

# Remote Northern and Dryland Phytoremediation of Contaminated Soil

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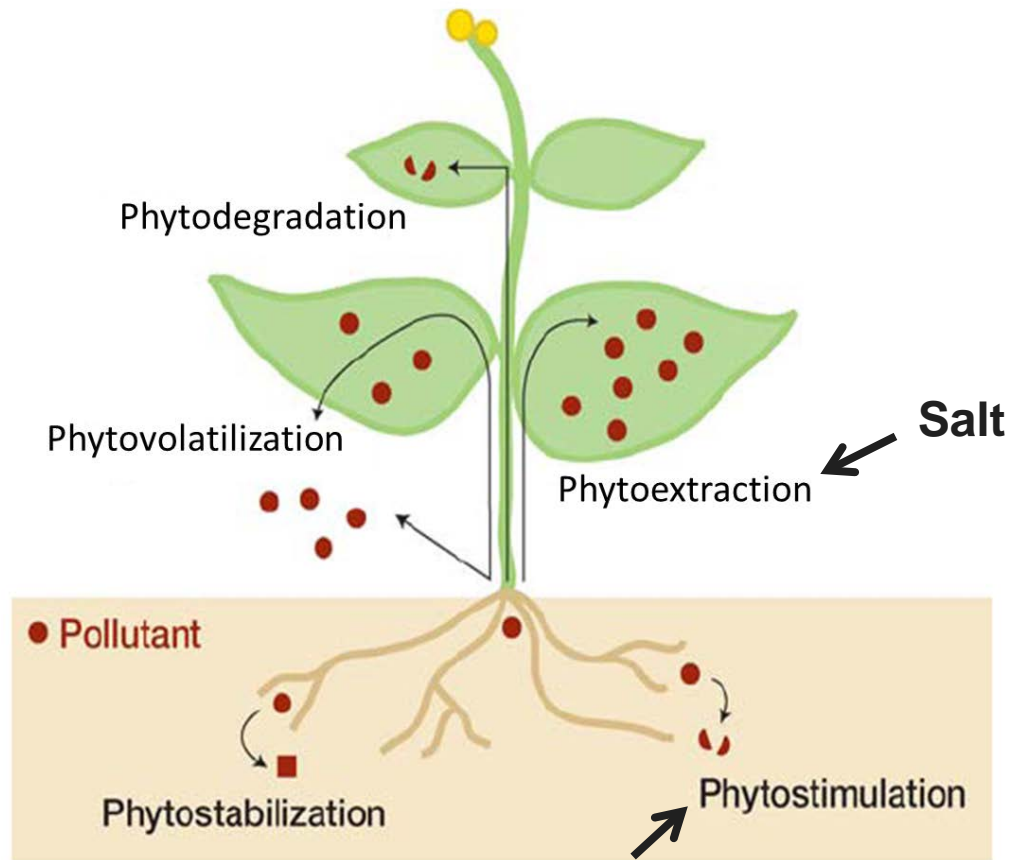
# Earthmaster Environmental Strategies Inc.

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## A Canadian environmental technologies company:

- Based in Calgary, Alberta.
- Founded in 1998.
- Specializes in providing environmental services to the commercial/industrial and upstream oil and gas industry in Western Canada.
- Team of environmental consultants consisting of professional agrologists, biologists, chemists, ecologists, engineers, geoscientists, soil scientists, plant scientists, aquatic specialists, and foresters.
- Co-developed commercial phytoremediation systems to treat contaminated soil in an eco-friendly and responsible manner.

