Technical Case Study

Phytoremediation of Petroleum Hydrocarbon Impacted Soil in North Central Alberta using PEPSystems®

Abstract

Earthmaster successfully treated petroleum hydrocarbon (PHC) and salt impacted soil using a PGPR (plant growth promoting rhizobacteria) enhanced phytoremediation system (PEPSystems®). Approximately 9,200 m^3 of impacted soil was spread across three treatment facilities and PEPSystems, utilizing perennial and annual grasses, was deployed. Within 4 growing seasons, all of the treated soil complied with surface soil and/or subsoil remediation guideline values and was suitable for re-use in the area.

PEPSystems® Technologies

PEPSystems is based on multiple complementary techniques that target different aspects of PHC and salt impacted soil remediation. PEPSystems not only removes PHCs from soil, but results in their metabolism to non-toxic molecules. PEPSystems also increases plant tolerance to elevated salt levels allowing improved plant growth with commensurate salt uptake into aboveground plant tissue. PEPSystems lowers stress ethylene in plants which allows for improved plant root and shoot growth on impacted soils and results in efficient and timely re-vegetation of impacted sites. Soil can be treated using PEPSystems both *in situ* and *ex situ*.

Project Background

The site was located in north central Alberta, approximately 400 km north of Edmonton, in the Central Mixedwood Subregion. Stockpiled soil (~9,200 m^3) from historical emulsion spills had undergone numerous unsuccessful treatment methods previously. Laboratory analyses of the soil completed in 2008 showed elevated salt, BTEX, and PHC fractions F1 to F4 levels. The client identified phytoremediation as a potential means of remediating the salt and hydrocarbon impacts. This would avoid having to dispose of the soil to an off-site landfill facility.

Remediation Objectives

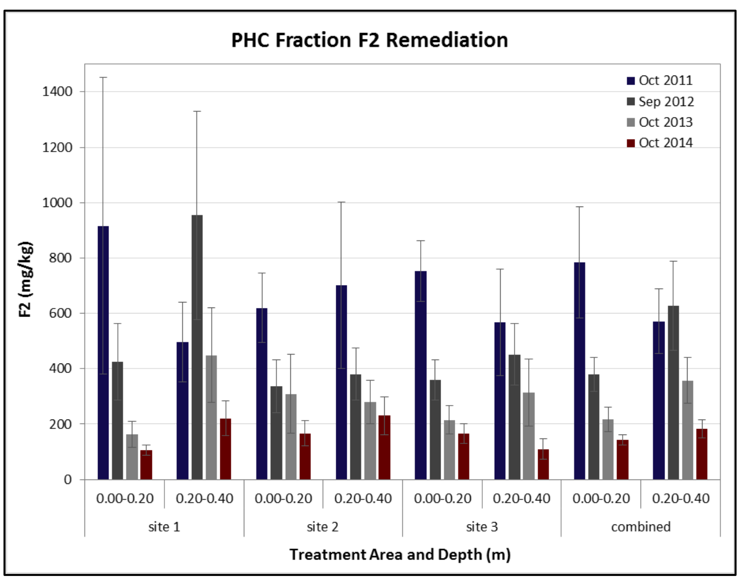
The remediation objectives were to reduce PHC and salt levels in the soil to comply with Alberta Tier 1 Soil and Groundwater Remediation Guideline values for natural area fine grain surface soil or subsoil, and to comply with the salinity/sodicity remediation endpoints agreed to by the Alberta regulator. The regulators approved the use of subsoil remediation guideline values for treated soil being placed deeper than 1.50 m below ground level.

