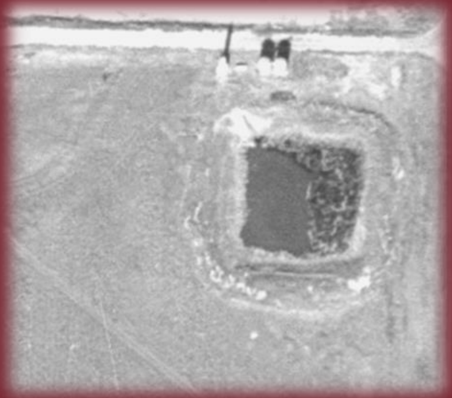
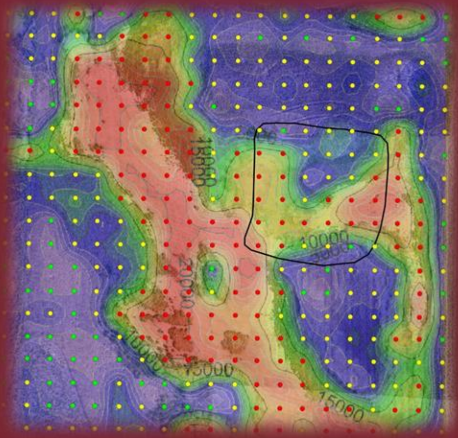
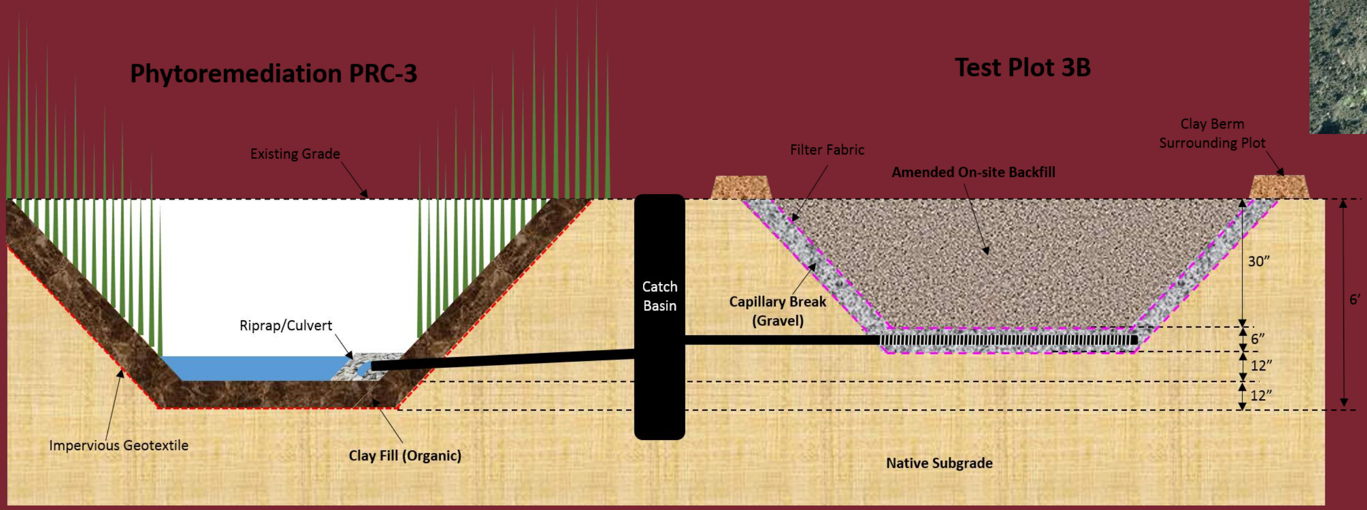




Innovative Techniques for Site Characterization and Remediation of Brine Impacted Soils

Jonathan B. Ellingson
Terracon Consultants Inc.
West Fargo, North Dakota



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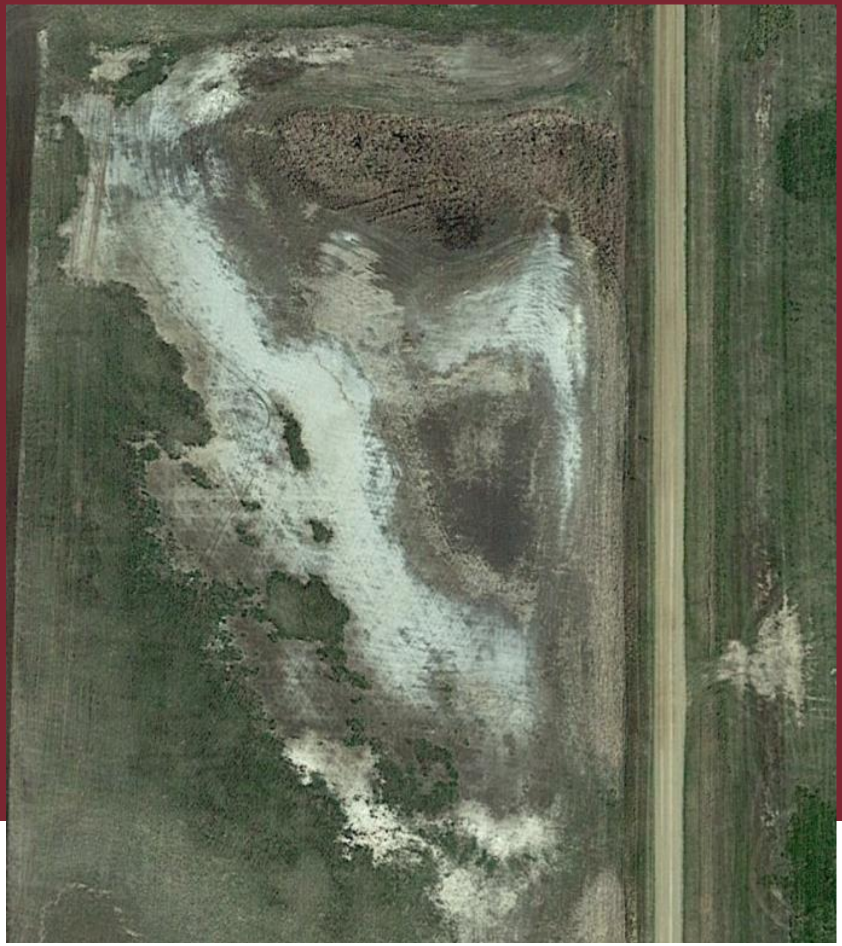
With increased activity within the oil industry in the last decade in western North Dakota, brine (produced water) spills and leaks occasionally occur. These spills, along with some of the estimated 2,600 brine ponds leaking (from the 1960s), are impacting the production of farm land, reducing crop yields, or even completely leaving the soil infertile.



Currently, the majority of brine-impacted soils are simply excavated to a landfill and replaced with clean soil. This method is typically very costly and can create soil storage issues in areas where landfills are not in close proximity to the site.

North Dakota Industrial Commission
RFP 405.2-17-010 – June 15, 2017
Brine Pond Remediation Techniques

Soliciting contractors to conduct a pilot project to study and test the best techniques for remediating salt and any other contamination from the soil surrounding brine ponds in the north central portion of North Dakota which were active between 1951 and 1984.

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Goals:

- Reclaim impacted areas back to productive crop land
- Research techniques
  - Minimize the time need to reclaim sites back to productive
  - Minimize cost to reclaim land to productive crop land
  - Minimize soil removal from the sites – in situ / amendments
  - Find a simplified solution that works – widespread application

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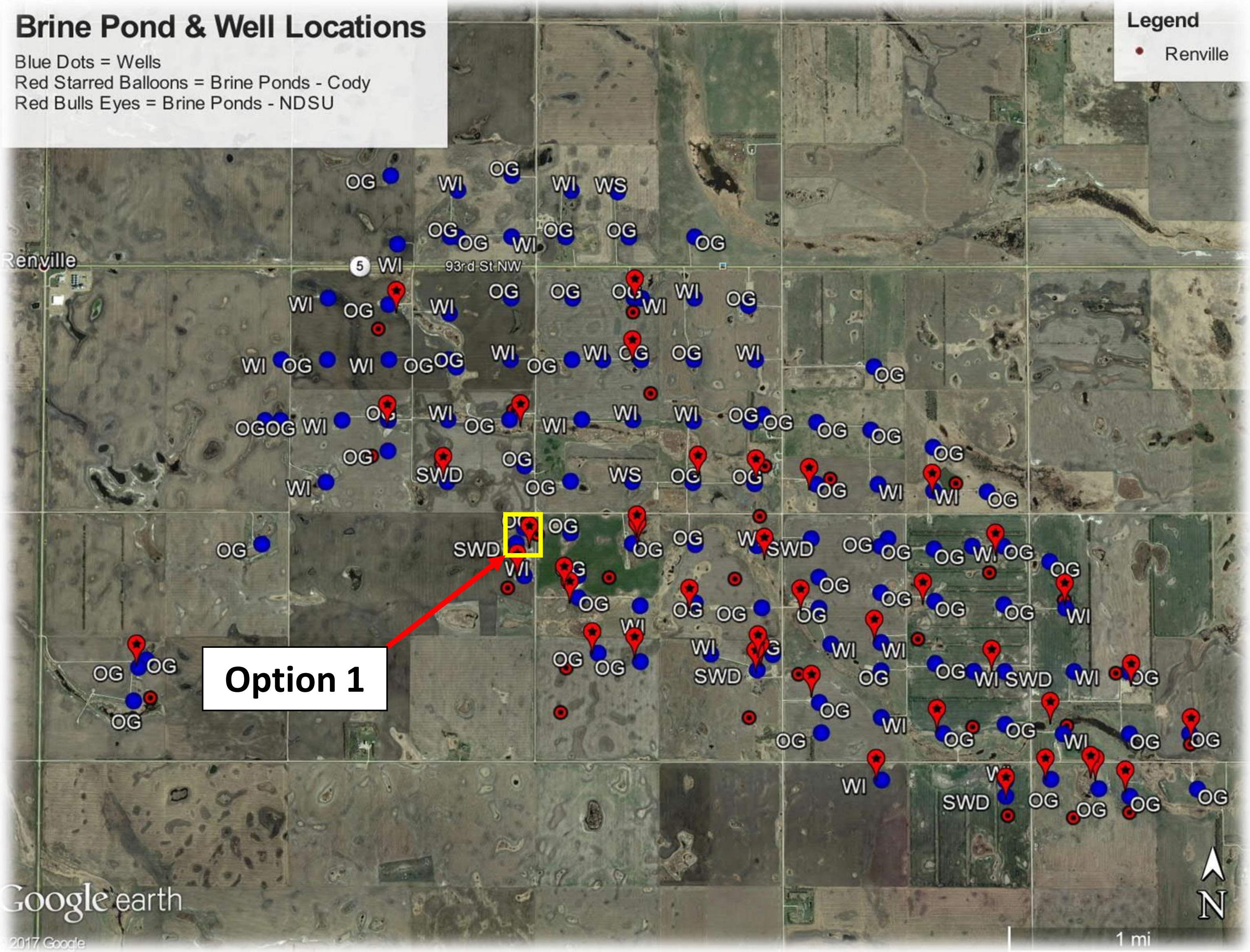
Site Selection

Historic Brine Pond Locations in Wiley Oilfield



Estimated Brine Ponds in the Wiley Oilfield

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Original Options for Study

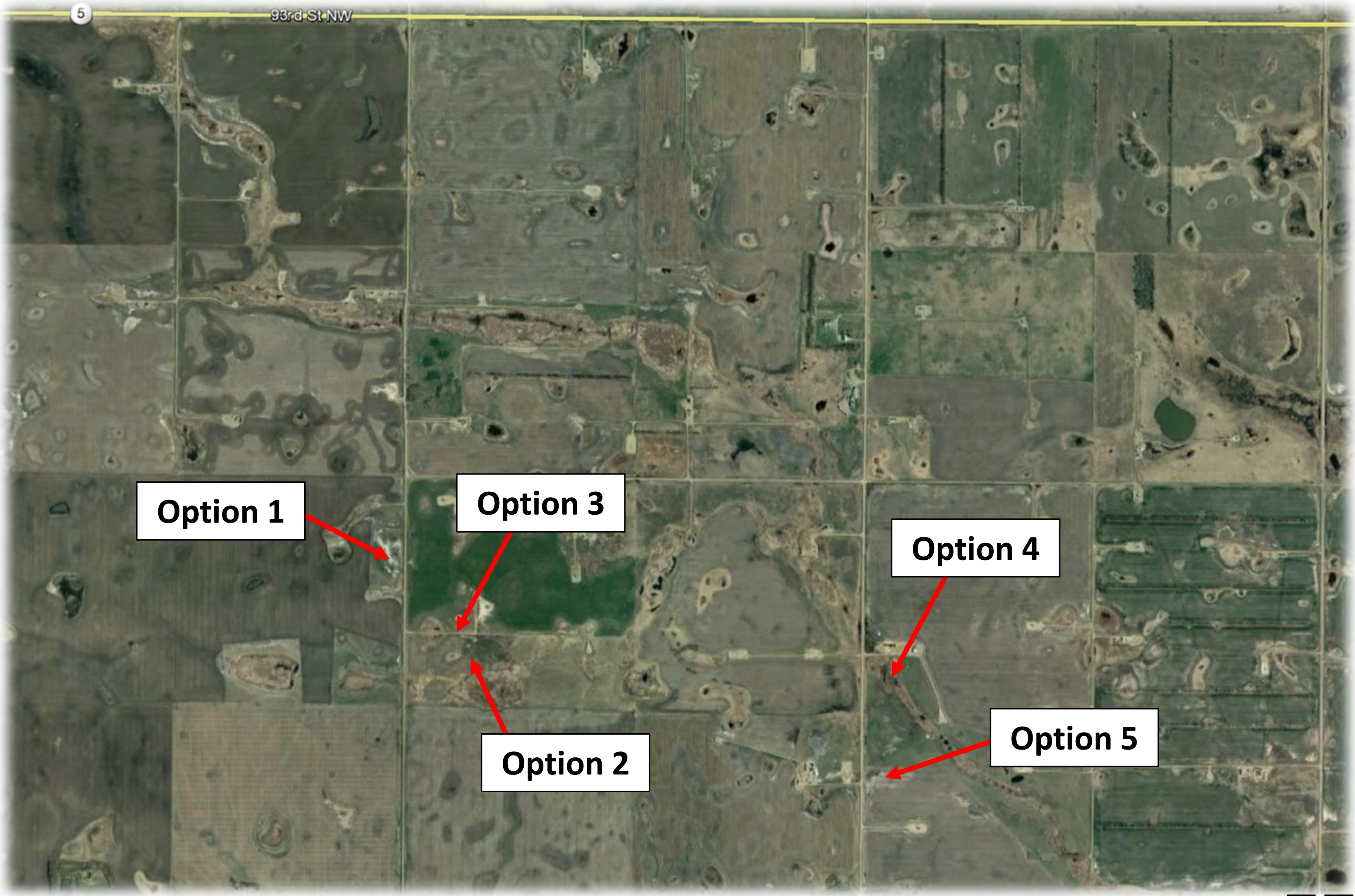

Image of Five (5) Options – Google Earth™ May 2016

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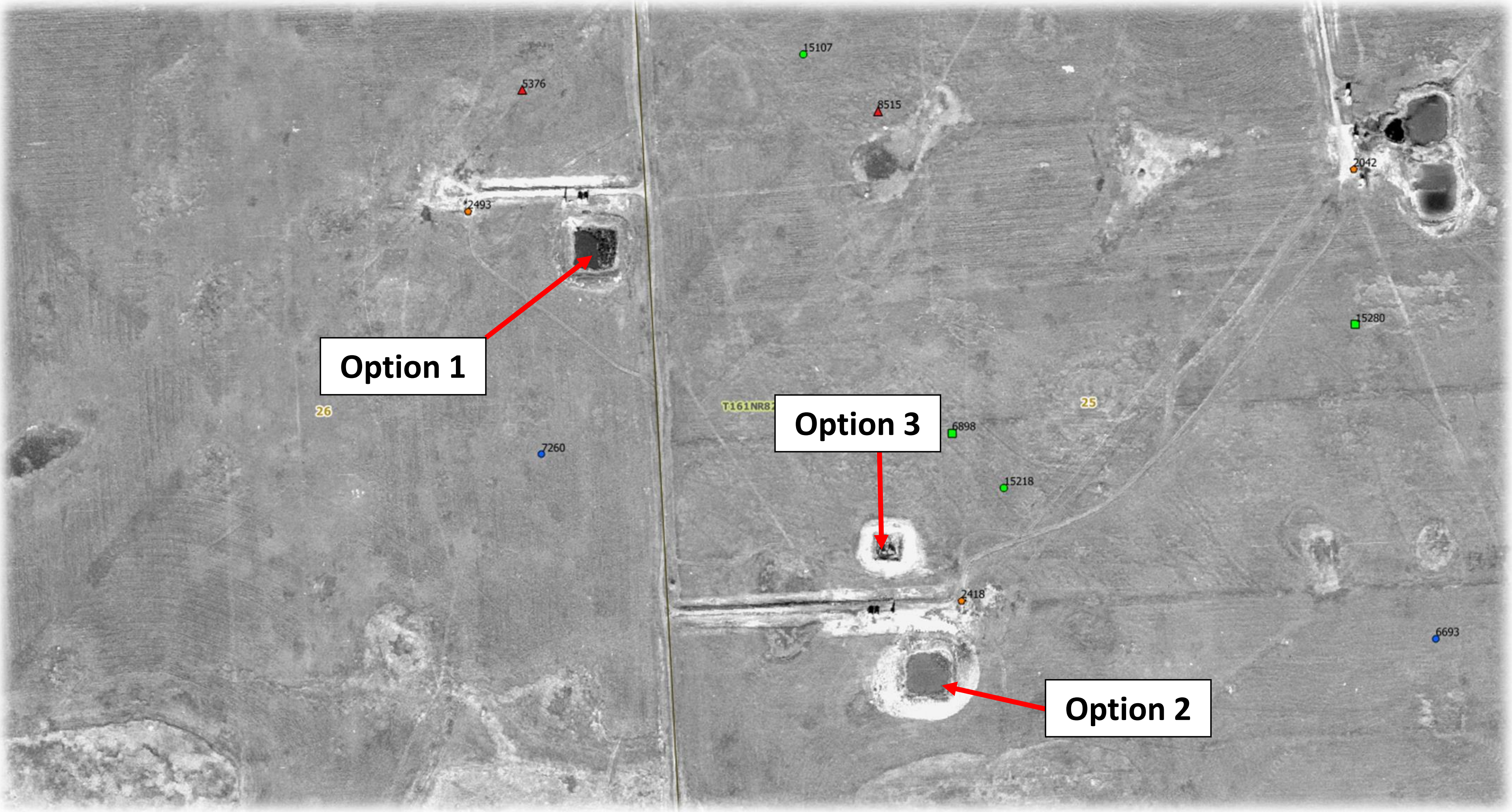
Area Brine Pond Options (Historic)



Options Image from ND GIS Hub 1957-1962

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Area Brine Pond Options (Current)

Options Image from Google Earth™ May 2016

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Historic Brine Pond Location

Option 1 Brine Pond – ND GIS Hub 1957-1962

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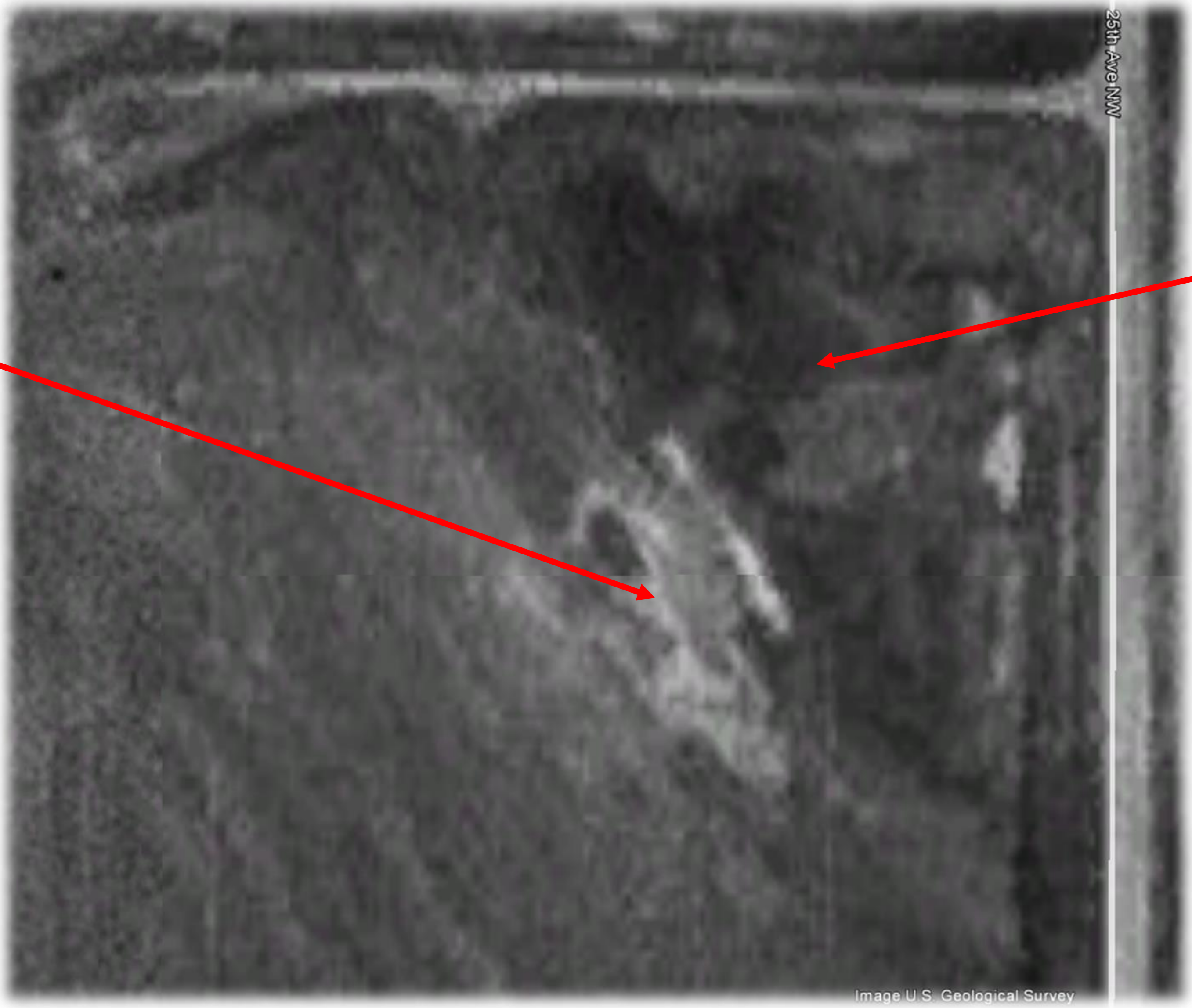
Historic Brine Pond Location

Possible Vegetative Distress Occurring



Filled In Brine Pit

Site Aerial Photograph – Google Earth™ (US Geological Survey 1997)

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Historic Brine Pond Location

Significant Vegetative Distress Occurring

Site Aerial Photograph – Google Earth™ May 2016

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Drone Aerial Photography

North of Site Looking South Prior to Field Work

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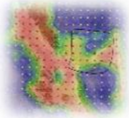
Site Evaluation

Fall 2017 Activities

Drone aerial photography and site assessment

Exploration drilling and sampling

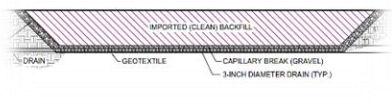
Field testing

- 

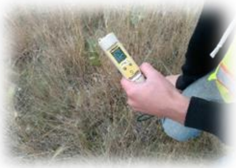
  Electric conductivity (EC)

