Stream Morphology

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What is a Stream?

… a body of water with a current, confined within a bed and streambanks

Synonyms: bayou, beck, branch, brook, burn, creek, crick, kill, lick, rill, river, rivulet, run, slough, syke

A stream is:
• conduit in the water cycle
• critical habitat
• connected to a watershed
Stream Assessment: Do you like this stream?
Stream Assessment: Do you like this stream?

Stream Functions

1. Transport water
2. Transport sediment
3. Habitat (aquatic & terrestrial)
4. Recreation & aesthetics
5. Safe Water Supply
Strahler Stream Order:
Classification system describing position within the drainage network

First order streams may be ephemeral, intermittent, or perennial in relation to groundwater connection.


Water Transport in Streams

**Hydrology:** The study of the flow of the earth’s waters through the hydrologic cycle

**Hydrograph:** Displays change in flow (discharge, Q, over time)

USGS 01516350 Tioga River near Mansfield, PA

Mean Daily Flow

www.Geology.com
Sediment Transport

Flowing water does work:

• Erosion
• Transportation
• Deposition (of alluvium)

http://www.uwsp.edu/gEo/faculty/ritter/geog101/textbook/fluvial_systems/geologic_work_of_streams.html
Erosion: *Detachment of material from bed and banks*

95% of stream energy used to overcome friction

Remaining energy used for Erosion Processes:
- Flowing water dissolves materials
- Hydraulic action dislodges materials
- Abrasion of heavy materials rolling on bottom

[Source](http://www.uwsp.edu/gEo/faculty/ritter/geog101/textbook/fluvial_systems/geologic_work_of_streams.html)

Transportation: *Movement of material by water*

**Stream Load** includes:
dissolved + suspended + bed load

**Capacity**: maximum load that can be transported for a given discharge
(increases with velocity and turbulence)

**Competence**: largest size material that can be transported for a given discharge

[Source](http://www.uwsp.edu/gEo/faculty/ritter/geog101/textbook/fluvial_systems/geologic_work_of_streams.html)
Deposition:

Aggradation: Raising the bed elevation

Bars: Depositional areas that may change flow directions

Fluvial Geomorphology:

study of landforms and the fluvial processes that shape them

http://www.uwsp.edu/gEo/faculty/ritter/geog101/textbook/fluvial_systems/geologic_work_of_streams.html
Fluvial Processes:
associated with flowing water, including sediment erosion, transport, and deposition

Stream: A system of fluvial forms & habitats
- Channel (bed & banks)
- Floodplain
- Water
- Sediment
- Plants & animals
Fluvial Forms

- Bar
- Channel
- Confluence
- Cutoff channel
- Delta
- Floodplain
- Gorge
- Gully
- Meander
- Oxbow lake
- Pool
- Riffle
- Stream
- Valley
- Waterfall
- Watershed

Sediment Deposition:

- Point bar
- Lateral bar
- Mid-channel bar
- Transverse bar
- Delta bar
**Point Bars:**

Inside meander bends

**Lateral Bars:**

Formed in straight channels
**Mid-channel Bars:**
Formed in over-wide channels

**Transverse Bars:**
Diagonal bars directing flow toward bank
Stream Morphology:
size and shape of channel & floodplain
(dimensions, pattern, profile)
Incised System: Floodplain Creation

Terrace

Floodplain

Valley type affects stream morphology

Colluvium is loose sediment transported by gravity and deposited at the bottom of a slope.

Alluvium is sediment deposited by a river in the channel or floodplain

Alluvial valleys occur where sediment particles are dropped by slow-moving water.
Valley Types:
(www.epa.gov/watertrain/stream_class)

Valley Type II
Moderately steep, gentle sloping side
slopes often in colluvial valleys

From EPA Watershed Academy: Fundamentals of the Rosgen Stream Classification System

Valley Types:
(www.epa.gov/watertrain/stream_class)

Valley Type VIII
Wide, gentle valley slope with well-developed
floodplain adjacent to river terraces

From EPA Watershed Academy: Fundamentals of the Rosgen Stream Classification System
Meandering Stream: Alluvial Forms

