4.2. Scenario results

A complete spring tide cycle was run using the modified bathymetries. The cases with no waves and idealized wave events (see Table 3.1) were simulated to identify modifications of the underlying tidal dynamics and wave-driven processes.

As in section 3.2, simulation outputs were averaged over the incoming, outgoing and total periods of that one spring tide, using the water level at the mouth as reference. Here the focus is mainly on the incoming phase that causes the most sediment transport into the Harbour.

4.2.1. Effects on tidal dynamics

Snapshots of peak flood water levels and currents are shown in Figure 4.4 for the existing and modified configurations (no waves).The main effect of the emergent segments is to enclose the Shelly Beach cell. During incoming tides, this modifies significantly the water level distribution along the beach, as the strong alongshore gradient that is currently developing (Figure 4.4, top) is compensated by the water mass being blocked by the emergent structure at the eastern end of the beach (Figure 4.4, middle and bottom). The balancing of water level significantly reduces the longshore currents along the eastern half of the beach and the emergent segments prevent the flow acceleration that is presently predicted over the Long Mac. The longer emergent structure (i.e. central and north segments emerged) provides a more significant retention of the incoming water mass, and is clearly more efficient in reducing the longhsore flow and transport along the eastern beach and in the vicinity of the existing structure.

The water mass compartmented by the emergent structure will have to eventually flow back into the channel. The relatively higher water levels along the eastern beach allowed by the enclosing result in a new surface gradient developing in the structure vicinity in a north/south axis, which is seen to force a northwards flow component along the structure. These flows are however opposite to the ambient incoming flows and their intensities appear relatively limited. It is noted that emerged longitudinal structure segments without a junction to the eastern beach tip would compress and guide the existing easterly flow and transport southwards along the lower spit shores, with likely adverse impacts on its stability.

A more problematic area is near the seaward end of the emerged segments. More intense water level gradients force currents bending around the tip, and the process is further enhanced as the flow merge with strong incoming channel flows. It is noted that the presence of emergent segments also changes the position where the flows originating from and off Shelly Beach branch to the channel flow. Snapshots of the predicted total tidal sediment transport (Figure 4.5) clearly show the differences in position of the strongest sediment transport zones, over and north of the channel trough. This will have likely consequences with respect to the equilibrium channel morphology, which may include a relative deepening of the trough northern slopes with associated infilling of its deepest part.

Peak ebb flows are provided in Figure 4.6 for completeness. The emergent sections of the Long Mac tend to slightly focus the ebb jet in its near vicinity, but overall changes are very limited.

4.2.2. Effects on wave-driven circulation and sediment transport

The sediment transport fluxes averaged over the incoming tide are presented in Figures 4.7 to 4.10 for the idealized wave events listed in Table 3.1. The raising of the central or central and north segments to emergent levels consistently result in a reduction of the eastwards fluxes predicted along the eastern half of Shelly Beach and over the existing Long Mac structure. The emergent segments act as physical barriers to the longhsore transport feature predicted for the existing configuration and also provide some local sheltering from the wave energy that would otherwise reach that region, thus further reducing the transport magnitude. Furthermore, the relatively higher water levels on the western side of the Long Mac with emergent segments will work against the wave-driven water level gradient that develop in the west-east direction due to gradients in wave energy exposure (e.g. Figure 3.24) and resulting wave setup distribution. In other words, the modified ambient water level distribution will balance the wave-driven gradient, instead of enhancing it as can presently occur (e.g. see net incoming flows in Figure 3.7, top, tide only, and Figure 3.12, right, northeast event).

A feature that is also consistently predicted in Figures 4.7 to 4.10 is the migration of the net sediment transport pathway from the Shelly Beach cell over, or around, the Long Mac and into the channel, during incoming tides. This “net” transport signal is due to a modification of the position where the flows originating from and off Shelly Beach merge with the main incoming channel flow. This was already identified in the snapshots of the tidal peak flood flows and transports shown in Figures 4.4 and 4.5.

These differences in sediment transport patterns are further characterized in Figure 4.11. An emergent structure guides the incoming flows from Shelly Beach around its seaward tip. This results in a locally increased eastwards transport component, which links to a zone of stronger transport magnitude within the channel over the northern slopes of the trough adjacent to Harrington Point. For completeness, the net transport field over the entire tide cycle is shown in Figure 4.12. The enhancement of the eastwards transport feature near the seaward end of the emergent structures is reproduced, particularly for the case with both central and north segments emerged. The channel region remains ebb-dominated however a reduction of the net magnitude is visible north of the channel trough for the cases with emerged segments.

These modifications of the net transport fields are expected to result in morphological adjustments of the channel and Long Mac vicinity. Near the existing Long Mac seaward tip, a small depositional feature is already present just north of the scour hole on the eastern side of the structure. This is likely due to the process identified here, either as a residual signal from times when the structure was shallower and/or progressive formation even with the present submerged level. The enhancement of the eastwards transport component (i.e. normal to channels flows) due to the raising of the structure central and north segments will likely further build this small delta-like depositional feature. A relocation and possible deepening of the scour hole is also likely to occur given the strong flows bending around the structure tip. In contrast, we can expect that the growth of the similar depositional feature south of scour hole, coinciding with the present eastward transport feature, will stop. For the configuration with only the central segment emerged, the predicted eastwards transport in the vicinity of the present transport feature remains significant so the present depositional feature south of the scour hole will likely continue its growth with only a slight readjustment of its position.

To provide a more quantitative characterization of these processes, predicted total sediment transport were extracted along a transect following the structure axis (Figure 4.13). It is noted that actual transport numbers should be interpreted with care as no calibration of the transport fluxes was undertaken, however, their relative importance is expected to remain relevant. The time series of total sediment volumes (i.e integrated along transect) moving across the transect over the tidal cycle considered is shown in Figure 4.14. The reduction of the eastwards transport for the configurations with emergent segments is clearly visible at incoming tide. The reduction is much more efficient when both the central and north segments are raised. The profile of net volumes transported across each transect point (i.e. integrated over the entire tidal cycle) are shown in Figure 4.15. The northwards shift of maximum transported volumes and overall reduction is again clearly seen for the configurations with emergent segment. It is noted that an intermediate length for the emerged section could be envisaged here, as along as the transport feature presently predicted is blocked. That being, it is likely that the residual sediment volume eventually transported past the seaward tip will generally decrease as the emerged section length is increased, since the driving flows will have more distance to be compensated by ambient adverse gradients. Overall, the significant reduction in transported sediment volumes when both segments are raised suggests that the “new” shifted eastwards transport feature near the structure seaward tip may not be as problematic as what is presently occurring, with respect to sediment recirculation the Harbour.