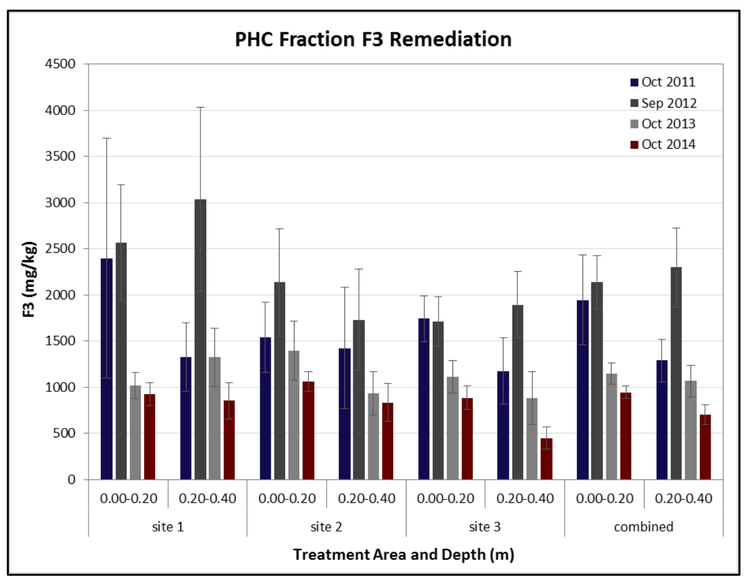
Solution

Following Alberta regulator approval, Earthmaster designed, constructed, and operated three one-time biopile soil treatment facilities at three active client lease locations. The treatment facilities consisted of compacted clay treatment pads and surface water run-off collection systems and sumps. Impacted soil was spread across the treatment pads within each of the treatment facilities. Permanent assessment points were established across the treatment areas for use in conducting regular soil sampling and vegetation analyses to monitor remediation progress. PEPSystems was deployed in the fall of 2011 using a combination of *Pseudomonas* bacteria with perennial and annual grasses. The treatment area soils were managed over several growing seasons to remediate the salt and hydrocarbons in the soil.

Results

From PEPSystems deployment in the fall of 2011 through the 2014 growing season, ~8,100 m³ of soil was successfully treated. As of the end of the 2014 growing season, laboratory soil test results for PHC fraction F4, BTEX, ECe, and SAR met remediation objectives. A total of 2,000 m³ complied with surface soil remediation guideline values for PHC fractions F1, F2, and F3 concentrations and ~6,100 m³ complied with subsoil remediation





guideline values. Remediated soil was stripped and placed into stockpiles for future use. The remaining ~1,100 m³ of impacted soil (i.e. material that was in treatment zone ‘hot spots’) was spread across portions of the treatment areas for additional phytoremediation. As of the summer of 2016, more than 900 m³ of the additionally treated soil complied with surface soil guideline values for hydrocarbons and the remaining (<200 m³) complied with subsoil guideline values. Remediation of the site was completed within a combined total of 4 full growing seasons.

Conclusion

Phytoremediation successfully removed salt and PHC impacts from the soil allowing the soil to be conserved and reused in the area. While PEPSystems technologies are more time consuming than traditional disposal based remediation methods, PEPSystems offers innovative and effective low cost green solutions to remediating and conserving contaminated soil. This technology is especially suited to remote and northern areas where traditional remediation techniques are not cost effective or sometimes practical.

References

Cowie, BR, BM Greenberg and GF Slater (2010) Determination of microbial carbon sources and cycling during remediation of petroleum hydrocarbon impacted soil using natural abundance 14C analysis of PLFA. Environmental Science & Technology, 44:2322-2327.

Gerhardt, KE, X-D Huang, BR Glick and BM Greenberg (2009) Phytoremediation of organic soil contaminants: potential and challenges. Plant Science. 176: 20-30.

Gurska, J, W Wang, KE Gerhardt, AM Khalid, DM Isherwood, X-D Huang, BR Glick and BM Greenberg (2009) Three year field test of a plant growth promoting rhizobacteria enhanced phytoremediation system at a land farm for treatment of hydrocarbon waste. Environmental Science & Technology, 43:4472-4479.