- 

  Chlorides



Construction of on-site test plots



Vegetation mapping study

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Drilling and Sampling

- **45 borings ranging in depth from 5 to 25 feet deep were drilled and sampled.**
- **Soils consist typically of lean clays, organic clays, and silts containing various amounts of sand.**

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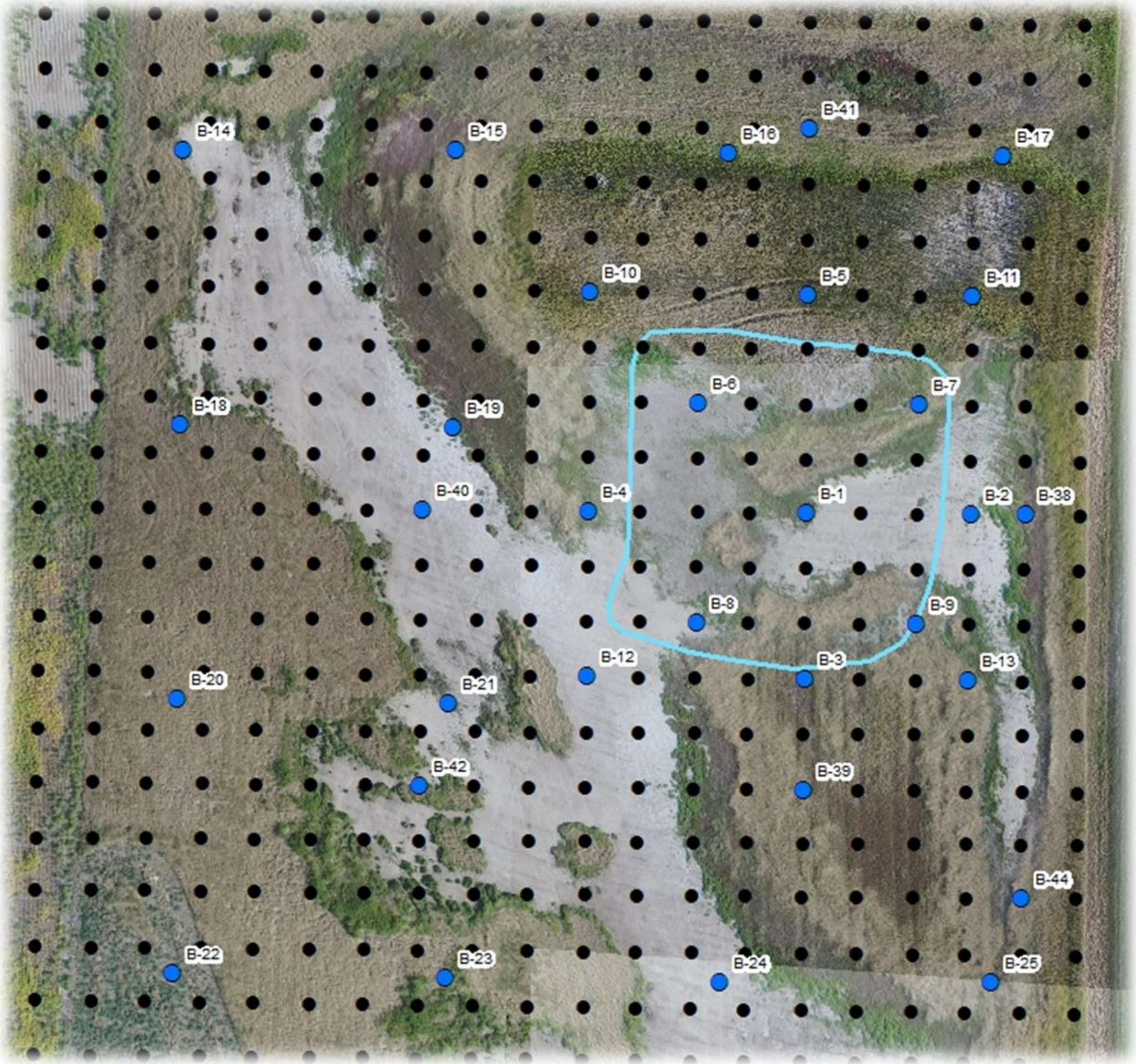
Historic Brine Pond Location



Pond Location Based on Results of Exploratory Borings

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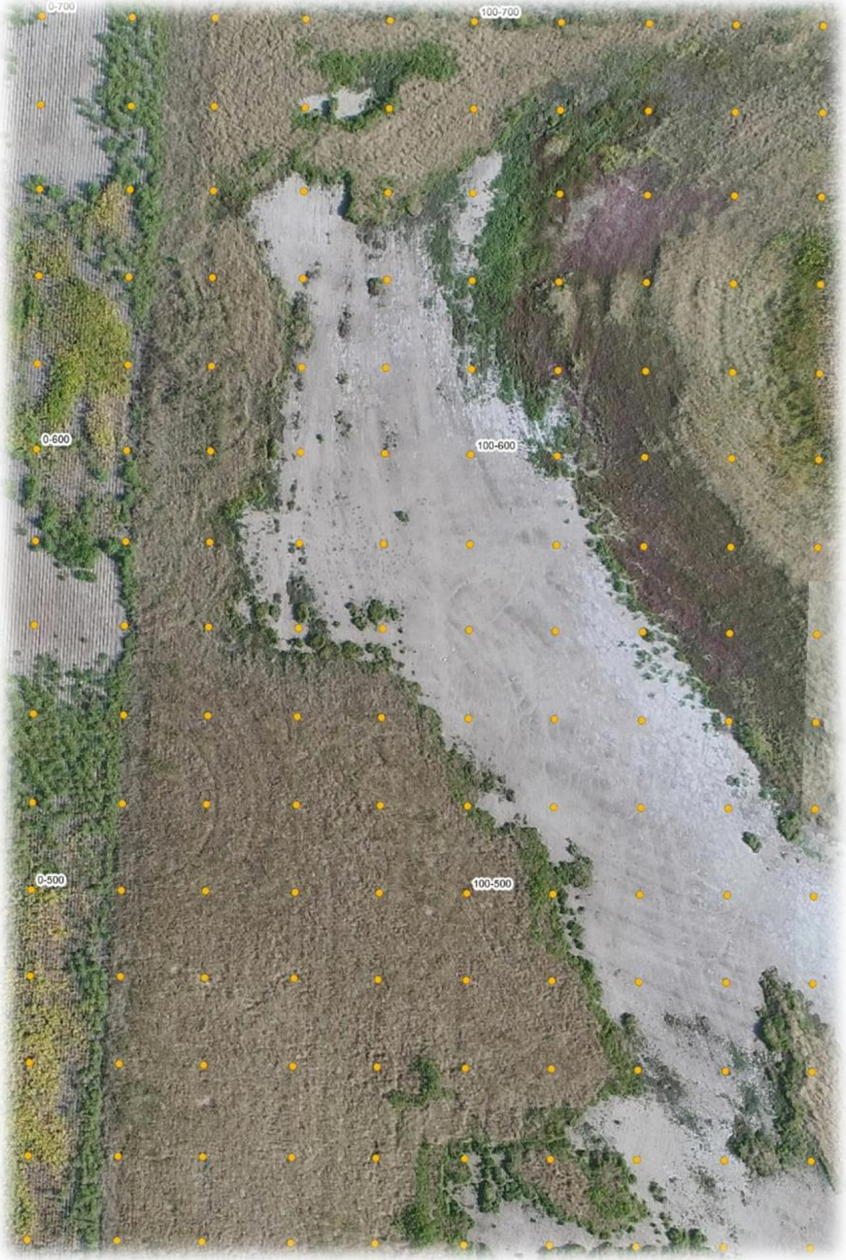
Field EC Testing



EC Test Grid (20’ on Center)

Field Testing EC

EC Meter

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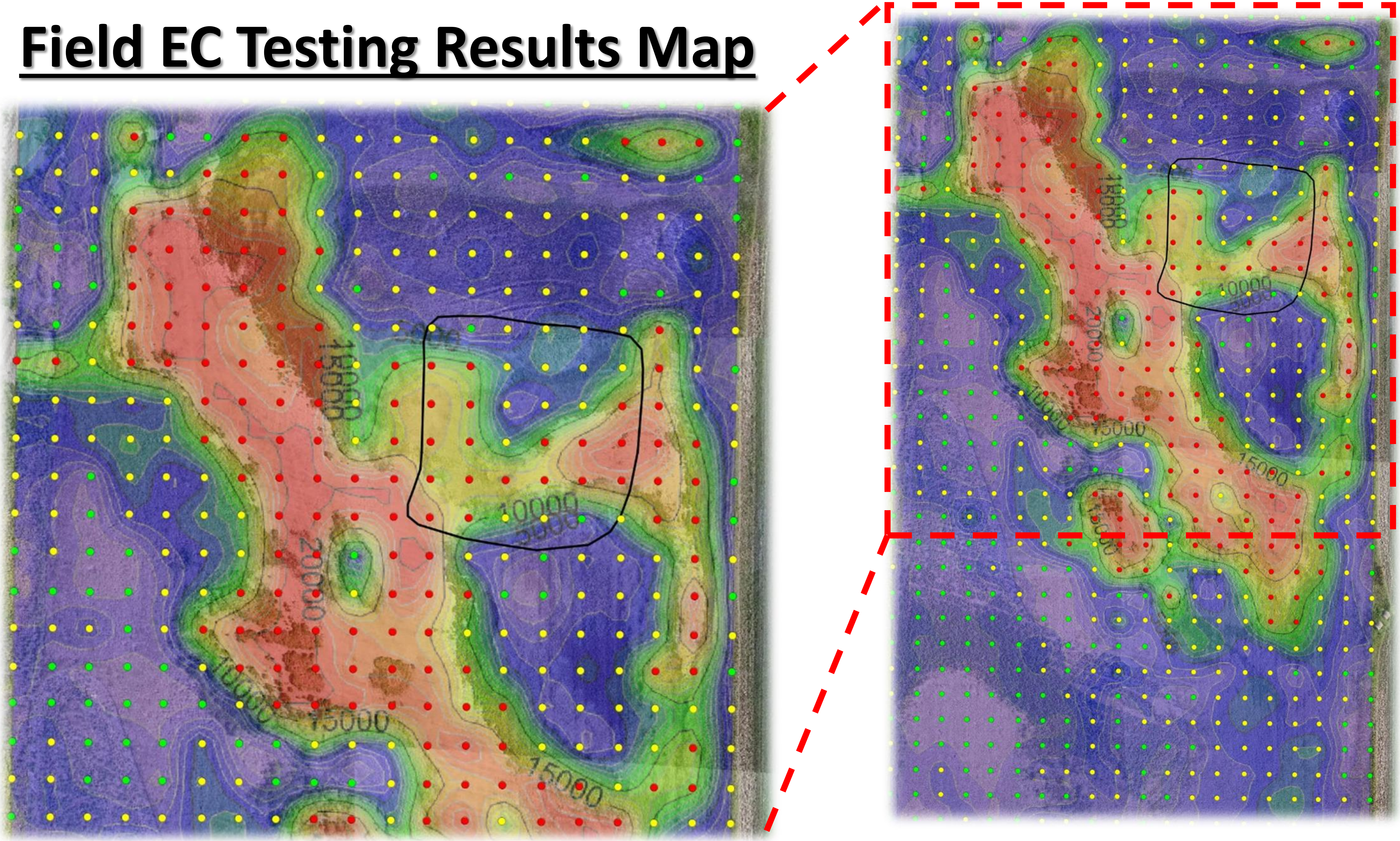
Field EC Testing Results Map



Contour Map of Surface EC Results

Field Chloride Testing

Chloride titration test strips

Field Test Methods Performed in the Laboratory

Vegetation Mapping

Drone Imagery Illustrating Site Vegetation

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Field Vegetation Study

EC Testing Near Cattails and Dogbane Willow

Switchgrass

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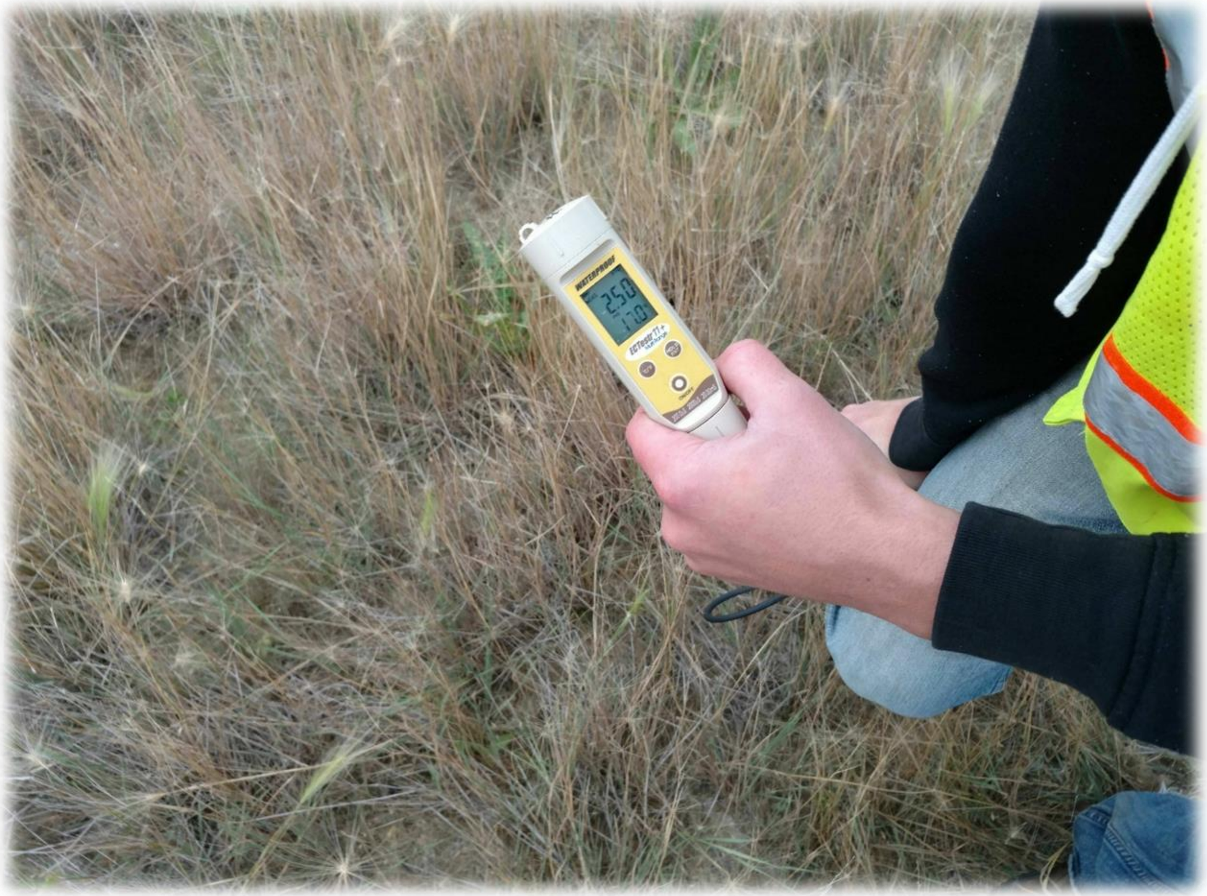
Field Vegetation Study

EC Testing Near Russian Tumbleweed



EC Testing Near Foxtail Barley

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Vegetation Mapping

Narrow-leaf Cattail (*Typha angustifolia*)

Surface = 2,200 μS/cm

Surface - 12″ = 2,300 μS/cm

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Western Wheatgrass (*Pascopyrum smithii*)

Surface = 2,400 µS/cm

Surface - 12" = 3,500 µS/cm

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Russian Thistle/Tumbleweed (*Salsola sp.)*

Surface = 6,800 µS/cm

Surface - 12" = 9,800 µS/cm

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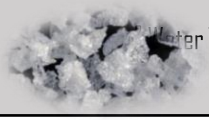
Species Comparison

Species	Root System	EC Surface	EC Surface to 12"
Alfalfa	Tap: Deep	300 µS/cm	3,300 µS/cm
Curly Dock	Tap: Shallow	400 µS/cm	2,600 µS/cm
Dogbane[2]	Rhizomatous/Branched: Deep	500 µS/cm	1,700 µS/cm
Cattail[2]	Rhizomatous and Fibrous: Shallow	2,200 µS/cm	2,300 µS/cm
Sweet Clover	Tap: Deep	2,300 µS/cm	4,100 µS/cm
Western Wheatgrass	Rhizomatous With Few Deep Roots	2,400 µS/cm	3,500 µS/cm
Switchgrass	Fibrous: Deep	2,400 µS/cm	3,500 µS/cm
Foxtail Barley[2]	Fibrous: Shallow	2,400 µS/cm	4,000 µS/cm
Spearscale[1]	Tap: Deep	3,300 µS/cm	8,000 µS/cm
Perennial Sow Thistle	Tap: Deep	3,500 µS/cm	3,500 µS/cm
Diffuse Knapweed	Tap With Laterals: Deep	3,500 µS/cm	3,500 µS/cm
Russian Thistle/Tumbleweed[1]	Tap With Extensive Laterals: Deep	6,800 µS/cm	9,800 µS/cm

[1] Salt/Alkaline Thriving

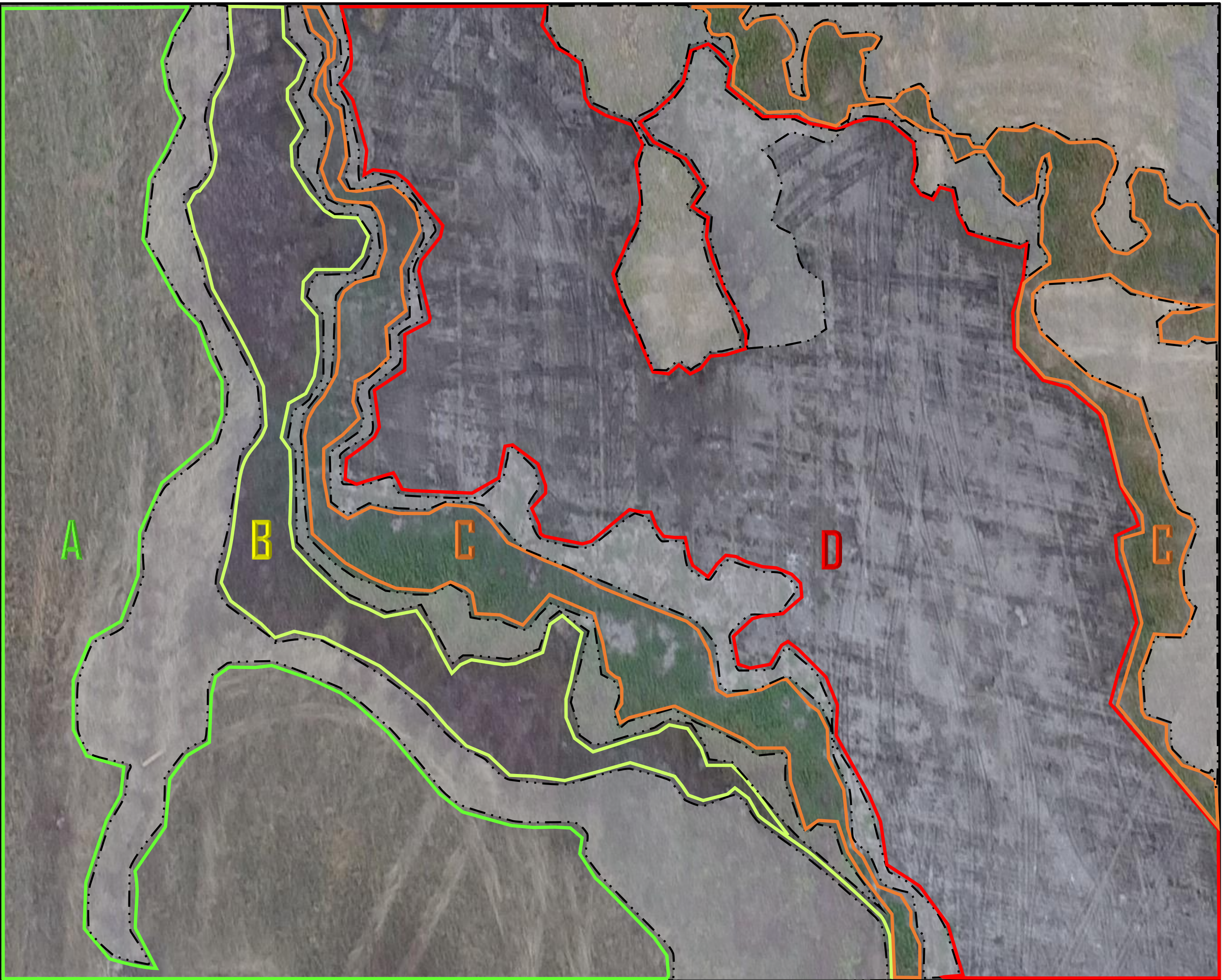


[illegible]ter Thriving

Salt/Water Resilience/Tolerance Has Not Been Evaluated Below "Thriving" Thresholds

"Thriving": When Species Prefer/Have Extraordinary Tolerance To Perspective Conditions

