Short-term relatively deep sedimentation on the Ebro delta coast. Opening the closure depth

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Abstract

Morphological changes at the shoreface of the Ebro delta have been analysed with emphasis on the Trabucador barrier, using two types of approximations: (i) an aggregated-scale approach, i.e. by evaluating the depth of closure from comparison of beach profiles from a data set of 4 years and, (ii) a process-oriented one, where changes are analysed in terms of driving factors and resulting sediment transport from a small scale experiment. Results from the depth of closure analysis show that acting processes are restricted down to an average depth of 6.5 m, with an important spatial variability. A year with high energy contents gives same results than using the whole data set. A sedimentation of about 7 cm was detected during the small scale experiment at 8.5 m and 12.5 m depth under the passage of several storms. The analysed velocity field and sediment flux showed that onshore transport close to the bottom and offshore transport in the upper part prevailed under storms. These forcing conditions were similar to the registered in previous analysis although no morphological changes were previously detected. Results show that the depth of closure analysis is a good starter point to define morphological activity in the nearshore profile, but it has to be complemented with other type of approaches such us the process-oriented one to accurately define the limits for morphological activity.

Introduction

The *closure depth* is a common concept, which is usually applied in coastal morphology studies. Basically it consists in the determination of a depth beyond that no significant changes can be detected in the bathymetry. Recently, some authors have introduced the effect of the temporal scale to permit its variation as the time scale increases and, as a consequence, the probability of occurrence of more energetic wave states (Nicholls *et al.* 1996).

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One of the intrinsic problems is that profiles used to estimate closure depth usually do not have a good temporal resolution or, its spatial coverage does not permit to measure the deepest part of the profile, which implies to make an initial assumption of negligible variation.

Recently, Gracia *et al.* (1998a) have estimated the averaged medium-term (at the scale of several years) closure depth along the Ebro delta coast to be about 7,5 -8 m. Their estimations were based in the analysis of beach profiles down to 15 m depth taken every 3-4 months during a period of 4 years. During that time span, several very energetic storms impacted the Ebro delta coast although no significant deep changes were observed in the surveyed profiles.

However, in a very recent experiment, in which two instrumented tripods were deployed on the Ebro delta shoreface at 8,5 m and 12 m depths (figure 1), an "unexpected" behaviour was observed (Jiménez *et al.* 1997a; Guillén *et al.* 1997), resulting in a sedimentation of about 7 cm at both places.

It is the aim of this paper to characterise the depth of closure at a medium term scale and to link it with the observed "deep" bottom changes. To do this, a process-oriented analysis of this sedimentation event is presented. The results are compared to estimates of the medium term depth of closure for the area.

Study Area

The Ebro delta is located on the Spanish Mediterranean coast, with a 50 km sandy shoreline with two spits at the north and southern part (see figure 1).

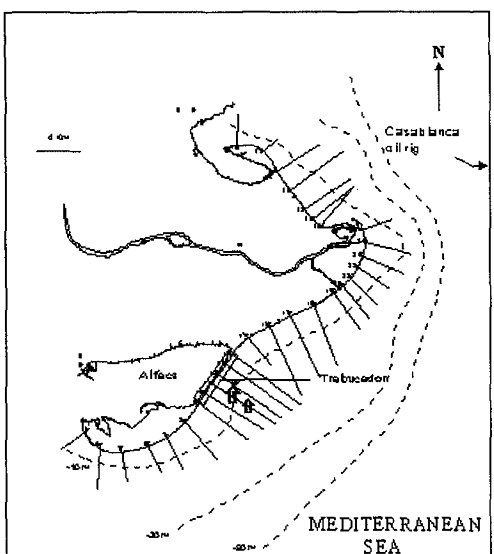

Figure 1. The Ebro delta. Arrows indicate Tripod deployment.

At present the delta is a micro-tidal wave dominated environment with an astronomical tidal range of about 0.25 m, being the average significant offshore wave height of about 0.7 m with an associated mean period of 4 s (Jiménez *et al.* 1997b).

Cross-shore distribution of sediment grain size (Guillén and Jiménez 1995) shows a finning trend offshore with medium sands (250 μm) at the shoreline to very fine sands (125 μm) at 12 m depth. At about 15 m depth there is a mud belt surrounding the delta and in consequence the system can be considered as close at the present evolutive state.

