Bachelor of Science in Umweltwissenschaften (Environmental Science)

Bachelor thesis

Topic:

London’s flood risk and flood defence management in times of climate change

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Oldenburg, 30 September 2010

Abstract (English version)

The thesis analyses the subject of flooding and its management in the London Thames estuary. Flooding is an important topic for the large metropolis London and contains a high risk for people, their properties and our environment. London's catchment is crossed by the river Thames and provides a low lying coastal area which was affected by historical storm surges from time to time. The current flood defences including walls, embankments, barriers, gates and culverts offer a high standard of protection. However, there is a disagreement between the present defence and required protection in the future. This prospective flooding will be affected a rising sea level, increasing tide surges, severe and frequent rain storms as well as land movement caused by climate and environmental change. Therefore and because of the fact that the defences will reach the end of their term. This requires a long-term flood management in order to preserve the standard of protection through adaptation to the changing conditions. There are various options that including the improvement and rising of present defences, the construction of new defences and the structure of a new barrier in the main Thames river. In the end, a decision about the future flood risk management is approximately made until 2050, including a first investment programme up to 2049.

Zusammenfassung (Deutsche Version)

Thematik der Bachelorarbeit ist das Hochwasser und dessen Management in der Themse-Mündung in London. Hochwasser, auch Überflutungen genannt, sind ein wichtiges Thema für die Metropole London und offenbaren ein Risiko für die Menschen, ihr Eigentum und deren Umwelt. London wird von der Themse durchflossen und liegt in einem tiefliegenden, küstennahen Gebiet, das von Zeit zu Zeit von historischen Sturmwellen heimgesucht wird. Der gegenwärtige Hochwasserschutz bietet einen hohen Schutzstandard und ist ausgezeichnet durch Mauern, Dämme, Barrieren, Sperren und Kanäle. Jedoch existiert ein Missverhältnis zwischen dem gegenwärtigen Schutz und dem zukünftig benötigen Schutzmaß. Die prognostizierten Überschwemmungen werden durch den Meeresspiegelanstieg, steigende Tiden-wellen, starke und lang anhaltende Regenfälle, die durch den Klimawandel ausgelöst werden, beeinflusst. Demzufolge und aufgrund dessen, dass viele der Flutabwehrvorkehrungen das Ende ihrer Laufzeit erreichen, ist der gegenwärtige Hochwasserschutz nicht ausreichend. Aus diesem Grund wird ein Langzeit-Hochwassermanagement benötigt, um den Schutzstandart durch Anpassung an die Veränderungen und Erneuerungen aufrecht zu erhalten. Es gibt verschiedene Optionen, die die Verbesserung und das Ansteigen der Schutzeinrichtungen und den Bau einer neuen Barriere in der Themse, beinhalten. Letztendlich wird ungefähr im Jahr 2050 eine Entscheidung über das zukünftige Hochwasserrisikomanagement getroffen werden müssen. Bis dahin gibt es Maßnahmen die im Rahmen eines Programms bis 2049 umgesetzt werden sollen.

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List of abbreviations

CEH	Centre for Ecology and Hydrology
CLG	Communities and Local Government
DEFRA	Department for Environment Food and Rural Affairs
EA	Environment Agency
FRA	Flood Risk Assessment
IDB's	International Drainage Boards
IPCC	Intergovernmental Panel on Climate Change
LPA's	Local Planning Authorities
mAODN	metres Above Ordnance Datum Newlyn
NaFRA	National Flood Risk Assessment
RASP	Risk Assessment for Strategic Planning
SEA	Strategic Environmental Assessment
SFRA	Strategic Flood Risk Assessment
TCFMP	Thames Catchment Flood Management Plan
TE2100	Thames Estuary 2100
UK	United Kingdom
UKCIP	United Kingdom Climate Impacts Programme

1 Introduction

Flooding is a part of our nature and can be occur as flash floods, river floods and coastal floods (Oldershaw, 2001). It has an international significance with a risk for human health, their properties and livelihood around the globe. Floods can never be prevented completely (EA, Flooding in England, 2009), however pattern can reduce the risk to its minimum.

This bachelor thesis deals with the tidal Thames flooding in the area of London. The study area is particularly defines the region between the tidal limit at Teddington Lock in the east and Sheerness and Shoeburyness in the west of London. This part of the Thames is influenced by the tides of the North Sea and provides the possibility to study the management of flood risk and flood defences. The river Thames is the main river in south-east England and is very important in the region. Additionally, London is the largest metropolis in Europe. Furthermore, it is interesting to analyse the London area because of the flooding history and the construction of flood defences in the past. The first flood was recorded in 1099 (Lavery and Donovan, 2005). Later, during the 1953 flooding, 300 people lost their lifes (Kendrick, 1988).

Currently, London's flooding contains a risk for people, approximately 500,000 properties and the environment (EA, TE2100 plan chapter 1-4, 2009). However, to reduce the risk a high standard of flood defences are offered by the moveable Thames Barrier, further barriers, walls, embankments, gates and culverts. Moreover, London's Thames basin is located in a low-lying and coastal area, which is more likely to be affected by flooding. Additionally, I will focus on environmental and climate changes, which are mostly recognized in the south east of England and the London area. The future flooding will be affected by increasing winter precipitation and extreme events such as heat waves, globally rising sea levels and the land movement of the British Isles. This is why an increasing flooding is especially predicted for the Thames estuary. Based on these facts, an increasing flooding is predicted in the Thames estuary. However, the present protection is only sufficient for the next 20 to 30 years. For this reason, London's currently high flood defence standard must be guided into an adapted long-term flood management strategy. This leads to the interest of the bachelor thesis. It offers a state of researches and provides current information of expert interviews. Most of all, it is an important issue of public interest and needs to be discussed. Furthermore actual inquiries are made to find a sufficient solution to avoid flooding.

The *aim* of this thesis is to determine the question of how flooding is characterised in the London Thames estuary and what is required for a long-term flood defence strategy. Therefore, historical and present flooding and its causes are explained. Furthermore the current flood defences management will be analysized. In this process, I especially emphasize on the difficulties which lead to the complexity of the topic. For this reason, approaches will be considered and discussed.

This bachelor thesis will first deal with the *Review Chapter* which provides the state of research. This chapter is structured by the background knowledge, the state of climate change, the flooding history, the flood risk in London, the current flood risk management and the future flood defence strategies. At that point, an overview will be given, however, just a short abstract of concrete flood defence implementations can be presented. Afterwards, the outcomes of the expert interviews will be provided in the *Results*. At the end review chapter and results will be combined in the *Discussion*.

2 Methodology

In the following chapter the methods of this thesis will be presented. First, it will give an overview of the research area including the surrounding landscape, the change and the reasons which cause the flood risk. Next, the main research about the flooding management, the current defences and future developments are presented. For this reason, the first part of the thesis, the 'Review Chapter', is secondary based. Second, the primary research in patter of the expert interviews will be presented.

2.1 Internet research

The internet research largely applied information about the responsibilities of flood management and climate research institutes. Most of the data is provided by governmental and independent authorities. Some information is provided by the Government, in particular by the Department for Environment Food and Rural Affairs (Defra) and the Department for Communities and Local Government. The Defra provides the *Making space for water* cross Government programme to develop the flood and coastal erosion risk management in England. The *Making space for Water* report holds four topics: the holistic approach about the risk management, the achieving of sustainable development, the increasing resilience to flooding and the funding. Furthermore, the Defra has published the *Climate Change Scenarios for the UK* as a part of the United Kingdom Climate Impact Programme (UKCIP). This report is the main basin for the climate change predictions in this dissertation besides the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Additionally, the *Planning Policy Statement 25* is provided by the Department for Communities and Local Government. This policy integrates and describes the development and flood risk in the planning process by risk appraising, managing and reducing. Furthermore, the *Environment Agency* is an independent institution and they have a close collaboration with the government. This authority has published most of the flood risk and management reports for example “Thames Catchment Flood Risk Management Plan”, “Flooding in England: A National Assessment of Flood Risk” and “Understanding Flood Risk: Our National Flood Risk Assessment”. Moreover, the

Thames Estuary 2100 (TE2100) project, led by the Environment Agency, was established to develop a tidal flood risk management *TE2100 plan* for London and the Thames estuary through to the end of the century. All of this research is characterised by actuality and therefore it provides the current state of this topic. In addition, E-Resources which are available on *ScienceDirect,* has been used to gather research data of other researchers. Significant E-Resources were provided by Lavery and Donovan (*Flood risk management in the Thames Estuary looking ahead 100 years*), Hornor (*The Thames Tidal Flood Prevention Scheme*), and Kendrick (*The Thames Barrier*).

All of this research could be well render accessible and therefore, these provide a significant data basin.

2.2 Literature

There were three books used to gather information about the research topic. These are *London's River and Guide to the Middle Thames* by Caisley and the *Tidal Thames: Landscape Assessment and Design Guidelines* by Environment Agency and last, *The Thames Barrier* by Gilbert and Horner. However, just a few books have been available for the access of the topic. Additionally, the books *Interviewing experts* by Bogner et al. and *Experteninterviews und qualitative Inhaltsanalyse* by Gläser and Laudel offered the basis for the realisation of the interviews.

2.3 Expert interviews

The *primary research* of this dissertation is based on the expert interviews. The decision to carry out interviews with experts in flooding was reached due to the requirement to obtain closer information about the flood management and to get a valuable insight on the progress, as secondary sources could not answer all research questions. Moreover, actual facts about the current situation seemed to be required for further research. In general, *expert interviews* are a "method of qualitative empirical research" (Bogner et al., 2009, Page 17) and to get "expert" knowledge from people who are contributed to the subject (Gläser and Laudel, 2009). The purpose of the interviews is to briefly reconstruct the expert knowledge (Bogner et al., 2009, Page 18).

To do this, the interview partners have to be chosen after their available knowledge (Gläser and Laudel, 2009). It was reasonable to contact experts of government and non-governmental authorities for my Bachelor topic. The Environment Agency is the operation authority which is mostly qualified to offer relevant information in an expert interview due to their general context to the Thames Estuary 2100 project. Authorities as the Department for Environment Food and Rural Affairs, the Department for Communities and Local Government as well as the Greater London Council referred to the EA. This Bachelor thesis includes the results of three interviews with the Environment Agency. The interviews were implemented with three different experts of various responsibilities.

The first expert is Anthony Hammond, who is responsible for flood risk mapping and data management. The second interview was realised with Ian Blackburn who is development control engineer. Lanny Davis, inspector of flood defences, is the last interviewed person of the *Environment Agency*. The interviews with the experts had the advantage to gather actual information which offers more details.

There are various forms how expert interviews can be realized. The interview which was carried with Davis, inspector of flood defences, was a face-to-face interview. This interview was not recorded due to technical problems. For this reason, it were made notes afterwards. In contrast to that, Hammond were interviewed over the phone. Furthermore an e-mail interview were prepared and sent to Blackburn. Only Lanny Davis could spend the time for a face-to-face interview. For this reason, two alternatives were implemented by the interviews with Hammond and Blackburn. In comparison to the phone and e-mail interview, the personal interview had the advantage of the being in place and check again when misunderstanding facts. Additionally I got some documents. However, phone and e-mail interviews are an alternative if the interviewers have no time for a personal meeting (Gläser and Laudel, 2009). Gläser and Laudel (2009) suggest that disturbances and background noises are a disadvantage of phone interviews. E-mail interviews have the disadvantage that the interviewee partner will try to make the answers short as these have to be written down (Gläser and Laudel, 2009). Evaluating the interviews, the face to face and e-mail interview could provide newest information and data. However, on the understanding that the study time for this dissertation had offered more time, it would have been reasonable to realise interviews with other stakeholders. The implemented interviews have been an appropriate method for the access of data and provided a new research method. The interviews are presented in the chapter 'Results'.

3 Review Chapter

3.1 Background: The River Thames Estuary

The Thames is an approximately 212 miles (or 341 km) long river (EA, Thames Barrier, 2010) and is located in the south east of England. The river has its origin near Cirencester in Cotwolds and flows into the North Sea (EA, 1996). In south-east England, the Thames is flowing through the city of London. The city approximately has 7.5 million inhabitants in the Greater London area and therefore is the largest city in Europe (McFadden et al., 2009). London's magic is impressed by historical places and architectural wonders (Caisley, 1954). Additionally, London holds one of the major financial and bank centres of the world and the main business centre in Europe (McFadden et al., 2009). However, two-third of London's area is characterised by water and green spaces (London climate change partnership, Adapting to climate change, 2009). According to Caisley (1954) the river Thames appears to be the greatest river in the world and is significant for London's economy. Moreover, it offers an inside into London's history, international trade and commerce, which is based on the fascination of the Thames (Caisley, 1954). The Thames is a tidal river, thus, it is influenced by ebb and flow through the gravitation of the moon (EA, 1996). Furthermore, the Thames is characterised by two high and two low tides per day (EA, Thames Barrier, 2010). For this reason, the Thames is a dynamic river with a tidal range of 8 m by a tide level of 7 m in low tides and 15 m in high tides at the Thames Barrier (EA, Thames Barrier, 2010). Moreover, the river presents a maximum speed of 3 mph or 2.75 knots (EA, Thames Barrier, 2010).

Figure 1 illustrates the tidal floodplain which is defined as the "land surrounding the estuary which could flood if a combination of freshwater flow and tidal waters rises" (EA, Thames Barrier, Page 13, 2010). The significant tidal floodplain of London's basin covers 35 000 hectares (Lavery and Donovan, 2005) which could be flooded without the defences (EA, Thames Barrier, 2010).

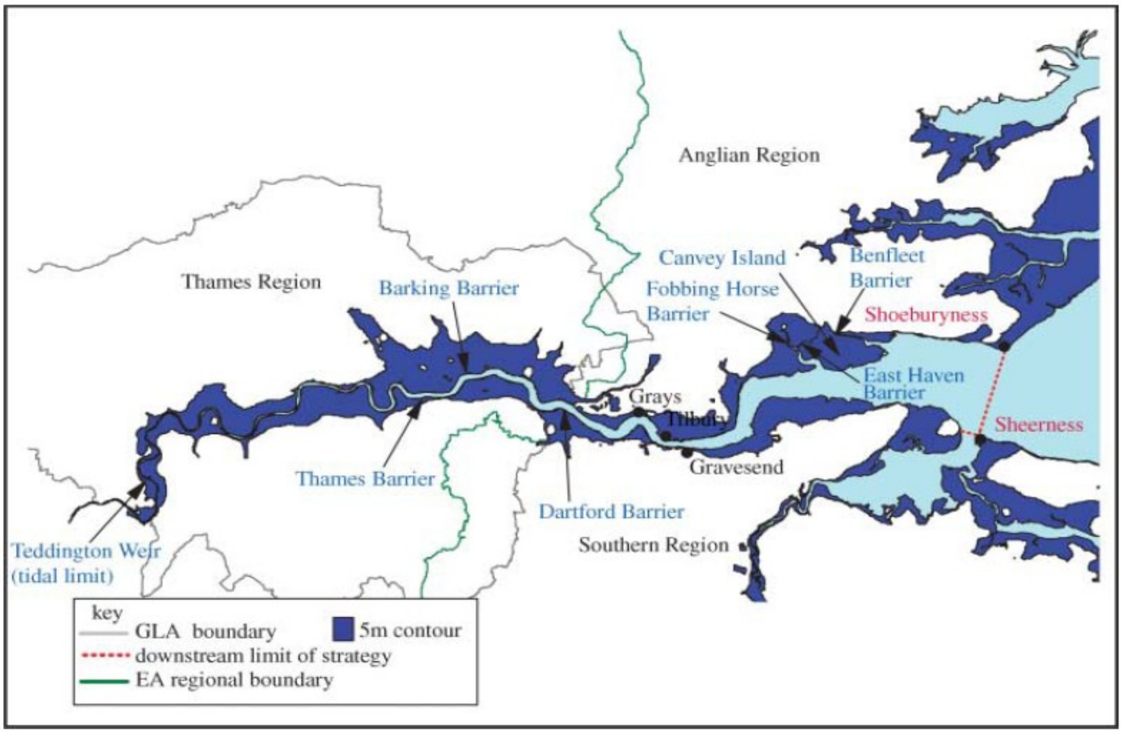

Figure 1: Thames Estuary and the defended Thames tidal flood-plain. Lavery and Donovan (2005).

Furthermore, the river Thames is important because of its various biodiversity, the social diversity and economic wealth of the region (McFadden et al., 2009). The Thames estuary, which covers the area from Teddington to the river mouth is "one of the five most important estuaries in Europe for birds" (EA, TE2100, 2009) and nursery ground for fish species (Lavery and Donovan,2005). In contrast to the biological 'death' in the 1950's the estuary currently provides "the widest biodiversity of any estuary in Europe" (Lavery and Donovan, 2005, Page 1463). However, the Thames water itself gives a muddy appearance due to the continually shifting of bottom sediment in the channels, sandbanks and mudflats (Lavery and Donovan, 2005).

If one looks at the Thames history, the current tidal Thames is a result of "its underlying physical conditions and long history of human settlement and use" (EA, 1996, Page 21). After the glacial erosion, 50 million years ago, the *River Thames Basin* was formed as a "wide bowl-like plain" circled by a rim of chalk (EA, 1996, Page 21). The subsurface geology inside this basin was accumulated by young clay and sand beds (EA, 1996). Clay of younger geological ages was characterised by an extensive deposition (EA, 1996). Thus, much of London's buildings are underlying by clay (EA, 1996). The structure of the London basin is shown in figure A 1. As one can see, the basin is characterised by Alluvium, sedimentation of materials along the river, by river terrace deposits, sands and beds.

Secondly, the nature of the estuary is influenced by the development of the river landscape (EA, 1996). 400,000 years ago, the Thames Valley was probably inhabited by Neolithic settlers first (EA, Thames Barrier, 2010). Due to an early settlement, it was impossible to build on marshes. Instead a loamy soil was developed on the Thames terrace (EA, 1996). However, the extent was restricted in spite of a wide spread of the march land (EA, 1996). The increase of a large area of intermediate or loamy soils was given through the spread of the clay (EA, 1996). In Roman times, the settlement of Londonium on the north bank of the river between forest, health, marsh and water was created and the river basin was therefore characterised by salt marshes and mudflats (EA, 1996). In Norman times, the marshes were available for grazing simple drainage and flood defences (EA, 1996). The inhabitants of the vast marshlands had been an important area for wildlife, particularly waterfowl (EA, 1996). However, most of the grazing marshland has been utilised for agriculture as well as urban and industrial expansion (EA, 1996). In the end of the 19^{th} century there were some areas of the Thames estuary which had not been modified by humans (EA, TE2100 plan chapter 1-4, 2009). Today, just a few ecologically important remnants of marshlands, mudflats and grazing marshes persist at Wennington, Rainham, Aveley and Erith and at Barking Levels and Crayford Marshes (EA, 1996).

The current character of the river landscape provides a rich variety. According to the *Tidal Thames landscape assessment and design guidelines* of the Environment Agency, the river Thames can be divided in three sections. First, the upper reaches around Teddington Lock and Putney contains historic parklands and a green 'Arcadian' character. Furthermore, they are characterised by a richness of riverside vegetation and greenspace. Next, the landscape with a various character between Hurlingham House and Wandsworth Park defines the middle reaches. On the one side, the landscape is dominated by trees and riverside greenspaces. On the other side, build forms with the highest concentration are in the inner city and the requirement of the land use characterise this metropolitan region. Furthermore, the expansive lower rich beyond the Isle of Dogs at Blackwall has a strong industrial dominated character and provides remains of the grazing marshes. All in all, the various landscape types developed over the time and are a result of these changes in land use and other activities (EA, 1996).

The river channel itself consists as a product of “continual modification of river banks suit evolving requirements, technical capabilities and environmental conditions” (EA, 1996). The channel types are more impressed by the encroachment of development, technological improvements in materials and construction techniques, and changes in sea levels as by land use behind the banks (EA, 1996). From Teddington to Dartford the river is characterised by a change of form and character (EA, 1996). In the upstream reaches the river provides a more compact and narrow meanders (EA, 1996). Furthermore, the river flows on a lower level and is not overly influenced by tides (EA, 1996). Due to the 'natural' characterisation with trees and well-vegetated riversides, the channel has a high quality in the upper reaches and through the centre of London (EA, 1996). Fom Teddington to the Tower Bridge, this reach is characterised by mainly land-derived sediments, a low suspended load and a little deposition of bed and bank in the Thames (Lavery and Donovan, 2005). The river bed is gravel or exposed and the suspended sediment is flowing downstream in the river (Lavery and Donovan, 2005). In contrast to that, the lower reaches the course of the river is becoming expanded and there are an increased tidal influence (EA, 1996). The reach around Gallions, Barking and Halfway Reaches comprises the turbidity maximum and covers areas around the null point (Lavery and Donovan, 2005). This zone is characterised by the accumulation of high concentration of suspended sediment (Lavery and Donovan, 2005). The encouragement of the flocculation and the deposition are occurred due to a turbulence and high concentration of the sediment at this point (Lavery and Donovan, 2005). Finally the upper end of the *Mud Reaches,* the sediment concentration, reaches its peak (Lavery and Donovan, 2005). Going downstream along the Gravesend Reach, bedload is mainly transported from the sea dominates the sedimentation (Lavery and Donovan, 2005). Due to the mostly industrial river side activities there are a low quality of the river channel in the lower reaches (EA, 1996).

The consideration of the river Thames estuary illustrates a product of through ancient and human development and land use impressed landscape. The influence of the nature and thus, the human activities to defend London from nature occurrences is the main purpose of the following treatment.

3.2 Climate Change in south east England

3.2.1 The global definition of climate change

Climate Change can be defined as “a change in the state of the climate that can be identified […] by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer” (IPCC Synthesis Report, 2007, Page 30). On our earth, this Climate Change is happening. The Synthesis Report of the Intergovernmental Panel on Climate Change of the year 2007 presents that “observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases” (IPCC Synthesis Report, 2007, Page 31). Furthermore, the IPCC (Synthesis Report, 2007) supports natural variability and human activity as causes of climate change.

In addition, climate changes have major outcomes which one can see today. The increases in global average air and water surface temperatures, the rising in global average sea level and the decrease in Northern Hemisphere snow cover are causes, which are concerning. These are illustrated in figure 2. The trend of the rising temperature shows an increase by about 0.6°C over the last 100 years (related to the difference of 1961 to 1990). As you can see, the global sea level has consistently risen to the global warming. At last, due to the rising temperatures the Northern Hemisphere, the snow cover is melting.

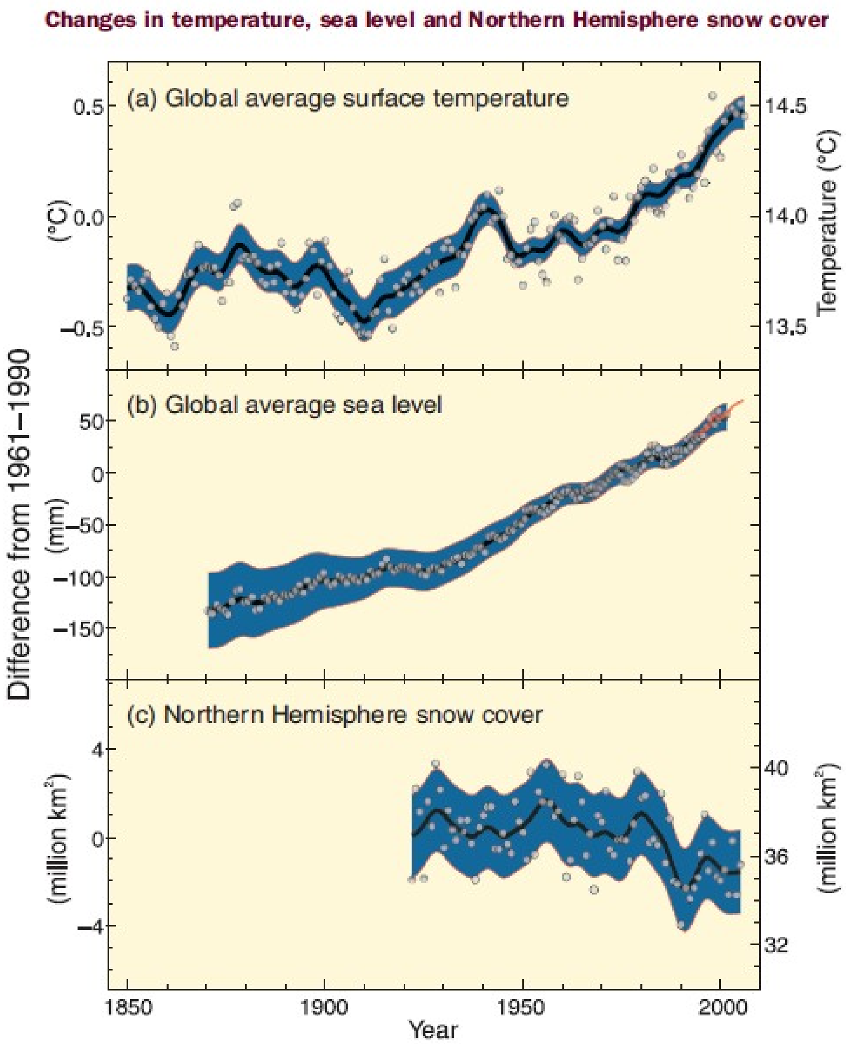

Figure 2: Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data; and (c) Northern Hemisphere snow cover for March-April. All differences are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c). IPCC Synthesis Report (2007).

3.2.2 South east England's climate change

The climate has changed in the United Kingdom (UK) as well as globally. These scenarios present predictions of the future climate for the United Kingdom (UKCIP02). The report differentiates four various scenarios of climate change effects in the UK: these are Low Emissions, Medium-Low Emissions, Medium-High Emissions and High Emissions, which are related to the future emissions of greenhouse gases (UKCIP, 2002).

Because of the fundamental consequences for the sea level rise in the south east, it is reasonable to consider the changes in the UK's climate and other environmental changes.

3.2.2.1 Climate change in the land surface

Temperatures

The temperature has increased of almost 1°C in central England over the last 100 years. Future predictions illustrate that the UK's average annual temperatures likely rise by between 2°C and 3.5°C by the 2080s. These temperatures will increase depending on the scenario (UKCIP, 2002). The mean temperature change is shown in figure 3. As one can see, in all scenarios the greatest warming is predicted for south east England, including the region of London. Furthermore, the London's summer will be more warming than the winter and in 2080's, the south east will probably become between 1.5°C and 5°C warmer in summer.

