REGENESIS

Field Results with an Alkaline *In-Situ* Chemical Oxidation Process

- High Concentration Source Areas and NAPLS -

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Bob Kelley Ph.D

Stephen S. Koenigsberg, Ph.D

ECOR-3 / DNAPL – Göttingen 2006

Two Categories of ISCO Agent

Strong Oxidisers

(e.g. Fenton's Reagent, H_2O_2)

- **Broad specificity (many treatable compounds)**
- **Highly reactive**
- **Poor penetration**
- **Difficult handling**

Long Lasting Oxidisers

(e.g. Permanganates, Persulphates)

- **Narrow specificity (few treatable compounds)**
- **Less reactive**
- **Good penetration**
- **Easy handling**

REGENESIS

Chemical Oxidation

RegenOx™

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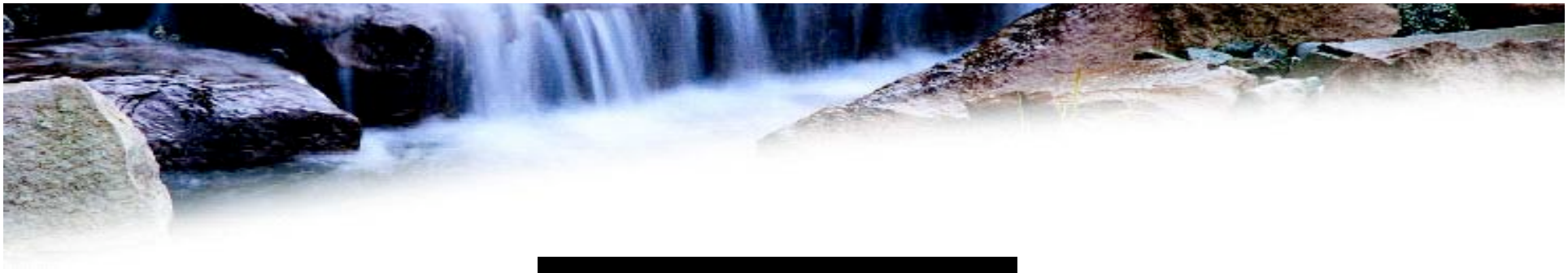


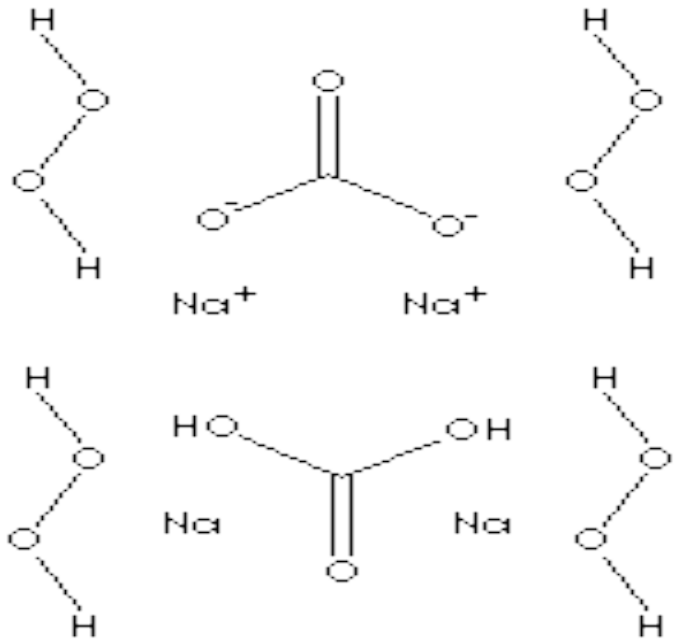
Chemical Oxidation

RegenOx™

- Slow release chemical oxidation product
- Creates Fenton's and other radicals

- Best of both worlds
  - Broad specificity
  - Easy safe handling
  - Long lasting / good penetration

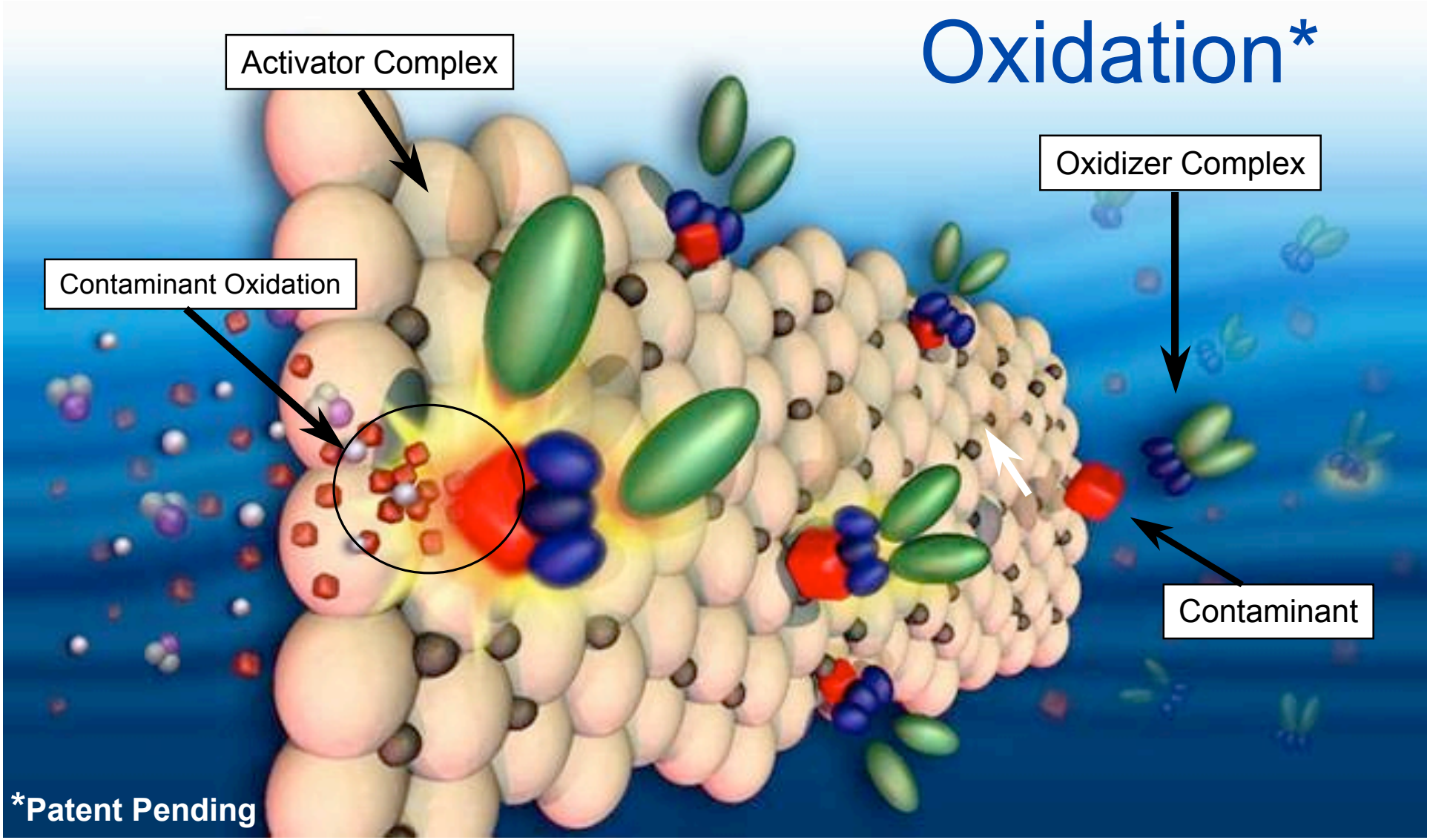
What is RegenOx™?



- A **solid alkaline oxidant** that employs a sodium percarbonate complex with a **dual-part catalytic formula**.
- RegenOx™ **Oxidizer Complex** (Part A) is combined with RegenOx™ **Activator Complex** (Part B), and is injected into the contaminated matrix.

Winner of the ICU 2006 Innovation Award

RegenOx™ Surface-Mediated Oxidation*



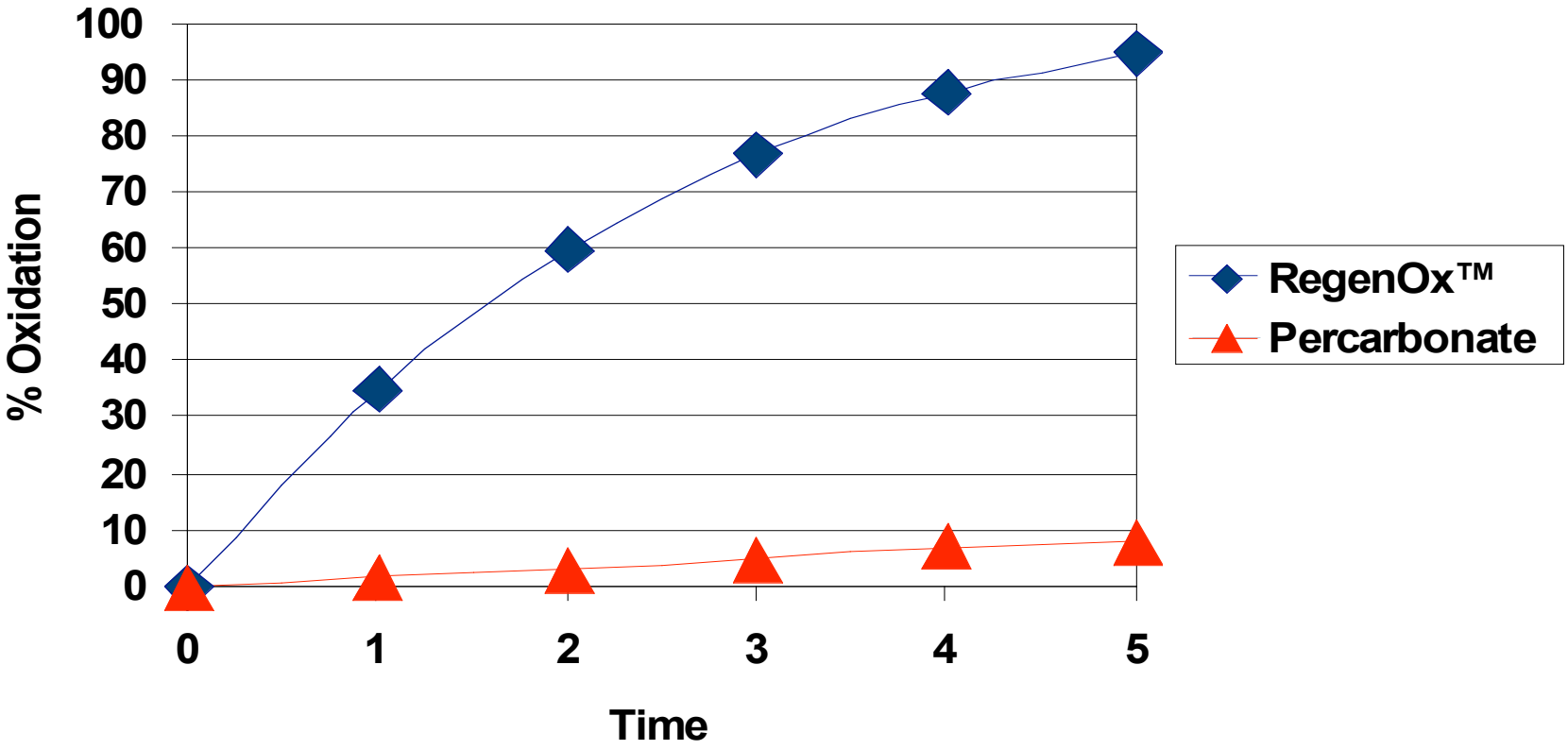
How does RegenOx™ Work?

