Finite element seepage analysis on a cap and cover reclamation

Iuri Lira Santos, MSCE
Leslie Hopkinson, PhD
John Quaranta, PhD
Levi Cyphers, MSCE

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Acknowledgements
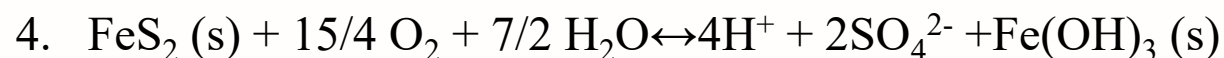
Collaborators include:
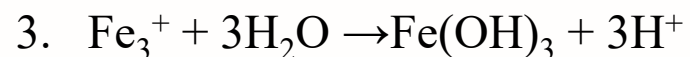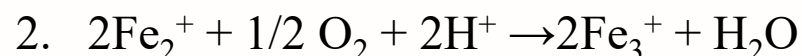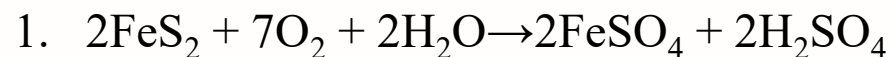
- West Virginia Water Research Institute: Paul Ziemkiewicz, Ph. D., Director

- West Virginia Department of Environmental Protection: Mike Sheehan

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Presentation Outline

- Introduction and background
  - Acid Mine Drainage
  - Cap and covers
  - Unsaturated soil mechanics
- Project description
  - Site description
  - Project rationale
  - Materials and methods
  - Results
  - Cost comparison
  - Conclusions

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Acid Mine Drainage

Acid Mine Drainage (AMD) is formed when sulfide minerals in the Coarse Coal Refuse (CCR) are exposed to oxidizing conditions (water and oxygen), forming highly acidic solution.

1. $2FeS_2 + 7O_2 + 2H_2O \rightarrow 2FeSO_4 + 2H_2SO_4$

2. $2Fe_2^+ + 1/2\ O_2 + 2H^+ \rightarrow 2Fe_3^+ + H_2O$

3. $Fe_3^+ + 3H_2O \rightarrow Fe(OH)_3 + 3H^+$

4. $FeS_2\ (s) + 15/4\ O_2 + 7/2\ H_2O \leftrightarrow 4H^+ + 2SO_4^{2-} + Fe(OH)_3\ (s)$

Source: Author

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AMD treatment

- Passive (low acidity and flow)
  - Wetlands: aerobic and anaerobic
  - Limestone drains, beds, channels,
  - etc.

- Active
  - Treatment ponds,
  - Clarifiers,
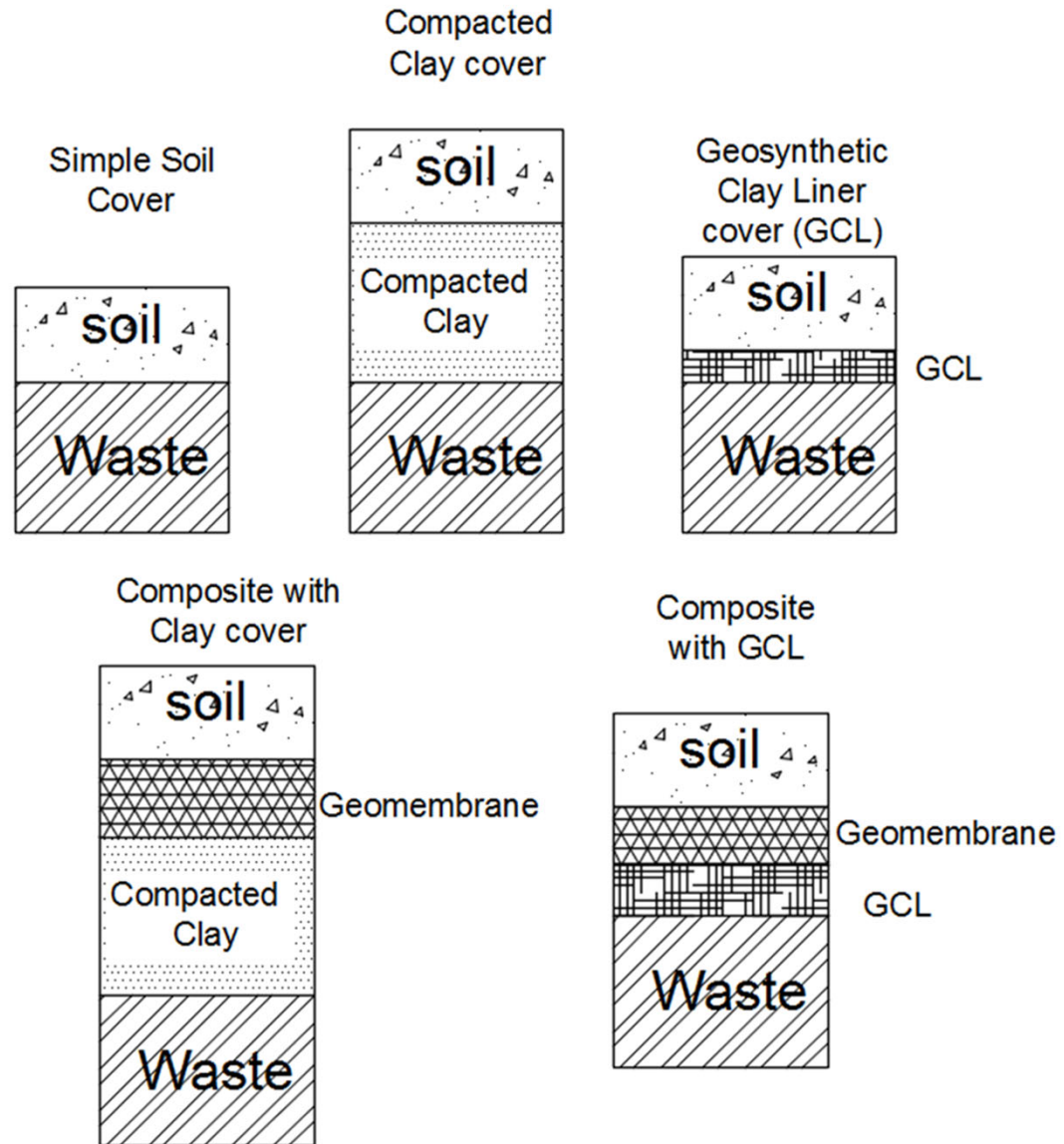 - etc.

