**Test 1 Scores**

- >77: A
- 66-76: B
- 55-65: C
- 44-54: D
- <44: not so good

**Test 1 Undergraduate Grades**

<table>
<thead>
<tr>
<th></th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2004</th>
<th>2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>A:</td>
<td>4</td>
<td>10</td>
<td>11</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>B:</td>
<td>15</td>
<td>11</td>
<td>10</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>C:</td>
<td>12</td>
<td>11</td>
<td>6</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>D:</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>F:</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Mean:
- 66.47
- 68.28
- 66.23
- **73.44**
- 67.26

**Test 1 2005**

- Overall Mean: 70.20
- Grad Students: 84.13
- Seniors: 65.60
- Juniors: 71.22
- Sophomores: 64.50
- Freshmen: **.**

**.** Data not shown if only 1 or 2 students in category
Test 1 2005
- Overall Mean: 70.20
- Geology & Pre-Geology: 67.62
- Env. Geosciences: 70.33
- Other majors: 74.93

Test 1 2000
- Overall Mean: 66.61
- Grad Students: 68.33
- Seniors: 67.25
- Juniors: 67.95
- Sophomores: 65.00

Test 1 2000
- Overall Mean: 66.61
- Geology: 67.40
- Pre-Geology: 67.56
- Env. Geosciences: 68.80
- Other majors: 64.33
Geo 321 Lecture 11

Zone 2:
Stream Channel Hydraulic Geometry

Sediment Yield
(= Sediment Load)
Total Amount of
Sediment Transported
Out of Basin by Streams
How Determined?

Sediment Delivery Ratio:

\[
\text{Sediment Delivery Ratio: } \frac{\text{Sediment Yield}}{\text{Soil Loss}} \times 100
\]

\[
\text{SDR not } = 100\% !
\]

Why?
Production of Sediments in Zone 1:
Slope Processes
Rill & Gully Erosion, Sheetwash

Downstream from Zone 1
Decrease in Slope Processes, etc.
Increase in Bank Erosion
Decrease in New Sediment Production

Zone 2:
"The Transport Zone"
Dominated by Channel Processes

Fundamentals of Stream Flow
Discharge (Q) = volume / time
Q = A V  (area x velocity)
Stage: Height of Water Surface

Typical Older-Style USGS Streamgage

Flow Meter

Other Rating Methods
Flow Regimes: Laminar Flow
• No Mixing Between Layers

Laminar-Turbulent Threshold Defined by Reynolds Equation:

\[ N_R = \frac{R_e}{\rho} = \text{dimensionless Reynold's number} \]
\[ R_e = \frac{\rho (V R)}{\mu} \]
\[ \rho = \text{[Rho]} = \text{density} \]
\[ \mu = \text{[Mu]} = \text{viscosity} \]

\( R_e \) between 300 and 600, possibly up to 2000, marks transition from laminar to turbulent flow

Flow Regimes: Turbulent Flow
• Mixing Between Layers
Turbulent flow
Froude number = \( F = \frac{V}{(gD)^{0.5}} \)

a. subcritical flow \((F < 1)\)
   tranquil flow, streaming flow, lower flow regime (flat water)

b. supercritical flow \((F > 1)\)
   jet flow, rapid flow, shooting flow, upper flow regime (white water)
Debris Fan

Upper Railroad Rapids, NRG: Subcritical Flow Transforms into Supercritical Flow

Supercritical Flow - Standing Wave, NRG
I Swam!
I Swam!
I Swam!
I Didn’t. So the Guide Got an A!

TYPES OF TURBULENCE:

Type 1: surge phenomena

Type 2: water rollers
   bank rollers
   bottom rollers

Type 3: eddies (local vortex, tornado-like)

Type 4: helical flow (like parallel coiled springs) may lead to meanders in streams.
Where Is Maximum Turbulence in a Stream?

