Estuaries: A Physical Introduction

K. R. Dyer

Unit of Coastal Sedimentation,
Taunton, Somerset

Visiting Lecturer, Department of Oceanography,
University of Southampton

A Wiley–Interscience Publication

JOHN WILEY & SONS

London · New York · Sydney · Toronto

Estuaries: A Physical Introduction

K. R. Dyer

Unit of Coastal Sedimentation,
Taunton, Somerset

Visiting Lecturer, Department of Oceanography,
University of Southampton

A Wiley–Interscience Publication

JOHN WILEY & SONS

London · New York · Sydney · Toronto

Copyright © 1973 John Wiley & Sons Ltd. All Rights Reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical photo-copying, recording or otherwise, without the prior written permission of the Copyright owner.

Library of Congress catalog card number 72-8598

ISBN 0 471 22905 9

Reprinted April 1977

Reprinted April 1979

Printed in Great Britain
By Unwin Brothers Limited
The Gresham Press, Old Woking, Surrey.
A member of the Staples Printing Group.

Foreword

Estuaries occur in many varied forms, ranging from the coastal plain type to steep-sided fjords, but they all share the common feature of being regions where rivers and sea water meet and interact. Along many coasts the interaction is made more complex by the action of tides and tidal streams, the range of which is often increased when they penetrate an estuary. To the hydrologist and physical oceanographer the water movements and the turbulent mixing which results present interesting and challenging problems in hydrodynamics. These features, moreover, largely control the transport of material in suspension and its erosion or deposition: topics with which the geologist is concerned. Together with the chemical composition of the inflowing water, these characteristics lead to the distinctive features of the estuarine environment which make it of special interest to the biologist.

Many of the world's seaports are situated on estuaries and access to them depends on maintaining navigable channels of sufficient depth, a task which becomes increasingly difficult with the use of larger ships and the demand for improved docking facilities. The presence of a port is usually associated with centres of industry and population and for centuries it has been customary for their sewage and other wastes to be disposed of directly into the estuary. By reason of the relatively rapid mixing between estuary water and the open sea, enhanced by tidal action, many estuaries have coped more or less successfully with this imposition in the past but, with the increasing volume of waste material and the introduction of new and persistent chemical compounds, much more attention will have to be given in future to the conditions under which wastes are discharged into estuaries. At the same time the estuary is often required to act as a source of water supply for industry or for the cooling of power stations. In some areas schemes for the abstraction of water or the control of river discharge for irrigation purposes modify considerably the natural river flow and its incidence in time.

There are, therefore, a number of good reasons, both scientific and practical, for intensifying the study of estuaries and for disseminating more widely the knowledge which is acquired. This book is a contribution to that end, in that it describes and explains the physical processes acting in estuaries, to the extent that they are understood at present. It should be of interest to geologists and biologists and to those concerned with the management of estuary resources as well as to oceanographers and engineers. As well as dealing with the basic principles, the author discusses in detail their application to particular estuaries, drawing in several cases on his own varied experience in such investigations.

K. F. BOWDEN

January 1973

此为试读,需要完整PDF请访问: www.ertongbook.com

Preface

This book arose from a series of lecture notes compiled for a course on Estuaries given to a post-graduate class in the Oceanography Department, Southampton University. The course included students with first degrees in Zoology, Chemistry and Geology as well as Physics and Mathematics and, consequently, was a fairly low-level introduction into how estuaries work. As there was no complete textbook on the physics of estuaries the notes were polished and extended, but I hope they will still perform the function of introducing the relevant physical processes to all disciplines.

I think that one of the most interesting things about estuaries is that they are so complicated. They are continually in motion with cycles of variation that may never be repetitive and there is such close interlinking between the physical, chemical, geological and biological systems that research workers cannot afford to be too specialized in their consideration of estuaries. Each discipline must be aware of the needs of others. This is especially so regarding the physical oceanographers who can so easily work in isolation, but whose work is essential to others who depend on their quantifying the processes which govern the distribution of suspended and dissolved constituents. In return the physical oceanographers can achieve more if the other disciplines can formulate within realistic bounds what physical input they require. Perhaps this book will help disperse the state of the estuarine art to all those interested.

