Use of GIS in Flood Risk Mapping

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Abstract

The Environment Agency invests substantial resources collecting hydrometric and topographical data using various techniques. This data is used for a wide range of purposes such as flood risk mapping, catchment flood management plans, shoreline management plans and integrated coastal zone management. These results provide essential information for day to day asset management and long term flood risk management.

GIS applications in flood risk mapping range from storing and managing hydrological data to generating flood inundation and hazard maps to assist flood risk management. Over the last decade in particular, a great deal of knowledge and experience has been gained in using GIS in flood risk mapping.

This paper illustrates through a case study of the Medway Estuary Strategic Flood Risk Assessment how a wide range of GIS data sets were integrated. It shows how near shore bathymetry, low level LIDAR, forward and downward looking video, LIDAR, flood defence asset data and a range of bespoke and other datasets were combined to assess flood risk for a tidal estuary. It explains how GIS can be used in manipulating and processing the various forms and types of spatial data for the strategic flood risk assessment; and how this links to 1D and 2D flood modelling techniques. Finally it summarises some of the experience and lessons learnt in applying GIS in modelling and flood risk mapping.

Keywords
GIS, Flood Mapping, LIDAR.

1. Introduction

The Medway Estuary is part of the Thames Gateway regeneration area and is striving to become the centre for learning, culture, tourism and high technology within the Gateway. Its population of 250,000 is set to grow to 300,000 in the next 20 years and there is an ambitious regeneration programme which is deemed fundamental for growth, change and reconnection to the river. This programme will see the redevelopment of brown field sites to deliver the required expansion of housing and employment facilities.

Mott MacDonald was commissioned by Medway Council in 2004 to carry out a Strategic Flood Risk Assessment (SFRA) of the Medway Estuary. The purpose of such assessment is:

> *"To identify the areas within a development plan that are at risk of flooding. To identify and detail those factors that are relevant to current and future flood risks and to outline policies to be applied to such areas to minimise and manage that risk."*

In addition, the SFRA has specific objectives to:

- provide a detailed and robust assessment of the extent and nature of the risk of flooding in the areas likely to accommodate significant growth in the next plan period.
- ensure that the Council meets its obligations under the Planning Policy Guidance Note 25: Development and Flood Risk (PPG25) which has subsequently been replaced by the Planning Policy Statement (PPS25).

The SFRA will provide the Council with the data to inform the decision-making process for future development planning and guide the future development. The SFRA will also provide the basis from which to apply the Sequential Test and Exception Test in the development allocation and development control process.

GIS has been used throughout the project from the planning of the flight route for the capture of the flood defence data, to the final production of the flood risk maps.

This paper describes the use of GIS in land classification, data processing, creation of Digital Terrain Model (DTM) and flood risk and hazard mapping. The integration of GIS with modelling is also discussed.

2. Project Approach

The land and properties along the Medway Estuary between Maidstone and Sheerness are protected by approximately 150 km of flood defences. These defences primarily consist of flood defence walls and earth embankments. They offer differing standards of protection, ranging between 50 years and 1000 years.

The Medway Council district lies some 50 km south-east of London, and includes the towns of Strood, Rochester, Chatham, Gillingham and Rainham together with more rural areas, including the Hoo Peninsula. The study area is shown in Figure 1.

Figure 1: Medway Estuary and Study Area

Examination of historical flood events indicates that although the Medway is considered to be tidal as far upstream as Allington Lock, fluvial flooding is significant in the first 5-10 km downstream of the lock. Beyond the M2 bridge, the risk of fluvial flooding is small compared to that of tidal inundation. Since all of the Council's primary development sites are downstream of the M2 bridge, flooding from tide, surge and sea level rise due to future climate change is considered to be the primary source of flood risk for the sites investigated in this SFRA.

Development of a 2D floodplain model has been identified as the preferred approach for predicting the risks for floods of various return periods under various climate conditions. In order to build a robust 2D model for the floodplain, detailed topographical data for the floodplain is essential.

The Environment Agency (EA) had collected some topographical data for the Medway Estuary and its floodplain in the past.

