Yorkshire and Humber regional adaptation study

Weathering the storm

yorkshirefutures

your climate
CLIMATE CHANGE PARTNERSHIP FOR YORKSHIRE & HUMBER

YORKSHIRE AND HUMBER ASSEMBLY
The Regional Strategic Partnership

Supported by
YORKSHIRE FORWARD
The Region's Development Agency

supported by
Environment Agency

Weathering the Storm, the Yorkshire and Humber Regional Adaptation Study. 2009

This report is based on original work carried out by Royal Haskoning.

The study was commissioned and funded by the following organisations:

yorkshirefutures

Supported by YORKSHIRE FORWARD The Region's Development Agency

YORKSHIRE AND HUMBER ASSEMBLY The Regional Strategic Partnership

supported by Environment Agency

The study was overseen by a steering group comprising:

Yorkshire Futures
The Yorkshire and Humber Assembly
The Environment Agency
Yorkshire Forward
Natural England
The Forestry Commission
Government Office Yorkshire and the Humber
UK Climate Impacts Programme

Published by Yorkshire Futures, 2009

Yorkshire Futures
Victoria House
2 Victoria Place
Leeds
LS11 5AE

Contents

List of tables and figures

Weathering the storm

The regional climate change adaptation study for Yorkshire and Humber.

1. Introduction

In recent years the UK Government has identified climate change as one of the greatest threats to society and has placed it high on the political agenda. There has also been much media interest in the topic, both in the UK and worldwide, and a recognition that action needs to be taken now to respond to the challenge posed. This includes both mitigation (reducing greenhouse gas emissions) and adaptation (responding to the impacts caused by climate change).

Recognising the growing need to take action now to adapt to the threats posed by climate change, a range of organisations in the Yorkshire and Humber region came together to commission a Regional Adaptation Study. The study aimed to improve understanding of climate changes, assess the threats and impacts they pose, and to identify how we need to adapt now to best manage these projected changes and impacts.

The study has:

- Projected climate changes across the region to the 2050s using state-of-the-art modeling techniques;
- Assessed the impacts of the projected climate changes on current services, assets, communities, business and infrastructure;
- Identified what needs to be done to adapt to the impacts; and
- Identified which organisations are best placed to take the lead in taking forward the identified adaptation actions;
- It is intended that this study output provides a catalyst and focus for action across all sectors operating across the region.

This study, which is based on sound scientific information, cutting-edge thinking and the latest best-practice guidance, can be used by businesses, organisations and individuals across the region in the development and delivery of their own climate change adaptation action plans, strategies or business planning. Information is available at a regional, subregional and local authority geography and is also available by theme. The themes are:

- Flooding
- Erosion
- Ground and minewaters
- Biodiversity
- Business and the economy
- Infrastructure
- Public and voluntary services
- Health and welfare

This report provides an overview of the study and lists the main cross-cutting findings. There is a great deal more information available on the website (www.adaptyh.co.uk) which is the main output from this project. The website includes detailed impacts and adaptation actions for each of the eight themes listed above, and also has downloadable factsheets for every local authority in the region. An example of one of these factsheets is included as an annex in this report. A summary booklet can also be downloaded from the website and printed versions of both the booklet and this report can be ordered from Yorkshire Futures. The study is intended to be a dynamic publication that will be updated whenever new scientific data are released.

This report is organised into five main sections - introduction, methodology, results, impacts, and adaptation actions. The adaptation section includes those actions which will deliver cross-cutting benefits to all sectors, and a list of blockers and enablers which are either preventing or facilitating adaptation. In addition, the entire flooding theme section has been included in this report, as flooding will have consequences for all the other themes and is probably the most serious climate related impact in terms of risk to lives, homes and businesses. An abstract of the other themes has been included here, but a much fuller discussion of these are available on the website.

This study is intended to be a catalyst for action, and it is hoped that the information provided here will be applied across all sectors, organisations and sub-regions. This will ensure that our region is best placed to tackle the challenges, and make the most of the opportunities that climate change will bring. At a strategic level, overall responsibility for ensuring the actions identified in the study are carried out will rest with the Climate Change Partnership. This is a high-level coalition of various regional organisations which is tasked with writing, updating and delivering the Climate Change Plan for Yorkshire and Humber - Your Climate, Our Future. The Climate Change Plan will reflect the findings of this study and is available at www.yourclimate.org.

