Evaluation of Geomorphic Reclamation Performance and Models in the Southwestern United States

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Presented by Colin Byrne, May 20th, 2014

Advances in Geomorphic Reclamation at Coal Mine Sites:
A Technical Interactive Forum and Field Tour
May 20-22, 2014

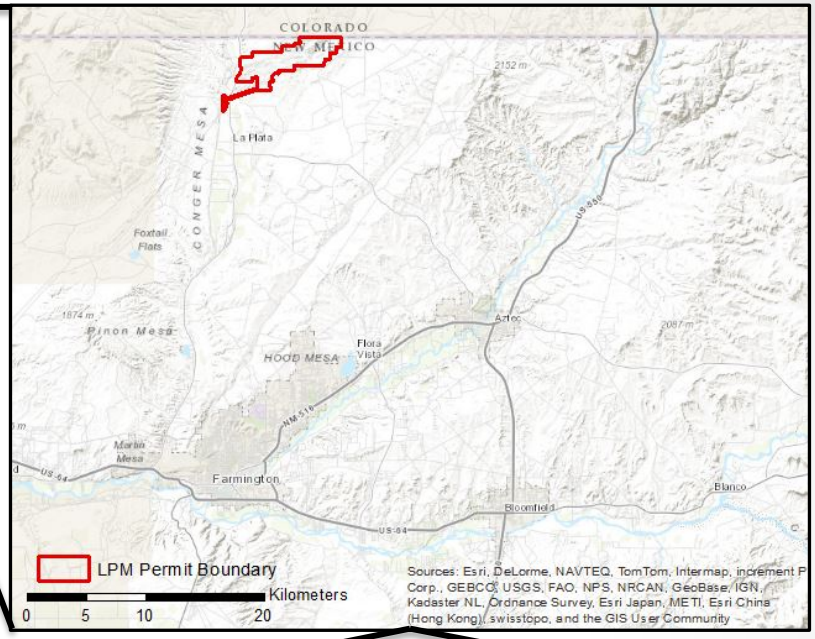
THE UNIVERSITY of NEW MEXICO

bhpbilliton

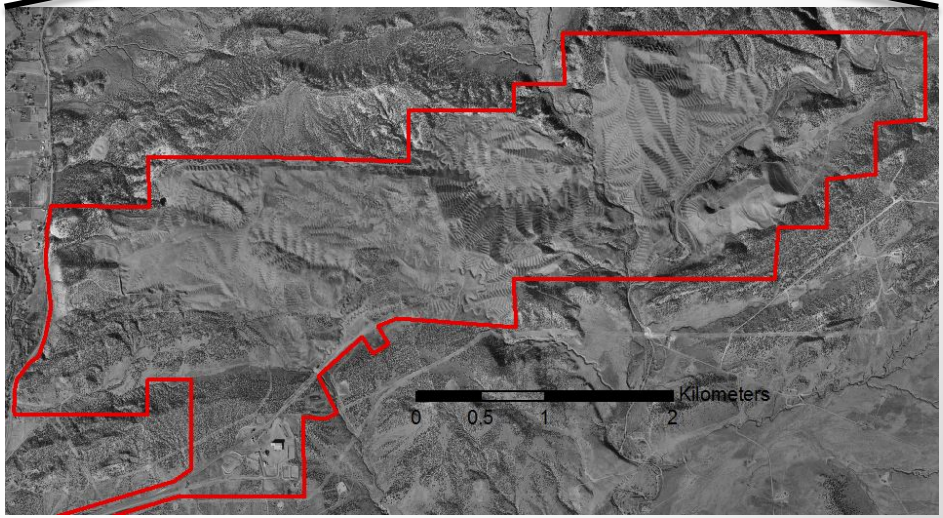
Study Background

- 2 year study began in August 2012
- Funded by Office of Surface Mining
- Working in collaboration with BHP-Billiton
  - La Plata Mine
- Results and Conclusions currently being developed

La Plata Mine, New Mexico



- Open pit mine that produced coal until 2002
- Over 800 hectares in size
- Approx. 6000 ft elevation
- Approx. 12 inches of annual precipitation
- Reclaimed using GeoFluv™ approach



Objectives

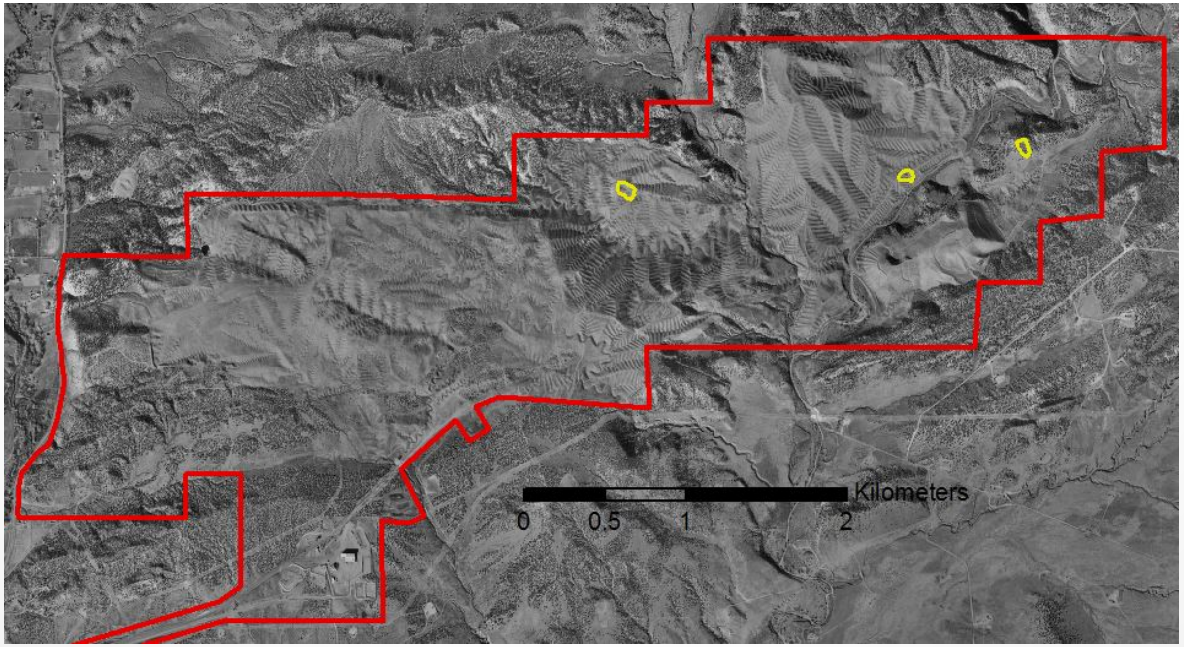
1. Evaluate the effectiveness of geomorphic reclamation at producing conditions that closely mimic those found in natural analog basins and channels

2. Assess the effectiveness of watershed models in informing the geomorphic reclamation process
   - Water Erosion Prediction Project (WEPP)
   - Sediment, Erosion, Discharge by Computer Aided Design (SEDCAD)

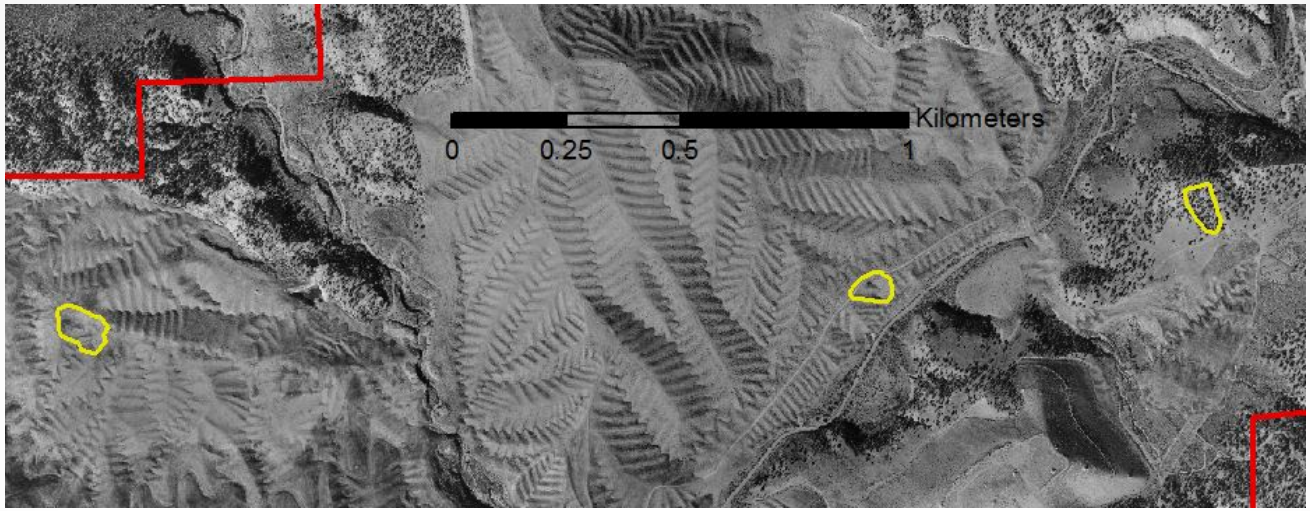
3. Assess seed germination potential based on soil characteristics using the Hydrus 1-D model

Selection of Watersheds

- Three watersheds selected due to similarities in slope, aspect, and size
  - Well Vegetated Reclaimed Site
  - Moderately Vegetated Reclaimed Site
  - Undisturbed Natural Site
- Watersheds sit within 2.5 km of one another



Selection of Watersheds



Moderately Vegetated Reclaimed Watershed

Well Vegetated Reclaimed Watershed

Undisturbed Natural Watershed

Objective 1

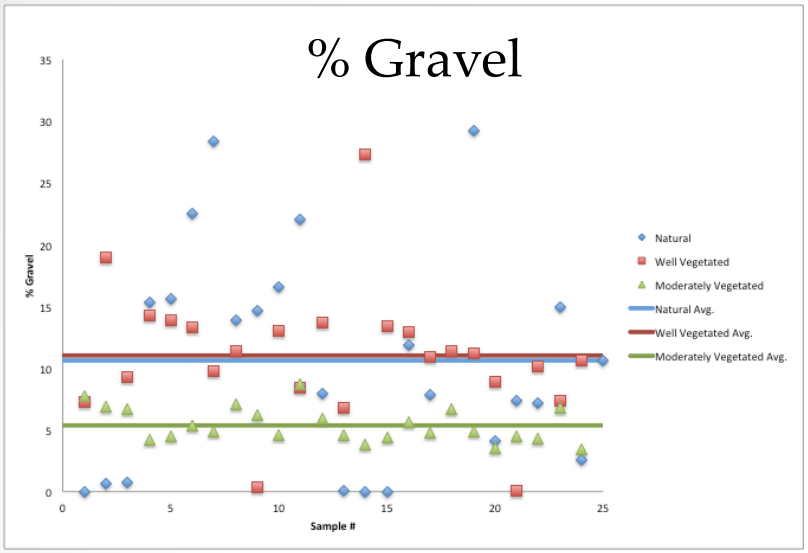
- Evaluate the effectiveness of geomorphic reclamation at producing conditions that closely mimic those found in natural analog basins and channels