Source: Author
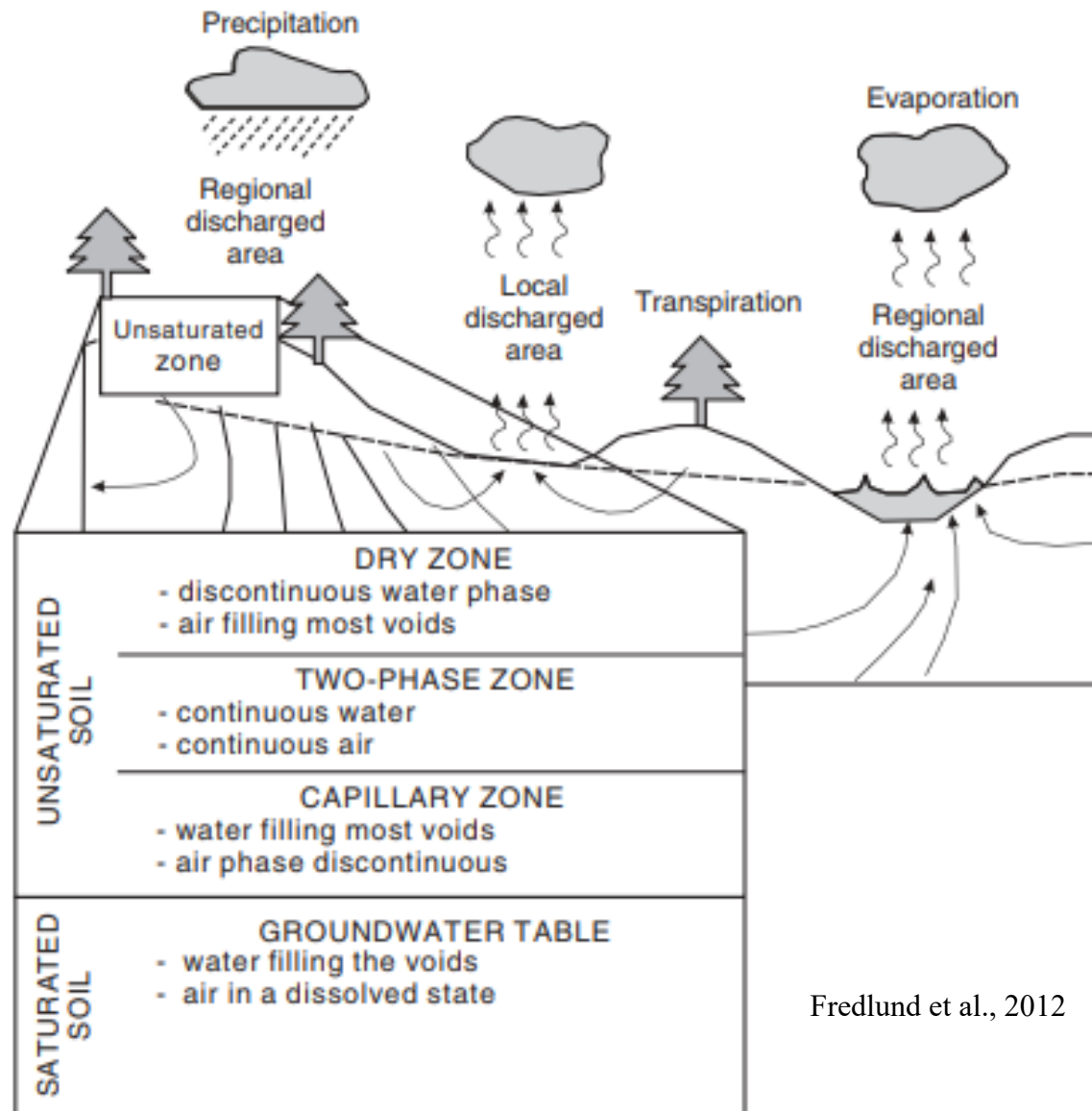
Cap and Cover Systems

- Minimize infiltration of precipitation into the subsurface and minimize gas venting to surface

- Provide vegetative surface to produce an ecological and resistive layer to erosion and freeze / thaw

Examples

- Low permeability layers
  - Seepage occurs on topsoil
  - Used in conventional (less hazardous waste) landfills

- High permeability layers over impermeable layer
  - Function as a protection cap
 - Surface texture has to be carefully selected

Simple Soil Cover

Compacted Clay cover

Geosynthetic Clay Liner cover (GCL)

Composite with Clay cover

Composite with GCL

soil

Waste

Compacted Clay

Geomembrane

GCL

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Unsaturated Soil Mechanics

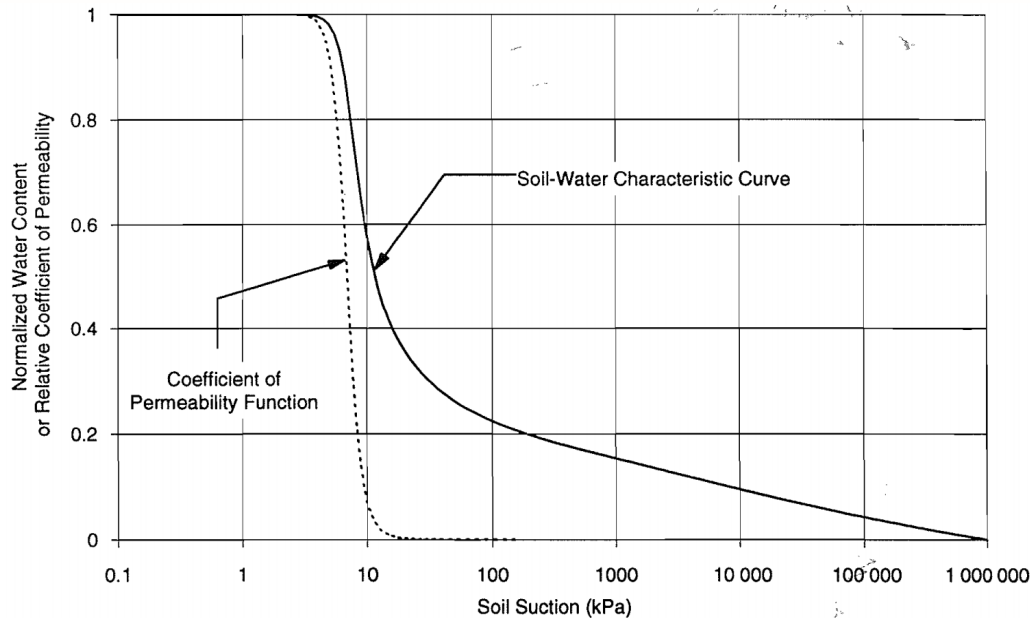Fredlund et al., 2012

Unsaturated Soil Mechanics

- Considers that the soil mass is conceived as a multi-stage system, composed of soil, water, air and a contractile skin
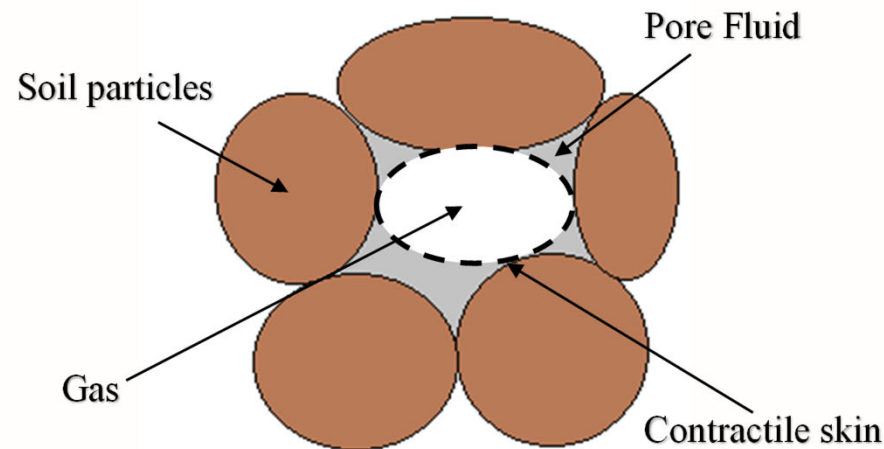
- Interaction of the air influences the water flow through a soil, affects soil strength parameters, stress-strain and deformation behavior,

- Soil-Water Characteristic Curve indicates soil-water interaction which correlates the water content and the soil suction

Soil Water Characteristic Curve (SWCC)

Fredlund et al., 1994

- Soil suction to water content drives permeability
- SWCC reflects the soil texture and granulometry

Project Description

Project Drivers

- The pile consists of pyritic coarse coal refuse shale producing acid mine drainage (AMD) to watershed,

- The site was abandoned in 1999 and is constantly being treated with conventional settlement ponds for pH stabilization and metal removal (caustic soda).

- Treatment cost averages on $220,000/ year

- One of highest cost AMD sites for WV

Royal Scot Demonstration Site

Adapted from Stevens, 2016

- Located in Greenbrier County, WV
- Coarse coal refuse disposal site
- Abandoned in 2001
- Ridge-top refuse disposal

Royal Scot Location

Source: Author

Source: Google earth
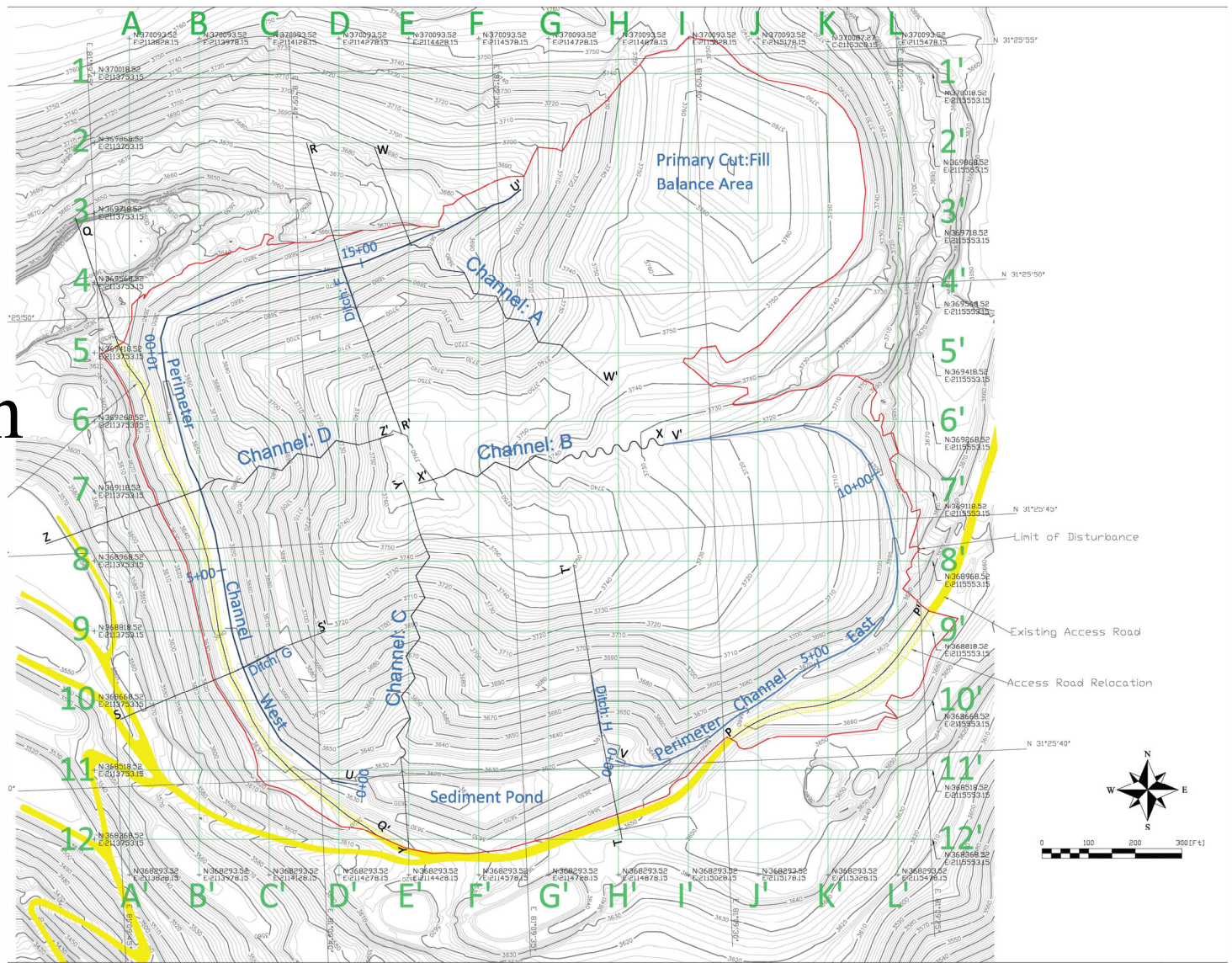
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Site Conditions

