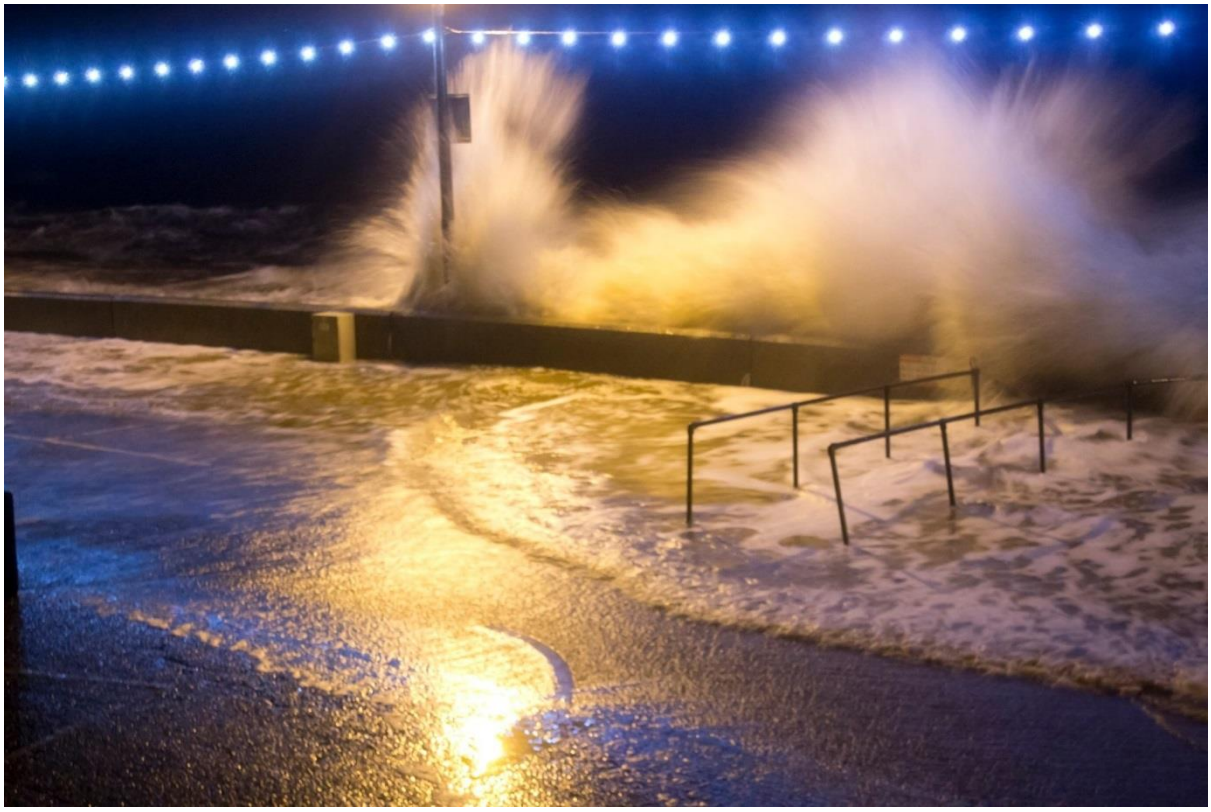
Borough Council of Kings Lynn and West Norfolk

Hunstanton Wave Wall Options



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September 2014

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Hunstanton Promenade Wave Wall Options

1. Executive Summary

1.1. During the December 2013 storm surge, the seaside resort of Hunstanton suffered damage to its seafront assets. The town is presently defended by a concrete sea wall, promenade and wave wall. These were overtopped and properties, the Sea Life Sanctuary in particular, experienced flooding sustaining damages costing around £3 Million. There is also evidence that some the flood boards placed in the gaps in the wave wall failed increasing the flood damage. (Note: The flood boards are the subject of a separate report.)

1.2. Options to reduce overtopping include upgrading the existing wave wall to conform to the wall owned by the Environment Agency to the south and demountable seasonal boards to increase the effective height.

1.3. The Sea Life Sanctuary also appeared to suffer from flows of water entering the property from north and south suggesting that measures to limit and control such flows would be beneficial and these should be considered as immediate short term measures along with refurbishing the flood boards / flood gates in the wave wall.

1.4. The Wash East Coastal Management Strategy recommends reconstruction / refurbishment of the sea walls, part in 20 years and the remainder in 50 years. In the long term, therefore, consideration should be given to enhancing the defences, including raising the height of the wave wall.

1.5. The economic case for significant works is not made. In particular the obvious option to extend the EA style wall northwards has a Benefit : Cost ratio of only 0.08:1 and would only serve to reduce the overtopping by around 25-30%.

1.6. None of the measures will completely eliminate the risks from either surface water or wave overtopping: they will however, reduce them. Further reduction of flooding resulting from wind borne spray could be achieved by the construction of a rock berm in front of the sea wall. This is not considered as one of the options at this stage but could be considered as part of a strategic review of the defences when they require renewal.

2. Background and Context

Policy

2.1. Hunstanton is a seaside resort on the east coast of The Wash. Its estimated population is 4,500 to 5,000. Its main economy is tourism, with over 600 permanently employed in the sector, increasing to 1,300 seasonally. It has been estimated that the tourism economy of Hunstanton is worth around £28 Million per annum.[1,2]

2.2. Coast defence policy is determined through the Shoreline Management Plan[3] published in 2010 and the policy for this frontage is to "Hold the Line". This is confirmed in the draft Wash East Coastal Management Strategy[4], the subject of a recent public consultation, now closed.