- In 1997 the EA undertook an aerial survey of the floodplain of the Medway Estuary upstream of the M2 crossing near Rochester. Photogrammetric data was derived from the stereo aerial photography at a scale of 1:3000. It provides contours at intervals of 250 mm within the floodplain.

- In 2001, the EA acquired LiDAR data for the floodplain of the Lower Medway from Allington to Sheerness. The LiDAR data has a grid resolution of 2 m. It provides a good representation of the ground surface and covers the entire study area for this project.

- In 2002, a hydrographical survey of the river channel cross sections was undertaken by the EA between Allington Lock and the M2 crossing.

The topographical data collected by the EA had been made available to this project. However, additional topographical data was required for the flood defence and for the river channel dimensions downstream of the M2 crossing.

This project was split into four stages:

Stage 1 - Acquisition of flood defence data and rich channel data.
Stage 2 - Data processing
Stage 3 - 2D modelling & scenario tests
Stage 4 - Flood risk and hazard mapping

3. Acquisition of Flood Defence Data and Channel Topographical Tata

In order to assess the flood risks behind the defences under both the current and future climate conditions, it is essential to know the location and the crest levels of these defences, as they form the critical interfaces between the river channel and the floodplain. However, investigation of the currently available defence data, including the Environment Agency's National Flood and Coastal Defence Database (NFCDD), LiDAR and some as-built drawings showed that details of the crest levels and the positioning/alignment of the defences along (97%) of the 150 km defences of the Medway Estuary were unavailable.

Although the existing LiDAR data covered the flood defences, it was inadequate to abstract crest height from the LiDAR data, particularly where the defences are made up of walls or narrow crested embankments, due to its horizontal resolution of 2 m.

In order to fill the large data gap on the flood defences, two alternative methods were examined:

(i) the traditional land based topographic and asset survey; and
(ii) airborne remote sensing techniques using helicopter mounted video and LiDAR - a process known as Low Level LiDAR.

The evaluations were focused on two principal uses of the data: (i) flood risk mapping (SFRM), and (ii) asset management.

For the reasons summarised below, the helicopter-borne Low Level LiDAR surveying method was chosen for capturing the flood defence data for the Medway Estuary and Swale as a pilot study:

- High level of detail captured
- Consistency of data
- Referenced digital video
- Fixed price per km
- Competitive price
- Less susceptible to delays
- No problems with access
- Suitable for strategic flood risk mapping
- Once obtained it is a valuable asset
- Wide range of use for the Environment Agency

The FLI-MAP system operated by BKS Surveys Ltd in the UK was selected for use on this project.

The key elements to the success of the flood defence survey were:

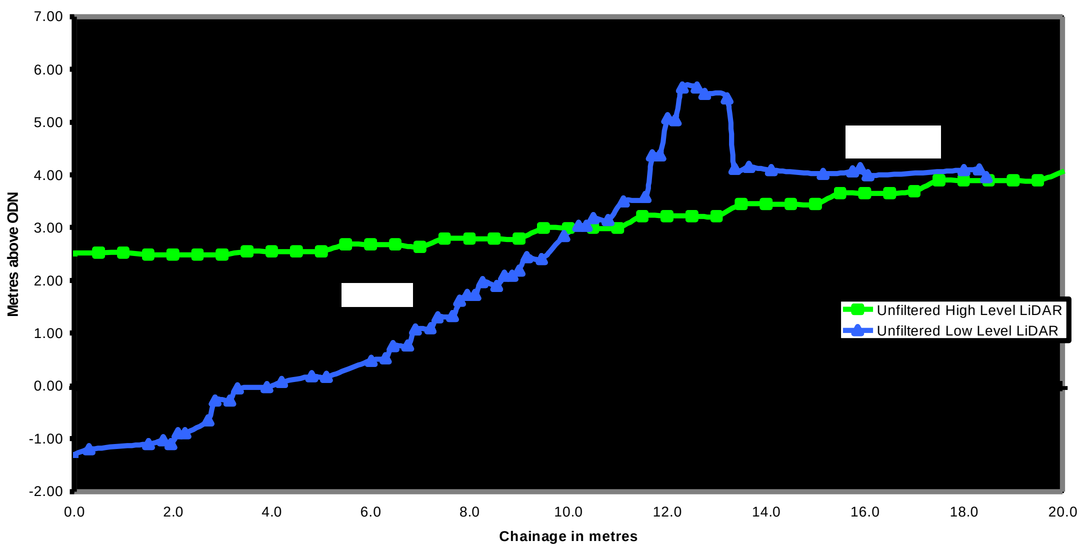
(i) detailed planning of the flight route;
(ii) the density of the point cloud data and the resolution of the images.