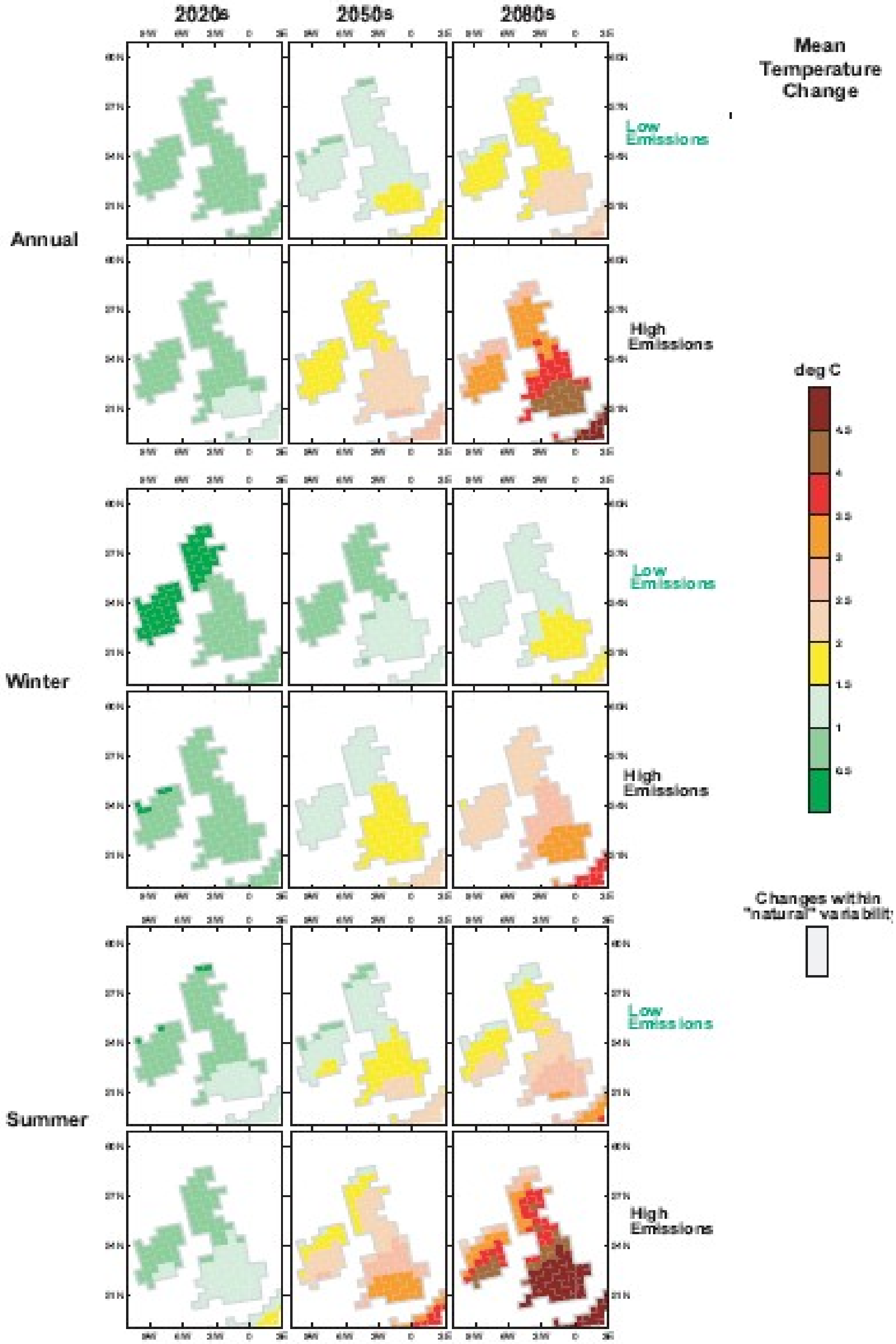

Figure 3: Change in average annual, winter and summer temperature for the 2020s, 2050s and 2080s for the Low Emissions and High Emissions scenarios. UKCIP Briefing Report (2002).

In south east England, central estimates of average summer temperature changes show an increase of 1.6°C during 2020's, 2.3°C by 2040's and 3.9°C by 2080's according to the the 2009 UK Climate Projection (Defra, 2009).

Precipitation

The forecast precipitation in south east England shows a low annual total change (figure 4). However, this is due to an increasing precipitation during the winter month and although a dryer summer. In the south east, a rainfall rise from 10 percent (Low Emissions) to more than 30 percent (High Emissions) and is predicted for the 2080s winters. The pattern for summer precipitation is reserved to the winter change and is characterised by increased aridity and a decreased precipitation from 20 to more than 50 percent addicted by those scenarios. In general, the pattern of precipitation in the south east is identified by higher changes than in the north west.

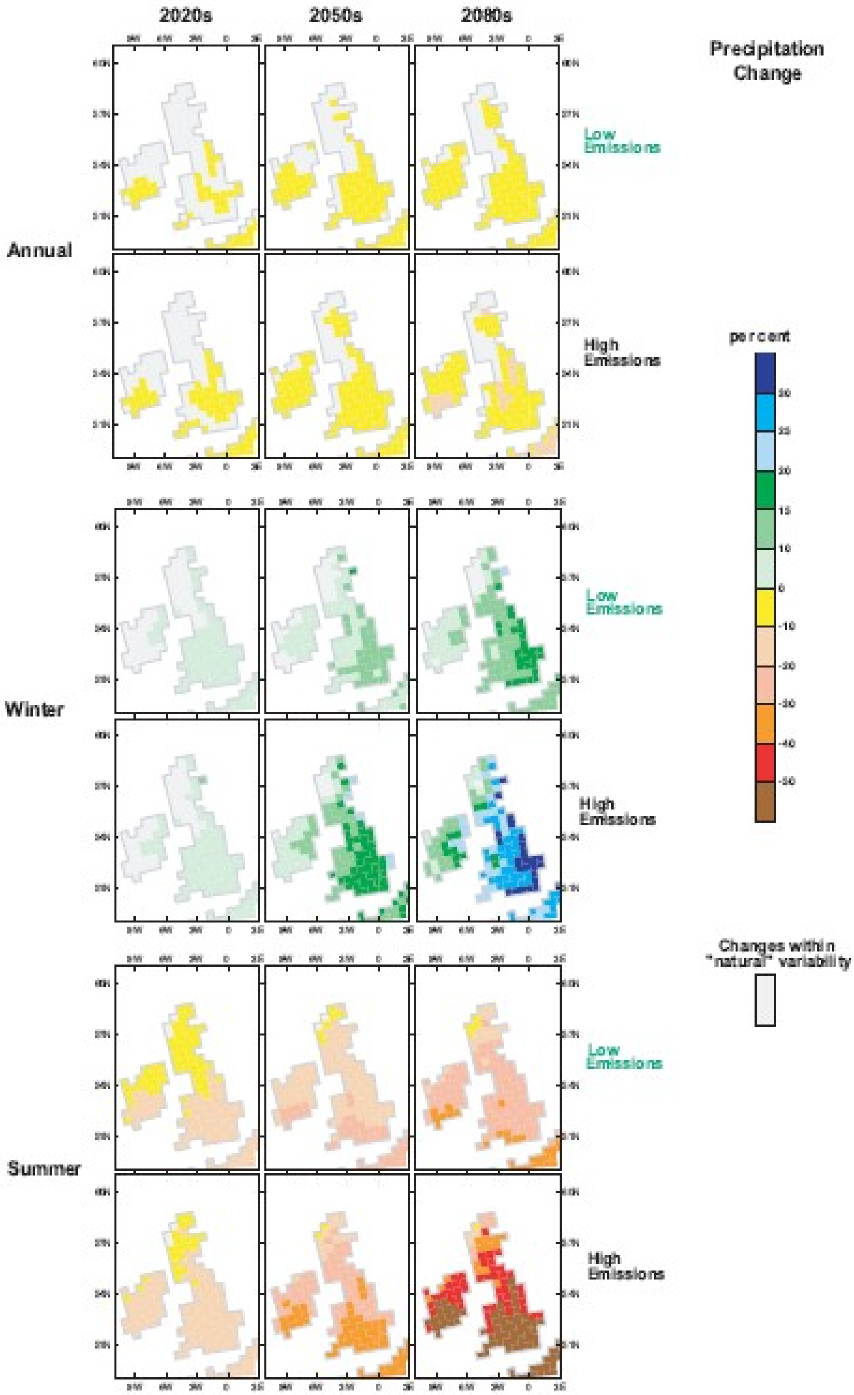

Figure 4: Percent change in average annual, winter and summer precipitation for the 2020s, 2050s and 2080s for the Low Emissions and High Emissions scenarios. UKCIP Briefing Report (2002).

In addition to the changes in precipitation there is an increase in "intense" precipitation events across the whole country during the winter months. In eastern

England wetter winters are a result in the frequency of wet days, however as well in the increase intensity of wet events (UKCIP, 2002).

Soil moisture

Changes in soil moisture are influenced by changes in temperature, precipitation, evaporation, wind speed and radiation. Soil moisture is demonstrated in the figure 5 as the amount of root zone for instance moisture as source for evapo-transpiration (UKCIP, 2002). The pattern of annual total soil moisture is likely to be decrease by the 2080's. In south east England, the predicted soil moisture is the highest in summer and autumn with a decline of 30 to 50 percent for the High Emission scenario, although the moisture could be halved for the Low Emission scenario. In winter, the decrease is characterised by up to 10 percent over England. As you can see, there is the highest change in soil moisture in the region around London. In spite of warmer summers with less precipitation and reductions in relative humidity, the soil moisture decreases mostly during the summer months (UKCIP, 2002).

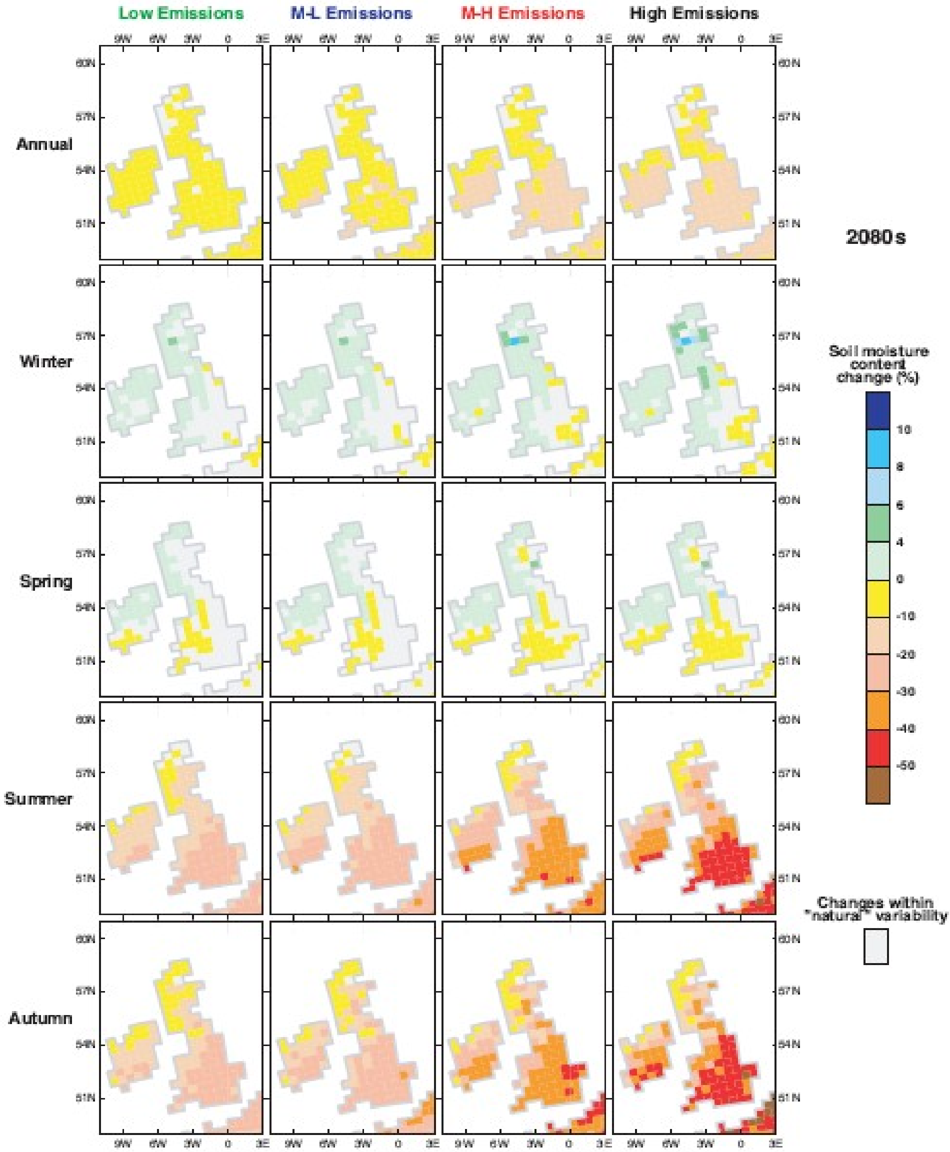

Figure 5: Soil moisture content change in percent by 2080's. UKCIP Scientific Report (2002).

3.2.2.2 Changes in marine climate

Sea surface temperatures

The temperature of water around the UK's coast will most probably increase. However, the warming will not be as rapidly as by the land surface. The temperatures will be risen highest in the south east by between 2°C and 4°C by 2080's (figure 6). In general, the greatest warming is illustrated for the water of the south east coast.

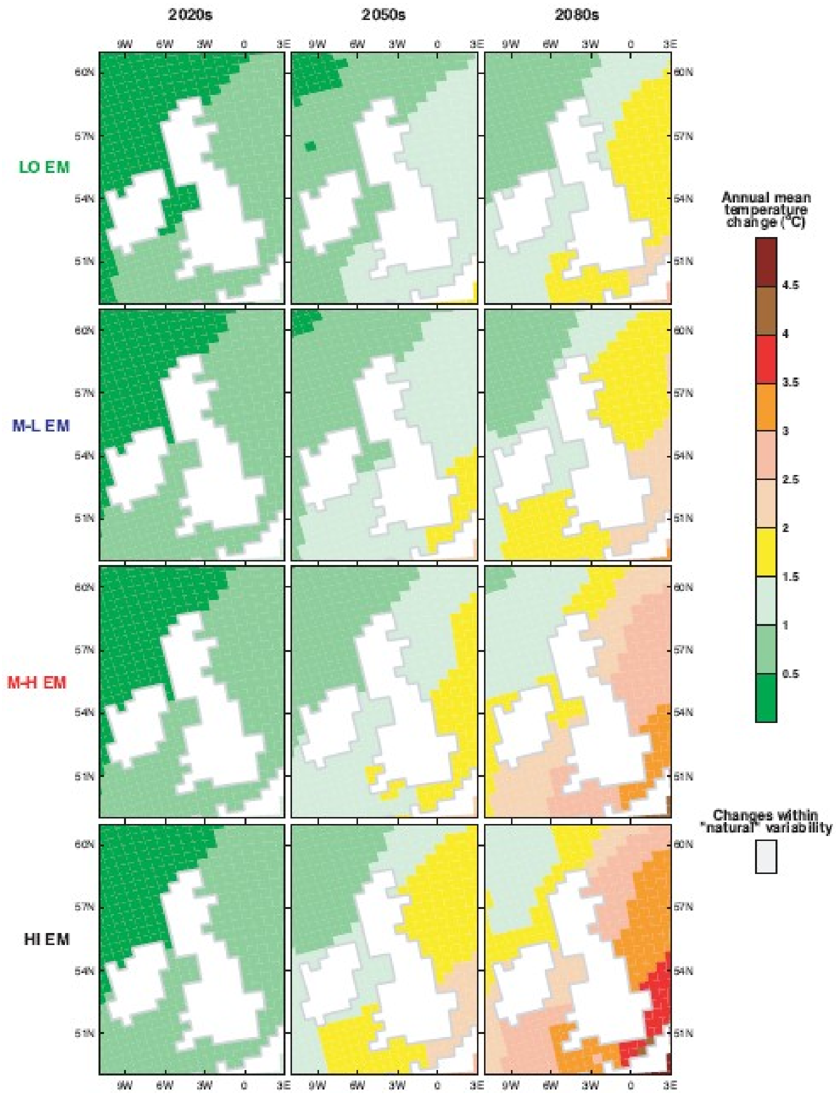

Figure 6: Changes in annual average sea-surface temperature by the 2020s, 2050s, and 2080s (wrt model-simulated 1961-1990 average) for the four scenarios; results from the regional model HadRM3. UKCIP Scientific Report (2002).

Wind speed and heat waves

The wind speed will increase around the British Isles. Figure 7 presents the change in a 2-year return period as well as daily-average wind speed. The wind speed will change in the south east to its highest in winter and spring with an increase between 2 and 8 percent by 2080's. In contrast to winter and spring, in summer and autumn decreases the wind speed up to 6 percent in the south of England.

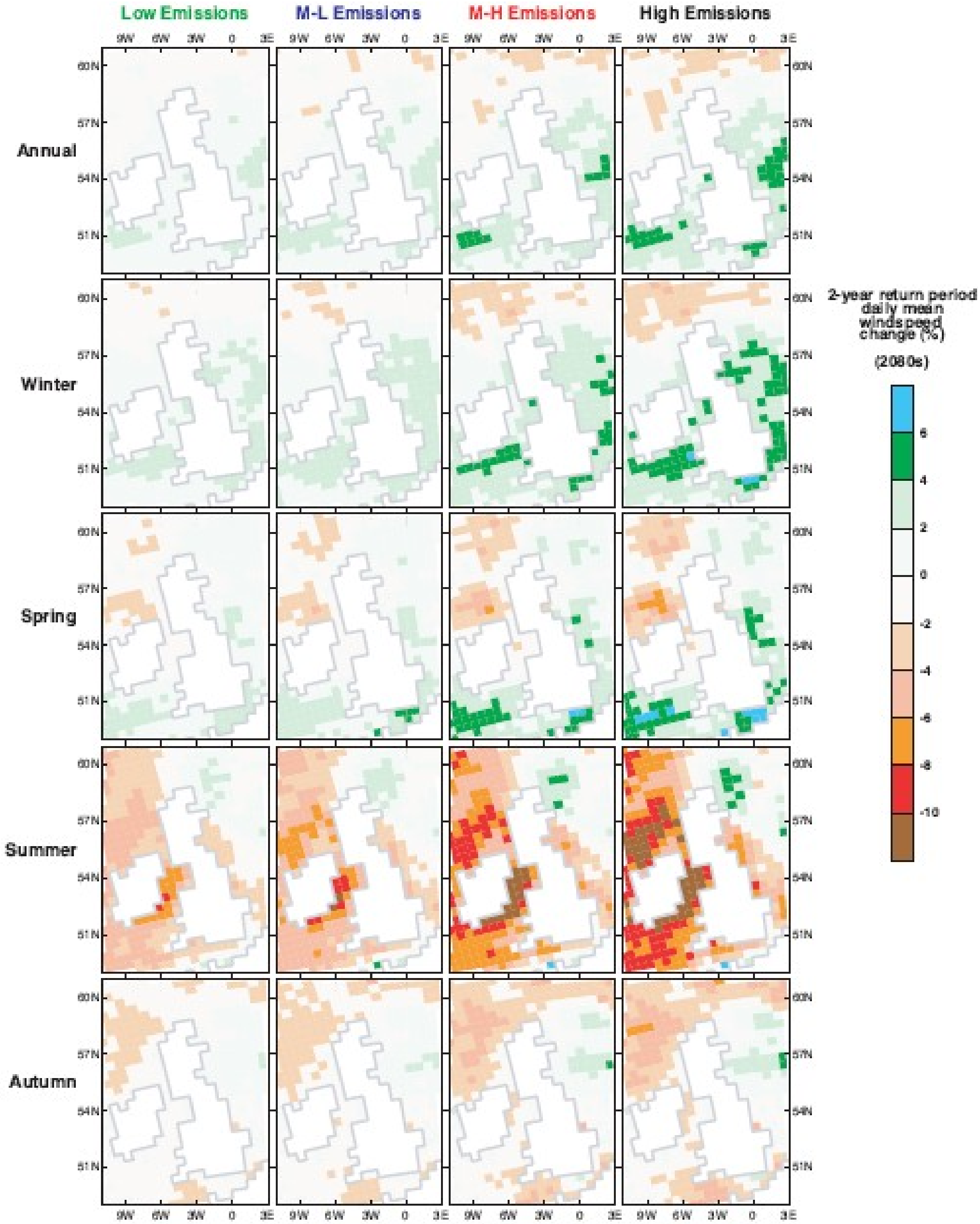

Figure 7: Percent change for the 2080s in the daily-average wind speed which can be expected, on average, once every 2 years. UKCIP Scientific Report (2002).

Due to the increased wind speed and extreme winds, a change of the offshore waves around the UK is likely. The height of waves is constrained to the strength of the wind. Additionally, the intensity of both is depended on the time of distance and length of the wind speed in the ocean surface. The changes in wind speeds have a high influence on the extreme sea levels, because strong winds have a high potential for damaging of coastlines and flood defences (UKCIP, 2002).

3.2.2.3 Climate change and the consequence to the sea level

London's flooding will be affected by a *global sea level rise*. During the twenty century the global sea level has risen about 1.5 mm per year (UKCIP, 2002). A global sea level rises from 9 to 48 cm under the Low Emission scenario and from 16 to 69 cm under the High Emission scenario is predicted by the 2080's (UKCIP, 2002). The ocean sea level rises due to a composition of various causes: First, it is likely that the expansion of warmer ocean water is the main key of the sea level rise by 2100 (UKCIP, 2002). Due to the global warming, the temperature of the surface water increases and it will be transported into deeper layers where the deeper and colder water will expand (UKCIP, 2002). By 2030's, the ocean expansion could lead to a sea level rise of 30 to 80 cm (IPCC, 2007). In addition, the Antarctic and Greenland ice-sheet melting due to global warming, because both are very vulnerable to temperature increases (UKCIP, 2002). The melting of the Greenland ice-sheet could contribute a global sea level rise between 3 and 6 meters for the next 1,000 years (UKCIP, 2002). The IPCC report (2007) proposed the sum of individual contributions to the sea level rise and supported that about 57 percent are contributed by the expansion of the ocean, approximately 28 percent by decreases in glaciers and the remainder by ice caps and losses from polar ice sheets.

The sea level rise will be characterised by regional differences, such as natural land movements. The British Isles is affected by a long-term subsidence of the south eastern corner. Due to the last ice age and sediment consolidation in local areas, there is an isostatic adjustment in the UK. Even 11,400 years after the disappearance of the ice, the uplift of the British upland is not complete. The south of the UK is characterised by a sinking of the land relative to the sea.

Figure 8 illustrates an uplift up to 2 mm per year and a long term subsidence with a magnitude up to 1 mm in the south. Additionally, a Defra and EA study published the South of England will subside by up to 1,2 mm per year (Defra and EA, 2007). As one can see, the greatest uplift is prognosticated for the Thames Estuary. This sinking of the south eastern corner carried to an increased relative sea level (UKCIP, 2002).

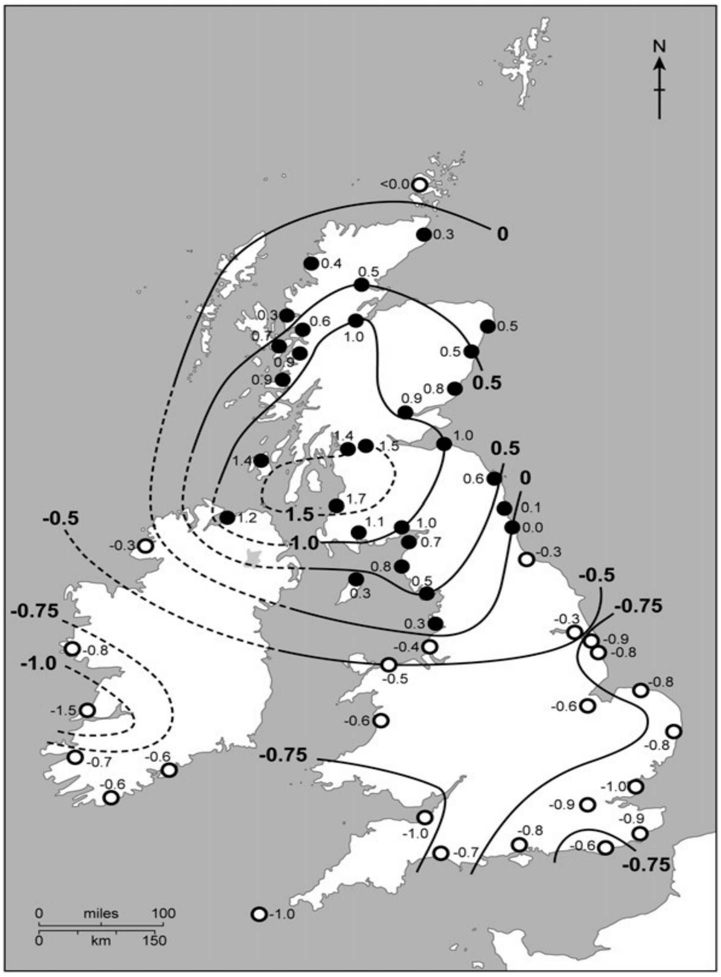

Figure 8: Estimates of present (late Holocene) rates of relative land changes (mm/yr); positive values indicate relative land uplift, negative values are relative land subsidence. Gehrels (2010).

Furthermore, the warming of the oceans is not uniform as a consequence of different sea level rises (UKCIP, 2002). The warming of the North Sea at the south east coast England's is due to the expansion of the ocean and furthermore to the highest sea level rise (UKCIP, 2002). In London, the sea level rise may increase by between 26 cm and 86 cm (figure 9).

	Regional Isostatic Uplift (+ve) or Subsidence (-ve)(mm/yr)	Net Sea-level Change 2080s (cm) Relative to 1961-90	
		Low Emissions scenario	High Emissions scenario
NE Scotland	+0.7	1	61
SE Scotland	+0.8	0	60
NE England	+0.3	6	66
Yorkshire	-0.5	15	75
East Midlands	-1.0	20	80
Eastern England	-1.2	22	82
London	-1.5	26	86
SE England	-0.9	19	79
SW England	-0.6	16	76
Wales	-0.2	11	71
Northern Ireland	n/a	~9	~69
NW England	+0.2	7	67
SW Scotland	+1.0	-2	58
NW Scotland	+0.9	-1	59
Orkney & Shetland	n/a	~9	~69
Global-average	**n/a**	**9**	**69**

Figure 9: Rates of vertical land movement due to isostatic adjustment for Wales, regions of Scotland and the administrative regions of England [Source: estimated from Ian Shennan, 1989]. Relative sea-level change is also shown for the 2080s with respect to the 1961-1990 period (i.e., including 110 years of assumed future land movement) using the low estimate for the Low Emissions (9 cm global rise) and the high estimate for the High Emissions scenario (69 cm global rise). Note: land movement data not available for Northern Ireland and Orkney & Shetland. UKCIP Scientific Report (2002).

Additionally, the UK Climate Projections project by central estimates a sea level rise of 18 cm by 2040 and 36 cm by 2080 in London including the land movement (Defra, 2009). A study by the Defra and the EA has estimated that the British coast including the Thames estuary is affected by a sea level rise of between 0.9 and 1.2 mm per year, without considering the land change (Defra and EA, 2007). In fact, the sea levels show an increase by around 2 mm each year three sites near London, Dover, Sheerness and Southend (EA, State of the Environment in London, 2010).

Moreover, the most coastal damage is occurred by *extreme sea levels*. Due to a combination of sea level rise, high tides and changes in wind speed, London's coast is affected by extremes. Figure 10 illustrates the changes in the 50-year return period water levels under the including of global sea level rise, changes in storminess and vertical land movement for the Medium Emission scenario. As one can see, the highest change in extreme sea levels by up to 1.3 m is predicted for the south east coast of

England. This occurs due to increased storms (see wind speed and heat waves) and the largest subsidence in the south east coast of England (see above) (UKCIP, 2002).

