Modeling: Stream Power Applications

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Stream Power Applications

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Agenda

- Potential Stream Power Applications
- What is Stream Power?
- Literature Review
- Local Stream Power Data
- Application Examples
Recent Stream Power Technical Applications

- NRCS 1997 – Emergency Earth Dam Spillways
- USACOE 2008 – Bedrock Spillway Scour
- Kleinhans 2010 – Channel Patterns
- FHWA 2012 – Bridge Pier Scour
- EU 2014 – Channel Processes and Classification

- MMI 2008-16: Channel Stream Continuity & Fish Passage
  Culvert Vulnerability Screening
  Geomorphic Evolution & Channel Classification
  Bridge and Culvert Scour
  Dam Removal
Stability Metrics

Flow Velocity \( (Q/A) \)
Shear Stress \( (\tau=\gamma RS) \)
Stream Power \( (\Omega=\gamma QS) \)
Thus rate of transportation, as well as capacity for transportation, is favored by fineness of débris, by declivity, and by quantity of water.

Load versus energy.—The energy of a stream is measured by the product of its discharge (mass per unit time), its slope, and the acceleration of gravity. In a stream without load the energy is expended in flow resistances.
When any real substance (water) impels any other real substance (sediment) to move, all experience shows that energy must be expended by the first substance in maintaining the motion of the second against some kind of dynamic opposition. And power—that is, a time rate of energy expenditure—is necessary to maintain the motion at a given time rate. Thus a stream can be regarded as a transporting machine; and we have the dynamic relation

\[ \text{rate of work done} = \text{efficiency} \times \text{available power} \quad (1) \]

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**An Approach to the Sediment Transport Problem From General Physics**

By R. A. Bagnold

**Physiographic and Hydraulic Studies of Rivers**

From considerations of energy balance and of mechanical equilibrium, a mathematical expression is derived relating the rate of sediment transport at bedload and as suspended load to the expenditure of power by a statistically steady flow of water.
Stream Power Particle Thresholds

empirical and semi-empirical bedload transport relationships (Bagnold, 1980; Costa, 1983; Williams, 1983) have been fairly successful in using stream power as a transport criterion. Bagnold (1966) defined unit stream power as:

\[ \omega = \frac{\gamma QS}{L} = \tau v \]  

Figure 3: Approximation of the likelihood of particle movement for a given particle diameter and unit stream power. (Source: Williams 1983).

Figure 9. Modified version of Williams' (1983) compilation of field-measured stream power as a function of transported boulder size. Williams (1983, p. 230) fitted, by eye, an approximate limiting line to represent the lowest unit stream power, which, according

O’Conner, 1986, GSA

Costa, 1983, GSA

Williams, 1983
Critical Specific Stream Power

Petit et al, 2005
High-Energy Floodplains

i) Con confined Coarse-Textured Floodplain
\[ \omega = >1000 \text{Wm}^{-2} \]

ii) Confined Vertical-Accretion Sandy Floodplain
\[ \omega = 300-1000 \text{Wm}^{-2} \]

iii) Cut and Fill Floodplain
\[ \omega = \sim 300 \text{Wm}^{-2} \]

Medium-Energy Floodplains

i) Braided River Floodplain
\[ \omega = 50-300 \text{Wm}^{-2} \]

ii) Lateral Migration, Scroll Floodplain
\[ \omega = 10-60 \text{Wm}^{-2} \]

iii) Lateral Migration / Backswamp Floodplain
\[ \omega = 10-\ll 60 \text{Wm}^{-2} \]

iv) Lateral Migration, Counterpoint Floodplain
\[ \omega = 10-\ll 60 \text{Wm}^{-2} \]

Source: Nanson and Croke, 1992
Channel Patterns Based Upon Stream Power

Kleinhans, 2010
River Styles By Specific Stream Power

Brierley & Fryirs, 2005, 2013
## THE REFORM FRAMEWORK: 3. ASSESSMENT, 1 RIVER TYPE

Modified from EU REFORM, 2014

### Steep → Less Steep

<table>
<thead>
<tr>
<th>BED MATERIAL CALIBRE</th>
<th>PLANFORM SINGLE-THREAD</th>
<th>Steep</th>
<th>Less Steep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedrock</td>
<td>Straight - Sinuous</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse - Mixed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bedrock and Colluvial</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>1000</td>
<td>300-1000</td>
</tr>
</tbody>
</table>

### Alluvial (confined single-thread)

| Bodock - Cobble      | Cascade                |       | 4          |
| Cobble - Gravel      | Step-pool              |       | 5          |
|                      | 1000                   | 1000  | 300-1000   |

### Unconfined

| Fine Gravel Sand     |                          |       | 10-60      |
|                      |                          |       | 0-10       |
| Fine Sand            |                          |       | 10-60      |
| Silt                 |                          |       | 0-10       |
| Clay (cohesive)      |                          |       | 0-10       |
|                      | 50-300                  | 15    |            |
|                      | 50-300                  | 9     |            |
|                      | 30-200                  | 10    |            |
|                      | 30-200                  | 11    |            |
|                      | 300                     | 12    |            |
|                      | 10-60                   | 13    |            |
|                      | 0-10                    | 16    |            |
|                      | 10-60                   | 17    |            |
|                      | 0-10                    | 18    |            |
|                      | 0-10                    | 19    |            |
|                      | 0-10                    | 20    |            |
|                      | 0-10                    | 21    |            |
|                      | 0-10                    | 22    |            |
Channel Degradation

SSP = 3504
Channel Degradation

Pre Flood, Cobble Bed

6-8 Feet Incision

Westkill Creek, NY, SSP = 1752
NY Road Embankment Scour

SSP = 1247
Floodplain Scour

Prattsville, SSP = 332
Frost Valley, SSP = 246

Pomperaug River
SSP = 78
Rondout Creek Van Aken Property

Wandering Channel

SSP = 132
West River, Low Energy Flood

SSP = 74
Bridge & Culvert Scour
Bridge Aggradation & Emergency Response

Phoenicia, SSP = 258 / 101
**Channel Prediction for Briggsville Dam Removal**

**Interpretation:** Confined high energy, gravel and cobble substrate channel.

**Design:** Create: stable straight plane bed (run) channel, active bed, with supplemental roughness and grade control riffles, plus local bridge scour counter measures.

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**The Issue:**
1. Preliminary design (by others) proposes unnatural step pool grade controls, overlooking channel type.
2. HEC-18 predicts deep bridge scour, ignoring bed load sediment.
3. MMI finds large upstream in-channel sediment sources.
4. MMI develops dynamic sediment transport model, predicting high sediment bedload (but model is quite expensive).
5. MMI designs for high bedload and minimal scour, no step pools.
6. Hurricane Irene validated MMI design assumptions.

**Goal:** Need simple ways to predict complex things.

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**Stream Power Analysis**

- **Q2 = 2360 CFS**
- **S = 0.014-0.022**
- **W=60 Ft**
- **D50=100 mm**
- **SSP = 800 WM⁻²**
- **EU Type 6**
Q2 = 80 CFS
S=0.014
W=25 FT
D50 < 0.1 mm, anticipated 1 mm
SSP=25 WM\(^{-2}\)
EU type 17

Interpretation: Unconfined medium energy, silty sand substrate
Create: stable sinuous pool riffle channel, minimal point bars, with supplemental gravel bed for habitat and roughness
The End