Defences

2.3. The main defences consist of a sea wall of varying ages and profiles and a promenade with a low wave return wall at its rear. The frontage is shown in Figure 1. Section A is owned and managed by the Environment Agency (EA). Sections B to G are managed by the Borough Council of Kings Lynn and West Norfolk (BCKLWN).

2.4. The main wall is fronted by a beach that is generally held in place by a groyne field. Beach levels vary widely, but in general display a seasonal cycle of lower winter beaches and higher summer beaches. All elements function together as a defence system. Inevitably though, there are occasions, such as December 2013 when the system is overwhelmed. However, the impact is lessened to the extent that the integrity of each element is maintained. For example, if the boards in the gaps in the wave wall are lost, the effective functionality of the wave wall itself is significantly reduced.

2.5. In Sections B and C the land behind the sea wall is lower than the wall trapping any water that does overtop the defences. There are few, if any, cross walls, and with the defence profile varying along the frontage full advantage cannot be taken of any upgrading. In Section E, north of the Oasis Centre the ground begins to rise and overtopping and flooding become less critical: water can drain back naturally. North of Section F the land is significantly higher and overtopping is even less of an issue, though it is still a hazard to human health and safety and may cause damage to buildings and structures.

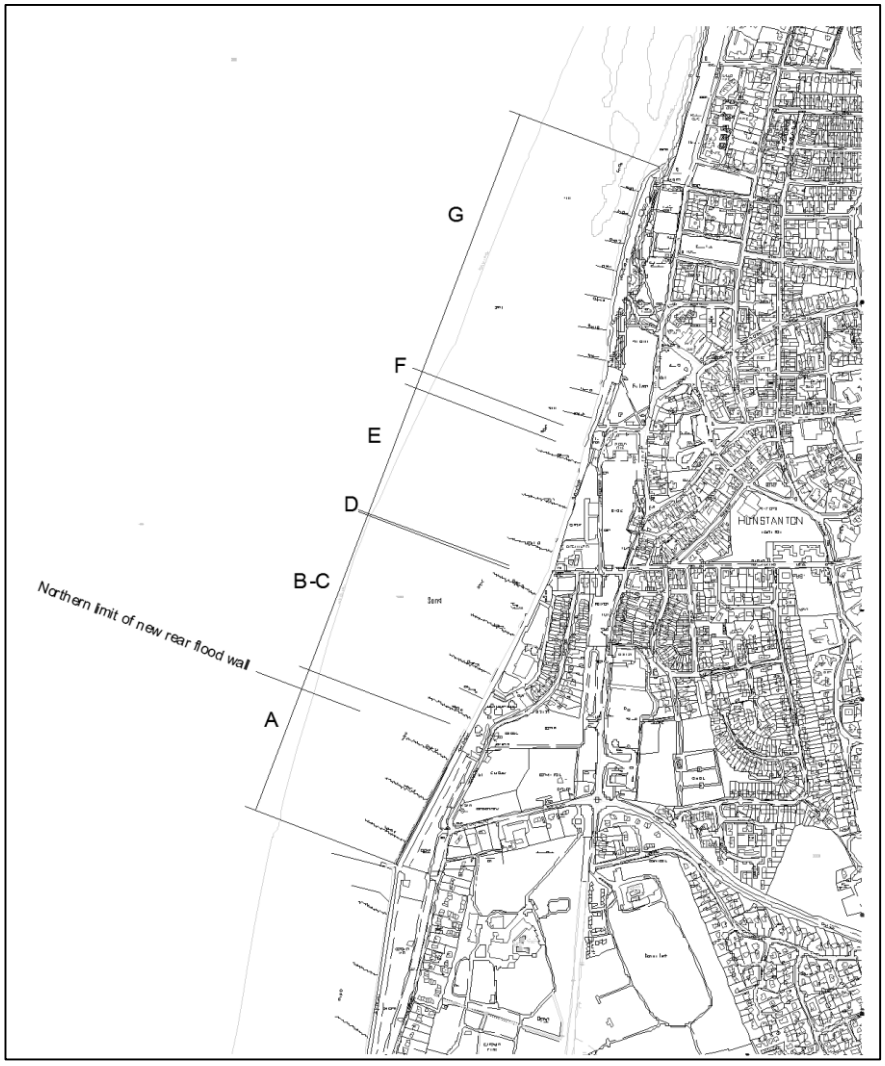

Figure 1 Hunstanton Frontage Defence Lengths

2.6. The storm surge of 05 December 2013 caused considerable damage along much of the east coast of Britain. Within The Wash, the Hunstanton frontage was no exception. The very high water levels, coupled with moderate wave conditions led to considerable wave overtopping of the defences and consequent damage. In particular the Sea Life Sanctuary suffered extensive damage and is not expected to re-open until October 2014, some 10 months after the event. Other property, not immediately behind the sea wall suffered flood damage; e.g. Searles Leisure Resort (Figures 2 – 4).

2.7. Data from the Environment Agency is not available specifically for Hunstanton. The nearest site is Kings Lynn. However, it is possible to derive approximate data using standard differentials. Tidal levels at Hunstanton are generally 0.12 metre below Kings Lynn and applying this differential gives a still water level for the surge of 5.93 metres. This approximates to a 1 in 250 year water level. Information on wave heights is not available. Evidence and eye-witness accounts suggest they were not large.