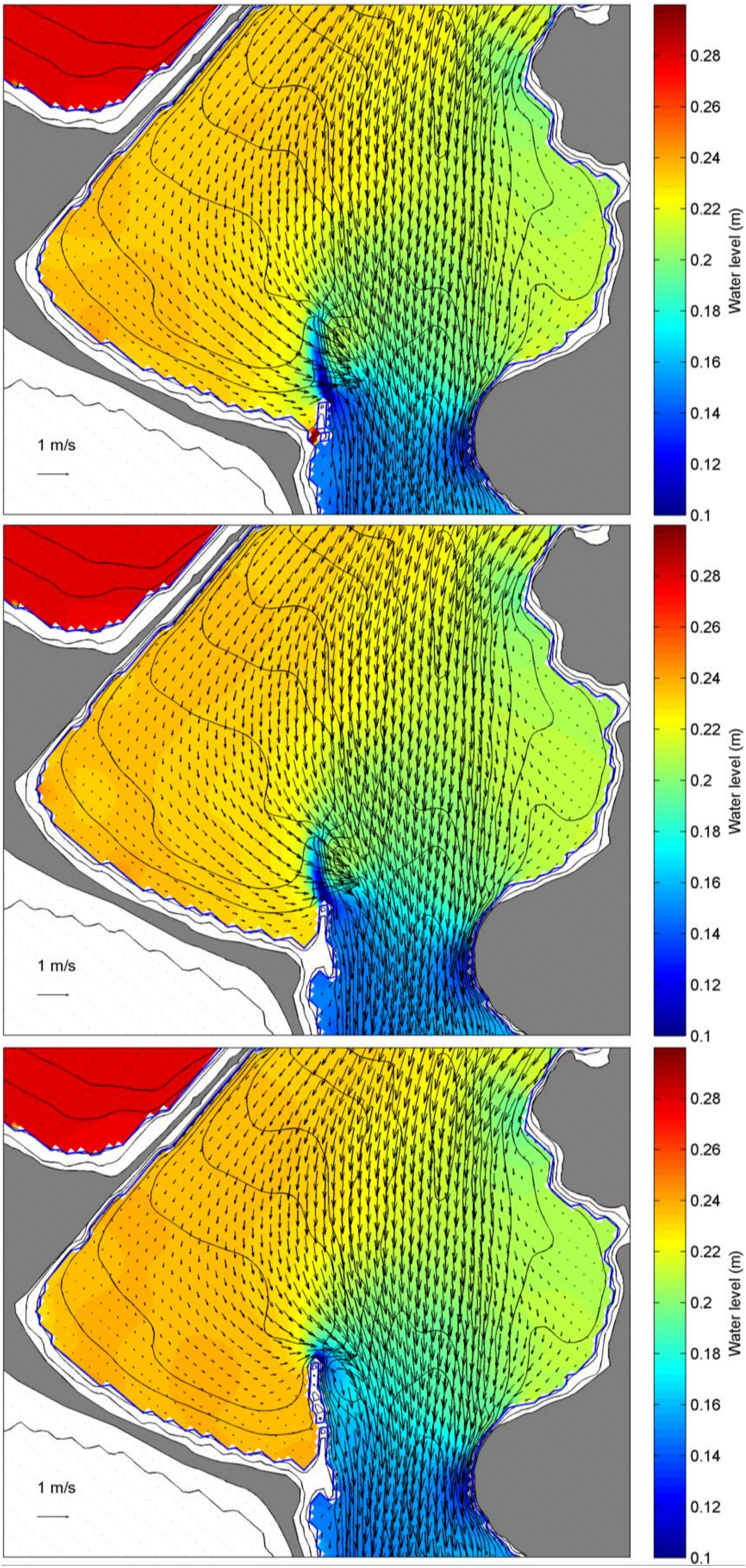

Figure 4.4 Peak flood flows for existing (top) and modified bathymetries (middle: central segment emerged, bottom: central and north segments emerged).

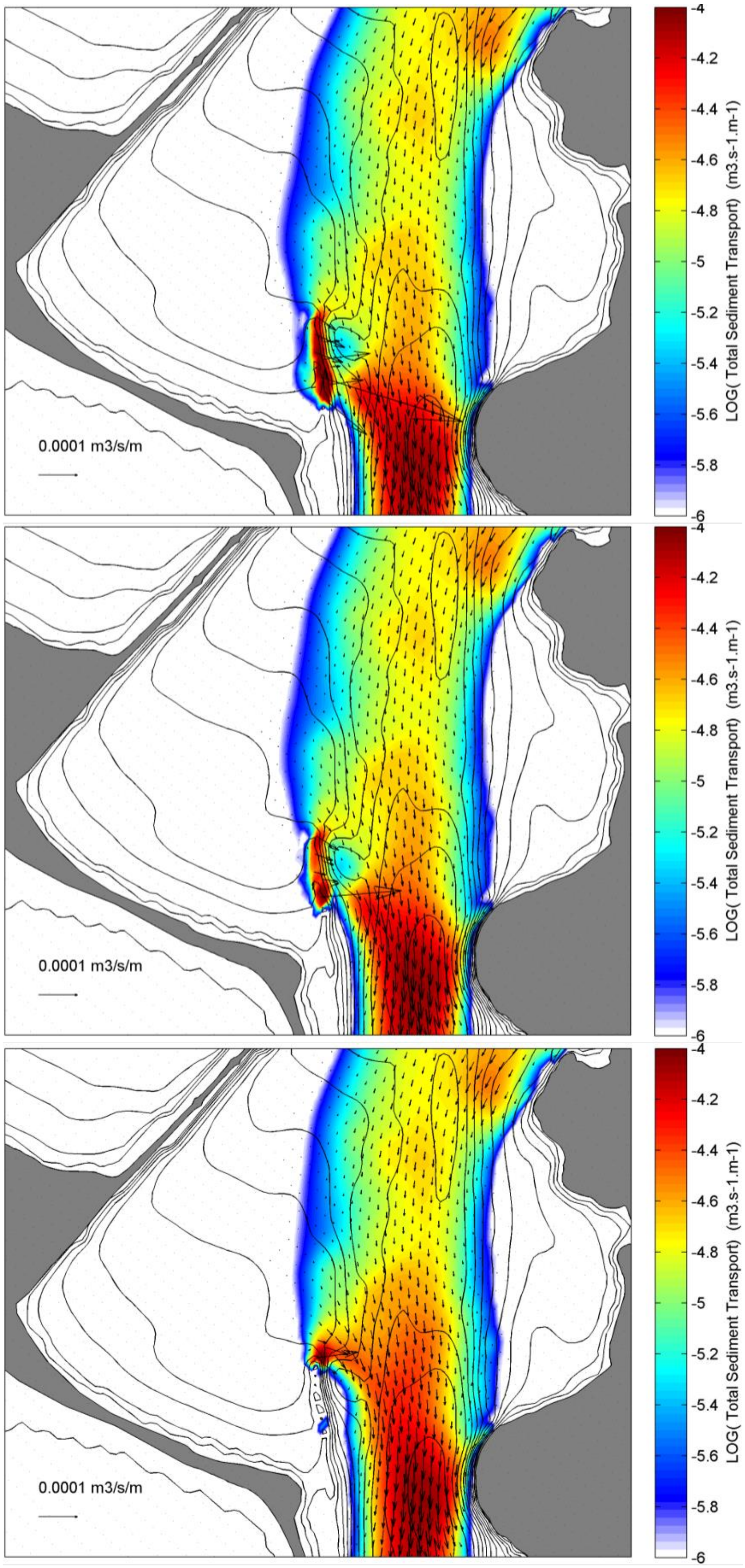

Figure 4.5 Peak flood total transport for existing (top) and modified bathymetries (middle: central segment emerged, bottom: central and north segments emerged).