The Study Area

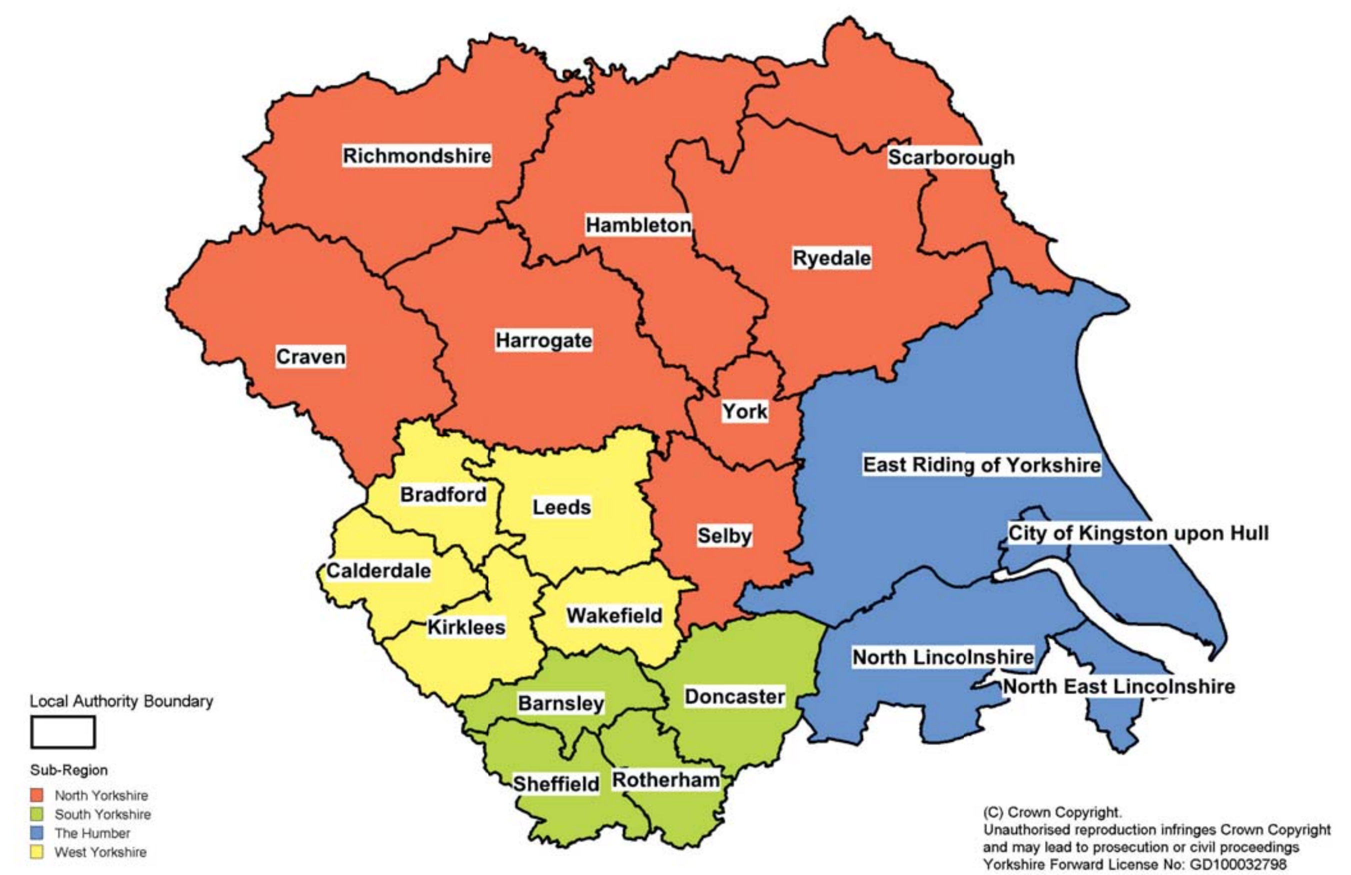
Yorkshire and Humber is a large and varied region encompassing busy urban centres such as Leeds, Bradford, Hull and Sheffield, and rural areas scattered with small market towns and villages, such as Northallerton, Ilkley and Pickering. The region extends from the Pennines in the west to the North Sea in the east and includes two National Parks.

The region has a significant amount of land at risk from sea and river flooding, and has the second highest value of assets at risk from flooding outside of London. In addition, its location at the centre of the east-west and north-south transport corridors, and the presence of the country's largest ports complex on the Humber estuary, means that any disruption to transport infrastructure can have wide-ranging impacts on the rest of the country. For example, this was seen during 2007 when the M1 motorway had to be temporarily closed due to the risk of the slipway at a nearby reservoir failing. Yorkshire and Humber is also home to several power stations including Drax which is the largest coal-fired power station in the UK, and other heavy industry such as steel manufacturing and cement works. This means that per capita carbon emissions are among the highest in England.

