
Basic Principles

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Landscape / Drainage Position

- **RSC placement**
  - Stormwater outfall discharges with distance from receiving stream, into ephemeral channels, and overland flow.
  - Any concentrated flow from human-caused impervious structures, i.e., parking lots, buildings, etc.

Photo Credits: Montgomery County, Maryland
Altered Geomorphic Processes

- **Force vs Resistance**
  - Force – reach-scale excessive stream power \( [\Omega = \gamma Q S / w] \); and local-scale hydraulic forces \([F = \rho q \Delta v]\)
  - Resistance – reach-scale composition of boundary material and roughness \([\text{avg. } \tau_c, n]\); and local-scale critical shear stress \([\tau_c]\).

[Credit: Fairfax County, Virginia]

Local hydraulic force \([F]\) in plunge pool *versus* reach-scale fluvial erosion \([\Omega]\) and possible bank geotechnical failures due to gravity forces

[Credit: Montgomery County, Maryland]
Altered Geomorphic Processes

• Influential Factors in Bank Erosion: Review of Dominant Processes

**Subaerial Processes:**
- microclimate (i.e., temperature, vegetation, valley aspect); *and*
- bank soil composition (especially silt/clay percentage)

**Hydraulic Fluvial Processes:**
- stream power; local shear stress distribution; secondary currents;
- local slope; bend morphology (curvature); bank composition;
- vegetation; *and* bank moisture content

**Geotechnical (Mass) Failure:**
- bank height; bank angle; bank composition; soil bulk
- weight, *and* bank moisture content (pore water pressure tension).

Credit: STREAM ATTRIBUTE ASSESSMENT METHODOLOGY (SAAM)
U.S. Army Corps of Engineers, Norfolk District
Altered Geomorphic Processes

• Hydraulic Erosion Processes

Terms used:

Hydraulic shear stress – the force exerted by water flowing over boundary material, Pascals (1 Pa = 1 N/m²)

Boundary shear stress - $\tau_o$, the shear stress developed by moving fluid at the boundary (no slip condition).

Critical shear stress - $\tau_c$, property of the boundary material where erosion of the boundary material starts

Excess shear stress - $\tau_e = \tau_o - \tau_c$

Erodibility – volume of erosion per unit excess shear stress, per unit time (cm³/Pa/sec). Per unit area it is termed as a coefficient - $k_d$

Erosion rate – rate of bank retreat (m/sec) and computed by the excessive shear stress equation: $E = k_d(\tau_o - \tau_c)^n$
Altered Geomorphic Processes

• Hydraulic Erosion Processes

The difference between total boundary shear stress, \( \tau_o \), and critical shear stress, \( \tau_c \), is the excess shear stress, \( \tau_e \). \[ \tau_e = \tau_o - \tau_c \]

This is the shear stress that is available to cause erosion. The amount of erosion (E) that occurs is a function of the erodibility, \( k_d \), and the excess shear stress, \( \tau_e \).

\[ E = k_d(\tau_e)^n \]

\( n \) is assumed to be equal to 1

Credit: Andrew Simon, Cardno, Inc.
Altered Geomorphic Processes

- Geotechnical Processes
  Forces affecting soil shear stress:

  - Cohesion: electro-chemical bonds between particles
  - Normal load - weight of bank increases friction
  - Friction - inter-particle roughness
  - Matric suction - apparent cohesion
  - Pore-water pressure - reduces effective friction

Credit: Andrew Simon, Cardno, Inc.
Altered Geomorphic Processes

• Geotechnical Processes: Prediction of Bank Failure

Framework for River Bank Stability Analysis:

\[ \text{FS} = \frac{FR}{FM} \]

Bank failure: \( \text{FS} < 1 \)

(Amri-Tokaldany et al. 2003)

\[
FR = CL + F_{npwp} + (W_{\text{force}} \cos \beta + F_{cp} \cos i - F_{\text{uplift}} - H_{\text{force}} \sin \beta) \times \tan \phi \\
FM = W_{\text{force}} \sin \beta - F_{cp} \sin i + H_{\text{force}} \cos \beta
\]

\( W_{\text{force}} \) = weight of the unit width of failure block; \( F_{cp} \) = hydrostatic confining pressure

\( H_{\text{force}} \) = hydrostatic force exerted by any water present in the tension crack on the block

\( F_{npwp} \) = force due to negative pore water pressure; \( F_{\text{uplift}} \) = positive pore water pressure

\( \tan \phi \) = the friction angle averaged across each layer; \( C \) = cohesion; \( L \) = length of failure plane
Altered Geomorphic Processes

• Geotechnical Processes

Force vs resistance:

\[
Factor of Safety (F_s) = \frac{\text{Resisting Forces}}{\text{Driving Forces}}
\]

If \( F_s \) is less than 1.0 the bank will theoretically fail.
If \( F_s \) is greater than 1.0, bank is considered conditional stable (\( F_s > 1.3 \) stable).

<table>
<thead>
<tr>
<th>Resisting Forces</th>
<th>Driving Forces (gravity)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil shear strength</td>
<td>Bank angle</td>
</tr>
<tr>
<td>Matric suction</td>
<td>Weight of soil mass</td>
</tr>
<tr>
<td>Root reinforcement</td>
<td>Weight of water in bank</td>
</tr>
<tr>
<td>Confining force</td>
<td>Bank height</td>
</tr>
<tr>
<td>Pore-water pressure</td>
<td>Surcharge</td>
</tr>
</tbody>
</table>

Credit:
Andrew Simon, Cardno, Inc.
Altered Geomorphic Processes

• Geotechnical Processes
  • **Channel incision** is a process involving both hydraulic erosion and geotechnical failure processes in streams.
  • Excessive stream and local fluid power concentrated overland.