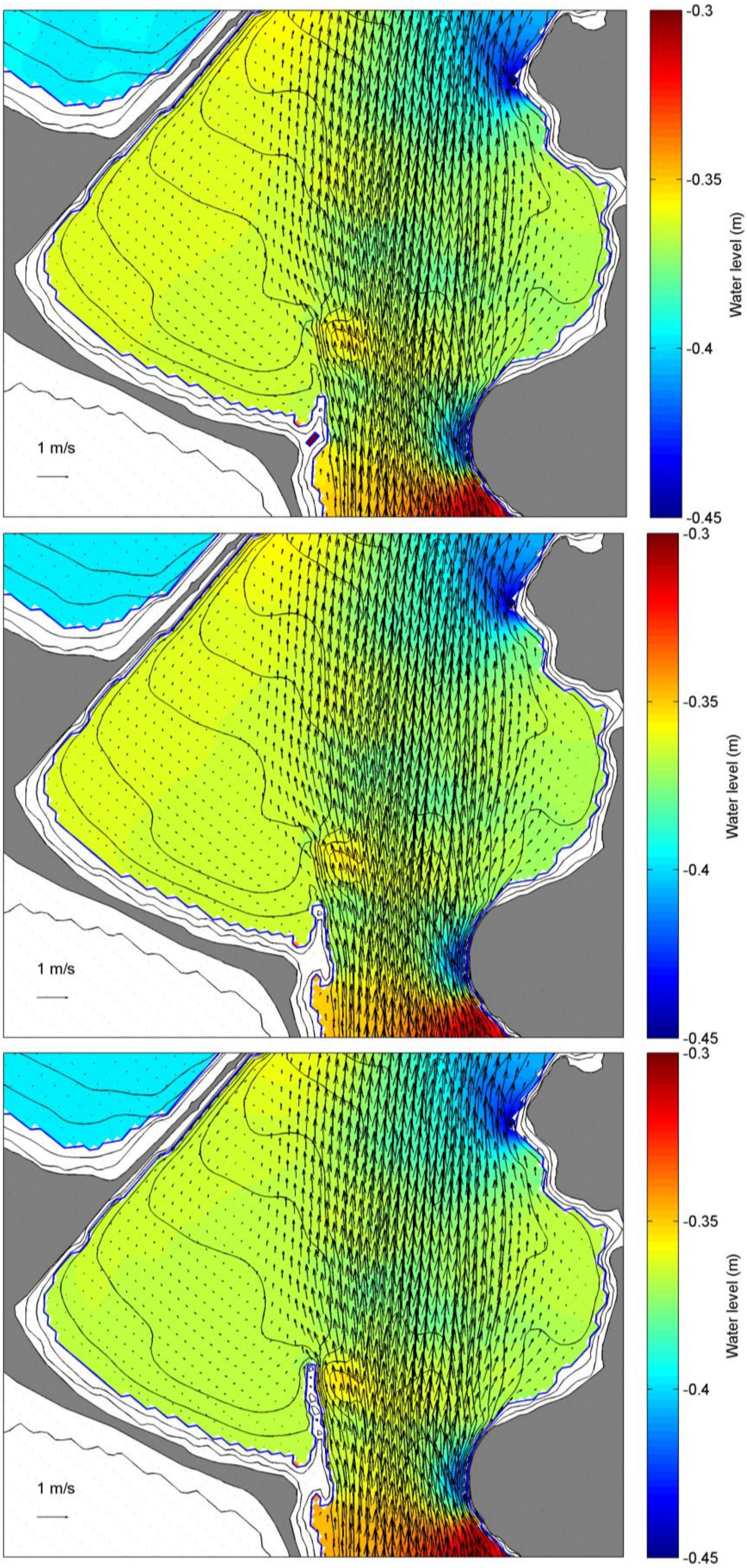

Figure 4.6 Peak ebb flows for existing (top) and modified bathymetries (middle: central segments emerged, bottom: central and north segments emerged).

