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environmental strategies

In Situ Salt Remediation - Carbon and Cost Benefits of Treating Soil in Place

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Earthmaster Environmental Strategies Inc.

A Canadian environmental technologies company:

- Founded in 1998 and based in Calgary, Alberta, Canada.
- Specializes in providing environmental services to the commercial/industrial and upstream oil and gas industry in Western Canada.
- In-house lab facilities for microbiological research and a growth facility for plant testing.
- Co-developed commercial phytoremediation systems (PEPSystems®) to treat contaminated soil in an eco-friendly and responsible manner.

Earthmaster uses a combination of plants and bacteria to remediate contaminants from soil in an eco-friendly way.

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In Situ Remediation

Manage contaminants in place:

- Conserve the soil.
- No transfer of liability.
- Often involves adding things to the soil to break contaminants down.
- Can be more cost effective.

The problem with high salinity:

- Plants have difficulty in drawing water from the soil.
- Plants will struggle to grow.
- Can’t break salts down to non-toxic components.
- If the salt isn’t removed it may come back to create additional problems.

Salt Remediation in Soil

What are the options?

- Remove the soil
  - Landfill
- Leave it in place and bind it
  - Commercial soil binders
- Wash it out
  - +/- surfactants
- Remove the salt
  - Electrokinetics
  - Phytoremediation

Former Battery Site - Southern Saskatchewan

48,000 m^2 (12 acres) of salt impacted surface soil with very poor growth.

- Salt impacts went to 6.00 m bgl.
- Since early 1990's numerous unsuccessful attempts had been made to re-vegetate the area.
- Groundwater recovery system was installed in 1997 (weeping tile and collection culverts).
- Many large bare areas. Any growth consisted of kochia, foxtail barley, etc.
- Laboratory analyses showed elevated:
  - ECe's up to 45.3 dS/m
  - chloride up to 12,000 mg/kg
  - SAR's up to 34.7
  - boron up to 23 mg/kg


Southern Saskatchewan

The Usual Solution - Landfill Then Backfill

Landfilling - the quick and easy solution.

Distance to nearest landfill is 100 km.

48,000 m^2 x 6.0 m = 288,000 m^3 → over 500,000 tonnes

Trucking costs $15/tonne x tipping costs $20/tonne = $35/tonne

Landfilling costs: = $17,500,000 (not including excavation or backfilling)

Landfilling costs = $3,000,000 for upper 1 m of soil

Landfilling is not feasible or practical, transfers liability.

Soil Salt Binders

Permanently binds salt (chlorides) so they can no longer interact.

- Does not remove the chloride from the soil.
- Byo-Gon's ByoSoil ByoDetox / Delta's BioLogix Salt Binder
  - Designed for low levels of salt (sodium chloride) contamination on agriculture land
  - Treats chloride levels up to ~3000 ppm
  - Humic acid based – provides organics with extremely high ion exchange capacity to bind the ions
  - Cost:
    - 1 gallon pail is $50 USD
    - 2 gallons per acre (12 acres) twice per year = $1,200 USD plus application
  - Depth of penetration?
  - Migration?
  - Regulatory closure?

Byo Soil

Leaching/Flushing

Adding large volumes of low-salt water to the soil surface

- Dissolve the salts and move them below the rooting zone
- Requires good soil structure and good drainage
- Requires a lot of water over multiple applications
- May need to add additional chemicals to the soil
  - Gypsum
  - Bioxy (organic polymer to bind ions and increase mobility)
  - Surfactants (Ivey International)
- Need to reduce soil evaporation to prevent the salts from being drawn up to the surface again
- Moves the salt – does not remove it unless the soil is flushed and the water collected

Cost?

Electrokinetic Remediation

- Requires electrodes and low voltage DC power in the ground to create a uniform electric field.
- Destabilizes bonds and moves ions to corresponding electrodes.
- Requires flushing the anodes and cathodes with water to recover salts.

GroundEffects.org (Regina)

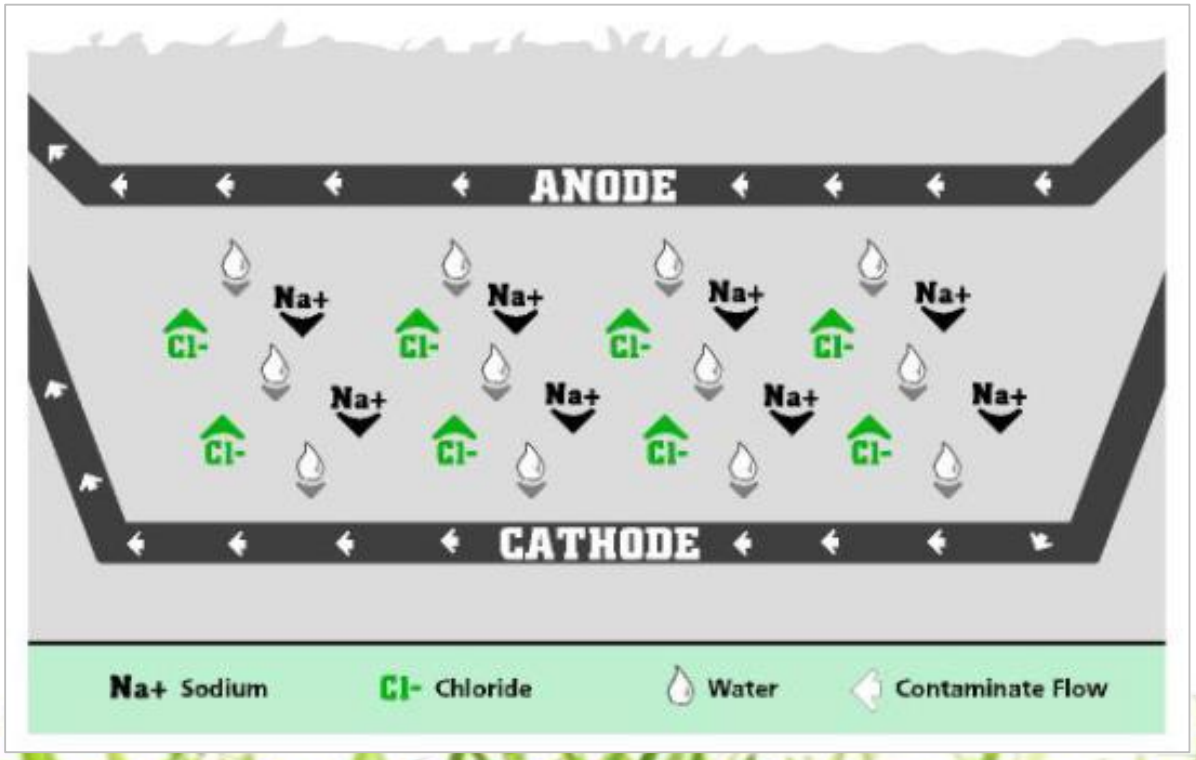
- Proprietary technology

Cost: $20-80/m³ for EK3

Based on 288,000 m³, cost would range from $5.7 MM to $23 MM.

Remediation of top meter of 48,000 m²: cost would be $960,000 to $3.8 MM.

Subsurface metal structures may cause problems.



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Plant Growth Promoting Rhizobacteria (PGPR) - Enhanced Phytoremediation Systems

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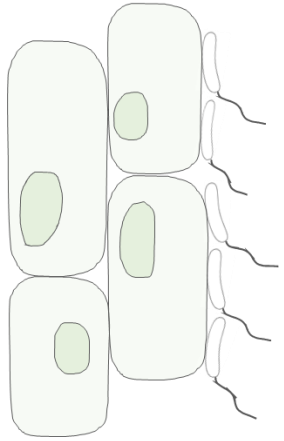
Use bacteria to help the plants grow in stressful conditions.