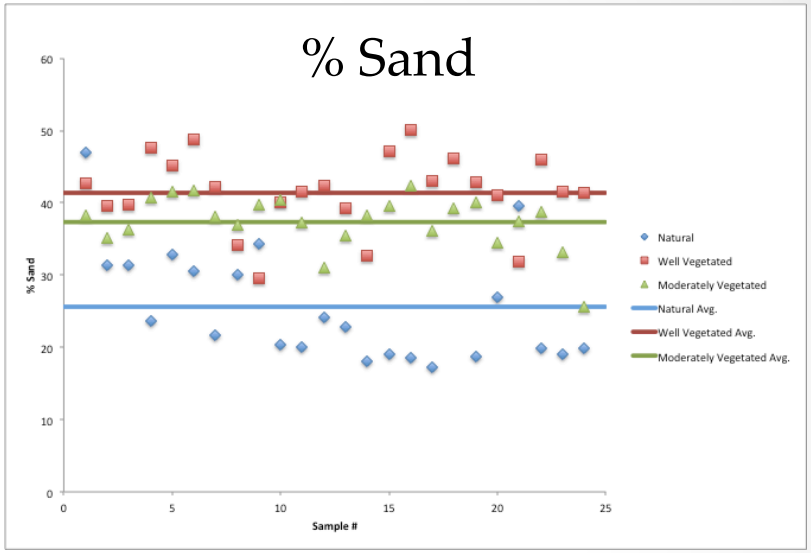
Field Sampling

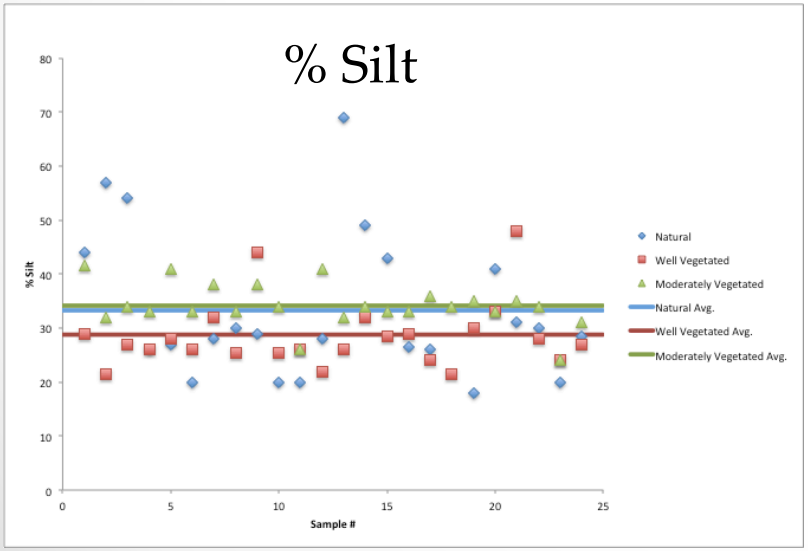
- In situ soil measurements
  - Temperature
  - Moisture content
  - Vegetation
  - Infiltration rates
- Disturbed soil sampling
  - Particle size distribution
  - Specific gravity
  - Organic matter
  - Cation exchange capacity
- Undisturbed soil sampling
  - Saturated hydraulic conductivity
  - Water retention curves
- Check-dams installed
- V-notch weirs installed

