Beyond Phytoremediation

Forensic Botany and Ecological Remediation of a 2,4-D Impacted Site

By Cheryl Hendrickson, President,
LandSaga Biogeographical Incorporated

Remtech 2019
Banff Alberta
October 16, 2019

LandSaga Biogeographical Incorporated

Overview

- Site history and characteristics
- Limiting factors
- External Review and Replanting: Strategies to overcome limiting factors
- Guiding Principles
- The future of phytoremediation: Ecological remediation

Site History

- Manufacturing of 2,4-D from 1961-1980
- Building demolition and asphalt capping early 1980s
- Full phytoremediation installation 2005
    - Objective of the system was the containment of groundwater
- Replanting 2007, 2011

Site Characterization

Soil stratigraphy and geology

0.3m-2m fill [*anthroposol*] and surficial sand overlying 10m thick lacustrine, 20m thick clay till, 5m thick empress formation, and bedrock

This impervious clay layer creates a perched groundwater lens.

Depth to groundwater

- Varies between 121-165 cm bgl between monitoring wells
- Fluctuates seasonally across individual monitoring wells 5.8 to 91 cm

Contaminants of Concern in 2005

- Total VOCs concentrations in groundwater:
  15 – 66 mg/L

- Total phenol concentrations in groundwater:
  120.7-204.5 mg/L

- 2,4-D concentrations in groundwater:
  970-1500 mg/L

LandSaga Biogeographical INCORPORATED

2018: Elevated EC

Ranging from.6-17.3 dS/m across 16 groundwater monitoring locations.

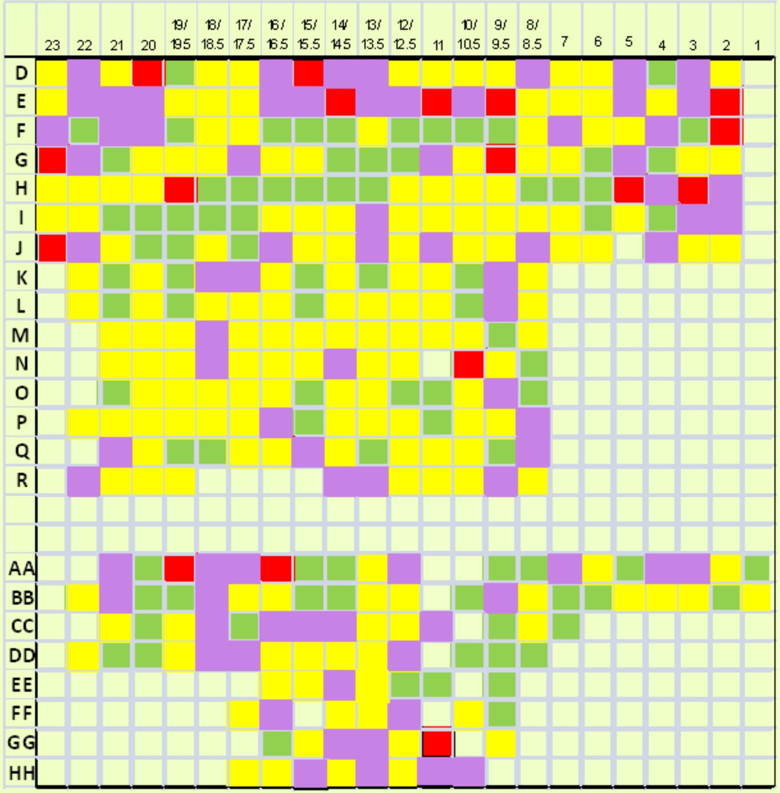
462 trees
on 1.8 ha

Species Planted

Species	**Total number planted 2002-2011**
Theves Poplar (*Populus nigra*)	82
Swedish aspen (*Populus tremula* "Erecta")	78
Birch (*Betula papyrifera*)	19
Laurel Leaf Willow (*Salix pentandra*)	191
Tricolor Ribbon Grass (*Phalaris arundinacea*)	4
Hackberry (*Celtis occidentalis*)	40
Sea Buckthorn (*Hippophae rhamnoides*)	4
Green Ash (*Fraxinus pennsylvanica*)	128
Russian Olive (*Elaeagnus angustifolia*)	236
Tamarack (*Larix laracina*)	4
Sugar Maple (*Acer saccharum*)	1
Gem Ash (*Fraxinus nigra x mandshurica*)	3
	790

Plants are indicators and recorders of site conditions over space and time.