Source: Author

Materials and Methods

- Reclamation utilized Geomorphic Landform Design principles

- Geotechnical material laboratory testing

- Slope stability analysis and design

- 3D Seepage analysis and cap/cover system design

Proposed reclamation plan

Soil Properties

- Coarse coal refuse
    - Sand-like material with gravel
- Short paper fiber composition-
    - Primary (~85%): Solids from primary clarification (wood fiber, lime, mineral additives)
    - Secondary (~15%): Microbial biomass from biological wastewater
- Has been tested as an amendment for soil
- Benefits to refuse: adds organic matter and nutrients, lowers pH

Background: Use of Paper Mill Residuals in reclamation

- Compacted to form hydraulic barrier
    - New England MSW landfills

- Soil Amendment
    - Has been successfully applied at WV sites
    - Short paper fiber produced by WestRock's Covington paper mill (marketed as MGro™)
    - Favorable characteristics for plant growth, acid-neutralization potential and suitable strength (internal angle of friction of approximately 30°)
    - Visual examination shows clumped masses of fibrous material with wood chips and clay-like material. The material swells noticeably when wet.

Typical MGro™ sample

Martinka Mine site: Marion County

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2 Layer Design

Growth Layer:

- Mixture of shale and MGro™ in fixed volumetric ratio.
- Initial results from the 60% shale: 40% SPF blend have been favorable.
- 60/40 Mgro Geotechnical properties defined in laboratory testing
- Proposed thickness = 1 feet

Impermeable Layer

- Intended for seepage infiltration control
- Compacted coarse coal refuse
- Preliminary thickness ranges = 1 - 2 ft

Refuse pile material (Cut / Fill)

- Homogeneous
- Source of the acid mine drainage
- Unit weight from 12.5(80.2) to 14.1(90.5) kN/m^3 (pcf)
- Thickness varies 9 ft. to 147 ft.

2 Layer Final Cover System

| Growth Layer |
| Low permeability Layer |
| Site Coarse Coal Refuse (CCR) |
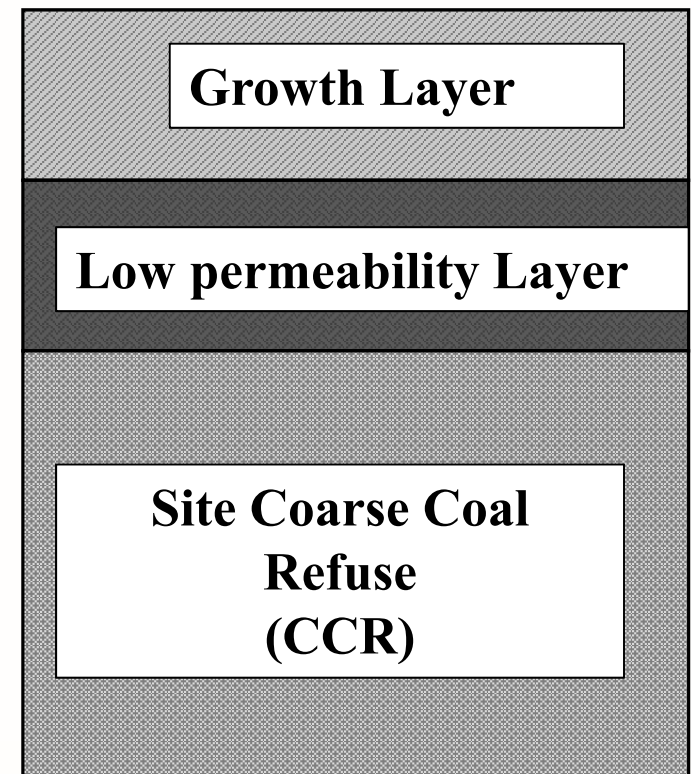
Final ASTM- USCS Grain Size Distribution & Classification

CCR Shale:	**SP - Poorly Graded Sand with Gravel (>15% gravel)**
MGro:	**SP - Poorly Graded Sand with Gravel (>15% gravel)**
60% CCR + 40% Mgro:	**SW - Well Graded Sand with Gravel**
80% CCR + 20% Mgro:	**SW - Well Graded Sand with Gravel**
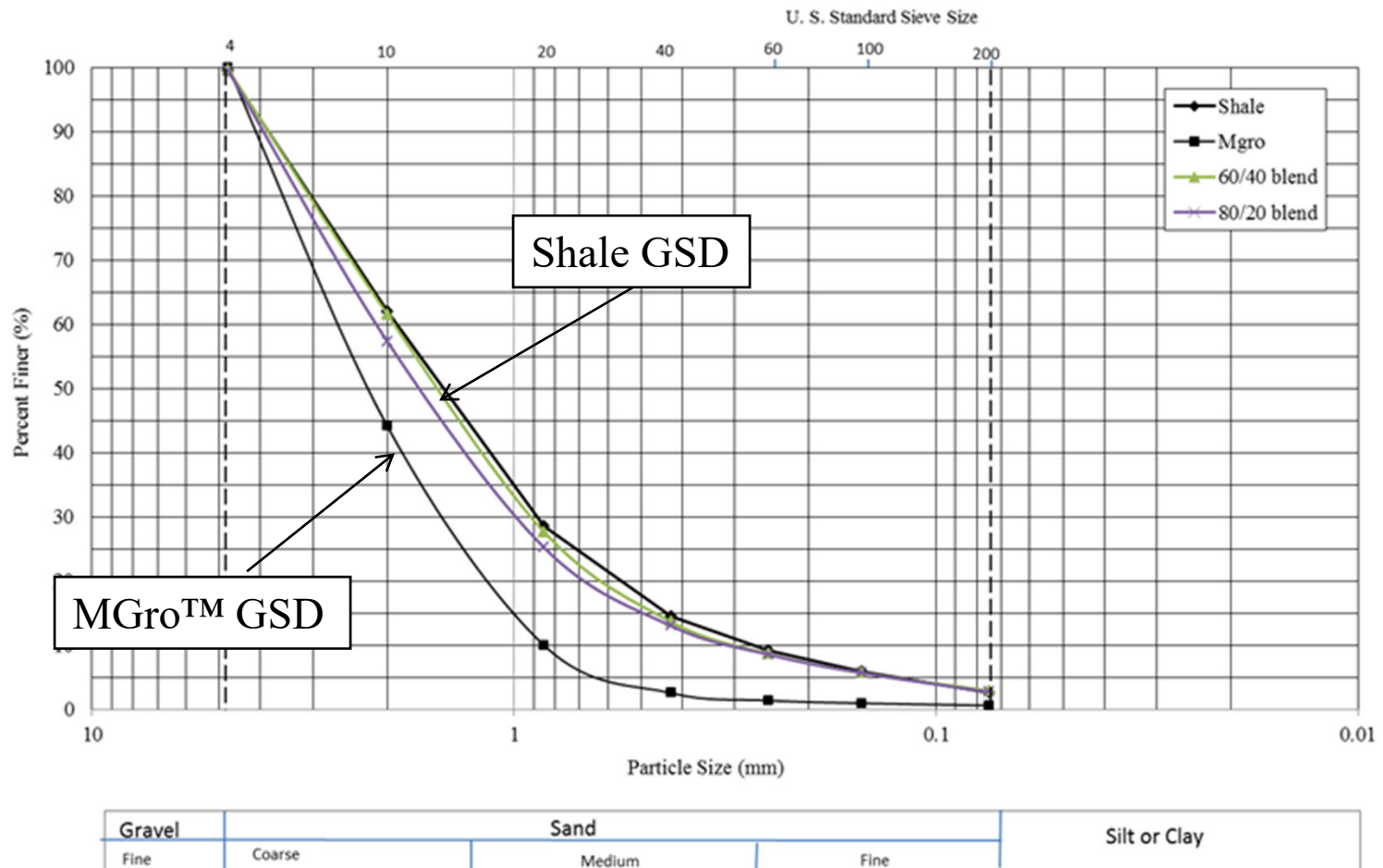
Materials Properties

