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## **Risk Assessment for the Lincolnshire Coastal Flood Unit - COMRISK Subproject 8**

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# Risk Assessment for the Lincolnshire Coastal Flood Unit COMRISK Subproject 8

ELISE POBJOY, PETER FLOYD, STEVE HAYMAN

## S u m m a r y

The North Sea countries (Belgium, Denmark, Germany, Great Britain and The Netherlands) have a number of different policies towards the assessment and management of flood risk. COMRISK aims to establish a transfer and evaluation of knowledge and methods through focussed subject and pilot studies. The UK Subproject Pilot Study examines Lincshire; a major UK coastal defence scheme between Mablethorpe and Skegness where nearly 9 million m<sup>3</sup> of beach material has been placed since 1994.

The Lincshire defence strategy is based on the maintenance of a design beach profile. By taking a simplified relationship between the design minimum berm width and the level of storm resistance (and, hence probability of flooding), it has been possible to show how risk-based approaches based on risks to people, risks to assets (mainly property damage) and risks to both people and assets can be developed.

There are numerous ways in which the effects of flooding can be 'measured'. Within the UK, great reliance is placed upon extensive modelling to generate flood depths which, in turn, are used to generate estimates of losses in monetary terms. In this case study, the much simpler approach of simply counting people in flood compartments close to the defences yielded similar minimum berm width requirements.

Broader examination has been made of flooding from one of the coastal zones to demonstrate how a desk-top tool could be generated to assist in the identification of optimal areas for the placement of recharge during the decision making process. Analysis to examine the effects of a range of profile variations on the resulting overtopping volumes and consequent flood areas, depths and hence damages has been used to generate a limited range of data and look-up tables for interpolation. Limitations, issues encountered and recommendations for development of similar approaches in the future have been identified.

## Z u s a m m e n f a s s u n g

*Die Nordsee-Anrainerstaaten (Belgien, Dänemark, Deutschland, Vereinigtes Königreich und Die Niederlanden) nutzen unterschiedliche Strategien zur Ermittlung und Handhabung von Flutrisiken. COMRISK bezweckt einen Austausch und die Bewertung von Kenntnissen und Methoden durch thematische und Fallstudien. Die Fallstudie Lincolnshire (England) untersucht ein umfassendes Küstenschutzschema zwischen Mablethorpe und Skegness, wo seit 1994 fast neun Millionen m<sup>3</sup> Strandmaterial aufgespült wurde.*

*Die Lincshore Küstenschutzstrategie basiert auf einem definierten Strandprofil. Anhand eines einfachen Ansatzes zwischen der minimal erforderlichen Strandbreite im Bemessungsfall und dem Grad des Sturmwiderstandes (und, in der Konsequenz, die Überflutungswahrscheinlichkeit), war es möglich zu zeigen wie risikobasierte Ansätze (Risiko für Menschen, Risiko für Sachwerte und in Kombination) entwickelt werden können.*

*Viele Ansätze zur Ermittlung der Konsequenzen von Überflutungen existieren. Im Vereinigten Königreich liegt großes Vertrauen in dem Modellieren der Überflutungshöhen als Basis für die Berechnung der monetären Schäden. In dieser Fallstudie konnte durch einfaches Zählen der Einwohner hinter den Schutzwerken eine vergleichbare benötigte Minimalbreite des Strandprofils ermittelt werden.*

*Für eine der Niederungen wurde eine vertiefte Untersuchung der Überflutung durchgeführt um aufzuzeigen, wie eine „desk-top“ Module zur Optimierung der Standortsuche für Sandaufspülungen entwickelt werden kann. Die Auswirkungen verschiedener Strandprofile auf die Überlaufmengen und resultierende Überflutungsflächen, -Tiefen und -Schäden wurden als Grundlage*

*für die Erstellung von Nachschlagetabellen für Interpolation analysiert. Schließlich wurden die Grenzen der Methodik und die behandelten Themen aufgezeigt sowie Empfehlungen für die Entwicklung ähnlicher Ansätze in der Zukunft definiert.*

### Keywords

Coast, risk management, flood defence, risk assessment, failure probabilities, vulnerability analyses, Lincolnshire

### Contents

1. Introduction.....	104
2. Sources of Risk.....	105
3. Risk Pathways.....	107
4. Beach Performance.....	109
5. Risk-Based Approaches.....	110
6. Desk-top Tool.....	112
7. Key Findings.....	113
8. References.....	115

## 1. Introduction

In the UK, the Environment Agency has permissive powers to maintain the coastal defences that provide protection to 24 km of the Lincolnshire coastline between Mablethorpe and Skegness, referred to as the ‘Lincshore’ coastline. Lincshore is the pilot study for Great Britain under Subproject 8 and has been undertaken jointly by Halcrow and Risk and Policy Analysts (RPA) for the Environment Agency.