Plant Communities



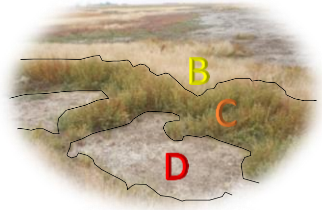
Community Transition Zones

Community A

~ 0 µS/cm – 2,300 µS/cm

Community B

~ 2,200 µS/cm – 4,000 µS/cm



Community C

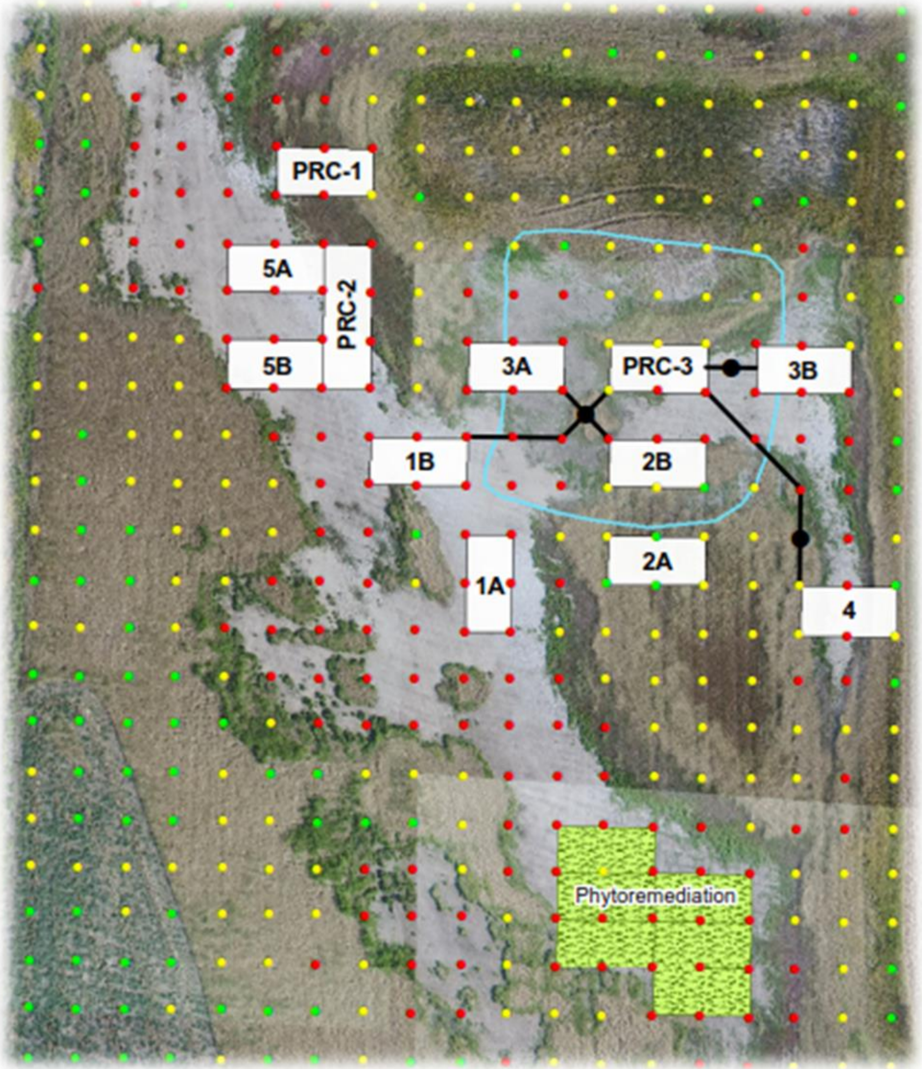
~ 3,300 µS/cm – 9,800 µS/cm

Community D

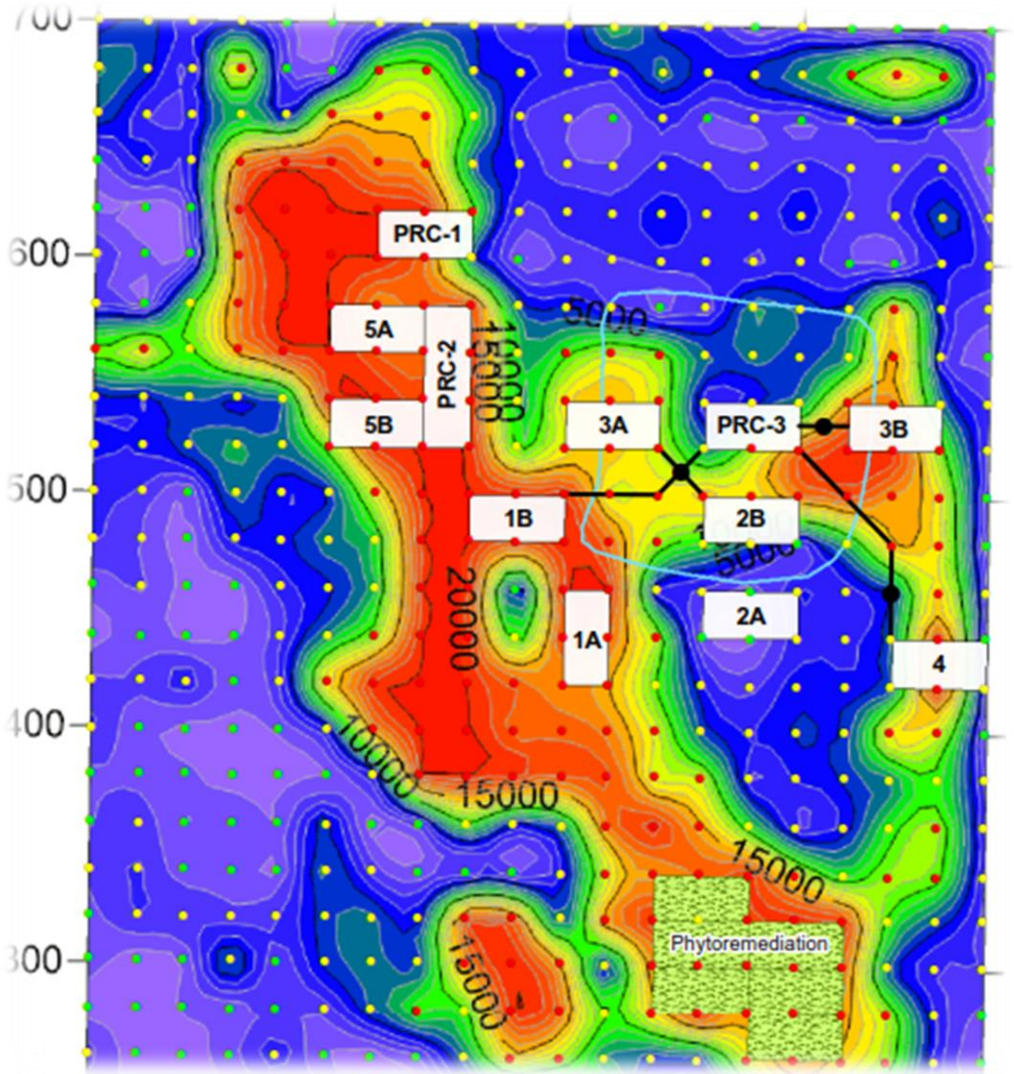
~ 9,500 + µS/cm

Test Plot Design and Construction

On-site Test Plot Locations



Test Plots Overlaid on Aerial Imagery



Test Plots Overlaid on EC Map

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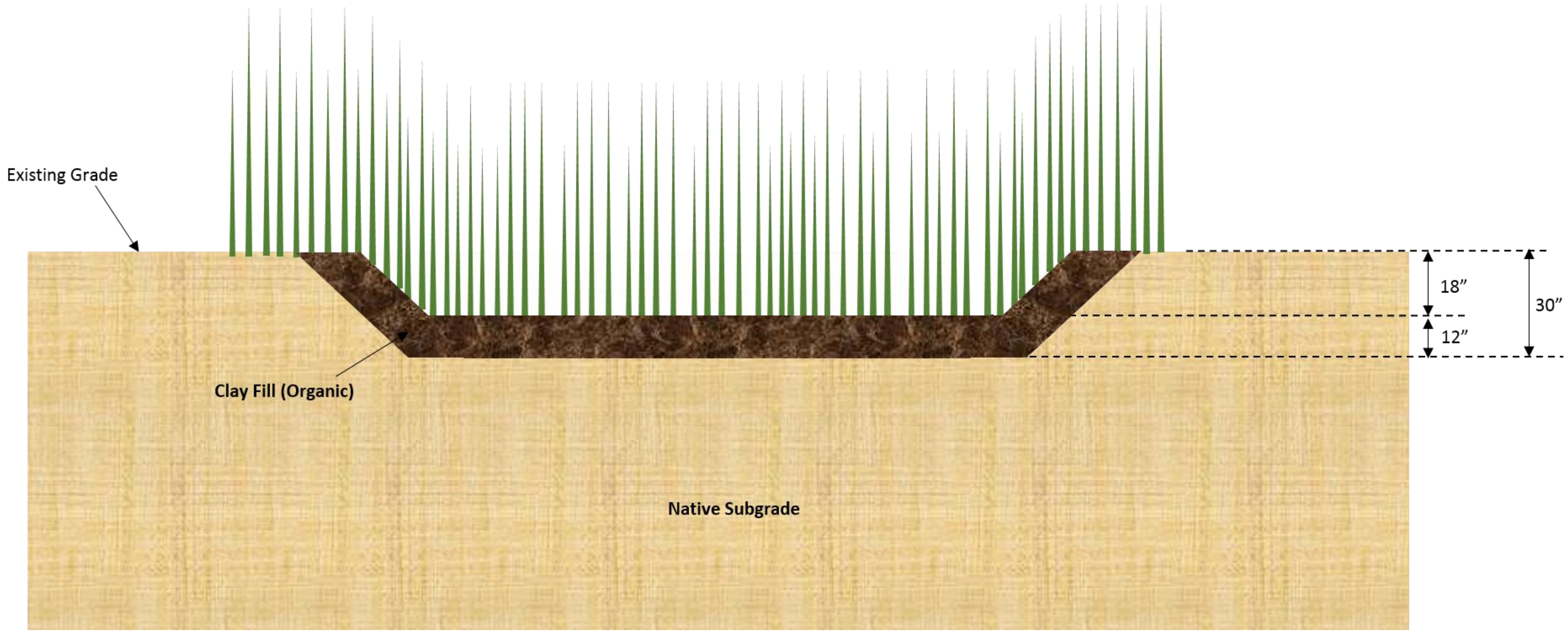
Phytoremediation 1 (PRC-1) Diagram



Test Plot Construction

PRC-1 After Excavation

After Backfilling to Cover Seeds/Cattail Bulbs

Planted Cattails and Cattail Seeds

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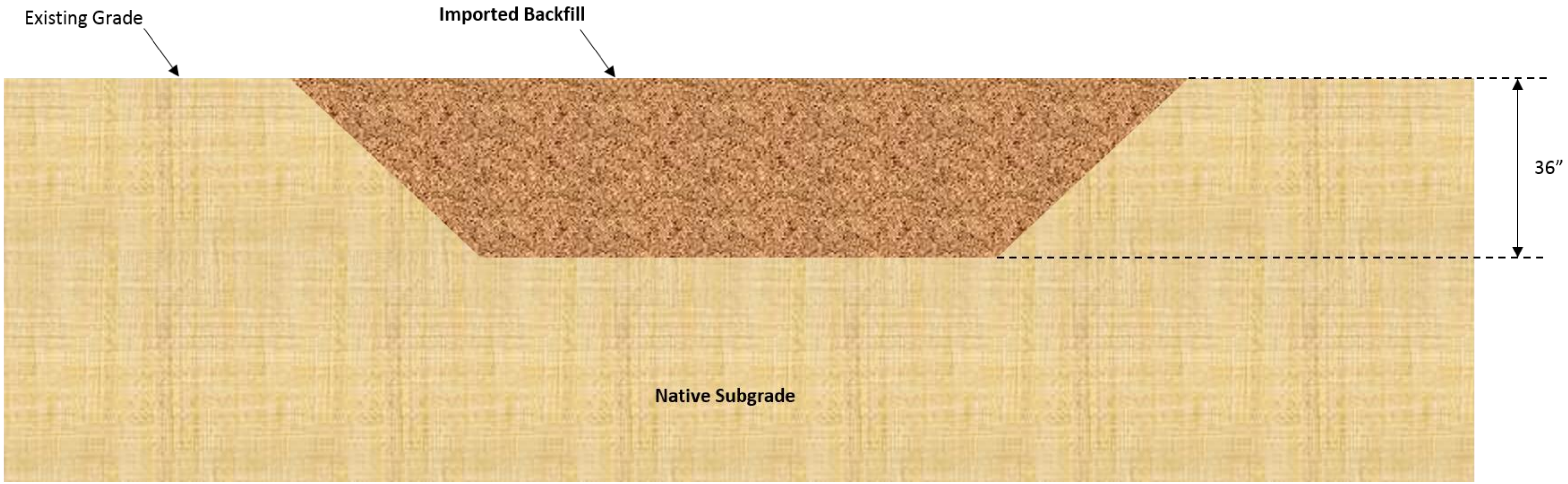
Test Plot 1A – Excavate-N-Replace



Test Plot Construction

Test Plot 1A After Excavation

Test Plot 1A After Backfilling

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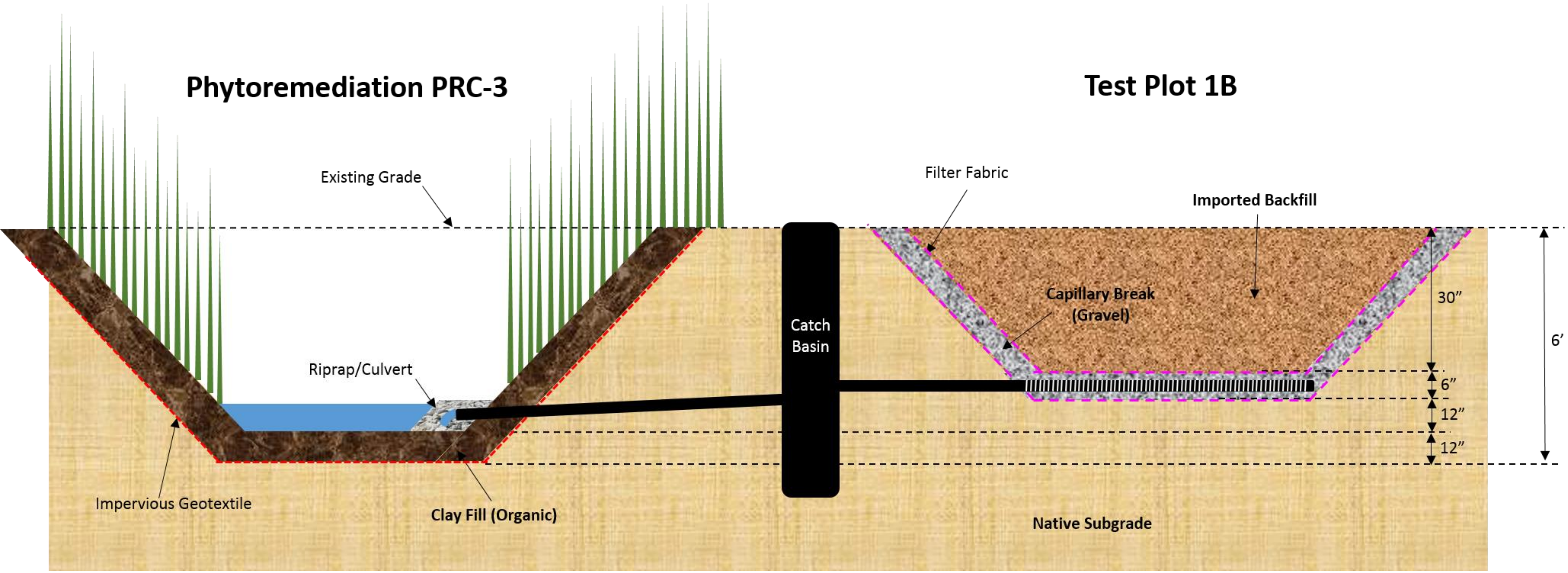
Test Plot 1B – Excavate-N-Replace with Capillary Break



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Test Plot Construction

Test Plot 1B After Excavation

Test Plot 1B After Backfilling

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Test Plot Construction

Sump Pit and Drainage Line Excavations

Completed Excavations

Sump Pit with Leak-Proof Caps

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Test Plot Construction

PRC-3 During Excavation

Drainage Outlet from Sump Pit

PRC-3 During Backfilling

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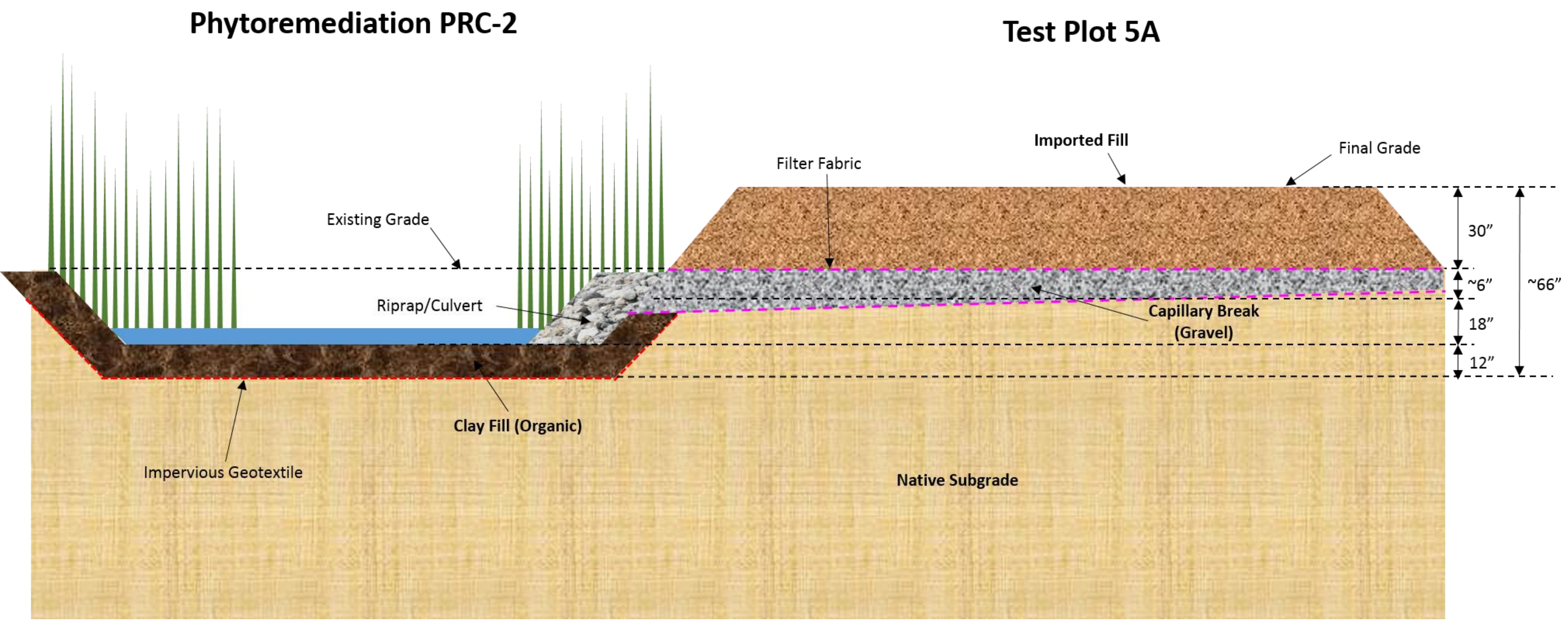
Test Plot 5A – Build-It-Up with Gravel



Test Plot Construction

Test Plot 5A After 2-3% Grading

Test Plot 5A Near Completion

Placement of Geotextile and Pea Gravel as Capillary Break

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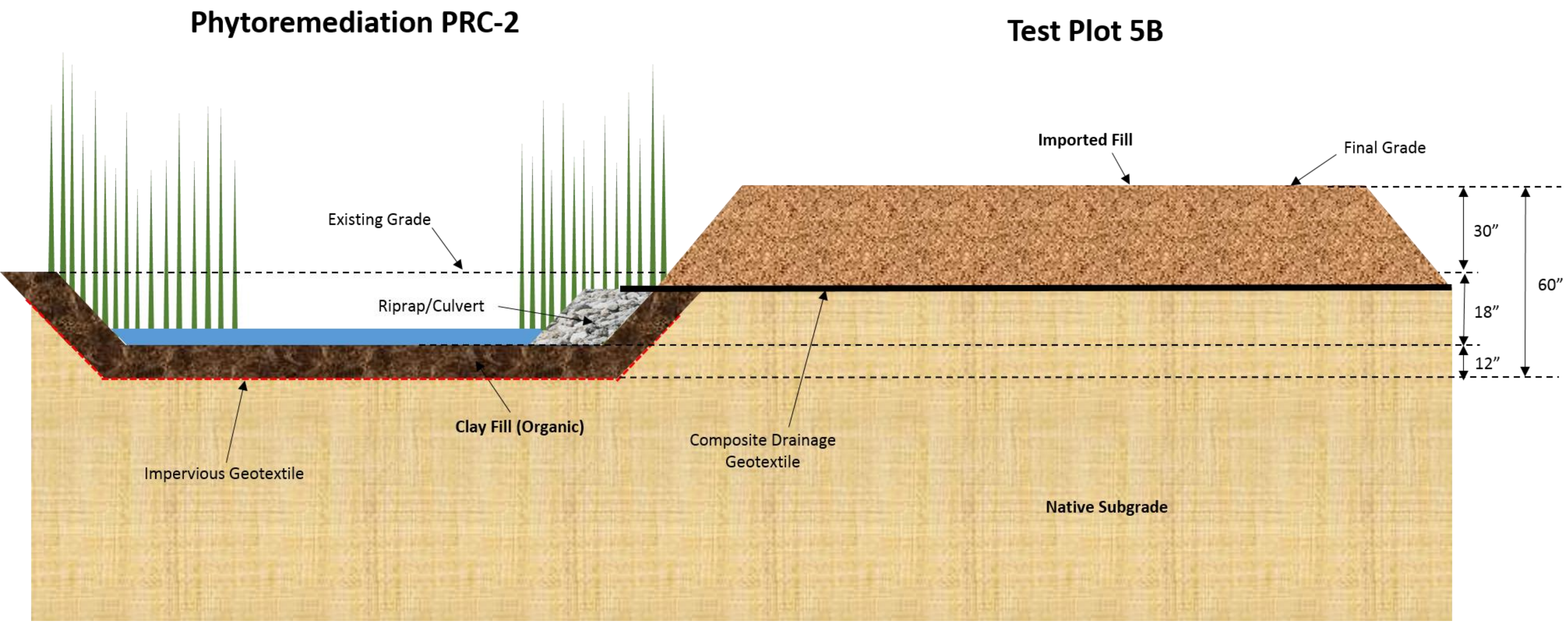
Test Plot 5B – Build-It-Up with Geotextile



Test Plot Construction

Test Plot 5B After 2-3% Grading

Completion of Test Plot 5B

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Test Plot Construction

PRC-2 After Excavation

PRC-2 During Backfilling

Impervious Liner Installed

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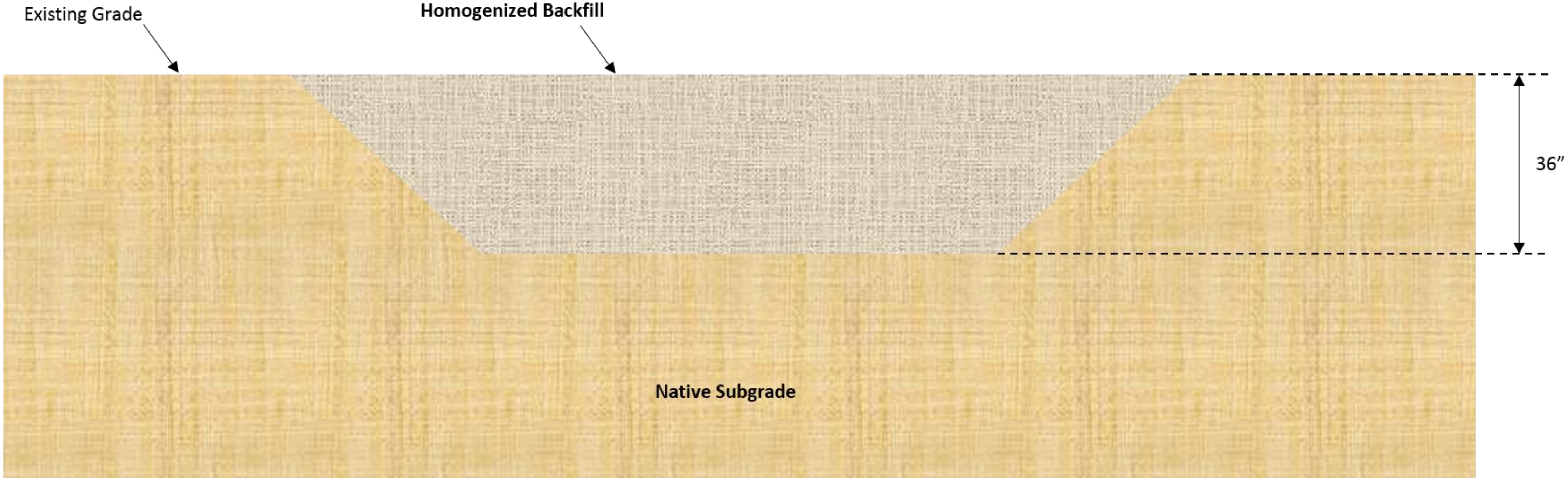
Test Plot 2A – Excavate-N-Mix