- Flow Downstream
- Floodplain
- Bankfull Stage
- Point Bar
- Scarp
- Pool
- Right Bank
- Left Bank
- Pool Cross-Section

Pool Cross-Section (Meandering Stream)

- Stream channel
- Scarp
- Thalweg

Bankfull Stage: “incipient flooding”

"corresponds to the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work results in the average morphologic characteristics” (Dunne & Leopold, 1978)

Channel-forming (dominant) discharge

Estimated using:

• Effective discharge (transports the most sediment over time)

• Bankfull discharge (fills active channel to point of incipient flooding)

• Discharge associated with recurrence interval (typically 1 to 2 year)
Bankfull Discharge

Flow fills active channel and spreads onto floodplain

 Represents break between channel & floodplain processes

For channel in equilibrium, assumed to equal the effective discharge

Return Period typically 1 to 2 years
Bankfull Indicators

- Top of streambank (floodplain)
- Break in slope on streambank
- Top of point bar
Channel Evolution (Succession)

Response to incising forces

Natural Stream Channel Stability
(from Leopold)

• River has a stable *dimension, pattern and profile*
• Maintains channel features (riffles, pools, steps)
• Does not aggrade (fills) or degrade (erodes)
Equilibrium Controlling Variables

- Width
- Depth
- Slope
- Velocity
- Discharge
- Flow resistance
- Sediment size
- Sediment load

*Leopold et al (1964)*

**Equilibrium Factors for Alluvial Streams**

From Rosgen (1996), from Lane, Proceedings, 1955. Published with the permission of American Society of Civil Engineers.
Dimension (cross-section)

- Area
- Width
- Depth
- Width/Depth Ratio
- Entrenchment Ratio
- Bank Height Ratio

Dimension: Cross-Section
Riffle Dimensions

Measure Bankfull Width ($W_{bkf}$) and Bankfull Area ($A_{bkf}$)

- Mean Depth, $d_{bkf} = A_{bkf} / W_{bkf}$
- Width to Depth Ratio, $W/d = W_{bkf} / d_{bkf}$

Bankfull Width, $W_{bkf} = 9.3$ ft; Bankfull Area, $A_{bkf} = 13.9$ ft$^2$

- Mean Depth, $d_{bkf} = A_{bkf} / W_{bkf} = 13.9 / 9.3 = 1.5$ ft
- Width to Depth Ratio, $W/d = W_{bkf} / d_{bkf} = 9.3 / 1.5 = 6.2$
Bankfull Width, $W_{bkf} = 36$ ft;  Bankfull Area, $A_{bkf} = 112$ ft$^2$
Mean Depth, $d_{bkf} = A_{bkf} / W_{bkf} = 112 / 36 = 3.1$ ft
Width to Depth Ratio, $W/d = W_{bkf} / d_{bkf} = 36 / 3.1 = 11.5$

Entrenchment Ratio

$ER = W_{fpa} / W_{bkf}$

$W_{fpa} =$ Width of Flood Prone Area measured at the elevation twice bankfull max depth above thalweg

$W_{bkf} =$ Width of Bankfull Channel
ER = \frac{W_{fpa}}{W_{bkf}} = \frac{75}{15} = 5.0

Flood water flows onto floodplain several times each year

Rocky Branch Phase II Reach 2:
Priority 2 (floodplain excavation, C channel)
Entrenchment Ratio = \frac{W_{fpa}}{W_{bkf}} = \frac{90}{20} = 4.5

Flood water flows onto floodplain several times each year
Rocky Branch Phase II Reach 1: Priority 3 (floodplain excavation, Bc channel)
Entrenchment Ratio = \( \frac{W_{fpa}}{W_{bkl}} = \frac{40}{20} = 2 \)

Bank Height Ratio

\[ BHR = \frac{LBH}{d_{mbkf}} \]

\( LBH \) = Low Bank Height (Max Depth to thalweg)
\( d_{mbkf} \) = Max Depth from bankfull stage to thalweg
Regional Curves
(Hydraulic Geometry Relationships)

- Relationships of measured stream morphology, discharge, and drainage area
- Valuable for geomorphic assessment to analyze departure from equilibrium conditions in disturbed ecosystems
- Valuable for restoration planning to determine approximate channel dimensions and discharge
The Hydraulic Geometry of Stream Channels and Some Physiographic Implications

By LUSA B. LEOPOLD and THOMAS MADDOK, Jr.