Figure 2: Overtopping and flooding at the Sea Life Sanctuary

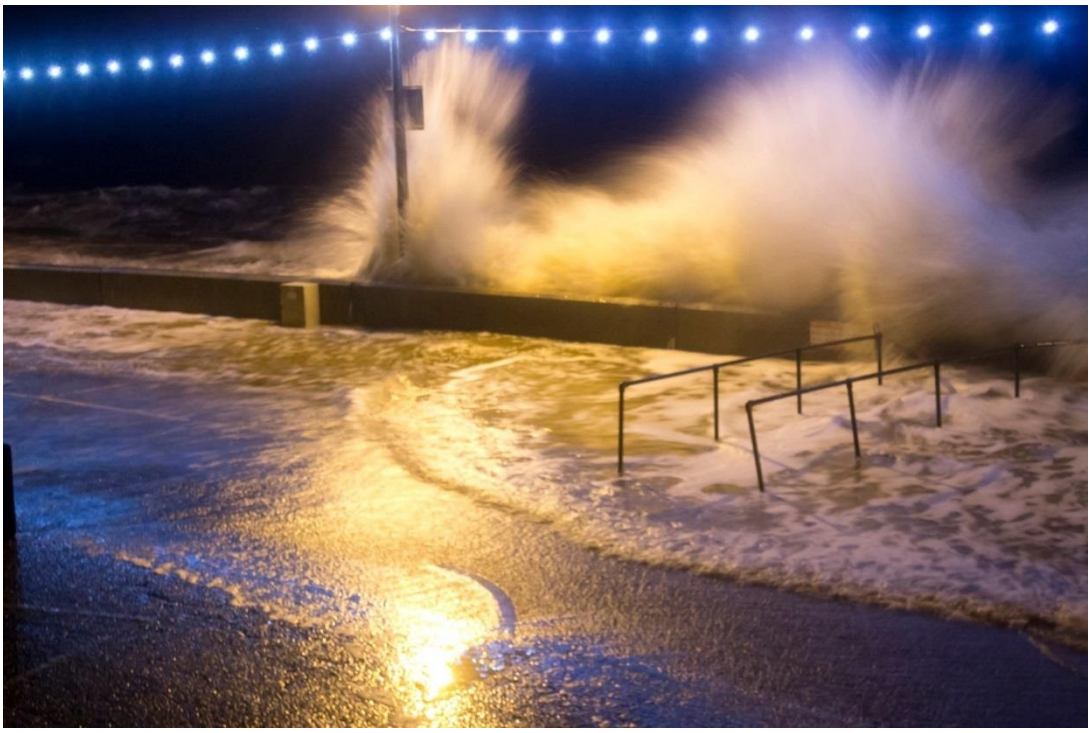

Figure 3: Overtopping and flooding at South Promenade car park

Figure 4: Conjectural route of flood waters affecting Searles Leisure Resort
(Map supplied by Searles Leisure)

2.8. A post storm inspection[5] by Royal Haskoning DHV (RH) considered the damage to the walls and promenade. Repair works identified are being procured separately and are programmed to start in September. In addition, enhancements to the flood gates / flood boards within the wave wall are being treated separately.

2.9. Previous reports (Mott MacDonald, 1995[6] and St La Haye, 2005[7]) reviewed the defence condition. Together with the post storm report[5], these reports obviate the need for any further general assessment of defence condition. This report, therefore considers only the options to reduce wave overtopping within Sections B to E and any further assessment of condition is only associated with the suitability of the wave wall to be modified.

2.10. In 2005 a report[8] commissioned by the EA identified options to enhance the protection from wave overtopping for its defences and this led to the Section A wave wall being raised by 430mm. The defences fronting the town centre, owned by the Borough Council of Kings Lynn and West Norfolk have not been similarly upgraded.

3. Defence Condition

3.1. The St La Haye Ltd[7] and RH[9] surveys of 2005 and 2013 both found the condition of the wave wall generally to be good. That assessment is still valid, although it should be noted that localised variations in profile may make it difficult to form a water tight seal with any demountable defence. However, as discussed later, this is unlikely to have a significant impact on the effectiveness of such a defence.

3.2. The residual life of Sections B and C of the main sea wall and promenade is estimated to be 30 – 50 years; that of Sections D and E somewhat lower, at 10 – 20 years. These estimates all assume that the recommended maintenance works[9] are undertaken. It can therefore be expected that major capital refurbishments or reconstruction of the whole defence structure should be anticipated over the period 2030 to 2050. This is covered in more detail in the Wash East Coastal Management Strategy[4].

4. Standards of Protection

4.1. The standard of protection afforded by a defence is not precise. It can only ever be an estimate as it is dependent on so many factors, such as water level, beach level, wind speed and wind direction. Additionally it is necessary to define what the purpose of the defence is. For example, is it to protect against inundation, erosion or overtopping?

4.2. Previous studies have considered the return periods for water levels and waves for Hunstanton and discovered significant variations. The table below gives the water levels used in the Wash Shoreline Management Plan, being the latest information available. Wave heights are taken from the 2005 report by Babtie, Brown & Root[8] to the EA.

Return Period	Water levels (m OD)	Waves (m)
MHWS	3.65	
1 Year	4.73	1.66
10 year	5.24	2.08
25 year	5.54	2.15
50 year	5.6	2.37
100 year	5.76	
200 year	5.9	
500 year	6.11	

Table 1: Theoretical water levels and wave heights

4.3. The current height of the crest of the Sections B to E wave wall is 6.77m above OD. The promenade level varies between 5.48m and 5.77m above OD. From the above it can be seen that the present defences provide protection in the case of still water up to and above the theoretical 1: 500 year level. However, this situation is hypothetical and unlikely to occur. Water levels of that magnitude are almost certainly to be accompanied by waves and hence the present defences provide protection for only the smallest of storm events; i.e. storms with a return period not much greater than 1 year of either waves or water levels.