- **Extraction**
- **Surface-Mediated Oxidation (Patent Pending)**
  - Adsorption➔Degradation
- **Direct Oxidation**

powerful

- **Free Radical Oxidation:**
  - Perhydroxyl Radical (HO_2•)
  - Hydroxyl Radical (OH•)
  - Superoxide Radical (O_2•)
  - Organic Free Radicals

RegenOx™ Oxidation of PCE



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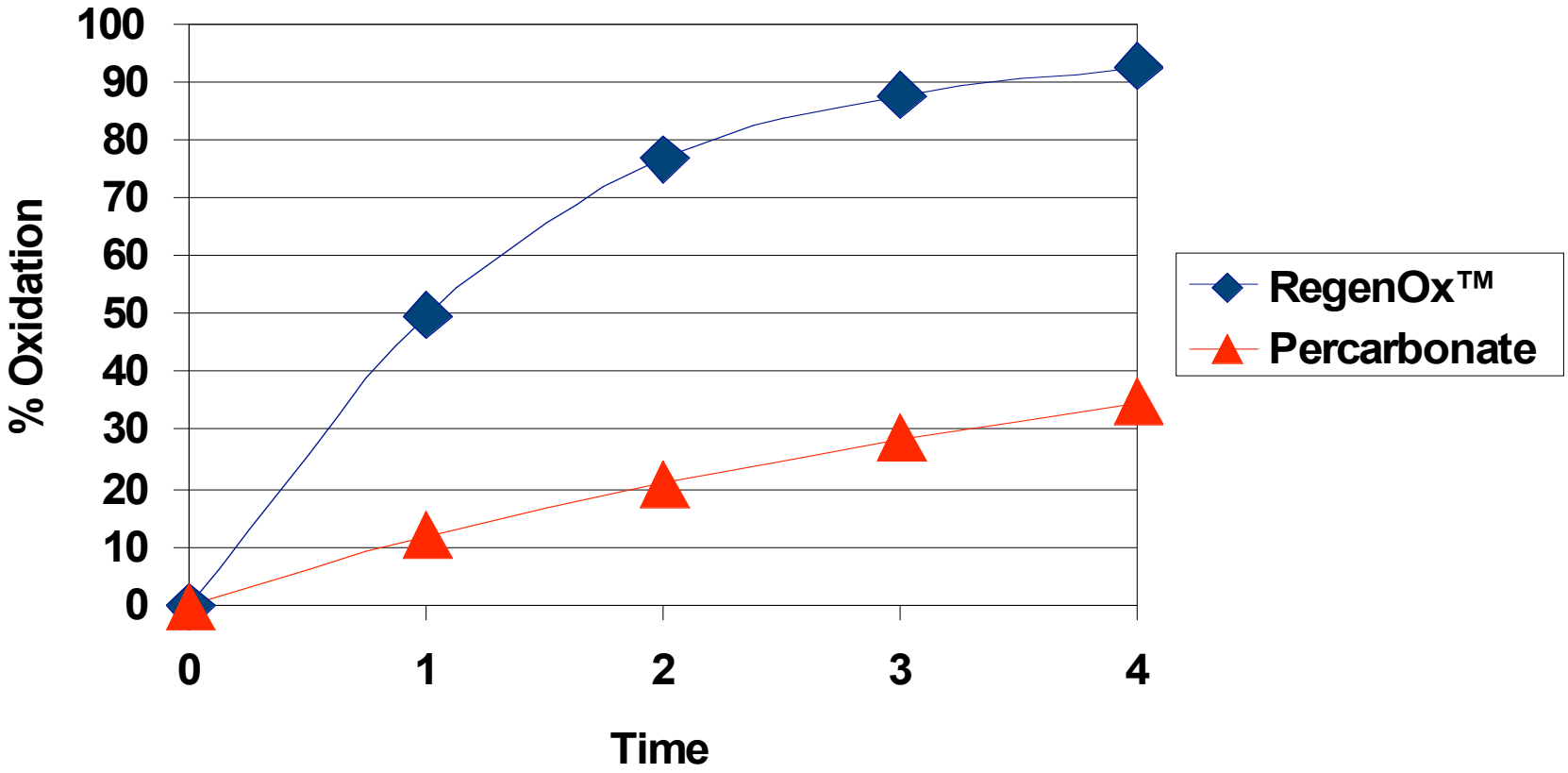
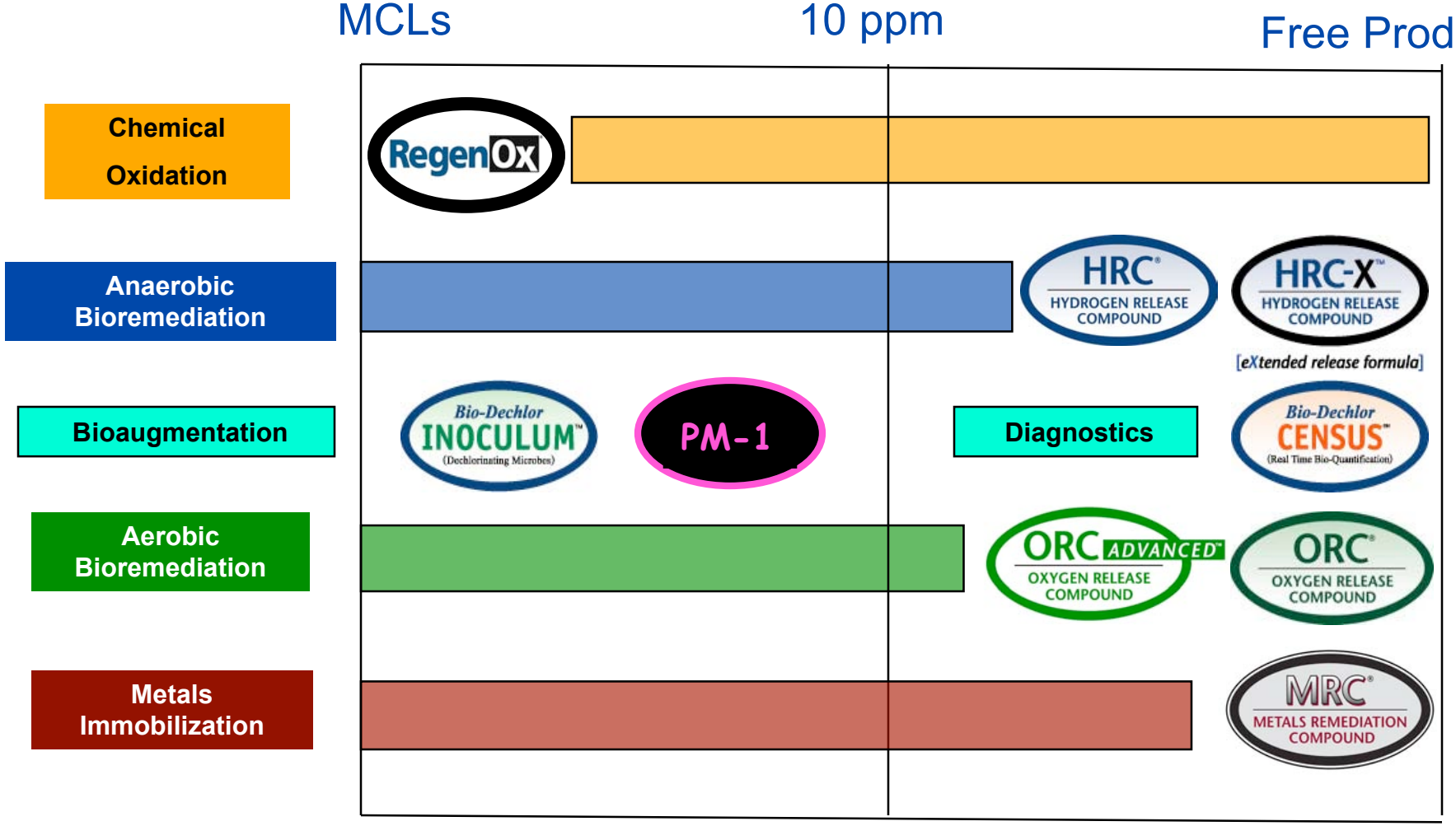
RegenOx™ Oxidation of Toluene



REGENESIS



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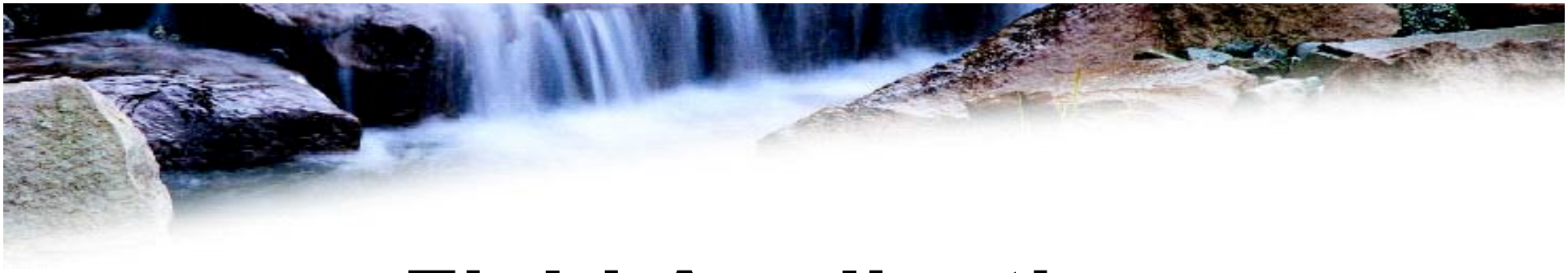

Field Application

Chemical Oxidation

RegenOx™

RegenOx Field Application

***RegenOx*™**
Delivered directly to site on pallets


RegenOx
PART A
REGENESIS
RegenOx
PART B
REGENESIS
…in 15 kg pails, Part A and Part B

Add 4 L water to RegenOx Part B (a grey gel)…

…and mix it into a silky liquid.

Add a pail of RegenOx Part A (a white powder) to 150 L water…

…and mix until it dissolves into a milky liquid.

Put the two liquids together…

www.


ARCO
Nitra
154/4 - Size 9
Mix them thoroughly…

***RegenOx*™ can be surface-applied if the contamination is shallow…**


Or injected using a direct-push rig
if the contamination is deep
(*no permanent injection wells or installations required*)

Seamless chem-bio

- RegenOx is designed for **seamless integration** with other Regenesis products

- Use RegenOx as a ‘front-end’ for bioremediation
  - Especially where smear is suspected
  - Excellent combination for post tank-pull clean-up

- Or use bioremediation to reach zones chemox was unable to reach and adequately contact
  - ORC® and HRC® work well in dual-porosity and low-permeability formations
  - Use when ISCO efficiency per application begins to tail-off


ORC-Advanced® mixed into RegenOx™


Mixed Thoroughly
Westbury
INERT / CLEAN
WASTE

‘surgically applied’


Mixed thoroughly into excavation base

Chemical Oxidation

RegenOx™

Performance?