In recent years there have been several major flood events in the region, most notably in York in 2000, 2001 and 2004, and widespread across South Yorkshire, Humber and Gloucestershire in the summer of 2007. These events tragically resulted in some loss of life and caused extensive flood-related damage to homes, industry and infrastructure.

There are 22 local authorities in Yorkshire and Humber which can be divided into four subregions, as shown in Figure 1.

Figure 1. Local Authority Districts in Yorkshire and Humber



Source: Yorkshire Futures

2. Study Approach

The study comprised three main stages:

Stage 1

This stage identified the climate changes projected by the 2050s across the Yorkshire and Humber region. The 2050s comprises the years between 2040 and 2070.

1. Establishing the baseline climate for the region

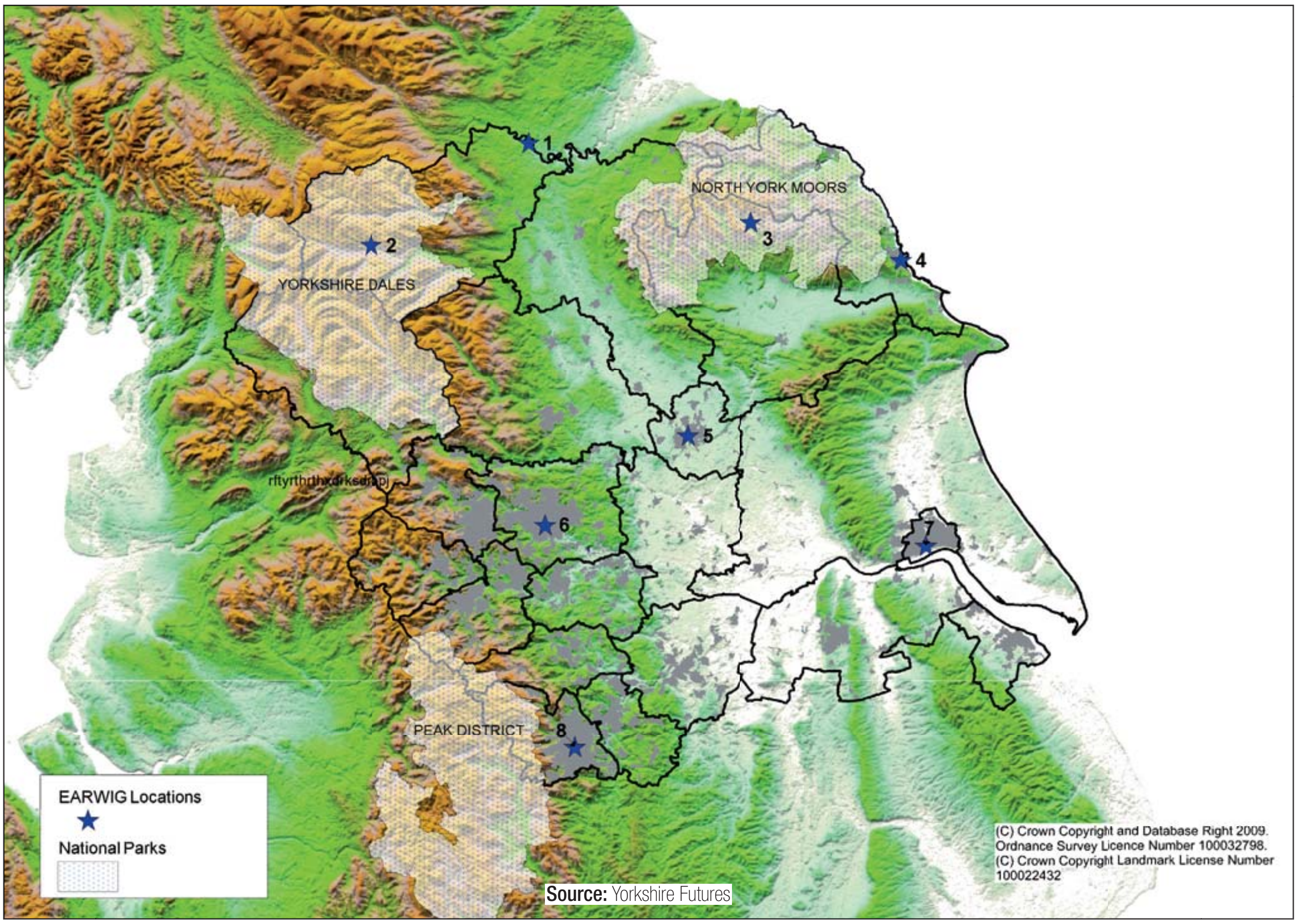
The baseline climate for the whole of the UK, and for the Yorkshire and Humber region, was established using Met Office data from the period 1971 to 2000 (the 1980s). The variables examined were temperature, sunshine, rainfall, snow, air and ground frost, soil temperature and thunder.
Maps showing these baseline climate variables can be found on the website www.adaptyh.co.uk.

