

Dear Prof. H.H.G. Savenije,

Thank you very much for your valuable comments. This discussion is very important and effective.

Specific comments

If we look at your Figure 2 in the reply, you define the exchange flux F as Q_1 . I, however, define the exchange flux as Q_2 . If we consider $x=0$ at the mouth with the x -axis pointing upstream, then in your definition $F = R$ for large values of x , while in my case $F=0$ for large values of x . Clearly my definition is better, since upstream from the salt intrusion, the exchange flux=0. The point is, that the exchange flux accounts for the dispersive transport and not for the advective transport. Near the mouth $Q_1 \approx Q_2$, but further upstream as R becomes larger, they become very different.

Answer:

Equation (4a) is reasonable as it has derived from salt balance. But it does not satisfy the mass balance that argued in our previous reply. In this study, the flushing rate (F) is defined as the rate at which the freshwater is exchanged with the sea (Officer and Kester, 1991 and Dyer, 1997) and satisfies the mass balance, seems more appropriate.

$$FS_0 = FS_1 + RS_0$$

$$F = F \frac{S_1}{S_0} + R$$

where S_0 is the salinity of the oceanward boundary and S_1 is the segment average salinity. When S_1 is equal to 0, the first term of rhs (FS_1/S_0) will be zero upstream from the salt intrusion. As a result F is equal to R where river discharge is transported by gravity and thus F is conserved by R .

The transport of salt downstream by the river discharge is balanced by the sum of the advective transport ($T_A = B \int_0^D usdz$) and a diffusive term ($T_D = -AK \frac{\partial s}{\partial x}$) given by Bowden and Gilligan (1971,

Characteristic features of estuarine circulation as represented in the Mersey estuary, Limnology and Oceanography, 16,490-502)

$$T_R = T_A + T_D$$

In flushing rate theory, F represents the combined effects of the diffusive tidal exchanges and the advective gravitational circulation exchanges, $F = F_{int} + G_c$.

Near the mouth where $S_1 = S_0$ this leads to $f \approx 0$ and $F \approx R/f$. Upstream, where S_1 approaches 0 this leads to $f \approx 1$ and $F \approx R/2$. In this way, indeed, the exchange flow always increases with discharge, as you indicated should be the case, and Figure 1 shows always increasing lines. But I am not sure if this is the right approach.

Answer:

The flushing rate was calculated using the equation $F = \frac{R}{f}(1 - f/2)$, as shown in Fig.1. It shows the same dynamics for the river discharge of $50 \text{ m}^3 \text{ s}^{-1}$ what is presented in our manuscript published in HESSD for high river discharges (it has also corrected for river discharge of $50 \text{ m}^3 \text{ s}^{-1}$ as per valuable comments of Referee#1 for final version). The advective and diffusive term can be quantified from this equation. But F is $\approx R/2$ upstream from salt intrusion. How the mass is conserved here as $F \approx R/2$? It is not clear.