4.4. In the recent event (December 2013) it was largely wave overtopping and failure of some of the flood boards within it that led to flooding behind the wall and caused the damage. Overtopping rates are more difficult to calculate as they depend on many factors, not all of which will come into play during any one event. For example, wind and wave direction, beach levels, sea wall profile and promenade width as well as wave wall height will all influence the degree of overtopping.

4.5. It should also be noted that heavy wind borne spray can cause significant flooding and this would not be significantly reduced by any increase in wave wall height. Rather it would require the wave impact to be mitigated by, for example, a rock berm in front of the sea wall.

4.6. Analysis using the formulae in the Eurotop manual[10] suggests a range of overtopping rates for the current walls as shown in Table 2 below.

Water level return period (Yrs)	Still water level (m OD)	Wave return period (Yrs)	Wave height (m)	Wave period (Sec)	Overtopping range (Litre/s/m)
MHWS	3.65	1	2.25	5.8	14 – 39
1	4.73	1	2.49	6.1	49 – 127
1	4.73	50	2.77	6.4	69 – 177
1	4.73	100	2.8	6.3	72 - 175
10	5.24	1	2.6	6.3	80 – 211
50	5.61	1	2.7	6.5	115 – 305
50	5.61	50	3.1	6.8	164 – 416
50	5.61	100	3.16	6.8	172 – 430
100	5.76	1	2.8	6.5	187 – 372
200	5.90	1	3.2	6.9	209 – 527
250	5.93	1	3.2	6.9	212 – 535

Table 2: Indicative overtopping rates of existing walls

4.7. These figures are calculated using idealised profiles adjusted (so far as it is possible) for the specific defences at Hunstanton. It should be noted that the rates will vary along the length of the frontage because of the variability of some the factors noted in 4.4 above.

4.8. Tolerable limits for overtopping vary according to the potential receptor; e.g. the structure itself, vehicles in motion, buildings or pedestrians. Clearly also, the proximity of the receptor to the wall is a very significant factor. The values given in Table 3 below are for receptors in the immediate vicinity unless otherwise stated.

Receptor	Acceptable overtopping rate (Litre/sec/m)
Existing defence structure	20 – 200
Vehicles on highways	10 – 50
Pedestrians	1 - 10
Buildings not set back	1
Equipment set back 5-10m	0.4

Table 3: Suggested limits for overtopping[10]

5. Overtopping Rates

5.1. Options for doing something need to be measured against a baseline of doing nothing. For the purposes of this report options only relate to overtopping either to reduce it or to minimise its impact.

5.2. As stated above the rate of overtopping can be influenced by many factors. The wave wall at the rear of the promenade is only one. However, its role in a system of defence is significant and it is the focus of this report. Other options, such as to raise the promenade or to widen it are possible, but are outside the scope of this report. Other options, undertaken in addition to wave wall enhancement, are included where they are relatively cheap and add to the value of any works to the wave wall.

5.3. The "Do something" options for the wall considered below generally fall into two categories; permanent alterations and demountable (or removable). In the case of the latter bespoke and proprietary systems are compared.

5.4. The aim is to reduce overtopping. Given the uncertainty over the absolute values for calculated rates, the measure that is used is the percentage reduction that can be achieved. This is largely related to the additional height of wall. In this respect it has been necessary to consider the joint probability of events and, as a benchmark, to consider what would be required to reduce overtopping by 50%. For this purpose the same criteria have been used as Babtie, Brown & Root[8], i.e. a 1 in 50 year water level accompanied by the 1 in 1 year wave height. The reasoning used by Babtie, Brown & Root remains valid: waves in The Wash tend to be depth limited and hence water level generally becomes the governing factor.

5.5. A comparison of relative rates of overtopping for different heights of wall is given in Table 4 below. It can be seen that an approximate 50% reduction can be achieved by raising the height of the defences by 1 metre. How this might be best implemented is discussed when considering the options in more detail in Section 6, and when each frontage length has been analysed separately.

	Percentage reduction in overtopping				
Scenario	430mm addition (As EA)	0.5 metre addition	1.0 metre addition	1.5 metre addition	2.0 metre addition
MHWS and 1 year wave	35	40	55	70	80
1 year water level and 50 year wave	28	32	47	62	72
50 year water level and 1 year wave	25	28	49	62	73
200 year water level and 1 year wave	25	28	42	56	67
250 year water level and 1 year wave (approximates to 2013 event)	25	28	42	56	67

Table 4: Percentage reduction in overtopping rates for differing heights of wave wall

6. Permanent and Temporary Solutions

6.1. Permanent solutions

6.1.1. Enlarged Wave Wall

6.1.1.1. For uniformity of appearance and performance, to replicate the EA wall to the south must be the favoured solution. Visually, it does not overly intrude and the comparison photographs below show that attractions and amenities would remain visible to adults from the promenade. It should, perhaps be noted that such a wall would be above the eye level of most children. However, it is not particularly effective as it only reduces theoretical overtopping rates by around 25 to 30%.

Figure 5: Comparison of existing (Left) with EA (Right)

6.1.1.2. The new profile has been constructed around the existing wall which remains as a core. While it has the advantage of low maintenance cost, it has a high capital cost. It is estimated that the cost of such a wall is £1,550 per metre run. This would include the necessary re-positioning of the amenity lighting columns and other furniture. The benefit : cost ratio at 0.08:1 is very low (See section 9) making this option of little economic value.

6.1.2. In a lower cost option, only marginally less effective, the existing wall would remain exposed and the higher profile achieved with a rectangular section pre-cast units suitably fixed to the top of the wall. The estimated cost of this option is £500 per metre run. A variation of this option using small blocks or bricks cemented in place is not recommended. There is a high risk that would become loose in storm conditions creating an added hazard.