The Lincshore coastal defences provide flood protection to the low-lying coastal plain, which extends up to 15 km inland and has a recorded history of flooding back to the 13th century. The coastal plain covers approximately 35,000 ha of both urban and agricultural land, and includes over 27,500 residential and 3,500 commercial properties. The coastal frontage is heavily used for recreation and tourism with major tourist resorts at Mablethorpe and Skegness. Fishing contributes to the local economy and, further inland, land-use is dominated by isolated rural communities within agricultural holdings. There are a number of conservation and heritage sites protected by the defences on both the Lincshore frontage and the adjacent coast.



Fig. 1: Location of the study area

Historically, the natural sand dunes have formed the coastal defences along the Lincshire coastline, supplemented by concrete revetments and seawalls around residential areas. In 1953 extreme surge tide levels and severe wave action caused erosion and breaching of the natural dunes and erosion of the rear of hard defences, resulting in their collapse. This led to 12 major breaches with floodwater spreading several kilometres inland, causing the loss of over 40 lives and major property damage.



Fig. 2: Flooding in Lincshire during the 1953 storm surge

Following 1953, many of the seawalls were rebuilt and have required maintenance, repair and upgrading ever since. During subsequent storm surges, breaking waves still reached the seawalls, leading to significant overtopping and damage (although no major flood event), which highlighted the flood risks and need for a detailed review of the Lincshire coastal defences.

UK defence systems are planned within a 'hierarchy', cascading from National policy, through large-scale plans, to strategies, and down to individual schemes. The Lincolnshire Shoreline Management Plan (SMP) sets out the high-level policy for the coastline taking into account coastal processes, human influence, land-use and other environmental matters. For the Lincshire coastline the preferred policy is to 'hold the line'.

In 1991, the first Lincshire Sea Defence Strategy was commissioned. The strategy concluded that holding the line through beach nourishment and maintenance of seawalls and promontories was the preferred long-term defence strategy from technical, environmental and economic considerations. The strategy was reviewed in 1997 and again in 2003/2004 in light of the coast's performance and updated guidance, and in both instances it was concluded that beach nourishment to provide a 1 in 200 standard of defence should continue as the preferred coastal defence option (referred to as Option 6b in the latest 2003 Strategy Review).

## 2. Sources of Risk

At any particular location, the likelihood of flooding will depend on:

- The presence and form of the coastal defences;
- The beach profile and nearshore bathymetry;
- the nearshore wave climate, which in turn is dependent on tidal and meteorological conditions and offshore wind and wave conditions.

The near-shore wave climate also affects the movement of beach material. Sediment movement along the Lincshire frontage is primarily governed by cross-shore processes, which tend to dominate during storm conditions. However, the beach material is also subject to some longshore movement, effectively acting as a loss from one length of coastline, but a gain to that downdrift.

### Coast Defence Structures

The coastal defence structures along the Lincshire coast have been developed over many years and hence have a number of different profiles. The flood defences consist mainly of beaches, groynes, dune systems, seawalls and promontories (Chapel Point, Vickers Point & Ingoldmells Point). Structural details of the seawall were taken from the Anglian Sea Defence Survey (MOTT, 1999) which contained photographs, profile sections and descriptive details of both visual and analytical information for each structure surveyed.

### Beach Profile/Sea Bed Conditions

For most of its length, the Lincolnshire coast is characterised by a narrow steep beach with little sand, backed by seawalls or revetments. The beaches comprise sand of variable thickness and consistency, overlying clay, which is subject to erosion when exposed. The available recharge material has a coarser grain size than the original insitu beach material; in 2001 the mean grain size sampled on the beach was 0.4 mm.

### Significant Wave Heights

In the latest Strategy Review, the offshore wave data were obtained from the UK Met Office for a point located near Dowsing Light for the period 1991–2001. Analysis of this data gave a 1:100 year offshore wave height of 5.82 m. Differences were observed between the analysis of historic vessel observed records (prior to 1991) and the more recent (lower) Met Office predictions. Therefore this remains a potential source of some uncertainty, but the impact is mitigated by the minimal resulting difference in nearshore wave heights.

### Tidal Conditions

The mean tidal range for Lincolnshire coast is 4.4m, around a mean sea level of 0.26m OD (4.01m CD). A joint analysis of water level and wave height extremes was undertaken for the assessment of defences in the Strategy Review using hourly measured water levels from Immingham.

Sea Level Rise (SLR) has been included as a constant increase over the appraisal period. For the Lincshire coastline, situated in the Environment Agency Anglian region, a value of SLR of 6mm/yr was used in accordance with the latest DEFRA Guidance. Secondary impacts such as changes in wave heights due to an increase in water depths have been examined in a sensitivity analysis.

