Diffusive-Based Aerobic Bioremediation of Petroleum Hydrocarbon Plumes in High Temperature, Saline Groundwater

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2015 REMEDIATION TECHNOLOGIES SYMPOSIUM

BANFF, ALBERTA

Agenda

Site Backgrounds
- Groundwater Salinity
- Groundwater Temperature

Pilot-Scale Designs

Results – Site A

Results – Site B

Sequential Remediation Approach

Questions?

Background

2 Sites (Site A, Site B)

Two bulk plants, refined petroleum hydrocarbon
- BTEX, MTBE, PAHs

Shallow groundwater
- ~ 5 and 2 mbgs

Groundwater velocity
- ~ 25 and 7 m/year

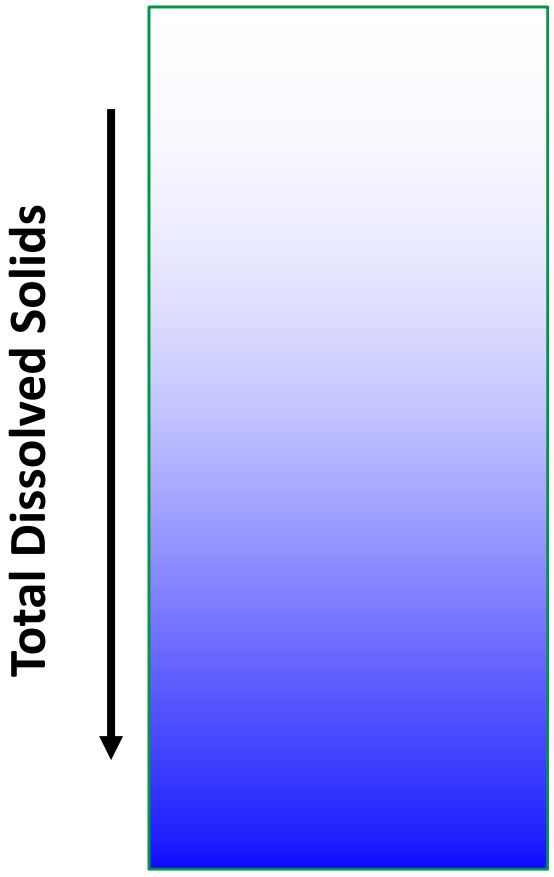
Carbonate buffered
- pH 6.7 to 7.1

Anoxic Groundwater (~0.2 to 0.7 mg/L O_2)
- Sulphate reducing

Diverse bacteria populations
- SRB, IRB, HAB

Site conditions – Large NAPL plumes, small dissolve plumes – why?
- Temperature?

