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ERDENHANCED™

Cost-Effective In-Situ Remediation

Biostimulation as a Residual Source Mass Remediation Strategy

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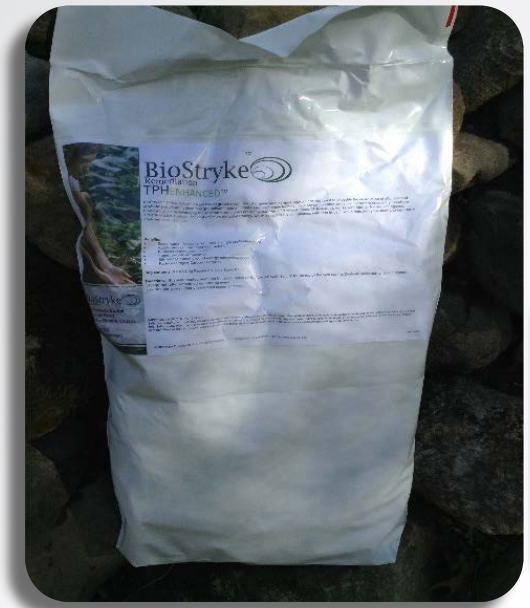


G2S Environmental Consulting Inc.

Safe Sustainable Effective

How is Biostimulation Cost-Effective?

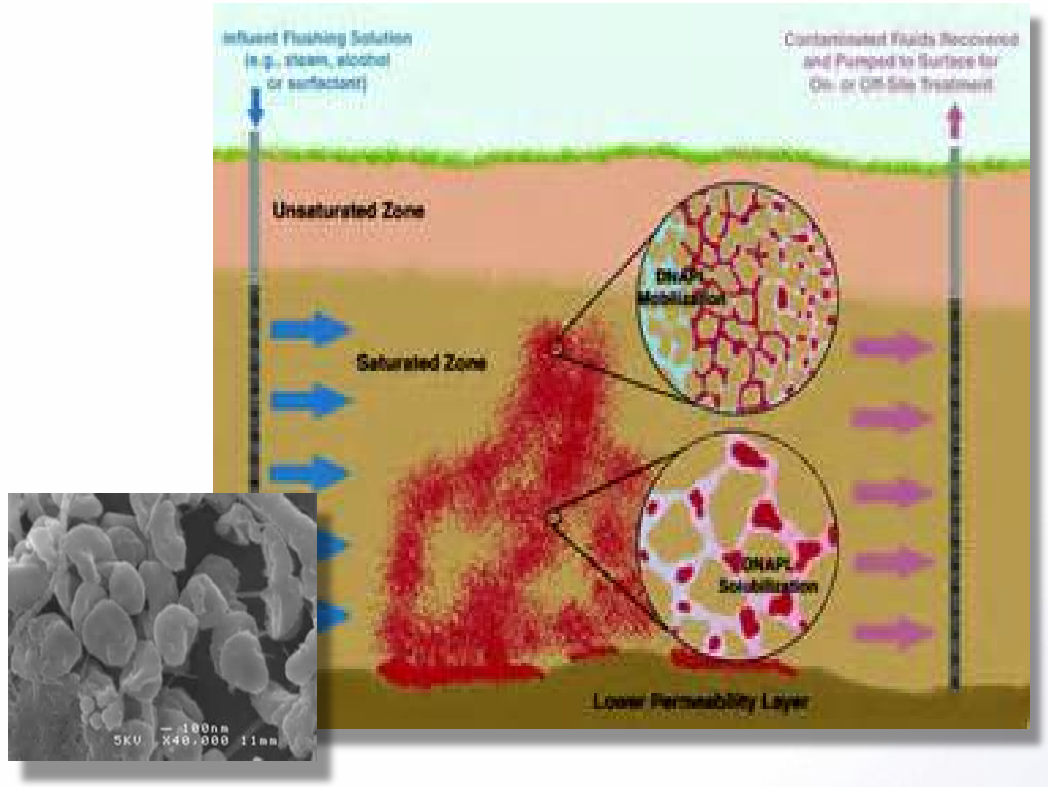
Biostimulation a proven remediation strategy

Nourishes and stimulates *native* microbial populations

Expedites solubilization of residual source mass contaminants

Increases contaminant bioavailability

Enhances dissolve phase contaminant dehlorespiration to Realize Long-Term Compliance



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Biostimulation of Chlorinated Alkanes and Alkenes

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Site is an Industrial Warehouse/Office Building
Located in Burlington, Ontario Canada

Past Site Use includes Environmental & Automobile Related Industries

Abutting Properties with Similar Past Site Operations
Both locations currently vacant

cVOC Contaminants documented in Site and off-Site groundwater and subslab saturated soils

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Biostimulation of Chlorinated Alkanes and Alkenes

Principal Contaminant(s)-of-Concern
Chlorinated Volatile Organic Compounds (cVOC)

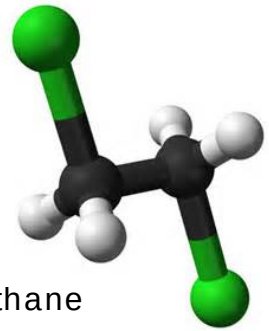
1,1,1-Trichloroethane (TCA)

Daughter/Breakdown cVOCs

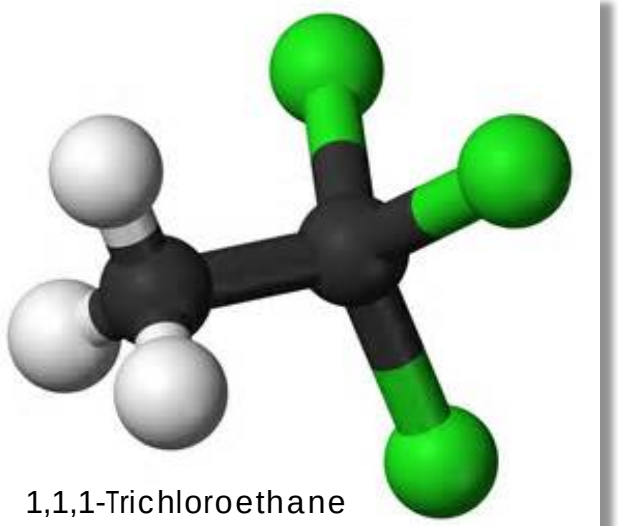
cis-1,2-Dichloroethylene (cis-DCE)

Dichloroethane (DCA)

