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Summary

Bridlington Harbour and Marina development

Hydrodynamic modelling study, Phase 1

Report EX 5969
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Bridlington Harbour Commissioners (BHC), Yorkshire Forward (YF) and East Riding of Yorkshire Council (ERYC) are working in partnership on the development of the existing harbour and provision of new marina facilities at Bridlington. The proposed developments include construction of a new outer tidal basin on the southern side of the existing harbour and conversion of the existing harbour basin into a marina with water impounded at half-tide level.

HR Wallingford were commissioned by Yorkshire Forward to study the effect on waves, flows and sedimentation of four proposed alternative schemes drawn up by Wheeler Trevitt (advising BHC) and Atkins (advising ERYC).

The existing and proposed harbour layouts have been modelled using the ARTEMIS wave disturbance model. Incident waves, each expected to occur 10 times, on average, per year have been simulated for a range of offshore wave directions or local wind conditions. A more extreme 10 year wave was also tested together with period-scanning runs to investigate the possible resonant response of each layout. Generally the wave conditions within the proposed new south basin were predicted to be similar to those in the existing harbour, however the new basin is likely to be more susceptible to resonance.

A TELEMAC 2D flow model was used to model tidal flows in and around the existing harbour and the four proposed new layouts of harbour. Generally the effect of the Schemes was to shift the pattern of flows southwards so that they are now relative to the end of the extended North Pier. Peak current speeds flowing around the end of the North Pier extension are about 0.5m/s which is approximately the same speed as flows past the existing North Pier in the existing layout. These locally accelerated flow speeds are, however, experienced over a wider area compared with the existing situation.

Dispersion of water discharges from Yorkshire Water's two outfalls south of the harbour was studied using the PLUME RW model.

Finally the impact of the proposed changes to the harbour on coastal sediment transport was assessed based on the results of the wave and flow modelling. Estimates of siltation inside the proposed new harbour were made.

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1. Introduction

1.1 BACKGROUND

Bridlington Harbour in Yorkshire lies on England's east coast, just south of Flamborough Head (see Figure 1.1). The existing harbour is formed by a pair of vertical wall breakwaters. The North Pier forms the harbours eastern boundary, while the South Pier forms its southern wall. A variety of craft currently use the harbour including private yachts, small commercial fishing vessels and day-cruise operators. Inside the harbour the water area is split into three regions by two open-piled jetties; the Chicken Run Jetty projects approx 110m Eastward across the central portion of the harbour, while the Crane Wharf Jetty protrudes about 60m South from the northern wall of the harbour. The layout of the existing harbour is shown in Figure 1.1.

Bridlington Harbour Commissioners (BHC), Yorkshire Forward (YF) and East Riding of Yorkshire Council (ERYC) are working in partnership on the development of the existing harbour and provision of new marina facilities at Bridlington. The proposed developments include construction of a new outer tidal basin on the southern side of the existing harbour and conversion of the existing harbour basin into a marina with water impounded at half-tide level.

HR Wallingford has carried out previous studies of wave and sedimentation assessment in the harbour (HR Wallingford, October 2005 and September 2006) for an earlier proposed scheme. These studies revealed potential problems due to wave resonance in the harbour and sediment deposits near the entrance.

Four potential future schemes have been derived by Wheeler Trevitt (advising BHC) and Atkins (advising ERYC). Yorkshire Forward has commissioned HR Wallingford to carry out an assessment of the likely impact of the four schemes on the waves, flows and sedimentation regime.

The principal features of the new developments are:

- Limited infilling at the western end of the harbour to allow the re-development of the land adjacent to South Cliff Road.
- Demolition of the 'Chicken Run' jetty.
- Impounding of around 80% of the existing harbour to provide dedicated water space for the development of a marina for yachts, power cruisers and ancillary small craft.
- Installation of a floating pontoon system, bunkering and boat lift facilities.
- Reclamation and marine civil engineering construction to provide an additional internal seawall and locked access to the new impounded water area.
- Provision of new piers for the seasonal operation of commercial vessels.
- Extension works to the existing 'listed' North Pier.
- Modifications to the existing 'listed' South Pier in order to retain the impounded water at all states of tide.
- The creation of a new harbour to the south comprising.
- Provision of a new pier to retain new reclaimed land areas and to provide shelter for the new harbour.
- Creation of new sheltered water areas including a tidal fishing/commercial harbour and a half-tide basin for small craft moorings and leisure use.
- Provision of new piers and/or pontoons for fishing and commercial vessels.
- Creation of new reclaimed land along the existing shoreline adjacent to The Spa.

The footprint and internal arrangements of the proposed new commercial basin to the south of the existing harbour are not fixed. Cases 1a, 2a and 3a (Figures 1.2, 1.3 and 1.4) show three different arrangements of the proposed new main pier. Case 1a, (Drg. 310A), shows the probable maximum size of any new works. Case 2a, (Drg. 311A), shows the probable minimum size of any new works. Case 3a, (Drg. 312A), is an intermediate size approximately half way between the maximum and the minimum.

All three cases show an area of impounded water, of different size and configuration, at the west end of the new basin. The interface between this impounded water and the fully tidal section of the commercial basin will comprise a solid pier at full quay level and a ‘half-tide’ gate at the locations shown on the drawings.

The impoundment level for all impounded water is mean tide level.

Case 4 (Drg.313, Figure 1.5), has the same arrangement for the new main pier as Case 2 but differs in that there is no impounded water within the new commercial basin and that there is a rock spending beach at the western end of the new basin.

The four cases are referred to as “Scheme 1a”, “Scheme 2a”, “Scheme 3a” and “Scheme 4” in this report, the existing Layout is referred to as “Existing”.

1.2 SCOPE OF WORK

This report describes Phase 1 of the study carried out by HR Wallingford. The primary purpose of Phase 1 of the study is to undertake wave disturbance and flow modelling and a desk top review of potential sedimentation for the four different arrangements of the extension of Bridlington Harbour, shown as Schemes 1-4, and to report the findings to the partners. Phase 2 studies, not included in this report, may be required to carry out more detailed wave penetration, wave disturbance, flow modelling and sediment transport modelling for the preferred scenario to define in more detail the wave conditions within the tidal harbour, potential siltation patterns, the effects on moorings, marine facilities and marine operations, the impacts on adjacent tidal waters and associated mitigation measures and maintenance requirements.