Background



Fresh Water 1 - 1,000 mg/L

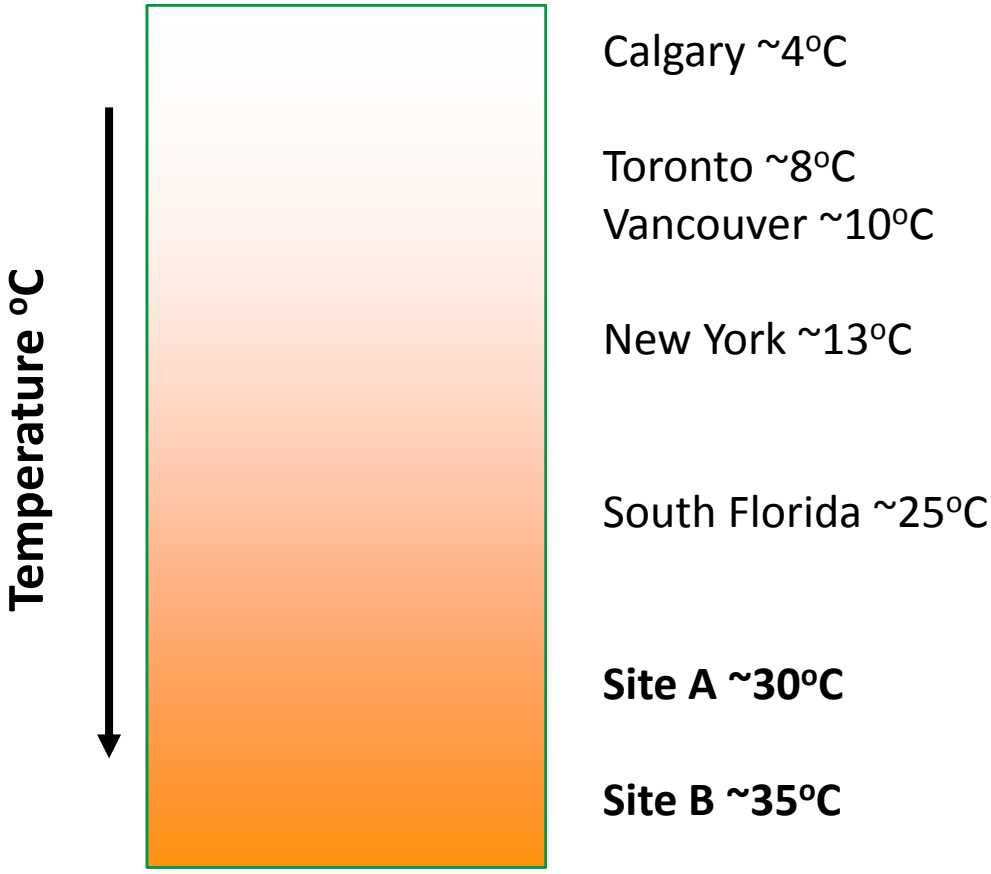
Site A ~ 5,700 mg/L

Saline Water >10,000 mg/L

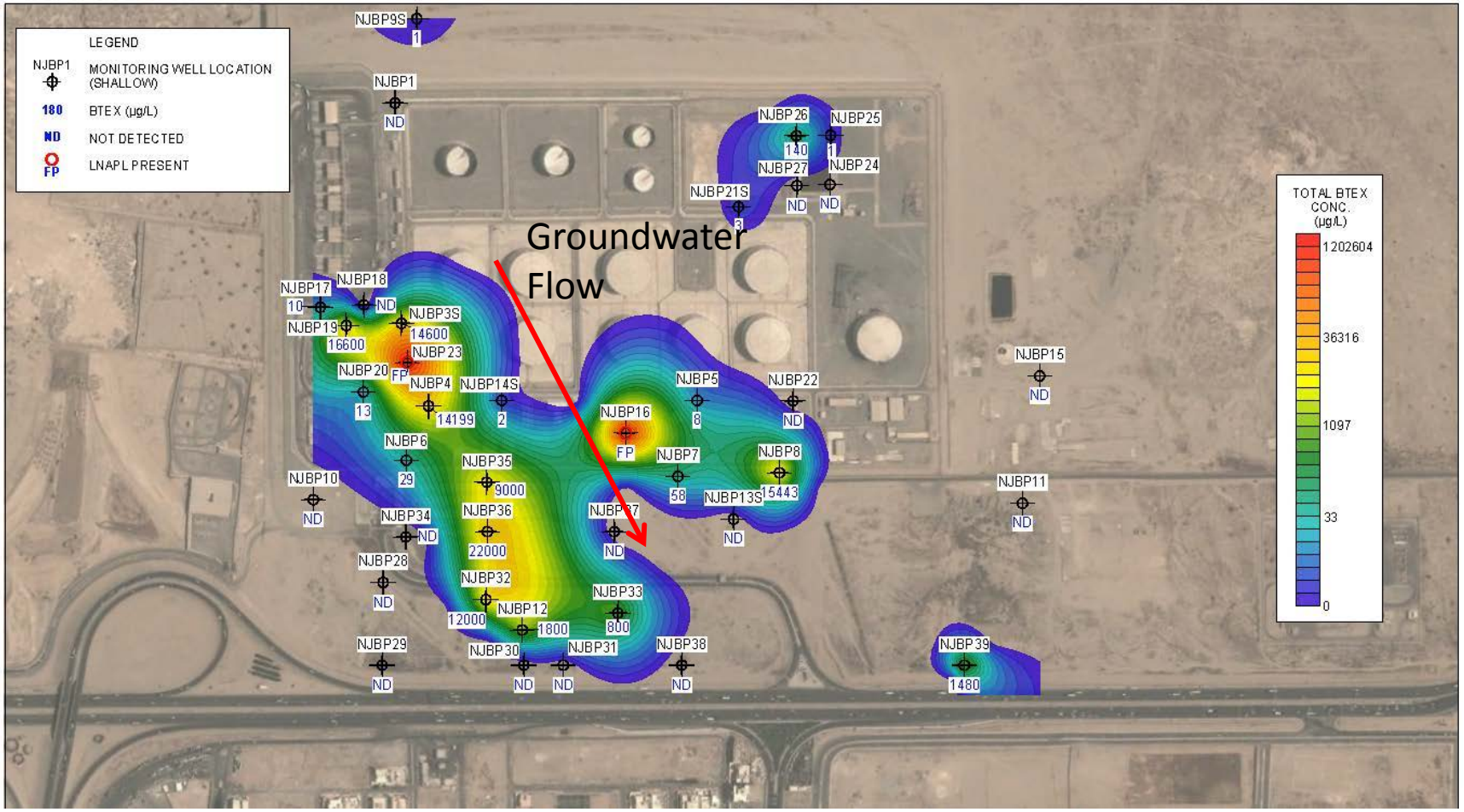
Site B ~16,600 mg/L

Sea Water ~ 35,000 mg/L

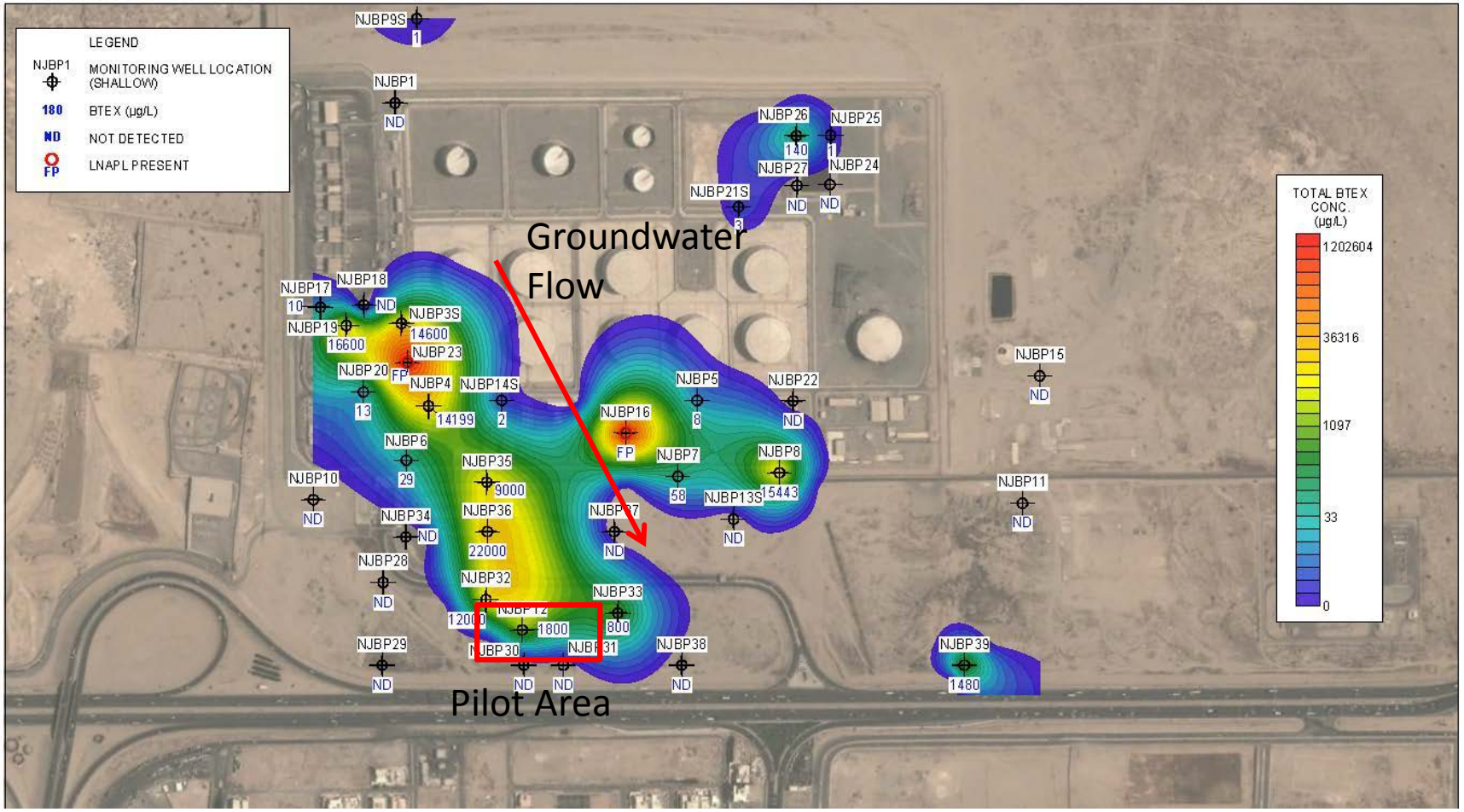
Background


Temperature °C
Calgary ~4°C
Toronto ~8°C
Vancouver ~10°C
New York ~13°C
South Florida ~25°C
Site A ~30°C
Site B ~35°C

