Stream Bluff Slumping and its Contribution to Suspended Sediment Loads

D. J. Mulla
Dept. Soil, Water and Climate
University of Minnesota
Background

- Lake Pepin - depositional basin
- Sedimentation rates increasing
- ~350 years until lake filled
- MN River contributes 25% of flow into Lake Pepin
- Currently, MN River contributes 88% of the sediment into Lake Pepin
MN River Background

• Greater Blue Earth River contributes 46% of flow, 44% of sediment at Mankato
• Of this, main stem of Blue Earth contributes 43% of flow and sediment
• Blue Earth River cuts into Steep Stream Banks creating large, unstable escarpments
• Controversy over where sediment originates – in-stream vs. upland
• Similar controversy in Seven Mile Creek watershed where bluffs exist along Steep Valley Walls
Total Suspended Solids
Seven Mile Creek Watershed

*Four Year Flow Weighted Average, 2000-2003
Estimated Sediment Sources
Seven Mile Creek Watershed

- Riparian: 49%
- Open Tile Intakes: 7%
- Upland: 31%
- Streambank Erosion: 13%
Objectives

- Estimate the significance of stream bluff slumping as a sediment source in the Blue Earth River watershed
- Estimate historical rates of downcutting in the Blue Earth River watershed going back 13,000 years
Methods

• Eleven sites used to evaluate long-term (1938-1994) changes in slumping by analysis of aerial photographs (Bauer)

• Seven sites on the main stem of Blue Earth River surveyed repetitively (1998-2000) using Total Station (Sekely)

• Results from these two approaches extrapolated to entire main step of Blue Earth River based on inventory of slumping bluffs sites identified by DOQ’s and canoe surveys (Bauer)
Methodology-Aerial Photos

- Aerial photos with a resolution of 1 m for 1938, 1964 and 1994 obtained from Borchert Map Library (UofM)
- Identified and digitized 11 sites with flat fields next to bluffs, no trees at top of bluff and nearby presence of a fixed landmark such as a barn or road intersection
- Photos were registered and rectified
- Upper boundary of bluff digitized and compared from 1938-1994, height and area lost used to estimate mass slumped
Methodology-Total Station Surveys

• Repeated 5m x 5 m topographic surveys with an accuracy of a few mm of actively slumping bluffs used to create DEMs using kriging

• Subtract one year’s DEM from the previous to determine volume change

• Multiply volume change by bluff sediment bulk density to obtain mass loss

• Calculate average annual erosion rate for each site over three-year period

• Determine relationship between surface area and erosion rate to derive an erosion rate constant
Entire River Bluff Inventory

- USGS 1:40,000 DOQ’s from 1994 used to digitize entire Blue Earth River (157 km)
- 136 actively slumping bluffs were identified on DOQ’s from light colored areas and contour map
- Height and area of exposed bluffs were estimated from contour map and canoe surveys
- Surface area calculated by assuming bluff is 40% vertical and 60% at an angle of 37 degrees
Extrapolation to Blue Earth River

• Use regression equation relating bluff area and slumping rate based on aerial photography (Bauer) and direct survey (Sekely) research to area of each of the 136 actively slumping bluffs along Blue Earth River

• Assume that slumped sediment delivered to mouth of watershed is 40% of total mass slumped based on particle size analysis (tills 49% clay and silt; alluvium 5% fine sand)
Historical Rates of Downcutting

- Assumed that area where Blue Earth River is presently located was flat at the end of glaciation (13,000 years ago)
- USGS DEM’s and GIS used to estimate the volume and mass (M) of sediment lost over the last 13,000 years by downcutting
Downcutting Model

• $M_t = M_0 \times \exp(-kt)$
  – $M_t$ is rate of downcutting at any time $t$
  – $M_0$ is rate of downcutting at end of glaciation
  – $t$ is time in years since glaciation ended (13,000 years ago)
  – $k$ is a rate constant for downcutting

• $M$ (known from GIS) = $\int M_0 \exp(-kt) \, dt$

• Solved for $k$ and $M_0$ using present day rate of downcutting (known from Sekely research) in an iterative process
Results