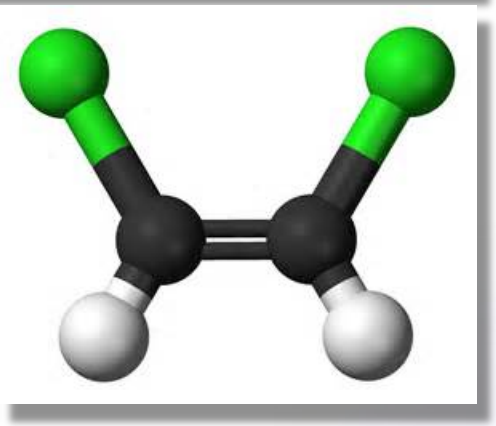
On-going litigation as to Responsible Parties,
Site Owner allowed evaluation –
'might as well do something' approach



Dichloroethane



1,1,1-Trichloroethane



cis-Dichloroethylene

What is ERDENHANCED™

ERDENHANCED™

Patented Biostimulation Additive

1) Complex Carbon Source
   - Requires microbial breakdown
   - Provides Long-Term Donor Source

2) Highly Saturated Carbohydrate providing food and fuel (H+)
   - Breakdown process also supports co-solvent effect

3) Proprietary blend of macro-micro nutrients
   - Supports microbial ‘fitness’ and,
   - Benefits of endogenous decay

What is ERDENHANCED™

ERDENHANCED™

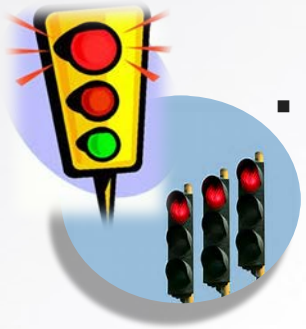
Lowers Carbon Footprint while Minimizing Site Impacts

Safe, Minimizing Secondary Impacts & Indoor Ambient Air Issues

Sustainable, Providing Long-Term Reducing Conditions

Effective, Eliminates Nuisance Noise, Emissions and Vapors

When is Biostimulation Appropriate?



- **Inappropriate without Physical Removal**
  - Pooled DNAPL/NAPL Source Zone
    - Time is of the essence

- **Appropriate with Remedial Design Considerations**
  - Heterogeneous matrix, silty/clay soil, fractured bedrock
    - Residual DNAPL, cVOC and non-cVOC mixture
      - Highly aerobic overburden

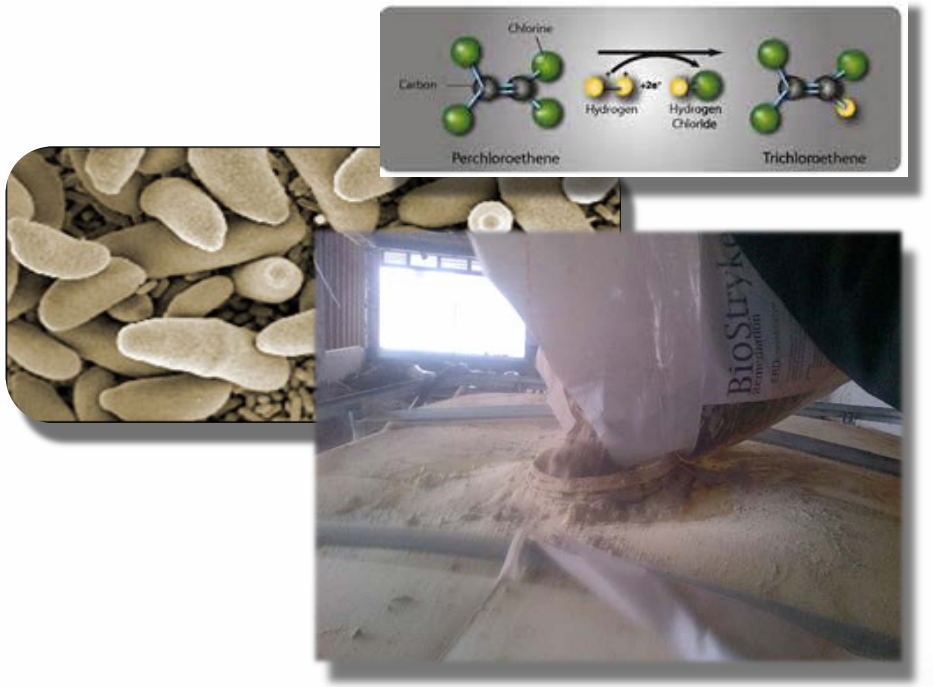
- **Ideal Situation**
  - Accessible saturated impact zone
    - Time constraints minimal
  - Homogeneous stratigraphic conditions

Enhanced Reductive Dechlorination
ERDENHANCED™ Biostimulation

- Biotic Reductive Dechlorination = Substitution of H^+ for Cl^-

- Environmental Conditions
  - ★ Anaerobic (<0.5 mg/L DO)
  - ★ Chemically Reducing (<50 mV ORP)
  - ★ Hydrogen ("Fuel" for Dechlorination)

- Additive Mechanisms
  - ★ Carbon expedites electron scavenging
  - ★ Nutrients enhance microbial activity
  - ★ Carbohydrate supplies food and H^+
  - ★ Co-Solvent Effect from assimilation of Carbohydrate
  - ★ Formulation maintains sustainable reducing conditions that have exceeded a <u>decade</u> in duration