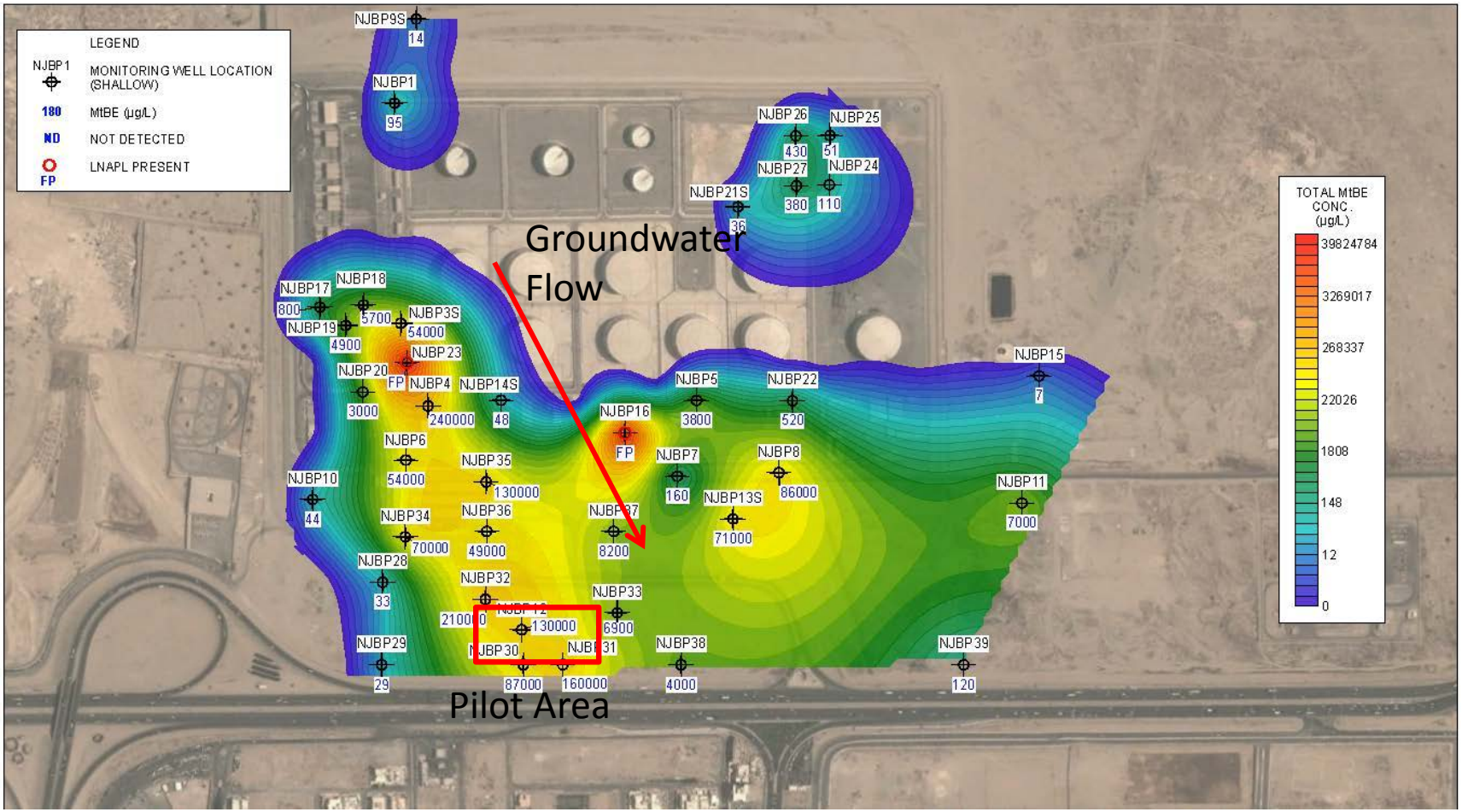
Site A - BTEX Plume



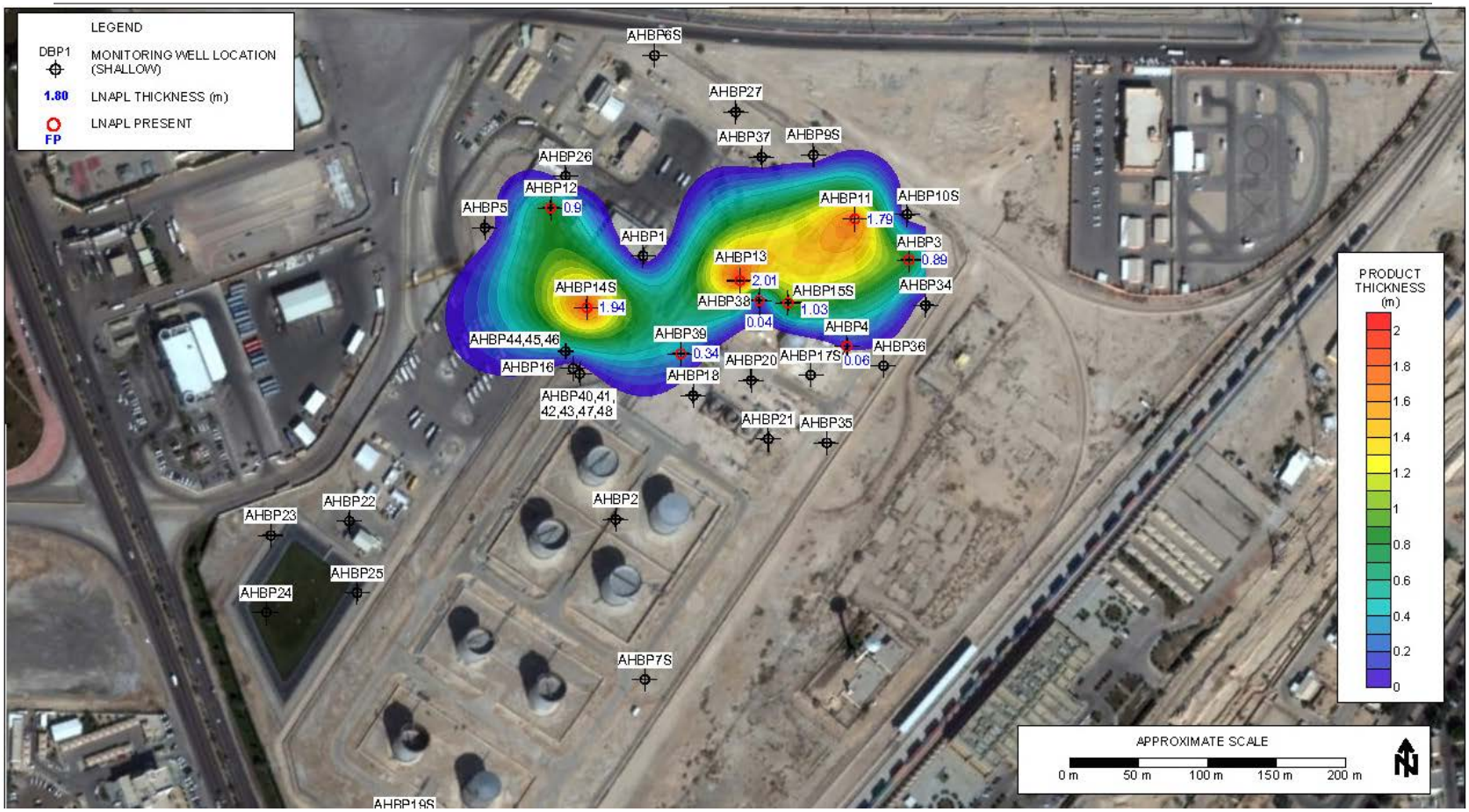
Site A - Pilot Area



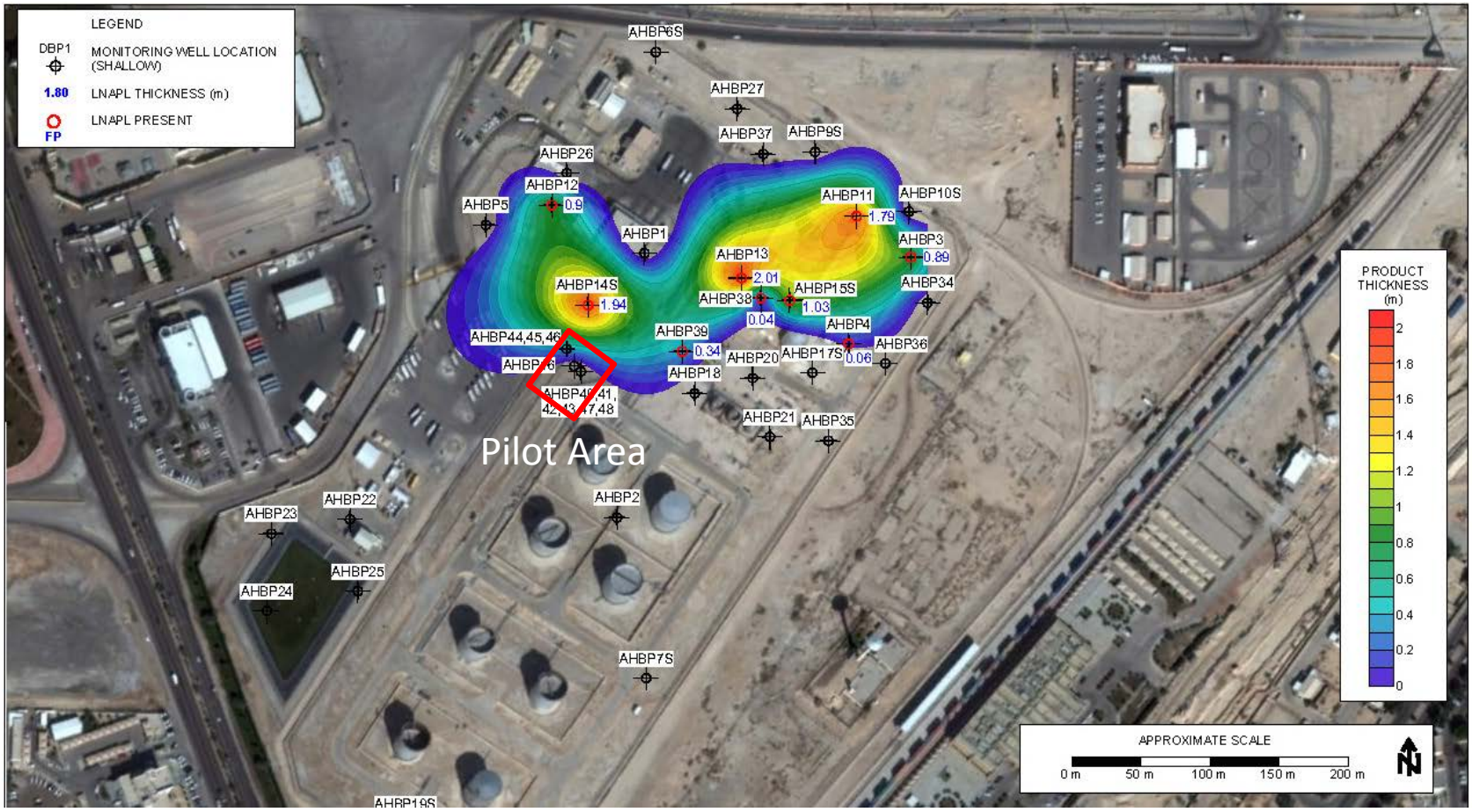
Site A - MTBE Plume



Site B – LNAPL Plume



Site B – Pilot Area



Pilot Scale

High dissolve concentrations

- BTEX – 8 mg/L and 11 mg/L
- MTBE – 0.2 mg/L and 120 mg/L

Sequential Treatment Approach

- Bioremediation - Diffusive device
  - Waterloo Emitters
- Chemox – percarbonate vs persulphate
  - Kashir & McGregor, 2014
- Sulphate reducing zone

Pilot Scale - Design

Will bio/chemox be effectiveness in warm/saline environment?

Oxygen solubility decrease with temp increase.

Studies/Project completed @ <10 to 20^{o}C

Corseuil & Weber Jr (1994)

- BTEX Degradation rates triple for every 10^{o}C increase.

Numerical modeling suggests degradation of 35x to 85x those published for low temperature sites.

Oxygen scavengers (Br, Cl, CO_3) in saline groundwater consume oxidant?

Saeed M.Sc. Thesis and laboratory work suggests chemox could be effective.

Pilot Scale - Design

Addition of oxygen diffusing devices

- Waterloo Emitters

Permeable reactive “barrier”

No vertical limitation (stackable)

O_2, H_2, Tracers (SF_6)

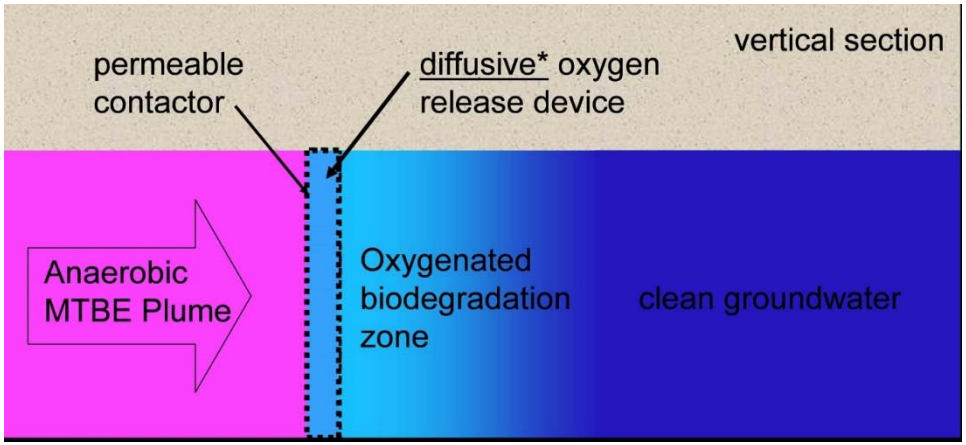
Fick’s Law

Pilot Scale - Design

Typical Southern Ontario Results (7-10^{o}C GW)

- Anaerobic influent – common of PHC plumes
- Supersaturated DO within emitter wells
- Saturated DO down gradient wells

Is the measurement of DO concentrations down gradient of the emitters a good measure of success?



Source: Wilson

Pilot Scale - Design

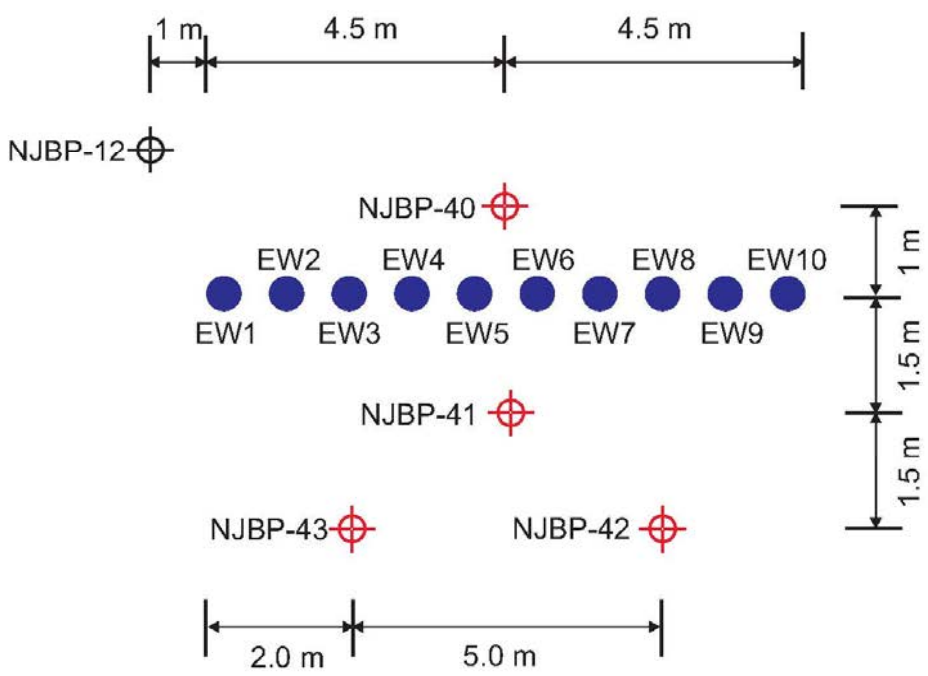
Perpendicular to groundwater flow
- ~ 1 to 1.5 m spacing

Tubing Selection
- LDPE – ~0.2 to 0.6 L/day/emitter
- Silicone – ~1.7 to 7.3 L/day/emitter