The key aims of Phase 1 are to:

- Identify potential ‘showstoppers’
- Establish the hydrodynamic and sedimentation characteristics of each case
- Assess wave penetration within the new harbour and identify appropriate mitigation if required
- Assess potential impacts on adjacent foreshore and coastal waters and identify appropriate mitigation if required
- Assess potential sedimentation issues and identify appropriate mitigation if required
- Identify potential pollution problems at the harbour arising from discharge from Yorkshire Water’s two sea outfalls.

1.3 REPORT STRUCTURE

The remainder of this report is structured as follows. Chapter 2 presents the wave impact for the four Schemes. Chapter 3 describes the tidal flow modelling studies, and Chapter 4 summarises the assessment of siltation within the harbour and sand deposition in the vicinity of the harbour entrance. Conclusions arising from this study are reported in Chapter 5.

2. Wave disturbance modelling

2.1 INTRODUCTION

In order to model the wave regime within the proposed new harbour basin and adjacent to the north pier and new south pier, it was proposed to extend the ARTEMIS wave disturbance model used in the previous study "Bridlington Harbour half-tide basin. Wave disturbance modelling" HR Wallingford, 2005, report EX5205 (Reference 1). That report describes the computational wave disturbance modelling of the (then) proposed harbour modifications.

In the present study, the existing ARTEMIS model (see Reference 1) was extended to include all of the existing harbour, the new basin and the coast approximately 100m either side of the harbour. The model bathymetry was based on the existing model bathymetry, supplemented by the Admiralty Chart and the more recent bathymetric survey that has been supplied by Wheeler Trevitt.

A total of four incident wave conditions were run in the model, representing operational conditions from a range of directions. These nearshore wave conditions were taken from the earlier modelling by Posfords described in their report "Yorkshire marina at Bridlington, numerical modelling report, Oct 2000" (Reference 2).

Once the existing harbour layout was modelled, the four versions of the proposed layout - Scheme 1a, Scheme 2a, Scheme 3a and Scheme 4 - shown in Wheeler Trevitt drawings lp1509/310A to 1509/313 (Figures 1.2 to 1.5) – were also tested with the same four wave conditions as the existing layout, in order to enable a comparison to be made. A period scanning run was also carried out for each layout to determine whether the new developments are likely to introduce or reduce resonance effects.

Section 2.2 describes the set up of the wave disturbance model, Section 2.3 displays the model results and Section 5 presents conclusions.

2.2 WAVE DISTURBANCE MODEL

2.2.1 The ARTEMIS wave disturbance model

ARTEMIS is part of the TELEMAC finite element hydraulic modelling system. The ARTEMIS model is based on the finite element solution of the Mild Slope Equation. It was developed by the National Hydraulics Laboratory (Laboratoire National d'Hydraulique – LNH) of the Research and Development Division of the French Electricity Board, Electricité de France (EDF-DER).

ARTEMIS is a linear finite element model, which is used to calculate wave heights in an area of interest corresponding to a given incident wave condition. ARTEMIS includes the effects of depth refraction and shoaling, diffraction due to the seabed and around surface piercing structures and complete or partial reflections from harbour boundaries. The energy dissipation processes of wave breaking and seabed friction are also included in the model. Further details of the model are given in Appendix 4.

Although the ARTEMIS model provides a good first estimate of wave disturbance, in the absence of calibration data, it is intended primarily as a tool for making comparative assessments. The most appropriate use of the model is to compare the behaviour of different model configurations. For more accurate estimates of absolute wave heights, physical modelling is recommended.

2.2.2 Application of ARTEMIS to Bridlington harbour

An ARTEMIS wave disturbance model has been set up to model the harbour. Initially, the model was set up to represent the existing harbour configuration, based on the existing layout in Reference 1. That model was extended to include the coast approximately 100m either side of the harbour. Once the existing layout had been modelled for the extended model area, the model was modified to include the new basin (four different schemes: Scheme 1a, Scheme 2a, Scheme 3a and Scheme 4).

2.2.3 Model coastline

The existing coastline was taken from the existing layout of the previous study (Reference 1), extended either side of the harbour with C-MAP digital Admiralty Chart data.

The coastlines of each of the four versions of the proposed layout have been extracted from Wheeler Trevitt drawings lp1509/310A to 1509/313 (Figures 1.2-1.5).

For each of the four versions of the proposed layout, the lock at the marina entrance was modelled closed in order to examine 'worst case' wave conditions within the outer part of the existing harbour. It is understood that – as part of the operation of the marina – it will be the intention to allow periods of free flow through the lock either side of high water. These periods may vary throughout the tidal cycle (springs/neaps) and will be dependent, among other things, on retained water levels, current speeds through the lock and siltation considerations. It is suggested that these issues might be given further consideration should the design be progressed.

2.2.4 Model bathymetry

The bathymetry for the model of the existing harbour is based on Shoreline Surveys Ltd survey drawings J035/01 and J035/02 (from the Drawing provided by Bridlington Harbour Commissioners). Outside of the survey area, data for the model was supplemented with bathymetry data from CMAP digital Admiralty Charts in the vicinity of Bridlington.

Figures 2.1 to 2.5 show the overall bathymetry of the model for the existing and proposed schemes, as well as the location of analysis points (A1 to A6) taken along a profile to the south of the South Pier These points were used as analysis points to assess the impact on waves affecting the beach to the south of the harbour. The points ran along a line from the coastline to the +0 mCD bathymetric contour. Coordinates of these points are listed below (Table 2.1).

Table 2.1 Profile probe points (National Grid coordinates)

Probe point	X coordinate	Y coordinate
A1	518061	466244
A2	518123	466186
A3	518185	466126
A4	518227	466086
A5	518291	466027
A6	518384	465938

2.2.5 Reflection coefficients

The reflection properties of the boundaries of Bridlington Harbour have been represented in the ARTEMIS model by assigning an appropriate reflection coefficient (Cr) to each of the different boundary types. A reflection coefficient of 1.0 indicates that all the incident wave energy will be reflected, while a lower reflection coefficient indicates that some wave energy will be dissipated.

