Dear Anonymous Referee#2,

We are very much grateful to you for valuable and fruitful comments to improve our manuscript (hess-2010-39). The responses to each comment (blue font) are given with black font in the following.

Specific comments:

1. The first problem is related to the applicability of the flushing rate theory. According to this approach the system is assumed to be at steady state and perfectly mixed. These two hypothesis should be carefully checked here (for both the whole estuary and the selected small segments) because their violation could affect the validity of the conclusions. This is for instance one of the immediate explanation for the large range of variability of the flushing-rate observed in some plots of figures 7 and 8. The results presented in figure 2 demonstrate such a variability. In section 4.1 it is said that "the difference between two subsequent high tides was approximately 3 psu due to **variation in the tidal amplitude**". One the one hand, this demonstrates that the system is far from steady state. On the other hand, I doubt that the variation of the tidal amplitude is the explanation for this variability; the tidal amplitude varies only slowly in 12 hours.

The flushing rate theory was developed assuming full mixing condition and steady state. However, the Sumjin River Estuary shows relatively strong vertical stratification, particularly in response to gravitational circulation during neap tides and high flow. The Sumjin River estuary was treated as a single layer with multiple segments to calculate flushing rate for both spring and neap tides in the earlier version of our manuscript. In the final revised paper as well here, single layer with multiple segmentations are used for spring tide due to well mixed condition with weak vertical salinity gradients. On the other hand, flushing rate equation is modified for two layer circulation with multiple segments during neap tide. For two-layer circulation Knudsen hydrographical theorem (Knudsen,1900, Ein Hydrographische Lehrsatz. Annal. Hydrog. Marinen Meteorol., 28, 316-320) is followed to calculate flushing rate.

A steady balance in which volume is conserved has volume fluxes

$Q_1 = Q_2 + R = F$

If salt flux through the mouth is dominated by the exchange flux, then the net salt balance is

$Q_1 S_s = Q_2 S_b$

where S_b is the bottom salinity and S_s the surface salinity.

$$Q_2 = \frac{RS_s}{S_b - S_s}$$

A flow of oceanic water (Q_2) enters the bottom layer; flows upward into the surface layer and out again from surface layer to the ocean with river discharge (Fig. 1). Flushing rate then reads the following:

$$F = \frac{RS_s}{S_b - S_s} + R$$

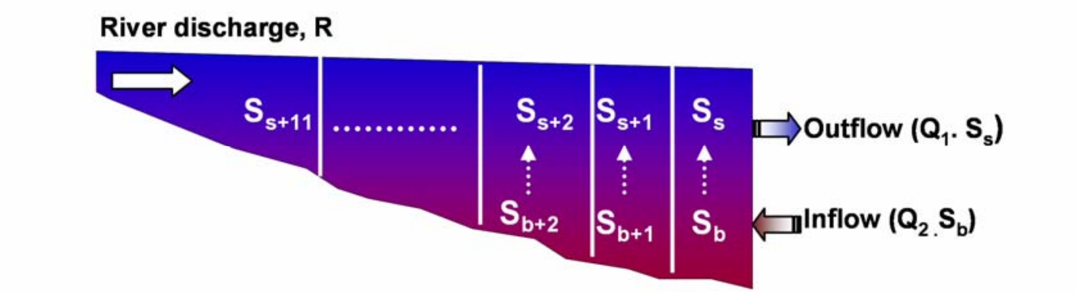

Fig. 1. Schematic diagram illustrating the calculation of flushing rate from water and salt budgets for stratified conditions during neap tide in the Sumjin River Estuary

As the SRE is stratified during neap tide, the upper stratified layer salinity were averaged to obtain $S_{s.}$ The bottom boundary layer was well mixed, as a result the maximum depth salinity is considered as S_b upto 18 km. Landward of 18 km depth average salinity is used to calculate flushing rate considering the system as one layer due to the absent of two layer circulation..