Operating pressure
- LDPE - ~60 to 100 psi
- Silicone - ~10 to 20 psi

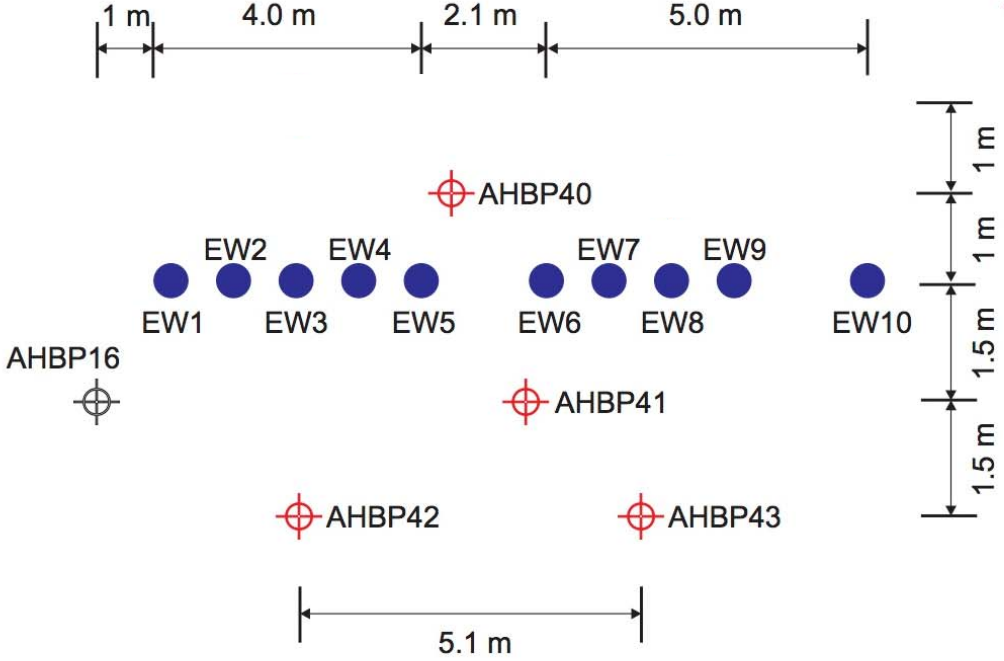
Source: Wilson

Pilot Scale Design - Site A



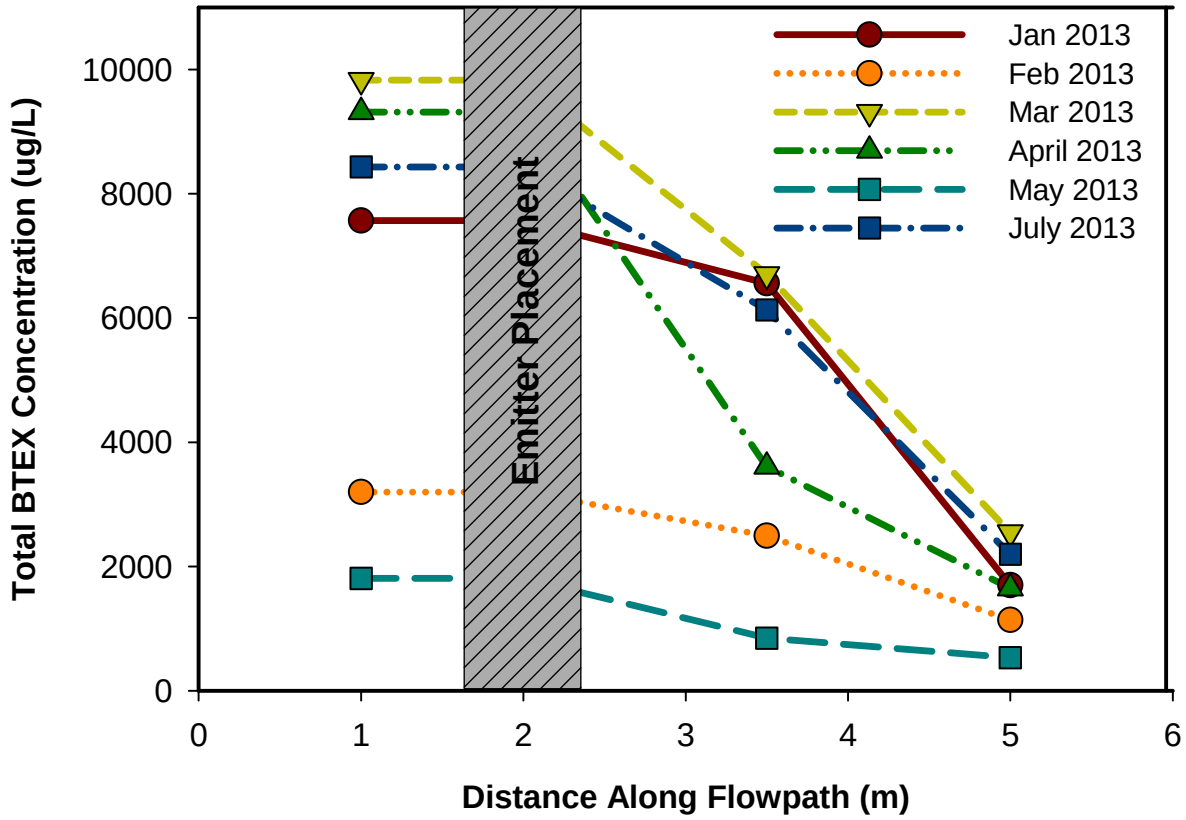
Groundwater Flow

Pilot Scale Design - Site B

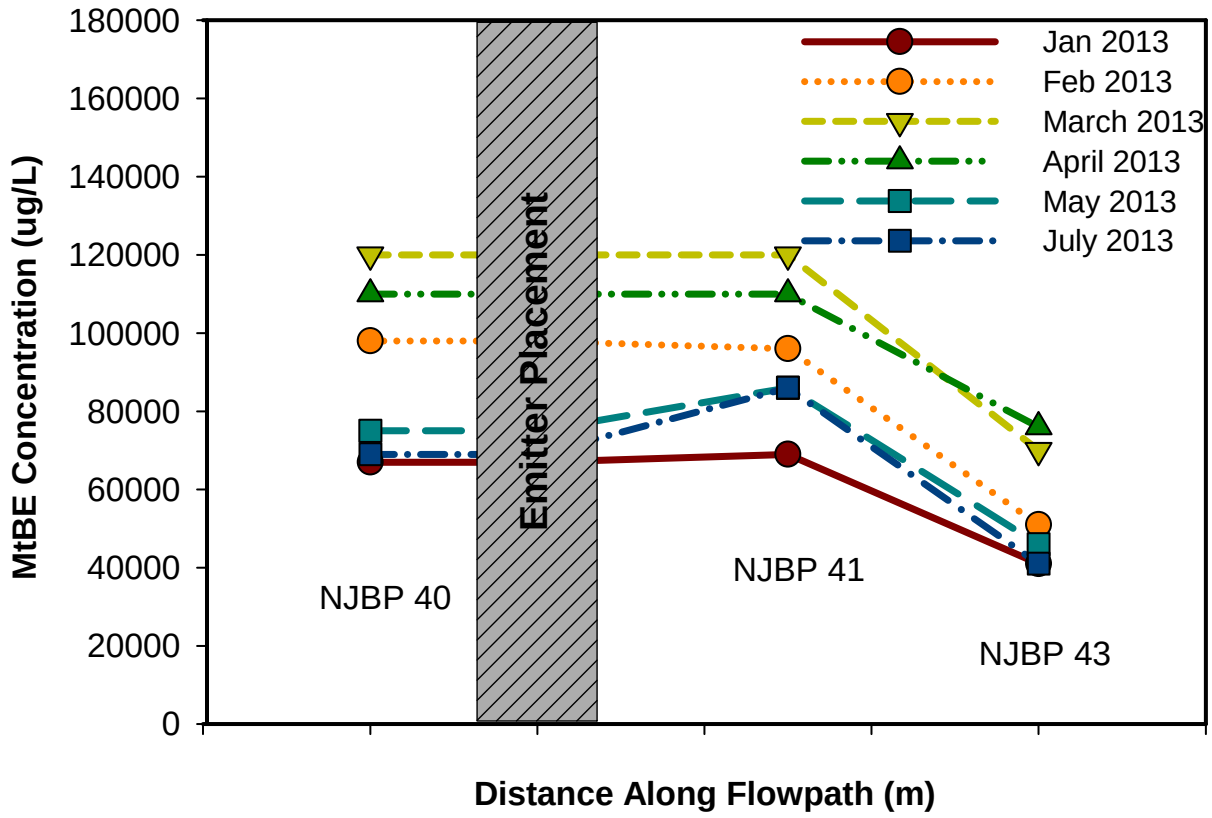


Groundwater Flow

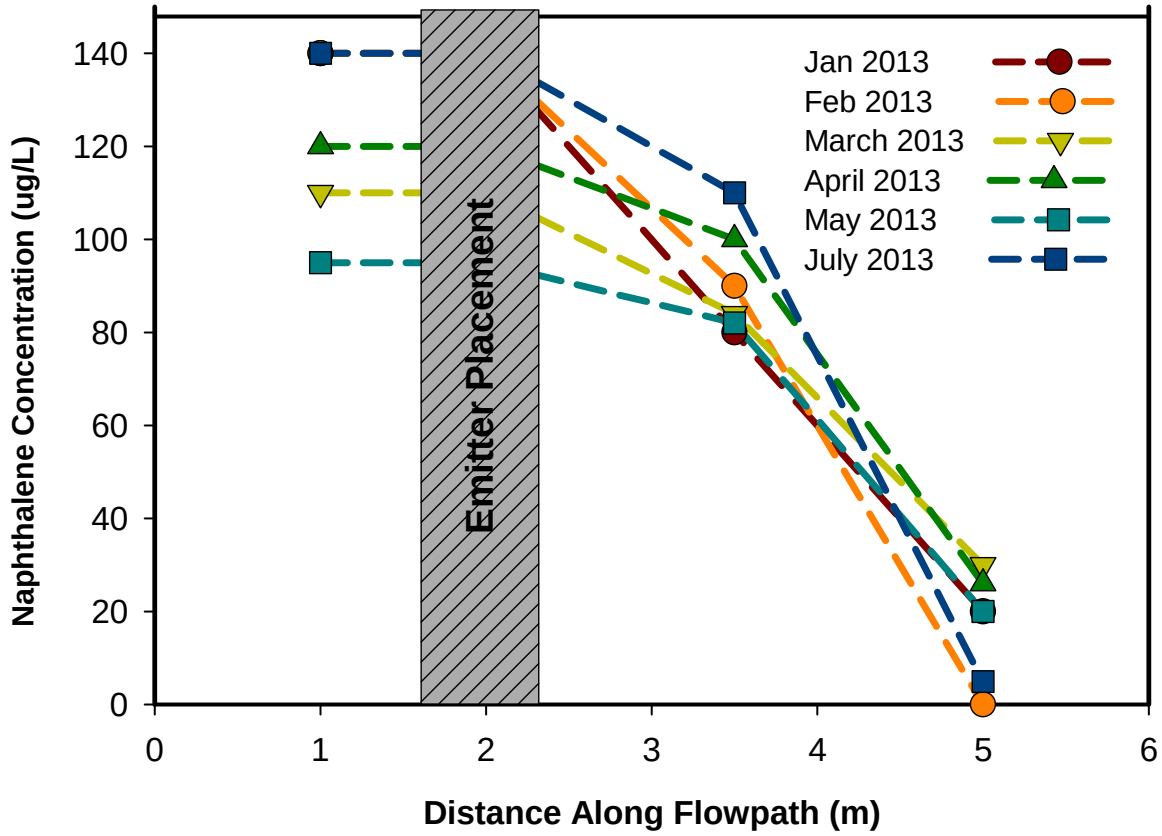
Site A - BTEX


Total BTEX Concentration (ug/L)
10000
8000
6000
4000
2000
0
0
1
2
3
4
5
6
Distance Along Flowpath (m)
Emitter Placement
Jan 2013
Feb 2013
Mar 2013
April 2013
May 2013
July 2013

