HUMBERSTON FITTIES
ANALYSIS OF FLOOD RISK

FINAL
JANUARY 2007

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SIGNATURE SHEET

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1 INTRODUCTION

1.1 BACKGROUND

The Humberston Fitties is a settlement of holiday homes and chalets to the south of Cleethorpes set immediately behind sand dunes which separate the community from the sea. The privately owned homes are built on plots of land that are leased from the council. The leases of some have elapsed and require renewal. Given the proximity of the settlement to the sea, the council wished to consider the risk and consequence of flooding before renewing the leases. **Accordingly, the council appointed Weetwood consultants to undertake an analysis of flood risk and to prepare a report to guide the renewal of the leases.**

The renewal of leases will be based on a range of issues, and should also include the seasonality and timing of flood risk. Planning guidance, regulations and practice concerning flood risk analysis are mostly constructed around an analysis of annual return periods with little consideration of seasonal issues. Whilst guidance mostly relates to the planning process, the renewal of leases may not require a planning application. This means that there is room to address the seasonal issue through a pragmatic approach without being constrained by formal guidance.

1.2 REPORT STRUCTURE

This report outlines the background and relevant information regarding the Humberston Fitties in section 2, provides a discussion of the flood risk issues in section 3, and describes the modelling of flood scenarios and results discussion in section 4. The application of these results are considered in section 5, and conclusions with guidance on lease renewal are given in section 6.

1.3 SOURCES OF DATA & INFORMATION

A number of data sources have been drawn upon for this flooding review. These are listed below in Table 1.

Table 1 Data Sources Used in Analysis

Area	Data Source.
Topographic Data	LIDAR obtained from the Environment Agency.
	Survey data obtained from land surveyors using GPS.
Site visit	Undertaken in May 2006. Photographs were also taken.
Flood Defences Information	Reports and some historic photographs.
	Selected Reports / Studies
Hydrology	Monthly maxima peak tidal Levels at Immingham and Boygrift.
	15 minute hydrographs from Immingham
	Joint probability results for Humber estuary
Academic and Technical Literature	Breach analysis
	Breach mechanisms

LIDAR is a flown survey technique collected by using a LASER to measure the distance from aeroplane to the ground. GPS is used to fix the position of the aeroplane. The advantages of this technique are that it can cover large areas of ground very quickly; however, the disadvantage is that there is a compromise in accuracy, particularly in areas of dense vegetation.

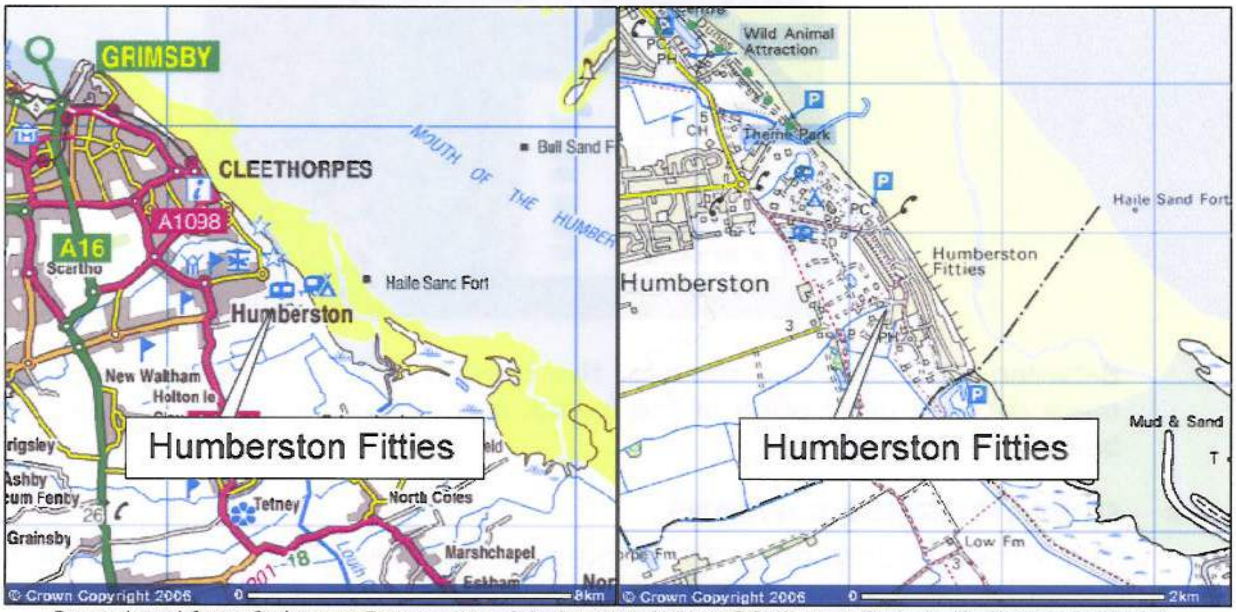
Land survey information should always be used to verify or correct flown survey data where land levels are critical to the outcome of the review. This was undertaken by topographic surveyors using GPS for the elevations of the crest levels.

2 HUMBERSTON FITTIES

2.1 OVERVIEW

The Humberston Fitties are described as "a unique 'plot land' development of holiday chalets which began at the end of the First World War" built upon reclaimed marshland"[1]. Chalets were originally constructed of wood, though in the 50's and 60's, concrete panelled chalets were also used. The site is accessed from the south of Cleethorpes via a road system past Thorpe Park Caravan Site. It is only recently that electricity has come to the Fitties, and the site is yet to be lit by streetlamps.

Figure 1 Site location and extent



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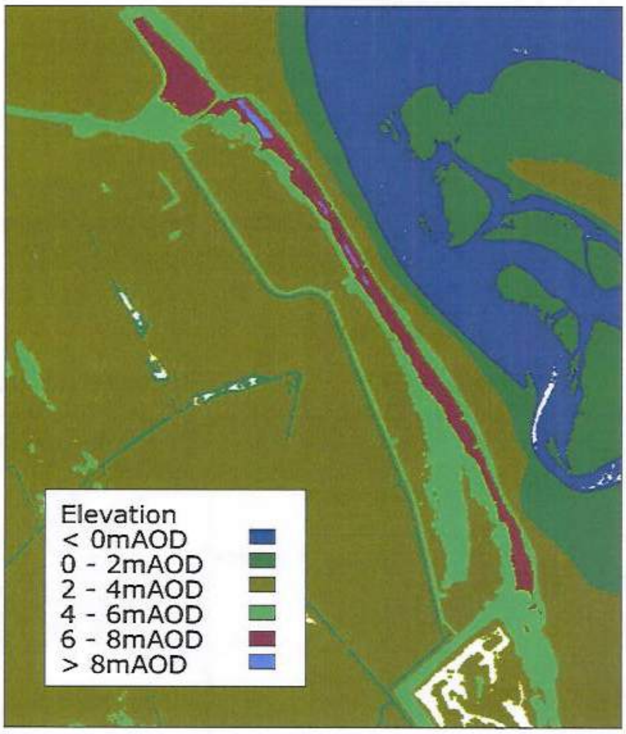
At the northern end of the Fitties, the site abuts Thorpe Park Caravan Site to both the north and the west. At the southern end, there is open agricultural land to the west inland and open marsh to the south. The sailing club is situated at the southern end of the Fitties.

The land is generally between 3.0mAOD[2] and 4.0mAOD, though the lowest chalets are at the back of the site behind the secondary flood embankment around 2.5mAOD high with the highest chalets to the south of the site on a tongue of land around 4.5mAOD and above. This is shown in Figure 2 below.

[1] North East Lincolnshire Website

[2] Metres Above Ordnance Datum

Figure 2 Ground Elevation Map



Between the Fitties and the sea, the coast is formed by a long sand dune. A more detailed description of the formal and informal flood defences is provided below in Section 2.3.

2.2 OPERATING REGULATIONS

The Fitties is only open 10 months for the year from 1st March until 31st December in keeping with its holiday park licence. In January and February, access to the Chalet Park is permitted only between the hours of 9.30am and 4.00pm for owners to undertake maintenance work, thereby precluding overnight stays during that period.

2.3 EXISTING FLOOD DEFENCES

This section considers the defences which are shown in Figure 3 shown overleaf.

At the northern end of the Fitties, the flood defence consists of a concrete wall on top of an embankment. This gives way to a higher area of land on the northern end of the sand dunes.

Figure 3 Diagram Showing Flood Defences

The dune then runs to the south of the Fitties near the sailing club. The dunes are supported at the toe by rock filled gabion boxes set within a concrete and timber frame. These are thought to have been constructed during 1963. The aerial photograph shown in Figure 4 below (taken in June 1964) shows that the rock filled gabions run along the complete length of the sea front, with the Fitties clearly visible behind the dunes This photograph was taken approximately one year after the construction of the gabions, also shown in Figure 4.

Figure 4 Humberston Fitties Gabions in the 1960s

Since this photograph was taken, the dunes have covered the gabions for a considerable length. The photographs in Figure 5 below show the location near the yacht club where the gabions are not covered by sand. The adjoining photograph also shows a location further north where the gabion is partially exposed from under the dune.

Figure 5 Humberston Fitties Gabions – Present Day

The NE Lincolnshire web page[3] also indicates that there are gabions at the north and southern end of the front. An inspection by Mott MacDonalds in 1998/99 for the Environment Agency[4] noted that it was assumed that gabions existed along the middle reach as well.

At the southern end, the gabions give way to higher land around the yacht club. For most of their length, the dunes are covered in marram grass and are partly wooded. Palisade fencing is also used to help stabilise the dunes. There are a number of locations where the dunes have been lowered for ease of access to the sea. The topographic survey shows that the access points have not been lowered beneath the gabion level. However, at the access points, erosion has removed the grass cover. This is important as the grasses help stabilise the dunes and reduce susceptibility to erosion should wave overtopping occur. Generally, the sand dunes are between 6 and 8.5mAOD high, and are between 50m and 75m wide.

Groynes are also located along the southern 2/3 of the dune front to minimise sand movement and undercutting. Note that these were not constructed at the time of the aerial photograph taken in June 1964 as shown above in Figure 4.

There is an earth embankment along the back and southern side of the Fitties.

Approximate levels of the above flood defences are shown in Table 2 below.

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[3] http://www.nelincs.gov.uk/environment/coastaldefence.htm

[4] Mott MacDonald 1998/99 Sea Defence Survey (Open Coast Condition Survey) commissioned for the Environment Agency

Table 2 Flood Defences and Elevations

Defence	Elevation
Concrete wall at north end of Fitties	6.64 mAOD
Sand dunes	6.0 mAOD – 8.5 mAOD
Top of Gabion baskets	6.14 mAOD – 4.49 mAOD
Earth embankment at yacht club	5 mAOD
Earth embankment at back of site	4.2 mAOD – 4.7 mAOD

2.4 EXISTING FLOOD WARNINGS

The Environment Agency is responsible for the provision of flood warning within England and Wales. There are 3 flood warnings, one for each level of severity, which include the Humberston Fitties. These are shown in Table 3 below along with the generic actions expected for each level of warning.

Table 3 Environment Agency Flood Warnings for the Fitties

Reference	Title	Likely Action Description
T600	Flood Watch	Flooding of low lying land and roads is expected. Be aware, be prepared, watch out! • Watch water levels • Stay tuned to local radio or TV • Ring Floodline on 0845 988 1188 • Make sure you have what you need to put your flood plan into action • Alert your neighbours, particularly the elderly • Check pets and livestock • Reconsider travel plans
T700	Flood Warning	Flooding of homes and businesses is expected. Act now! As with Flood Watch plus • Move pets, vehicles, food, valuables and other items to safety • Put sandbags or floorboards in place • Prepare to turn off gas and electricity • Be prepared to evacuate your home • Protect yourself, your family and others that need your help
T800	Severe Flood Warning	Severe flooding is expected. There is extreme danger to life and property. Act now! As with Flood Warning plus • Be prepared to lose power supplies - gas, electricity, water, telephone • Try to keep calm, and to reassure others, especially children • Co-operate with emergency services and local authorities • You may be evacuated

These warnings are triggered primarily from observed sea levels at Immingham, but also from South Ferriby in the Humber Estuary and Boygrift further down the Lincolnshire coast. Tidal levels are also forecast using Storm Tide Forecasting residual data and also wind speed and direction data.