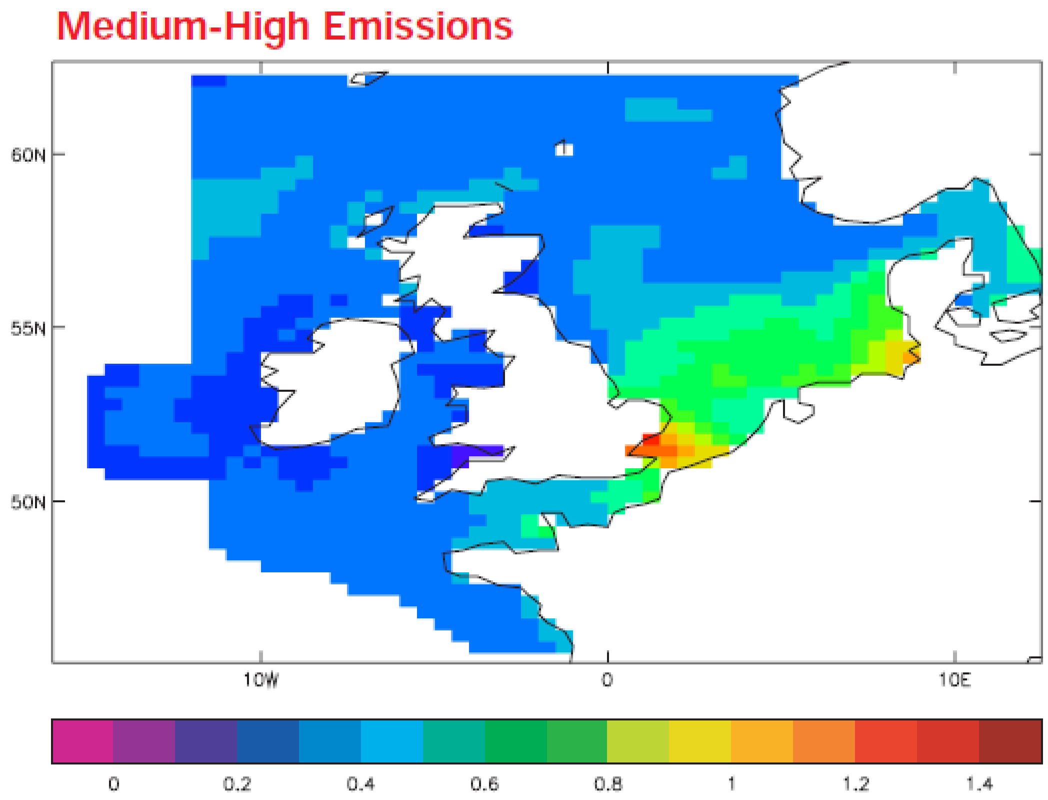

Figure 10: Change in 50-year return period surge height (metres) for the 2080s for Medium-High Emissions scenario (central estimate; 30 cm sea level rise). Defra, UKCIP Technical Report (2002).

To sum up the sea level at the south east coast England's will increase in spite of the global sea level rise, regional land movement and increasing extreme weather which are influence the flood risk in London.

3.3 Flooding history

Globally, 37 percent of natural disasters are accounted by floods in 1999 and more than 100 million people are concerned by flood risk (Oldershaw, 2001). Catastrophic floods are occurred in Pakistan and Poland (2010), Romania and Ukraine (2008), Africa (2007), Indian Ocean (2007), Hungary, Romania and Bulgaria (Danube, 2006), America (New Orleans, 2005), Germany (2002), Bangladesh (1999), China (1998) and the Netherlands (1953). Historically, floods have threatened the humans life and their properties. In comparison with the UK, much more people lost their life direct or indirect because of flooding (Oldershaw, 2001). Nevertheless, over the past years there have been any flood events in the UK.

Referring to London, flooding has a long history. In 1099, the first flooding in the Thames Estuary was recorded by Anglo Saxon Chronicle (Lavery and Donovan, 2005). The earliest defence was probably created by Peter of Stonechurch in 1179, as a form of a timber bridge which is close to the old London Bridge (Kendrick, 1988). In 1236 John Stow wrote in the Survey of London that "a great number of inhabitants there were drowned, and in the Palace of Westminster men did row with wherries (rowboats) in the midst of the Hall" (EA, Thames Barrier, 2010). In 1663 "...the greatest tide that ever was remembered...all Whitehall having been drownes..." was recorded by Samuel Pepys (Lavery and Donovan, 2005). By 1864, Joseph Bazalgette built a massive sewer system which was designed by him many years ago (EA, Thames Barrier, 2010). London's sewer system is still based on Bazalgette's today (EA, Thames Barrier, 2010). Due to a series of damaging floods during the 19th century, the first London *Flood Act* was established and thus, higher river walls and embankments were designed (figure 11; EA, TE2100 plan chapter 1-4 2009). The 1928's flood, where 14 people drowned, was the last severe flood of central London (EA, Thames Barrier, 2010). Subsequently the 1930's Flood Act was passed (figure 11). The most important flood disaster was in 1953 where 300 people lost their lives during a east-coast storm-tide (Kendrick, 1988). In the night to the 1st February 1953, the recorded high-water level was 1.83 m higher than the predicted level (Kendrick, 1988). This flooding event did not reach central London though. However, it was a great catastrophe for the east coast and the lower Thames Estuary (Lavery and Donovan, 2005). Lavery and Donovan (2005) published that when the tidal defences in the historical context have mostly been developed after flood events in the River Thames. Especially, the disaster in 1953 should be emphasized, because this event has started the improvement of a range of current tidal flood defences (Lavery and Donovan, 2005). Further high tides are occurred in the years 1965, 1978 and 1996 (Lavery and Donovan, 2005). According to the Report by Sir Hermann Bondi (Government Chief Scientific Advisor) in 1966, the construction of a tidal surge barrier with movable gates, the raising of the river bank height and flood warning systems seemed to be required (Lavery and Donovan, 2005). Embankments along both sides the river has been built stronger and up to 0.78 m higher in 1971/72 (Kendrick, 1988). In the Greater London area flood bank with a total of over 23 km were improved (Kendrick, 1988). In addition, barriers across the tributaries were created as at Barking and Dartford Creek (Kendrick, 1988). With the Thames Barrier and Flood Prevention Act in 1972, the legislation for the design of the Thames Barrier was given (EA, Thames Barrier, 2010). Late in 1974, the construction of the Thames Barrier was started (EA, Thames Barrier, 2010). While this process, other flood defences, for example banks downstream the barrier were improved (figure 11; Kendrick, 1988). In 1982, the Thames Barrier became operational (Lavery and Donovan, 2005). The 1 February 1983, exactly 30 years after the flood of 1953, was the first time that the Barrier was closing to protect London for flooding (Lavery and Donovan, 2005). A recent flood event was in 2007 where 390 houses have been flooded by surface water due to overwhelmed drainage system through heavy rainfall (EA, State of the Environment in London, 2007).

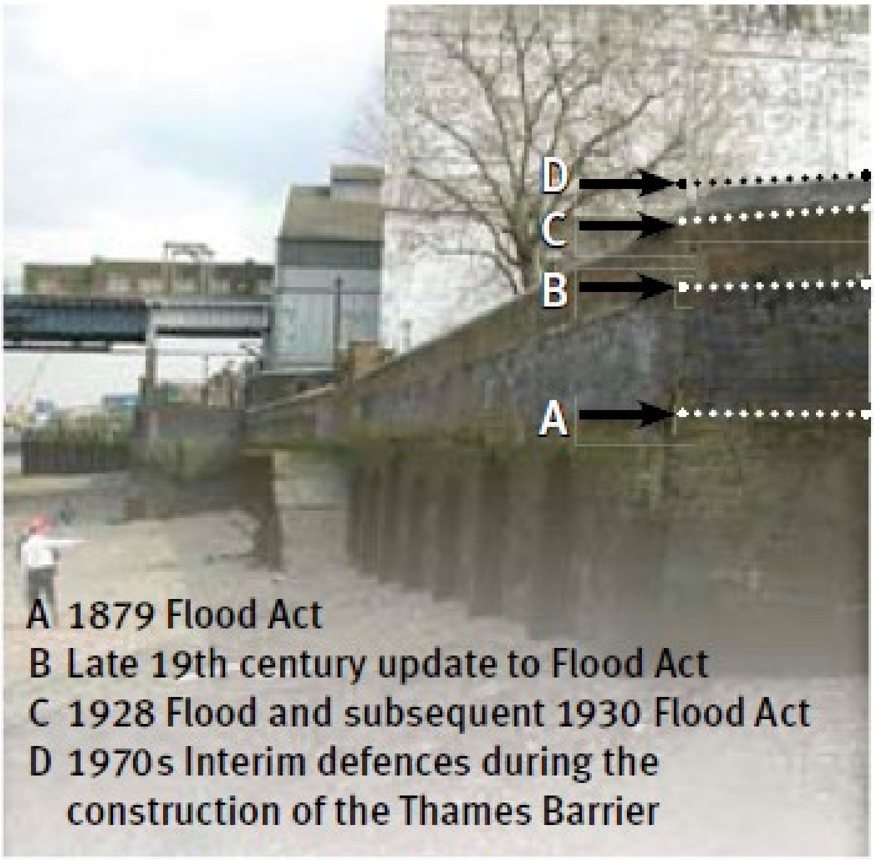

Figure 11 : Responses to past flooding events, river wall at Greenwich. EA, TE2100 plan chapter 1-4 (2009).

In the beginning of the twenty century, the UK's government's regeneration initiative, “The Thames Gateway”, was created. In cooperation with the Environment Agency, they have the challenge to create “planning defences for the next generation” and to find decisions in relation to the building in the tidal floodplain (Lavery and Donovan, 2005, page 1456).

3.4 Risk of flooding in London

3.4.1 Causes of flooding

Flooding can be defined as a natural process which can happen conditioned to the region at any time (Communities and local government, PPS25, 2010). According to the Centre for Ecology and Hydrology, flooding occurs as a product "of a complex interaction between rainfall, urban and rural land surfaces, soil types, topography, drainage and river channels, and other man-made changes" (CEH, 2007). For this reason, there are different forms of flooding which provide risk (Communities and local government, PPS25, 2010). These forms are flooding from the sea and the rivers, directly flooding from the rainfall on the land and the rising groundwater level and flooding from sewers and drainage systems (Communities and Local Government, PPS25, 2010).

The London River Thames is located in a low-lying land and it is characterised as a tidal estuary. Storm surges and high tides in these areas are the main causes of *flooding from the sea*. In the North Atlantic, storm surges occur in areas of low atmospheric pressure when the Gulf Stream and the cold Labrador Current converge (Gilbert S. and Horner R., 1984). The general sea level is risen in spite of a low pressure (Gilbert S. and Horner R., 1984). Around the centre of the deep depression, cyclonic winds are generated which are moving from the west coast of Ireland in a north easterly direction into the North Sea as shown in figure 12 (Horner, 1976). The velocity of the surge is something of the order of 40 or 50 miles per hour (Gilbert S. and Horner R., 1984). For this reason, the water movements contains a lot's of energy and dynamic which effects the height of the hump (Gilbert S. and Horner R., 1984). The high pressure is moving into the west and the low pressure is pushing the `surge` into the Thames Estuary (Horner, 1976). In addition, the surge height can be increased through strong northerly winds (EA, Consultation Document, 2009).

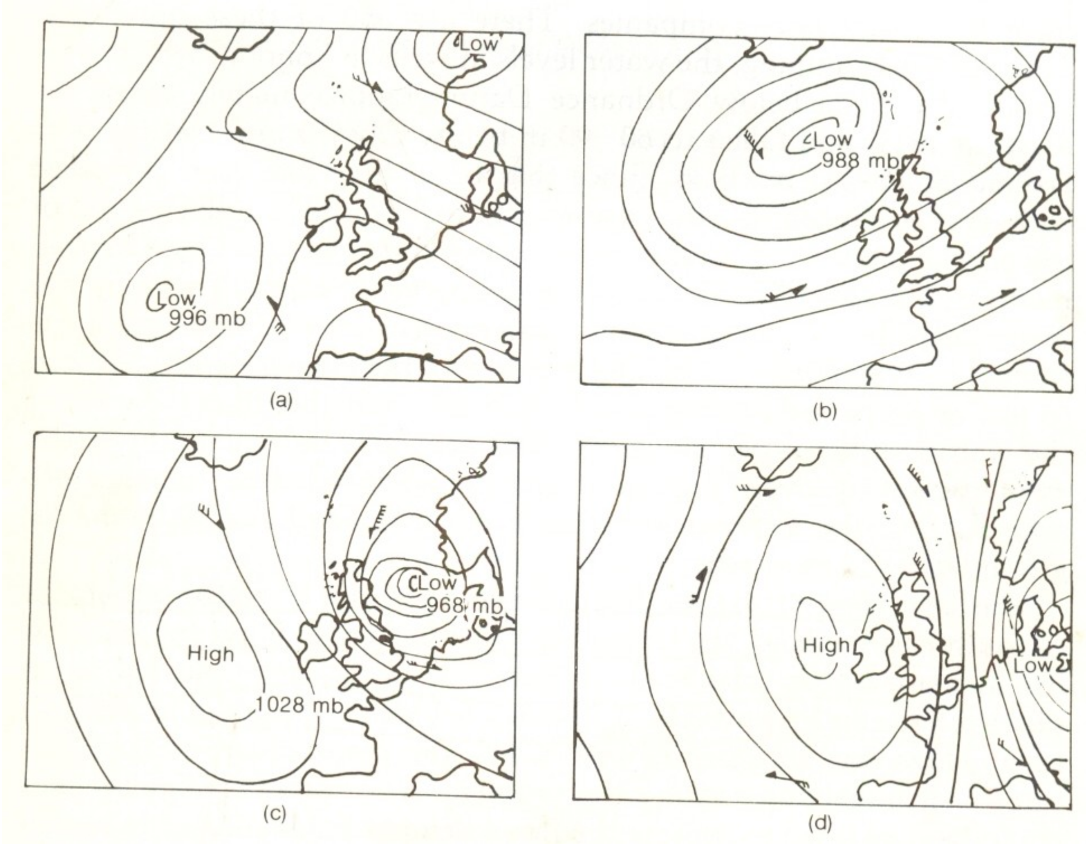

Figure 12: Weather map showing development of surge tides. Gilbert S. and Horner (1984).

The river Thames coast holds flood defences, which protect London for regular flooding (UKCIP, 2002). However, the most damage is occurred by surge tides at 'spring' or high tides (UKCIP, 2002). Furthermore, extreme sea levels are influenced by climate change as a result of increase number and strength of storms due to average sea level rise (UKCIP, 2002).

The next form, *river flooding*, is occurred when "the amount of water in them exceeds the flow capacity of the river channel" (Communities and Local Government, PPS25, 2010, page 18). The most rivers hold a natural floodplain regulator which spills the water by slowly rising flood levels (Communities and Local Government, PPS25, 2010). Flooding from the river is depended from the steep of the ground rises and the velocity of the water runs off into the watercourses (Communities and Local Government, PPS25, 2010). Due to local intensive rainfalls on small and steep catchments "rapid onset of deep and fast-flowing flooding" is possible (Communities and Local

Government, PPS25, 2010, page 18). The river Thames in London is characterised by channels which would create artificial and straightened (EA, TCFMP, 2009). It indicates that the floodplains of the nine main Thames tributaries have been highly developed (EA, TCFMP, 2009). For this reason, urbanisation carried to a fast flooding (EA, TCFMP, 2009).

Furthermore, *flooding from the land* is occurred by intense rainfall. The water is running off the land when the rainwater cannot sink into the ground or the drainage capacity is overwhelmed. In cities such as London, this form of flooding is highly influenced by the architecture of the urban area. One reason might be the high sealing of the ground do not gives much possibilities for the direction and the depth of flow. This carried to surface run off. For this reason, the urban development should include the overland flow paths into the planning (Communities and local government, PPS25, 2010).

Groundwater flooding occurs when "water levels in the ground rise above surface levels" (EA, Flooding in England, 2009, page 7). London's settlement is identified by a clay catchment (EA, TCFMP, 2009). Because of the impermeable clay (figure A 2), rain water soaks directly into the rivers and less into the ground (EA, TCFMP, 2009). This occurs due to quick increasing water levels (EA, TCFMP, 2009). During wet winters, the water level below the ground increase, and they fall when the water flows out into the river in the summer months (Communities and Local Government, PPS25, 2010). Thus, groundwater flows are slower than surface water and the groundwater level needs longer to going down, the dissipation time after flooding requires weeks or months (Communities and Local Government, PPS25, 2010). Between 1990 and 1998 the groundwater level has increased with approximately 2 meters per year in consequence to the termination of the past intensive abstraction of groundwater (City of London, 2007). The groundwater level rose from about -52 AOD to -34 AOD (Above Ordnance Datum), however, it is present stabilised below -35 AOD (City of London, 2007).

Next, *sewer flooding* occurs when "sewers are overwhelmed by heavy rainfall […] when they become blocked" (EA, Flooding in England, 2009, page 7) or when there are an inadequate capacity. When its happen that surface and waste water are combined, the risk of land and property flooding “with water contaminated with raw sewage as well as pollution of rivers due to discharge from combined sewer overflows” is high (Communities and Local Government, PPS25, 2010, page 19). London has commonly old sewer systems (City of London, 2007). As a result, sewer flooding occurs more often although with smaller consequences (City of London, 2007). Due to more intense summer storm and more prolonged winter storms the sewer flood risk will increase (City of London, 2007).

The last sources of *flooding from reservoirs, canals and other artificial sources* such as as lakes, are all non-natural or artificial and “where water is retained above natural ground level, operational and redundant industrial processes including mining, quarrying and sand and gravel extraction, as they may increase floodwater depths and velocities in adjacent areas” (Communities and Local Government, PPS25, 2010, page 19). In addition, it is required to consider the flood risk of infrastructures and reservoir or canal flooding due to dam or bank failure (Communities and Local Government, PPS25, 2010).

3.4.2 Overview and assessment of the present and future flood risk

First of all, it is required to understand flooding as a “part of nature” (EA, Flooding in England, 2009, page7). The prevention of all properties by flooding is “neither technically feasible nor economically affordable” (EA, Flooding in England, 2009, page 7). Due to flood risks for people, their properties as well as the environment there are the aim to reduce these (EA, Flooding in England, 2009).

To assess the flood risk in London and all areas in England and Wales, the National Flood Risk Assessment (NaFRA) was established in order to examine the occurrence of flooding and possible ways to build flood defences and minimise flood risks. Furthermore it is interesting to have a closer look at the causes when defences overtop or fail (EA, Flooding in England, 2009). In 2004, the first NaFRA was undertaken in whole England and Wales under integration of the new and innovative ‘Risk Assessment for Strategic Planning’ (RASP) method (EA, NaFRA, 2008). This method currently offers the best available flood risk assessment which shows an image of vulnerability. Furthermore, it has great impacts on floods and the costs can be estimated of damage as well as number, types and location of affected properties (EA, Flooding in England, 2009). The assessment occurs on the division of the floodplain in cells with an area of land measuring 100 m by 100 m or smaller areas which are intersected by a river or a coastline (EA, NaFRA, 2008). The calculation of likelihood for flooding in the centre of each cell offers the base for the three risk categories (EA, NaFRA, 2008). For this reason, NaFRA is the standard dataset for flood risk assessment in the insurance industry and follows the aim of implementing the Association of British Insurers (ABI) flood agreement in cooperation with the government.

A low risk is provided if the chance of flooding less than 0.5 percent (one in 200 chance in any given year). Furthermore, a moderate risk category is characterised by 0.5-1.3 percent chance of flooding (one in 200 to 1 in 75 chance in any given years). Finally, the flooding chance should be analysed. If it is higher than 1.3 percent (one in 75 chance in any given year), a significant flood risk will exist. If a risk is low, moderate or significant will be depending on flooding which is caused by weather conditions and the likelihood that the defences will overwhelm or fail (EA, Flooding in England, 2009). The map of risk categories according to the NaFRA in the Greater London area is shown in figure 13.

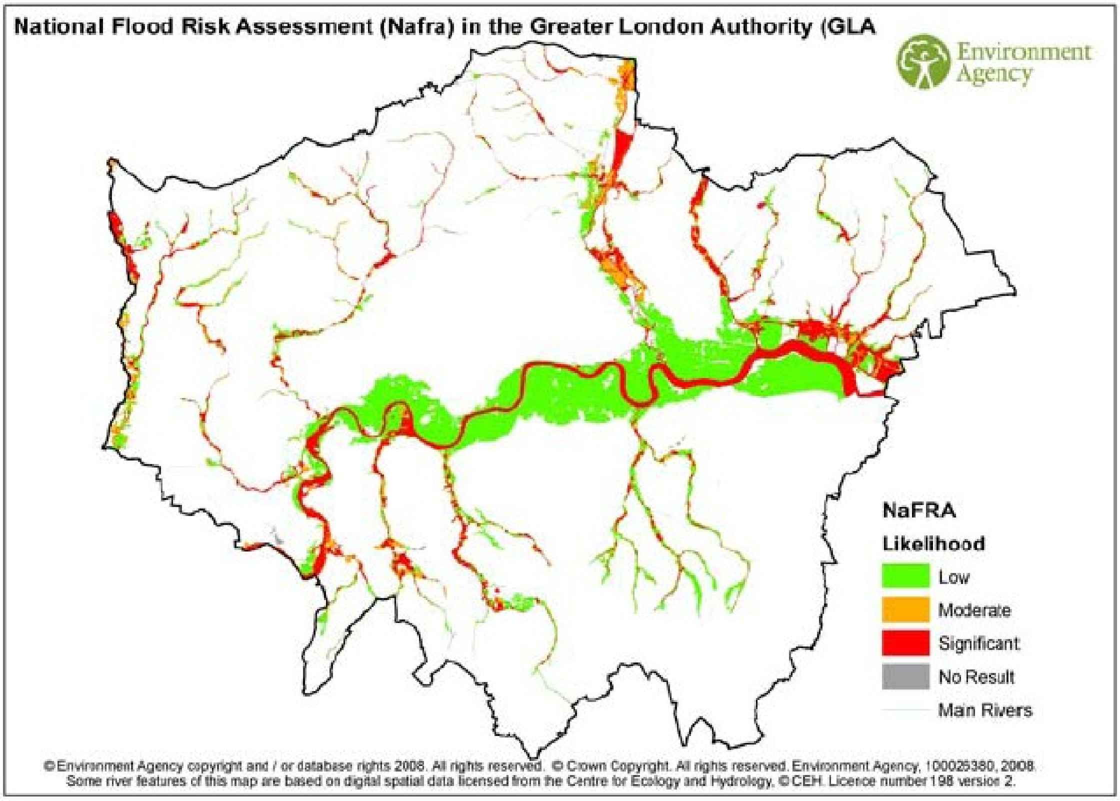

Figure 13: Map of flood risk categories in the Greater London area. EA, State of the Environment in London (2010).

The Environment Agency's National Flood Risk Assessment (2009) publicised 5.2 million properties or one in six properties are threaten by flood risk in England. Moreover, in the 2.4 million properties which are at risk of sea and river flooding living and working more than 5 million people (EA, Investing for the future, 2009). Furthermore 1 million people are also affected by surface water flooding. Besides that, surface water flooding alone offers a flood risk for 2.8 properties (EA, Investing for the future, 2009). On a regional scale based on the NaFRA (2008), emphasises on London offers and the highest number of people in flood risk in England (figure A 3). Currently about 500,000 homes and 1.25 million residents as well as 40,000 commercial and industrial properties are at risk from flooding within London's floodplain (figure 14; EA, TE2100 plan chapter 1-4, 2009). The Thames covers an area of 350 km^2 and includes important government buildings, major transport links, 400 schools, 16 hospitals and 4 World Heritage sites (more details see figure A 4; EA, TE2100 plan chapter 1-4 2009).

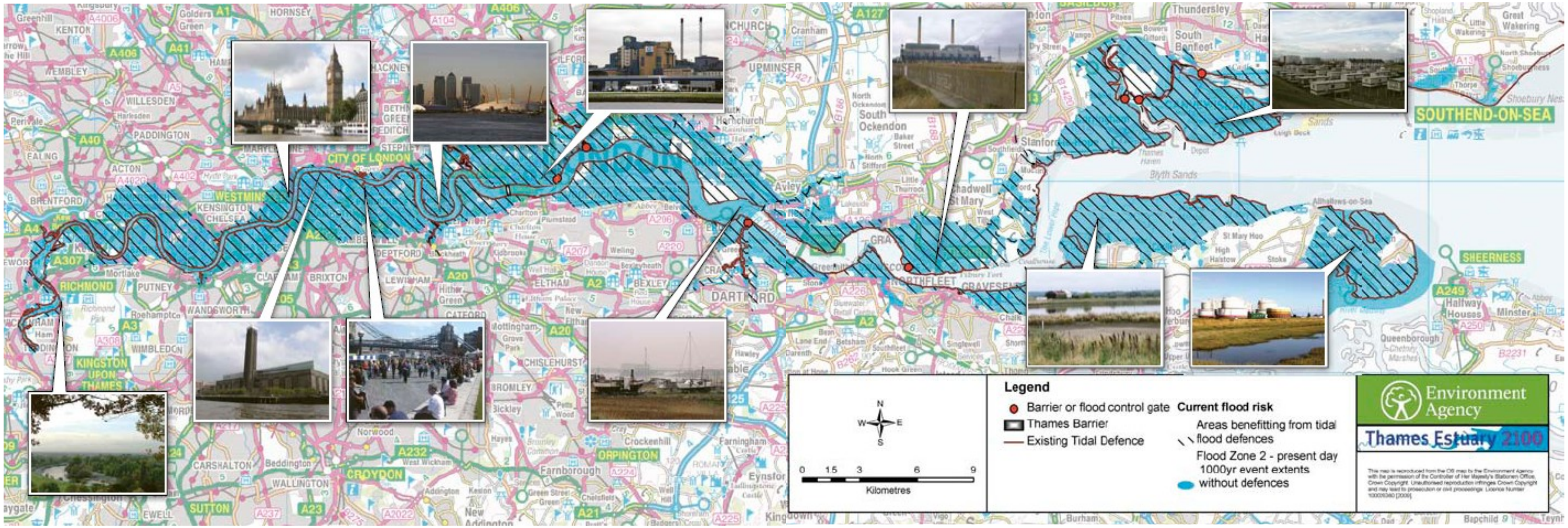

Figure 14: Flood risk in the Thames floodplain. EA, TE2100 plan chapter 1-4 (2009)

In the Greater London area, 458,000 properties of 542,000 properties (84 percent), have a low chance of flooding (EA, Flooding in England, 2009). As you can see in figure 15, the areas around the main river Thames are affected by an 1 in 1000 year flood risk. This means that the chance of flooding is up to 0.1 percent any one year until 2030 (EA, TE2010 summary report, 2009). This is a low flood risk due to the major defences, including the Thames Barrier which reduces the tidal flooding. As it is shown in figure 15 higher flood risks are offered by the tributaries of the Thames with a more than 1 in 20 years return period in north and south London. In the Greater London area 84,000 properties or 16 percent (basin: 542,000 properties in total) are influenced by a moderate or significant flood risk on the rivers such as Lee, Brent and Ravensbourne (EA, Flooding in England, 2009). These flood risk is mostly caused by fluvial flooding due to heavy rainfall (EA, Flooding in England, 2009). Additionally, the highly urbanised river catchments offer the risk of surface water flooding (EA, Flooding in England, 2009).