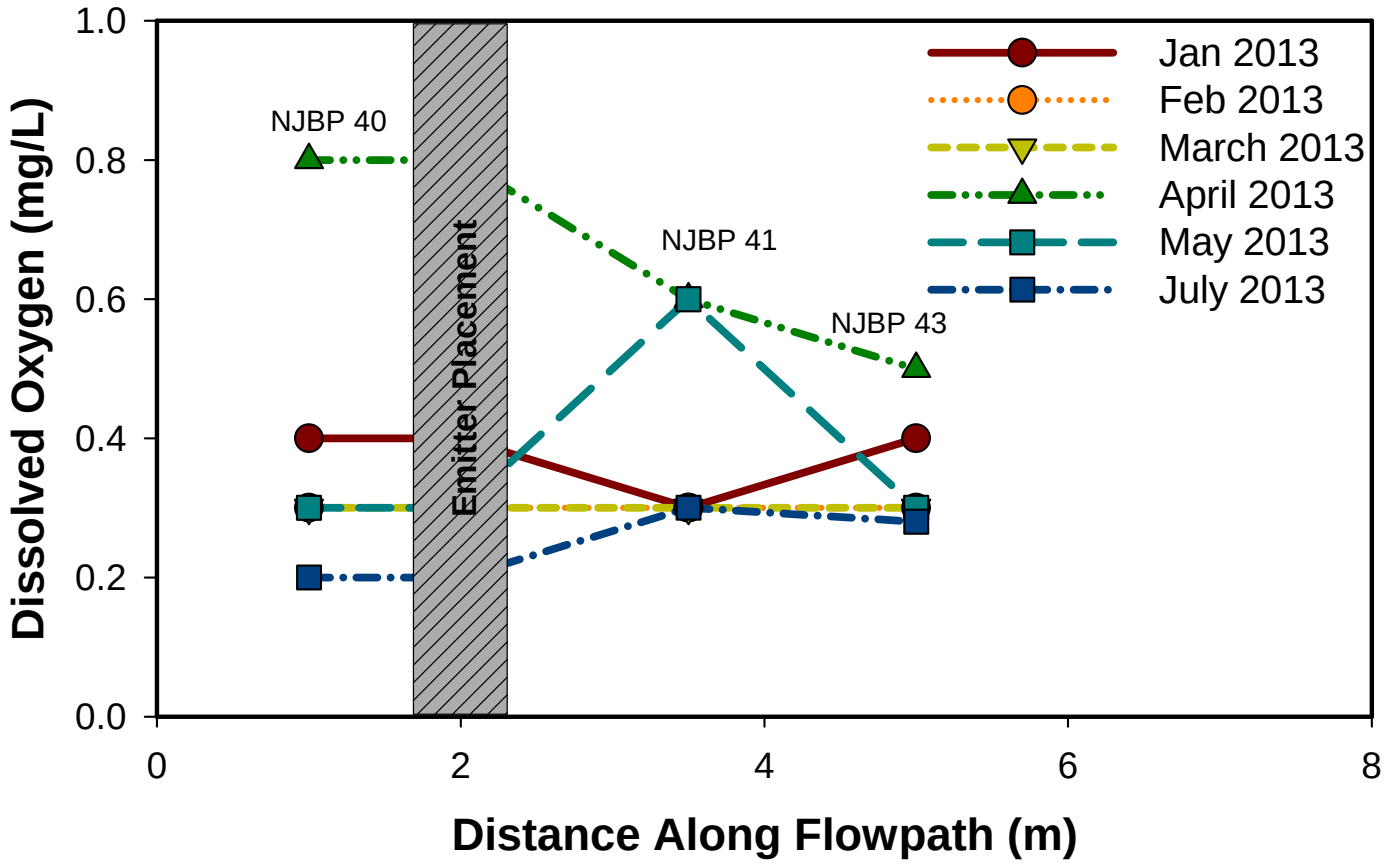
Site A - MTBE


180000
160000
140000
120000
100000
80000
60000
40000
20000
0
MtBE Concentration (ug/L)
Emitter Placement
NJBP 40
NJBP 41
NJBP 43
Jan 2013
Feb 2013
March 2013
April 2013
May 2013
July 2013
Distance Along Flowpath (m)

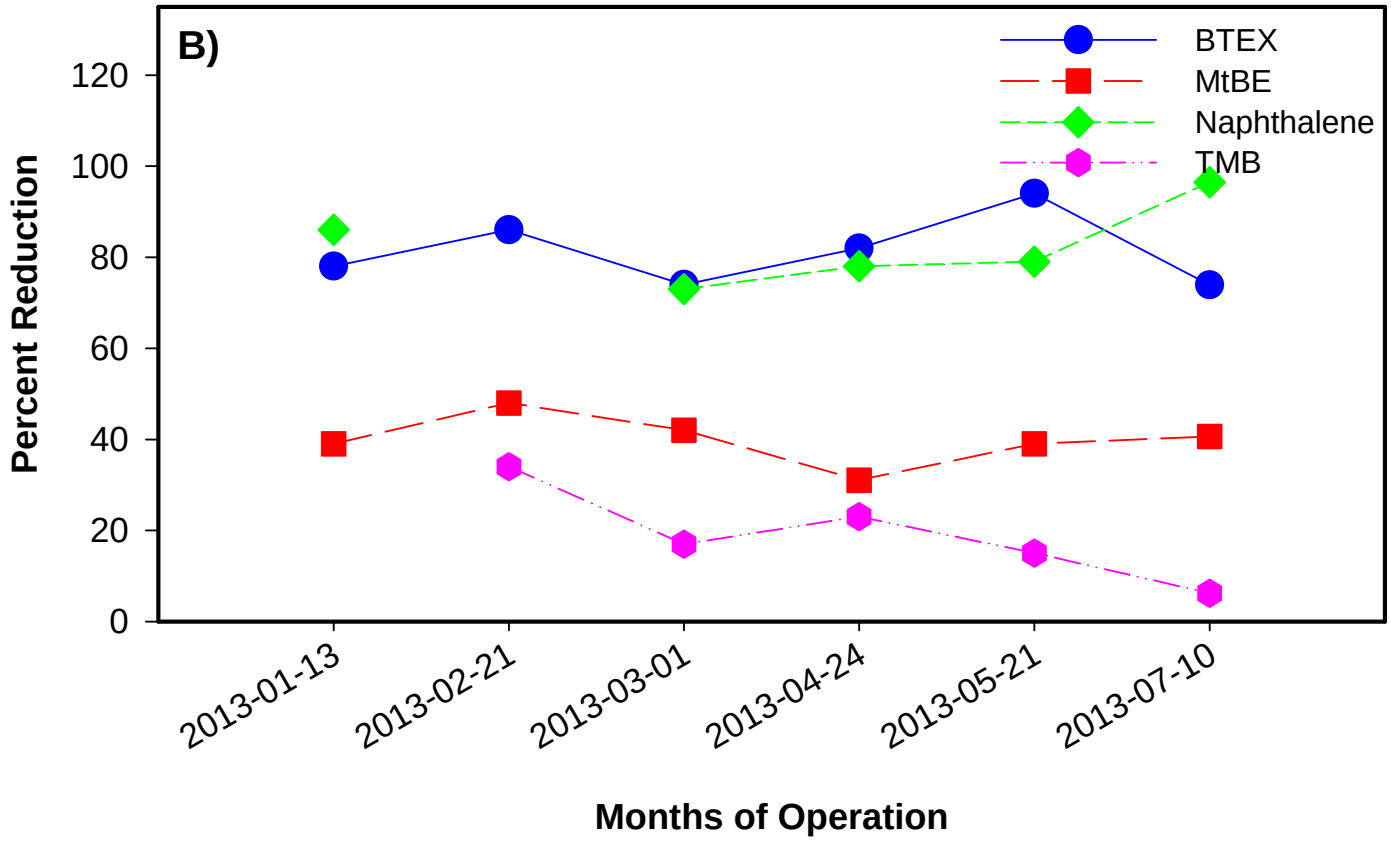
Site A - Naphthalene



Site A – DO


1.0
0.8
0.6
0.4
0.2
0.0
Dissolved Oxygen (mg/L)
0
2
4
6
8
Distance Along Flowpath (m)
NJBP 40
NJBP 41
NJBP 43
Emitter Placement
Jan 2013
Feb 2013
March 2013
April 2013
May 2013
July 2013

Site A - % Reduction w/ Time



Site A

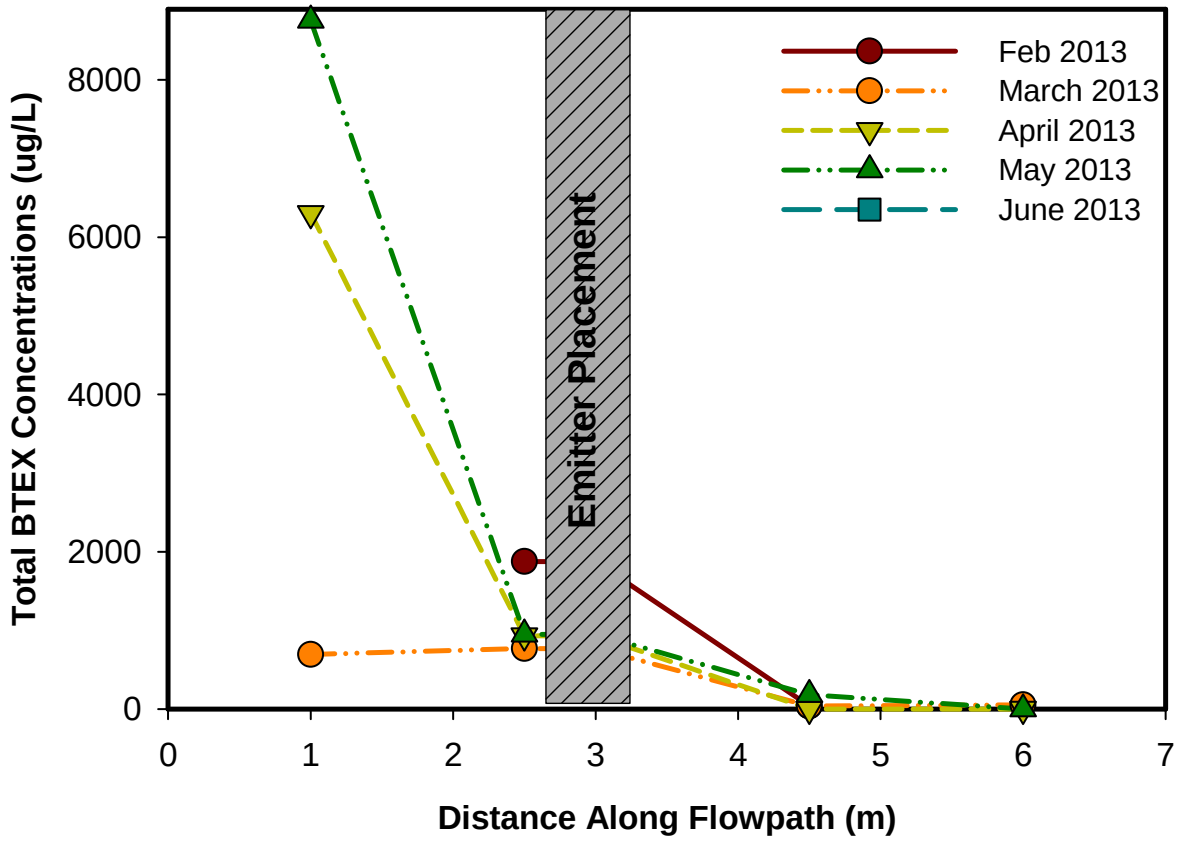
Percent Reduction (%)

Month	BTEX	MtBE	Naphthalene	TMB
2	78	39	86	34
4	82	31	78	23
7	74	41	97	6
Mean	81	40	85	33

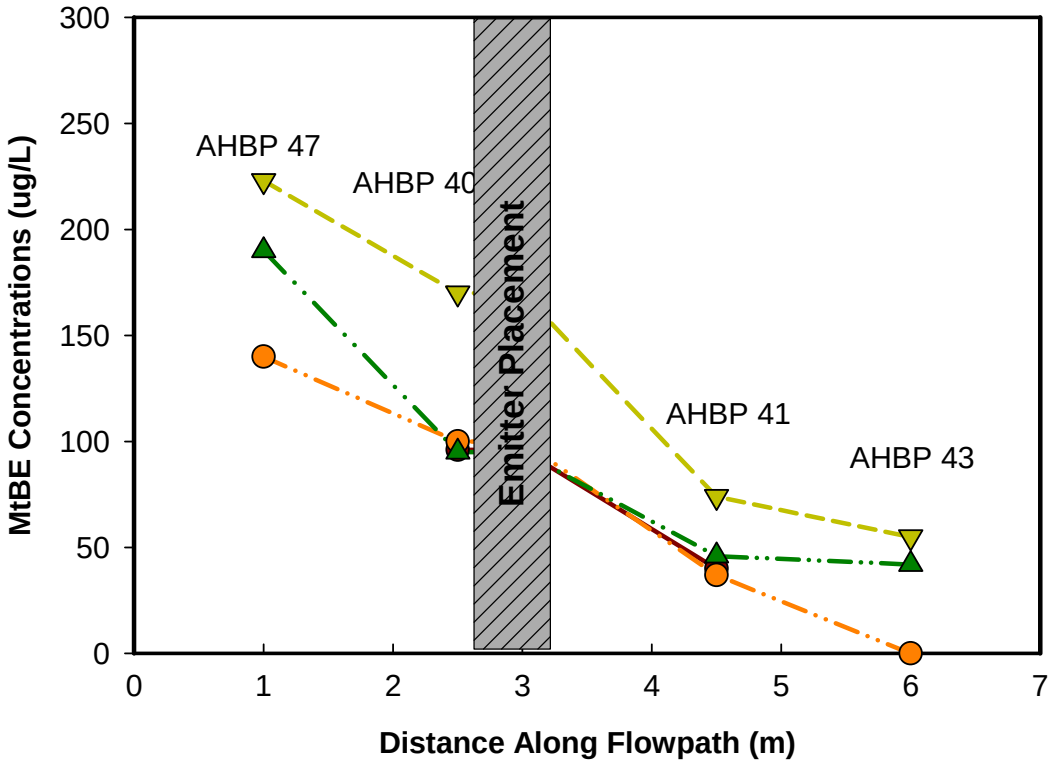
Mass Flux (g/day)