All properties at Humberston Fitties have been offered the Environment Agency's direct Flood Warning Service based on the Automatic Voice Messaging Service. Those that accepted have since been transferred onto the new Floodline Warnings Direct system. This means that people will receive a direct Flood Warning to a nominated telephone call 24 hours a day.[5]

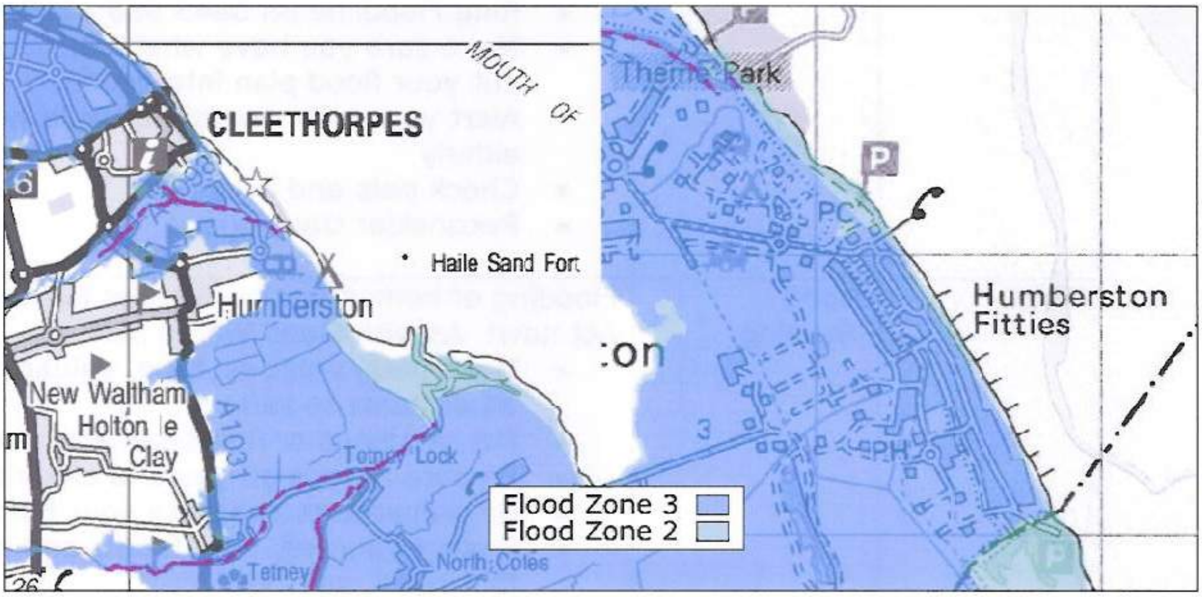
In addition to Floodline Warnings Direct, warnings are also broadcast via the local media.

2.5 EXISTING GUIDANCE

2.5.1 Flood Zone Maps & PPS25

The Environment Agency has published its flood zone maps on the Environment Agency website[6]. These are shown in Figure 6 below.

Figure 6 Environment Agency Flood Zone Maps



These zones relate to a framework for the planning process, e.g. new development, change of use etc and the definitions of these are given by PPS25[7] shown in Table 4 overleaf. Note that PPS25 has recently replaced PPG25[8] during December 2006.

[5] Letter from Sarah Smith (Environment Agency) to John Jepps (Weetwood) dated 9th June 2006, reference CCN/2206/15801
[6] www.environment-agency.gov.uk
[7] Planning Policy Statement 25: Development and Flood Risk
[8] Planning Policy and Guidance 25: Development and Flood Risk

This shows the whole of the Humberston Fitties as being within the 'High Risk' Flood Zone 3a (as the site cannot be considered as functional flood plain). The maps ignore the presence of any defences and do not distinguish between defended and undefended areas due to risks of breaching, overtopping and sea level change. Note that the extent of defences shown in pink is incomplete and at present does not include the extent of coastal defences.
PPS25 continues to note that on the topic of developed areas, new developments for the more vulnerable and essential infrastructure uses should only be permitted in this zone if the exception test is passed. The exception test is used in the context of the sequential test to direct new development towards the areas with the lowest flood risk and does not apply to existing development. PPS25 defines more vulnerable uses as:

- Residential institutions such as residential care homes, children's homes, social services homes, prisons and hostels.
- Buildings used for: dwelling houses; student halls of residence; drinking establishments; nightclubs; and hotels.
- Non-residential uses for health services, nurseries and educational establishments.
- Sites used for holiday or short-let caravans and camping, subject to a specific warning and evacuation plan

Table 4 Flood Zone Definitions

- **Flood Zone 1 – Low Probability**

This zone comprises land assessed as having a less than 1 in 1000 annual probability of river or sea flooding in any year (<0.1%).

- **Flood Zone 2 – Medium Probability**

This zone comprises land assessed as having between a 1 in 100 and 1 in 1000 annual probability of river flooding (1% - 0.1%) or between a 1 in 200 and 1 in 1000 annual probability of sea flooding (0.5% - 0.1%) in any year.

- **Flood Zone 3a – High Probability**

This zone comprises land assessed as having a 1 in 100 or greater annual probability of river flooding (>1%) or a 1 in 200 or greater annual probability of flooding from the sea (>0.5%) in any year.

- **Flood Zone 3b – Functional floodplain**

This zone comprises land where water has to flow or be stored in times of flood. SFRAs [see below] should identify this Flood Zone (land which would flood with an annual probability of 1 in 20 (5%) or greater in any year or is designed to flood in an extreme (0.1%) flood, or at another probability to be agreed between the LPA and the Environment Agency, including water conveyance routes).

Source: PPS25: Planning Policy Statement 25 : Development & Flood Risk; ODPM

2.5.2 Strategic Flood Risk Assessment

A Strategic Flood Risk Assessment (SFRA) was undertaken for the North East and North Lincolnshire Councils during 2003[9]. This included the Humber estuary as far as and including the Fitties.

The SRFA revised the Flood Zone 3 'High Risk' subdivisions into

- Appropriate defences and acceptable flood risk
- No appropriate defences or unacceptable flood risk
- Functional flood plains

Definitions of these are given within the SFRA in sections 3.18 and 3.19. The SFRA states that the sand dune in front of the Fitties provides a standard of protection significantly less than 1 in 200 years, and therefore falls into category (i) "No appropriate defences or unacceptable flood risk".

Within the context of both the PPS25 and the SFRA, no increase to risk or consequence of flooding would be endorsed. For the Fitties, this would generally preclude constructing new chalets or lengthening the operating season of existing chalets if the flood zoning shown on the Agency's Flood Zone Map were to be confirmed.

[9] Rye Consultancy, NELC / NLC Strategic Flood Risk Assessment Final Report

3 FLOODING RISK REVIEW

There are two sources of flooding which may potentially impact the Fitties: coastal and fluvial. Coastal flooding can occur either through overtopping of embankments and defences, or breaching through embankments. Both of these processes are influenced by the characteristics of the sea and its level, as well as by the nature of the defence. In order to manage the risk, an understanding of the processes is required.

This section considers a discussion of the components of the tide, a review of wave analysis, and a consideration of the probability of large tides occurring at the same time as large waves. The seasonality of tides is also considered and a review of the likely situations needed to create a breach. This section concludes with a review of fluvial flooding.

3.1 TIDAL COMPONENTS

The tidal cycle is made up of a number of components layered upon each other. These include:

- Astronomic tide
- Surge tide
- Sea level rise
- Wave action

3.1.1 Astronomic Tide

The astronomic tidal cycle is principally determined by the movement of the moon and the sun relative to the earth. These provide gravitational forces that pull the earth's oceans. As the movement of the sun and moon are well understood, the astronomic tide is readily predictable. The pattern of (approximately) 2 tidal cycles[10] per day reflects the lunar day, where the moon's gravitational pull is strongest when overhead, and when on the opposite side of the earth.

The highest astronomic high tides are known as spring tides. Spring tides also have the lowest astronomic low tides and therefore have the greatest tidal range. These occur during new and full moons when the gravitational pull of the moon and the pull of the sun are coincident. During neap tides[11], the pull of the sun limits the influence of the moon and tides are reduced in range.

Table 5 Astronomical tide data for the East Coast

Condition	Tide Levels (mAOD)		
	Immingham	Spurn Head	Bridlington
Mean High Water Springs	3.4	3.0	2.75
Mean High Water Neaps	1.9	1.6	1.35
Mean Low Water Neaps	-1.3	-1.2	-1.05
Mane Low Water Springs	-3.0	-2.7	-2.25

[10] A tidal cycle consists of a high tide and a low tide. The time between successive high tides is typically around 12 ½ hours.
[11] Neap tides have the lowest astronomic high tides and the highest astronomic low tides.

The magnitude of the astronomic tides varies throughout the year. Importantly, part of this variation is seasonal, resulting primarily from the angle of the earth to the sun. This means that the highest astronomical tides generally occur immediately after the vernal and autumnal equinoxes on 21st March and 23rd September respectively when the sun is over the equator.

Additionally, the elliptical nature of the earth's orbit around the sun means that the earth is closest during January and furthest in July creating higher and lower gravitational pulls respectively. However, this process is of secondary importance to the angle of the earth as described above.

The elliptical orbit of the moon around the earth also means that gravitational pull varies throughout the year. However, this does not have a regular seasonal component to it.

3.1.2 Surge Tides

The surge tidal component is primarily caused by atmospheric pressure and can have the effect of either increasing the astronomic tide (a positive surge) or decreasing the astronomic tide (a negative surge). A low pressure weather system (depression) therefore increases tidal levels and a high pressure weather system (anticline) decreases tide levels. In addition to pressure, the impact of high tides is also affected at the coast due to wind direction and strength causing the sea to move up against the land body.

The resulting high water level analysis for different return periods[12] for key locations on the North East coast is shown in Table 6 below.

Table 6 High Water Level Analysis

Return Period	1 in 10 years (mAOD)	1 in 100 years (mAOD)	1 in 1000 years (mAOD)
Withernsea	3.84	4.08	4.25
Spurn Head	4.14	4.44	4.64
Grimsby	4.31	4.6	4.83
Immingham	4.62	4.94	5.21

3.1.3 Sea Level Rise

Sea level rise is an accepted part of flood planning. It is caused by both global warming and land movements. Global warming is anticipated to increase sea levels through thermal expansion of the oceans and the melting of ice caps in polar and alpine regions. Global warning is also anticipated to have secondary impacts such as frequency of depressions from climate change and impact on wave heights. Land movement is as a result of isostatic rebound following the last glaciation[13] and is generally lowering land in the east and south of Great Britain whilst rising it in the north and west. The effect of isostatic rebound is limited as Cleethorpes is close to the pivot position.

[12] A return period defines the rarity of an event, e.g. of a high tide occurring. It is a statistical measure which defines the average occurrence over an extended period of time

[13] Isostatic rebound is the process of land being depressed from glaciers, and recoving after they have melted. In the UK, glaciers covered the north and west, and as this land is now rising, means that land in the south and east is falling. This is due to the approximate pivot point between the rivers Tees in the North East and Exe in the South West.

PPG25 (which was current at the time of preparation of this technical work) reported that the current best estimate of sea level rise is 210mm between 2000 and 2050, but this could range from 100mm to 550 mm. The government advice is that relative sea level rise is dependant upon regionality, and identified rates included within PPG25 are presented in Table 7 below. This shows that for the area of Cleethorpes, 6mm of relative sea level rise per year should be considered. This equates to 300mm by 2050. Using the more recent figures in PPS25[14], a sea level rise of 312.5mm by 2050 is obtained.

Table 7 Sea Level Change Allowances

Environment Agency Region	Allowance
North West and North East (north of Flamborough Head)	4mm per year
South West	5mm per year
Anglian, Thames, Southern and North East (north of Flamborough head)	6mm per year

These estimates do not include the secondary impacts such as the increased frequency of depressions resulting from climate change, or varied magnitude of wave height.

3.1.4 Waves

Waves in open sea are produced primarily by the wind and are influenced by the following wind characteristics:

- Wind velocity
- Duration of time for which the wind blows
- Distance of open water over which wind blows (fetch)

The direction also indirectly influences the wave formation as this will limit the fetch of the wind.

Given that one wave may be considerably higher than its immediate predecessors or successors the concept of the magnitude of a wave is difficult to define. Coastal engineering uses the definition of the significant wave height (HSig) as being "the average height (trough to crest) of the highest of one third of the waves in a given sea state". This means that when a significant wave height is determined, this will not refer to the maximum wave that can be expected.