6.1.3. The preceding options all involve a solid structure. With advances in technology it becomes realistic to consider alternatives to concrete. A glass topped wall has been used successfully in some places (See Appendix 2). A budget price is around £1,600 per square metre for the glass wall alone. While not relevant for the whole frontage, it may be appropriate for the Oasis Centre

where it is desirable to avoid interfering with the seaward view. Hence this may be an option to consider in the future in conjunction with other refurbishment.

6.2. Temporary or Demountable Solutions

6.2.1. Proprietary solutions

6.2.1.1. Many proprietary flood defence systems are coming on to the market. They have been driven by the series of flood events that have hit the UK in the last 15 or so years. In that time they have improved from simple barriers that are erected to prevent localised flooding to sophisticated systems that are hidden in a purpose made housing and are erected when required.

6.2.1.2. However, in almost all cases these systems are designed to prevent flooding from still or parallel flowing water: they are not designed for wave impact from the sea. The Environment Agency guidance[11] identifies a number of proprietary as well as temporary options (e.g. filled bags) and details their capabilities, vulnerabilities and deficiencies. Given their limitations they are not considered further in this report.

6.2.2. Bespoke solutions

6.2.2.1. The defences already include simple flood boards that are used to infill the gaps in the wave wall (Figure 6). Outside the winter season they are removed to permit free pedestrian passage through the wall. The gaps are only completely sealed when a storm event is forecast. The principle can be extended to an extension of the wave wall, though the boards and their supports should be installed at the start of the winter season as a precautionary measure and left in place throughout the winter simply because of the risk that the work necessary to install them could not be undertaken in the time available in advance of a storm.

6.2.2.2. Two forms are suggested. The first involves bolting steel supports to the top of the wall, with gaps at each lamp column. The second (which eliminates the gaps) involves bolting steel supports to the rear face of the wall. It is probable that in a severe event when the boards are tested that some boards and their steel supports will be damaged and require replacement, but they will have served their purpose. The estimated costs are the same for either form and are around £425 per metre.

6.3. Other Options

6.3.1. Eye witness accounts and evidence from damage caused suggest that once behind the sea defences water was trapped and being unable to flow directly back to the sea, tended to disperse to north and south leading to increased flooding as well as some flooding of properties away from the direct impact of the overtopping.

6.3.2. Evidence suggests that the flooding to the Sea Life Sanctuary was exacerbated by such waters and that Searles Leisure Resort experienced flooding when it was otherwise protected.

6.3.3. Ground profiles suggest that water behind the sea walls will eventually flow towards the south, but that it may become trapped in low spots, such as the Sea Life Sanctuary.

6.3.4. It is recommended that reducing water dispersal such as occurred in December 2013 could significantly reduce consequent damage. This may be effected by some simple cross banks. Although they may not entirely impede flows they may reduce them sufficiently for other measures such as temporary bunds to be put in place. A budget price of £30,000 is suggested.

6.3.5. The suggest locations are shown on the Drawing at Appendix 3. The bank at the north end of Seagate Road would have the additional advantage that surface water would be diverted away from low areas and discharge to the sea.

7. Sectional Consideration of options

7.1. Section B – Fairground

7.1.1. Section B is 117 metres long and is the most southerly section of wall owned by BCKLWN. The primary defence is a concrete sea wall of the top of the beach. Beach level varies. The wall profile consists of an upper vertical section atop a stepped revetment. The promenade is over 10 metres wide. To the rear of the promenade is a 1.15 metre high wave return wall. This wall is breached in a number of places to permit movement between the promenade and the fairground (Golden Sands Amusements) that is immediately behind these defences. Provision has been made to insert flood boards, located within steel channel or 'H' sections and held in place with timber wedges. (Figure 6)

Figure 6: Fairground with wave wall and flood boards

7.1.2. East of the fair ground is the Seagate car park.

Figure 7: Seagate Car Park

7.1.3. Water overtopping the Section B wall in large volumes will spread inland and flow to north and south. There are limited natural return pathways, especially if the flood boards are in place in the gaps. Damage will be sustained to the fairground facilities (rides and stalls). Further damage will be sustained to properties adjoining the Seagate car park, particularly to the south, in severe events with large volumes breaching or overtopping the defences.

7.1.4. The direct benefits are limited and it is generally the adjoining areas that will benefit. There are few permanent structures within the potential benefit area. The exceptions are the amusement arcades, houses in South Beach Road and Searles Leisure Resort. The latter reported flood waters entering from the north, but were short lived. However, including these properties in any economic justification for grant aid may prove difficult as they will have been the justification for the EA work to the south.

7.1.5. To the south (Section A) the wall is owned by the EA. This wall has been raised by 430mm by enlarging the pre-existing wave return wall. Clearly one obvious option is to continue the EA profile northwards. Such a wall would reduce overtopping by approximately 25% in storm conditions. However, it is estimated the cost would be around £181,350 at today's prices. This is likely to be considerably in excess of any direct benefit that can be derived, though it should be considered in conjunction with any major refurbishment of the defences.

Figure 8: EA Section A defences with raised wave wall (front and rear views)

7.1.6. Any immediate enhancement of Section B, therefore, should probably be of lower initial cost. Because it largely protects a seafront fair ground, it is considered that a permanent raising of the wall may not be acceptable visually and would significantly detract from the enjoyment of the fairground, even if it is perceived rather than real. Hence, a removable solution is recommended.

