Journal of Coastal Research	SI 64	1272 - 1276	ICS2011 (Proceedings)	Poland	ISSN 0749-0208

Rehabilitation and protection of Colwyn Bay beach: a case study

F. S. B. F. Oliveira†, P. Freire†, F. Sancho†, C. M. Vicente‡ and M. Clímaco†

†Laboratório Nacional de Engenharia Civil, 1700-066 Lisboa, Portugal
{foliveira, pfreire, fsancho, mclimaco}@lnec.pt

‡ claudino.mvicente@gmail.com

ABSTRACT

Oliveira, F.S.B.F., Freire, P., Sancho, F., Vicente, C.M. and Clímaco, C., 2011. Rehabilitation and protection of Colwyn Bay beach: a case study. Journal of Coastal Research, SI 64 (Proceedings of the 11th International Coastal Symposium), 1272 – 1276. Szczecin, Poland, ISNN 0749-0208

Colwyn Bay beach is undergoing a process of erosion. The present study aims at characterizing the beach dynamics and developing alternative solutions for beach rehabilitation and protection. The method applied to characterize the foreshore morphological evolution was the assessment of the shoreline evolution, the analysis of the foreshore 3D evolution and the analysis of cross-shore profile evolution. The sedimentologic contents of the beach were characterized based on the analysis of superficial samples. The hydrodynamic characterization was based on the analysis of the wave climate at three inshore points in front of the beach and of the tidal and surge levels. These data provided the necessary information for the characterization of the longshore transport and evaluation of the beach active zone. The first part of developing alternative solutions was the definition of the optimum long-term recharged beach profile, which, due to the high tidal range, was calculated based on the 2S-EBP method. The beach berm was designed to avoid direct wave action on the seawall existent at the beach backshore. For that, a morphodynamic model was applied to test the beach retreat under storm events. Finally, alternative long-term solutions based on a nourishment strategy were tested with two shoreline evolution models. Two initial alternative solutions of beach recharge with different grain size sand followed by six alternative solutions of beach recharge with sand retention structures arrangements were tested. The results, here qualitatively and quantitatively compared, point out to a best solution based on shore-normal structures to retain the beach recharge.

ADITIONAL INDEX WORDS: *Erosion, Beach dynamics, Beach nourishment*

INTRODUCTION

Colwyn Bay is a seaside holiday resort located in the North Wales coastline of the United Kingdom which faces the Irish Sea (Figure 1). It has an historic link with tourism, which drives the economy of the coastal region through the development of the towns frontage and associated coastal and marine environments. However, the beach of Colwyn Bay, which has a shoreline extension of about 3.5 km and is backed by a seawall, is undergoing an erosion process, with notable reduction of the beach width and lowering of the beach berm and face. As result, the beach has been degrading its recreational and bathing value and also its coastal protection function. Presently, seawall overtopping and consequent flooding of the promenade occur frequently under maritime storm events. For this reason, the Conwy County Borough Council decided on the development of a coastal defence strategy plan for Colwyn Bay. The present paper describes the study performed by Laboratório Nacional de Engenharia Civil, Portugal, for rehabilitating and protecting Colwyn Bay beach.

METHODS

Characterization of the Beach Dynamics

The beach dynamics characterization included the analysis of the foreshore morphological evolution, the analysis of the foreshore sedimentology, the characterization of the wave climate at three inshore points in front of the beach, the analysis of the tidal and surge levels, the evaluation of the beach submerged active zone, and the evaluation of the cross-shore distribution of the sediment drift.