### Near-shore Wave Climate

The near-shore wave climate is typified by waves from the north-east. Waves were propagated inshore using Halcrow's in-house mathematical model, which is based on a new formulation of the mild slope equation for water waves, allowing for refraction, diffraction, breaking and bottom friction. The coastline was divided into seven zones, broadly based upon the management units defined in the SMP (Posford Du Vivier, 1996) and the offshore wave heights were transformed to inshore points within each of the zones. Wave heights are slightly larger towards the southern part of the coast. The results of the joint probability analysis for zone 2 are shown in the table below. Despite the difference in offshore wave conditions it should be noted that the wave heights in the table below are comparable with those derived in the 1990 Strategic Approach Study:

Zone	Return Period	Water Level, WL(mOD)	Future Water Level, WL+300mm (mOD)	Significant Wave Height, Hs (m)	Zero Crossing Tz (s)
2	1 in 1	3.35	3.65	2.80	7.75
	1 in 10	4.00	4.30	3.20	8.29
	1 in 20	4.15	4.45	3.50	8.67
	1 in 50	4.40	4.70	3.50	8.67
	1 in 100	4.50	4.80	3.70	8.91
	1 in 200	4.65	4.95	4.00	9.27
	1 in 300	4.79	5.09	4.07	9.35
	1 in 500	5.00	5.30	4.10	9.38

### 3. Risk Pathways

#### Flood Events

As already indicated, coastal flooding is caused by seawater overwhelming the defences. In practice, this can occur either by seawater coming over the top of the defence; and/or through a breach (i.e. failure) of the defences. The subsequent extent and severity of the resultant flooding will be governed by numerous factors including the nature and timing of the flooding. (Eg, there are likely to be far fewer people at risk in the static caravan parks in winter when storms are more likely).

#### Failure and Inundation Mechanisms

Different modes of failure (overtopping, undermining, face or toe erosion, overturning, piping, reduction in bearing capacity) were evaluated. The most prevalent structural failure mechanism for the seawalls was due to extreme overtopping of the structure. Overtopping of structures only leads to a breach once certain defined limiting values for discharge rates have been exceeded. Guidance for critical overtopping discharges for serviceability and ultimate limit states (CIRIA/CUR, 1991) were used as the means to assess breach failure.

Overtopping analysis was undertaken under a number of return periods to enable a robust assessment of the limits of the current standard of defence. Discharge quantities for overtopping of the initial return wall (OT1) and the rear of the embankment (OT3) were calculated directly from the overtopping modelling package. Overtopping of the intermediate splash wall (OT2) was calculated by means of a reduction co-efficient, determined as a function of the crest width and potential presence of a splash wall.

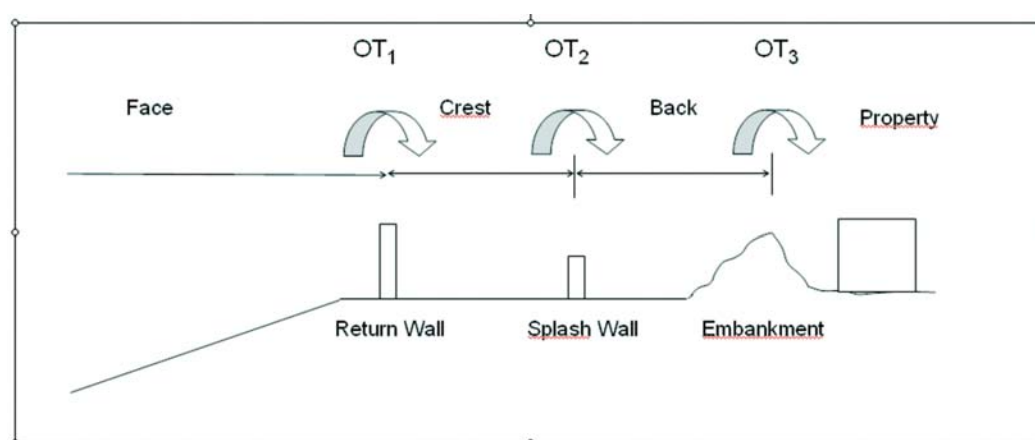


Fig. 3: Overtopping analyses of the defences

The discharges from the overtopping analysis were reviewed against a number of sources, including visual reference information of overtopping events for location, quantity and damage sustained to the defences. The results of the overtopping discharge assessment of the existing structures were compared against the critical overtopping limits to provide an assessment of the integrity and standard of each of the defences.

