Cost-Effective In-Situ Remediation
Biostimulation as a Residual Source Mass Remediation Strategy
Summary of Site Conditions

Former Dry Cleaner

[PCE] in saturated soil/groundwater above MOECC Table 3 SCS
Concentrations above solubility indicative of residual source mass in saturated soils

Site Conditions
Generally Coarse Textured Soils
Silty Sand w/ Silt Generally moist
0.5m – 4.9m bgs, elevated PID readings
Weathered Shale 5-8m bgs
Bedrock below at ≈8m bgs

Property Value
Property attained by current Owner through bankruptcy
2011 Appraised Value $680,000.00
**Site Conditions (cont.)**

**Groundwater Conditions**
Flows generally southeast towards Lake Ontario
[PCE] in saturated soils and groundwater
Total [cVOC] ranged 15,000 – 130,000 ug/L
Parent:Parent/Daughter Molar Ratio ≈100%

**Initial Consultants Recommendation**
12-15 Year Pump-and-Treat Program
Indicated Bioremediation *not* Appropriate
Geochemistry not supportive of Enhanced Reductive Dechlorination (ERD)
Residual Source Mass Inhibitive
Cost Estimates in Excess of $650,000
Cost of Remediation Negated Property Value
Summary of Remediation Activities

G2S Consultants Recommendation

Perform on-Site Pilot Study ≤$5,000

Evaluate additive efficacy under actual Site biogeochemical conditions

Assist further understanding of subsurface conditions:
- presence/absence residual source mass
- rates of dechlorination

Remove source zone contaminants

Excavate subslab source soils

Full-Scale In-situ biostimulation strategy to address residual source mass & dissolve phase contaminants

Estimated Remediation Cost ≈$100,000.00 - $200,000.00

Retained Property Value ≈$500,000.00
Enhanced Reductive Dechlorination

Patented (US/Canada)

Carbon-Carbohydrate formulated with proprietary blend of macro-micro nutrients

- Nourish native microbial populations
- Expedite electron scavenging, attaining methanogenic conditions faster
- Enhance solubilization of residual (DNAPL) *co-solvent effect*
- Realize superior kinetics
- Greater longevity
- Safe, Sustainable, Effective

Leverage Mother Nature’s Momentum
Safely - Sustainably - Cost-Effectively

Attain methanogenic conditions faster to favour ERD
Increase contaminant bioavailability & dissolve phase destruction
Minimize site activities while maximizing performance
Ground surface

Groundwater Flow Direction

Area of Influence

‘Go-no-Go’ evaluation
Additive filled Passive Release Sock (PRS)
Deployed into existing 2-inch gw monitoring well
Passively amend saturated screened interval
Create 1-2 meter area-of-influence
Replace PRS units every 6-8 weeks

- Monitoring Program
  - Baseline
  - Each replacement event
  - Non-purge
  - Low-flow
  - 6-8 replacement events typical

Not for compliance testing
Reproducible, not scalable
PRS Pilot Study
Groundwater Monitoring Metrics

 Indicator Metrics

Field Parameters
ORP, DO, pH, Temperature

Geochemistry
Nitrates (NO3)
Diss. Iron/Manganese (Fe/Mn)
Sulphates (SO₄)
Ethane/Methane/Ethene (MEE)
Chloride (Cl)

Analytical
Contaminant of Concern (EPA 8260)

Comparison of baseline data to performance data is basis for efficacy determination
PRS Pilot Study
Geochemical Metrics

mV


-300  -200  -100  0  100  200

+92 mV  -195 mV  -170  -69 mC  -95 mV
PRS Pilot Study

cVOC Reductions

- PCE
- ORP

 ug/L

13,000 ug/L
2,400 ug/L
81.5% Reduction

mV

13-Apr-11
8-Jun-11
21-Jul-11
1-Sept-11
11-Oct-11
PRS Pilot Study

cVOC Reductions/Chloride Generation

- PCE
- TCE
- cis-DCE
- Cl-

[TOC] 5.2 mg/L

[TOC] 504 mg/L

[TOC] 834 mg/L

[TOC] 748 mg/L
**PRS Pilot Study**

*Parent:Parent-Daughter Molar Ratio*

- **Test Location MW-2**
  - 96.5%

- **Solubilization**
- **PCE Dehalorespiration**
- **PCE DNAPL Destruction**

- **P:PD Ratio**
- Confirms Biotransformation
- Molecular transformation of Parent into Daughter [cVOC’s]
- Not chase water remediation