The characterization of the foreshore morphology was based on: the analysis of the shoreline evolution, the analysis of the foreshore 3D evolution and the analysis of cross-shore profile evolution. The shoreline evolution analysis was carried out using the Digital Shoreline Analysis System software, extension of ESRI ArcGIS, that enables the calculation of shoreline rate-of-change statistics from multiple historic shoreline positions (Thieler *et al*., 2009). Five different shorelines, corresponding to the dates 1956, 1980, 1990, 2002 and 2007, were analysed. The 3D morphologic evolution analysis, comprising the entire foreshore since the seawall, at 2.5 m above Ordinance Datum Newlyn (ODN), to approximately 1.5 m below ODN, was obtained through the comparison of full topographic surveys. The surveys available, from October 2001 to November 2007 (approximately 2 surveys per year), were compared based on Digital Terrain Models for the common area. The cross-shore evolution analysis was obtained based on two different topographic datasets: historical beach profiles from 1956 to 1995; and topographic surveys, including cross-shore profiles, from November 1997 to May 2009. The results obtained from these three analyses provided a large amount of relevant data, like shoreline positions, cross-shore profiles and volumes of erosion and accretion, essential also for the short- and long-term beach modelling.

Figure 1. Location of the study area.

The characterization of the foreshore sedimentology was based on the analysis of superficial samples collected in the foreshore. The parameters median diameter, D_{50}, geometrical spreading, $\sigma=(D_{84}/D_{16})^{0.5}$, and particles density were determined.

The characterization of the wave climate was based on the analysis of a wave climate time series supplied at 3 inshore points in front of the study area. The data corresponds to hindcast predictions from a numerical model and covers the period from October 1986 to March 2006. The data files contain the hourly values of: significant wave height, Hs, mean wave period, Tz, and mean wave direction (with respect to true North), Dir.

The characterization of the tidal and surge levels was based on the analysis of the time series of the water level at Llandudno, Wales, for the period from May 1994 to December 2008. The data contains both measured water levels and calculated residuals, which result from the difference between the observed sea level and the predicted tidal level.

The characterization of the cross-shore distribution of the sediment drift in the submerged active zone was based on the application of the numerical model LITDRIFT (DHI, 2008), a 2D-vertical process-based deterministic model which accounts for the geometrical and sedimentologic variation of the sea bottom in the cross-shore direction. Due to the wide variety of sediment that can be presently observed in the foreshore surface, a sensitivity analysis aiming to evaluate the impact of the sedimentologic characteristics in the longshore transport was performed before applying the model for the complete hydrodynamic conditions, i.e., the 19-year series of wave climate and sea level conditions. The model allowed to evaluate the longshore transport series in both (East and West) directions, its distribution across-shore and identify the limits of the active zone of the beach (where the significant longshore transport occurs).

Definition of Optimum Recharged Beach Profile

The design of the long-term cross-shore beach profile was based on the equilibrium beach profile concept. In this study, due to the high tidal range (commonly from 4 to 8 m), the tidal effect was not neglected and thus, to account for it, the two-slope equilibrium beach profile (2S-EBP) model of Bernabeu *et al*. (2003) was used. The height of the berm, on the top of the 2S-EBP, was mainly determined by the water level. The width of the beach berm was designed taking into account the short-term cross-shore profile evolution under severe storms, for different combinations of profile and sediment size, based on numerical modeling. The morphodynamic model LITPROF (DHI, 2008) was applied. The aim was to guarantee a minimum berm width, left intact after the storm, to avoid the direct wave action on the seawall and thus, provide a natural beach defence against erosion.

Long-term Shoreline Modelling

Alternative long-term solutions of beach protection and rehabilitation were tested based on two shoreline evolution models, with different characteristics and capacities, LITMOD (Vicente and Clímaco, 2003) and LITLINE (DHI, 2008). Despite they are both One-Line type of models, the reason for applying them both is that they allow to account for different conditions in association with their features. For example, LITLINE model simulates the sea level variation (tide motion) and LITMOD does not, whereas LITMOD model simulates fishtail groynes and LITLINE does not. The application of both offers a wider range of capacities for testing solutions of beach control arrangements.

The first stage of the methodology was the calibration of both models. It was performed for the period Oct/2001- Jul/2005, because the first survey of the complete zone is dated of Oct/2001 and the wave climate series ends in 2005. The shorelines (0 m ODN) used for calibration were: the shoreline of Oct/2001, as the initial line; and the four shorelines of Oct/2002, Jul/2003, May/2004 and Jul/2005, as verification lines. Both models consider the three wave climate series (at West, Central and East points) but the sea level variation is only considered in LITLINE model. LITMOD model simulates beach shoreline evolution at mean sea level (0.11 m above ODN).