Technical Case Study

The PEPSystems® Advantage

For Re-vegetation of Salt Impacted Soil

Abstract

Earthmaster successfully re-vegetated salt impacted soil using a PGPR (plant growth promoting rhizobacteria) enhanced phytoremediation system (PEPSystems®). A poorly vegetated area, approximately 48,000 m² in size, contained soil impacted with produced water (which contained sodium chloride) at an oil and gas production site in southern Saskatchewan, Canada. PEPSystems, used in combination with several species of grass and oats, was deployed following repeated remediation attempt failures using other technologies for over 20 years, including salt leaching and groundwater recovery systems, to reduce salinity impacts. The goal of the PEPSystems technology was to facilitate re-vegetation of the salt impacted site. Over three growing seasons, the bare areas were successfully re-vegetated and a substantial amount of sodium and chloride was removed from the site following harvest of the resulting aboveground plant biomass at the end of each growing season.

PEPSystems® Technologies

PEPSystems is based on multiple complementary techniques that target different aspects of salt and PHC impacted soil remediation. PEPSystems increases plant tolerance to elevated salt levels allowing improved plant growth with commensurate salt uptake into aboveground plant tissue. PEPSystems not only removes PHCs from soil, but results in their metabolism to non-toxic molecules. PEPSystems lowers stress ethylene levels in plants which allows for improved root and shoot growth on impacted soils resulting in efficient and timely re-vegetation of impacted sites. Soil can be treated using PEPSystems both *in situ* and *ex situ*.

Project Background

The site was located in southern Saskatchewan, approximately 25 km southeast of Weyburn, in a Moist Mixed Grassland Ecoregion. Soil salinity impacts resulted from the release of produced water. Various techniques were attempted to remediate the site plus a groundwater recovery system was installed and used on the site from 1997 to 2002 to aid in recovery of the salts that leached downwards within the soil profile. Laboratory analyses of the soil completed in 2009 showed elevated ECe (up to 45.3 dS/m), chloride (up to 12,000 mg/kg), SAR (≤34.7), and boron (≤23 mg/kg) levels. The client identified phytoremediation as a potential means of re-vegetating the site and reducing salinity levels to avoid having to dispose of the considerable volume of contaminated soil at an offsite landfill.

Remediation Objectives

The remediation objectives were to revegetate the site to at least 70% of the background area plant growth levels and to reduce soil salt levels over time to allow for sustainable plant growth. Note that soils in the area were naturally saline showing ECe levels of 4-8 dS/m.

Solution

Following a detailed evaluation of soil and site conditions and characteristics, a phytoremediation deployment strategy was prepared. Earthmaster amended the surface soil and prepared a suitable seed bed into which PGPR treated seed was sown. Permanent assessment points were established across the treatment area for use in conducting regular soil sampling and vegetation analyses to monitor progress. PEPSystems was deployed in the summer of 2010 using a combination of *Pseudomonas* bacteria with perennial and annual grasses, and oats. The treatment area soils were managed over three growing seasons to revegetate the area.

Results

PEPSystems treatment was continued through the 2012 growing season. Excellent plant growth was obtained through all three growing seasons; however, the end of the 2012 growing season experienced severe drought conditions which caused increased evapotranspiration resulting in early season plant senescence. There were a few remaining small areas of poor vegetation growth which were associated with higher sodium, chloride and ECe levels. These areas were generally low lying and would accumulate run-off water following significant rainfall events.