Plant seeds:
Coated with natural soil bacteria

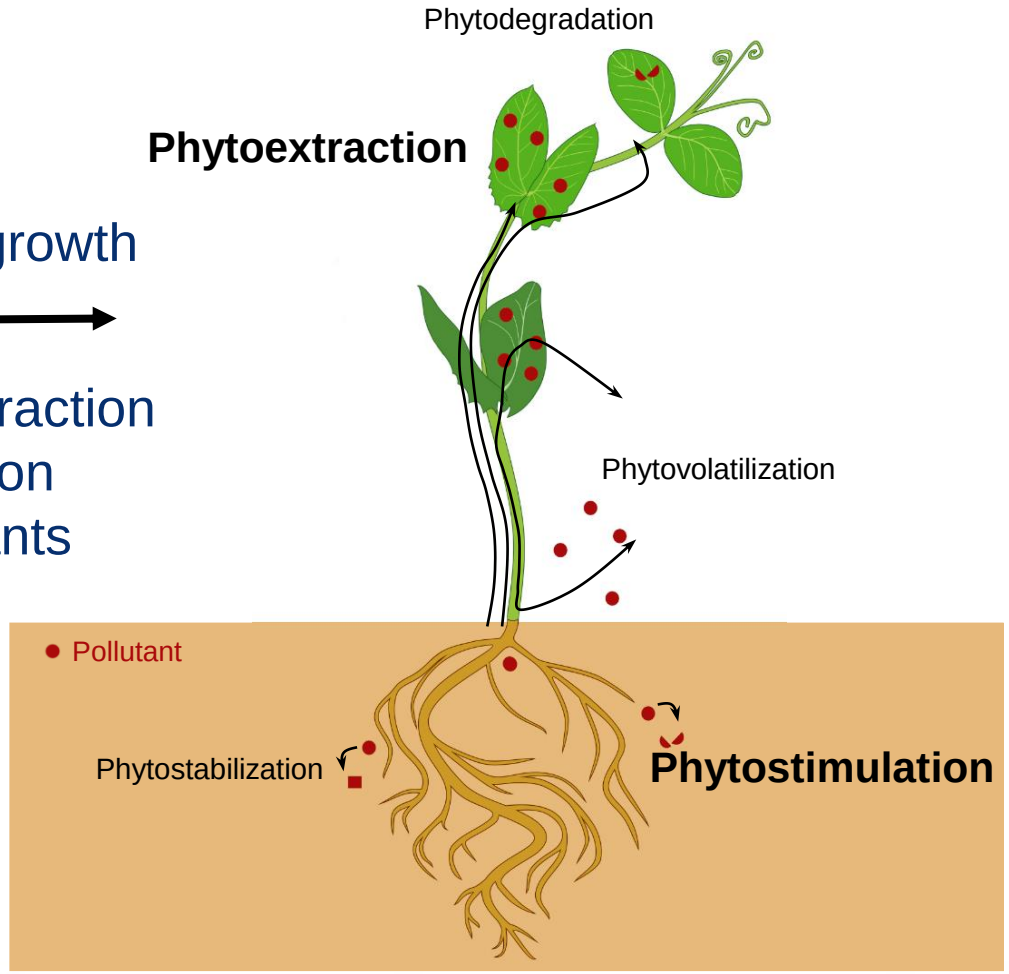
Active rhizosphere:
bacteria co-localize with developing roots



Plant cell:
bacteria interact with root cells –
↑ hormones
↓ stress response

Facilitate plant growth

Exploit phytoextraction & phytostimulation properties of plants



Seed Germination Studies – Produced Water

Seeds

- Different species
- +/- PGPR
- +/- other additives

Contaminant

- Produced water 0-100%

Growth conditions

- 25°C for 14 days

Sample Description	Routine Chemistry								
Sample Location	Chloride (mg/L)	Calcium (mg/L)	Potassium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Sulphate (mg/L)	pH	EC (dS/m)	SAR
Alberta Tier 1 Groundwater Remediation Guidelines Agricultural Land Use: Fine Soil	100	-	-	-	200	429	6.5-8.5	1	5
AEP EQGASW - Protection of Aquatic Life	120	-	-	-	-	429	6.5-9.0	-	-
Water samples									
Produced Water 1	36775	4223	406	498	18430	1372	7.1	73	71
Produced Water 2	78870	9264	4054	1839	32970	997	6.5	125	82

LEGEND

Denotes values that exceed Alberta Tier 1 Soil and Groundwater Remediation Guidelines and/or Surface Water Quality Guidelines for Use in Alberta as described in the text of the letter/report.

Environmental Quality Guidelines for Alberta Surface Waters (EQGASW) - Alberta Environment and Parks (AEP). July 2014.