In a second stage, the shoreline evolution for two cases of beach recharge with different type of sediment and respective 2S-EBP was simulated with both models. In these cases, sediment retention structures were not considered. The last stage was the numerical simulation of alternative solutions of beach recharge with structures arrangements implemented for the retention of the beach fill.

RESULTS AND DISCUSSION

Characterization of the Beach Dynamics

Within the study period, 1956-2007, the maximum shoreline displacement was 76 m landward (erosion) and occurred between 1980 and 1990. The maximum net shoreline movement was 50 m of erosion and 20 m of accretion (seaward displacement). The average net movement was 13 m (erosion), corresponding to a shoreline area displacement of about $51x10^3$ m^2. The rate of shoreline evolution is presented in Figure 2, for different transects along the beach length. Results show that between 1956-1980 almost all the shoreline is in slow accretion, more evident in the central area of the beach. In the period 1980-1990 an important retreat of the shoreline is observed, with an average retreat rate 5 $m.year^{-1}$ and a maximum value of almost 8 $m.year^{-1}$. Two important storm events which occurred in 1988 and 1990 could have contributed to the observed erosion. Moreover, the construction of coastal defences, the Rhos-on-Sea breakwater on the early 1980's and the Penrhyn Bay breakwaters in 1989/90, could have contributed to the cut off of material supply and sand deficit at the beach foreshore. Between 1990-2002 the beach recovered, showing general accretion with an average rate 2 m.year^{-1} and a maximum rate 5 m.year^{-1}. After 2002 the shoreline shows a general stabilization with average displacement rate lower than 0.5 m.year^{-1}. Within the study period the beach lost an area of about 51x10^3 m^2, from which about 50% was recovered after the erosion period of 1980-1990.

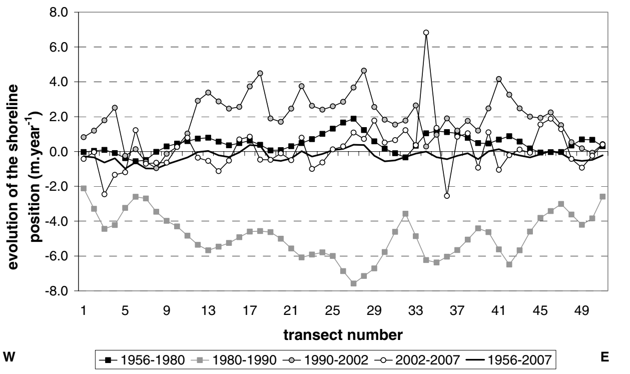

Figure 2. Shoreline evolution rate between 1956 and 2007.

The 3D morphologic evolution results show that the evolution of the foreshore in the study period was dominated by erosion with sediment loss of about 40x10^3 m^3, that corresponds to an erosion rate of 7x10^3 m^3.year^{-1} and an average vertical loss of 15 mm.year^{-1}.

The cross-shore evolution analysis shows that the beach level at the toe of the seawall, between 1956-1990, presented a similar lowering along the entire beach, except in the West limit were accretion was observed due to the construction of the Rhos-on-Sea breakwater. Results also show that between October 2001 and May 2009 the beach lost a volume of about 30x10^3 m^3 corresponding to an erosion rate of 4x10^3 m^3.year^{-1}.

Sediments in Colwyn Bay frontage are mostly sand-sized but shingle and cobble is present through the entire beach, covering the upper foreshore or in local pockets. At Rhos-on-Sea, the breakwater construction promoted conditions for fine-grained sediment deposition and a mud layer covers the lower foreshore. Underlying boulder clay is exposed at the East end of the foreshore. The results of the surface sediment sampling analysis showed that the upper foreshore sediments are mainly coarse-grained sands and gravel, with D_{50}=0.6-3 mm. These sediments are poorly sorted, with σ values over 3. In some cases sediment is almost totally composed by bioclasts. At the lower foreshore, sediments are mostly fine to medium-grained sands (D_{50}=0.2-0.3mm). These sands are well sorted, presenting a σ value close to 1. Particles density for the sediments analysed was 2.7.