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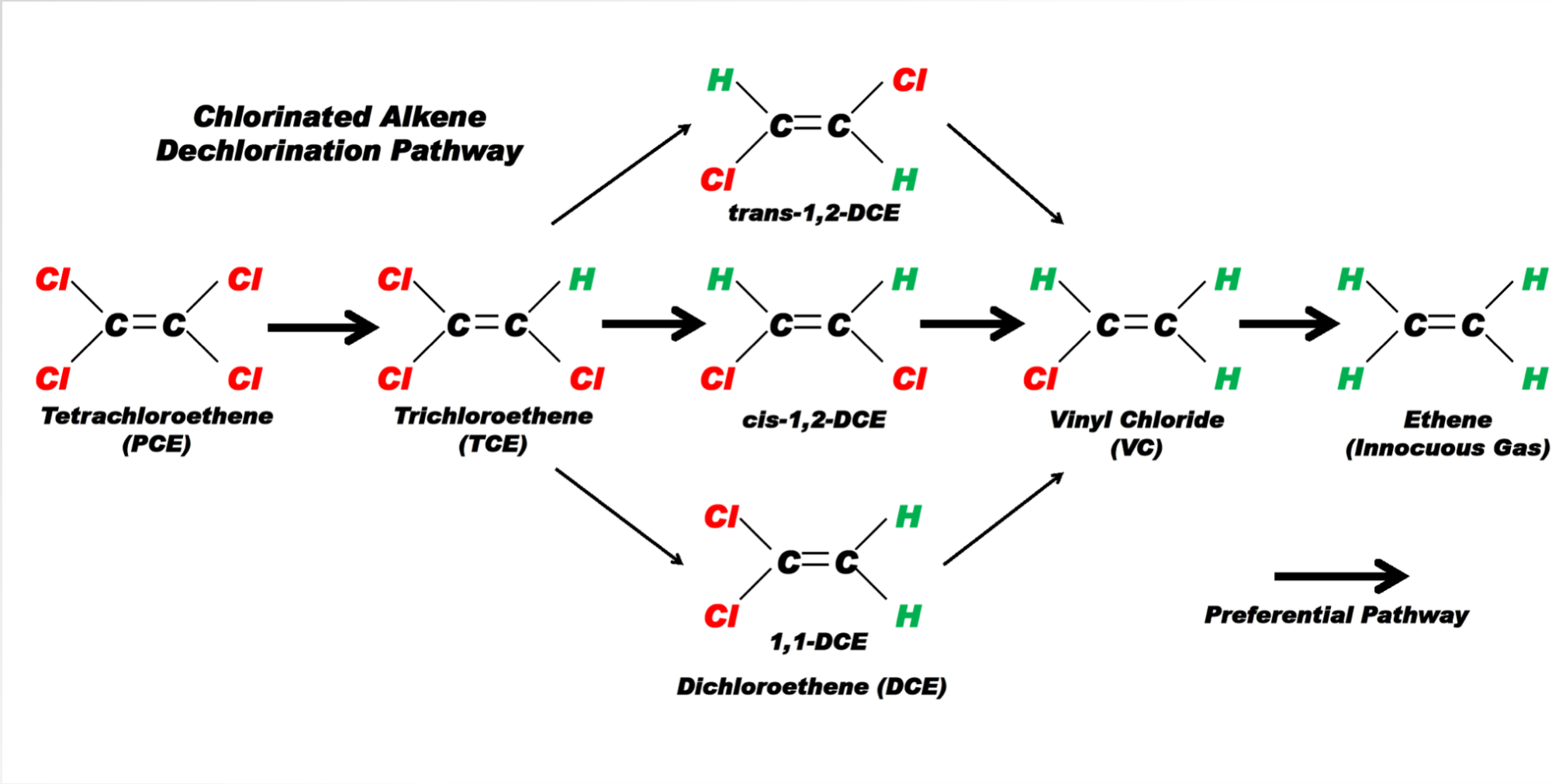
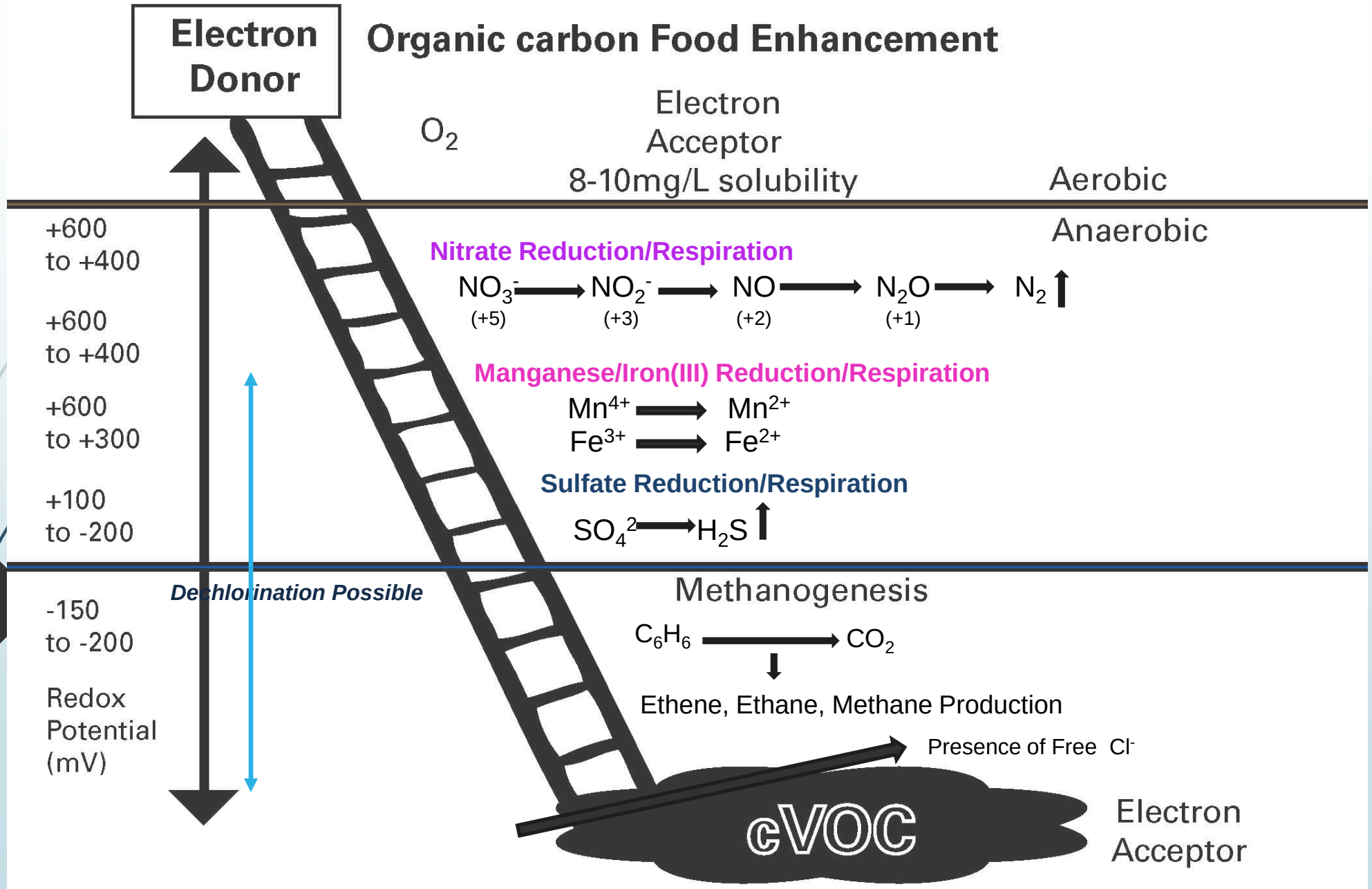
cVOC Biotransformation Pathway