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Phytoremediation

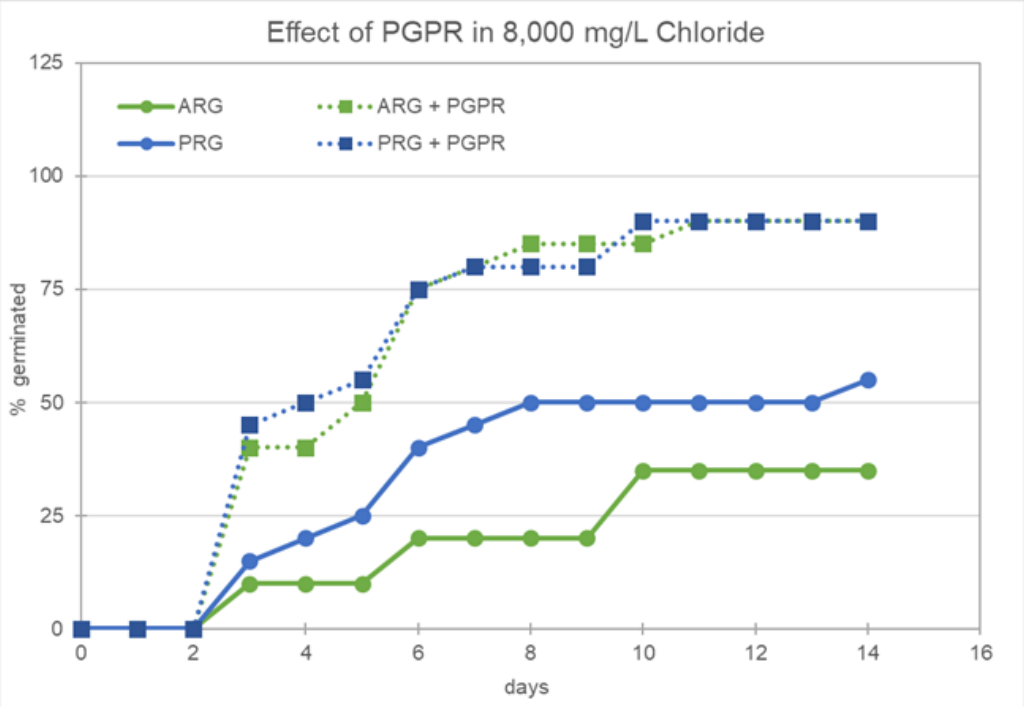
Plants naturally accumulate salts

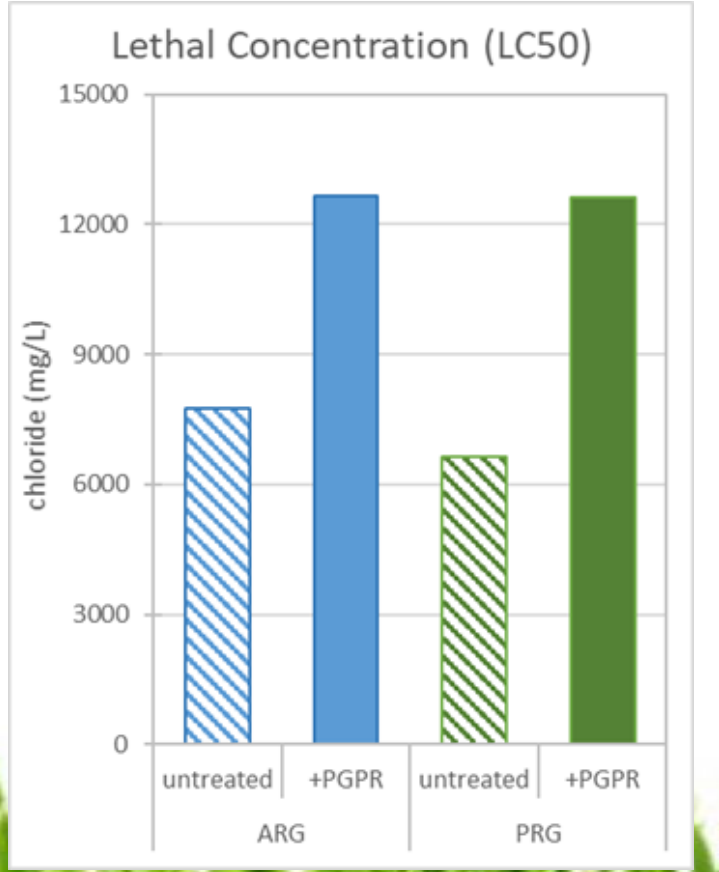
- Will extract them from the soil (hyper-accumulation vs. excretion)

Problem – how to get the plants to grow in elevated salt conditions?

- Toxicity is a problem

Solution – add a PGPR





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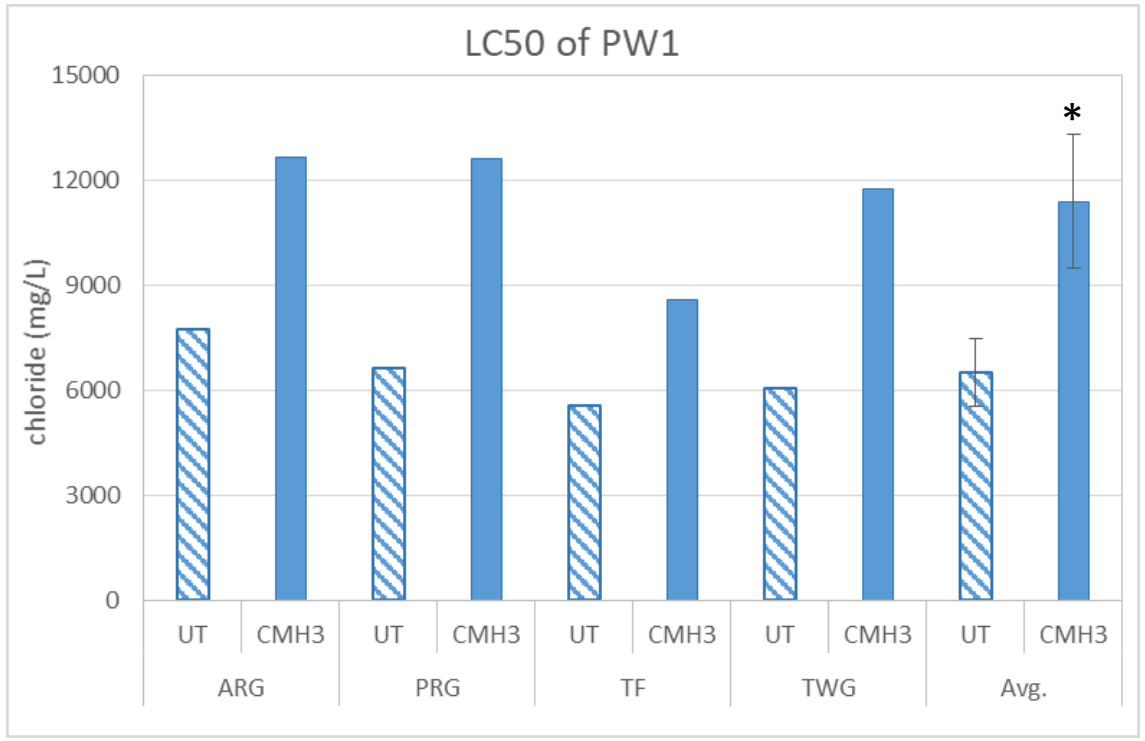
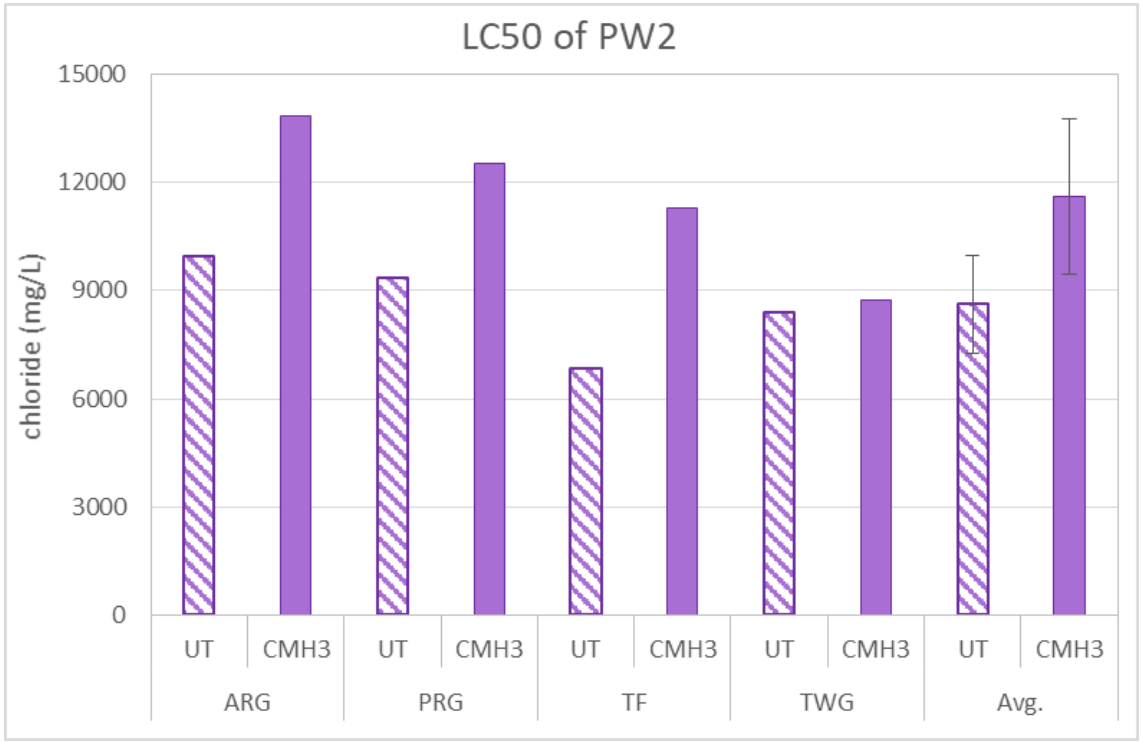
Quantifying the Effects of PGPR - LC50 (Tolerance)





seed	UT	CMH3	%change
ARG	7760	12651	63
PRG	6649	12614	90
TF	5553	8583	55
TWG	6064	11731	93
Avg.	**6506**	**11395**	**75**

seed	UT	CMH3	%change
ARG	9953	13857	39
PRG	9346	12525	34
TF	6846	11302	65
TWG	8392	8755	4
Avg.	**8634**	**11610**	**34**

