Salinity Stratification and Vertical Shear Transport in an Estuary

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ABSTRACT

The intratidal behaviour of the vertical shear dispersion transport for salt over three cross-sections in the upper reaches of the Tamar Estuary is presented for spring and neap tides. A variable, $\psi$, is defined which is proportional to the vertical shear salt flux at each instant and is equal to the negative salt flux due to vertical shear divided by the tidally-averaged longitudinal salinity gradient. The tidal average of $\psi$ can be compared with dispersion coefficients deduced from tidally-averaged or long-term data from other estuaries. Temporal variability in $\psi$ is discussed in terms of the root-mean-square deviations (about the depth-mean values) of the vertical profiles of salinity and longitudinal current over each tidal cycle. During spring tides $\psi$ maximizes on the ebb within 3 h of high water and, depending on the section, this maximum lies in the range of 100-310 m$^2$/s (compared with 140-470 m$^2$/s at neap tides), with large values occurring for 2-3 h periods during the ebb. At the end of the ebb and during the flood $\psi$ is very small and can be negative. Similar behaviour is exhibited by $\psi$ during neap tides at the cross-section nearest the head. However, at the most seaward cross-section the velocity shear, stratification and $\psi$ maximize at low water rather than the early ebb. A one-dimensional model of the vertical current structure which uses prescribed salinity fields and which calculates $\psi$ is able to reproduce this behaviour. The model is also used to provide insight into the effects of stratification and its ebb-flood asymmetry on the intratidal and tidally-averaged (residual) currents.

I. Introduction

This paper has two objectives. First, to present data on the intratidal salt transport due to vertical shear dispersion in a partly mixed estuary and the associated vertical structure in salinity and longitudinal current throughout a tidal cycle. Second, to theoretically investigate the effect of stratification on the vertical distribution of longitudinal current and thereby explain the intratidal behaviour of the vertical current shear and shear dispersion of salt.

A knowledge of the various dispersion mechanisms for salt and other solutes is necessary for depth-averaged and cross-sectionally averaged water quality and salt budget modelling of estuaries (e.g. Lepage and Ingram, 1988; Fischer et al., 1979). The major unknown parameter in cross-sectionally averaged solute-budget models is the dispersion coefficient. Early measurements of salt transport indicated that transverse contributions to the shear dispersion (due to transverse shear in residual and oscillatory tidal currents and associated salinity variations) were small in a highly stratified estuary, whereas in partly mixed estuaries the transverse and vertical shear contributions were comparable (Dyer, 1974). However, according to Rattray and Dworski (1980) the role of vertical shear dispersion may have been underestimated in some of these studies.
In the upper and central reaches of the macrotidal, partly-mixed Tamar Estuary, Southwest England (Fig. 1) vertical shear dispersion dominates transverse shear dispersion and is an important component of the total salt transport (Uncles et al., 1985). Therefore, it is of fundamental and practical interest to investigate the intratidal variations in vertical shear dispersion transport and to relate these to properties of the tidal flow in order to isolate the mechanisms which lead to large dispersive fluxes. Tides in the Tamar are semidiurnal with mean neap and spring ranges of 2.2 and 4.7 m, respectively. Variations in total water depth within a tidal cycle are therefore considerable, and tidal averaging, while providing a useful summary of data, conceals much of the physics involved in the transport processes.

![Figure 1](image-url)

**FIGURE 1.** The Tamar Estuary, showing distances every 5 km along its axis and the locations of cross-sections 1-3 and synoptic, single-point anchor stations 1, 3, 4 and 5. Measurements were made on separate occasions over complete cross-sections at 1, 2, and 3. Measurements at single-point stations were made in the deep channel at different times to the cross-sectional surveys.

The experiments were of two types. In the first, measurements of salt fluxes over complete cross-sections were undertaken in the shallow upper and central reaches of the Tamar Estuary (less than 7 m depth at spring-tide, high water). These cross-sections are numbered 1, 2, 3 in Fig. 1. In the second, synoptic measurements of salt fluxes were made in the deep channel at single-point Stations 1, 3, 4, 5.