Quantifying Streambank Erosion and Phosphorus Load for Watershed Assessment and Planning

Final Report Presentation
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Research Objectives

1. Estimate streambank erosion in Barren Fork Creek watershed

2. Develop and test new streambank erosion model for SWAT

3. Predict streambank erosion and P load for the Barren Fork Creek watershed using the improved SWAT model
Illinois River (IRW) and Eucha-Spavinaw Watersheds (ESW)
IRW and ESW Water Quality Issues

- Phosphorus
  - Poultry litter
  - Cattle
  - Point sources
  - Streambank erosion
  - Soil Test P (STP)
  - Urban

- Sediment
  - Pasture
  - Urbanization
  - Streambank erosion
  - Crops
  - Roads
  - Construction
Legacy Phosphorus

- Accumulated P in soils and water, which may serve as a long term P source
- May mask or buffer impacts of conservation practices and other water quality improvement practices
Soil and Water Assessment Tool (SWAT)

- Product USDA Agricultural Research Service
- Used worldwide
- Predicts streamflow, sediment, nitrogen, P, crop yields, etc.
- Evaluates conservation practices
- Pollutant loads for TMDLs
SWAT Model Data Requirements

- Landcover
- Topography
- Soils

Model Predictions

- Weather
- Management
- Point Sources
Phosphorus Sources
SWAT Model Predictions 2004-2013

Lake Tenkiller Total P Load Distribution
- Overgrazing: 21%
- Cattle/Pasture: 4%
- Point Sources: 7%
- Litter: 9%
- Urban: 8%
- Crops: 7%
- Baseflow: 11%
- Elevated STP: 24%
- Hay to Forest: 9%
- Other Non-Point Sources: 7%

Barren Fork Creek Particulate P Load

Lake Tenkiller Total P Load
190,00 kg/yr

Streambank Erosion is Missing!
Streambank Erosion

- TMDL being developed for Illinois River watershed not explicitly accounting for P from streambanks
- Barren Fork Creek Watershed - 36% streambanks unstable, estimated erosion 93 Mg TP/yr
- Illinois River Watershed - recent estimates >350 Mg TP/yr from eroded streambanks
- Note: not all streambank erosion & P reaches lake!
Objective 1: Measuring Streambank Erosion

- Lake Tenkiller Total P load
  - 190,000 kg/yr
- Period 2003-2013
  - Single 190 m reach - 40,000 Mg eroded soil
  - >5,000 kg Total P
  - 26% annual Total P load
Objective 2

- Modify and test streambank erosion model for SWAT
  - Compare field measured and SWAT default parameter values
  - Analyze SWAT predictions using literature and field-based data
  - Evaluate observed vs SWAT predicted streambank erosion at ten sites

- Develop guidance for watershed modelers and managers on data collection, parameter estimation and use of the new SWAT model
Typical Stream Channel Profile
Barren Fork Creek
Excess Shear Stress

\[ \varepsilon_r = k_d (\tau - \tau_c) \]

- \( \varepsilon_r \): erosion rate (cm s\(^{-1}\))
- \( k_d \): erodibility coefficient (cm\(^3\) N\(^{-1}\) s\(^{-1}\))
- \( \tau \): applied shear stress (Pa)
- \( \tau_c \): critical shear stress (Pa)
SWAT Streambank Erosion Modifications

- Replace empirical applied shear stress equation with process-based

Empirical

$$\log(SF_{bank}) = -1.4026 \times \log\left(\frac{P_{bed}}{P_{bank}} + 1.5\right) + 2.247$$

$$\frac{\tau_e}{\gamma \times \text{depth} \times \text{slp}_{ch}} = SF_{bank} \times \left(\frac{(W + P_{bed}) \times \sin \theta}{100 \times \frac{4 \times d}{3}}\right)$$

Process-based

$$\tau = \lambda \times R \times S_f$$

$$S_f = \frac{n^2 \times Q^2}{A^2 \times R^3}$$

- Replace bankfull width and depth with top width and bank height

[Graph showing flow depth versus months (January to December)]
SWAT Streambank Erosion Modifications

- SWAT assumes 2:1 homogenous trapezoidal cross-section (—)

- Area adjustment factor, $a$ ($\leq 1$): $A_{adj} = a \times A_{SWAT}$
Streambank Data Collection

- Tested new SWAT model on Barren Fork Creek watershed using ten study sites (Miller et al., 2014)
- Characterize stream channel parameters using 28 cross-sectional surveys
Model Parameter Estimates

- Literature Based
  - Sinuosity
  - Radius of curvature
  - Bed slope

- Field Measured
  - Bankfull width and depth
  - Bed slope
  - Critical shear stress and erodibility coefficient
  - Top width and bank height
  - Side slope
  - Area adjustment factor
Observed vs Simulated Streambank Erosion

![Graph showing observed, empirical, and process-based streambank erosion for different study sites over the years 2003 and 2013.]