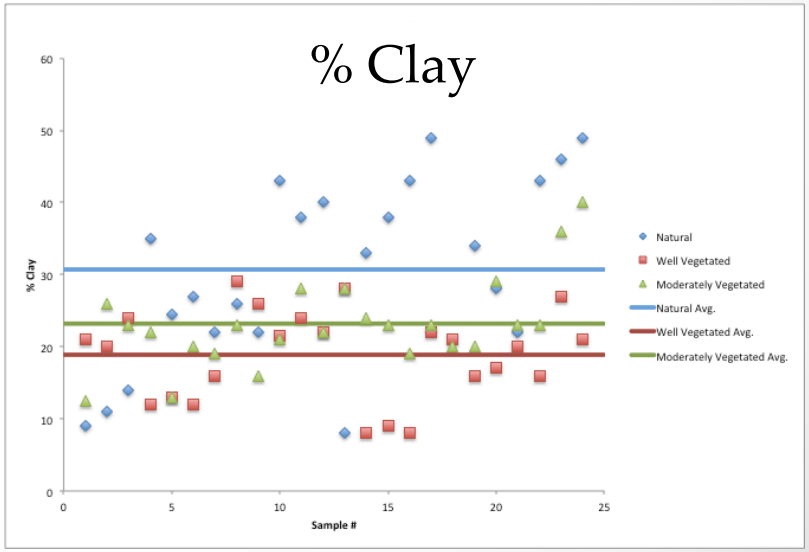
Field Sampling

Site Soil Characteristics

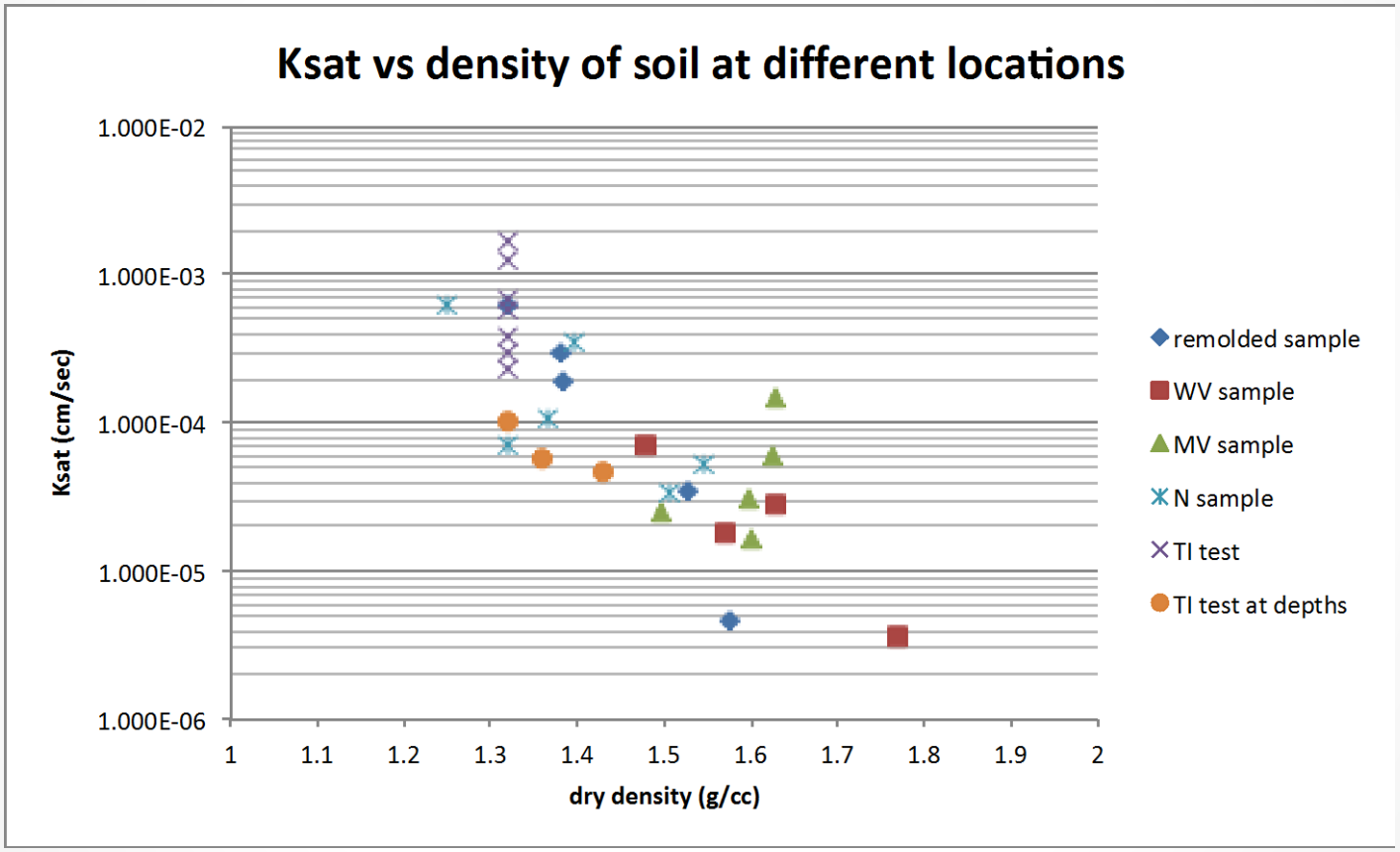






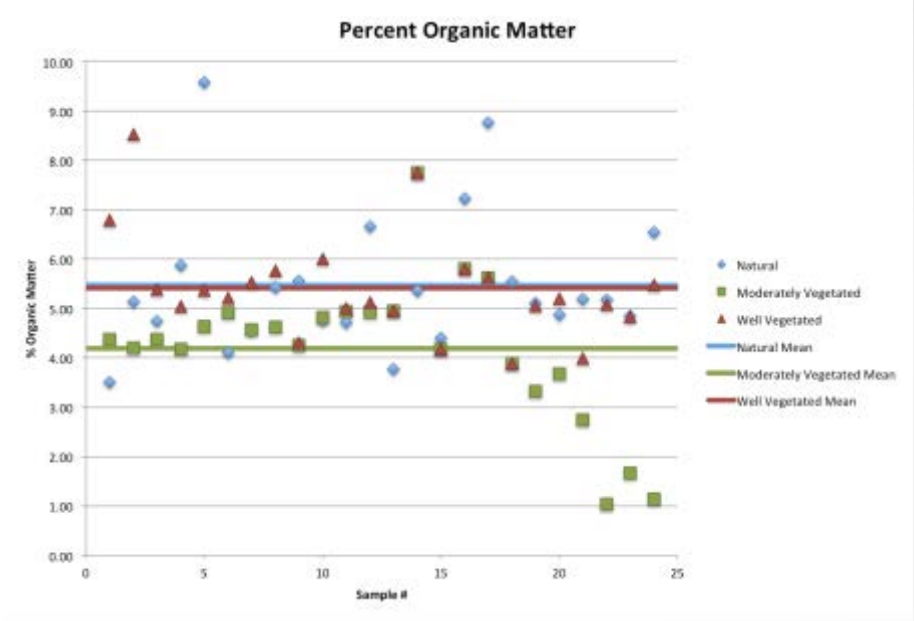


Site Soil Characteristics

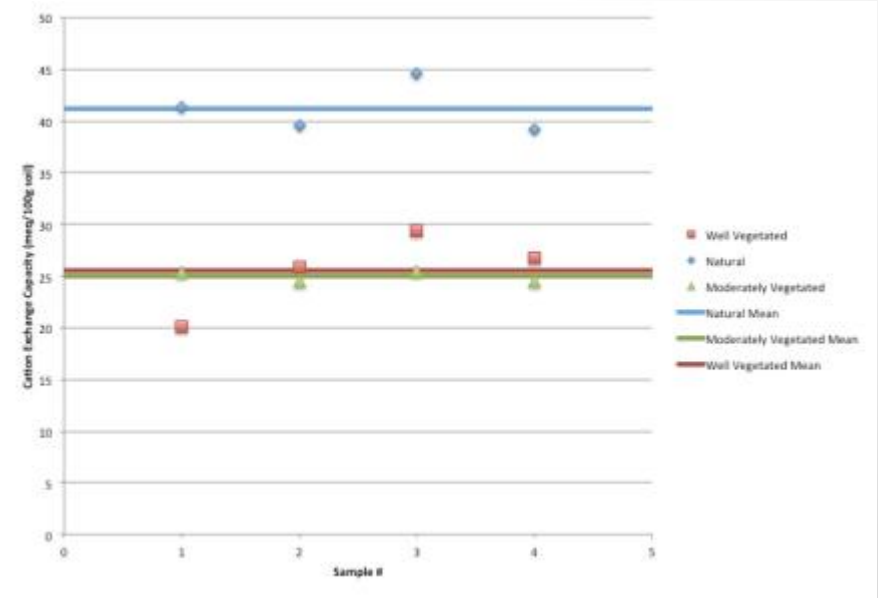


Site Soil Characteristics

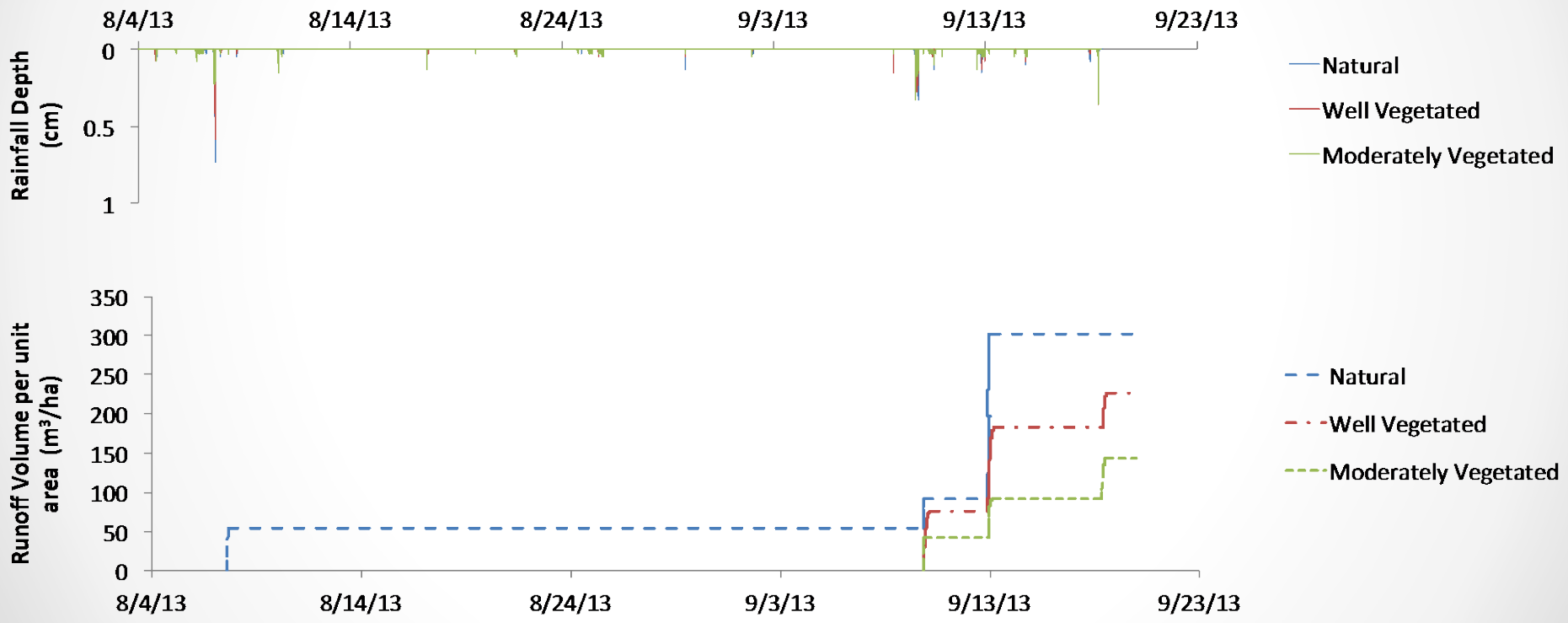
Organic Matter



Cation Exchange Capacity



Rainfall-Runoff Field Data



Objective 2

- Assess the effectiveness of watershed models in informing the geomorphic reclamation process
  - How well do the models predict runoff and erosion totals from sites?
  - How much field collected data is necessary to produce reasonable results?

Water Erosion Prediction Project (WEPP)

- Development by the USDA began in 1985 to expand upon the Universal Soil Loss Equation (USLE)
  - USLE – gives annual erosion predictions
  - WEPP – spatial and temporal information about erosion and deposition on a hillslope or watershed

Applications of WEPP

- Agricultural Sites
- Forested Sites
- Rangeland Sites
- **Geomorphic Reclamation Sites at La Plata Mine**

WEPP Overview

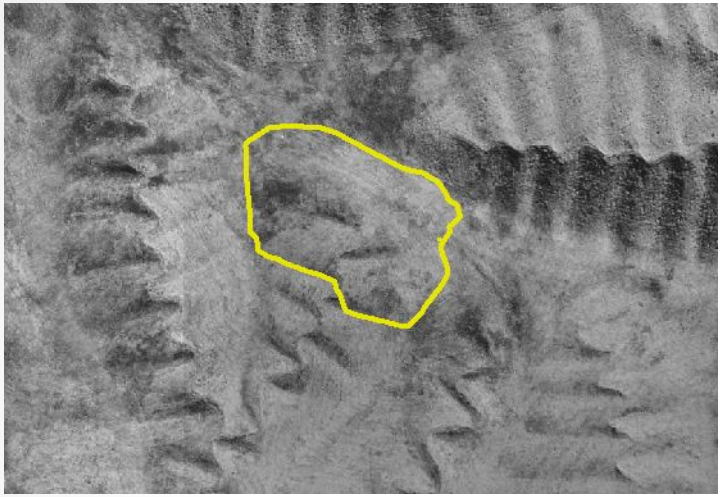
Model Inputs

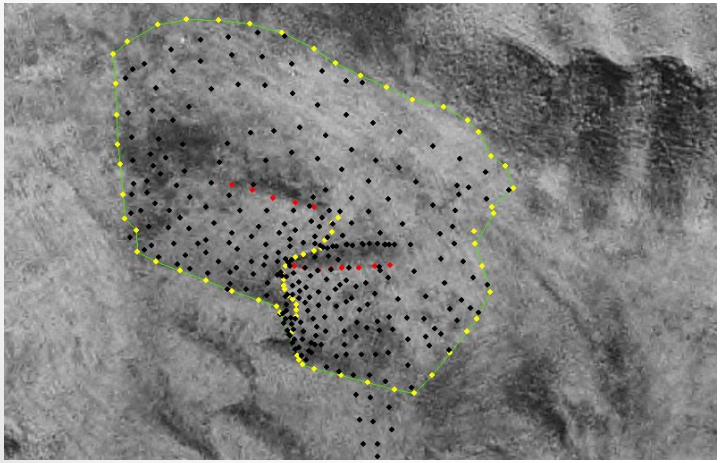
- Topography
  - Hillslope
  - Watershed
    - Channels, hillslope, impoundments, outlets
- Climate data
- Soil data
- Vegetation management

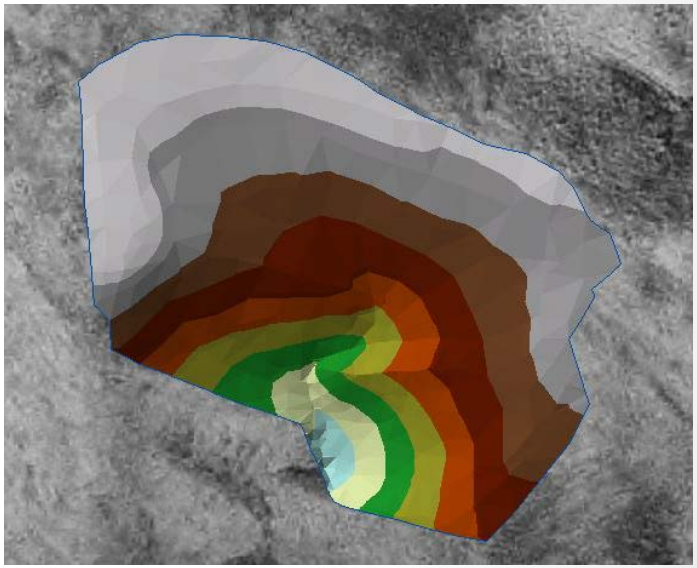
Model Output

- Runoff Volumes and Hydrographs
- Sediment yields
- Characteristics of Eroded Sediment