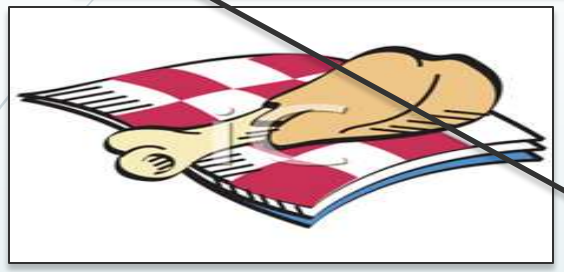
The Terminal Electron Ladder



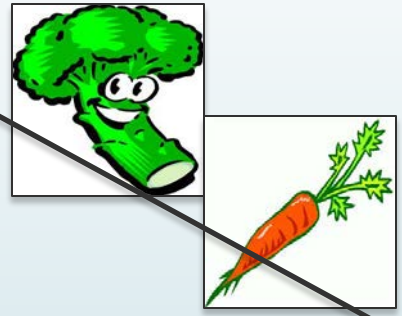
Aerobic Respiration

O_2 e^- consumption complete

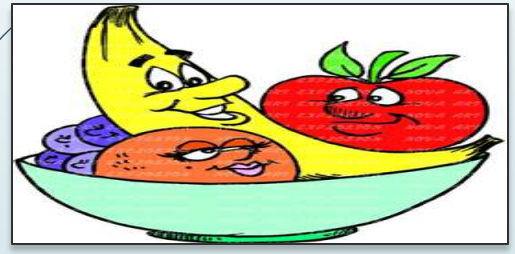
Anaerobic Conditions



Nitrate Respiration

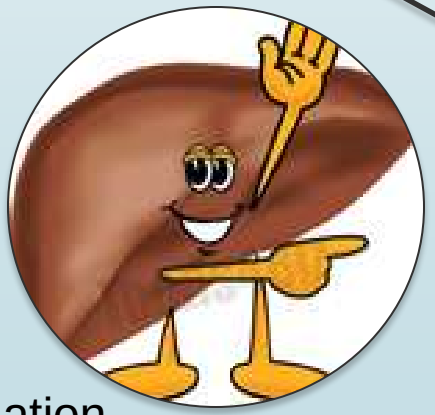


Iron – Manganese Respiration



Sulphate Respiration

CO_2 Respiration



Methanogenesis

cVOC biotransformation

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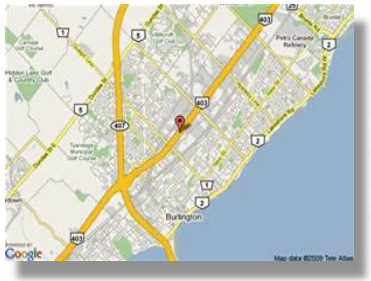
Biostimulation of Chlorinated Alkanes and Alkenes

- Groundwater solute plume migrating downgradient, off-site, in concentrations above Ontario Ministry of Environment (MOE) Table 2 criteria.
- Concentrations [*total* cVOCs]range from 10 ug/L to > 1,000 ug/L at source zone locations
  - Maximum [TCA] 240 ug/L
    - [DCA] 11 ug/L
    - [cis-DCE] 170 ug/L



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Biostimulation of Chlorinated Alkanes and Alkenes

- Groundwater flows southerly, towards Lake Ontario
- Site soils described as reddish brown silty-sand to a depth of ≈26ft below ground surface (bgs)
- Assumed 25% effective porosity
- Limited Interior Access; Unlimited Exterior Access

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Biostimulation of Chlorinated Alkanes and Alkenes

✦ **Indicator Metrics**

Field Parameters:

- ORP, DO, pH, Temperature

Geochemistry:

- Nitrates (NO3), Sulphates (SO4) , dissolved Iron/Manganese
- Methane/Ethane/Ethene, Chloride

Analytical:

- Contaminant(s)-of-Concern (EPA 8260)

✦ **Field Indicator Parameters Recorded *Every* Event**

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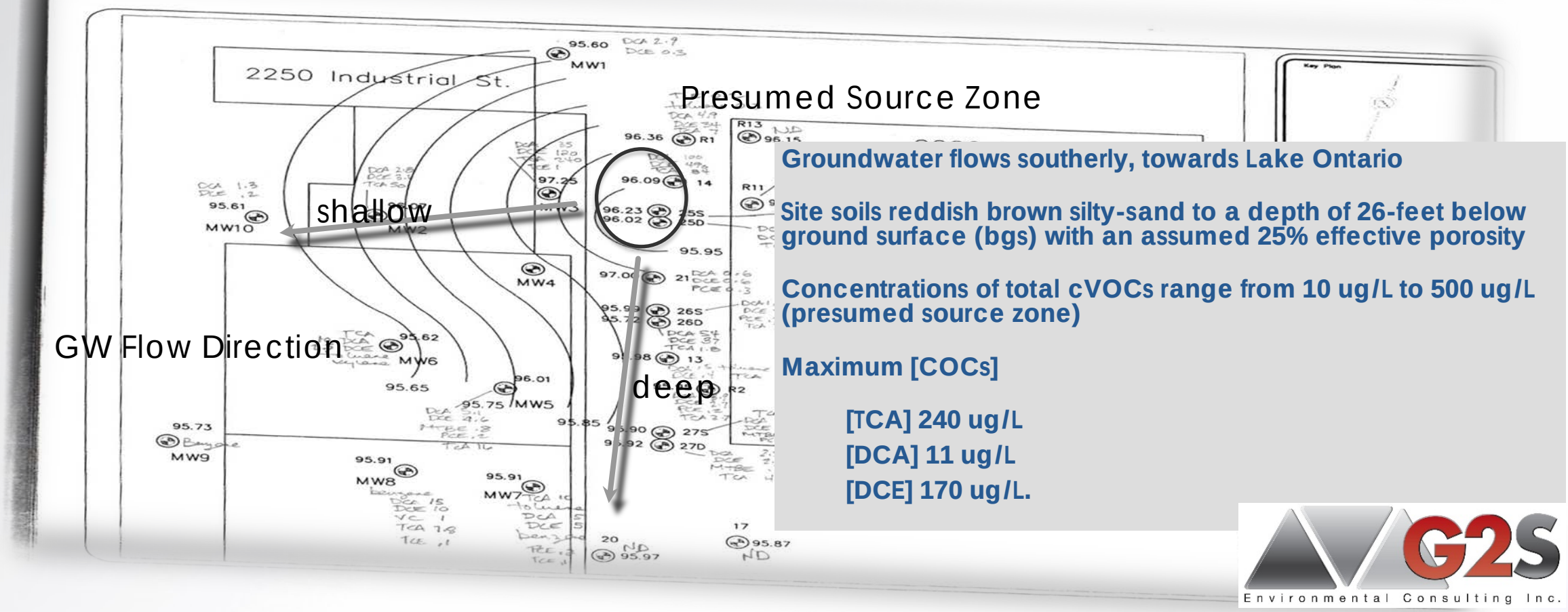
Biostimulation of Chlorinated Alkanes and Alkenes



Groundwater flows southerly, towards Lake Ontario

Site soils reddish brown silty-sand to a depth of 26-feet below ground surface (bgs) with an assumed 25% effective porosity

Concentrations of total cVOCs range from 10 ug/L to 500 ug/L (presumed source zone)

Maximum [COCs]

[TCA] 240 ug/L
[DCA] 11 ug/L
[DCE] 170 ug/L.