GEOLICAL SURVEY PROFESSIONAL PAPER 252

Quantitative measurements of some of the hydraulic factors that help to determine the shape of natural stream channels: depth, width, velocity, and suspended load, and how they vary with discharge as simple power functions. Their interrelations are described by the term "hydraulic geometry."

Regional Curves

Hydraulic Geometry Relationships: Leopold and Maddock, 1953

EXPLANATION

1. Red Fork near Burren, Tex.
2. Middle Fork Powder River near Kenny, Wyo.
3. Middle Fork Powder River near Vassar, Wyo.
7. Powder River at Suuns, Wyo.
8. Middle Fork Gros Ventre Creek near Gillette, Wyo.
9. South Fork Gros Ventre Creek near Buffalo, Wyo.
11. Crazy Horse Creek near Evanston, Wyo.
15. South Fork North Fork Clear Creek near Buffalo, Wyo.
17. South Platte River at Wadell Park, Wyo.
18. Upper Platte River at Laramie, Wyo.
19. Missouri River at Fort Pierre, S.D.
20. Missouri River at Yankton, S.D.
21. Red Fork near Spearfish, S.D.
Regional Curves

(bankfull width, depth, cross-sectional area related to drainage area)

*Dunn and Leopold, 1978*

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Regional Curve Development: Site Selection

- USGS Gage Stations with long-term records in stable watersheds
- Reference streams (ungaged) representing the range of stream sizes to be assessed
**USGS Gage Stations**

- Use maps to confirm no impoundments and stable watershed land use over time
- Measure drainage area (StreamStats)
- Collect USGS records including stage-discharge relationships

**Bankfull Stage at USGS Gage Stations:**

- Assess indicators upstream and downstream to determine bankfull stage in relation to water surface
- Translate bankfull stage to gage plate reading
- Determine bankfull discharge from USGS stage-discharge relationship for that gage
Reference Streams:

- Channels well-connected to alluvial floodplains with little evidence of incision (bank height ratios less than 1.2)
- Freely-formed meanders with alternating riffles and pools
- Streambanks and floodplains well-vegetated with no erosion
- Upstream watersheds mostly forest and agriculture
- Stable and unconfined for a length 20 times bankfull width
AL EGM Project
Funded by USEPA

• Develop regional curves for AL Piedmont
• Quantify ecological endpoints
  – Riparian vegetation and soils
  – Aquatic biota
• 21 streams in AL Piedmont
  – 0.1 – 100 mi²
  – Free-flowing, floodplain connection, high quality in-stream habitat, no invasive floodplain vegetation

Reference Streams:
• Upstream/downstream
• Similar watersheds
• Databases
• Historical photos

Similar bed/bank materials, hydrology, sediment inflow, slope, valley
Low Bank Height and Natural Grade Control

Alabama Piedmont Reference Streams

Bankfull Cross-sectional Area, Width, and Depth Related to Drainage Area
Alabama Piedmont Reference Streams
Bankfull Discharge Related to Drainage Area

Pattern (plan form)

Alluvial (low-gradient) streams naturally meander across a valley with a somewhat predictable pattern.
Chute cutoff across tight meander bend

Sinuosity = stream length / valley length
K = 1850 / 980 = 1.9
Plan Form Relationships

Meander Length Ratio = meander length / width = 78/15 = 5.2
Meander Width Ratio = belt width / width = 57/15 = 3.8
Radius of Curvature Ratio = radius / width = 23/15 = 1.5

\[ W = Q^{0.5} \]

\[ \lambda \approx 10 \text{ to } 14 \times \text{channel width (w)} \]

Modified from Simons and Senturk, 1973; and Leopold, et al., 1954
Stream Bedform Variability:

<table>
<thead>
<tr>
<th>Slope</th>
<th>Substrate size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity</td>
<td>Oxygenation</td>
</tr>
<tr>
<td>Shear stress</td>
<td>Habitats</td>
</tr>
</tbody>
</table>