# Phytoremediation – How it Works



**Rhizodegradation – Petroleum Hydrocarbons**

- Improved rhizosphere
  - Soil
  - Organic matter
  - Bacteria
  - Water
  - Roots
  - Contaminants
- Rhizodegradation
  - Petroleum Hydrocarbons
- Phytoextraction
  - soil → root → foliage
  - Salts
  - Metals

**Challenge – getting the plants to grow.**

# PEPSystems: Plant Growth Promoting Rhizobacteria (PGPR) - Enhanced Phytoremediation Systems



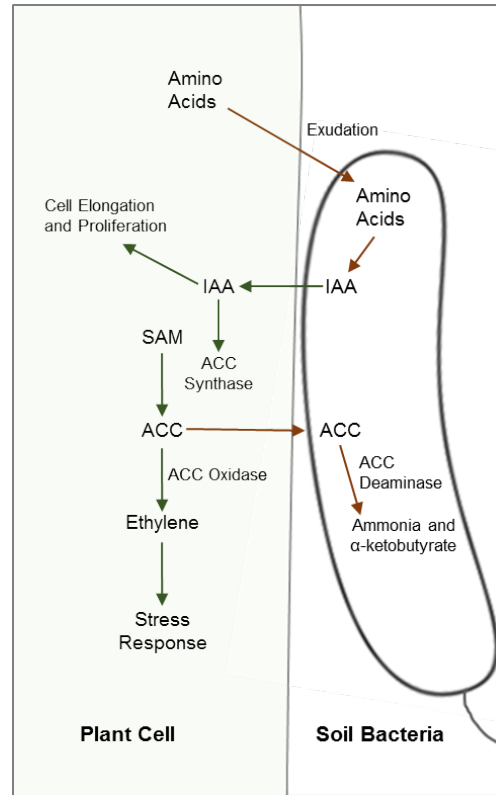
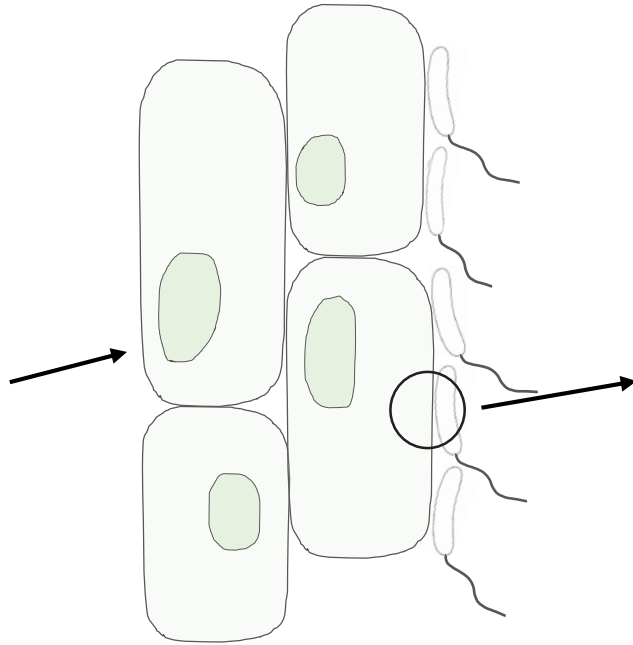


# PEPSystems

- Developed through collaboration between Dr. Bruce Greenberg of the University of Waterloo and Earthmaster for contaminated site clean-up.
- Earthmaster has assumed control of the PEPSystems technology and now manages all PGPR testing, selection, seed treating, and overall site specific remediation system design in Calgary. Dr. Greenberg continues to collaborate on PEPSystems.
- Earthmaster continues to conduct research on how to improve PEPSystems for remediation of contaminated sites or other applications such as to enhance plant growth on marginal or poor quality soils.



# PGPR – Facilitating Plant Growth in Challenging Conditions



- ↓ Stress ethylene
- ↑ Plant vigor
- ↑ Root development
- ↑ Rhizobacteria
- ↑ Leaves
- ↑ Salt and metals uptake
- ↑ Degradation of PHC

**Active rhizosphere:**  
PGPR co-localize with developing roots

# Large Scale Phytoremediation

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## Two project summaries:

- Salt and hydrocarbon contaminated site in the Northwest Territories
  - Nota C-17
  - Remote site located 40 km southeast of Norman Wells
  - Did not utilize a treatment pad
- Hydrocarbon contaminated site in central Alberta
  - Craigmyle area
  - Former gas plant site in an agricultural area
  - Utilized a one-time biopile soil treatment facility
- PHC degradation modeling