The approximate locations and the alignment of the primary and secondary flood defences were digitised using a combination of OS data, high level LiDAR data and the information collected from site visits. These digitised flood defence lines were then used for the planning of the flight route of the helicopter survey.

During the helicopter survey, the point density was set at, at least 12pt/m^2 to enable measurements on thin wall defences. Additionally, digital images at 8 cm pixel size were captured to ensure they are detailed enough to distinguish the defence types. Geo-referenced downward and forward videos were made which were extremely useful. They enable the modellers to visually examine/assess the entire flood defence from their desks whenever required.

The survey results showed that a greater point density was achieved than was specified. This is particularly beneficial and important to accurately define the height and location of a flood defence. Figure 2 (1) shows a flood defence wall which was not apparent when surveyed by the high level LiDAR technique with 2 m resolution, but was clearly shown by the low level LiDAR technique.

Figure 2: Comparison of High Level and Low Level LiDAR Data(1)



In addition to the flood defence data, topographical data for the river channel downstream of the M2 bridge was collected by the EA using bathymetric survey techniques during this project.

4. Data Processing

4.1. Abstracting Flood Defence Data

Once the low level LiDAR data was captured, the next key activity was to analyse and abstract flood defence data. FLIP7 software, a fully developed extension for ArcGIS, developed by Fugro was used for this purpose. FLIP7 offers various ways to look at the LiDAR data using different viewing perspectives, such as plan view, profile view, dynamic 3D view and user adjustable colouring schemes. It was used to merge the system position altitude information with the LiDAR sensor data, video and digital still imagery. Most importantly, it was used to create long profiles of the defences. The flood defence profiles were then exported into ASCII format for input to the 2D model.

4.2. Creation of Digital Terrain Model (DTM)

Following the collection of the flood defence and bathymetric data, the DTM for the entire 2D modelling area was derived primarily from the following five data sources:

(i) photogrammetric data collected in 1997 upstream of the M2 crossing;
(ii) 2 m resolution LiDAR data captured in 2002;

(iii) hydrographical survey data collected in 2002;
(iv) bathymetric survey data collected in 2005; and
(v) lower level LiDAR survey data captured in 2005.

Prior to the creation of the DTM, certain data checking and processing activities were carried out. Where the photogrammetry and LiDAR datasets overlap, photogrammetric data was used and elsewhere LiDAR data was used.

Finally the combined DTM was treated to remove any small areas of grid cells that had no elevation data. This was done in ArcGIS, assigning elevation values to the missing cells based on the average value of the surrounding cells. The final DTM was then imported into MapInfo to be used as the foundation for the 2D model floodplain representation. Any further treatment of the DTM was performed within the model domain.