If we look at the vertically averaged salinity of the Sumjin River estuary during spring and neap tide, the horizontal gradient of salinity was above 5 psu for each segment of 4 km long (Fig. 2). As the average salinity of each segment (4 km long) was used to calculate flushing rate published in HESSD, it showed broad scattering in SEG1, SEG2 and SEG3 in Fig. 8. The flushing rate presented in Fig. 7 in HESSD was the total sum of each segment's flushing rate for the entire estuary. As a result, it also showed the broad scattering. To reduce this broad scattering, we took the advantage of horizontal resolution and resultant the number of segments has been increased from 6 to 12 with 2 km in length for each segment. It will be described in section three elaborately. The high water height differences between two subsequent high tides were 0.71m in 2005 and 0.67 m in 2006. Therefore, we assume that the difference in salinity (approximately 3 psu) between two subsequent high tides was due to the variation in the tidal amplitude. To evaluate some errors caused by assuming steady state, hydrodynamic model, which include all forcings (tide, river discharge, wind and heatflux) and consider temporal evolution of salinity, will be applied in the next study.

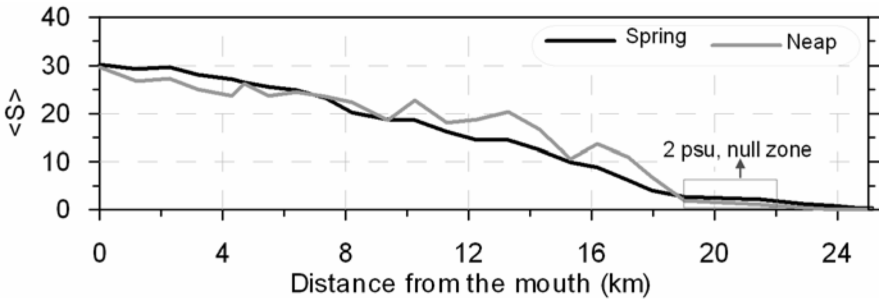

Fig. 2 Spatial variation in the vertically average salinity during spring and neap tides along the Sumjin River Estuary. Each contour is the average of twelve samples obtained from August 2004 to April 2007.

2. The second issue that needs some clarification is the kind of simplified circulation model that is implied by the use of the flushing rate. For years, many authors have been using the very same term "flushing rate" with many different physical meaning. For this reason, it would be useful to explain the physical interpretation that must be given to the "flushing rate" here. Is it related to some rate of advective exchange between the different estuarine segments, to the flow rates between the segments? Does it include mixing? A kind of schematic model of the exchange within the estuary with quantification provided by the flushing rate theory would clarify this issue.

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).

$$F = \frac{RS_0}{S_0 - S_1}$$

where S_0 is the salinity of the oceanward boundary and S_1 is the segment average salinity. The flushing rate F represents the combined effects of the diffusive tidal exchanges and the advective gravitational circulation exchanges

$F = F_{int} + G_c$

In this study, the diffusive tidal exchange (F_{int}) and gravitational circulation exchange flux (G_c) were quantified for each segment using consistent set of observation data. Some extents of advective exchange between the different segments were not considered in this calculation. The following schematic diagram (Fig. 3) illustrates the calculation of flushing rate for well and partially mixed condition during spring tide (upper) and for stratified condition during neap tide (lower) with low and high river discharge (R) conditions. At low river discharge condition during spring tide (neap tide), the flushing rate increased by a factor of 97 (23) from upstream end to the mouth of the SRE, and by a factor of 3 (3) between SEG1 and SEG2 near the mouth. Upstream end the flushing rate was not equal to the rate of river discharge due to the salt content at low river discharge. At high river discharge during spring tide (neap), the flushing rate increased by a factor of 23 (9) from upstream end to the mouth of the SRE, and by a factor of 2.5 (2) between SEG1 and SEG2 near the mouth. The flushing rate was equal to the rate of river discharge upstream end at high river discharge rate due to the flushing of salt content.

