

# Contents

<b>1</b>	<b>Introduction to Estuary Studies</b> . . . . .	1
1.1	Why to Study Estuaries? . . . . .	1
1.2	Origin and Geological Age . . . . .	4
1.3	Definition and Terminology . . . . .	7
1.4	Policy and Actions to Estuary Preservation. . . . .	18
	References. . . . .	20
<b>2</b>	<b>Circulation and Mixing in Estuaries</b> . . . . .	25
2.1	Hydrologic Processes: Ocean-Drainage Basin-Estuary . . . . .	25
2.2	Temporal and Spatial Scales of Sea-Level Variations . . . . .	33
2.3	Dimensional Analysis Applied to Equations and Processes . . . . .	43
2.4	What Generates the Circulation and Mixing in the Estuary? . . . . .	44
2.5	Tidal Wave Propagation in an Estuary . . . . .	52
2.6	Non-dimensional Numbers . . . . .	61
2.7	Mixing and Entrainment . . . . .	68
	References. . . . .	69
<b>3</b>	<b>Estuary Classification</b> . . . . .	73
3.1	Geomorphologic Types of Estuaries . . . . .	75
3.1.1	Coastal Plain . . . . .	75
3.1.2	Fjord . . . . .	76
3.1.3	Bar-Built (or Coastal Lagoons) . . . . .	77
3.1.4	Tectonic, Deltas and Rias . . . . .	78
3.2	Salinity Stratification. . . . .	80
3.2.1	Salt Wedge Estuary (Type A) . . . . .	80
3.2.2	Moderately or Partially Mixed (Type B) . . . . .	82
3.2.3	Vertically Well-Mixed (Types C and D) . . . . .	83

3.3	Classification Diagrams. . . . .	88
3.4	Estuarine Zone . . . . .	105
3.5	Coastal Lagoons . . . . .	106
	References. . . . .	112
<b>4</b>	<b>Physical Properties and Experiments in Estuaries . . . . .</b>	<b>117</b>
4.1	Research Planning. . . . .	117
4.2	Current Measurements, Tide and Hydrographic Properties . . . . .	122
4.2.1	Current Velocity . . . . .	122
4.2.2	Tide. . . . .	126
4.2.3	Hydrographic Properties . . . . .	127
4.3	Density and Equations of State. . . . .	134
	References. . . . .	140
<b>5</b>	<b>Reduction and Analysis of Observational Data:</b>	
	<b>Flux and Transport of Properties . . . . .</b>	<b>143</b>
5.1	Decomposition of Velocity . . . . .	143
5.2	Vertical Velocity Profiles . . . . .	147
5.3	Temporal and Spatial Averages . . . . .	155
5.4	Reduction and Analysis of Temporal Data Series . . . . .	160
5.5	Isopleths Method and Mean Vertical Profiles . . . . .	167
5.6	Flux and Transport of Properties. . . . .	169
5.7	Advective Salt Transport Components . . . . .	174
5.8	Advective Concentration Transport. . . . .	181
5.9	Tidal Prism Determination . . . . .	182
	References. . . . .	182
<b>6</b>	<b>Mixing Processes in Estuaries: Simplified Methods . . . . .</b>	<b>185</b>
6.1	Fundamental Concepts . . . . .	186
6.2	Tidal Prism. . . . .	194
6.3	Segmented Tidal Prism Model . . . . .	196
6.3.1	High Tide Fresh Water Balance. . . . .	210
6.3.2	Low Tide Fresh Water Balance . . . . .	211
6.3.3	Fresh Water Balance During the Tidal Cycle . . . . .	211
6.4	Concentration Estimates of a Conservative Pollutant . . . . .	218
6.5	Water Mass Exchange at the Estuary Mouth . . . . .	224
6.6	Mixing Diagrams . . . . .	228
	References. . . . .	231
<b>7</b>	<b>Hydrodynamic Formulation: Mass and Salt Conservation</b>	
	<b>Equations . . . . .</b>	<b>233</b>
7.1	State of a Volume Element. . . . .	234
7.2	Mass and Salt Conservation Equations . . . . .	235