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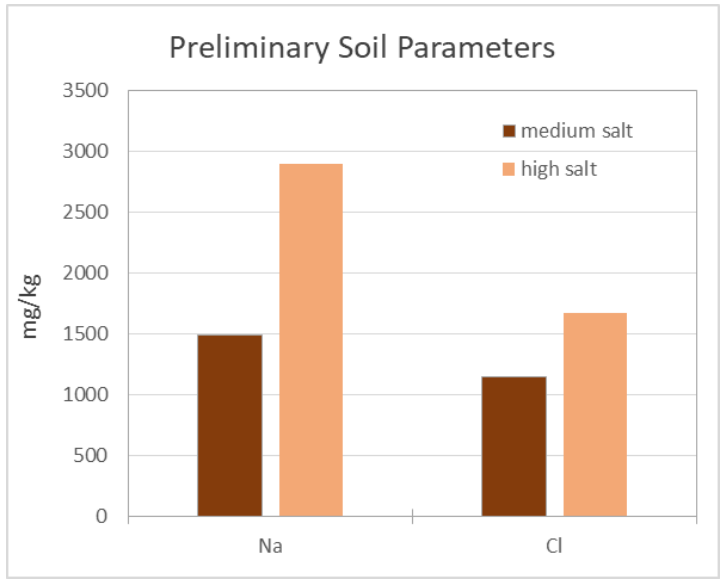
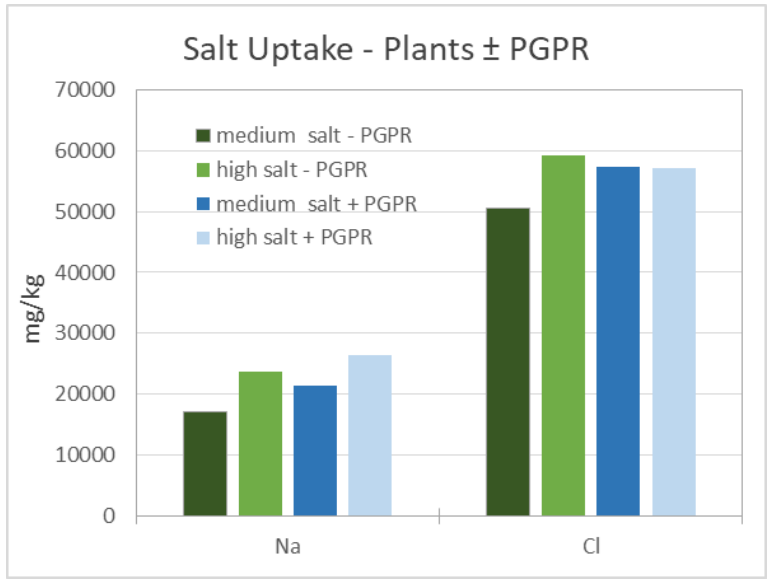
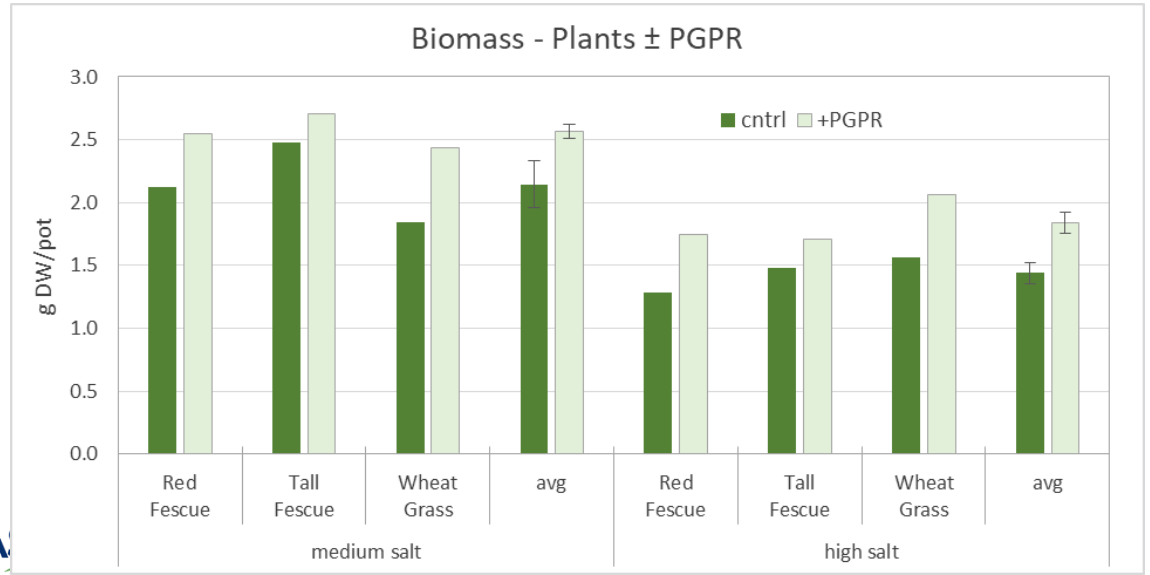
Initial Laboratory Experiments – Elevated Salinity







The advantages of PGPR:

- Regardless of soil salt content, plants take up approximately the same amount of Na^+ and Cl^-.
- PGPR has no effect on the ability of plants to take up Na^+ and Cl^-.
- PGPR significantly increases the biomass of the plants grown in higher salt conditions:
  - 19.5% ↑ in medium salt
  - 27.7% ↑ in high salt
- The increase is species dependent.
- Grasses are able to remove ~65 g NaCl per kg of dry plant material.

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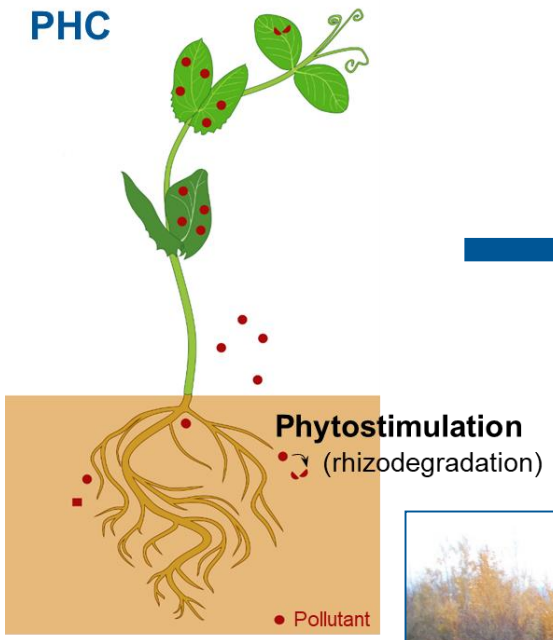
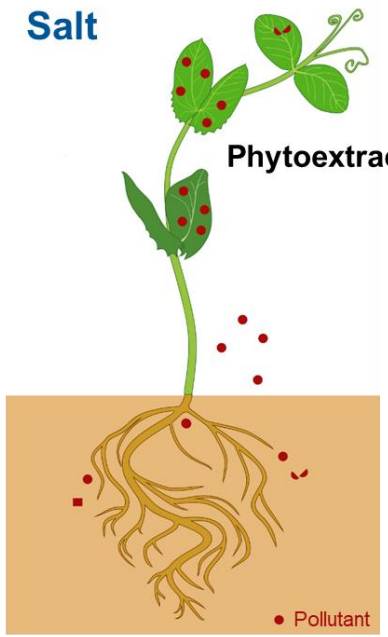
Southern Saskatchewan Site
Time = 0