7.1.7. Any permanent raising of the wall would also be likely to necessitate alterations to the promenade lighting. At present the columns are mounted on top of the wave wall: each would need to be removed and resited. A temporary solution could be designed to avoid this additional work and still remain effective. The addition of removable flood boards to Section B as described in 5.2.2.2 is estimated to cost approximately £50,000

7.1.8. It is however recommended that the present bank between the fairground and caravan park is extended west to join with the wave wall and so provide a better impediment to shore parallel flows. For security, if desired, the close boarded fence can be repositioned on the top of the bank. (Figure 9)

Figure 9: Existing fence between Fairground and Caravan Park

7.2. Section C – Sea Life Sanctuary

7.2.1. Section C is 204 metres long and is similar to section B, but with the inclusion of a wave return element at the top of the sea wall at the front edge of the promenade. The rear wave wall is identical to Section B with similar facilities for pedestrians. At one point timber steps have been constructed for a similar purpose, but clearly without the same suitability for all users. The land behind the defences is lower than the promenade preventing water from returning to the sea by gravity. The area is a collecting point for water from surrounding areas as well as direct overtopping or breach. This section, therefore, lends itself to solutions that limit or restrict the influx of water from whatever source.

Figure 10: Sea Life Sanctuary

Figure 11: Walkway between wave wall (R) and attractions (L)
showing timber steps over wave wall

7.2.2. The primary beneficiary of defences within Section C is the Sea Life Sanctuary. Other beneficiaries include a go kart track and crazy golf. During the December 2013 surge event the Sea Life Sanctuary suffered extensive damage. Repair costs are estimated to be in excess of £3 Million and it has been unable to re-open for the 2014 summer season. The other attractions also suffered, but to a lesser extent, being outdoor structures any way, and have re-opened for the season.

7.2.3. The Sea Life Sanctuary also suffered from flows of water from both north and south. It is located on the site of the former boating lake and is at a low point.

7.2.4. The main means of accessing the attractions within Section C is from the Promenade, although there is a walk way immediately behind the wave wall. Hence visibility is an essential factor. This tends to direct away from options that raise the height of the wave wall permanently. An exception to this would take the form of a glass extension to the wall. It is, however, relatively expensive. The estimated cost for the whole of Section C is £326,000.

7.2.5. To avoid this high cost Section C lends itself to a temporary (seasonal) solution. As with Section B obstacles exist, principally the promenade lighting. Again these can be accommodated within a demountable solution. There is, in addition, a set of wooden steps passing over the wall. Incorporating them at the same level in a water-tight arrangement is difficult though not impossible. They can be raised, but any solution that retains them does nothing to lessen their vulnerability to storm damage. It is recommended they be removed: there are gaps in the wave wall within 30 metres in either direction. The estimated cost of flood board extension as described in 5.2.2.2 is £86,700.

7.3. Sections D & E

7.3.1. For the purposes of this report, these two sections are considered together; the differences relate to a 6 metre length of the sea wall (Section D). The total length is 266 metres.

7.3.2. Within this length the ground begins to rise and it is almost entirely above the level of the promenade. Therefore the problems encountered in Section C of trapped water do not occur. Natural pathways for water to escape exist, though water escaping south will cause flooding in the adjoining Section C. The usage of the land behind the wall is predominantly open ground or car park, but with one notable exception, the Oasis Leisure Centre.

Figure 12: Oasis Leisure Centre

7.3.3. Except for the Oasis Centre there is little or no economic benefit to be gained from preventing overtopping of this section, other than to prevent water flowing to adjoining sections, with consequent damage to properties in these sections. Therefore it is recommended that solutions in this section focus on preventing movement of water, particularly to the south towards the Sea Life Sanctuary. They should also seek to ensure that there are clear pathways for water to return to the sea as waves and tides permit.

7.3.4. The Oasis Leisure Centre within this section can be treated separately. The basic form of the defence structure is as the remainder of the section, but since the floor level of the Centre is approximately 225mm above the top of the wave wall, two courses of brickwork have been added to the wall raising it by 225mm (Figure 13).

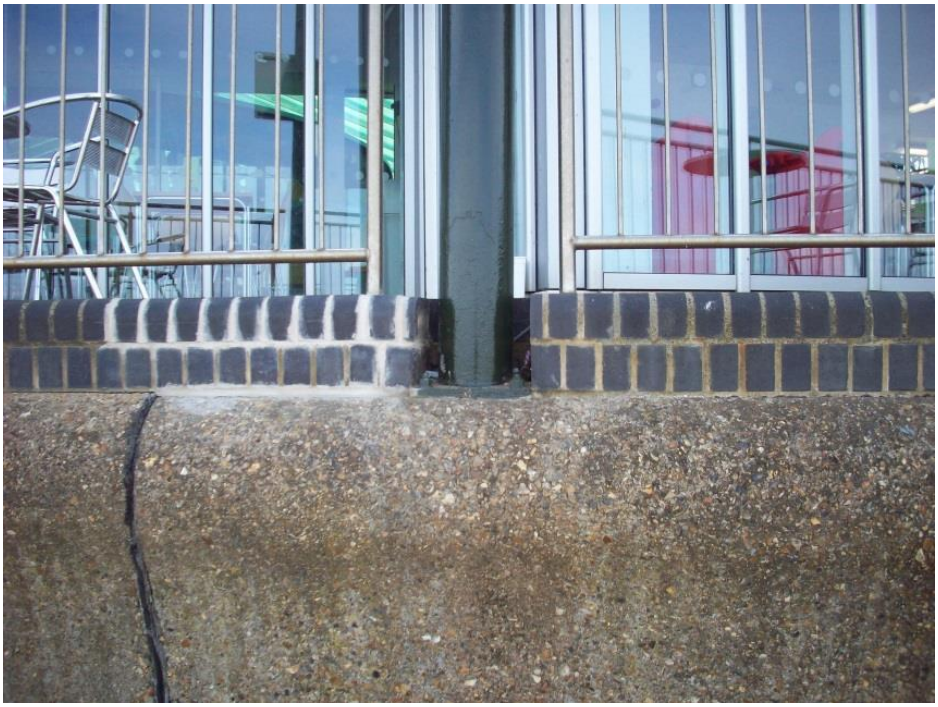

Figure 13: Oasis leisure Centre – detail of railings, lamp column and brickwork

7.3.5. In the 2013 event, the building's North-west corner suffered some damage to doors with some resulting damage to carpets in the immediate area.