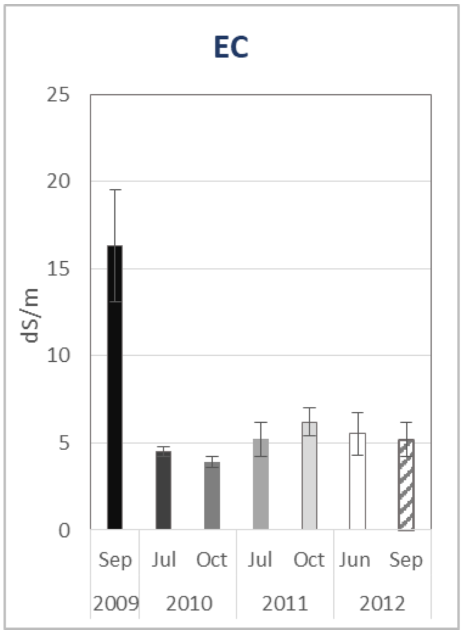
Sep 2009

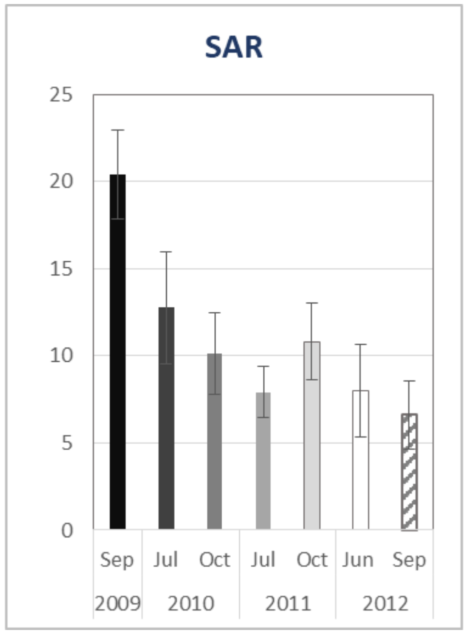
Oct 2010

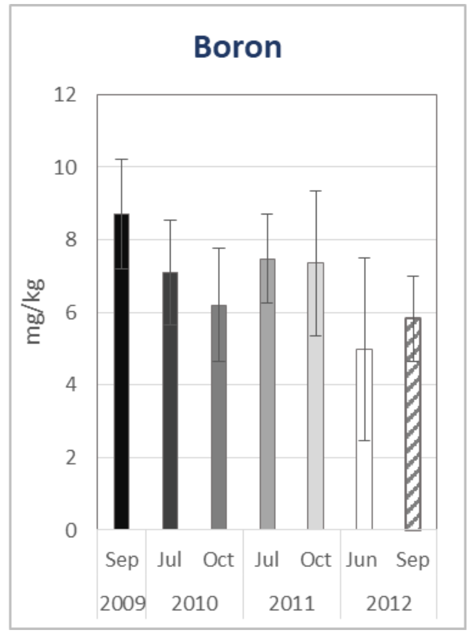
Oct 2011

Jun 2012

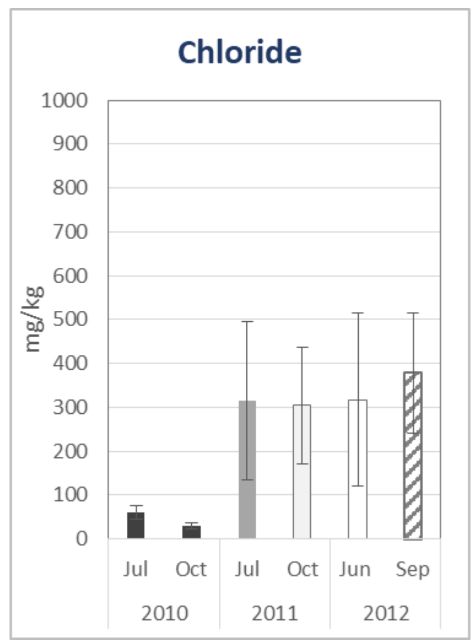
The aboveground plant biomass increased in each successive year (533 g/m² in 2010, 596 g/m² in 2011, and 796 g/m² in 2012) for a total increase of 50% from the start of PEPSystems deployment in 2010 until the end of the growing season in 2012. The overall salt load at the site decreased due to plant uptake of salts (i.e. sodium chloride). While ECe levels remained relatively constant throughout the three growing seasons, both SAR and boron levels decreased from the levels present in soil samples collected in 2010 when PEPSystems was deployed.







Chloride concentrations increased in the surface soil as PEPSystems treatment continued through to 2012. Chloride ions are extremely mobile in soil enabling them to migrate upwards in the soil profile (reducing the subsurface salt concentration) due to evapotranspiration. Over three growing seasons, despite challenges from drought, a total of 314 kg of sodium and 1,352 kg of chloride were removed from the site through harvesting of the aboveground plant biomass which had accumulated the salt.



