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Defining the distribution of transverse mixing coefficients across a rough laboratory flood plain

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ABSTRACT

Large horizontal eddies form due to the transverse exchange of longitudinal momentum between the main channel and the flood plain during floods, resulting in lateral variation of the transverse mixing coefficient. This variation on the flood plain and across the channel is established using the generalised change in moments method for concentrations from steady point sources in a laboratory overbank flow.

1. Introduction

Defining the lateral transport of pollutants between the main channel and floodplain during flood events is important for establishing affected areas downstream of pollution mobilised during storm events. These impacts in flood flows are frequently depth averaged and modelled in two dimensions, where the outcome will be influenced by the definition of the lateral variation of the transverse mixing coefficient. This cannot yet be forecast with certainty where there is interaction of main channel and floodplain flows. Examination of the concentration profiles of injected tracer allows empirical development of the understanding of mixing processes in this region. For steady flows where there are lateral variations in depth mean longitudinal velocity, depth and local transverse mixing coefficients, a generalised change of moment method (GCMM) can be adopted (Holley et al., 1972), which in the absence of any longitudinal change in cross-section, is given by

$$\frac{d}{dx}\left[\frac{\int_A^B huc(y-\bar{y})^2dy}{\int_A^B hucdy}\right] = -2\frac{\int_A^B hk_y\frac{\partial c}{\partial y}(y-\bar{y})dy}{\int_A^B hucdy} \quad \text{or} \quad \frac{d\sigma^2}{dx} = 2f(x)$$

where x and y are the longitudinal and transverse directions respectively, $\bar{y}$ = the centroid of the distribution of mass flux, h = depth, u = depth mean longitudinal velocity, c = tracer concentration, k_y = local transverse mixing coefficient. A and B are the limits of integration, such as the channel width. The left hand side of the equation is the longitudinal rate of change of the mass flux variance whilst the right considers the influence of any assumed lateral variation of the local transverse mixing coefficient, all other variables being experimentally determined. The equation is solved by integrating over the longitudinal distance, where the variation of k_y is optimised so $d\sigma^2/d(-F(x)) = 2$. Where du/dy is zero, the that the local transverse mixing coefficient is constant, as in an infinitely wide channel, and can be calculated using the ordinary change in moment method ($k_y = 0.5ud\sigma^2/dx$)

2. Methodology

A uniform flow of 10.8 l/s in a 20 m long and 1.218 m wide symmetrical compound channel at a bed slope S_0 of 0.00123 gave main channel and flood plain depths of 0.0812 m and 0.0158 mm respectively (Fig. 1). The main channel bed was glass reinforced plastic with smooth side walls of varnished high density foam set at 45°. The 0.446m wide flood plain surface was varnished aggregate; the mean surface roughness = 3.29 mm at an average floodplain height of 65.4 mm. Two dimensional LDA mounted beneath the channel measured instantaneous longitudinal and transverse velocities. Velocities were averaged over the depth and curve fitted.

Rhodamine WT tracer was fed from a constant head reservoir to the floodplain at 0.446m from the channel centreline, where dU/dy is zero. Downstream tracer concentrations were measured via a horizontal array of five sampling tubes 5mm below the water surface on the floodplain to Series 10 Turner Designs fluorometers. The logging duration at each point was 3 mins. Concentrations were plotted in real time to ensure five to ten background data points beyond each plume tail to allow the rate of increase in background concentration to be established, and hence removed from measured concentrations.

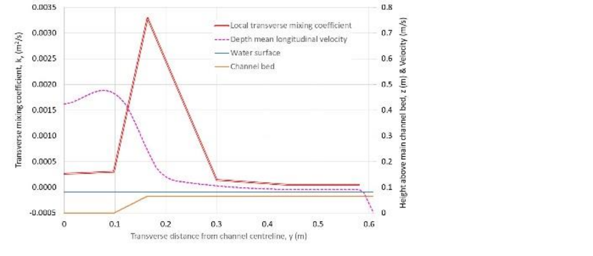

Figure 1 Variation of channel shape, depth, velocity and local transverse mixing coefficient

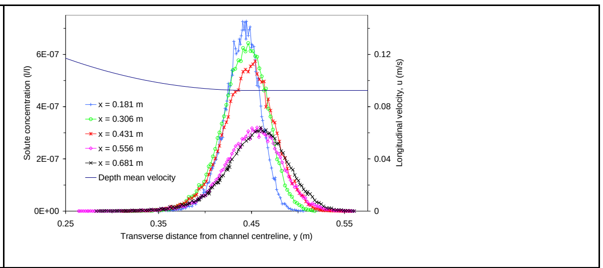

Figure 2 Flood plain solute concentrations from continuous injection at x = 0m, y = 0.446m & z = 65.4 mm

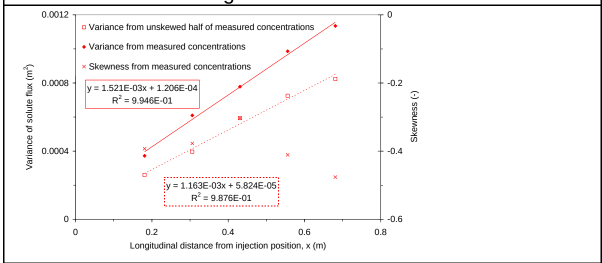

Figure 3 Variances of floodplain solute mass flux

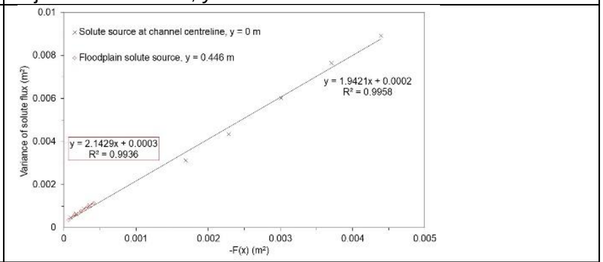

Figure 4 Solution of generalised method of moments for floodplain and main channel tracer sources

3. Results

The long tail and skew of each distribution (Figs. 2 & 3) indicate higher local transverse mixing towards the towards the main channel. Where dU/dy is zero, k_y is 5.37x10^{-5} m^2/s, found by mirroring the right hand half of each concentration distribution (Fig. 1). Normalising k_y by dividing by the depth and shear velocity (= $ghS_0^{0.5}$) gives 0.25 and is within the bounds described by Rutherford (1994). The assumed variation of k_y with y may mimic the lateral variation of eddy diffusivity, Reynolds stress in the x-y plane, du/dy or any other desired function, provided equation 1 is satisfied. As the lateral variation of ky will be unique to particular channel properties and discharge, then this must be independent of the tracer injection position. In spreadsheet calculations, the distribution of ky shown (Fig. 3) was adjusted until equation 1 was satisfied for concentrations from both floodplain and channel centreline sources (Fig. 4). The gradient is not 2 in both cases, thus some small improvement to the shape of k_y is required.

Conclusions

Application of the GCMM to transverse mixing experiments allows the variation of k_y with y to be empirically determined. Use of more than one source location assists in moving towards a unique solution.

References

Holley et al., 1972

Rutherford, 1994