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Test Plot Construction

Test Plot 2A During Construction

Test Plot 2A After Completion

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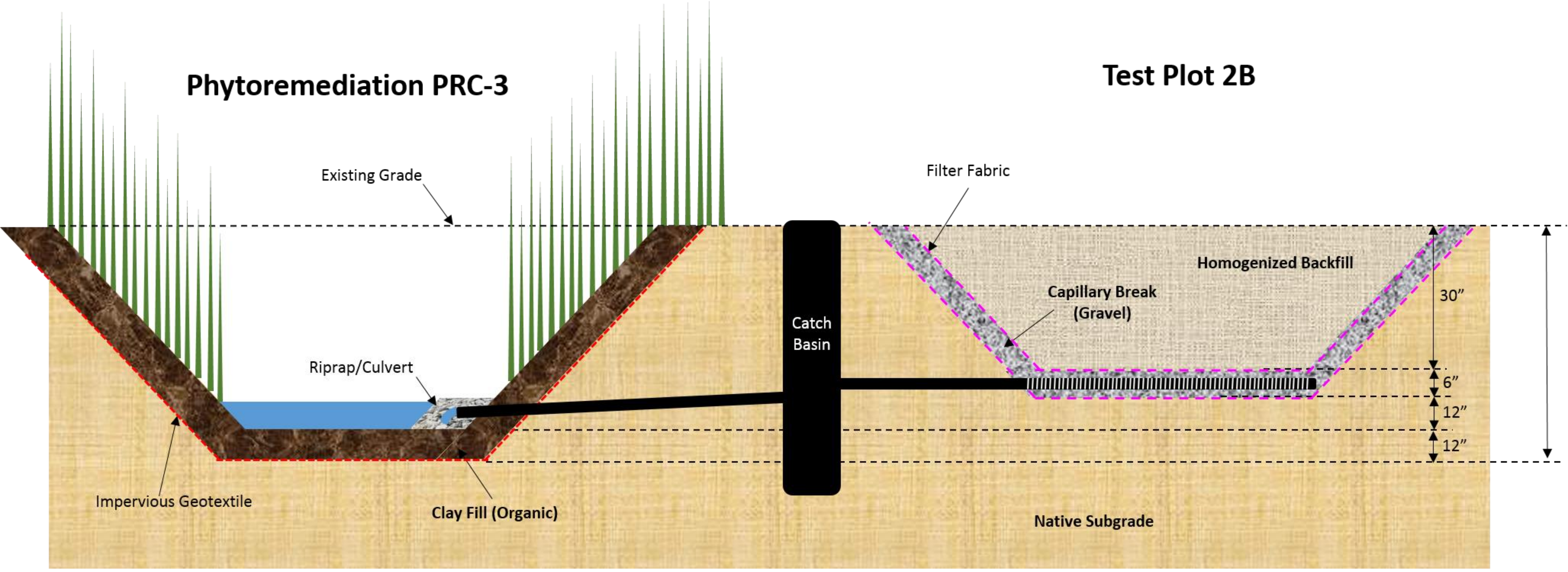
Test Plot 2B – Excavate-N-Mix with Capillary Break



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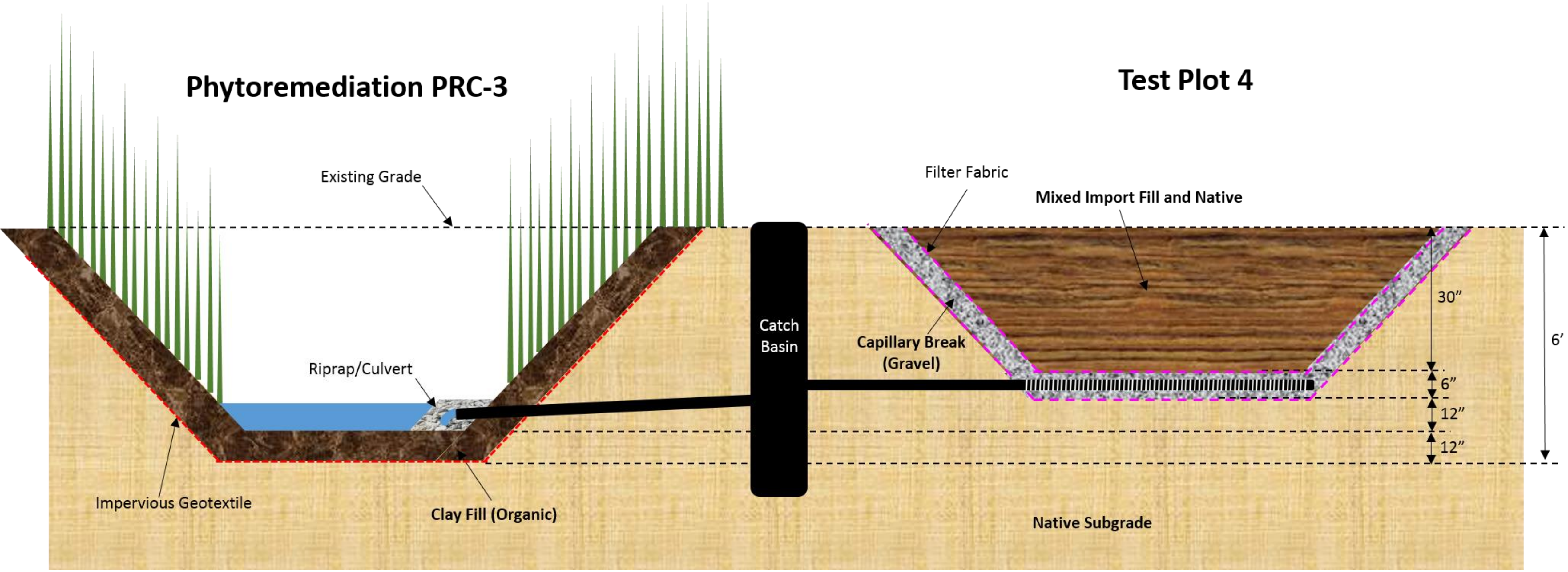
Test Plot Construction

Test Plot 2B After Excavation

Test Plot 1A After Backfilling

Installation of Drainage System

Test Plot 4 – Dirty-N-Clean Mixed



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Test Plot Construction

Test Plot 4 After Excavation

Drainage System and Pea Gravel Placed

Completed Test Plot

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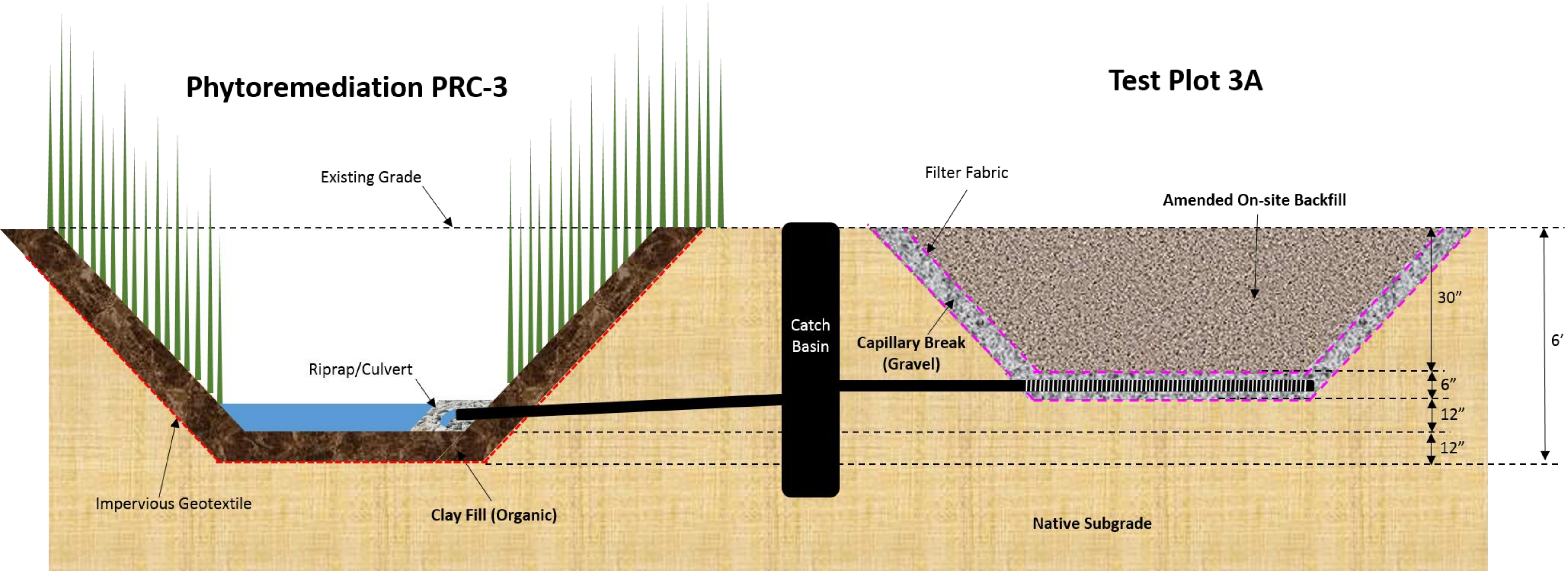
Test Plot 3A – Amended Soil



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Test Plot Construction

Test Plot 3A After Excavation

Test Plot 3A After Backfilling and Berm Construction

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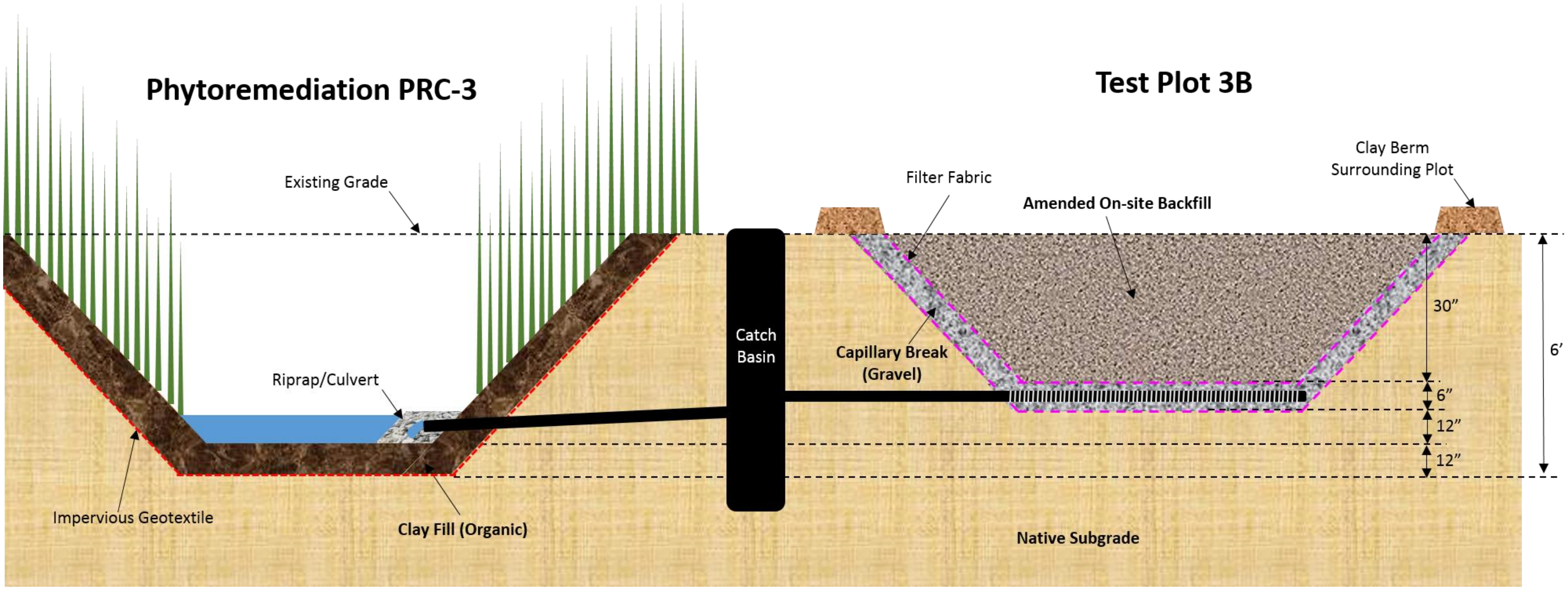
Test Plot 3B – Amended Soil with Water Flooding



Test Plot Construction

Test Plot 3B After Backfilling and Berm Construction

Flooding with Approximately 4 Inches of Water

Water Draining from 3B into Catch Basin

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Drone Aerial Photography During Construction

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November 30th Site Visit

Test Plot 3B Illustrating the Majority of the Water was Drained

Catch Basin with Secured Lid and Reflective Marker

Viewing Site from NE Corner Facing SE

Winter Activities

Laboratory amendment soil test cell implementation

On-going monitoring and testing of laboratory test cells

Planting several crop varieties in on-going test cells

- Soybeans
- Alfalfa
- Canola
- Sunflower
- Wheat

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Laboratory Test Cells

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Amended Soil Laboratory Test Cell Construction

Drilling Holes for Drainage

Pea Gravel as Drainage Layer

Filter Fabric Between Gravel
and Amended Soil

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Amended Soil Laboratory Test Cells

<u>158</u> Total test cells were prepared using <u>eight</u> different amendment techniques

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Amended Soil Laboratory Test Cells

Test Cells with Drainage for Water Collection

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Testing and Monitoring of Laboratory Test Cells

Weekly watering to simulate natural precipitation

Weekly EC testing

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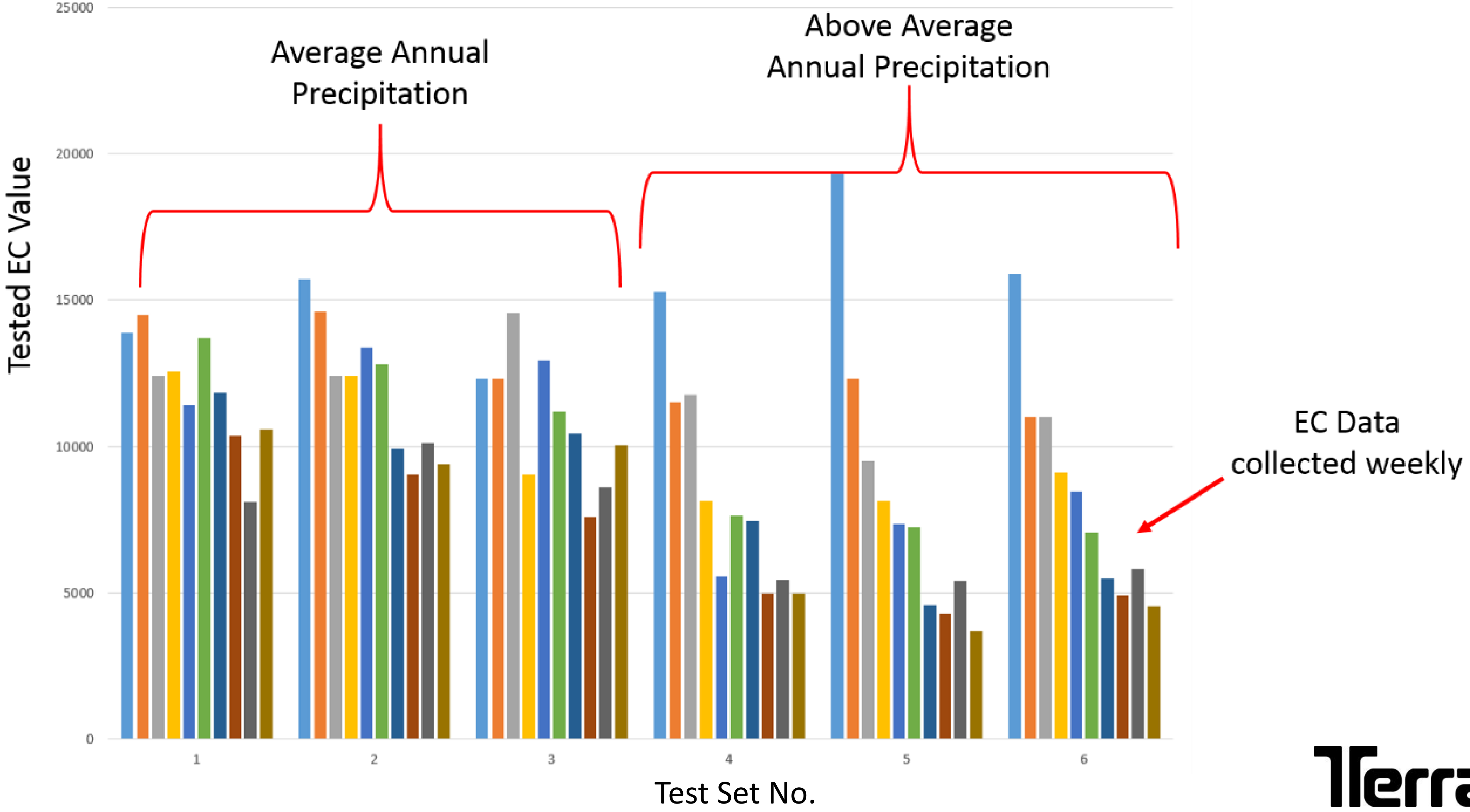
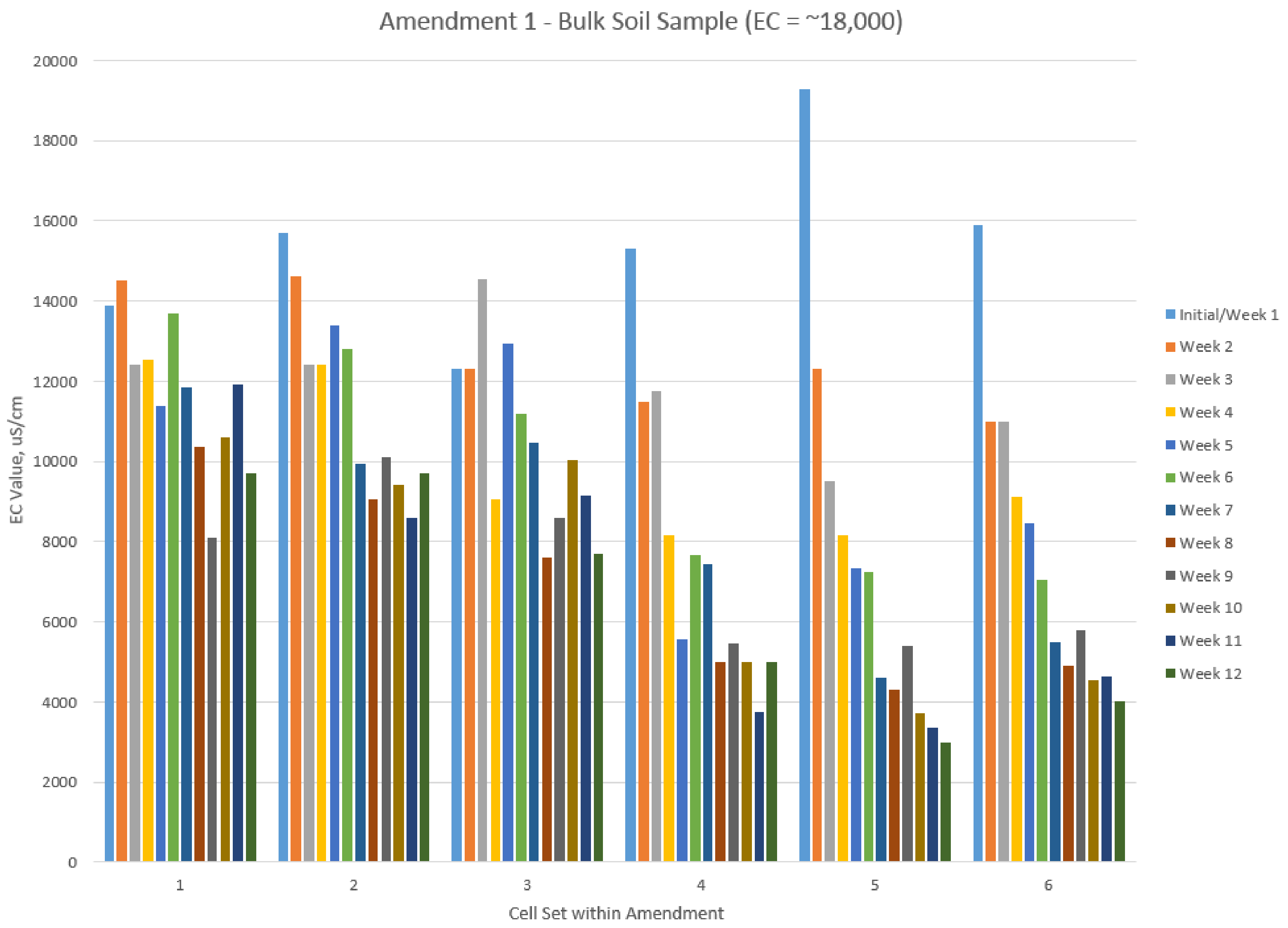
Preliminary Test Cell Data

Example of Data Set Organization for Weekly EC Data



Preliminary Test Cell Data

Amendment 1 (BioFlora Spray and Fertilizer) EC Data Set



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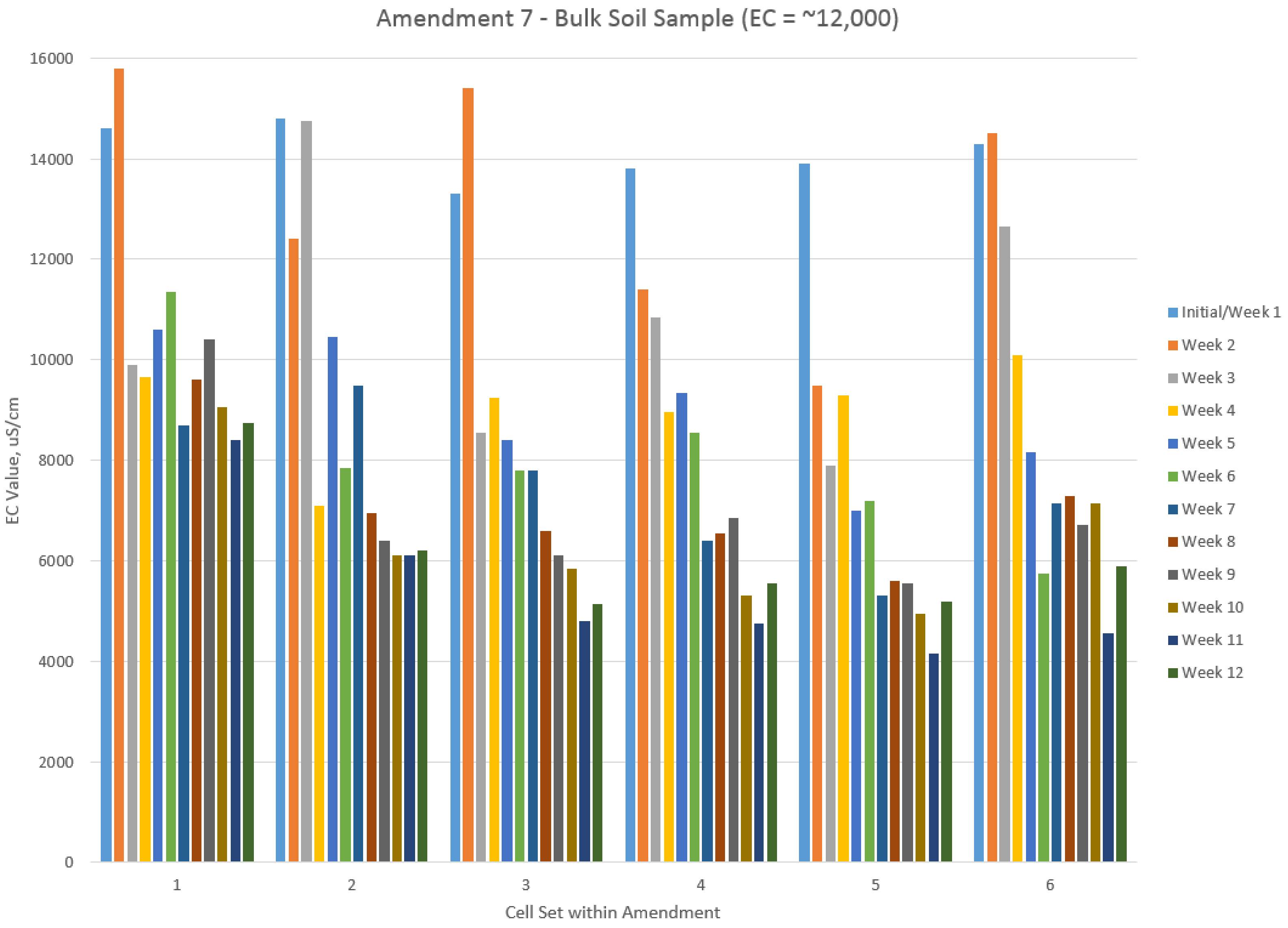
Preliminary Test Cell Data