7.3.6. It is recommended that the configuration of the flood boards in this area (Figure 14) is altered to reduce the vulnerability of the building, while at the same time permitting drainage through the wave wall.

Figure 14: Oasis Leisure Centre – NW steps and access

7.3.7. Consideration could be given to two further property level measures: a) removable steel shutters to the seaward facing large windows and b) glass screens to supplement or replace the steel railings that presently top the wave wall in front of the Centre. Alterations would be required to the wall and railings to accommodate the glass wall. A budget price for the glass screen is £135,000 to £140,000.

7.3.8. The area in front of the building is used for seating. Hence, while the prime purpose of such a wall is to reduce overtopping, a glass screen has the additional function of serving as a wind break without any loss of visibility. Such a screen could be considered as part of any other refurbishment works if or when they are considered in the future.

8. Summary of Options

8.1. In table 5 below, the options for each section with a budget price for each.

	Section B 117 metres	Section C (whole) 204 metres	Section C Sea Life only 80 metres	Section C excluding Sea Life 124 metres	Sections D & E 266 metres	Oasis 45 metres
Option 2 Raise wave wall by 0.43m as EA £1,550/m	£181,350	£316,200	£124,000	£192,200	£412,300	N/A
Option 3 0.43m Precast extension to wave wall £500/m	£58,500	£102,000	£40,000	£62,000	£133,000	N/A
Option 4 1.0m high Glass screen £1,600/m	N/A	£326,400	£144,000	£198,400	N/A	£140,000
Option 5 1.0m high Seasonal boards £425/m	£50,000	£86,700	£34,000	£52,700	£94,000	N/A

Table 5: Summary of option costs

9. Economic Evaluation

9.1. A broad brush analysis has been undertaken to establish the economic benefits in general terms. The costs of options have been compared with the likely benefits. Costs have included both initial capital costs of provision with allowance for maintenance or running (operational) costs.

9.2. The benefits are the damages avoided by the construction or installation of each of the options. The benefits in this case are the avoidance or reduction of overtopping and they are calculated as average annual damages avoided (AAD). Because the particular event that caused the damage had a relatively high return period (1 in 250

years or 0.4% probability of occurrence in any one year) the average damages are in consequence relatively low, even though the individual losses resulting from the event are high in some cases.

9.3. The most significant damage occurred to the Sea Life Sanctuary (in excess of £3 Million), but other property also experienced damage: the Oasis Leisure Centre, fairground, crazy golf and Searles Leisure Resort, and sums have been included in the calculations. The value of any wider tourism loss is difficult to quantify. Most facilities were fully functional within a short period and so the losses are minimal. Direct losses experienced by the Sea Life Sanctuary are included.

9.4. Table 6 below summarises the costs (capital, maintenance and Present Value) together with the Present Value of Benefits. It has been assumed that Sections B and C will be rebuilt in year 50 and Sections D and E in year 20.

Option Description	**Capital cash value**	**Indicative Average annual cost**	**Whole life Present Value Costs (PVc)**	**Whole life Present Value Benefits (PVb)**	**BCR (Capital)**	**BCR (Whole Life**
Whole frontage options						
EA Type wall	£909,850	£338	£916,816	£72,982	0.08	0.08
PCC Extension	£293,500	£425	£302,214	£72,982	0.25	0.24
Demountable boards	£230,700	£6,000	£362,178	£145,965	0.63	0.40
Sectional Options						
Sea Life glass screen	£144,000	£400	£153,717	£136,344	0.95	0.89
Oasis glass screen	£140,000	£250	£146,073	£2,291	0.02	0.02
Demountable boards (Sections B & C)	£136,700	£3,000	£210,264	£145,507	1.06	0.69
Demountable boards (Section C)	£86,700	£2,000	£130,513	£136,344	1.57	1.04
Cross Banks	£30,000					

Table 6: Summary of Costs and Benefits

9.5. It can be seen that in simple economic terms the benefit cost ratios are low, with few showing above unity. This is explained by the long return period of storms causing significant damage as referred to above.

10. Conclusions and Recommendations

10.1. While the 2013 surge caused significant damage this was largely restricted to one building, the Sea Life Sanctuary. In that the case the cost was high both in actual cost and in loss of business. There may have been a wider loss to the economy of the town as potential visitors went elsewhere, but this is difficult to

quantify: a detailed visitor study would be required with specific reference to this attraction.

10.2. With only two structures within the frontage that can be regarded a permanent it is difficult to justify a frontage wide solution at this time. The lowest cost option of demountable boards has an initial cost of £230,700, significant running costs and a low benefit cost ratio of 0.4.

10.3. Considering a sectional approach would offer better returns with, perhaps, attention focused on the Oasis Centre and Sea Life Sanctuary.

10.4. In the short term consideration should be given to altering the flood board arrangement on the NW corner of the Centre to give that corner and its entrance doors better protection. This could also be arranged to provide a return pathway for any overtopping. In the longer term consideration could be given to a protective glass screen on top of the wave wall in front of the building.

