River mechanics

This textbook offers a thorough mechanical analysis of rivers from upland areas to oceans. It scrutinizes state-of-the-art methods, underlining both theory and engineering applications.

Each chapter includes a presentation of fundamental principles, followed with an engineering analysis and instructive problems, examples, and case studies illustrating engineering design. The emphasis is on river equilibrium, river dynamics, bank stabilization, and river engineering. Channel stability and river dynamics are examined in terms of river morphology, lateral migration, aggradation, and degradation. The text provides a detailed treatment of riverbank stabilization and engineering methods. Separate chapters cover physical and mathematical models of rivers. This textbook also contains essential reading for understanding the mechanics behind the formation and propagation of devastating floods, and offers knowledge crucial to the design of appropriate countermeasures to reduce flood impact, prevent bank erosion, improve navigation, increase water supply, and maintain suitable aquatic habitat.

More than 100 exercises (including computer problems) and nearly 20 case studies enhance graduate-student learning, while researchers and practitioners seeking broad technical expertise will find it a valuable reference.

Pierre Y. Julien is Professor of Civil Engineering at Colorado State University.

River mechanics

PIERRE Y. JULIEN

CAMBRIDGE
UNIVERSITY PRESS

PUBLISHED BY THE PRESS SYNDICATE OF THE UNIVERSITY OF CAMBRIDGE
The Pitt Building, Trumpington Street, Cambridge, United Kingdom

CAMBRIDGE UNIVERSITY PRESS
The Edinburgh Building, Cambridge CB2 2RU, UK
40 West 20th Street, New York, NY 10011-4211, USA
477 Williamstown Road, Port Melbourne, VIC 3207, Australia
Ruiz de Alarcón 13, 28014 Madrid, Spain
Dock House, The Waterfront, Cape Town 8001, South Africa

http://www.cambridge.org

First published 2002

Printed in the United Kingdom at the University Press, Cambridge

Typeface Times Roman 10/13 pt. *System* LaTeX 2ε [TB]

A catalog record for this book is available from the British Library.

Library of Congress Cataloging in Publication Data

Julien, Pierre Y.
River mechanics / Pierre Y. Julien.
p. cm.
Includes bibliographical references and index.
ISBN 0-521-56284-8 (pc.)
1. River engineering. I. Title.
TC405 .J85 2002
627′.12–dc21 2001035678

ISBN 0 521 56284 8 hardback
ISBN 0 521 52970 0 paperback

Dedicated to
Helga and Patrick

Contents

Preface

Rivers have fascinated humanity for centuries. Most prosperous cities around the world have been founded along rivers. Today, river engineers are still designing structures to draw benefits from the fluvial system for developing societies. It is clear that river engineering is not based solely on a simple understanding of local hydrodynamic forces, but also on an encompassing knowledge of the watershed that supplies water and sediment to dynamic river systems. Expertise in river mechanics combines knowledge of watershed climatology, geomorphology, and hydrology, with a deep understanding of hydrodynamic forces governing the motion of water and sediment in complex river systems. State-of-the-art teaching of river mechanics clearly requires study material that emphasizes both theoretical concepts and practical engineering technology. Ideally, scientists should develop new concepts that may be applicable to engineering design, and practitioners should understand why certain structures work and why others fail.

This textbook has been prepared for engineers and scientists seeking broad-based technical expertise in river mechanics. It has been specifically designed for graduate students, for scholars actively pursuing scientific research, and for practitioners keeping up with developments in river mechanics. The prerequisites simply include basic knowledge of undergraduate fluid mechanics and partial differential equations. The textbook *Erosion and Sedimentation*, by the same author and Cambridge University Press, serves as prerequisite material for the graduate course on river mechanics taught at Colorado State University.

Rather than a voluminous encyclopedia, this textbook scrutinizes a selected number of methods to meet pedagogical objectives underlining both theory and engineering applications. This text has been designed to be covered within a regular 45-lecture-hour graduate-level course.