The Humber Estuary Coastal Authorities Group Shoreline Management Plan reports on an analysis of significant wave heights at the Dowsing Light Vessel in the North Sea some 20 km due east of the Humber Estuary. This analysis identified significant wave heights for different return periods for a number of wave directions. These are shown in Table 8 overleaf.

[14] PPS25 advises that for the East of England and up to 2025, sea level rise is at 4mm per year, and between 2025 and 2055, at 8.5mm per year

Table 8 Deep Water Wave Heights for Dowsing Light Vessel

Return Period (years)	Origin of Wave					
	345° - 15°	15° – 45°	45° – 75°	75° – 105°	105° - 135°	135° - 165°
1	5.4m	5.8m	3.3m	3.5m	3.0m	2.7m
10	7.7m	8.4m	4.5m	4.7m	3.9m	3.6m
50	9.2m	10.3m	5.1m	5.5m	4.4m	4.2m
100	9.9m	11.0m	5.4m	5.8m	4.6m	4.4m
500	11.4m	12.8m	6.0m	6.5m	5.0m	4.9m

This shows that the largest waves originate from northerly sectors.

On approaching the coast, waves originating from deep water as described above are transformed by local conditions, most notably the shape of the sea bed (bathymetry). The shallow water causes waves to be reduced in magnitude through refraction, deflection, shoaling and wave breaking.

The angle at which the wave approaches the coast is also important and interactions with local currents are also influential. A number of studies have been undertaken to investigate the wave conditions, and these are presented in detail in the Shoreline Management Plan, Volume 2[15].

3.1.5 Joint Probability of Tides and Waves

The combination of tides and waves has to be considered jointly rather than separate treatment. This is because an event of a particular frequency (for example the 200 year event) is a combination of a water level and a wave height. It is not correct to assume that the 200 year event consists of the 200 year water level and the 200 year wave pattern on as this would overstate the risk: the actual return period would be significantly in excess of 200 years. Conversely, assuming the 200 year event was made up of just the 200 year water level or wave height would underestimate the risk.

In reality, there are a number of combinations of possible high tides and simultaneous wave heights that could occur with a particular rarity and the combinations of these are analysed through Joint Probability Analysis. The Environment Agency commissioned a joint probability analysis[16] to determine the likelihood of high water levels occurring under differing wave conditions for a range of locations and return periods. The combinations for the 20 year, 200 year and 500 year return periods are shown in Figure 7 below. 200 year occurrences are shown in Table 9 with 20 and 500 year combinations shown in Appendix A. This table also shows the elapsed time in seconds (the period) between successive waves.

[15] Shoreline Management Plan Vol 2

[16] Joint Probability Analysis Reference

Figure 7 Joint Probability of Water Level and Wave Heights for Humberston Fitties

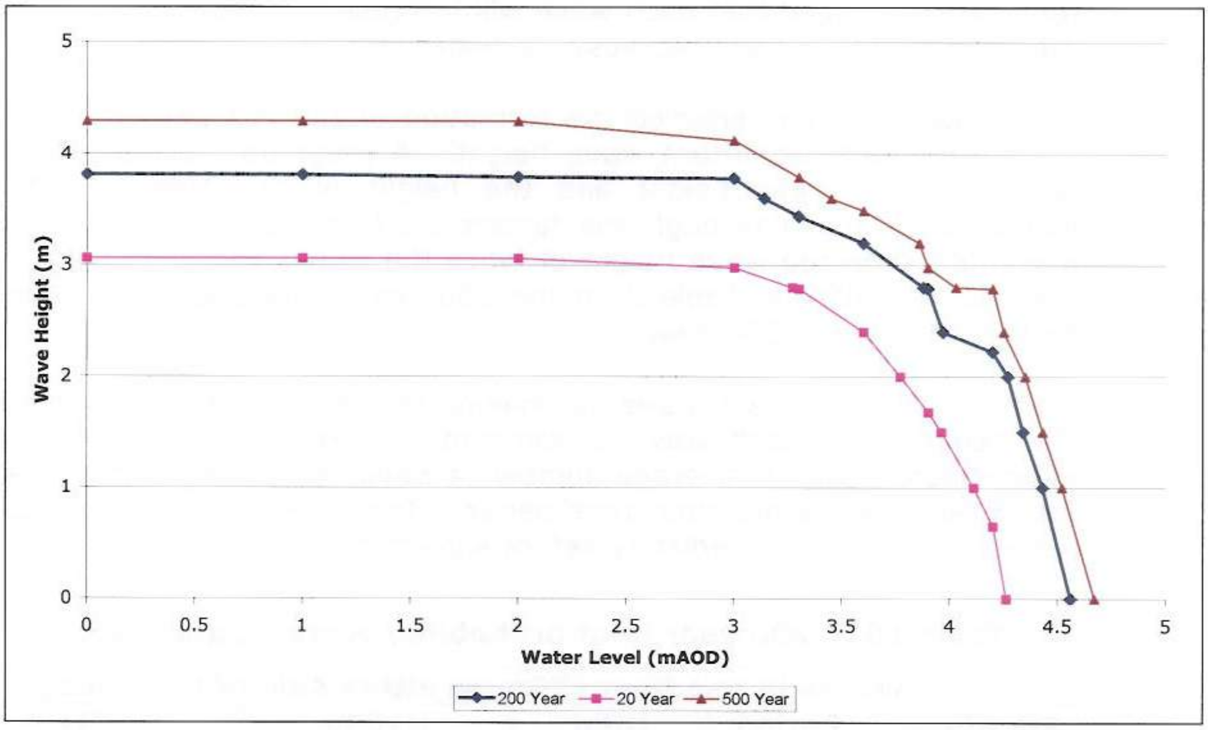


Table 9 200 year joint probability water level and wave heights

Wave Heights						Water Level (mAOD)
Significant Wave Height (m)	Period (s)	Largest 2/3 Average Wave Height Peak Increase (m)	H10% Wave Height (m) Factor of 1.27	H1% Wave Height (m) Factor of 1.67	HMax Wave Height (m) Factor of 2	
3.81	6.83	2.54	3.23	4.24	5.08	0
3.81	6.83	2.54	3.23	4.24	5.08	1
3.79	6.81	2.53	3.21	4.22	5.06	2
3.78	6.80	2.52	3.20	4.21	5.04	3.0
3.60	6.64	2.40	3.05	4.01	4.80	3.14
3.44	6.49	2.29	2.91	3.82	4.58	3.3
3.20	6.26	2.13	2.70	3.56	4.26	3.6
2.80	5.86	1.87	2.37	3.12	3.74	3.88
2.79	5.85	1.86	2.36	3.11	3.72	3.9
2.40	5.42	1.60	2.03	2.67	3.20	3.97
2.22	5.21	1.48	1.87	2.47	2.96	4.2
2.00	4.95	1.33	1.69	2.22	2.66	4.27
1.50	4.29	1.00	1.27	1.67	2.00	4.34
1.00	3.50	0.67	0.85	1.12	1.34	4.43
0.0	0.0	0.0	0.0	0.0	0.0	4.56

At the trough of each wave, there will be a temporary reduction in water level and at the peak, there will be a temporary increase. Based on the shape of a wave, it is assumed that each wave will increase the water level by 2/3 of it's the wave height and will decrease the water level by 1/3.

This assumption has enabled the formation of the 2/3 positive wave height column for each significant wave height. A pragmatic relationship between the significant wave height and the height of the 10% and 1% wave magnitude is given through the factors 1.27 and 1.67 respectively, with a maximum expected wave height of twice the significant wave height. These are also presented in Table 9 for the 200 year event and also in Appendix A for the 20 year and 500 year.

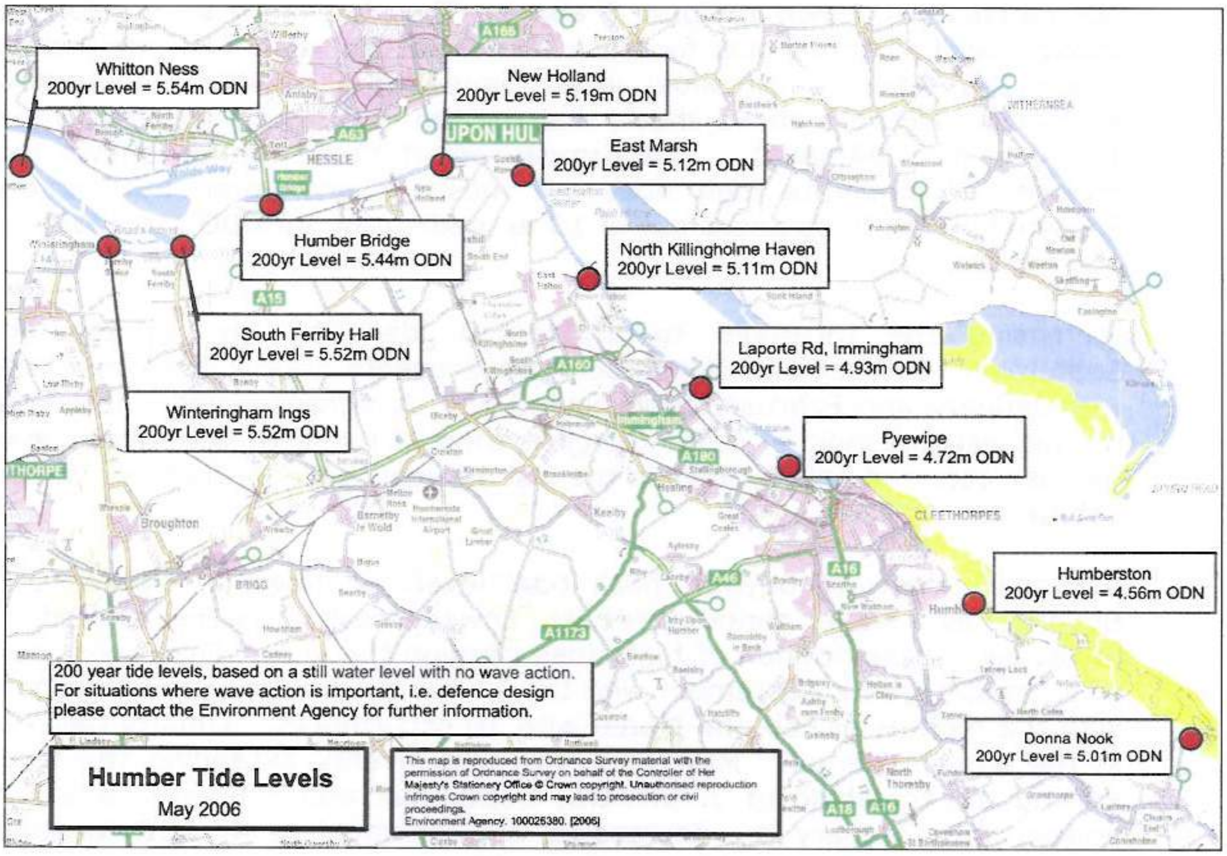
From the period of each wave, by making the (conservative) assumption that the frequency of each wave is constant, a given wave magnitude can be approximated, and an average number of waves exceeding a given magnitude estimated within a one hour time period. This is selected as it will cover the period of high tide immediately before and after high water.

Table 10 200 year joint probability wave frequencies

Waves in one hour (30mins either side of high tide)				
Significant Wave Height (m)	**Period (s)**	**HSig**	**H10%**	**H1%**
3.78	6.8	174	53	5
3.44	6.49	183	55	5
3.20	6.26	190	57	6
2.79	5.85	203	61	6
2.22	5.21	228	69	7
1.50	4.29	277	84	8
1.00	3.50	339	103	10
0.0	0.0	NA	NA	NA

The Environment Agency's 200 year maximum still water levels for the whole of the Humber estuary are presented in Figure 8 below. From this figure, it is seen that generally the still water level 200 year level increases with distance up the estuary. Predicting levels at Humberston are the lowest, reflecting the site location at the mouth of the estuary.