10.5. Clearly the Sea Life Sanctuary sustained damage and some further protection could be beneficial. The lowest cost option is demountable boards provided along the whole of Section C. To be of real benefit this limited solution should be coupled with steps to compartmentalise the frontage. Cross banks is the cheapest option. If it is necessary to leave access gaps these can be filled on an ad hoc basis when significant storms are forecast. The permanent solution to form ramps would be excessively costly, but could be considered in the longer term in conjunction with other works if / when these are planned.

10.6. A higher cost option for Section C is to incorporate a permanent glass screen over the Sea life frontage. However, the cost is £144,000 making this a less economic option, unless a contribution can be found, suggesting this should be postponed to a later date, possibly in conjunction with other work to the building.

10.7. The foregoing, however, is limited to the immediate frontage. The wider context of the Wash East Coastal Management Strategy envisages renewal of the Hunstanton defences as they reach the end of the design lives. In broad terms this will require the reconstruction or structural refurbishment of Sections D and E in 20 years and Sections B and C in 50 years. At this time it would be appropriate to consider enhancement of the wave wall when a) a review of the defence standard would be required and b) any additional costs would be largely contained within the overall project cost.

Appendices

1. References
2. Glass wall by IBS Engineered Products Ltd
3. Drawing showing locations for flood cross banks

Appendix 1: References

1. Beatty C, Fothergill S, Gore T, Wilson I (2010) *The Seaside Tourist Industry in England and Wales: Employment, economic output, location and trends.* Sheffield Hallam University, Sheffield, UK.
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4. Royal Haskoning DHV (2014) *Managing our Coastline: The Wash East Coastal Management Strategy for public consultation.* Royal Haskoning DHV, Peterborough, UK. Report for Environment Agency and Borough Council of Kings Lynn and West Norfolk.
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7. St La Haye Ltd (2005) *Hunstanton Sea Walls: Condition Survey.* St La Haye Ltd, Norwich, UK. Report for Borough Council of Kings Lynn and West Norfolk.
8. Babtie, Brown & Root (2005) *Hunstanton Hard Defences: Design report.* Babtie, Brown & Root, Ipswich, UK (Now Jacobs). Report for Borough Council of Kings Lynn and West Norfolk.
9. Royal Haskoning DHV (2013) *Hunstanton Promenade and Sea Wall Condition Assessment: Condition assessment report.* Royal Haskoning DHV, Peterborough, UK. Report for Borough Council of Kings Lynn and West Norfolk.
10. Pullen T et al (2007) *Eurotop: Wave overtopping of sea defences and related structures :Assessment Manual.* HR Wallingford UK, et al. Report for Environment Agency, UK, Rijkwaterstaat, Netherlands and Coastal engineering Research Council (KFKI) Germany.
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Appendix 2

Glass wall by IBS Engineered Products Ltd

Glass Screen, Keswick, Cumbria

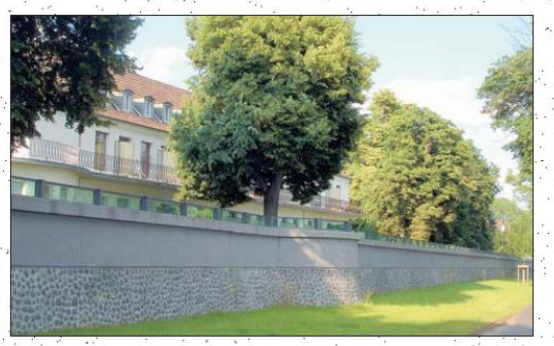
Glass Wall
Cologne-Westhoven on the Rhine

The district of Cologne, Westhoven, is defended by a permanent reinforced concrete flood wall. To build the wall to the full flood protection height would have meant that the river views would have been obstructed.
In the Rheinaustrasse area the missing 400 mm protection height was achieved using a demountable aluminium flood defence system.
In the area between Rheinaustrasse and Pfarrer-Nikolaus-Vogt-Weg demountable flood defences were not an option due to the private properties that border directly to the permanent wall.
In order to surmount this problem a permanent glass wall of 400 mm height was constructed on the top of the reinforced concrete wall. This solution ensured that the required protection height was achieved, whilst at the same time taking into account all the design criteria, the adherence to this ensured the stability of the individual property values.

It was crucial for the glass wall sections to be as long as possible to reduce the number of support posts so as not to obstruct the views, but at the same time the sections had to be robust enough to withstand the heavy loads. With this in mind high performance laminated safety glass was used combined with slim yet exceptionally strong frames, this allowed spans of 2 m in length.
The laminated safety glass element was made up from a single pane of safety glass with two external sacrificial panes plus two internal support panes. All glass elements were heat soak tested in order to meet the high safety requirements. In spite of all safety measures used, at some points safety glass elements may need to be replaced. The design allows that each element contained within its frame can be lifted out from the support posts with relative ease; the damaged glass element can then be removed from its frame and replaced. Because EPDM seals are used to create a seal between the glass support frame and post instead of silicone or adhesive sealants no damage results when individual frames are removed.

The glass wall construction not only fits into the architecture of the waterside promenade and the mobile flood defence system ideally, but it also enhances the situation with the high-quality and resilient workmanship quality of the transparent glass wall elements.

Client: Stadtentwässerungsbetriebe Köln, AöR
Approving authority: District government of Cologne
Protection Height: HQ100 + 0.1 m freeboard
Design Criteria: hydr. water pressure + 30 kN single load or 20 kN/ m² dummy load
Heights: 0.4 m
Length of the defence line/Area: 310 m/124 m²



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Appendix 3

Drawing showing locations for flood cross banks