For each of the four versions of the proposed layout, the reflection coefficient of every vertical or near vertical seawall within the model domain was set to 0.96. Boulders at the south and north pier were assumed to be at the toe of the wall, causing very little effect on waves, at high tide levels, compared to the almost vertical structures.

The reflection coefficients of the rock armoured slopes were calculated using methods developed at HR Wallingford, (Allsop, 1990), which take into account the type of construction and slope of the boundary as well as the incident wave conditions. The reflection coefficients vary depending on the wave condition with an average value of 0.35.

2.2.6 Incident wave conditions

Nearshore wave conditions were taken from the previous study (Reference 1). These wave conditions are listed below (Table 2.2):

Table 2.2 Incident wave conditions at the ARTEMIS boundary

Condition	Hs (m)	Tm(s)	Tp (s)	Dir (°N)
10 in 1 year swell from 90°N offshore†	2.3	5.3	6.9	91‡
10 in 1 year swell from 150°N offshore†	1.9	4.9	6.3	133‡
10 in 1 year local wind from South	1.6	4.0	5.1	155
1 in 10 year swell from 150°N offshore*	4.1	7.1	9.2	131

† As derived by Posford Duvivier (Reference 2)
‡ Calculated by HR Wallingford for previous study (Reference 1)
* Estimated by HR Wallingford based on Posford Duvivier (2000) for previous study (Reference 1)

2.2.7 Water level

All runs were carried out with a still water level equivalent to Mean High Water Springs (MHWS) of 6.1m above CD.

2.3 MODEL RESULTS

2.3.1 Summary of results

The results of the model runs for the existing and the four versions of the proposed harbour for the incident wave conditions displayed in Table 2.1 are presented as colour contour plots of significant wave height in:

- Figures 2.6 to 2.10 for 10 in 1 year swell from 90°N offshore.
- Figures 2.12 to 2.16 for 10 in 1 year swell from 150°N offshore.
- Figures 2.18 to 2.22 for 10 in 1 year wind from 180°N offshore.
- Figures 2.24 to 2.28 for 1 in 10 year swell from 150°N offshore.

Figures 2.11, 2.17, 2.23 and 2.29 show a comparison of the significant wave height (Hs) along the profile defined by probe points A1 to A6, for all the layouts, and for each incident wave condition, in order to investigate the impact on the beach to the south of the harbour.

2.3.2 10 in 1 year swell from 90°N offshore wave condition

Figure 2.6 shows the results for the existing harbour, subject to 10 in 1 year waves from the East. The North Pier provides a good degree of shelter and the harbour is relatively calm for this condition. Wave heights are typically in the range Hs = 0 – 0.4m, rising to Hs = 0.4 – 0.8m as waves run along the inside of the North Pier.

Figures 2.7 to 2.10 show the results for each version of the proposed layouts. The wave conditions within the new basin are similar to those experienced in the existing harbour for the existing layout with significant wave heights generally less than 0.4m.

Waves at the new entrance are similar to those experienced at the existing harbour entrance. Scheme 1a (Figure 2.7) provides slightly greater shelter from easterly waves within the entrance area because of a greater overlap of the North breakwater. Scheme 1a also provides better shelter to the area near the lock at the entrance to the new half-tide basin.

Figure 2.11 and Table 2.3 show the significant wave height at the profile of probe locations south of the harbour. This shows the wave height amplification close to the coastline due to reflections from the new Main Pier, which is closer to the profile than the South Pier of the existing layout. Further offshore at Points A2 and A3 there is a slight sheltering effect due to the North Pier extension, especially for Scheme 1a.

Table 2.3 Wave heights at profile probe points for 10 in 1 year swell from 90°N offshore wave condition

Wave condition	Probe point	Distance from coastline (m)	Hs (m)				
			Existing layout	Scheme 1a	Scheme 2a	Scheme 3a	Scheme 4
10 in 1 year swell from 90 offshore	A1	5	1.65	1.87	1.97	1.97	1.97
	A2	90	1.53	1.30	1.49	1.44	1.48
	A3	175	1.82	1.74	1.81	1.80	1.81
	A4	230	1.96	1.92	1.95	1.95	1.95
	A5	320	2.01	2.03	1.99	1.99	1.99
	A6	450	2.07	2.10	2.08	2.08	2.08

2.3.3 10 in 1 year swell from 150ºN offshore wave condition

The 10 in 1 year waves from 150°N offshore for the existing layout (Figure 2.12) give somewhat greater disturbance in the harbour. Wave heights in the range Hs = 0.2 – 0.6m extend over most of the harbour, rising to Hs = 0.6 – 0.8m alongside the Fish Market and as high as Hs = 0.6 – 1.2 along the inside of North Pier.

Figures 2.13 to 2.16 show the results for each version of the proposed layouts. Wave conditions within the new basin are generally similar to those in the existing basin of the existing layout, with Scheme 4 showing an improvement due to the rock spending beach.

For waves from this 150°N, wave reflections occur between the head of the new Main Pier and the North Pier extension, causing a worsening of wave conditions in the entrance, especially for Schemes 1a and 3a. This wave energy reflects into the outer harbour area near the new lock.

Figure 2.17 and Table 2.4 show some increase in wave energy especially close to the coastline due to additional wave reflections from the new Main Pier.

Table 2.4 Wave heights at profile probe points for 10 in 1 year swell from 150°N offshore wave condition

Wave condition	Probe point	Distance from coastline (m)	Hs (m)				
			Existing layout	Scheme 1a	Scheme 2a	Scheme 3a	Scheme 4
10 in 1 year swell from 150 offshore	A1	5	1.17	1.38	1.40	1.41	1.40
	A2	90	1.27	1.28	1.33	1.33	1.33
	A3	175	1.76	1.62	1.70	1.71	1.70
	A4	230	1.72	1.79	1.80	1.80	1.79
	A5	320	1.86	1.96	1.97	1.96	1.96
	A6	450	1.86	1.80	1.84	1.90	1.85

2.3.4 10 in 1 year wind from 180ºN wave condition

The pattern of wave disturbance resulting from the 10 in 1 year wind from the South is shown in Figure 2.18. Despite having the smallest incident wave height tested, this gives a similar pattern of disturbance to that for offshore waves from 150°N, however noticeably greater disturbance is predicted alongside the Fish Market, where Hs = 0.8 – 1.0m.