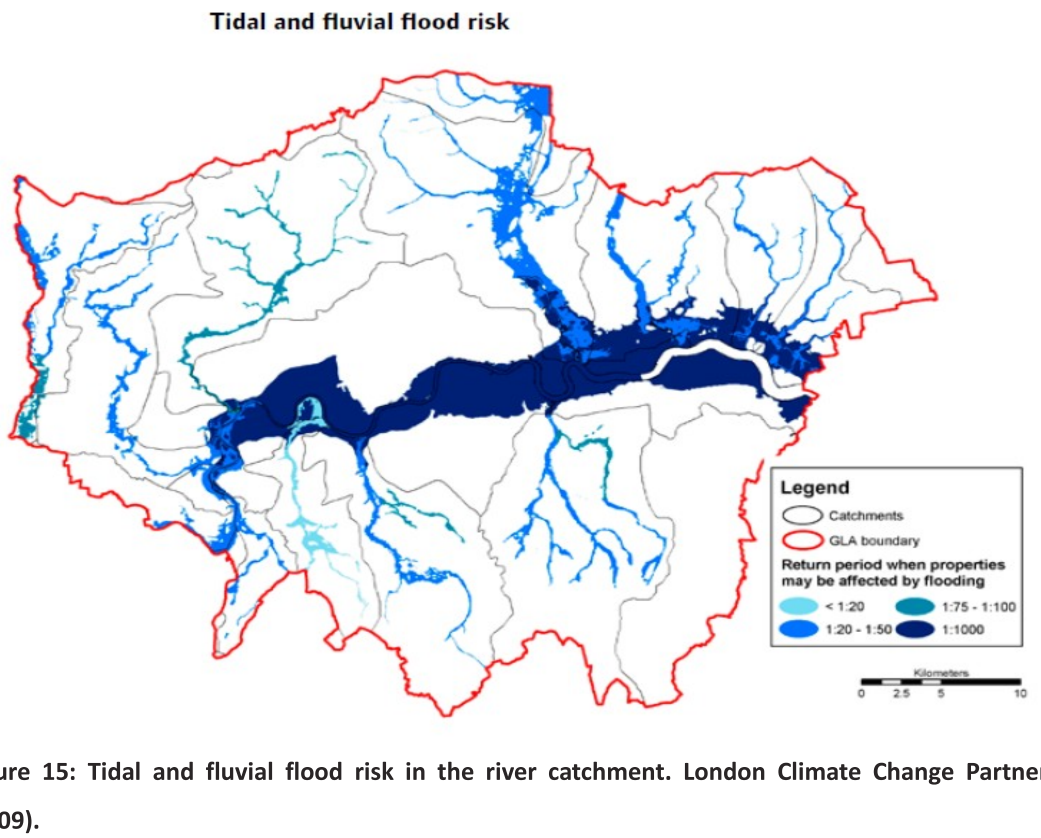

Figure 15: Tidal and fluvial flood risk in the river catchment. London Climate Change Partnership (2009).

The current flood risk leads to the essential question: How high will be the future flood risk? The *Foresight Future Flooding Report* predicts a climate change as well as a change in socio-economic factors as main drivers of the future flood risk (Foresight, 2004). First of all, socio-economic factors includes for examples urbanisation, rural land management, environmental regulations and social impacts (Foresight, 2004). Furthermore, the future flooding will certainly be increased through a high influence of climate change and impacts on sea level risings (Foresight, 2004). For the UK, higher temperatures, rising sea levels and a greater frequency of extreme events such as heatwaves, flooding and drought are predicted (UKCIP, 2002). For London the forecast predicts a climate change that will certainly rise to potential flooding through increasing and frequent “intense rainfall, rising sea levels and increased tidal surges” (London's Climate Change Partnership, 2009, page 6). In the 2080's, various scenarios suggest that the extreme sea levels could be 1.2 m higher than present high water levels (Lavery and Donovan, 2005). Thus, the risk of flooding from rivers will increase and the number of properties with a risk of flooding from 1 percent will rise as it shown in figure 16.

Sub-area	Current	Future (2100)
Beam	1190	1630
Beverley Brook	6010	No data
Brent	1920	2260
Crane	200	230
Graveney	4200	4570
Middle Roding	4240	4880
Ingrebourne	310	330
Ravensbourne	9440	10960
Wandle	10720	11860

Figure 16: The number of properties with a 1 percent risk of flooding from rivers. EA, TCFMP (2009).

An adaptation to climate change is a challenge to reduce the flood risk. It implies to learn to live with the impacts of changes and to protect oneself (Defra, 2010). For this reason, it is essential to examine how sufficient is the current flood protection and how it can be improved. The Government funded 600 million pounds in 2007-2008 and decided to increase the flood risk management investigations in England to 800 million pounds in 2010-2011 (EA, Flooding in England, 2009).

In addition, it will be important to mitigate climate change (Foresight, 2004) to minimise the extent of the future climate change (Defra, 2010). It is essential to reduce the global emissions now to decrease the risks of flooding in the 2050s and beyond due to the long time lag of emissions in the atmospheric system (Foresight, 2004). According to Schellnhuber et al. (2006) imaginative actions are required to stabilise the atmospheric greenhouse gas concentration. As set by the Kyoto Protocol, the UK want to achieve a reduction of 12,5 percent (relative to 1990) in six main greenhouse gases by 2010. The Foresight Future Flooding Report published, that to minimise climate change "will not solve our future food risk problem by itself, but it could substantially ease them" (Foresight, 2004, page 39). Furthermore the Foresight Future Flooding Report (2004) instances socio-economic factors will be a further driver of the future flood risk. These factors includes for examples urbanisation, rural land management, environmental regulations and social impacts (Foresight, 2004). The socio-economic development has been extensive and therefore the potential flood damages of properties have risen (Foresight, 2004).

3.5 Current flood management

3.5.1 Flood defence responsibilities

The flood defence responsibility to plan and manage flooding is offered by a number of organisations and individuals across the Thames estuary. They all aim to manage and minimise the flood risk in the present and future.

The *Department for Environment Food and Rural Affairs (Defra)* "has overall policy responsibility for flood and coastal erosion risk management" (Communities and Local Government, PPS25, 2010, page 40). The Defra provides a significant funding and holds the national policy (Defra, 2008). It is not their challenge to built or manage flood defences, however they have to ensure that the main program is as effective as possible (Defra, 2008).

Communities and Local Government is another UK department as well as the successor of the Deputy Prime Minister Office since 2006. It provides the spatial planning policy and the operation of England's planning system (Communities and Local Government, PPS25, 2010). CLG holds the responsibility for the administration of development and land use in the public interests as well as planning regulations related to environmental affect as flood risk and coastal planning (Communities and Local Government, PPS25, 2010).

The operational responsibility is provided by the Environment Agency, Local Authorities and the International Drainage Board which carries out the flood defence activities. The *Environment Agency* was established under the Environment Act in 1995 (EA, 1996) and is the biggest and principal authority to reduce the risk of flooding to people who work and live near rivers and seas (Communities and Local Government, PPS25, 2010). Under the Water Resources Act of 1991, the EA has the responsibility to manage the flood defences as well as flood forecasting and warnings for the expansion of the public awareness concerning flood risk (Communities and Local Government, PPS25, 2010). Around 60 percent of the work is funded by the government. The EA works closely together with the government, however it is an independent institution (Communities and Local Government, PPS25, 2010). On a local scale, local authorities and community groups are working together with the EA. In addition, the EA is required “to arrange for all its flood defence functions (except certain financial ones) to be carried out by *Regional Flood Defence Committees* under 106 of the Water Resources Act 1991” (Communities and Local Government, PPS25, 2010, page 43). This includes the statutory powers “to maintain and improve any watercourses which are designated as Main rivers and any sea or tidal defences, to install and operate flood warning equipment, to control actions by riparian owners and occupiers which might interfere with the free flow of watercourses, and to supervise internal drainage boards” (Communities and Local Government, PPS25, 2010, page 43).

Local Authorities and *International Drainage Boards* are working under the Land Drainage Act 1991. The realisation of flood defence activities “on watercourses which have not been designated as Main Rivers and which are not within internal drainage board area“are provided by the *Local Authorities* (Communities and Local Government, PPS25, 2010, page 43). Furthermore, the 88 maritime district councils have the challenge to protect the land against coastal erosion under the Coast Protection Act 1949 (Defra, 2008). Future, local authorities will be responsible for surface water management including the *Surface Water Management Plans* under the control of the Environment Agency (Defra, 2008). Additionally, they provide the emergency planning by flooding and offer help by recovering of flooding affected areas (EA, Flooding in England, 2009). *International Drainage Boards* are working independently to manage land drainage in areas with a special require and secure drainage and water level management (Communities and Local Government, PPS25, 2010). There are approximately 170 boards in England which are mostly in low-lying areas (Defra, 2008). They have the challenge to realise flood defence works, however without the main river designated watercourses (Communities and Local Government, PPS25, 2010). Additionally, IDB's maintain and improve rivers, drainage channels and pumping stations (Defra, 2008).

Furthermore, there are *Local Resilience Forums* for developing plans in case of an emergencies, the *Insurance Industry* to cover and handling claims for damages caused by flood events, and the *National Flood Forum* which holds information about flood risks and campaigns for a better flood protection (EA, Flooding in England, 2009).

3.5.2 Methods of protection

3.5.2.1 London's flood defences

Currently, London's flood protection system is characterised through walls, embankments, barriers, gates, culverts and local flood storage along the tributaries (EA, TE2100 plan chapter 1-4, 2009). A high standard of defence is provided by the Thames Barrier (figure A 5), because it protects 125 km² from tidal surges in central London (EA, TE2100 plan chapter 1-4, 2009). In addition to the Thames Barrier, the defended Thames flood-plain is characterised by "eight other major barriers owned and operated by the Environment Agency, 36 major industrial flood gates, 400 movable structures in private ownership and 337 km of tidal walls and embankments" (Lavery and Donovan, 2005, page 1457). The flood defences of the Thames estuary are illustrated in figure 17.

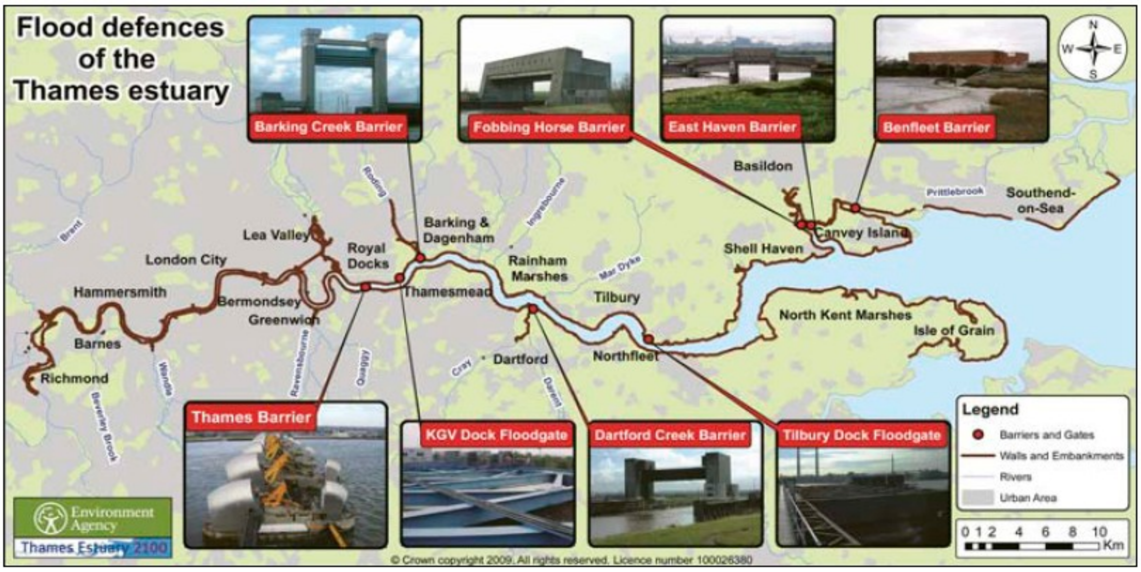

Figure 17: Flood defences of the Thames estuary. EA, TE2100 plan chapter 1-4 (2009)

Approximately 1.25 million people who are living and working in the floodplain can be protected by these defences (Lavery and Donovan, 2005).

Along the Thames river channel, London is protected by different river bank and flood defences (figure A 6). From Teddington to Dartford the most defences are artificial, however, they "vary considerably in height, profile, materials and ornamentation and the extent to which they support vegetation or allow access to the river" (EA, 1996, page 45). The channel types can be classified into six main categories. First, there are *natural river banks* that are really rare and occurring just upstream of the river Thames at Syon House. These banks are characterised by low riverside and dense vegetation with mature trees. Furthermore, there are *sloping artificial banks* in the upper reaches. These banks can be provided with vegetation along the face or on the top of the barrier. Therefore, vegetated or unvegetated sloping revetments and bank with or without tree-lined margins needs to be differentiated. The predominant channel type consists of *vertical banks with access* to the bank top However, character, scale and enclosure are different. The typical Thames embankments which are attended by the road and trees, are characterised by formal, dresses stone river walls. Other vertical banks are occurred in the upper and middle reaches with open spaces and trees as well as below the Thames Barrier where they are higher flood defence walls behind the banks in the front. Vertical banks with a restricted access are often existed in the lower reaches where industrial land predominates. These banks can be divided into industrial banks with vertical piling, rarely additionally with a sloping revetment. In some upper reaches, there are some examples of vertical banks with overhanging vegetation. In addition, there are *traditional riverside wharves* and particularly *mixed banks* in the upper reaches (EA, 1996).

Thames Barrier would be operational in 1982 (EA, Thames Barrier, 2010). It is currently the largest and only flood defence in London (Lavery and Donovan, 2010) and protects an area of 125 square kilometres (EA, Thames Barrier, 2010). The barrier has been designed by Charles Draper and was built by the Greater London Council (EA, Thames Barrier, 2010). The construction of the Thames Barrier costs over 535 million pounds altogether (EA, Thames Barrier, 2010). It consists of 10 steel gates and provides the function as flood defence by high tides (EA, Thames Barrier, 2010). The whole barrier can be closed in 1.5 hours that occurs in pears from the outside into the centre (EA, Thames Barrier, 2010). The closuring after low tides offers the ideal situation (EA, Thames Barrier, 2010). In 2005, the average closure of the Thames Barrier integrated around 3.3 times per year (Lavery and Donovan, 2010). The Thames Barrier has been closed in 119 occasion to protect London from flooding since its commission in 1982 to 16 April 2010 (EA, Operating the Thames Barrier, 2010). In 78 times the barrier has been closed due to tidal flooding and in 41 times due to prevent rainfall and fluvial flooding (EA, Operating the Thames Barrier, 2010). It was closed 443 times altogether which includes the monthly closure to test the barrier and operate experiments (EA, Operating the Thames Barrier, 2010). The design and construction of the barrier was anticipated and therefore the defence would have be closed for fluvial flooding to "reduce peak levels in upper part of the tide-affected river, in effect reducing the amount of tidal water entering the upper estuary, which already has high water levels from high river flows" (Lavery and Donovan, 2005, page 1461).

The increasing closure of the barrier is shown in figure 18. As one can see, the barrier had to be raised 4 times in the 1980's, 35 times in the 1990's and 80 times science 2000. That implies that there were over two third of closures since the beginning of this century. In 2001 and 2003 the barrier has been closed for a high number of times. In winter of 2000 and 2001, the Thames barrier was closed 24 times (Lavery and Donovan, 2010), mostly due to tidal flooding. Moreover, there were 19 closures of the barrier in January 2003 to minimize the fluvial and tidal flooding (Lavery and Donovan, 2010). Additionally, there were high numbers of closure in 1990, 1993, 2000 and 2007. As it shown in figure 18, in the years from 2004 to 2008 the barrier had to be just closed because of tidal flood events. In contrast, since 2009 the Thames Barrier is especially operated due to fluvial flooding. The barrier must raised five times due to the combination of high fluvial flows and high spring tides during the first week in 2010 (EA, Thames Barrier closures, 2010). At last, the number of closures offers a direct indication of occurred high tides, river levels and storm surges as well as the efficiency of the barrier and the operation in protecting London (EA, State of the Environment in London, 2007).

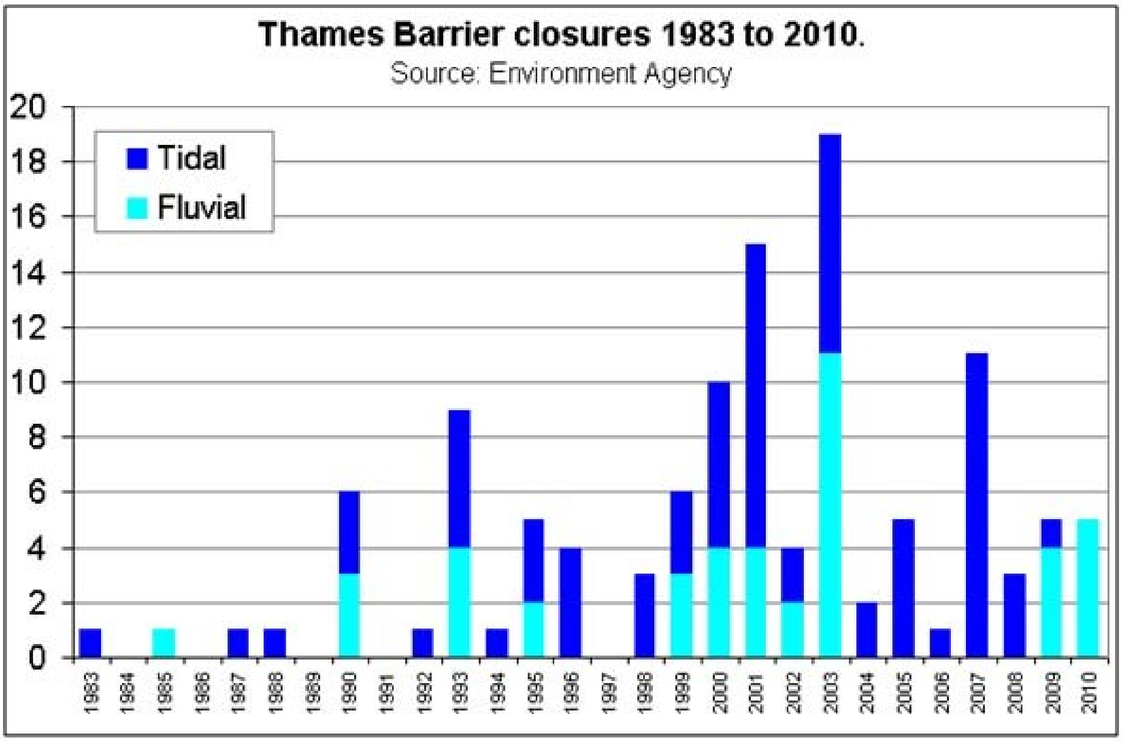

Figure 18: Thames Barrier tidal and fluvial closures. EA, Barrier Closures (2010).

The Thames Barrier is part of the comprehensive flood defence system. Lots of the flood defences have been constructed approximately 30 years ago (EA, TE2100 summary report, 2009). For this reason, the Environment Agency proposed that the present flood defences“will reach the peak of their design lives over the next 20 to 30 years” (EA, TE2100 summary report, 2009, page 2). Furthermore, the Environment Agency recognised that many of the present flood protections are not sufficient in relation to future impacts of climate change (EA, TCFMP, 2009). In addition, the Thames riverside and their utilisation are changing and therefore changes in form and position of the defences are required (EA, TE2100 plan chapter 1-4, 2009). For examples the Thames Barrier will operate more frequently due to sea level rise and an increased risk that flood defences are up streaming of the barrier could overtop (EA, State of the Environment in London, 2007). However, every closure rises the risk of a barrier failure and the maintenance regime will be affected (EA, State of the Environment in London, 2007). For this reason, it is essential to develop and improve defences dependent on the future conditions. The EA suggest that costs of several billion pounds are required to replace and major repair defences.

3.5.2.2 Flood forecasting and warnings

The complicated challenge of forecasting and warnings is to ensure the emergency service and the access in the public to know "where and when it will be flood and how serious the flooding will be" (EA, Flooding in England, 2009, page 19). To *forecast* scale, time and location of the flood risk is often the first grade (EA, Flooding in England, 2009). The Environment Agency can forecast weather conditions in an advance of up to 36 hours (EA, Thames Barrier, 2010). Forecasting of probably flooding events is managed by the control room at the Thames Barrier for 24 hours a day in 365 days of the year (Lavery and Donovan, 2005). In addition, data are provided by the *Meteorological Office* every 12 hours which is running trough a series of 'hint cast' models to forecast the Thames tide levels (Lavery and Donovan, 2005). The *Met Office* is a *Flood Forecasting Centre* and has the task to predict "rainfall amounts and the scale of tidal surges" (EA, Flooding in England, 2009, page 19). An essential part are live data which are showing what is happen in the atmosphere, on land and in the sea and rivers (EA, Flooding in England, 2009). To improve the models and forecast the number of gauging stations, data sites of the river level are increased in the recent years (EA, Flooding in England, 2009). Additionally, the number of tide level and wave gauges are rising to increase the quality of forecast coastal flood events (EA, Flooding in England, 2009). From 1970 to 1979 1,159 river measuring sites have been available to identify flood risk (EA, Flooding in England, 2009). In the 1990's, the number has increased until 2,624 and it has risen again to 3,432 measuring sites in 2005-07 (EA, Flooding in England, 2009).

The second step is a *system to warn* people at risk through sounds and specific information (EA, Flooding in England, 2009). The forecasts are the basin to ensure the flood warning as accurate as possible (EA, Flooding in England, 2009). All these have occurred in a quickly path to offer enough time for people to protect themselves and their properties (EA, Flooding in England, 2009). In the past years, the availability of flood warning service has increased around England and Wales (EA, Flooding in England, 2009). Currently, there are two main flood warning services. First, *Floodline Warnings Direct* (FWD) is established to communicate the flood risk by telephone, fax, mobile, SMS text message, e-mail or pager. The number of people who are registered, has continuously been increased. The second service is offered by a 24-hours telephone Floodline. This provides the access to up-to-date information about currently floods and flood predictions. In addition, the Environment Agency offers on their web page the possibility to receive current flood warnings, to find a flood map and provides help by the design of persons own flood plan. The *Flood Map* has the aim to offer a picture of the flood risk in England and Wales, furthermore to show the flood zones and the defences (EA, Understanding flood risk, 2006). This map is renewed every three month to guarantee to be updated (EA, Understanding flood risk, 2006). Furthermore, the Environment Agency advices emergency services during a flood and other professional partners are involved to guarantee a quick flood help (EA, Thames Barrier, 2010). The Environment Agency Customer Charter has its own aim to "...provide flood warnings at least two hours before flooding happens in areas where a service can be provided" (EA, Flooding in England, 2009, page 21). Prospective flood warning systems will be improved by higher services for surface and groundwater flooding. Furthermore the communication for emergency and public services will be increased before the flood events and the access to the flood warning services has to rise. More people should know about there own possibilities to prepare themselves for flood risk (EA, Flooding in England, 2009). For this reason, all parties have to carry their responsibility (EA, TE2100 plan chapter 1-4, 2009).

3.6 Future flood defence strategies

The Thames estuary is a dynamic and changing system which provides the challenge to "review the current flood risk management activities" (EA, TE2100 plan chapter 1-4, 2009, page 20) and to prepare these for future changes. As discussed, terms which influence possible future changes are climate change (see 3.2), ageing of flood defences (see 3.4.1), changes in physical environment (see 3.2.2.3), socio-economic change (see 3.4.2) and public and institutional awareness of flood risk (EA, TE2100 plan chapter 1-4, 2009).

The fundamental strategy for a future management of flood a coastal erosion risk is provided by the Department for Environment Food and Rural Affairs in the *Making space for water* response. The aim will be the "reduction of threat to people and their properties" under allocation of the "greatest environmental, social and economic benefit, consistent with the Government's sustainable development principles" (Defra, 2005, page 8). According to the Brundtland Report, this policy strategy provides a sustainable development which is "the development that meets all the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations World Commission on Environment and Development, 1987). It will be implemented in "all flood risk management and coastal erosion decisions and operations" (Defra, 2005, page 14). Furthermore, the risk management will be integrated in a range of Government policies e.g. planning, urban and rural development, transportation and agriculture (Defra, 2005). According to the Future Flooding Foresight Report, future strategies are uncertain and therefore it is significant to develop a robust policy with various outcomes which can adapt to future situations (Foresight, 2004). Sir David King the Chief Scientific Adviser (Foresight, 2004) concluded that "hard choices need to be taken – we must either invest more in sustainable approaches to flood and coastal management or learn to live with increased flooding."

In general, the Environment Agency provides an environmental and sustainable vision of objectives to achieve future flood defence management according to the policy by the Defra. First, they will integrate further flood warnings and sustainable defences to prevent deaths from flooding. Second, the EA will minimise the damage and distress of properties. Additionally, they will integrate marshlands to reduce the flood risks and last, maximize all the environmental benefits from natural floods (Harman et al., 2002).

The Environment Agency provides the challenge to design a plan for a long-term flood management strategy for the next 100 years (EA, TE2100 summary plan, 2009) with the *Thames Estuary 2100 project* (TE2100). In 2001, the project was established due to predicted climate change and the advance in years of walls, embankments and barriers (EA, TE2100 plan, chapter 1-4, 2009). The Thames Estuary including its tributaries and the floodplain covers the area from Teddington to Shoeburyness and Sheerness (EA, TE2100 summary plan, 2009). This TE2100 study area contains 500.000 homes and 40.000 non-residential properties (EA, TE2100 summary plan, 2009). Due to the end of the existing defences and the predicted climate and environmental changes, it will be required to renew and replace current flood defences and to integrate socio-economic and environmental solutions in the planning (EA, TE2100 summary plan, 2009). Thus, the TE2100 study follows the governmental policy to design a technically plan under consideration of sustainability factors (DEFRA, 2005). Moreover, the plan will include international guidelines and other legislations like the Birds and Habitat Directives to protect the nature conservation sites and the Water Framework Directive to maintain and improve the quality and environment of the water (EA, TE2100 summary plan, 2009). For this reason, a Strategic Environmental Assessment (SEA) environmental report is included in the planning the flood defences (EA, TE2100 summary plan, 2009).

The flood risk management is divided into three time horizons. From 2010 to 2034, the first period is called “maintaining confidence and planning together”. The aim in this period is to continue the maintenance and operation, to establish essential improvements, to create the basin for the future flood management and to include the TE2100 in regional and local plans. The “Renewal and reshaping of the riverside” is the theme from 2035 to 2069. This period offers the raising and major refurbishment or replacement of many of the existing walls, embankments and smaller barriers and provides the opportunity to renew the riverside environment through co-operations from planning and environmental organisations. From 2077 a major decision about the flood defence option will be required to “prepare for” a long-term flood management strategy in order to “move into the 22 century” (EA, TE2100 plan chapter 9 Zone 0 estuary-wide, 2009).

Thames Estuary 2100 Action Plan

The Thames Estuary 2010 plan provides an action plan which are required at local and estuary-wide levels. This action plan can be characterised by 8 action zones plus an estuary-wide zone demonstrated in figure 19.

