Ritter, D.F., Kochel, R.C., and Miller, J.R., 1995, Process Geomorphology 3rd Ed.: W.C. Brown Publishers, Dubuque, IA, 539 pp.

Chapter 6 Fluvial Processes

I. Introduction

A. Important Geomorphic Considerations

1. rivers = most ubiquitous and important on landscape
2. early studies = qualitative (early 1900's)
3. Quantitative studies: difficult for direct measurement

a. most studies derived from lab, flume

(1) limited in terms of modeling large scale rivers

B. Important References to Start

1. Leopold et al, 1964; Graf, 1971; Schumm, 1972,1977; Richards, 1982, 1987; Hey et al,1982; Morisawa, 1985; Schumm et al, 1987; Baker et al, 1988; Billi et al., 1992.

II. The River Channel

A. Basic Mechanics

1. Driving vs. Resisting Forces

a. potential energy to kinetic energy to dissipation by resisting medium (stream channel, load)
(1) driving force = gravity
(2) resisting framework = bed friction, water turbulence

(a) drive > resistance = acceleration
(b) resistance < drive = deceleration

b. Energy Dissipation

(1) most via turbulence, internal friction
(2) some via sediment transport

2. Hydraulic flow

a. laminar flow- straight, parallel paths to water molecules, water velocity changes proportionally to depth and viscosity

(1) internal resistance

(a) bed friction
(b) viscosity of fluid
  i) f(sediment conc., temperature)

b. Turbulent flow- water molecules do not flow in straight parallel paths, velocity fluctuates in all directions

  (1) eddy viscosity: turbulent interchange of stress amongst layer boundaries

    (a) > flow resistance, > dissipation of energy

  (2) transition from lower energy laminar flow to higher energy turbulent flow = f(velocity and channel configuration)

c. Equations describing flow

  (1) Reynolds number (Re)

    (a) Re = VRp/u where V = mean vel., R = hydraulic radius, p - density, u = viscosity

      i) R = A/P = cross-sectional area of channel/wetted perimeter
      ii) kinematic viscosity = v = u/p

    (b) thus Re =VRp/u = VR/v = driving force/resisting force

      i) Re < 500 = laminar flow
      ii) Re > 750 =turbulent flow

  (2) Froude Number (Fr)

    (a) Fr = V / sqrt(dg) where V = mean velocity, d = depth, g = gravity

    (b) Fr defines subtypes of turbulent flow

      i) tranquil flow Fr < 1
      ii) critical flow Fr = 1
      iii) rapid flow Fr >1

B. Flow Equations and Resisting Factors

1. Chezy Equation

a. V = C sqrt(RS) where V - velocity, C = chezy coefficient, R = hydraulic radium, S = slope

2. Manning Equation

a. $V = (1.49/n)R^{2/3}S^{1/2}$ where V = velocity, n = manning roughness coefficient, R = hydraulic radius,and S = Slope

(1) e.g. n in $Ft^{1/6}$

(a) smooth glass = 0.01
(b) earth canals = 0.017
(c) rocky vegetated beds = 0.04-0.05

b. bedforms and changes in n along channel bottom

(1)

Bedform	n
Lower Regime	
Ripples	0.017-0.028
Dunes	0.018-0.035
Washed out dunes/transition	0.014-0.024
Upper Regime	
Plane Bed	0.011-0.015
Standing waves	0.012-0.016
Antidunes	0.012-0.02

c. General Relations

(1) > bed roughness, > n, < V
(2) > n, > turbulence, < V
(3) > suspended sediment, < turbulence, > laminar

III. Sediment in Channels

A. Transportation

1. Suspended load: fine silt and clay supported in body of fluid

a. occasionally may include coarser seds.

2. Bedload: seds. transported close to channel bottom by rolling,. sliding or bouncing (saltation)

a. any given particle may experience bedload or suspended load conditions depending on energy in system
b. difficult to measure directly, often done emprically from flume studies

3. Washload: particles so small that they are essentially absent on stream bed

B. Entrainment

1. entrainment: processes that initiate sediment motion

   a. most larger particles are not consistently transported down stream, but episodically

   b. e.g. processes

      (1) shear by fluid impact
      (2) drage,
      (3) hydraulic lift

2. Competence: largest clast size capable of being transported by fluvial system

   a. complicating factors in measuring

      (1) variable hydraulic conditions in channel
      (2) variable velocity
      (3) variable particle packing/friction

   b. Critical Bed Velocity: "sixth power law" = volume or weight of largest particle carried by stream = f(of 6th power of velocity)

   c. Critical Shear Stress (critical tractive force) = downslope component of fluid weight exerted on a bed particle