#### Flood Propagation

A dynamic method was used for flood propagation prediction, which takes account of the tidal range at the site and spreads the flood volume over consecutive tides by the application of hydrodynamic modelling. A digital terrain model (DTM) of the frontage was

developed based on Ordnance Survey profile data (made up of nationwide photogrammetry estimates and random spot heights), LIDAR data (1 km coastal strip), and Agricultural spot height co-ordinates and levels from Lindsey Marsh Drainage Board. From the DTM and OS profile information the location and level of the reservoir boundaries were defined and converted into ISIS spill lengths, across which flow would take place between adjacent reservoirs. Over 100 reservoirs and 700 spill units were established for the flood model for the coastline to reproduce the hydraulic characteristics of the flood area.

The 1953 documented flood event was used to calibrate the model. The 12 breach locations and extents were included in the flood model as well as the 1953 surge water levels as a tidal head boundary. Model calibration (breach widths, secondary defences etc) was then undertaken to reflect the 1953 flood limits.

Where either OT1 or OT2 exceeded the defined overtopping limits, the structure was deemed to have failed, and for each length failed, a breach width of 100 m (determined through a sensitivity analysis of breach widths) was entered into the model. OT3 was modelled as an inflow into the model over the peak of the tide.

Assets have been defined for each reservoir and the economic 'benefits' associated with the provision of standards of defence are dominated by the damages avoided to residential properties and industrial/commercial properties incurred through flooding. The capital value of residential assets at risk over the entire Lincshire frontage was over £ 2 billion.

### **Movement of Beach Materials**

In recent decades, wide accreting sandy beaches have been present both to the north of Mablethorpe and to the south of Skegness (POSFORD DUVIVIER, 1991 and HALCROW, 2003). Between these locations, the beaches have a history of erosion. Prior to beach recharge, the main supply of material for these accreting beaches was considered to be off-shore banks with a limited littoral movement (north to south) of 130,000 m<sup>3</sup>/year (Posford Duvivier, 1991). Recent coastal process modelling for the site suggests a southerly longshore movement with rates of around 100,000 and 250,000 m<sup>3</sup>/yr in the northern and southern parts respectively.

### **Design Principle**

The basic design principle is based around the provision of sufficient beach width to protect the seawall. The design beach profiles for different levels of protection have been established by increasing the width of the profile until the overtopping discharge falls below the acceptable overtopping limits. The volume of overtopping of the chosen design profile is that which would be expected once the profile had eroded after a storm event; this is calculated by extrapolating the overtopping between beach and clay profiles in proportion to (the eroded) volume change. The design berm width was then increased to account for annual erosion losses, and the cross shore modelling of the beaches determined a need for an average 8m increase in the berm width to account for the 300 mm increase in water level due to SLR over the strategy period of 50 years.

Using the October 2002 beach profiles as a baseline, digital terrain modelling was undertaken to determine the volume of material required to build up the beaches to the minimum profile widths for the 100 year design, the 200 year design and the 300 year design.

### **Overtopping Assessment**

The overtopping modelling results show that overtopping rates increase with decreasing berm width. However, as separate models were used to predict beach draw-down and then overtopping rates were based on the eroded beach profile, no simple linear correlation was derived between the starting beach profile and overtopping rates.

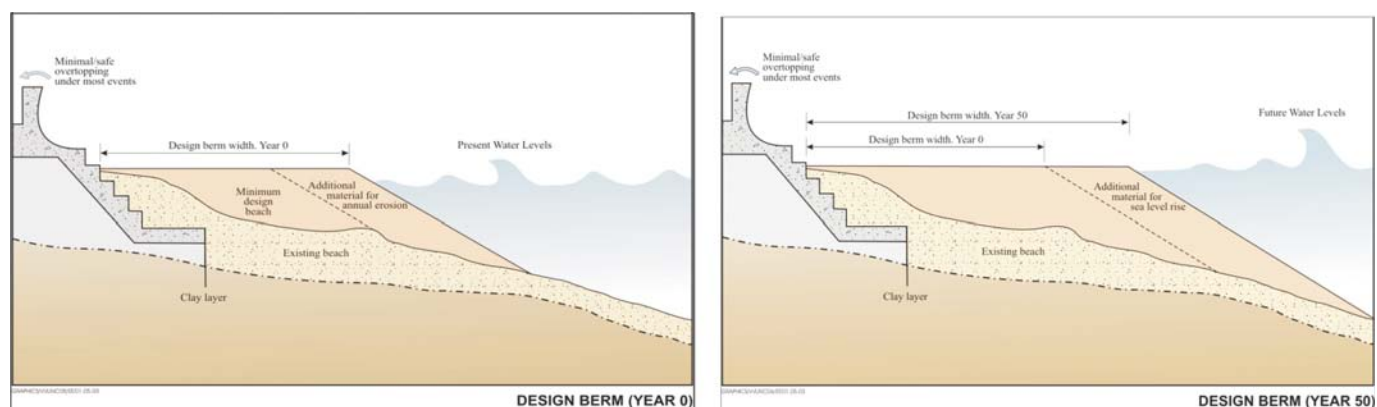


Fig. 4: Design berm without and with additional material for sea level rise

#### 4. Beach Performance

Nourishment of the Lincshore frontage has been ongoing since 1994. Over the ten year period, 1994–2003, nearly 9 million m<sup>3</sup> of beach material has been placed on the Lincolnshire coast between Mablethorpe and Skegness. Photographs demonstrate that the beach is now significantly wider than it was in 1994.