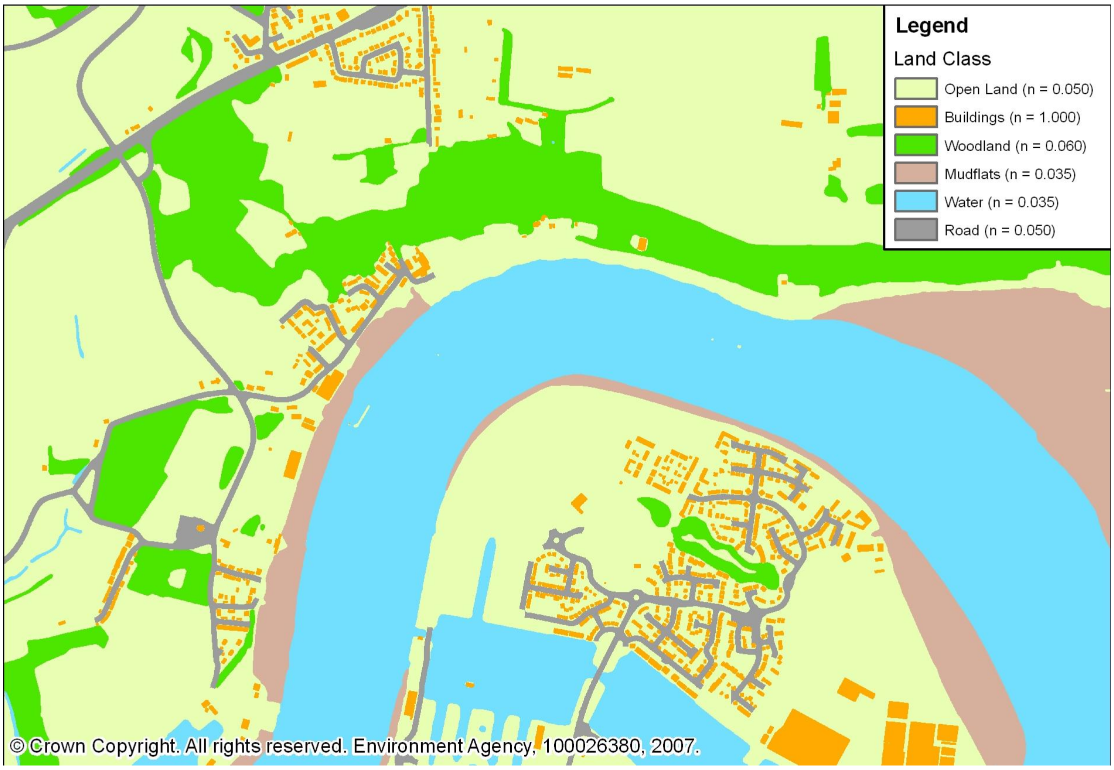
4.3. Land Classification

Different land use types have different levels of resistance to flood flow. Roughness values are used in the 2D model for the floodplain.

The 1: 10,000 OS digital data set was used to define various types of land use. The land use units were represented by individual polygons. Appropriate Manning's 'n' values were assigned to these polygons and the individual grid cells adopted the Manning's 'n' values of whichever polygon they were located within.

The land use categories identified were: buildings, roads, rails, paved area, woodlands, grasslands, water bodies, etc. The classified data was verified against the aerial photographs and spot checked by the field observations. The roughness values used for each of the land use categories are shown in Figure 3.

Figure 3: Land Classification and Manning's n Values



5. Modelling

TUFLOW software was selected for this project with the consideration of its advanced 1D/2D integration and 'commercial maturity'[(2)]. It was used to simulate flood extent, depth and velocity. In addition to the flood inundation maps, flood hazard maps were also derived for a wide range of tide and climate conditions.

5.1. Representation of the River Channel and Floodplain

The river system was modelled using ESTRY, a one-dimensional model. The 1D model of the river consists of a series of channel cross sections connected by river reaches. The floodplain was modelled using TUFLOW. It was primarily represented by a computational grid mesh with a cell size of 15 m. Each grid cell is assigned attributes, including cell reference number, ground elevation, material or relative flow resistance. The model topography is defined by elevations at the cell centres, mid sides and corners.

5.2. Dynamic Link Between the Channel and the Floodplain

River banks and embankments act as the interfaces between the 1D model representing the river channel and the 2D model representing the floodplain. They directly control the water level at which flow can be transferred from the 1D channel to the 2D floodplain, or vice versa. Break lines representing the flood defence/embankment and river banks have been created using ArcGIS. Elevation values were abstracted from the Low Level LiDAR survey data using FLIP7.

5.3. Representation of Floodplain Features

The decision on which floodplain features should be included in or excluded from a floodplain model requires a large amount of field knowledge combined with modelling experience[(2)]. For this project, roads and railway embankments have been identified as the key features in the floodplain that could present a potential barrier to floodplain flow paths. They were represented by 3D polylines.

Other hydraulic structures in the floodplain, such as culverts or pipes underneath the roads and railway embankments that would influence flooding mechanisms, were also identified. Their locations and dimensions were obtained through a combination of terrain and mapping analysis, previous asset surveys and site visits. These structures were modelled as 1D elements within the 2D model domain.

6. Flood Risk/Hazard Mapping

The SFRA considered six combinations of water level and climate change. These were the 200 year and 1000 year tidal events for the current day, 2060 and 2100 scenarios. The flood extent and flood depth maps were produced for these six combinations.