The chapters of this book contain, besides theory and lecture material, various exercises, general problems, data sets, computer problems, examples, and case studies. They illustrate specific aspects of the profession from theoretical derivations through exercises, to practical solutions to real problems through the analysis of case studies. Most problems can be solved with a few algebraic equations; others require the use of computers. The computer problems offer students the opportunity to develop skills for solving physical problems with computers. No specific computer code or language is required. Instead of using existing software packages, I stimulate student creativity and originality in developing the students' own computer programs. Throughout, a solid diamond (♦) denotes equations and problems of particular significance. Problems with a double diamond (♦♦) are considered most important.

I am grateful to D. B. Simons, E. V. Richardson, H. W. Shen, H. Rouse, M. Frenette, J. L. Verrette, Y. Ouellet, C. F. Nordin, S. Schumm, S. R. Abt, and J. Ruff, who influenced my teaching over the years. I am also particularly thankful to P. G. Combs and D. C. Baird for sharing their practical expertise in river engineering. This book also benefits from numerous suggestions formulated by a generation of graduate students at Colorado State University. They helped me tailor this textbook to meet their needs under the constraints of quality, concision, and affordability. Jenifer Davis diligently typed successive draft versions of the manuscript, and Jean Parent prepared the figures. Finally, it has been a renewed pleasure to collaborate with Florence Padgett, Ellen Carlin, Zach Dorsey, and the Cambridge University Press production staff.

Cambridge University Press
0521562848 - River Mechanics
Pierre Y. Julien
Frontmatter
More information

Notation

Symbols

a	acceleration
a	reference elevation
a	pier width
a_{cent}	centrifugal acceleration
a_{cor}	Coriolis acceleration
a_i	incremental cross-section area
a_{i+1}	coefficient of h_{i+1}
a_t	partial watershed area
a_θ	particle-stability coefficient
$\tilde{\mathbf{a}}$	wave amplitude
a, b	coefficients of the resistance equation
a, b	transform coefficients for duration curves
A	surface area
A_a	amplitude factor
A_{sb}	surface area of a settling basin
A_t	watershed drainage area
$\tilde{\mathbf{A}}, \tilde{\mathbf{B}}$	wave coefficients
b_r	river-bend coefficient
c	wave celerity
c_G	group velocity
C	Chézy coefficient
C_a	reference concentration
C_s	Courant number
C_{fl}	Courant–Friedrich–Levy coefficient
C_k	grid dispersion number
C_{0i}	upstream sediment concentration
C_r	runoff coefficient
C_u	velocity Courant number

$C_v, C_w, C_{\mathrm{ppm}}, C_{\mathrm{mg/l}}$	sediment concentration
d_{10}, d_{50}	particle size distribution, % finer by weight
d_m	effective riprap size
d_s	particle size
d_*	dimensionless particle diameter
D	pipe diameter
D_d	degree-days
D_p	drop height of a grade-control structure
e	void ratio
E	specific energy
E_{tons}	expected soil loss in tons
$\tilde{\mathrm{E}}$	total energy of a wave
$E()$	exceedance probability
ΔE	specific energy lost in a hydraulic jump
f	Darcy–Weisbach friction factor
f_l	Lacey silt factor
$f(t)$	infiltration rate
F	force
$\tilde{\mathrm{F}}$	fetch length of wind waves
F_B	buoyancy force
F_c	centrifugal force
F_D	drag force
F_g	gravitational force
F_h	hydrodynamic force
F_i	inertial force
F_L	lift force
F_M	momentum force
F_p	pressure force
F_s	shear force in a bend
F_S	submerged weight of a particle
F_w	weight of water
F_W	weight of a particle
$F()$	nonexceedance probability
$F(t)$	cumulative infiltration
$F_a(t)$	actual cumulative infiltration
$F_p(t)$	potential cumulative infiltration
Fr	Froude number
g	gravitational acceleration
G	specific gravity of sediment
Gr	gradation coefficient