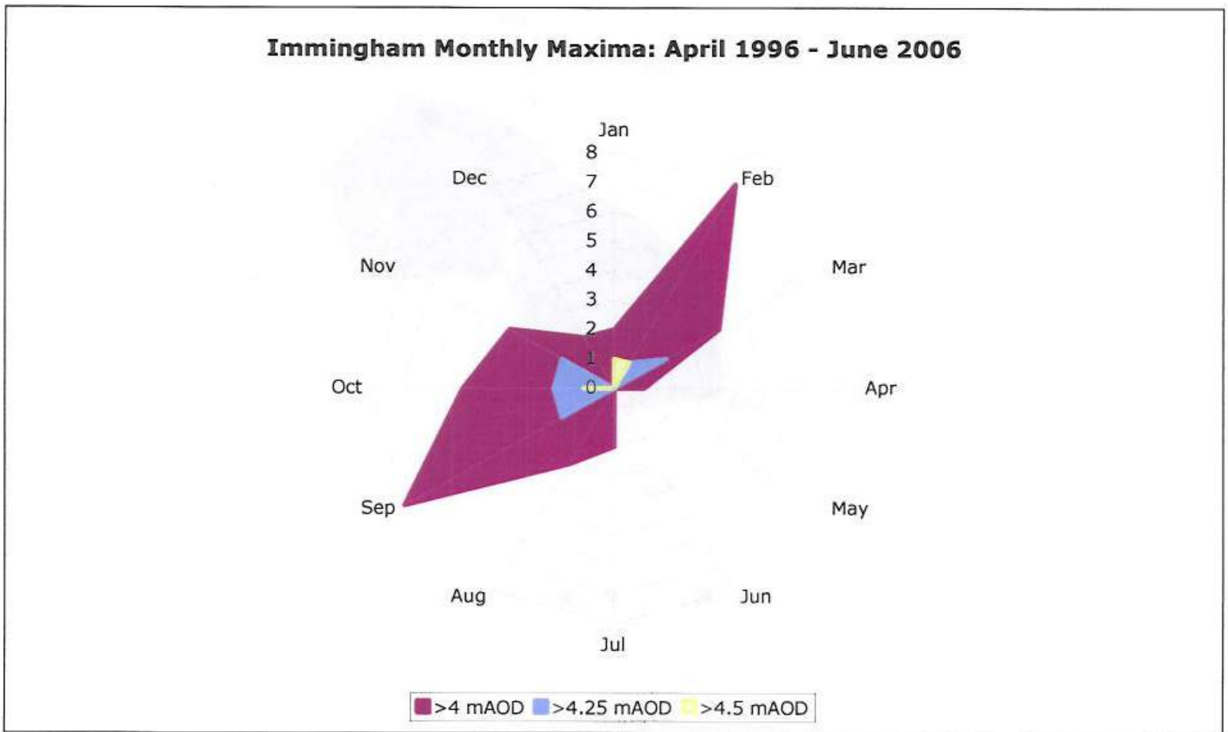
Figure 8 200 year still water levels



3.2 SEASONAL ANALYSIS

Section 3.1.1 identifies that the highest astronomical tides occur soon after the vernal and autumnal equinoxes. Weather processes which lead to the formation of a positive surge are also more likely to occur outside of summer with the possibility of increasing the highest tides further.

Figure 9 Immingham Monthly Peak Tidal Data

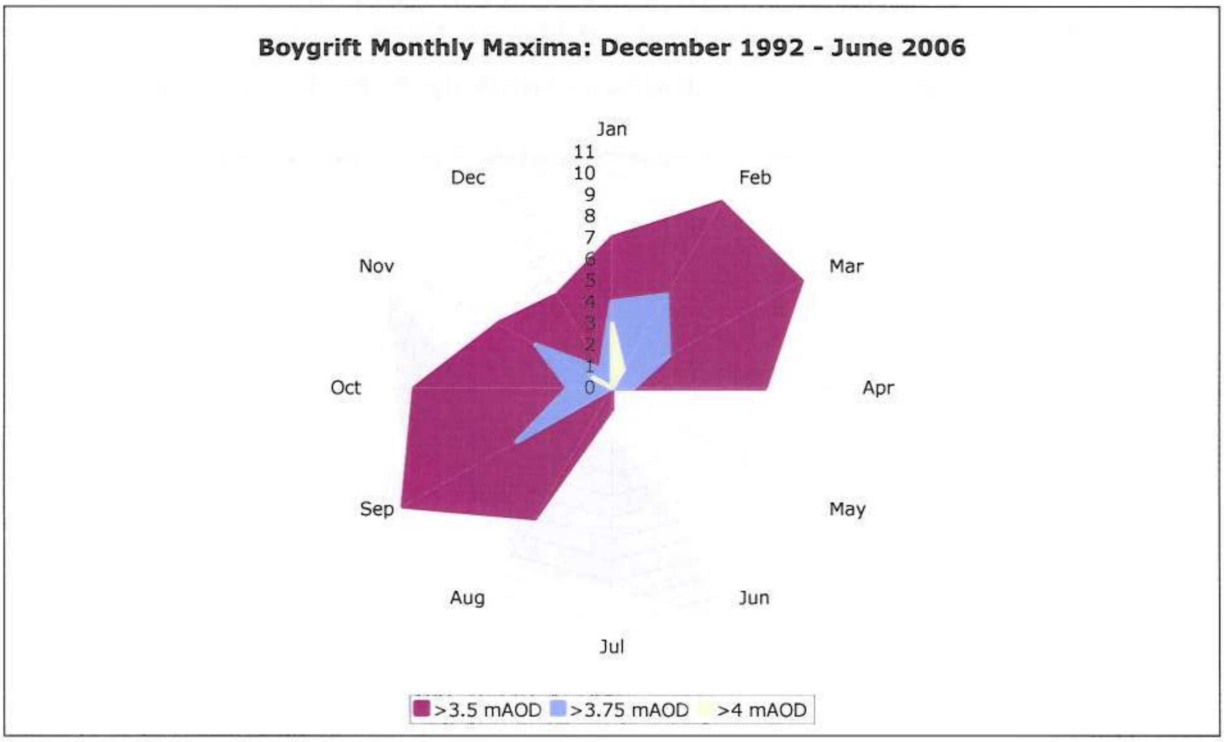


An analysis of monthly maximum observed tides for Immingham and Boygrift[17] tide gauges are shown in Figure 9 above. The plots show the number of tides above specified thresholds for each month of the year. For Immingham tide gauge the arbitrary threshold levels were set at 4mAOD, 4.25mAOD and 4.5mAOD. Figure 9 above shows that the ten year tide is 4.62mAOD, and the 100 year is 4.94mAOD. The comparison of these figures shows that the majority of moderate high tides are mostly concentrated in February and September with 8 instances out of 10 exceeding the 4mAOD threshold in these two months.

Increasing the threshold to 4.25mAOD identifies the months of Mar, September, October and November with 2 events greater than the threshold, with January and February both having one significant event. An increase to the highest threshold of 4.5mAOD (just short of the 1:10 year tide) shows that this has occurred only 3 times in the last 10 year, once in October, January and February.

A similar review of Boygrift peak tidal levels is shown in Figure 10 below. Boygrift has a longer period of record. Lower thresholds were selected in order to review the distribution of high tides through the year. The lowest threshold of 3.5mAOD shows September with the 11 events exceeding the threshold, and with the months of Feb and March with 10 occurrences. January has 7 events in the sample period. May, June have no events exceeding the threshold. Raising the threshold to 3.75mAOD, September and February have 5 events apiece, with January 4. Increasing the threshold to 4mAOD identifies the month with the highest tides as being January with 3 exceedances, and with November and February 1 apiece.

Figure 10 Boygrift Monthly Peak Tidal Data



[17] Boygrift is located to the south of Cleethorpes

This analysis shows that whilst there are not frequent large tides in January and February, when they do happen they can be very significant. This is consistent with anecdotal records of the January 1953 floods which devastated much of the east coast of England (and the Netherlands). Whilst not a notably high astronomic tide, the presence of a very significant surge increased tide heights to a level sufficient to breach many of the then inadequate coastal defences.

3.3 BREACH PROCESSES

In terms of Coastal flood risk, a breach may be described as "a breach in the natural or man-made defences"[18]. As noted above, coastal breaches are most often caused by high tide levels combined with high energy wave conditions. These conditions may result in overtopping of coastal defences, which is the process most likely to initiate a breach in coastal defences.

3.3.1 Breach Initiation & Expansion

Breaches develop as the result of two distinct erosional processes: hydraulic erosion and slumping[19]. As water begins to move over or through the defence, unconsolidated materials become eroded and transported into the floodplain. Muir-Wood and Bateman (2005) describe that as this gap enlarges, flow velocities increase through the gap, bringing about an increase in the rate of erosion. This paper also presents the results from experiments which show that "with a 3-4m hydraulic head, a breach in *unconsolidated* sand embankment can expand at several metres a minute".

However, it is important to note that anything within the defence that increases consolidation (i.e. well rooted grass/vegetation in dunes) can act to restrict the initiation of a breach by reducing erosion and downcutting. Whilst the dunes at the Fitties are unconsolidated (albeit supported through rock filled gabions), they are mostly well vegetated along their length providing additional cohesion.

A presentation to Floodrisknet members during 2002[20] stresses the fact that although initiation of a breach may occur with and without overtopping, it is "far more likely to occur when defences are overtopped". The size of the final breach may be controlled by the following factors:

- Hydraulic gradient across the breach during surge tide
- Erodability of materials of the defence and substrate
- The extent of the floodplain behind the defence, and the effect this has upon ponding (which potentially reduces the hydraulic head across the breach)

Other factors may also influence the size of a final breach. One important factor is the effect of nearby breaches on the chance of a breach occurring. Flooding from an initial breach into an area behind defences has the effect of reducing the hydraulic gradient across other nearby defence breaches. This reduces the speed with which the breaches will form and the rate at which they widen.

[18] EA/DEFRA: Best Practice in Coastal Flood Forecasting, R & D Technical Report FD2206/TR1
[19] Morris and Hassan, 2002.
[20] Muir-Wood, R., Sensitivity of storm surge loss to flood defence performance in eastern England, 2002, Accessed online at http://www.floodrisknet.org.uk, 17 July 2006.

3.3.2 Predicting a breach

Although there are both physical and numerical models which exist to model the inundation occurring from defined breaches, currently there are no models which exist to predict the onset or growth of a breach.

The presentation to Floodrisknet members from Risk Management solutions in 2002 highlights the principle sources of uncertainty in the process of coastal surge modelling as:

- Defence performance and initiation of breaching
- Breach growth and inter-breach connections

In brief, although we know how and why breaches occur, there is still much uncertainty involved with the assessment of when a breach may occur, and the scale of the breach that is expected. This knowledge gap makes it difficult to assign a probability to the likelihood that a breach will occur in any given section of defence. The Environment Agency presents the probability of defence failure with defence 'fragility curves' (detailed in DEFRA/EA report W5B-030/TR1[21]). These take into account the following factors:

- Condition survey
- Expert judgement
- Reliability analysis

These fragility curves relate the height of the high water level to the probability that breaching is initiated. The probability of a breach occurring increases with the duration of the high water event. This is because there is the combined effect of prolonged wave action, but also saturation of the defence material. As the water level increases, the erosion caused by overtopping increases the likelihood of a breach occurring, as does the accompanying wave action.

To conclude, although there are useful tools and methods available to assist in representing the probability of a breach occurring at any given point, these are subjective and ultimately user judgment informed by collation/analysis of relevant information is the key to assessing the likelihood of a breach occurring.

3.4 FLUVIAL FLOODING

Within the vicinity of the Fitties, there are two sources of fluvial flooding: the Buck Beck to the north and the local drainage to the west and south.

The Buck Beck has a catchment of approximately 20km2, and drains through a flap valve through the embankment to the sea approximately 1km to the north of the Fitties. The Strategic Flood Risk Assessment reports that the Buck Beck is capable of containing and discharging the 100 year flow. In the event of a flood either due to extreme flows or the failure of the flap valve, there are large areas of land beneath 4mAOD which would fill before flood water overtopped the defences and spilled into the Fitties at their northern extent. Flooding is not expected on the Fitties from the Buck Beck.

[21] DEFRA/EA W5B-030/TR1 - High Level Methodology, R & D Technical Report (May 2003)

The local drainage system to the west and south of the Fitties discharges into the Louth Canal downstream of Tetney Lock. This system is managed by LMIDB. This system is also understood to be capable of accommodating the 100 year flood.

Flooding from fluvial systems is not considered further.