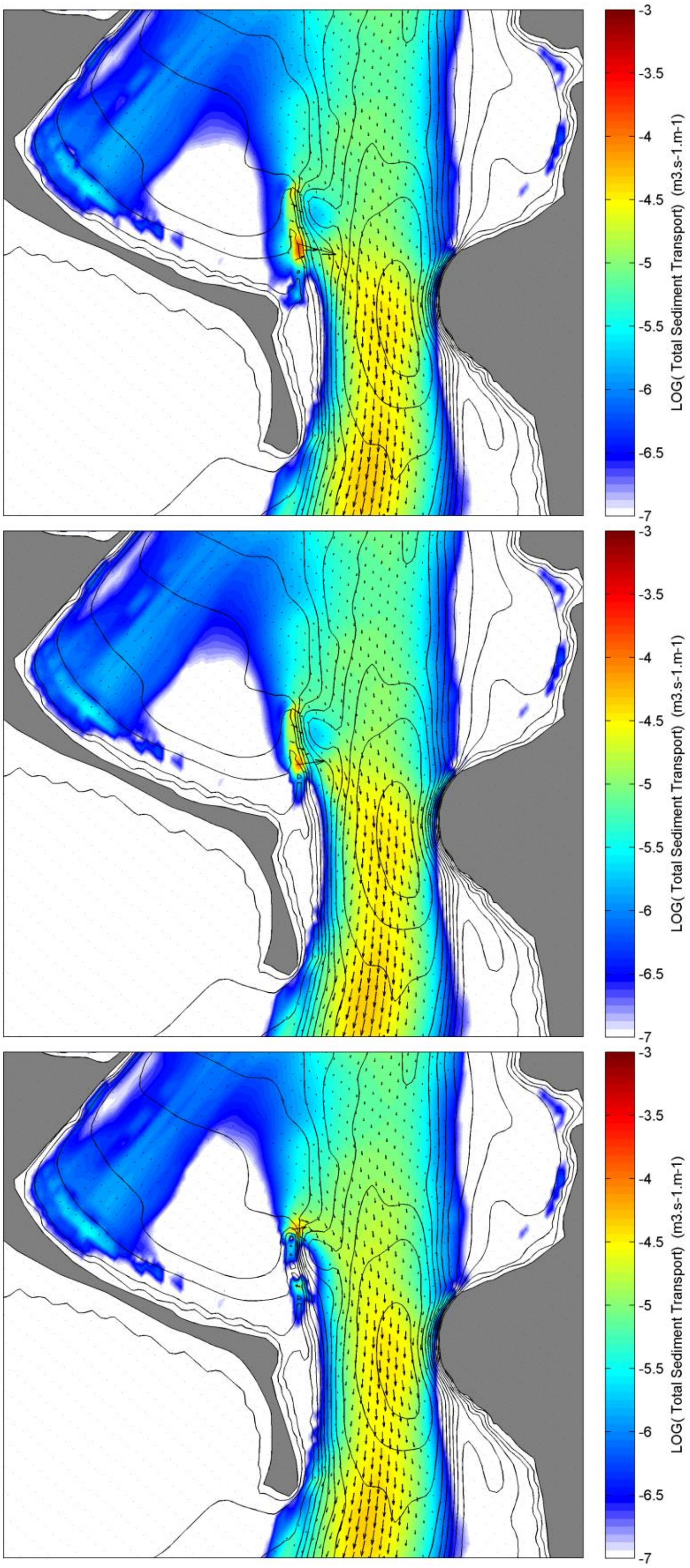

Figure 4.7 Mean total sediment transport fluxes within the entrance region over an incoming tide, for a high energy southeast event (Hs=3m, Dir=135 deg., Tp=14 s), (top:existing, middle: central segment emerged, bottom, central and north segments emerged).

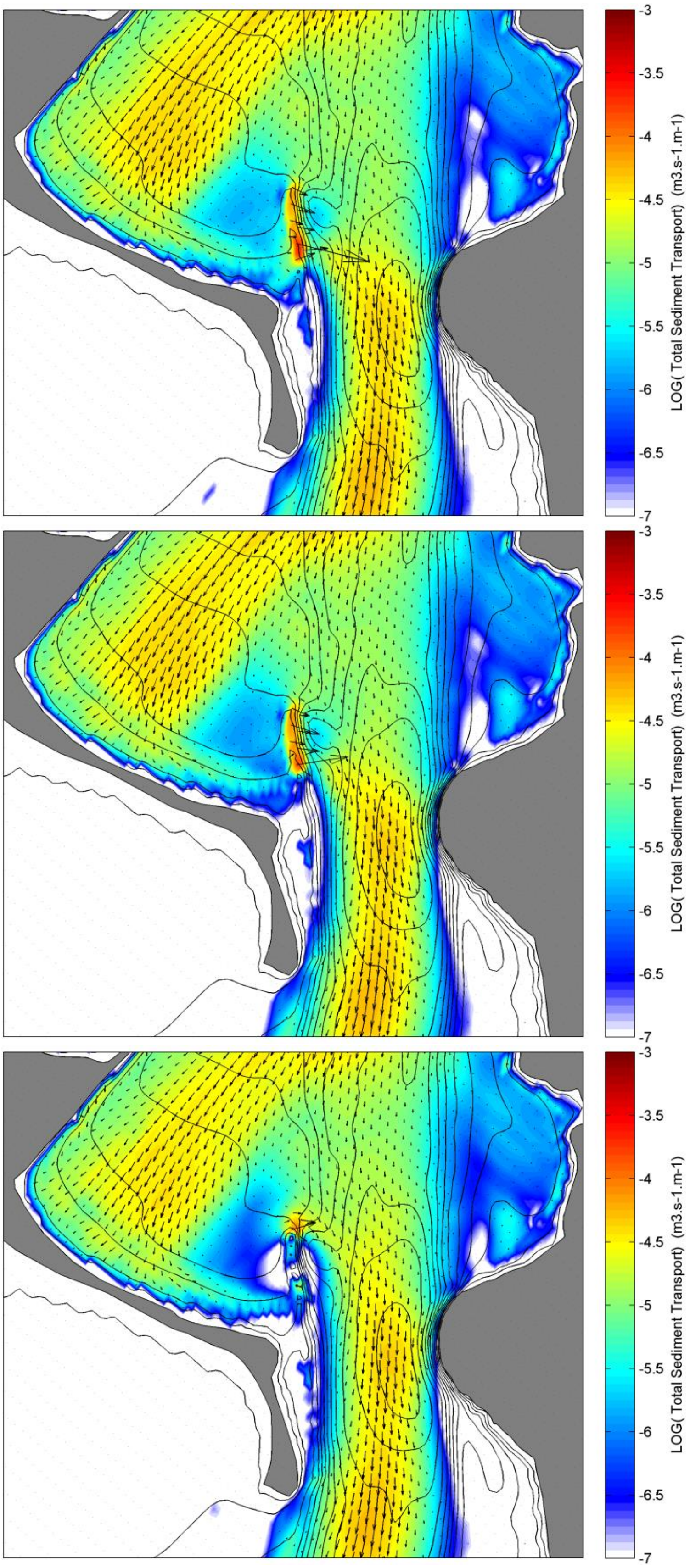

Figure 4.8 Mean total sediment transport fluxes within the entrance region over an incoming tide for a high energy northeast event (Hs=3m, Dir=45 deg., Tp=10 s.) (top:existing, middle: central segment emerged, bottom, central and north segments emerged).