G_u	universal gravitation constant
h	flow depth
h_c	critical flow depth
h_d	downstream flow depth
h_n	normal flow depth
h_p	pressure head at the wetting front
h_r	rainfall depth
h_s	cumulative snowmelt
h_t	tailwater depth
h_u	upstream flow depth
h_w	partial elevation drop on a watershed
Δh	local change in flow depth
ΔH	energy loss over a meander wavelength
H	Bernoulli sum
H_w	elevation drop on a watershed
$\mathrm{H}_s = 2\tilde{a}$	wave height
i	rainfall intensity
i_b	riverbed infiltration rate
i_e	excess rainfall intensity
i_f	snowmelt rate
j	space index
k	time index
k_0	resistance parameter for laminar overland flow
k_s	surface roughness
k'_s	grain roughness
k_t	total resistance to laminar overland flow
$\tilde{\mathrm{k}}$	wave number
K	saturated hydraulic conductivity
K_1, K_2	coefficients of the pier scour equation
K_c	riprap coefficient
K_d	dispersion coefficient
K_{num}	numerical dispersion coefficient
K_p	plunging jet coefficient
K_{sj}	submerged jet coefficient
l_1 to l_4	moment arms
l_c, l_d	moment arms in radial stability of river bends
L_a	abutment length
L_f	depth of the wetting front
L_p	pier length
L_r	river length

L_r	length ratio
L_{sb}	settling-basin length
L_M	runoff-model grid-cell size
L_R	grid size of rainfall precipitation
L_S	correlation length of a storm
L_W	length scale of a watershed
L_Δ	length of arrested saline wedge
m	exponent of the resistance equation
m_s	sediment mass eroded from a single storm
m_E	mass of the Earth
m_M	mass of the Moon
M	mass
M	specific momentum
M_1, M_2	first and second moments of a distribution
M, N	particle-stability coefficients
n	Manning coefficient n
ñ	wave number index
N	number of points per wavelength
N	number of storms
$O()$	order of an approximation
p	pressure
$p()$	probability density function
p_0	porosity
p_{0e}	effective porosity
p_{0i}	initial water content
p_{0r}	residual water content
Δp_c	fraction of material coarser than d_{sc}
Δp_i	sediment size fraction
Δp_0	change in water content at the wetting front
P	wetted perimeter
$\tilde{P}$	total power of a wave
ΔP	power loss in a hydraulic jump
$P()$	probability
P_0	power loss
P_Δ	grid Peclet number
q	unit discharge
q_{bv}	unit sediment discharge by volume
$q_{bv}^* = q_{bv}/\omega_0 d_s$	dimensionless unit sediment discharge
q_l	lateral unit discharge
q_m	maximum unit discharge

q_s	unit sediment discharge
q_t	total unit sediment discharge
Q	river discharge
Q_{bv}	bed sediment discharge
Q_e	watershed size correction factor
Q_p	peak discharge
Q_s	sediment discharge
r	radial coordinate
r^*	dimensionless radius of curvature
r, θ, z	cylindrical coordinate system θ downstream, r lateral, and z upward
R	radius of curvature of a river
ΔR_e	excess rainfall
R_h	hydraulic radius
R_m	minimum radius of curvature of a channel
R_E	radius of the Earth
Re	Reynolds number
Re_*	grain shear Reynolds number
$\text{Re} = Vh/\nu$	Reynolds number
$\text{Re}_* = u_* d_s/\nu$	grain shear Reynolds number
$\text{Ro} = \omega/\kappa u_*$	Rouse number
S	slope
S_e	effective saturation
S_0, S_f, S_w	bed, friction, and water-surface slope
S_o, S_f, S_w	radial water-surface slope
S_r^*	dimensionless radial slope
S_r, S_{wr}	radial water-surface slope
S_{DR}	sediment delivery ratio
t	time
Δt	time increment
Δt_s	time increment for sediment
t_a	cumulative time with positive air temperature
t_e	time to equilibrium
t_f	cumulative duration of snowmelt
t_r	rainfall duration
$t_r^* = t_r/\bar{t}_r$	normalized storm duration
t_t	transversal mixing time
t_v	vertical mixing time
T	period of return of extreme events
T	wave period