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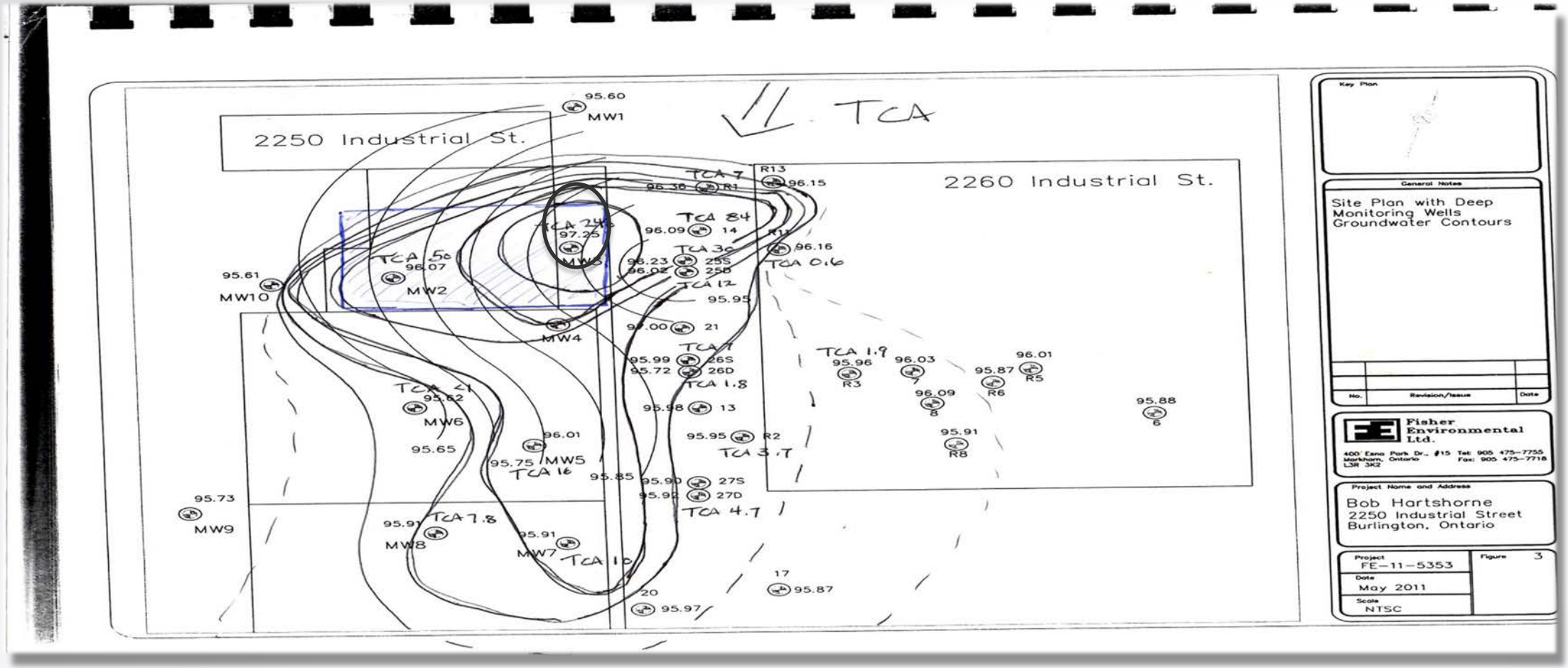
TCA Plume – Shallow and Deep Components



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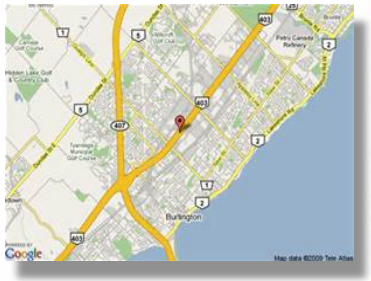
Biostimulation of Chlorinated Alkanes and Alkenes

- May 2013, G2S Environmental, Inc. (G2S) of Burlington Ontario initiated in-situ treatability program
- Purpose:
  - Evaluate efficacy of biostimulation as a remediation strategy to destroy [cVOC] contaminants in groundwater and saturated soils
  - Evaluate distribution capabilities using passive deployment
- Amendment chosen was biostimulant ERDENHANCED™ distributed by TerraStryke® Products LLC.



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Biostimulation of Chlorinated Alkanes and Alkenes

- Five injection nodes installed
- Treatment Zone approximately 13M x 8M
- Vertical impact estimated to extend 3M for total of ≈250M^3.
- Each injection node consist of 2-inch diameter PVC
- Extends approximately 3M bgs, with bottom five-feet screened.
- Each node assumed to generate ≈5ft Area-of-Influence (AOI).
- *Total* of 294 pounds of additive deployed via gravity.

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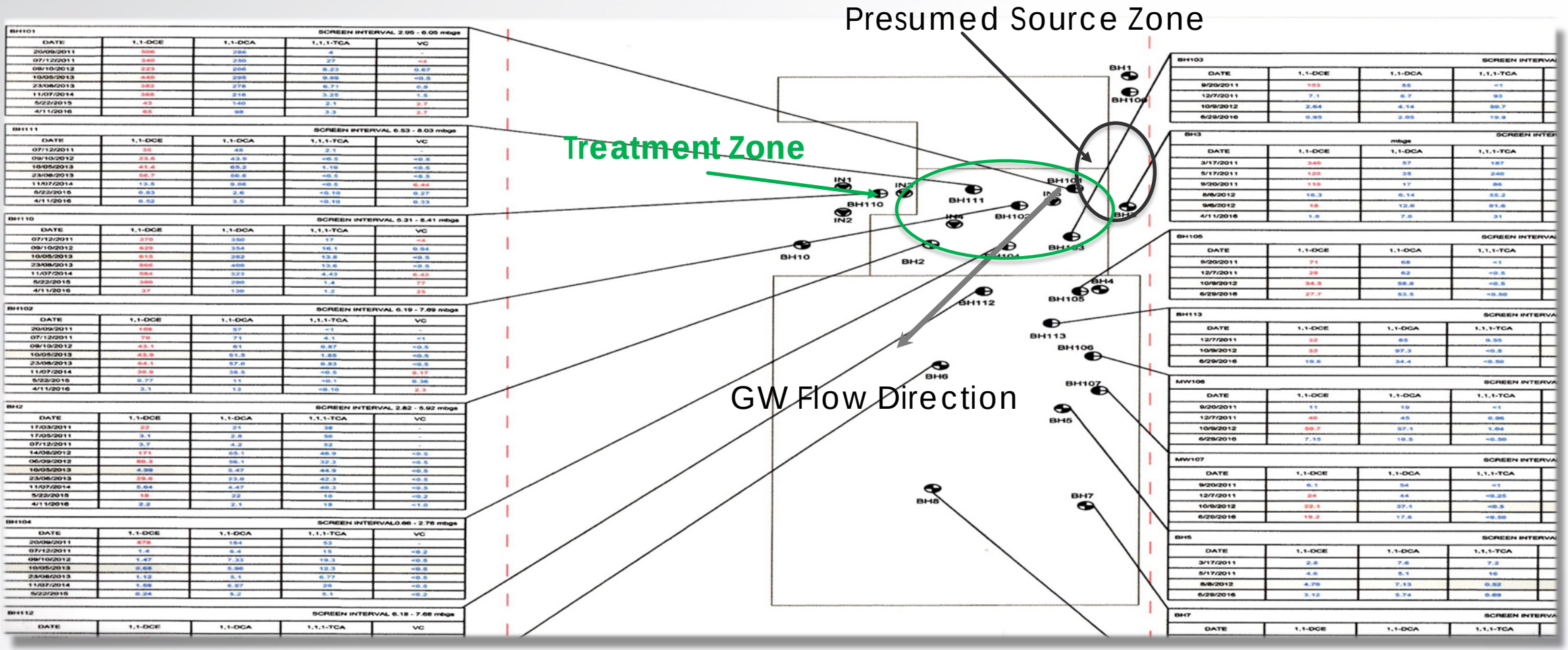
Biostimulation of Chlorinated Alkanes and Alkenes