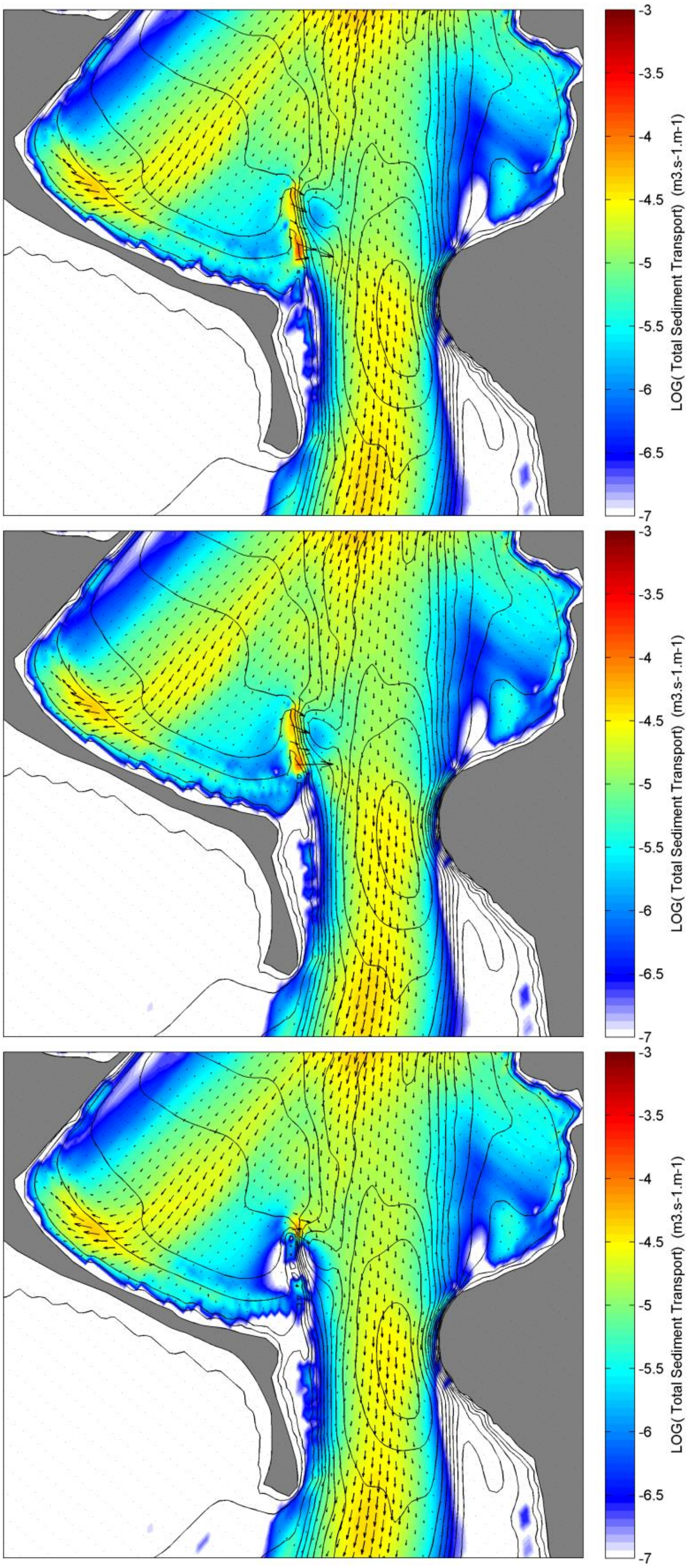

Figure 4.9 Mean total sediment transport fluxes within the entrance region over an incoming tide, for a high energy north swell event (Hs=2m, Dir=0 deg., Tp=14 s) (top:existing, middle: central segment emerged, bottom, central and north segments emerged).

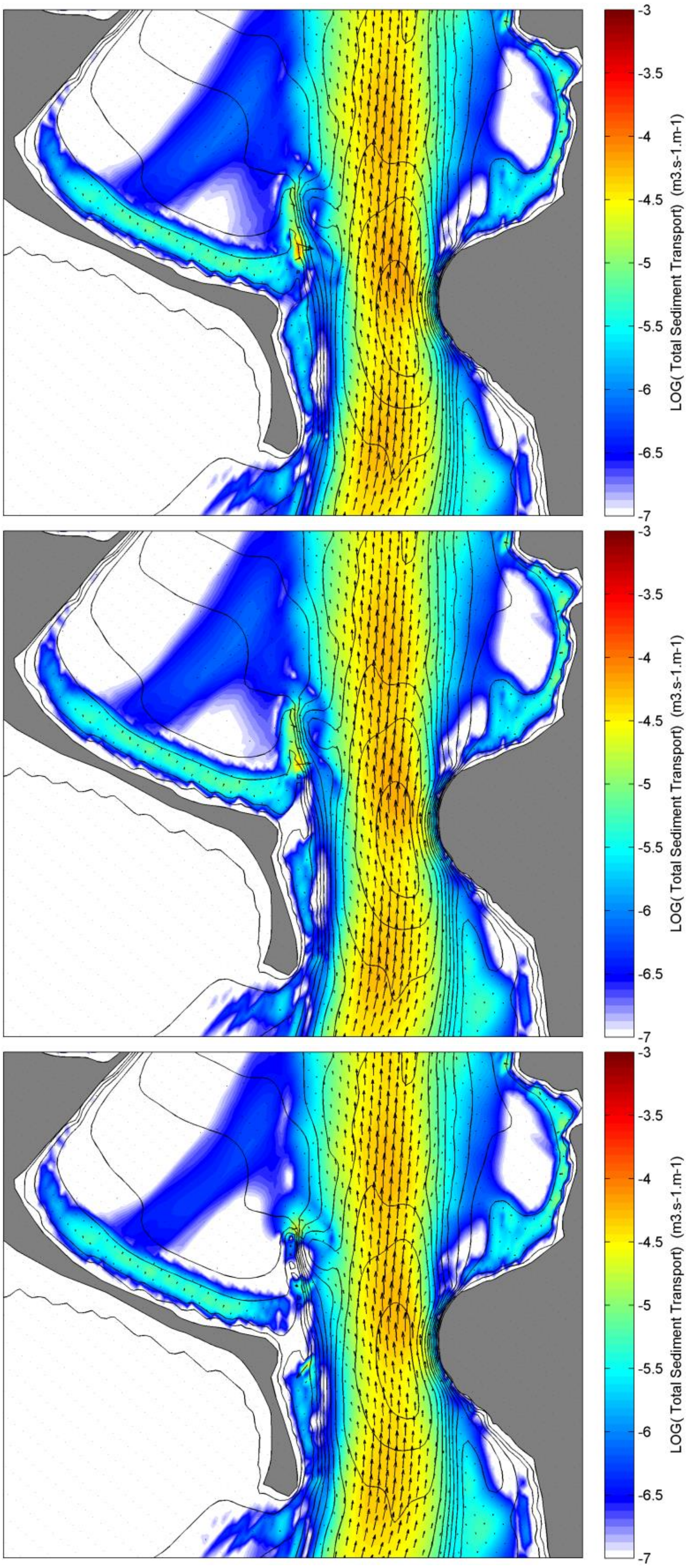

Figure 4.10 Mean total sediment transport fluxes within the entrance region over an incoming tide, for low energy north sea waves (Hs=1m, Dir=0 deg., Tp=8 s.) (top:existing, middle: central segment emerged, bottom, central and north segments emerged).