Compound	Entering	1.5 m DG	3.0 m DG
MtBE	26	33	16
BTEX	2.90	0.32	0.84
TMB	0.66	0.43	0.33
Naphthalene	0.05	0.03	0.02

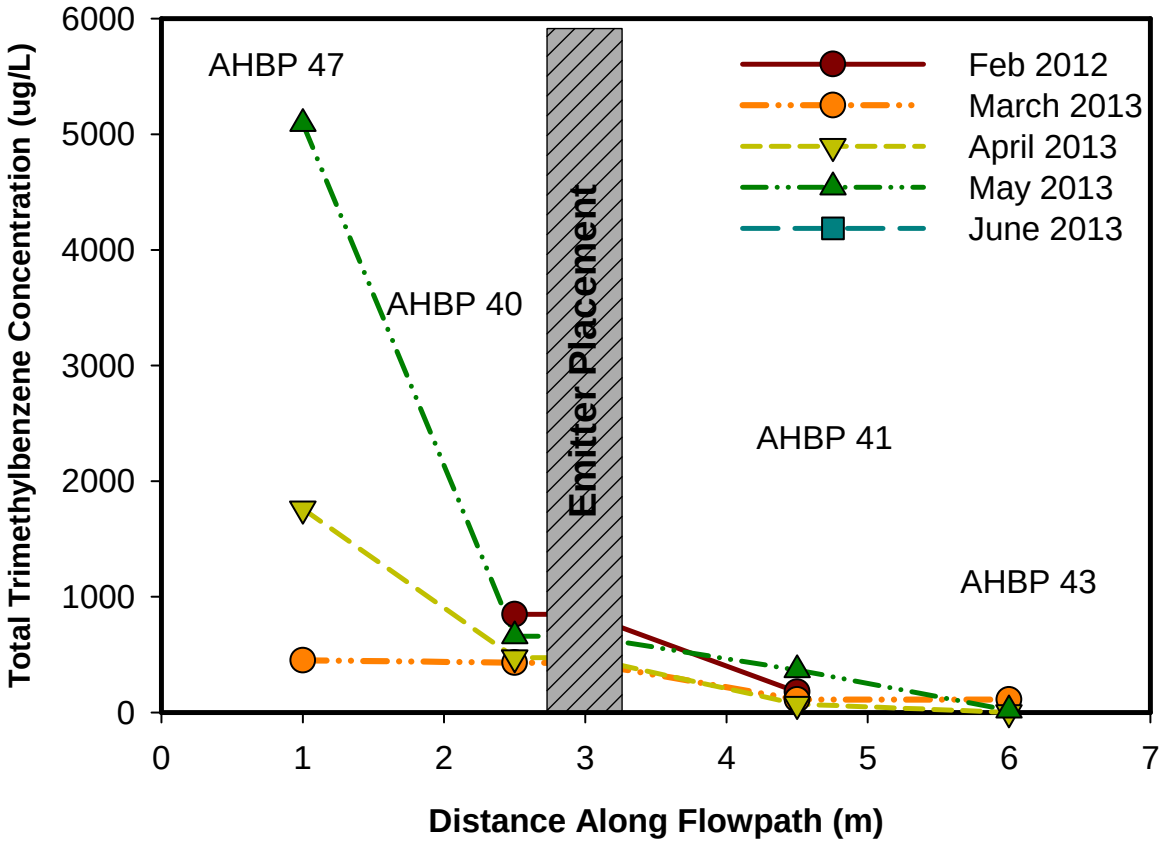
Site B - BTEX


Total BTEX Concentrations (ug/L)
8000
6000
4000
2000
0
0
1
2
3
4
5
6
7
Distance Along Flowpath (m)
Emitter Placement
Feb 2013
March 2013
April 2013
May 2013
June 2013

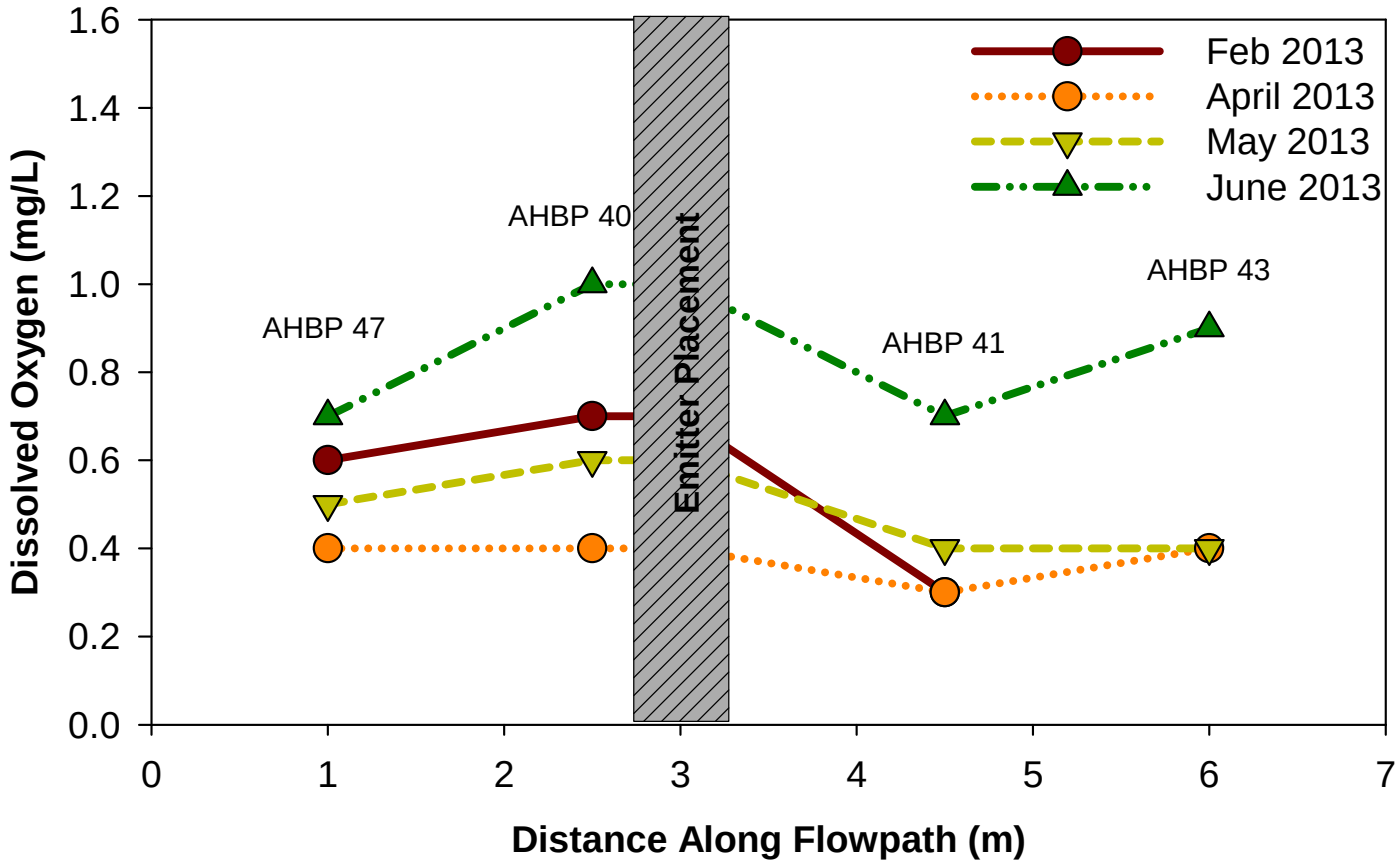
Site B - MTBE


300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
MtBE Concentrations (ug/L)
Distance Along Flowpath (m)
AHBP 47
AHBP 40
Emitter Placement
AHBP 41
AHBP 43

Site B - TMB


Total Trimethylbenzene Concentration (ug/L)
6000
5000
4000
3000
2000
1000
0
0
1
2
3
4
5
6
7
Distance Along Flowpath (m)
AHBP 47
AHBP 40
AHBP 41
AHBP 43
Emitter Placement
Feb 2012
March 2013
April 2013
May 2013
June 2013

Site B - DO


Dissolved Oxygen (mg/L)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
7
Distance Along Flowpath (m)
Feb 2013
April 2013
May 2013
June 2013
AHBP 47
AHBP 40
Emitter Placement
AHBP 41
AHBP 43

Site B

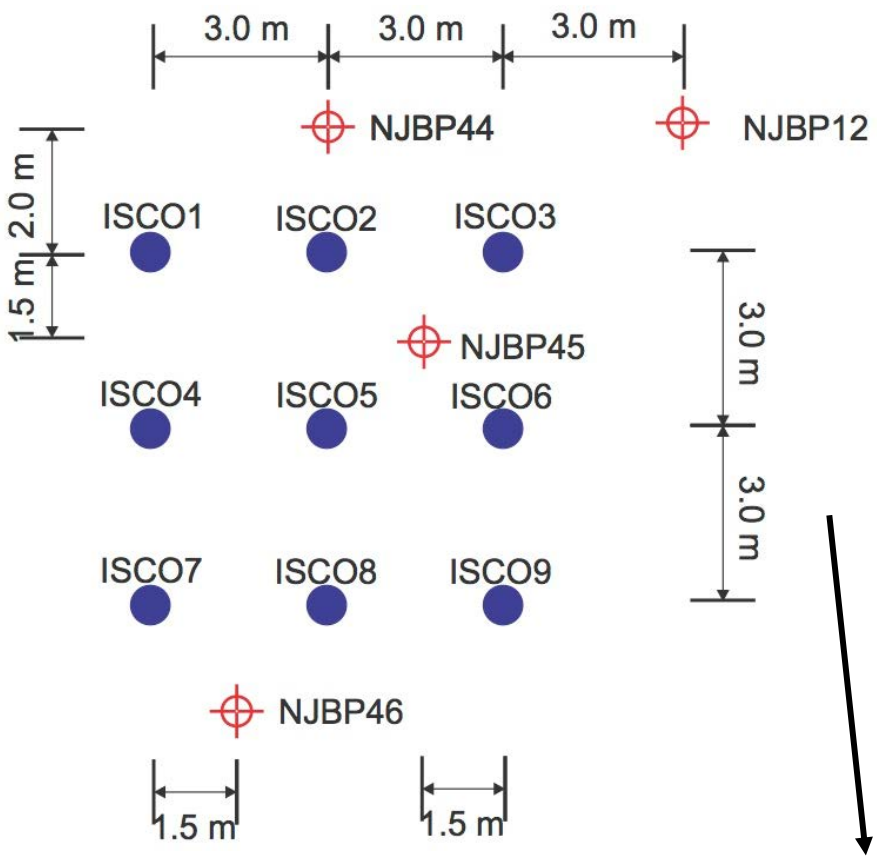
Percent Reduction (%)