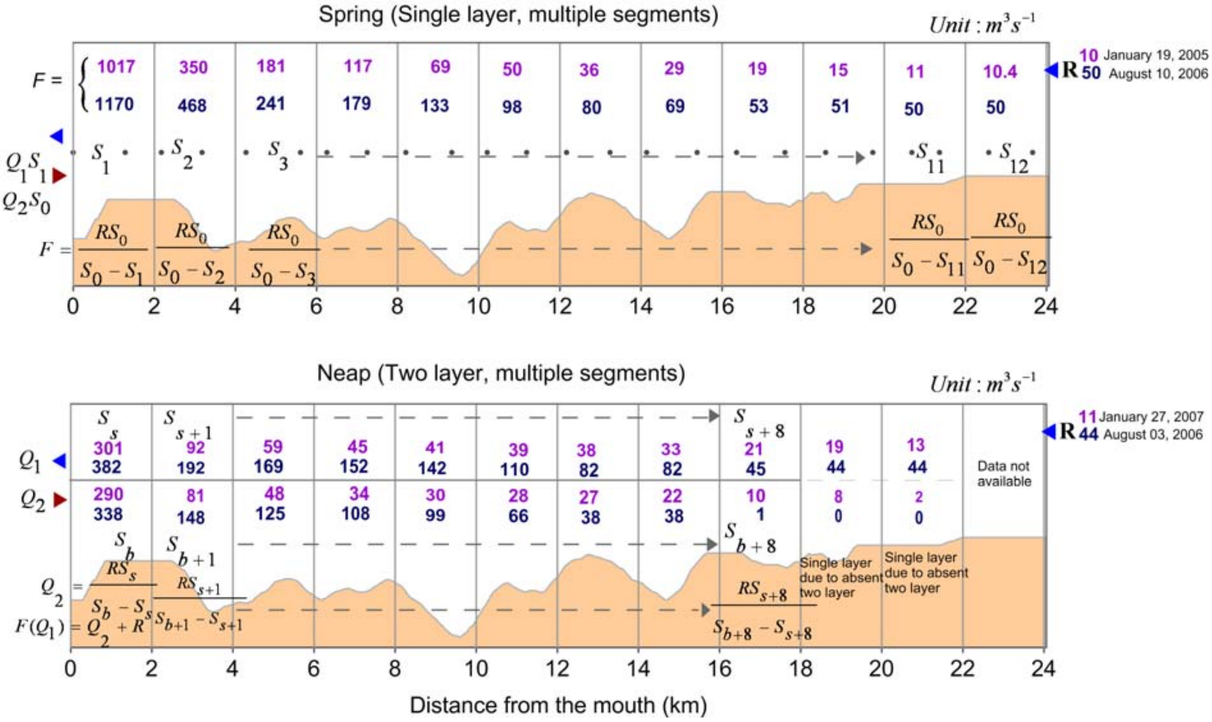

Fig.3. Schematic diagram illustrating the calculation of flushing rate for well and partially mixed condition during spring tide (upper) and for stratified condition during neap tide (lower) with low (10 and 11 m^3s^{-1}) and high (44 and 50 m^3s^{-1}) river discharge (R). Each segment is about 2 km in length with two CTD stations (marked with solid gray circle). In two layer system during neap tide, the outflow (Q_1) from the surface layer to the ocean is the sum of deep flow volume (Q_2) plus river discharge (R).

3. The third issue is related to the poor statistical treatment of the results in figures 7 and 8, which form the core of this manuscript. In most of this figures, the regression line has no statistical significance. The form of the relationship (i.e. linear vs exponential) does not matter. A quick look at the two panels of figure 7 reveals a very wide range of flusing rates for low discharge situations and these cannot be reconciled with any reasonable statistical model. In particular, the value of F_{int} cannot be defined by regression or only within a very broad confidence interval. One could even claim that the tidal exchange should be identified from the analysis of the results for very low discharge, i.e. disregarding

the flushing rate values computed for high discharge. The picture appears then even more confused and the correlation coefficient decreases drastically. As a result, the amounts in excess, indicating the gravitational circulation exchanges (G_c) cannot be defined either using these data sets. (By the way, the value of G_c varies with the discharge rate. So, what is the meaning of the single value printed in figure 7?)

To improve poor statistical treatment of the results in figures 7 and 8, attention was paid to the horizontal resolution. In this purpose, we took the advantage of horizontal resolution and resultant the number of segments has been increased from 6 to 12. The horizontal resolution of each segment is now 2 km whereas it was 4 km previously. Near the mouth, very small variation in salinity gradient provides large scale variation in flushing rate. As the freshwater fraction is very small near the mouth, its small variation cause large scale variation in flushing rate. As a result salinity gradient near the mouth is very sensitive and important to calculate flushing rate. Figure 2 clearly shows the horizontal variation in salinity gradient. Even, the vertical salinity profile published in HESSD shows large scale salinity gradient (29–33 psu) near the mouth which made broad scatter. Therefore, fine resolution segment has been used in our new calculation to resolve this broad scatter. The flushing rate presented in Fig. 7 (HESSD) was the total sum of each segment's flushing rate for the entire estuary. Volume average salinity (S) for the Sumjin River estuary, Ocean salinity (S_0), river discharges (R) for various periods along with calculated flushing rate (F) during spring and neap tides are given in Table 1.