RegenOx™

Laboratory Studies

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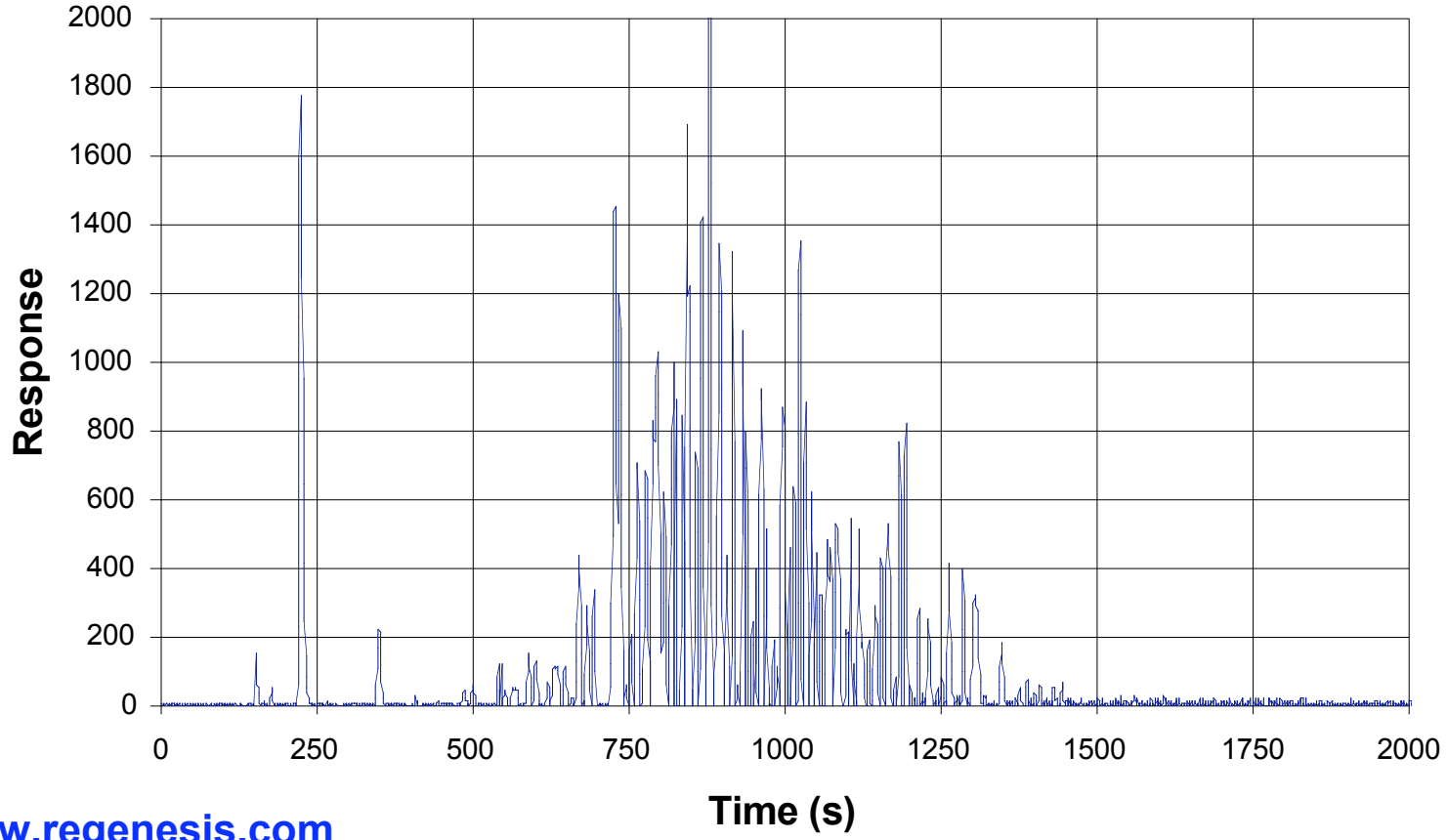
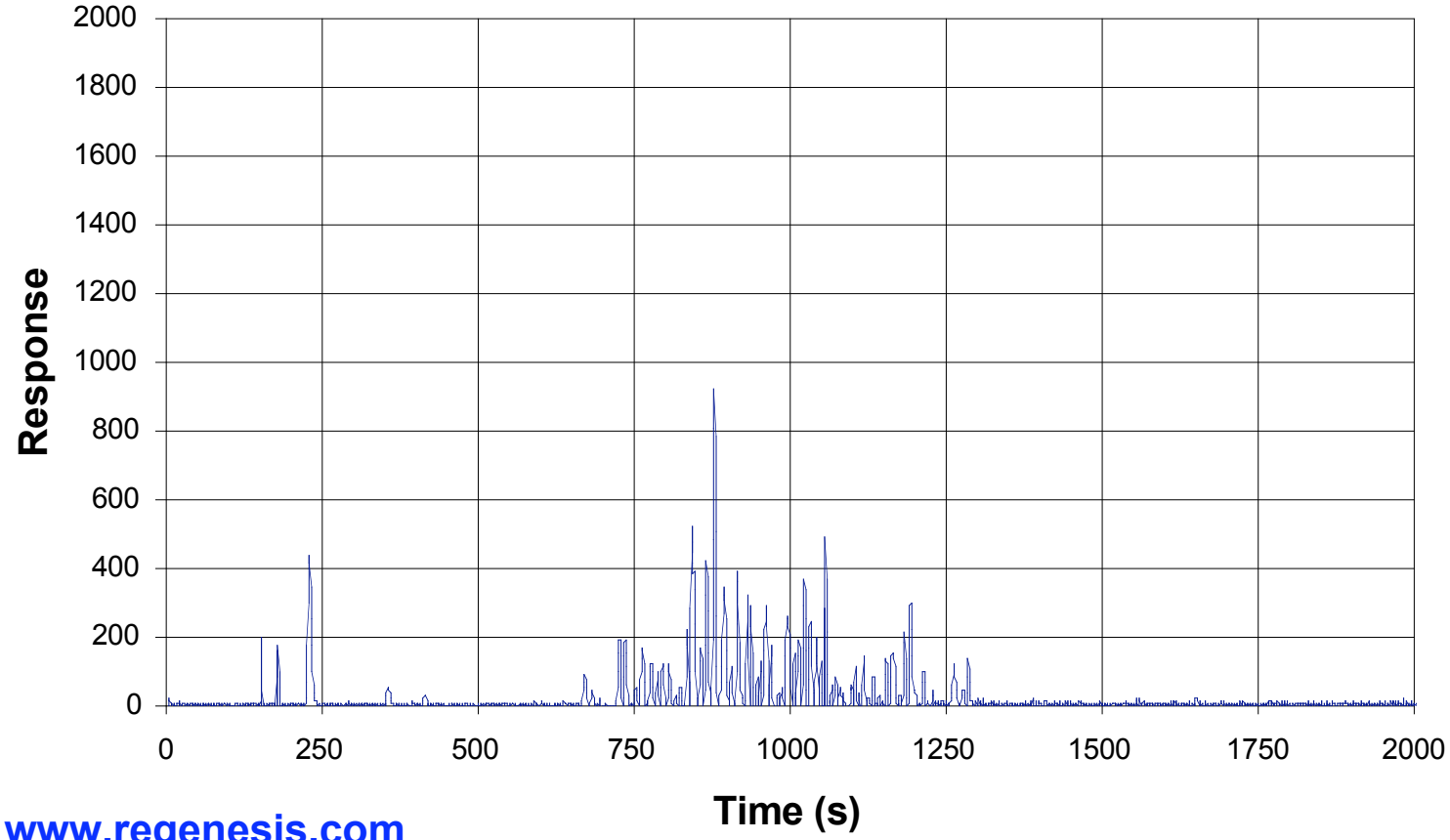
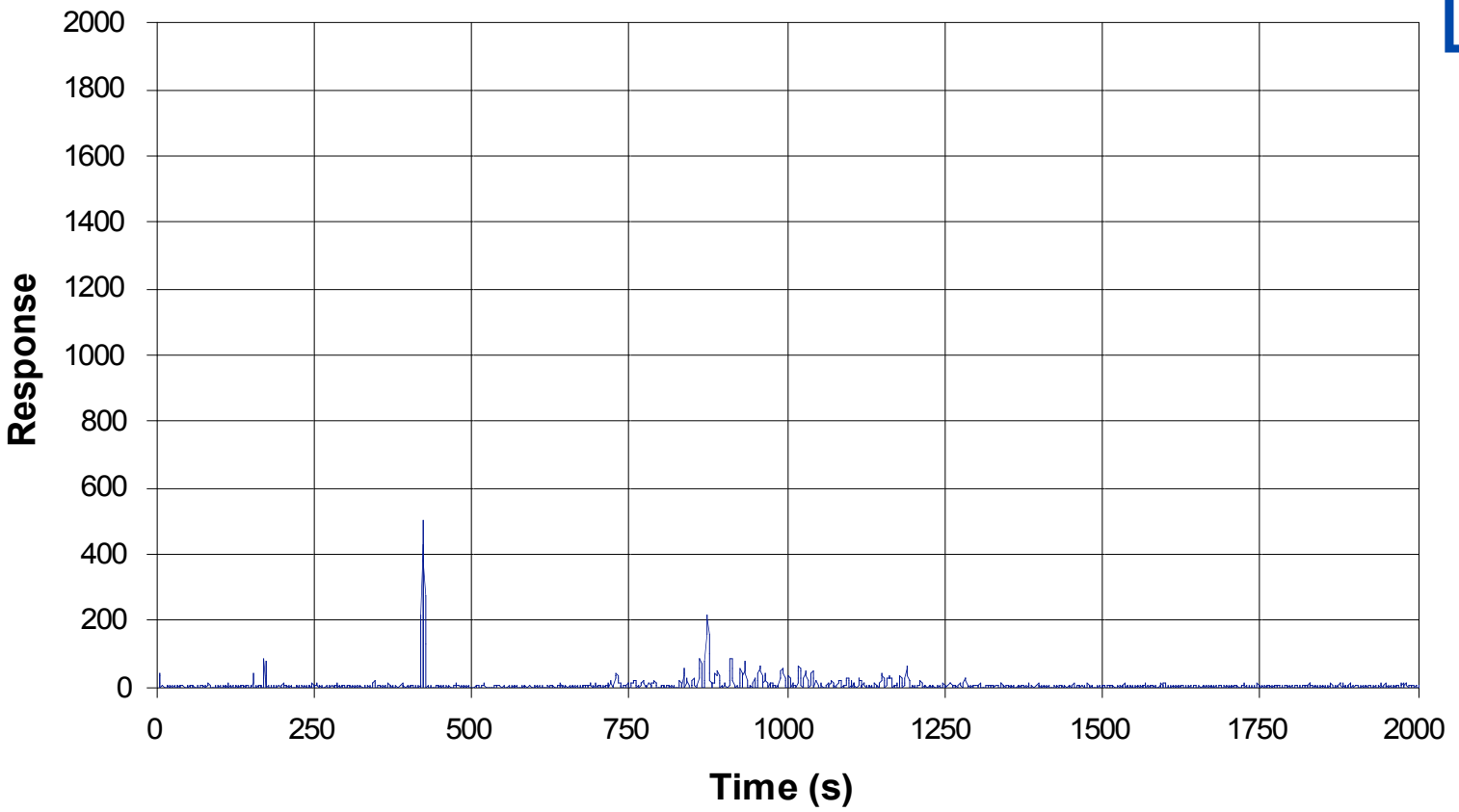
GC Scan of Soil Core Sample Containing Jet Fuel: Day 1



GC Scan of Soil Core Sample Containing Jet Fuel: Day 7



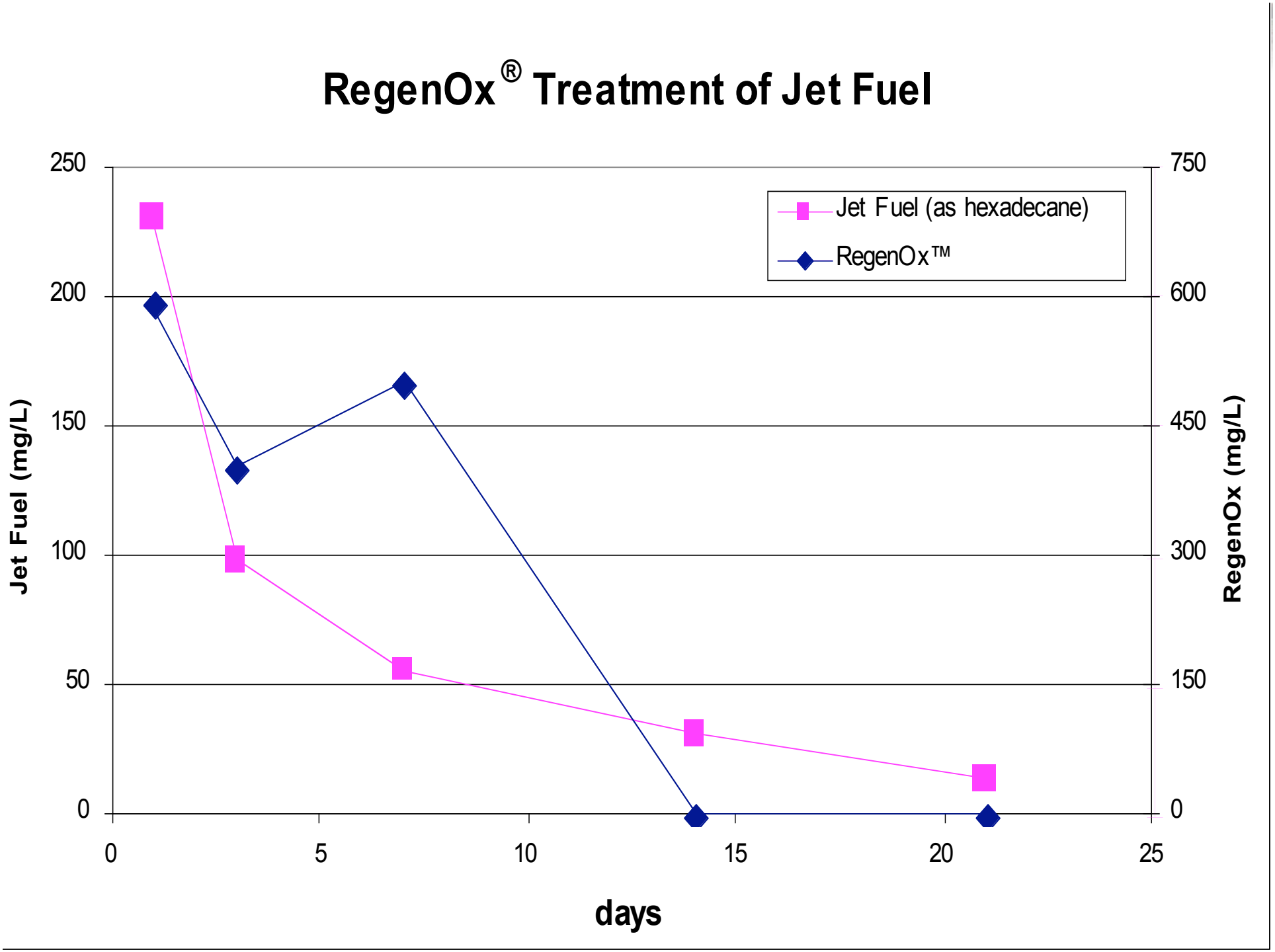
GC Scan of Soil Core Sample Containing Jet Fuel: Day 21



Summary of Jet Fuel "Bench Study"