- Volume changes
- Erosion rates
- Erosion rate constant
- Extrapolation to entire river
- Historical context for rates of downcutting
## Erosion Rates

<table>
<thead>
<tr>
<th>Site</th>
<th>Surface area</th>
<th>Total volume change</th>
<th>Erosion rate</th>
<th>Erosion rate</th>
<th>Bauer erosion rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m²</td>
<td>m³</td>
<td>t yr⁻¹</td>
<td>t ha⁻¹ yr⁻¹</td>
<td>t ha⁻¹ yr⁻¹</td>
</tr>
<tr>
<td>amb1</td>
<td>624</td>
<td>356</td>
<td>249</td>
<td>3995</td>
<td></td>
</tr>
<tr>
<td>gth17</td>
<td>590</td>
<td>235</td>
<td>110</td>
<td>1860</td>
<td>6485</td>
</tr>
<tr>
<td>gth2</td>
<td>3811</td>
<td>444</td>
<td>207</td>
<td>544</td>
<td></td>
</tr>
<tr>
<td>vc1</td>
<td>6859</td>
<td>3700</td>
<td>1980</td>
<td>2887</td>
<td></td>
</tr>
<tr>
<td>vcgt18</td>
<td>722</td>
<td>98</td>
<td>69</td>
<td>951</td>
<td>4835</td>
</tr>
<tr>
<td>vcgt2</td>
<td>816</td>
<td>478</td>
<td>223</td>
<td>2733</td>
<td>2482</td>
</tr>
<tr>
<td>win2-1b</td>
<td>874</td>
<td>395</td>
<td>184</td>
<td>2110</td>
<td></td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>****</td>
<td>****</td>
<td><strong>2154</strong></td>
<td><strong>3404</strong></td>
<td>****</td>
</tr>
</tbody>
</table>
### Severity Class

- **Minor (35 sites)**: 2000-5000 m²
- **Moderate (73 sites)**: 5000-10000 m²
- **Severe (28 sites)**: >10000 m²
$R^2 = 0.83$
Distribution of Total Loss by Severity Class

- Minor (35 sites): 8%
- Moderate (73 sites): 43%
- Severe (28 sites): 43%
**Annual Sediment Loss Estimates**


<table>
<thead>
<tr>
<th>Class</th>
<th>Slumped</th>
<th>Delivered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor</td>
<td>4642</td>
<td>1717</td>
</tr>
<tr>
<td>Moderate</td>
<td>41039</td>
<td>15184</td>
</tr>
<tr>
<td>Severe</td>
<td>60533</td>
<td>22397</td>
</tr>
<tr>
<td>Total</td>
<td>106213</td>
<td>39299</td>
</tr>
<tr>
<td>% of Measured Sediment at Mouth</td>
<td>44 ± 3.5</td>
<td></td>
</tr>
</tbody>
</table>
Historical Downcutting Model

- Volume of sediment removed over last 13,000 years by downcutting along Blue Earth River: 2.4 billion m³
- Mass of sediment removed: 3.6 billion tons
- Downcutting model $M_t = M_o \times \exp(-kt)$
  - $M_o$ is 573,840 tons initially removed by downcutting in first year (compared with present day rate of slumping 106,213 tons)
  - $k$ is 0.0013
Downcutting Model
(from end of glaciation to present)

Downcutting (tons/yr)

Initial Rate

Present Rate

Time (years)

0 2000 4000 6000 8000 10000 12000 14000

Downcutting Model
(from end of glaciation to present)
Conclusions

• Streambank slumping along the Blue Earth River contributes roughly 44% of total suspended sediment load at the mouth
• Over 90% originates from sites > 5000 m²
• Median erosion rate of 428 t yr⁻¹
• Historical rates of downcutting since end of glaciation have removed 3.6 billion tons of sediment, the initial rate of downcutting was 5 times larger than present day rates
Acknowledgements

• This research was supported by a grant from the Minnesota Corn Research and Promotion Council