Open Channel Flow: Flow Resistance Velocity Variation

7 September 2016

Flow resistance (frictional effects)

- Free surface resistance = waves and hydraulic jumps
- Channel resistance = bank irregularities, changes in channel alignment
- Boundary resistance = bed material (grain roughness) and bedforms (form roughness)
  - This one is key.

Flow resistance equations

- Manning's equation
  - n=Manning's n
  - k_m = 1.49 for ft/s
    1.0 for m/s

$$v = \frac{k_m}{n} R^{2/3} S^{1/2}$$

- Chezy equation
  - C = coefficient

$$v = C\sqrt{RS}$$

- Darcy-Weisbach
  - Dimensionally correct

$$f = \frac{8gRS}{v^2}$$

Manning's n values

Calculated, visually estimated, or from tables

http://wwwrcamnl.wr.usgs.gov/sws/fieldmethods/Indirects/nvalues/

n = 0.037 Wenatchee River, Washington

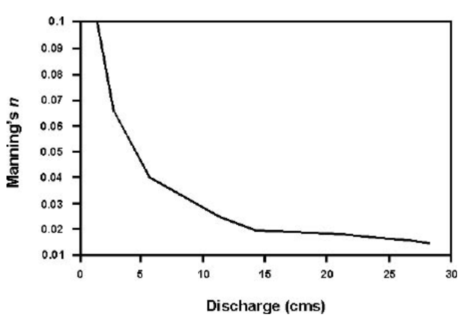
n = 0.073 Boundary Creek, Idaho

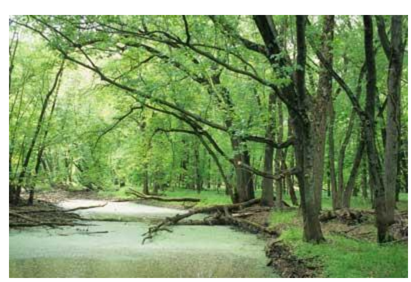
Manning-Strickler relation

- $n = 0.0132 d_{50}^{1/6}$ for d_{50} in mm
- $n = 0.0342 d_{50}^{1/6}$ for d_{50} in ft
- d_{50} is median grain diameter
- This relation assumes roughness is from grains and d_{50} is a good way to represent grain roughness.
  - This is always going to underestimate the true roughness.

n depends on stage

- n decreases as stage increases (until bankfull)
- Once out of banks, n increases





Baraboo River floodplain, WI (photo by Thomas A. Meyer)
http://dnr.wi.gov/topic/Lands/naturalareas/index.asp?SNA=212

What type of resistance do these pictures represent?

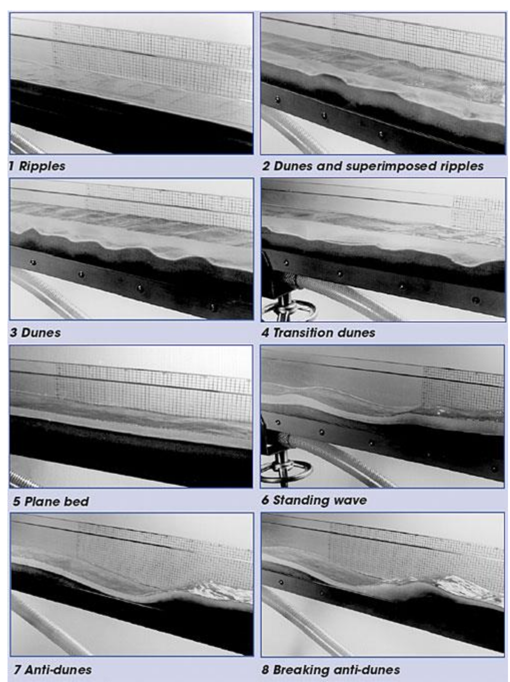
Linton Creek, Oregon Cascades,
Photo by A. Jefferson, 2005

Meanders of the Rio Cauto at Guamo Embarcadero, Cuba.
Photo from Wikimedia.