Time (Days)	RegenOx™ Concentration (ppm)	Contaminant Concentration* (ppm)
1	589	230
3	402	98
7	501	56
14	ND	31
21	ND	14

* As calibrated to Hexadecane
ND = non-detect


RegenOx® Treatment of Jet Fuel
Jet Fuel (as hexadecane)
RegenOx™
Jet Fuel (mg/L)
RegenOx (mg/L)
days
250
200
150
100
50
0
750
600
450
300
150
0
0
5
10
15
20
25

Chemical Oxidation

RegenOx™

Field Case Studies

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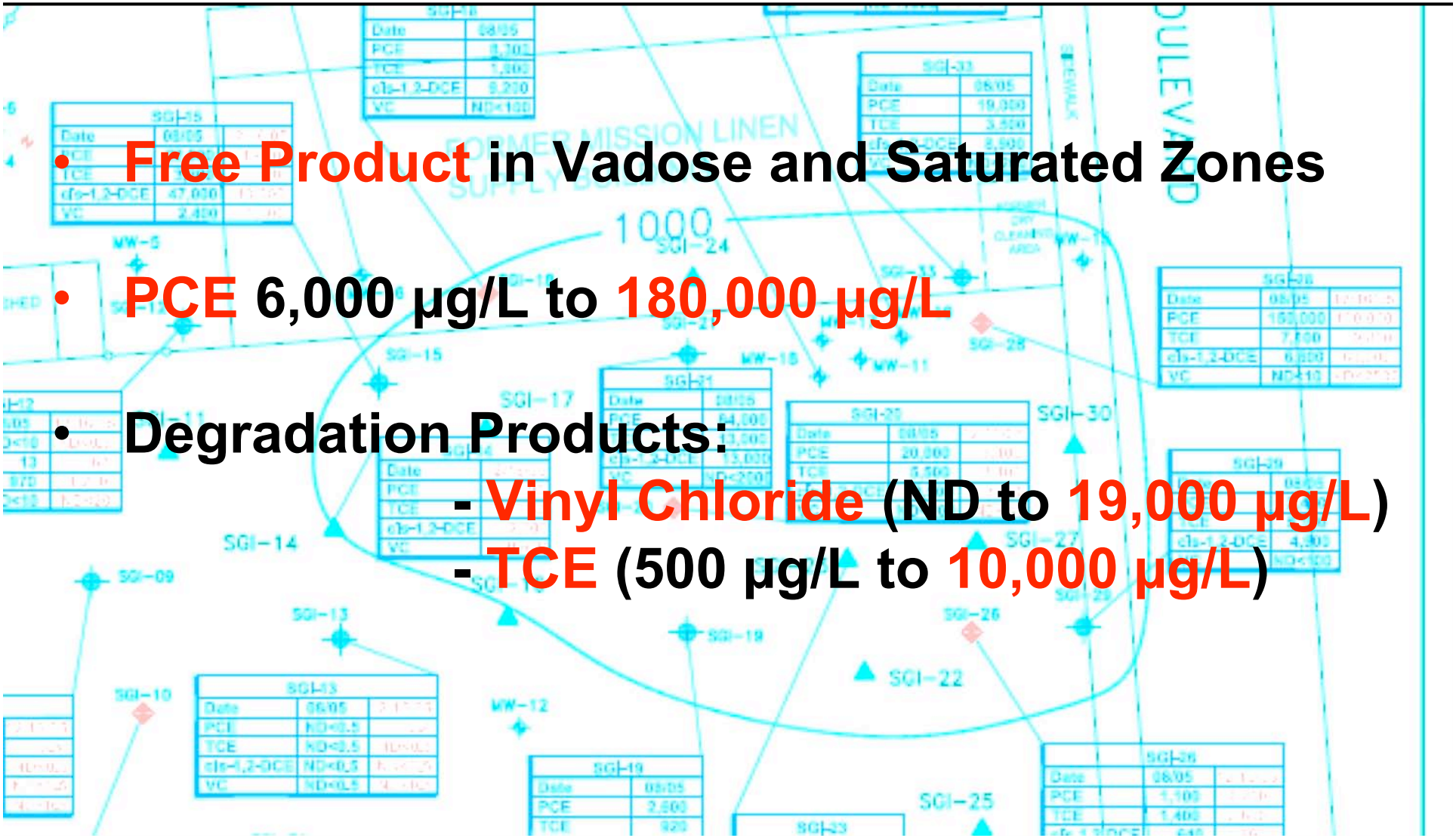
RegenOx Application: Industrial Dry Cleaner in California

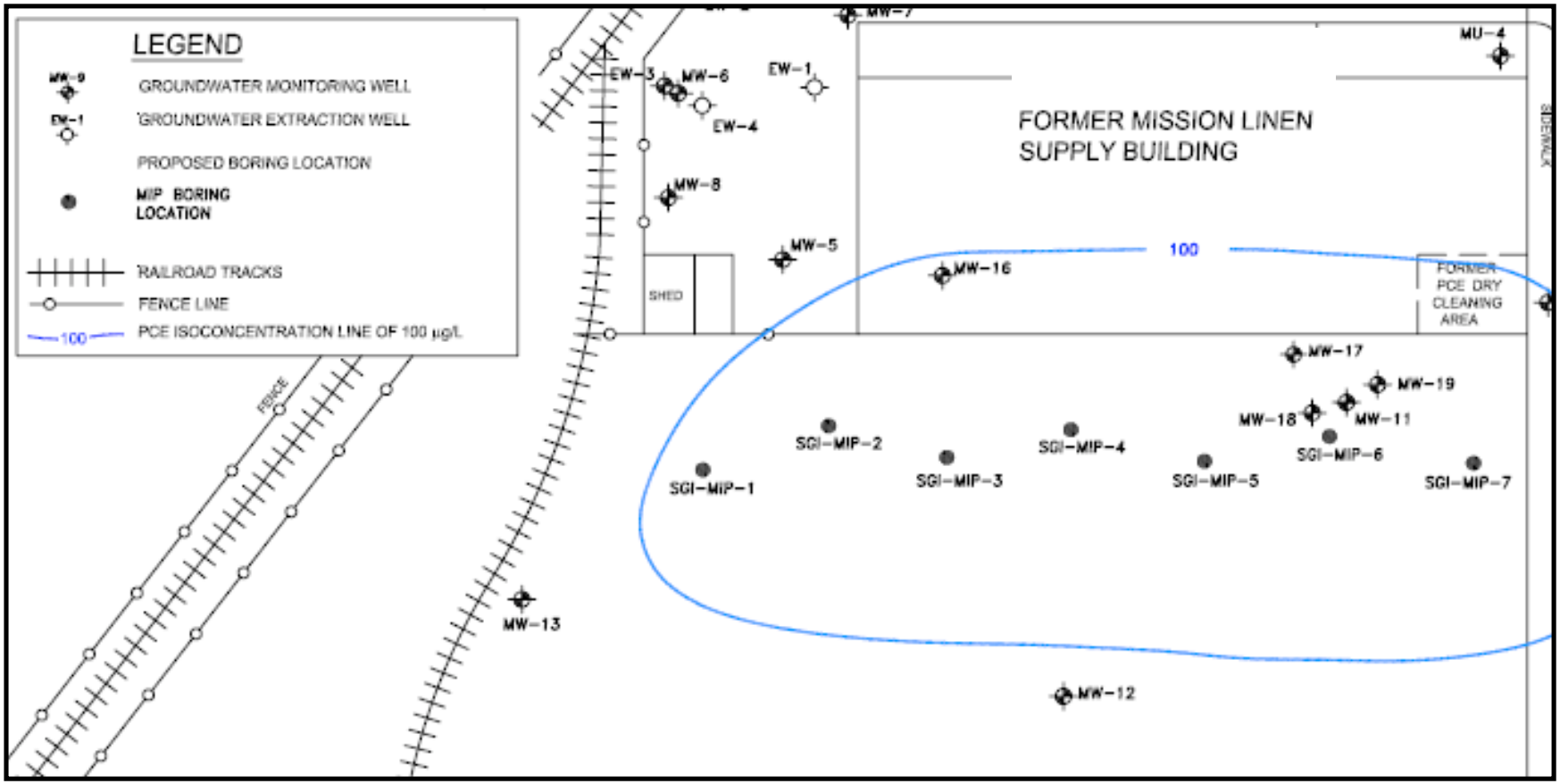
www.regenesis.com

RegenOx: California dry cleaner



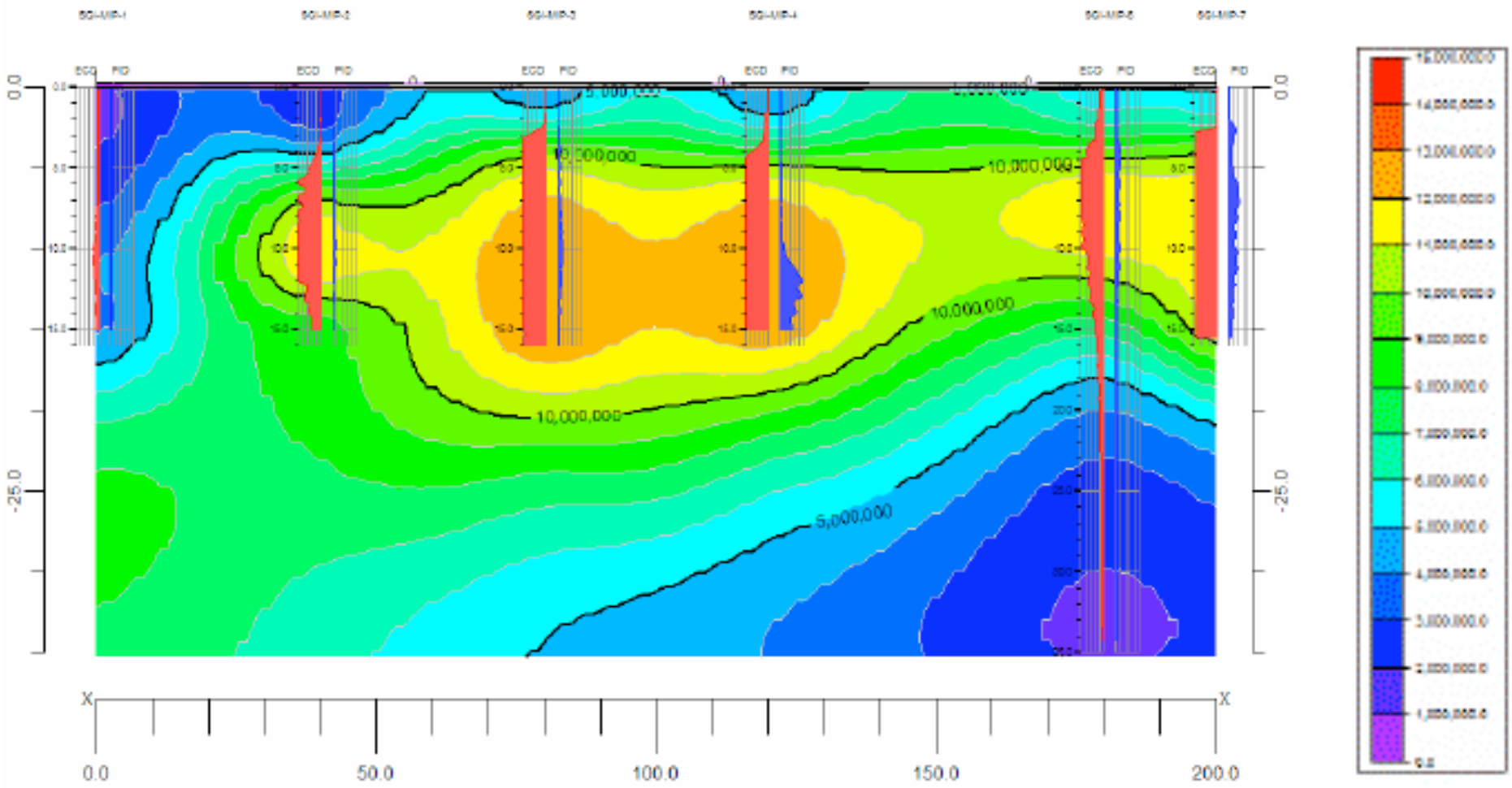
- **Free Product** in Vadose and Saturated Zones
- **PCE** 6,000 µg/L to **180,000 µg/L**
- Degradation Products:
  - **Vinyl Chloride** (ND to **19,000 µg/L**)
  - **TCE** (500 µg/L to **10,000 µg/L**)

Membrane Interface Probe (MIP) Characterization



MIP Characterization

ECD Cross Section with logs with ECD and PID



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RegenOx: Dry Cleaner Application

Treatment Area:
4,800 m^2

Soil Type:
Sand/Silt/Fill

Groundwater Velocity:
1.5 m/day

Depth to Groundwater:
2.6m (perched)