##### Beach Profiles

One of the key features of Lincshore is that use has been made of material with a mixture of grain sizes. This has led to ‘natural’ grading on the beach with medium sand found on the upper beach, very coarse sand on the middle beach and fine/medium sands on the lower beach (BLOTT & PYE, 2001). A number of data sets on the grain sizes exist, with samples taken over a number of transects by various parties at differing times and for a variety of purposes. Correlation between the observed beach profiles and equilibrium beach profiles (based on DEAN 1991) derived using certain of the data sets suggested that the profiles may be a direct consequence of the grain size distribution of the material used for beach nourishment and renourishment. However, this analysis did not fit all the available (different) data sets.

##### Net Movement of Material

Budgetary constraints for recharge activities mean that the beach still has a substantial shortfall from the original 1991 design profile. It has been recognised that the annual recharge is an ongoing commitment, ie it is addressing a shortfall in the sediment budget due to historic defence measures that have reduced feed to the frontage, and to address climate change in the longer term.

Considerable resources have been devoted to the collection and analysis of data over the last 15 years, and whilst it is accepted that there will always be a degree of uncertainty in predicting material losses from a renourished beach, it has proved difficult to conclusively relate the observed rate of loss to the rate of renourishment. Between Mablethorpe and Skegness the mean nourishment rate has been 0.785 million m<sup>3</sup>/year and (net) losses from the upper/middle beach (excluding Gibraltar Point), have averaged 0.598 million m<sup>3</sup>/year. These losses are predominantly cross-shore. However, despite one anomalous year of data, general trends can be extrapolated and the degree of uncertainty is within the sensitivities examined in the Strategy Review.



## 5. Defence Option Assessment

Within the UK, options for flood and coastal defence schemes and strategies are subjected to a formal appraisal process, including an environmental, technical and economic assessment (as set out by DEFRA) to ensure that the optimal defence option and standard is selected. For the Lincolnshire coastline the required indicative standards of protection for the land usage can only be achieved by 'do something' options.

### Beach Management Options

The preferred Strategy defence option (Option 6b) entails annual beach recharge quantities of around 0.3 million m<sup>3</sup> following the initial capital recharge campaign. There are a variety of methods which could be used to determine where this material could practically be best placed.

For each length of beach (as characterised by the beach profile), it is possible to estimate either the shortfall in beach volume between the current and design profile, or the present standard of defence (as 'probability of critical overtopping'). Those profiles with the greatest shortfall of material or lower standard of defence could be given priority for beach recharge. However, this would not account (explicitly) for the associated risks.

Alternative approaches could be based on risks to either people or assets situated behind the defences, or even a combination of the two. The management options for material emplacement outlined in the previous sub-sections are summarised below.

#### *Summary of Management Options for Material Emplacement*

<i>Option</i>	<i>Simple?</i>	<i>Relevant?</i>	<i>Risks to People Considered?</i>	<i>Risks to Assets Considered?</i>
Vol. differences – original design	Yes	No	No	No
Volume differences – latest design	Yes	Yes	No	No
Maintain standards of defence	Yes	Yes	No	No
Risk-based approach				
(with focus on risks to people)	No	Yes	Yes	No
(with focus on risks to assets)	No?	Yes	No	Yes
Combined risk-based approach	No	Yes	Yes	Yes

### Risk-Based Approach

At a particular location, the risk to people behind the defences is a function of the standard of defence, the presence of people behind the defences and their vulnerability to flooding (eg flood depth and velocity and nature of buildings). Consideration of a range of flood events (at a particular location) would enable the baseline risk of death to a hypothetical individual stood outside for 24 hours a day to be determined and be presented graphically in the form of a series of 'risk contours'. These contours should then be passed through a logic gate to confirm the probability that someone would be present at each location in order to provide the 'real' risk. Those areas with the highest 'real' risk could then be given priority for beach recharge.

Similarly, the risk to assets behind the defences is a function of the standard of defence, the presence of assets behind the defences and damage-depth relationships. This is a similar approach to that taken in determining average annual damages (AADs). It should be noted that taking the AAD values effectively takes account of the flood reservoir location since the damages are associated with the flood level predicted in each of the flood reservoirs.

Damages (for a range of extreme events) should be considered on a profile by profile basis.