The main results of the wave climate analysis for the three inshore points were:

- Concerning Hs, all the wave height histograms are similar. Approximately half of the data was between 0 and 0.25m, and the maximum is below 3.25m. Thus, in general, the wave climate can be considered quite mild.
- Regarding Tz, the most frequent class is 3<Tz<4 s. This corresponds mainly to local wind sea waves generated in the Irish Sea. Small differences are found amongst the 3 inshore-points. The maximum Tz is 7.1 s, and the highest waves correspond to the largest wave periods.
- Regarding Dir, most inshore waves reach from the Northwest quadrant, with predominance of directions 285°<Dir<345°, which sum up to approximately 65% in all nearshore points (Figure 3). Secondly, waves from the Northeast quadrant sum to 28% of all data. The most notorious difference between all nearshore regimes occurs for the direction Dir_{median}=290°, which occurs more frequently in the East point.
- For all the nearshore points, the majority of the highest waves (3.0<Hs<3.25 m) arrive from the North (Dir=0°), this direction being slightly rotated clockwise (Dir=10°) in the West point. Also, a greater number of waves with 3.0<Hs<3.25 m occur in the East point, in comparison with the other two locations.

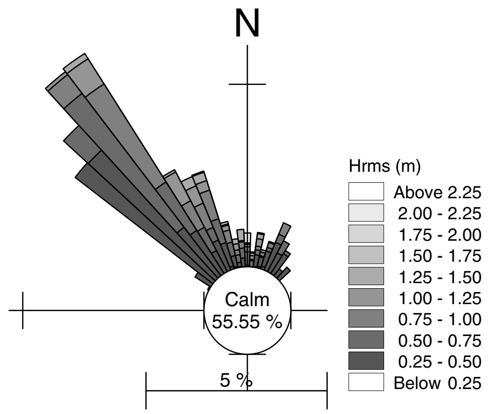

Figure 3. Wave climate for the central point in year 1990.

The modal tidal range from the 19-year tidal water elevation prediction was computed, yielding TR=6.25 m.

The analysis of the results of the longshore transport between 1986-2005 revealed average values of the parameters net transport capacity and gross transport capacity 103.5x10^3 and 116.3x10^3 m^3.year^{-1}, respectively. The results also revealed a significant interannual variation of the transport during the study period, between 187.5x10^3 and 51.9x10^3 m^3.year^{-1} for the net transport capacity (Figure 4). The average values of the parameters West and East longshore transport capacity are 6.3x10^3 and 109.9x10^3 m^3.year^{-1}, respectively. The results agree with previous knowledge, i.e., the predominant longshore transport is directed towards East. The average East transport is 95% of the average gross transport. Due to the depleted state of the beach, i.e., the present absence of sediment available for mobilization in areas of the foreshore where large extensions of rocky outcrops and boulder clay are visible, the longshore transport potential must be higher than the real longshore transport.

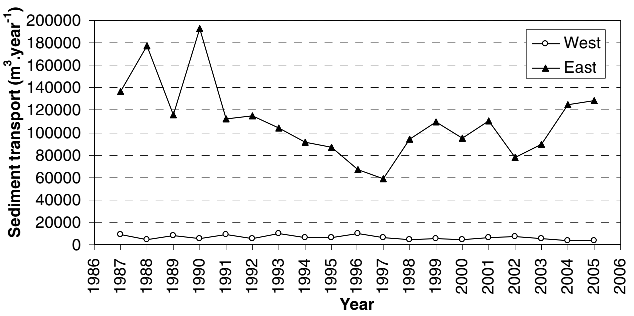

Figure 4. West and East transport capacity (1987-2005).