7.3	Integral Formulas: Mass and Salt Conservation Equations . . . .	242
7.3.1	Volume Integration . . . . .	242
7.3.2	Bi-Dimensional Formulation: Vertical Integration . . . .	252
7.3.3	Bi-Dimensional Formulation: Lateral Integration . . . .	258
7.3.4	One-Dimensional Formulation: Integration in an Area. . . . .	263
7.4	Simplified Forms of the Continuity Equation. . . . .	268
7.5	Application of the One-Dimensional Continuity Equation . . . .	270
7.6	Application of the One-Dimensional Salt Conservation Equation . . . . .	272
7.7	Steady-State Concentration Distribution of a Non- conservative Substance . . . . .	277
	References. . . . .	281
<b>8</b>	<b>Hydrodynamic Formulation: Equations of Motion and Applications . . . . .</b>	<b>283</b>
8.1	Equations of Motion . . . . .	283
8.2	Boundary and Integral Conditions. . . . .	291
8.3	Bi-Dimensional Formulations: Vertical and Lateral Integration. . . . .	298
8.3.1	Vertical Integration . . . . .	298
8.3.2	Cross-Section Integration. . . . .	301
8.4	One-Dimensional Formulation . . . . .	303
8.5	Simplified Formulation and Application. . . . .	308
8.5.1	Velocity Generate by the River Discharge. . . . .	308
8.5.2	Velocity Generate by the Wind Stress . . . . .	313
8.6	Shallow Water Tidal Current and Phase Velocity . . . . .	318
8.7	Periodic Stratification Tidal Generate: Potential Energy Anomaly. . . . .	321
	References. . . . .	324
<b>9</b>	<b>Circulation and Mixing in Steady-State Models: Salt Wedge Estuary. . . . .</b>	<b>327</b>
9.1	Hypothesis and Theoretical Formulation. . . . .	330
9.2	Circulation and Salt-Wedge Intrusion . . . . .	331
9.2.1	The Upper Layer . . . . .	331
9.2.2	The Lower Layer (Salt-Wedge). . . . .	335
9.2.3	Vertical Velocity Profile . . . . .	338
9.2.4	Salt-Wedge Intrusion Length. . . . .	338
9.3	Theory and Experiment. . . . .	346
	References. . . . .	348

<b>10</b>	<b>Circulation and Mixing in Steady-State Models: Well-Mixed Estuary</b>	351
10.1	Hydrodynamic Formulation and Hypothesis	351
10.2	Solution with Maximum Bottom Friction	355
10.3	Vertical Velocity Profile: Moderate Bottom Friction	361
10.4	Theory and Observational Data	364
10.5	Longitudinal Salinity Simulation	366
10.6	Analytical Simulation	369
10.6.1	Basic Equations: Upper and Lower Boundary Conditions and Integral Boundary Condition	369
10.6.2	Barotropic Pressure Gradient, Wind Stress and Maximum Bottom Friction	371
10.6.3	Barotropic Pressure Gradient, Wind Stress, River Discharge and Maximum Bottom Friction	374
10.6.4	Barotropic Pressure Gradient, River Discharge, Wind and Moderate Bottom Friction	376
10.6.5	Barotropic and Baroclinic Pressure Gradient, River Discharge, Wind Stress and Bottom Friction Proportional to the Square of the Velocity	380
10.6.6	Vertical Salinity Profile	381
	References	383
<b>11</b>	<b>Circulation and Mixing in Steady-State Models: Partially Mixed Estuary</b>	385
11.1	Physical-Mathematical Formulation	387
11.2	Hydrodynamic Solution: Maximum Bottom Friction	393
11.3	Hydrodynamic Solution: Moderate Bottom Friction	397
11.4	Theoretical Vertical Salinity Profile	401
11.5	Theoretical and Experimental Velocity and Salinity Profiles	405
11.5.1	Longitudinal and Vertical Velocity Profiles	406
11.5.2	Vertical Salinity Profile	406
11.5.3	Validation of Experimental Velocity and Salinity Vertical Profiles	409
11.6	Hansen and Rattray's Similarity Solution	409
11.7	Estuary Classification: Stratification-Circulation Diagram	418
11.8	Hansen and Rattray's Velocity and Salinity Vertical Profiles: Results and Validation	421
11.9	Salinity Intrusion	425
11.10	Secondary Circulation	426
	References	436

- 12 Numerical Hydrodynamic Modelling** . . . . . 439
  - 12.1 Briefy Outline on Numerical Models . . . . . 440
  - 12.2 The Finite Difference Method . . . . . 442
  - 12.3 Explicit and Implicit Schemes . . . . . 449
  - 12.4 The Volume Method of Finite Difference . . . . . 453
  - 12.5 A Simple Unidimensional Numeric Model . . . . . 456
    - 12.5.1 Explicit Solution . . . . . 456
    - 12.5.2 Implicit Solution . . . . . 461
  - 12.6 The Blumberg’s Bi-dimensional Model . . . . . 462
  - 12.7 Results on Numerical Modelling: Caravelas-Peruípe Rivers Estuarine System . . . . . 472
- References . . . . . 480



<http://www.springer.com/978-981-10-3040-6>

Fundamentals of Estuarine Physical Oceanography  
Bruner de Miranda, L.; Andutta, F.P.; Kjerfve, B.; Castro  
Filho, B.M. de  
2017, XXXII, 480 p. 138 illus., 17 illus. in color.,  
Hardcover  
ISBN: 978-981-10-3040-6