A typical cross-shore profile of the area shows up to 3 bar systems which have experienced in some sites an important longshore growth (Guillén and Palanques, 1993; Gracia et al. 1995).

The study is focussed in a barrier beach, the Trabucador bar, located at the southern part of the delta which has a length of about 5 km, a width between 150 m to 200 m and a height above the mean sea level of 1.5 m.

Medium term closure depth

The Medium term closure depth has been analysed by Gracia et al. (1998a) using a set of bathymetric profiles surveyed every 3 to 4 months from 1988 to 1992, which basically consists of 36 nearshore profiles spaced every 1-2 km reaching depths up to 15 m. Two techniques were used: a topographic survey for the inner part and a vessel with echo-sounder with a positioning system for the deeper one, giving a nominal accuracy of ± 5 cm, which defines a non significant change threshold value of 10 cm (the best case).

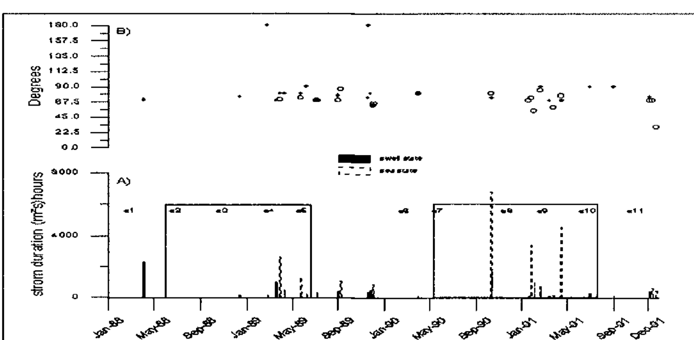

Figure 2. Wave energy events during the surveyed period and associated direction, from visual observations at Casablanca oil ridge.

The analysis has been done in three different time frames according to the wave energy conditions observed during the surveys (see figure 2). The first window corresponds to fair-weather year with a moderate wave energy content. The second is defined as a year of high energy conditions, with several eastern storms, where one of them impacted the coast producing the breach of the barrier (Sanchez-Arcilla and Jiménez, 1994). This high-energy event had a significant wave height of 4.5 m and peak period of 10 s, being the associated return period of 10 years. Finally, the depth of closure has been analysed using the overall data set, *i.e.* 4 years. Moreover within these 3 time frames the Hallermeier formula was also tested. The equation was fed with the corresponding local significant wave height propagated from offshore to 10 m depth for each profile, in order to have a more realistic charaeterisation (in terms of nearshore waves) and to account spatial variability in wave conditions due to changes in bathymetry.

Among the different methods analysed by the authors by comparing cross-shore profiles the standard deviation of bottom depths is presented here for the entirety coast (see figure 3). This technique is usually applied when a relative large number of campaigns are available, although they must be well distributed on time to avoid "false" values. Moreover, the standard deviation is the most proper technique to retain short-term changes, *i.e.*, the highest variability (Gracia *et al.*, 1998a).

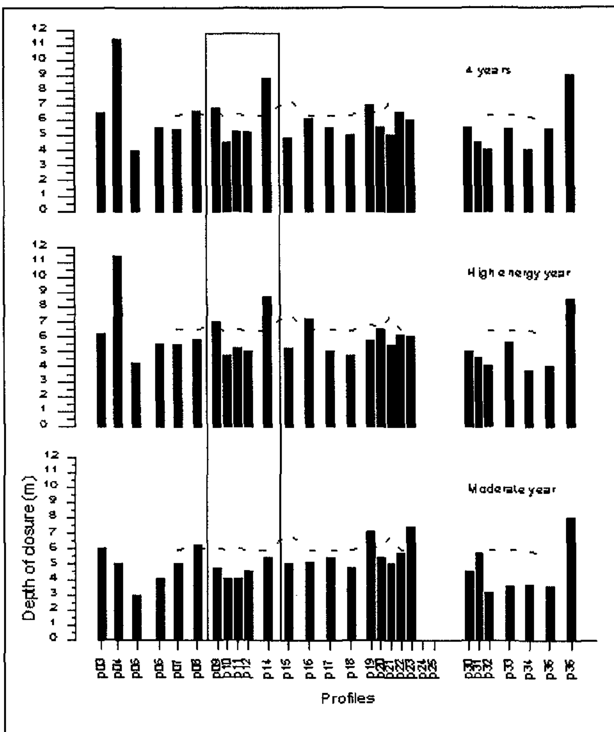

Figure 3. Depth of closure for the Ebro delta coast using the standard deviation method applied at tree different time frames (Trabucador bar indicated in a window).