Conclusion

Deployment of PEPSystems led to the successful re-vegetation of a large area of salt impacted soil which initially supported very poor plant growth. Phytoremediation removed substantial amounts of salt while also improving soil physical characteristics that provide for sustainable and enhanced plant growth. While PEPSystems technologies are more time consuming than the only other proven soil salt remediation method for heavier textured soils, (excavation and offsite landfill disposal), PEPSystems offers innovative and effective low cost green solutions to remediating and conserving contaminated soil. This technology is especially suited to remote impacted sites where traditional remediation techniques are not cost effective nor practical.

References

Gerhardt, KE, GJ MacNeill, PD Gerwing, and BM Greenberg (2017) Phytoremediation of Salt-Impacted Soils and Use of Plant Growth-Promoting Rhizobacteria (PGPR) to Enhance Phytoremediation in *Phytoremediation*

Management of Environmental Contaminants Volume 5. Ansari, A.A., Gill, S.S., Gill, R., Lanza, G., Newman, L. (Eds.). Springer. Pages 19-51.

Cowie, BR, BM Greenberg and GF Slater (2010) Determination of microbial carbon sources and cycling during remediation of petroleum hydrocarbon impacted soil using natural abundance 14C analysis of PLFA. Environmental Science & Technology, 44:2322-2327.

Gerhardt, KE, X-D Huang, BR Glick and BM Greenberg (2009) Phytoremediation of organic soil contaminants: potential and challenges. Plant Science. 176: 20-30.

Gurska, J, W Wang, KE Gerhardt, AM Khalid, DM Isherwood, X-D Huang, BR Glick and BM Greenberg (2009) Three year field test of a plant growth promoting rhizobacteria enhanced phytoremediation system at a land farm for treatment of hydrocarbon waste. Environmental Science & Technology, 43:4472-4479.

EARTHMASTER
environmental strategies

Technical Case Study

Phytoremediation of Salt and Hydrocarbon Impacted Soil at a Remote Northern Location Using PEPSystems®

Abstract

Earthmaster successfully treated petroleum hydrocarbon (PHC) and salt (NaCl) impacted soil using a PGPR (plant growth promoting rhizobacteria) enhanced phytoremediation system (PEPSystems®) at a remote northern location. Approximately 7,800 m³ of impacted soil was successfully treated with PEPSystems utilizing perennial and annual grasses. Following treatment, all of the soil complied with surface soil and/or subsoil remediation guideline values and was suitable for re-use on the site.

PEPSystems® Technologies

PEPSystems is based on multiple complementary techniques that target different aspects of PHC and salt impacted soil remediation. PEPSystems not only degrades PHCs in the soil, but results in their metabolism to non-toxic molecules. PEPSystems also increases plant tolerance to elevated salt levels allowing for improved plant growth with commensurate salt uptake into aboveground plant tissue. PEPSystems lowers stress ethylene levels in plants which allows for improved plant root and shoot growth and results in efficient and timely re-vegetation of impacted sites. Soil can be treated both *in situ* and *ex situ* using PEPSystems.

Project Background

The site was located in the Sahtu Region of the Northwest Territories (NT), ~40 km SE of Norman Wells. The site had winter road access only. Portions of the salt and PHC impacted soil from drilling activities had previously undergone unsuccessful treatment using bioremediation. Several contaminated open and buried pits and sumps remained on-site. Laboratory analyses of the soil completed in 2008 showed elevated salt and PHC fraction F2 levels. Phytoremediation was identified as a potential means of remediating the salt and PHC impacts to avoid the costly and difficult option of off-site landfill disposal.

Remediation Objectives

The remediation objectives were to reduce PHC and salt levels in the soil to comply with Alberta Tier 1 Soil and Groundwater Remediation Guideline values for industrial land use for coarse grain surface soil or subsoil as agreed to by the NT regulator. The regulators approved the use of subsoil remediation guideline values for treated soil being placed deeper than 1.50 m below ground level. It was required that soil treatment be completed on-site.

