Lecture 12

• Zone 2 of the Fluvial System, Continued

Stream Entrainment, Erosion, Transportation & Deposition

Erosion in a Fluvial Landscape

Corrosion  Chemical Erosion
Corrasion  Mechanical Weathering
Cavitation  Pressure Decrease in Constriction

Increasing Velocity - Air Bubbles
Decreasing Velocity - Bubbles Collapse:
Shock Waves, Rapids, Waterfalls
Hjulstrum's Diagram,  
(Ritter & others, 2002, p. 197, Fig. 6-7)

Mean Velocity

Transportation

Total Sediment Load =  
Dissolved Load +  
Suspended Load +  
Bed (Tractive) Load +  
Floatation Load

Flotation Load, Deckers Creek, Mon Co.
Dissolved Load

Chemical Weathering Products: Anions, Cations in Solution
10 to 120,000 ppm (mg/l): Varies with Climate, Rock Type, etc.
WV Typically 100 to 400 ppm

Organic Complexes
May Precipitate in Proper Geochemical Environment
Easily Measured in Lab

Falling Spring Marl-Travertine Deposit, Rt. 220, Near Covington, Virginia
Virginia Division of Mineral Resources Photo
www.mme.state.va.us/Dmr/GALLERY/historic/Images/BWMORP/bwcov.jpg

Suspended Load:
Sand, Silt or Clay Kept "Aloft" in Water by Current (Turbulence)
Easiest to Measure
Very Important in “Non-Point” Sediment Pollution
Stoke’s Law

\[ v = \frac{2/9 \cdot g \cdot r^2 \cdot (d_1 - d_2)}{\mu} \]

- \( v \): settling velocity
- \( r \): particle radius
- \( d_1 \): density of grain
- \( d_2 \): density of liquid
- \( \mu \): viscosity of liquid

Bedload

- Competence - Largest Particle Stream Moves
- Capacity - Total Bedload Amount Stream Moves

How Does Bedload Move?

Sliding, Rolling, Saltation

Sliding
Saltation
Bernoulli Principle

Tractive force = drag = shear stress = $\tau$

Tractive Force Equation
Expresses Energy Available to Transport Bedload In a Stream
\[ \tau = \gamma D S \]

\( \gamma = \) gamma = specific weight of water
\( D = \) depth
\( S = \) gradient (slope)

**What Might Cause \( \tau > \) Predicted by Tractive Force Equation**

- Kolks ( = Macroturbulence)
- Ice Push
- Debris Flow, etc.

**Stream Power (\( \Omega = \) Omega): Another Measure of Energy**

\[ \Omega = \gamma QS \]

Unit Stream Power, across 1 m width of channel

\[ \omega = \tau v \]

\( v = \) Mean Velocity
Nature of Bedload

Imbrication
Armoring ("Pavement")
Lag
Transitory Lag

Gravel-Bed Stream Bedforms

Transverse Bars "Dunes"
Longitudinal Bars
Diagonal Bars

Longitudinal Bar
Sand-Bed Stream Bedforms

Subcritical Flow (Lower Flow Regime)
\( F < 1 \)

- Ripples: \( \phi \leq 0.13 \)
  \( n \approx 0.025 \) to 0.030
- Dunes and superimposed ripples
  \( n \approx 0.035 \) to 0.035
- Dunes: \( \phi \leq 0.16 \)
  \( n \approx 0.035 \) to 0.04


Transition into Critical Flow (Upper Flow Regime)
Ripples & Dunes
“Wash Out”

\( F = 1, n = 0.03 \) to 0.02

Plane Bed

\( F \geq 1 \)
\( n = 0.012 \)

Bank-Full Discharge, Bank-Full Stage

The discharge or stage that achieves the greatest amount of work through time, and therefore is the dominant control of stream geometry and pattern.

Wolman & Miller (1960) Hypothesis. Moderate flows do more total work than the sum of infrequent High-Magnitude floods. 

Bank-full flow recurs ~1.1 to 2 yr. 

Concept valid for most streams, but not all!
Prediction from Gage Records

Gumbel Plot
Log-Pearson Type III
Used for High Flows or Low Flows
Annual Series: Extremes for Each Year Only
Partial Duration: All Events Beyond Threshold

Station 03069500 Cheat R. @ Parsons Annual Flood Series

<table>
<thead>
<tr>
<th>Date</th>
<th>Discharge</th>
<th>GageAtPeak</th>
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<tbody>
<tr>
<td>05/26/1990</td>
<td>42500</td>
<td>14.79</td>
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<tr>
<td>12/03/1991</td>
<td>30600</td>
<td>12.93</td>
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<tr>
<td>07/27/1992</td>
<td>26900</td>
<td>12.31</td>
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<td>04/01/1993</td>
<td>22300</td>
<td>11.47</td>
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<td>02/09/1994</td>
<td>78300</td>
<td>18.85</td>
</tr>
<tr>
<td>08/06/1995</td>
<td>19700</td>
<td>10.94</td>
</tr>
<tr>
<td>01/19/1996</td>
<td>90100</td>
<td>19.84</td>
</tr>
</tbody>
</table>
Cheat R. @ Parsons 1995-1996 Partial Duration Series