LandSaga Biogeographical INCORPORATED



	23	22	21	20	19/ 19.5	18/ 18.5	17/ 17.5	16/ 16.5	15/ 15.5	14/ 14.5	13/ 13.5	12/ 12.5	11	10/ 10.5	9/ 9.5	8/ 8.5	7	6	5	4	3	2	1
D	🟨	🟪	🟨	🟥	🟩	🟨	🟨	🟪	🟥	🟪	🟪	🟨	🟨	🟨	🟨	🟪	🟨	🟨	🟪	🟩	🟪	🟨	
E	🟨	🟪	🟪	🟪	🟨	🟨	🟨	🟪	🟪	🟥	🟪	🟪	🟥	🟪	🟥	🟨	🟨	🟨	🟪	🟨	🟪	🟥	
F	🟪	🟩	🟪	🟪	🟩	🟨	🟨	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟨	🟪	🟨	🟨	🟪	🟩	🟥	
G	🟥	🟪	🟩	🟨	🟨	🟨	🟪	🟨	🟨	🟩	🟩	🟩	🟪	🟨	🟥	🟨	🟨	🟩	🟪	🟩	🟨	🟨	
H	🟨	🟨	🟨	🟨	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟥	🟪	🟥	🟪	
I	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟪	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟨	🟩	🟪	🟪	
J	🟥	🟪	🟨	🟩	🟩	🟨	🟩	🟪	🟨	🟨	🟪	🟨	🟪	🟨	🟨	🟪	🟨	🟨		🟪	🟨	🟨	
K		🟨	🟩	🟨	🟩	🟪	🟪	🟨	🟩	🟨	🟩	🟨	🟨	🟩	🟪	🟨							
L		🟨	🟩	🟨	🟩	🟨	🟨	🟨	🟩	🟨	🟨	🟨	🟨	🟩	🟪	🟨							
M			🟨	🟨	🟨	🟪	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟨							
N			🟨	🟨	🟨	🟪	🟨	🟨	🟨	🟪	🟨	🟨		🟥	🟨	🟩							
O			🟩	🟨	🟨	🟨	🟨	🟨	🟩	🟨	🟨	🟩	🟩	🟨	🟪	🟩							
P		🟨	🟨	🟨	🟨	🟨	🟨	🟪	🟩	🟨	🟨	🟨	🟩	🟨	🟨	🟪							
Q			🟪	🟨	🟩	🟩	🟨	🟨	🟪	🟨	🟩	🟨	🟨	🟨	🟩	🟪							
R		🟪	🟨	🟨	🟨					🟪	🟪	🟨	🟨	🟨	🟪	🟨							
AA			🟪	🟩	🟥	🟪	🟪	🟥	🟩	🟩	🟨	🟪			🟩	🟩	🟪	🟨	🟩	🟪	🟪	🟨	🟩
BB		🟨	🟪	🟩	🟩	🟪	🟨	🟨	🟩	🟩	🟨	🟨		🟩	🟪	🟨	🟩	🟩	🟨	🟨	🟨	🟩	🟨
CC			🟨	🟩	🟨	🟪	🟩	🟪	🟪	🟪	🟨	🟨	🟪		🟩	🟨	🟩						
DD		🟨	🟩	🟩	🟨	🟪	🟪	🟨	🟨	🟨	🟨	🟪		🟩	🟩	🟩							
EE								🟨	🟨	🟪	🟨	🟩	🟩		🟩								
FF							🟨	🟪		🟨	🟨	🟪		🟨	🟩								
GG								🟩	🟨	🟪	🟪	🟨	🟥		🟨								
HH							🟨	🟨	🟪	🟨	🟪	🟨	🟪	🟪									