Material	Saturated Hydraulic Conductivity (cm/s)	Porosity	Specific Gravity
Fill	4×10^{-4}	0.45	2.65
Low permeability layer	2×10^{-6}	0.18	2.31
Growth layer	1×10^{-3}	0.52	2.00

Compaction Energy (kJ/m^3)	Optimum dry unit weight (kN/m^3)	Optimum moisture content (%)
67.85 (11% Proctor)	14.6	17.5
203.58 (34% Proctor)	15.1	17.0
592.5 (Standard Proctor)	15.9	14.3

Calculated SWCC
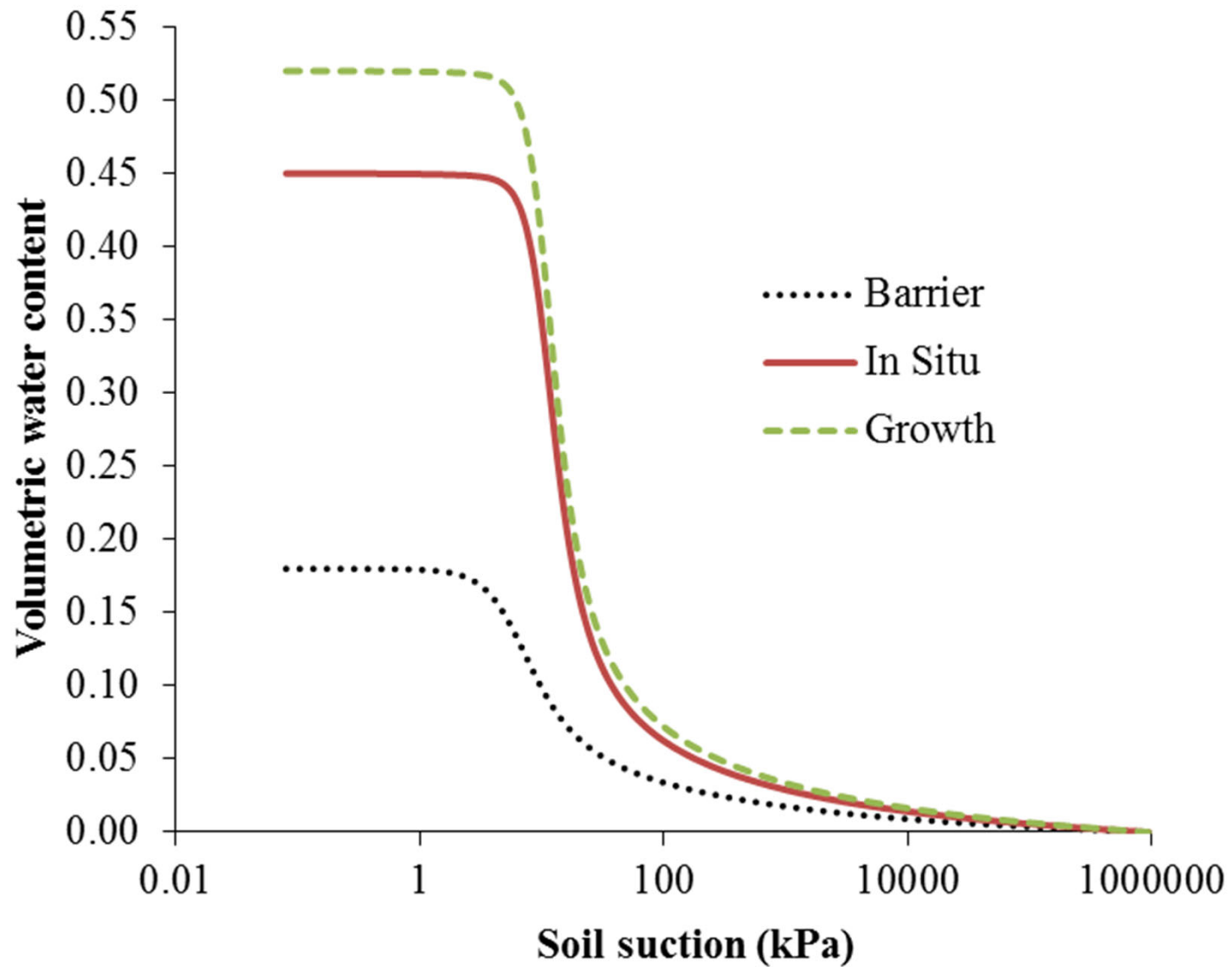
Calculated K$_{unsaturated}$
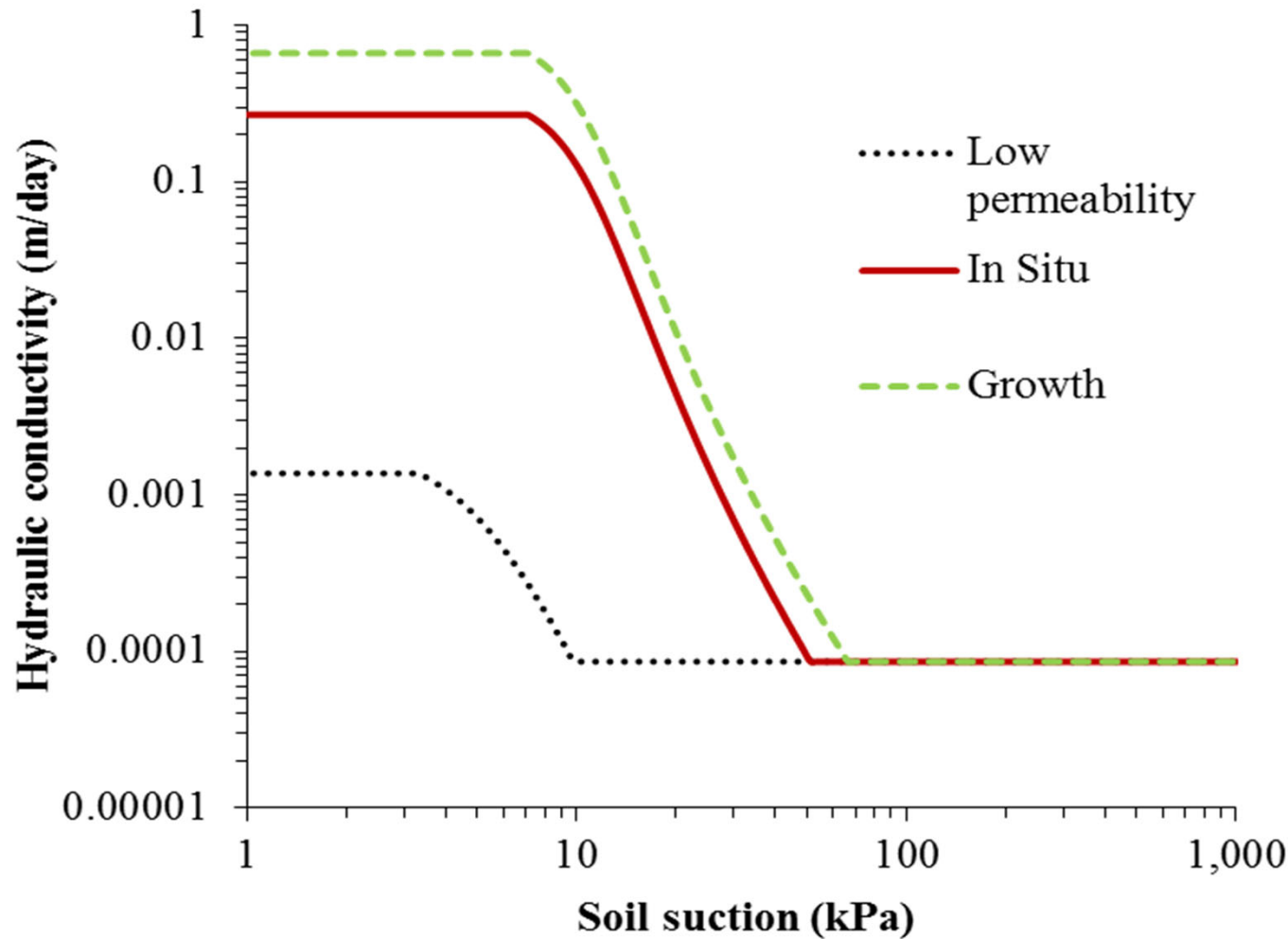
Growth
$K_{sat} = 8.1 \times 10^{-4}$ cm/s
$K_{min} = 10^{-7}$ cm/s

In situ
$K_{sat} = 3 \times 10^{-4}$ cm/s
$K_{min} = 10^{-7}$ cm/s

Low permeability
$K_{sat} = 10^{-6}$ cm/s
$K_{min} = 10^{-7}$ cm/s

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Modeling Analysis

- Plaxis (former Soil Vision) finite element software
- Unsaturated soil mechanics
- Transient analysis
- 3D aspects - Directional flow and Evaporation

Simulation Input Variables

- Precipitation
  - 1-yr., 5-yr., 25-yr., 100-yr. 24-hour rainstorms
  - 59 mm, 82 mm, 112 mm, and 139 mm respectively.
  - Precipitation applied at day 1 of modeling.