Figures 2.19 to 2.22 show the results for each version of the proposed layouts. Again, the wave conditions within the proposed new basin are similar to those within the existing harbour in the existing layout, except for Scheme 4 which is calmer with waves generally less than 0.4m.

The short period waves reflect backwards and forwards in the entrance, giving confused patterns of standing waves in the entrance and in the outer harbour area towards the new lock. Scheme 1a seems to give calmest conditions at the entrance to the new basin, whereas Scheme 4 dissipates the energy best giving lower waves within the new basin.

Figure 2.23 and Table 2.5 show the significant wave height at the profile of probe locations south of the harbour. Whilst all the layouts give a slight increase in waves near the coast (locations A1 and A2) due to wave reflections, Scheme 1a differs from the rest of the proposed layouts by also showing an increase in wave energy at locations A5 and A6. This is because the straight, vertical face of the Main Pier wall is perpendicular to the waves for this wave direction.

Table 2.5 Wave heights at profile probe points for 10 in 1 year swell from 180°N offshore wave condition

Wave condition	Probe point	Distance from coastline (m)	Hs (m)				
			Existing layout	Scheme 1a	Scheme 2a	Scheme 3a	Scheme 4
10 in 1 year local wind from South	A1	5	0.79	0.93	0.94	0.94	0.94
	A2	90	1.26	1.40	1.44	1.43	1.43
	A3	175	1.37	1.21	1.27	1.28	1.27
	A4	230	1.48	1.36	1.46	1.45	1.47
	A5	320	1.40	1.66	1.34	1.28	1.31
	A6	450	1.47	1.63	1.42	1.40	1.37

2.3.5 1 in 10 year swell from 150ºN offshore wave condition

Figure 2.24 shows the results for the existing harbour, subject to 1 in 10 year waves from 150ºN. For this extreme wave condition, waves of up to 2m penetrate along the inside of the North Pier. The waves are of longer period than the 10 in 1 year waves from 150 °N and set up some standing wave patterns across the harbour to the Fish Quay giving values of Hs within the basin between 0.6m to 1.25m.

Figures 2.25 to 2.28 show the results for each version of the proposed layouts. Figure 2.25 shows that Scheme 1a gives the most sheltered wave conditions in the outer harbour near the new lock, however waves in the harbour entrance are as bad, if not worse than the other layouts because of the waves reflecting from the vertical head of the new Main Pier.

Figures 2.26, 2.27 and 2.28 show a similar behaviour at the harbour access, but with worse wave conditions within the basin for Schemes 2a and 3a where standing waves are set up across the narrower part of the basin, driving a response in the rest of the basin. Scheme 3a dissipates this energy to some degree but is still worse than Scheme 1a. In Scheme 4, the rock spending beach is effective at reducing the standing waves in the basin leading to the calmest conditions in the basin for this layout. For Schemes 1a and 4, the waves in the new basin are generally calmer than in the existing harbour basin in the existing layout.

Figure 2.29 and Table 2.6 show the significant wave height at the profile of probe locations south of the harbour. All the layouts give a slight increase in waves near the coast (location A1) due to wave reflections, but there is little change further offshore.

Table 2.6 Wave heights at profile probe points for 1 in 10 year swell from 150°N offshore wave condition

Wave condition	Probe point	Distance from coastline (m)	Hs (m)				
			Existing layout	Scheme 1a	Scheme 2a	Scheme 3a	Scheme 4
1 in 10 year swell from 150 offshore	A1	5	1.73	1.89	1.90	1.89	1.90
	A2	90	1.76	1.74	1.75	1.75	1.75
	A3	175	2.22	2.17	2.17	2.18	2.17
	A4	230	2.50	2.47	2.46	2.44	2.46
	A5	320	2.67	2.73	2.70	2.68	2.69
	A6	450	3.01	2.98	3.03	3.00	3.03

2.3.6 Period scanning results

The results for the period-scanning runs examining the four versions of the proposed harbour are presented in Figures 2.31 to 2.34 as colour contour plots of wave amplification factors. The equivalent results from the existing harbour are presented in Figure 2.30 for comparison. The wave amplification factor is a measure of the degree of amplification (or damping) of wave heights at the specific wave period in question. While there may be amplification of energy at a particular period, it does not follow that the whole energy spectrum of a wave with that mean or peak period is similarly amplified.

There are potentially strong resonant patterns across much of the period range tested, with resonance near the entrance at periods even shorter than 8 seconds, for the proposed schemes. The existing layout does also show resonance, but this is mainly restricted to the inside of the North Pier or for longer wave periods (25-30 s).

For shorter period waves (<15s), all layouts show some resonance at different periods depending on the dimensions of the harbour. Layout 4, with the rock spending beach is least affected and gives a similar response to the existing harbour basin; however Layouts 1a, 2a and 3a exhibit potential resonant responses worse than in the existing harbour basin. Layout 1a is generally slightly better than Layouts 2a or 3a for this period range; however, with a basin that is wider near its entrance, Layout 1a experiences strong resonance for periods of 15 or 16 seconds.

All the proposed layouts show strong resonant behaviour for waves of periods longer than 20s. In Scheme 4 the rock spending beach dampens out the resonance to some degree. Generally for these longer periods, Scheme 2a is the worst affected.

It must be pointed out that all the walls within the harbour domain were assumed vertical, with a reflection coefficient of 0.96. Moreover, the rectangular shapes of the four versions of the proposed harbour help to give strong resonance patterns for the majority of the periods tested.

3. Tidal flow modelling

3.1 INTRODUCTION

Tidal flows in and around Bridlington Harbour were modelled for the existing situation and the four proposed layouts, to examine the impact of the four schemes on flow conditions and for input to an assessment of the change to the sediment transport regime in the vicinity of the harbour entrance. For this study, it was decided that tidal processes would dominate the flows, and accordingly, wind action was not simulated, nor was any flow from the Gypsey Race. The lock gates in the proposed layouts were modelled as shut as they are only expected to be open around high water when flows are small. In addition, this assumption gives the minimum ebb flow and therefore least scouring of the harbour mouth.