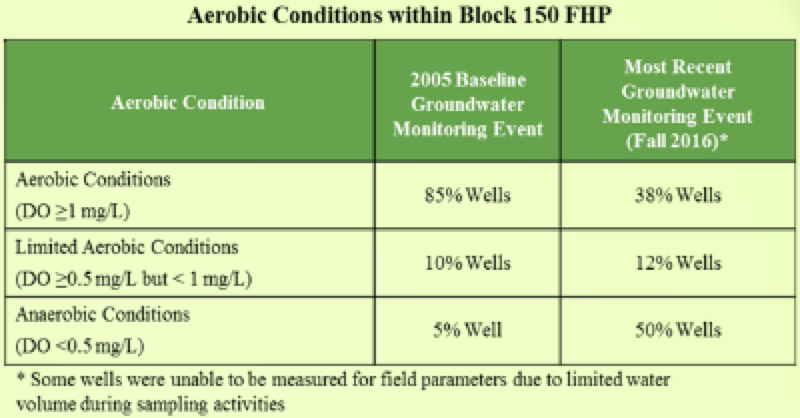
Figure 1. Tree planting, replanting and mortality by location, 2005-2017.

108	🟩	Original trees planted 2005 still living (planted once)
200	🟨	Original tree replaced once (planted twice)
79	🟪	Original tree replaced twice (planted three times)
19	🟥	Tree has died four times (or nearly dead) (planted three times, 2018 planting candidate)

Source: Knoblauch 2018. Tree Evaluation - Mortality by type (for replanting data) and Tree data and comparison (for dead and weak assessments). Dow Chemical Canada, Fort Saskatchewan AB

System status 2018:

- Decreasing DO = slower anaerobic degradation
- Asphalt limiting infiltration of high DO rainwater
- Microbe metabolism using up O2

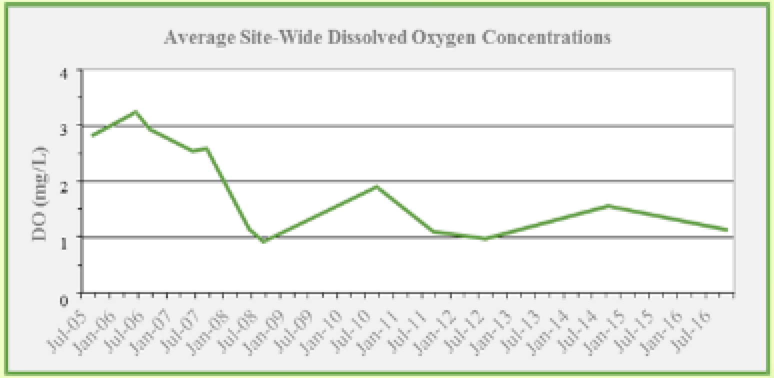


Aerobic Conditions within Block 150 FHP

Aerobic Condition	2005 Baseline Groundwater Monitoring Event	Most Recent Groundwater Monitoring Event (Fall 2016)*
Aerobic Conditions (DO ≥1 mg/L)	85% Wells	38% Wells
Limited Aerobic Conditions (DO ≥0.5 mg/L but < 1 mg/L)	10% Wells	12% Wells
Anaerobic Conditions (DO <0.5 mg/L)	5% Well	50% Wells

* Some wells were unable to be measured for field parameters due to limited water volume during sampling activities

Average Site-Wide Dissolved Oxygen Concentrations across Block 150 FHP



2,4-D breakdown

- The primary degradation pathway is microbial
- Half life of 10-15 days under ideal conditions – aerobic and aqueous.
- In an anaerobic environment the breakdown rate may be as much up to 30 times slower.
- A range of degradation rates can be expected depending on the soil and groundwater conditions and microbial degraders.

- *Fifty percent of well locations are anaerobic and not supportive of rapid degradation of 2,4-D.*

- *Trees at grid points that have been replaced 3 and 4 times (111), ongoing tree mortality (57% of all trees planted) and slow growth caused by phytotoxic conditions.*

External Review and Tree Replacement Plan:

Why mortality?

- Trees as dicots are targets of 2,4-D
- Chlorophenol (a breakdown derivative) levels are toxic
- As are elevated EC levels, a product of its breakdown.

LandSaga Biogeographical
INCORPORATED

Phytotoxicity: 2,4-D induced etiolation

Phytotoxicity: High EC

EC levels from 0-4 dS/m are elevated but still classified as low. However, a level above 3.0 becomes toxic to ***poplar, aspen, birch, and willow*** (Haas 1997). **Eleven wells** are in this category with levels from .6-3.9 dS/m, averaging 2.41 dS/m .