Amendment with Straw and Gypsum and Sulfuric Acid Mixed Together Before Mixing into Soil



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Preliminary Test Cell Data Summary

- Amendment 1 – BioFlora Spray/Fertilizer
  - Average 38% Reduction in EC Levels
- Amendment 2 – Straw/Gypsum/Molasses/Fertilizer
  - Average 1% Reduction in EC Levels
- Amendment 3 – Straw/Gypsum/Beet Molasses/BioFlora Spray/Fertilizer
  - Average 19% Reduction in EC Levels
- Amendment 4 – Straw/Gypsum/Beet Pulp/BioFlora Spray/Fertilizer
  - Average 22% Reduction in EC Levels

**Reduction in EC levels are based on the most recently data collected on 2/23/18 compared to initial test values

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Preliminary Test Cell Data Summary

- Amendment 5 – Straw/Sulfuric Acid/BioFlora Spray/Fertilizer
  - Average 37% Reduction in EC Levels
- Amendment 6 – Straw/Gypsum/BioFlora Spray/Fertilizer
  - Average 47% Reduction in EC Levels
- Amendment 7 – Straw/Sulfuric Acid-Gypsum Mix/BioFlora Spray/Fertilizer
  - Average 52% Reduction in EC Levels
- Amendment 8 – Straw/Gypsum/Beet Pulp/BioFlora Spray/Fertilizer
  - Average 41% Reduction in EC Levels
- Control Samples – Soil Watered Only (No Amendments Added)
  - Average 54% Reduction in EC Levels

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Crop Planting in Test Cells (On-going)

Construction of "Greenhouse" for Crop Planting

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Amended Soil Laboratory Test Cells

Volunteer wheat seedlings in several test cells

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Crop Growth in Test Cells (On-going)

Plant Growth After About One Week

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Crop Growth in Test Cells (On-going)

Plant Growth After About One Month

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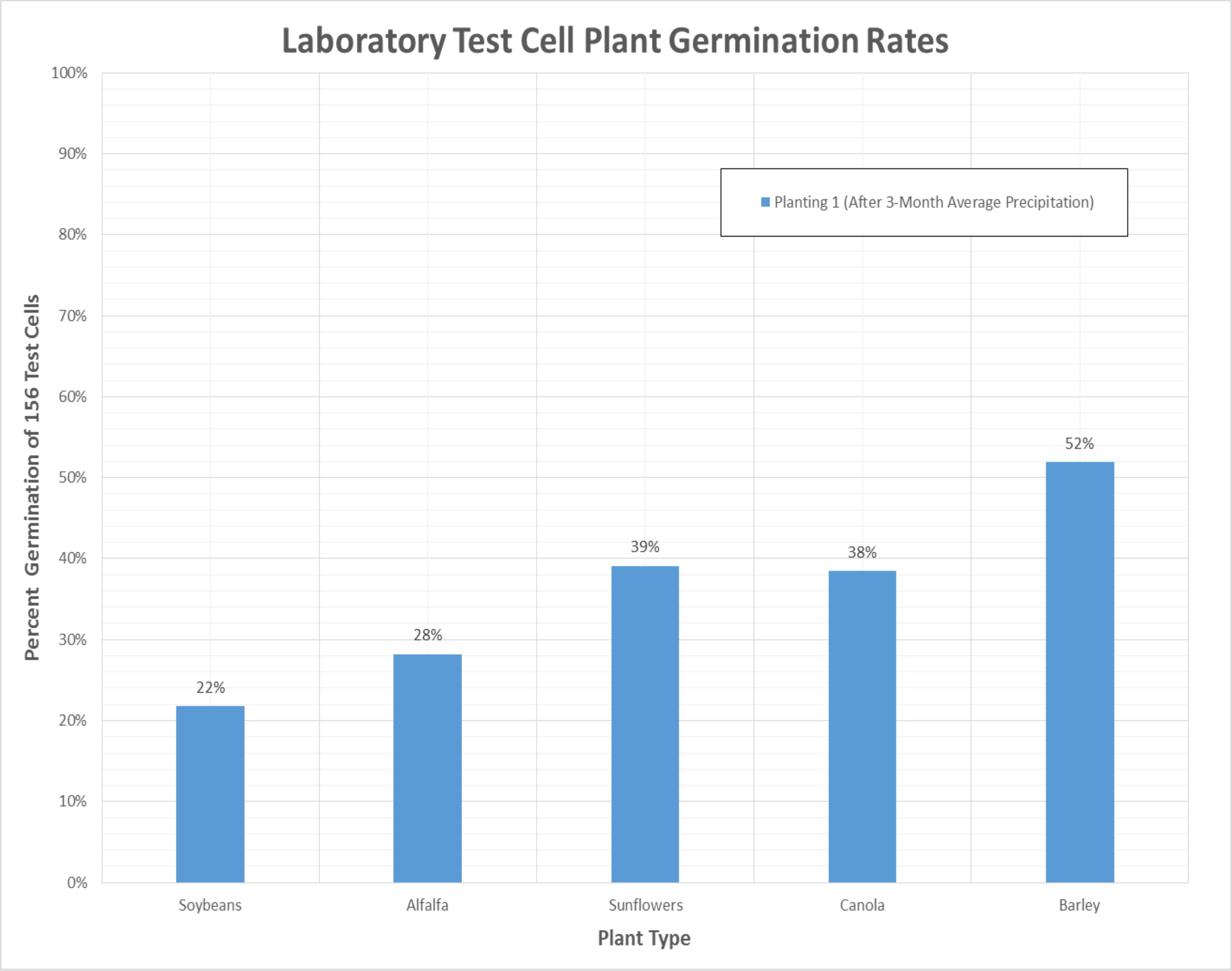
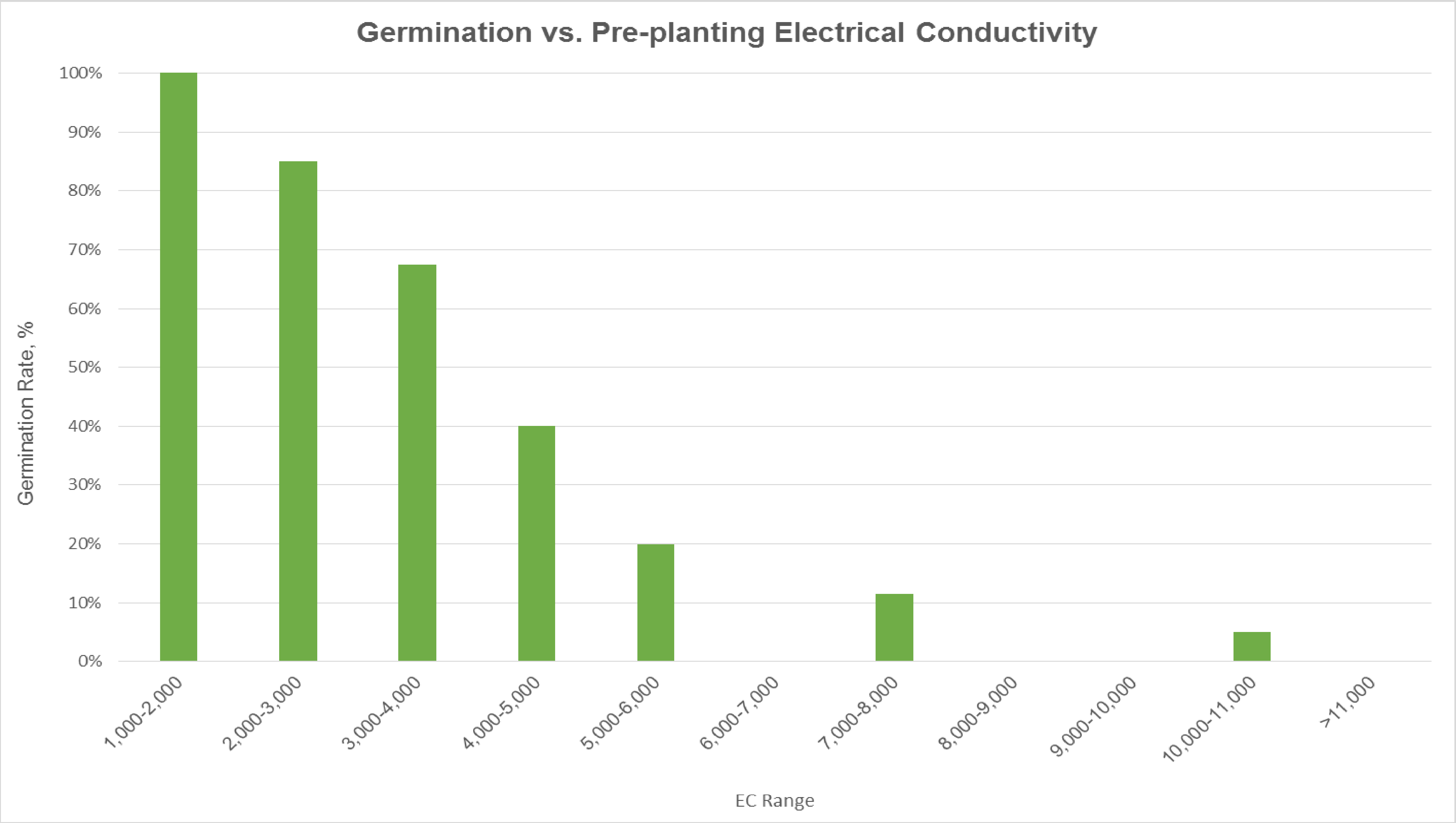

Laboratory Test Cell Plant Germination Rates
Planting 1 (After 3-Month Average Precipitation)
Percent Germination of 156 Test Cells
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
22%
28%
39%
38%
52%
Soybeans
Alfalfa
Sunflowers
Canola
Barley
Plant Type


Germination vs. Pre-planting Electrical Conductivity
Germination Rate, %
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1,000-2,000
2,000-3,000
3,000-4,000
4,000-5,000
5,000-6,000
6,000-7,000
7,000-8,000
8,000-9,000
9,000-10,000
10,000-11,000
>11,000
EC Range

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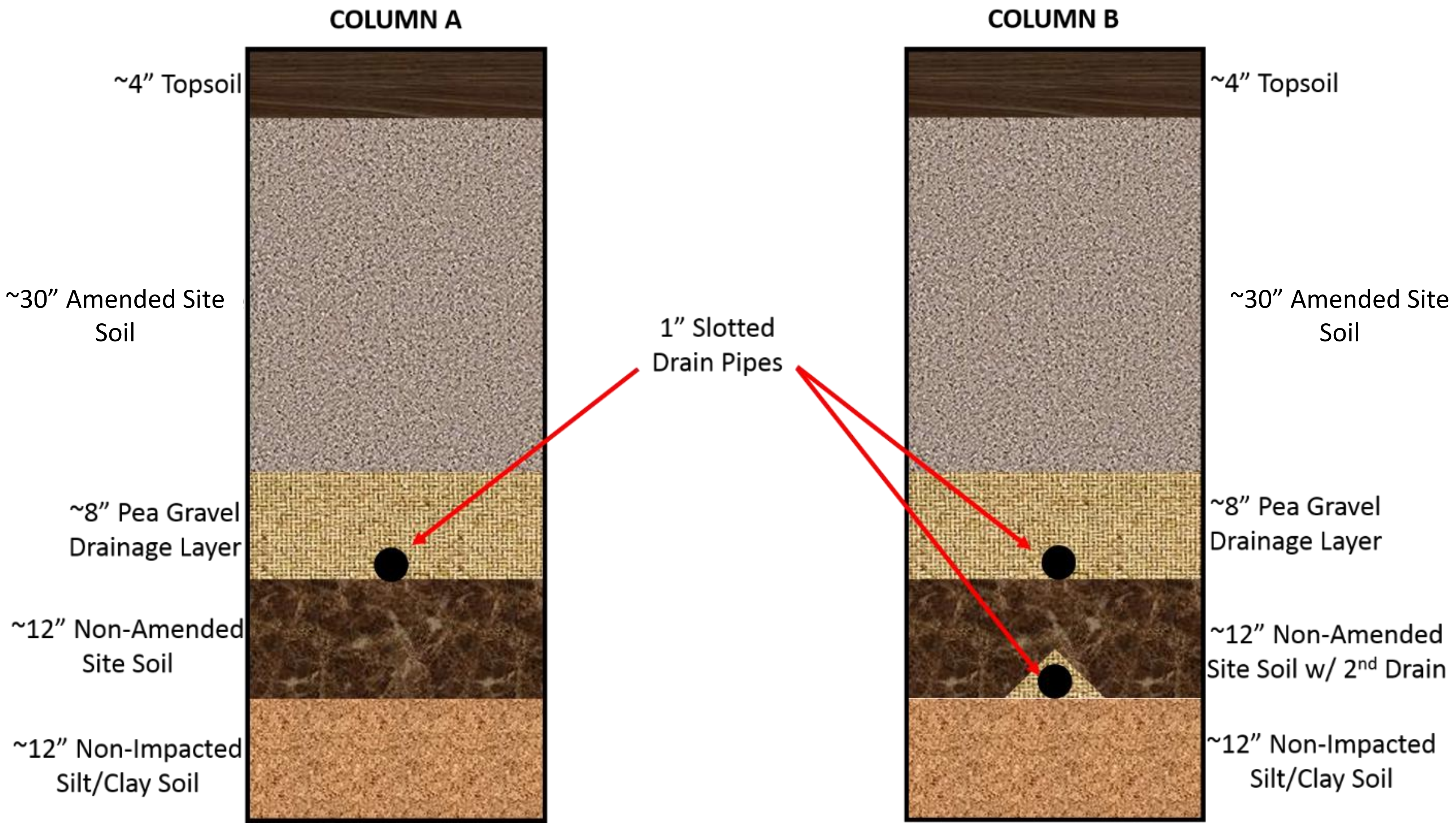
Amendment No.	Amendment Description	Average EC Reduction	Average EC Reduction After 1-Yr Flooding
1	BioFlora spray/fertilizer	42%	77%
2	Straw/gypsum/beet molasses/fertilizer	12%	66%
3	Straw/gypsum/beet molasses/Bioflora spray/fertilizer	22%	71%
4	Straw/gypsum/beet pulp/BioFlora spray/fertilizer	24%	75%
5	Straw/sulfuric acid/BioFlora spray/fertilizer	40%	81%
6	Straw/gypsum/BioFlora spray/fertilizer	50%	83%
7	Straw/sulfuric acid-gypsum mix/BioFlora spray/fertilizer	53%	80%
8	Clean, coarse sand	40%	80%
Controls	No soil amendments added	54%	81%

EC Soil Level	Soil Amendment Number/EC Reduction								
	1	2	3	4	5	6	7	8 [1]	Control
~5,000 µS/cm	61%	45%	49%	58%	64%	68%	64%	66%	66%
~12,000 µS/cm	82%	71%	79%	79%	85%	89%	86%	89%	85%
~18,000 µS/cm	87%	83%	86%	89%	92%	92%	90%	84%	91%

1. Amendment number 8 was the only amendment method to not indicate the trend of greater reduction with higher original EC level soil.

Soil Column Plans/Schematics



N.T.S.

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Soil Column Construction

Columns Being Constructed and Painted

Drainage Pipe in Column

Attaching Plexiglass Front

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Soil Column Construction

Drainage Layer

Various Brine Impacted Soils

Completed Soil Column

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Completed Soil Columns

Both Columns Completed

Initial Watering with 6 Gallons of Water

Collection System

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Field Test Plots


Test Plot 1A
Description: Excavate and replace brine-impacted soil with clean fill

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Test Plot 5A
Description: grade area for drainage, place pea gravel with filter fabric, fill above grade with clean fill
Phytoremediation PRC-2
Test Plot 5A
Imported Fill
Final Grade
Filter Fabric
Existing Grade
Riprap/Culvert
Capillary Break (Gravel)
Clay Fill (Organic)
Native Subgrade

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Test Plot 5B
Description: grade area for drainage, place composite drainage geotextile, fill above grade with clean fill
Test Plot 5B
Phytoremediation PRC-2

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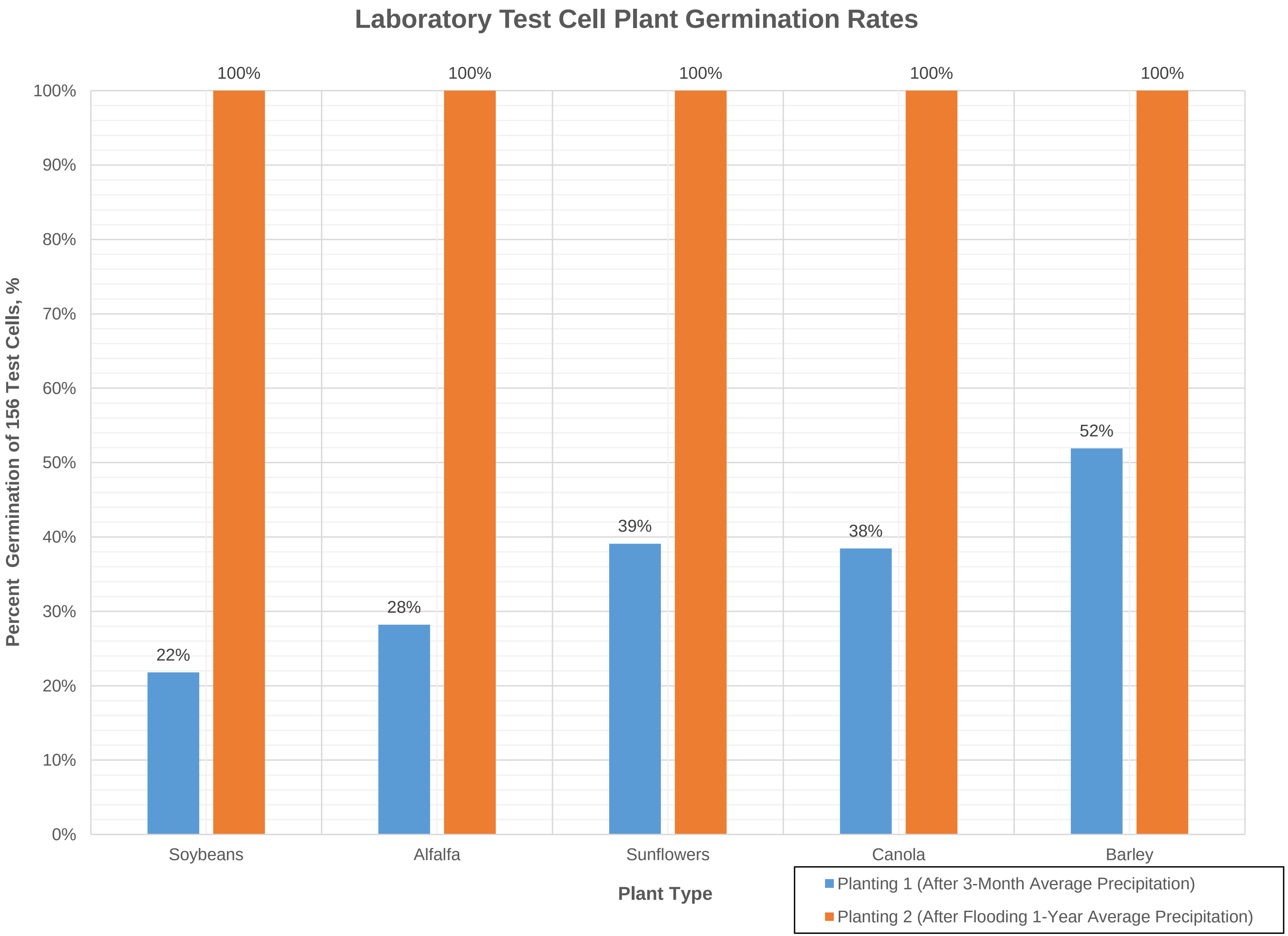
Laboratory Test Cell Plant Germination Rates
Percent Germination of 156 Test Cells, %
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
22%
100%
28%
100%
39%
100%
38%
100%
52%
100%
Soybeans
Alfalfa
Sunflowers
Canola
Barley
Plant Type
Planting 1 (After 3-Month Average Precipitation)
Planting 2 (After Flooding 1-Year Average Precipitation)