3.2 FLOW MODEL SET-UP

The two-dimensional (2D) depth-averaged model TELEMAC 2D was used for this study. The model is part of the TELEMAC hydrodynamic modelling suite. TELEMAC was originally developed by the National Hydraulics Laboratory (Laboratoire National d'Hydraulique – LNH) of the Research and Development Division of the French Electricity Board, Electricité de France (EDF-DER). The modelling system uses a finite element grid, enabling accurate representation of complex coastlines and detailed bathymetry with maximum computational efficiency. Full details of TELEMAC-2D are provided in Appendix 1.

A tidal flow "Local model" of Bridlington Harbour was set up. According to the previous study (HR Wallingford, September 2006), the model extends from Scarborough in the North to near Cromer in the South. The offshore boundary of the model was set in deep water approximately along a streamline identified from the results of earlier studies (HR Wallingford, September 1999).

The existing HR Wallingford TELEMAC model of the Southern North Sea (HR Wallingford 2002 and 2006), named "Global model" in this report, was re-commissioned to provide the boundary conditions of the "Local model".

Figure 3.1 illustrates the extent of the local model areas, as well as the location of the relevant Admiralty tidal diamonds (Charts 1190, 1503 and 1882) used for calibration of the model.

The horizontal co-ordinate system is the UK National Grid, while the vertical datum is Ordnance Datum Newlyn (ODN); this vertical datum is 3.35m above local Chart Datum at Bridlington.

The bathymetry for the model of the existing harbour was based on Shoreline Surveys Ltd survey drawings J035/01 and J035/02 (from the Drawing provided by Bridlington Harbour Commissioners). Outside of the area of these surveys, data for the model was supplemented by bathymetry data from CMAP digital Admiralty Charts in the vicinity of Bridlington.

The bathymetry and model mesh in the harbour area are shown in Figure 3.2 for the existing harbour layout. The bathymetry and model mesh for the four schemes are presented Figures 3.3 to 3.6.

The elevations and the currents were extracted from the “Global model” at 13 points and applied throughout the open boundary of the “Local model” with “soft conditions”. It means that the imposed elevation is proportional to the “Global model” elevation corrected with the difference between the currents of the “Local” and “Global” models. The initial conditions of the “Local model” were also extracted from the Global model.

A mean spring tidal cycle was modelled.

3.3 FLOW MODEL CALIBRATION

The model was carefully calibrated and verified against Admiralty diamond current data (Charts 1190 and 1503) across the model domain (Figure 3.1) and a good degree of agreement obtained for the offshore results (See Appendix 2).

Near shore, a further comparison was made between the model output and data from the nearest Admiralty diamond to Bridlington (Diamond A, Chart 1882). The comparison is presented in Figure 3.7. The agreement between the model and diamond data is generally good. Flow directions are well reproduced while the magnitude of the speed is similar. However there is a phase difference between the model results and the Admiralty chart data. These results are similar to those obtained in the previous study (HR Wallingford, September 2006).

On the basis of the model reproducing both the large scale current patterns and demonstrated agreement with the nearest tidal diamond, the model was considered to be suitably calibrated for use in this study.

3.4 FLOW MODEL RESULTS

Following calibration, the model results for the spring tide conditions were processed and analysed to provide flow vectors at the time of peak flood and ebb current and time-histories of currents at strategic locations.

3.4.1 Comparison of the time-histories

For reference and comparison with the proposed layouts, the locations of the 10 time-histories of tidal currents are shown in Figure 3.8. The time-histories plotted in Figures 3.9 to 3.18 show that:

- **Points A and B:** the magnitude of the current speed is significantly decreased during peak ebb and flood for Scheme 1a (Point A: 0.2m/s vs. 0.25m/s for the Existing and Point B: 0.15m/s vs. 0.3m/s for the Existing) but stays constant over the high tide (0.15m/s vs. 0.08m/s for the Existing). For the other schemes, the peak flood currents are decreased but the ebb currents are slightly increased; the direction of the current is mostly Eastwards and Westwards for all the schemes; for Point B the direction of the currents for Scheme 1a varies between North and South-East; there is no real difference between Scheme 2a and Scheme 4.

- **Points C and D:** the current speed is increased for all the schemes during peak ebb and flood, the greatest increase is for Scheme 1a (speeds are 0.1m/s greater than for the Existing); there is no significant modification of the directions between the Existing and the four Schemes; there is no real difference between Scheme 2a and Scheme 4.

- **Point E**: for Schemes 2a, 3a and 4 the current speed is increased (0.1m/s greater than the Existing during peak ebb); the Scheme 1a is identical to the Existing for the flood but there is no current (speed < 0.05m/s) during the ebb; directions are very similar for all the cases except for Scheme 1a during the ebb.

- **Points F and H:** the current speed is decreased for all the schemes (Point F: 0.15m/s vs. 0.3m/s for the Existing); the directions during the ebb are southwards for all the schemes; the directions between Scheme 2a and Scheme 4 are quite different during the flood, there is thus an important influence of the half tide gate at these locations in the new harbour entrance.

- **Points G and I:** the current speed is decreased for all the schemes (Point I: 0.1m/s during peak flood vs. 0.35m/s for the existing) and almost null during the ebb (Point G was 0.4m/s for the Existing at peak ebb).

- **Point J:** there is no significant modification of the flow between the existing and the four schemes, except that the peak ebb speeds are greater.

The comparison of the different time series show that Scheme 1a has the most noticeable impact on the tidal circulation near the harbour, all the schemes considerably decrease the current speed within the entrance of the existing harbour and the half tide gate does not seem to much influence the current speed.

3.4.2 Comparison of the vector plots

The vector plots of the currents show the difference between the existing and new tidal circulation for each scheme during peak ebb (Figures 3.19 to 3.26) and peak flood (Figures 3.27 to 3.34). Flows for the existing layout are shown as blue vectors, whereas the flows with the scheme are shown in red vectors. For each layout, on both flood and ebb, two plots are presented: one showing the wider area and one zoomed in to show the detail in and around the harbour.

Generally speaking, the wider offshore circulation is not influenced by the harbour development during the peak ebb and flood (Figures 3.19, 3.21, 3.23, 3.25, 3.27, 3.29, 3.31 and 3.33).