Month	BTEX	MtBE	Naphthalene	TMB
2*	99	>99.9	70	-
4	93	>99.9	76	76
6	>99.9	78	93	99.6
Mean	98	84	90	92

Mass Flux (g/day)

Compound	Entering	1.5 m DG	3.0 m DG
MtBE	0.05	0.02	0.02
BTEX	2.50	0.07	0.0004
TMB	0.11	0.15	0.01
Naphthalene	0.06	0.05	0.01

Zone 2 – Chemical Oxidation



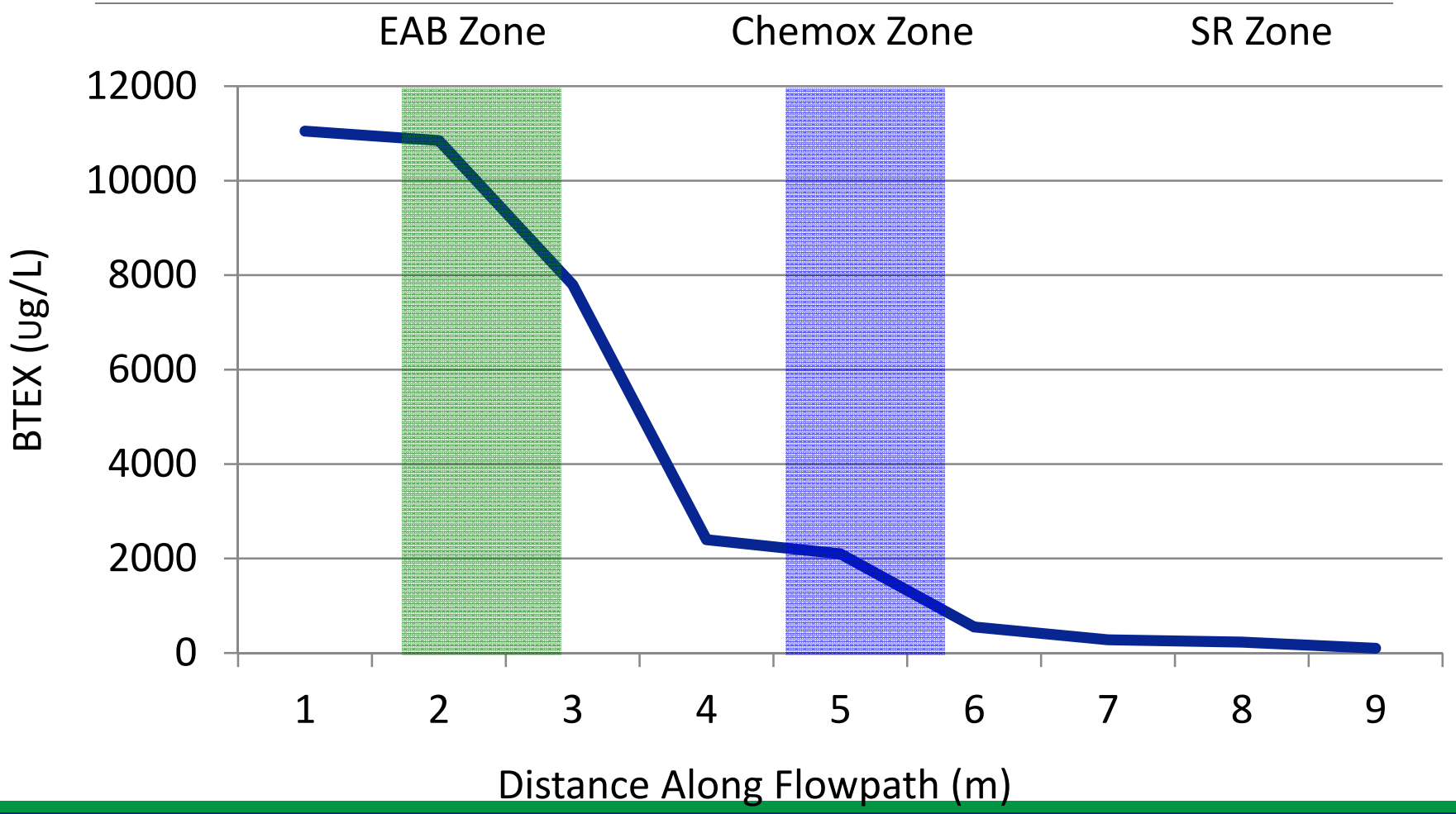
Groundwater Flow

Pilot Scale - Design

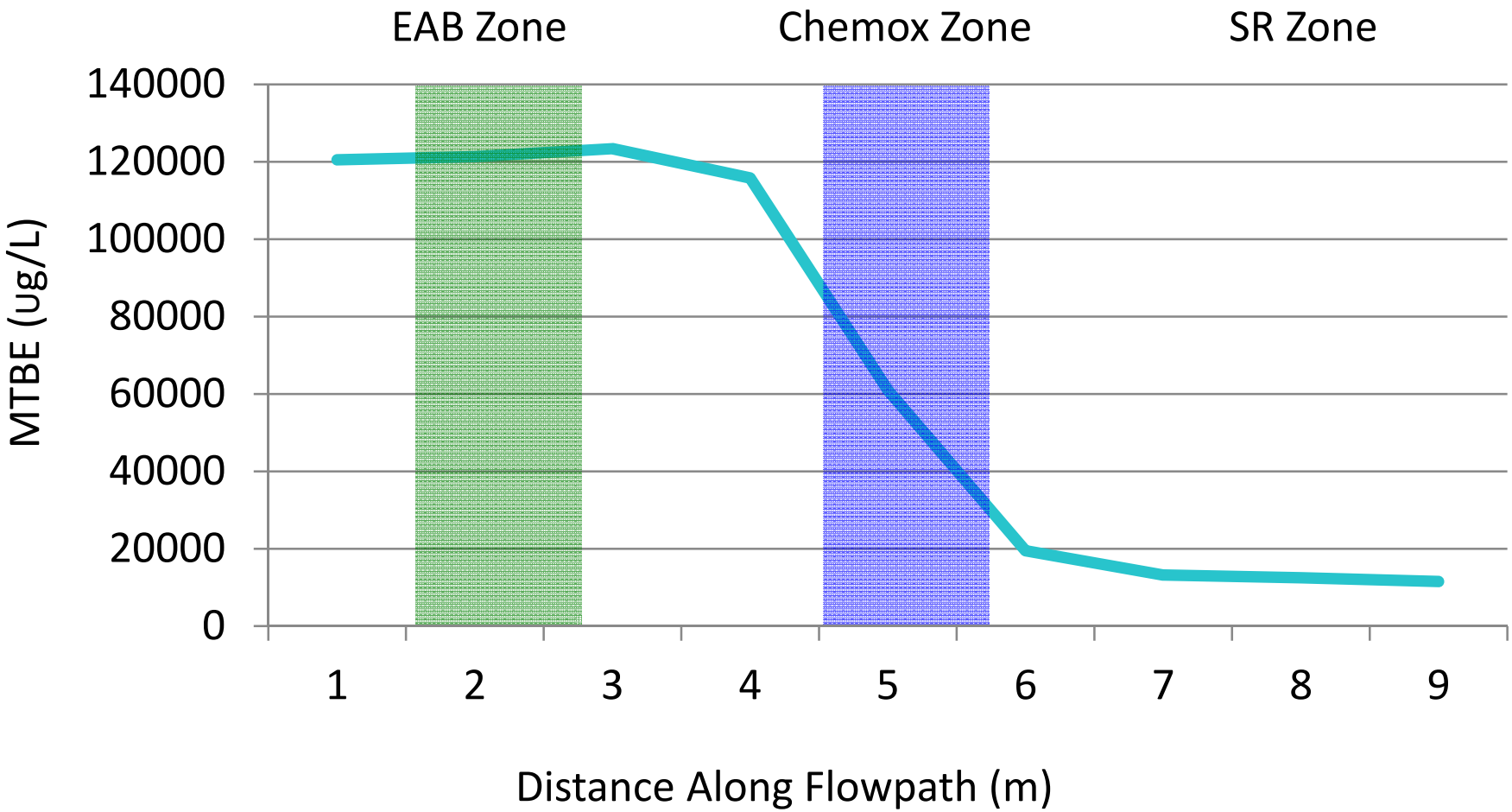
Zone 2 – Chemical Oxidation

- Persulphate vs. Percarbonate – Bench scale
- Unactivated Persulphate @ 15 wt. %
- Injection through 50 mm wells at low pressure and flow