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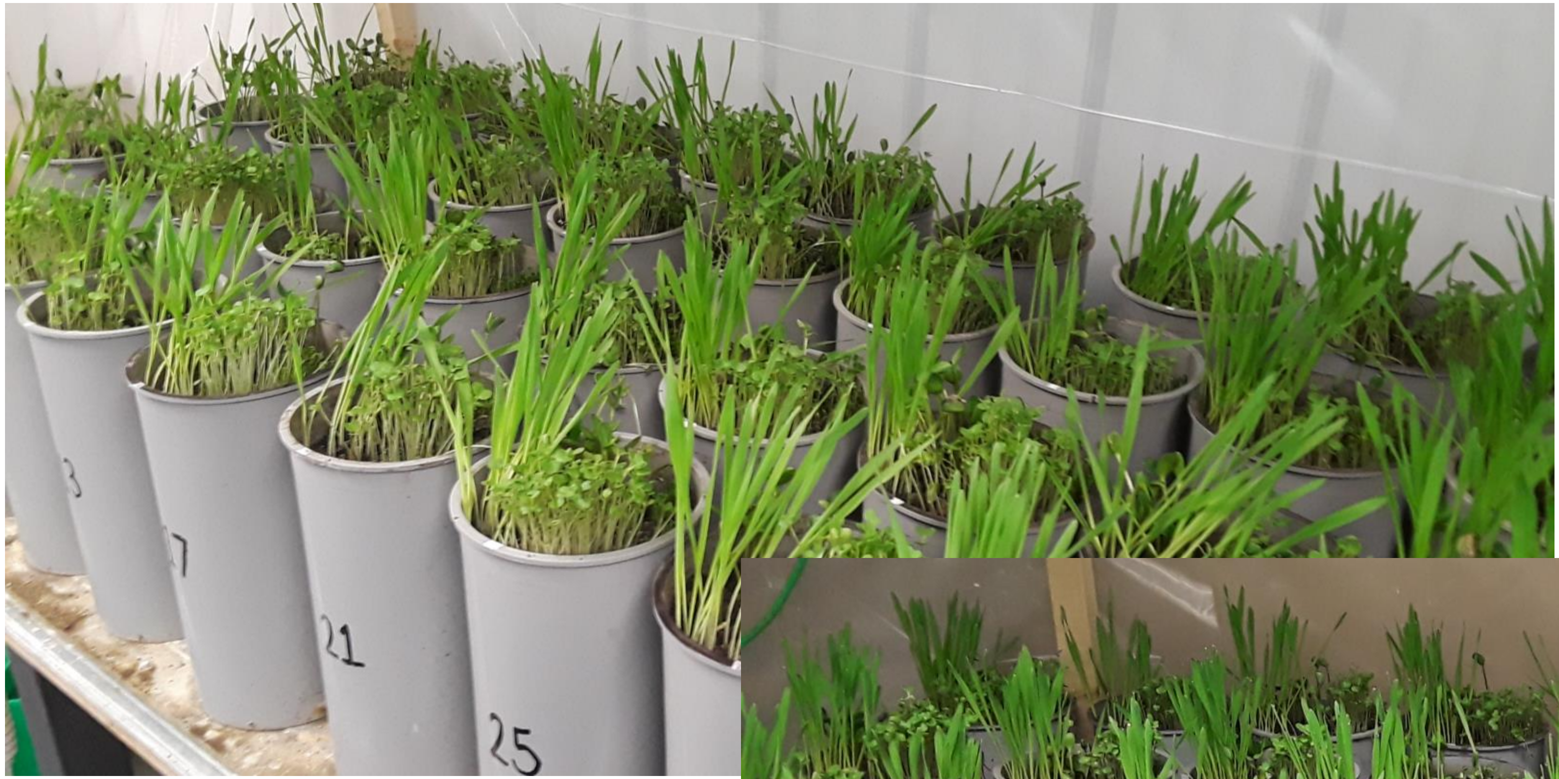
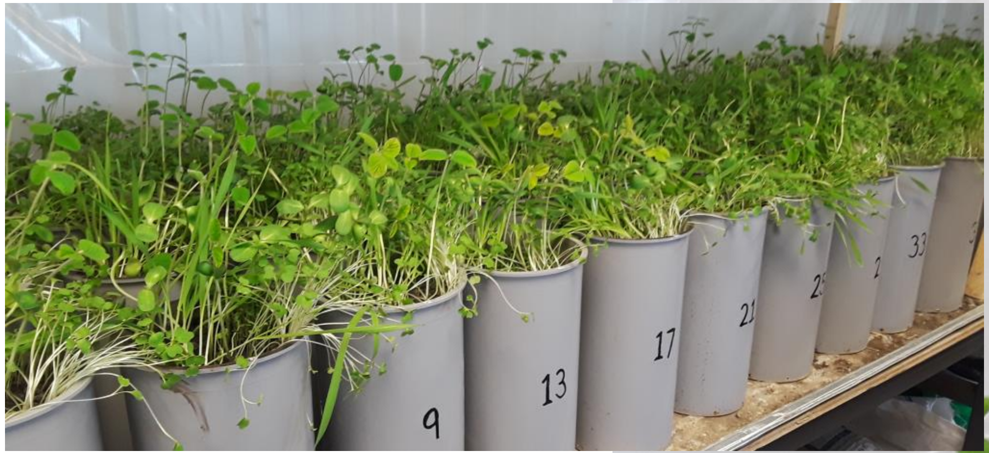

21
25


Acid
85
Acid
89
93
97
101
105
109
Terracon

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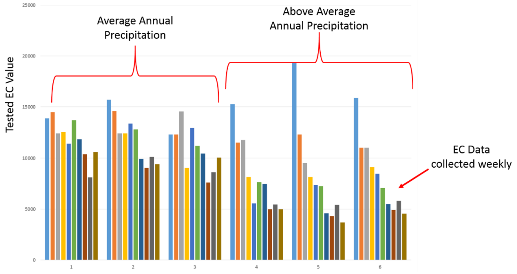
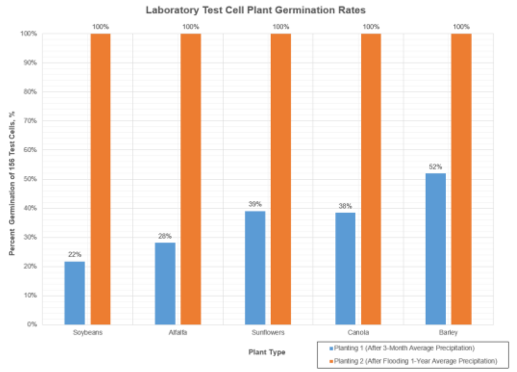
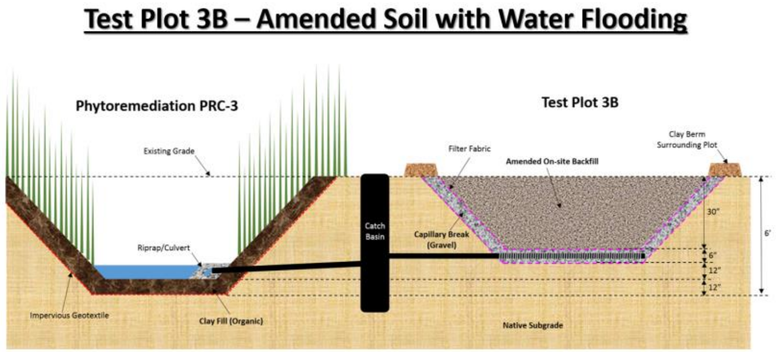


Research Summary

- The clean-up costs are being significantly reduced
- The amount of material hauled to landfills is minimized or eliminated.
- Through our new research methods, brine-impacted soils are being remediated faster
- Through laboratory and field experimentation and testing:
    - Return brine-impacted land to its original land use.
    - Return brine-impacted land in a relatively short time frame.





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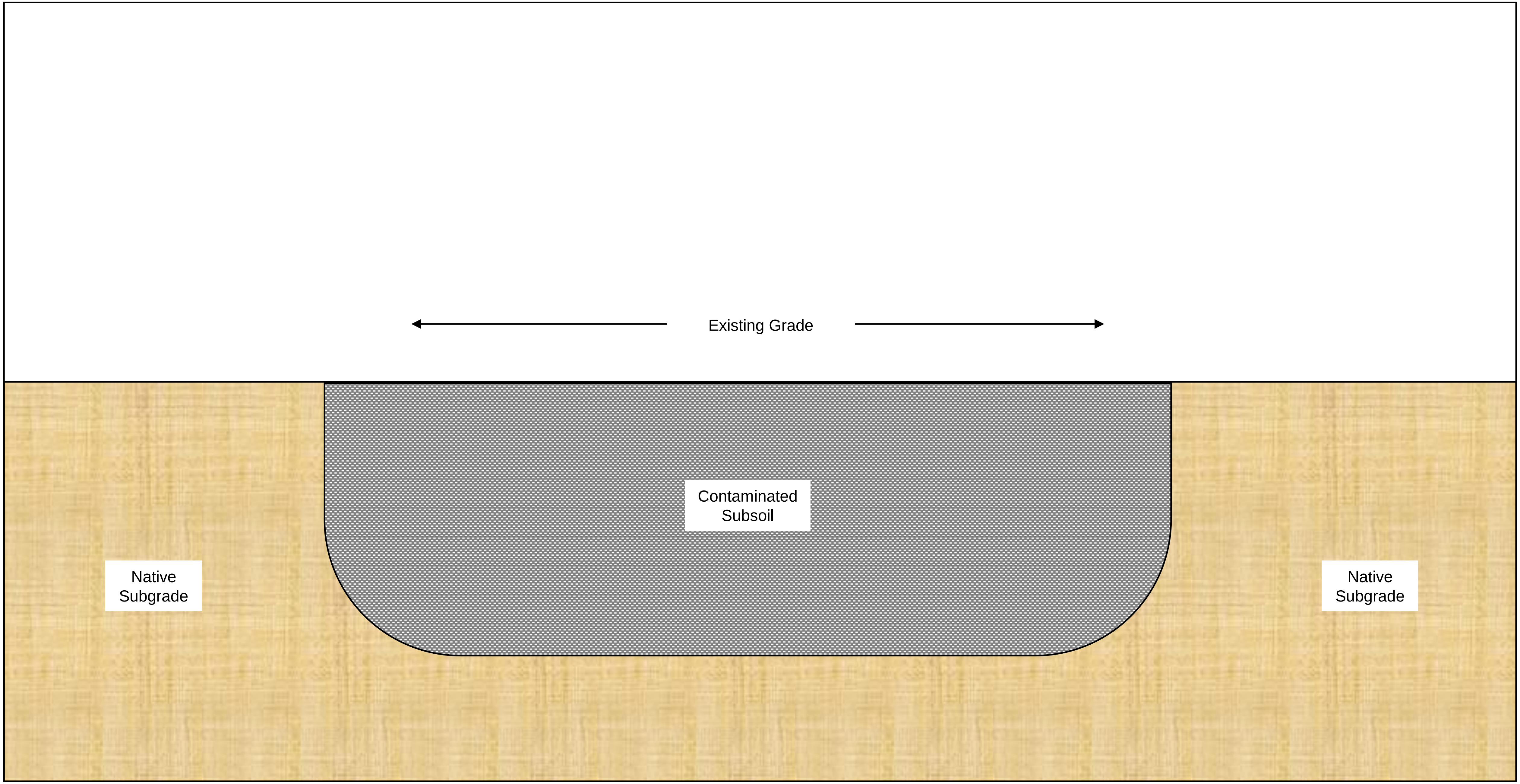
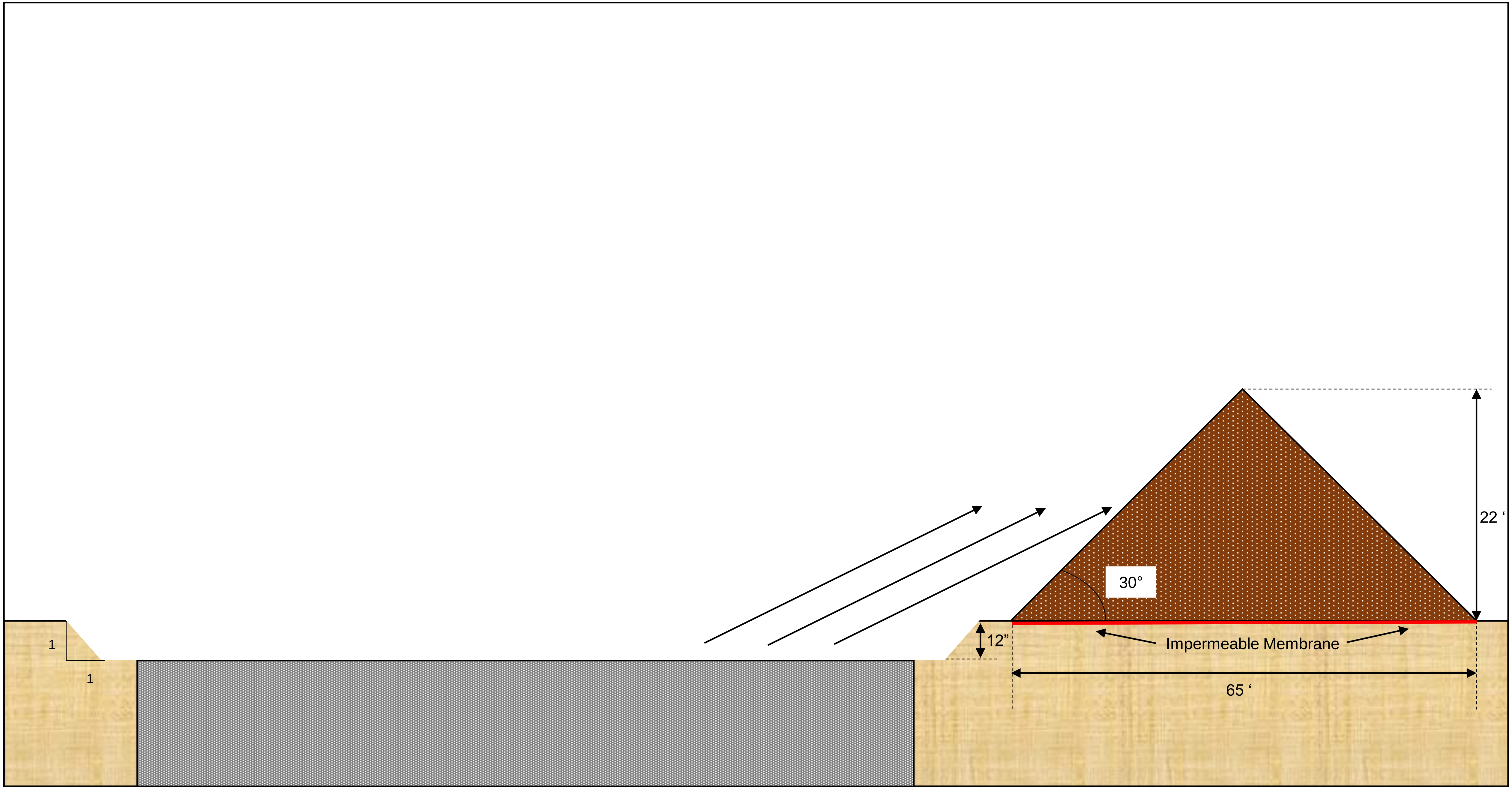
Large Scale Pilot Study