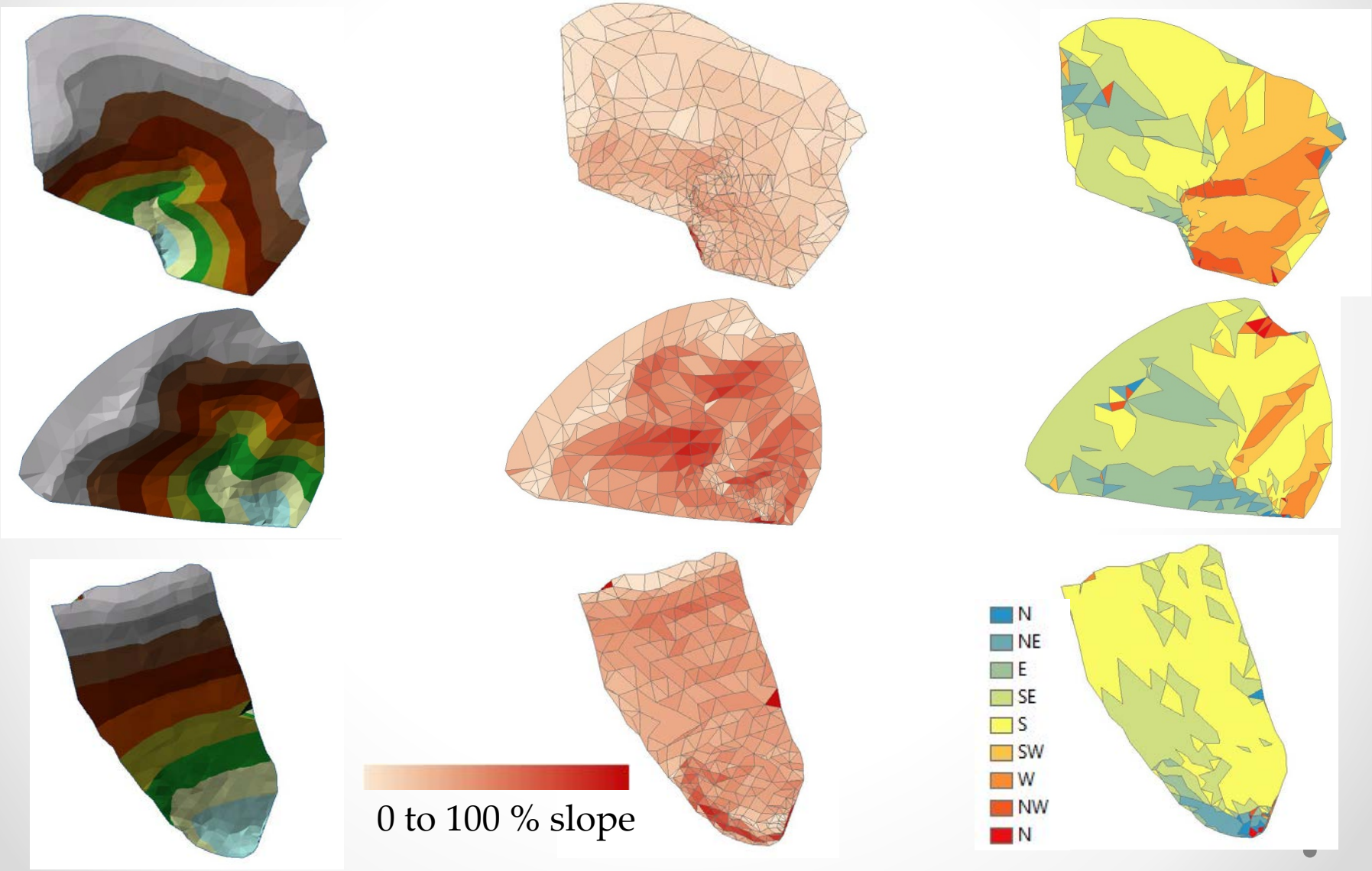
Delineation of Watersheds



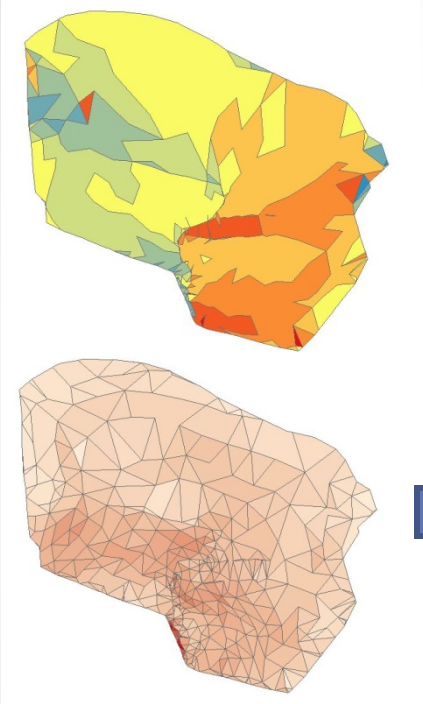


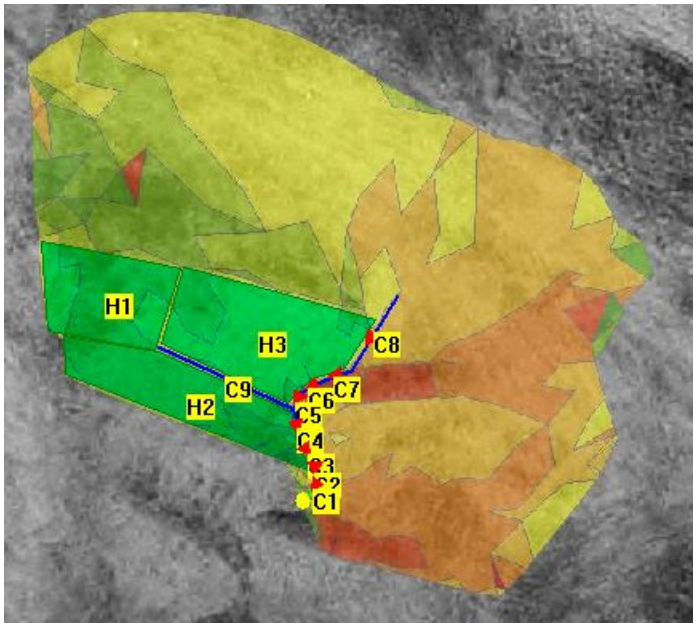


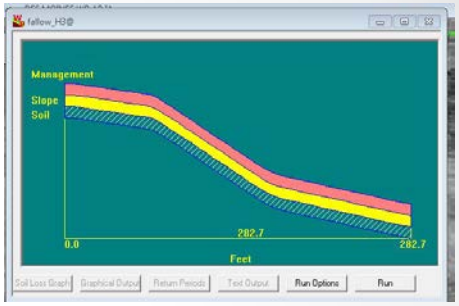
Study Watersheds at La Plata Mine

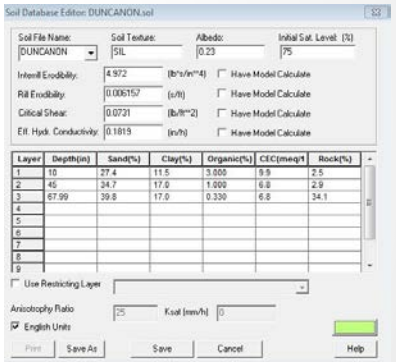


Importing Watersheds to WEPP Model







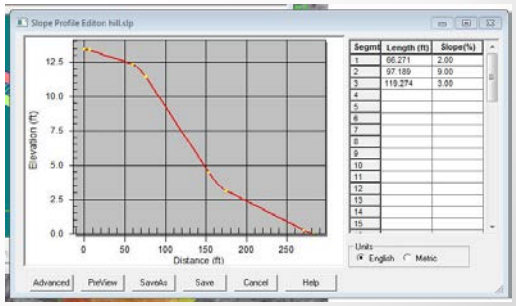


with correction for gravel soil (MV)

	11T	12T	13T	21T	22T	23T	31T	32T	33T	41T	42T	43T
Sand	39.3283	37.7014	37.8349	40.501	42.4084	41.9219	39.0116	38.1055	41.3646	41.2998	38.6637	30.9245
Silt	45.5038	32.2234	35.3698	35.4906	43.4555	35.9029	39.9579	38.0603	39.9787	35.6394	27.9299	44.6134
Clay	15.1679	30.0752	26.7953	24.0084	14.1361	22.1753	21.0305	25.8342	18.6567	23.0608	33.4064	24.4421
	Loam	Clay Loam	Clay Loam	Loam	Loam	Loam	Loam	Loam	Loam	Loam	Clay Loam	Loam

with correction for gravel (WV)

	11T	12T	13T	21T	22T	23T	31T	32T	33T	41T	42T	43T
Sand	43.9051	43.8272	41.5656	52.7421	50.0581	53.2526	43.459		48.7952	42.5287	43.2314	45.5388
Silt	31.2837	25.3086	29.7685	30.9218	28.4553	29.9885	37.1397		25.1004	28.7356	27.8384	24.3337
Clay	24.8112	30.8642	28.6659	16.3361	21.4866	16.1476	19.4013		26.1044	28.7356	28.9301	30.1275
	Loam	Clay Loam	Clay Loam	Sandy Loam	Loam	Sandy Loam	Loam		Sandy Clay Loam	Clay Loam	Clay Loam	Sandy Clay Loam

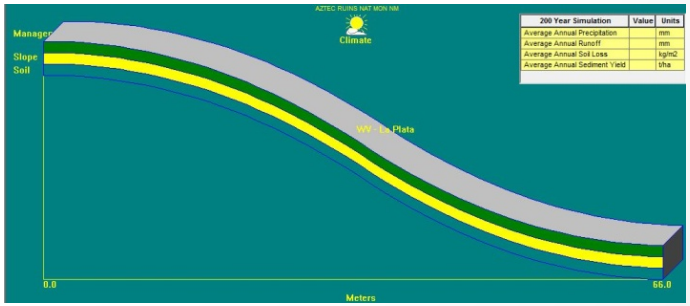


Defining Hillslopes

Hillslope defined by cross-section taken in Arc-GIS

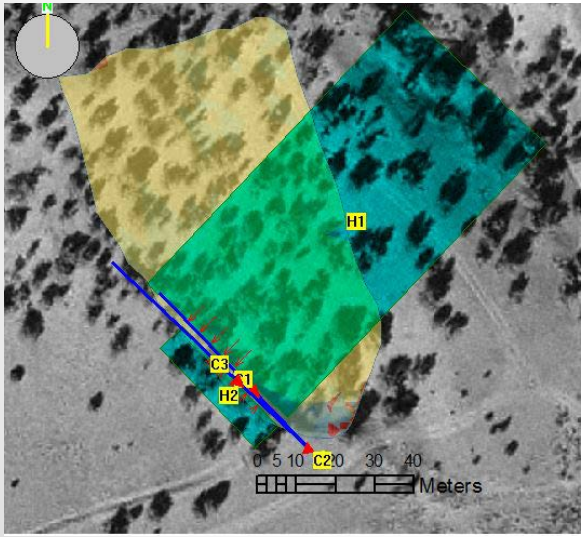
Hillslope defined by 10 equidistant slope points

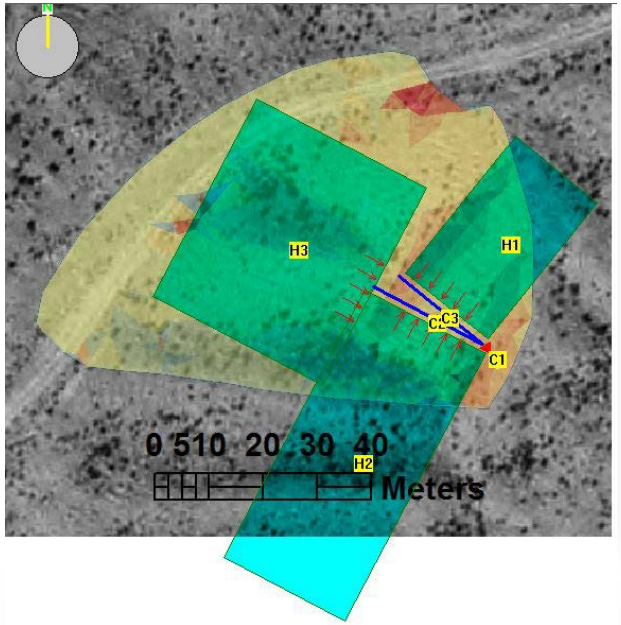
Hillslope defined by simplified S-shape using average slope