Riffles

- Steep slope
- High velocity
- High shear stress
- Large substrate
- High porosity
Pools

- Flat slope
- Low velocity
- Low shear stress
- Small substrate
- Scour during high flow

Profile (bedform)

Water Surface
Riffle Slope
Run Slope
Glide Slope
Pool Slope
Thalweg
Pool Spacing, \( L_{p-p} \)

Riffle Slope Ratio, \( S_{rif} / S_{av} \)
Pool Slope Ratio, \( S_{pool} / S_{av} \)
Pool-to-Pool Spacing Ratio, \( L_{p-p} / W_{b kf} \)
Longitudinal Profile to Measure Ranges and Trends of Riffle/Pool Bedform Morphology

Total Station Surveys of Multiple Riffle/Pool Sequences

Typical Longitudinal Profile Showing Relative Elevations of Thalweg, Water Surface, Bankfull Stage, and Top of Bank
Alabama Piedmont Reference Streams

Pool lengths are consistently greater than riffle lengths, with both increasing with drainage area.

Pool and riffle lengths increase with channel width in nearly parallel relationships.

Riffle Lengths are Consistently Shorter than Pools
**Alabama Piedmont Reference Streams**

*Pool spacing increases with channel width with approximately a square root proportionality*

*Pool spacing ratios decrease from 4-5 in first-order streams to 2-3 in third-order streams*

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**Alabama Piedmont Reference Streams**

*Channel and riffle slopes decrease as drainage area increases in nearly parallel relationships*

*Riffle slope is nearly linearly related to channel slope with an average multiplier of just over 2*
Riffle Slopes are Higher in Small Streams

Riffle Slope is 2-5 Times Channel Slope Across the Range of Drainage Areas
Profile is related to Pattern

Step Pool Streams (high gradient)

Grade Controls

Nickpoints

High Gradient Reference Streams:
Joyce Kilmer/Slickrock Wilderness
Velocity & Discharge

\[ Q = V A = \text{Discharge (cfs)} \]
\[ V = \text{Velocity (ft/s)} \]
\[ A = \text{Cross-Section Area (ft}^2\text{)} \]
\[ V \text{ related to slope, channel shape, and channel roughness} \]


Velocities:
Low flow and Flood flow

Little Garvin Creek, Clemson, SC
Manning Formula

\[ V = \frac{k}{n} R_h^{2/3} \cdot S^{1/2} \]

where:
- \( V \) is the cross-sectional average velocity (ft/s, m/s)
- \( k \) is a conversion constant equal to 1.486 for U.S. customary units or 1.0 for SI units
- \( n \) is the Gauss-Manning coefficient (independent of units)
- \( R_h \) is the hydraulic radius (ft, m)
- \( S \) is the slope of the water surface or the linear hydraulic head loss (ft/ft, m/m) \( (S = h_r / L) \)

\[ R_h = \frac{A}{P} \]

where:
- \( R_h \) is the hydraulic radius (m)
- \( A \) is the cross-sectional area of flow (m²)
- \( P \) is wetted perimeter (m)

Manning’s n for Channels (Chow, 1959).

<table>
<thead>
<tr>
<th>Type of Channel and Description</th>
<th>Minimum</th>
<th>Normal</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural streams - minor streams (top width at floodstage &lt; 100 ft)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Main Channels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. clean, straight, flat stage, no riffles or deep pools</td>
<td>0.025</td>
<td>0.030</td>
<td>0.033</td>
</tr>
<tr>
<td>b. same as above, but more stones and weirs</td>
<td>0.030</td>
<td>0.040</td>
<td>0.040</td>
</tr>
<tr>
<td>c. clean, winding, some pools and shoals</td>
<td>0.033</td>
<td>0.040</td>
<td>0.040</td>
</tr>
<tr>
<td>d. same as above, but some weirs and stones</td>
<td>0.035</td>
<td>0.045</td>
<td>0.050</td>
</tr>
<tr>
<td>e. same as above, lower stages, more ineffective slopes and sections</td>
<td>0.040</td>
<td>0.048</td>
<td>0.050</td>
</tr>
<tr>
<td>f. same as “d” with more stones</td>
<td>0.045</td>
<td>0.060</td>
<td>0.060</td>
</tr>
<tr>
<td>g. sluggish reaches, weedy, deep pools</td>
<td>0.050</td>
<td>0.070</td>
<td>0.080</td>
</tr>
<tr>
<td>h. very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush</td>
<td>0.075</td>
<td>0.100</td>
<td>0.150</td>
</tr>
<tr>
<td>2. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. bottom: gravels, cobbles, and few boulders</td>
<td>0.030</td>
<td>0.040</td>
<td>0.050</td>
</tr>
<tr>
<td>b. bottom: cobbles with large boulders</td>
<td>0.040</td>
<td>0.050</td>
<td>0.070</td>
</tr>
</tbody>
</table>