# Site 1 - Nota C-17 Pre-deployment 2008

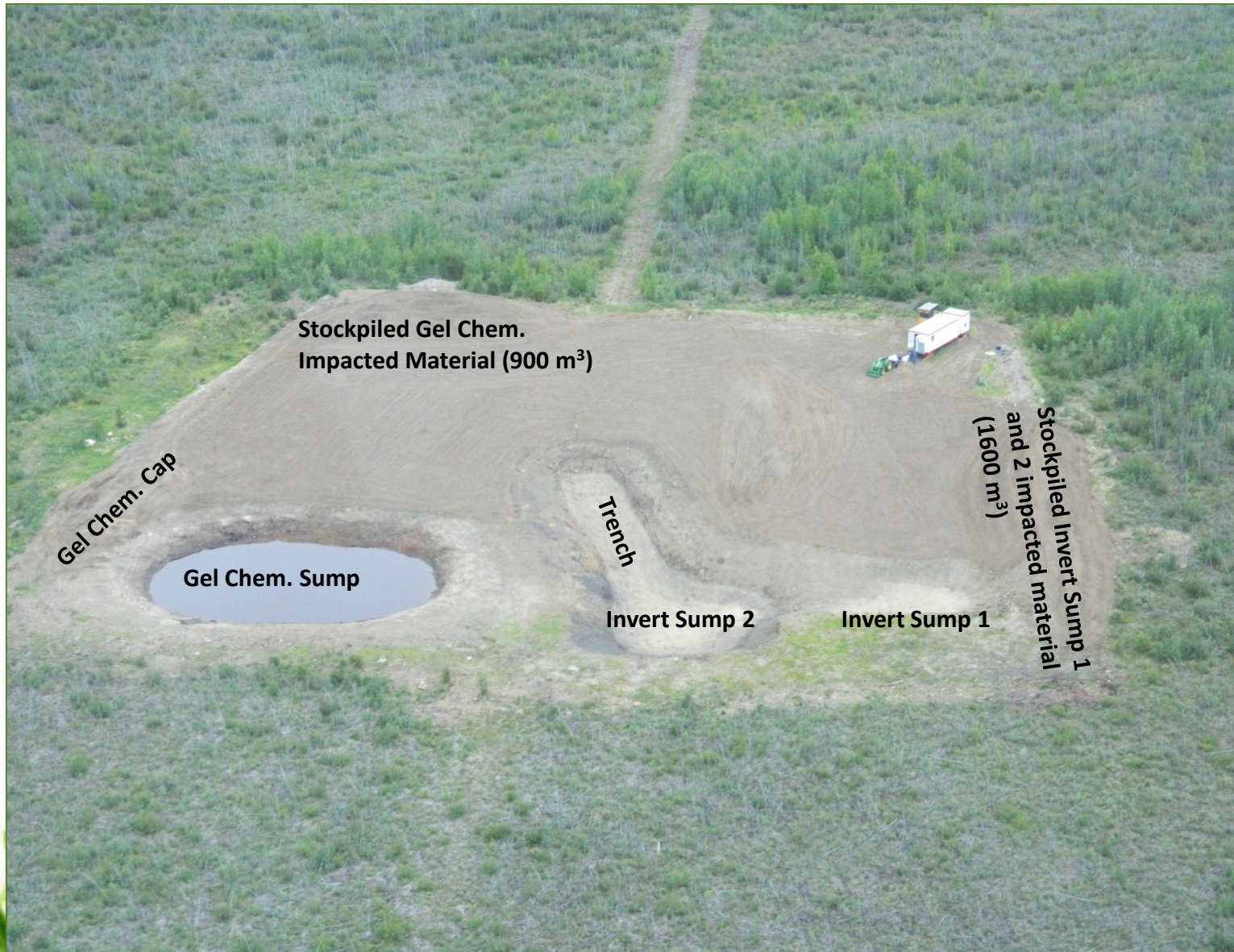


Approximately 5,800 m<sup>3</sup> of material were excavated from former pits and sumps onsite to be treated for PHC contamination resulting from historical drilling activities:

- Land use – industrial
- Soil texture – coarse
- CCME remediation guideline values F2:
  - surface soil – 260 mg/kg
  - subsoil – 320 mg/kg
- Seed – Arg, Prg, TF
- PGPR – *Pseudomonas corrugata* and *P. marginalis*.
- **Lift #1** T=0 June 2008
  - Surface soil treated for salt and PHC.
  - Completed in July 2011 and left in place.
  - Additional material was excavated and placed on top of Lift #1 for treatment.



# Lift #2 Post Seeding July 2011



## Lift #2:

2,125 m<sup>3</sup> were excavated and spread on lift #1 in July 2011. Treatment for PHC F2 contamination was completed in June 2013 and left in place.

$$y/C_0 = e^{-0.45x}$$

Using July 2011  $C_0$  values:

Depth	T=0 ( $C_0$ )	x yrs	$C_{2.0 \text{ yrs}}$
0.00-0.30 m	549	1.7	84





**Stockpiled Invert Sump  
1 and 2 impacted  
material (1600 m<sup>3</sup>)**

**Invert Sump 1**

**Invert Sump 2**

**Trench**

**Gel Chem. Sump**

**Gel Chem. Cap**

**Stockpiled Gel Chem. Impacted  
Material (900 m<sup>3</sup>)**

**Lift #2 Two Months After Planting September 2011**



# Lifts #2 and #3 September 2013



A. Plant growth and ground coverage, Sept 16, 2013



B. Mowing, Sept 17, 2013



C. Spreading new impacted soil, Sept 18, 2013



D. Homogenizing, Sept 19, 2013

## Lift #3:

900 m<sup>3</sup> were spread on lift #2 in September 2013. Treatment for PHC F2 contamination was completed in June 2016 and left in place.

Lift #3 Sample Chemistry T = 0				
Depth	PHC	Sep 2013		
		# samples	range	average*
0.00-0.30 m	F2	17 of 17	830-1900	1418±90

# samples exceeding surface soil guideline value

\*average mg/kg ± standard error



# Lift #3 Seeding June 2015



Using the September 2013  $C_0$  value:

Depth	T=0 ( $C_0$ )	x yrs	$C_{2.1}$ yrs
0.00-0.30 m	1417	3.8	275

## Lift #3:

Earthmaster assumed control of the site in 2015.





Lift #3 September 2015



# Lift #4 – Ripping to Incorporate Organics



## **Lift #3:**

End of growing season (September 2015) and preparation for lift #4.



# Lift #4 – Challenges



June 2016



# Lift #4 September 2016



## Lift #4:

1,600 m<sup>3</sup> were spread on lift #3 and treated for PHC F2 contamination. 1,250 m<sup>3</sup> were stripped in June 2017 and placed in an excavation.

Lift #4 Sample Chemistry T = 0				
Depth	PHC	Jul 2016		
		# samples	range	average*
0.00-0.30 m	F2	23 of 25	268-1350	644±73

# samples exceeding surface soil guideline value

\*average mg/kg ± standard error

Depth	T=0 (C <sub>0</sub> )	x yrs	C <sub>0.3 yrs</sub>
0.00-0.30 m	644	2.0	360



# Lift #4 - Challenges



## LEGEND



Wellbore



Sample Location (Remediated)



Sample Location (Exceedance)



Control Area



Former Gel Chem.  
Impacted Material Area



Topsoil Stockpile



Historical Excavation



Plant Growth Area



CFIA Control Area



Field Trailer



Field Equipment



Shrubs / Trees Edge



Slope Direction



**Lift #5 January 2017**



# Lift #5 - September 2017



## Lift #5:

350 m<sup>3</sup> from lift #4 were mixed with 750 m<sup>3</sup> of additional soil. Lift #5 was treated for PHC F2 contamination starting in June 2017.