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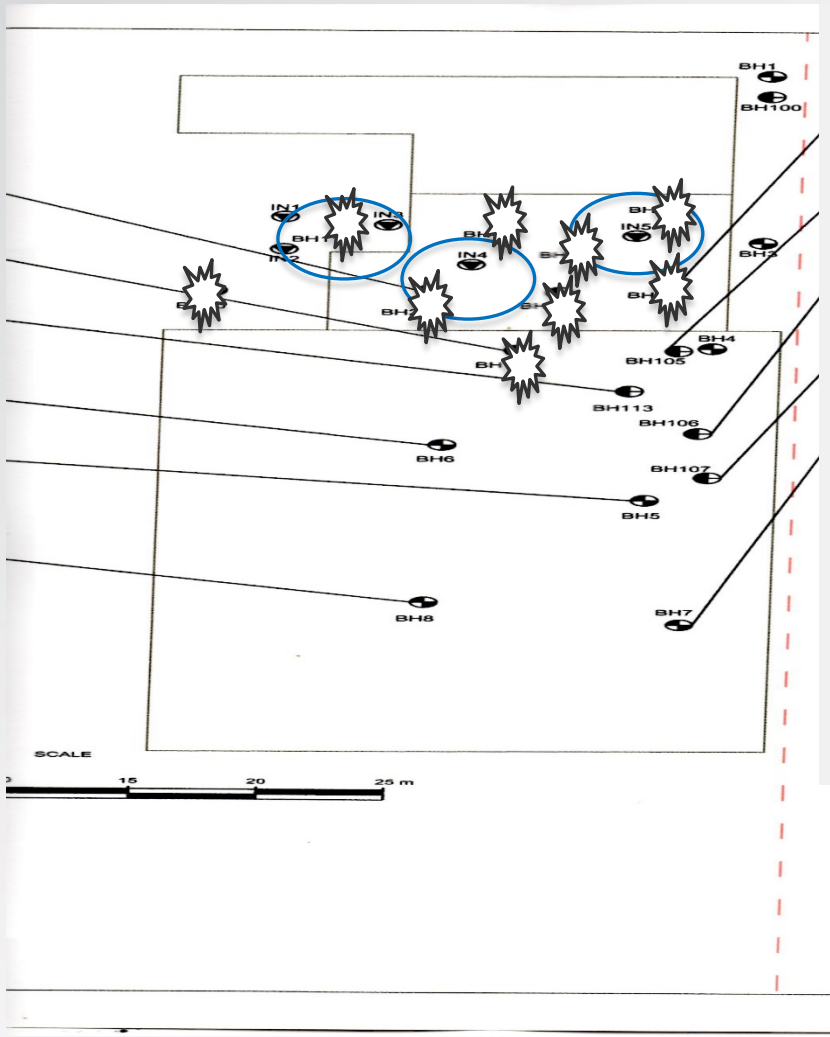
Area of Influence



- Two deployment events; May 29, 2013, and June 28, 2013.
- Each injection node amended with 30-Liters additive slurry
- Groundwater monitoring points located within treatment zone
- Groundwater monitoring points located upgradient the TZ
- Groundwater monitoring points located lateral the TZ
- and downgradient the TZ

2250 INDUS
PROJECT:
G2S12505
FIGURE:
Scale:
Date:

G2S Environmental Consulting Inc.

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Results within Treatment Zone

February 2013 prior to amendment with ERDENHANCED™

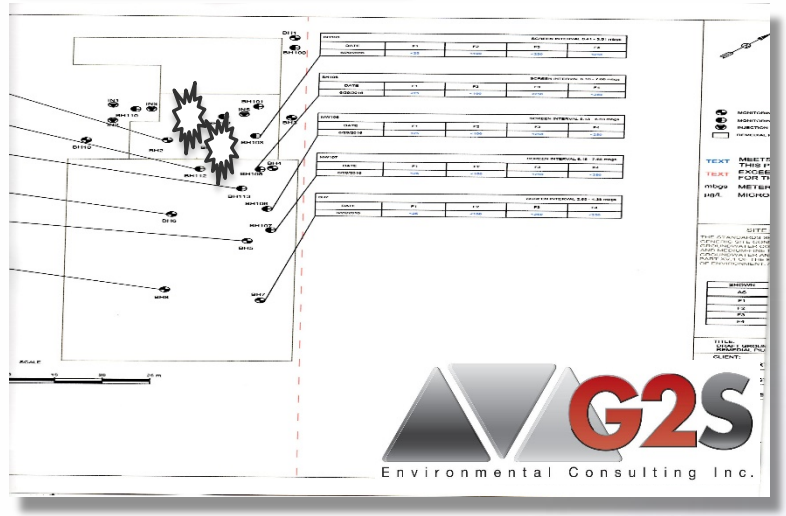
Total cVOCs ([$cVOC_{TOTAL}$]) within the Treatment Zone

Ranged ≈97.5 µg/L to ≈911.5 µg/L.

April 2016, 3-years post deployment

[$cVOC_{TOTAL}$] decreased an average of **87.0%**

[$cVOC_{TOTAL}$] decreased from 77.3% (BH101) to 95.9% (BH111).



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Biostimulation of Chlorinated Alkanes and Alkenes

With regards to specific reductions

BH111 in the approximate 'upper' center of the TZ, rectangle

April 2016 performance data recorded:

95.8% reduction in 1,1,1-TCA,

94.6% reduction in 1,1-DCA,

99.1% reduction in 1,1-DCE and

94.9% reduction in Vinyl chloride

with a corresponding 98.8% reduction in P:PD ratio.