"Open-Channel Hydraulics, originally published in 1959, has been described as one of the best textbooks ever written. It’s clear descriptions of timeless fundamental principles make Chow a classic. Anyone wanting to learn, to teach, and to work with water and fluids must own a copy."
Shear Stress: fluid force per unit area acting on the streambed

\[ \tau = \gamma R S = \text{Shear Stress (lb/ft}^2) \]
\[ \gamma = \text{Unit Weight of Water} = 62.4 \text{ lb/ft}^3 \]
\[ S = \text{Average Water Surface Slope (ft/ft)} \]
\[ R = \text{Hydraulic Radius (ft)} = A / P \]

*R is slightly less than mean depth in wide streams*

\[ A = \text{Riffle Cross-Section Area (ft}^2) \]
\[ P = \text{Wetted Perimeter (ft)} \]
\[ P = W_{b kf} + 2d_{b kf} \text{ (approx)} \]
A = 40 sq ft
W = 22 ft
d = 1.8 ft
R = 1.7 ft
S = 0.010 ft/ft

\[ \tau = \gamma R S = 1.0 \text{ lbs/sq ft} \]

Competence = 80 to 250 mm

Stream Competence (www.epa.gov/WARSSS)

Figure 126: Critical Shear Stress (tc: Range .001 to 10) Required to Initiate Movement of Grains (particles), revised for Colorado Rivers.
$R = 1.5 \text{ ft}$

$S = 0.0012 \text{ ft/ft}$

$n = 0.038$

$V = 1.8 \text{ ft/s}$

$Q = 89 \text{ cfs}$

$\tau = 0.11 \text{ lbs/sq ft}$

Competence = 8 to 25 mm

Parkerson Mill Creek, Auburn, AL (Piedmont)
Parkerson Mill Creek, Auburn, AL (Piedmont)

USGS StreamStats: Drainage Area = 3.0 sq mi
(34% impervious surface area)
Parkerson Mill Creek, Auburn, AL (Piedmont)

2-year Q = 390 cfs

**Urban Watershed:**

2-year Q = 1040 cfs

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### Urban Watershed: 2-year Q = 1040 cfs

```
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak 1-year Duration (day)</td>
<td>3.0</td>
<td>2.5</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>Peak 1-year Peak Flow (cfs)</td>
<td>1040</td>
<td>920</td>
<td>1200</td>
<td></td>
</tr>
</tbody>
</table>
```

### Peak Flow Statistics

- **Rating Curve:**
  - Equation: \( y = 70.002x^{0.7575} \)
  - \( R^2 = 0.9225 \)

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**Drainage Area (mi²)**

```
<table>
<thead>
<tr>
<th>Drainage Area (mi²)</th>
<th>Bankfull Discharge (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>30</td>
</tr>
<tr>
<td>0.02</td>
<td>60</td>
</tr>
<tr>
<td>0.03</td>
<td>90</td>
</tr>
</tbody>
</table>
```

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*Images of StreamStats Version 3.0 Flow Statistics Ungaged Site Report*
Parkerson Mill Creek, Auburn, AL (Piedmont)

![Graph showing the relationship between Bankfull Cross-sectional Area (ft²) and Drainage Area (mi²). The equation is \( y = 24.179x^{0.6526} \) with \( R^2 = 0.9588 \).]