Table 1. Volume average salinity (S) for the Sumjin River estuary, Ocean salinity (S_0), and river discharges (R) for various periods along with calculated flushing rate (F) during spring and neap tides

Spring				Neap			
R (m^3s^{-1})	S	S_0	F	R (m^3s^{-1})	S	S_0	F
46	15.42	31.46	90.20	26	17.75	32.07	58.22
29	16.92	31.16	63.48	22	18.42	31.02	54.14
10	20.27	32.43	26.67	16	20.10	32.82	41.26
18	21.17	33.57	48.75	26	12.36	32.36	42.07
58	14.59	30.46	111.32	77	9.29	30.61	110.57
16	16.27	31.59	32.98	13	19.44	31.58	33.81
20	20.92	32.55	56.00	14	19.20	32.73	33.88
11	24.45	33.51	40.69	30	16.22	33.16	58.72
50	12.45	30.00	85.47	44	12.80	29.24	78.25
9	22.20	31.83	29.75	15	19.75	31.08	41.15
12	25.88	32.94	56.03	11	19.97	32.71	28.23
21	18.87	32.95	49.14	14	17.88	32.83	30.74

The plot of the flushing rate (F) calculated for the average salinity of the Sumjin River Estuary against the river discharge (R) during spring and neap tides shows well fitting (Fig.4a-b). The intercept value, $F_{int,}$ denotes the tidal exchanges. The amounts in excess of F_{int} for the various river discharge indicate the gravitational circulation exchanges (G_c). Figure 4c-d is the sum of each segment flushing rate for the entire estuary which shows some scatter than in Fig.4a-b. Fig. 4a-b will be replaced with Fig. 7 published in HESSD in the final revised paper.