During peak ebb (Figures 3.20, 3.22, 3.24 and 3.26), the most important differences in the circulation, between the existing and the four schemes are:

- the absence of currents inside the marina because of its closure and the decrease of the current speeds (< 0.01m/s vs. 0.08m/s for the existing) in the eastern part of the marina (between the existing North Pier and the marina lock). Should the lock be operated to allow "traffic free flow" either side of high water, flows in this area, and in the harbour entrance will increase.
- very weak currents (< 0.025m/s) inside the new southern harbour extension instead of the 0.15m/s eastward currents in this area in the existing layout.
- the generation, inside the harbour, of a southward flow out of the harbour along the extension of the existing North Pier for the four schemes.
- the diversion of flows eastward along the new southern pier and northeastward around the end of the north pier extension. This leads to an acceleration of the currents close to the new harbour entrance. Scheme 1a, with its longer North Pier extension causes a diversion of the flow over a larger area than the other layouts.

During peak flood (Figures 3.28, 3.30, 3.32 and 3.34), the most important differences in the circulation, between the existing and the four schemes are:

- the absence of currents inside the marina because of its closure (existing currents are quite strong, 0.15m/s) and the decrease of the current speeds (< 0.01m/s vs. 0.15m/s for the existing) in the eastern part of the marina (between the existing North Pier and the marina lock). Currents in the new Southern basin are also weak (< 0.05m/s).
- the deviation of the main south-westward jet toward the south of the existing harbour entrance with an acceleration of the currents close to the new harbour entrance .
- the re-location of the gyre generated at the entrance of the existing harbour to form a new gyre off the entrances of each of the four schemes. The gyre in Scheme 1a extends furthest because of the longer extension to the North Pier. Schemes 2a and 4, with the set back breakwater, draw more of the flow from this gyre into the harbour.
- the generation, inside the harbour, of a northward flow into the harbour along the extension of the existing North Pier for the four schemes.
- a decrease in the current speeds along the outside of the new southern pier, outside of the harbour.

Figures 3.35 and 3.36 show colour contour plots of the current speeds at peak ebb and peak flood for the existing harbour and each of the proposed Schemes. Each of the proposed Schemes gives reduced currents in the entrance compared with those experienced in the existing harbour entrance. As the flow diverts around the North Pier, peak current speeds reach about 0.5m/s which is approximately the same speed as flows past the existing North Pier in the existing layout. These accelerated flow speeds are, however, experienced over a wider area compared with the existing situation.

3.5 IMPACT OF THE TWO OUTFALLS

In order to investigate potential pollution problems at the proposed harbour arising from discharge from Yorkshire Water's two sea outfalls, the PLUME RW 2D model was used.

PLUME-RW represents pollutant discharges as regular releases of discrete particles. These particles move in response to tidal currents simulated by TELEMAC-2D and turbulent motions (For a complete description of the PLUME RW model, see Appendix 3).

The PLUME RW 2D model was set-up for both the existing flow conditions and with the four schemes for 2 different sources at locations corresponding to the ends of Yorkshire Water's long and short sea outfalls south of the harbour.

Figures 3.37 to 3.46 show the dispersion of the discharge water from the outfalls at peak ebb and flood for the existing layout and each of the proposed layouts.

The results of these simulations show that, for the existing conditions and the four schemes, the discharge from the long sea outfall never affects the harbour.

Water discharged from the short sea outfall is shown to remain close to the coast and enter the existing harbour. On the ebb, the discharged water carried northwards, past the harbour entrance and around the harbour. On the flood the water flows back southwards and the eddy at the harbour entrance carries some of it into the harbour.

Each of the proposed harbour layouts show a similar behaviour with discharged water from the short sea outfall carried into the new southern harbour basin. The significance of this will depend on whether the discharge from the short sea outfall is likely to be polluted, however the proposed Layouts do not seem to any worse affected than the existing harbour.

4. Sedimentation assessment

4.1 INTRODUCTION

In this project the scope of work in respect of sedimentation was to carry out a desktop assessment of sedimentation issues drawing on the results of the flow modelling, to enable a relative comparison of the potential sedimentation processes for each of the layouts tested.

The approach adopted followed the same methodology applied in the earlier studies undertaken by HR Wallingford on behalf of Bridlington Harbour Commissioners, in the form of detailed tidal flow modelling and desk assessment of sedimentation (taking into consideration wave effects from the companion wave modelling studies where appropriate). Using the information arising from the earlier studies in respect of the existing maintenance dredging requirement for the harbour, estimates of the potential future maintenance dredging requirement have also been inferred.

In addition, the flow modelling results were also interpreted to identify potential for further coastal impacts along shorelines adjacent to the Harbour; although it should be borne in mind that a full coastal assessment will require littoral drift analysis which is the subject of more detailed studies to follow at a later date.

4.2 SEDIMENT TRANSPORT PATHWAYS - EXISTING CONDITIONS

The previous study undertaken by HR Wallingford (as described in HR Wallingford report EX5266) highlighted the presence of a well-defined large flood-tide gyre to the south of Bridlington Harbour which results in an easterly current running along the outside face of the South Pier. These patterns were reproduced in the present study.

Hence on flood tides there is a strong current running south alongside the North Pier, and corresponding easterly current running along the south pier. On the ebb tide the easterly current persists along the South Pier, whereas the general tidal stream then detaches from the North Pier leaving a relatively quiescent area to the north and east of the North Pier. The consequence of this flow pattern is that the residual *potential* sediment transport pathways are one of net southerly transport along the outer face of the North Pier, and net easterly transport along the South Pier. Whether such transport is realised depends on the supply, and whilst the littoral drift supply to this zone is not the subject of this study, it is noted that the bathymetry contours do not deviate significantly to the south of the harbour whereas on the north side of the harbour there appears to have been general accretion (suggesting a net southerly drift at this site). Other processes (e.g. wave reflections and mach-stem effects) may have additional localised effects on the nearshore seabed levels to either side of the harbour piers.

Hence on the flood tide it is likely that some sediment may pass along the North Pier and beyond, effectively supplying the shoal area known as The Canch. Locally strong easterly currents running along the South Pier, and past the end of the North Pier tend to sweep sediment away from the structures, occasionally causing The Canch to be locally shallower near to the North Pier.