As expected, the fair-weather year presents the lowest values being the average closure of about 4 m depth for the central part of the barrier with a maximum value of about 5.5 m. The resulting closure using the Hallermeier equation at this time windows was almost constant along all the barrier and about 6 m depth. For the stormy year an average depth of closure (d_c) of about 6 m was found whereas the predict d_c was about 6.5 m. Using the overall data set similar values of d_c were obtained. In any case, the Hallermeier equation over predicts the values obtained by comparing profiles, and these differences are greater in the Trabucador bar.

Another aspect that must be pointed out is the high spatial variability in the estimated d_c. This is, the spits, and, in the area of interest at the Trabucador bar, which maintains a more or less constant value in the central part while at the ends of the barrier there is an important increase, with independence of the time span analysed.

As a summary, looking at the aggregated scale, *i. e.* morphological changes, most of the acting processes in the area of study are important (in terms of the observed changes) down to 6.5 m depth (as an average value), *i.e.*, the estimated medium-term depth of closure. However, since this d_c has been obtained from a discrete set of data, this result can not be generalised without including some "confidence band", since changes between surveys are not recorded unless they are reflected in a longer time scale. Moreover, it has to be stressed that d_c does not represent a limit for sediment movement and, in this sense, it can not be used as an indicator of sediment mobility.

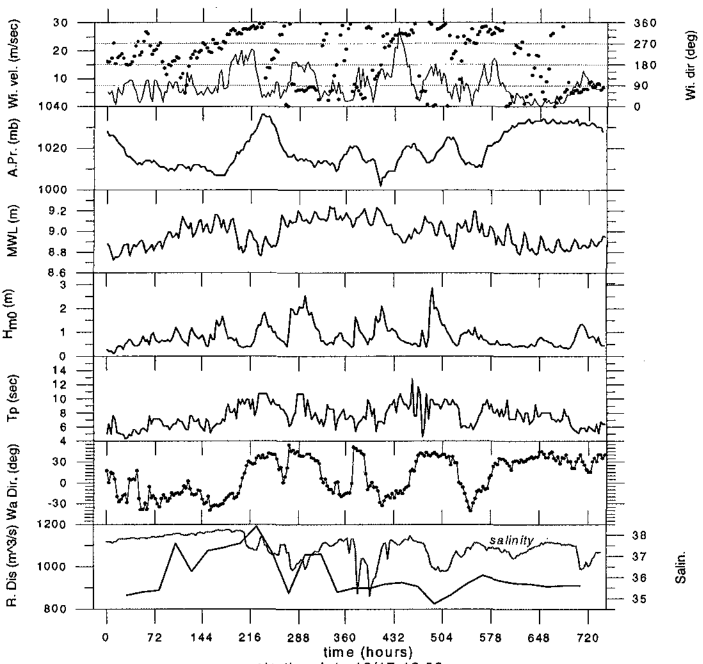

Figure 4. Forcing conditions during the inner shelf campaign at the shallowest position (8.5 m depth).

Inner shelf experiment

From December'96 till January'97 an inner shelf experiment was carried out in the surveyed area (Trabucador bar), which basically consisted in the deployment of two instrumented tripods at depths of 8.5 m and 12.5 m (see fig 1 for location). The basic configuration was, three bi-axial electromagnetic current meters (Delft

Hydraulics, 1993) and three optical backscatterance sensors (D & A Instruments, 1991), placed at 0.1 m, 0.5 m and 1 m above the bottom, an absolute pressure transducer (Druck PDCR-1830) and a compass (KV Industries C-100). The sampling interval selected during the experiment was 1 Hz obtaining data during 20 minutes every 3 hours (see Jiménez et al., 1998, for further details). Additionally, the outer tripod had a Doppler current meter with a nephelometer. Before deployment and after recovery, bottom surface sediment and core samples were taken.

