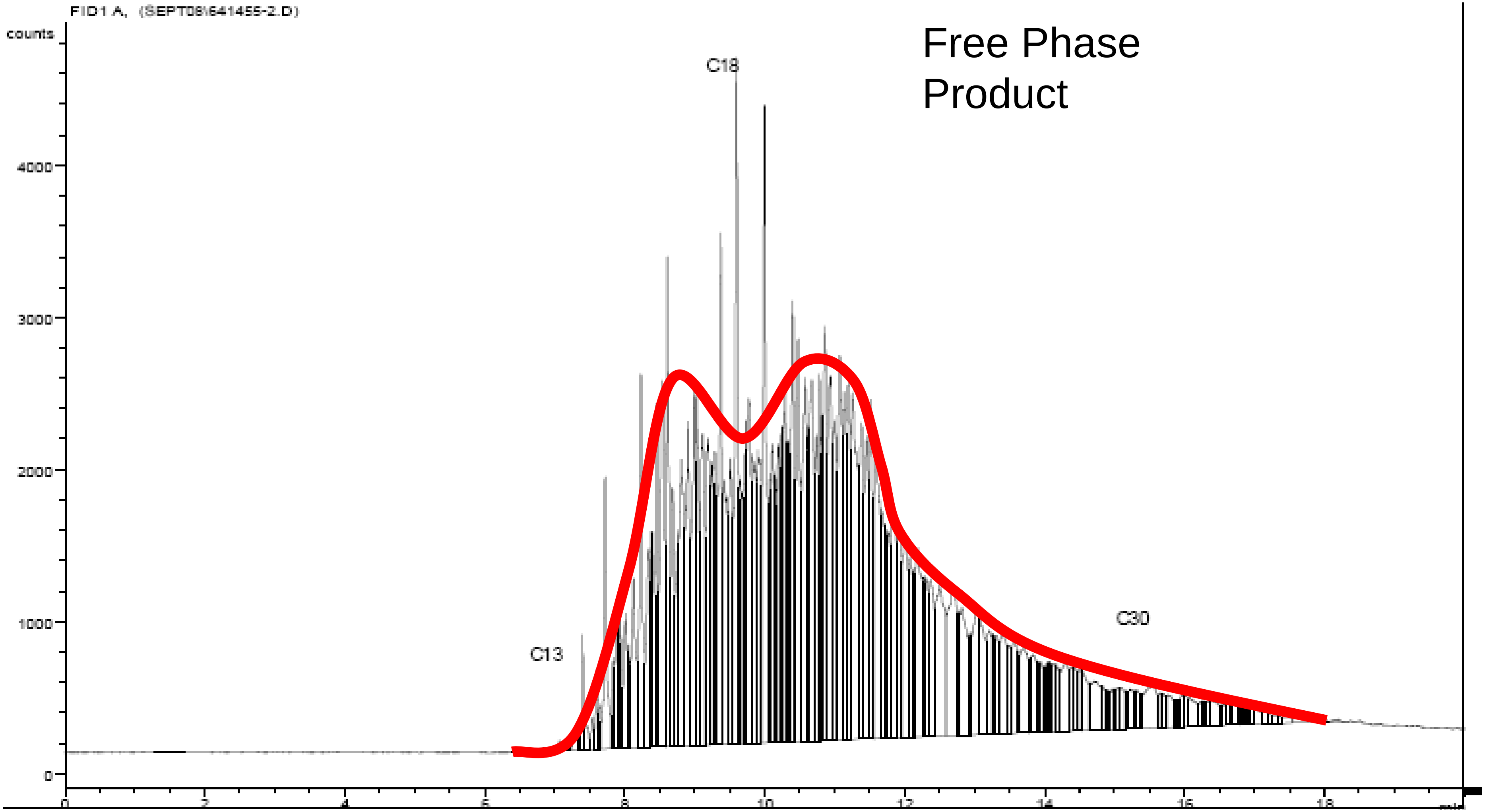
Terminal Methyl Oxidation