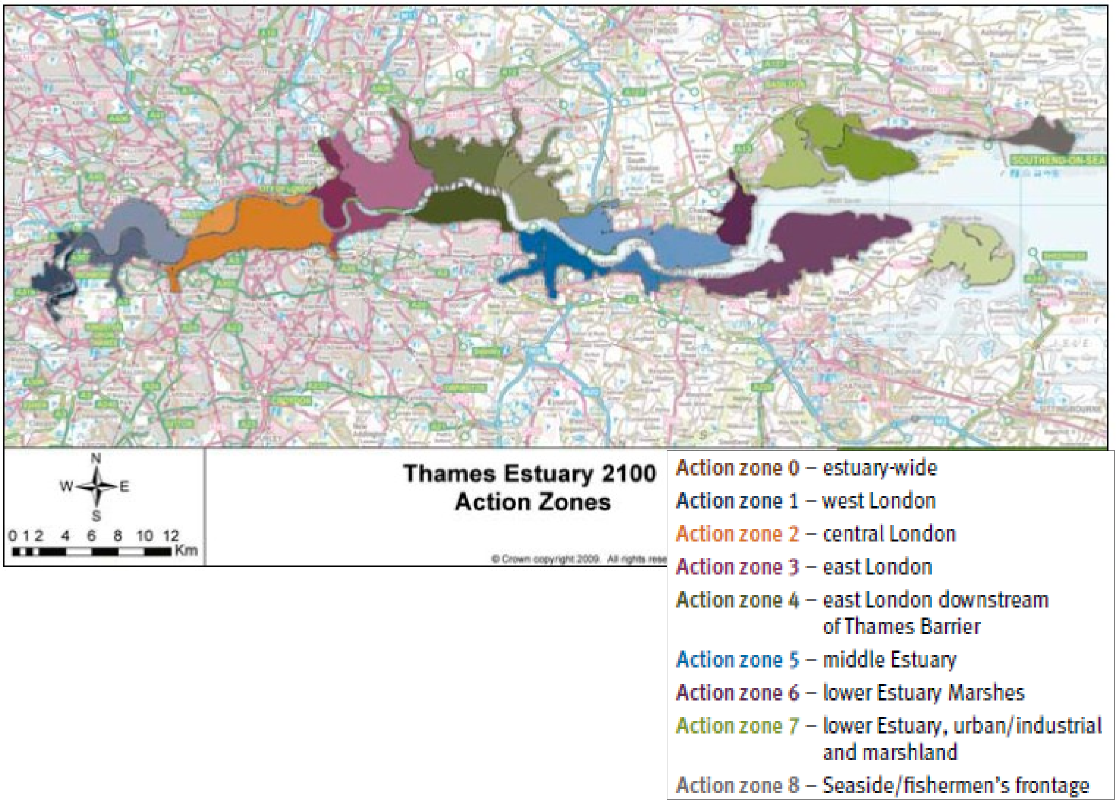

Figure 19: Thames Estuary 2010 Action Zones. EA, TE2100 plan chapter 6-8 (2009).

Currently, the Environment Agency (TE2100 plan chapter 9 zone 0 estuary-wide, 2009) provides four main options for the estuary-wide action zone 0. *Option 1* provides to improve the existing defences and is considered in four sub-options: 1.1 raising defences when needed, 1.2 allowing for future adaptation defences, 1.3 raising defences when they are replaced and 1.4 optimising the defence repair and replacement. The difference of the sub-options is characterised by the maintenance of schedules and by the ways of deciding about the time of rising and number of rising walls. This option includes the improvement of the Thames Barrier and the rising of defences alongside the river (figure A 7).

The storage for tidal flooding is characterised by *option 2* and it represents the creation of four heritage sites to store tidal waters and reduce the level of storm surges. Erith Marshes, Aveley and Wennington Marshes, Dartford and Crayford Marshes, and Shorne and Higham Marshes are the four identified areas to design flood storage sites. These sites would be coupled with new defences for these (figure A 8). They have the aim to reduce the extreme water levels at the Thames Barrier during high surge tides (EA, TE2100 plan chapter 9 zone 0 estuary-wide, 2009).

The design of a new barrier is proposed by *option 3.* There are two preferred locations: Tilbury and Long Reach. The aim of the construction is to resist the highest surge tides. Due to the closure of the barrier for a certain number of times, the increase of flood defences upstream would be required (figure A 9) (EA, TE2100 plan chapter 9 zone 0 estuary-wide, 2009).

Option 4 offers the construction of a barrier with locks shown in Tilbury, Long Reach and the location of the Thames Barrier are the proposed locations. The advantage is that ships can pass the barrier either when the barrier is open or closed through the locks. Furthermore, the barrier can be closed as frequently as required. There are no losing of the reliability, however it is the most expensive option (figure A 10) (EA, TE2100 plan Chapter 9 zone 0 estuary-wide, 2009).

By comparison, all options illustrate the requirement to integrate new defences and to raise the exit defences in the lower Estuary by up to 0.3 m by 2040 and again by 2100 (Action zones 6, 7, 8). In addition, all options include potential structural measures the fluvial flood management in west London (Action zone 1). Next, options 1, 2 and 3 show the rising of the defences in west and central London up to 0.5 m by 2065 (Action zones 1 and 2). Just under the option 1 and 2 the Thames Barrier will be improved in 2070.

The two front-runners

The Environment Agency proposed two front-runners. The first of the two front-runner options is preferred from an environmental view: to optimise defence improvement (option 1.4) (EA, TE2100 summary plan, 2009). In other words, existing systems should be improved by optimising the defence repair as well as the replacement regime (EA, TE2100 summary plan, 2009). It signified, that existing walls and embankments will be higher and improved and additionally, exist barriers will be optimized (EA, TE2100 summary plan, 2009). These defences include the Thames Barrier and other active barriers like Barking, Dartford as well as gates and movable defences. Thames Barrier will come to the end of their design lives in approximately 20 years (TE2100 summary plan, 2009). However, the structure itself was constructed for more years than 50 years (Lavery and Donovan, 2005). For this reason it will be required to renew and replace the operating infrastructure of the barrier to confiscate the protection of the barrier (Lavery and Donovan, 2005). Option 1.4 deals with the modification of the barrier in order to protect London for an additional 1.2 m flood level over the next 100 years and is illustrated in figure A 11 (Lavery and Donovan, 2005). Due to that, the height of the sector gates and other improvements would cost millions of pounds, although it would be cheaper than the construction of a new barrier (Lavery and Donovan, 2005). In addition to the improvement of the barrier, upstream and downstream of the river defences will be raising as well as rebuilt and refurbished by the period of 2035 to 2069. Parts of the flood-plain could moreover establish a more natural system by the removal of active defences (EA, TE2100 summary plan, 2009). Furthermore, the project includes the creation of new habitats which are estuary-wide marshlands to offer a naturally defence function on the coast and along the stream courses (EA, TE2100 plan Chapter 1-4, 2009). In 2020 the first of four habitats will be implemented to compensate the loss of designated freshwater and grazing marshes (EA, TE2100 plan Chapter 1-4, 2009). The other habitat creations are planned by 2040, 2050 and 2065 as well as further sites to establish 1200 hectares of intertidal habitats (EA, TE2100 plan Chapter 1-4, 2009). This option is likely to be 10 percent less expensive than the other sub-option (EA, TE2100 plan Chapter 1-4, 2009). Disadvantages are the long-term increased flood risk and the decreased water quality due to increased exigency for barrier closure. In addition, coastal squeeze could decrease intertidal habitats (EA, TE2100 summary, 2009).

In contrast to the first option, the second one is identified from economics and about building a *new barrier at Long Reach* (option 3.2). The advantage of this strategy is that this new barrier will be situated closer to the estuary and thus, a larger landscape of London could be protected. The Environment Agency suggests that, the influence of the environment would be high, the water quality could decrease as well as the commercial use of the river and the loss of intertidal habitats is likely due to the coastal squeeze. Furthermore, the construction of a new barrier would due to high costs. All in all, a combination of the both strategies is likely. Currently, the ecological option is promoted for the period before 2070 and the front-runners for the period after 2070 (EA, TE2100 summary plan, 2009).

Examples out of the action zones

The action plan is divided into eight action zones (figure 19 above). These areas consist of different structures and which are affected by various causes of flooding. Thus, various defences are persisted and required to minimise the flood risk. Some examples with contrasts will be considered.

The action zone 1 consists of the reach Richmond (figure 20). This reach includes "the most upstream section of the tidal Thames" which covers approximately 6 kilometres from Teddington to Richmond Lock (EA, 1996, 59). The policy unit is characterised by a relatively narrow floodplain (EA, TE2100 Chapter 9 Zone 1 Richmond, 2009) with open spaces and residents (EA, 1996), although the area of Richmond is occupied by the town centre and commercial uses. The river landscape in this reach is characterised by unique 'rural' quality (EA, 1996). There is a "predominance of riverside greenspace" occupied by parks and gardens like the Richmond Park and Kew Gardens which have ecological and historical significance (EA, 1996, 62). Additionally, the "historic and elegant built waterfronts" and the high quality housing along the riverside are important for this region (EA, 1996, 62). This zone provides a risk of tidal flooding from the Thames, fluvial and tidal as well as fluvial flooding. The risk is probably 0,1 percent per annum. A higher flood risk is provided by fluvial and tidal or fluvial flooding with up to 1 percent per annum. If the Thames Barrier failed flood depths up to 3 m are likely. A further source of flooding is the local drainage system (EA, TE2100 Chapter 9 Zone 1 Richmond, 2009).

At present, the flood risk management is prepared by the Thames Barrier to control the tidal water level and reduce the fluvial flooding. Moreover, there are tidal defence along the frontage and the high standard of flood forecasting and warning. However, there are no fluvial flood defences which exist in this area. The area is highly environmental sensitive. For this reason the vision for the unit is a management and improvement of the landscape without adverse impacts. Over the next 25 years, the utilisation of the Thames Barrier for fluvial flooding will be decreased due to the increasing tidal flood risk by climate change. For this reason, the improvement and the construction of new defences will required to design an alternative to measure the freshwater flood risk. The TE2100 project provides the raising of the walls, a better protection of undefended islands, a specific protection of properties and an increased reliance on flood warning (EA, TE2100 Chapter 9 Zone 1 Richmond, 2009).

An example of reduction in flood risk in the Borough of Richmond upon the Thames river provides the Third Cross Road in Twickenham less than one mile away from the Thames. The probability of flooding is less than 1 in 1000 years, however, surface water flooding offers a less to intermediate risk. To minimize the flood risk the tarmac surface in the access road and the parking place will be replaced with a permeable surface. Due to the surface water run off could decrease. Additionally, further hard landscapes will be changed with green landscapes to raise the infiltration. Another intention provides the facility of commercial building with a green roof. Thus, the surface water runs off and potential flash floods could be reduced (London Borough of Richmond upon Thames, 2010).

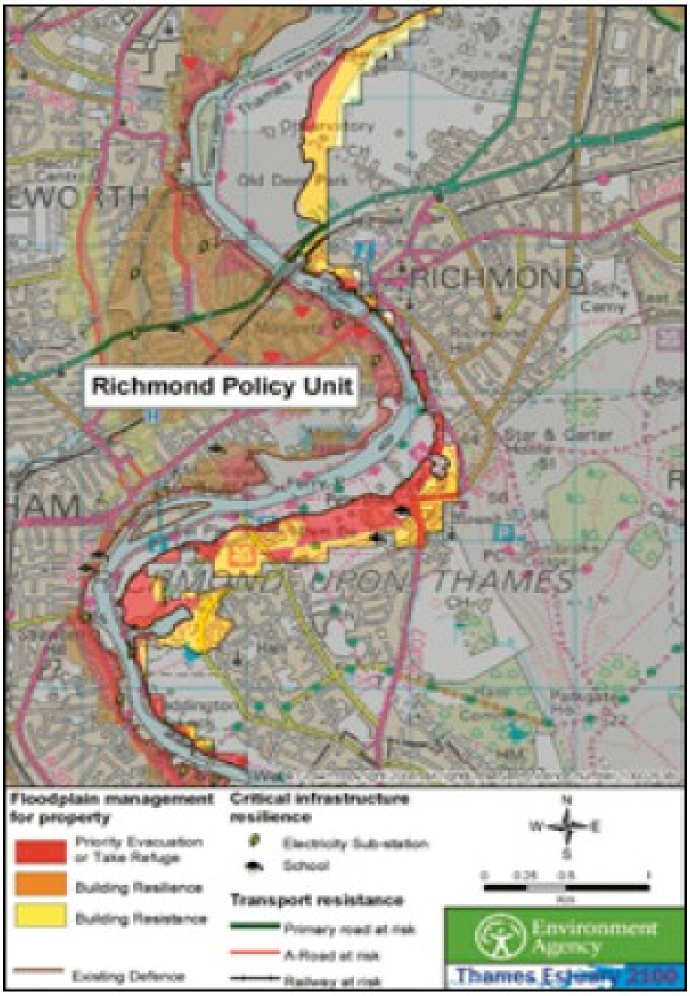

Figure 20: Richmond Policy Unit. EA, TE2100 Plan Chapter 9 Zone 1 (2009).

Much of Westminster, Charring Cross, London Bridge and many other historical building are covered by the *action zone 2* in the policy unit *City of London*. This area is characterised by a relatively small however highly developed area with the seat of the government, World Heritage sites Palace of Westminster and the Tower of London as well as underground stations, schools, electricity substations and a hospital (figure 21). For this reason the region offers limited opportunities for redevelopment.

A source of flooding is provided by the Thames tidal flooding with a probability of 0.1 percent per yeat. Pluvial and urban drainage systems, particularly in the area of Westminster and groundwater flooding from superficial strata which are probably connected to Thames water levels are further sources.

For this reason, the Thames Barrier operates as an important control system of the tidal water level. Second, the Thames frontage provides tidal flood defences. Furthermore, there are 22 combined sewer overflows (CSOs) for urban drainage flood mitigation and flood forecasting and warning are offered additionally. However, in the future it will be required to increase the standard of protection as well as the awareness of the flood risk for residents, commuters and tourists. The tidal flood management will be provided by the Thames Barrier for the foreseeable future. Fluvial flooding is unlikely to be a risk before the tidal defences and behind these, pluvial and fluvial flooding might be possible. Future vision in this area provides the opportunity to relocate the defences into the urban landscape. This is justified to the adverse impacts on the riverside to raise the tidal flood defences and furthermore, due to the fact that this regions would be inundated in the future. The aim is to improve the riverside environment and to alleviate the maintenance of the defences. In addition, the accretion of the river bed could maintain to the improvement of the ecological capacity and appearance at Wapping and Westminster. Another problem is the erosion which influences long length of foreshore at Shadwell, Blackfriars, Pimlico and Chelsea. Therefore it might be required to relocate the defences if these will be upgraded to avoid damage on them. Moreover, the incorporating of flood gates or other measures will be required to protect the dock gate entrances for flooding. Last, defences for fluvial and pluvial drainage flooding must be proved and may be improved in its local problems.

The city of London offers previous pavements and green roofs as good sustainable urban drainage systems. Previous pavements approve rainwater to infiltrate in the ground. First, this pavements can be achieved by utilisation of porous materials which filtrate across their entire surface e.g. grass, gravels or concentrates and second, by utilisation of impermeable materials with voids to achieve permeable surfaces e.g. brick paving. Green space on roofs can increase the infiltration and reduce surface run off. This green roofs can be established as extensive green rood with low growing, low maintenance plants or as intensive green rood which include planters or trees and which are characterised by a greater load on the roof structure. The city of London offers the possibility for on-line or off-line storage which are tanks or other underground storage structures (City of London, 2010).

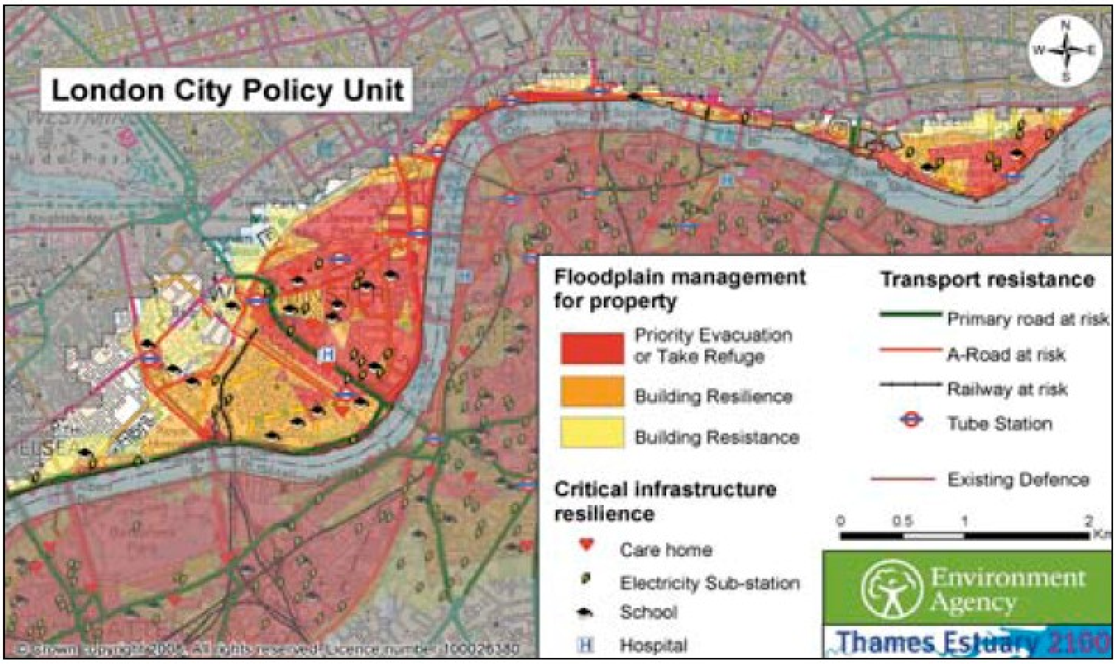

Figure 21: City of London Policy Unit. EA, TE2100 Plan Chapter 9 Zone 2 (2009).

Dartford and Erith are parts of the middle estuary *action zone 5*. This unit is characterised by developed and undeveloped marsh lands. Residences persist at the riverfront town of Greenhithe as well as parts of Dartford and Crayford. In addition, there are residents at the east side of Erith and the Stone Marshes near the Queen Elisabeth II Bridge are affected by commercial development. As you can see in figure 22 the policy unit is flown by the river Darent and its tributary the river Cray which pass the largely undeveloped Dartford and Crayford Marshes in the lower reaches. This policy unit is persisted of a flood risk with various flood sources. Flooding may occur due to tidal flooding from the Thames or the rivers Darent and Cray. This source is Thames Barrier controlled and offers a possible flood risk probably 0.1 percent per year. A higher flood risk with up to 20 percent is provided by fluvial flooding of the two rivers. Additionally, fluvial flooding could occur from the marsh drainage systems on Crayford Marshes, and Dartford and Stone Marshes. Last, local drainage and groundwater from aquifers increase furthermore the flood risk.

Existing defences are Thames tidal flood defence, the Dartford Creek Barrier to prevent tidal flooding in the tributaries, tidal and fluvial flood defences on the rivers Darent and Cray, local fluvial flood defences as well as drainage system outfalls including Crayford, Dartford and Stone Marshes.

In the policy unit, it is likely that there will be considerable new developments which due to the requirement of new defences and defence improvements. It is considered to combine the new development with the new defences. Furthermore, in some resilient developed areas on the riverward side defence will probably be relocated. The largely marsh land should be retained and may be used for tidal flood storage. Although, the Dartford Marshes are a part of the Thames Gateway Parkland vision to "regenerate and develop urban and rural open spaces which are connected together to create an accessible and coherent landscape" (Department for Communities and Local Government, Thames Gateway Parkland Vision, 2008, page 8). For this reason, independent from the flood storage opportunities the marshes could be important for habitats and recreation. Future, the most significance will be the measuring of tidal and fluvial flooding from the rivers Darent and Clay.

The *Dartford Creek Barrier* (figure A 14) was built in 1981 to control the tidal flooding from the Thames. This and next summer, the overhaul of the barrier including the replacement of engineering controls is planned. The work will be carried between May and September because the tidal flood risk is then at its lowest and furthermore, one of the two gates is always operational. The aim is to ensure the reliability of the barrier operation for the next 20 years (EA, Dartford Creek Barrier, 2010).

Besides the Dartford Barrier defence raising will be required to protect the Drant river by tidal flooding. In addition, a fluvial flood risk management scheme might be occurred including fluvial storage in the marshes, outfall improvements and local fluvial flood storage and management of surface run off.

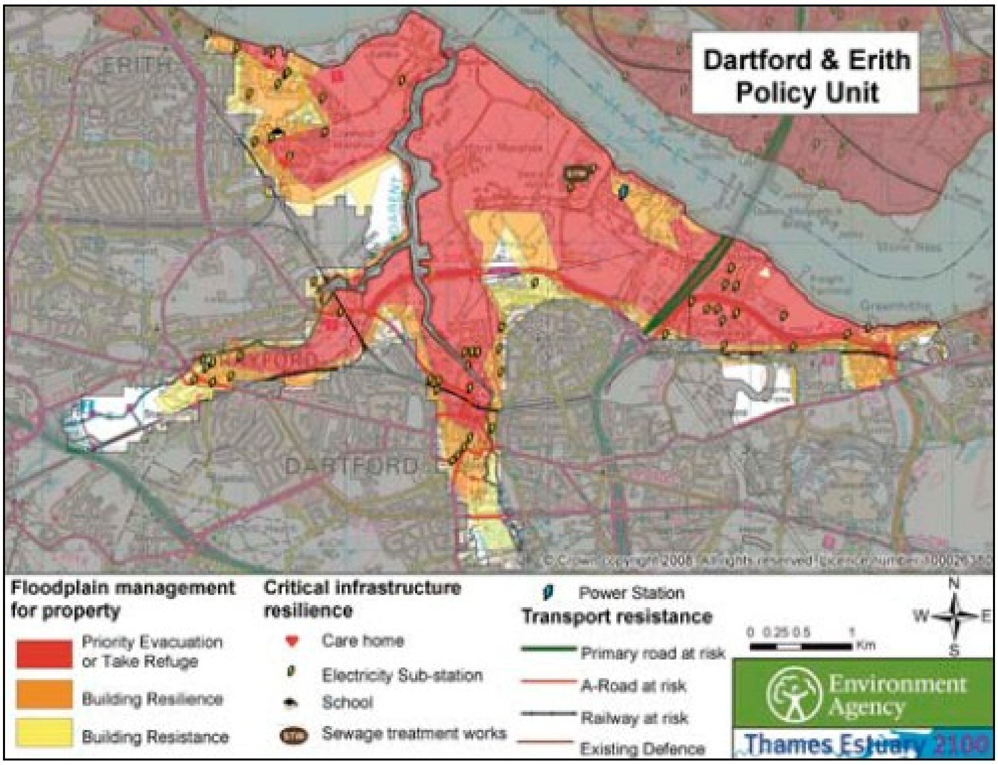

Figure 22: Dartford and Erith Policy Unit. EA, TE2100 Plan Chapter 9 Zone 5 (2009).

4 Results

4.1 Flood risk and flood risk assessment

Hammond said that the flood risk is based on the probability of occurrence multiplied by the consequence. He emphasized that the calculated risk is depending on the location of calculation. The three factors that change depending on location would be tide level (source) standard height and condition of the tidal defence (pathway) and whatever is behind that defence in the possible flow path (receptor). Hammond (2010) said how fast the flood risk will grow is depending on the change to the areas behind the defences. He gave the example that the flood risk would grow related to the consequences if the population would rise in areas affected by a breach or overtopping of defences. Furthermore, Hammond quoted that the probability of breach or overtopping would likewise be increased by rising tide levels. The defences are inspected twice a year by the Environment Agency to ensure their reliability because an increasing disrepair causes consequently to an increasing risk (Hammond, 2010).

Hammond emphasized that London's current protection offers the highest in the UK. The probability of flooding is 1:1000 this implies the defences are at a height that is at least as high as a water level that has a 0.1 percent annual probability of occurring (Hammond, 2010).

The EA provides a National Flood Risk Assessment (NaFRA). NaFRA categories the likelihood that areas will be flooded behind the defences through the information of regarding defences and water levels and flows in rivers. The categories are significant with greater than 1.3 percent annual probability, moderate with an annual probability between 0.5 percent and 1.3 percent and low with 0.5 percent or less annual probability. Hammond emphasized that NaFRA implies no risk assessment and accounts no flood consequences. It is just the likelihood of flooding (Hammond, 2010).

4.2 Thames tidal defence levels and measuring of the sea level

The sea level in the Thames is measured by tide gauges (Hammond, 2010). Around the UK coast, a lots of tide gauges are existed (Hammond, 2010). In the Tidal Thames between Teddington lock and the river Darent, there are eight tide gauges (Davis, 2010). These are located at Richmond, Hammersmith, Chelsea, Westminster, Tower Pier, Charlton, Silvertown and Erith (Davis, 2010). Down river of this, there are four more heading out towards the outer estuary (Davis, 2010). These are the tide gauges at Tilbury, Corytown, Southend and Sheerness (Davis, 2010). The figure 23 offers some data compiled by the port of London authority and illustrates the mean tide level at Tower Pier and Southend. Hammond (2010) noticed the mean tide level is derived by obtaining a mean high water and a mean low water for each year and then averaging them.

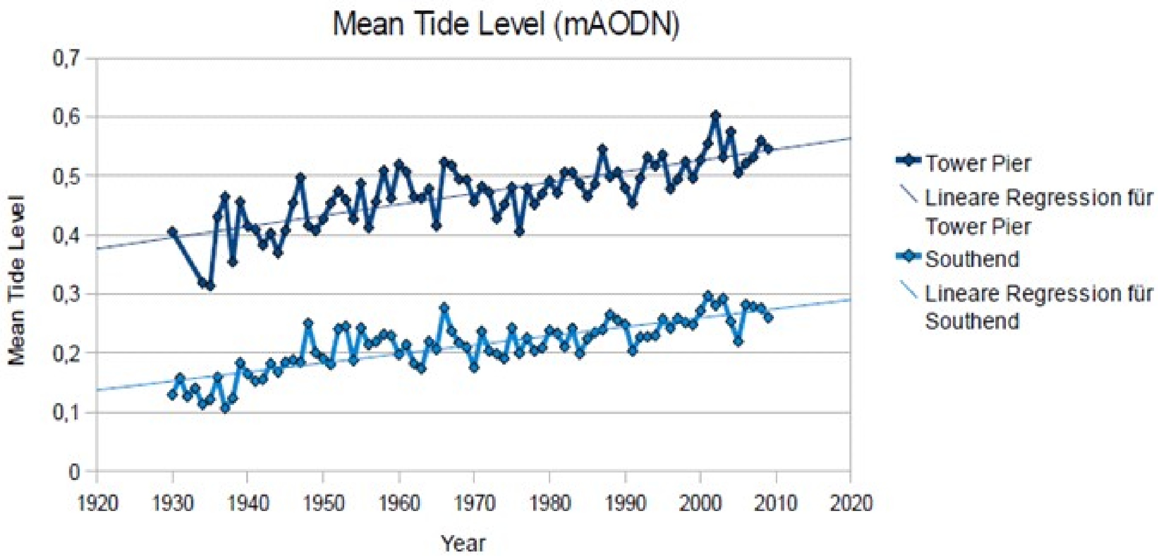

Figure 23: Mean Tide Level at Tower Pier and Southend; for table see table A 1; data provided by Hammond (2010)

This figure shows that the mean tide level has increased between 1930 and 2010. There are changes in the mean tide level every year, however, the main trend illustrates a rising measured by the gauges at Tower Pier and Southend.

4.3 Thames defence types

According to Davis (2010) London's defences vary in composition from masonry, concrete, sheet piles, anchored walls, cantilever driven sheet piles, sheet piles with tie rods, earth embankment with clay core or natural embankment. However, there are three main types in which the tidal defence walls and embankments can be lumped. These are high ground, slopes or embankments and vertical walls. An indication of defence types within the Thames tidal area is illustrated in the Thames tidal defence map (figure 24). Davis emphasized that the map is just an indication of defence types at a strategic level.