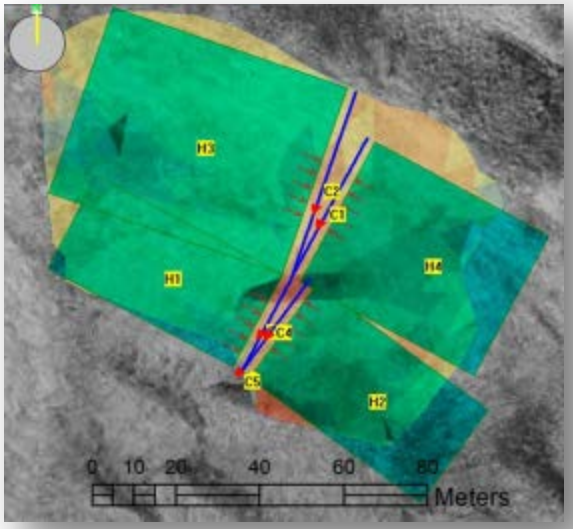


WEPP Watershed Approaches

- Natural, Well Vegetated, & Moderately Vegetated
  - Cross-section Hillslope
  - 10 slope points Hillslope
  - Simplified S-shape Hillslope





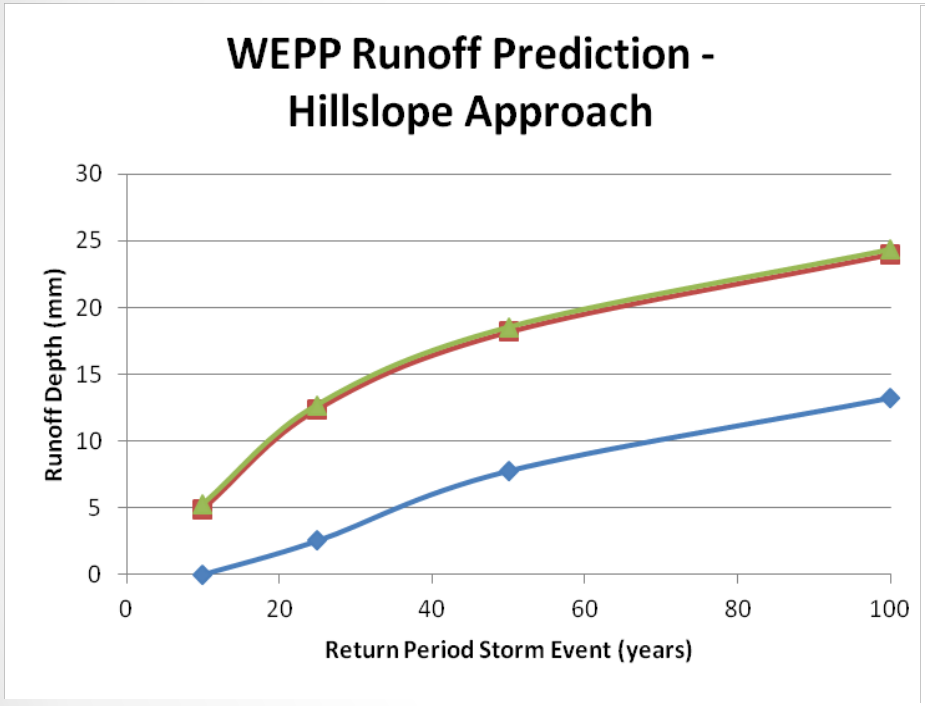


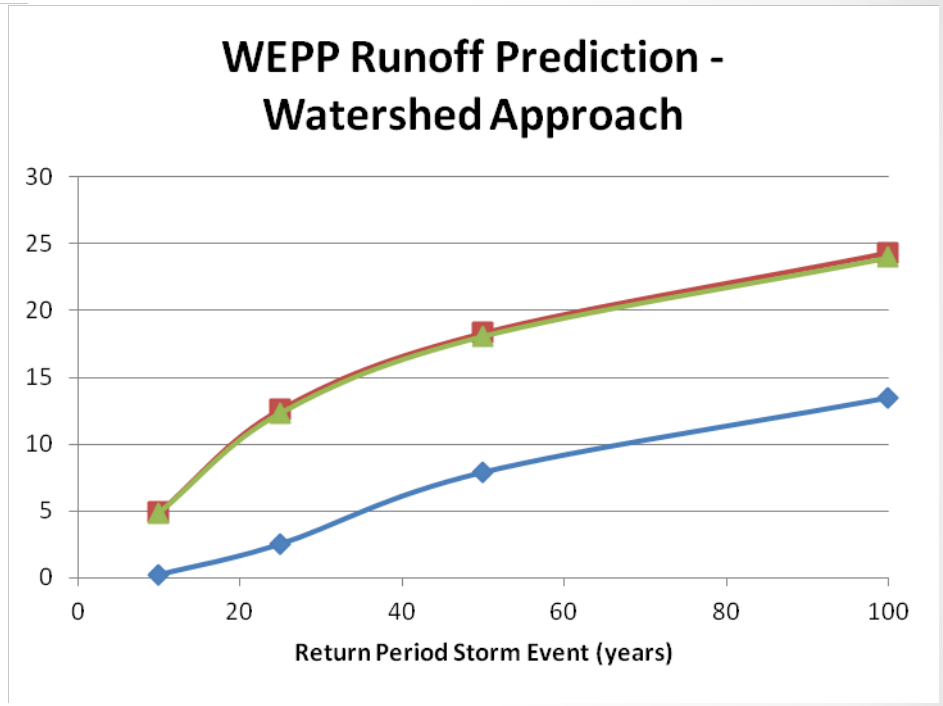
Initial WEPP Results

Average Depth of Eroded Sediment (mm) assuming 1.5 g/cc				
	Storm Frequency (years)			
Well Vegetated	10	25	50	100
Profile Hillslope	70.05	245.27	425.53	658.67
10 point Hillslope	0.08	0.25	0.38	0.51
Simplified Hillslope	0.04	0.16	0.26	0.36
Watershed - Profile	0.45	1.33	2.13	2.99
Watershed - 10 point	0.03	0.12	0.19	0.27
Watershed - S simplified	0.03	0.10	0.17	0.23

- WEPP model unable to handle the complexities of the cross-sectional description of the hillslope