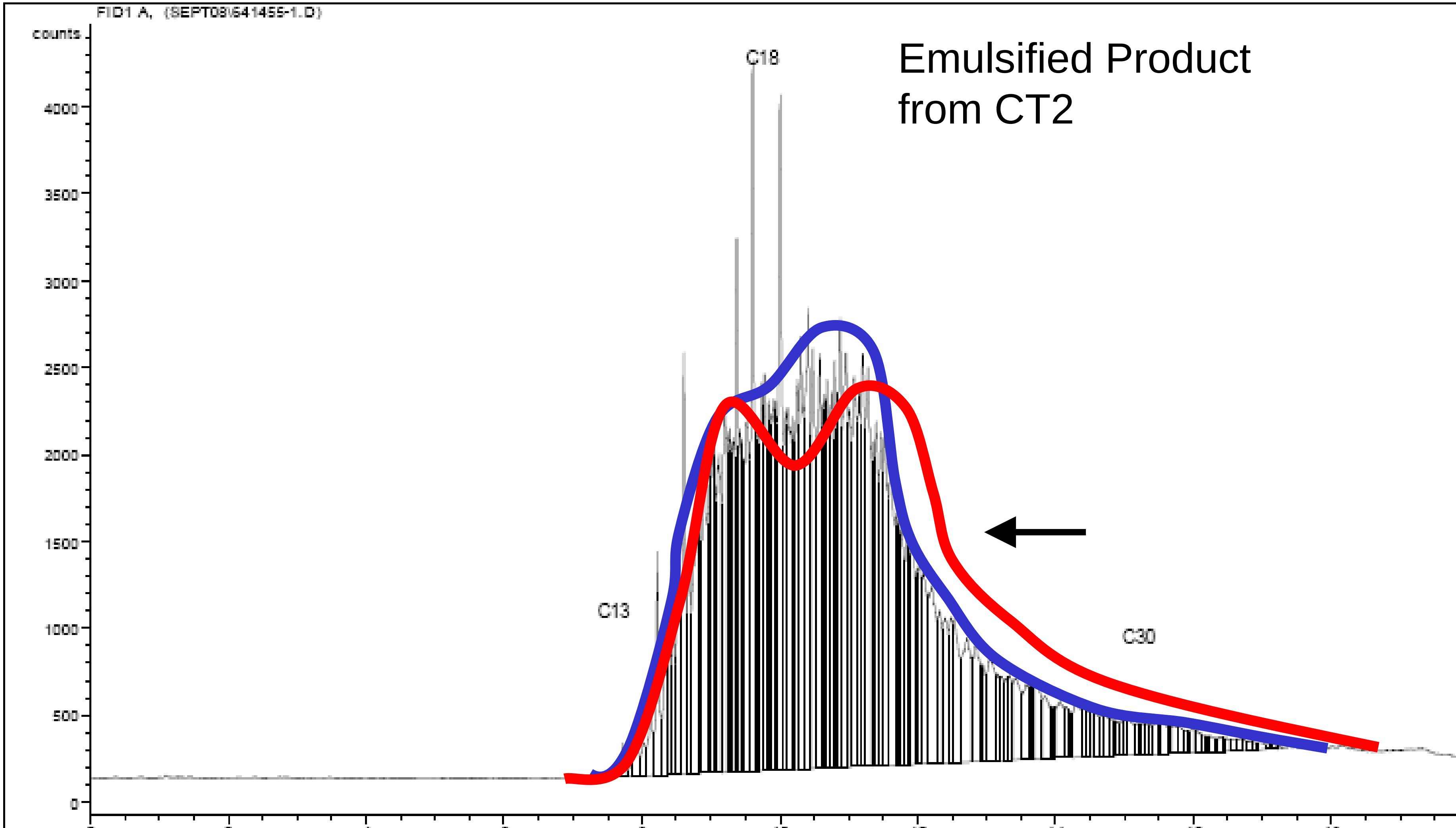
Subterminal Methyl Oxidation

Adapted from Chapelle. 2001.