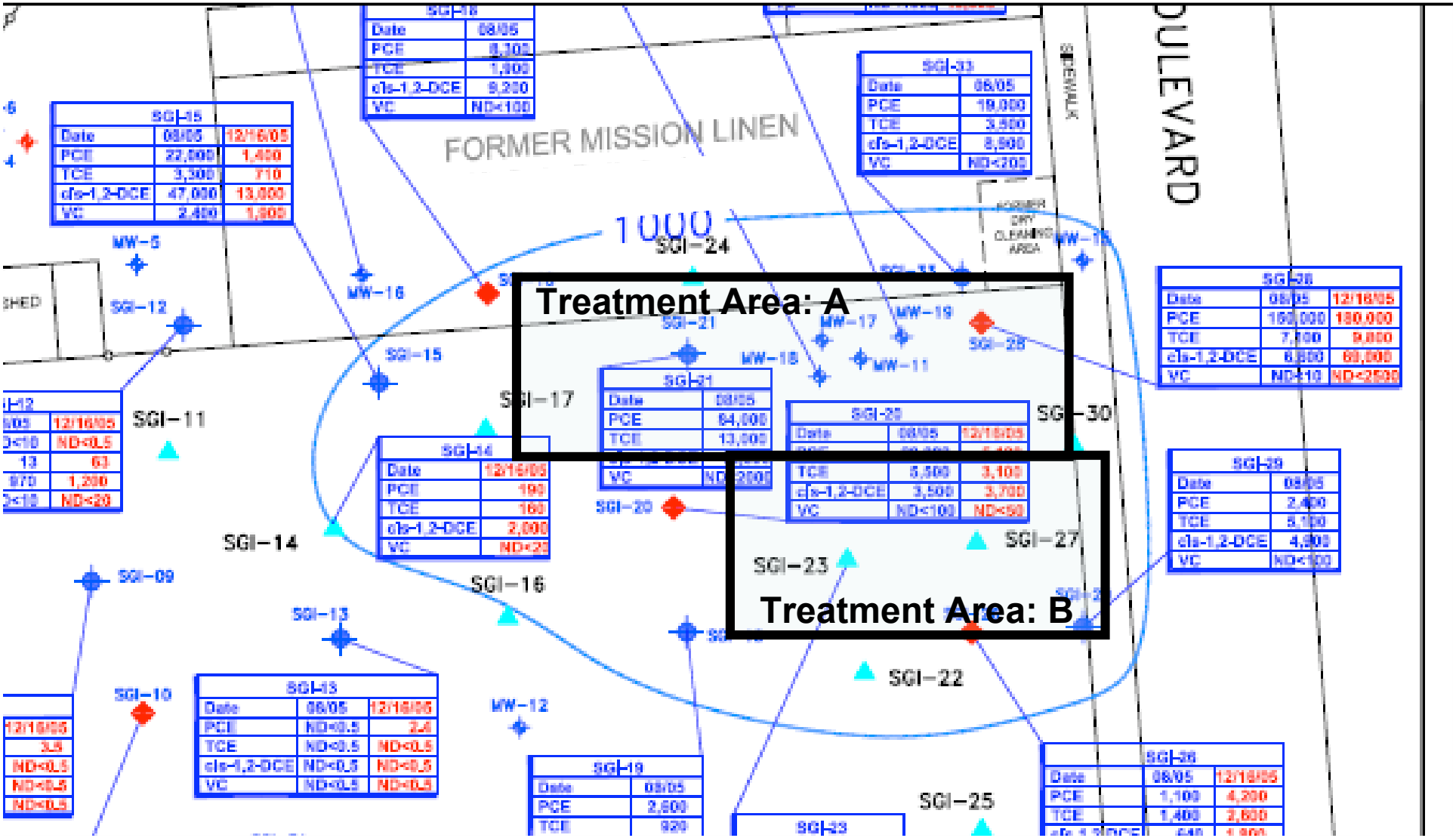
Application Rate:
10 kg/m

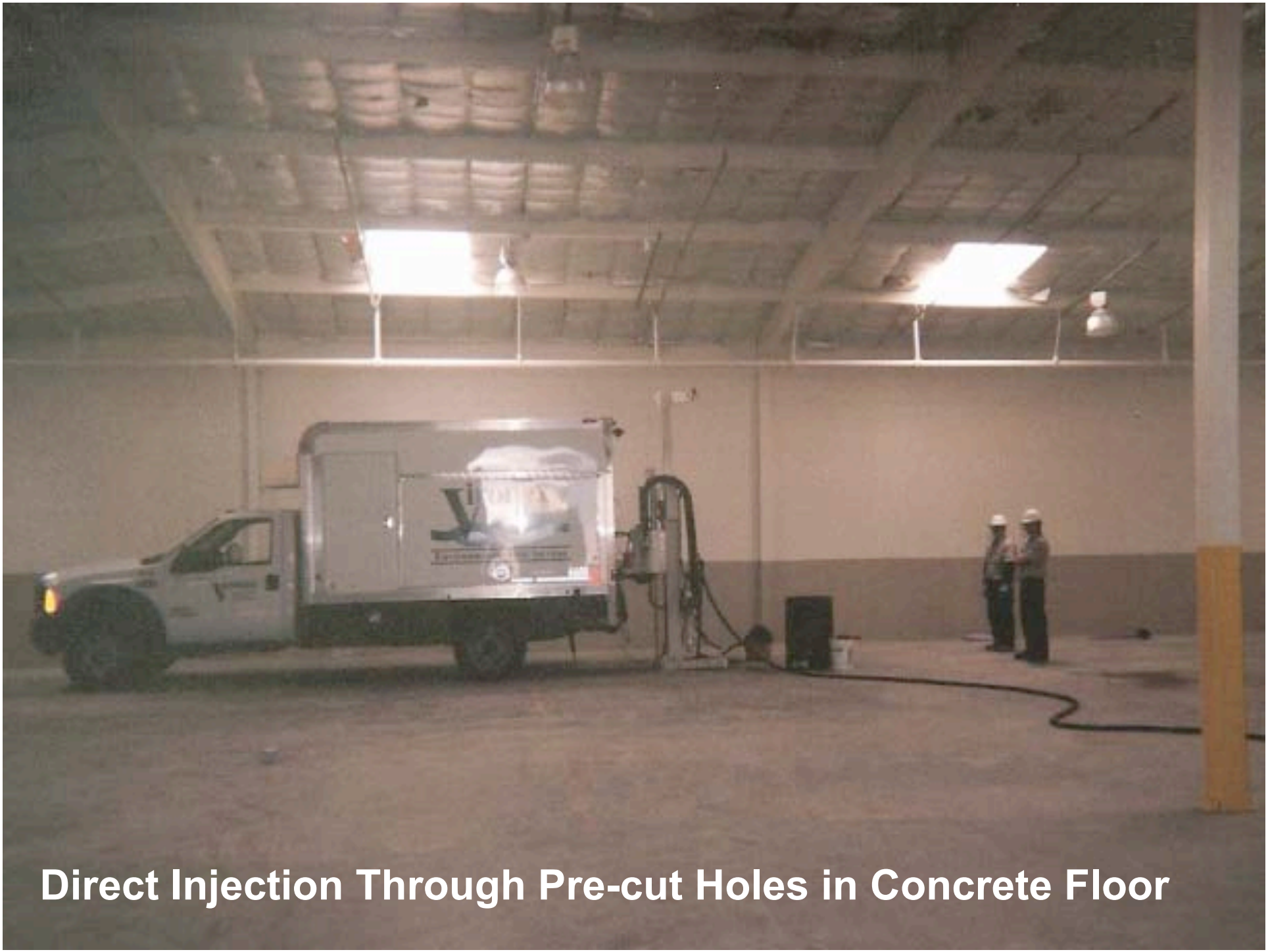
Application Volume:
~**50,000 L / injection**