- **80.2% overall DECREASE P:PD Molar Ratio**
Importance of P:PD Molar Ratio
Contaminant Reduction?

MW-32A

Time of surface Water Intrusion

TCE ug/L

[Image of graph showing TCE, Sulfate, and ORP over time]

ORP mV
SO4 mg/L

TCE [mg/L]
Sulfate
ORP

MW-32A

TCE ug/L

[Graph showing data points and trends]

2-May-13: 250,000
7-Aug-13: 500,000
2-Oct-13: 750,000
19-Feb-14: 1,000,000
6-May-14: 1,250,000
2-Jul-14: 0
5-Sept-14: 0
6-Nov-14: 0
Solution to Pollution….Biotransformation! not dilution!

- Period of **No** Biotransformation of Parent TCE Contaminant
- **No Change in P:D Ratio Regardless of [SO4] or [TCE]**
- **Potential Start of Biotic Activity**

---

**TCE ug/L**

2-May-13 7-Aug-13 2-Oct-13 13-Dec-13 19-Feb-14 6-May-14 2-Jul-14 5-Sept-14 6-Nov-14

**ORP mV**

0 250,000 500,000 750,000 1,000,000 1,250,000

**SO4 mg/L**

0 150. 225. 300.

**TCE**

2-May-13 7-Aug-13 2-Oct-13 13-Dec-13 19-Feb-14 6-May-14 2-Jul-14 5-Sept-14 6-Nov-14

**P:D Ratio**

2-May-13 7-Aug-13 2-Oct-13 13-Dec-13 19-Feb-14 6-May-14 2-Jul-14 5-Sept-14 6-Nov-14

**Sulfate**

2-May-13 7-Aug-13 2-Oct-13 13-Dec-13 19-Feb-14 6-May-14 2-Jul-14 5-Sept-14 6-Nov-14

---

**[TCE]**

2-May-13 7-Aug-13 2-Oct-13 13-Dec-13 19-Feb-14 6-May-14 2-Jul-14 5-Sept-14 6-Nov-14

---

**Potential Start of Biotic Activity**
Contaminant Location
Subslab soils
Full soil source removal unfeasible
Residual Mass Remains

Excavation – Source Removal
Excavation removed 250m³ contaminated soils
Infiltration gallery installed w/in footprint
Clear stone, 6-inch slotted PVC, 2-3m bgs

Groundwater Conditions
Residual mass likely in saturated soils not excavated
Post-excavation [PCE] in area 5,000-30,000 ug/L
Daughter products remain absent

ORP Values
MW2 -278
MW3 -187
MW5 -156
MW6 -199
Additive Deployment

- Additive deployed 2-times passively
- Used infiltration gallery
- Limited matrix ability to receive slurry
- 9% additive slurry
- 990kg to 1,100 gallons chase water (March 2014)
- 840kg to 1,100 gallons chase water (July 2014)
Groundwater Monitoring Performed @ MW-2 over 6yrs
- 5 rounds March 2011 to October 2011 (PRS Pilot)
- 1 pre-excavation round September 2013
- 8 additional rounds March 2014 to May 30, 2017
- Other locations monitored Sept 2013 – May 2017
- MW-3, MW-5, MW-6 on-Site
- MW-15, MW-16 and MW-17 off-Site
## Results