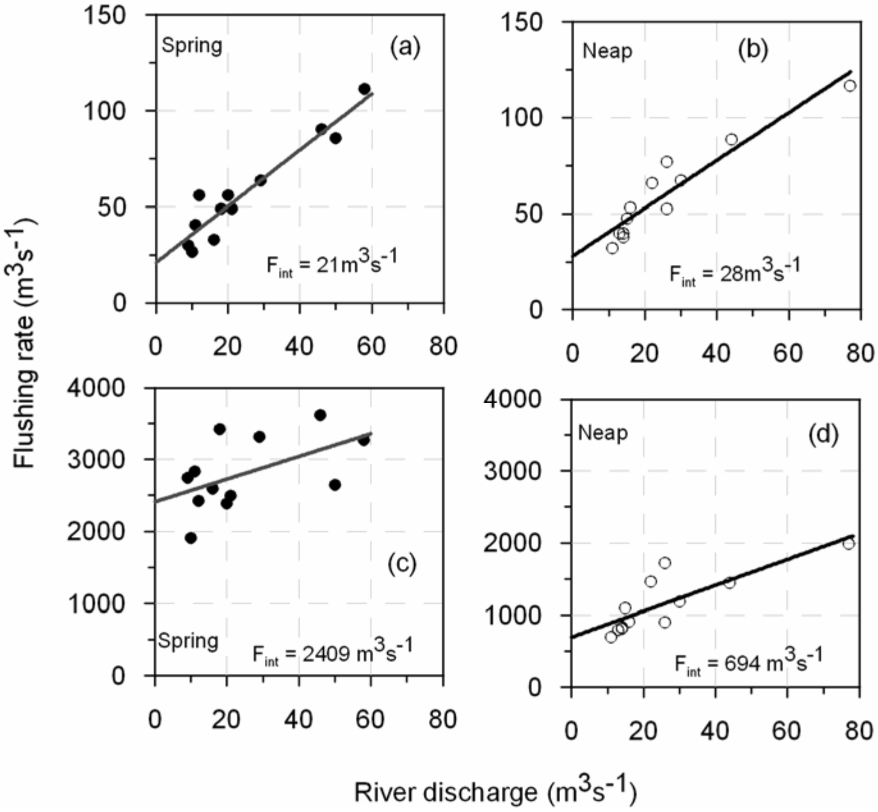

Fig. 4. Plot of the flushing rate (F) calculated for the average salinity of the Sumjin River Estuary against the river discharge (R) during spring and neap tides (4a-b). 4c-d are the sum of each segment flushing rate for the entire estuary The intercept value, $F_{int,}$ denotes the tidal exchanges. The amounts in excess of F_{int} for the various river discharge indicate the gravitational circulation exchanges (G_c).

You are right that tidal exchange should be identified from the analysis of the results for very low discharge. It has also been recognized that tidal (diffusive) exchange processes are dominant at low values of the freshwater input and diffusive flux exceeds advective flux (Pilson, 1985, available in hess-2010-39; Fram et al. 2006, Dispersive fluxes between the Coastal Ocean and a semienclosed estuarine Basin, Journal of physical Oceanography, DOI:10.1175/JPO3078.1). To estimate the tidal or diffusive exchange and the gravitational circulation exchange using the flushing rate (F) theory, the necessary quantities are the freshwater inputs to the estuary at various times of the year and the corresponding values of the salinity within the estuary (Officer and Kester, 1991; Dyer, 1997). Therefore, if the flushing rate is calculated for various river discharge (various times of the year), an intercept value at zero river discharge will show the diffusive flux and the amounts in excess of the intercept value for various river discharge conditions will represent the advective gravitational circulation exchange flux. If only low river discharges are used to calculate flushing rate, a better slope can not obtain to quantify above two fluxes that you also mention in your valuable comments. Therefore, it has suggested to use freshwater inputs to the estuary at various times of the year to apply flushing rate theory. Moreover, it is very difficult to distinguish the effects of tide on vertical salinity profile in short range of low discharge (in our published manuscript in HESSD, Fig. 3b-d; 4a-b, 4d, 4e-f, 4h) as the profiles were very similar, when river discharges were 26, 29, 22, 10, 16, 18, 26, 16 and 13 m^3s^{-1}. Therefore, year round (3 years) freshwater and salinity data were used in this calculation.

In our new calculation, fine horizontal resolution (increasing segment numbers by reducing length of segment from 4 km to 2 km) estimates flushing rate more accurately than with larger boxes for the longitudinal salinity gradients (Fig. 5 and 6). It improves statistical treatment many folds by reducing scatter than that published in HESSD. Figure 7 shows the spatial variation of flushing rate along the Sumjin River estuary during spring and neap tides. The flushing rate varies significantly landward of 10 km from the mouth of SRE. This length is consistent with the observed maximum tidal excursion length of 9.4 km (Shaha and Cho, 2009).

Figure 8 shows the effects of tidal exchanges (F_{int}) and gravitational circulation exchanges (G_c) on each estuarine segment of the Sumjin River Estuary during spring (upper) and neap (lower) tides in different freshwater input conditions. In our manuscript published in HESSD, G_c was calculated considering only high river discharge condition. Here G_c has calculated for both low (10 and 20 m^3s^{-1}) and high (50 m^3s^{-1}) river discharge condition that clearly illustrates the hydrodynamic processes along the Sumjin River Estuary. The advective and dispersive fluxes were differed with the salt content rate of exchange. At low river discharge conditions (10 and 20 m^3s^{-1}), tidal diffusive exchange was dominanted along the estuary during both spring and neap tide. This result is consistent with the calculation of Fram et al. (2006, Dispersive fluxes between the Coastal Ocean and a semienclosed estuarine Basin, Journal of physical Oceanography, DOI:10.1175/JPO3078.1). They found that dispersive flux exceeds advective flux during a period of decreasing freshwater flow into the bay. On the other hand, gravitational circulation exchange was dominated along the SRE during neap tide at river discharge of 50 m^3s^{-1}. However, tidal diffusive exchange was dominated landward of 9 km from the mouth of SRE at river discharge of 50 m^3s^{-1}during spring tide and thereafter gravitatianal circulation exchange exceeded tidal diffusive exchange upstream from 9 km.