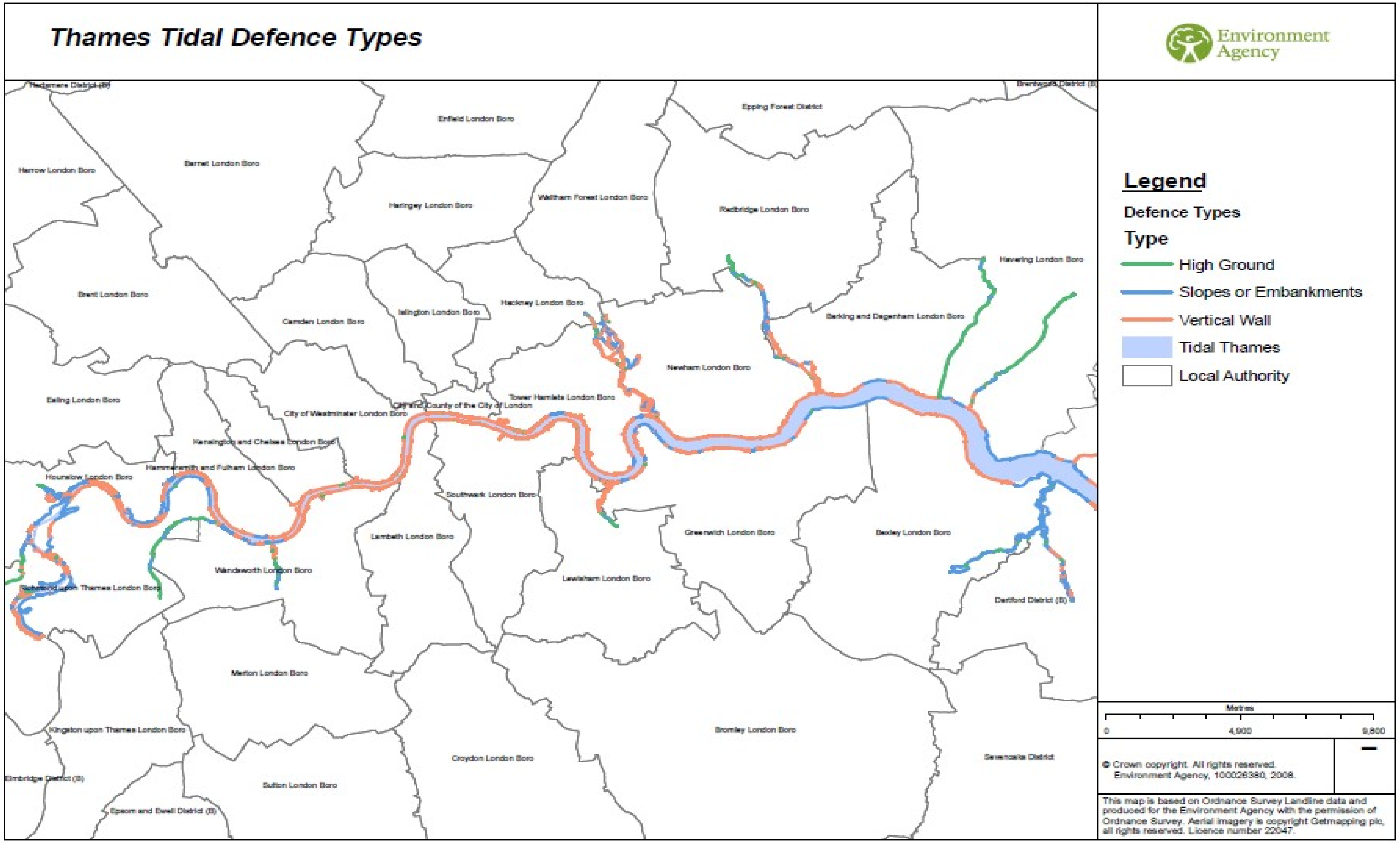

Figure 24: The defence types in the tidal Thames

Figure 24 illustrates the most High Ground defences on the rivers Rom (also known as river Beam) and Ingrebourne in east London. A high ground is defined when the ground or the bank adjacent to the river is already above the desired defence level and therefore no formal defence construction is necessary (Davis, 2010). Slopes and embankments represent the dominant defences and vertical walls are predominant (for explanation see 3.5.2.1).

Furthermore, London is at risk from fluvial and pluvial flooding. Fluvial flooding is caused direct from freshwater rivers such as the river Wandle. Davis (2010) mentioned river walls or banks vary in height along the Thames, however, they offer a specified standard of protection. It implies that the defences set of minimum levels to be built to (Davis, 2010). This is why a specific standard of protection from tidal flooding must be guaranteed. As considered, in the tidal Thames it is a standard of 1000. The tidal defence level is state as the height of the defences and it is derived from statistical analysis of tide gauge information and the probability of a particular tide level occurring (Davis, 2010). The minimum level of defence for the tidal Thames between Teddington and Purfleet is shown on the map in figure 25.

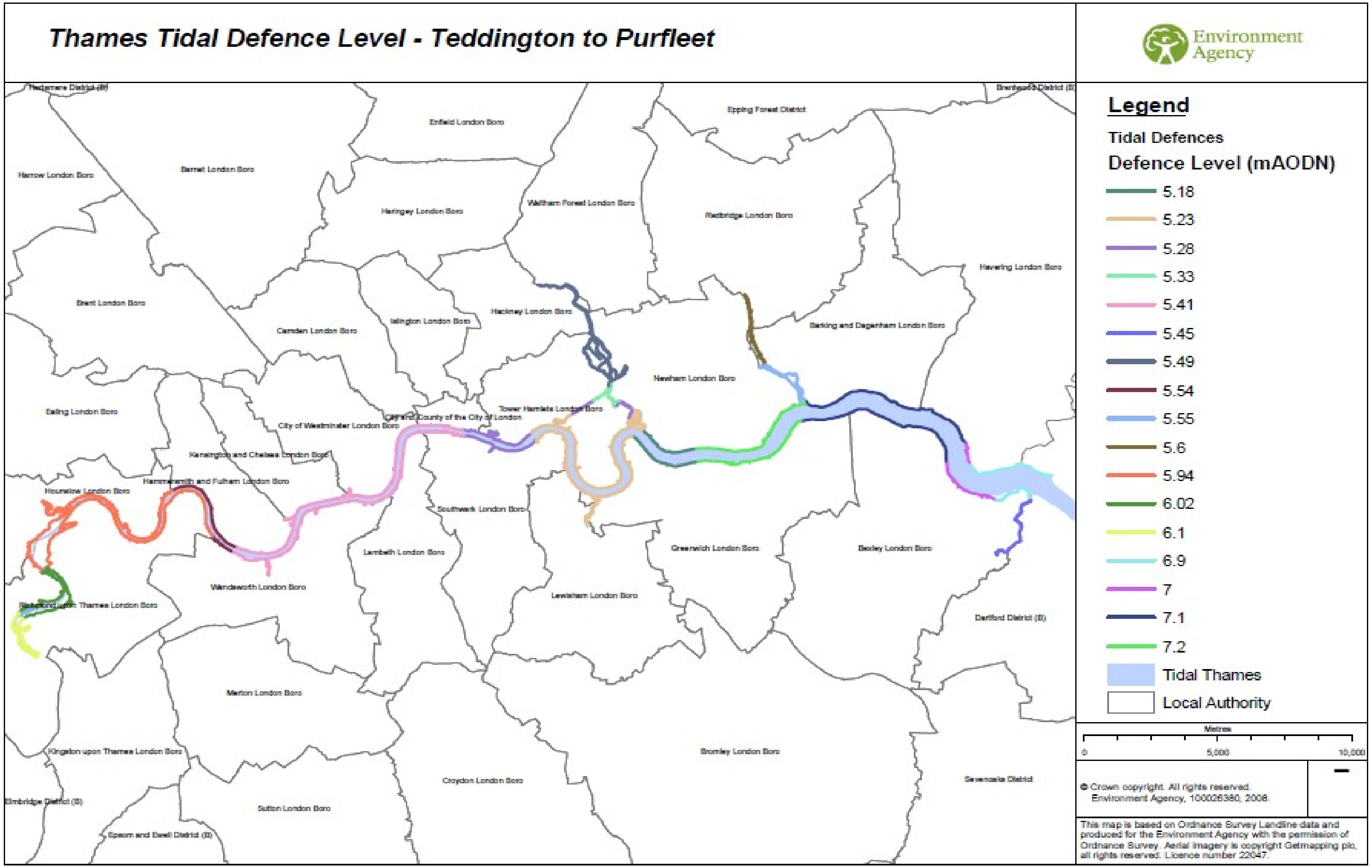

Figure 25: The tidal Thames defence level from Teddington to Purfleet

As it is shown in figure 25, the defence level is with about 7 metres above ordnance datum Newlyn (mAODN) and is essential to the mean sea level. According to Davis (2010) the datum is the level at which all the levels with mAODN are measured from. Moreover, Newlyn is a place in Cornwall and the sea there were measured over a long period of time to find the mean sea level. This mean sea level was then set as the ordnance datum. In contrast to the hight, there is no set value for the broadness of the defences. According to Davis (2010) it is changing depending on the type and style of defence.

Additionally, there is a pluvial flood risk caused by heavy rain, the rising water table and/ or the backing up of sewage systems. Currently, the London sewage system dates back to the Victorian period and Davis (2010) emphasized that an upgrade is required. For this reason, a project is underway to build a super sewer to supplement the current system in times of heavy rainfall. Thus, the aim of the super sewer is, to prevent a capacity peak of the current system. Furthermore, it will lead in large parts of the river to an improvement of the state of the river and it’s water quality.

4.4 The Barriers

According to the *Thames Barrier Act* its aim is to reduce the probability at the source by preventing the extreme water levels propagating upstream. Hammond quoted the Barrier was originally designed to protect to the 1:1000 standard until the year 2030, when the standard would slowly decrease over time. The TE2100 plan clarified that the Thames Barrier will offer a 1:1000 protection standard until at least 2070.

The Thames Barrier is subjected to the closure regime. This regime provides the general rule of the barrier closure. The closure is based on a matrix of factors which are forecast in advance. Hammond mentioned the tide height at Southend, the accompanying surge and the freshwater flow over Teddington Weir as factors. However, Thames Barrier can only be closed a certain number of times. Hammond underlined the reason that the barrier is an engineered structure which required ongoing maintenance. Furthermore instanced Hammond that a barrier closure in every high tide would not offer enough time for the maintenance. He added for consideration that the requirement for maintenance will rise due to the predicted increased barrier closures (Hammond, 2010).

There are three models contribute to forecast the barrier closure: the North Sea Model, the Continental Shelf Model, River Thames Model or ISIS model (Davis, 2010). The Meteorological Office (Met Office) supplies the information provided by the models (Hammond, 2010). In addition, real time information are provided by the National Tide gauge Network around the east and south coast and tide gauges located on the tidal Thames (Hammond, 2010). Tides can be tracked approximately 36 hours in advance of reaching the estuary as they travel down the East Coast (Hammond, 2010). Three major factors decide if the Thames Barrier will closed (Davis, 2010). First, the height of the tide is measured at the Thames estuary which is usually a spring tide (Hammond, 2010). Secondly, the closure is based on the tidal surge, which naturally accompanies each tide and last, the fluvial flow entering the tidal Thames, measured as it passes over Teddington Weir (Hammond, 2010). Davis (2010) emphasized, that the barrier may close due to heavy rainfall which could occur high flows in upstream reaches. Thus, the barrier would prevent that the coming tide spills over the river banks.

Generally, the Thames Barrier closure would begin approximately 1.5 hours after low water at North Woolwich. All 10 gates are closed in approximately 1.24 hours and they create an 'empty reservoir' which is approximately 26 miles long and 4 square miles in area, for fluvial/freshwater flow entering the tidal Thames at Teddington. The Thames Barrier will then first open when water level down stream of the Thames Barrier has reduced to the same level as upstream. An individual trigger level for closure is not provided by the barrier. Therefore, every 20 minutes hydrological and meteorological data is fed to the control room by telemetry. The closing regime is guided by a mathematical matrix considering fluvial flow, tide and surge from this data. The duty controller at the time holds the end decision for closure the Thames Barrier (Hammond, 2010).

Besides the Thames Barrier, there are other barriers for example the Barking Barrier and Dartford Creek Barrier which are located downstream of the Thames Barrier to protect the major tributaries by flooding (Blackburn, 2010) and extreme tides propagating (Hammond, 2010). In front of the barriers there are defences on the Thames. These are higher than the defences on the tributaries behind them (Hammond, 2010). Barking, Dartford and Thames Barrier provide the aim to maintain the current standard of protection. Hammond (2010) gave examples of the difference in the defence high. He said, the defences on the tributary (Dartford Creek) immediately upstream of the Dartford Barrier are 5.45 mAODN (metres Above Ordnance Datum Newlyn) downstream and on the Thames area the defence is 6.9 mAODN high. Likewise, the defence height immediately upstream of the Thames Barrier is 5.18 mAODN and the projected 0.1 percent annual probability water level is 6.2 mAODN (Hammond, 2010). The defence height immediately downstream of the barrier is 7.2 mAODN (Hammond, 2010).

4.5 Teddington Lock

The Teddington Lock is located in the upper reaches of west London and provides the Gateway in the non-tidal Thames. From Teddington to the North Sea, the Thames is characterised by tides, however, from Teddington to the origin there is no tidal influence. For this reason, its purpose is the maintaining of the river level upstream (Davis, 2010).

The flooding at Teddington Lock is characterised by a returning period of 1 in 20 years. Generally, a 1000 standard of protection is provided by the tidal Thames defences against tidal flooding. However, the flood risk can be higher through the influence if fluvial/freshwater flooding. Thus, the standard of protection on the Teddington area is just 20 against a combined fluvial and tidal water level (Davis, 2010).

In a general term, all flood defences are counted on the Thames Barrier. Teddington Lock provides various flood defences of which some stretches along the riverside. The area before the Teddington Lock is characterised by walls, banks and natural defences. Davis (2010) recounted that defences are often not plainly visible. For examples, seemingly steps function as defences or houses are endued with defences. Davis pointed (2010) to walls that have a wider margin than normally. In addition, the houses present a special structure. The buildings are constructed to can be flooded through a special covering of the houses and special windows (figure A 15). Moreover, houses are often constructed higher and occupy a higher lying entree which you can reach be steps (figure A 16). There are approximately 300 to 350 properties in west London which have privately owned defences along their riparian frontage. These defences vary in form, from brick walls e.g. with perspex extensions, sheet piles, flood gates and embankments. Additionally, there are mixed defences (figure A 17) and green bunded defences (figure A 18). Alongside the Thames stretches walls which are characterised by an active side to the river and a positive side to the land (Davis, 2010). Last, Teddington Lock offers examples there the nature and human influence threaten the reliability of the defences (figure A 19 and 20).

4.6 The TE2100 project

According to Hammond (2010), the Environment Agency provides the future aim to maintain the standard protection at the current level. For this reason the TE2100 project was established to outline the methods which are required to achieve this aim. He instances that influencing of development, is one method to minimise the risk (Hammond, 2010). The EA ensures that a flood risk assessment was completed if a development is proposed. Thus, the EA provides with the results of the flood risk assessment the decision if the development is appropriate or which changes are required to reduce the consequence of predicted flood events. Another method said Hammond, is to ensure the maintenance and reparation if required by flood defence owners. However, he enhanced that it is impossible to quantify the overall reduction of risk due to the on going expiring processes without end (Hammond, 2010).

The TE2100 plan has the aim to develop a flood defence management strategy for the next 100 years. Many option for a future strategy were considered. To preserve the preferred options, all benefits were involved as well as the costs which were weighed up under implication of future prediction (Hammond, 2010). Hammond (2010) emphasized that each option provides cost whether it be economical, ecological or social. The two front-runner are option number 1.4 (optimisation of defence improvement) and 3.2 (New Barrier at Long Reach). The realisation of the option 1.4 will be different depending on the location as outlined in the Review Chapter chapter 6

(Hammond, 2010). Hammond (2010) further underlined that these options are adaptable to possible changes in the physical environment. Furthermore, the barrier at Long Reach would be under current predictions a similar barrier to the Thames barrier, in that, it will allow the natural flow of water except in extreme tidal events (Hammond, 2010). However, if the predictions change, it would be possible to change the implementation.

The TE2100 plan is divided into four phases: Tools, models and techniques to develop the flood risk management option were developed in the phases 2 and 3. The best options to be investigated further were identified through investigations and assessments by the EA. Some options could be excluded due to investigations, consultation and appraisal. For examples the building of a throttle structure to narrow the estuary mouth was discounted because of the ineffectiveness in reducing flood levels. Moreover, a tide-excluding would have adverse impacts in water quality, morphology and drainage. Barriers with or without looks in the outer estuary, downriver of Canvey Island, would have both high costs and adverse effects on the environment. Last, improved channel conveyance from Teddington to Brentford was excluded because of high environmental influence and the excluding of sustainability.

Two 'front runner' options were determined for the period from 2070 through the ratio of benefits to costs. Hammond (2010) mentioned as first option the optimised maintenance and enhancement of the existing system with modifications made to the Thames Barrier for the period by 2070, and further adapting the structure to become a barrier with locks after 2135. According to Blackburn, the Thames barrier will remain a key element in flood defence for London throughout the next century. Second option is the optimised maintenance and enhancement of the existing system to 2070 and the building a new barrier at Long Reach by 2070. In addition, the converting to a barrier with locks or “open” barrage is suggested after 2135. Further, Hammond (2010) estimated that the TE2100 plan recommended the current strongly preferred option to maintain and enhance the current system up to 2070 regardless to of the “end-of century” approach.

Consequently, the option 2, dealing with the tidal flood storage and option 4, focusing on the construction of a barrier with locks, are not the favoured options. A barrier with

locks would be more expensive, however, could close more frequently than a barrier like the Thames Barrier. Current predictions of future sea level rise do not justified the cost, however, if the current predictions would rise, such as this barrier would be required.
The investigations of flood storage are not a 'front runner' option because of some serious issues regarding its reliability using current forecasting technology. Therefore, it posed significant risks to health and safety. Last the option 2 was more expensive than either of the two ‘front runner’ options. However, uncertainties lead to the existence of both options as candidates for future appraisal post-2050.

Approximately 2050, a decision of the government's current climate change guidance will be needed so that changes to the flood risk management system can be planned and be commissioned ready for use by 2070. Hammond (2100) suggested that by 2050 climate and other conditions my change. However, there is a fair degree of certainty about flood risk management requirements for the next 40 years. Therefore, a detailed investment programme up to 2049 was issued, with an additionally high level programme to the end of the century.

5 Discussion

In the following section the data of the state of research and the results of the interviews should be discussed and the question of the beginning of the dissertation answered.

London is affected by flood risk and this risk will increase over the next years. In fact, the minimizing of flooding is present and in the future an important challenge for London. The results of the interviews reflect the actuality and significance of flooding management in London. Historically floods show which damage flood events can cause. It can be concluded that a flood risk assessment is important to assess the standard of protection and the required level. Next, according to various authorities and the interviews, the flood defences offer a high standard of protection. For example, the probability of a tidal flooding is less than 0.1 percent in any one year. However, the present flooding is not just caused by tidal flooding also by fluvial, pluvial, sewer and groundwater flooding. For this reason, the high tidal flood defence standard is not provided across London. The responsibility of the flood risk management is mainly provided by the Department for Environment Food and Rural Affairs, the Environment Agency, Local Authorities and Local Drainage Boards. In addition, London's flood management includes defences e.g. barriers, walls, embankments, gates, culverts, and sewer and drainage systems, as well as flood forecasting and warning provisions. It made clear, an important role provides the Thames Barrier which became operation in 1982 and since then protects London by tidal and fluvial flooding. However, most of the defences are 30 years or older. All experts agreed on the indication that the defences have to be renewed and improved to maintain the high standard of protection. Additionally, there are uncertainties about the future flooding. The climate and the environment is changing according to the global climate predictions by the IPPC and the UK projections by the UKCIP. The south east England will be affected by a higher winter precipitation of up to 30 percent (by 2080), an increasing sea temperature of up 4°C (by 2080), rising storm surges and the subsidence of the British island by up to 1,2 mm per year. According to the global sea level rise, current measurements show an increasing mean sea level in the Thames estuary and predictions mention an sea level rise of up to 86 cm by 2080. Presently, it is evidenced that climate change in London is happen due to increasing mean tide levels and the increasing requirement for the Thames Barrier closure. The forecasting for the barrier closure is sophisticated and exactly because there are three models and real time tide gauge stations to forecast it. The experts noted that the rising closure of the barrier lead to an increasing possible barrier failure and to the requirement for maintenance. For this reason the EA is the authority which integrated the TE2100 project. Currently, there are two front-runners of flood defence options. In order to optimise the defence repair and replacement regime (1.4) and a new barrier at Long Reach (3.2). Both strategies are preferred because of their flood defence efficiency, their profitability and their lower environmental impacts. In addition, the ecological and economic strategy is adaptable to and sufficient for the future climate change. A combination of both front-runners could be the best solution. For this reason, the option 1.4 is preferred for the time before 2070 and options 1.4 and 3.2 beyond 2070. The interviewee view a long-term flood management as required and prefer the two front runner options because of economically and environmentally reasons. However, they do not want to specify for one of the options due to uncertainties about future climate and flood risk conditions. According to Hammond a decision will be made by 2050 to start with the implementation by 2070.

The *central question* of this bachelor dissertation was to characterise London's flooding and to determine requirement of and the way in a long-term flood defence strategy. The flooding is characterised by a since 1099 beginning flooding history. Furthermore, London's flooding is caused by its location in a low-lying coastal area and by the various flooding sources. This gives distinction to the high standard of the current flood risk management. The requirement for a long-term flood defence strategy is based by the fact that the current defences will be reach the end of their life time and that climate and environmental change will increase the required extent of protection. The way for a long-term flood risk management was provided in base by the Department for Environment Food and Rural Affairs with the *Making space for water* response and particularly by the Environment Agency with the *Thames Estuary 2100 study*. The TE2100 plan supplies the main options for a flood management plan over the next 100 years. However, there is not just one current option which could be implemented. This is why a decision will be first made in about 2050 and because the future conditions and therefore the required protection are uncertain. Thus, the question can be answered first through prospective conditions.

In conclusion, London provides a standard of flood protection which must be preserved by a sustainable long-term flood risk management. Currently, there are uncertainties about the future flood intensity. For this reason, it is first essential to integrate an adaptable flood risk management and second, to minimise the increasing of flood risk through mitigation.

6 Outlook

To sum up, London has taken measurements to protect London against flooding. This fact is however not sufficient to confront the impacts of climate change. For this reason, London requires a prospective flood defence strategy which is adaptable to changing conditions. The TE2100 project provides various options of strategies for the next 100 years. However, which options will be implemented depending on the future requirements. The time will show how fast the sea level will increase and how high tidal storm surges will rise. Thus, new climate projections will be done and the sea level has to be controlled continuously. Furthermore, the tide levels and other causes of floods will be observed daily. Afterwards, it will be required to weight up the flood risk, the cost and the environmental influence to start to implement actions. For that reason, different authorities will be involved to maintain the current standard of defence to protect against a tide level that has a 0.1 percent probability of occurring in any one year. Last, in London and the Thames estuary will be covert a flood management plan which “is risk based, takes into account existing and future assets, is sustainable, includes the needs of stakeholders and addresses the issues in the context of a changing climate and varying socio-economic conditions that may develop over the next 100 years” (EA, TE2100 summary plan, 2009, page 2).

7 References

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8 Appendix

8.1 Figures

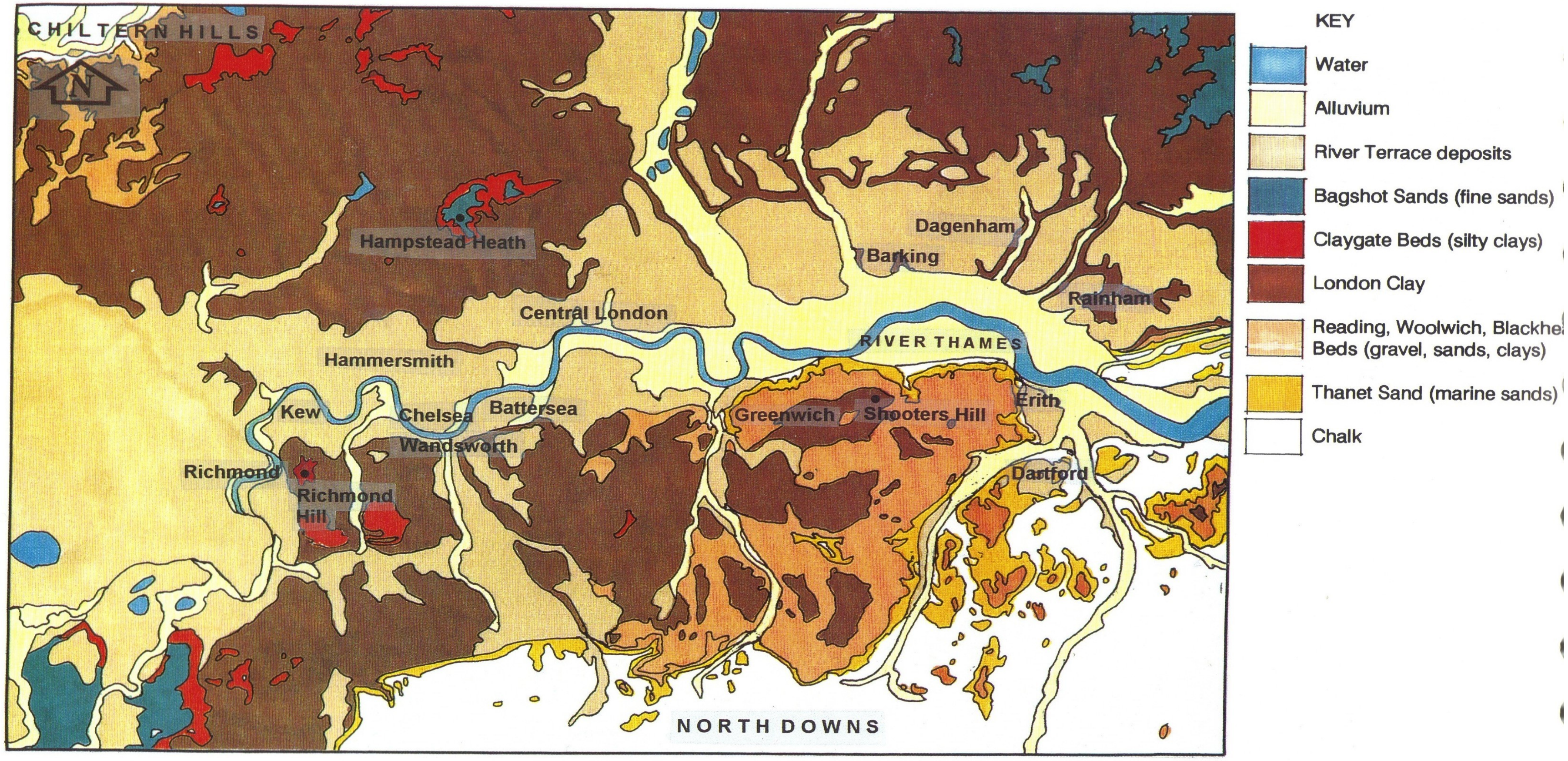

Figure A 1: Geology of London. EA (1996).