I would like to thank Professors K. F. Bowden and H. Charnock for their very helpful criticisms on the manuscript and Drs. J. Hinwood and P. A. Taylor for helpful discussions and advice. I also wish to thank Mrs. Bernardette Walling and Mrs. Joan Wedge for the typing and my wife and family for their continual encouragement.

'The search for truth is in one way hard and in another easy. For it is evident that no one can master it fully or miss it wholly. But each adds a little to our knowledge about Nature, and from all the facts assembled there arises a certain grandeur.' (Aristotle)

K. R. DYER

November 1972

Notation

A	Cross-sectional area of estuary
$\overline{A}$	Mean cross-sectional area
A_o	Tidal amplitude, Amplitude of tidal fluctuation in cross-sectional area
A	Tidal fluctuation of cross-sectional area
a	Pipe radius
B	A constant
b	Estuary breadth
C	A constant, Concentration of pollutant
C_o	Concentration of pollutant in segment at outfall
c	Wave celerity $= \sqrt{gh}$
D	A depth
D	Thickness of salt wedge
D	Dynamic depth
F	Flushing number
F	Density current transport
F	Flux of pollutant or salt through cross-section
F_i	Interfacial Froude number
F_m	Densimetric Froude number
f	Fresh water fraction, Frequency
f	Coriolis Parameter, $f_1 = 2\omega \sin \phi$, $f_2 = 2\omega \cos \phi$
G	Rate of energy dissipation per unit mass of water
g	Gravitational acceleration
H	A depth
h	Estuary depth
J	Rate of gain of potential energy
K_x	Coefficient of longitudinal eddy–diffusion
K_y	Coefficient of lateral eddy–diffusion
K_z	Coefficient of vertical eddy–diffusion
K_q	Coefficient of eddy–diffusion for pollutant
k	Wave number $k = 2\pi/\lambda = 2\pi n/u$, Coefficient of mortality, Coefficient of friction
k_o	Von Karman Constant $= 0{\cdot}4$
L	Length of salt wedge, Length of estuary, Amplitude of pollutant dispersal
l	Length scale of diffusion
M	Tidal mixing parameter

N_x	Coefficient of longitudinal eddy-viscosity
N_y	Coefficient of lateral eddy-viscosity
N_z	Coefficient of vertical eddy-viscosity
n	A number, Frequency
$\mathbf{P}$	Tidal prism volume, A factor
P	Ratio of surface to r.m.s. tidal velocity
P	Rate of introduction of a pollutant
p	Pressure
$\mathbf{Q}$	Volume rate of transport of salt per unit width, Volume rate of transport of water
Q	Amount of water in a section of an estuary
R	River discharge
R_{10}	River discharge averaged over ten days
Ra	Estuarine Rayleigh number
Re	Reynolds number
Ri	Richardson number
Ri_{E}	Estuarine Richardson number
r	Exchange ratio
r	Radius of curvature of streamlines
S	Tidal fluctuation in salinity
$\mathrm{S_o}$	Mean salinity in segment, Amplitude of tidal fluctuation of salinity
S_n	Mean salinity in segment n of estuary
$\mathrm{S_s}$	Salinity of undiluted sea water
s	Salinity, Subscripts, superscripts etc., for s the same as for u
T	Tidal period, Period of Turbulent oscillation, Tidal range
T	Dimensionless wind stress
$\mathbf{T}$	Flushing time
t	Time, Time constant
U	Tidal variation of longitudinal velocity
$\mathrm{U_o}$	Amplitude of tidal variation of longitudinal velocity
U_*	Friction velocity $= \sqrt{\tau_o/\rho}$
u	Longitudinal velocity
$\mathrm{u_o}$	Observed longitudinal velocity averaged over a period of minutes
u'	Turbulent velocity fluctuations of period less than a few minutes
$\bar{\mathrm{u}}$	Tidal mean velocity
$\langle\bar{\mathrm{u}}\rangle$	Tidal mean velocity averaged over depth
$\langle\mathrm{u}\rangle$	Depth mean velocity
u_1	Deviation of longitudinal velocity from depth mean velocity
u_2	Deviation of depth mean velocity from cross-sectional mean
$\mathrm{u_A}$	Velocity averaged over cross-section
$\mathrm{u_c}$	Critical velocity for entrainment
$\mathrm{u_d}$	Deviation of velocity from cross-sectional average
$\mathrm{u_f}$	Fresh water velocity $= \mathrm{R}/\bar{\mathrm{A}}$