Hydrocarbon vs. Salt Phytoremediation



incorporate plants into the soil



harvest above ground biomass

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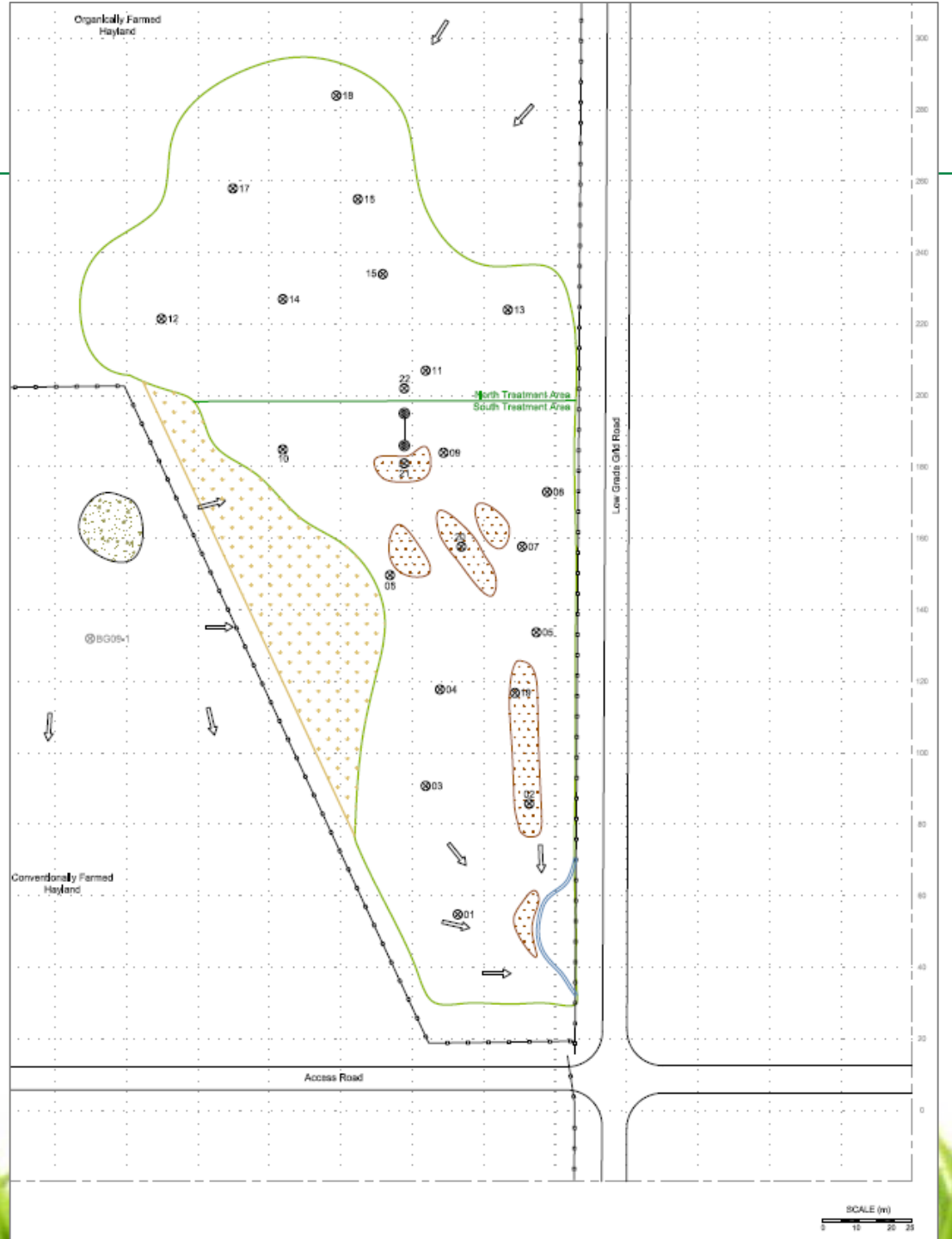
Weyburn Area

Project Goals:

- Re-vegetate the grassland site to at least 70% of background levels.
- Reduce soil salt levels over time to allow for sustainable plant growth.
- PEPSystems was deployed in the summer of 2010
  - Seed – ARG, PRG, Oats, TW
  - PGPR – *Pseudomonas corrugata*
- Treatment area soils were managed over three growing seasons to re-vegetate the area.



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Seed Bed Preparation

Mulch Amendment

Three Months After Seeding

Vegetation/Salt Removal


Year 3

Sustainability - Year 7 (2019)

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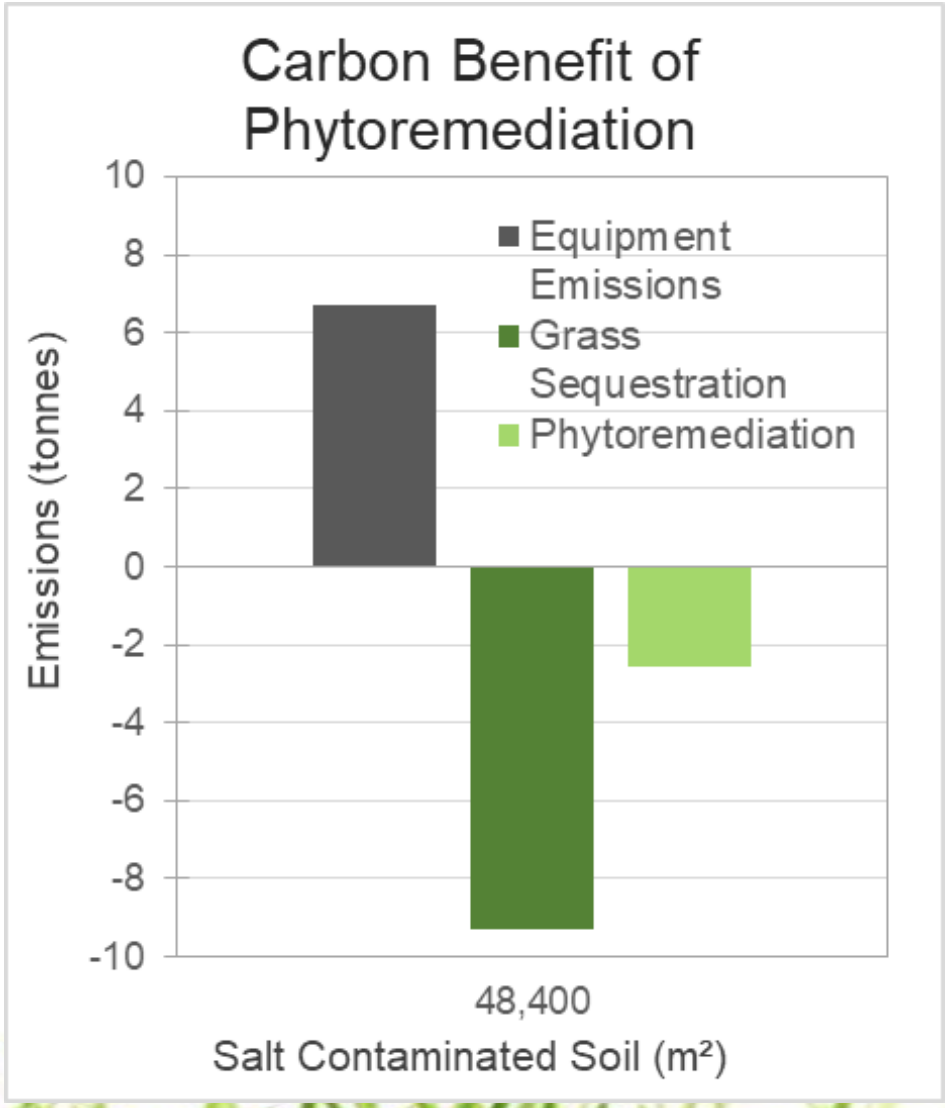
Costs & Emissions

- Phytoremediation costs were $195,000 over 3 years.
- Site was re-vegetated at a cost of $4/m².
- All previous re-vegetation attempts had been unsuccessful.
- Due to the depth of contamination at this site, landfilling/disposal costs would be substantial.