The region's baseline climate is strongly influenced by two principal factors, altitude, and proximity to the coast.

The baseline rainfall, snowfall and frost vary across the region, and this is attributable to altitude. Greater rainfall, snowfall and frost occur in upland areas compared with the lowlands and coastal locations.

The latent heat of the sea means that it warms up and cools at a slower rate than the land, resulting in sea temperatures having a big influence on air temperatures close to the coast. This means that the warmest temperatures are usually along the coastal margin. The inland sites have a slightly lower baseline temperature as they are too far inland to be influenced by sea temperatures. The upland baseline temperatures are lower again still and this is due to their increased altitude in comparison with the other sites. This results in a temperature gradient across the region, from the typically cooler uplands of the North York Moors and the south Pennines to the warmer climate of the lower lying inland areas and warmer still at the coastline.

Figure 2. Relief Map of Yorkshire and Humber



Source: Yorkshire Futures

Having established the baseline climate, the study then looked at data from weather stations at Sheffield, Cleethorpes and High Mowthorpe for the period 1961 to 1990 (the 1970s) to see if any changes could be discerned between this time period and the 1980s. Long-term records from weather stations at Sheffield (dating back to 1883) and Bradford (dating back to 1908) were also examined.

This analysis found that several changes in climate have already occurred:-

- A rise in temperatures
- Increased amount of summer sunshine hours
- Less rainfall annually
- Reduced incidents of air frost
- A general trend of decreasing summer rainfall but with an exceptional event identified in the Sheffield data record during summer 2007, when major flooding affected South Yorkshire and the Humber.

As well as looking at Met Office data, this study also looked at the information gathered by the UK Climate Impacts Programme (UKCIP). Comparison with this data showed similar changes to those listed above. For the Yorkshire and Humber region, the mean temperature increased by between 0.2°C and 0.3°C from the 1970s to the 1980s. There were also three to seven fewer days per year when frost was recorded. Changes were also seen in sea level pressure, relative humidity, rainfall and the number of days that domestic heating or cooling would be required.

2. Review of press cuttings

A review of press cuttings was carried out which looked at weather-related stories in the regional press between the years 2000 and early 2008. The Yorkshire Post, Yorkshire Evening Post, Scunthorpe Evening Telegraph and the Grimsby Evening Telegraph were all reviewed for stories about floods, storms and lightning, snow and blizzards, gales and tornados, erosion and landslips, and heatwaves.

The following is a summary of the press cuttings review, more detail of individual events can be found on the website, www.adaptyh.co.uk.

- Since the year 2000, a number of extreme weather conditions have affected the Yorkshire and Humber region.
- Most frequently, the region is affected by floods, storms and lightning. These types of weather events, which often occur simultaneously, have caused severe damage to the region over the period of investigation and evidence also shows that with each year the damage caused is increasing in magnitude.
- Snows and blizzards are also quite common in the region, with the added problem that snow melt can also cause flooding, although there appears to be a reduction in these types of incidents.
- Gales are also relatively common across the region and tornadoes appear to be occurring more frequently.
- Extreme weather events have affected homes, businesses and travel throughout the region, some with more devastating results than others.
- Heatwaves are now also becoming a more regular occurrence. Many people may look forward to these but the heatwaves that have been happening in the Yorkshire and Humber region have been leading to increased mortality rates, exacerbated health problems and an increase in wild fires. There have also been problems with travel as speed restrictions have had to be placed on trains and the roads across the region were under such high temperatures they were, in places, in danger of melting.

- Erosion of the coastline is a common occurrence along the region's North Sea margin. Parts of this are subjected to erosion by savage seas and strong winds. Such erosion can lead to loss of land or assets directly or can be a preparatory factor leading to increased potential for coastal landslips. Inland slips in features such as embankments have also become a problem during times of flooding, and there have been events where there have been landslips over busy roads.
- Overall there appears to have been an increase in the frequency of occurrence and severity of most extreme weather conditions across the region, with devastating results to those who live here. This was most notably demonstrated in the summer of 2007 when major flooding occurred across large parts of South Yorkshire and Humber leading to loss of life, damage to property, infrastructure and livelihoods, and disruption to continuity of public and voluntary services and business operations.

