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PIERRE Y. JULIEN is Professor of Civil and Environmental Engineering at Colorado State University. He has co-authored more than 400 scientific publications including two textbooks, 20 lecture manuals and book chapters, 145 refereed journal articles, 130 professional presentations, 150 conference papers, and 100 technical reports. As a Professional Engineer, he has completed projects and assignments for at least 50 different agencies and consulting firms world-wide. He is member of 12 professional societies and served as Editor of the ASCE *Journal of Hydraulic Engineering*. He has delivered numerous keynote addresses at international conferences. In 2004, he received the H. A. Einstein Award for his outstanding contributions to sedimentation and river mechanics. He is also the author of the textbook *River Mechanics* (2002, Cambridge University Press).

EROSION AND SEDIMENTATION

2nd Edition

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To Helga and Patrick

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Preface

This textbook has been prepared for graduate students and professionals keeping up with recent technological developments in the field of sedimentation engineering. This text is not a voluminous encyclopedia; it is rather a concise digest to be found in the briefcases of students and professionals. It scrutinizes selected methods that meet learning objectives, underlining theory and field applications.

The material can be covered within a regular forty-five-hour graduate-level course at most academic institutions. Colorado State University offers several graduate courses in hydraulics, sedimentation and river engineering, and stream rehabilitation. Two advanced courses CIVE716 Erosion and Sedimentation and CIVE717 River Mechanics are offered in sequence. This book has been prepared for the first course and the author's companion book entitled *River Mechanics*, at Cambridge University Press, has been tailored to the needs of the second course. The prerequisites include undergraduate knowledge of fluid mechanics and basic understanding of partial differential equations.

The chapters of this book contain a variety of exercises, examples, problems, computer problems, and case studies. Each type illustrates a specific aspect of the profession from theoretical derivations through exercises and derivations, to practical engineering solutions through the analysis of simple examples and complex case studies. Most problems can be solved with a few algebraic equations; a few require the use of a computer. Problems and equations marked with a single diamond (♦) are important; those with a double diamond (♦♦) are considered most important. The answers to some problems are provided to check calculations. Tests and homework assignments can include problems without answers.

Recent technological developments in engineering encourage the use of computers for quantitative analyses of erosion, transport, and sedimentation. Numerous algorithms in this text can be easily programmed. No specific computer code or language is emphasized or required. Instead of using old software packages, the textbook promotes student creativity in developing their own tools and programs with the best software available at any given time.

This second edition has been significantly revised and improved. Specific goals with the revisions have been twofold: (1) clarify and reinforce the most important concepts and principles through added explanations, figures, examples, and new homework problems; and (2) expand and update the technical content in the light of recent developments in the literature and engineering practice. Throughout the revisions, the main objectives have been to keep this text: (1) concise and effective when learning new concepts and derivations; and (2) helpful as a reference for future use in engineering practice. A major concern throughout the revisions has been to keep this textbook light and affordable.

I am grateful to my own teachers and professors at Laval University, and particularly to my advisors M. Frenette, J. L. Verrette, Y. Ouellet and B. Michel. I am also grateful to my mentors at Colorado State University, and specifically to D. B. Simons, H. Rouse, E. V. Richardson, and my esteemed colleagues. Many graduate students offered great suggestions for improvement to this textbook. Jenifer Davis diligently typed successive drafts of the manuscript and Jean Parent prepared professional figures. Finally, it has been a great pleasure to collaborate with the Cambridge University Press production staff.