Carbon emissions from equipment were captured completely by the grasses and were reduced by an additional 35%



The Carbon Benefits of PEPSystems

Average carbon sequestration for grasslands:

- 639 kg/ha/year

Compare carbon amounts emitted by:

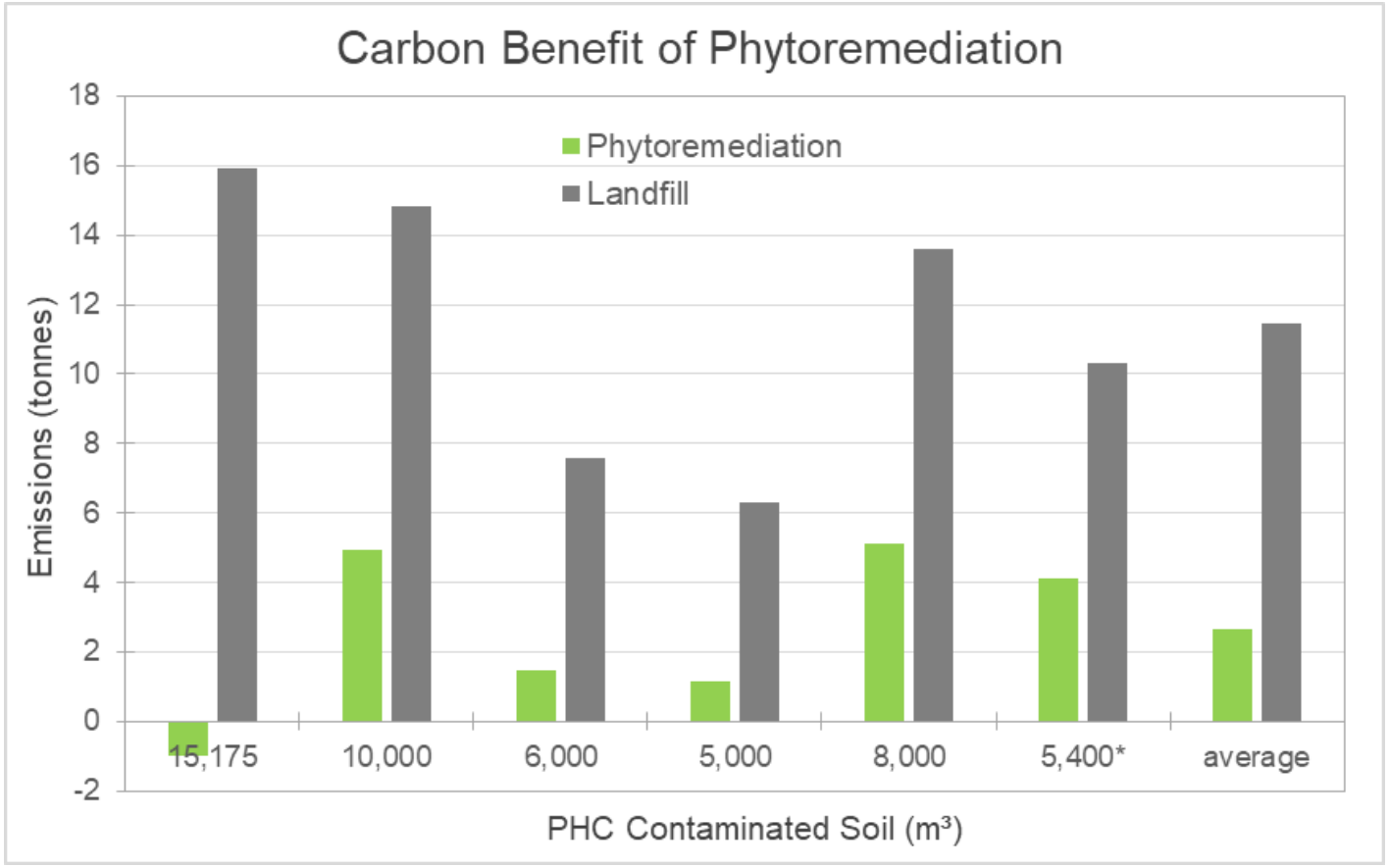
- equipment in phytoremediation activities (-sequestration)
- trucking to nearest landfill

Source of equipment emissions values:

- Published papers
- Industry information

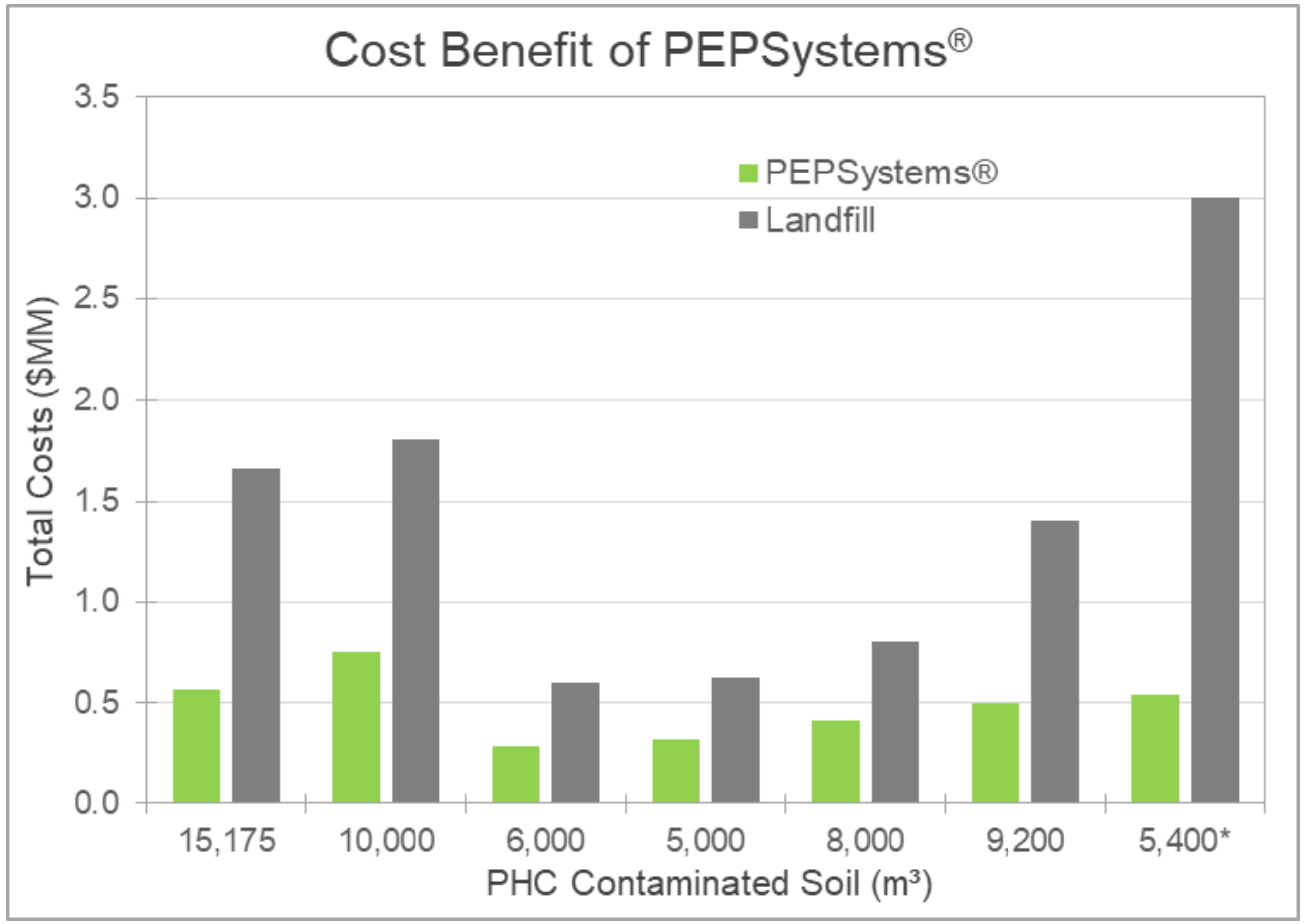
Source of carbon sequestration values:

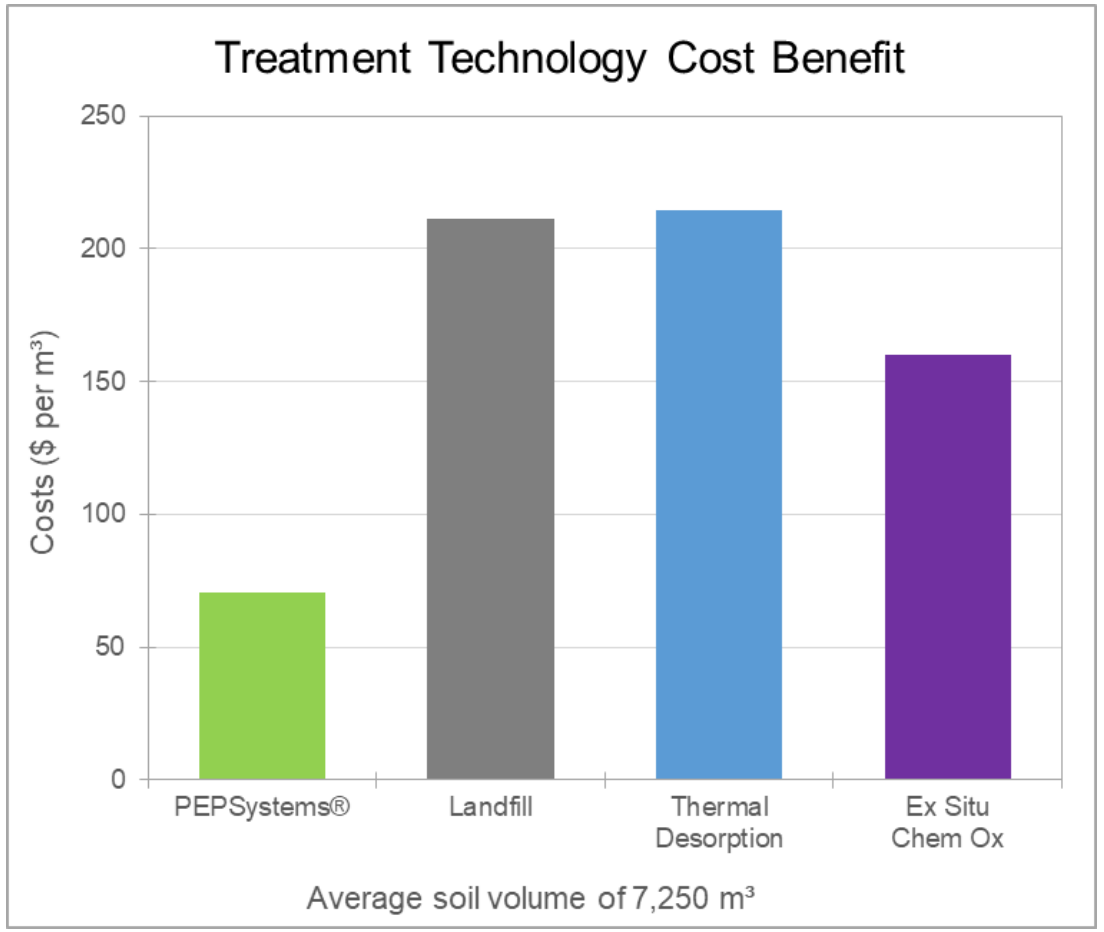
- Zirkle, et al. 2011. HortScience 46:808–814.
- Ginkel, et al. 1999. J. Environ. Qual., 28:1580-1584.
- Qian, et al. 2010. Soil Sci. Soc. Am. J. 74:366–371.
- Jones and Donnelly. 2004. New Phytologist 164:423–439.
- Hungate at al. 1997. Nature 388:576-579.
- Integrated Crop Management Volume 11-2010.



The Economics of PEPSystems

PHC Remediation





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Native Species

Can PEPSystems be adapted to native species?

- PGPR offer an advantage when the growing conditions are challenging.
- There will not be an advantage when growing conditions are good.

Challenging soil:

- Poor quality soil lacking topsoil or organics.
- Naturally occurring elevated salinity.

Challenging species:

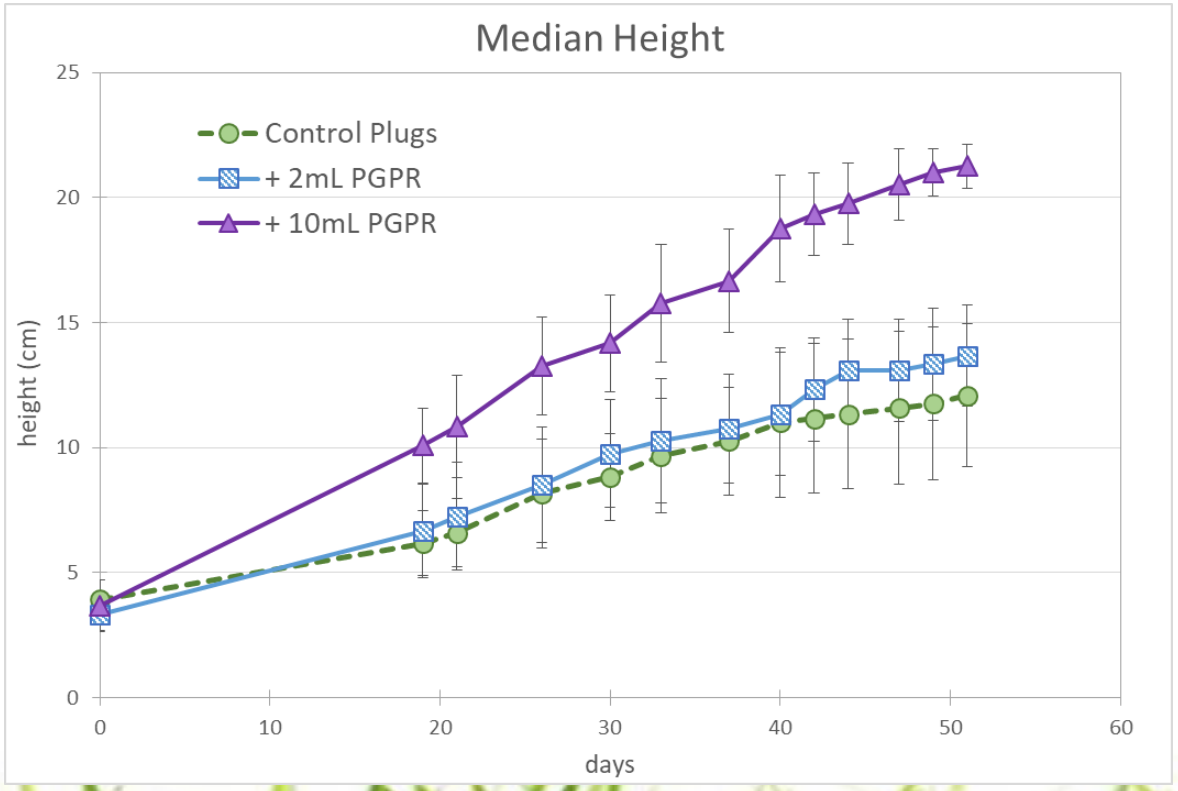
- Native prairie species are hard to grow and get established.

Field trials:

- Re-vegetation of a very poor quality soil.
- Native grass plugs to re-vegetate.