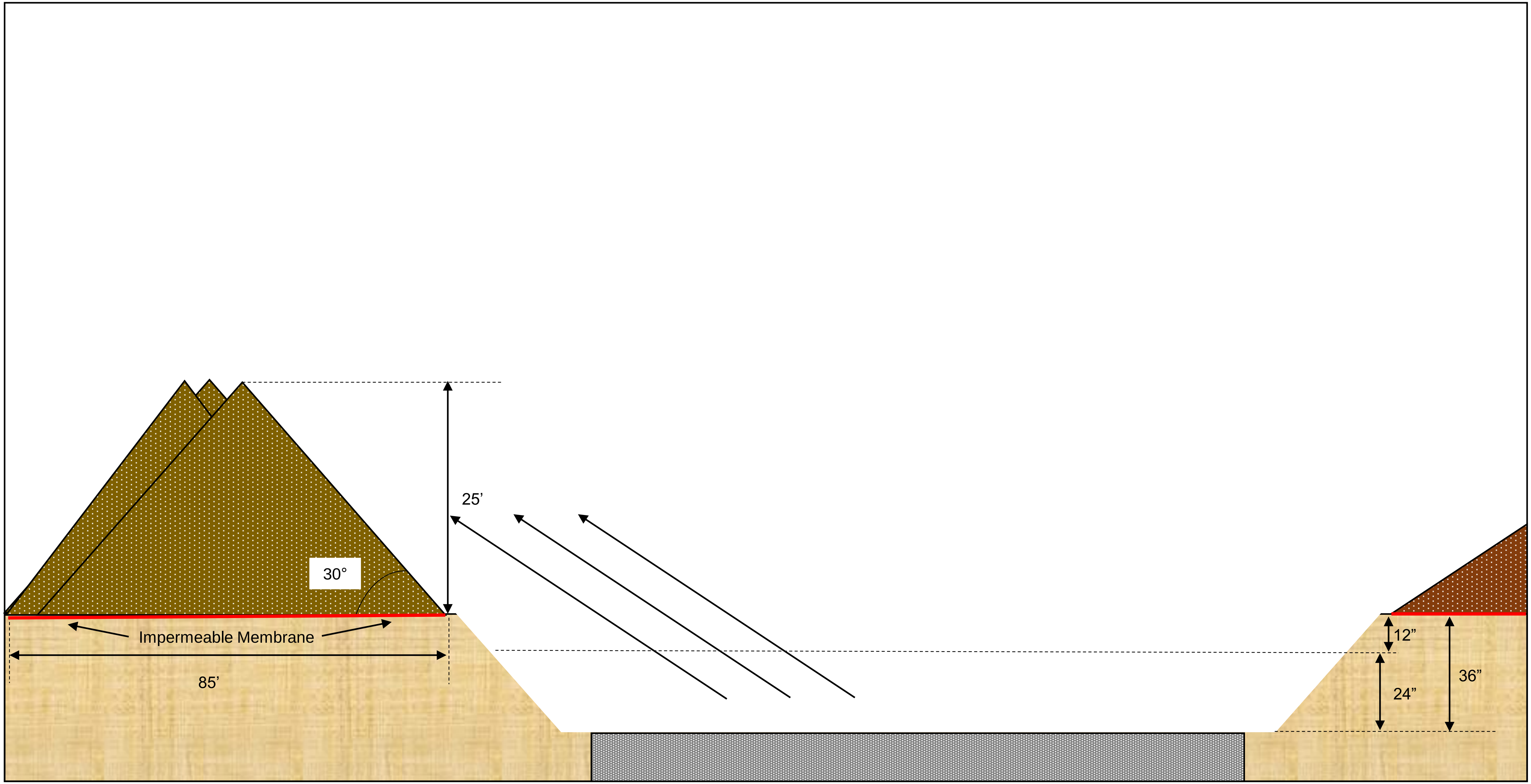
Brine Pond Remediation



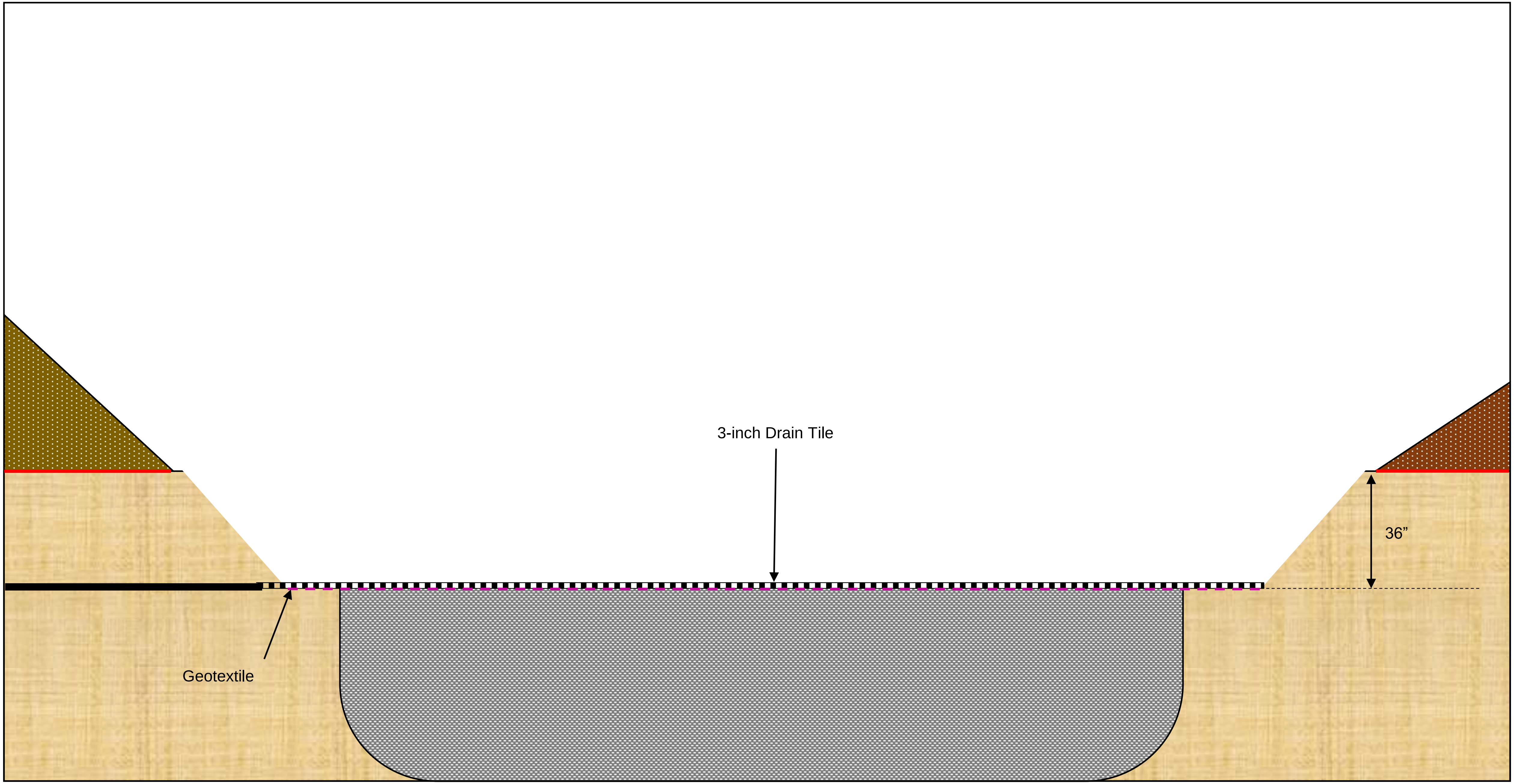
Brine Pond Remediation



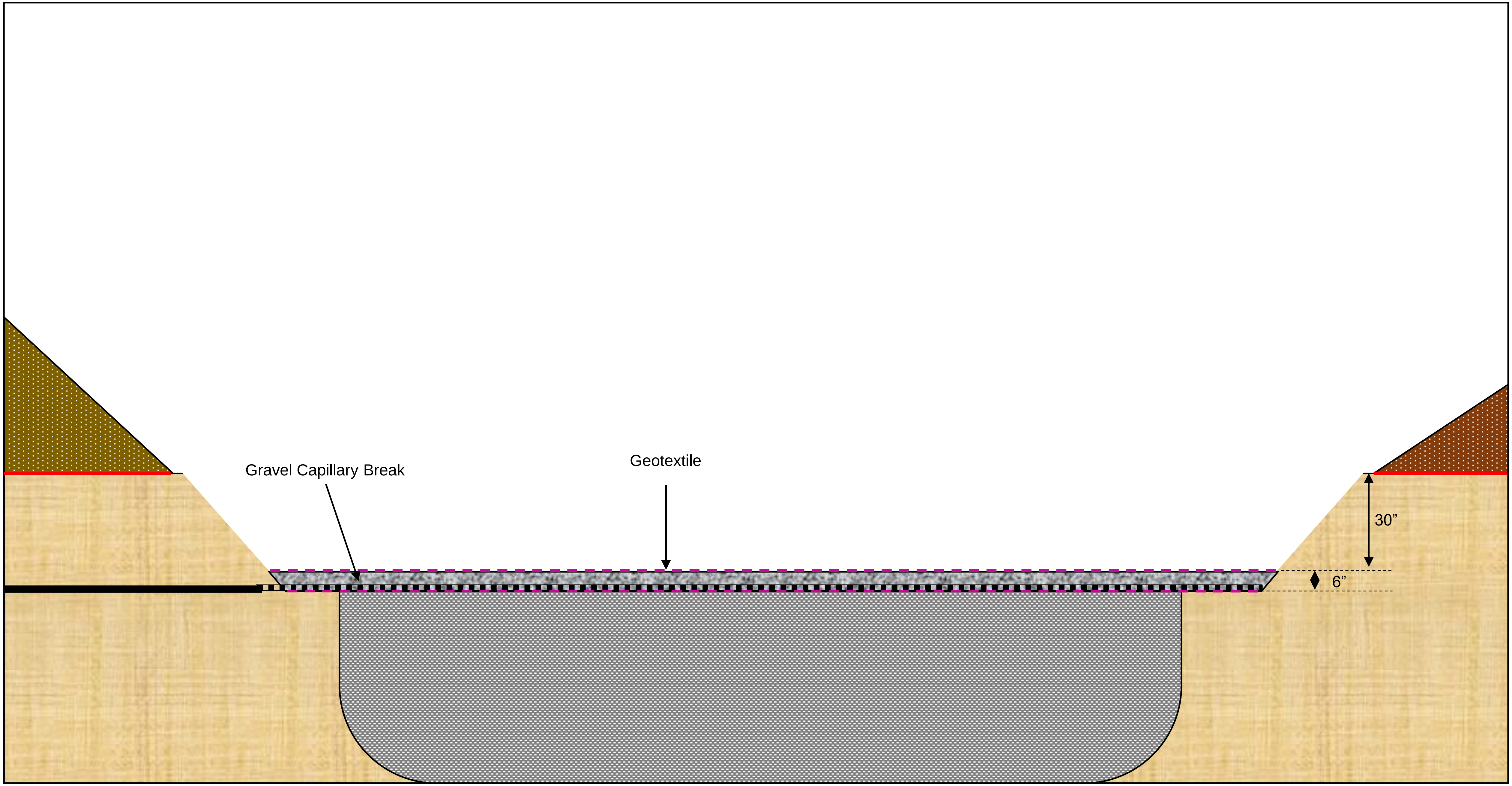
Brine Pond Remediation



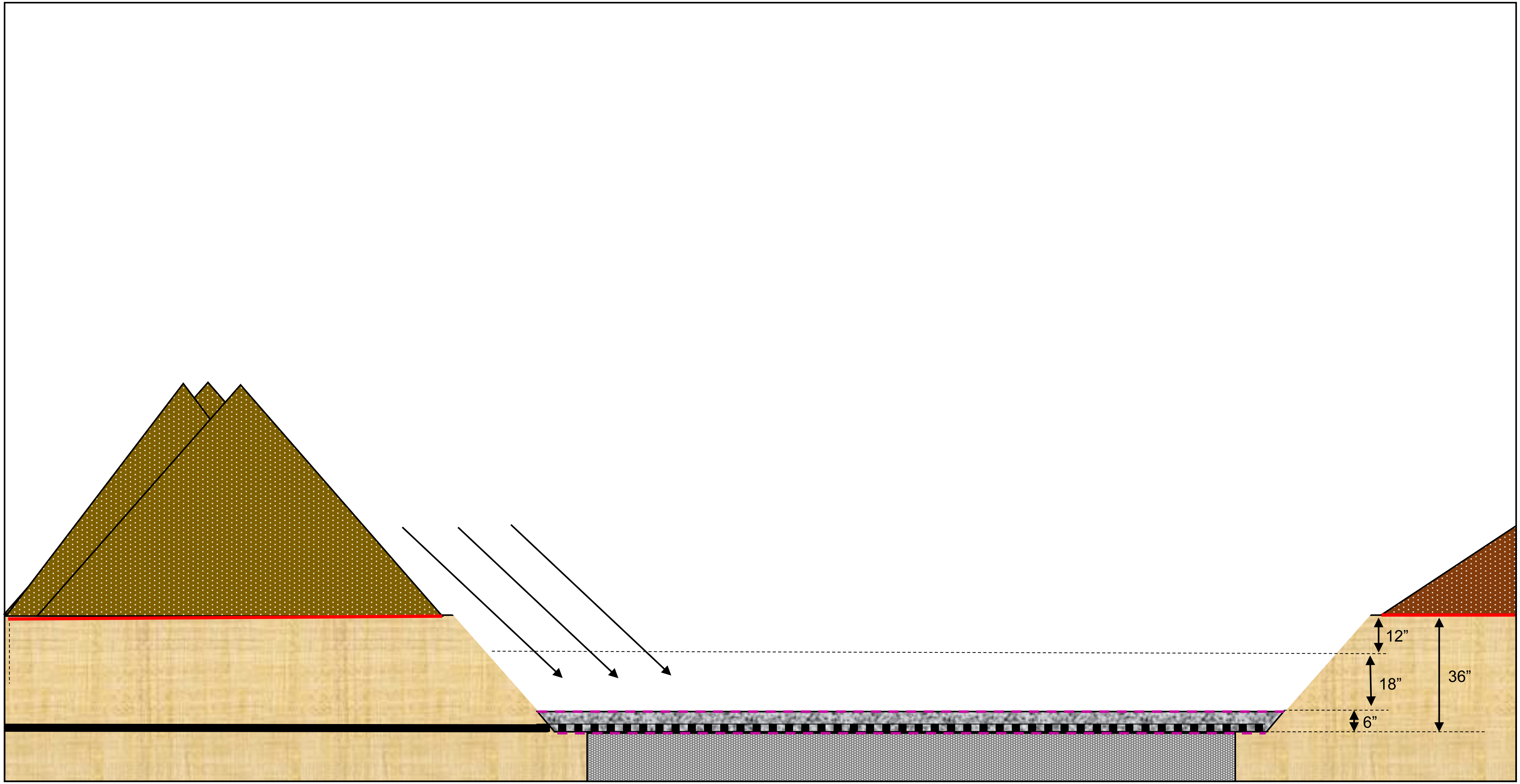
Brine Pond Remediation



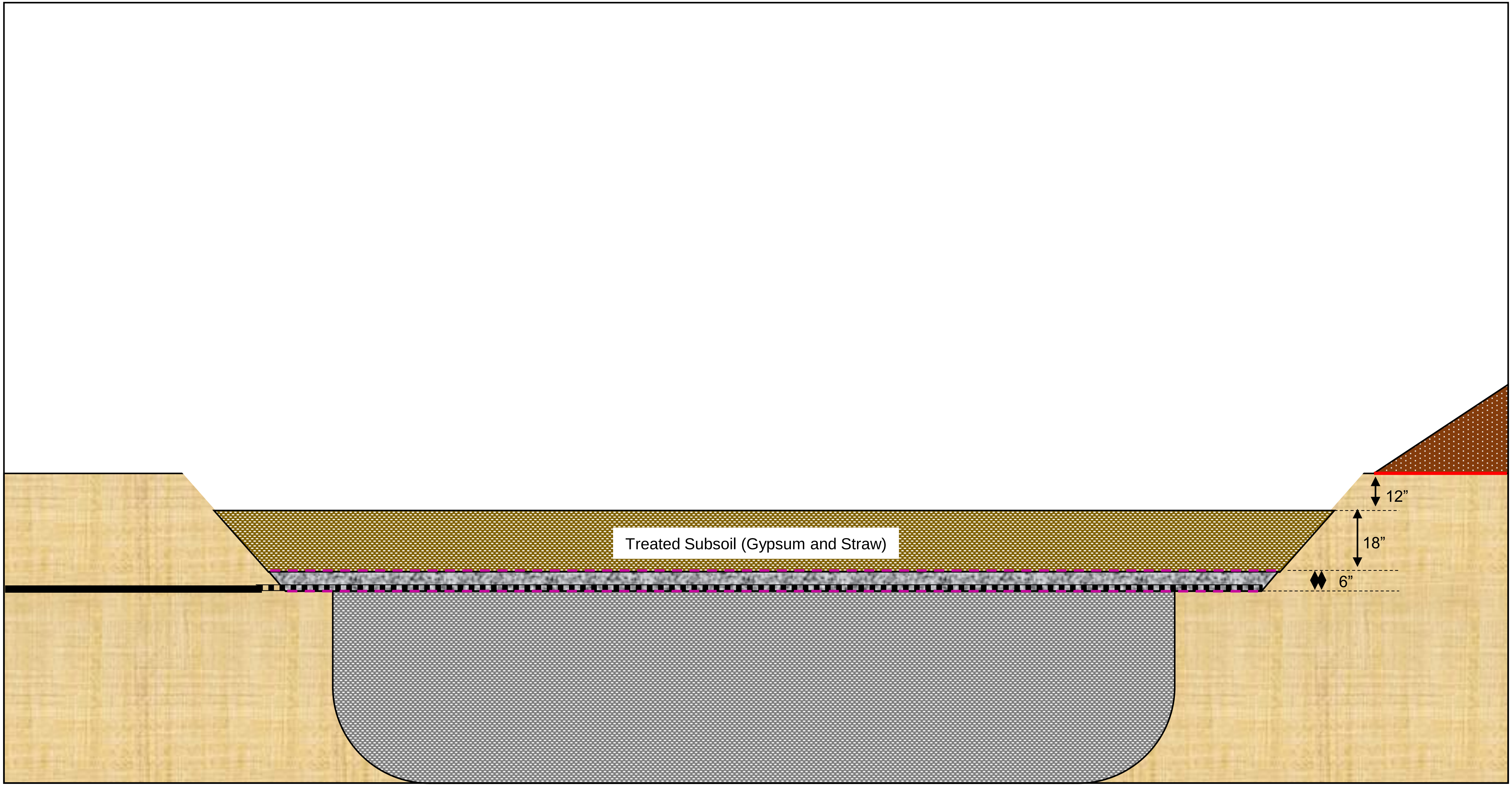
Brine Pond Remediation



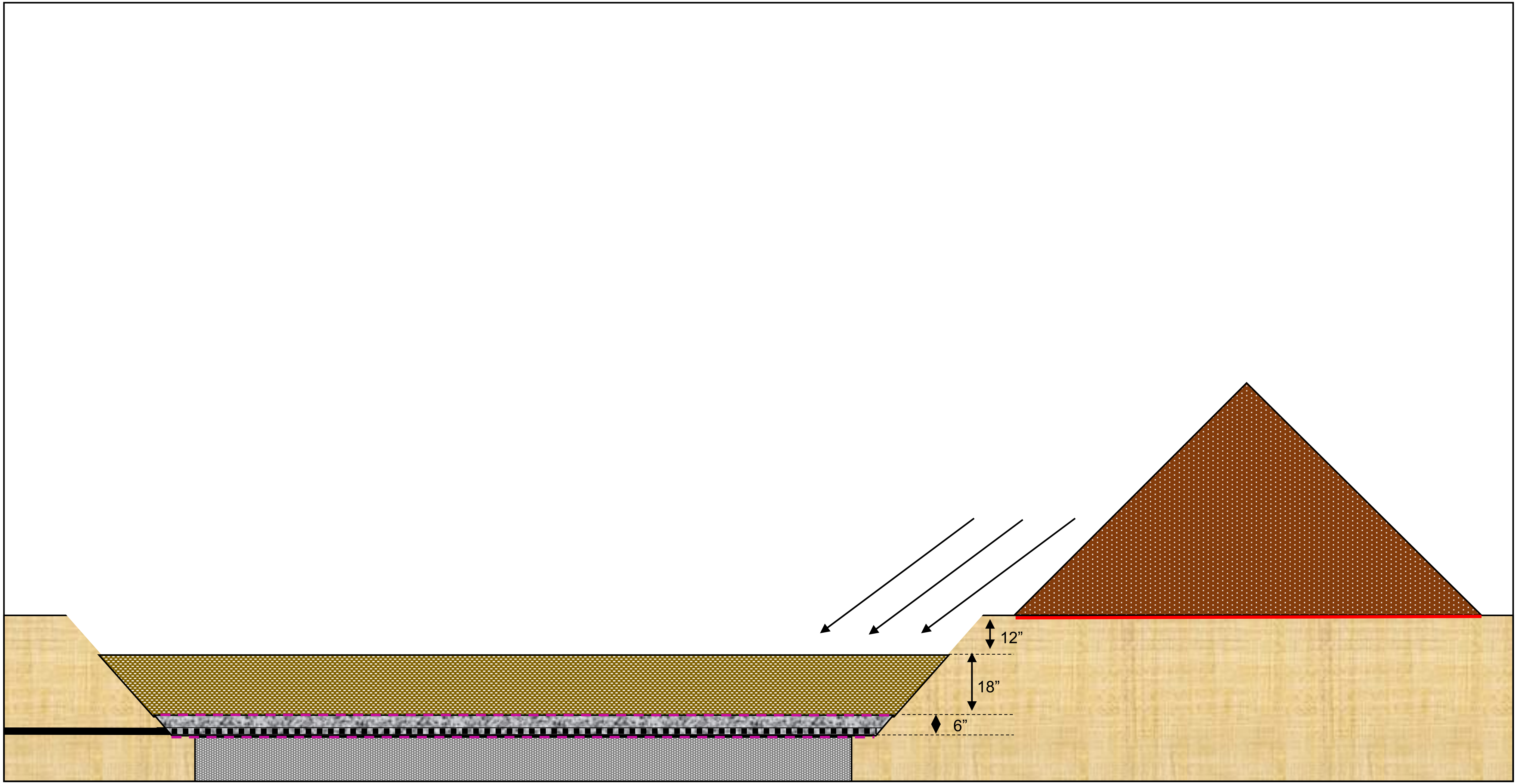
Brine Pond Remediation



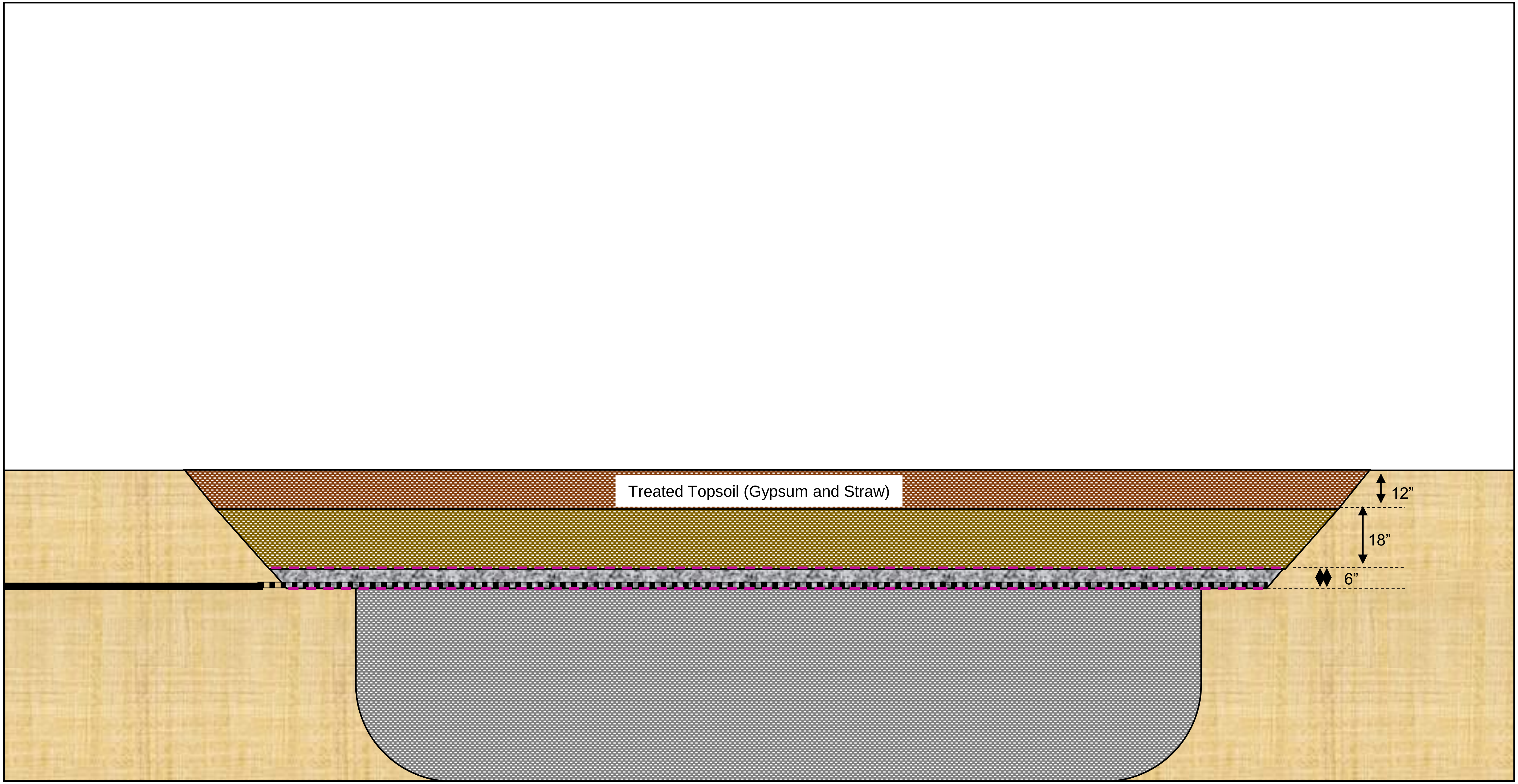
Brine Pond Remediation



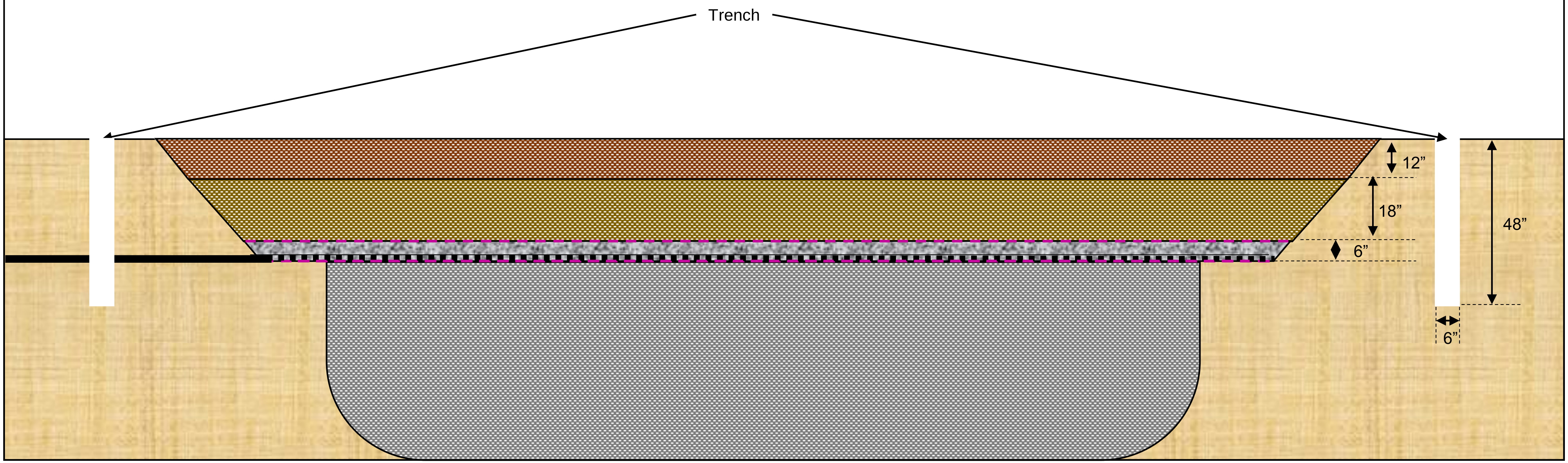
Brine Pond Remediation



Brine Pond Remediation



Brine Pond Remediation



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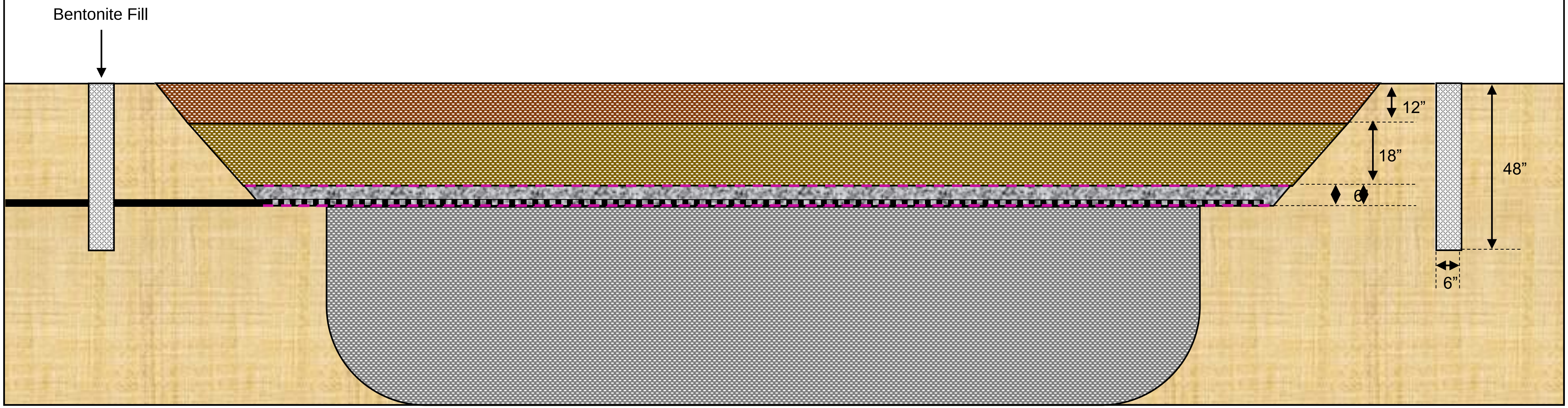