Form roughness

- Important in sand-bed streams and step pool streams

http://watershed.montana.edu/hydrology/Stream_project.htm



http://www.armfield.co.uk/images/s8bedforms.jpg

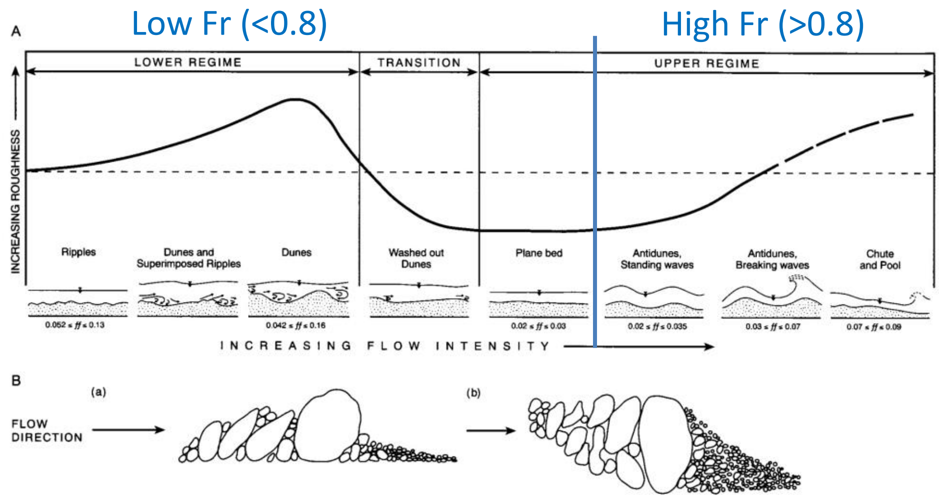
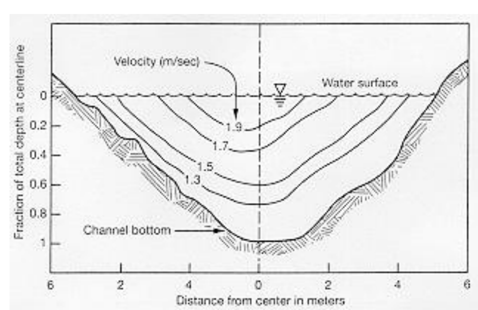


Figure 4.3 Form roughness elements. (A) In sand-bed streams: variations in flow resistance with the sequence of bed forms related to increasing flow intensity; values of the Darcy–Weisbach friction factor (ff) in flume experiments are shown (after Simons and Richardson, 1966). (B) In gravel-bed streams: pebble clusters in profile (a) and plan (b).