- **Study Site**: Observations and simulations for different sites labeled F to G.
- **Erosion (Mg yr⁻¹)**: The x-axis represents the study sites, and the y-axis shows the streambank erosion in Mg yr⁻¹.
- **2003** and **2013**: Comparative images showing the erosion in different years.

**Downstream** arrow indicates the direction of flow.
## Observed vs Simulated Streambank Erosion

- Substantial improvement in model predictions
  - SWAT using new streambank erosion model
  - Field measurement-based parameter estimates

- Observed Streambank Erosion - 2,800 Mg yr\(^{-1}\)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Applied Shear Stress Equation</th>
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<th>Applied Shear Stress Equation</th>
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<td></td>
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<td>Empirical</td>
<td>Process-Based</td>
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<td>Empirical</td>
<td>Process-Based</td>
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<td></td>
<td></td>
<td>Erosion (Mg yr(^{-1}))</td>
<td>R(^2)</td>
<td>NSE</td>
<td>Erosion (Mg yr(^{-1}))</td>
<td>R(^2)</td>
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<td>Field-based + A(_{adi})</td>
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<td>0.34</td>
<td>0.31</td>
<td>3,080</td>
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Objective 3

- Predict streambank erosion using SWAT for the Barren Fork Creek watershed with modified streambank erosion routine
- Use SWAT to predict P load in with and without new streambank erosion routine
- Assess significance of streambank as P source
Extending Field Measurement to Watershed Streambank Parameter Characterization

- **Longitudinal trend**
  - Bed slope
  - Top width
  - Streambank total & dissolved P
  - Radius of curvature

- **Average**
  - Bank height
  - Critical shear stress & erodibility coefficient
  - Side slope
  - Bank composition
  - Area adjustment factor

- **Measured for each reach**
  - Sinuosity
  - Cover factor
Observed vs Simulated P Without Streambank Erosion

- Under predicts P for large storm events
- Over predicts P for several small events
Phosphorus Sources

- >100 Mg yr$^{-1}$ total P load to Barren Fork Creek
- Streambank erosion contributed 47% total P load
- Total P Load
  - 65% leaves watershed
  - 35% remains in watershed (stream, floodplain)
OBSERVED vs SIMULATED P WITH STREAMBANK EROSION

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Without Streambank Erosion</th>
<th>With Streambank Erosion</th>
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<tr>
<td></td>
<td>Calibration</td>
<td>Validation</td>
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<td>$R^2$</td>
<td>0.82</td>
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<tr>
<td>NSE</td>
<td>0.60</td>
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Total Phosphorus (Mg yr$^{-1}$)

- Observed
- Simulated without Streambank Erosion
- Simulated with Streambank Erosion

Year: 2004 to 2013
Conclusions

- Modified streambank erosion routine adequately predicted streambank erosion for composite streambanks in Barren Fork Creek watershed
- Process-based applied shear stress equation, area adjustment factor and other changes improved model predictions
- Literature-based stream parameters provided reasonable estimates and predictions
Recommendations

- Watershed-based plans must consider legacy P sources when selecting conservation practices.
- Cross-sectional surveys should be conducted when resources permit.
- P from streambanks need to be considered, especially for nutrient impacted migrating streams and their receiving waterbodies.
Student Support

- Ph.D. Students: 2
- Undergraduate Student: 1

Questions
Future Work

- Incorporate multiple bank layers and mass wasting into SWAT streambank erosion routine
- Consider incorporating BSTEM or CONCEPTS into SWAT
- Measure P deposition on non-critical bank and floodplain to improve model
- Quantify vegetation and root density effects on streambank erosion
- Test proposed streambank erosion and in-stream P modifications on other watersheds
- Modify SWAT to adjust channel dimensions on a daily time step