Lift #5 Sample Chemistry T = 0				
Depth	PHC	Jun 2017		
		# samples	range	average*
0.00-0.30 m	F2	21 of 25	263-826	385±41

# samples exceeding surface soil guideline value

\*average mg/kg ± standard error



# Lift #5 September 2017



Depth	T=0 $C_0$	x yrs	$C_x$ yrs
0.00-0.30 m	385	0.9	?



# Nota C-17 Site Summary to Date

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- 4,300 m<sup>3</sup> of impacted soil have been treated in 4 soil treatment lifts.
- Impacted soil contained BTEX, PHC F1 to F4, salts (sodium and chloride), and some metals.
- Following treatment all soil met applicable remediation criteria.
- Approximately 1,100 m<sup>3</sup> of PHC impacted soil remains on-site in the treatment area (treatment lift #5).
- All soil treatment should be complete in 2018 and final site restoration can proceed (i.e. contouring and re-vegetation).



# Site 2 – Craigmyle Pre-deployment May 2015



Former gas plant site with PHC F1 to F4 and BTEX contamination:

- Some site infrastructure needed to be removed.
- A one-time soil treatment facility needed to be constructed.





# Infrastructure Removal and Site Preparation





**Berm Construction,  
Compaction,  
Permeameter Testing**

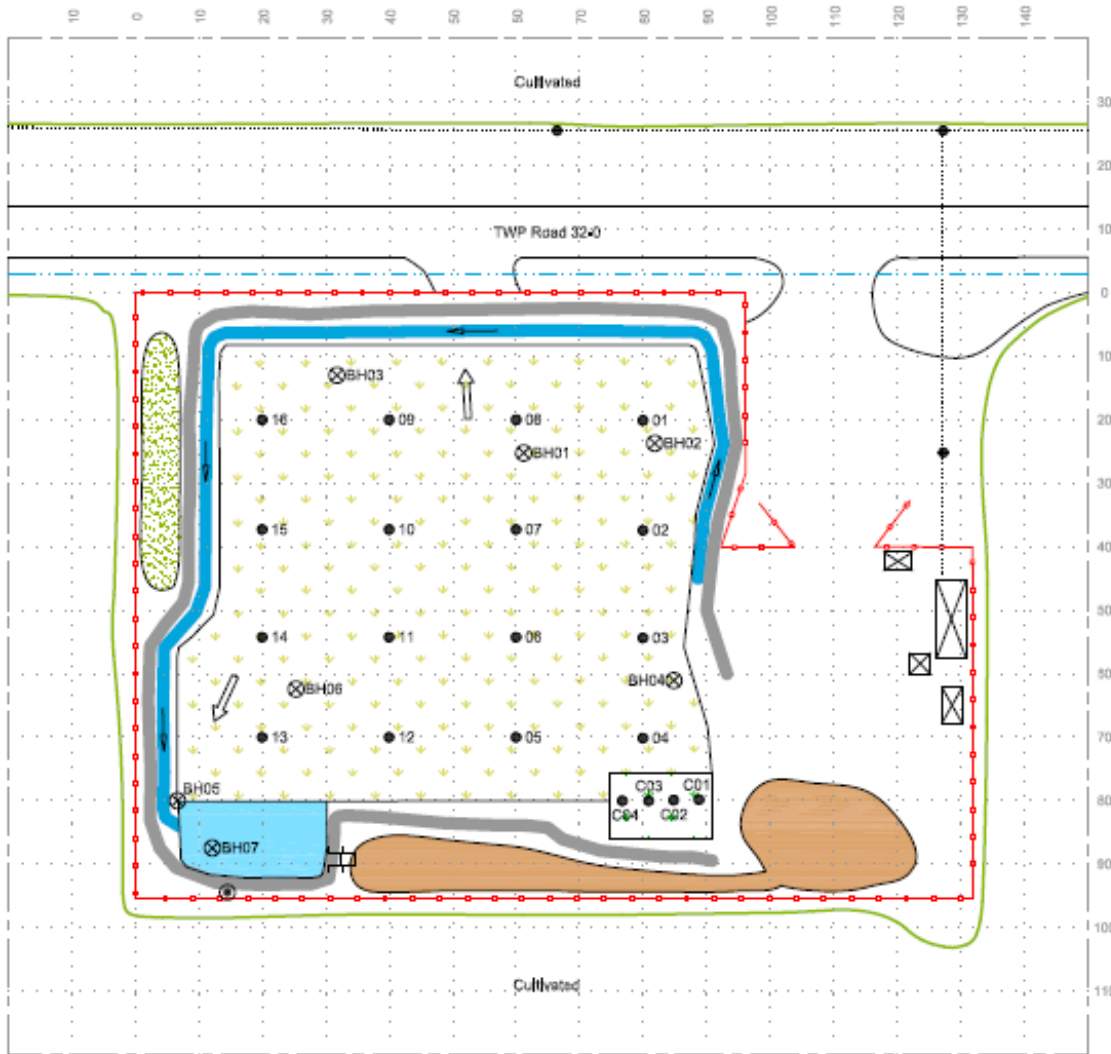




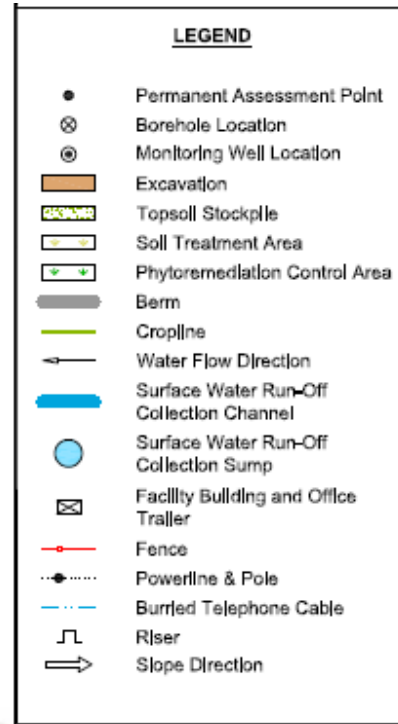
**Placement of  
Contaminated Soil**



# Lift #1 – Started June 2015



Approximately 8,000 m<sup>3</sup> of PHC contaminated material were excavated from the former gas plant site spread to a depth of 1.60 m:



- Land use – agricultural
- Soil texture – fine
- AB Tier 1 remediation guideline values F2:
  - surface soil – 150 mg/kg
  - subsoil – 300 mg/kg
- Seed – Arg, Prg, TF
- PGPR – *Pseudomonas sp.*
- Lift #1 T=0 June 2015
- 0.00-0.25 m
- Herbicide had been applied to the NE corner



# Lift #1 September 2015



## **Lift #1:**

Treatment for PHC F2 contamination was completed in September 2015. 1,200 m<sup>3</sup> were stripped and placed back in the open excavation. 1 grid was excluded.





Stripping of Lift #1  
September 2015



# Lift #2 Stripping November 2015



## Lift #2

Completed in November of 2015. 800 m<sup>3</sup> (depth of 0.25 m) were stripped from the site and placed into the open excavation. 2 grids were excluded.

**Summary of Treatment Area Lift #2 Sample Chemistry Not Complying with Surface Soil Guideline Values**

Depth	PHC	Sep 2015		
		# Samples	Range (mg/kg)	Average†
0.00 - 0.25 m	F2	1 of 16	180	30.1±12.1
	F3	1 of 16	1400	227±82
	benzene	1 of 16	0.27	0.026±0.016
	ethylbenzene	2 of 16	0.51-0.59	0.092±0.045

# number of samples exceeding Alberta Tier 1 remediation guideline value for fine grain surface soil

†average mg/kg for all samples ± standard error



# Lift #3 June 2016



## Lift #3

Completed in June 2016. 1,000 m<sup>3</sup> (depth of 0.20 m) were stripped from the site and placed into the open excavation. 3 grids were excluded.

