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


Presented by Colin Byrne, May 20th, 2014

Advances in Geomorphic Reclamation at Coal Mine Sites: A Technical Interactive Forum and Field Tour
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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
  o 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
  o Temperature
  o Moisture content
  o Vegetation
  o Infiltration rates

• Disturbed soil sampling
  o Particle size distribution
  o Specific gravity
  o Organic matter
  o Cation exchange capacity

• Undisturbed soil sampling
  o Saturated hydraulic conductivity
  o Water retention curves

• Check-dams installed
• V-notch weirs installed
Field Sampling
Site Soil Characteristics

Ksat vs density of soil at different locations

Ksat (cm/sec) vs dry density (g/cc)

- Remolded sample
- WV sample
- MV sample
- N sample
- TI test
- TI test at depths
Site Soil Characteristics

Organic Matter

Cation Exchange Capacity
Rainfall-Runoff Field Data

- **Rainfall Depth (cm)**
  - 8/4/13: 0
  - 8/14/13: 0
  - 8/24/13: 0
  - 9/3/13: 0
  - 9/13/13: 0
  - 9/23/13: 0

- **Runoff Volume per unit area (m³/ha)**
  - 8/4/13: 50
  - 8/14/13: 50
  - 8/24/13: 50
  - 9/3/13: 250
  - 9/13/13: 250
  - 9/23/13: 250

Legend:
- Natural
- Well Vegetated
- Moderately Vegetated
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

0 to 100 % slope
Importing Watersheds to WEPP Model
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

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

WEPP Runoff Prediction - Hillslope Approach

WEPP Runoff Prediction - Watershed Approach

Return Period Storm Event (years)

Runoff Depth (mm)

Natural
Well Vegetated
Moderately Vegetated
WEPP Erosion Prediction – Hillslope Approaches

WEPP Erosion Predictions - Simplified S-shape hillslopes

WEPP Erosion Predictions - Hillslopes with 10 slope points defined

- Natural
- Well Vegetated
- Moderately Vegetated

Return Period Storm Event (years)

Depth of Eroded sediment (mm)
WEPP Erosion Prediction – Watershed Approaches

WEPP Erosion Predictions - Watershed approach using simplified S-shape hillslopes

WEPP Erosion Predictions - Watershed approach with 10 slope points per hillslope

- Natural
- Well Vegetated
- Moderately Vegetated
Effects of Increased Vegetation at Reclaimed Sites

WEPP Erosion Predictions - Watershed approach with 10 slope points per hillslope

![Graph showing erosion predictions with different vegetation types and storm events.](image)
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:
  o Soils layer
  o Vegetation/Land Use file
**GeoWEPP – Best Calibration Inputs**

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

![Graphical representation of GeoWEPP settings]

![Table of WEPP/TOPAZ parameters]
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
Objective 3

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

- Van Genuchten unsaturated hydraulic properties
  \[
  \theta(h) = \begin{cases} 
  \theta_r + \frac{\theta_s - \theta_r}{[1 + |\alpha h|^n]^m} & h < 0 \\
  \theta_s & h \geq 0 \\
  m = 1 - 1/n, & n > 1 
  \end{cases}
  \]
  \(\theta_r\) = residual water content
  \(\theta_s\) = saturated water content
  \(h\) = pressure head
  \(\alpha, n, m\) = 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

\( \theta_{HT} \) = Hydrothermal time (MPa-degree-days)

\( t_g \) = Germination time for g fraction

\( T_b \) = Threshold temperature

\( \psi_b \) = Threshold water potential

PTG = Progress towards germination

Germination of

- Bottlebrush squirreltail
- Squirreltail
- Blue grama
- Cheat grass

North aspect

- Blue grama
- Cheat grass

South aspect

- Blue grama
- Cheat grass

Dry weather

- Blue grama
- Cheat grass

Wet weather

- Blue grama
- Cheat grass

South aspect

- Blue grama
- Cheat grass
Conclusions

• WEPP hillslopes and watersheds cannot be too complex, as the model will overpredict 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
Questions?