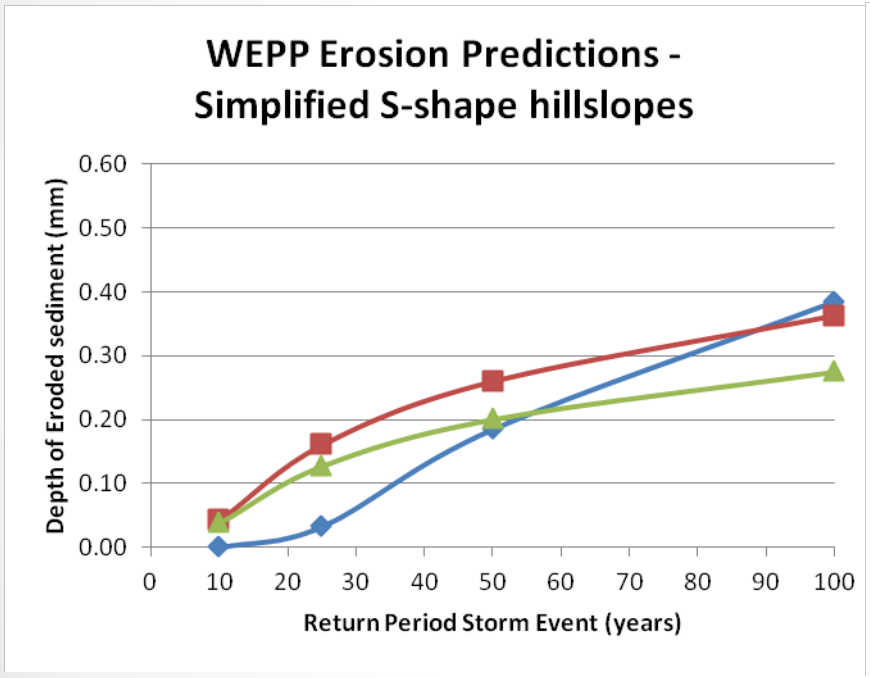
WEPP Runoff Prediction

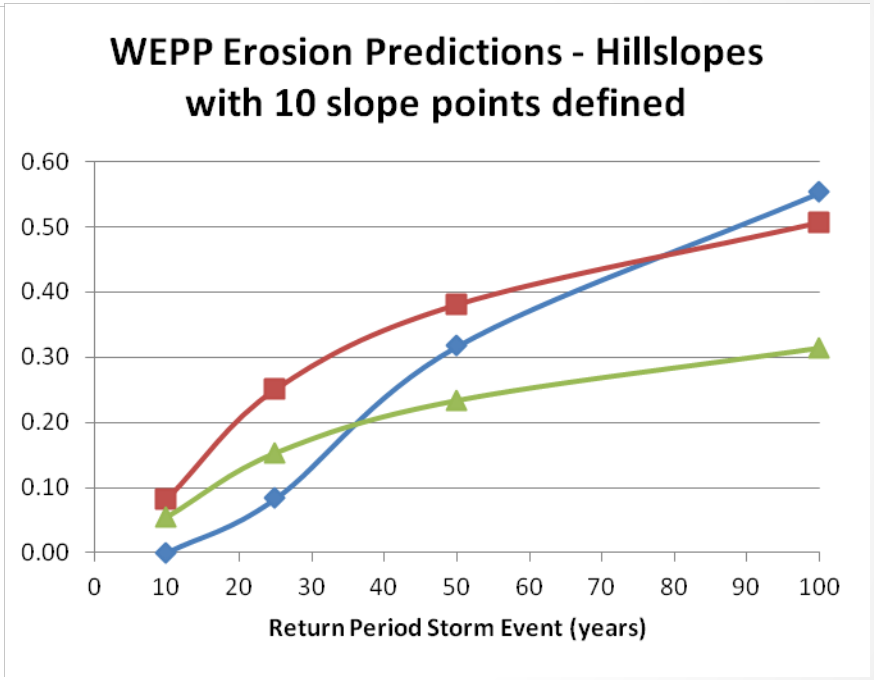




Natural
Well Vegetated
Moderately Vegetated

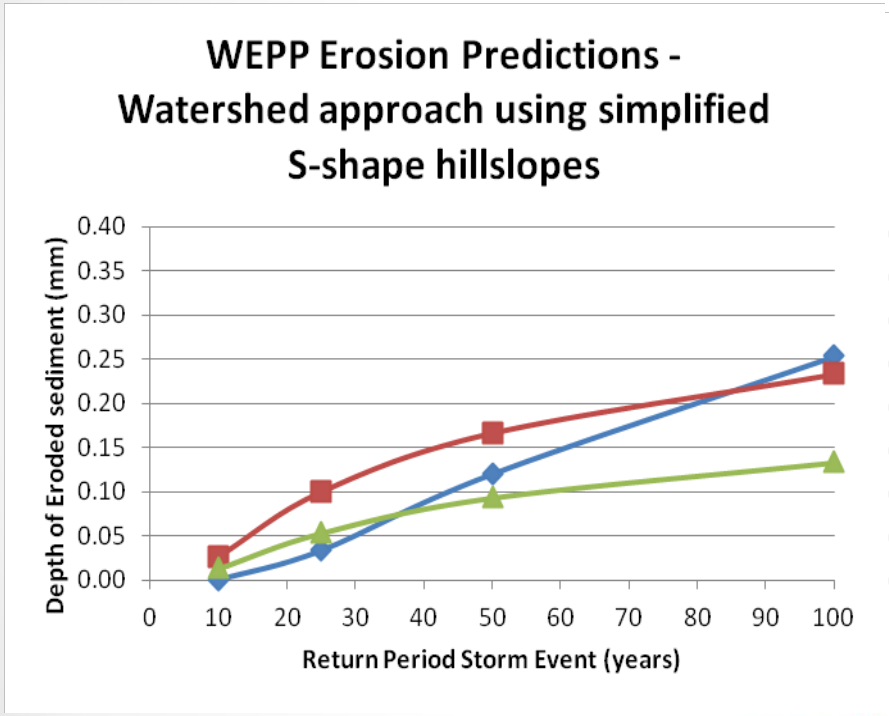
WEPP Erosion Prediction – Hillslope Approaches

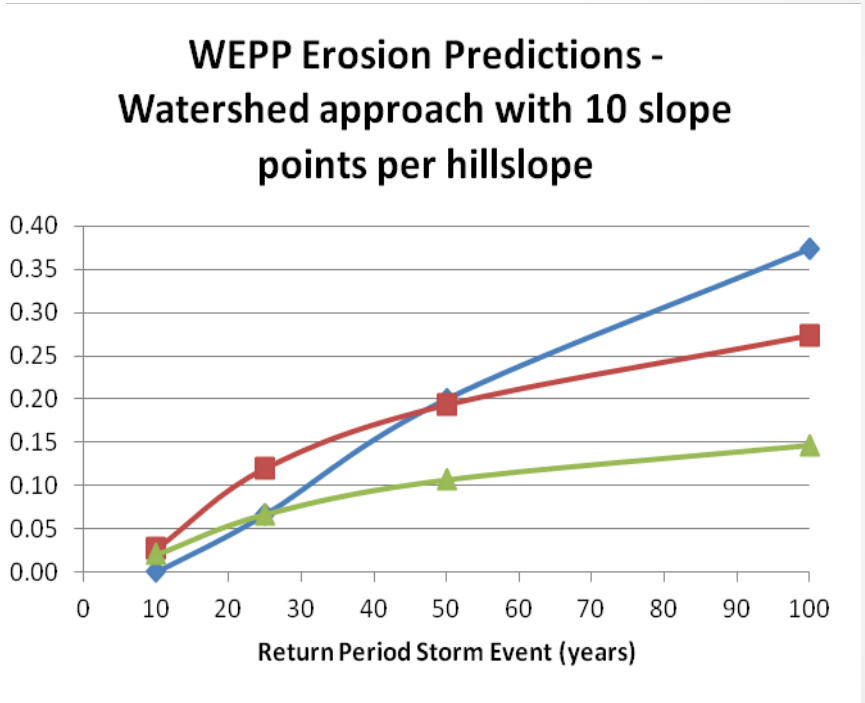




Natural
Well Vegetated
Moderately Vegetated

WEPP Erosion Prediction – Watershed Approaches



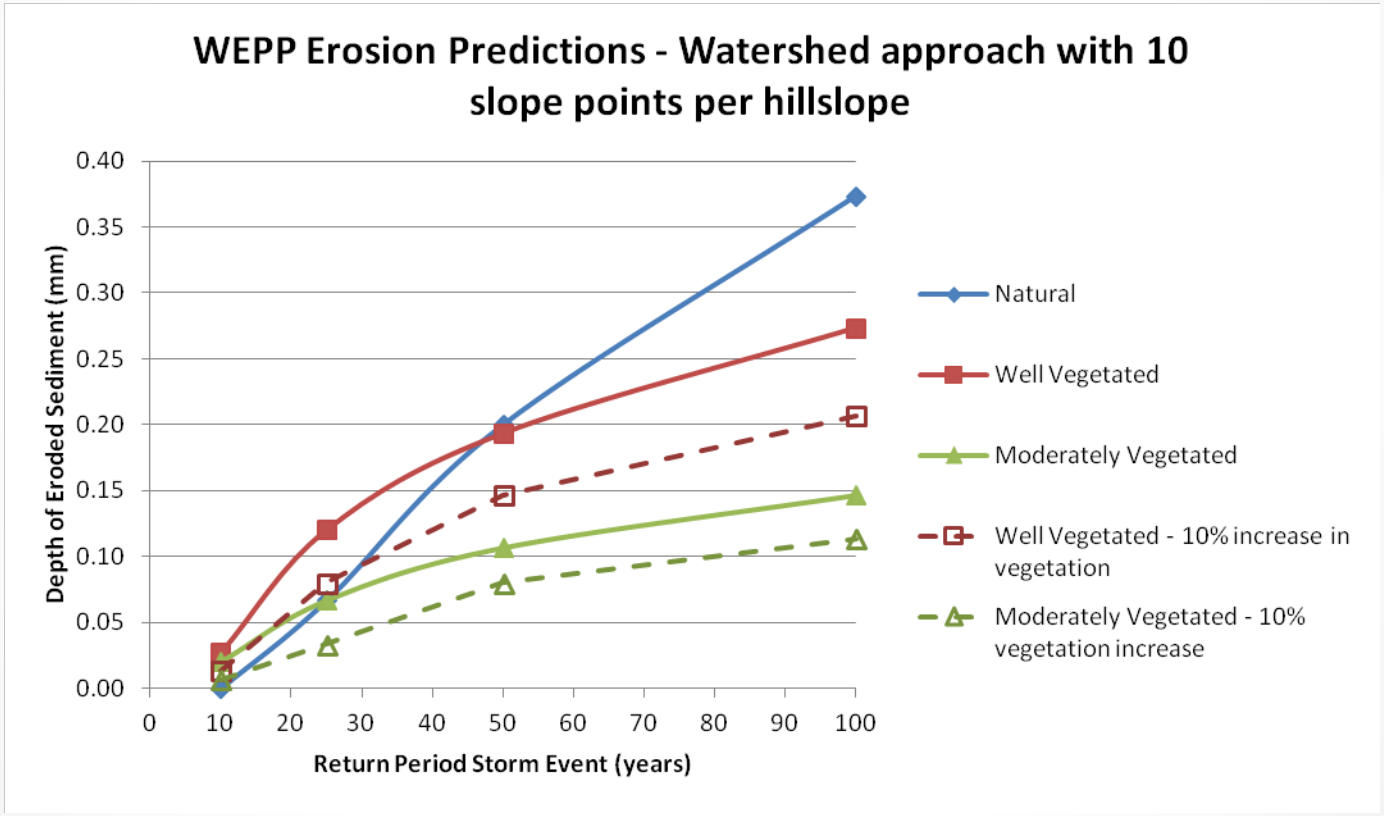


Natural

Well Vegetated

Moderately Vegetated

Effects of Increased Vegetation at Reclaimed Sites

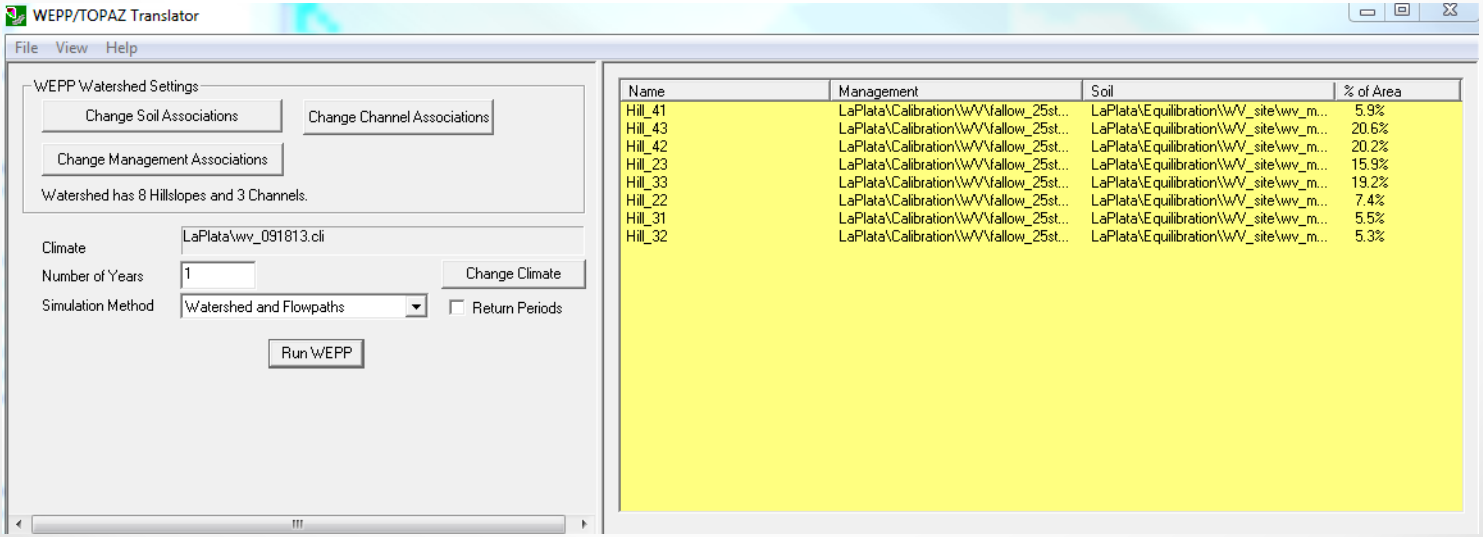


GeoWEPP

- Geospatial interface for the WEPP model developed at the University at Buffalo
- Works as an add-on to ArcMap
- A DEM of the modeled site is required
- Optional layers include:
  - Soils layer
  - Vegetation/Land Use file