Additionally, in order to identify the potential danger or hazard associated with the flood, flood hazard maps were derived taking into account the depth and velocity of the flood waters.

The calculation of flood hazard is based upon the following formula [(3)]:

$$\text{Flood Hazard Rating (HR)} = D \times (V + 0.5) + DF$$

where:

V = velocity (m/s)
D = depth (m)
DF = debris factor (= 0, 0.5, 1 depending on probability that debris will lead to a significantly greater hazard).

Table 1 below outlines the flood hazard ratings adopted for this study assuming insignificant debris presence with DF = 0.

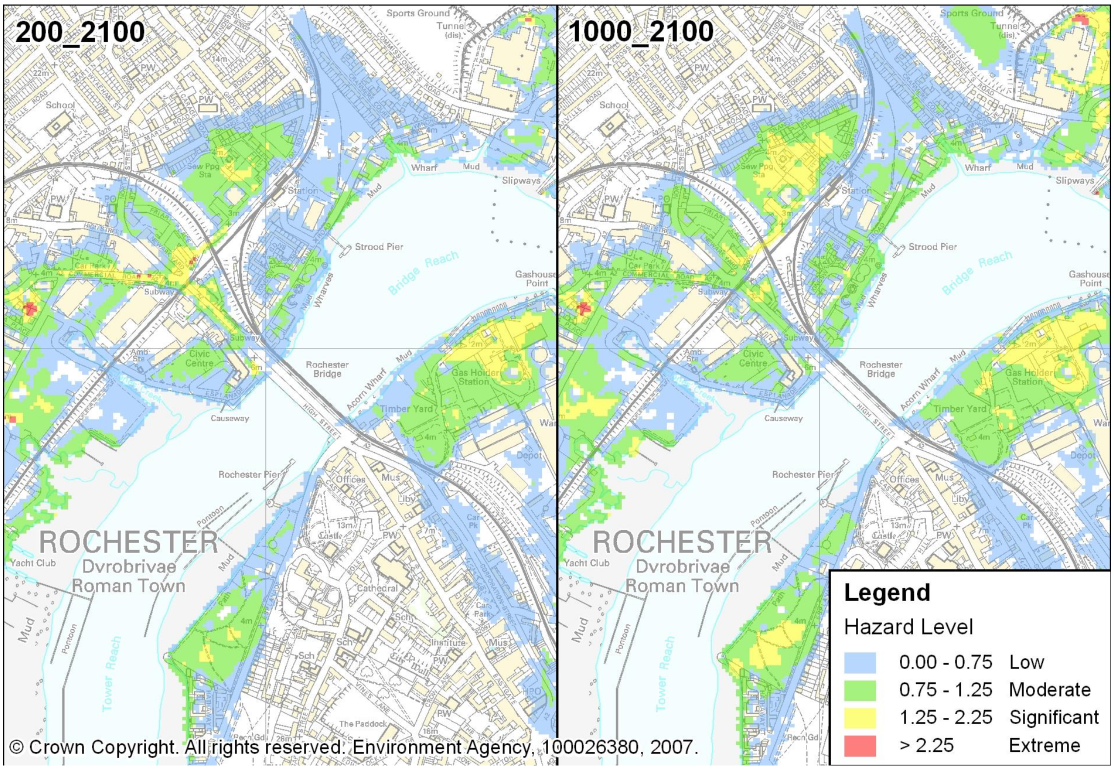
Table 1: Flood Hazard Categories

Flood Hazard Value	Flood Hazard Category	Description
> 2.25	Extreme	Dangerous for all *"Extreme danger: flood zone with deep fast flowing water"*
1.25 – 2.25	Significant	Dangerous for most people *"Danger: flood zone with deep fast flowing water"*
0.75 – 1.25	Moderate	Dangerous for some (i.e. children) *"Danger: flood zone with deep or fast flowing* water"
0 – 0.75	Low	Caution *"Flood zone with shallow flowing water or* deep standing water"

Figures 4 shows the flood hazard maps for design runs of 200_2100 and 1000_2100 scenarios.[1]. The model results suggest that:

- under the 200_2100 conditions, the majority of the flooded area fell into the 'Low' or 'Moderate' categories with a few isolated areas falling into the 'Significant' or 'Extreme' categories:
- However, under the 1000_2100 conditions, the areas with a hazard level of 'Moderate' or 'Significant' would increase and with some areas could change from the 'Low' category into the 'Moderate' category compared with 200_2100 conditions.