Bioreactor Study
Results

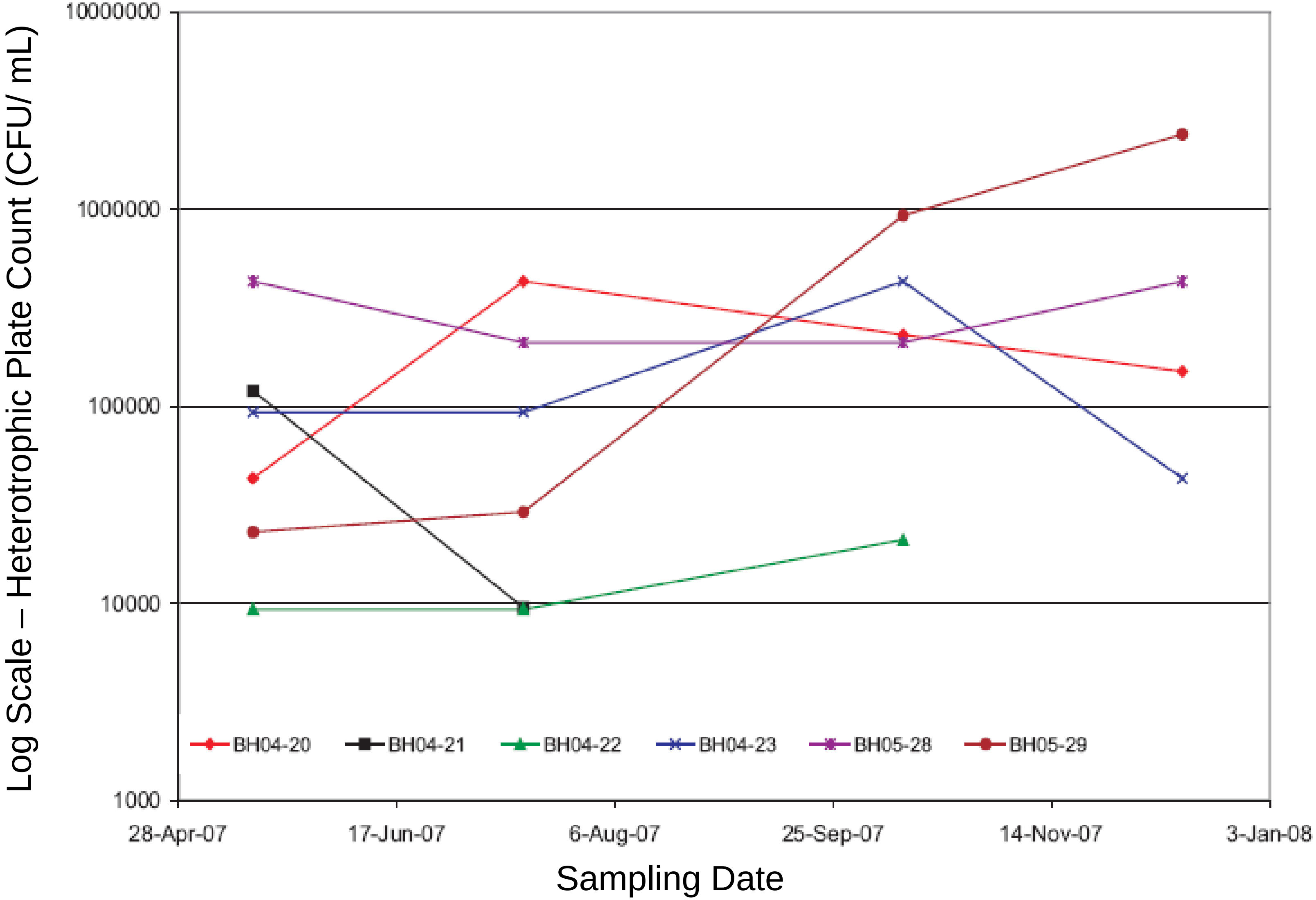


Bioreactor Study
Results



Bioreactor Study

Results



Stantec

Nutrient Amendment Study

Objectives

Compare two different nutrient amendments:

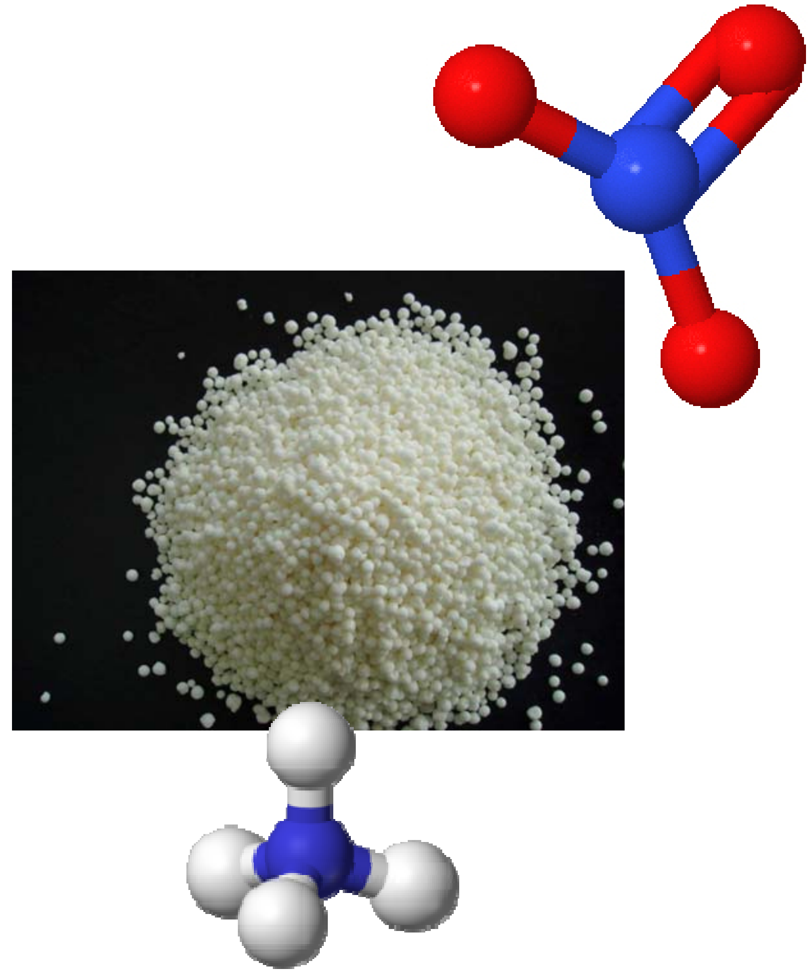
Calcium Nitrate and Urea

Elemental specific; a modified bacterial media

Nutrient Amendment Study

Methods

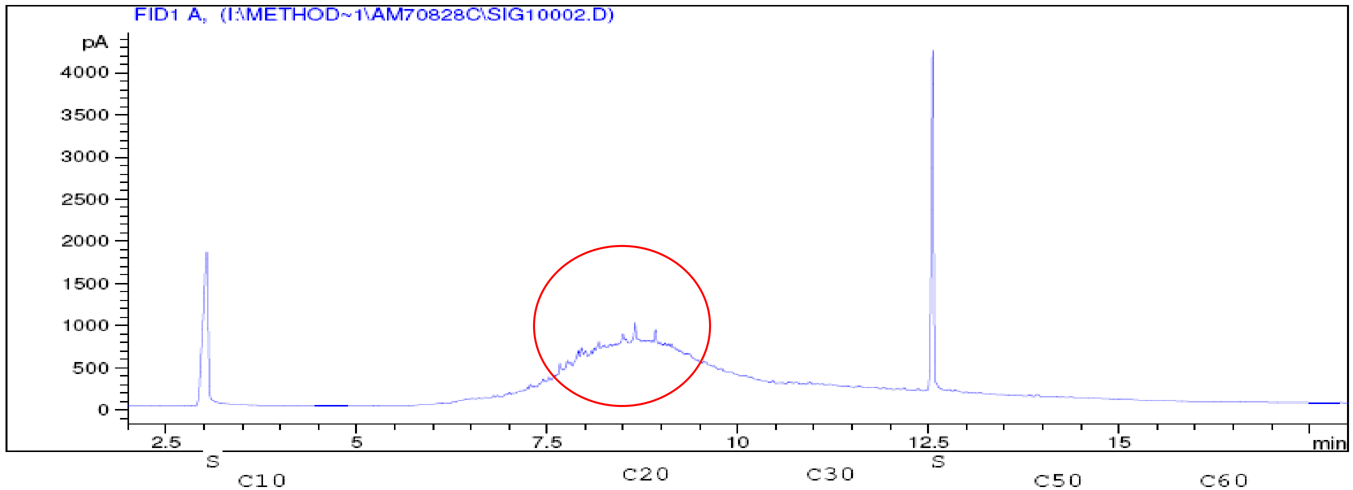
- CT1 – Elemental Amendment
- CT2 – Calcium Nitrate Amendment
- Sample each culture tank before nutrient addition and after the incubation period
- Compare dissolved hydrocarbon concentrations, bacterial counts and gas chromatogram (GC) results