Injection Spacing:
4.5 m

Cost ~ €10,000

RegenOx: Dry Cleaner Site

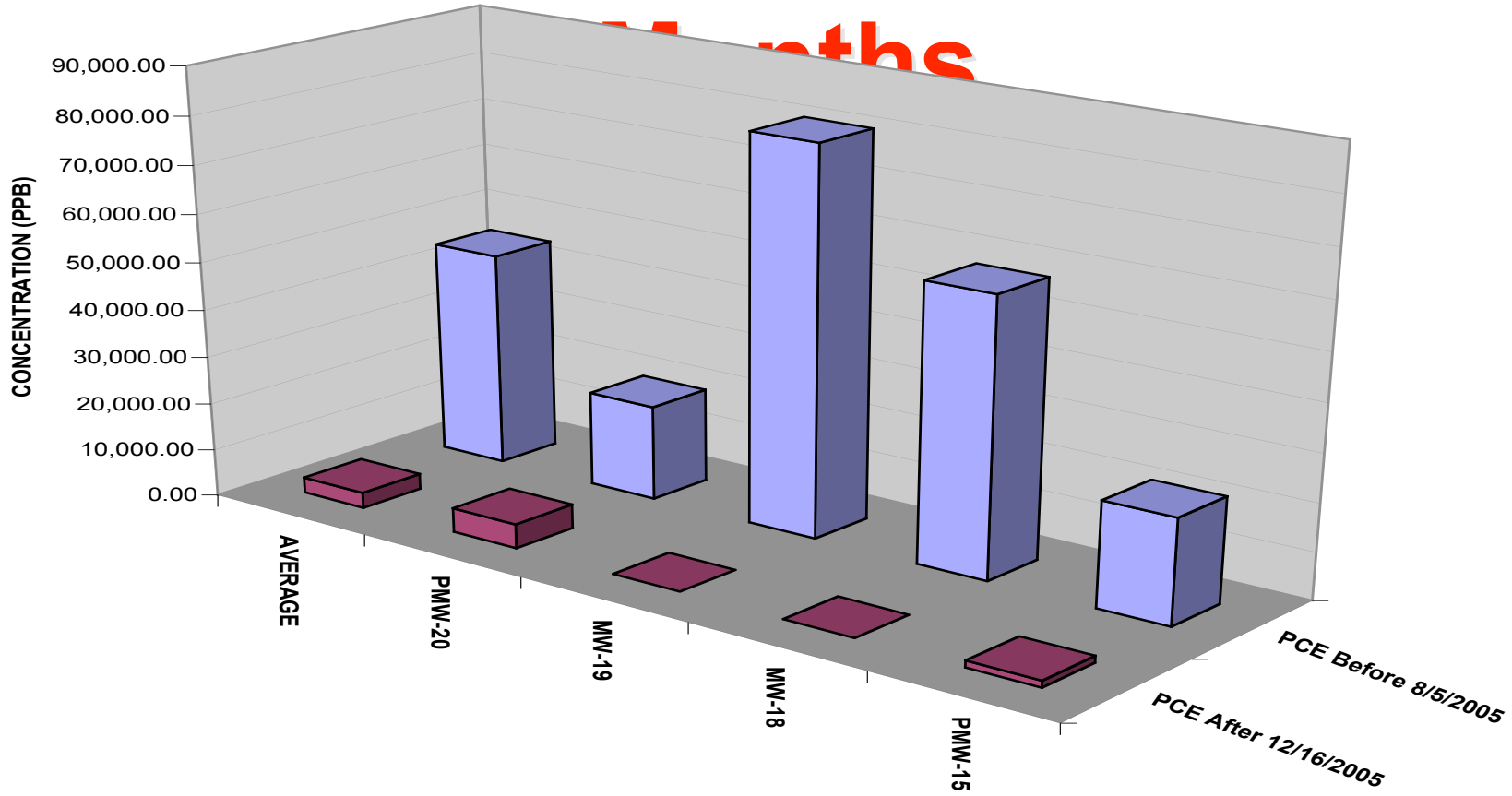




Direct Injection Through Pre-cut Holes in Concrete Floor

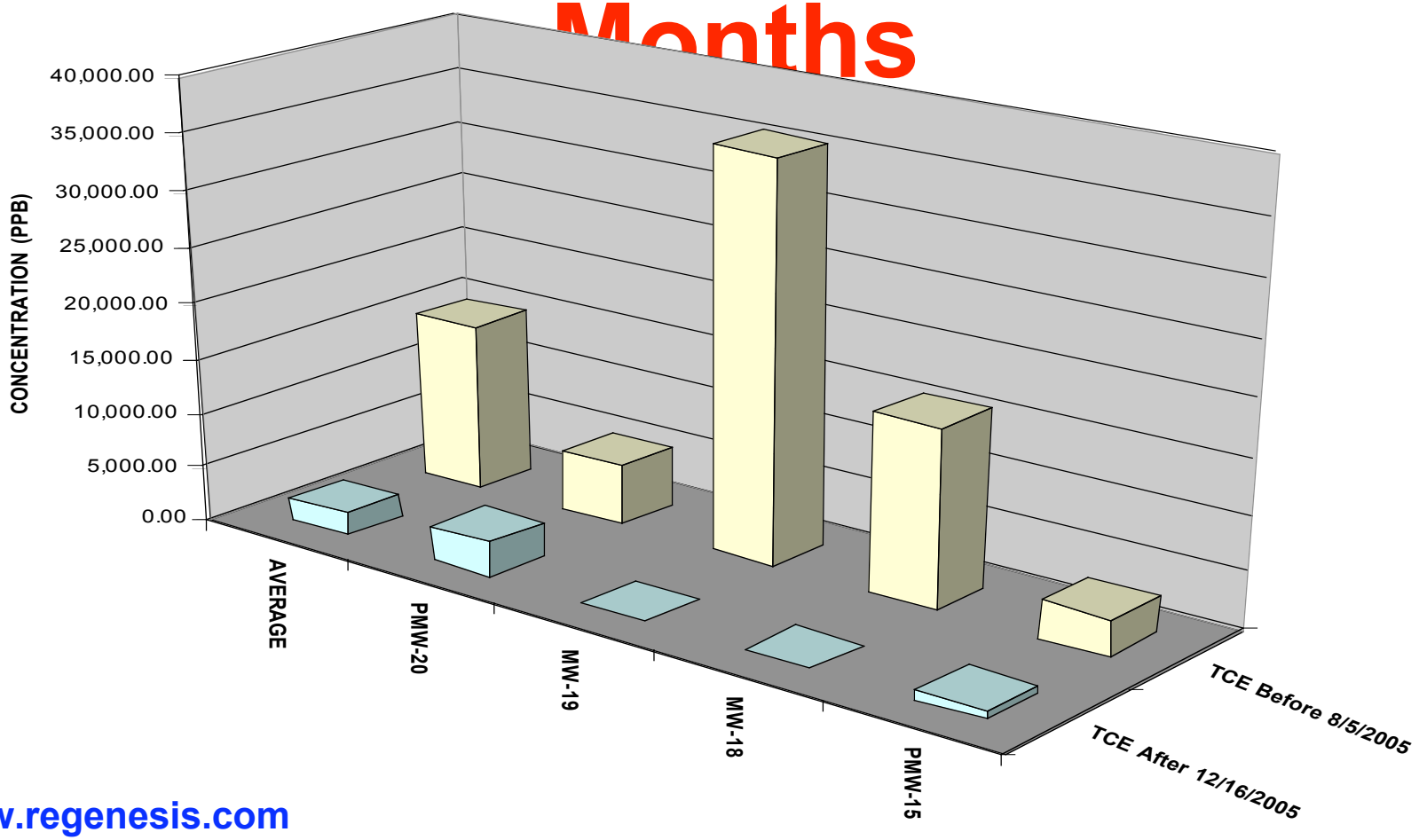
Remediation of High VOC Levels:

93% Reduction of PCE in 4 Months



Remediation of High VOC Levels:

88% Reduction of TCE in 4 Months



RegenOx Application: Industrial Dry Cleaner Site in California

Conclusions:

- Effective degradation in the presence of Free Phase VOCs

- **~90% Contaminant reduction** in a **single application** (muliple applications usually required)

RegenOx™

Case Study:

Morayshire, Scotland

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Project Details

- Residential property
- Heating oil leak
- Insurance job

Treatment Objective

- Achieve significant TPH reduction prior to installation of a vapour barrier
- *"Best endeavours"*

Soil Sample	Initial TPH Concentration
B016	27,300 mg/kg
B011	14,700 mg/kg
B021	6,950 mg/kg

RegenOx™ Application

BELFOR

- **Direct application from pails**
- **Shallow trenches**
- **Targeting of gross contamination**
- **Dug and watered in**

Results (soil) - *after 4 weeks*

Sample	Pre-RegenOx (mg/kg)	Post-RegenOx (mg/kg)	Reduction
B011	14,700	570	96%
B016	27,300	981	96%
B021	6,950	360	95%
Average (12 samples)	4,824	405	92%

Outcome

- **Four weeks after RegenOx™ application**:
  - No hydrocarbon odours for first time
  - **Average 92% TPH reduction** from % levels
  - Regulators required no further action

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BELFOR

Chemical Oxidation

RegenOx™

Mixed Chlorinated Solvent and Hydrocarbon plume

- Alberta, Canada

Chemical Distribution Facility
Alberta, Canada

Site Details

- Treatment area: - 250m^2
- Soil type: - clay
- Groundwater velocity - zero
- Depth to groundwater - 1.5 m
- BTEX - **104,700 µg/L**
- MIBK - **240,000 µg/L**
- Chlorinated ethenes - **45,000 µg/L**

RegenOx™ Application

- Direct-push injection
- Grid of 2 m centres

- Hit #1 – 860 kg RegenOx
- Hit #2 – 680 kg RegenOx

- Application cost:
  - *ca*. **€ 6,500 RegenOx**
  - *ca*. € 18,000 injection

- Total application < € 25,000

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RegenOx™ Distribution

- **first injection left**
- **second injection right**

First and second application points offset to increase coverage

Variable application rates achieved due to low-permeability of clay matrix

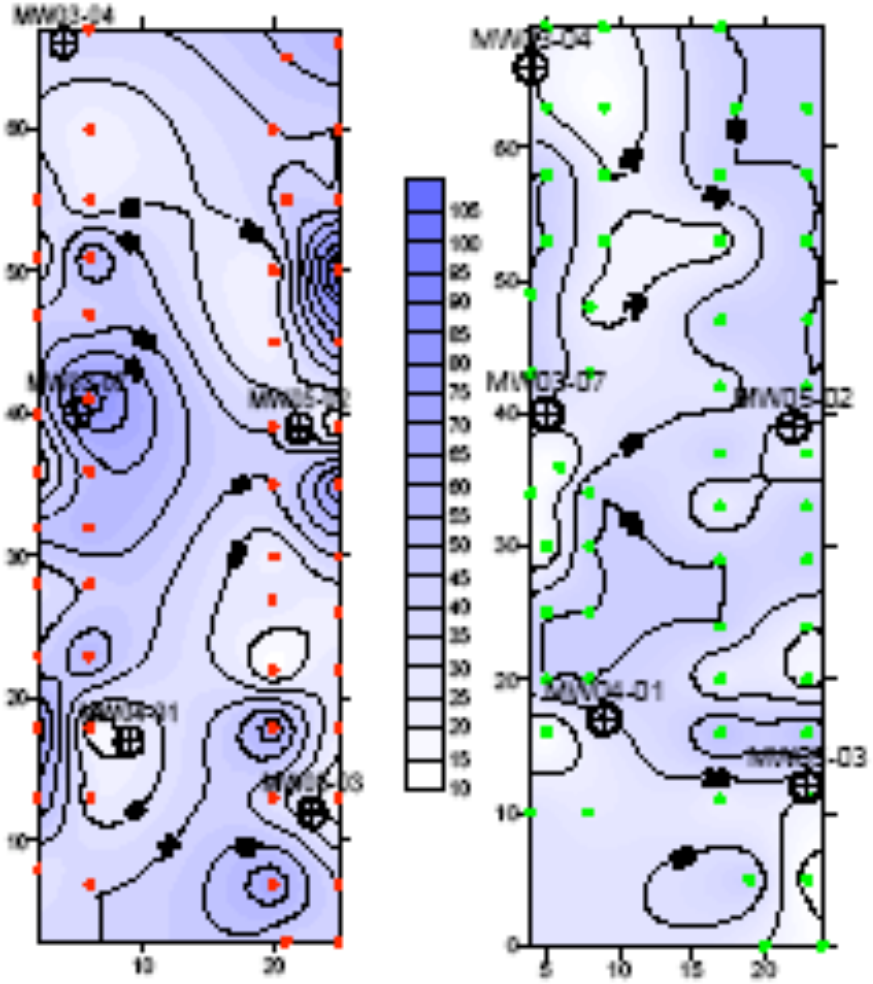


Figure 3. RegenOx product distribution based on injection volume (gal): 1st injection (left) and 2nd injection (right)

Vinyl Chloride
- first injection

Pre-treatment
mean = 10,900 µg/L
max = 20,000 µg/L

Post-treatment
mean = 620 µg/L
max = 1,200 µg/L

Average reduction = 94%

Peak reduction = 94%

(first injection only)

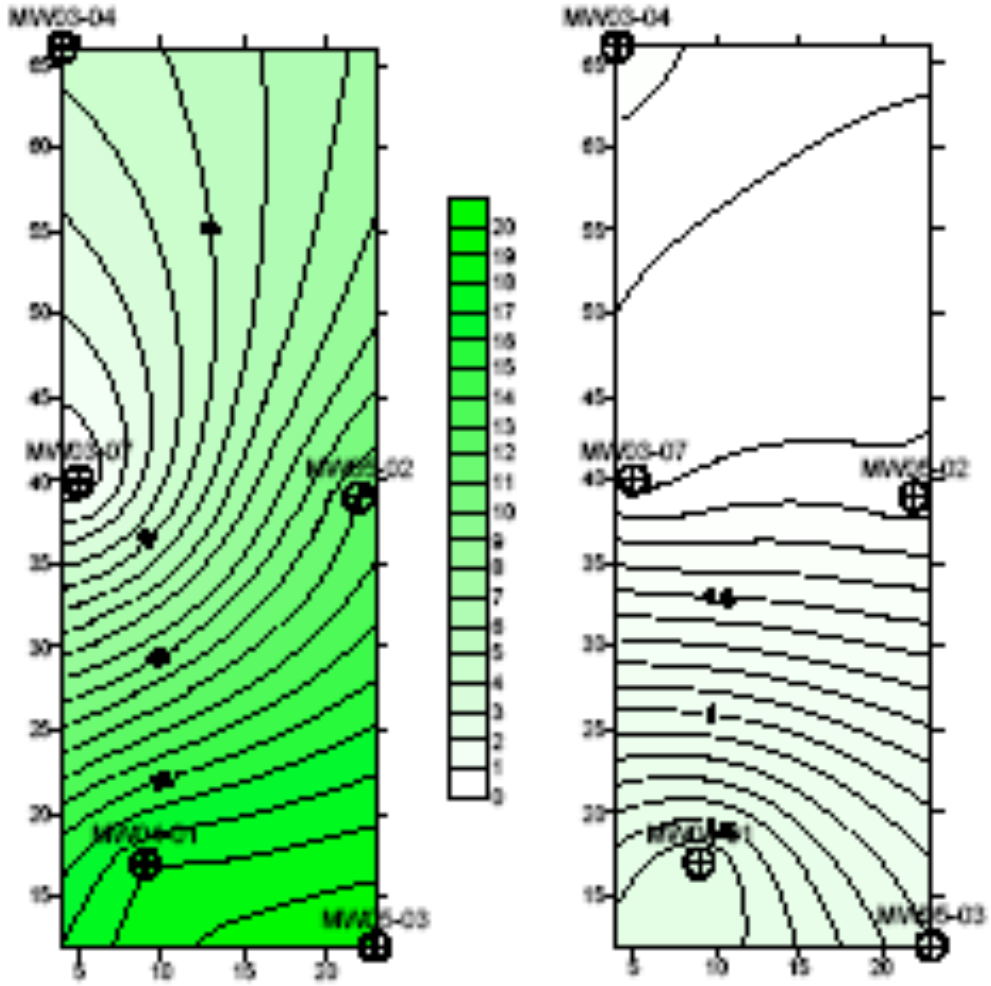


Figure 6. Vinyl chloride concentrations (mg/L) pre-injection July 2005 (left) and post-injection Oct 2005 (right)

Toluene

- first injection

Pre-treatment

mean = 19,000 µg/L

max = 87,000 µg/L

Post-treatment

mean = 10,400 µg/L

max = 44,000 µg/L

Average reduction = 45%

Peak reduction = 49%

(first injection only)