Symbols

Symbols

a, a_x	acceleration
a	thickness of the bed layer
A	surface area
A_T, A_U, A_G, A_B	gross, upland, gully, and bank erosion
A_t	basin drainage area
B	constant of the resistance formula
B	bulking factor
c_Δ	bedform celerity
c_0	integration constant
c_{Bd}, c_{cl}	coefficients
C	Chézy coefficient
C_a	near-bed sediment concentration
$\mathrm{Co} = l_c/\sqrt{l_a\, l_b}$	Corey particle shape factor
$C_v, C_w, C_{ppm}, C_{mg/l}$	sediment concentration by volume, weight, in parts per million, and milligrams per liter
$C_t, C_\forall, C_f$	time-, spatial-, and flux-averaged concentration
C_D, C_E	drag and expansion coefficients
$\hat{C}$	cropping-management factor of the USLE
d_{10}, d_{50}	grain size with 10%, or 50%, of the material finer by weight
d_s	sediment size
d_*	dimensionless particle diameter
D	molecular diffusion coefficient
e	void ratio
e_B	Bagnold coefficient
E	specific energy
E_b	near-bed particle pick-up rate
f	Darcy–Weisbach friction factor $E = 2d_s/h$

F	force
Fr	Froude number
Fr_d	densimetric Froude number
$F_1, F_2, J_1, J_2, I_1, I_2$	components of the Einstein integrals
g	gravitational acceleration
G	specific gravity
Gr	gradation coefficient
h	flow depth
h_c, h_n	critical and normal flow depth
H	Bernoulli sum
He	Hedstrom number
i	rainfall intensity
I	universal soil-loss equation rainfall intensity
k_s, k'_s	boundary and grain roughness height
K	consolidation coefficient
$\hat{K}$	soil erodibility factor of the USLE
K_d	dispersion coefficient
ℓ	liter
ℓ_a, ℓ_b, ℓ_c	particle dimensions
ℓ_1, ℓ_2, ℓ_3, ℓ_4	moment arms for particle stability analysis
ℓ_m	mixing length
l, L	lengths
L_b, L_s, L_t	bedload, suspended load, total load
$\hat{L}$	field length factor of the USLE
m, M	mass
M, N	particle stability coefficients
M'_D, M''_D	moments
n	Manning n
$\vec{n}$	vector normal to a surface
p	pressure
p_0	porosity
P	wetted perimeter
$\hat{P}$	conservation practice factor
q	unit discharge
q_b, q_s, q_t	unit sediment discharge (bed, suspended, total)
Q	total discharge
Q_b, Q_s, Q_t	sediment discharge (bed, suspended, total)
r	radial coordinate
R	radius of a sphere
$\hat{R}$	rainfall erosivity factor of the USLE
R_T	sampler lowering rate

Re, $\mathrm{Re_B}$, $\mathrm{Re_d}$, $\mathrm{Re_p}$	Reynolds numbers
$\mathrm{Re}_* = \frac{u_* d_s}{\nu}$	grain shear Reynolds number
$R_h = A/P$	hydraulic radius
Ro	Rouse number
Sh	Shen–Hung parameter
$S_p = (\ell_b \ell_c / \ell_a^2)^{1/3}$	sphericity of a particle
S_0, S_f, S_w	bed, friction, and water surface slopes
$\hat{S}$	slope steepness factor of the USLE
SF	particle stability factor
S_{DR}	sediment-delivery ratio
t, T	time
t_d, t_t, t_v	dispersion, transversal, and vertical time scales
T	sediment transport parameter
T_c	consolidation time
T_E	trap efficiency
T_R	life expectancy of a reservoir
T_w	wave period
$T^\circ{}_C$, $T^\circ{}_F$	temperature in degrees Celsius and Fahrenheit
u, v_x, v_y, v_z	velocity
u^*	shear velocity
V	depth-averaged flow velocity
$\forall$	volume
W	channel width
x, y, z	coordinates
X_C	settling distance
X_D	total rate of energy dissipation
X_r	runoff length
Y	sediment yield
$\hat{z}$	upward vertical direction
z_b	bed elevation
z_0	elevation where the velocity is zero
Z	dependent variable

Greek symbols

α_e	energy correction factor
β, δ, λ, θ	angles of the particle stability analysis
β_m	momentum correction factor
β_s	ratio of sediment to momentum exchange coefficient
γ	specific weight