      (1) Tc = gamma(RS)   where Tc = critical shear stress, gramma = specific weight of water, R = hydraulic radius, S - slope

3. Hjulstroms Diagram: relates current velocity,particle size and process(erosion, transportation and deposition)

4. Bagnolds concepth of Stream Power:

   a. w = gamma(QS)   where w = stream power, gamma = specific weight of water, Q = discharge, S = slope

   b. where stream power is greater than that needed to transport load, bed scour/entrainment will occur.

C. Bank Erosion

1. bank erosion: lateral erosion and modification of channel

2. Processes

a. Fluvial Entrainment

(1) corrasion: direct shear stress by water on bank material with attendant undercutting
(2) cantilevers: undercut overhangs on bank with attendant mass wasting

b. Weakening and Weathering of Bank Material

(1) processes reduce and weaken bank materials promoting erosion and slope failure

(2) Controlling factors

(a) soils moisture content

i) > soil moisture, < cohesion, > failture/erosion
ii) saturated pores = positive pore pressure, < cohesive strength
iii) vadose zone hydrology on flood plain can influence erosion along channel banks

(b) Sapping or piping: through-flow of groundwater carries fine particles out of sediment medium

i) removal of clay, < cohesive force, > failure

(c) Seasonal effect (spring, winter > moisture, > freeze thaw > failure)

(d) planar slide failure/mass wasting, slumping

D. Deposition

1. function of density of water, fluid viscosity, sediment size-shape-density, velocity/energy of fluid medium

2. fluvial deposition/erosion spasmodic process on short term time interval

3. Fluvial aggradation: net long term accumulation of sediments

4. short term deposition: ripples, dunes, riffles, sediment bars.

E. Frequency and magnitue of River work

1. time frame: when is work done? million year flood or the day to day conditions

2. Wolman and Miller idea:

a. 90% of sediment transport (i.e. work) completed by day to day activities of river

b. amount of work done during major floods secondary

3. Dominant Discharge: discharge rate that primarily controls channel shape and form

4. Recovery Time: time needed for river to readjust channel morphometry following a major flood modification

IV. Quasi-Equilibrium Condition

A. Tendency for river to establish equilibrium between dominant discharge and sediment load

1. via adjustments in channel width, depth, velocity, roughness, and water slope

a. processes are differential, mutually changing variables, thus river can never truly establish equilibrium, but "quasi equilibrium".

B. Leopold and Maddock, 1953 "Hydraulic Geometry" Relationships

1. Hydraulic Geometry: relationship between open channel morphology and discharge

a. Independent Variable = discharge (climatically controlled)

b. Dependent Variables = width, depth, velocity

2. $w = aQ^b$; $d = cQ^f$; $v = kQ^m$, where w = width, d = depth, v = velocity, a,c,k,b,f and m are constants

a. exponents indicate rate of increase in hydraulic variable (w,d,v) with increasing discharge

b. because Q = product of wdv

(1) $Q = aQ^b \times CQ^f \times kQ^m$ or $Q = ackQ^{b+f+m}$ thus ack and b+f+m must = 1

(a) exponents change according to location, climate and discharge conditions

3. General Relations and Discussion

a. w, d and v increase downstream and Q > downstream

(1) depth influences velocity much more significantly than slope

b. Hydraulic geometries have been empirically defined for a wide range of rivers throughout U.S.

(1) generally assumed, relations are climatically controlled.

4. Suspended load as related to discharge, as Q > suspended load increases

a. $L = pQ^j$ where L = suspended load, Q = discharge

C. The Influence of Slope

1. discussion

a. Slope important for river to maintain balance

(1) graded, concave up long. profile
(2) slope adjustments according to sediment load, climate, veg., etc.

b. recognized as an adjustable property of rivers
c. concave up long. profile = graded equilibrium profile
d. observations suggest as Q>, slope is maintained, as measured at gaging stations

(1) river must change other variables to accommodate Q while maintaining S

(a) > Q = > vel as a result of >depth, < roughness, or both
(b) downstream < slope, any > vel in downstream direction resulto > depth