4 BREACH MODELLING

4.1 OBJECTIVE

The objective of the breach modelling was to develop a hydraulic model which could represent the behaviour of the Fitties following a breach event for a range of tidal flood events. As shown in Section 3, high sea levels coupled with the risk of a breach in the defences represent the biggest threat to the Fitties. Though there are uncertainties regarding the probability of a risk occurring, this section describes the use of hydraulic modelling to further quantifying the risk posed to the Fitties.

The software chosen to model the flooding was TUFLOW, a 2-dimensional (2D) finite-difference model. Unlike traditional 1-dimensional flood models TUFLOW does not require the flow paths to be predefined by the user, which makes it a powerful tool for coastal studies. Importantly for the study requirements, TUFLOW has the ability to generate expected depths and velocities of flooding for given events. This information can be used to express the hazard posed to people from those events.

The approach taken is summarised below and is followed by a discussion of the modelling output.

4.2 MODEL DESIGN SCENARIOS

A range of likely flood scenarios are proposed, to reflect the possible flooding conditions. Three locations were identified as possible breach locations. Design scenarios were primarily based upon the 200 year joint probability wave & water level events. This is because the 200 year event is widely used within flood risk planning for coastal regions. The 20 and 500 year events were also considered because thought needs to be given to floods that are both smaller and larger than the 200 year event, and the findings reflected in the leasing policy.

4.2.1 Overtopping Scenarios

A review of the crest levels of the dunes and embankments showed that the low point of the defences is around 5.05mAOD to the south east of the site. This is sufficient to contain the still water peak 500 year flood level (i.e. with very limited wave action). Increasing the magnitude of the waves will, as shown in Table 9 in the joint probability of waves and water level, reduce the 'still' water level. This means that there will be no constant overtopping of water over the defences. Rather, in these scenarios overtopping will be limited to (albeit potentially locally significant) wave wash. A constant flow into the site will only be achieved if the defences are compromised through erosion or breach.

The following section considers the likely effects of a breach upon the Fitties. Figure 11 overleaf illustrates the selected breach locations.

4.2.2 Breach through sand dunes (location 1)

Breach Dimensions:

A likely breach location was highlighted at the low points through the sand dunes facing out to sea to the south towards the yacht club. Here, the low points of the dunes are around 5.0mAOD, with a width of around 150m spanning between two low points. However, at this location, the low elevations coincide with an area of higher ground inland within the Fitties of around 4.5mAOD. This would restrict the lowering of the sand dune in a breach scenario. Consequently, to establish the worst case scenario, an alternative breach location was selected towards the northern end of the dunes. Here the ground level of the chalets behind the dunes is in the region of 4mAOD, and with a low point of around 5.9mAOD.

Figure 11 Modelled Breach Locations

At this point two breaches are to be modelled:

- 150m breach: instantaneous lowering down to inland level of around 4mAOD*
- 300m breach: instantaneous lowering down to inland level of between 3.5mAOD to 4mAOD*

*Note that both of the scenarios lower the dunes to beneath the current top of the gabions and therefore assumes that they have been undermined.

Design Tide:
The still water level and wave height that was used to model a breach at this location was the combination where the top 1% of the waves overtopped the dune (at 5.9mAOD). It is estimated that this gives approximately 10 waves within a one hour period which would overtop the dunes, undermine the dune and lead to a breach. The highest water level associated with waves that would achieve this frequency of overtopping is 4.36mAOD. The 500 year scenario was also determined using this method, and this gave a maximum water level of 4.47mAOD.

A model run demonstrating the effect of the 20 year flood event was considered. However comparison between design water levels and ground levels on the northern boundary of the site demonstrates that a breach of the dunes would not be expected to occur during the 20 year flood event, even if some of the waves associated with event were high enough to overtop the embankment. This is due to the surrounding ground levels being almost as high or higher then the generated water levels. The 20 year scenario was therefore not considered further.

4.2.3 Breach through embankment at Sailing Club - locations 2 and 3

Two further breach locations were selected at the low point of the embankments to the south of the Fitties. These are described below:

- **Location 2:** located to the north east of the secondary embankment through the centre of the site. Instantaneous lowering down to inland level of 4mAOD
- **Location 3:** located to the south west of the secondary embankment through the centre of the site. Instantaneous lowering down to inland level of 4mAOD

Design Tide:
At this location the embankment is lower than the dunes to the front of the Fitties, and this means that the same frequency of wave overtopping is achieved with a higher water level compared to the breach location on the dunes.

Note that this south easterly facing embankment is protected by a large area of wetland to the south east of the Fitties, and is also protected by the south extension of the dunes down to and beyond the sailing club. This means that any waves approaching the embankment will be moderated by these features. Consequently, this represents a precautionary interpretation of the flood hazard. Here, maximum water levels of 4.44mAOD for the 200 year event and 4.56mAOD for the 500 year event.

Similarly to breach location 1, a model run demonstrating the effect of the 20 year flood event was considered. However comparison between design water levels and ground levels at the southern boundary of the site demonstrates that a breach of the dunes would not be expected to occur during the 20 year flood event, even if some of the waves associated with event were high enough to reach the top of the embankment. As a result the 20 year scenario was therefore interpreted to not result in flooding of the site, and was not included in the model runs.

4.3 MODEL DEVELOPMENT

4.3.1 Boundary Conditions

Boundary conditions are used within modelling packages to represent inflows into the system. A water level (mAOD) against time boundary input has been used to represent the design tide events. The tidal shape was taken from the highest observed event at Immingham. The shape was adjusted by a constant to achieve the desired water level for each scenario. This reflects the likely impact of a surge. To minimise the calculation times involved in the modelling, one tidal cycle only was included in the modelling input.

4.3.2 Geometry Representation

The model has been built using the following topographical data sources:

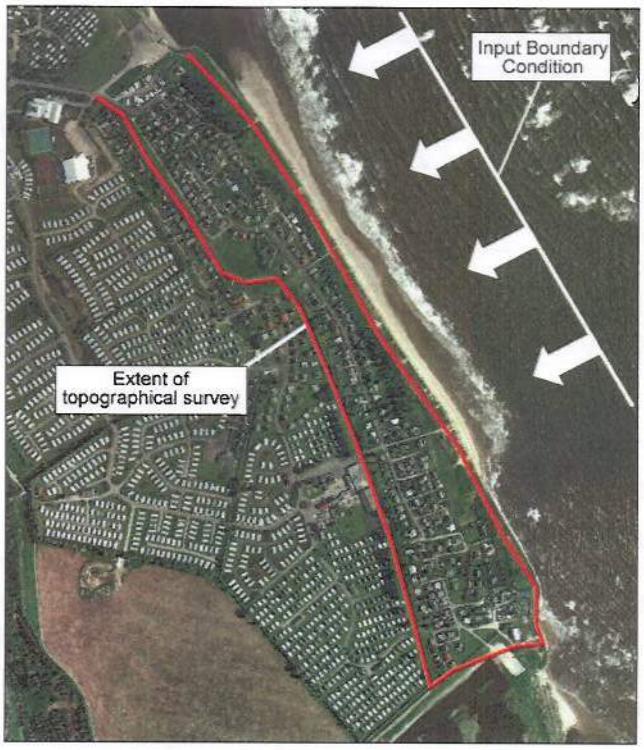
1. LIDAR
2. Topographical survey of crest levels

LIDAR, as previously described is collected remotely, and so is well suited to studies where large areas of elevation data are needed. This has been used to provide elevation data for the background gridded dataset underlying the TUFLOW model.

For the sections of the model which require more accurate and reliable data, topographical survey data was collected. This was collected showing crest levels and break in slope for the sand dunes along the front of the Fitties, and for the embankment which is located adjacent to the ditch running through the centre of the Fitties site.

3D polylines were input as breaklines from a GIS package into the model forcing various scales of breach to be represented. The extent of the topographical survey collected is shown below in Figure 12.

Figure 12 Model boundary conditions and crest survey



4.3.3 Roughness Coefficients

Roughness coefficients are used to describe the varying levels of friction that different surfaces provide to flood waters. In hydraulic modelling, roughness is often described in terms of Manning's N values.

Table 11 below lists the values of Manning's N used:

Table 11 Manning's N Values

Code	Value	Description
1	0.03	Waterways
2	0.05	Short cropped grass
3	0.02	Roads and pavements
4	0.04	Parks and gardens
5	0.06	Dune scrub
6	0.12	Dense woodland

4.3.4 Grid Size & Time step

Grid size is an important factor in how representative a 2D model is of flooding processes in a study area. The grid resolution must be fine enough so that any major low points which could define overland flow routes are presented in the model topography. However, the smaller the cell size the greater the run time for the same model area - a factor which must be taken into account. The final cell size used for the Fitties model was 5m x 5m square.

The timestep is also important in allowing TUFLOW to run with stability - a rough guide is half the cell size (in seconds). The timestep which provided the best stability for the Fitties model was using a 2 second interval.

4.3.5 Model Runs

To assess the risk associated with a breach occurring in various locations along the Fitties boundary, the following model runs were carried out:

Table 12 Description of TUFLOW modelling runs

Ref:	Description:	Breach Location	Breach Width	Breach Level	High water level
18	200 year	2	160m	3.0 mAOD	4.44 mAOD
21	200 year	3	~80m	3.5 mAOD	4.44 mAOD
23	500 year	3	~80 m	3.5 mAOD	4.56 mAOD
24	200 year	1	150 m	4.0 mAOD	4.36 mAOD
26	500 year	1	150 m	4.0 mAOD	4.47 mAOD
27	200 year	1	300m	3.5-4 mAOD	4.36 mAOD

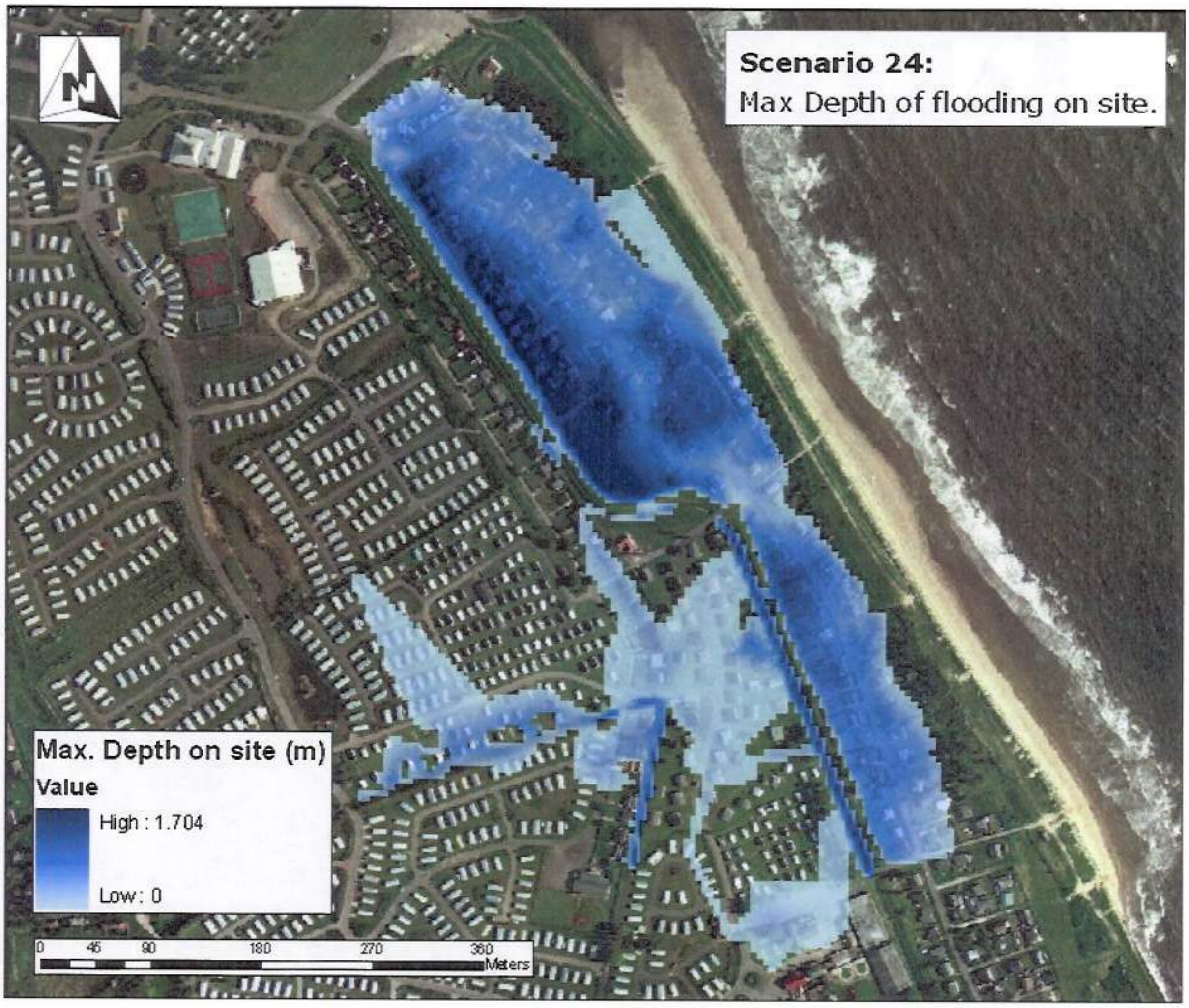
4.4 RESULTS

4.4.1 Breach Location 1

200 Year, 160m Breach

The modelling runs carried out for the breach events at location 1 provided the greatest extent of inundation of the site. A plot showing the peak depth occurring from the 200 year, 160m breach scenario is shown below. The maximum depth modelled on site was 1.7m at the back of the site against the internal secondary embankment.