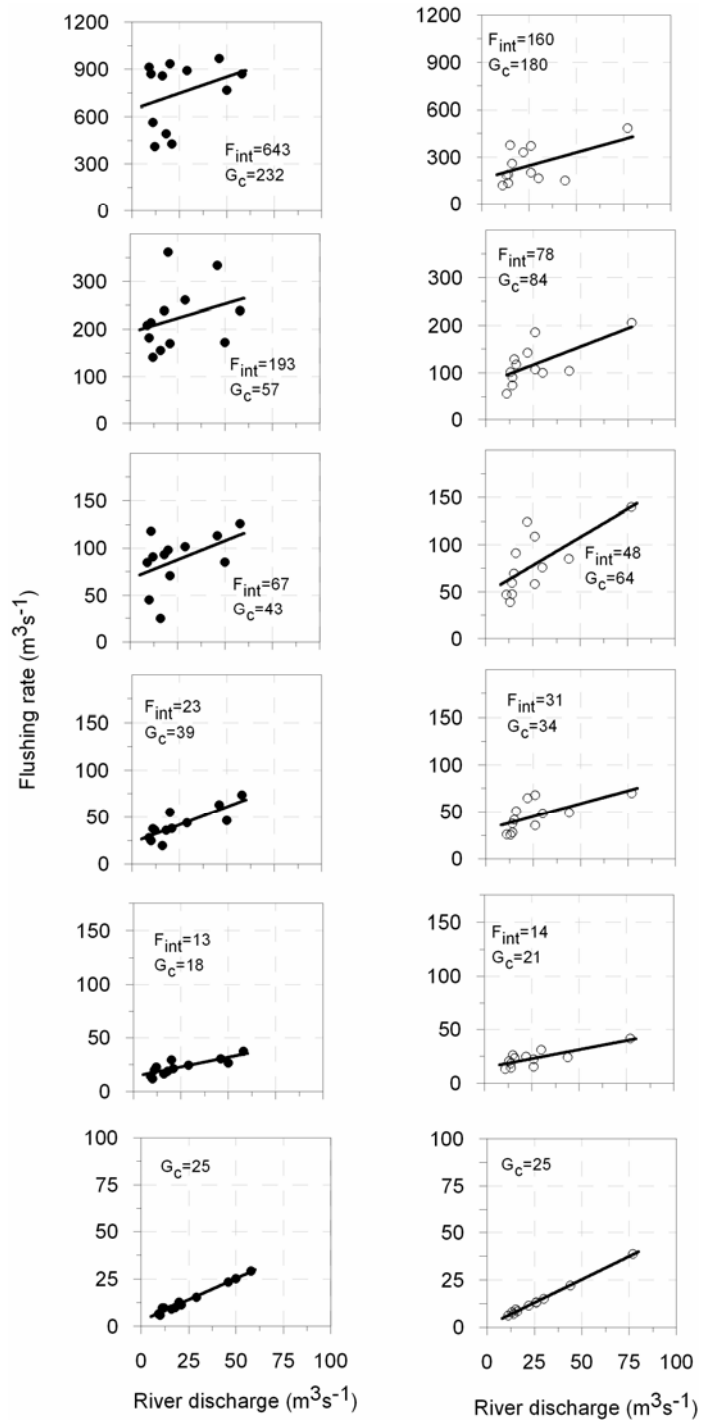


Fig. 1 Flushing rate calculated using $F = \frac{R}{f}(1 - f/2)$ versus river discharge. G_c is calculated for the river discharge of $50 \text{ m}^3 \text{ s}^{-1}$.

I think one has to separate the advection and the exchange (the dispersion). The exchange is responsible for the dispersion. v is the proportion of tidal mixing to total mixing, or of tidal exchange to total exchange. But this exchange flow should not include R . Hence, I think my equation (4a), based in Q_2 is correct and not Dyer's equation. Your Figure 1 shows that upstream the exchange flux becomes zero at high discharge. This is because the fresh water entirely fills the tidal prism and Q_2 is zero. This is what happens in reality as well when there is no tidal slack anymore and the flow becomes uni-directional. Or in other words there is no flood flow anymore, only a fluctuating ebb flow. According to me, Dyer's method to calculate works near the mouth, but I have not yet worked out how it works further upstream. Maybe you can think about that.

Answer:

v is the ratio of diffusive tidal exchange (F_{int}) to the total exchange ($F = F_{int} + G_c$) given by Officer and Kester (1991) and Dyer (1997).

Estuarine parameter v reads

$$v = \frac{T_D}{T_A + T_D} \quad (\text{Bowden and Gilligan, 1971})$$

$$v = \frac{F_{int}}{G_c + F_{int}} \quad (\text{Officer and Kester, 1991; Dyer, 1997})$$

Bowden and Gilligan (1971) calculated estuarine parameter v from observed data (Table 5) and compared with the Hansen-Ratray diagram (1965,1966). The agreement was fairly consistent where the highest value is near the mouth and lowest one upstream. In our calculation, v represents the same dynamics. As F_{int} was near to zero upstream end during both spring (2.83) and neap (0.82) and these values were not mentioned on Fig. 8 (HESSD), the referee may therefore be confused. Equation 4a is appropriate but it is not clear how to quantify the advective and diffusive exchange from the flushing rate of Eq. 4a upstream in turns to calculate v and to describe the dynamics.

By the way, I would like to know how you calculate the points in Figure 1. Is this by using eq.(4) or (4a) on observed values of f and R ?

Answer:

Flushing rate plotted in Figure 1(AC C307, in reply of Referee#1) was calculated using Eq. 4a based on observed values of f and R . It was mentioned in Figure caption and text in that previous reply also.