- Environmental
  - Evapotranspiration estimated by modified Wilson-Pennman (Wilson et al., 1994)
  - Temperature 20^oC, 70% humidity, 20 Mj/m^2/day, wind speed 1 m/s.

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Model conception

- Comparison between bare refuse to cap and cover
- Two topographical characteristics evaluated:

  Steep (> 1V : 4H)

  Flat   (< 1V : 4H)

- Extrapolate the infiltration rates for whole site
- Why? – issues with geometry due to compacted layer did not converge the model
- 2ft. layer was too thin

Note:
140m = 459ft
160m = 525ft

Steep slope model – relative coordinates (m)
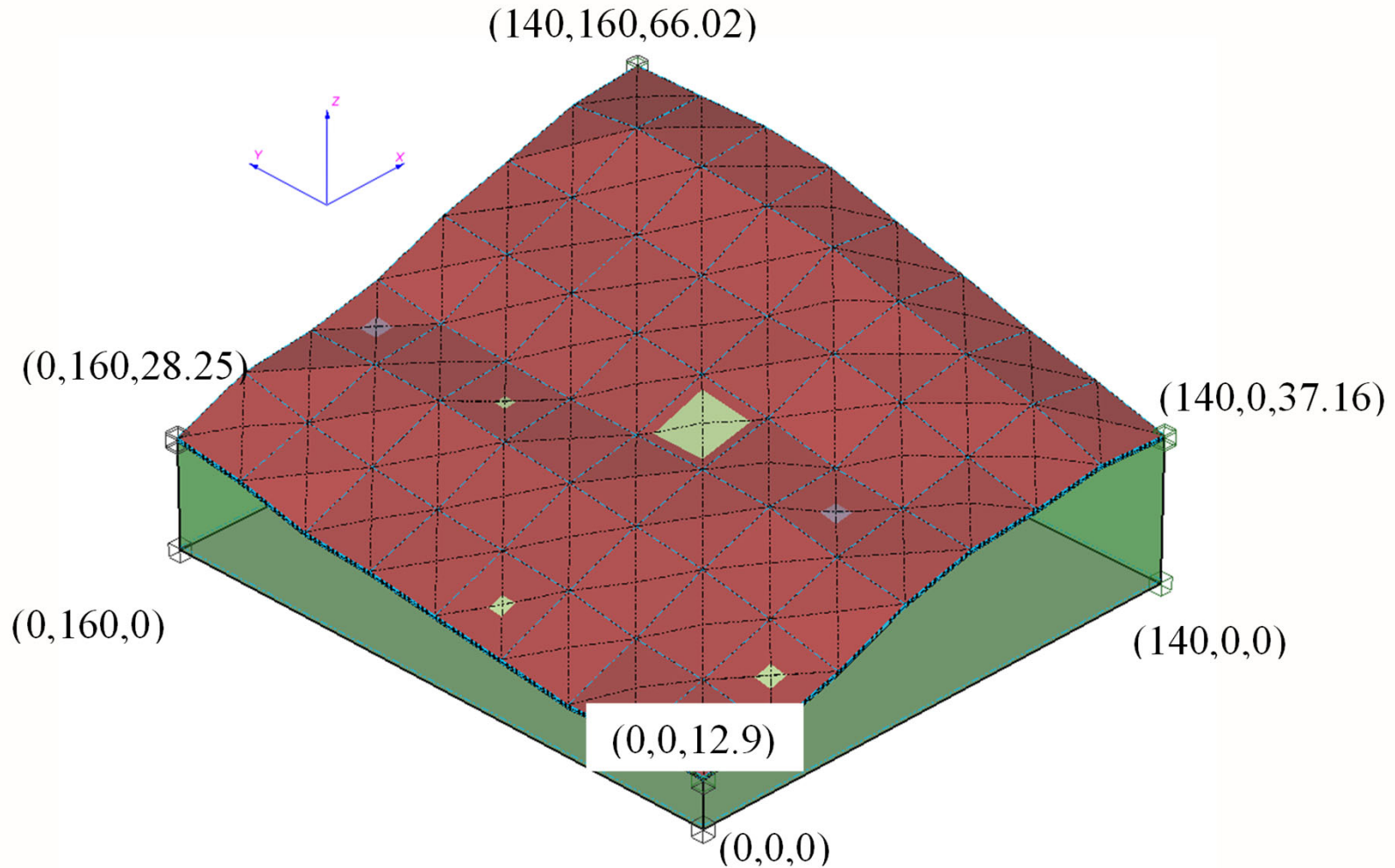
Flat slope model – relative coordinates (m)
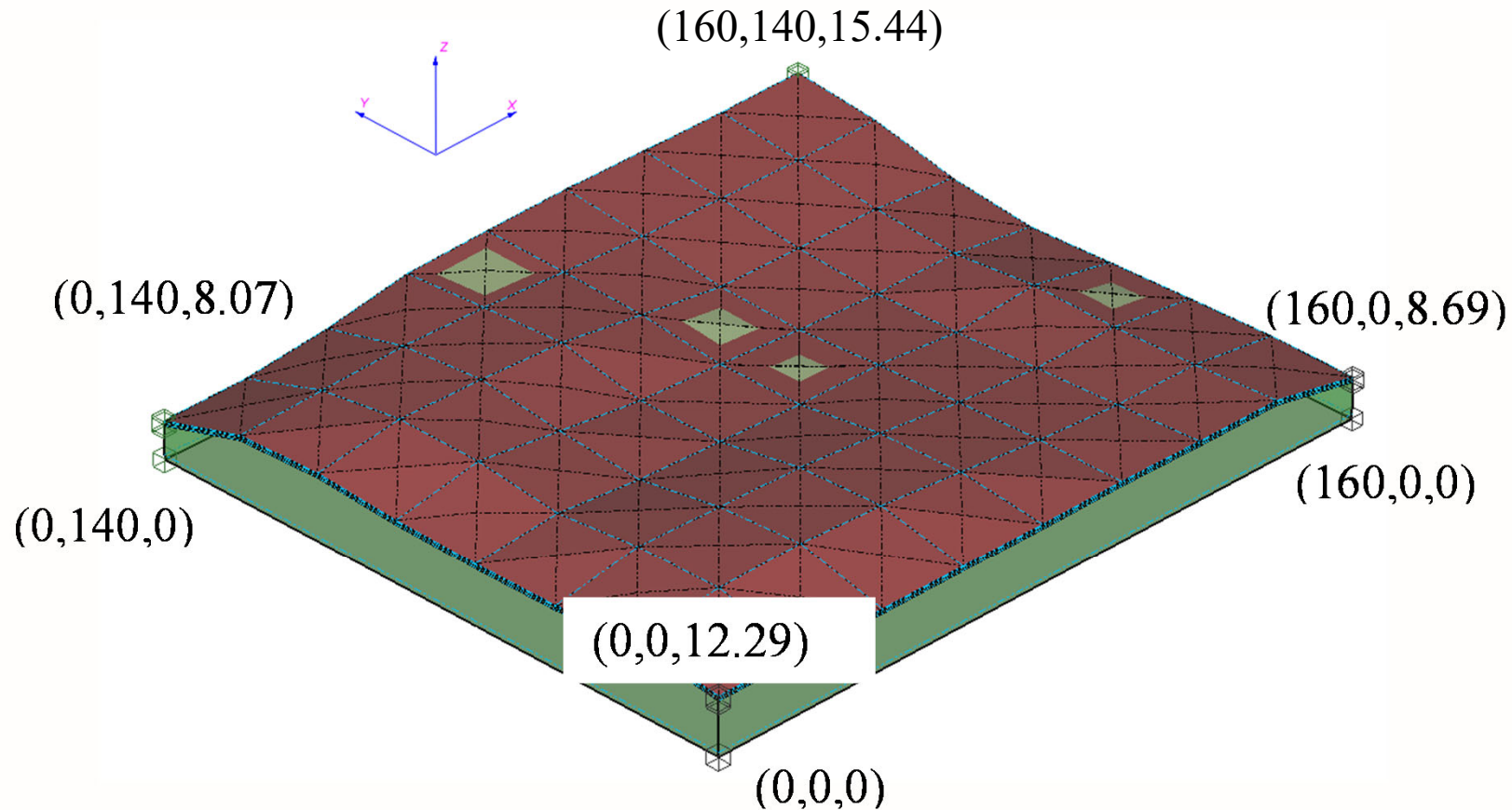
Results

