HYDRAULIC ASPECTS OF MODELLING WATER QUALITY
IN DEEP ESTUARIES AND ENCLOSED BAYS

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ABSTRACT

The physical causing and modifying unsteady gravitational circulation in deep estuaries and enclosed bays is described with examples. The manner in which the gravitational circulation controls water quality in a deep estuary is illustrated with special reference to the dissolved oxygen distribution in the Tyne Estuary in 1969.

The failings of one-dimensional and depth-averaged models are assessed and the problems and performance of various types of multidimensional models are discussed.

INTRODUCTION

The Mersey, Tyne and Tees, which are three of the most polluted tidal rivers in the U.K. (National Water Council, 1980), can be categorised as deep estuaries. The Santos Estuary in Brazil, The Rotterdam Water Way in Holland the Tejo Estuary in Portugal are also deep estuaries with significant pollution problems. Liverpool Bay in the U.K. and Tolo Harbour in Hong Kong are example of deep bays with brackish water and potential pollution problems.

The depth of an estuary is measured in absolute terms and relative to the tidal range. For practical purposes, one can assume that a deep estuary is one with mean depths in excess of about ten metres and a tidal range to mean depth ratio of less than about 0.5. The tide usually propagates through the deep regions of such estuaries without significant distortion due to shallow water effects.
GRAVITATIONAL CIRCULATION

One of the most important aspects of the hydraulics of deep estuaries is the longitudinal gravitational circulation that is driven by the longitudinal density gradients within the estuary.

The magnitude of the net longitudinal pressure gradient, $\frac{dp}{dx}$, at a depth, $z$, which causes the gravitational circulation is a function of the slope of the mean tide level, $\frac{dn}{dx}$, and the vertical variation in the tide averaged longitudinal density gradient, $\frac{dp}{dx}$, as follows:

$$\frac{dp}{dx} = -g \frac{dn}{dx} + g \frac{dp}{z} \frac{dz}{dx}$$

where $\rho_s$ is the density of surface water (Kg/m$^3$), and $g$ is the acceleration of gravity (9.81 m/s$^2$).

The strength of the gravitational circulation varies directly with the magnitude of the product of the depth and the longitudinal density gradient. It is reduced by vertical mixing, which is usually heavily damped in stratified flows, and by energy dissipation at the bed, which is increased by the occurrence of high tidal velocities in the lower layers. The presence of a longitudinal density gradient within an estuary causes the mean tide levels to rise in a landward direction. The net landward pressure gradient and the net landward residual flow disappear at a 'null point' in the estuary where the two terms on the right hand side of equation (1) cancel each other out. The pattern of the gravitational circulation will vary according to the degree of stratification, but it is not dependent on the existence of vertical density stratification. Many deep estuaries with weak or negligible vertical stratification have strong gravitational circulations. The longitudinal density gradients tend to distort the shape of the velocity profile on the flood and ebb phases of the tide and thereby induce a net landward longitudinal amovement of water in the bed layers seaward of the flow of water in the surface layers of the estuary giving rise to a two-layer circulation.

Mersey Estuary, U.K.

The vertical distribution of the tide-averaged residual velocities in the deep part of the Mersey Estuary, shown in Fig. 1, is typical of many deep partially-stratified estuaries. The landward velocities are almost uniform over the depth of the lower layer but the seaward velocities in the upper layer increase linearly towards the surface. The level at which the residual currents reverse direction varies with the position in the estuary. If the tidal range is significant compared to the mean depth, there may be a three layer structure with a small net landward movement of water in the layers above mean tide level.