Maximum Turbulence

Erosion with Slight Downward Component

Deposition = Accretion
Lateral “Accretion”

λ = Meander Wavelength

P = Sinuosity = River Distance / Straight-Line Distance

Meander Development

Maximum Erosion Occurs Downstream from Outside Bend:
Thus, Meanders “Grow” & Migrate Downstream with Time
Maximum Erosion Occurs Downstream from Outside Bend: Thus, Meanders “Grow” & Migrate Downstream with Time
Meander Development

Note “Kinks” w/in Meanders

Cut-Off Meander

Ox-Bow Lake
Meandering Stream, Sinuosity >3

http://www.geosurv.gov.nf.ca/education/features/geomorph.html

Photo: Geological Survey of Newfoundland & Labrador

Meander-Scroll
Topography Showing
Downstream Migration

Meanders and Oxbow Lakes

Oxbow Lakes
Cut Off

Neck
Point Bar
Stream Entrainment, Erosion, Transportation & Deposition

Erosion in a Fluvial Landscape

<table>
<thead>
<tr>
<th>Corrosion</th>
<th>Chemical Erosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrasion</td>
<td>Mechanical Weathering</td>
</tr>
<tr>
<td>Cavitation</td>
<td>Pressure Decrease in Constriction</td>
</tr>
</tbody>
</table>

Increasing Velocity - Air Bubbles
Decreasing Velocity - Bubbles Collapse: Shock Waves, Rapids, Waterfalls

Hjulstrum’s Diagram,
(Ritter & others, 2002. p. 197, Fig. 6-7)
Transportation

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

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)
Critical Tractive Force = 
\( \tau_c = 166 \, d \)

\( d = \text{grain diameter (mm)} \)

Critical Tractive Force: Force Required to Move Particle of diameter = d

Exceptions to the Critical Tractive Force Equation

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

Stream Power (\( \Omega \) = Omega): Another Measure of Energy
\( \Omega = \gamma Q S \)

Unit Stream Power, across 1 m width of channel
\( \omega = \gamma \tau v \)
\( v = \text{Mean Velocity} \)
Nature of Bedload

Imbrication
Armoring
Lag
Transitory Lag

Gravel-Bed Stream Bedforms

Transverse Bars "Dunes"
Longitudinal Bars
Diagonal Bars

Sand-Bed Stream Bedforms

Look at Figure 6.3 in Ritter & Others, 1995
Diagram From Schumm, 1977, p. 133
Bedforms & Flow Regime vs. Manning’s N
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!

Wolman-Miller Hypothesis Conceptual Basis

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Event Sediment Transport</th>
<th>Cumulative Sediment Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>200.2</td>
</tr>
</tbody>
</table>

Graphic: S. Kite, WVU

Bank Erosion, Undercutting (Corrasion, Slope Failure)

<table>
<thead>
<tr>
<th>Overbank Silt Loam</th>
<th>Sand &amp; Gravel Channel Deposits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bank-Full Stage</td>
</tr>
<tr>
<td></td>
<td>Bedrock</td>
</tr>
</tbody>
</table>
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)
Cheat River in Upper Cheat Canyon, W.Va.

Wolman-Miller Hypothesis Bedrock-Bed “Exception”

<table>
<thead>
<tr>
<th>Dominant Flow</th>
<th>Entrainment Threshold</th>
</tr>
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<tbody>
<tr>
<td>200</td>
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</table>

Recurrence Interval (Years)

Cumulative Sediment Transport

Event Sediment Transport

Frequency

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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**

$b = 0.461$  \  $f = 0.383$  \  $m = 0.155$

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 = \( p = \) channel length / valley length

\[ p = 0.94 \quad m^{0.25} \]

Schumm:

Meander wavelength = \( \lambda = \) lambda = \n
\[ Q_m^{0.48} / m^{0.74} \]

\( Q_m \) = mean annual flow
\( m \) = % silt + % clay in wetted perimeter
Summary Hydraulic Geometry In Two Equations

$Q = \text{(width)} \times \text{(depth)} \times (\lambda) / \text{(slope)}$

Examples of $Q^+$ and $Q^-$

$Q_{sed} = \text{(width)} \times (\lambda) \times \text{(slope)} / \text{(depth)} \times (p)$

Examples of $Q_{sed}^+$ and $Q_{sed}^-$

Review: Concept of Graded Stream

Review: Concept of Graded Stream
Unpaired Stream Terraces:

Paired Stream Terraces:

Strath = Erosional (Unpaired) Terraces
Armoring of Hollows

Topographic Inversion
W-Shaped Hollows

Gully Gravure

Kite Stream, Victoria Valley, Antarctica
Prediction from Geomorphology & Holocene Stratigraphy

Deposits
- Slackwater: Stage
- Bedload: Tractive Force, Stream Power

Paleosols
- Interruption of Stability

Landforms
- Slackwater Terraces

Tool kit for the paleohydrologist

- See 2001 Lecture for a bunch of slides