Seepage summary: days to return to initial (day 0) water content

		Precipitation Event			
		1-yr	5-yr	25-yr	100-yr
Steep	Without cover	17	30	50	61
	With cover	25	36	58	63
Flat	Without cover	17	21	29	45
	With cover	26	32	51	66

25-year storm – Steep model

a) Day 0
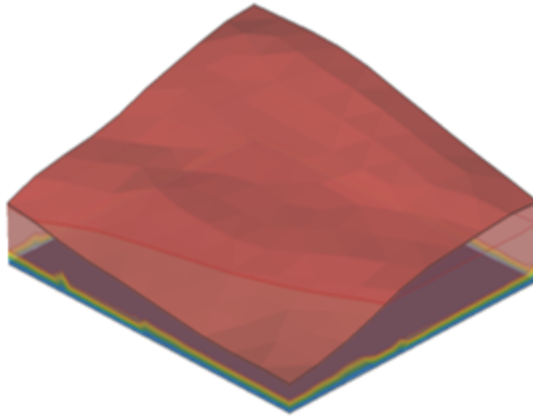
b) Day 2
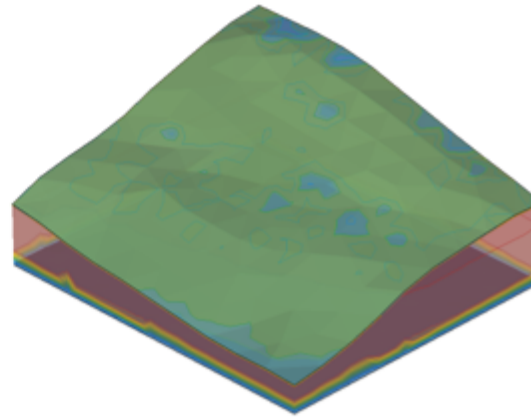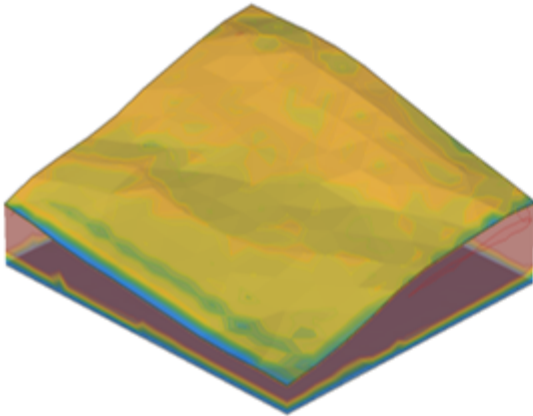
c) Day 10

d) Day 15

e) Day 45

Degree of Saturation
Sat

0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
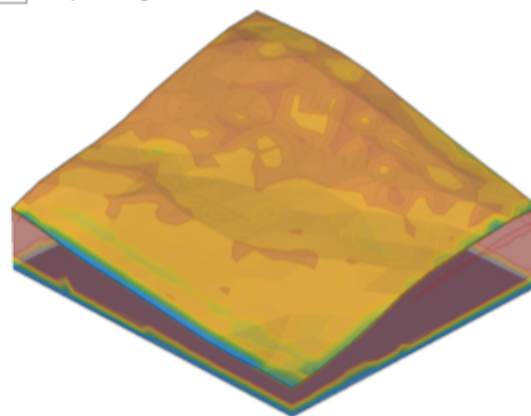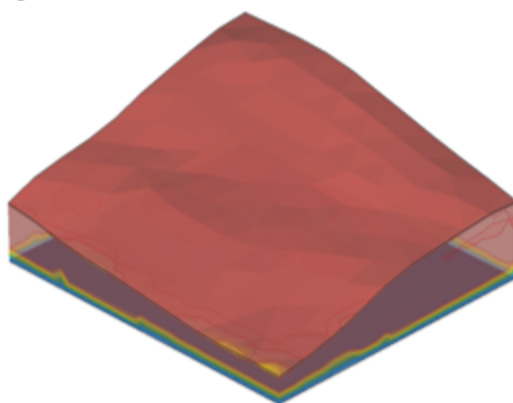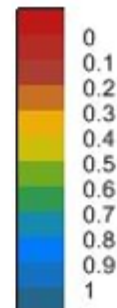
a) Initial volumetric water (dry)
b) Day after precipitation; 60%-70% saturation
c) Saturation reduction by evapotranspiration and seepage
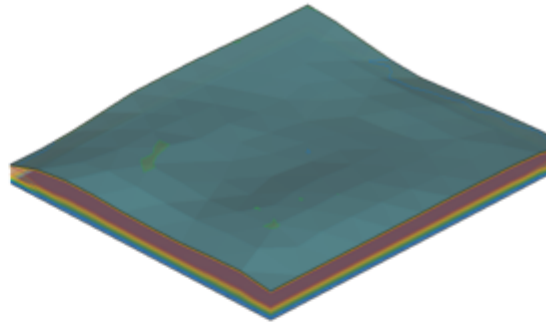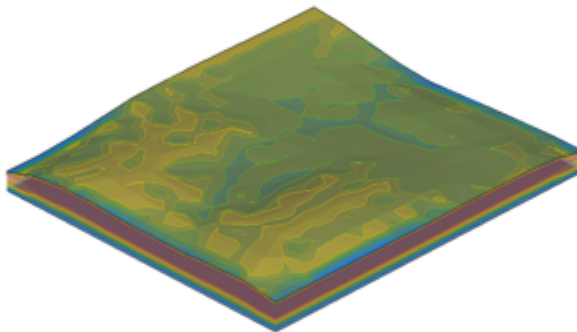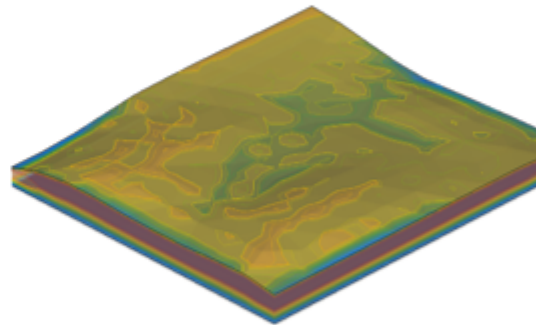d) Desaturation progress
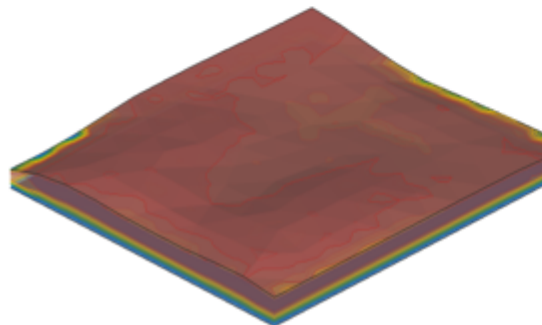e) Almost dry