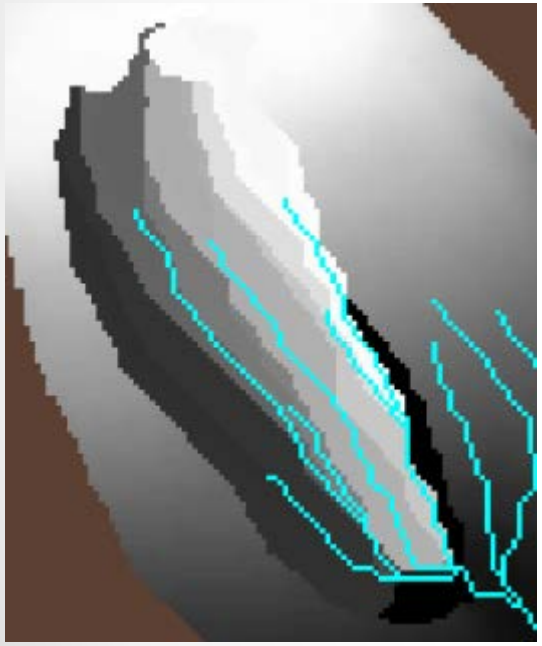
GeoWEPP – Best Calibration Inputs

Site	Effective Hydraulic Conductivity (mm/hr)	Percent Saturation	Vegetation
Natural	2.25	30/90	20% pinon, juniper, sage brush canopy, 5% ground cover
Well Vegetated	1.5	50/90	25% steppe ground cover
Moderately Vegetated	0.25	90	15% fallow ground cover