March 2014 pre Full-Scale deployment
≈2½ years after PRS Pilot Study

<table>
<thead>
<tr>
<th>Location</th>
<th>[PCE]</th>
<th>[TCE]</th>
<th>[cis-DCE]</th>
<th>[VC]</th>
<th>P:PD Ratio</th>
<th>[TOC]*</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW-2*</td>
<td>370 ug/L</td>
<td>29.6 ug/L</td>
<td>5.4 ug/L</td>
<td>80.3</td>
<td>58.8%</td>
<td>434 mg/L</td>
</tr>
<tr>
<td>MW-3</td>
<td>1,030 ug/L</td>
<td>&lt;0.05 ug/L</td>
<td>&lt;0.05 ug/L</td>
<td>ND</td>
<td>99.9%</td>
<td>1.7 mg/L</td>
</tr>
<tr>
<td>MW-6</td>
<td>1,950 ug/L</td>
<td>0.67 ug/L</td>
<td>&lt;0.05 ug/L</td>
<td>ND</td>
<td>99.9%</td>
<td>1.8 mg/L</td>
</tr>
<tr>
<td>MW-209</td>
<td>1.93 ug/L</td>
<td>1.2 ug/L</td>
<td>4.66 ug/L</td>
<td>ND</td>
<td>30.4%</td>
<td>1.3 mg/L</td>
</tr>
</tbody>
</table>

Pre-Pilot [PCE] 13,000 ug/L
[PCE] at MW-2 post-Pilot ≤84.6% (2,400 ug/L)
P:PD Molar Ratio 19.1%.

MW-2 former PRS location
MW-209 ≈abuts
MW-3 MW-6 not effected by PRS evaluation
Non-effected areas with >99% P:PD Ratio
Indicative of little to no biotic activity evident

*Total Organic Carbon (TOC) levels recorded August 19, 2014
ORP VALUES OCTOBER 23, 2014
MW2 -32
MW3 +16
MW5 +20
MW6 +16
**Results**
October 2015
≈1½ years post Full-Scale deployment

*Total Organic Carbon (TOC) levels recorded April 24, 2015

<table>
<thead>
<tr>
<th>Location</th>
<th>[PCE]</th>
<th>[TCE]</th>
<th>[cis-DCE]</th>
<th>[VC]</th>
<th>%Δ[cVOCtotal]</th>
<th>P:PD Ratio</th>
<th>[TOC]*</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW-2</td>
<td>BDL</td>
<td>BDL</td>
<td>48 ug/L</td>
<td>BDL</td>
<td>84.1% reduction</td>
<td>8.7%</td>
<td>211,110 mg/L</td>
</tr>
<tr>
<td>MW-3</td>
<td>51 ug/L</td>
<td>2.7 ug/L</td>
<td>170 ug/L</td>
<td>26 ug/L</td>
<td>78.3% reduction</td>
<td>0.8%</td>
<td>700,000 mg/L</td>
</tr>
<tr>
<td>MW-6</td>
<td>41 ug/L</td>
<td>12 ug/L</td>
<td>130 ug/L</td>
<td>50 ug/L</td>
<td>88.0% reduction</td>
<td>3.7%</td>
<td>239,000 mg/L</td>
</tr>
<tr>
<td>MW-209</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>-% reduction</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>MW-15</td>
<td>10,000 ug/L</td>
<td>BDL</td>
<td>BDL</td>
<td>BDL</td>
<td>NA</td>
<td>100%</td>
<td>NR</td>
</tr>
</tbody>
</table>

**Average 94.9% Reduction P:PD Ratio 17-months Post Deployment**

Near 100% *REDUCTION* at MW-3

* TOC readings recorded April 24, 2015
Results
July 2016
2 years 2 months post Full-Scale deployment

- Plot averages [cVOC] at MW2, MW3, MW6
- **96.9%** overall reduction [PCE]
- **88.2%** reduction [TCE] from peak bioavailability
- **94.5%** reduction [cis-DCE] from peak bioavailability (after >1,600% increase)
- **92.3%** reduction [VC] after several occasional increases/descreases
- **No** Indoor Ambient Methane/VC Issues
- Redevelopment planning is initiated

