Quantifying BMP effects on sediment delivery at forest road stream crossings

email: krisrb3@vt.edu

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Forest road-stream crossing approaches

• Sediment delivery potential is greatest at the road-stream interface

• Issue has sparked legislative debates about CWA permits and NPSP status of forest roads
Need to demonstrate the application of cost-effective BMPs... How?

Turton et al. (2009)

Robichaud and Brown (2002)
Objectives

• Quantify annual sediment delivery rates for bare and graveled stream crossing approaches

• Quantify surface hydrologic processes and sediment transport of stream crossing approaches during storm events

• Utilize field data in soil erosion models (USLE-forest, WEPP) and evaluate model performance at the road-stream interface
Reynolds Homestead
Site Bare 3 after a thunderstorm on 22-Jun-2012.

Plan view of two idealized stream crossing approaches.
Repeated measurements of sediment delivery
Statistical design

• Annual sediment delivery rates (Mg ha\(^{-1}\) yr\(^{-1}\))
  ▪ Two-sample t-test by surface type (bare, gravel)
  ▪ N = 9

• Repeated measurements of sediment (Mg ha\(^{-1}\))
  ▪ Repeated measures ANOVA
  ▪ Model components: Surface Type (bare, gravel), Time (measurements 1-12), Surface*Time interaction
  ▪ N = 108
Bare approaches were 7.5X greater than gravel.
Gravel was significantly less than Bare (t-test difference = $-1.4$, df = 4.2, $p = 0.001$).
Sediment delivery rates over time

![Graph showing sediment delivery rates over time with data points for different time periods and categorical comparisons: Bare, Gravel, and Rainfall. The graph includes a legend and an axis for precipitation (cm).]

<table>
<thead>
<tr>
<th>Effect</th>
<th>Numerator df</th>
<th>Denominator df</th>
<th>F value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road surface</td>
<td>1</td>
<td>6</td>
<td>38.32</td>
<td>0.0008</td>
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<tr>
<td>Time</td>
<td>11</td>
<td>66</td>
<td>13.60</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Surface*Time</td>
<td>11</td>
<td>66</td>
<td>0.95</td>
<td>0.4979</td>
</tr>
</tbody>
</table>
Field data to parameterize soil erosion models

- USLE-forest: $A = RKLSCP$

- C sub-factors were evaluated 3 times from Aug. 2011 to Aug. 2012.

- Erosion predictions were averaged by site to produce annual estimates of sediment delivery ($Mg \text{ ha}^{-1} \text{ yr}^{-1}$) ($N=9$).
Building WEPP hillslope profiles

• 4 main files needed to run WEPP (Windows ver. 2012.8)
  ▪ Climate
  ▪ Slope
  ▪ Soil
  ▪ Management

Neither model performed well in predicting annual sediment delivery rates

Both models predicted substantial annual sediment delivery rates for sites with inadequate surface cover and minimal sediment delivery rates for the gravel approaches

WEPP performed better than USLE-forest in ranking the problem road approaches
Rainfall simulation study

**Left approach**
- Runoff
- Rain gauge
- Irrigation pipe
- Flume outflow, ISCO
- Streamflow

**Right approach**
- Cutslope
- Road approach
- Fillslope
- Waterbar/turnout
- Waterbar/turnout

**Other components**
- Riser with sprinkler
- Water line
- Intake pond
- Sand bag dam
- Pump

Photo on the right shows a real setup of the simulation.
Bare treatment

10-19% cover
Low Gravel treatment

34-60% cover
High Gravel treatment

50-99% cover
Gravel volume (m$^3$) = Depth (0.08 m) X Width (2.5-3.2 m) X Length (9.8 m)
Gravel mass (tonnes) = Volume (m$^3$) X 2.65 tonnes m$^{-3}$
Gravel cost ($) = Mass (tonnes) X $27.56/tonne

Mean cost for Low Gravel = $151.99; High Gravel = $303.97
Sediment-reduction efficacy of gravel

Median TSS concentration for the Bare treatment was 2.6 and 3.5X greater than Low Gravel and High Gravel, respectively.
Cost-effectiveness of gravel

• $152 reduced TSS by a factor of 2.6
• $304 reduced TSS by a factor of 3.5

• Implies that cost effectiveness could be increased by minimizing the drainage length of stream crossing approaches
Use of hydrographs and sediment transport data to model event-based sediment delivery with WEPP
Monte Carlo approach

• Following Brazier et al. (2000)
• Uncertainty in WEPP model input and outputs

1. Specify a range for WEPP’s most important model parameters
2. Run WEPP 5000 times for each experiment (N = 54)
3. Evaluate model performance based on observed runoff and sediment

Can WEPP predict the treatment effects observed in field experiments?
Conclusions

• Problem road approaches had poor water control and minimal surface cover

• Judicious BMP usage can reduce road approach sediment delivery

• Despite poor accuracy, USLE-forest and WEPP identified problem stream crossing approaches
Questions?