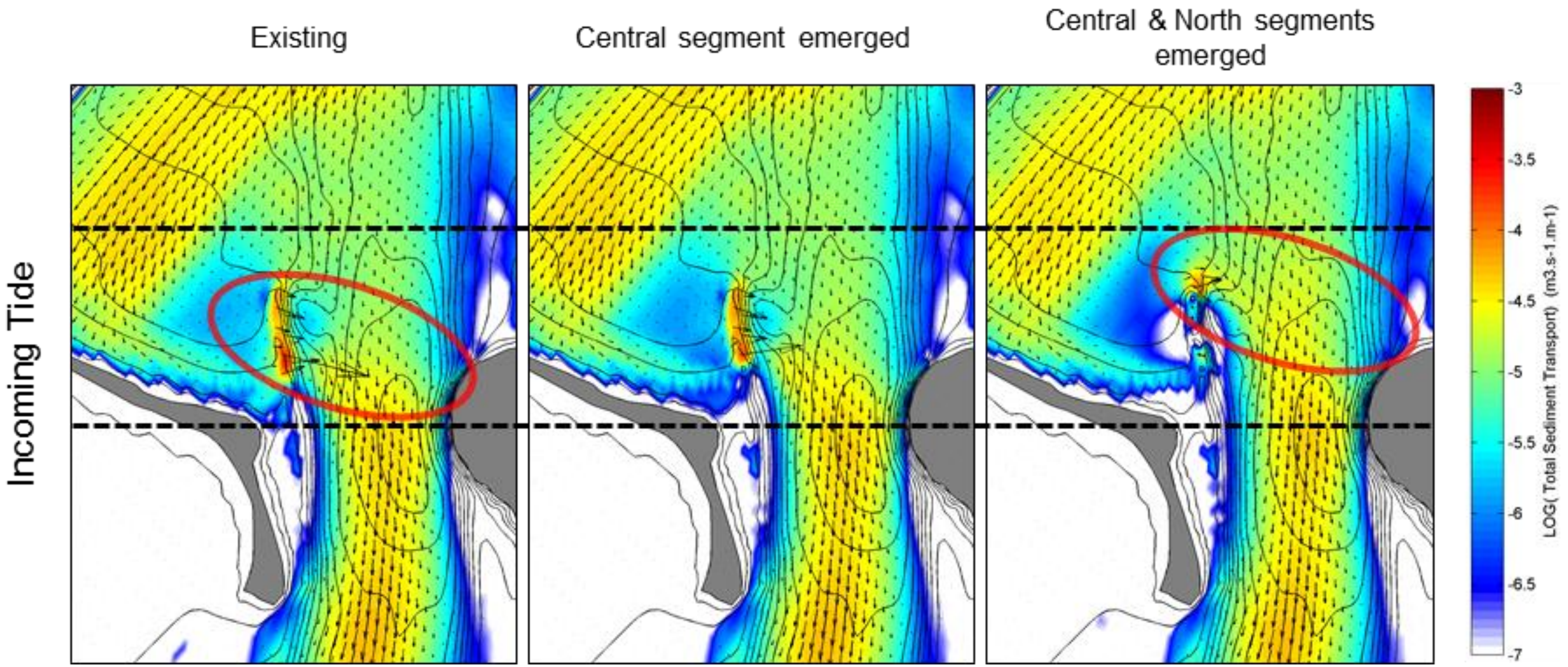

Figure 4.11 Difference in net sediment transport fluxes over the incoming tide for a high energy northeast event (Hs=3m, Dir=45 deg., Tp=10 s.), for the 3 bathymetries considered (left to right, existing, central segment emerged, central and north segments emerged). Note the difference in sediment transport patterns and magnitudes in the vicinity of the Long Mac structure and within the adjacent channel area. Eastwards transport over the existing Long Mac (left) is reduced by an emergent structure (right) but this tends to result in an enhanced transport around its seaward end.

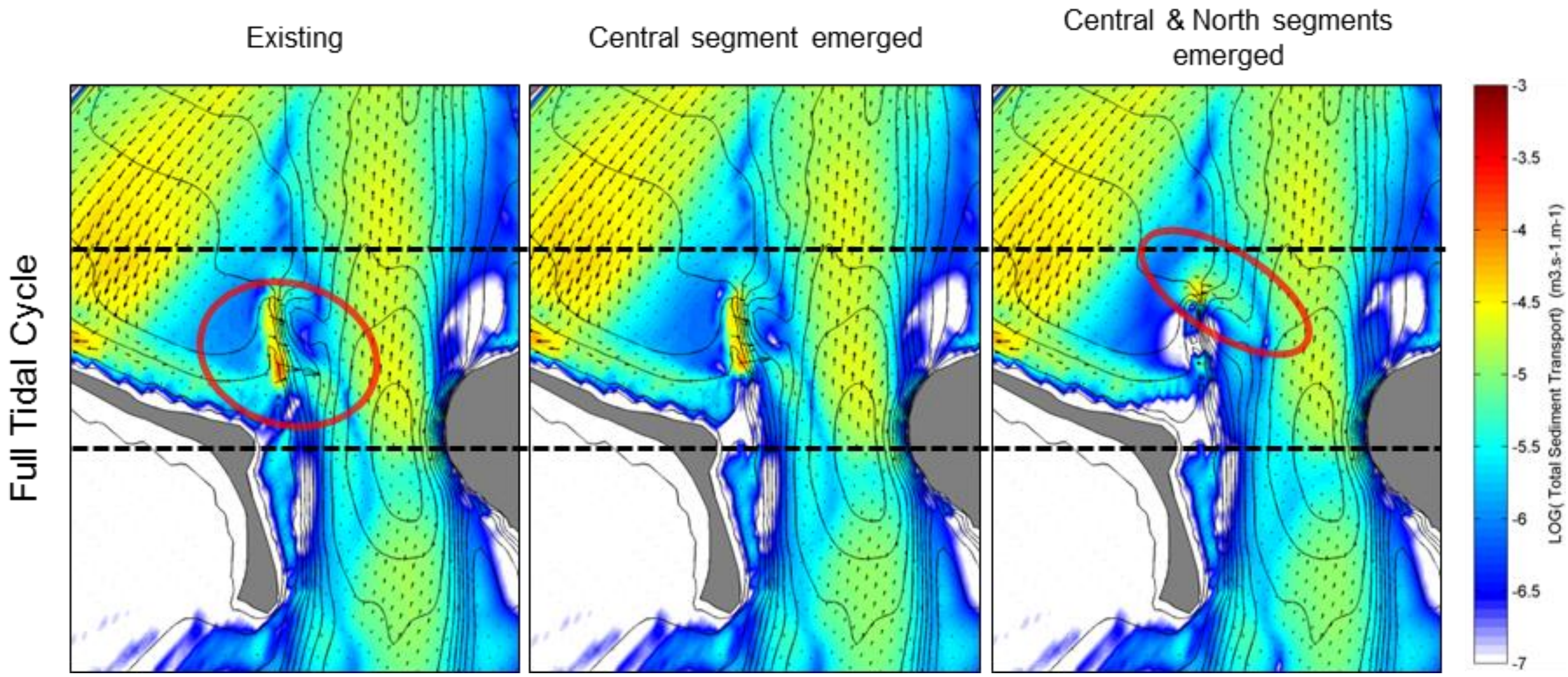

Figure 4.12 Difference in net sediment transport fluxes over the full tidal cycle for the a high energy northeast event (Hs=3m, Dir=45 deg., Tp=10 s.), for the 3 bathymetries considered (left to right, existing, central segment emerged, central and north segments emerged. Note the progressive reduction of the present eastwards transport feature over the Long Mac on the existing bathymetry and associated enhancement of the transport seaward of the emerged tip.