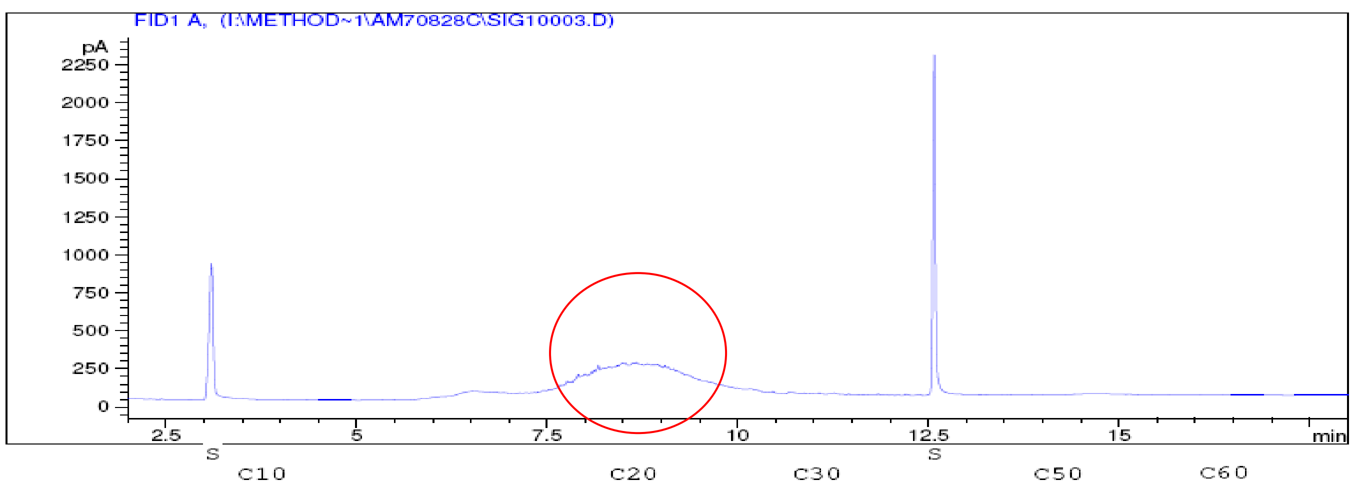
Nutrient Amendment Study

Results

CT2 – Calcium Nitrate Amendment

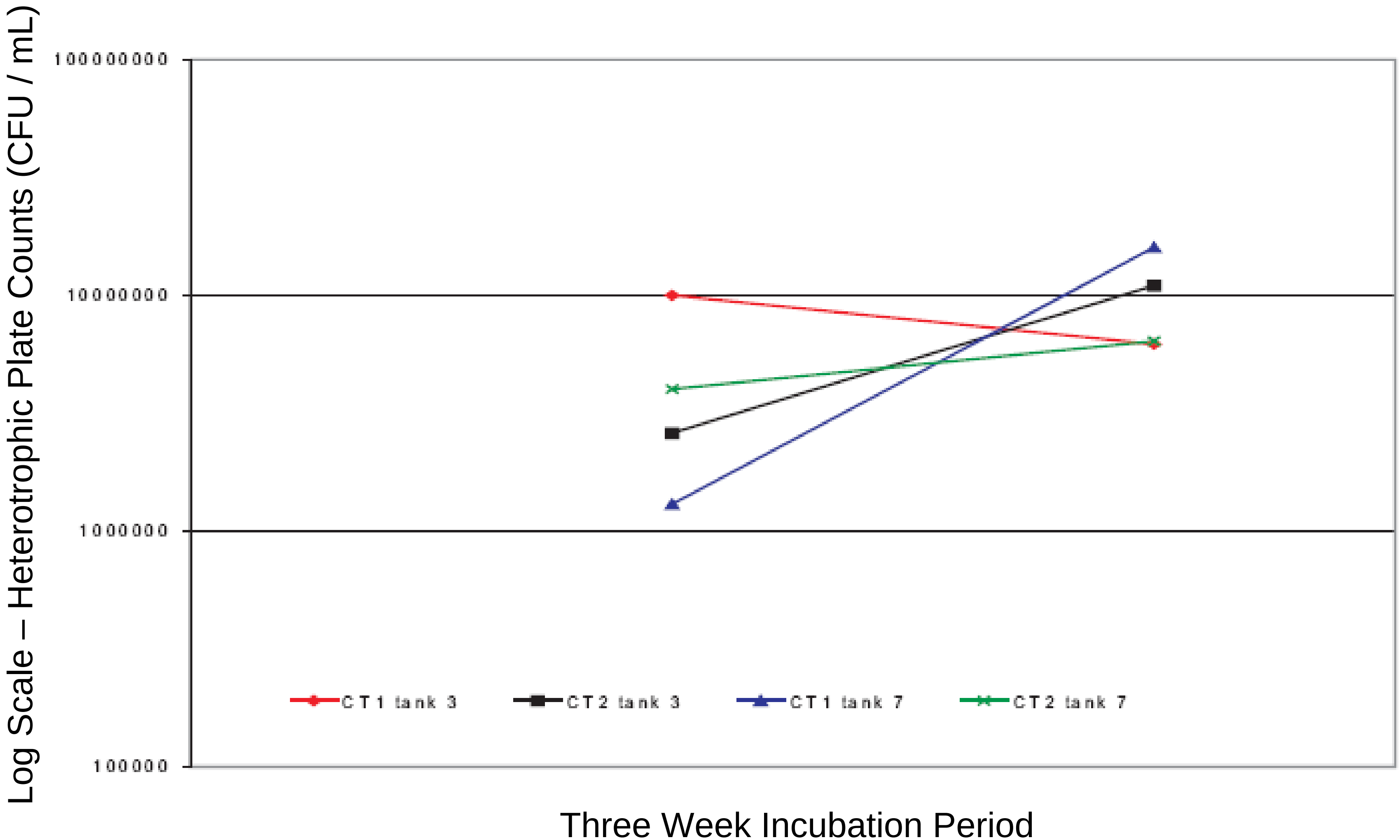


CT1 – Elemental amendment



Nutrient Amendment Study

Results

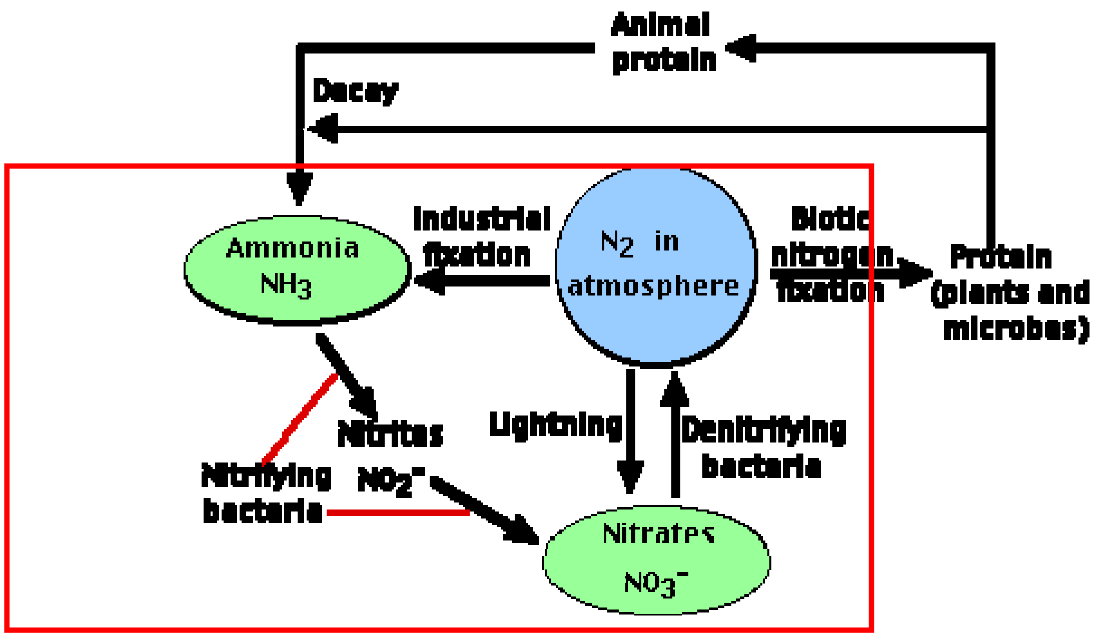


N_2O Activity Study
Objectives

- Denitrifiers produce N_2O as a metabolic by-product

Higher N_2O production = Higher bacterial activity

- Bacterial activity/ metabolism needed for hydrocarbon breakdown



N_2O Activity Study
Methods

- Control group – no nutrients added
- CT1 – elemental amendment
- CT2 – calcium nitrate amendment
- Steel wool – Eh poiser
- Gas syringe sampling