Within each flood reservoir, the assets were detailed and the associated monetary damages determined under a range of storm events. The risks to both people and property obviously decrease with distance from the coast. For Option 6b, the AAD figures indicate that over half of the total calculated damages occur in flood reservoirs which are located immediately behind the defences. Furthermore, 95 % of the damages are associated with the 61 flood reservoirs which, at their closest, are within two kilometres of the defences. It therefore appeared reasonable to develop a simplified risk-based approach based on those 61 flood reservoirs.

Flood risks to an individual are, primarily, a function of depth and velocity, both of which are related to location. The overall risk is also a function of the total number of people. Determining the precise levels of risk to particular people in particular locations is a complex task and is beyond the scope of this study. However, a simple function was formulated based on numbers of people and location. A simple risk score was assigned to each flood reservoir under consideration. For risk to people this was based on its proximity to the defences and the number of people at risk. For risk to assets, risk was assigned based on the level of damage.

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#### Risk Scores for Flood Reservoirs (based on Risks to People)

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Boundary of Flood Reservoir	Number of People within Flood Reservoir					
	People at Risk = Nr of residential + industrial/commercial properties x 2.5					
	up to 10	>10	>30	>100	>300	>1000
Adjacent to Defences	0	1	2	3	4	5
Within 2 km of Defences	0	0.5	1	1.5	2	2.5

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#### Risk Scores for Flood Reservoirs (based on Risks to Assets)

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Level of Damage	Predicted Annual Average Damage (AAD)					
	up to £3k	>£3k	>£10k	>£30k	>£100k	>£300k
Risk Score	0	1	2	3	4	5

---

From these risk values, a relationship to the design berm was determined:

$$\text{Berm Width} = 6 \times \text{Risk Score} + 5$$

At each location along the Lincolnshire coastline, breaching or overtopping of defences could affect more than one flood reservoir. The flood reservoirs were 'mapped' against each of the profile numbers in order to develop a means of providing sufficient berm width for all the flood reservoirs that could be affected from a single stretch of coastline. It was found that the berm width requirements are dominated by the risks associated with flood reservoirs which are immediately behind the defences.

A comparison of the result can be seen below. There was a strong correlation between the results from both approaches which indicates a strong correlation between the derived

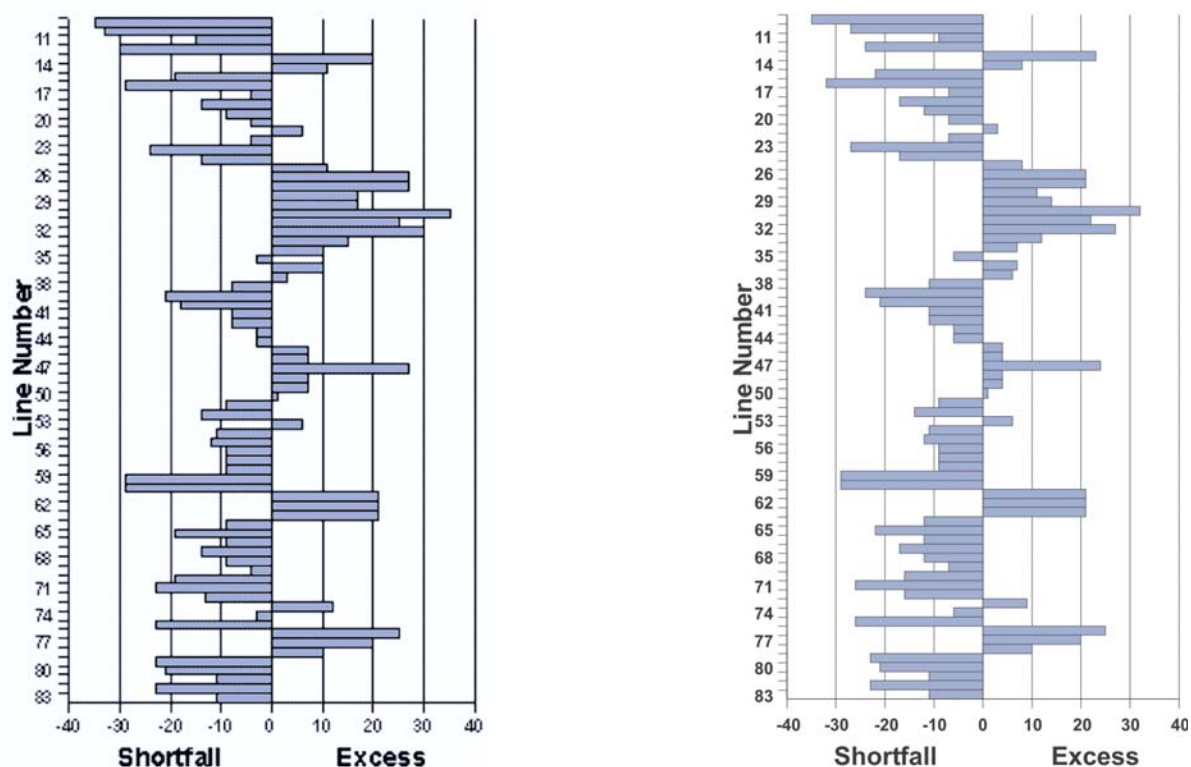


Fig. 5: Comparison of berm widths based on risks to people (left), and to assets (right)

risk scores. ie, as might have been expected, in areas with relatively high annual average damages there will also be a relatively high level of risk (as both are a function of the numbers of people/assets at risk and the floodwater depth).