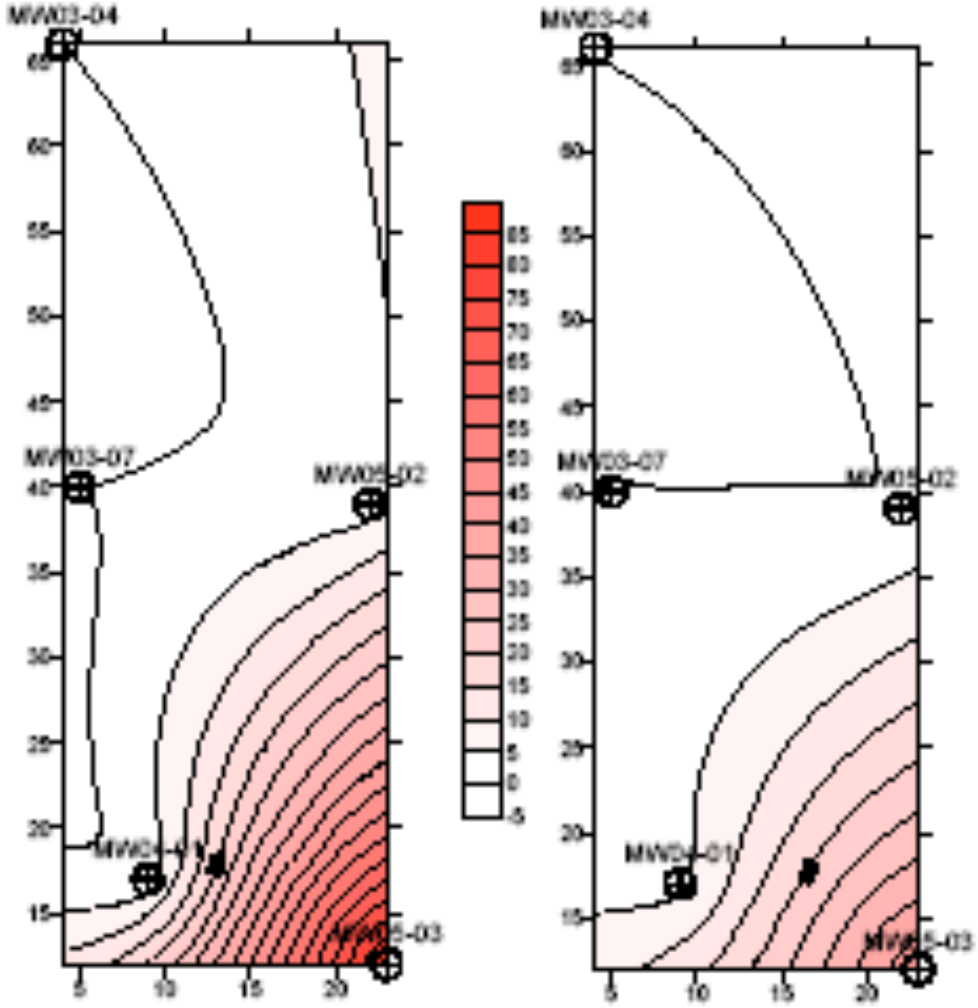


Figure 4. Toluene concentrations (mg/L) pre-injection July 2005 (left) and post-injection Oct 2005 (right)

Data Summary MW 05-03
(*First application only* - peak well)

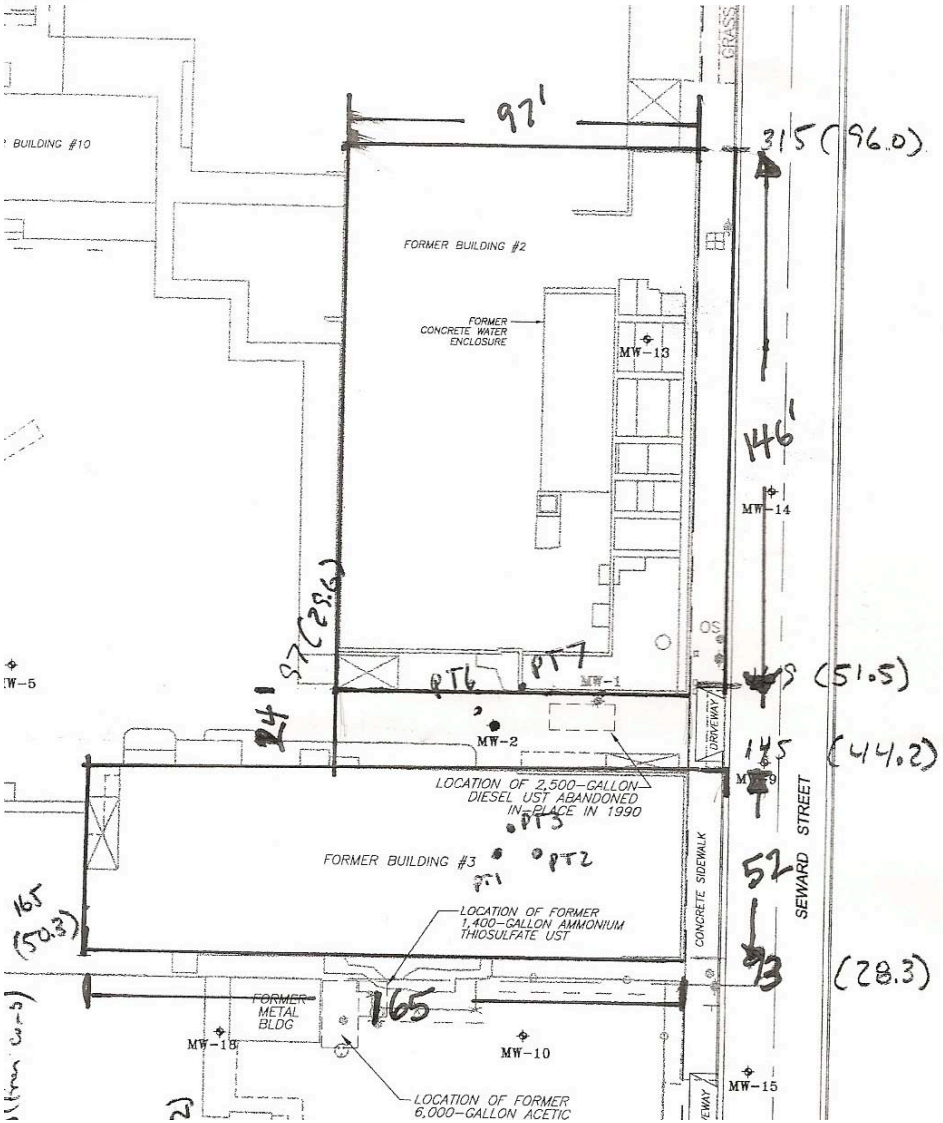
Contaminant (µg/L)	Pre-RegenOx™	Post-RegenOx™	Reduction (%)
Toluene	87,000	44,000	49%
Ethylbenzene	2,700	910	66%
Xylenes	15,000	5,800	61%
Vinyl Chloride	20,000	1,200	94%
***cis*-DCE**	25,000	9,200	63%
PCE	54	13	76%
MIBK	240,000	53,000	78%
TOTAL	**390,000**	**114,000**	**71%**

Chemical Distribution Facility - Conclusions

- Application rates uneven due to clay formation
- Chorinated and non-chlorinated species oxidised together (**45% – 94% reduction**)
- Mean **source area reduction = 71%** (390,000 µg/L to 114,000 µg/L)
- From **first injection only** – second injection followed (second injection data not available at time of writing)


VIRONEX
6610DT
It's behind you...!

RegenOx™ Application at Hollywood Site



Treatment Area:

4,500 m^2

14,700 m^3

Soil Type: Fill

Groundwater Velocity:

NA (vadose)

Depth to Groundwater:

6 m (perched)

Application Design

Quantity Applied:

- Injection #1: 910 kg RegenOx
- Injection #2: 890 kg RegenOx

Application Rate:

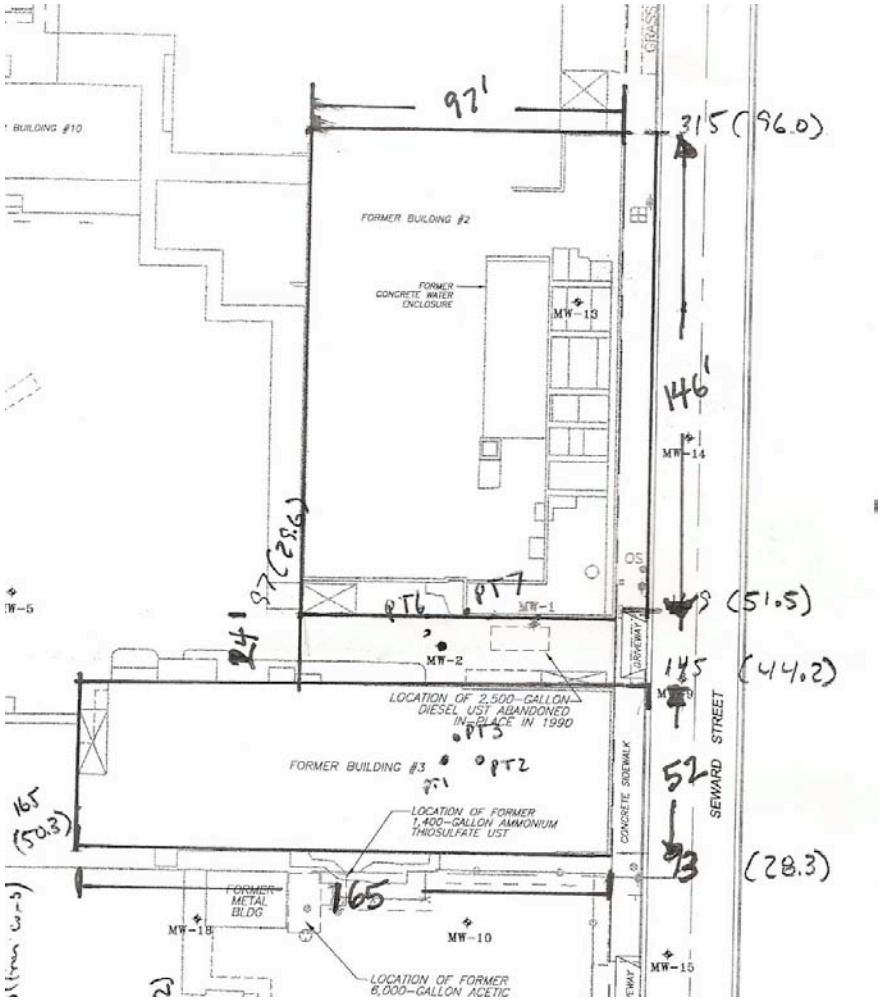
- 2.5 kg/m^3 (design)
- 6.5 kg/m^3 (as built)

Application Volume:

- ~1 900 L / injection point
- *In Situ* Mixing

Injection Spacing:

- 2.5 m

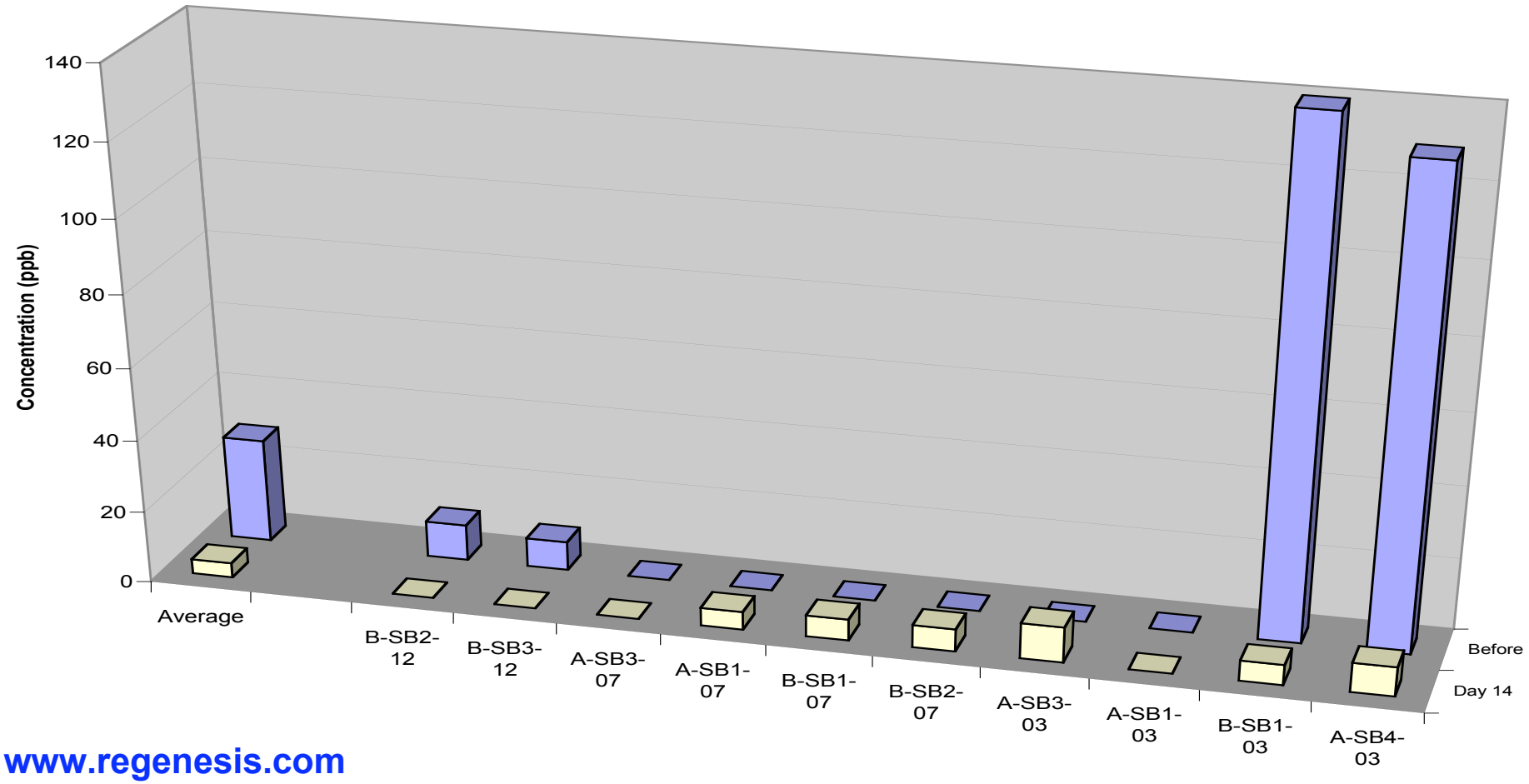


Hollywood Site Preliminary Data:

	PCE	
	Before	Day 14
A-SB4-03	130	8.1
B-SB1-03	140	5.6
A-SB1-03	ND	ND
A-SB3-03	ND	9.8
B-SB2-07	ND	6.2
B-SB1-07	ND	5.9
A-SB1-07	ND	5.0
A-SB3-07	ND	ND
B-SB3-12	8	ND
B-SB2-12	10	ND
Average	28.8	4.1

PCE (µg/kg)

Hollywood Site
Preliminary Data: PCE



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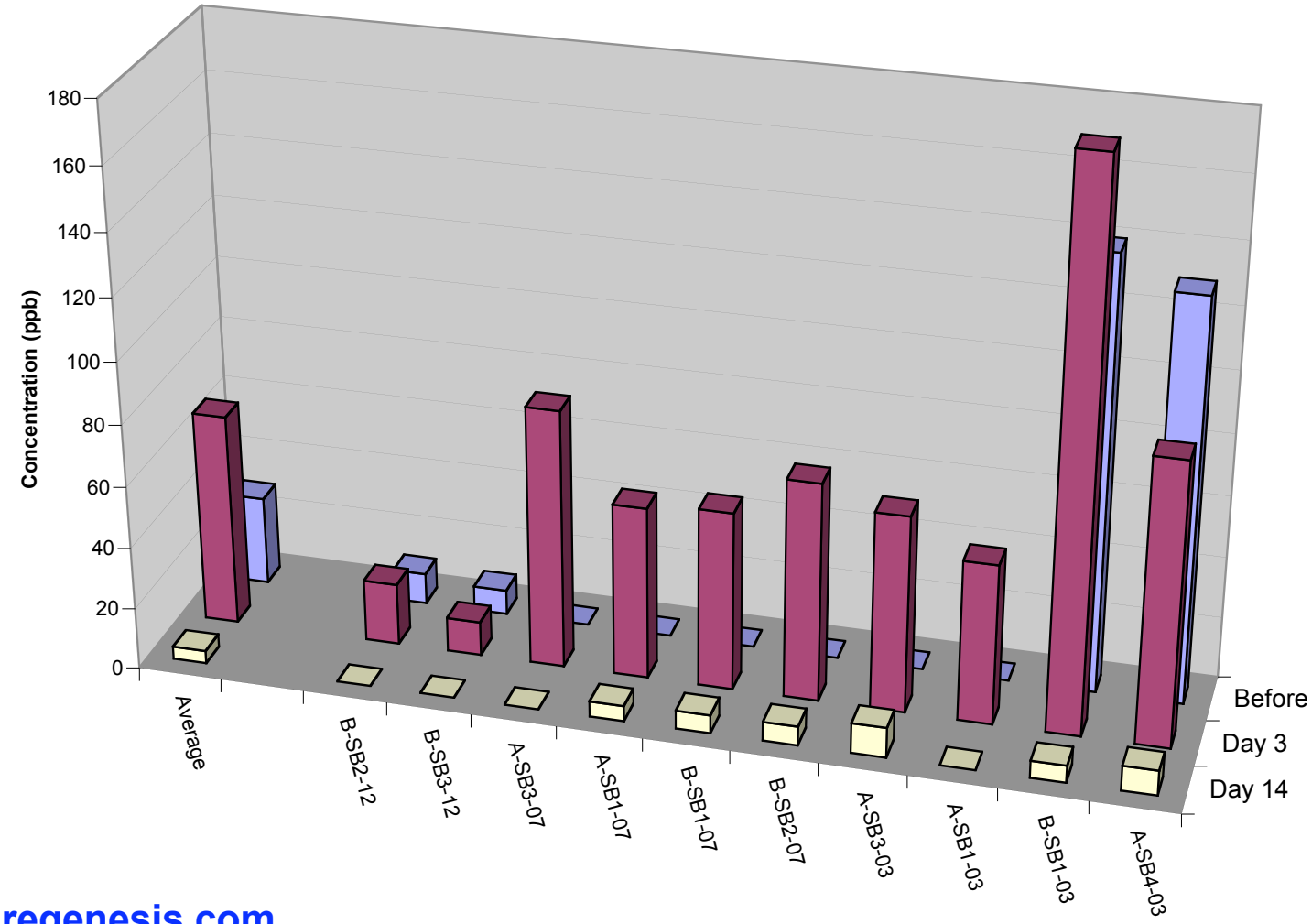
Hollywood Site Preliminary Data

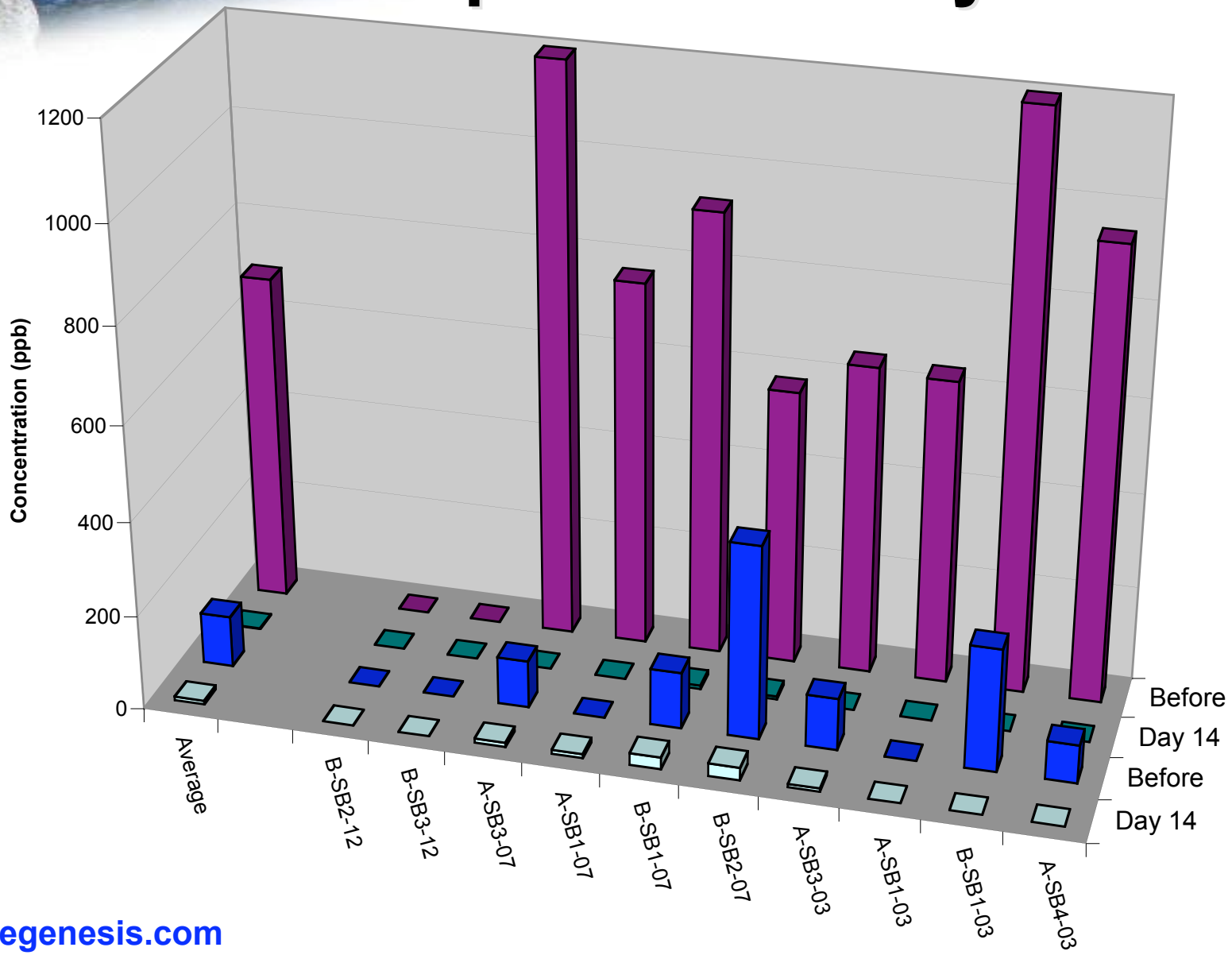
	PCE		
	Before	Day 3	Day 14
A-SB4-03	130	92	8.1
B-SB1-03	140	180	5.6
A-SB1-03	ND	52	ND
A-SB3-03	ND	64	9.8
B-SB2-07	ND	71	6.2
B-SB1-07	ND	58	5.9
A-SB1-07	ND	56	5.0
A-SB3-07	ND	84	ND
B-SB3-12	8	11	ND
B-SB2-12	10	20	ND
Average	28.8	68.8	4.1

Hollywood Site Preliminary Data



Hollywood Site Preliminary Data:

Napthalene & Styrene



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DPT Application Conclusion

- **DPT was working but…**
  - Too Slow
  - Too Inefficient

In situ mixing

In Situ Mixing

Adding of RegenOx

in situ Mixing

Mixing Head

May require assistance from conventional excavation equipment


RegenOx™ Application by *In Situ* Mixing

Results

Weather: Warm and Partly Sunny

Cells Treated today

Sample Id	TCE	Styrene	Sample Id	TCE	Styrene
2E11-3	34	N / D	2F10-3	24	N / D
2E11-6	42	N / D	2F10-6	56	N / D
2E11-9	59	N / D	3H8-3	6.1	N / D
2E10-3	47	N / D	3H8-6	5.9	N / D
2E10-6	46	N / D			
2E10-9	100	N / D			

Part "B" lbs.

Buckets Part "A"	153
Buckets Part "B"	

Building 3

Building 2

3I7 3H7 3I8 3' - 6.1 6' - 5.9 3H8 2G8 2F8 2E8 2D8 2C8 1B8 1A8

This cell retreated on 6-9-06 to 7' 56 buckets of ea. A and B

This cell retreated on 6-9-06 to 10' 80 buckets of ea. A and B

3I9 3H9 2G9 2F9 2E9 2D9 2C9 1B9 1A9

This cell retreated on 6-8-06 to 4' 32 buckets of ea. A and B

3I10 3H10 2G10 3' - 24 6' - 56 9' - N/D 2F10 2E10 3' - 47 6' - 46 3' - 100 2D10 2C10 1B10 1A10

This cell was retreated on 6-7-06 Used last of Part A

3I11 3H11 2G11 2F11 2E11 3' - 34 6' - 42 3' - 53 2D11 2C11 1B11 1A11

215'

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

J I H G F E D C B A

Seward St.

Direct Injection vs. *in situ* Mixing

Direct Push Injection

- Cost per Week
  - $60,000
- Treatment per day
  - 750 m^3
- Success Rate
  - 70%

In situ Mixing

- Cost per Week
  - $50,000
- Treatment per day
  - 1,500 m^3
- Success Rate
  - 90%

Conclusions

- ***In situ* mixing was**:
  - **Better**
  - **Cheaper**
  - **Faster**
  - (In a shallow unsaturated formation)

- Regenesis is currently working with selected engineering contractors to develop novel or improved *in situ* and *ex situ* application processes

Conclusions

- *In situ* mixing should be considered when treating **vadose zone**
- Efficiency is site specific, but can be cost effective
- **Clean-up criteria met in 1 ½ months**
- Site closure application pending

Presentation Conclusions

- **RegenOx™ easy and safe to handle**
  - flexible application
  - opportunities for creative engineering
  - This means ***low project costs***

- **Strong oxidising power**
  - Wide range of treatable contaminants
  - Solvents, hydrocarbons, PAHs, mixed plumes…etc.

- **Vadose zone** and **saturated zone** treatment

REGENESIS

Chemical Oxidation

RegenOx™

it works

www.regenesis.com

REGENESIS

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