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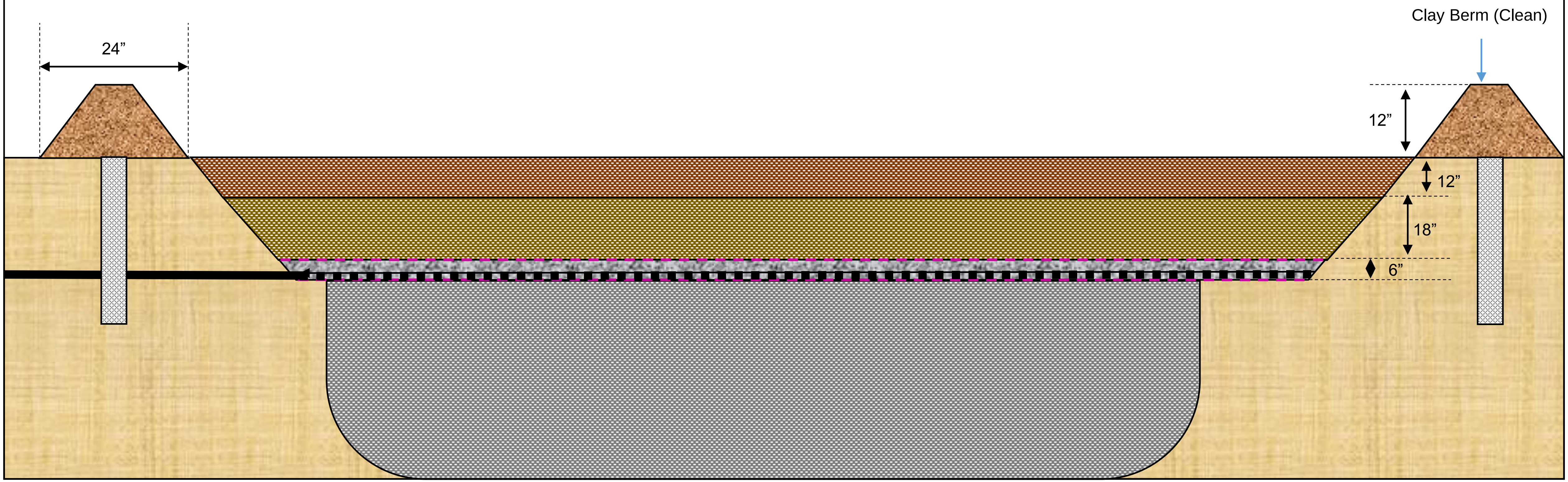
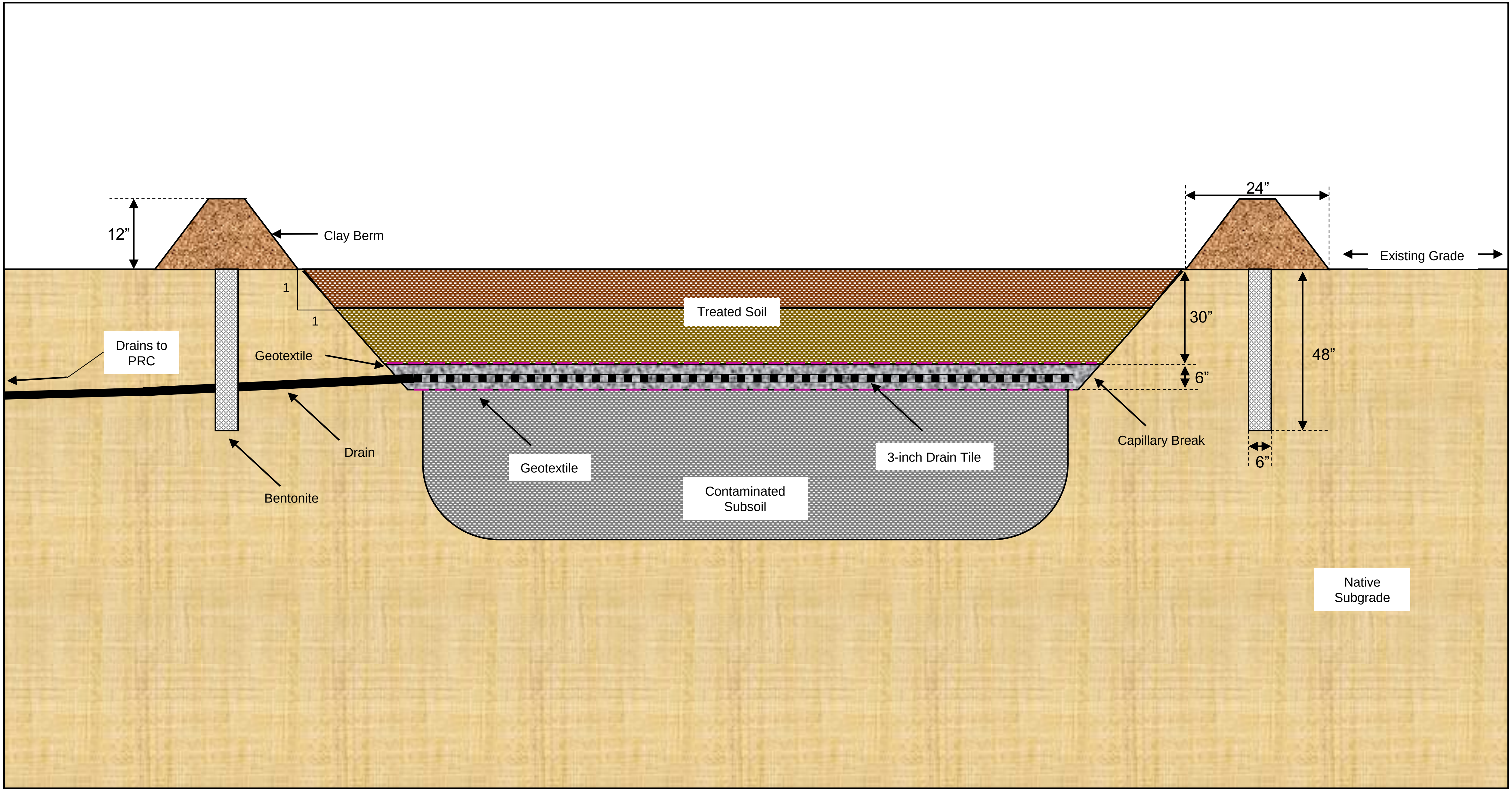
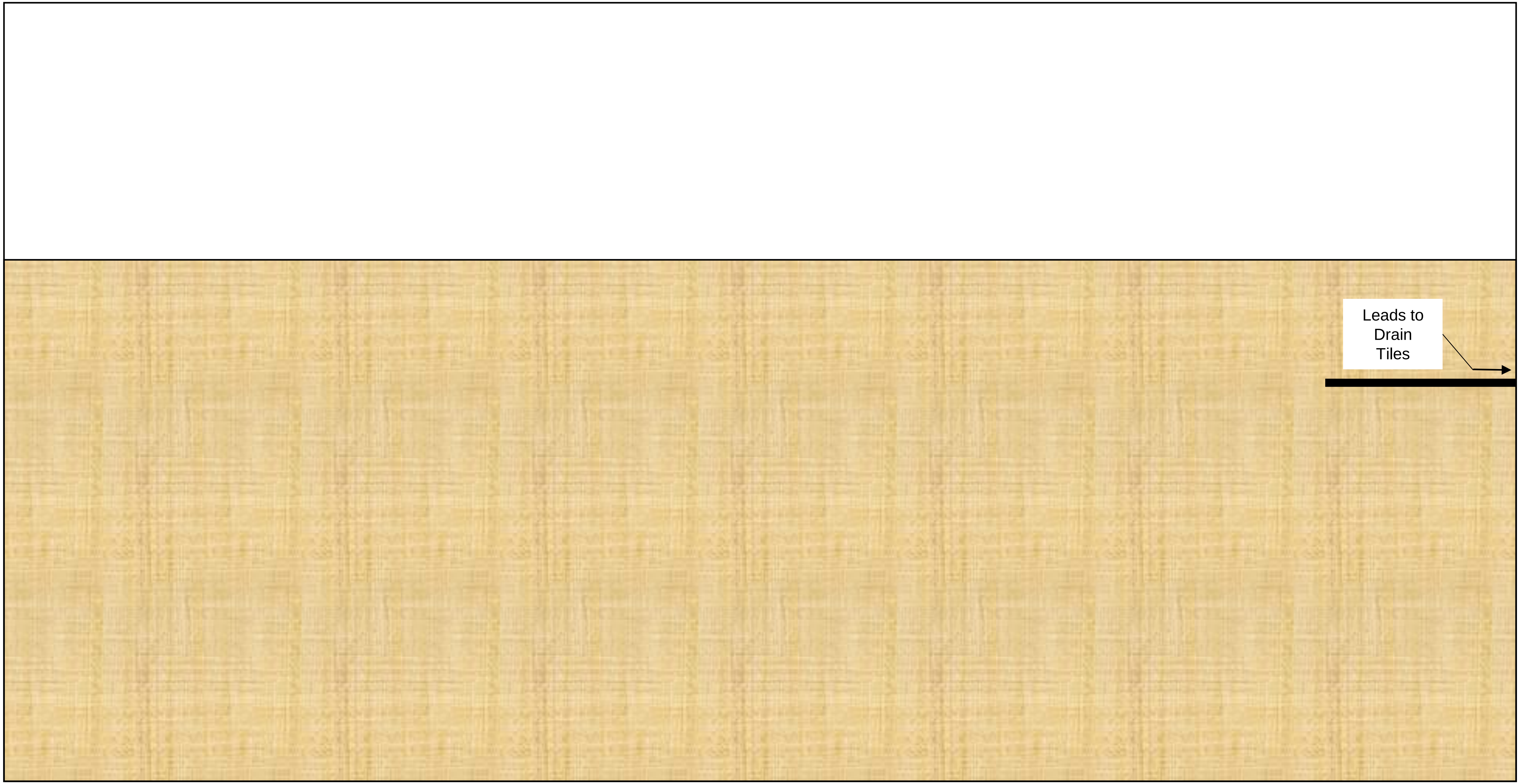


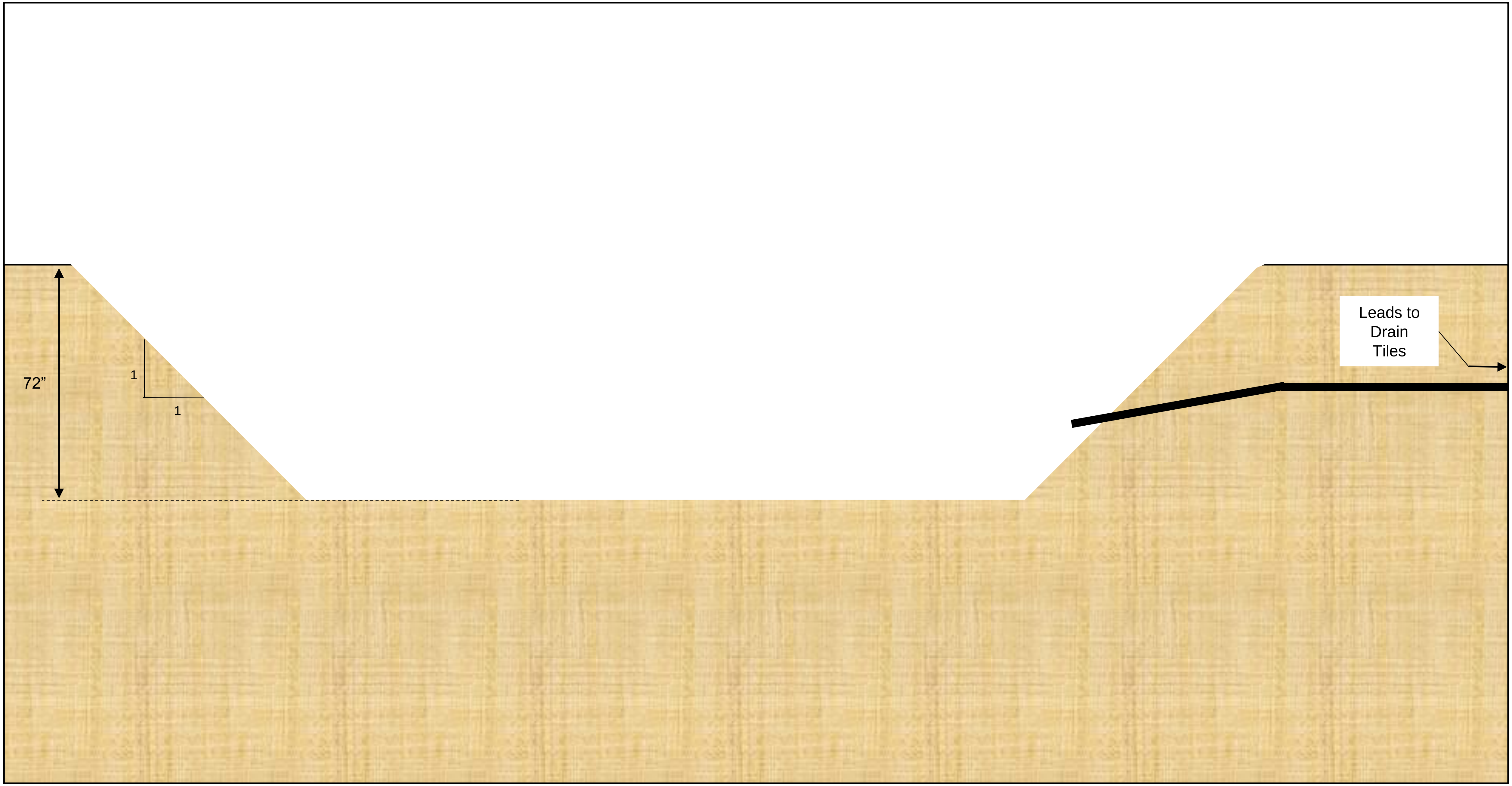
Brine Pond Remediation



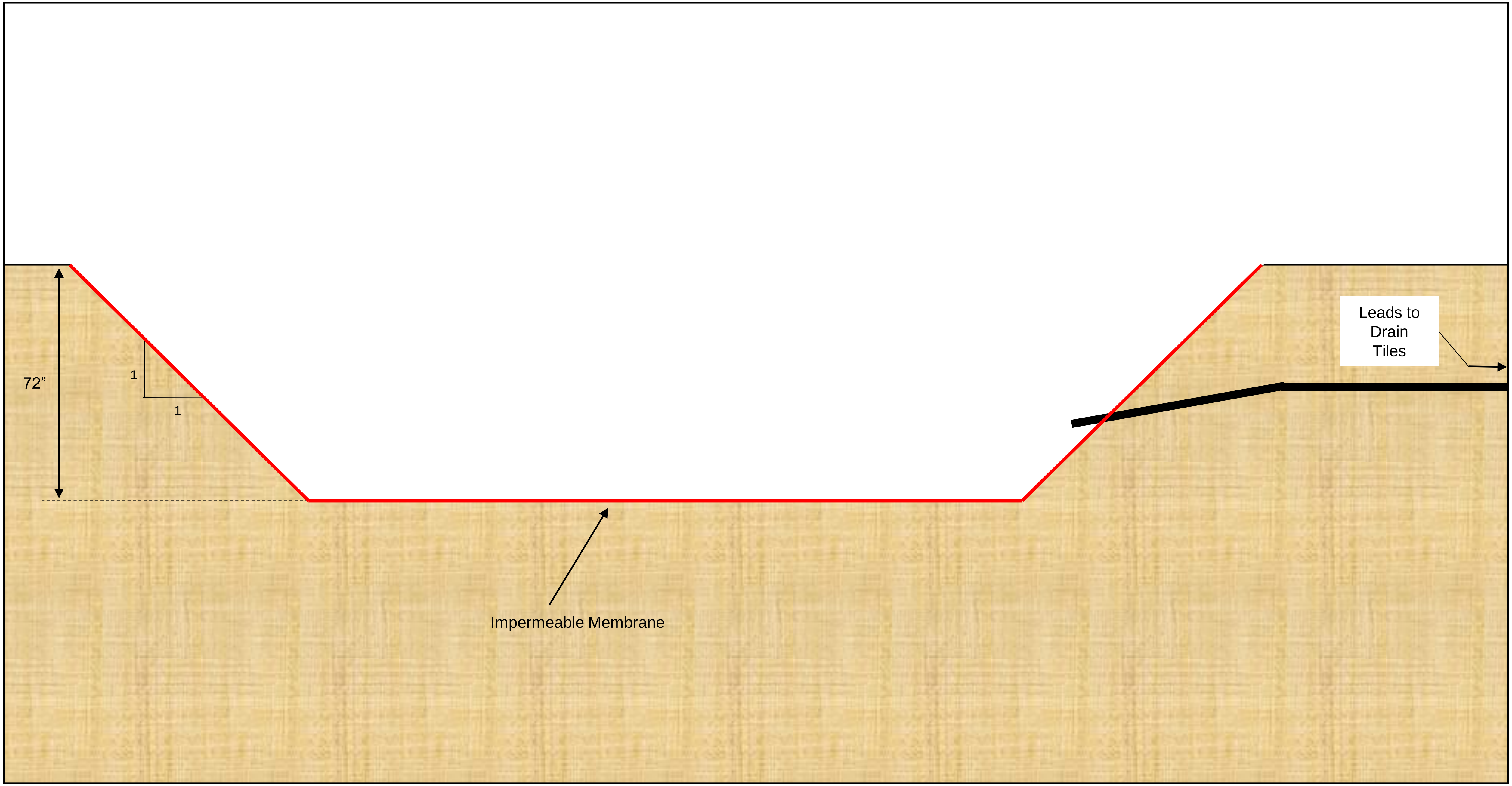
Phytoremediation Cell Installation



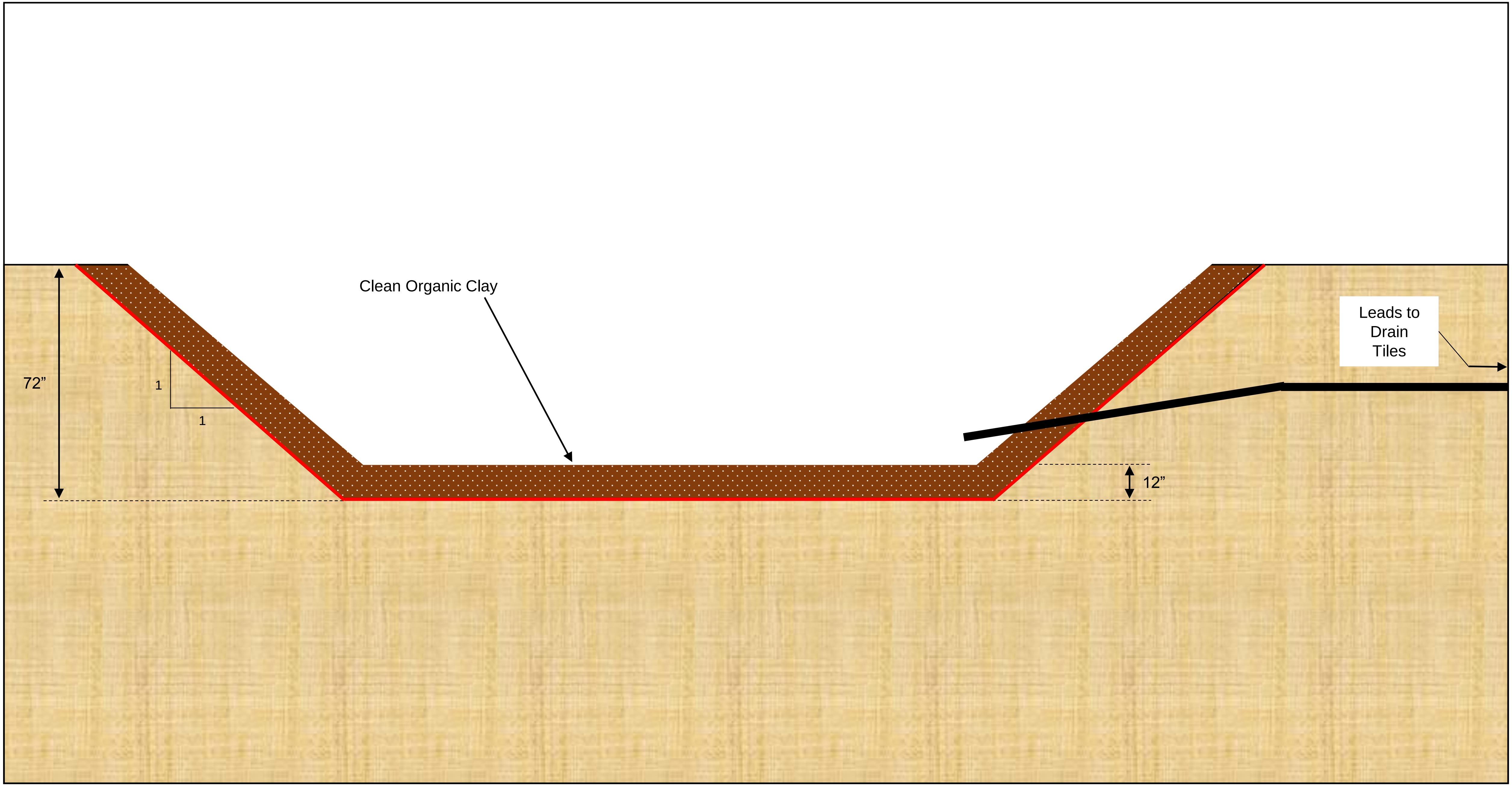
Phytoremediation Cell Installation

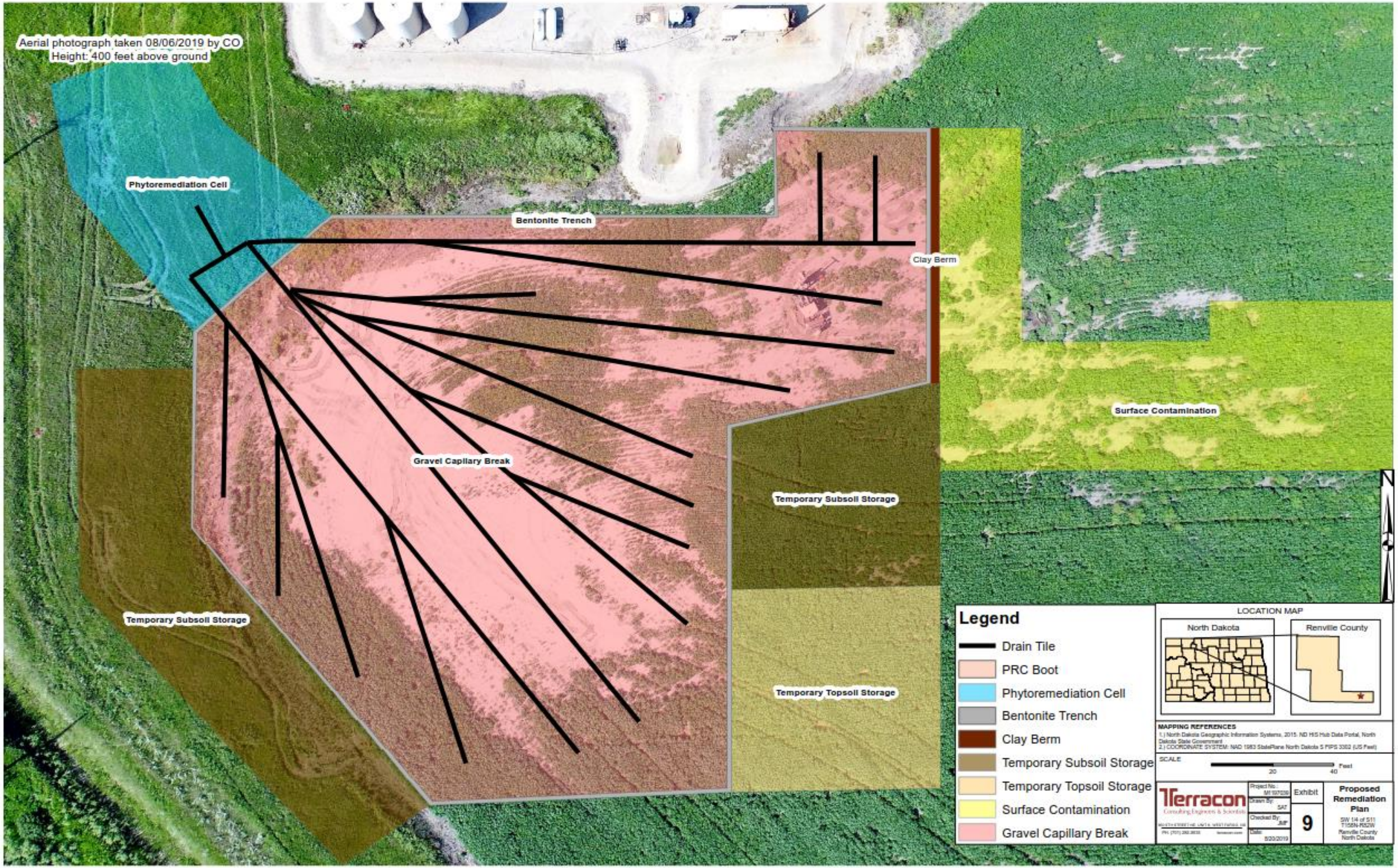


Phytoremediation Cell Installation



Phytoremediation Cell Installation





Aerial photograph taken 08/06/2019 by CO
Height: 400 feet above ground
Phytoremediation Cell
Bentonite Trench
Clay Berm
Surface Contamination
Gravel Capillary Break
Temporary Subsoil Storage
Temporary Subsoil Storage
Temporary Topsoil Storage
Legend
Drain Tile
PRC Boot
Phytoremediation Cell
Bentonite Trench
Clay Berm
Temporary Subsoil Storage
Temporary Topsoil Storage
Surface Contamination
Gravel Capillary Break
LOCATION MAP
North Dakota
Renville County
MAPPING REFERENCES
1.) North Dakota Geographic Information Systems, 2015. ND HIS Hub Data Portal, North Dakota State Government
2.) COORDINATE SYSTEM: NAD 1983 StatePlane North Dakota S FIPS 3302 (US Feet)
SCALE
20
40
Feet
Terracon
Consulting Engineers & Scientists
Project No.:
Drawn By:
SAT
Checked By:
JMF
Date:
8/20/2019
Exhibit
9
Proposed Remediation Plan
SW 1/4 of S11
T158N-R82W
Renville County
North Dakota


CX160D


CASE

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QUESTIONS?

[INNOVATIVE TECHNIQUES FOR SITE CHARACTERIZATION AND REMEDIATION OF BRINE IMPACTED SOILS]

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