Hydrological Functioning of Surface-Mined Watersheds in Western Maryland: Restoration or Reclamation?

Keith N. Eshleman and Brian C. McCormick

Appalachian Laboratory, University of Maryland Center for Environmental Science, Frostburg, MD

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Research Questions

• What changes in the hydrologic balance of mined lands can be attributed to surface mining?
• Are normal hydrologic functions typically restored by current reclamation practices?
• How well does the SCS-CN method accurately predict storm runoff responses of mined/reclaimed watersheds?
• Is the SCS-CN method biased in any way?
• How might we improve land reclamation in a way that reduces disturbances to the hydrologic balance both on-site and to the larger basins within which the mining has occurred?
Flooding on the Central Appalachian Plateau (CAP): interaction among precipitation, topography, and land use change
Savage River (127 km²)
Georges Creek (187 km²)
ROCA Watersheds (TNEF, TMAT)
Georges Creek
69% Forested
17% Mined/Reclaimed
8% Agriculture
7% Developed

Savage River
82% Forested
15% Agriculture
3% Developed
TNEF (Tributary to Neff Run)

TMAT (Tributary to Mathews Run)
Results: ROCA Watersheds\textsuperscript{1,2}

- Similar annual and long-term water balances
- No significant difference in timing of stormflow
- Similar unitgraphs
- Higher peak runoff and total storm runoff due to mining/reclamation (on average by a factor of 2-3)
  - Reduced soil infiltration capacity due to loss of forest floor and topsoil; soil compaction
  - Overland flow vs. subsurface stormflow
- Observed differences are conservative

\textsuperscript{1}Negley and Eshleman (\textit{Hydrological Processes}, 2006)
\textsuperscript{2}Simmons \textit{et al.} (\textit{Ecological Applications}, 2008)
TSSR (Tributary to Seldom Seen Run)
TSNR (Tributary to Squirrel Neck Run)
## Watershed Characteristics

<table>
<thead>
<tr>
<th>Site</th>
<th>Area (ha)</th>
<th>Map HSG</th>
<th>Mined Area</th>
<th>Year reclaimed(^1)</th>
<th>Elevation (m MSL)</th>
<th>Flume Installed</th>
<th>Flume Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tributary Matthew Run (TMAT)</td>
<td>27.1</td>
<td>C</td>
<td>47%</td>
<td>~1982</td>
<td>830m</td>
<td>10/1999</td>
<td>10/2008</td>
</tr>
<tr>
<td>Tributary East Branch Neff Run (TNEF)</td>
<td>3.0</td>
<td>C</td>
<td>0%</td>
<td>-</td>
<td>720m</td>
<td>10/1999</td>
<td>Active</td>
</tr>
<tr>
<td>Tributary Squirrel Neck Run (TSNR)</td>
<td>11.1</td>
<td>B/C</td>
<td>100%</td>
<td>~1982</td>
<td>580m</td>
<td>1/2005</td>
<td>Active</td>
</tr>
<tr>
<td>Tributary Seldom Seen Run (TSSR)</td>
<td>5.1</td>
<td>C</td>
<td>100%</td>
<td>~2002(^2)</td>
<td>630m</td>
<td>9/2004</td>
<td>Active</td>
</tr>
</tbody>
</table>

1) All mined areas reclaimed by regrading to approximate original contour and replanting with grasses per PL95-87

2) Reclamation in this watershed has continued with the planting of some woody vegetation (black locust trees), regrading including filling of rills and gullies, and liming and reseeding.
## Small Watersheds: Runoff Results

TSSR > TMAT > TNEF ≈ TSNR

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Events</th>
<th>Date</th>
<th>Rainfall (mm)</th>
<th>Runoff (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TMAT</td>
<td>64</td>
<td>6/2000-9/2008</td>
<td>18-170</td>
<td>0-93</td>
</tr>
<tr>
<td>TSNR</td>
<td>29</td>
<td>1/2005-9/2008</td>
<td>18-90</td>
<td>0-11</td>
</tr>
</tbody>
</table>
HYDROLOGY: SOLUTION OF RUNOFF EQUATION

\[ Q = \frac{(P - 0.2S)^2}{P + 0.85S} \]

- \( P \geq 0 \) to 12 inches
- \( Q \geq 0 \) to 6 inches

Curves on this sheet are for the case \( I_a + 0.2S \), so that:

\[ Q = \frac{(P - 0.2S)^2}{P + 0.85S} \]

PREDICTED RUNOFF (Q) IN INCHES

REFERENCE:
Mockus, Victor; Estimating direct runoff amounts from storm rainfall:
Central Technical Unit, October 1955

MINE LAND RUNOFF FROM SCS METHOD
MINELAND RUNOFF FROM SCS METHOD

MINELAND RUNOFF FROM SCS METHOD

Hydrology: Solution of Runoff Equation

Runoff = 2.3"

CN = 76

Rainfall = 4.67"
(25 yr/24 hr storm)
TR-55 Tabulated Value

Observed Value

TMAT (reclaimed)
Estimated and Observed CNs for Reclaimed Watersheds

<table>
<thead>
<tr>
<th>Source</th>
<th>Location</th>
<th>Watershed</th>
<th>TR-55/NEH-4*</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ritter and Gardner (1991)</td>
<td>Central PA</td>
<td>Browncrest</td>
<td>74</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moshannon</td>
<td>75</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Snow Shoe</td>
<td>77</td>
<td>88</td>
</tr>
<tr>
<td>Bonta et al. (1997)</td>
<td>East Central OH</td>
<td>C06</td>
<td>-</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M09</td>
<td>-</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td></td>
<td>J11</td>
<td>-</td>
<td>88</td>
</tr>
<tr>
<td>McCormick and Eshleman (this study)</td>
<td>Western MD</td>
<td>TMAT</td>
<td>74</td>
<td>81</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TMAT (Reclaimed Area)</td>
<td>74</td>
<td>92</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TSNR</td>
<td>68</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TSSR</td>
<td>74</td>
<td>87</td>
</tr>
</tbody>
</table>
### Peak Runoff Rates