Comparison of the overall minimum berm widths with actual berm widths would enable the areas requiring additional recharge material to be identified. A combined approach could be based on simply averaging the minimum berm widths for each flood reservoir.

## 6. Desk-top Tool

A desk-top tool has been developed to assist in the identification of optimal areas for the placement of limited recharge. The tool examines the flooding associated with Zone 2 (selected as being representative of average conditions along the frontage).

The steps for using the tool are as follows:

- Import latest survey results (or historic surveys held within the spreadsheet can be used)
- Working through the zone, beach profiles are presented, and by inspection, the user selects an appropriate toe level for each. Toe levels are collated into a table of results.
- Once all profile information has been collated, the programme interpolates from a look-up table to determine overtopping volumes for each reservoir and whether a breach is likely to have occurred.
- The programme then uses a second look-up table to relate the derived overtopping volume or breach scenario to a consequential value of damages caused by this flooding. These damages are related to the damages anticipated with the design profile in place, and hence the value of damages avoided calculated.

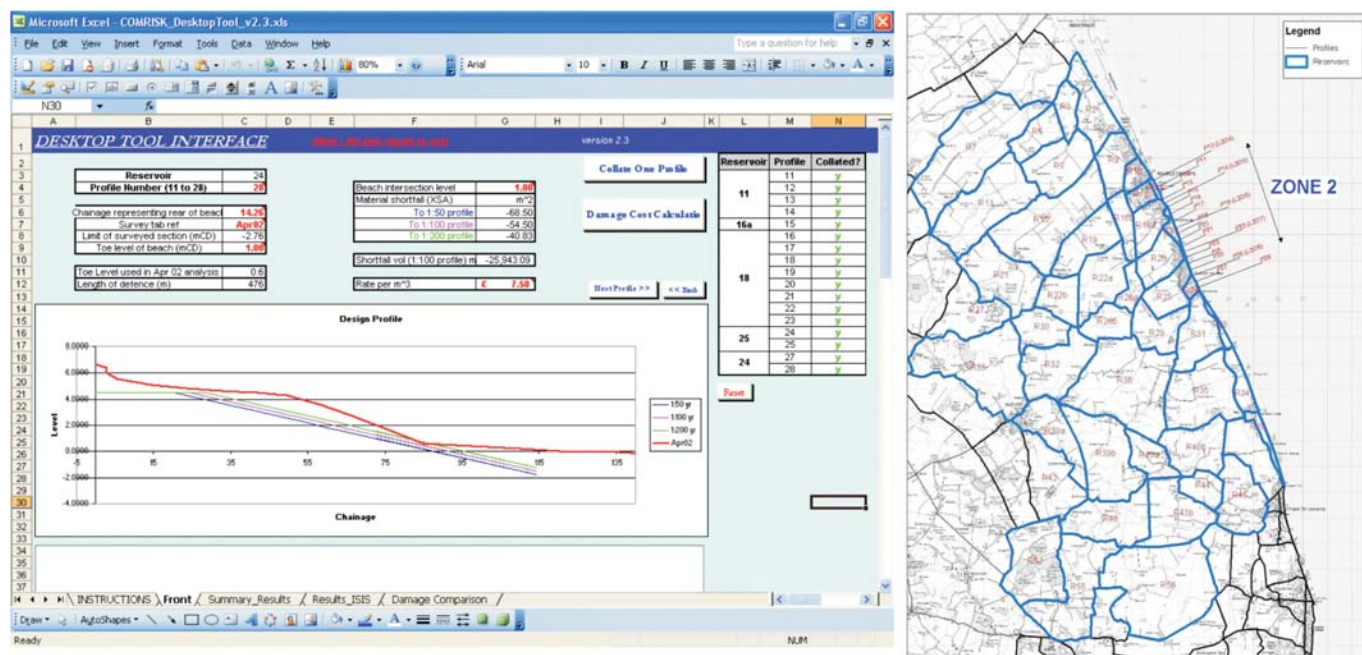


Fig. 6: Screen shot of desk-top tool to assist in identifying optimal locations for recharges (left), and locations of the profiles in the screen shot (right)

- From the design profile for the different standards of defence (1:50, 1:100, 1:200) and the beach survey levels, a table of shortfall volumes to different design standards is calculated.
- From the shortfall volumes and the value of damages avoided, a cost:benefit comparison for recharging to different standards of defence throughout each reservoir is derived. This can then be examined in light of any budgetary constraints in order to determine the optimal economic solution for the placement of material.