Credits: Gannett Fleming, Maryland

Credit: Cabin Branch, State of Maryland

Dry Channel // Ephemeral

Wet Channel // Stream
Altered Geomorphic Processes

• Streams: Channel Evolution Model

Simon and Darby (1999)
Altered Geomorphic Processes

- **Channel Evolution Model**
  - **Knickpoints**: upward moving point of erosion with steep (nearly vertical) bed slope
  - **Headcuts**: same as a knickpoint but can migrate upstream or downstream
  - **Grade Controls**: a hard point in the channel that prevent further upstream/downstream migration of a knickpoint

Simon and Darby (1999)
Altered Geomorphic Processes

• Ephemeral Channels: Headcuts, Knickpoints, Grade Controls:
  • D/S migration from plunge pool due to excessive stream power and little bedload supply
  • U/S migration from channel incision in the receiving stream.
  • D/S and U/S can occur.
  • Grade controls, natural or artificial can stop channel degradation processes.
Environmental Impacts

- Excessive Channel Erosion
  - Increased fine sediment yields to the receiving stream
  - Receiving streams may be impaired for siltation and habitat alteration – 303(d) list
  - Embeddedness in receiving stream’s riffle habitat, impacting benthic macroinvertebrates and fish
  - Increased stream turbidity
  - Increased nutrient $[PO_4^{3-}]$ transport and excessive biofilm growth
Environmental Enhancements

- **RSC Water Quality and Ecological Benefits**
  - Reduced fine sediment into the receiving stream
  - Improved water quality (↓ nutrients & temperature) through bio-media filtration
  - Create habitat space for wetland flora
  - Provide aquatic habitat for benthic macroinvertebrates, and through BMI drift generate food for fish in receiving stream
  - Increase fine organic matter (FOM) carbon loads to the receiving stream for enhanced ecosystem processes

Credit: Nat’l Park Service

Credit: Univ. of Maryland, Center for Environ. Science
Geomorphic Relations with Stream Processes

- RSC emulating stream processes
  - Riffle-pool sequences ::: step-pool sequences
  - Hyporheic zone for water quality ::: enhanced with bio-media as used in bioretention facilities
  - Groundwater influence and stream recharge.

Credit: wisc.edu
Geomorphic Relations with Stream Processes

- **Stream Geomorphology: Pool-riffle sequences**

  Generally associated with meanders, but bar unit can occur in straight channels.

  Photo Credits: geosciences.wisc.edu
Geomorphic Relations with Stream Processes

• Riffle-pool spacing ::: step-pool features

**Riffle-Pool Spacing:** Average 5-7 channel unit widths from a range of 1.5 to 23.3 channel unit widths formed by sediment aggradation and degradation.

**Step-Pool Spacing:** Variable based on geomorphic controls formed by hydraulic forces and scour-resistance large immobile bed materials (e.g., boulders).

*In general,* riffle-pool sequences occur with bed slopes < 2%, and step-pool sequences occur with bed slopes > 5%.
Geomorphologic Relations with Stream Processes

- Riffle-pool spacing ::: step-pool features
  - Hydraulic maintenance processes defer than those in 2\textsuperscript{nd}+ order streams
  - Physical structure represents those in 1\textsuperscript{st} to 2\textsuperscript{nd} order streams/tributaries

<table>
<thead>
<tr>
<th>2\textsuperscript{nd} - 3\textsuperscript{rd} + order streams</th>
<th>1\textsuperscript{st} - 2\textsuperscript{nd} order streams / RSC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reach-scale helical flow development, hydraulics governed by bed and bank resistance (vegetation).</td>
<td>No helical flow development; local hydraulics governed by instream structural controls.</td>
</tr>
<tr>
<td>Riffle-bar development depends on bedload sediment supply – a bar unit feature.</td>
<td>Bedload sediment transport controlled by channel capacity hydraulics (scour).</td>
</tr>
<tr>
<td>Shear-reversal from low flow to high flow. During low flows, shear stress ↓ in pools, ↑ in riffles; during high flows, shear stress ↑ in pools, ↓ in riffles.</td>
<td>Flow acceleration and deceleration; vertical flow more dominant.</td>
</tr>
</tbody>
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Geomorphic Relations with Stream Processes

- Hyporheic flow

Interactions at the surface-water/groundwater interface can play an important role in the concentration and load of constituents and can have significant environmental influences on biogeochemical processes (Bencala, 2005)

The hyporheic zone is a region beneath and lateral to a stream bed where there is mixing of shallow groundwater and surface water

Winter et al. (1998); Bencala (2005)
Geomorphic Relations with Stream Processes

• 4D stream view: longitudinal, lateral, vertical, and hyporheic

Water Quality Literature:
> Aerobic-anoxic denitrification
> Dissolved organic carbon (DOC) dynamics
> Metals adsorption

Credit: wisc.edu
Geomorphic Restoration Goals

- RSC Designs
  - Geomorphic threshold design – stabilize channel boundary with fixed geometry and sediment transport to pass through with minimal aggradation.
  - Hydraulic retention in pools and water filtration through riffles to improve water quality
  - Promote wetlands vegetation