Each of the above percentages are reductions in contaminant concentrations from peak bioavailability

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Biostimulation of Chlorinated Alkanes and Alkenes

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Date	1,1-DCE	1,1-DCA	1,1,1-TCA	VC
May 2013	41.4	65.2	1.19	<0.05
August 2013	56.7	50.6	<0.05	<0.05
July 2014	13.5	9.06	<0.05	6.44
May 2015	0.83	2.6	<0.10	0.27
April 2016	0.52	3.5	<0.10	0.33

All values in micrograms per Liter (ug/L)

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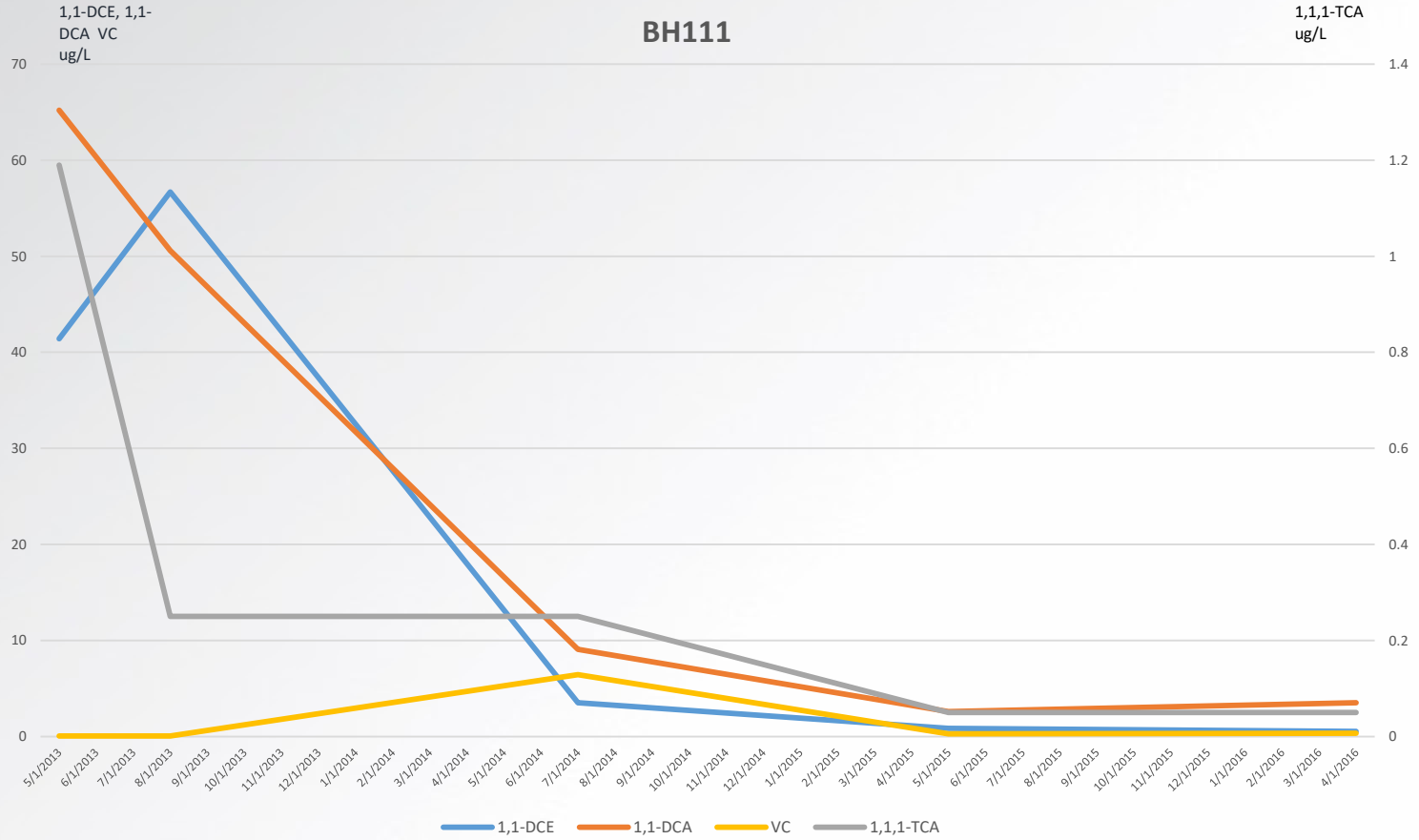
Biostimulation of Chlorinated Alkanes and Alkenes



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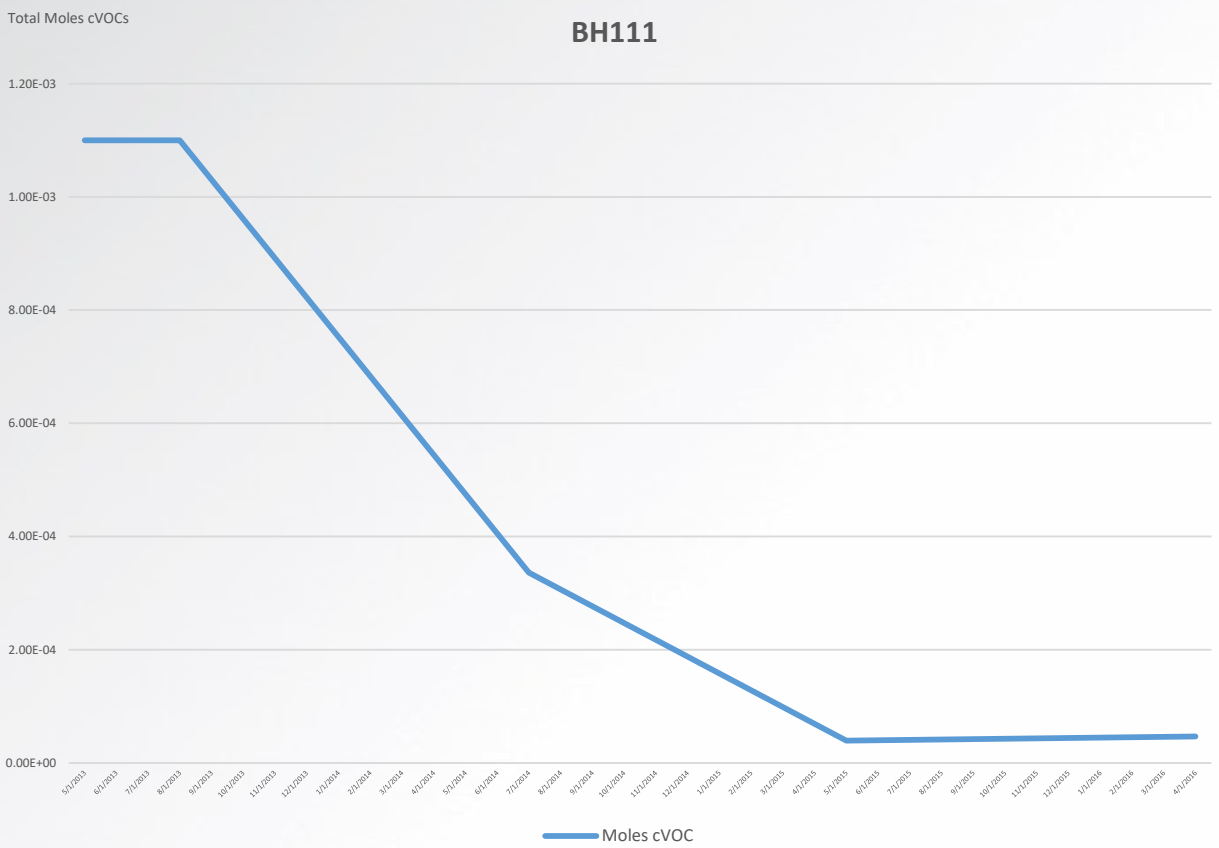
Biostimulation of Chlorinated Alkanes and Alkenes