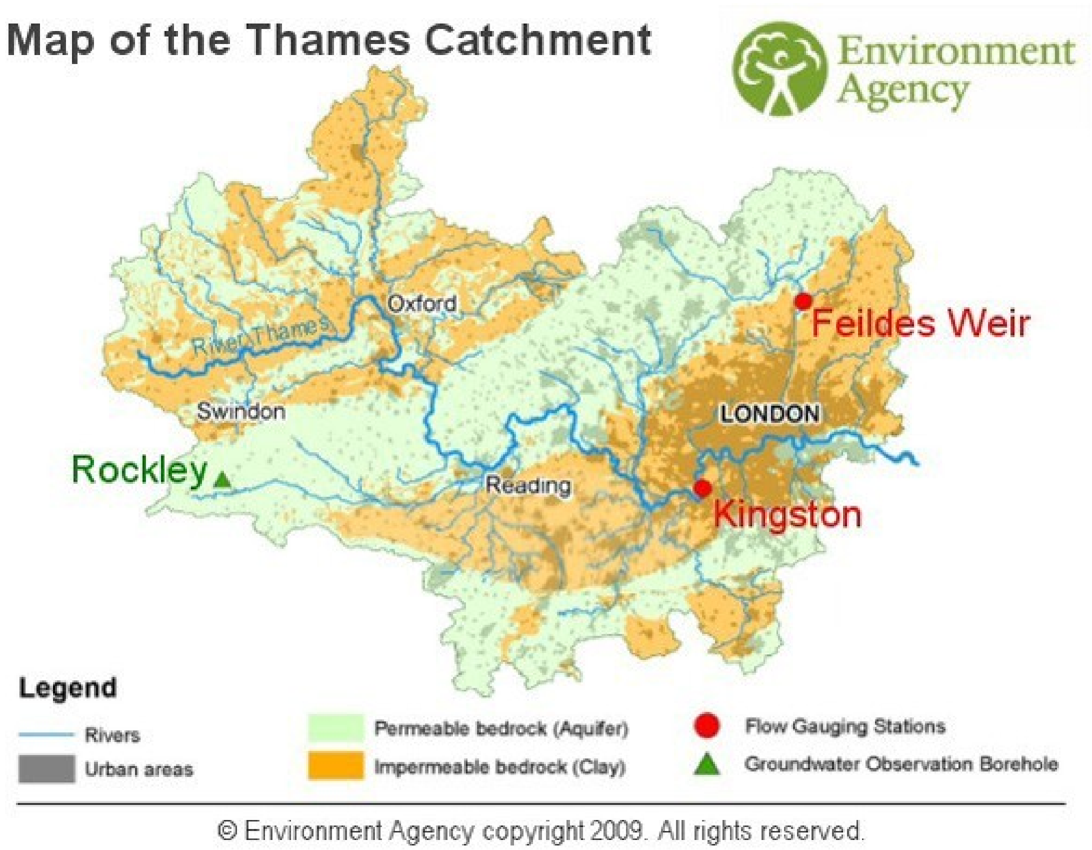

Figure A 2: Impermeable bedrock in the region of London due to groundwater flooding. EA (2010), available at http://www.environment-agency.gov.uk/research/library/publications/115917.aspxF.

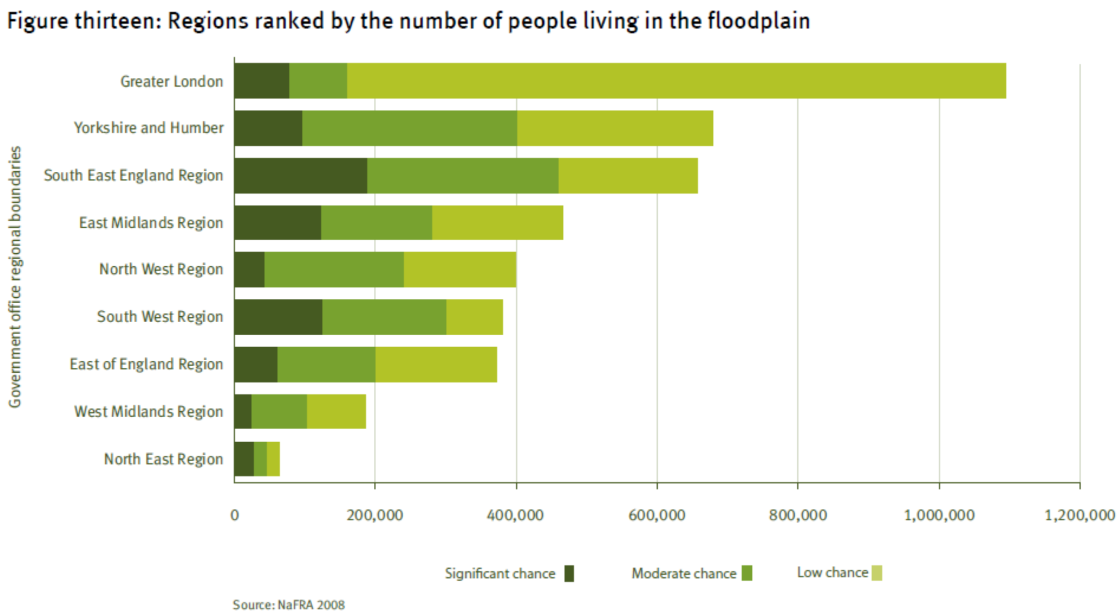

Figure A 3: Regions ranked by the number of people living in floodplain. EA, Flooding in England (2009).

350 sq km land area
55 sq km designated habitat sites
1.25 million residents (plus commuters, tourists and other visitors)
Over 500,000 homes
40,000 commercial and industrial properties
£200 billion current property value
Key Government buildings
400 schools
16 hospitals
8 Power stations
More than 1000 electricity substations
4 World Heritage sites
Art galleries and historic buildings
167 km of railway
35 Tube stations
51 Rail stations (25 mainline, 25 DLR, 1 international)
Over 300 km of Roads

Figure A 4: Assets and people at risk in the tidal Thames floodplain. EA, TE2100 plan Chapter 1-4 (2009).

Figure A 5: Thames Barrier

Examples of river channel types:

1	Natural banks types	3	Vertical banks with access	5	Riverside wharf types
2	Sloping artificial bank types	4	Vertical banks with restricted access	6	Mixed bank types

Figure A 6: River channel types. EA (1996).

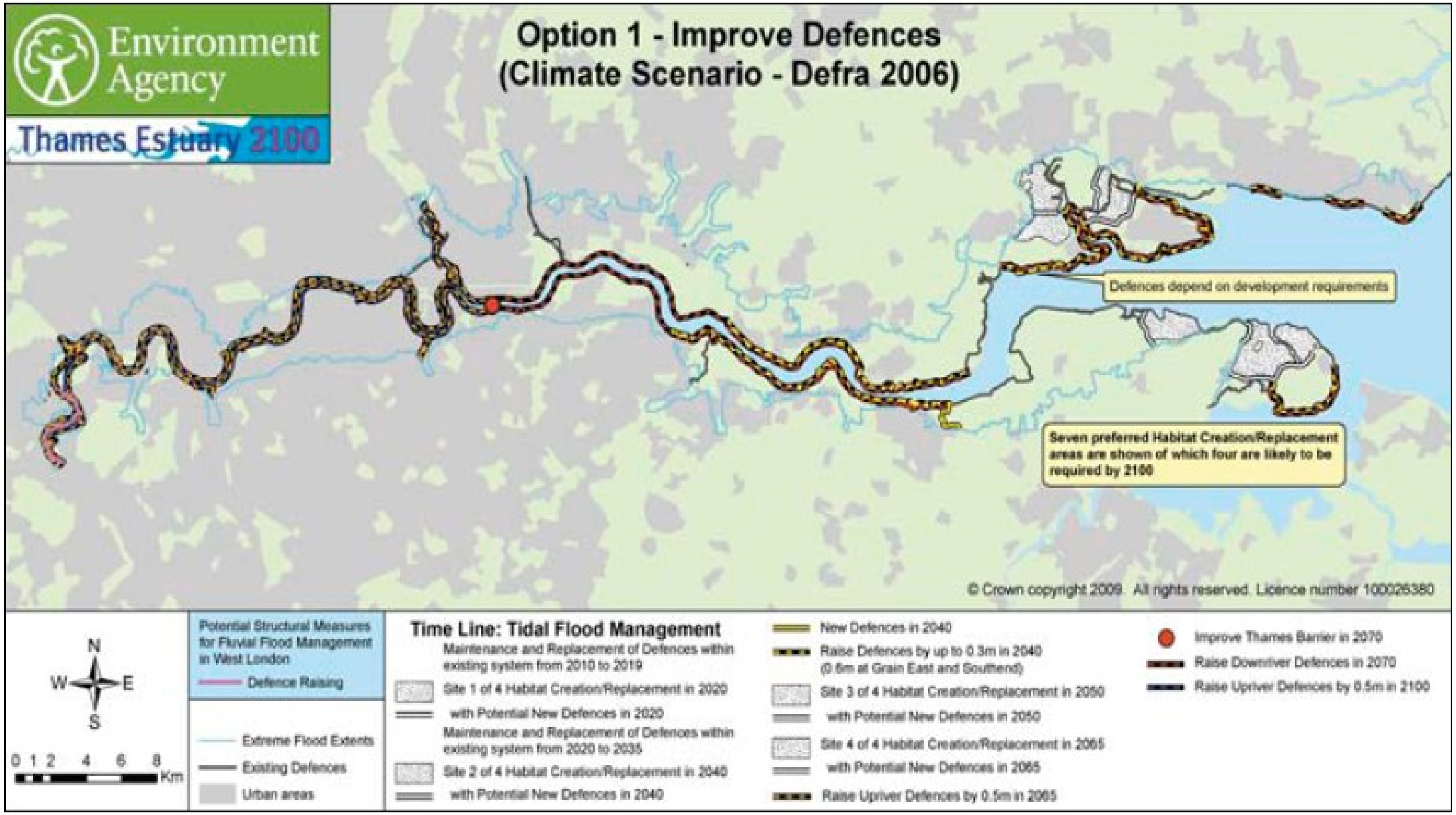

Figure A 7: Option 1 of the TE2100 plan. EA, TE2100 plan chapter 9 zone 0 (2009).

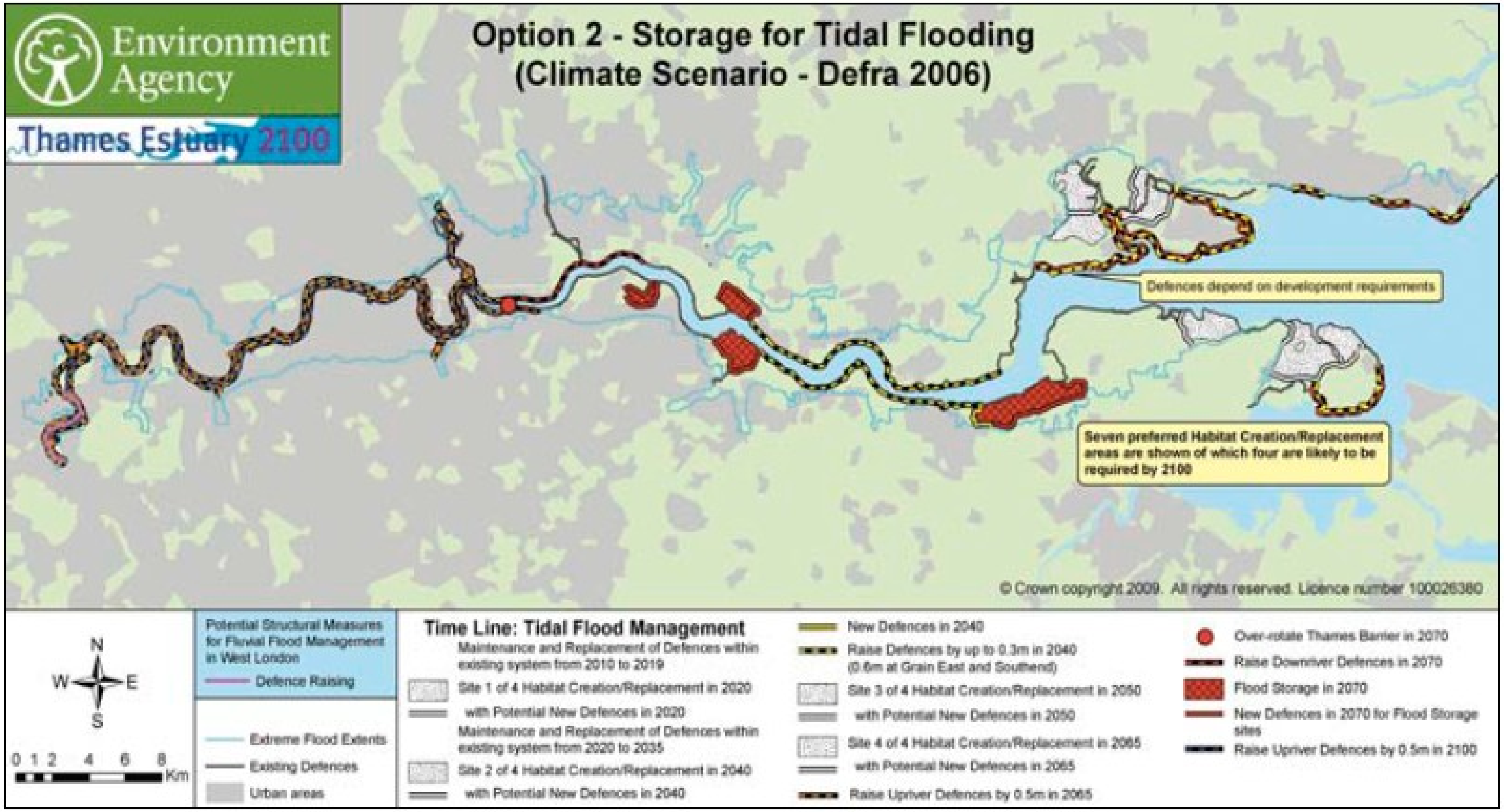

Figure A 8: Option 2 of the TE2100 plan. EA, TE2100 plan chapter 9 zone 0 (2009).

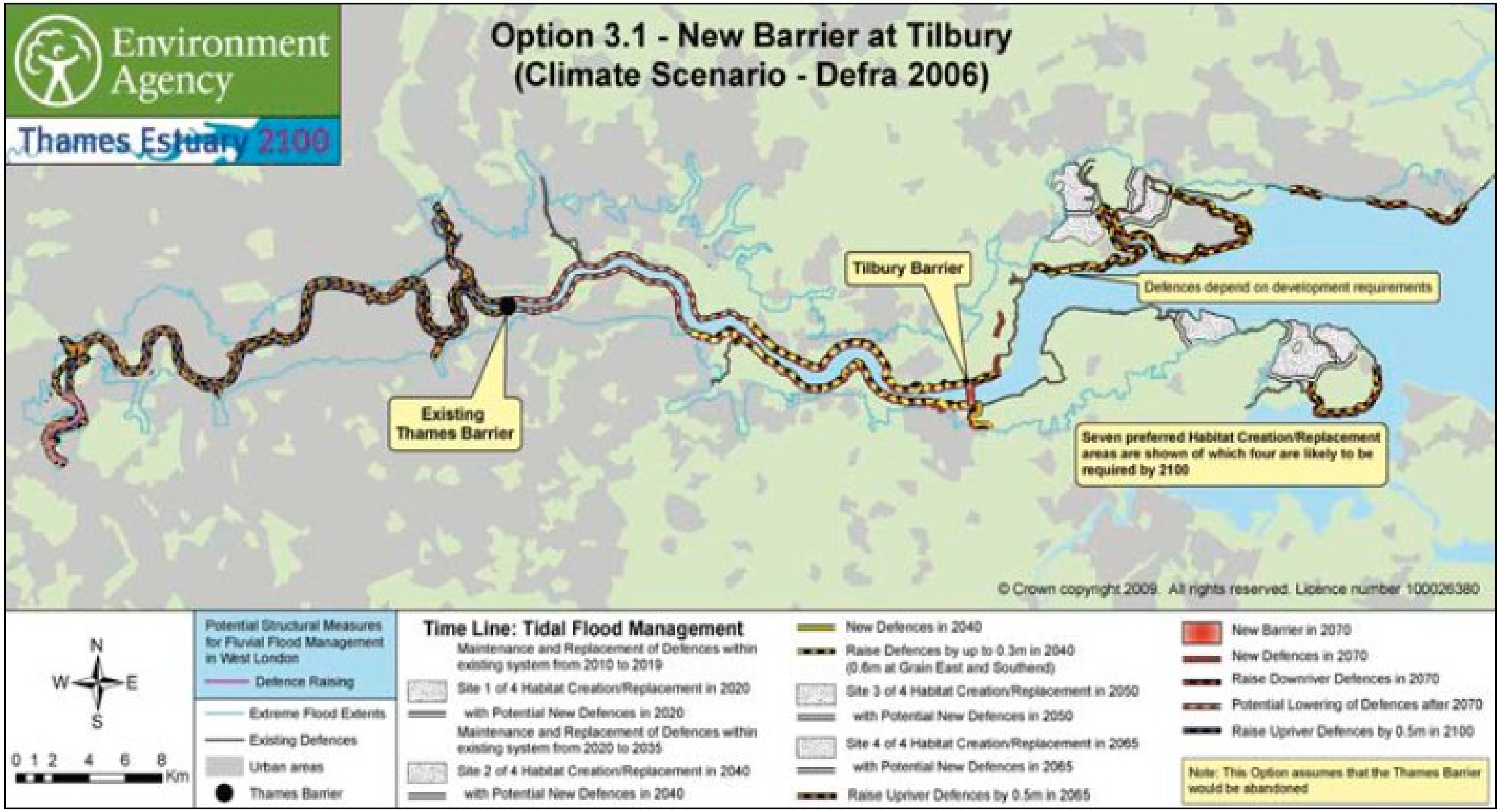

Figure A 9: Option 3.1 of the TE2100 plan. EA, TE2100 plan chapter 9 zone 0 (2009).

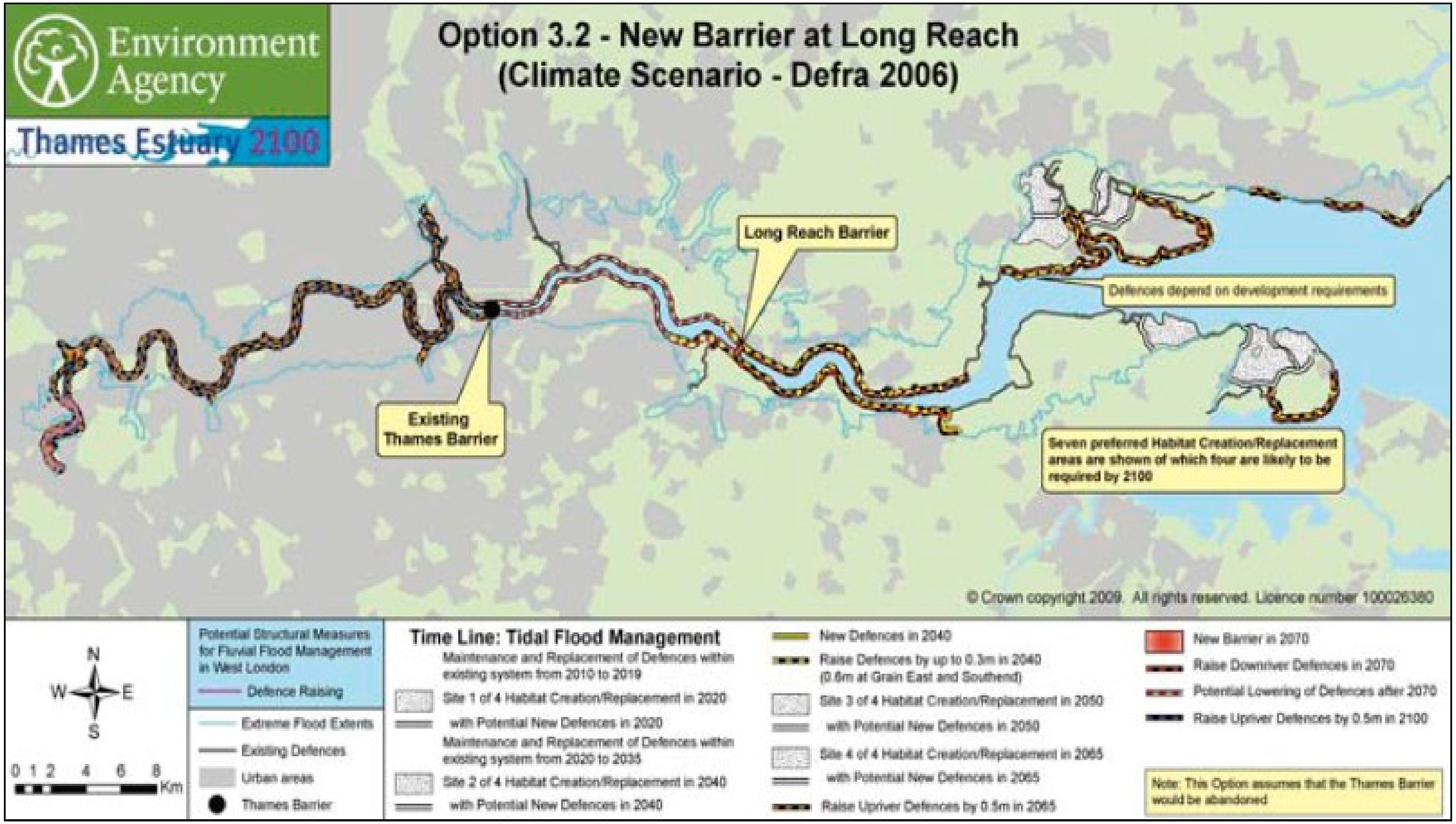

Figure A 10: Option 3.2 of the TE2100 plan. EA, TE2100 plan chapter 9 zone 0 (2009).

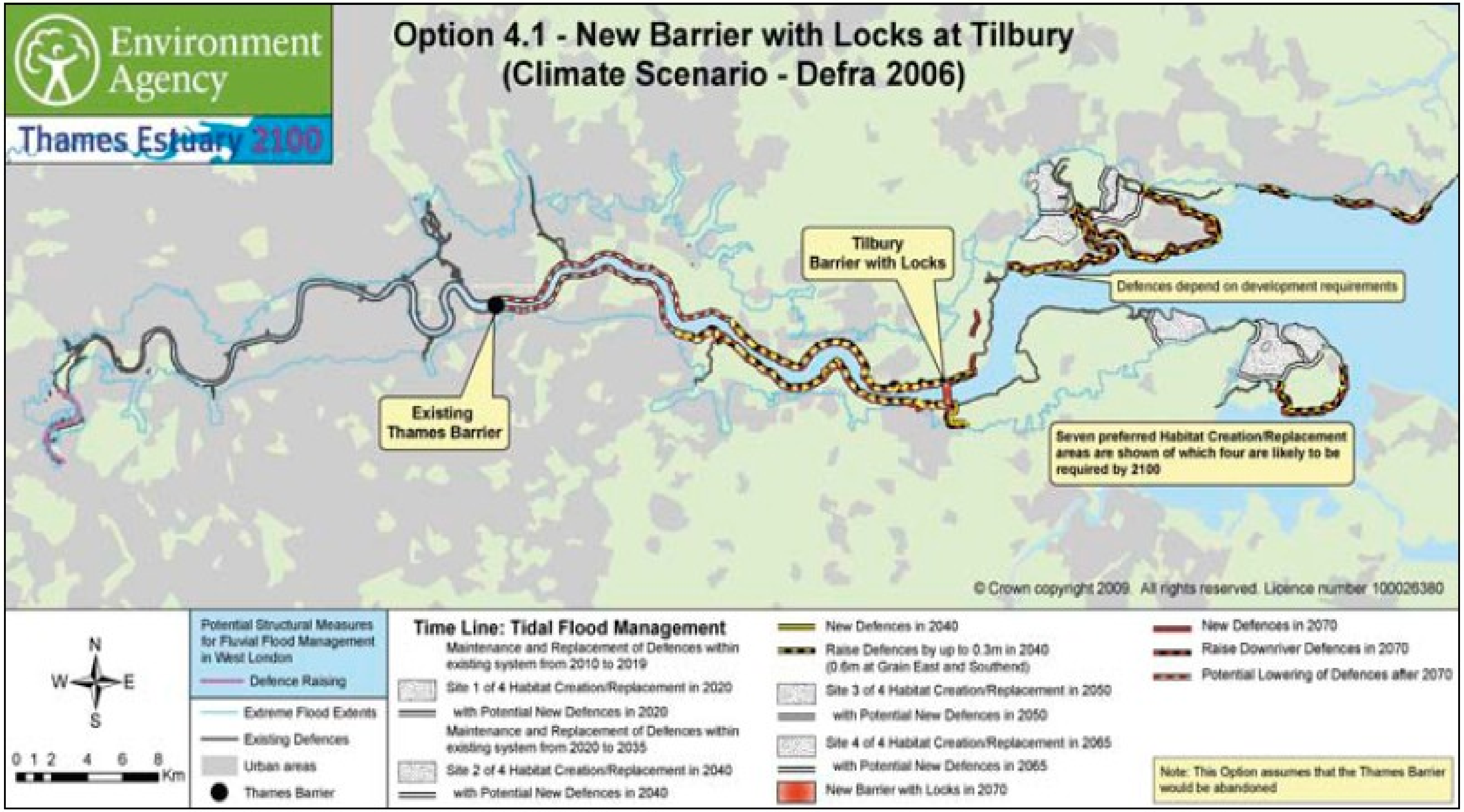

Figure A 11: Option 4.1 of the TE2100 plan. EA, TE2100 plan chapter 9 zone 0 (2009).

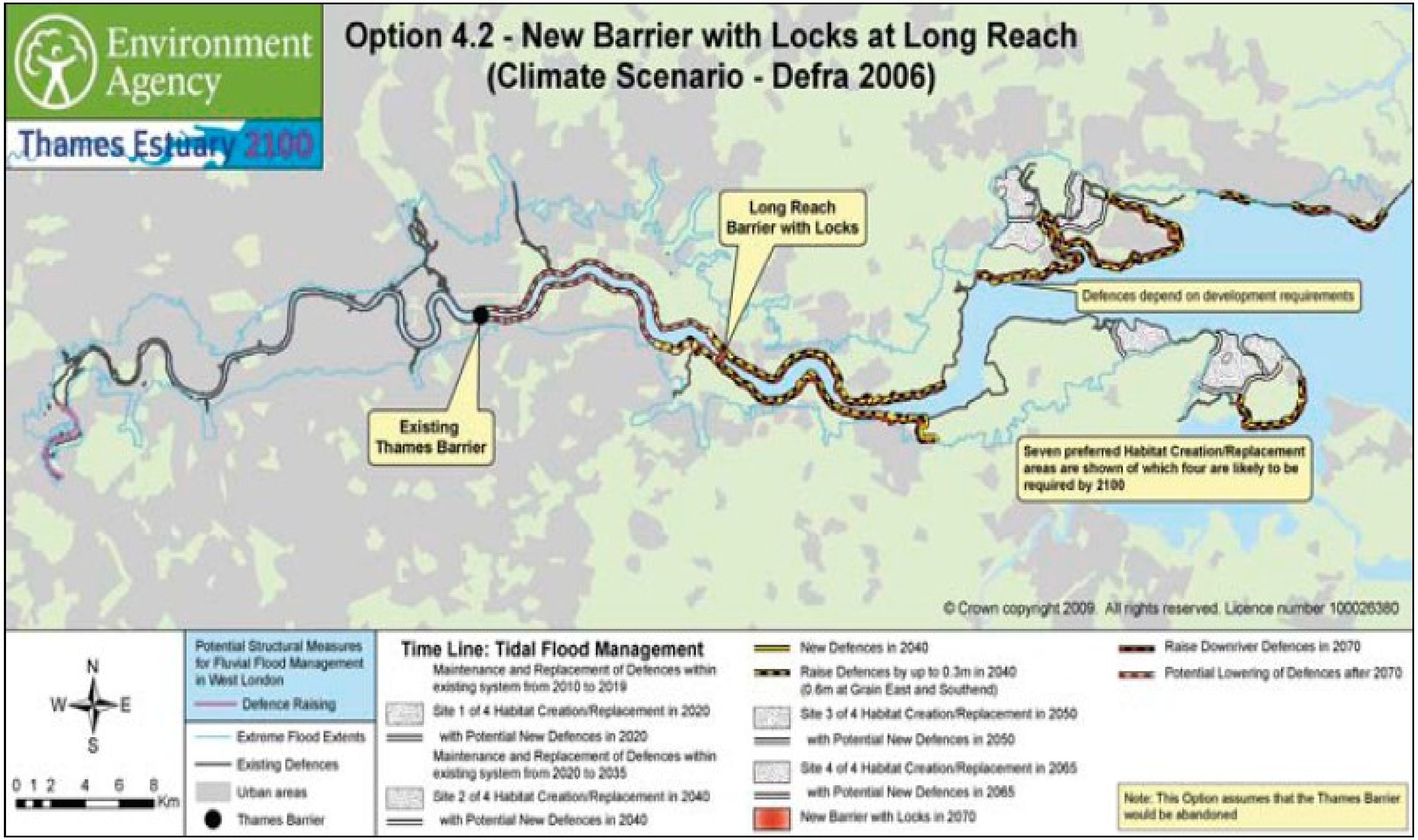

Figure A 12: Option 4.2 of the TE2100 plan. EA, TE2100 plan chapter 9 zone 0 (2009).

