Surface Processes and Landforms (12.163/12.463)
Fall 02 -- K. Whipple

FACTORS INFLUENCING HYDRAULIC ROUGHNESS

Bed material size (D_{50}, D_{84}, k_s, z_o, n_g); Relative roughness (h/D_{50}); Presence of sediment transport (momentum extraction); Bedforms and barforms; Vegetation; Obstructions (tree stumps, logs, boulders, bedrock outcrops, ect); Variations in channel width and depth; Channel curvature (sinuosity)

METHODS FOR ESTIMATING ROUGHNESS PARAMETERS

"Roughness" is represented in various ways in familiar flow velocity equations. We will consider: Chezy's equation, Manning's equation, the Darcy-Weisbach equation, and a generalized D-W equation (all for average velocity), and the "Law of the Wall" equation for the velocity profile or a turbulent flow near a boundary (logarithmic).

Variables Used:

S : Water surface slope (= bed slope for steady uniform flow) [m/m]
R_h : Hydraulic radius ($R_h = A/P$ = flow depth for infinitely wide channel) [m]
A : Cross-sectional area [m^2]
P : Wetted perimeter [m]
Q : Water Discharge [m^3/s]
$\overline{u}$: Cross-sectionally averaged velocity [m/s]
z : cartesian coordinate (perpendicular to bed) [m]
h : flow depth (perpendicular to bed) [m]
τ_b : basal shear stress [Pa]
k : von Karman's constant = 0.40
C : Chezy roughness coefficient [$m^{1/2}/s$]
f : Darcy-Weisbach friction factor [ ]
n : Manning's roughness factor [$s/m^{1/3}$]
C_f : Generalized non-dimensional friction factor [ ]
k_s : grain roughness scale ~ D_{84}

Chezy's Equation:

$$\frac{Q}{A} = \overline{u} = C\sqrt{R_h S}$$

without looking at the variable list above, work out the units of C.

Surface Processes and Landforms (12.163/12.463)
Fall 02 -- K. Whipple

Manning's Equation: (metric units!!)
(1840's; observed chezy's C = function of depth)

$$\frac{Q}{A} = \overline{u} = \frac{1}{n} {R_h}^{2/3} S^{1/2}$$

what are the units of n?

Darcy-Weisbach Equation: (pipe flow & theory; f is non-dimensional)

$$\overline{u}^2 = \frac{8 g R_h S}{f}$$

Generalized Darcy_Weisbach:

$$\overline{u} = \frac{\sqrt{g R_h S}}{C_f^{1/2}} \quad ; \quad \tau_b = \rho C_f \overline{u}^2 \quad \text{(for } R_h \sim h\text{)}$$

Law of the Wall:

(for turbulent flow, applies strictly just near the boundary, z < .2h, but works fairly well for entire profile)

$$u = \frac{u_*}{k} \ln \frac{z}{z_o}$$

where $u^* = \sqrt{\frac{\tau_b}{\rho}}$, "shear velocity"
k = 0.40 (Von Karman's Constant)

z_o is the point where idealized velocity profile goes to zero (a fictional level in the flow)

Integrating over flow depth and dividing by h (for vertically averaged velocity):

$$\langle u \rangle = \frac{u_*}{k}\left(\ln\frac{h}{z_o} - 1\right)$$

The 4/10s Rule:

$$\langle u \rangle = \frac{u_*}{k}\left(\ln\frac{h}{z_o} + \ln(.37)\right) = \frac{u_*}{k}\ln\frac{.37h}{z_o} = u(z = .37h)$$

I. Visual Estimates of Manning's n:

1. Visual estimate of field conditions using experience, "type" photographs, and published tables. Tables are found in most geomorphology texts. "Type" photos are in Water Supply Paper 1849. Listed below are examples (from Richards):

Description	Manning's n
Artificial channel, concrete	.014
Excavated channel, earth	.022
Excavated channel, gravel	.025
Natural channel, < 30 m wide, clean, regular	.030
Natural channel, < 30 m wide, some weeds, stones	.035
Mountain stream, cobbles, boulders	.050
Major stream, > 30 m wide, clean, regular	.025

2. Estimate from Table given by Chow (1959), where n is given by:

$$n = (n_0 + n_1 + n_2 + n_3 + n_4)\, m_5$$

Material, n_0	
earth	.020
rock	.025
fine gravel	.024
coarse grav.	.028

Degree of Irregularity, n_1	
smooth	.000
minor	.005
moderate	.010
severe	.020

Variation of cross-section, n_2	
gradual	.000
alt. occasionally	.005
alt. frequently	.010-.015

Channel obstructions, n_3	
negligible	.000
minor	.010-.015
appreciable	.020-.030
severe	.040-.060

Vegetation n_4	
low	.005-.010
medium	.010-.025
high	.025-.050
v.high	.050-.100

Degree of meandering, m_5	
none	1.000
minor	1.000
appreciable	1.150
severe	1.300

Surface Processes and Landforms (12.163/12.463)
Fall 02 -- K. Whipple

II. Empirical relationship between the Darcy-Weisbach friction factor and grainsize and flow depth (Leopold et al., 1964).

Empirical data fits the line:

$$\frac{1}{\sqrt{f}} = 2.0\log\left(\frac{h}{D_{84}}\right) + 1.0$$

see figure, next page.

D_{84} = 84th percentile value from cum. freq. distribution (grain diameter)

III. Back-calculation of n or f from field data using velocity equations given above.

$$\overline{u} = \frac{1}{n} R_h^{2/3} S^{1/2}$$

S = slope of the water surface

Method: u (cross-sectional average), R, and S are measured,
n and/or f is back-calculated.

IV. Calcualtion of local hydrodynamic roughness ("grain roughness": z_o) from velocity profiles using the Law of the Wall.

$$u = \frac{u_*}{k} \ln\frac{z}{z_o}$$

where $u_* = \sqrt{\frac{\tau_b}{\rho}}$, k = 0.40 (Von Karman's Constant)

First we must define hydraulically rough (HRF) vs. hydraulically smooth (HSF) flow. Given that k_s = grain diameter, $\delta\nu$ = thickness of the viscous sub-layer, and ν = kinematic viscosity, we define the shear Reynolds number (R_*) as

$$R_* = \frac{u_* k_s}{\nu}$$

HSF occurs where $R_* < 3$, and HRF where $R_* > 100$, from Nikaradse's data.

Case 1. HSF:

$$z_o = \frac{\nu}{9u_*}$$

Case 2. HRF:

$$z_o = \frac{k_s}{30} \quad ; \qquad k_s \sim D_{84} \text{ (grain roughness)}$$

If $3 < R_* < 100$, then find z_o form Nikaradse's diagram, see next page.

Note, for typical river temperatures, $\nu = 1.514 \times 10^{-2}$ cm2/s.