Attributes of a stream channel

- Cross-section size and form, including connection with floodplain
- Bed material size and organization
- Planform
- Gradient

Hierarchy of controls on channel attributes (Brierley and Fryirs, 2005)

- Valley confinement
- Planform
  - Floodplain characteristics
  - Channel size
  - Channel morphology
  - Bank morphology
  - Bed morphology
Relation of channel attributes to project attributes

- Valley confinement (w)
- Planform (w,p,d)
- Floodplain characteristics (w, p, d)
- Channel size (w, d)
- Channel morphology (d)
- Bank morphology (w, d)
- Bed morphology (d)

Watershed control: sediment supply to reach, valley slope; valley alluvium characteristics

Project scale: width of valley acquired for project

Design scale: width/slope necessary to maintain sediment mass balance; capacity at flood stage

Different attributes have different characteristic spatial scales and adjust at different characteristic temporal scales
Valley confinement

- a major control on river morphology
- narrow valleys are more closely linked with hillslope processes (Grant and Swanson, 1995)

- primary control on differentiating geomorphic process zones (sediment source, sediment transfer, sediment accumulation)
- controls capacity for sediment storage or reworking
- control spatial patterns of erosion during large floods
- situations where confined valleys occur; floodplain pockets may exist
  - Steep headwater rivers and mountain streams
  - Gorges/canyons
- partly-confined valleys (lateral and vertical accretion models)
Channel planform (configuration of the channel in plan view)

- Number of channels
- Sinuosity (channel length/valley length)
  - Degree
  - Type
- Lateral stability-- capacity of the channel to adjust its position on the valley floor; includes meander growth and shift, degree of braiding and thalweg shift, tendency for avulsions
Measures of planform

Number of channels  |  Sinuosity  |  Lateral stability
---|---|---
(a) Number of channels
large | Degrees of sinuosity (after Church, 1989)
up to 3 (wandering) | 1–1.05 (straight) |
3 (fixed) | 1.06–1.20 (slightly meandering) |
> 3 | 1.21–2.5 (moderately meandering) |
(b) Sinuosity
- Regular meanders (passive)
- Mech sandbars
- Chute cut-offs
- Charater of bedform (after Church, 1989)
- 1st order avulsion
- 2nd order avulsion
- 3rd order avulsion
- Character of bedform (after Church, 1989)
(c) Lateral stability
- Mean lateral growth and shift
- Extension / Increasing amplitude
- Translation / Downstream amalgamation
- Rotation
- Shove cut-offs
- Mostly bars
- Mostly islands
- Mostly sand bars
- Mostly sand bars

Number of channels can vary from place to place on the same river

(Brierley and Fryirs, 2005)
Sinuosity and other measures of meander geometry

**Wavelength**

 Radius of curvature

- Long recognized relationships
  - Wavelength
    - $\lambda = (10 \text{ to } 14) \ B$
  - Radius of curvature
    - $R_c = (2 \text{ to } 3) \ B$

riffle-to-riffle spacing = (5 to 7) \ B

Should every bend be the same? (Williams 1986)

Ratio $R_c/W$

Geom. Mean for natural meanders is 2.43

2/3 of all natural meanders fall between 1.6 and 3.4

Mean + 1sd
Most bends are not symmetrical

- Thalweg extends to the outside of most bends

Big Creek near Randolph, UT

Active meandering (floodplain erosion and formation)

Passive meandering (planform is imposed)
- little bedload transport
- little point bar development

Meandering planform may have different inherent lateral stability
The instability characteristics of a meandering channel differ from place to place.

Meander belts typically include areas of instability and areas of stability.

The other primary channel type: braided channel.

Snake River, Grand Teton National Park
Braiding indices

- Counting mean number of active channels or braid bars per transect across the valley
  - This is the mode of the river
- Ratio of sum of channel lengths to reach length, called total sinuosity
  - A combined measure of sinuosity of each channel part and degree of braiding
- Better to determine the mode of entire river and sinuosity of each channel part

Linking planform, lateral stability, and analysis of channel change

Many reaches with high channel activity
Most reaches more deposition than erosion
2 reaches more narrow; 1 reach wider
Several reaches more braided
Changes occurred close and far from tributaries