Figure 4: Rochester Flood Hazard Maps



[1] 200_2100: 200 year tide under 2100 climate condition
1000_2100: 1000 year tide under 2100 climate condition

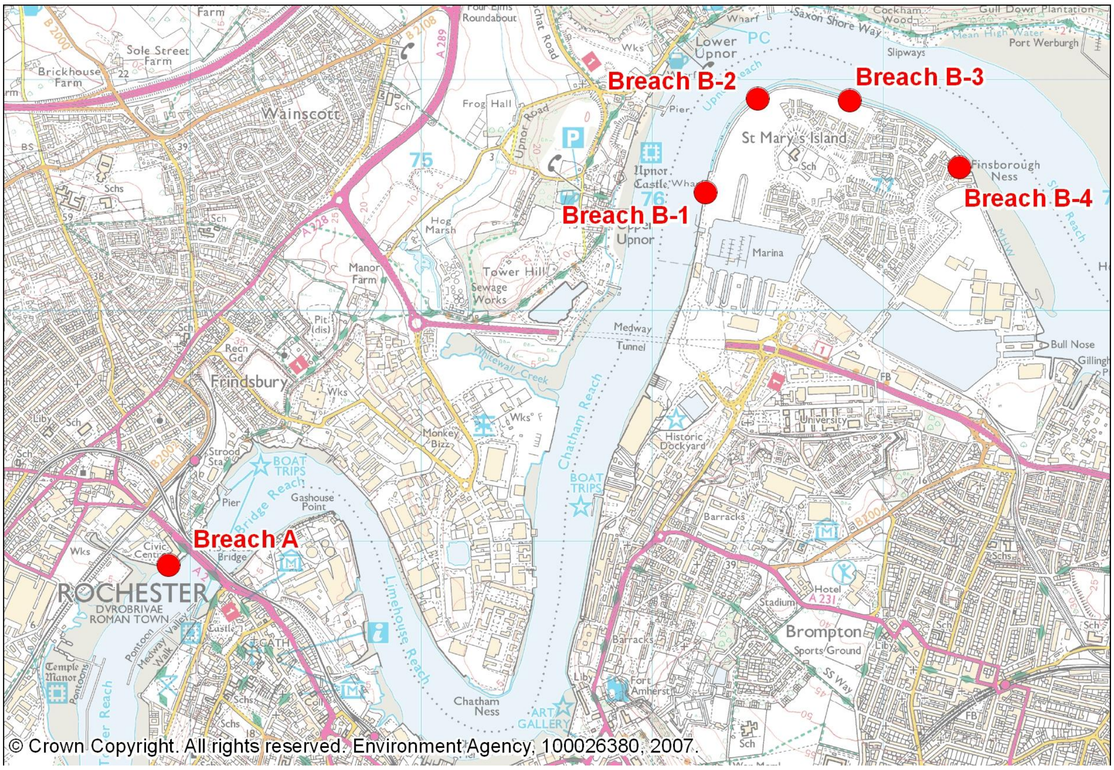
7. Simulation of Breach Scenarios

Flooding in the lower Medway reach is dependent on the fluvial flow conditions and the combined tide and surge conditions. It is also a function of level, strength and conditions of the defences. The land and properties along the Medway estuary are protected by a combination of hard defences and earth embankments. Low lying marsh areas are irregularly bounded by high ground. Most of these marsh areas are now protected by earth embankments but the standards of defence vary.

Breach scenarios were investigated to assess the impact of a potential failure of the flood defences in certain significant locations. A breach is modelled by lowering a small section of the flood defence to the surrounding ground level to allow the flood waters to flow through.

Two breach scenarios were identified and simulated. One breach was located on the left bank just south of the A2 bridge outside the Council Offices in Rochester (Location _A), and the other breaches were at four locations on the right bank flood defence protecting St Mary's Island (Location_B) as shown in Figure 5.