2. GK Gilbert

a. S inverserly related to Q

(1) Q > with > basin area and stream length
(a) slope must decrease downstream

3. Slope as a function of bed material size

a. S < with < particle size; S > with > particle size
b. however Hack in VA found no consistent relationship

4. Hack Observation:

a. $S = 18(M/A)^{0.6}$
where s = slope, m = median size of bed material, A = basin area in sq. mi

b. Net idea: both Q and grain size control slope

D. Channel Shape

1. basic observation with > Q, cross-sectional area >
2. Other controls on channel shape (width to depth relations)

a. Schumm's studies

(1) W/D ratio as a function

(a) sediment size of bank material

i) silt/clay = channels narrow and deep

a) suspended load channels
b) > bank cohesion from clays

ii) coarse = wide shallow channels

a) coarse material more easily transported by shallow water, as vel > near channel floor

(b) $F = 255M^{-1.08}$

i) where F = W/D, M = %silt and clay

(c) Vegetation may also control channel geometry

(d) carbonate rich soils/cement may also > bank cohesion in seds, affecting W/D ratio

V. Channel Patterns (Plan view shape)

A. General

1. sinuosity

a. sinuosity = stream length/valley length

(1) straight: < 1.5
(2) meandering > 1.5

2. Braided

a. river divided into more than one channel
(1) consists of divided reaches

3. River Pattern may change form along its course from straight to meandering to braided, according to discharge, load, vegetation

B. Straight

1. General

a. rather uncommon

2. Features

a. Alternate bars- alternate accumulation of sediment on different sides of channel
b. Thalweg-line connecting deepest part of channel along its length
c. riffles- shallow channel floor
d. pools-deep channel floor

(1) pools opposite alternate bars
(2) riffles midway between successive pools
(3) pool and riffle sequences

(a) f(bedforms, flow, transport)
(b) riffle spacing: 5-7 times channel widths on average
(c) riffle velocity: shallow, > V, > slope, coarse sediment
(d) pools: deep, < V, < slope, fine sediment

3. Flow hydraulics

a. convergent flow- surface water flow is toward axis of channel, max. vel near channel bottom, scour dominant

b. divergent flow-surface water diverges away from channel axis, < vel, deposition common

C. Meandering Channels

1. General

a. most common form by far
b. similar features to straight: pools, riffles, bars
c. thalweg migrates back and forth across channel, toward outer bends

2. Features

a. points bars
b. cutbanks

3. Flow hydraulics

a. helicoidal flow

(1) water forced to outside of bend
(2) forced downward along cutbank, back towards point bar
(3) transfers and reverses motion around next alternating bend

4. Lateral Migration of Channel

    a. via cutbank erosion + point bar deposition

5. Meander geometry

    a. lambda = meander wavelength

        (1) related to radius of curvation of meander loop

6. Why do rivers meander?

    a. random channel perturbations (e.g. boulders)
    b. development of secondary helicoidal flow cells
    c. bedload content
    d. bank erosion

    e. Minimum energy condition (close to equilibrium)

        (1) meandering tends to dissipate energy to minimum levels along length of channel
        (2) meandering minimizes energy state, more efficient

D. Braided Channels

1. General

    a. multiple, divided channels
    b. intervening braid bars

2. Origin/Requirements

    a. erodible banks (< cohesion, < vegetation)
    b. sediment transport and abundant bedload
    c. rapic and frequent variations in Q

3. compared to meanders

    a. braided = depth <, vel >, slope >, W/D >

E. Anabranching Streams

1. General

    a. rather uncommon

2. defined

   a. Anastomosed streams: interconnected network of channels

      (1) individual channels separated by islands of floodplain material
      (2) low gradient, deep and narrow channels, stable banks and suspended-load dominated

3. Origins

   a. channel aggradation
   b. stable cohesive banks (limited widening)
   c. flood-prone hydrologic regime
   d. avulsion process, channel shifting and abandonmnet during flood period.

F. Controls on continuity of channel patterns

1. channel pattern = continuum of shapes
2. controlling factors

   a. flow strength, Q
   b. bank erodibility
   c. sediment type and supply

VI. Rivers, Equilibrium and time

A. Discussion

1. rivers change character through time as a function of
   a. discharge
   b. sediment load

      (1) both functions of climate, geology, tectonics

B. Adjustment of Gradient

1. aggradation vs. incision
2. gradient adjustment to base level changes

C. Adjustment of shape and pattern