**Summary of Treatment Area Lift #3 Sample Chemistry Not Complying with Surface Soil Guideline Values**

Depth	PHC	Nov 2015		
		# Samples	Range (mg/kg)	Average†
0.00 - 0.25 m	F1	1 of 16	220	42±16.8
	benzene	3 of 16	0.052-0.38	0.044±0.024
	ethylbenzene	2 of 16	0.60-1.1	0.146±0.073

# number of samples exceeding Alberta Tier 1 remediation guideline value for fine grain surface soil

†average mg/kg for all samples ± standard error



# Lift #4 October 2016



## Lift #4

Completed in October 2016. 1,900 m<sup>3</sup> (depth of 0.35 m) were stripped from the site and placed into the open excavation. 3 grids were excluded.

**Summary of Treatment Area Lift #4 Sample Chemistry Not Complying with Surface Soil Guideline Values**

Depth	PHC	Jun 2016		
		# Samples	Range (mg/kg)	Average†
0.25 – 0.50 m	F3	1 of 20	1400	341±83
	benzene	2 of 20	0.058-0.73	0.044±0.036
	ethylbenzene	1 of 20	0.69	0.048±0.034
	xylenes	1 of 20	2.6	0.185±0.128

# number of samples exceeding Alberta Tier 1 remediation guideline value for fine grain surface soil

†average mg/kg for all samples ± standard error



# Lift #5 September 2017



Summary of Treatment Area Lift #5 Sample Chemistry Not Complying with Surface Soil Guideline Values				
Depth	PHC	Oct 2016		
		# Samples	Range (mg/kg)	Average†
0.00 - 0.25 m	F1	1 of 16	240	46±16
	F2	2 of 16	210-320	58±21
	ethylbenzene	2 of 16	0.095-0.18	0.029±0.012
0.25 - 0.50 m	F1	2 of 16	280-380	62±27
	F2	2 of 16	420-530	79±39
	F3	3 of 16	2000-2900	590±230
	benzene	2 of 16	0.056-0.42	0.037±0.026
	ethylbenzene	4 of 16	0.15-2.4	0.225±0.151
	xylenes	2 of 16	1.0-2.1	0.246±0.137

# number of samples exceeding Alberta Tier 1 remediation guideline value for fine grain surface soil

†average mg/kg for all samples ± standard error



# Lift #5 September 2017



## **Lift #5**

Completed in September 2017 and 1,700 m<sup>3</sup> (depth of 0.50 m) were stripped from the site and placed into the open excavation. 2 grids were stripped to a depth of 0.25 m.



# Craigmyle Site Summary to Date

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- 6,600 m<sup>3</sup> of impacted soil has been treated in 5 soil treatment layers.
- Impacted soil contained BTEX, PHC F1 to F3.
- Following treatment all soil met applicable remediation criteria.
- Approximately 1,400 m<sup>3</sup> of PHC impacted soil remains on-site currently in the treatment area (treatment layer 6).
- All soil treatment should be complete in 2018 and final site restoration can proceed (i.e. contouring and re-vegetation).



# Conclusions

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Earthmaster has successfully deployed PEPSystems:

- to treat multiple lifts
- in 2 very different geographic locations
  - Remote
  - Dryland / agricultural
- using different site design strategies
  - As is
  - Using a treatment pad

PEPSystems has proven to be a commercially viable field system for the remediation of PHC and salt contamination in soil.



# Enhancement of PEPSystems

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## Research & Development:

- Improve speed to remedial endpoint
- Evaluate and test technology for deployment:
  - Different types of contaminants (e.g. metals and organics)
  - Different soil types
  - Different moisture regimes (e.g. wetlands)
  - Various disturbed soils (i.e. enhanced reclamation)



# Bear Rock Sinkhole NWT





# Acknowledgements

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Clients who have allowed Earthmaster to conduct field trials to advance the PEPSystems technology.

**Thank You**  
**Questions?**