u_s	Net surface current
u_t	Root mean square tidal current
V	Tidal variation of lateral velocity
V	Low tide volume of segment of estuary
v	Lateral velocity, Subscripts, superscripts etc for v the same as for u
W	Tidal variation in vertical velocity
W_e	Vertical velocity of entrainment
w	Vertical velocity, Subscripts, superscripts, etc. for w the same as for u
x	Longitudinal distance
y	Lateral distance
z	Vertical distance
z_o	Bed roughness length
α	Specific volume $= 1/\rho$
δS	Surface to bottom difference in tidal mean salinity
ε	Molecular diffusion coefficient for salt
ζ	Elevation of water surface
η	Dimensionless vertical co-ordinate $= z/h$, Ratio between lateral and vertical shearing stresses
Θ	Criterion of mixing
θ	A phase lag, An angle
κ	Constant in equation of state for sea water
λ	Wavelength, A dimensionless length
μ	Damping coefficient, Coefficient of molecular viscosity
ν	Kinematic viscosity $= \mu/\rho$, Diffusive fraction of upstream salt flux
ξ	Dimensionless horizontal co-ordinate
ξ_o	Amplitude of horizontal tidal displacement
ρ	Water density
ρ_f	Density of fresh water
ρ_s	Density of surface water
σ_{tH}	Time of high water relative to high water at estuary head
σ_{rc}^2	Variance of dye distribution
τ	Shearing stress
τ_o	Shearing stress at the bed
ϕ	Dissipation constant, Angle of latitude
ψ	Stream function
ω	Angular frequency of tide, Angular velocity of earth's rotation

Contents

此为试读，需要完整PDF请访问：www.ertongbook.com

CHAPTER 1

Introduction

An estuary can be defined in a variety of ways depending on one's immediate point of view. As far as most oceanographers, engineers and natural scientists are concerned, estuaries are areas of interaction between fresh and salt water. Consequently the definition most commonly adopted is that of Cameron and Pritchard (1963) who state that 'An estuary is a semi-enclosed coastal body of water which has a free connexion with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage'. In this case we are restricting our interest to what have been termed positive estuaries (Pritchard, 1952b). A positive estuary is an estuary where the fresh water inflow derived from river discharge and precipitation exceeds the outflow caused by evaporation. Surface salinities are consequently lower within the estuary than in the open sea. Negative estuaries are those where evaporation exceeds river flow plus precipitation and hypersaline conditions exist, e.g. Laguna Madre in Texas. Most estuaries are positive ones and we will confine our attention to those.

The interaction of fresh and salt water provides a circulation of water and mixing processes that are driven by the density differences between the two waters. The density of sea water depends on both the salinity and temperature, but in estuaries the salinity range is large and the temperature range is generally small. Consequently temperature has a relatively small influence on the density and there is little information published on temperature fluctuations in estuaries. One can visualize estuaries, however, where temperature could be a dominant factor at times. Many tropical estuaries have little river flow entering them during the hot season. Surface heating could then provide sufficient density difference between the estuary and the sea to maintain a gravitational circulation. Because of the diurnal variation of temperature, however, these effects would be transitory. In many fjords there is no river discharge in winter and surface cooling is intense. The surface waters can then become more dense than those at depth and will tend to sink. This vertical circulation phenomenon is known as thermohaline convection. The effects of temperature, therefore, must not be forgotten.