- Date              Discharge    GageAtPeak
- 08/06/1995        19700         10.94   1995 Annual Flood
- 05/14/1995        18600         10.72
- 01/19/1996        90100         19.84   1996 Annual Flood
- 05/05/1996        18200         10.33
- 05/06/1996        23300         11.43   >1995 Annual Flood
- 05/17/1996        50000         15.71   >1995 Annual Flood
- 05/28/1996        17800         10.25
- 07/19/1996        52500         16.06   >1995 Annual Flood
- 07/31/1996        50000         15.72   >1995 Annual Flood
- 08/13/1996        22000         11.17   >1995 Annual Flood
- 09/06/1996        46600         15.23   >1995 Annual Flood

Recurrence Interval (T_r)

\[ T_r = \frac{1}{p} = \frac{n+1}{m} \]

- \( p \) = Probability
- \( n \) = Number of Years in Record
- \( m \) = Rank of Event

Wolman-Miller Hypothesis Conceptual Basis

Dominant Flow
Entrainment Threshold

Graphic:
S. Kite, WVU
Bank Erosion, Undercutting (Corrasion, Slope Failure)

- Overbank Silt Loam
- Sand & Gravel Channel Deposits
- Bank-Full Stage
- Bedrock

Mill Creek, Canaan Valley State Park

Find Bank-Full Stage on Deckers Creek, Morgantown, W. Va.
Bank Erosion, Undercutting (Corrasion, Slope Failure)

Overbank Silt Loam
Sand & Gravel Channel Deposits
Bank-Full Stage
Slope Failure
Low-Flow Stage
Bedrock

Exceptions to Wolman & Miller Hypothesis:

Sand-bed streams where frequent flows transport sediment most of the time. (Dominant flow < 0.5 yr)

Bedrock and large boulder-bed streams in which moderate flows do not cross thresholds of entrainment. (Dominant flow > 50 yr)
Wolman-Miller Hypothesis Sand-Bed "Exception"

Dominant Flow

Recurrence Interval (Years)

Event Sediment Transport

Cumulative Sediment Transport

Entrainment Threshold

Frequency

0.2 2 20 200

Graphic: S. Kite, WVU
Wolman-Miller Hypothesis Bedrock-Bed “Exception”

<table>
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<tr>
<th>Recurrence Interval (Years)</th>
<th>Event Sediment Transport</th>
<th>Cumulative Sediment Transport</th>
<th>Entrainment Threshold</th>
<th>Dominant Flow</th>
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HYDRAULIC GEOMETRY:
Empirical Studies by Leopold & Maddock

\[ w = a Q^b \]
\[ d = c Q^f \]
\[ v = k Q^m \]

because \[ Q = A V = W D V \]

\[ Q = (a Q^b) (c Q^f) (k Q^m) \]

so, \[ b + f + m = 1.00 \]

\[ w = a Q^b \]
\[ d = c Q^f \]
\[ v = k Q^m \]
Downstream Changes in a Stream

\[ b = 0.461 \quad f = 0.383 \quad m = 0.155 \]

What does it all mean?

\[ w = a \, Q^b \]
\[ d = c \, Q^f \]
\[ v = k \, Q^m \]

Changes at a Station

\[ b = 0.26 \quad f = 0.40 \quad m = 0.34 \]

What does this mean?

\[ w = a \, Q^b \]
\[ d = c \, Q^f \]
\[ v = k \, Q^m \]
Hydraulic Geometry Applies to Pattern, Too

Sinuosity = \( p = \frac{\text{channel length}}{\text{valley length}} \)

\( p = 0.94 \text{ m}^{0.25} \)

\( m = \% \text{silt} + \% \text{ clay in wetted perimeter} \)

Schumm:

Meander wavelength = \( \lambda = \text{lambda} = \frac{Q_m^{0.48}}{m^{0.74}} \)

\( Q_m = \text{mean annual flow} \)

\( m = \% \text{silt} + \% \text{ clay in wetted perimeter} \)

Summary Hydraulic Geometry
In Two Equations

\( Q = (\text{width}) (\text{depth}) (\lambda) \div (\text{slope}) \)

Examples of \( Q^+ \) and \( Q^- \)

\( Q_{sed} = (\text{width}) (\lambda) (\text{slope}) \div (\text{depth}) (p) \)

Examples of \( Q_{sed}^+ \) and \( Q_{sed}^- \)