Figure 5: Breach Locations at Rochester and St Mary's Island



Breaches at Location A and Location B were modelled independently by assuming that breaches occur shortly before high tide and persist for more than two tide cycles.

The breach scenarios were undertaken with two sets of downstream boundary conditions:

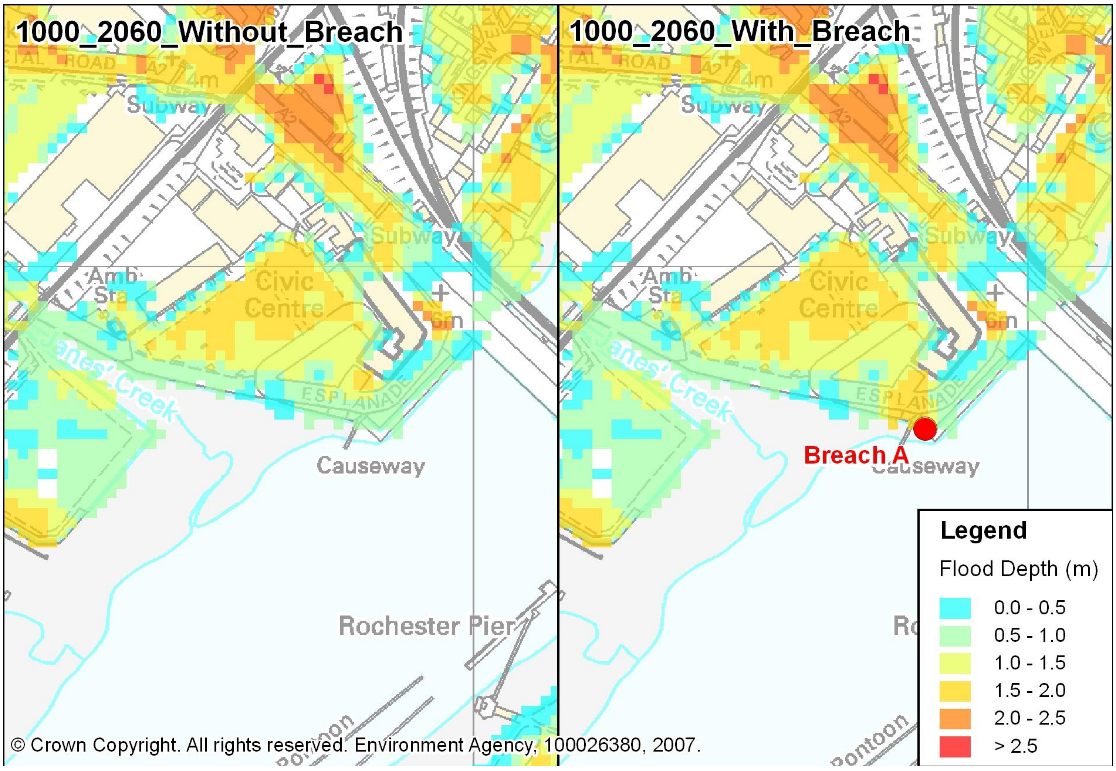
- A 1 in 1000 year tide under 2060 climate conditions, with a maximum water level of 5.3 m AOD at Sheerness;
- A 1 in 1000 year tide under 2100 climate conditions, with a maximum water level of 5.5 m AOD at Sheerness.