Estuaries are formed in the narrow boundary zone between the sea and the land and their life is generally short. Their form and extent is being constantly altered by erosion and deposition of sediment and drastic effects are caused by a small raising or lowering of sea level. These sea level alterations may be eustatic, variations in the volume of water in the oceans, or isostatic, variations in the level of the land. In the recent geological past there have been very large eustatic changes in sea level. About 18000 years ago the sea level stood about 100 m below its present level, the water being locked up in extensive continental ice sheets. As the ice retreated the sea rose at a rate of about 1 m a century, drowning the valleys incised by the rivers. This Flandrian transgression ended about 3000 B.C. when sea level was more or less the same as at present. Since then some authorities have suggested that minor fluctuations have occurred, but these are probably mainly isostatic in origin. Scotland is rising at a rate of about 3 mm yr^{-1} in response to the removal of the ice sheet, whereas areas formerly peripheral to the ice sheet, such as southern England and Holland, are now sinking at about 2 mm yr^{-1}.

Further large eustatic changes are possible. If all the world's ice were melted, it has been estimated that sea level would rise by about 30 m. If this happened, new estuaries would be formed in the upper valleys of the present rivers. Little sediment would appear from the rivers, but large quantities would be available from renewed coastal erosion. A reduction of sea level would produce shallow estuaries which would quickly fill with sediment derived from the rejuvenated upper river valleys. In either case, because of the increased, or reduced, depths of the gulfs and seas into which the estuaries emptied, the tidal conditions would be modified. At present, following the Pleistocene ice age which overdeepened the river valleys, and the subsequent inundation which flooded them, estuaries are both well-developed and numerous. In geological terms this situation may not last long.

Though they are a particularly ephemeral feature of the earth's surface, estuaries have probably been extremely important in the world's development. They have generally high inflows of nutrients from the land, but, because of their range of conditions, tend to have a lesser diversity of life than other aquatic environments. Individual species are numerous, but are specialized and often tolerant to large extremes of temperature and salinity. It is thought by many zoologists that estuaries may have been the most likely situation in which the first signs of organic life evolved. Almost certainly the estuaries were the route by which, many millions of years later, animal life slowly adapted itself to a land-living and air-breathing existence.

Because of their fertile waters, sheltered anchorages and the navigational access they provide to a broad hinterland, estuaries have been the main centres of man's development. The promotion of trade and industry has led to large-scale alteration of the natural balance within estuaries by alteration of their topography, making for easier navigation for larger ships, and large-scale pollution, as a result of industrialization and population increases. Deforestation of the land leads to increased run-off from the land, increased flashiness of the discharge and increased sediment load in the rivers. Building and paving of large areas also produce a quick response of run-off to rainfall. These effects may be controlled by the building of dams and may be reduced by the removal of river water for industrial processes and household use. However, maintenance of river flow at a set level will decrease the natural tendency for rivers to flush sediments out of their estuaries and consequently may aggravate shoaling problems. Deepening of the estuary by dredging will increase the estuary volume and reclamation of intertidal areas will decrease the tidal flow, alter the mixing processes and circulation patterns and perhaps decrease the flushing time of the estuary. With decreased flushing time the estuary cannot cope with and dispose of such large quantities of effluent. To understand and to be able to predict these effects is essential if mankind is not to do undue damage to his environment.

The main drawback in studying estuaries is that river flow, tidal range and sediment distribution are continually changing and consequently some estuaries may never really be steady-state systems, they may be trying to reach a balance they never achieve. Because of the interaction of so many variables no two estuaries are alike and one never knows whether one is observing general principles or unique details.

Many studies of individual estuaries are available in the literature and there are several texts that sift the details and produce the relevant general principles. These include Cameron and Pritchard (1963), Lauff (1967) and Ippen (1966). In this book some of the many examples will be discussed and used as illustrations of the techniques of analysis and computation useful for estuarine studies.