The wave and atmospheric conditions are summarised in figure 4, up to six consecutive moderate storms can be identified with significant wave heights up to 3 m and associated peak periods from 4 s to 10 s. These storms mobilised large amounts of sediment, reaching near-bottom suspended sediment concentration up to 8 gr./l. The resulting morphological response was a sedimentation of about 7 cm at both locations.

The surface granulometric distribution obtained before and after deployment in the inner site shows a very small change in fine percentages of 1%, a slight increase in mean grain size (from 150 μm to 160 μm) and better classified sediments. On the other hand, in the deepest site (12 m depth) the fines percentage drastically increased (from 15% to 40%), the mean grain size decreased from 90 μm to 30 μm and the sediment was better sorted (decrease in deviation).

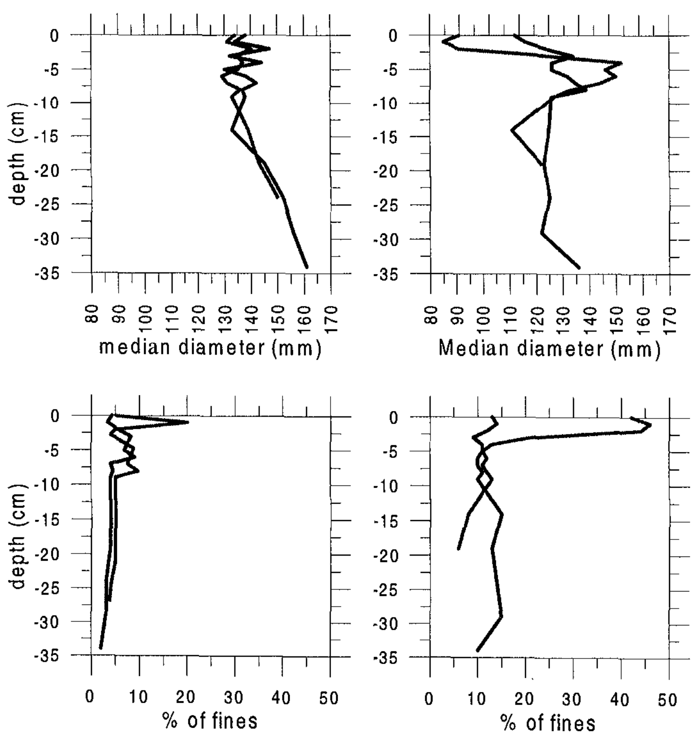

Figure 5. Vertical distribution of core samples before and after recovery. From left to right 8.5 m and 12.5 m depth deployment

Figure 5 shows the vertical distribution of fine percentages and median diameter at both locations before and after tripod recovery for the first 20 cm below the bottom. In the inner site, the median diameter is almost the same whereas the fine percentage increases in the upper part reflecting the changes observed in the surface samples. The highest variations are detected in the outer location, where, in the upper layer there is a significant decrease of the grain size diameter with an associated increment of fines of about the 40%.

Therefore, the resulting morphological response of the energetic conditions during the surveyed period was visible and, in principle, if it was "permanent" has to be detected in the previous analysis. However, wave conditions are not more energetic to those covered in the analysis of d_c for the stormy year.

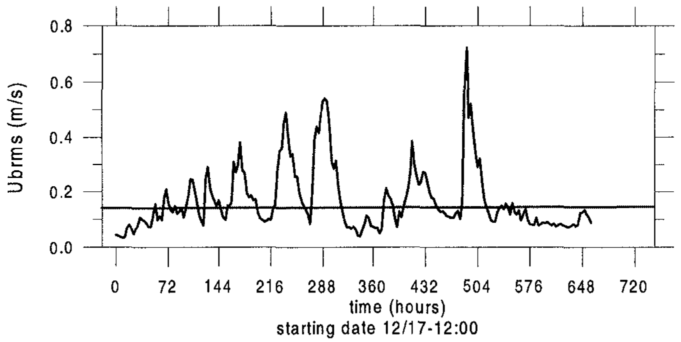

Figure 6. Near-bottom cross-shore velocity at 8.5 m depth and initiation of sediment movement according to Shields criteria.