Figure 13 Max depth of flooding on site, S.24



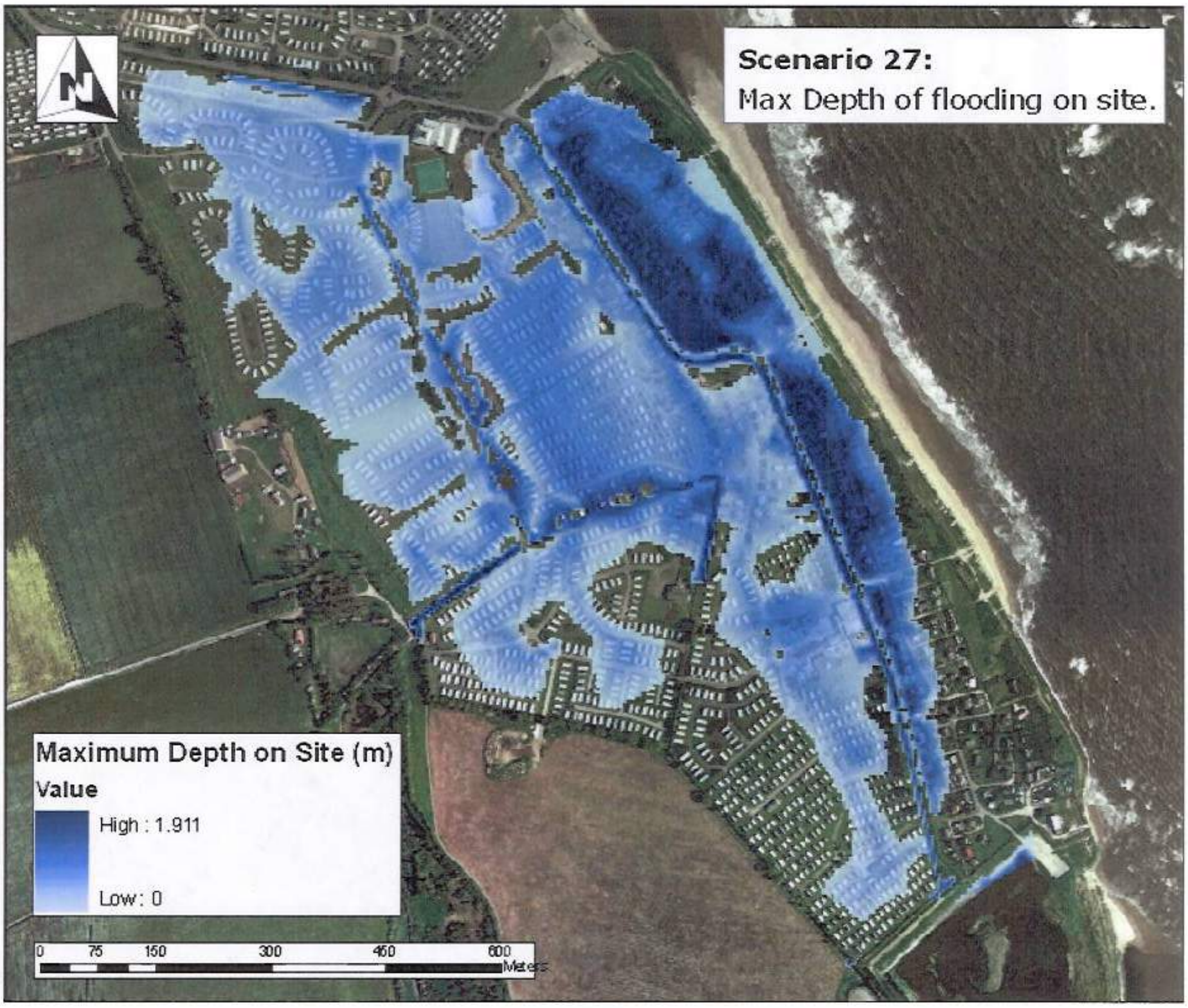
This shows that all chalets to the west of the secondary embankment remain dry during this modelled breach. This is because the secondary embankment alongside the ditch provides additional defence which is not overtopped. It should be noted however that ground levels surrounding these chalets (~2.5mAOD) are considerably lower than the rest of the Fitties, and if this secondary embankment were to fail, then flooding depths could be significantly greater.

200 Year, 300m Breach

The flood extent resulting from the modelled 300m breach shows a much greater extent of inundation at the site. This is shown below in Figure 14. During the 300m breach event the properties to the west of the embankment through the centre of the site are also shown to be inundated. Modelled maximum flooded depths are also greater than those modelled for the 150m breach scenario, with a maximum on site depth of 1.91m. Again, this is located up against the secondary embankment.

In this scenario the chalets to the immediate west of the yacht club remain dry. This is because ground levels in the region of these chalets are high enough to protect them from inundation from this breach scenario. However, it should be noted that these chalets are located at the opposite end of the site to the location of the breach and this does not mean that they are immune from inundation in an extreme event.

Figure 14 Max depth of flooding on site, S.27



Maximum velocities for the 200 year event are located at the outlet from the breach into the Fitties. These velocities are in the region of 0.6 – 0.8m/s at their greatest.

The 500 year return period event showed a similar pattern of inundation at breach location 1 to the 200 year return period event, although derived depths and velocities were greater.

4.4.2 Breach Locations 2 and 3

The modelled 200 year event resulted in some limited inundation of the site from breach location scenarios 2 and 3, but similarly to the 20 year event for breach location 1, the ground levels of the surrounding area in land of the embankment are likely to limit significant development of any breach.

The 500 year event for breach location 2 extends inundation further inland, and demonstrates that the chalets behind the sailing club do carry some risk of flooding depending on the locality of the breach.

5 RISKS TO PEOPLE

The Environment Agency and DEFRA have commissioned work as part of their Flood and Coastal Defence Research and Development Programme into a consideration of flood risks to people. This work was jointly undertaken by HR Wallingford, Flood Hazard Research Centre at Middlesex University, and by Risk & Policy Analysts Ltd. The final reports from the second and final phase of this study were published in March 2006, and of particular interest to this study are the Guidance[22] and Methodology[23] Reports.

The methodology aims to define a flood risk to people for a given flood event. In the case of the Fitties, the probability of breaching is unknown. Therefore, the methodology has not been applied to the study case, however, the themes of the project are explored because they do help focus on the risk facing people on the site, and will be useful to manage that risk.

The research identifies that overall, flood risk is based on 3 aspects:

- Flood Hazard
- The Vulnerability of the area
- The People Vulnerability of the people

5.1 FLOOD HAZARD

Flood Hazard is a function of both flood water depth and velocity. The interpretation of the hazard rating is based on studies of water depth and velocity combinations at which people were knocked off their feet. A relationship was derived between the characteristics of people and their stability in deep and fast flowing water, and this gave rise to the following classifications.

Table 13 Description of Hazard Rating

Hazard Rating d x (v+ 0.5)	Degree of flood hazard	Description
< 0.75	Low	Caution "Flood zone with shallow flowing water or deep standing water"
0.75 - 1.25	Moderate	Dangerous for some (i.e. children) "Danger: flood zone with deep fast flowing water"
1.25 - 2.5	Significant	Dangerous for most people "Danger: flood zone with deep fast flowing water"
>2.5	Extreme	Dangerous for all "Extreme danger: flood zone with deep fast flowing water"

The combinations of depth and velocity and the resulting flood hazards are shown in the figure below.

[22] EA / DEFRA R&D Flood Risks to People FD 2321 - Guidance
[23] EA / DEFRA R&D Flood Risks to People FD 2321 - Methodology

Figure 15 Hazard Ratings for Depth and Velocity of Flooding

(V+C) * D

Velocity \ Depth	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
0.00	0.13	0.25	0.38	0.50	0.63	0.75	0.88	1.00	1.13	1.25
0.50	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
1.00	0.38	0.75	1.13	1.50	1.88	2.25	2.63	3.00	3.38	3.75
1.50	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
2.00	0.63	1.25	1.88	2.50	3.13	3.75	4.38	5.00	5.63	6.25
2.50	0.75	1.50	2.25	3.00	3.75	4.50	5.25	6.00	6.75	7.50
3.00	0.88	1.75	2.63	3.50	4.38	5.25	6.13	7.00	7.88	8.75
3.50	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
4.00	1.13	2.25	3.38	4.50	5.63	6.75	7.88	9.00	10.13	11.25
4.50	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00	11.25	12.50
5.00	1.38	2.75	4.13	5.50	6.88	8.25	9.63	11.00	12.38	13.75

	From	To	
Class 1	0.75	1.25	Danger for some
Class 2	1.25	2.50	Danger for most
Class 3	2.50	20.00	Danger for all

The methodology also proposes that the flood hazard can be increased, sometimes significantly, by the presence of flood debris. This may include debris from flattened chalets. The flood hazard rating is increased by either 0.5 or 1 depending on the depth and velocity of the water, and the land use. The matrix for these decisions is given in the table below.

Table 14 Debris Factors for Different Land Use and Flood Conditions

Depths	Pasture / Arable	Woodland	Urban
0 to 0.25m	0	0	0
0.25 to 0.75m	0	0.5	1
D > 0.75m and\or v>2m\s	0.5	1	1

The combination of flood depths, velocities and a debris factor of 1 for urban gives a hazard rating of 'danger for most' for much of the inundated site.

5.2 AREA VULNERABILITY

The report also identifies issues for consideration determining the vulnerability of an area to flooding. Three issues are considered to be important:

- Flood warning
- Speed of onset of flood
- Nature of the area

A summary of how the above influences vulnerability is given in Table 15 overleaf.

Table 15 Characterisation of Risk for Area Vulnerability

Parameter	1 – Low Risk Area	2 – Medium Risk Area	3 – High Risk Area
Flood Warning	Effective tried and tested flood warning and emergency plans	Flood warning system present but limited	No flood warning system
Speed of Onset	Onset of flooding is very gradual (many hours)	Onset of flooding is gradual (an hour or so)	Rapid flooding
Nature of Area	Multi-storey apartments	Typical residential area (2 storey homes)	Bungalows, mobile homes, campsites

With regard to flood warning, a well established flood warning scheme that reaches the people reduces the risk to people. The speed of onset can relate to both an overtopping event, where a high astronomic tide will be known for some time, and plenty of warning will be had. Alternatively, a breach may lead to rapid flooding. Finally, the nature of the area is mostly wooden bungalows and these also fall into the high risk area as they offer people to opportunity to move upstairs to escape rising water.

5.3 THE VULNERABILITY OF PEOPLE

The report states that the risk is particularly increased if population characteristics of the site include a significant component of a) the very old (>75) and b) infirm / disabled / or long term sick. Risks are also increased if there are significant populations of the financially deprived, single parents and children, non or poor English speakers, and a transient community (immigration or tourism). Despite being a holiday area, most will be repeat visitors who will be familiar with the site and gain knowledge of existing and future flood warning arrangements.

5.4 FLOOD HAZARD MAPS

For each scenario, flood hazard was calculated for each model timestep. The maximum flood hazard was then compiled for each scenario. Note that the maximum flood hazard does not necessarily occur at the same timestep during a flood, nor does it necessarily occur at the same time as the greatest depth of the greatest velocity. The resulting flood hazard maps are shown in Appendix B and have a key consistent with Figure 15.