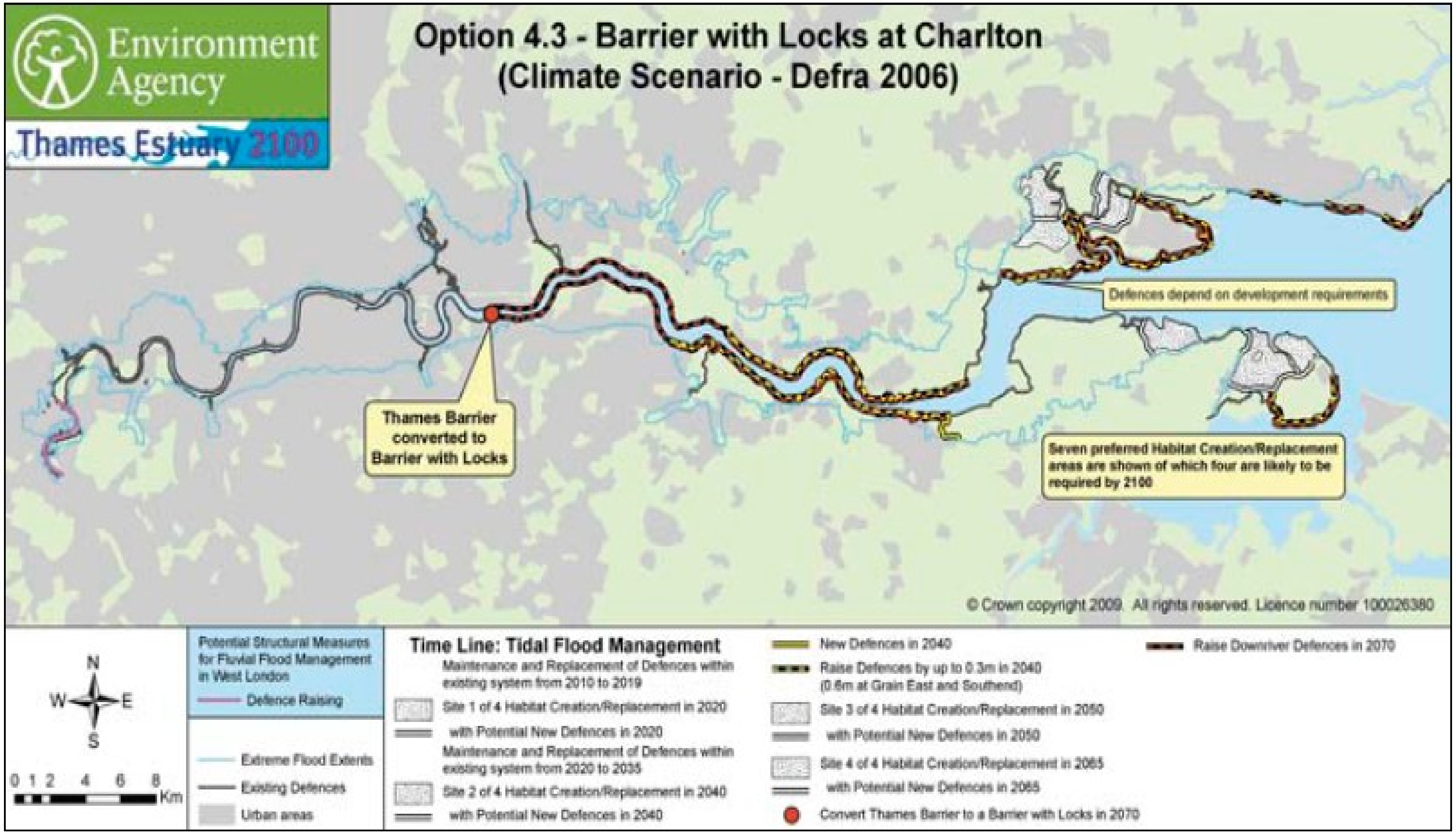

Figure A 13: Option 4.3 of the TE2100 plan. EA, TE2100 plan chapter 9 zone 0 (2009).


Figure A 14: Dartford Creek Barrier. EA, Dartford Creek Barrier (2009) .


Figure A 15: Wall, specific house wall and latticed windows.

Figure A 16: Different house wall and higher lying entrance by steps.

Figure A 17: Mixed defences with natural defence and accessible wall.

Figure A 18: Green bunded defence.

Figure A 19: Extra broadly wall destroyed by tree.

Figure A 20: Green bunded defence destroyed through walking over the defence.

8.2 Tables

Year	Tower Pier	Southend
1930	0,41	0,13
1931	no data	0,16
1932	no data	0,13
1933	no data	0,14
1934	0,32	0,11
1935	0,31	0,12
1936	0,43	0,16
1937	0,47	0,11
1938	0,35	0,12
1939	0,46	0,18
1940	0,42	0,17
1941	0,41	0,15
1942	0,38	0,16
1943	0,4	0,18
1944	0,37	0,17
1945	0,41	0,19
1946	0,45	0,19
1947	0,5	0,19
1948	0,42	0,25
1949	0,41	0,2
1950	0,43	0,19
1951	0,45	0,18
1952	0,47	0,24
1953	0,46	0,25
1954	0,43	0,19
1955	0,49	0,24
1956	0,41	0,22
1957	0,46	0,22
1958	0,51	0,23
1959	0,46	0,23
1960	0,52	0,2
1961	0,51	0,22
1962	0,47	0,18
1963	0,46	0,17
1964	0,48	0,22
1965	0,42	0,21
1966	0,52	0,28
1967	0,52	0,24
1968	0,49	0,22
1969	0,49	0,21
1970	0,46	0,18
1971	0,48	0,24

Year	Tower Pier	Southend
1972	0,47	0,2
1973	0,43	0,2
1974	0,45	0,19
1975	0,48	0,24
1976	0,41	0,2
1977	0,48	0,23
1978	0,45	0,2
1979	0,47	0,21
1980	0,49	0,24
1981	0,47	0,23
1982	0,51	0,21
1983	0,51	0,24
1984	0,49	0,2
1985	0,47	0,23
1986	0,49	0,24
1987	0,55	0,24
1988	0,5	0,27
1989	0,51	0,26
1990	0,48	0,25
1991	0,45	0,2
1992	0,5	0,23
1993	0,53	0,23
1994	0,52	0,23
1995	0,54	0,26
1996	0,48	0,24
1997	0,49	0,26
1998	0,52	0,25
1999	0,5	0,25
2000	0,53	0,27
2001	0,56	0,3
2002	0,6	0,28
2003	0,53	0,29
2004	0,58	0,25
2005	0,51	0,22
2006	0,52	0,28
2007	0,53	0,28
2008	0,56	0,28
2009	0,55	0,26

Table A 1: Mean Tide Level (mAODN). Provided by Hammond (2010).

8.3 Interview

Phone Interview and E-mail interview

Name: Anthony Hammond

Institution: Environment Agency

Position: Flood Risk Mapping & Data Management

Contact: anthony.hammond@environment-agency.gov.uk

Date: 8 May 2010

How high is the risk of flooding in the present? Would you assess the existing flood protection system in London as high?

Risk is based on the probability of occurrence multiplied by the consequence.

The risk therefore changes depending on where the flood risk is being calculated. The factors that change depending on location would be tide level (source) standard/height and condition of the tidal defence (pathway) and whatever is behind that defence in the possible flow path (receptor).

We do have a national flood risk assessment (NAFRA) that uses the information regarding defences and water levels/flows in rivers to categorise the likelihood of flooding in areas behind the defences. The three categories are Significant, moderate and low. Respectively, these stand for; greater than 1.3 percent annual probability, between 0.5 percent and 1.3 percent annual probability and 0.5 percent or less annual probability. However, despite the title NAFRA, this is not a risk, it is only the likelihood of flooding and therefore does not take into account the consequences.

Currently the standard of protection is the highest in the UK at 1:1000. This means that the defences are at a height that is at least as high as a water level that has a 0.1 percent annual probability of occurring.

In this context, could you explain me the rule of the Thames Barrier?

The Thames Barrier rule is a reference to the closure regime. This is the general rule by which the decision to close the barrier is made. It is based on a matrix of factors which are forecast in advance. These factors include the tide height at Southend, the accompanying surge and the freshwater flow over Teddington Weir.

Can you give me an estimate of how fast the flood risk will grow?

As mentioned previously it depends on the change to the areas behind the defences. If the population increased in an area that would flood in the event of a breach or overtopping of defences, then the consequences would increase and therefore the risk.

Likewise if the tide levels increase, this will increase the probability of breach or overtopping and therefore the risk. The current sea level rise allowances have been outlined by DEFRA in the planning policy statement 25 under Annex B: Climate Change.

Currently the defences are inspected by us to ensure they are fit for purpose twice a year. If these were to fall in to disrepair then the probability would increase and again therefore, so would the risk.

How much could the flood risk be reduced in the future?

Our aim for the future is to maintain the standard protection at the current level. This is the aim of the TE2100 project; to outline the methods we need to do so.

One way we try to reduce the risk, is by influencing development. If a development is proposed in the flood zones we ask that a flood risk assessment is completed. With the results of the flood risk assessment we decide whether or not development is appropriate. We may also discuss with the developers changes to development designs to reduce the consequence of a proposed flood (derived from the flood risk assessment). An example of this would be to have ground level parking for a building so that the occupancy of the proposed development would not be as badly affected by the flood. It would also ensure that the affect of the flood on the building wouldn't be as *significant and costs (consequence) would be reduced.*

Another method is ensuring that owners of flood defences maintain them, and repair them if they begin to decline in condition.

As these are on going processes, that have no fixed end, the reduction of risk overall is impossible to quantify.

Which function/significance does the Thames Barrier have today and in the future?

The Thames Barrier acts to reduce the probability at the source by preventing the extreme water levels propagating upstream. The Barrier was originally designed to protect to the 1:1000 standard until the year 2030, when the standard would slowly decrease over time. The TE2100 project, which studied the flood risk before outlining future ways of managing the risk, concluded that the Thames Barrier, as it is, will protect to the 1:1000 standard until at least 2070.

Why can barriers only be closed a certain number of times per year?

The Thames Barrier can only be closed a certain number of times because it is an engineered structure and requires ongoing maintenance. If we had to close, for example, every high tide, there wouldn't be enough time for the maintenance. This situation in increased because the more it is used, the more maintenance is needed.

How important are the Barking Barrier and Dartford Creek today and in the future? Could you explain me, why these two are especially important?

The defences on the tributaries behind these barriers are lower than the defences on the Thames in front of them. The barriers prevent extreme tides propogating up the tributaries and overtopping the defences. In the same manner, the Thames Barrier prevents the tide overtopping the defences up river of itself. All three barrier are integral to maintaining the current standard of protection. For example the defence height immediately upstream of the Thames Barrier is 5.18 mAODN and the projected

0.1percent annual probability water level is 6.2 mAODN. The defence height immediately downstream of the barrier is 7.2 mAODN. Likewise, the defences on the tributary (Dartford Creek) immediately upstream of the Dartford Barrier are 5.45 mAODN; downstream and on the Thames in the area the defence height is 6.9 mAODN.

Could you explain the measuring of the sea level in the Thames to me?

The sea level is measured using Tide gauges. There are many tide gauges around the coasts of the UK. In the Tidal Thames we have 11 tide gauges from Teddington out to Sheerness, including a tide gauge at Tower Pier near London Bridge. I am compiling some up to date data in regards to sea level rise. I will send it through as soon as I can.

How you decide, when the Thames Barrier will be closed? There are models of the forecasting?

The operation of the Thames Barrier and it's Associated Gates is governed by the Thames Barrier and Flood Prevention Act 1972.

Three models contribute to the forecast procedure for Tidal Thames:

- *North Sea Model*
- *Continental Shelf Model*
- *River Thames Model, known as the ISIS model*

These models have been in operation, modified and refined over a number of years. This process is ongoing. The information provided by the models is supplemented by information supplied by the Meteorological Office and real time information provided by the National Tide gauge Network around the east and south coast and tide gauges located on the tidal Thames. Tides are tracked as they travel down the East Coast (approx. 36 hrs in advance of reaching the Thames Estuary). The decision to close or not is based on three major factors:

-The height of the tide (usually a spring tide) measured at the Thames Estuary

-The tidal surge, which naturally accompanies each tide.

-The fluvial flow entering the tidal Thames, measured as it passes over Teddington Weir.

In general terms of the Thames Barrier would start to close approximately 1.5 hours after low water at North Woolwich. Closure of all 10 gates takes approx. 1.24 hours and creates an 'empty reservoir' (approximately 26 miles long and 4 square miles in area) for fluvial/freshwater flow entering the tidal Thames at Teddington. The Thames Barrier will then remain closed over high water until the water level down stream of the Thames Barrier has reduced to the same level as upstream. This is a managed process to provide for different circumstances and takes approx. 5 hours to achieve. The Thames Barrier is then opened, allowing the water upstream to flow out to sea with the outward-bound tide. The Thames Barrier may also be used for freshwater closures as well as tidal. In the event of heavy rainfall there could be high flows upstream of the tidal area. In these occasions we may close the Barrier to prevent the tide coming in. If we did not, the tide can have the effect of backing up the freshwater which could then spill over the river banks.

The Barrier has no individual trigger level for closure. Hydrological and meteorological data is fed to our control room every 20minutes by telemetry. The closing regime is guided by a mathematical matrix considering fluvial flow, tide and surge from this data. The end decision for closure lies with the Thames Barrier duty controller at the time.

Can you tell me why the optimisation of defence improvement (1.4) and the new barrier at Long Reach (3.2) are the currently front-runners? Could you give me more details about the both?

In summary many options were considered and all have associated benefits included within them. However, each option comes at a cost, whether it is economical, ecological or social. The benefits and costs were weighed up, in relationship with the current future predictions, to arrive at the preferred options.

The implementation of 1.4 will be different depending on the location. The project outlines the general way of implementing in each area using the policy units. As you will have seen, the report has various sections regarding each area of the Thames

Estuary. In these sections there is a suggested policy unit with a 'vision' of the changes needed to be implemented to adhere to option 1.4.

The options in the report are designed to be adaptable to the changes that may occur in the physical environment. Therefore the Long Reach barrier, under current predictions would be a similar barrier to the Thames barrier, in that, it will allow the natural flow of water except in extreme tidal events. There is of course the option to change this if the predictions change.

Runners

In phases 2 and 3 of the TE2100 project we developed tools, models and techniques to help us develop a range of options to manage flood risk. We studied a wide range of possible options and through our investigations and assessments we identified the most promising options to be investigated further.

Following investigation, consultation and appraisal, some of these options have been excluded:

• Throttle. Narrowing the mouth of the estuary by building a throttle structure was investigated but was discounted because our further investigations showed that it was not effective in reducing flood levels.

• A tide-excluding barrage was excluded because of the adverse impacts that impounding the estuary would cause, including water quality, morphology and drainage.

• A Barrier with locks in the outer estuary (downriver of Canvey Island) was excluded because of cost, environmental impacts and constraints to navigation to the Thames Gateway Port and other port facilities on the estuary.

• A Barrier in the outer estuary (downriver of Canvey Island) was excluded because of cost and adverse impacts on the estuary environment and navigation.

• Improved channel conveyance from Teddington to Brentford. This was excluded on the grounds of adverse environmental impact and lack of sustainability.

Assessing the ratio of benefits to costs for all of the options considered in the final stage of the Plan development, led to two "front runners" being determined for the period from 2070.

These are: • Option 1.4 – Optimised maintenance and enhancement of the existing system with modifications made to the Thames Barrier by 2070, and further adapting the structure to become a barrier with locks after 2135.

• Option 3.2 – Optimised maintenance and enhancement of the existing system to 2070 and building a new barrier at Long Reach by 2070; (converting to a barrier with locks or "open" barrage after 2135).

Our current (2009) appraisal does not favour tidal flood storage (Option 2) or a barrier with locks (Option 4). Current sea level rise predictions do not justify the cost of building a barrier with locks, which could close more frequently than a barrier like the Thames Barrier. However, such a structure would be needed if water levels in the estuary rise above current predictions. Our further investigations of flood storage indicated that there were some serious issues regarding its reliability using current forecasting technology and that it posed significant risks to health and safety. It was also more expensive than either of the two 'front runner' options.

However, because of the uncertainties in the assessment post-2070, all four of our generic options will remain as candidates for future appraisal post-2050. Detailed planning for the next 40 years will be based on our Option 1.4.

Option 1: Improve the existing defences

1.1 Raise defences when needed

1.2 Allow for future adaptation of defences

1.3 Optimise the balance between defence replacement and repair

1.4 Optimise defence repair & replacement and allow for adaptation to future change

Four different sub-options were considered, involving different maintenance schedules, and different ways of deciding when and by how much walls should be raised. Our appraisal indicates that option 1.4 is the preferred option until 2070.

Option 3: New barrier

3.1 Tilbury location

3.2 Long Reach location

Barriers would be designed to resist the highest surge tides predicted under government's current climate change guidance.

Both options assume that the barrier can be closed only a certain number of times per year, so there would still be a need for defence raising upstream.

Excuse me, where would the Barrier Long Reach be exactly?

Although the exact location of this proposed barrier has not been finalised, it is thought that it would be located approximately between Purfleet on the north bank and Dartford Marshes on the south bank.

For the period up to 2070, maintaining and enhancing the current system is strongly preferred, regardless of the "end-of century" approach selected thereafter. This is the key recommendation of the TE2100 Plan. Uncertainty in the assessment post-2070, and the absence of an immediate need to decide on the preferred strategy beyond that point, mean that a single preferred "end of century" option is not being promoted at this time.

When will a decision be made?

A decision will need to be made in approximately 2050 (based on government's current climate change guidance) so that changes to the flood risk management system can be planned and be commissioned ready for use by 2070. Climate and other conditions may change by the time of our 2050 review but we have a fair degree of certainty about flood risk management requirements for the next 40 years. We have therefore prepared a detailed investment programme up to 2049, with a high level programme to the end of the century.

E-Mail interview

Name: Ian Blackburn

Institution: Environment Agency

Position: Development Control Engineer

Contact: ian.blackburn@environment-agency.gov.uk

Date: 12 May 2010

What are the reasons for the flood risk in London?

Tidal flood risk from the river Thames, Fluvial flood risk from the tributary rivers, surface water (pluvial) flooding, groundwater flooding, sewer floding, flooding from failure of infrastructures such as dams canal and water supply network.

How high is the risk of flooding in the present?

The tidal flood defences offer a very high standard of protection. The Drain London project is looking at flood risk from all sources across London and may be able to make some comparison on the severity of flooding across different sources.

How much influence has the climate change had on the flood risk (present and future)?

I am only broadly aware of studies comparing past and present flood risk. Levels in the Thames have risen perhaps most graphically represented by the raising of walls in the 1930s and 1970/ 80s.

Which function/significance does the Thames Barrier have today and in the future?

The Thames Barrier is crucial in preventing tidal flooding to London both the Thames and its tidal tributaries. It will remain a key element in flood defence for London throughout the next century.

Why can barriers only be closed a certain number of times per year?

Due to the legislation that governs the barrier operation.

How important are the Barking Barrier and Dartford Creek today and in the future?

These Barriers protect major tributaries that enter the Thames downstream of the Thames Barrier at Woolwich.

Which roles do embankments and walls play and how could these be improved?

The majority of tides upstream of the barriers and all tides downstraem of the barriers still occur twice aday. Land is defended by virtue of these walls and embankments etc.

Personal interview

Name: Lenny Davis

Institution: Environment Agency

Position: Inspector of flood defences

Contact: Lenny.Davis@environment-agency.gov.uk

Date: 20 June 2010

Could you explain my the function of Teddington Lock?

Teddington Lock is the Gateway in the non-tidal Thames. Its challenge is the maintaince of the river level upstream. Upstream means the river part which is non tidal, it is the "head". Downstream means the tidal river from Teddington to the North Sea.

How high is the flood risk at Teddington Lock?

There is a return period of 1 in 20 years. The Tidal Thames Defences are designed to have a 1000 standard of protection [explained in more detail later] *against tidal flooding. However; with a fluvial/ freshwater influence the water levels can be higher. Therefore due to the fluvial influence the tidal defences in the Teddington area, only protect to a standard of 20 against a combined fluvial and tidal water level.*

What are the flood defences at Teddington Lock?

Generally, all flood defences are counted on the Thames Barrier. Some of the defences which you can find at Teddington Lock that stretches along the river Thames. At Teddington you can find walls, banksand natural defences. Often you cannot see the *defences on the first look. For examples steps are defences or you can find defences on houses. When you look at the walls, you can see that they have a wider margin than normally. All houses have a special structure. They are constructed that the buildings can be flooded through a special covering of the houses and special windows. Moreover, they built the houses higher and often you can see a higher lying entree which you can reach be steps. In addition, there are green bunded defences. As you can see, there are a grass landscape or berm before the bund which exchange into a hill defence or bund. Alongside the Thames stretches walls which have an active side to the river and an positive side to the land. However, as you can see, defences are being destroyed by nature and humans. For this reason it will be required to renew those.*

How much houses with flood defences there are in London?

The defences along the Thames in London are all privately owned by the riverside (riparian) property owner. In west London (Teddintton to Putney Bridge) there are approximately 300 to 350 properties that have defences along their riparian frontage. These defences vary in form, from brick walls (with perspex extensions), sheet piles, flood gates and embankments.

Which structure have the bunded defences at Teddington Lock and otherwhere? Which materials are being used?

The defences in London vary in composition from masonry, concrete, sheet piles, anchored walls, cantilever driven sheet piles, sheet piles with tie rods, earth embankment with clay core or natural embankment. However the tidal defence walls and embankments can be lumped into three main types: high ground, slopes or embankments and vertical walls. Please find attached a map giving an indication of defence types within the Thames tidal London area. Please be aware that this is a strategic level map and only gives an indication of defence types at a strategic level.

Why has the active side of the walls an rippled surface?

This is simply the way the sheet piles are designed to ensure that the sheet piles fit together securely.

Could you tell me what the inspectors at Teddington Lock are doing when the Thames Barrier had to be closed and then there are a risk of tidal flooding?

There are many upstream gates and other moveable defences. When the barrier is due to close the inspectors inspect them to ensure they are closed and in working order.

How much flood gates and gauges there are in London approximately?

There are approximately 320 flood gates of varying types.

Between Teddington lock and the river Darent, there are eight tide gauges at the following locations: Richmond, Hammersmith, Chelsea, Westminster, Tower Pier, Charlton, Silvertown and Erith. Down river of this, there are four more heading out towards the outer estuary; Tilbury, Corytown, Southend and Sheerness.

There are the Thames Barrier to protect London for tidal flooding. What are the main defences against flooding from the land, flooding from the sea, flooding from groundwater and sewers?

Aside from tidal flooding, London is at risk from fluvial flooding direct from freshwater rivers such as the river Wandle. In these cases we have river walls or banks built to a specified standard of protection. It is also at risk from what is collectively known as pluvial flooding. This is flooding from overland/surface water from heavy rain, the rising of the water table and/or the backing up of sewage systems. Currently the London sewage system dates back to the Victorian period and is in need of an upgrade. A project is underway to build a super sewer to supplement the current system in times of heavy rainfall. The super sewer will ensure that the current system does not reach its capacity and over flow into the river Thames. Although this is, in large part, to improve the state of the river and its water quality, it will also contribute to the flood risk management of pluvial sources.

Which materials are used for the design of non-natural 'green' embankments like at the Thames Barrier?

The green embankment adjacent to the Thames Barrier is held up by sheet piling at the river front and within the bund there is a clay core surrounded by a soft earth revetment.

How do you decide to close the Thames Barrier?

The Thames Barrier will be closed because of tidal and fluvial events. We close the barrier as well, when the tide level maybe is not high enough, but there is strong rain. We control predictions 365 days per year and assess hydrological and meteorological data and data from flood gates and gauges. An individual trigger level for closure isn't provided by the Thames Barrier. The barrier has no individual trigger level for closure. The Thames Barrier duty controller has the end decision to close the barrier. When the Thames Barrier starts normally, it will be closed about 1.5 hours after a low tide at New Woolwich. The completely closure of all 10 gates takes 1.5 hours. When there is a tidal flooding at London Bridge, the water needs one hour to flow to Teddington Lock.

To forecast the closures we use three computer models: North Sea Model, Continental Shelf Model and River Thames Model or ISIS model. Data by the models are given by the Meterological Office. The National Tidegauge Network gives information from real time data at the coast and tide gauges at the Thames. There are 420 movable flood gates and gauges upstream and 19 downstream.

Which strategies are discussed to improve the Thames Barrier?

The Thames Barrier is not improved in the sense that it is not being radically changed in one large project. It is constantly being maintained and where necessary improved due to new technology or ideas; on an ‘as and when’ basis.

For instance, at all times, there will be components of the Thames Barrier being maintained and/or improved. This can be said for all our flood management systems.

Approximately, how high and how broad are the walls and banks currently in the different areas along the Thames and how much higher they will be in the future?

The walls along the Thames vary in height between and within each and every defence. However, along the river there are a set of minimum levels for the defences to be built to. These levels are to guarantee a specific standard of protection from tidal flooding. In this case it is a standard of 1000. This means that the defences protect against a tidal flooding event that has a 0.1 percent annual probability of occurring. Please find attached a map showing the minimum level of defence for the Tidal Thames between Teddington and Purfleet.

There is no set value for the broadness of the defences. It changes depending on the type and style of defence.

Would you say that there is the most interest to protect the area of London city?

It is not our policy to put a higher interest in protecting one area over another. However our flood risk management projects are based on the application for local or government funding. These applications are primarily assessed on the consequences of not implementing the project. If it is deemed that an area is at greater risk than another, then it will more likely be allocated funding. Risk in this case is, as mentioned in a previous response to you, the probability of a flood occurring, multiplied by the consequence of the flood.

Could you tell me how you implement the actions of the TE2100 plan?

The implementation of the TE2100 plan will be in conjunction with multiple agencies and organisations. The local authorities in any given area will be the principle organisation in regards to the funding, implementation and therefore, timing, of the plan. In many cases it will be achieved over time, in cooperation with any development *agencies and associated consultancies that are planning to, or contracted to develop in the areas in question.*

9 Affidavit

I hereby assure that I wrote this work by myself and that I have not used any other references and facilities than those mentioned. All pictures, figures and tables are marked with a source or created by myself. Moreover I assure that I obeyed the general principles of scientific work and publication as determined in the guide lines for good scientific practice of the Carl von Ossietzky University Oldenburg.

Oldenburg, 30 September 2010 ______________ ____________________________

Diana Süsser