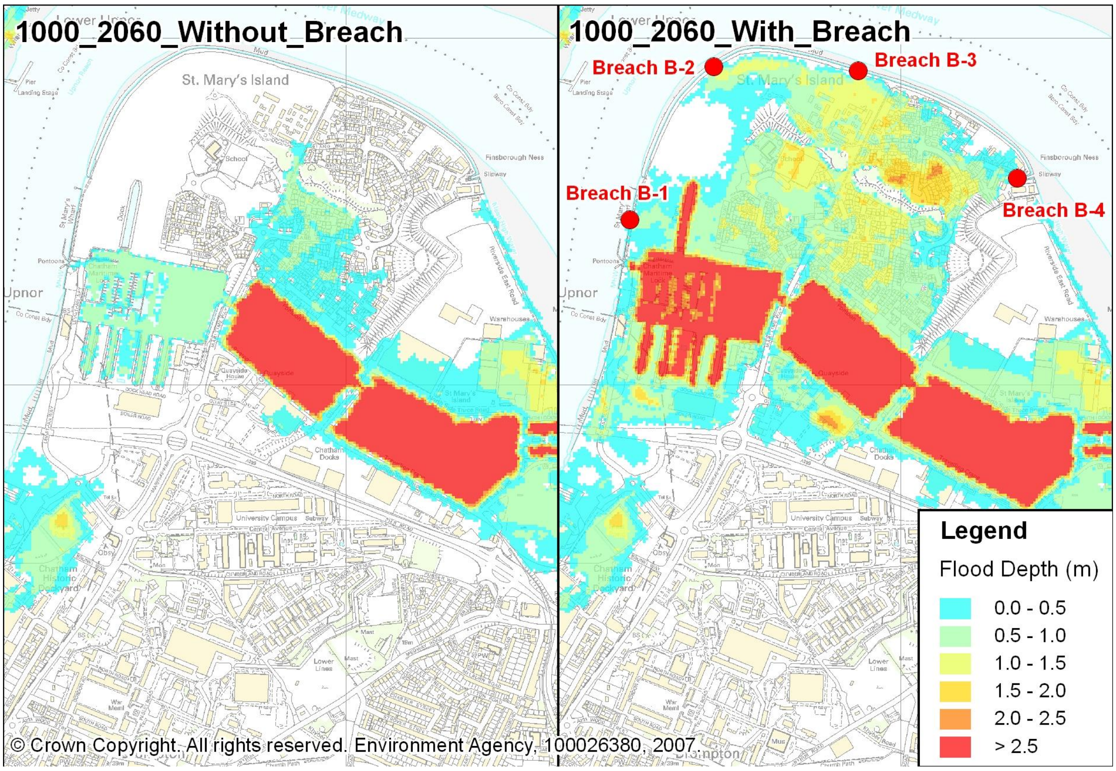
The downstream boundary conditions for the year 2100 and 2060 take into account a 6 mm per annum rise in sea levels as an allowance for the possible effects of climate change.

The results are shown in Figure 6 and Figure 7. The following observations can be made from the breach scenario analysis:

- Rochester - A single 30 m breach at Rochester could cause a maximum increase in flood depth of around 1.2 m. The impact of a breach in this location is confined to the area in the immediate vicinity of the breach. There is no change to the flooding extent under either of the tide and climate change conditions as the area surrounding the breach is already flooded under both the design runs.

- St Mary's Island – A multiple breach at four locations in the flood defence surrounding St Mary's Island, with the breach dimension of 30 or 40 m at each location, could cause a maximum increase in flood depth of 0.2 m for the 1000_2060 tide and climate condition. The increase in depth is greater nearer the breach locations and decreases towards the south and east of St Mary's Island. The breach increases the extent of flooding under by approximately 600 m^2 under the 1000_2060 scenario, to the north and south of St Mary's Island.





8. Summary and Conclusions

(i) 2D modelling can offer an effective way of assessing the flood risk for a floodplain as complex as the Medway Estuary. SFRA provides the necessary data to inform the decision-making process for future development planning.

(ii) The effective acquisition and manipulation of high resolution spatial data will be an important part of flood risk management.

(iii) High level LiDAR data at 2 m grid provides a good representation of the floodplain topography. However, it is inadequate to abstract crest height from such data, particularly where the defences are made up of walls or narrow crested embankments.

(iv) Combined bathymetric survey and high level and low level LiDAR survey techniques provided a comprehensive spatial data set for the river channel, floodplain and the flood defence of the Medway Estuary.

(v) GIS played a central role in integrating, organising, processing and visualizing the spatial data from multiple sources. Its application is fundamental to the efficient and effective creation of DTM and for the construction of a 2D model.

(vi) Representation of the model results, such as flooding extent, depth, velocity, flood progression, and flood hazard levels in a GIS environment has been a very effective way of conveying the flood risk and flood hazard.

(vii) As more and more spatial data is captured and more modelling results and flood maps become available, developing and improving information management system to effectively handle all the information will remain a challenge.

9. Acknowledgements

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