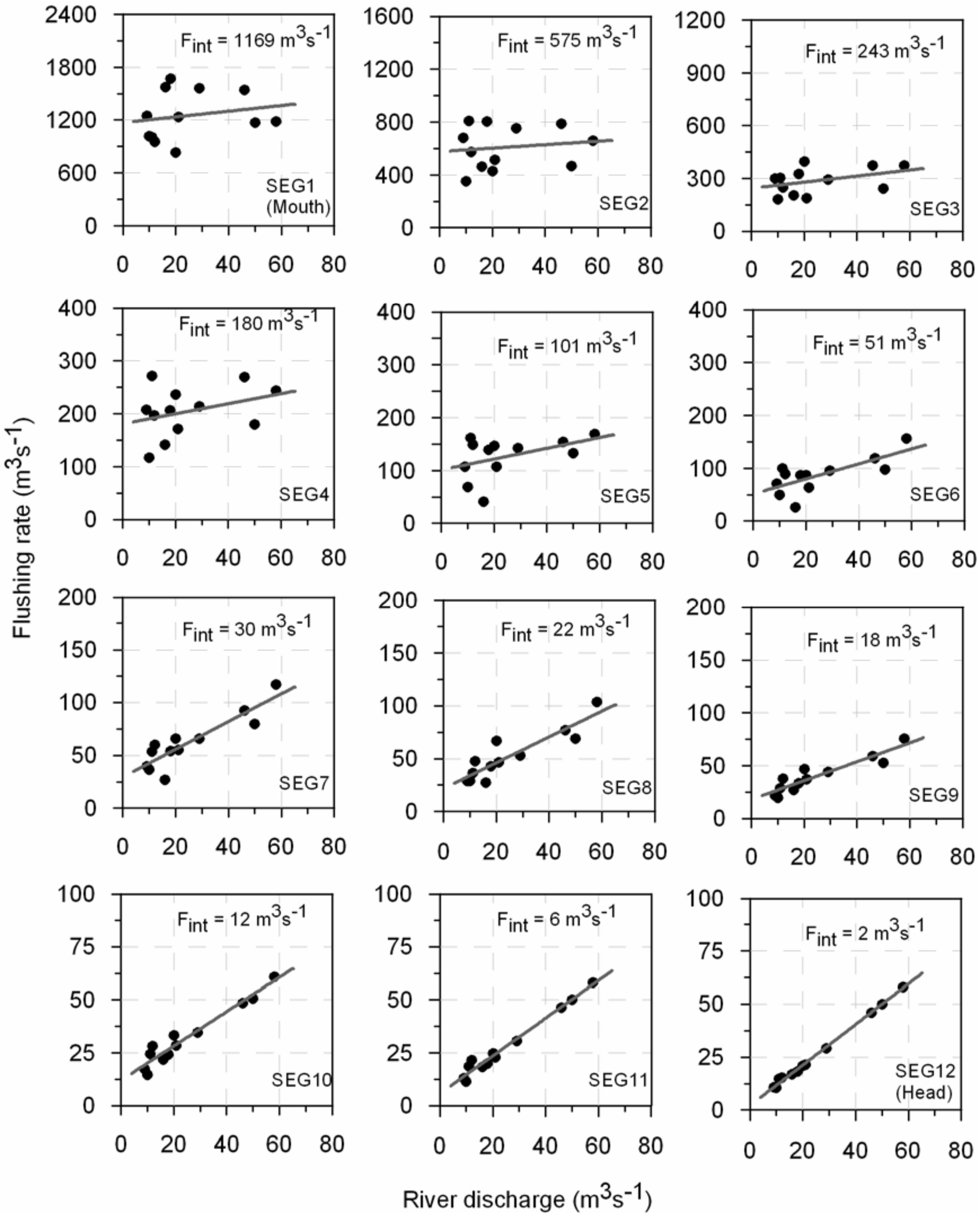

Fig. 5. Plot of the flushing rate (F) against river discharge (R) for various segments of the Sumjin River Estuary during spring tide. The intercept value, F_{int}, indicates the tidal exchanges. The amounts in excess of the F_{int} value for various river discharge indicate gravitational circulation exchanges (here expressed by G_c). Only the gravitational circulation exchanges dominated upstream end where the fitting line is linear with an intercept at zero and the F value increases with increasing R value.