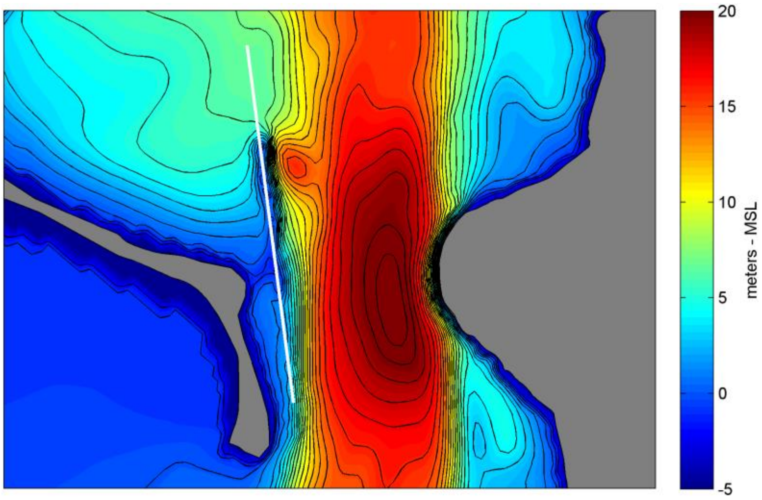

Figure 4.13 Transect position.

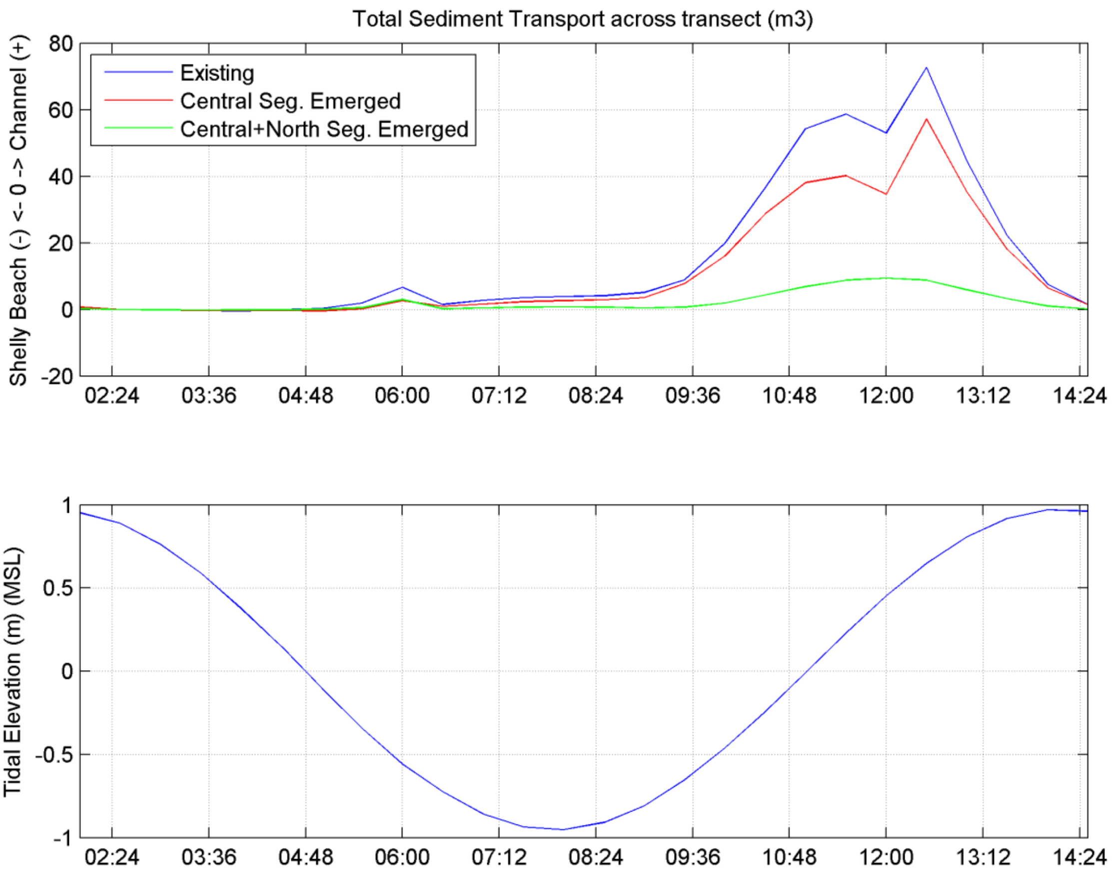

Figure 4.14 Total sediment volumes transported across the transect shown in Figure 4.13 (top) over the tidal cycle considered (bottom). Note the reduction in transport peaks at incoming tide for the cases with emerged segment(s). A positive transport is towards the channel while a negative one is towards Shelly Beach.

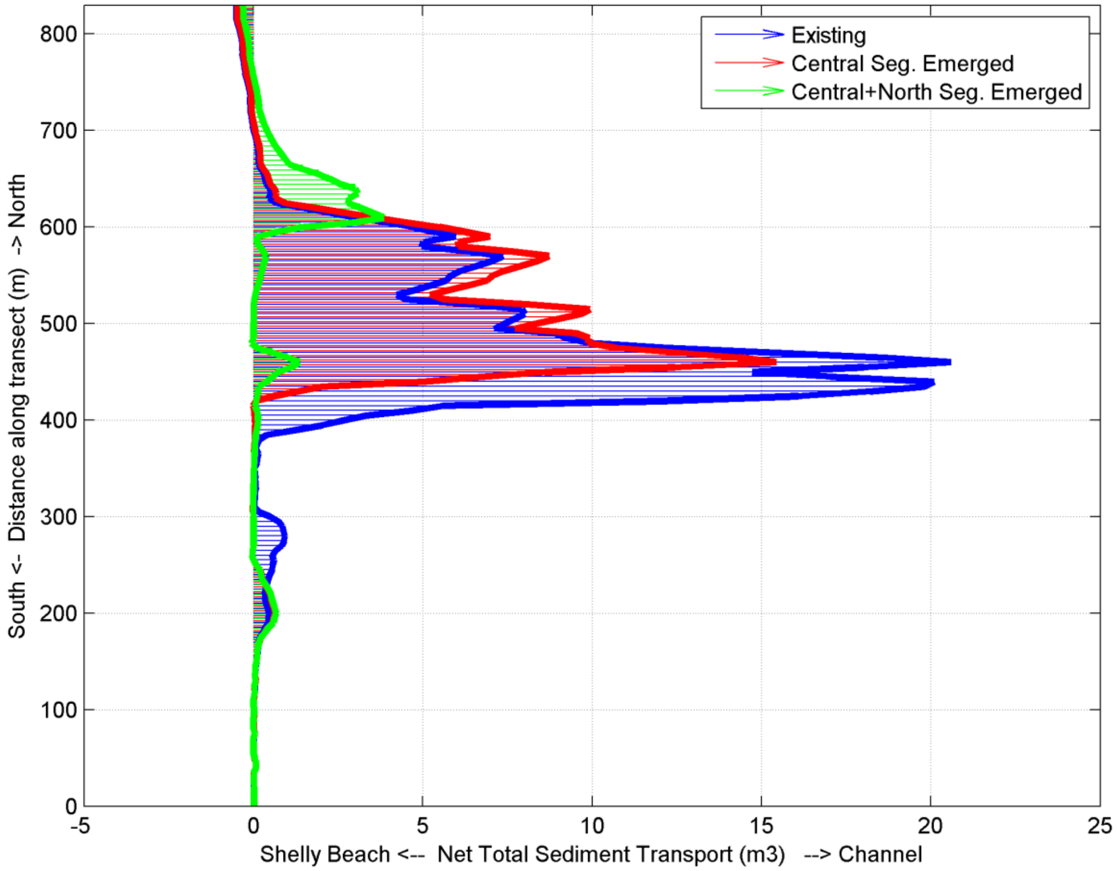

Figure 4.15 Net volumes of sediment transported across each point of the transect shown in Figure 4.13, over the tidal cycle considered. A positive transport is towards the channel while a negative one is towards Shelly Beach. Note the northwards shift in maximum transport position and the magnitude reduction provided by a structure with emergent segment(s).