Definition of Optimum Recharged Beach Profile

The surf and shoaling parts of the 2S-EBP depend on the beach shape parameters proposed by Bernabeu *et al*. (2003). For their calculation it is required to estimate the dimensionless fall velocity, Ω, defined as $\Omega = H_s / w\, T_p$, where T_p is the wave peak period, and *w* is the sediment fall velocity, determined here in as given by Jiménez and Madsen (2003). The results from the hydrodynamic analysis yielded: Hs=0.44 m, Tp=3.84 s, TR=6.25 m. Thus, for borrow sediments with D_{50}=0.25 and 0.45 mm (and density 2.65), the obtained Ω was 1.2 and 2.0, respectively. The correspondent 2S-EBPs are in Figure 5, against 4 present natural beach profiles.

The morphological response of different combinations of profile geometry and sediment characteristics for the designed beach were tested through numerical modelling for two maritime storms, February 1990 and December 1990. The first storm corresponds to the longest period of consecutive waves with Hs higher than 3 m within the 19-year wave series and the second to the period in which the water level reached highest values due to the surge. The short-term profile evolution under the storm conditions of February 1990, which happened to cause more beach erosion, for two beach nourishments with borrow sediments with D_{50}=0.25 and 0.45 mm, can be seen in Figure 6. The resulting large values for the berm retreat, defined as the distance from the original berm position at which no profile variations were observed, indicate that under this extreme storm event most of the berm eroded (although associated to a maximum lowering of 28cm). A major finding from this analysis was that a 50 m berm width at 4 m ODN is insufficient to prevent direct wave action on the seawall in the case of sea state conditions as the ones of February 1990. Only the 50 m width and 1:100 slope berm, from 5 m ODN at the seawall until 4.5 m ODN, showed enough resilience to the erosion process to prevent direct wave action over the seawall.

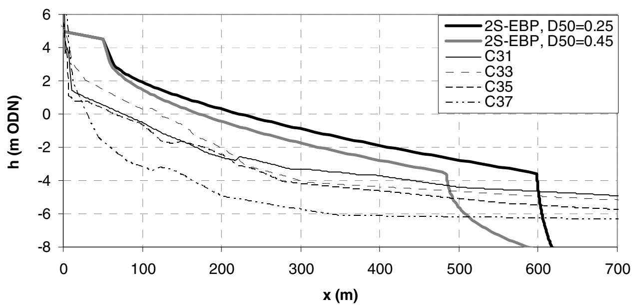

Figure 5. 2S-EBP against present beach profiles (C31 to C37).

Long-term Shoreline Modelling

Two initial cases of beach fill with borrow sediment with characteristics D_{50}=0.25mm (and σ=1.72) and D_{50}=0.45mm (and σ=2.1) were tested. The design beach morphology is a planar sloping berm (1:100), between 5 and 4.5 m ODN, followed by a 2S-EBP (Figure 5). The calculated recharge volumes are 3.3×10^3 m^3 for D_{50}=0.25mm and 2.2×10^3 m^3 for D_{50}=0.45mm.

The long-term (for the 19-year wave climate and sea level series) shoreline evolution was estimated for both cases with both models. There was a good agreement between both models results in the prediction of sediment loss in 10 years after the nourishment. It was about 17% and 20% for LITLINE and LITMOD models, respectively, for both cases. The loss of sediment is larger for the case with D_{50}=0.25mm, making the beach recharge with D_{50}=0.45mm potentially more economic. Both models predict two hot spots of beach retreat, at both extremes of the recharge. The East extreme showed the highest retreat rate.