To study the capacity of mobility of the monitored conditions, a detailed process-oriented analysis is done. The objective is to see if hydrodynamic conditions and resulting sediment transport were important enough to explain such sedimentation. Figure 6 shows the near bottom velocity (10 cm) at 8.5 m depth where the pass of the different storms are reflected. According to the sediment characteristics for the area it can bee seen that during most of the time the threshold value for initiation of movement (according to the Shields criteria) was exceeded in a significant manner, *i.e.* there was a high capacity of transport. Considering the third order velocity moment as an indicator of the transport capacity (figure 7) it can be seen that during the storms it was significantly different from zero and directed onshore (negative values in the figure).

Computing the mean and total cross-shore sediment flux directly from the measurements at 8.5 m depth (see figure 8), the impact of the different storms at all elevations can be identified, more evident at the lowest level. However a differential behaviour is detected in the water column: close to the bottom, most of the transport is directed onshore whereas in the upper part some reversals can be observed. These reversals were found to be related to the presence of seaward directed currents due to the presence of strong wind blowing offshore (Jiménez *et al.* 1998). Preliminary analysis of the vertical structure of the current showed that under certain conditions (just after storms), the mean current close to the bottom (0.1 m) was onshore whereas in the upper part of the water column was offshore (Gracia *et al.* 1998b).

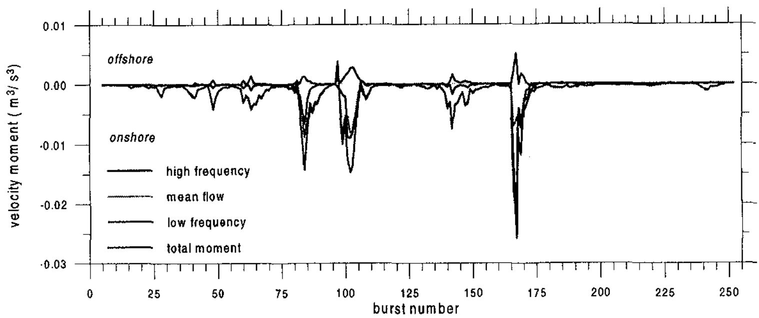

Figure 7. Third order velocity moment at 10 cm above the bottom for the 8.5 m depth deployment.

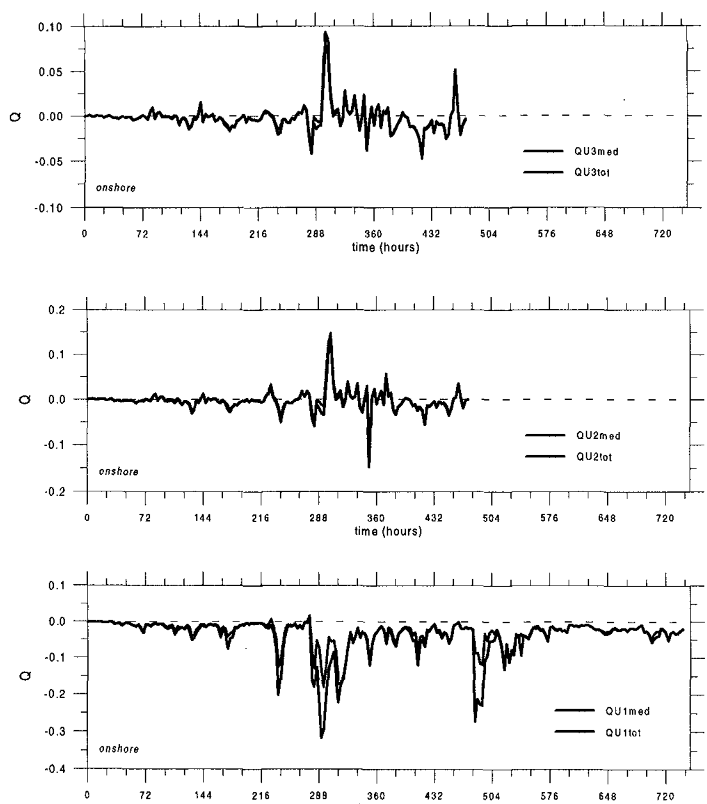

Figure 8. Cross-shore transport rates (gr./l·m/s) at 8.5 m depth. From top to bottom. 1 m, 0.5 m and 0.1 m above the bottom.

Mean current (assuming waves energetic enough to mobilise the sediment) mainly controls sediment flux but during storms the asymmetry of the wave-induced velocity field increases and largely contribute to it. This can be clearly seen in figure 8, where the contribution of the mean current to the total transport increases towards the surface due to an increase in current speed whereas oscillatory velocity is almost the same.