Grass Plugs – Laboratory Trial in High Salt

- Soil with elevated salinity – EC ~17 dS/m.
- PGPR solution injected into plug.
- Grasses show a positive response to PGPR at higher application rates.



Day 33

Re-vegetation – Commercial Site

Project Goals:

- Revegetate commercial site for use by owner.
  - Highly compacted, poor quality subsoil
  - Difficult to re-vegetate
- Owner has an on-site reverse osmosis system - generates effluent with elevated salinity.
  - Use to irrigate revegetated area
  - Minimize salinity accumulating in the soil or affecting vegetation.

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25 weeks post seeding


1 Year


2021

Salt Removal

Parameter	Value
Annual Decrease in EC_e	1 to 2 dS/m
Na^+ and Cl^- Uptake into Foliage	29 g/kg dry mass
Na^+ : Cl^- Ratio in Plant Foliage (mass basis)	25:75
Na^+ and Cl^- Removed from Project Sites in Foliage	150 kg/ha
Change in EC_e Accounted for by Foliar Uptake of Salt	Up to 95%

Site salt removal: site is 4.8 ha in size – regular harvesting will remove approximately 700 kg/year.

Challenges – limited by rooting depth and this takes time.

Phytoremediating Subsoil in Lifts

Advantages of PEPSystems

Environmentally Responsible

- Green technology, driven by solar energy.
- Soil is conserved and reused, quality is improved.
- Small carbon footprint (no offsite disposal; minimal heavy equipment usage).

Suitable for remote locations

- Fly in seed and amendments, etc.
- No large scale equipment requirements or hauling requirements reducing truck traffic on roads.

Effective for challenging contaminants

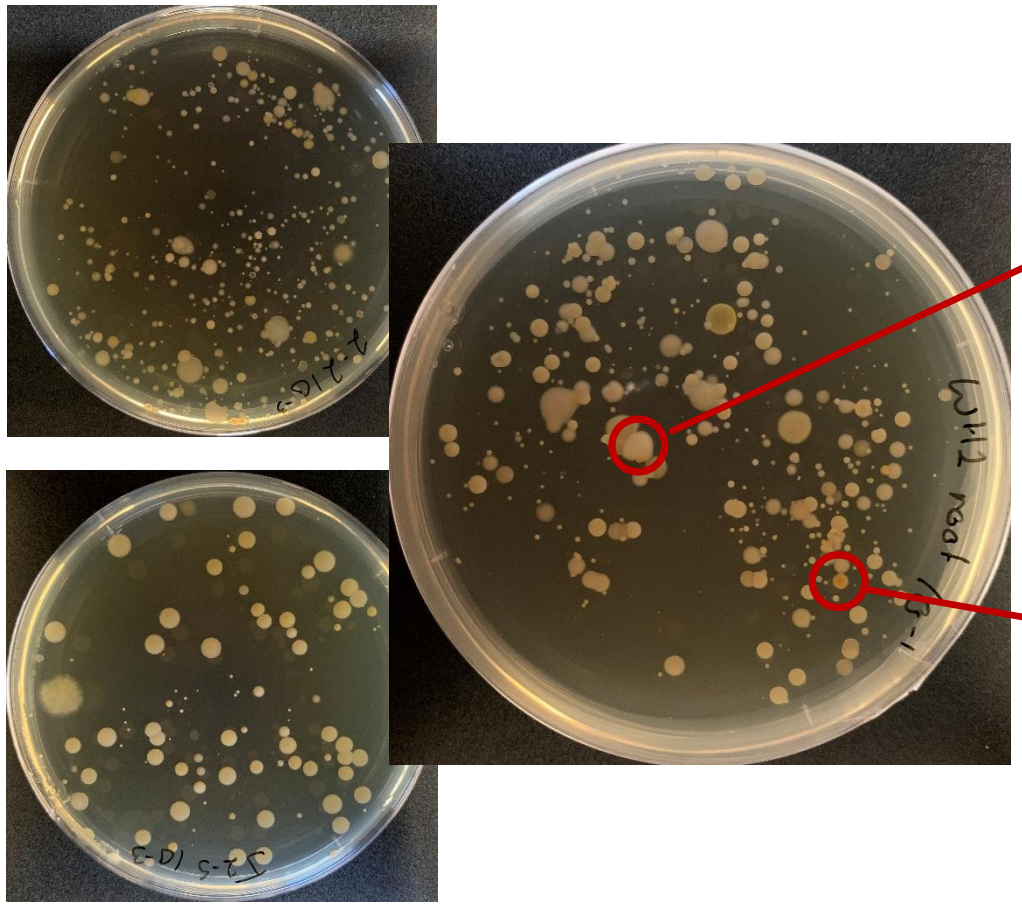
- PHC fractions F3 and F4.
- Salts and metals.

Economic advantages

- Low cost as compared to other technologies.
- Overall remediation cost spread out over several years.

Next Steps - Isolation of New PGPR

Culture bacteria from contaminated soil: identify using 16s rRNA genomic sequencing



interesting morphology

interesting colour

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Next Steps - Reclamation

16th Ave NE, Calgary, 2021

Acknowledgements

National Research Council – Industrial Research Assistance Program (IRAP).

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

Thank You

Questions?

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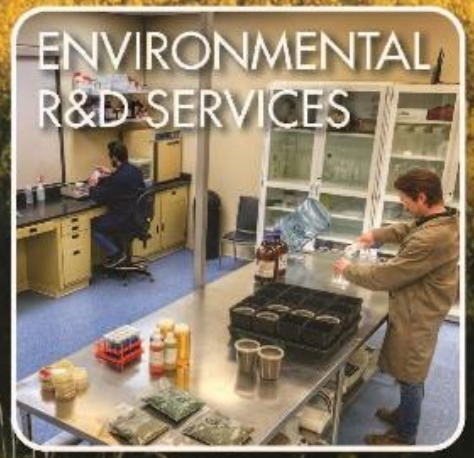

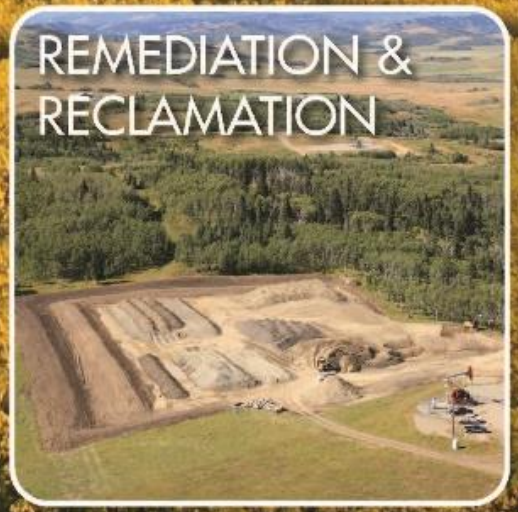

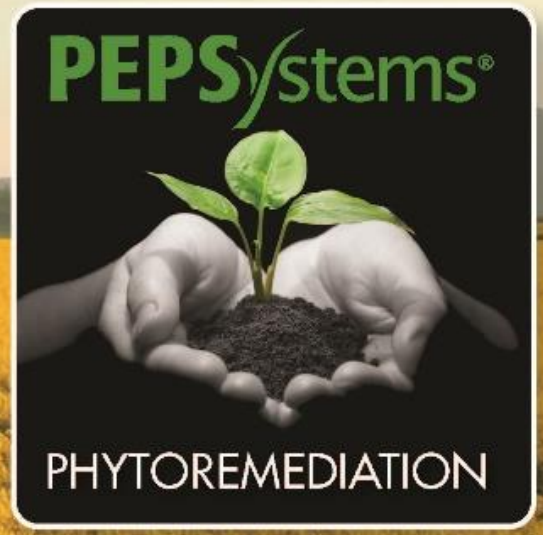

Remediating the past. Reclaiming our future.

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