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Area (ha)</th>
<th>Tc (min)</th>
<th>CN TR-55</th>
<th>Obs</th>
<th>Error</th>
<th>CN Obs</th>
<th>Error</th>
<th>CN TR-55</th>
<th>Obs</th>
<th>Error</th>
<th>CN TR-55</th>
<th>Obs</th>
<th>Error</th>
<th>CN TR-55</th>
<th>Obs</th>
<th>Error</th>
<th>CN TR-55</th>
<th>Obs</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>TNEF</td>
<td>3.0</td>
<td>20</td>
<td>70</td>
<td>72</td>
<td>+2</td>
<td>0.13</td>
<td>0.16</td>
<td>23%</td>
<td>0.38</td>
<td>0.41</td>
<td>8%</td>
<td>0.68</td>
<td>0.73</td>
<td>7%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TMAT</td>
<td>27.1</td>
<td>30</td>
<td>74</td>
<td>81</td>
<td>+7</td>
<td>1.29</td>
<td>2.03</td>
<td>57%</td>
<td>3.26</td>
<td>4.28</td>
<td>31%</td>
<td>5.62</td>
<td>6.80</td>
<td>21%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TSNR</td>
<td>11.1</td>
<td>27</td>
<td>68</td>
<td>64</td>
<td>-4</td>
<td>0.24</td>
<td>0.21</td>
<td>-13%</td>
<td>0.89</td>
<td>0.84</td>
<td>-6%</td>
<td>1.78</td>
<td>1.71</td>
<td>-4%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TSSR</td>
<td>5.1</td>
<td>11</td>
<td>79</td>
<td>87</td>
<td>+8</td>
<td>0.54</td>
<td>0.80</td>
<td>48%</td>
<td>1.15</td>
<td>1.47</td>
<td>28%</td>
<td>1.86</td>
<td>2.20</td>
<td>18%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
River Basins: Method #1

Comparison of flood frequency distributions (log Pearson Type III = LP3 w/ weighted skew) computed using the annual maximum series of daily streamflow (AMSS)

a) Differences for 2 time periods (1949-1975; 1976-2006): assumes \textit{episodic} non-stationarity

b) Differences in moments using a 21-year moving window: better for addressing a \textit{secular} change

McCormick et al., \textit{WRR}, in revision
**QP and P Trends**

- **Georges Creek**
  - Graph showing trends in Qp and P over time.
  - Regression lines shown.
  - No trends were statistically significant ($p < 0.05$) using 3 different tests.

- **Savage River**
  - Graph showing trends in Qp and P over time.
  - Regression lines shown.

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**R’ Trends**

- Graph showing trends in R’ over time for Georges Creek and Savage River.
- Regression lines shown.

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**River Basins: Method #2**

- *regression lines shown*
- *no trends were statistically significant ($p \leq 0.05$) using 3 different tests*

McCormick et al., *WRR*, in revision
Paired rainfall-runoff analysis of 27 contemporary warm season storm events (1996-2006)

a) Classical hydrograph separation: computation of normalized runoff volume ($R_v$) and peak runoff ($R_p$)

b) Total event areal rainfall ($P$) and peak areal intensity ($p_{max}$) from the NWS WSR-88D (NEXRAD) “Stage III” operational radar rainfall product (archived)

c) Compare $R_v:P$, $R_p:p_{max}$, and centroidal lag ($L_C$)

d) Eleven events culled \textit{a priori} for violating pre-set conditions
Remnants of Hurricane Ivan (September 2004)

Mc Cormick et al., WRR, in revision
16 Runoff Events (1999-2006)

**$L_C$ (hr)**
- $y$-int = -2.7
- $r^2 = 0.93$
- $p = 0.045$

**$R_P:p_{max}^*$ (dim.)**
- $x$-coef = 1.45
- $r^2 = 0.77$
- $p = 0.10$

**$R_V:P$ (dim.)**
- $x$-coef = 0.66
- $r^2 = 0.89$
- $p = 10^{-5}$

The Legacy of Deep Mining in Georges Creek

Photo Credit: USGS

McCormick et al., WRR, in revision
Stormflow peaks increase with increasing LCLUC: 25% mineland causes enhancement by a factor of about 40% at all frequencies.

Ferrari et al., WRR, in press
Conclusions

• Surface mining and land reclamation can amplify storm runoff responses of small catchments.
  – SCS-CN method often underestimates actual response

• Effects of mining were not detectable at the river basin scale using long gage records and conventional flood frequency methods.

• A comparative paired analysis produced significant results, in particular:
  – Comparable flood volumes (assumed)
  – Decreased centroidal lag (~ 3 hr)
  – Higher normalized peaks (~ 40%, across the board)

• Modeling suggests that increased mining and reclamation will further “enhance” flooding responses in Georges Creek.
Acknowledgments

Collaborators

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Data & Permissions

MDE - permits
MBOM - mining history
NRCS - aerial photography
USGS - historical streamflow data
NCDC-NOAA - historical precipitation data
Ian Littlewood - IHACRES
Paul Willison & Simon Mohr (deceased) - landowner permissions

Sponsors

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