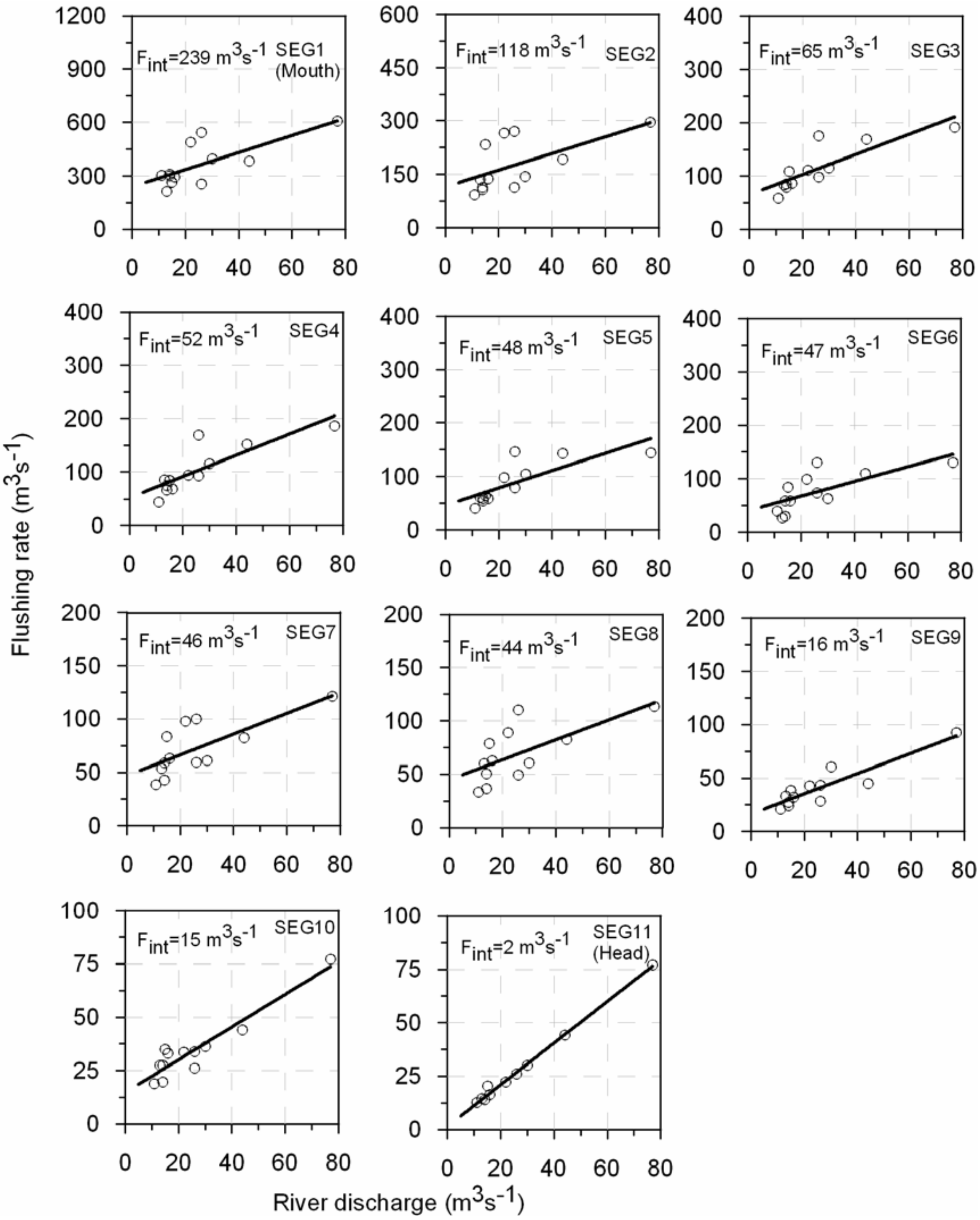

Fig. 6. Plot of the flushing rate (F) against river discharge (R) for various segments of the Sumjin River Estuary during neap tide. The intercept value, F_{int}, indicates the tidal exchanges. The amounts in excess of the F_{int} value for various river discharge indicate gravitational circulation exchanges (here expressed by G_c). Only the gravitational circulation exchanges dominated upstream end where the fitting line is linear with an intercept at zero and the F value increases with increasing R value.