Species	**Percent Mortality**
Theves Poplar (Populus nigra)	95
Swedish aspen (Populus tremula "Erecta")	87
Birch (Betula papyrifera)	84
Laurel Leaf Willow (Salix pentandra)	75

LandSaga Biogeographical Incorporated

EC levels of 4-8 dS/m will impact most species, but there are several that will tolerate this range, such as ***green ash, Siberian elm and Russian olive***. **Three wells** have EC of 5.2, 6.0, and 6.2 dS/m.

Species	**Percent Mortality**
Green Ash (Fraxinus pennsylvanica)	40
Russian Olive (Elaeagnus angustifolia)	29

EC levels from 8-16 dS/m prohibit most species. This limits the species choices and anything above 8 dS/m requires careful consideration. Two wells have EC of 11.9 and 17.3 dS/m. Levels above 16 are extreme.

The phytotoxic effects are related to the level of exposure rather than the concentration. ***The level of exposure is determined by the volume of water transpired.***

The mortality pattern corresponds well with species tolerance to increasing EC levels.

LandSaga Biogeographical
INCORPORATED





Sub-lethal EC levels - plants limit their top growth, reduce transpiration rates to conserve water. Growth will be slowed, even without any other toxicity symptoms.

Salt Phytotoxicity

Salt-tolerant Russian olives have been relatively successful on the block, and the replacement tree of choice because of it, comprising 150 or 51% of pre-2018 trees.

They owe their success to their conservative use of water (high WUE) that minimizes their exposure to CoCs.

LandSaga Biogeographical INCORPORATED

“Phreatophytic” *vs*. “Water use efficiency”

- *Phreatophytic* plants obtain their water from the water table or the capillary fringe in *desert climates* where there is no soil moisture at the surface
- In humid regions or where water is close to the surface, they utilize water that is closest to the roots, which may be near the surface. (*see* T.W. Robinson, 1958)
- *Water use efficiency* (WUE) is a trait in plants that describes how much water they use, with willows having low WUE, and Russian olives having high WUE.
- Low WUE is the preferred trait for hydraulic control.
- Not all phreatophytes have low WUE. Some (willows) are both phreatophytic, and have low WUE.

LandSaga
Biogeographical
INCORPORATED

LandSaga 2018 Tree Replacement

Managing Limiting Factors

Creating a Remediating Ecological Community

- Managing low DO that limits degradation rates
- Managing high EC
- Managing 2,4-D exposure

Limiting factor: low DO

Daylighting 111 gridpoints with a history of mortality: Increasing opportunities for high DO rainwater to infiltrate, increasing aerobic degradation of 2,4-D

LandSaga Biogeographical
INCORPORATED

LandSaga Biogeographical INCORPORATED

Planting augured holes

Limiting factor: low DO

Planting colonial plants that could slowly contribute to asphalt breakdown as they spread

LandSaga Biogeographical Incorporated

Limiting factor: high EC that is phytotoxic

Planting salt-tolerant shrubs and salt-tolerant grasses

silver buffaloberry (*Shephardia argentea*)
lilac (*Syringa vulgaris*)
green ash (*Fraxinus pennsylvanica*)
Siberian larch (*Larix sibirica*)
sandbar willow (*Salix exigua*)
hybrid willow “India” (*Salix dasyclados*)
wolf willow (*Eleagnus commutata*)
Russian wildrye (*Psathyrostachys juncea*)
tall wheatgrass (*Thinopyrum ponticum*)

LandSaga Biogeographical Incorporated

Limiting factor: 2,4-D broadleaf phytotoxicity

Include robust, deep rooted salt-tolerant grasses:

tall wheatgrass and Russian wildrye

LandSaga Biogeographical INCORPORATED

Mortality of all tall wheatgrass and Russian wildrye planted as seed or rooted plugs in 2018:

0%

Average mortality of all broadleaf shrubs and trees planted in 2018:

25%

August 2019
Daylighted gridpoints
Islands of Biodiversity

LandSaga Biogeographical Incorporated

LandSaga Biogeographical INCORPORATED

Spontaneous novel ecosystem – the environmental sieve

- Salt tolerant
- 2,4-D resistant
- Asphalt
    - as a physical barrier to germination
    - as rainwater and oxygen exclusion feature

Asphalt niche exploiters

Salt tolerant shrubs: Schubert Cherry

Herbaceous Opportunistic Species on Daylighted Gridpoints

*Known tolerance to 2,4-D or saline soils

Scientific Name	**Common Name**
*Artemesia vulgaris**	common wormwood
Capsella bursa-pastoris	shepherd's purse
Chenopodium species	goosefoot
Cirsium arvense	Canada thistle
Galeopsis tetrahit	hemp nettle
*Hordeum jubatum**	foxtail barley
*Kochia scoparia**	Kochia
Melilotus sp.*	Sweetclover
*Panicum capilare**	Witchgrass
Plantago major	plantain
Polygonum aviculare	prostrate knotweed
Polygonum scandens	climbing false buckwheat
Potentilla norvegica	rough cinquefoil
Salsola sp.	Russian thistle
*Sonchus arvensis**	sow thistle
Trifolium sp.	clover

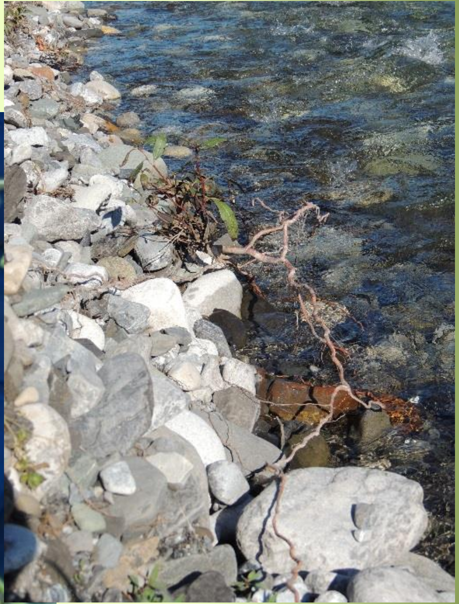
LandSaga
Biogeographical
INCORPORATED

Significant volunteers:
263 balsam poplars
over 30 cm high

LandSaga Biogeographical Incorporated

Strategy:

- Extensive horizontal roots
- Sharing resources between ramets



LandSaga Biogeographical Incorporated

Guiding Principles

- Identification and correction of limiting factors keeps the Remediation Endpoint in sight.

External Reviews

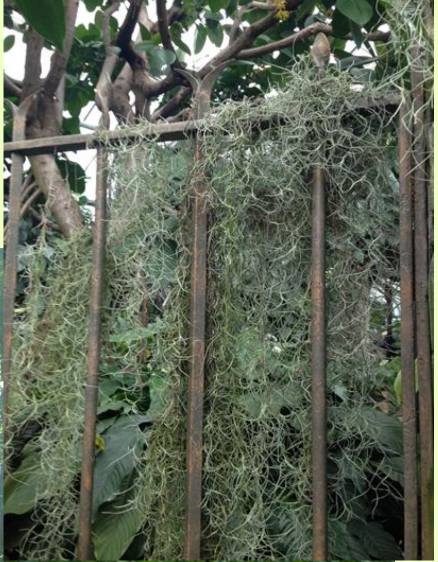
- External Reviews are valuable at the feasibility, design and O&M stages.

LandSaga Biogeographical INCORPORATED

Forensic Botany and Biogeography of Phytoremediation

Plants are indicators and recorders of site conditions over space and time.

- Work with the system by understanding the environmental sieve:
  - nature of the disturbance (limiting factors, i.e. contamination),
  - the receiving environment (site characteristics) and
  - the biology (ecological strategies) of the remediating or colonizing species.


Ecological Remediation – the Future of Phytoremediation

Phytoremediating systems are ecosystems:

- Create a taxonomically diverse, self-sustaining system that remediates and provides ecosystem services over a longer time scale.

- The informed design of self-sustaining *novel ecosystems* that remediate provides a new economically feasible solution for orphan brownfields

LandSaga Biogeographical INCORPORATED

Thank you!

LandSaga Biogeographical
INCORPORATED