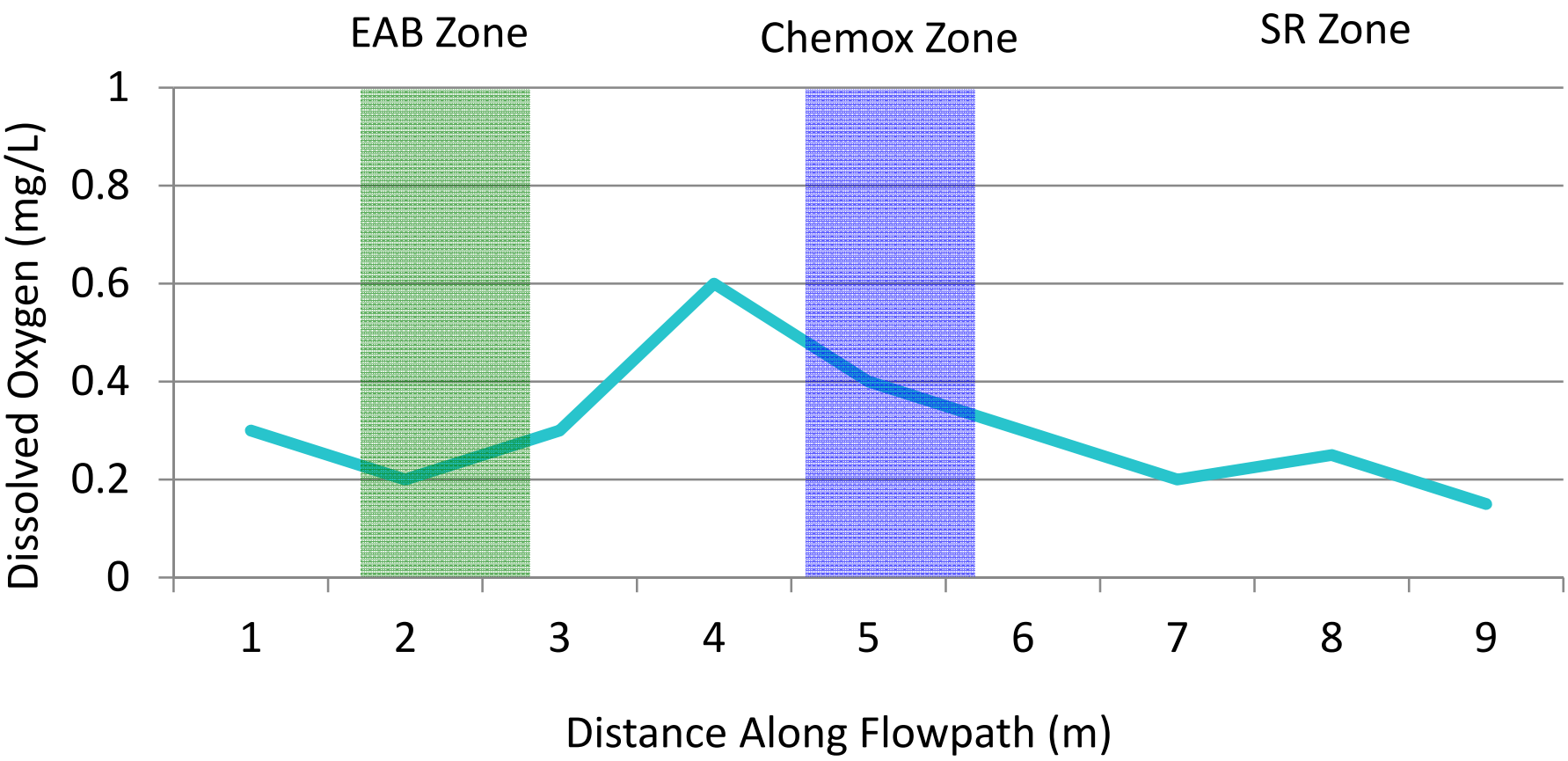
BTEX


EAB Zone
Chemox Zone
SR Zone
12000
10000
8000
6000
4000
2000
0
BTEX (Ug/L)
1
2
3
4
5
6
7
8
9
Distance Along Flowpath (m)

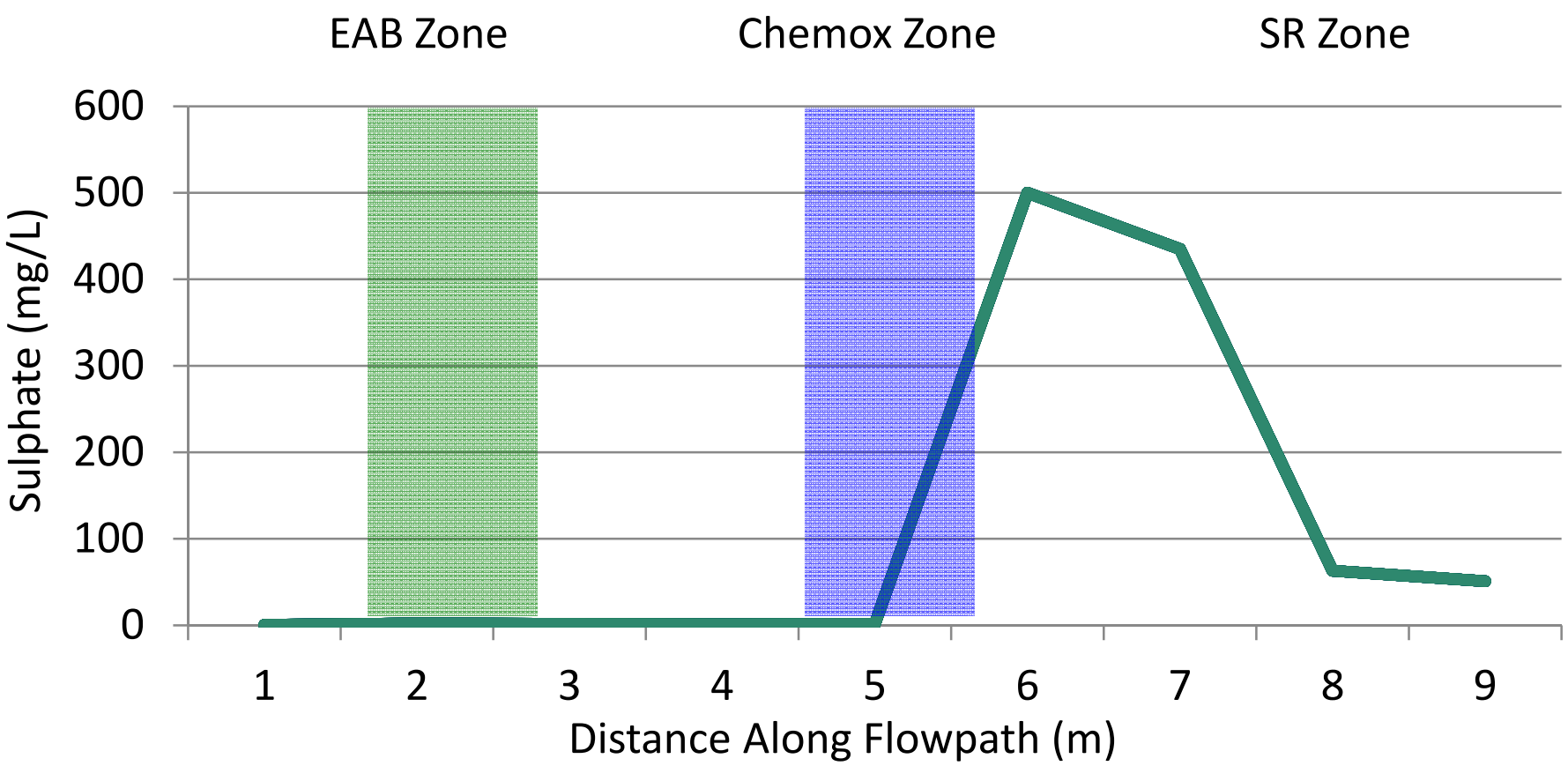
MTBE


EAB Zone
Chemox Zone
SR Zone
140000
120000
100000
80000
60000
40000
20000
0
MTBE (Ug/L)
1
2
3
4
5
6
7
8
9
Distance Along Flowpath (m)

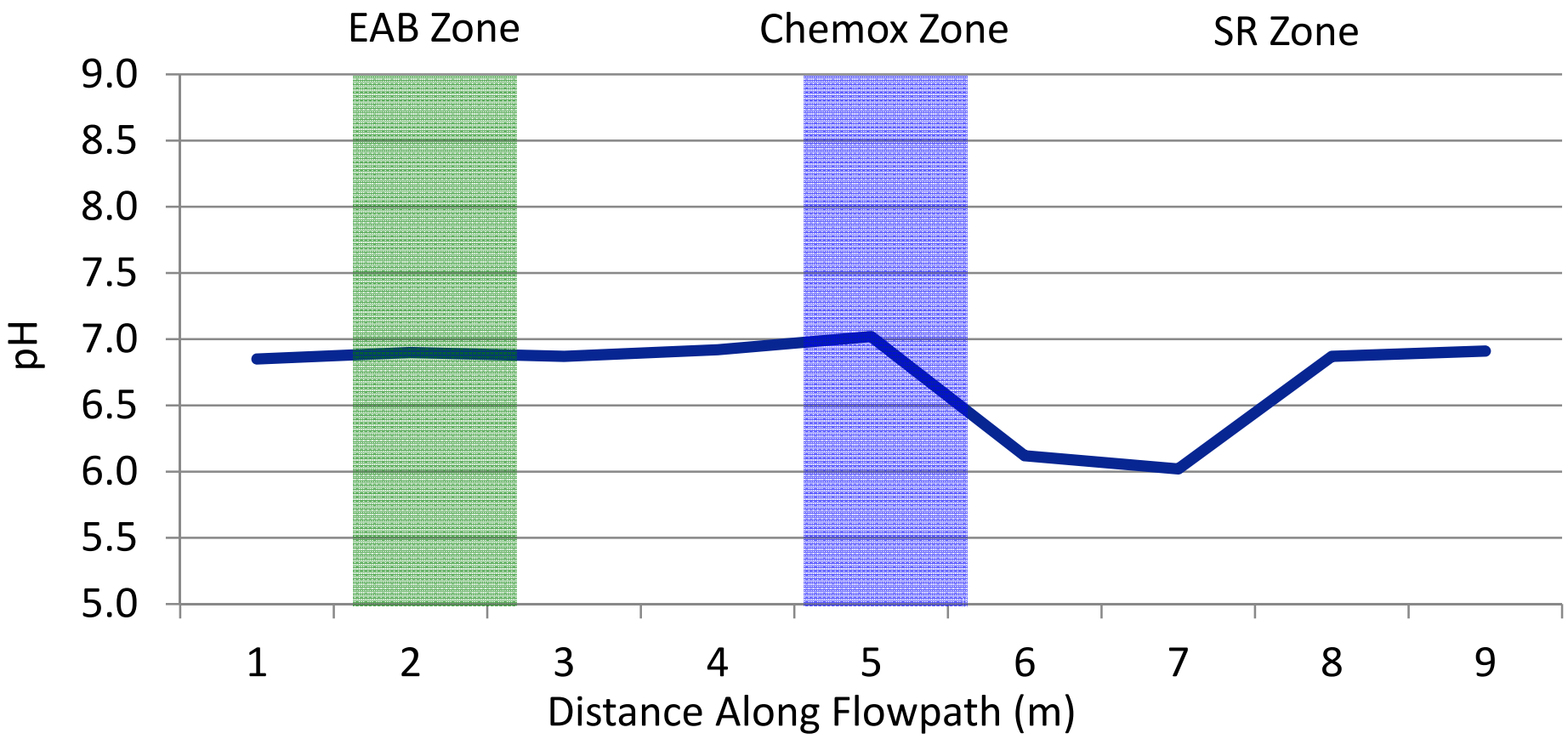
DO


EAB Zone
Chemox Zone
SR Zone
Dissolved Oxygen (mg/L)
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
7
8
9
Distance Along Flowpath (m)

Sulphate


EAB Zone
Chemox Zone
SR Zone
600
500
400
300
200
100
0
Sulphate (mg/L)
1
2
3
4
5
6
7
8
9
Distance Along Flowpath (m)

pH


EAB Zone
Chemox Zone
SR Zone
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
pH
1
2
3
4
5
6
7
8
9
Distance Along Flowpath (m)

Removal

Percent Reduction (%)

Zone	BTEX	MtBE	Naphthalene	TMB
EAB	98	84	90	92
Chemox	98	99.9	>99	>86
ESR	78	28	-	-
Total	>99	98	>99	>99

Mass Flux (g/day)

Compound	Entering	POST EAB	POST Chemox
MtBE	0.05	0.02	<0.001
BTEX	2.50	0.0004	<0.0001
TMB	0.11	0.01	0.001
Naphthalene	0.06	0.01	0.001

Acknowledgements

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IRSL

- Rick McGregor & Adria Kelleher

Questions?

Future/Ongoing Studies

Effects of Varying Tubing and Pressure

Isotopic and biological changes with time

Effects of thermal enhancement of Emitters/AS

- Ontario Site – Preliminary results indicate 3.5 to 33x higher biodegradation rates

Sequential Remediation Approach