Modeling Sediment Loss on Geomorphic Graded Reforestation Lands in Kentucky

Geomorphic Reclamation and Natural Stream Design at Coal Mines: A Technical Interactive Forum

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Sustainable Mining/Reclamation

• Similar (minor changes)
  – Hydrology
  – Sediment
  – Water quality
    • chemistry
    • organic material
    • nutrients
  – Visual
    • geomorphic
      – land form
      – natural streams
    • forest
Objective

- Contrast hydrologic and sediment response of two alternative head-of-hollow fill design and reclamation techniques
  - Traditional (compacted spoil with grass cover)
  - Geomorphic (landform, natural streams and Forest Reclamation Approach)
Objective

- Design a head-of-hollow fill that mimics the natural landform, forest, hydrology and erosion of pre-development natural Appalachian forest
  - peak flow
  - runoff volume
  - hydrograph characteristics
  - erosion rates
  - sediment concentration and loads
Key Modeling Timeframes

• Natural forest
• Traditional head-of-hollow fill
  – compacted spoil
  – grass vegetated cover
• Geomorphic head-of-hollow
  – loose-dumped spoil overlays compacted fill
  – ephemeral and intermittent streams
  – forest cover
Key Modeling Parameters

• Hydrologic
  – curve number
  – time of concentration
  – unit hydrograph shape

• Sedimentologic
  – erodibility (K)
  – eroded particle size distribution (EPSD)
  – cover factor (C)
  – length-slope factor (LS)
  – slope geomorphic shape
Little Millseat Storm Events

• Pre-Development Monitoring
• Robinson Forest Data
  – 12 storm events
  – 2000-2004
  – 28.4 to 67.6 mm rainfall
• CN Mean – 83
• CN= 73 currently used in KY Permit Applications
## Natural Forest Curve Numbers: Literature

<table>
<thead>
<tr>
<th>Location</th>
<th>Area (ha)</th>
<th>CN</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southern Ohio</td>
<td>20</td>
<td>77</td>
<td>Bonta et al. (1997)</td>
</tr>
<tr>
<td>Eastern Kentucky</td>
<td>82</td>
<td>85</td>
<td>Hawkins (1993)</td>
</tr>
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<td>86</td>
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<tr>
<td>Eastern Kentucky</td>
<td>202</td>
<td>83</td>
<td>Taylor et al. (2009)</td>
</tr>
<tr>
<td>Western North Carolina</td>
<td>46</td>
<td>55</td>
<td>SCS (1972)</td>
</tr>
</tbody>
</table>
Compacted Mine Spoil

- **Hydrology** - Flooding (increase peak flow)
- **Sediment** - High erosion rates (until vegetation establishment)
- **Visual** - Not a forest, no stream, flat
## Compacted Spoil Curve Numbers: Literature

<table>
<thead>
<tr>
<th>Location</th>
<th>Area (ha)</th>
<th>CN</th>
<th>Reclamation Method</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western Kentucky</td>
<td>-</td>
<td>82-86</td>
<td>Constructed profile; heavy compaction</td>
<td>Ward (1981)</td>
</tr>
<tr>
<td>Southern Ohio</td>
<td>10-17</td>
<td>87-97</td>
<td>Graded spoil; planted to grass and trees</td>
<td>Bonta et. al. (1997)</td>
</tr>
<tr>
<td>North Dakota</td>
<td>8.8 x 10^{-4}</td>
<td>96-97</td>
<td>Unspecified</td>
<td>Schroeder (1987)</td>
</tr>
</tbody>
</table>
Compacted Spoil Study Site Characteristics

- Drainage area: 7.7 ha (19.3 ac)
- Slopes: 1.3% upper catchment, 14% lower catchment
- Soils
  - Weathered spoil (sandstone and shale)
  - Compacted
    - Infiltration rate \(\sim\) 2 mm/hr (0.08 in/hr)
- Hydrologic soil group B
Compacted Spoil

- Monitoring
- 42 storm events
- May 1990 to Sept. 1991
- Rainfall 6 to 59 mm
- **CN Mean: 85** (P. Taylor et al., 1995)
  - Range 62 to 94
Loose-dumped Spoil Curve Number

- head-of-hollow (end-dumped)
- generated rainfall
  - antecedent application of 2.1 in
  - 2.5 in/hr for ½ hour
- measure runoff volume
- curve number = 35
Loose-dumped Spoil Curve Number

- Loose-dumped spoil surface runoff plots
- 3 monitoring locations – spoil and diversion
- natural rainfall
  - RF7 – 14 events, RF8 – 0 events, RF9 4 events
- runoff only from adjacent outslope and diversion
Loose-dumped Spoil Curve Number