Snake River in GTNP: channel change 1945-1969
• External controls on planform

Braided channels are steeper than meandering channels

(Ferguson, 1987; Knighton and Nanson, 1993)

van den Berg, 1995)

Incorporating planform considerations in project design

Provo River Restoration Project
Channel activity
Success or failure?
where bends are very tight, bank erosion
Leads to wood recruitment
Floodplain form and process

- Lateral accretion -- bedload deposits on the inside of bends is incorporated into the floodplain and the channel migrates
- Vertical accretion -- as a river overtops its banks, fine sediment is transferred from the top of the water column out onto the floodplain where it is laid down as a horizontal layer
  - In confined valleys
  - In wide alluvial valleys
  - Counterpoint and oblique accretion
- Filling of abandoned channels
- Formation of braid plains

These observations underlie some fundamental design attributes
The most influential model of floodplain and channel form is but one of many characteristic types.

Lateral accretion model of floodplain accretion

Over time, the channel migrated across its valley, depositing a point bar on the inside of the meander bends. Erosion approximately equaled deposition. There was no significant overbank deposition.

Bank retreat

Construction of point bar; the upper surface is called the active floodplain.

Watts Branch, Rockville, MD
There is a landform called the active floodplain that is being constructed in the present hydrologic regime. This landform is inundated by frequent floods. The elevation of flow that just begins to inundate this feature is the bank full stage.

There is evidence that the balance between the channel and the active floodplain have not always been the same.
But lateral accretion is not the only mechanism by which floodplains build.

Vertical accretion under sediment surplus conditions.
narrowing near Green River, UT

Allred and Schmidt (1999)

Narrowing by vertical accretion
Floodplain erosion also determines floodplain form

- Rate of reworking due to rate of channel migration
- Extent of flood channels and floodplain stripping (Nanson, 1986)
Channel occurs within the valley flat; bankfull channel, active floodplain, terraces comprise the valley flat
Qualitative Generalizations

- Channels with steep slopes and channels transporting large volumes of coarse bedload with braided channels are typically wide and shallow.
- Channels, especially sand channels, with flashy discharge are typically wide.
- Channels with dense understory riparian vegetation are narrower and deeper than with sparse vegetation.
- Regime theory and hydraulic geometry -- be aware of regional setting of the data and condition of the channels that were measured.
The longstanding characterization of channel size is the hydraulic geometry. Here is the at-a-station relationship.

(Leopold and Maddock, 1953; Leopold, 1994)

The size of the channel, defined by the point at which flow just begins to inundate the flat surfaces of the point bars, contains a moderate flood, such as one whose recurrence is between 1.5 and 3 yrs.
The mathematical form of these relations is:
\[ \begin{align*}
B &= aQ^b \\
h &= cQ^f \\
U &= kQ^m
\end{align*} \]

Note: \[ Q = B \, h \, U = ackQ^{(b+f+m)} \]

This plot is an at-a-station hydraulic geometry plot, because it depicts changes that occur at one place on the channel.

This is a downstream hydraulic geometry plot, in which stream flow characteristics are plotted for different locations within the same watershed. Each data point is depicted at the same frequency of discharge, and more downstream locations have correspondingly larger discharges.

Powder River, Montana and Wyoming

(Leopold, 1994)
Leopold and Maddock (1953) argued that there is a commonality in the slope of downstream hydraulic geometry relations for many of the world’s watersheds.

\[ b = 0.5 \quad B = aQ^b \]
\[ f = 0.4 \quad h = cQ^f \]
\[ m = 0.1 \quad U = kQ^m \]

Thus, streams get wider downstream in relation to their depth.

There are also commonalities in the at-a-station hydraulic geometry

for a large number of midwestern and western streams (Leopold and Maddock, 1953)

\[ b = 0.26 \quad B = aQ^b \]
\[ f = 0.40 \quad h = cQ^f \]
\[ m = 0.34 \quad U = kQ^m \]

This means that stream flow gets deeper and faster as Q increases; there is relatively little change in width.
Hydraulic geometry has led to the development of regional curves. Why?

\[ Q = f(A_D) \]

Thus can transform \( B = aQ^b \) to \( B = aA_D^b \)

(note: the \( a \) and \( b \) are not necessarily the same values)

A - San Francisco Bay area
B - eastern U.S.
C - upper Green River, WY
D - upper Salmon River, ID
Application to channel design:

We do not yet have a good physically-based model that predicts channel width. The downstream hydraulic geometry is a good predictor of channel width. There is no need to seek precision in this width because the data from which the relations are based have significant variation.

\[ B = aQ^{0.5} \]

(Leopold, 1994)

Need to know the value of “a”

There is considerable variation in exponent values in hydraulic geometry relations. The smallest variation is the width exponent in the downstream direction.