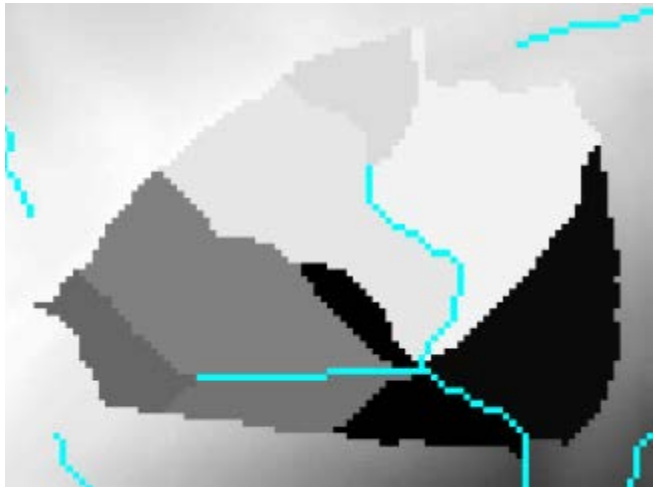


GeoWEPP – Flowpaths and Hillslopes

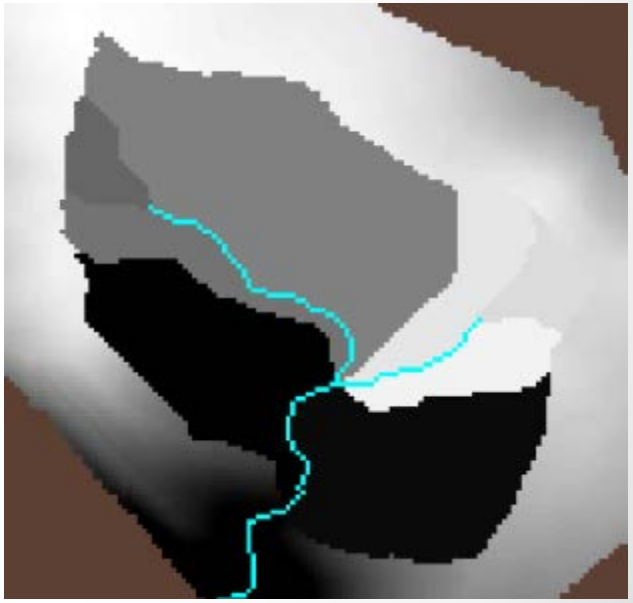
Natural Site



Well Vegetated Site

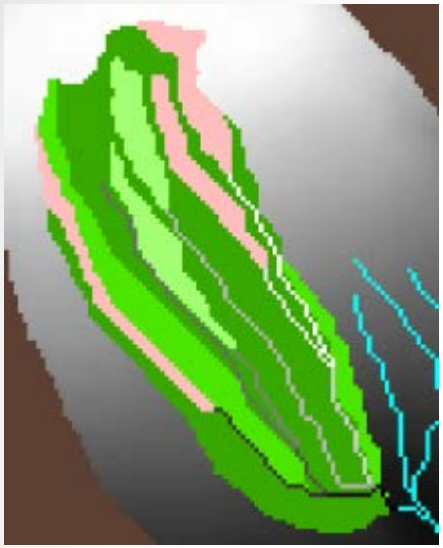


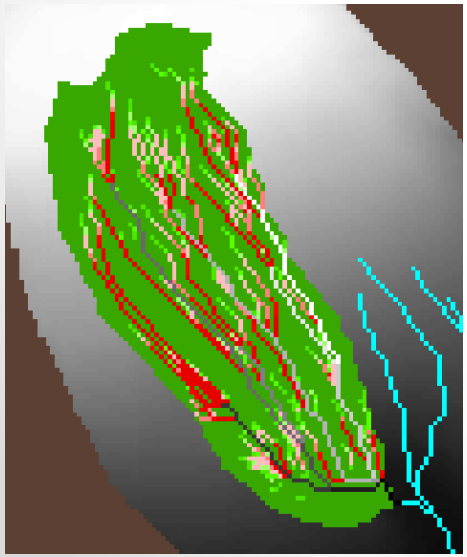
Moderately Vegetated Site



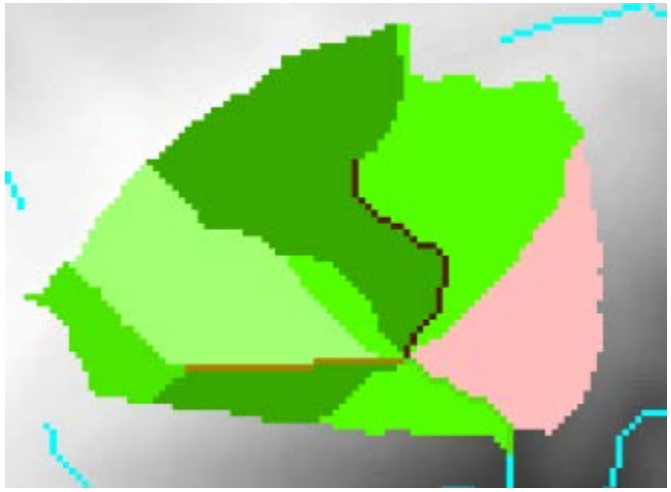
Spatial Erosion Prediction

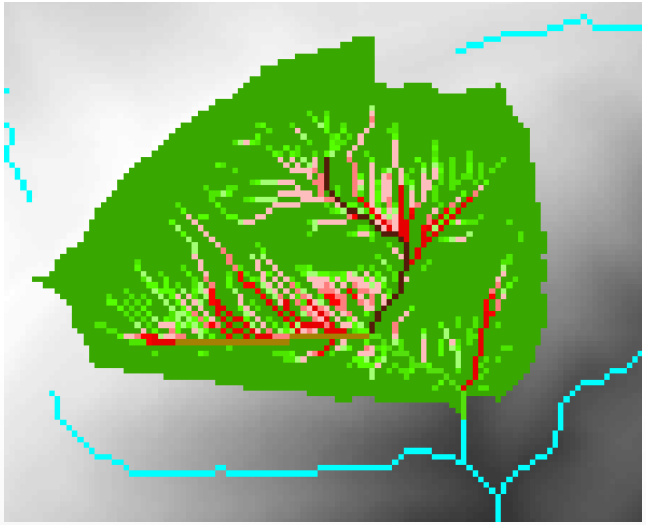
Natural Site



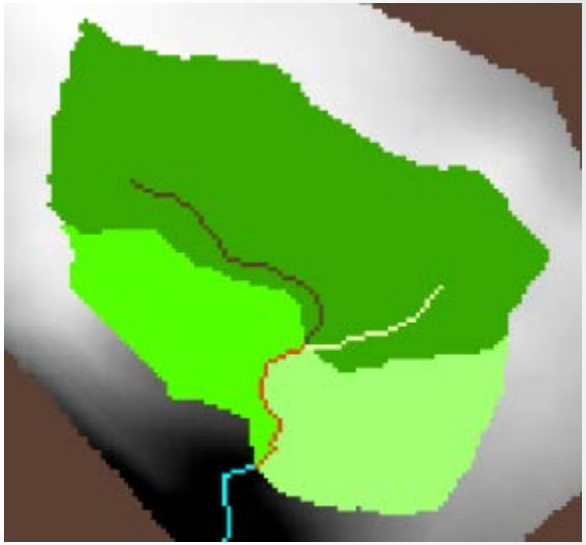


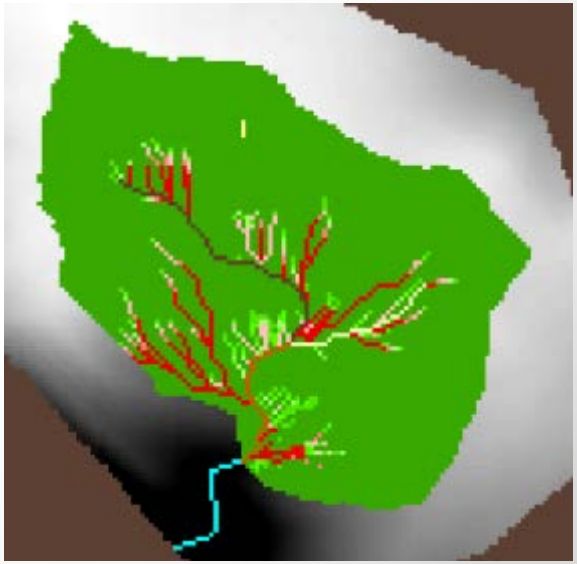
Well Vegetated Site



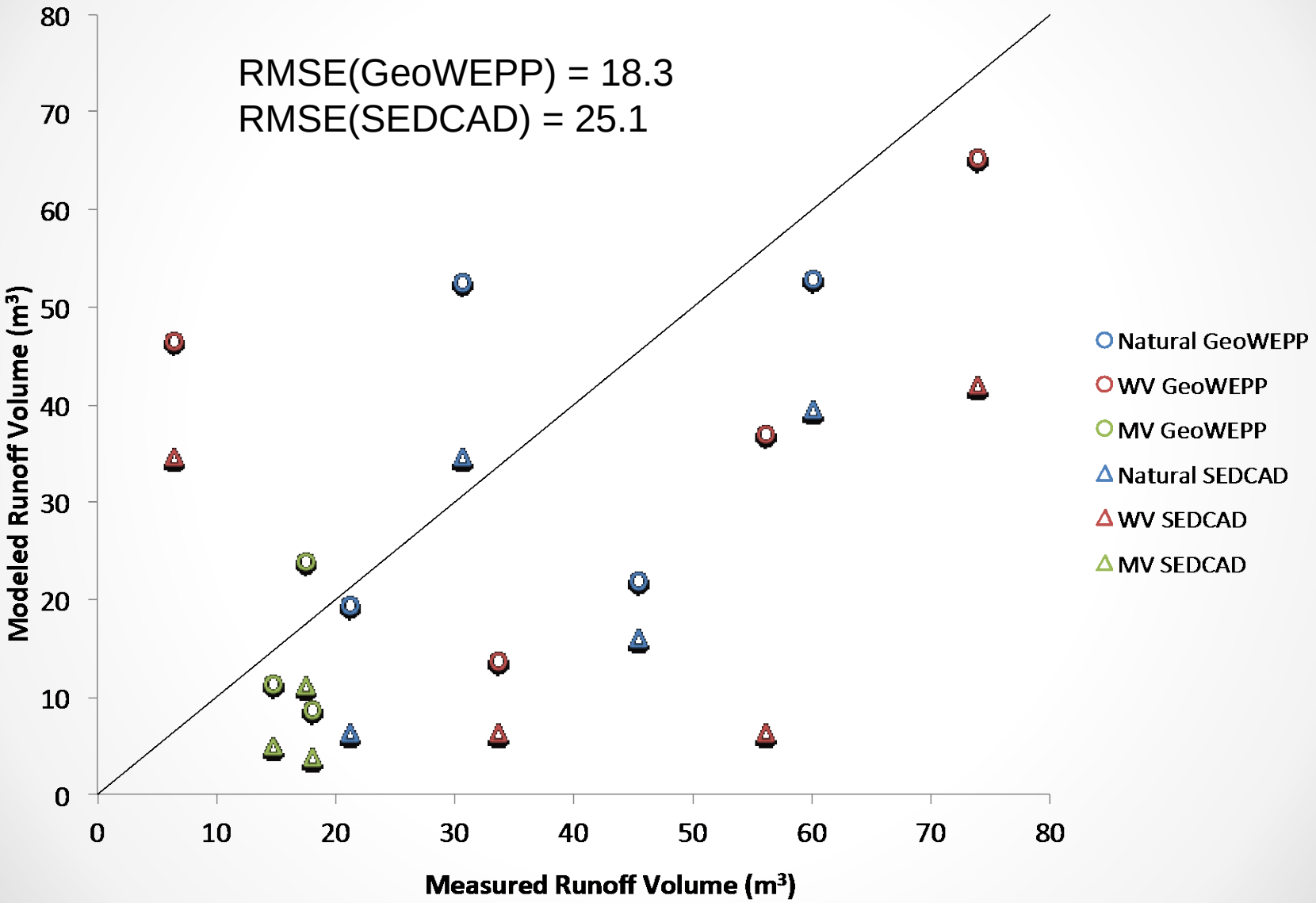


Moderately Vegetated Site





Results


RMSE(GeoWEPP) = 18.3
RMSE(SEDCAD) = 25.1
Modeled Runoff Volume (m³)
Measured Runoff Volume (m³)
0
10
20
30
40
50
60
70
80
Natural GeoWEPP
WV GeoWEPP
MV GeoWEPP
Natural SEDCAD
WV SEDCAD
MV SEDCAD

Objective 3

- Assess seed germination potential based on soil temperature and moisture content using the Hydrus 1-D model

Soil Hydraulic Properties

- Van Ganuchten unsaturated hydraulic properties

$$\theta(h) = \begin{cases} \theta_r + \dfrac{\theta_s - \theta_r}{[1+|\alpha h|^n]^m} & h < 0 \\ \theta_s & h \geq 0 \\ m = 1 - 1/n\ , \quad n > 1 \end{cases}$$

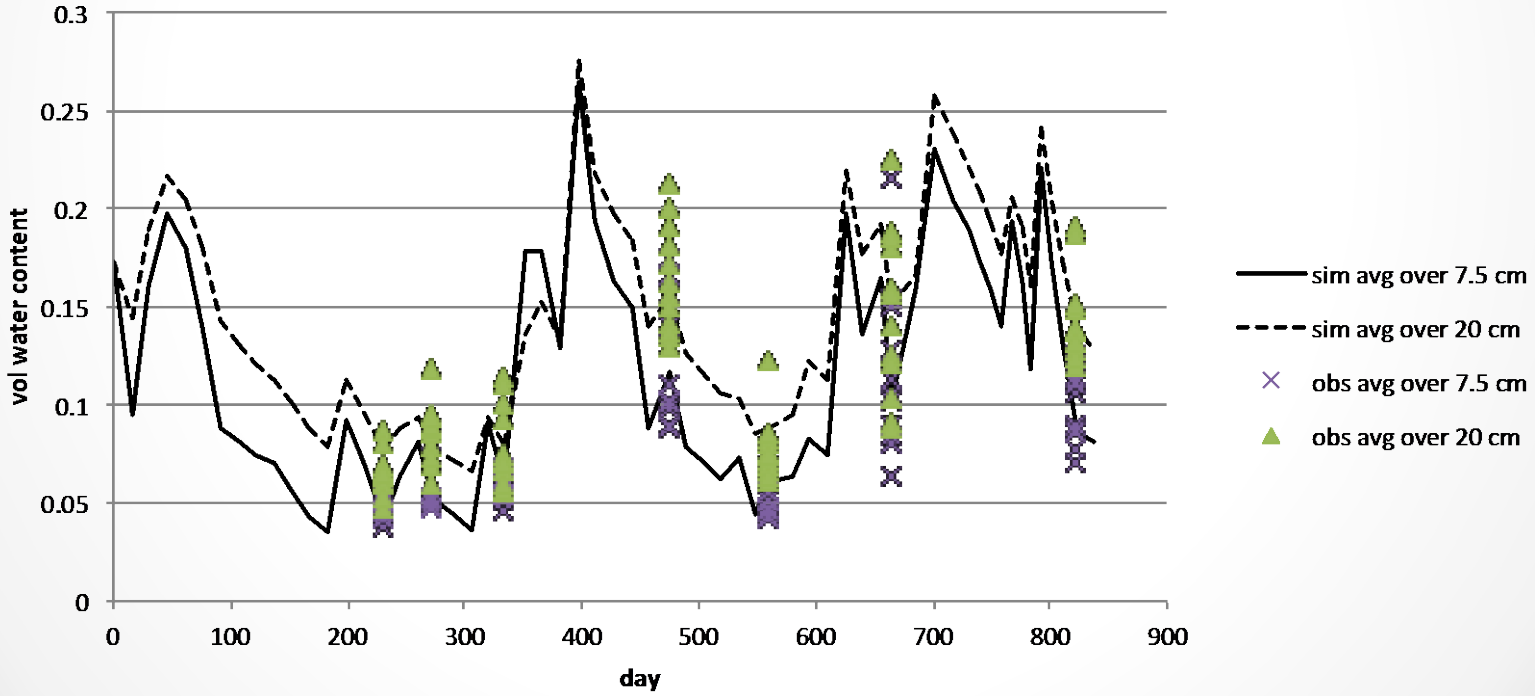
θ_r =residual water content
θ_s =saturated water content
h =pressure head
α, n, m =empirical coefficient

- Field test and laboratory experiments
  - -Tension infiltrometer test
  - -Falling head test
  - -Hanging column test
  - -Pressure plate test
  - -Dew point potentiometer test

- Determination technique
  - -Curve fitting by RETC
  - -Inverse simulation by HYDRUS 2D

Soil Moisture Measurement and Modeling

- Volumetric water content by TDR
- Solving Richard's unsaturated flow equation by HYDRUS 1D

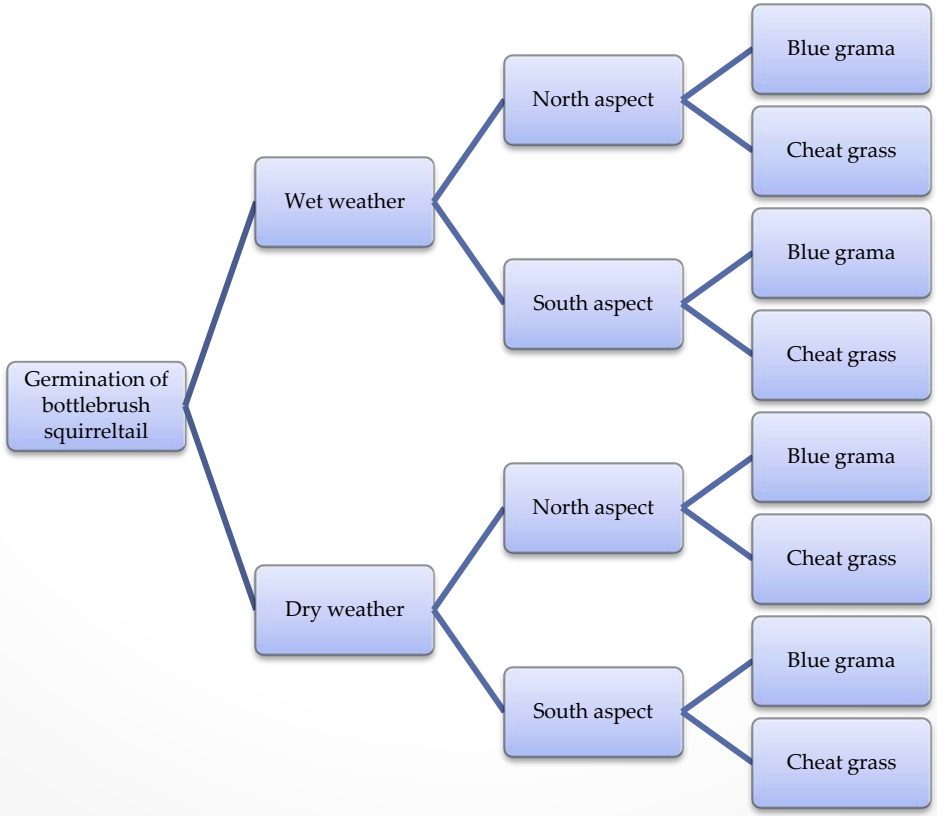


Determination of Germination Potential

$$\theta_{HT} = (T - T_b)(\psi - \psi_b(g))t_g$$

1/PTG/hour= 1/tg/24

θ_{HT} = Hydrothermal time (MPa-degree-days)
t_g = Germination time for g fraction
T_b = Threshold temperature
ψ_b = Threshold water potential
PTG = Progress towards germination



Conclusions

- WEPP hillslopes and watersheds can not be too complex, as the model will over predict sediment yields
- Based on soil properties, topography, and vegetation, WEPP predicts the reclaimed sites will perform in a similar manner to surrounding natural landscapes
- Calibration of models is difficult and results have proven insignificant, perhaps due to climate or soil densities below the surface
- GeoWEPP may aid in a qualitative assessment of site performance, providing information about which areas are most susceptible to runoff and eroded sediment production
- Hydrus 1-D is able to produce soil moisture contents within the range measured throughout the course of the study. Application of this data to study seed germination potential is underway

Acknowledgements

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Questions?