- Loose-dumped spoil surface infiltration plots
- 38 5m X 5m lysimeters
- Spoil 6 to 8 ft deep (ROM)
- Annual infiltration rate – 32.2%
- Natural Appalachian forest - ~ 30 – 35%
Loose-dumped Spoil Curve Number

- Depression Storage Calculation
- Starfire Mine – UK BAE
- Depressions will contain >6 in rainfall
- Conclusion: no surface runoff except for spoil piles at boundary adjacent to streams
Loose-dumped Spoil Curve Number

- Loose-dumped spoil
  - Brown weathered sandstone
  - grey un-weathered sandstone
  - ROM sandstone and shale
- 6 monitoring locations –
- natural rainfall
  - 12 events
  - measure runoff volume
- No surface runoff
- Mean curve number (interflow) – 77
Curve Numbers Measured at Study Sites

- Forested (Little Millseat)
  - Mean: 83 (T. Taylor et al., 2007)

- Compacted spoil (Starfire)
  - Mean: 85 (P. Taylor et al., 1995)

- Loose-dumped spoil (Bent Mountain)
  - Mean: 77 (T. Taylor et al., 2007)
  - no surface runoff
Starfire - 10 years growth
Loose-dumped versus Compacted

- Hydrologic Inputs
  - Time of concentration
    - forest (few hours)
    - loose-dumped (many hours)
    - compacted (fraction of an hour)
  - Unit hydrograph shape
    - forest loose-dumped (slow to very slow)
    - compacted (medium to fast)
Natural Forest & Loose-dumped Spoil Hydrographs

[Graph showing discharge over time for Little Millseat and Cell 5]
Compacted Spoil Hydrograph

[Graph showing various parameters like Flow Rate (cfs), Precipitation (in.), Suspended Sediment Conc. (mg/L), Settleable Solids Conc. (mL/L), and Turbidity (NTU) over time from 6/11/03 13:15 to 6/11/03 16:30.]

Geomorphologic Head-of-Hollow Fill Reclamation Approach

- **Advantages**
- **Hydrology (similar to pre-mining forest)**
  - Reduce peak flow
  - Increase flow duration (intermittent streams)
  - Increase evapotranspiration
- **Sediment**
  - Erosion rate and sediment load (similar to pre-mining forest)
- **Visual**
  - Reconstruct a forest
  - Watershed provides for the natural stream
    - nutrients/carbon
    - forest liter
- **Water chemistry**
Key Modeling Parameters

• Hydrologic
  – curve number
  – time of concentration
  – unit hydrograph shape

• Sedimentologic
  – erodibility (K)
  – eroded particle size distribution (EPSD)
  – cover factor (C)
  – length-slope factor (LS)
  – slope geomorphic shape
K-factors

• Starfire Mine Soil & Spoil Analysis
• K-factors
  – Undisturbed forest topsoil (0.206 – 0.256)
  – 0-2 month old spoil (0.126 -0.133)
  – 2 to 6 month old spoil (0.139 – 0.145)
• Modeling inputs
  – forest – 0.23
  – 0-2 month spoil – 0.13
  – 2 – 6 month spoil – 0.14
C -factor

- Function of
  - Vegetation (forest or grass)
  - Surface roughness
  - Surface rock fragment
- Forest (0.002)
- Compacted spoil with grass cover (0.1)
- Loose-dumped spoil (without forest) (.02)
Slope shape and length factors

• Slope shape
  – Convex
  – Uniform
  – Concave
  – Complex

• Gradient

• Length
Slope inputs

- **Forest**
  - L 25ft, S 50%, Complex
- **Traditional Compacted Spoil (crown)**
  - L 150ft, S 2%, Uniform
- **Geomorphic Loose-dumped Spoil (crown)**
  - L 20ft, S 40%, Uniform
SEDCAD Modeling Inputs

- **Area**: 100 ac forest, 80 ac crown
- **Design storm**: 2.5 in NRCS Type II - 24 hour
- **Forested**
  - Time of concentration: .36 hr
  - Unit hydrograph shape: slow
- **Compacted spoil**
  - Time of concentration: .22 hr
  - Unit hydrograph shape: fast
- **Loose-dumped spoil**
  - Time of concentration: 1.5-2 hr
  - Unit hydrograph shape: slow
## SEDCAD Results

<table>
<thead>
<tr>
<th>LandUse</th>
<th>Peak flow (cfs)</th>
<th>Runoff Vol. (ac-ft)</th>
<th>Sediment (tons)</th>
<th>Peak Sediment (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>40.1</td>
<td>5.9</td>
<td>4.4</td>
<td>980</td>
</tr>
<tr>
<td>Geomorphic</td>
<td>12.5</td>
<td>4.5</td>
<td>5.7</td>
<td>1340</td>
</tr>
<tr>
<td>Traditional</td>
<td>93.2</td>
<td>8.6</td>
<td>14.9</td>
<td>2470</td>
</tr>
</tbody>
</table>