CHAPTER 2

Classification of Estuaries

In order to compare different estuaries and to set up a framework of general principles, within which it may be possible to attempt prediction of the characteristics of estuaries, a scheme of classification is required. Many different schemes are possible, depending on which criteria are used. Topography, river flow and tidal action must be important factors that influence the rate and extent of the mixing of the salt and fresh water. Locally, and for short periods, wind also may become significant. The resultant mixing will be reflected in the density structure and the presence of stratification may cause modification of the circulation of water. Obviously all of these causes and effects are interlinked and it would be difficult to take account of them all in one classification system.

CLASSIFICATION BY TOPOGRAPHY

A topographic classification has been presented by Pritchard (1952). He divides estuaries into three groups: coastal plain estuaries, fjords and bar-built estuaries.

Drowned River Valleys (coastal plain estuaries)

These estuaries were formed during the Flandrian transgression by the flooding of previously incised valleys. Sedimentation has not kept pace with the inundation and the estuarine topography is still very much like that of a river valley. Consequently maximum depths in these estuaries are seldom as much as 30 m. They have the cross-section of subaerial valleys and deepen and widen towards their mouths, which may be modified by spits. Their outline and cross-section are both often triangular. The width–depth ratio is usually large, though this depends on the type of rock in which the valley was cut. Extensive mudflats and saltings often occur and the central channel is often sinuous. The entire estuary is usually floored by varying thicknesses of recent sediment, often mud in the upper reaches, but becoming increasingly sandy towards the mouth. A remarkable characteristic of some is that the increase in cross-sectional area towards the mouth is exponential; this may reflect a long-term equilibrium adjustment between sedimentation and erosion by tidal currents.

Coastal plain estuaries are generally restricted to temperate latitudes, where, though river flow may be large at times, the amount of sediment discharged by the river is relatively small. River flow is generally small compared with the volume of the tidal prism (the volume between high and low water levels).
Examples: The Chesapeake Bay estuary system in the United States and the Thames, Southampton Water and the Mersey in England.

Fjords

Fjords were formed in areas covered by Pleistocene ice sheets. The pressure of the ice overdeepened and widened the pre-existing river valleys, but left rock bars or sills in places, particularly at the fjord mouths and at the intersection of the fjords. These sills can be very shallow. In Norway a number have sill depths averaging $4\frac{1}{2}$ m and their presence can restrict the free exchange of water with the sea. The inlets of British Columbia, however, have deeper sills. Pickard (1956) has listed the physical features of several of these inlets and the sill depths are mainly between about 40 m and 150 m. Inside the sills the maximum depth of the inlets reaches almost 800 m.

Because of overdeepening, fjords have a small width–depth ratio, steep sides and an almost rectangular cross-section. Their outline is also rectangular, but sharp, right-angled bends are common. Some fjords reach 100 km in length and the width–depth ratio is commonly 10 : 1.

Fjords generally have rocky floors, or very thin veneers of sediment, and deposition is generally restricted to the head of the fjord where the main rivers enter. River discharge is small compared with the total fjord volume, but, as many fjords have restricted tidal ranges within their mouths, the river flow is often large with respect to the tidal prism. Their occurrence is restricted to high latitudes in mountainous areas.
Examples: Loch Etive (Scotland), Sogne Fjord (Norway), Alberni Inlet (British Columbia) and Milford Sound (New Zealand).

Bar-built Estuaries

These estuaries could also be called drowned river valleys as they have experienced incision during the ice age and subsequent inundation. However, recent sedimentation has kept pace with the inundation and they have a characteristic bar across their mouths. This bar is normally the break-point bar formed where the waves break on the beach and for this to be well developed the tidal range must be restricted and large volumes of sediment available. Consequently, bar-built estuaries are generally associated with depositional coasts. The estuaries are generally only a few metres deep and often have extensive lagoons and shallow waterways just inside the mouth. Because of the restricted cross-sectional area current velocities can be high at the mouth, but in the wider parts further inland they rapidly diminish.

此为试读，需要完整PDF请访问：www.ertongbook.com