T_E	trap efficiency
T_s	windstorm duration
u, v	velocity along a vertical profile
$\bar{u}$	average flow velocity
u_*	shear velocity
U_w	wind velocity
v_s	velocity against the stone
v_x, v_y, v_z	velocity components
V	cross-section averaged velocity
V_c	critical velocity
V_Δ	densimetric velocity
V_θ	downstream velocity in cylindrical coordinates
W	channel width
W_m	meander width
W_o	overland plane width
x, y, z	coordinates usually x downstream, y lateral, and z upward
x_r, y_r, z_r	length ratios of hydraulic models
Δx	grid spacing
X	runoff length
X_c	reach length
X_e	equilibrium runoff length
Y	sediment yield
z_b	bed elevation
z_w	water-surface elevation
z^*	dimensionless depth
Δz	scour depth

Greek Symbols

α	coefficient of the stage–discharge relationship
α_b	deflection angle of barges
α_e	energy correction factor
β	exponent of the stage–discharge relationship
β	bed particle motion angle
β_m	momentum correction factor
γ	specific weight of water
γ_m	specific weight of a water–sediment mixture
γ_{md}	dry specific weight of a water–sediment mixture
γ_s	specific weight of sediment
$\Gamma(x)$	gamma function

δ	angle between streamline and particle direction
ξ	ratio of exceedance probabilities
$\tilde{\xi}$	displacement in the x direction
η	sideslope stability number
$\tilde{\eta}$	displacement in the y-direction
λ	streamline deviation angle
λ	wavelength
λ_f	snowmelt intensity
$\lambda_r = t_r/t_e$	hydrograph equilibrium number
Λ	meander wavelength
μ	dynamic viscosity of water
ν	kinematic viscosity of water
ϕ	angle of repose of bed material
ϕ	latitude
ϕ	dimensionless soil mass eroded from a single storm
Φ	velocity potential
ρ	mass density of water
ρ_m	mass density of a water–sediment mixture
ρ_{md}	dry mass density of a water–sediment mixture
ρ_s	mass density of sediment
ρ_{sea}	mass density of seawater
$\Pi = \ln[-\ln E(x)]$	double logarithm of exceedance probability
ω	settling velocity
ω_E	angular velocity of the Earth
Ω	sinuosity
Ω_R	coefficient of secondary flows in bends
θ	downstream orientation of channel flow
θ	angular coordinate
θ_j	jet angle measured from the horizontal
θ_m	maximum orientation of channel flow
θ_p	flow orientation angle against a pier
θ_r	raindrop angle
θ_0, Θ_0	downstream bed angle
Θ_1	sideslope angle
$\Theta = (t - t_r)/t_e$	dimensionless time
σ	stress components
σ_d	standard deviation of dispersed material
σ_g	gradation coefficient
$\tilde{\sigma}$	angular frequency of surface waves
τ	shear stress

τ_0, τ_b	bed shear stress
τ_{0x}, τ_{0y}	downstream and lateral bed shear stress
τ_{bn}	bed shear stress at a normal depth
τ_c	critical shear stress
τ_r	radial shear stress
τ_r^*	dimensionless radial shear stress
τ_s	side shear stress
τ_{sc}	critical shear stress on a sideslope
τ_w	wind shear stress
τ_{zx}	shear stress applied in the x direction in a plane perpendicular to z
τ_*	Shields parameter
τ_{*_c}	critical value of the Shields parameter
$\psi = q/i_e L$	dimensionless discharge
ψ, θ	weighting coefficients
Ψ	reduced variable
ζ_n^k	Fourier coefficient

Superscripts and Diacriticals

$\hat{a}$	coefficient of the logarithm resistance equation
$\tilde{n}$	wave properties
$\hat{C}$	parameters of the universal soil-loss equation
$\bar{e}$	average value
h^k	time index k

Subscripts

a_r, a_θ	cylindrical coordinate components
a_x, a_z	Cartesian components
τ_c	critical shear stress
h_{j+1}	space index at $j + 1$
L_m, Q_m	model value
L_p, Q_p	prototype value
L_r, Q_r	similitude scaling ratio
ρ_m, γ_m	properties of a water–sediment mixture
ρ_{md}, γ_{md}	properties of a dry water–sediment mixture
ρ_s, γ_s	sediment properties