Park, 1977
Riparian vegetation makes a difference to channel width

Aside from measuring wetted channel width, is there a universal feature that could be measured in the field?

- Criteria for identifying bankfull stage
  - Top of the point bar
  - Marked by change in vegetation
  - Topographic break
  - Change in size distribution of surface materials

Andrews, 1984
To what flows is the channel sized? Significance of the bankfull channel.

Andrews (1980) found that the effective discharge essentially was the same as the bankfull discharge at gaging stations in the Yampa River basin, CO and WY. This finding, hinted at by Wolman and Miller, substantially increased the significance of the bankfull discharge, because it represents a field-identified feature that can be used to estimate the discharge responsible for transporting most of the annual sediment flux.
Many designers calculate effective discharge for designed channels.

**Channels have shape as well as size**

- Channel form involves the bed and the banks
- Typically, the bed is more transient and composed of younger materials than are the banks
- Often, the banks include cohesive material and the bed is noncohesive
- Bed is reworked annually, banks may be an artifact of history
- The primary control on channel shape is the texture of the sediment
- Secondary controls are fluctuations in $Q$ and $Q_s$
Bank morphology

- Bank morphology records the balance of erosional and depositional processes associated with different transport, alignment, and flow energy at different discharges
- Bank angle primarily is determined by the stratigraphy of the bank material
  - Cohesive material forms steeper banks

Bank erosion processes

- Existence of cohesion
- Stability controlled by strength of basal materials
- Weakening mechanisms
  - Prewetting
  - Desiccation
  - Freeze-thaw
- Processes
  - Hydraulic action
    - Fluvial entrainment
    - Undercutting
  - Mass failure
    - Slab failures
    - Rotational failures
Channel bed

- The bed is molded into coherent structures that are determined by the flow and sediment supply
  - Hydraulic features
    - Small scale and related to local flow features
    - Scale to the size of the largest clast
  - Sediment storage features
    - Large scale in-channel landforms
- The molded bed affects flow resistance, sediment transport dynamics, channel bed form
- When sediment begins to move, bedforms develop
  - Bed form -- a single geometrical element
  - Bed configuration -- assemblage of bed forms of a given type

Bed organization

- Bank attached and mid-channel bars (build or result of sediment transport and planform)
- Sculpted geomorphic units (design and build)
- Sand and gravel bedforms (irrelevant to design)
Alluvial geomorphic units -- bars (mid-channel, alternate, point)

- Finite width and depth gives rise to bars
- Bars are scaled to the dimensions of the channel; related to channel shape and planform
- Reflect sediment supply conditions and channel-scale processes, not local hydraulics
- Bars systematically change downstream because D, S, Q change downstream
- Interact with, and influence the flow field

Lateral bar accreting to floodplain -- Green River, Uinta Basin

1963 1993
Point bar --
Arcuate shape; attached to inside of bend; helical flow moves sediment to inside of bend

Eddy bar accreting to floodplain
Alluvial bed

Creation of alluvial bed on Provo River
Sculpted geomorphic units

- Waterfalls/bedrock steps
- Rapids
  - arrangements of boulders on steep slopes; individual particles break the water surface at base flow; may be organized as a series of ridges of coarse clasts spaced proportionally to the size of the largest clast

Sculpted geomorphic units

- Cascades
  - Disorganized (laterally, longitudinally) bed material that is typically cobbles and boulders
**Step-pool sequences** Channel-spanning stair-like features comprised of boulder/cobble clasts or woody debris separated by areas of quieter flow; backwater pool above and plunge pool below; keystones; 0.03 - 0.1 m/m slopes

Forced riffle-pool morphology

Spacing controlled by woody debris, bedrock outcrops, channel bends

(Montgomery et al., 1995)
Constrained by watershed
Design to pass sediment
Set by slope
Regional characteristics; design capacity
Set by planform, LWD, bank elements

Design considerations