The location of breaches have been manually overridden as "Danger for all".

5.5 DISCUSSION OF MODELLING RESULTS

With the 150m width breach at location 1, the 200 year event (scenario 24) is predicted to cause quite extensive inundation. However, much of this is at shallow depths and low velocities and consequently, falls within the 'No danger' category. However, towards the back of the site up against the secondary embankment where the inundation depths are anticipated to be deepest, the hazard rating is predicted to reach "Danger for most". Importantly, the main egress route at the north west of the site extends through area that falls within "Danger for some".

Scenario 26 representing the same breach but for the 500 year event shows a similar picture with an increased flood hazard. The largest significant difference is that the secondary embankment is predicted to be overtopped and inundation extends over a considerable part of the site behind the Fitties. However, in front of the secondary embankment, there is a marginal increase in flood hazard.

The 300m breach at the same location for the 200 year event (scenario 27) shows further inundation but with little increase in maximum flood risk, though there are areas of increased hazard within the "Danger for most" category. Apart from the breach location, there are no areas where the hazard rating is "Danger for all".

For the breaches at the southern end of the fitties, the 200 year event (scenarios 18 and 21) shows little inundation with nearly all the risk falling into the "no danger" category. It is only for the 500 year event (scenario 23) that limited areas of "Danger for some" are introduced.

The discussion in section 5.2 above notes that whilst the Fitties has the characteristics of a high risk site in terms of the speed of onset of a flood and the nature of the site, the risk can be reduced by ensuring that there is an effective flood warning system in place. This will therefore form part of the recommendations of this project. The mitigation should also extend to ensuring that there is an effective evacuation plan in place.

6 CONCLUSIONS

The following sections recap the salient points of the study, and focus upon the thinking steering the proposed leasing policy.

6.1 BACKGROUND

The elevations of the Fitties is mostly between 3.0mAOD and 4.0mAOD.

The main access and egress route to the site is from the north west of the site past Thorpe Park caravan site, with elevations between 4.5mAOD and 5.5mAOD.

The site is protected by natural sand dunes along the sea front that have been reinforced at the toe by a line of rock filled gabions.

The sand dunes are generally high, between 6.0mAOD and 8.5mAOD. Access areas to the beach through the dunes have lead to erosion of the marram grass with localised lowering down to around 5.9mAOD

At the southern extent of the site near the boat club, there are earth embankments. These are consistently around 5mAOD

A review of breach processes indicates that a breach is most likely to occur when preceded by overtopping.

The maximum still water tidal level quoted by the Environment Agency for the 200 year flood event is 4.56mAOD, assuming current climate conditions. Allowing for climate change, this level is expected to increase by approximately 300mm to 4.86mAOD over the next 50 years. These levels assume minimal wave action.

Waves attacking the sand dunes along the sea front will generally be larger than those attacking the earth embankment at the south of the site. This is because the waves from the south will need to have travelled over the mudflats which will have moderated their magnitude. Larger waves also originate from the north and east.

The maximum wave & water level combination for the 200 year event with 1% of waves reaching 5.9mAOD (sufficient to overtop the low point of the sand dune and possibly lead to erosion) is generated with an equivalent average water level of 4.36mAOD (Higher 'average water level' events tend to be combined with lower wave heights, thereby reducing the maximum water level reached by 1% of waves). Combined with a breach of 150m wide, this leads to widespread inundation of much but not all of the site. The resulting hazard maps show that apart from the breach location, the maximum hazard is "Danger to most".

6.2 SEASONALITY OF FLOODING

Coastal flooding follows a well established seasonal pattern. This consists of a predictable astronomic pattern, and a less predictable surge pattern.

The astronomic pattern is highly seasonal as the highest tides occur around the spring and autumn equinoxes, and the lowest tides between the two in July.

Surge tides do not have the predictability of astronomic tides, but positive surges can be most significant in winter.

Winter months (January & February) have a low proportion of relatively large tides, but a high proportion of the most extreme tides. This is supported by the anecdotal evidence of the January 1953 floods which devastated much of the East Coast of Britain were the result of a very significant surge on top of a high tide. Autumn floods are also large, but these are influenced more by predictable astronomic tides than surge dominated extreme winter tides.

6.3 MANAGING FLOOD RISK

Flood warnings are managed by the Environment Agency and are based on forecast tide levels. The warning also reflects the likelihood of large waves which reflects the propensity to overtop and potential breaching. Large waves are shown to come from the north. These warning are achieved through triggers from different combinations of forecast water level, wind direction and wind strength.

The Agency does not (and cannot) forecast the risk of a breach, nor its likely location and dimensions. These processes are uncertain, but have the greatest impact on flood hazard at the Fitties.

There is the residual risk of a breach occurring without being preceded by overtopping. Such an event is very difficult to forecast or model.

6.4 IMPACT ON LEASES AND COUNCIL ACTIONS

The potential consequences of a flood must not be increased by the actions of the Council. Initial soundings from the Environment Agency also suggest that the Agency would be uncomfortable about increasing the consequence of a potential flood. Accordingly, Weetwood advocates that:

- No extension should be made to the leases into the current closed season. This would introduce people onto the site at a time when the coastal flooding presents the greatest risk, and greatest uncertainty

- No additional development should be permitted within the Fitties which would increase the number of people in the flood-risk area.

- Currently unoccupied plots should not be developed, but the council may consider offering them to neighbouring plots to extend as garden / recreational areas. This represents a pragmatic use of the land without significantly increasing the consequences should a flood occur through allowing additional people to remain on site overnight.

Given the tourist nature of the development, the peak occupancy of the Fitties will be during the summer months when coastal flood risk is lowest. Extra vigilance is required during the spring, and autumn periods when the flood risk is increased. Weetwood proposes the following actions to help manage the any flooding consequences:

- The council should instruct their emergency planners to prepare a briefing note explaining the flood risks at the Fitties particularly in relation to seasonal and weather conditions.

- The Flood Warning scheme operated by the Environment Agency is critical to relaying predictive information about conditions which are most likely to cause inundation of the Fitties through a breach of the defences. The council should provide all occupants with details of the Environment Agency flood line

- The council's emergency planners should consider liaising with the Environment Agency in order to prepare the council's response to any flooding of the Fitties

Consideration was also given to looking at differing levels of risk for different parts of the site. The chalets on the higher land to the south of the site have less risk of being flooded than others at lower levels. There is a strip of plots behind the earth embankment to the west of the site. Whilst this is an attractive option, it has not been pursued as the plots on the higher ground also use the same access and egress routes through flooded areas. The chalets behind the secondary embankment are also considerably lower than surrounding land and the consequence of flooding would be that much more serious in a catastrophic breach.

The possibility of a catastrophic breach should not be ignored (but not overstated) and could be potentially disorientating as the source of flooding may not necessarily be visible. Clear evacuation plans should be prepared and adhered to.

The condition of the embankments, in particular the low spots on the dune frontage, should not be worsened, and if possible should be strengthened. The council should discuss monitoring or maintenance of these locations with the Environment Agency.

PPS25 notes that the impact of climate change is increasing. The council may wish to review the flood risk prior to the next round of renewal of the leases in 10 to 20 years time.

7 BIBLIOGRAPHY

- HR Wallingford (1999) Wave Overtopping of Seawalls – Design and Assessment Manual, R&D Technical Report W178
- Rye Consultancy, NELC / NLC Strategic Flood Risk Assessment, Final Report
- Morris, M. W. & Hassan, M., 2002, Breach formation through embankment dams and flood defence embankments: state of the art review Impact Project Workshop, 16th and 17th May. Wallingford, UK: HR Wallingford.
- Muir Wood, R., Drayton, M., Berger, A., Burgess, P and Wright, T., 2005. Catastrophic loss modelling of storm-surge flood risk in eastern England, *Phil. Trans. R. Soc. A* **363,** 1407 - 1422
- Muir-Wood, R., Sensitivity of storm surge loss to flood defence performance in eastern England, 2002, Accessed online at http://www.floodrisknet.org.uk, 17 July 2006.
- European Overtopping Manual web page
- DEFRA / EA FD2317/TR1 – Flood Risks to People – Phase 2 – The Flood Risks to People Methodology, Flood and Coastal Defence R&D Programme
- DEFRA / EA FD2317/TR1 – Flood Risks to People – Phase 2 – Guidance Document, Flood and Coastal Defence R&D Programme
- DEFRA / EA FD2317/TR1 – Flood Risks to People – Phase 2 – Project Record, Flood and Coastal Defence R&D Programme
- DEFRA/EA W5B-030/TR1, May 2003, High Level Methodology, R & D Technical Report

APPENDICES

APPENDIX A:

20 year Joint Probability Wave and Water Level Analysis
500 year Joint Probability Wave and Water Level Analysis

20 year Joint Probability Wave and Water Level Analysis

Wave Heights					Water Level (mAOD)
Significant Wave Height (m)	2/3 Positive Wave Height (m)	H10% 1.27	H1% 1.67	HMax 2	
3.06	2.04	2.59	3.41	4.08	0
3.06	2.04	2.59	3.41	4.08	1
3.06	2.04	2.59	3.41	4.08	2
2.98	1.99	2.52	3.32	3.97	3
2.8	1.87	2.37	3.12	3.73	3.27
2.79	1.86	2.36	3.11	3.72	3.3
2.4	1.60	2.03	2.67	3.20	3.6
2	1.33	1.69	2.23	2.67	3.77
1.68	1.12	1.42	1.87	2.24	3.9
1.5	1.00	1.27	1.67	2.00	3.96
1	0.67	0.85	1.11	1.33	4.11
0.65	0.43	0.55	0.72	0.87	4.2
0	0.00	0.00	0.00	0.00	4.26

500 year Joint Probability Wave and Water Level Analysis

Wave Heights					Water Level (mAOD)
Significant Wave Height (m)	**2/3 Positive Wave Height (m)**	**H10%** **1.27**	**H1%** **1.67**	**HMax** **2**	
4.29	2.86	3.63	4.78	5.72	0
4.29	2.86	3.63	4.78	5.72	1
4.29	2.86	3.63	4.78	5.72	2
4.12	2.75	3.49	4.59	5.49	3
3.79	2.53	3.21	4.22	5.05	3.3
3.6	2.40	3.05	4.01	4.80	3.45
3.49	2.33	2.95	3.89	4.65	3.6
3.2	2.13	2.71	3.56	4.27	3.86
2.98	1.99	2.52	3.32	3.97	3.9
2.8	1.87	2.37	3.12	3.73	4.03
2.79	1.86	2.36	3.11	3.72	4.2
2.4	1.60	2.03	2.67	3.20	4.25
2	1.33	1.69	2.23	2.67	4.35
1.5	1.00	1.27	1.67	2.00	4.43
1	0.67	0.85	1.11	1.33	4.52
0	0.00	0.00	0.00	0.00	4.67

APPENDIX B:

Humberston Fitties Max Flood Hazard – Scenario 18
Humberston Fitties Max Flood Hazard – Scenario 21
Humberston Fitties Max Flood Hazard – Scenario 23
Humberston Fitties Max Flood Hazard – Scenario 24
Humberston Fitties Max Flood Hazard – Scenario 26
Humberston Fitties Max Flood Hazard – Scenario 27

NOTES or LEGEND

- No danger
- Danger for some
- Danger for most
- Danger for all

Humberston Fitties
Max Flood Hazard
Scenario 18: 200 Year Event, 160 m Breach Width