It is reasonably expected that the proposed developments will alter the current patterns mainly by way of transposing the regime southward. Given the findings from the previous studies, it is also anticipated that the degree of overlap between the North and South Pier (which depends on the various schemes proposed) may significantly affect the flow (and sedimentation) regime. It is also considered possible that the larger basin would give rise to greater tidal exchange so that the entrance may experience stronger currents that could have the beneficial effect of sweeping this area clear of accumulation. Operating the lock gates to give a period of “traffic free flow” around high water would further increase the tidal exchange and the additional flow from the Gypsey Race may also occasionally help to keep the entrance clear.

The results of the flow modelling were therefore interpreted to investigate the effects of the proposed developments on the tidal flow regime with the aim of addressing the above (and any other) points.

4.3 SEDIMENT TRANSPORT PATHWAYS – DEVELOPMENT OPTIONS

The flow modelling simulations indicate that the proposed extension to the North Pier and additional South Pier will have a significant effect upon local tidal streams, with the general flow pattern being displaced southwards. The strong flood current extends along the extended North Pier, and the gyre at the new entrance to the harbour persists giving an easterly current along the (eastern end) of the South Pier. On the ebb tide the current runs along the South Pier and is deflected around the tip of the North Pier. There is a notable current at the harbour entrance on filling and emptying, which will clearly depend on the volume of the basin (so is affected by the presence of impounded areas and half-tide basins, etc) and on the ebb tide the flux of water out of the harbour tends to enhance the easterly jet away from the tip of the North Pier so that the quiescent zone on the seawards face of the North Pier during this phase of the tide is also maintained (as in the existing scenario).

The volume of water entering and leaving the basin over the spring tide simulation that was performed is provided in Table 4.1 below, indicating that all the schemes will lead to an increase in the tidal volume of the harbour, with Layout 1a giving rise to the greatest increase in volume of average (over the tide) of 36%. Operating the lock gates to give a period of “traffic free flow” around high water would further increase the tidal volume.

Table 4.1 Mean spring tide volume of water entering and filling the harbour

	Volume in m^3
Existing	222,975
Layout 1a	312,684
Layout 2a	262,172
Layout 3a	263,550
Layout 4	287,008

On the basis of the above discussion it is anticipated that a new Canch and Gyle system will develop, and that the Canch will occupy an area to the south of the extended North Pier tip by a distance approximately given by the present configuration. The greater flux of water into and out of the larger harbour is, however, expected to give rise to a slightly deeper new Gyle channel, which should aid navigability.

What are the relative pros and cons of the various schemes tested? In general terms it is considered that the effects of the various schemes on the flow (and hence sedimentation) patterns are unlikely to be the governing factor in scheme choice (space considerations and wave agitation being likely to be more significant). It is noted that for the Schemes 2a, 3a, 4, with a stepped South Pier, the flood gyre at the harbour entrance simply migrates to fill the space created by these alternative schemes. On the ebb tide the flow runs along the South Pier, and in the case of the stepped schemes, detaches, continuing east past the tip of the North Pier. It is possible that a bar will form from the "step" of Schemes 2a, 3a, 4, and that this bar may extend across toward the harbour entrance and thereby pose a threat to navigation. On this basis Scheme 1a is considered favourable on sedimentation grounds since it generates the least complex gyre (and potential sedimentation) patterns. That said, none of the schemes tested are considered to be "showstoppers". Operating the locks to allow a period of "traffic free flow" is unlikely to significantly alter the possibility of bar formation as it would be carried out around high water. Flows from the Gypsey Race would occasionally help to produce some scour to help keep the Gyle clear.

In terms of harbour sedimentation, the previous study estimated that approximately ¾ of the siltation within the harbour arises from marine sources, with the remaining ¼ arising from the Gypsey Race. A larger harbour will have a proportionately greater tidal volume filling and emptying each tide, in proportion to the increase in the area. Hence the volume of harbour siltation arising from marine sources should be expected to increase in proportion to the additional area, with the contribution from the Gypsey Race remaining largely unchanged (it is assumed that all material from the Gypsey Race is trapped within the harbour). A pro rata increase in siltation in relation to the increase in the tidal volume is a sensible estimate of the increase in volume of siltation from marine sources. On past figures of maintenance dredging from BHC (estimated to be 6,000m^3/year from marine sources, and 2,000m^3/year from the Gypsey Race) this would amount to a new volume of order 8,000m^3/year from marine sources for Layout 1a plus 2,000m^3/year from the Gypsey Race giving a new annual maintenance commitment of order 10,000m^3/year. The other schemes would give slightly lower infill from marine sources. As stated above, it is likely that the new harbour entrance would require infrequent dredging of silt (due to the relatively high currents), with the volume tending to settle out relatively evenly over the basin area. If the lock gates are operated to allow "traffic free flow" around high water, this would allow a small amount of additional sediment laden water to enter the inner basin, giving a further small increase in the overall maintenance commitment, depending on the length of time on the flood tide that the gates were open.

In terms of potential coastal impact, there does not appear to be any significant benefit of one scheme over another. It is likely that bypassing of the present North Pier occurs (with sediment moving southward), and since the extension of the North Pier is approximately along the seabed contour (rather than running into deeper water) it is expected that this bypassing will continue. There may be a short period following construction during which sediment moving south infills the present channel associated with the Gyle, but this is expected to be relatively short-lived (ie months) before the transport of sediment passes on beyond the tip of the new North Pier. To the south of the harbour, it is anticipated that the beach will evolve in a similar manner to the present scenario (ie relatively little impact apart from immediately adjacent to the South Pier, where wave reflections are likely to make the area more energetic and thereby give rise to a degree of beach lowering.

5. Conclusions

Conclusions arising from this study are as follows:

5.1 WAVES

The existing and proposed harbour layouts have been modelled using the ARTEMIS wave disturbance model. Incident waves, each expected to occur 10 times, on average, per year have been simulated for a range of offshore wave directions or local wind conditions. In addition, period-scanning runs have been conducted for each layout to investigate the possible resonant response of the harbours.

Each of the layouts provides good shelter from waves from 90 ºN with wave conditions inside the new basin being similar to conditions presently experienced in the existing basin. Waves at the new entrance are similar to those experienced at the existing harbour entrance. Scheme 1a provides slightly greater shelter from easterly waves within the entrance area because of a greater overlap of the North breakwater. Scheme 1a also provides better shelter to the area near the lock at the entrance to the new half-tide basin.