25-year storm – Flat model

a) Day 0
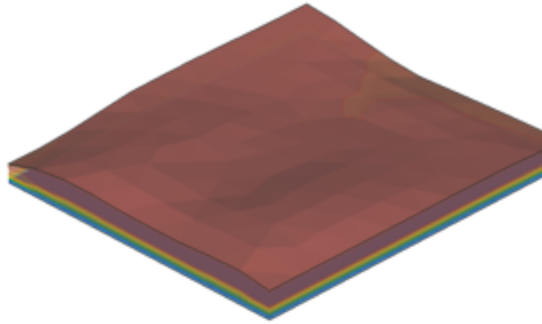
b) Day 2

c) Day 10

d) Day 15

e) Day 45

Degree of Saturation
Sat

0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
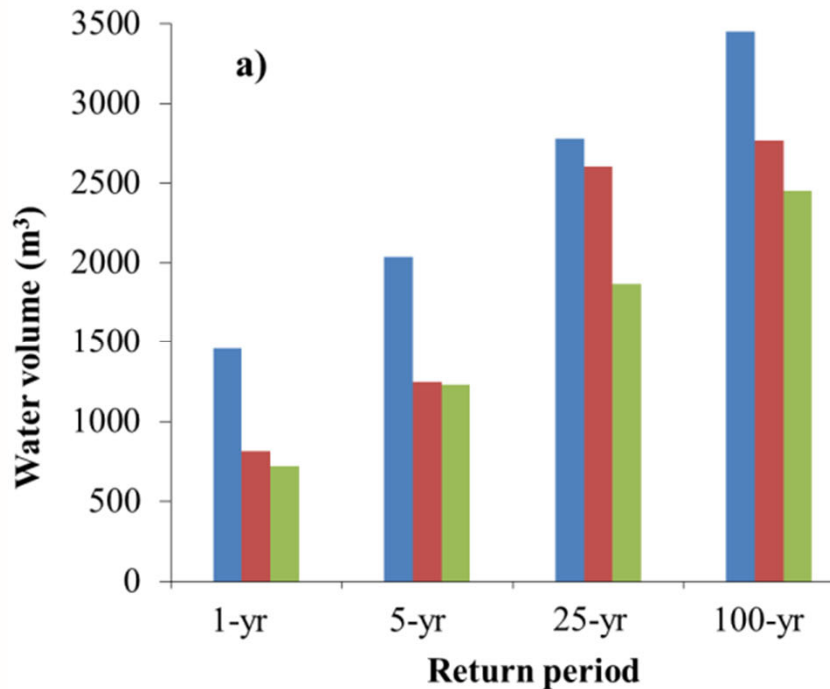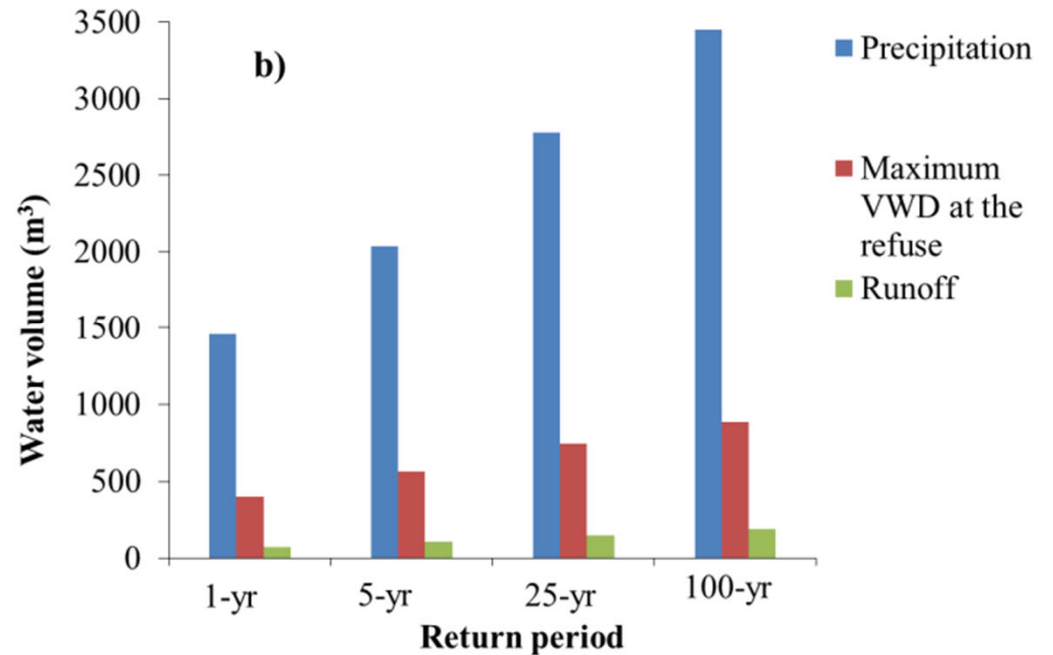1
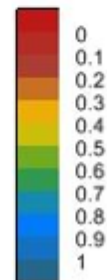
a) Initial volumetric water (dry)
b) Day after precipitation; 70%-80% saturation
c) Saturation reduction by evapotranspiration and seepage
d) Desaturation progress
e) Almost dry

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Steep slope water balance

a) Without cover
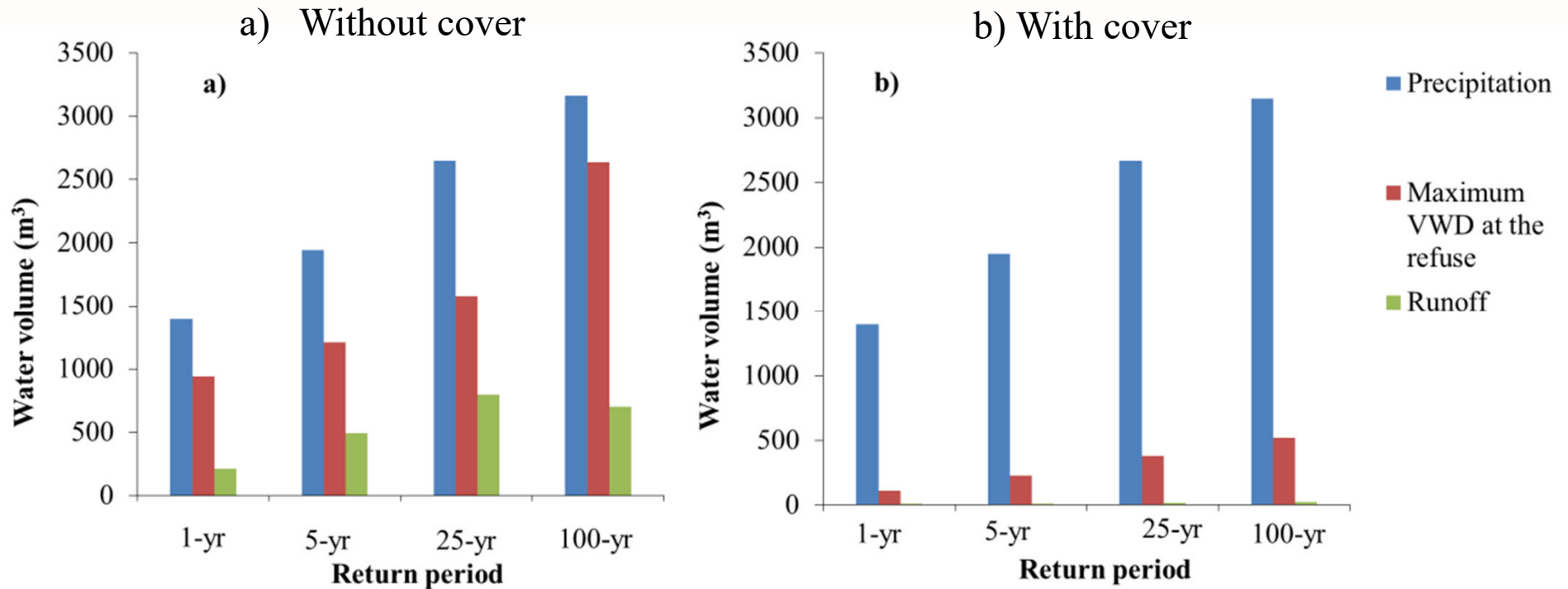
b) With cover

Note: runoff was mis-calculated in this case
due to model runoff calculation method

Flat slope water balance
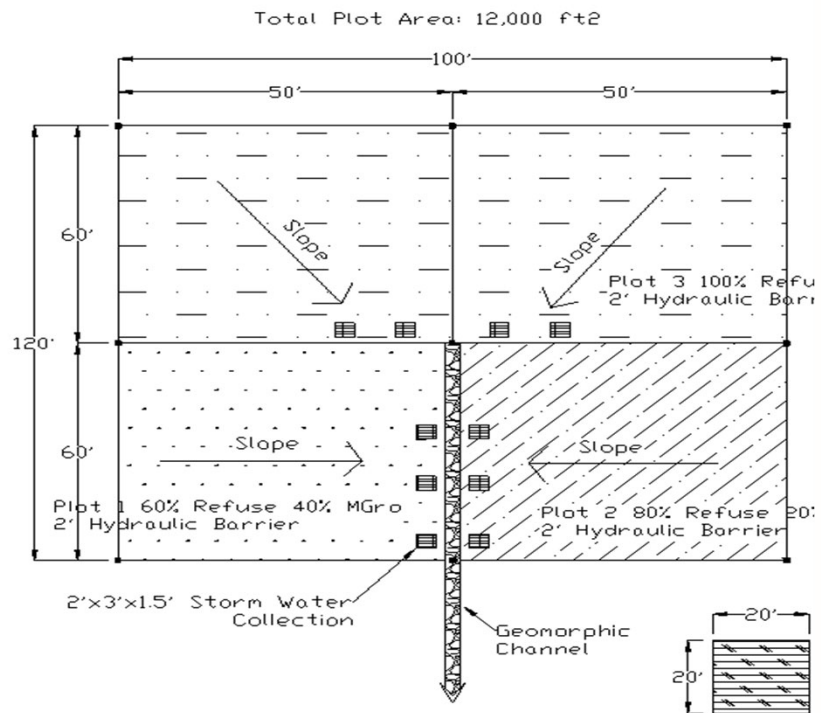

a) Without cover   b) With cover

Slope stability analysis

- Regrade to maximum 2H:1V slopes

- Establish hydraulic barrier with compacted coal refuse

- Develop growth layer composed of paper fiber and coal refuse manufactured topsoil