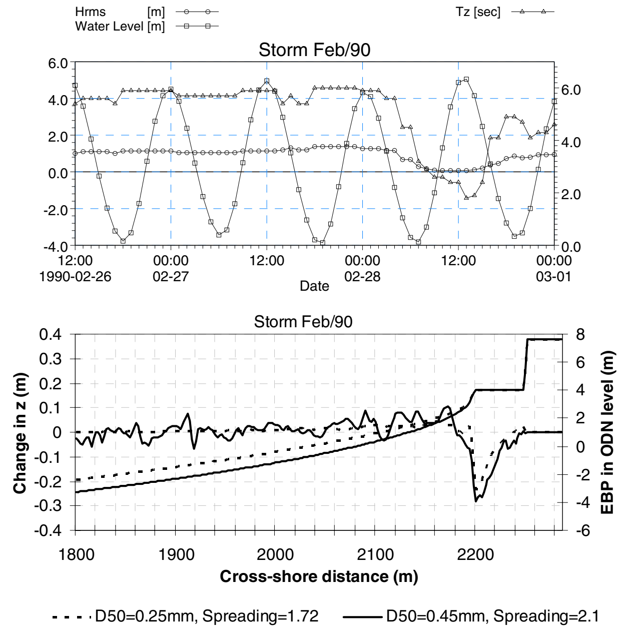

Figure 6. Storm of Feb/1990: parameters Hrms, Tz and water level (above); cross-shore morphological evolution (below).

The following stage was the testing of six alternative solutions based on the implementation of structures arrangements to retain the beach nourishment with D_{50}=0.25mm:

- Option 1: One fishtail groyne with 250 m length;
- Option 2: Two fishtail groynes with 250 m length distanced 1000 m (Figure 7);
- Option 3: Two groynes with 250 m length distanced 1000;
- Option 4: Three detached breakwaters with 280 m length (Figure 7);
- Option 5: Two fishtail groynes with 250 m length distanced 1600 m;
- Option 6: One groyne with 250 m length.

These six alternative solutions were qualitatively and a quantitatively compared. The parameters considered for the qualitative comparison were: beach partition, uniform beach width, eventual use of existing structures, safety for recreational use, view to the sea and likelihood to occur siltation problems. The minimalist solutions (in terms of structures), which consist on the implementation of groynes, options 3 and 6, are the ones that offer the conditions most compatible with the future beach use, which is bathing, nautical sports, walks with sea views, and other types of leisure.

The quantitative comparison of the alternative solutions was based on the shoreline positions obtained after 1, 5, 10 and 19 years of simulation, on the position of the crest of the 2S-EBP (line of + 4.5 m ODN) after 10 years, and on the loss of sediment from the stretch recharged after 10 years. The main results were:

- After 10 years, the loss of sediment from the beach recharge varied only 3% amongst the solutions (between 17 and 20%);

- The worst solution was option 4, with 20% of sediment loss after 10 years. The shoreline, which after 5 years became already rather irregular, continued to retreat in front of the central part and East extreme of each detached breakwater until the end of the simulation. The significant retreat of the beach profile in these locations can cause localized erosion if the wave action reaches the seawall due to the absence of the beach berm.
- The fishtail groyne with 250 m length is more efficient in retaining sand in its adjacent area, particularly in the downdrift side of the structure, the East side, than a groyne with the same length (comparing options 2 and 3).
- The displacement of the western fishtail groyne towards West, reduces the uniformity of the beach width in the stretch between the fishtail groynes, particularly in the East side of the western groyne (comparing options 2 and 5).

The three first options were also tested considering an increase of 50 m in the length of the shore normal structures. The results show that during the first 10 years after the beach recharged the loss of sand was reduced to 12% of the total nourishment, for the three cases. The reason for such improvement is the fact that the closure depth is significantly larger (further seaward) than the depth at the seaward extreme of these sediment blocking structures.

CONCLUSIONS AND RECOMMENDATIONS

The present study aimed at developing alternative solutions for Colwyn Bay beach rehabilitation and protection and was divided in three phases: characterisation of the beach dynamics, definition of optimum recharged beach profile, and long-term shoreline modelling of alternative solutions. The large quantity of data provided by the characterization of the beach dynamics was used as input and verification data for the numerical models applied in the definition of optimum recharged beach profile and in the long-term solutions testing.