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Biostimulation of Chlorinated Alkanes and Alkenes

Additionally, at monitoring location BH111 in treatment zone center:

Moles of 1,1,1-TCA increased >1,300% from August 2013 to May 2015;

then,

Precipitously decreased **99.6%** from May 2015 to April 2016

Concurrently; and as noted previously,

Overall **95.8%** reduction in total moles cVOCs was realized over the three year evaluation/treatment period

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Results within Treatment Zone

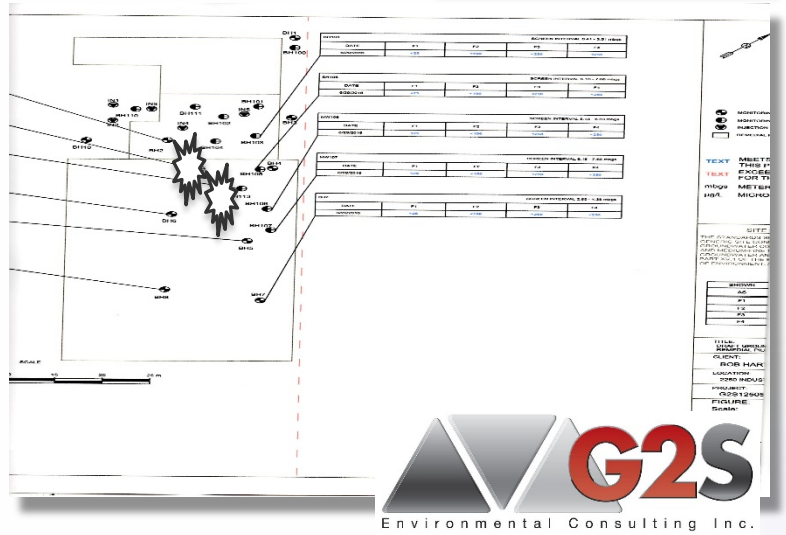
Performance data indicates ERDENHANCED™

Increased contaminant bioavailability

Enhanced dissolve phase cVOC dehalorespiration/biotransformation

Treatment zone groundwater realized significant P:PD reductions

Indicates molar/mass transformation of parent to groundwater samples collected were not analyzed for geochemical metrics



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Results Downgradient from TZ

In summary

Solubilization and enhanced dissolve phase dechlorination was observed in 3 of 4 monitoring locations within the TZ

General reductions in [$cVOC_{TOTAL}$] were observed in all TZ monitoring locations

Downgradient to the TZ at BH104

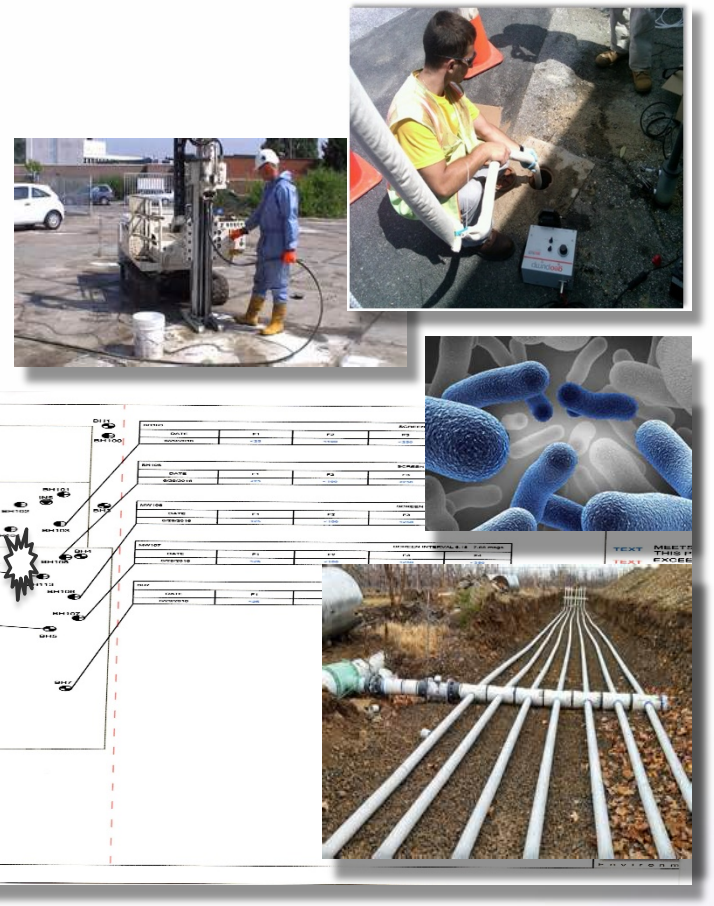
[$cVOC_{TOTAL}$] increased 114.5%; then,

Decreased by 62.0% from peak bioavailability

Similarly, [$cVOC_{TOTAL}$] lateral to the TZ at BH2

Increased 72.2% post initial amendment; then,

Decreased 76.2% from peak bioavailability



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Biostimulation of Chlorinated Alkanes and Alkenes

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Conclusions

- Site locations passively amended with minimal amounts of ERDENHANCED™
- Amendment with additive slurry affected treatment zone biogeochemistry
- Biostimulating enhanced reductive dechlorination of chlorinated alkane and alkene contaminants in saturated soils and groundwater.
- Changes in P:PD Ratios confirms mass solubilization, biotransformation
- Primary/Secondary evidence supports dissolve phase reductions result of enhanced reductive dechlorination by native microbial populations
- Project exceeded expectations
- Affirming cost-effectiveness of ERDENHANCED™
- Safe, Sustainable and Effective Remediation Strategy