- **Factor of Safety of 2.3**

Pilot Test

Test Plot Construction

Total Plot Area: 12,000 ft2
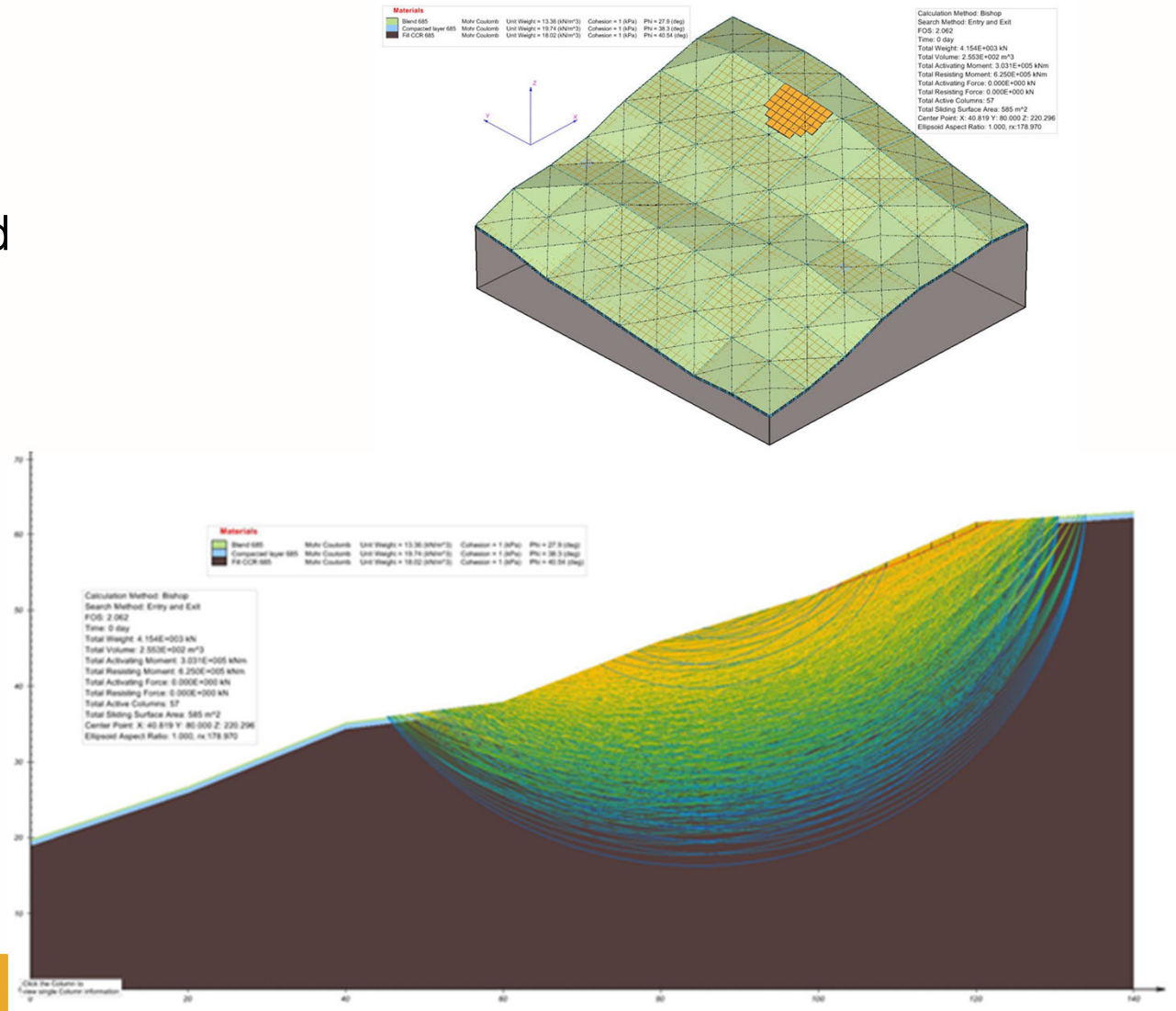
Variety of Seed	Application Rate (lb/acre)
Orchardgrass	15
Birdsfoot Trefoil	15
Red Clover	10
Annual Ryegrass	15
Bicolor Lespedeza	1
Winter Wheat	20

Source: WVDEP

Test Plot Evaluation

- Reseeded May 9th w/straw,
- Paper fiber provided necessary nutrients and pH balance for grass to germinate,
- Slope aspect (north facing) provided a large advantage,
- 70% ground cover was met for NPDES permit.

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September 11, 2018
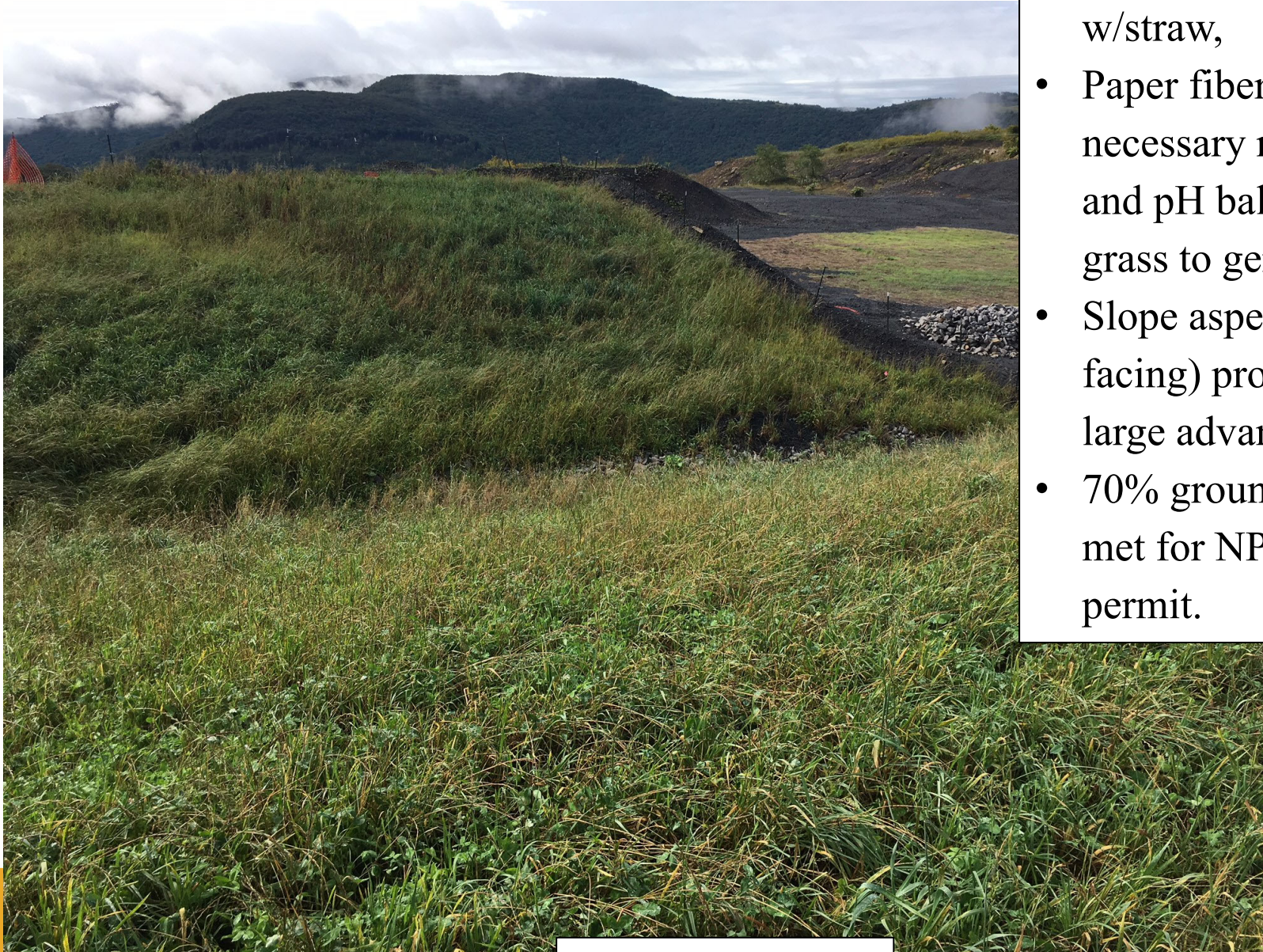
Conclusions

- Implementation of cap and cover reduced water seepage into refuse for the different tested storms,

- Different responses of the models for the simulated precipitations, with maximum volumetric water difference varying from 50% to 88%,

- Slope stability analysis demonstrated safe slopes with FoS of 2.3,

- Growth layer retains water, a benefit for vegetation,

- Short paper fiber blend material utilization shows potential in surface mine reclamation.

Thank you!

Questions?