Waves from 150 ºN and 180 ºN penetrate more directly into the harbour. Wave conditions within the new basin are generally similar to those in the existing basin of the existing layout, with Scheme 4 showing an improvement due to the rock spending beach.

For waves from these directions, wave reflections occur between the head of the new Main Pier and the North Pier extension, causing a worsening of wave conditions in the entrance, especially for Schemes 1a and 3a. This wave energy reflects into the outer harbour area near the new lock.

South of the harbour there is some increase in wave energy due to additional reflections from the new South Pier, but only within 50-100m of the coast. For southerly waves, Layout 1a with a straight South Pier perpendicular to the waves also causes increased waves further offshore near the low tide mark.

Period scanning results show potentially strong resonant patterns across much of the period range tested (3-30s), with resonance near the entrance at periods even shorter than 8 seconds, for the proposed schemes. The existing layout does also show resonance, but this is mainly restricted to the inside of the North Pier or for longer wave periods (25-30s).

Layouts 1a, 2a and 3a exhibit potential resonant responses worse than in the existing harbour basin at different periods depending on the dimensions of the harbour. Layout 4, with the rock spending beach is least affected and gives a similar response to the existing harbour basin. The rectangular shapes of the basins and near vertical walls make the proposed harbour schemes susceptible to resonance. Some form of wave dissipation such as the rock spending beach in Layout 4 is recommended.

5.2 FLOWS

With the existing harbour, the ebb current flows eastward along the outside of the South Pier before being concentrated past the entrance, accelerating north-eastwards around the end of the North Pier. This leaves a quiescent area along the outer face of the North

Pier. On the flood tide, the southward flow past the end of the North Pier then forms a clockwise gyre in the harbour entrance.

The main effect of introducing the new Layouts is to shift the pattern of flows southwards so that they are now relative to the end of the extended North Pier. Peak current speeds flowing around the end of the North Pier extension are about 0.5m/s which is approximately the same speed as flows past the existing North Pier in the existing layout. These locally accelerated flow speeds are, however, experienced over a wider area compared with the existing situation.

Each of the Schemes of harbour extensions only has a local effect on flows, with current speeds and directions 500 m away from the harbour being almost identical to those experienced with the existing layout. Scheme 1a, with its longer North Pier extension causes a diversion of the flow over a larger area than the other layouts.

Each of the proposed Schemes gives reduced currents in the entrance compared with those experienced in the existing harbour entrance.

Dispersion of water discharges from Yorkshire Water's two outfalls south of the harbour was studied. The results of these simulations show that, for the existing conditions and the four schemes, the discharge from the long sea outfall never affects the harbour. Water discharged from the short sea outfall is shown to remain close to the coast and enter the existing harbour. Each of the proposed harbour layouts show a similar behaviour with discharged water from the short sea outfall carried into the new southern harbour basin. The significance of this will depend on whether the discharge from the short sea outfall is likely to be polluted, however the proposed Layouts do not seem to any worse affected than the existing harbour.

5.3 SEDIMENTATION

On the flood tide some sediment passes along the North Pier of the existing harbour, effectively supplying the shoal area known as The Canch. Locally strong easterly currents running along the South Pier, and past the end of the North Pier tend to sweep sediment away from the structures, leaving The Canch as a remote feature on the seabed separated from the North Pier by a shallow channel (The Gyle).

With each of the proposed Schemes, it is anticipated that a new Canch and Gyle system will develop, and that the Canch will occupy an area to the south of the extended North Pier tip extending a similar distance relative to the new tip as it does from the existing North Pier tip. The greater flux of water into and out of the larger harbour is, however, expected to give rise to a slightly deeper new Gyle channel, which should aid navigability.

It is noted that for the Schemes 2a, 3a, 4, with a stepped South Pier, the flood gyre at the harbour entrance simply migrates to fill the space created by these alternative schemes. On the ebb tide the flow runs along the South Pier, and in the case of the stepped schemes, detaches, continuing east past the tip of the North Pier. It is possible that a bar will form from the "step" of Schemes 2a, 3a, 4, and that this bar may extend across toward the harbour entrance and thereby pose a threat to navigation. On this basis Scheme 1a is considered favourable on sedimentation grounds since it generates the least complex gyre (and potential sedimentation) patterns. That said, none of the schemes tested are considered to be "showstoppers".

In terms of harbour sedimentation, the previous study estimated that approximately ¾ of the siltation within the harbour arises from marine sources, with the remaining ¼ arising from the Gypsey Race. The volume of water entering and leaving the basin over a spring tide is predicted to increase for each of the schemes; the greatest increase being by 36% for Scheme 1a. Hence the volume of harbour siltation arising from marine sources should be expected to increase, with the contribution from the Gypsey Race remaining largely unchanged. Based on past figures of maintenance dredging from BHC (estimated to be 6,000m^3/year from marine sources, and 2,000m^3/year from the Gypsey Race) this would amount to a new volume of order 8,000m^3/year from marine sources for Layout 1a plus 2,000m^3/year from the Gypsey Race giving a new annual maintenance commitment of order 10,000m^3/year. The other schemes would give slightly lower infill from marine sources. It is likely that the new harbour entrance would require infrequent dredging of silt (due to the relatively high currents), with the volume tending to settle out relatively evenly over the basin area.

Should the lock gates be operated to allow “traffic free flow” either side of high water, this will increase the tidal exchange potentially giving additional sedimentation in the inner basin. The additional flows due to the operation of the locks may, however, help to scour the harbour entrance clear. It is recommended that further study of possible operational practices of the locks is carried out at detailed design stage.

In terms of potential coastal impact, there does not appear to be any significant benefit of one scheme over another. It is likely that bypassing of the present North Pier occurs (with sediment moving southward), and since the extension of the North Pier is approximately along the seabed contour (rather than running into deeper water) it is expected that this bypassing will continue. There may be a short period following construction during which sediment moving south infills the present channel associated with the Gyle, but this is expected to be relatively short-lived (ie months) before the transport of sediment passes on beyond the tip of the new North Pier. To the south of the harbour, it is anticipated that the beach will evolve in a similar manner to the present scenario (ie relatively little impact apart from immediately adjacent to the South Pier, where wave reflections are likely to make the area more energetic and thereby give rise to a degree of beach lowering.

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