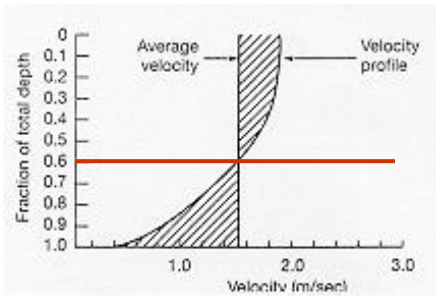
Knighton 1998

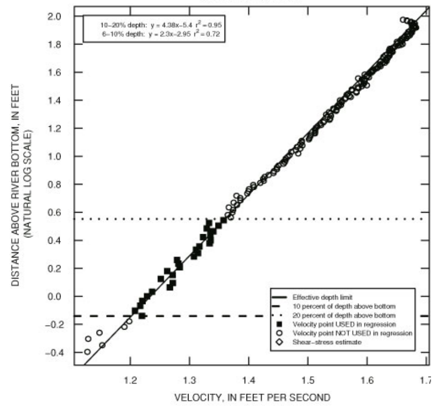
Velocity varies in 4 dimensions

- Vertically
- Across stream
- Downstream
- In time

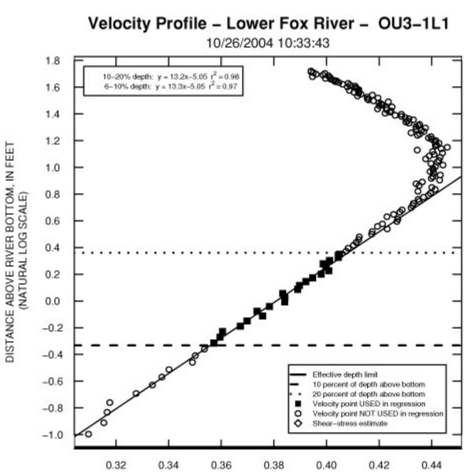


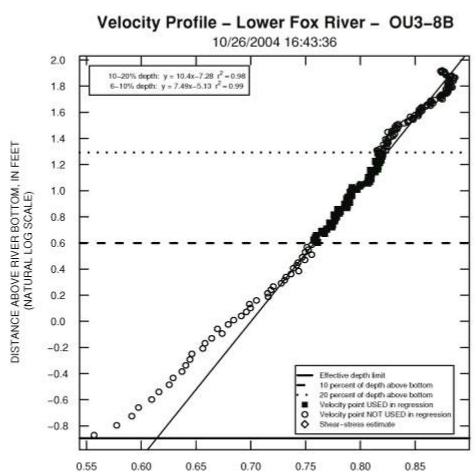
Vertical Velocity Profiles



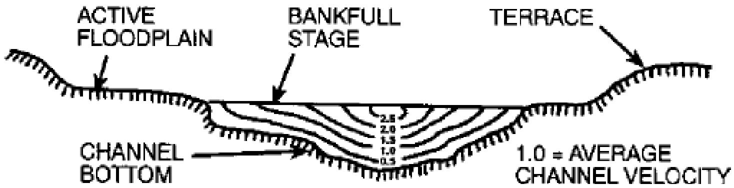


Vertical velocity profiles

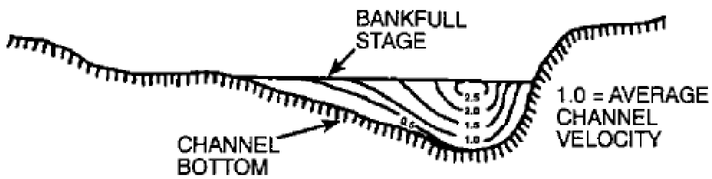




http://pubs.usgs.gov/sir/2006/5226/
Estimates of Shear Stress and Measurements of Water Levels in the Lower Fox River near Green Bay, Wisconsin



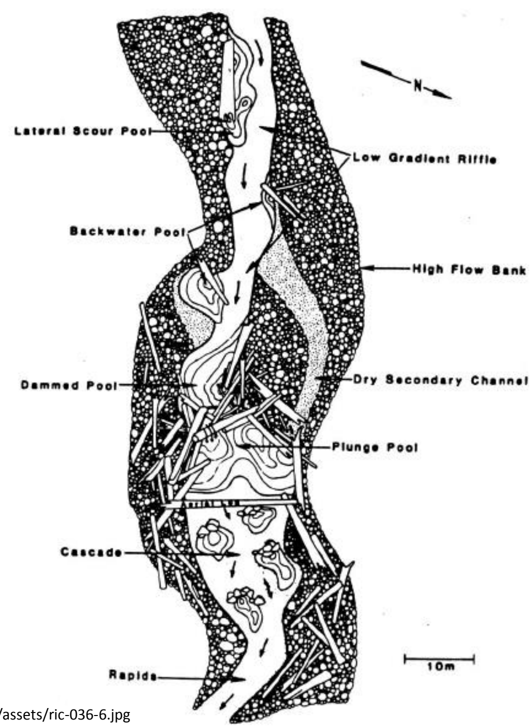
(a) STRAIGHT CHANNEL



(b) CHANNEL BEND

Downstream variations

- Local changes in velocity (constrictions, pools, etc.)
- Channels become bigger, smoother → less bed and bank resistance



http://ilmbwww.gov.bc.ca/risc/o_docs/aquatic/036/assets/ric-036-6.jpg

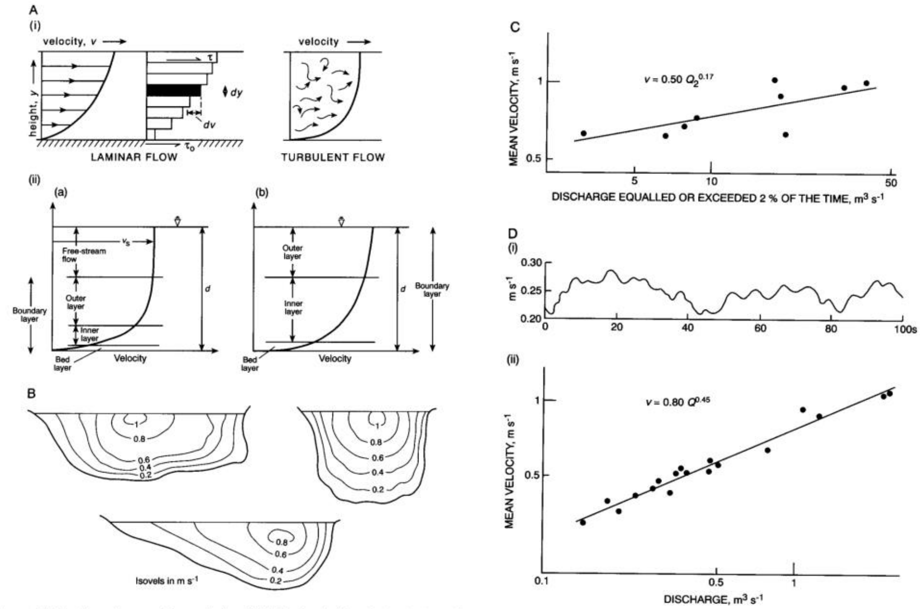


Figure 4.1 Variations in streamflow velocity. (A) With depth: (i) typical velocity profi.. for laminar and turbulent flow; (ii) the structure of the boundary layer in deep (a) and shallow (b) flow. (B) At natural channel cross-sections. (C) (opposite) Downstream – relationship of velocity to discharge, Brandywine Creek (after Wolman, 1955). (D) With time: (i) velocity fluctuations at a point over a short time period; (ii) at-a-station changes in velocity with discharge measured over two years, River Bollin.

Knighton 1998