**Average [cVOC]**

- TOC 200-500+K
- TOC 434 mg/L recorded

**Graph:**
- PCE
- TCE
- DCE
- VC

**Results:**
- July 2016
- 2 years 2 months post Full-Scale deployment

**Graph Details:**
- Average [cVOC] from 1-Mar-14 to 1-Jul-16
- TOC 200-500+K
- October 2015
- Ethene recorded MW-2, MW-15
Results
September 2016
2½ years after Full-Scale deployment

- **MW-2**
  - 99.4% reduction [PCE]
  - 99.9% reduction [TCE] after 32.1%↑
  - ≈100% reduction [cis-DCE] after 3,600%↑
  - 99.9% reduction [VC] after 16.8%↑
  - 99.5% reduction in [cVOCtotal]
  - [Ethene] detected = complete biotransformation
  - Demonstrated safe, sustainable and effective enhanced dehalorespiration
  - All but [PCE] (2.4 ug/L) within MOE Criteria (1.6 ug/L)

**TOC Levels**
MW-2 13 mg/L
MW-15 130 mg/L

[Ethene] MW-2 and MW-15
Results
September 2016
2½ years after Full-Scale deployment

MW-3
- **87.4%** overall reduction [PCE]
- Max. ↓ [PCE] >95% (T=18-months)
- **90.2%** reduction [TCE] first 6-months; then [TCE] increases Five Orders-of-Magnitude
- **86.6%** reduction [TCE] from peak
- **95.9%** reduction [DCE] from peak
- **89.1%** reduction [VC]; to <1.6 ug/L, from max. increase of ≈500%

TOC Levels
MW-3 12 mg/L
No Ethene Detected
Results

September 2016
2½ years after Full-Scale deployment

- 90.1%↓ P:PD Molar Ratio T=month18 (October 2015)
- 41.2%↓ overall reduction P:PD Molar Ratio
- P:PD Ratio confirms dehalorespiration molecular change of PCE
- 98.8% reduction [cVOC_{total}] @ MW-6

TOC Levels
MW-6 83 mg/L

No Ethene Detected
Results
May 26, 2017
3 years after Full-Scale deployment
6 years after PRS Pilot Study

<table>
<thead>
<tr>
<th>Location</th>
<th>[PCE]</th>
<th>[TCE]</th>
<th>[cis-DCE]</th>
<th>[VC]</th>
<th>Change</th>
<th>[TOC]</th>
<th>ORP</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW-2</td>
<td>BDL</td>
<td>BDL</td>
<td>330 ug/L</td>
<td>210.0 ug/L</td>
<td>&lt;0.01% P:PD</td>
<td>34 mg/L</td>
<td>-123 mV</td>
</tr>
<tr>
<td>MW-3*</td>
<td>130 ug/L</td>
<td>3.7 ug/L</td>
<td>BDL</td>
<td>BDL</td>
<td>87.0% reduction [cVOC\text{total}]</td>
<td>12 mg/L</td>
<td>-50 mV*</td>
</tr>
<tr>
<td>MW-6</td>
<td>80 ug/L</td>
<td>BDL</td>
<td>BDL</td>
<td>BDL</td>
<td>95.9% reduction [cVOC\text{total}]</td>
<td>13 mg/L</td>
<td>-79 mV</td>
</tr>
<tr>
<td>MW-15</td>
<td>4,300 ug/L</td>
<td>270 ug/L</td>
<td>1,200 ug/L</td>
<td>71 ug/L</td>
<td>≈50% Reduction P:PD Ratio</td>
<td>8.1 mg/L</td>
<td>-92 mV</td>
</tr>
</tbody>
</table>

- TOC Levels at MW-15 130 mg/L September 2016
- *MW-3 monitoring well destroyed after this round

MW-2
- >99.9% Reduction P:PPD
- 96.1% Reduction [cVOC\text{total}]
- Compliant [PCE] & [TCE]