4.3. Discussion

The physical blocking of the existing incoming flows by a structure with emergent segments appears to be relatively efficient in reducing the main predicted transport feature along Shelly Beach and over the Long Mac that is likely responsible for most of the sediment recirculation into the channel. With respect to the upper entrance region, the flows forced around the emerged structure tip may be the feature with the most potential adverse effects due to possible combination of scour formation and deposition, where Shelly Beach flows merge with the channel. However the “new” predicted transport appears to be at least an order of magnitude less significant than the presently predicted magnitude, especially when both the central and north segments are raised. Since the base mechanism of blocking the water to reduce the water level gradient seems quite efficient, a slightly more inward (i.e. towards Shelly Beach) structure orientation may be interesting to further investigate, as this mechanism will be conserved but any depositional feature would be expected to be similarly shifted inward and thus further away from the channel.

With respect to the lower part of the entrance region, a potential issue that could arise following the compartmenting of Shelly Beach cell is a loss of stability of the lower part of the spit (i.e. south of structure junction to Shelly

Beach) due to relatively reduced sediment supply. There are no obvious signals in the model predictions suggesting that this will be problematic but results should be interpreted with care as that area is not necessarily represented fully realistically given the small scale of structural features, possibly at subgrid resolution, and uncertainties in bathymetry. That being it is expected that alternating ebb and flood flows around the fixed junction would still help to provide a consistent and fairly balanced sediment supply base. Some mitigation of possible adverse effects could include upgrading and/or reconfiguration of the secondary groins already present.

A “softer” measure to allow a better sediment transport balance of the Shelly Beach cell, that can be applied alone or in combination with any structure upgrade, is the use of the return flow along the Mole that seems to generally relax the eastwards transport along the eastern half of the beach. This feature was particularly evident for the high energy north swell event, for which the wave energy reaches the more central part of the beach (Figures 3.14, 3.15, left). The present disposal ground main position seems appropriate, however predominant sediment disposal on the eastern half of the area could help to re-center the wave energy along the beach and drive this return flow along the Mole for a wider range of wave incidence.

5. SUMMARY

A numerical model of the Otago Harbour entrance region has been implemented to investigate the local circulation and sediment transport patterns, with a particular attention to the potential for sediment recirculation into the Harbour. The Delft3D model system coupling wave, circulation and sediment transport models was run for a range of idealized wave events reproducing typical forcing at the site, during a spring tide period.

The main findings of the study are as follows:

- The area is subject to complex tidal hydrodynamics due to the strong water level gradients developing from the coupling of the Harbour with the larger scale regional tidal regime. Outgoing tides are characterized by a strong ebb jet constricted at the Harbour mouth and extending well seaward of the entrance region, all along the large submerged delta bar. The entrance region provides a buffer area to incoming tides. The area fills in faster than what is discharged through the mouth, which results in a distinct eastward flow along Shelly beach accelerating over the Long Mac and meeting constricted flood flows of the channel. This forces eastwards sediment transport fluxes (i.e. channel-directed) in the vicinity of the Long Mac. This process is significant with respect to sediment recirculation in the Harbour.

- Significant amounts of wave energy can reach the entrance region, with magnitude and patterns depending on the incident wave conditions. An onshore sediment transport vector over the disposal ground seaward of Shelly Beach is consistently predicted by the model, coinciding with the overall location of transmitted wave energy bands. This area exposed to wave energy and associated onshore sediment transport coincides with a clear onshore translation of surveyed depth contours thus providing some degree of validation. This indicates the importance of wave-driven sediment transport due to wave asymmetry effects over the disposal ground.

- Wave-driven effects modify the circulation patterns and induce significant sediment transport along Shelly beach. The northeast and southeast cases result in wave energy reaching predominantly the western half of Shelly Beach; at incoming tide phases, wave-driven currents tend to enhance the ambient tidal easterly flows directed towards the channel and associated sediment transport. When the wave energy reaches the central parts of the beach for more northerly wave incidence, an alongshore flow and transport component is forced along the western half of the beach, eventually veering along the Mole in a clockwise motion. This pattern is also reproduced for the northeast event at outgoing tides due to favourable ambient tidal level gradient and slightly shifted wave energy incidence. Net flow fields suggest that the return flow along the Mole can subsequently merge with incoming eastwards currents in the vicinity of the Long Mac. This pattern is not obvious in the net total sediment transport fields but it is present in net suspended sediment fluxes, with magnitude an order of magnitude less than the total transport. This feature is likely to provide a secondary path for sediment transport back into the Harbour.

- The direct vicinity of the Long Mac is consistently characterized by an eastwards sediment transport vector (i.e. channel-directed) in net sediment transport fields. It is expected that incoming tide phases, when tidal water level gradients work in combination with any superimposed wave-driven easterly longshore flow, will be the most critical times for sediment transport into the Harbour. Based on the wave events considered, it is likely that when wave energy reaches the central part of the beach, rather that its western half, the return flow forced towards and along the Mole may provide a degree of relaxation to the eastwards transport in the Long Mac vicinity.

- Options to reduce sediment recirculation into the Harbour were investigated simulating the effects of a modified Long Mac structure with its central segment emerged, and both its central and north segments emerged. Emergent segments provide a physical barrier to the incoming water mass and modify the water level distribution along the beach. Elevated water levels along the eastern half of the beach tend to balance the longshore level gradient that is presently predicted at incoming tide (i.e. from the beach to the channel), thus relaxing the forcing for the strong longshore flows and transport over the Long Mac.

- For the configurations with emergent structure segments, the merging of the currents originating from and off Shelly Beach with the incoming channel flow is shifted northwards around the structure seaward tip. This results in locally enhanced eastwards transport features (i.e. channel-directed) and modification in transport distribution within the channel north of the existing trough between Harrington point and Shelly Beach eastern end. Channel-directed transport features in the structure tip vicinity are likely to induce some small delta-like features, similar to that presently visible in the latest bathymetric survey where the most intense transport presently occur. However a significant reduction of the net transported sediment volumes can be obtained with the configuration with both the central and north segments emerged, thus reducing the potential for any large depositional feature. Some morphological adjustment of the channel in the present trough vicinity trough is also expected given the different flow dynamics induced by the emerged segments.

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