Remediation Methods

Dr. Bruce Greenberg from the University of Waterloo isolated and characterized PGPR from soil collected at the site, and conducted greenhouse trials to identify effective bacteria and plant combinations to achieve remediation goals. PEPSystems utilizing Nota 4/7 *Pseudomonas* bacteria with perennial and annual grasses was deployed at the site in 2008 to treat surface soil for salt impacts (soil layer #1). Permanent assessment points were established across the treatment area for use in conducting regular soil and vegetation sampling and analyses to monitor remediation progress. Following remediation of a soil layer, additional impacted soil was excavated from the pits and sumps and was spread across the treatment area. PEPSystems was re-deployed to treat the additional soil (layers #2 to #5). Aboveground plant biomass containing accumulated salts was harvested and landfilled.

Results

From PEPSystems deployment in June of 2008 through the 2017 growing season, a large volume of soil (~7,800 m^3) was successfully treated in five different soil layers as necessitated by the small size of the on-site treatment area. At the end of the 2017 growing season, laboratory soil test results for EC (electrical conductivity) and PHC complied with remediation objectives. Remediated soil was placed back into the excavations and the site was re-contoured and re-vegetated to ensure successful closure based reclamation. Contaminant remediation at the remote site was completed within eight growing seasons. The cost to phytoremediate the contaminated soil on-site was 20% of the cost for off-site landfill disposal.

Layer #	Treatment Start Date	Treatment End Date	# Growing Seasons	Source	Soil Volume (m^3)	Contaminant Concentrations	
						average at start	average at end
1	Jun 2008	Spring 2011	2	landfarm and lease surface soil	2,100	EC - 14.5 dS/m EC - 5.2 dS/m EC - 3.6 dS/m	EC - 5.3 dS/m (↓63%) EC - 2.2 dS/m (↓58%) EC - 2.2 dS/m (↓39%)
2	Jul 2011	Jun 2013	2	pits and sumps	2,100	EC - 5.5 dS/m F2 - 549 mg/kg	EC - 2.9 dS/m (↓47%) F2 - 84 mg/kg (↓84%)
3	Sep 2013	Sep 2015	2	pits and sumps	900	F2 - 1418 mg/kg	F2 - 307 mg/kg (↓79%)
4	Jun 2016	Jun 2017	1	pits and sumps	1,600	F2 - 644 mg/kg	F2 - 360 mg/kg (↓44%)
5	Jun 2017	Sep 2017	1	pits and sumps	1,100	F2 - 385 mg/kg	F2 - 152 mg/kg (↓60%)

Conclusion

Phytoremediation successfully removed salt and PHC contaminants from the soil allowing the soil to be conserved and reused on-site. While PEPSystems technologies are more time consuming than traditional disposal based remediation methods, PEPSystems offers innovative and effective low cost green solutions to remediating and conserving contaminated soil. This technology is especially suited to remote and/or northern areas where traditional remediation techniques are not cost effective nor practical.

References

Cowie, BR, BM Greenberg and GF Slater (2010) Determination of microbial carbon sources and cycling during remediation of petroleum hydrocarbon impacted soil using natural abundance 14C analysis of PLFA. Environmental Science & Technology, 44:2322-2327.

Gerhardt, KE, GJ MacNeill, PD Gerwing, and BM Greenberg (2017) Phytoremediation of Salt-Impacted Soils and Use of Plant Growth-Promoting Rhizobacteria (PGPR) to Enhance Phytoremediation in Phytoremediation Management of Environmental Contaminants Volume 5. Ansari, A.A., Gill, S.S., Gill, R., Lanza, G., Newman, L. (Eds.). Springer. Pages 19-51.

Gerhardt, KE, X-D Huang, BR Glick and BM Greenberg (2009) Phytoremediation of organic soil contaminants: potential and challenges. Plant Science. 176: 20-30.

Gurska, J, W Wang, KE Gerhardt, AM Khalid, DM Isherwood, X-D Huang, BR Glick and BM Greenberg (2009) Three year field test of a plant growth promoting rhizobacteria enhanced phytoremediation system at a land farm for treatment of hydrocarbon waste. Environmental Science & Technology, 43:4472-4479.