The longshore component (see figure 9) shows a more or less similar pattern. It is mainly directed towards the north changing the direction during the pass of storm events.

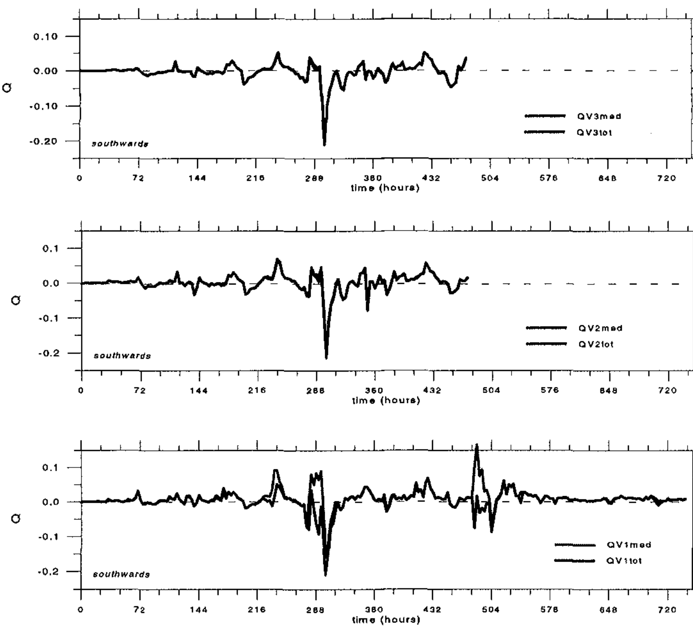

Figure 9. longshore transport rates (gr./l·m/s) at 8.5 m depth. From top to bottom. 1 m, 0.5 m and 0.1 m above the bottom.

Summary and discussion

Results of the depth of closure analysis show that at the aggregated-scale, morphological changes in the study area (Trabucador bar) are restricted down to an average depth of 6.5 m. However, in a yearly scale analysis, the deepest closure is obtained for high energetic periods, which fully control this depth when a longer time span is considered, i.e. the time window is not relevant per se but the energetic conditions during the considered time frame. Moreover, a high spatial variability in d_c was found, mainly at the spits and the area of interest (Trabucador Bar), the former presenting deepest values and the latter showing an important decrease. Thus, the Trabucador bar is usually overwashed during E storms (two to three times per year) which can "subtract" energy from the outer coast resulting in a decrease in the magnitude of the return flow in the upper shoreface. This could explain the shallower depth of closure values obtained in the central part of the barrier, in comparison with those observed at the barrier ends.

When a deterministic approach such as the Hallermeier's method is applied, an overprediction of the depth of closure is obtained. In this sense, it is a conservative choice for engineering purposes. However, it is not able to reproduce the actual spatial variability unless other factors such as the evolutive behaviour of each coastal stretch or alongshore variability in wave conditions are considered.

Thus, results following this approach seems to suggest that the maximum depth for morphological changes is restricted to 6.5 m. However, during an experiment at the inner shelf, a sedimentation event of about 7 cm was detected at 8.5 m and 12.5 m depth. This occurred under the action of several storms in one month, but the energetic content of the storms did not exceed the recorded in previous data (those included in the previous analysis). A detailed analysis of the velocity field and the sediment fluxes close to the bottom showed a strong sediment mobility, specially under the storms. In a general manner, onshore sediment transport close to the bottom and offshore transport in the upper part of the water column prevailed during storms. The high mobility as well as the magnitude of the sediment concentration measured during the experiment are able to explain the observed changes, including the variability of the sediment grain size distribution in the first cm of the bottom layer.

Since the forcing conditions during this small scale experiment are relatively frequent in the area (at least one per year), this type of "deep" changes should be relatively frequent, although they had not been detected at the aggregated scale analysis. The only way to do it, is by increasing the frequency of profile data acquisition (covering periods before and after storms) and reaching the deeper parts of the profile.

As a summary, although depth of closure is a good starter point to define morphological activity in a nearshore profile, the analysis has to complemented with other type of approaches, not only to define the limit of sediment transport (which in fact cannot be considered as included in the depth of closure analysis) but also to characterise the induced changes.

Acknowledgements

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