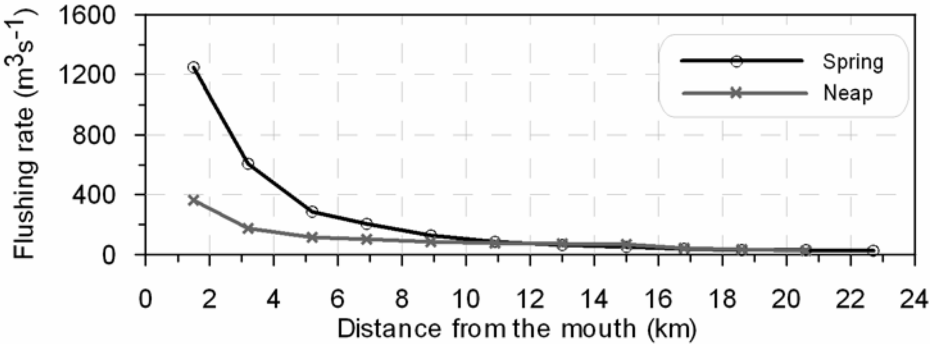

Fig. 7. Spatial variation of the mean flushing rate (m^3s^{-1}) during spring and neap tides.

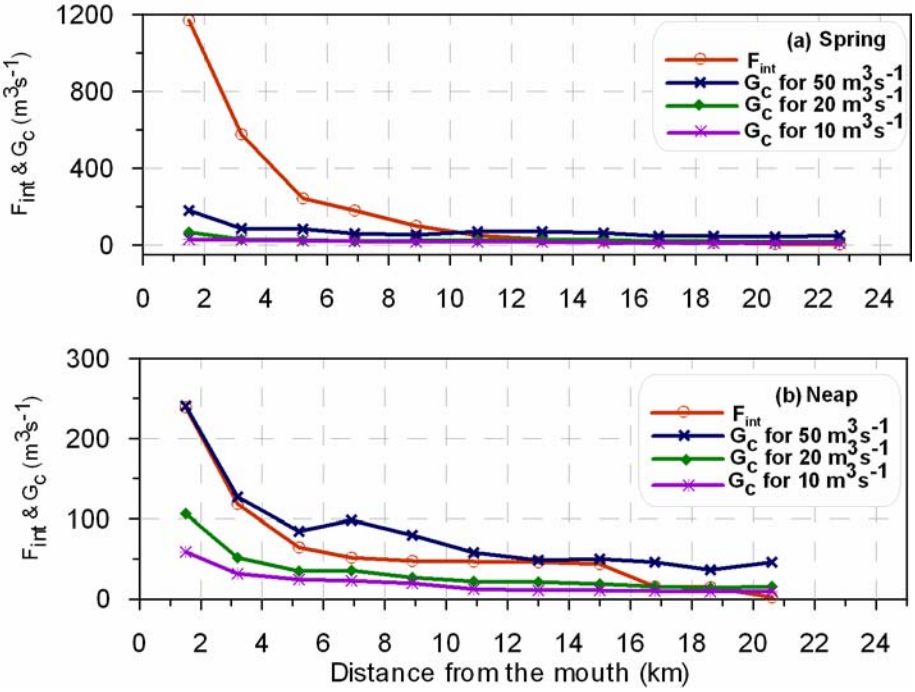

Fig. 8. Effects of tidal exchanges (F_{int}) and gravitational circulation exchanges (G_c) on each estuarine segment of the Sumjin River Estuary during spring (upper) and neap (lower) tides in different freshwater input conditions.

At line 2, page 1629, it is said that the flood phase last for more than 5 hours while the ebb phase takes about 2.5 hours. Such a dissymmetry is not apparent in figure 2.

- Line 10, page 1629 : "The difference in the vertical salinity at high water during neap tide was smaller **due to** an 85% lower river discharge. . . " There is no argument to support this claim/conclusion.
- Line 25, page 23 : "The flushing rate increased in the central and inner regimes during neap tide relative to spring tide **due to** enhancing the gravitational circulation".

Idem

The minor corrections will be fixed in the final revised paper.