MW-3
- 87.0% Reduction [cVOC\text{total}]
- Compliant [TCE], [cis-DCE], [VC]

MW-6
- 95.9% Reduction [cVOC\text{total}]

MW-15 (off-Site)
- 50 meters downgradient gallery
- P:PD↓ dec. 99.97% to 50.81%
- 71.6%↓ dec. [cVOC\text{total}] from peak bioavailability
Results MW-2

May 2017
3 ½ years after Full-Scale deployment
6+ years post PRS evaluation

MW-2 over 6+ years
- 2-years after 24-lbs additive
  >98%↓ Moles cVOCs/P:PD
- PRS Pilot Study demonstrated solubilization/biotransformation
- 3-years post full-scale deployment
  >99.99%↓ P:PD Ratio/Moles cVOCs
- [PCE] & [TCE] below MOE Table 3
- Criteria non-Potable groundwater
- Site currently undergoing redevelopment
- No Indoor Ambient Air issues recorded throughout 6+ years
MW15 ≈50 meters downgradient
- Monitored since 2011 Pilot Study
- [TOC] not recorded until Sept. ‘16
- [Ethene] detected since April ‘16
- P:PD ratio >99% to <63%
  last 12-months of evaluation
- Max. reduction P:PD ≈50%
- Moles cVOCs 73%↓ since peak TOC
- Gallery influence extending beyond property boundary
- ORP Values -92 mV
- ORP MW16 -51 MW17 -15

Results
May 26, 2016
2½ years after Full-Scale deployment

Solubilization and Biotransformation?

MW15

TOC 130 mg/L
TOC 8.1 mg/L

MW-15

PRS Study
Full-Scale Deployment

Area of Amendment Influence

[TCE] [PCE] [cis-DCE] [VC]
Results
May 26, 2016
2½ years after Full-Scale deployment

- P:PD Ratio
  Steady ≈100%
  Through 2015

- No amendment influence

- 2016 TOC levels increase

- P:PD Ratio ↓
  40%-50%
  2016-2017

- Enhanced additive influenced ERD
  3-years later

Moles cVOCs

Solubilization and Biotransformation?
BOTH

Area of Amendment Influence
Conclusions  ERD<sup>ENHANCED™</sup>

- **Safe Sustainable and Effective**
- **Enhance Native Microbial Populations to:**
  - Realize Superior rates of Dehalorespiration
  - Expedite Residual Mass Solubilization
    2° Co-Solvent Effect
- **Sustainability**
  - Proprietary nutrient package vital to longevity
  - Extends/Recirculates Carbon/nutrient availability
  - Maintained reducing conditions for over six years
  - Minimize deployment efforts
  - Maximize remediation $dollars$ and project margins
Conclusions  The Real Story

Property Values

- Without contamination issues $680,000
- Initial P&T Costs Estimated @ $650,000 12-15 yrs (minimum)
- Property Value effectively $0.00
- Proved cost-prohibitive and Owner chose not to pursue

Biostimulation Remediation Strategy

- Total project Costs
  - Soil removal/gallery install $38,000
  - Pilot and Full-Scale Additive $35,000
  - Consulting and Analytical $150,000
  - $85.00/yard
- 6-years and Site under redevelopment

- Property Value Assessed 2017 @ 2.5 million dollars
- Property Manager attributes $1 million in increase to remediation strategy
Thank You

Carl Galli – Property Owner

Geoff Bell – G2S Environmental Consultants
3370 S. Service Drive, Suite 107
Burlington, ON L7N 3M6
(905) 331-3735

Environmental Services Association of Alberta (ESSA) and all the RemTech Staff

Kent C. Armstrong, President
TerraStryke Products, LLC
karmstrong@terrastryke.com

P.O. Box 254
284 Depot Street (Route 4)
Andover, NH USA 03216
950 Fennell Avenue East
Suite 150
Hamilton, ON CDN L8V 1X2

October 11-13, 2017 Banff Alberta, Canada