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Estimating bankfull discharge and depth in ungauged estuaries

Jacqueline Isabella Anak Gisen[1,2] and Hubert H.G. Savenije[1]

[1]Water Management, Civil Engineering, and Geosciences, Delft University of Technology, Delft, Netherlands, [2]Civil Engineering and Earth Resources, Universiti Malaysia Pahang, Kuantan, Pahang, Malaysia

Key Points:

- Establish a method to estimate the estuarine number (Canter-Cremers)
- Find the applicability of regime theory in tidally influenced estuaries
- Find a method to estimate bankfull discharge and depth in estuaries

Supporting Information:

- Supporting Information S1
- Figures S1 and S2
- Table S1

Correspondence to:

J. I. A. Gisen,
j.isabellaanakgisen@tudelft.nl

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Abstract It is difficult to measure river discharge accurately in an estuary, and particularly, in the region where the tidal flow dominates over the river discharge. River discharge is important for the morphology and hydrodynamics of estuaries as it influences the salt intrusion process, tidal dynamics, freshwater supply (water resources management), and the occurrence of floods. Here we try to derive river regime characteristics from the seaward end: the estuary. It is found that there are empirical relationships that link the geometry of an estuary to its river regime, which can be used to estimate river discharge characteristics with the least of data available. The aims of this study are: (1) to derive empirical relations between geometrical characteristics of estuaries and the bankfull discharge; (2) to explore a physical explanation for this relation; and (3) to estimate the bankfull discharge in estuaries. The physical connection between an estuary and its river regime is found by combining estuary shape analysis, tidal dynamic analysis, and Lacey's hydraulic geometry theory. The relationships found between the estuary depth, width, and bankfull river discharge have been tested in 23 estuaries around the world (including seven recently surveyed estuaries). From the analysis, it shows that the depth of an estuary is a function of the bankfull flood discharge to the power of 1/3, which is in agreement with Lacey's formula. This finding not only provides a method to estimate estuary depth, it also allows estimating flood discharge characteristics from readily available estuary shape indicators.

1. Introduction

Estimating river discharge in the tidal region of estuaries accurately is difficult when the ratio of tidal flow to river discharge is large [*Cai et al*., 2014]. As a result, gauging stations are generally situated well outside the tidal region. The river discharge is not only important for determining the salt intrusion, the potential for irrigation, or for ecological reasons, it is also important for understanding the morphology of estuaries. Recently, a new technology for estimating river discharge has become available using Horizontal Acoustic Doppler Current Profiler (H-ADCP) [e.g., *Bechle and Wu*, 2014; *Hoitink et al*., 2009; *Sassi et al*., 2011a]. However, this approach involves an extended period of repeated surveys which generally consumes considerable amount of time, energy, and money. *Moftakhari et al*. [2013] introduced an analytical solution known as tidal discharge estimation (TDE) to hindcast river flow in San Francisco Bay, making use of time series analysis, but this requires extended periods of observation data.

Little research has been done on the relationship between estuary shape and hydrodynamics in alluvial estuaries and even less linking the shape to the hydrology of the drainage basin. Only in recent years, efforts have been taken by *Sassi et al*. [2012] to study the downstream hydraulic geometry in a tidally influenced estuary, incorporating a moving boat technique with mounted H-ADCP. *Townend* [2012] established an idealized 3-D model to predict the geometry of a range of UK estuaries, using the hydraulic geometry theory.

This study aims to develop empirical relations between estuary shape and river discharge, which are particularly useful for ungauged estuaries, and to investigate the physical explanation involved. The study focuses on estuaries that are fully alluvial, with limited upstream regulation or dredging. Being alluvial implies that there is a substantial contribution of occasional sediment-laden river discharge [*Savenije*, 2005]. Examples of alluvial estuaries include deltas and funnel-shaped estuaries, but exclude tidal inlets, bays, rias, fjords, sounds, and submerged river valleys. Data from literature, national authorities, and field surveys have been collected to derive empirical relations between the geometry and bankfull river discharge. The main contribution of this research is the development of simple approaches to estimate estuary depth and bankfull