Long-term erosion monitoring on Niagara Escarpment watercourses

Anna C.J. Howes, Aquafor Beech Ltd.
Roger T.J. Phillips, Aquafor Beech Ltd. and Western University
Long Term Erosion Monitoring

- Used to assess impacts from land development (i.e. success of SWM measures)
- Important to distinguish between natural variations and development-related impacts
- How much natural variability is expected?
Overview

1. Monitoring methodology
2. Site classification
3. Site statistics
4. Target thresholds
5. Conclusions
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Site Information

- 20 sites
- 4 to 10 cross-sections per site
- 135 cross-sections total
- 3 surveys per year (spring, summer, fall)
- 6 years of data
Survey Control
Survey Control
Data Collection
Cross-Section Analysis

• Area

• Width

• Depth
Overview

1. Monitoring methodology

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Site Classification

- Cobble and fine grain
- Fine grain dominated
- Cobble dominated
- Queenston shale and gravel
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Site Statistics

Mean

\[ \mu = \frac{\sum_{i=1}^{N} X_i}{N} \]

Coefficient of Variance

\[ C_v = \frac{\sigma}{\mu} \]

Standard Deviation

\[ \sigma = \sqrt{\frac{\sum_{i=1}^{N} (X_i - \mu)^2}{N}} \]
Cross-Sectional Area Standardized Data
Field Site Average Standardized by Monitoring Period Average

- ◇ fine-grained
- • cobble
- × Queenston shale

Monitoring Events, 2010-2015 (3 events per year)
## Spatial versus Temporal Variability

Coefficient of Variation (CoV)

### Average Spatial Variability (between cross-sections)

<table>
<thead>
<tr>
<th>CoV Data</th>
<th>Average</th>
<th>Standard Deviation</th>
<th>Max / Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross-Sectional Area</td>
<td>31%</td>
<td>15%</td>
<td>89% / 5%</td>
</tr>
<tr>
<td>Bankfull Width</td>
<td>21%</td>
<td>10%</td>
<td>54% / 6%</td>
</tr>
<tr>
<td>Bankfull Depth</td>
<td>24%</td>
<td>10%</td>
<td>73% / 9%</td>
</tr>
</tbody>
</table>

### Average Temporal Variability (between seasonal monitoring events)

<table>
<thead>
<tr>
<th>CoV Data</th>
<th>All Events</th>
<th>Annual Averages</th>
<th>Seasonal Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross-Sectional Area</td>
<td>5.7%</td>
<td>4.5%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Bankfull Width</td>
<td>5.0%</td>
<td>3.7%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Bankfull Depth</td>
<td>5.2%</td>
<td>4.3%</td>
<td>0.9%</td>
</tr>
</tbody>
</table>

**Expected Range:**

- All Stream Classes: 5 – 6%
- All Parameters: 4 – 5%
- Seasonal Only: 1 – 2%

**Note:** Spatial variability is an order of magnitude larger than the seasonal variability!
Variance by Stream Class
CoV for Each Cross-Section through Time

Coefficient of Variance, CoV

Area
- cobble
- fine-grain
- shale

Width
- cobble
- fine-grain
- shale

Depth
- cobble
- fine-grain
- shale

All Seasonal Data

Annual Average Data

\[ t\text{-tests: Is the mean CoV statistically different between the stream classes?} \]
**Differences in Variance between Stream Classes**

p-values (two-tail) for t-tests assuming unequal variances (log-transformed data)
95% Confidence for Significance (p-value < 0.05)

<table>
<thead>
<tr>
<th></th>
<th>Cross-Sectional Area</th>
<th>Bankfull Width</th>
<th>Bankfull Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All Seasonal Data</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cobble ≠ Queenston</td>
<td>0.022</td>
<td>0.984</td>
<td>0.067 ~</td>
</tr>
<tr>
<td>Cobble ≠ Fine-grained</td>
<td>0.019</td>
<td><strong>0.040</strong></td>
<td>0.897</td>
</tr>
<tr>
<td>Fine-grained ≠ Queenston</td>
<td>0.567</td>
<td>0.045</td>
<td>0.156</td>
</tr>
</tbody>
</table>

| **Annual Data**      |                      |                |                |
| Cobble ≠ Queenston   | 0.043                | 0.408          | 0.044          |
| Cobble ≠ Fine-grained| 0.374                | 0.349          | 0.477          |
| Fine-grained ≠ Queenston | 0.611              | 0.156          | **0.031**      |

**Observations**

Queenston and fine-grained variances are statistically different from cobble for cross-sectional area

Differences in variance of fine-grained are explained by *seasonal variability* in bankfull width

Differences in variance of Queenston are largely explained by variance in bankfull depth (bed dynamics), which is NOT as sensitive to seasonal variability
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Erosion Target Thresholds
to detect signals of development impacts

Cross-sectional area (typically ± 20% threshold)

<table>
<thead>
<tr>
<th>Cross-Sectional Area</th>
<th>Avg. CoV</th>
<th>95th Percentile</th>
<th>99th Percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobble</td>
<td>4%</td>
<td>7%</td>
<td>11%</td>
</tr>
<tr>
<td>Fine-grained</td>
<td>7%</td>
<td>15%</td>
<td>24%</td>
</tr>
<tr>
<td>Queenston</td>
<td>7%</td>
<td>15%</td>
<td>32%</td>
</tr>
</tbody>
</table>

Bankfull depth (typically ± 20% threshold), substrate aggradation/degradation

<table>
<thead>
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<th>Bankfull Depth</th>
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<th>95th Percentile</th>
<th>99th Percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobble</td>
<td>4%</td>
<td>7%</td>
<td>11%</td>
</tr>
<tr>
<td>Fine-grained</td>
<td>5%</td>
<td>15%</td>
<td>17%</td>
</tr>
<tr>
<td>Queenston</td>
<td>7%</td>
<td>21%</td>
<td>33%</td>
</tr>
</tbody>
</table>

Typical 20% thresholds, may overestimate cobble, but OK for fine-grained and Queenston.

Local cross-section exceedances are common in the Queenston sites, but site averages typically remain below the erosion target threshold.
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Stream Morphology Monitoring Recommendations
to detect signals of development impacts

• Spatial variability is greater than temporal variability
  – Monitor more cross-sections rather than more often

• Fine-grained head water channels see higher seasonal variation
  – Multiple measurements annually are useful for these sites
  – Annual monitoring (once per year) may be sufficient for cobble and Queenston shale sites

• Variability differs by channel type
  – A “one-size-fits-all” approach to target thresholds may under-estimate or over-estimate natural variability
  – Classification by alluvial bed material type is useful
  – Monitoring schemes and target thresholds should reflect the expected natural variation of different stream types