## 7. Key Findings

Lincshire is a major UK coastal defence scheme which has involved the emplacement of nearly 9 million cubic metres of material upon the beach between Mablethorpe and Skegness since 1994. There has been extensive work over a period of time on beach monitoring, modelling of flood events and comprehensive evaluations of the costs and benefits of various options for maintaining appropriate standards of defence.

### Risk-Based Approaches

Lincshire is based on the maintenance of a design beach volume to protect a hard defence line. The latest design incorporates a minimum berm width to provide, in effect, the required level of storm resistance (and, thus, reduce the probability of flooding). However, the strong temporal variability in the beach response and influence of coastal geomorphology, storm sequencing and persistence make it difficult to identify a simple relationship between design berm widths and probabilities of flooding, which has proved to be an obstacle to the development of a 'calibrated' example of a risk-based approach for the Lincolnshire coastline.

Nevertheless, on the simplified assumption that the probability of flooding is directly proportional to the berm width, risk-based approaches have been developed based on risks to people, risks to assets (mainly property damage) and risks to both people and assets. The results from all three approaches were very similar and could provide an alternative (simplified) basis on which to allocate beach material along the coastline.

### **Desk-Top Tool Development**

A number of points or note came out of the development of the desk-top tool:

#### *Uncertainty in Analysis*

The tool uses a combined assessment of drawdown and overtopping to determine an overtopping volume for the eroded beach profile. The degree of accuracy of the overtopping calculations is generally appreciated to be order of magnitude, hence the validity of comparison with a single critical overtopping value to assess whether or not a breach has occurred is questionable. Calibration with real events would help to improve confidence, but (fortunately) there is limited data on breach failure scenarios. This does, however, mean that the prediction of circumstances when breach and overtopping failure would occur is uncertain, and a full system model of flood risk is required to enable testing of a wide range of combinations of beach state and forcing conditions to assess the sensitivity of management assumptions to the underpinning analysis and assumptions.

#### *Potential for Changes to the System*

The analysis used is founded on an assessment of the response of the beach defence system for the current wind and wave climate and existing bathymetric levels, with beach gradings based on the current understanding of available recharge sources. The tool does not allow for these parameters to be varied, nor does it account for whether erosion rates at this location are likely to be high, medium, low or what would happen to the material if placed there in the near or more distant future. As described, the coastal system is very complex and material can remain stored in offshore banks for some time, making assessment of movement trends difficult. However, as the purpose of the tool is for short-term management decisions, this is not viewed as a major constraint.

#### *Reservoirs with Damages*

The majority of the damages from breaches and/or flooding in Zone 2 occur within a limited number of reservoirs, located adjacent to the coast and which cover the urban areas of Mablethorpe and Sutton on Sea.

#### *Look-up Tables*

The look-up tables used in the desk-top tool are based on coarse interpolation between a limited number of model runs to generate data for a range of toe levels, overtopping volumes, flood limits and damages. To get a comprehensive table of the full range of beach profiles, forcing conditions, breach/non-breach scenarios, flood pathways and relative overtopping contributions from adjacent coastal reservoirs to determine independent and in-combination events for the entire coastline would require a vast amount of modelling.

#### *Data Management System*

Examination and review of the scheme has been ongoing for the last 15 years. An efficient data management system is vital to collate the vast amounts of data associated with a project spanning over this length of time. Any database system should permit comments to

be added pertaining to the source, reliability and methodology adopted and enable identification of any issues to be noted as records are collated and any assessments of the raw data or trends are undertaken.

### Recommendations

There are numerous ways in which the effects of flooding can be 'measured'. Within the UK, great reliance is placed upon extensive modelling to generate flood depths which, in turn, are used to generate estimates of losses in monetary terms. In this instance, the much simpler approach of counting people in flood compartments close to the defences yielded similar minimum berm width requirements. Consideration should therefore be given to the ability of the appraisal method to deliver the required results in an efficient manner.

A desktop tool has been developed which enables a strategic approach to recharging the beach and allows the sensitivity of flood risk to beach condition in each coastal cell to be tested to identify trends. Such a tool could be useful for Flood managers to provide short-term management decision support as a relative measure of qualitative benefits of alternative recharge locations when there are budgetary constraints. However, it does not consider longer term impacts of the wider geomorphology of the system and therefore does not replace the deterministic assessment of failure required to put forward the longer-term business case for the recharge works.

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