Γ	circulation
δ	laminar sublayer thickness
∂	partial derivative
∇^2	Laplacian
Δ, Λ	dune height and wavelength
Δp_i	sediment size fraction
ε	turbulent mixing coefficients
ε_m	eddy viscosity
ζ	turbulent-dispersive parameter
η_0, η_1	particle stability number
θ	angular coordinate
Θ	angle
ϑ	mixing stability parameter
κ	von Kármán constant
λ, δ, β	angles of particle stability analysis
λ	linear concentration
μ	dynamic viscosity
υ	kinematic viscosity
$\xi = z/z_m$	normalized depth
ρ, ρ_s	mass density of water and sediment
Π	dimensionless parameter
Π_W	wake strength
σ	normal stress components
σ	standard deviation for sediment diffusion
σ_g	gradation coefficient
σ_t	mixing width
τ_{yx}	shear stress in x direction from gradient in y
τ_0, τ_c	bed shear stress and critical shear stress
τ^*	Shields parameter
τ_y, τ_d	yield and dispersive stresses
ϕ	angle of repose
Φ, Ψ	potential and stream functions
χ	rate of work done per unit mass
χ_D	dissipation function
$\odot, \ominus, \oslash, \otimes$	modes of deformation
ω	settling velocity
ω_f	flocculated settling velocity
$\vec{\omega}$	vorticity
Ω_e , Ω_g	elastic energy and gravitation potential
$\forall$	volume

Superscripts and diacriticals

$a, b, \hat{a}, \hat{b}$	coefficient and exponent of resistance formula
$(\hat{v}), \bar{v}, v^+$	fluctuating, average and time velocity
F'_D, F''_D	surface and form drag
τ', τ''	grain and form resistance
$\tilde{E}, \tilde{H}$	integrated value
$\dot{m}, \dot{C}_v$	point source
$\tilde{u} = v_x/u_*$	relative velocity

Subscripts

a, C_a, v_a	bed layer characteristics
a_x, a_y, a_z	x, y, z acceleration components
C_0, C_1, C_2	concentration at different times
$d_i, \tau_{ci}, \tau^*_{ci}, \Delta p_i$	characteristics of size fraction i
d_s, ρ_s, γ_s	sediment properties
E_{min}	minimum specific energy
f_b, f_w	bed and wall friction factor
f_p, h_p, T_p	upper-regime plane bed parameters
F_D, C_D	drag force and coefficient
F_H, F_V	horizontal and vertical forces
F_W, F_B, F_D, F_L	weight, buoyant, drag, and lift forces
h_c, h_n	critical and normal flow depth
h_d, V_d, f_d, α_d	densimetric values
L_b, L_s	bedload, suspended load
L_m, L_u	measured, unmeasured load
L_w, L_{bm}	washload, bed material load
M_w, M_s, M_T	mass of water, solids, and total
p_r	relative pressure
q_{bv}, q_{bm}, q_{bw}	unit sediment discharge by volume, mass, and weight
S_0, S_f, S_w	bed slope, friction slope, and water surface slope
$T^\circ{}_F, T^\circ{}_C$	temperature in °F and °C
u_∞, p_∞	velocity and pressure infinitely far
v_a	near-bed particle velocity
v_r, v_p	reference velocity and velocity against a particle
W, W_L, W_p, W_s	water content, liquid, plastic, and shrinkage limits
X_d, X_t, X_v	lengths for dispersion, transversal, and vertical mixing
ρ_{md}, γ_{md}	dry specific mass and weight of a mixture
ρ_m, ν_m, μ_m	properties of a water–sediment mixture
τ_c, τ^*_c	critical shear stress and critical Shields parameter
τ_0, τ_b, τ_s	boundary shear stress, at the bed, and on the side slope
τ^*, d^*	dimensionless sedimentation parameters