N_2O Activity Study

Bacterial Growth

L = log colony forming units

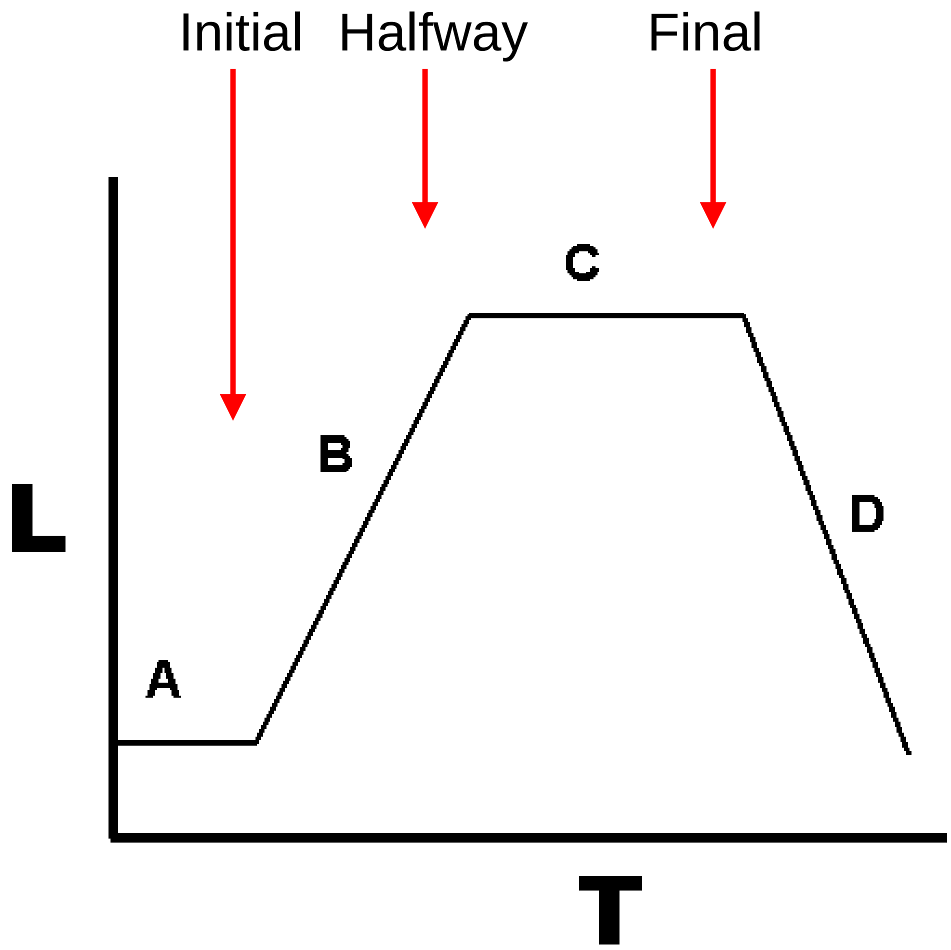
T = Time

A = Lag phase

B = log or exponential phase

C = Stationary phase

D = Death phase



N_2O Activity Study
Results

Sample position in experiment	Sample Date	Sample					
		CT0-N	CT0-SW	CT1-N	CT1-SW	CT2-N	CT2-SW
		ppmv	*ppmv*	*ppmv*	*ppmv*	*ppmv*	*ppmv*
Initial	20-Nov-07	7.0	7.0	13.0	11.0	3.0	4.0
Halfway	27-Nov-07	9.93	8.92	7.59	46.5	2.26	3.65
Final	13-Dec-07	5.52	2.43	3.76	3.82	2.82	1.99

Conclusions

- Bioreactor reduced dissolved impacts and shifted the free phase product towards C_{18}
- Elemental nutrient amendment increased bacterial populations and reduced dissolved impacts
- Elemental nutrient amendment produced higher N_2O activity

Limitations

The presence of free product on the site masks the effects of the bioreactor on the site

Future Remedial Activities

Additional site characterization for model building and effective LNAPL removal

Questions?

devon

Stantec