The main conclusions and recommendations of this study are:

- The beach recharge volume should guarantee a beach berm that avoids direct wave action on the seawall during storms. Thus, it is recommended a planar sloping berm (1:100), between 5 and 4.5 m ODN, followed by a 2S-EBP.
- From the six alternative solutions of beach nourishment with control structures tested and compared, the one that gives the best guarantee of retaining the sand recharge and simultaneously offers conditions compatible with the future beach use is option 2, two fishtail groynes with 250 m length distanced 1000 m.
- The increase, in 50 m, of the fishtail groynes for options 1 or 2, would have a benefit in reducing the nourishment loss after 10 years to about 12%, instead of 18%.
- Monitoring the beach morphology, from the seawall until the seaward limit of the beach active zone, should be performed during and after the nourishment project, and will allow quantifying the project performance. It will also allow to acknowledge the typical cross-shore and alongshore transferences of sediment, and thus, to alert if any atypical situation occurs.
- The comparison of the alternative solutions was executed based on a strictly technical analysis. However, a cost/benefit analysis should also be performed in order to select a sustainable solution.

LITERATURE CITED

Bernabeu, A.M., Medina, R. and Vidal, C., 2003. A morphological model of the beach profile integrating wave and tidal influences. *Marine Geology*, 197, 95-116.

DHI, 2008. Litpack. Noncohesive Sediment Transport in Currents and Waves. User Guide. Danish Hydraulic Institute, Denmark.

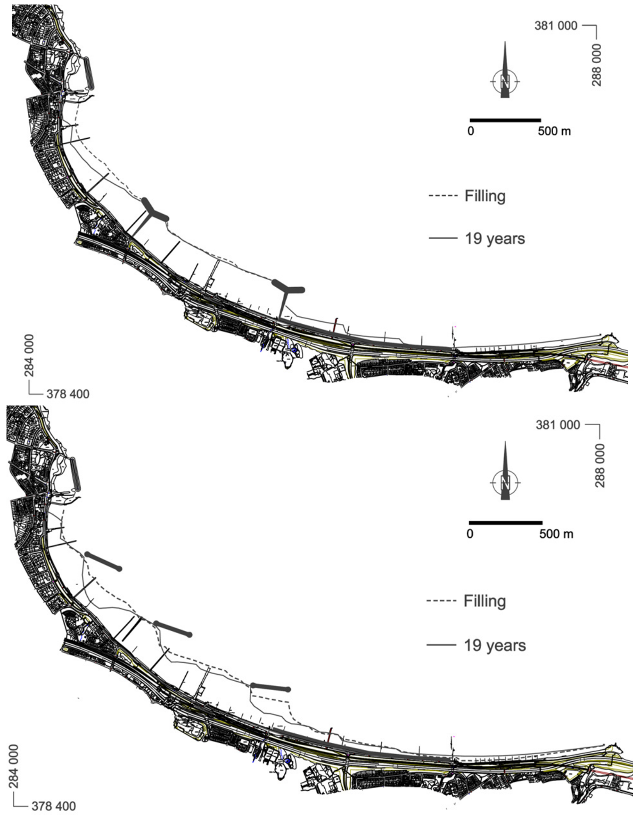

Figure 7. Shoreline evolution for options 2 (above) and 4 (below).

Jiménez, J.A. and Madsen, O.S., 2003. A Simple Formula to Estimate Settling Velocity of Natural Sediments. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, Vol. 129, No. 2, 70-78.

Thieler, E.R., Himmelstoss, E.A., Zichichi, J.L., and Ergul, A, 2009. Digital Shoreline Analysis System v4.0—An ArcGIS extension for calculating shoreline change: U.S. Geological Survey Open-File Report 2008-1278.

Vicente C. and Címaco, M., 2003. Shoreline Evolution. Development and application of a numerical model. Report ICT/ITH-42, Laboratório Nacional de Engenharia Civil, Portugal, 167 p.

ACKNOWLEDGEMENT

The authors thank Dr. Lourival Trovisco, Mr. Luís Simões Pedro, Mr. Victor Pisco and Mr. Fernando Brito, for their contribution to this study, the Conwy County Borough Council, for financing the project, and Royal Haskoning, UK, for the consortium established.