Drawing Ref: 608/SM/S18

Drawn By: SM
Checked By: JJ
Date: Jan 2007

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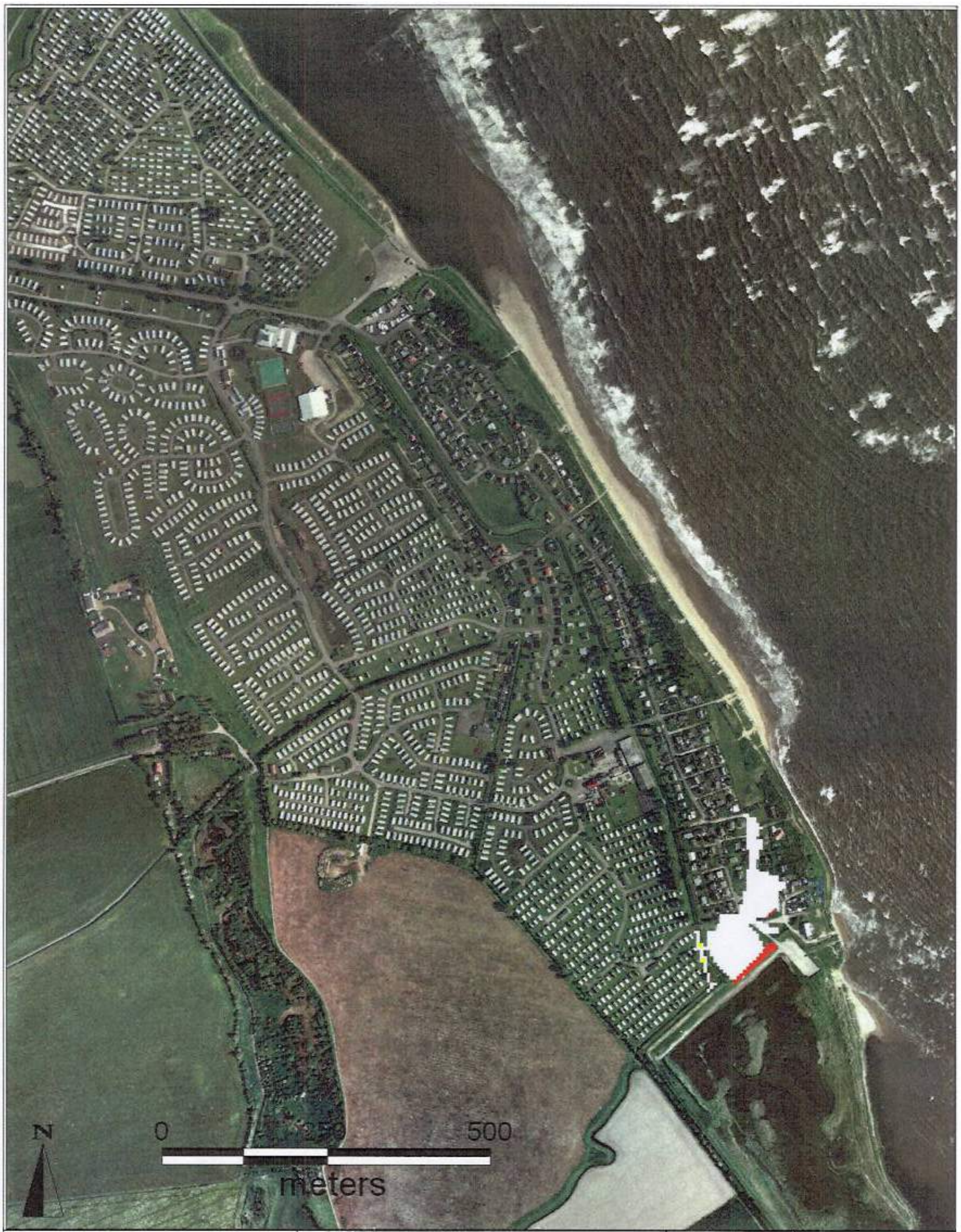

NOTES or LEGEND

- No danger
- Danger for some
- Danger for most
- Danger for all

Humberston Fitties
Max Flood Hazard
Scenario 21: 200 Year Event, ~80 m Breach Width

Drawing Ref: 608/SM/S21

Drawn By: SM
Checked By: JJ
Date: Jan 2007

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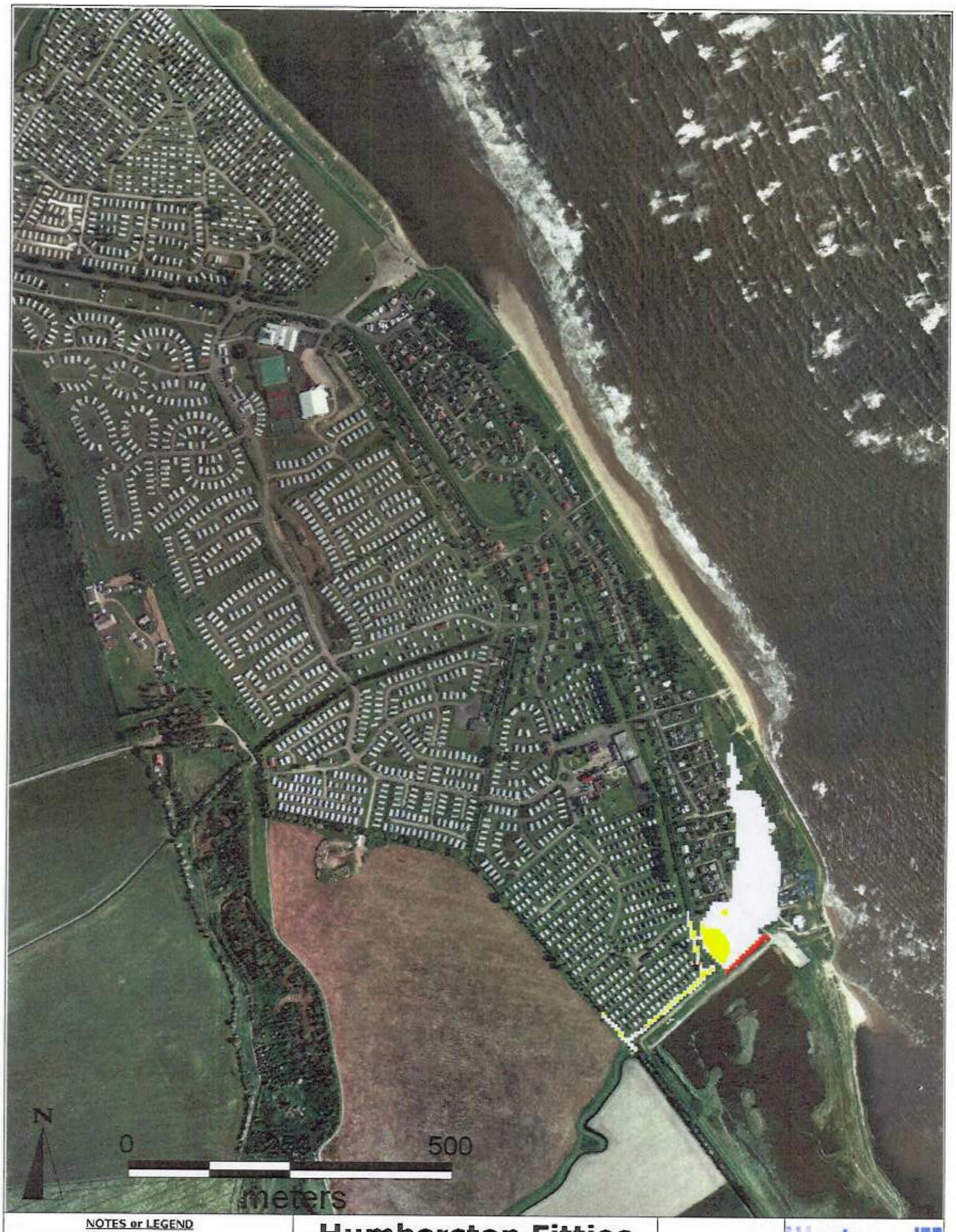

NOTES or LEGEND

- No danger
- Danger for some
- Danger for most
- Danger for all

Humberston Fitties
Max Flood Hazard
Scenario 23: 500 Year Event, ~80 m Breach Width
Drawing Ref: 608/SM/S23

Drawn By: SM
Checked By: JJ
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NOTES or LEGEND	Humberston Fitties		
No danger Danger for some Danger for most Danger for all	**Humberston Fitties** **Max Flood Hazard** **Scenario 24: 200 Year Event, 150 m Breach Width** Drawing Ref: 608/SM/S24	Drawn By: SM Checked By: JJ Date: Jan 2007	Weetwood www.weetwood.net Tadcaster Business Centre 4-6 Bridge Street Tadcaster North Yorkshire LS24 9AL Phone: 01937 831424 Fax: 01937 831424

NOTES or LEGEND		
No danger	**Humberston Fitties Max Flood Hazard**	Drawn By: SM
Danger for some	**Scenario 26: 500 Year Event, 150 m Breach Width**	Checked By: JJ
Danger for most	Drawing Ref: 608/SM/S26	Date: Jan 2007
Danger for all		

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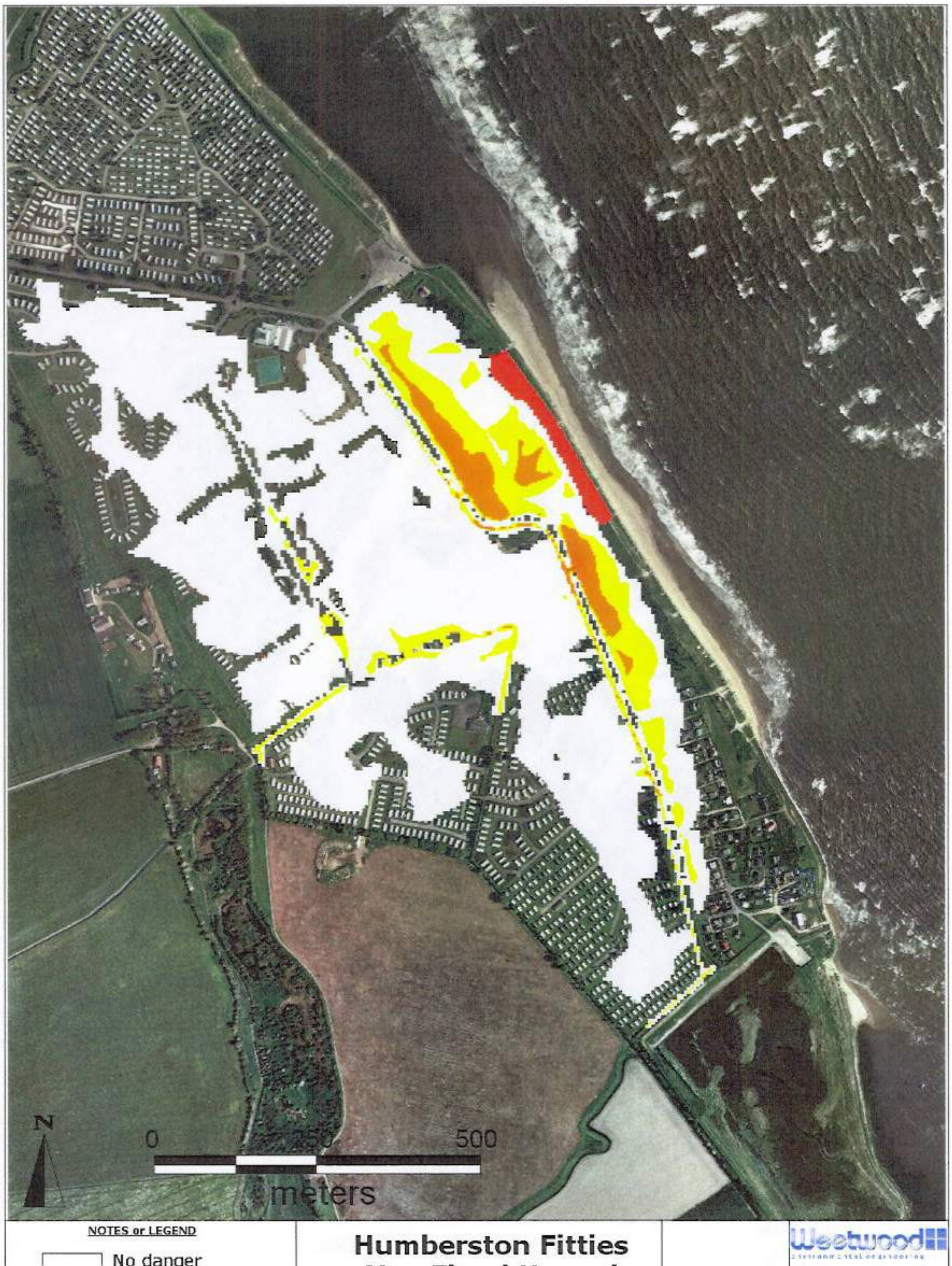

NOTES or LEGEND

- No danger
- Danger for some
- Danger for most
- Danger for all

Humberston Fitties Max Flood Hazard

Scenario 27: 200 Year Event, 300 m Breach Width

Drawing Ref: 608/SM/S27

Drawn By: SM
Checked By: JJ
Date: Jan 2007

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