3. Modeling future climate

Climate Models

Modeling future climate is a massively complex and uncertain process which uses numerical models of the earth-atmosphere-ocean system. These models (known as general circulation models or GCMs) represent all of the important physical processes in the atmosphere, oceans and on the land surface of our planet, including radiation, cloud, thermodynamics, precipitation (snow and rainfall) and heat transport.

Because we do not know how much carbon dioxide will be emitted in the future, scenarios have been devised that range from low (which assumes major reductions in emissions are made) through to medium-low, medium-high (assuming business as usual) to high (assuming greater economic growth and no controls on emissions). When these scenarios are fed into GCMs, the results are generally available as averages across a 30-year period, so for example, the 2020s covers the period from 2010 to 2040, the 2050s covers 2040 to 2070, and the 2080s covers 2070 to 2100.

The validity of GCMs is tested by seeing if they can accurately predict our current climate when given historical data, generally from the period 1961 to 1990. GCMs give impressive results for large-scale atmospheric and oceanic circulations and for the average climate, however there are well-known shortcomings with their estimates of variability and extremes (i.e. they are poor at predicting unusual events such as heavy rain storms and droughts). This is partly because they use a large grid size - typically 300km. Various downscaling techniques have been developed which use smaller grid cell sizes, typically 50km, and which can take into account the important effects of topography, such as mountains and land-sea effects, in determining surface temperatures and rainfall patterns. This produces a regional (rather than global) climate model and generally covers a smaller, although still substantial area, such as the UK. In 2002 the UK Climate Impacts Programme published results from a regional climate model run by the Hadley Centre known as HadRM3. These results, known as the UKCIP02 scenarios, have been the standard basis for climate impact assessment in the UK.

Although these scenarios provide a major advance over GCM outputs, the results are still at quite a broad scale - 50km. This study has used the UKCIP02 results alongside a different type of model known as a weather generator. The weather generator used in this study is called EARWIG (the Environment Agency Rainfall and Weather Impacts Generator) and was developed for the Environment Agency by Newcastle University and University of East Anglia. It produces internally consistent time series, at daily and hourly intervals, of weather variables including rainfall, temperature, humidity, wind and sunshine. EARWIG uses two models to produce results - the first model produces results for rainfall which are then fed into a second model which produces results for the other variables which are dependant on rainfall. Outputs are available at a 5km grid cell resolution, which is 100 times greater resolution than the outputs available from UKCIP and so provide a greater level of detail, which is especially useful when considering climate impacts at a regional and sub-regional scale. The map below shows the cells which were used to generate climate projections for the Yorkshire and Humber region. These locations have been selected to represent coastal, inland and upland locations in order to identify subtleties in future projections due to altitude or proximity to the coast. These locations cover both urban and rural areas and also represent a good geographical distribution across the region.

Figure 3. EARWIG Cell Locations

EARWIG cell	Name
1	Stapleton/Darlington
2	South Pennines/Yorkshire Dales (Askrigg)
3	North York Moors (Rosedale Abbey)
4	Scarborough
5	York
6	Leeds/Bradford
7	Hull
8	Sheffield

EARWIG has been widely used for studies across the UK in the water sector (see Kilsby et al., 2007 for a full description) and has recently been used in a number of climate adaptation studies, including a corresponding study of climate change adaptation carried out in the North East region in 2007. It has also been used in the development of the most recent set of UKCIP projections (UKCP09).

For this study EARWIG has been used to generate weather projections for a single future time period (the 2050s) and uses a single emissions scenario (medium-high). Choosing these particular time frames and emissions scenarios has important consequences for both the range and magnitude of climate change impacts. The 2050s was chosen because it was felt to be the most relevant time frame in terms of regional strategies and long-term planning, and is also the lifespan of much of our region's building stock and infrastructure. The medium-high scenario was felt to be a plausible indication of future carbon emissions and has the added benefit of being the most extensively studied scenario in the UKCIP02 programme.

It is important to be aware that modeling the climate is a complex process which involves many uncertainties. The outputs from models are consciously labeled as 'projections' (of what might plausibly happen) because they are not intended to be 'predictions' (of what will definitely happen). The results from a climate model, as with any model, are dependent on the quality of the input and the assumptions used in the process.

As one moves down through the different stages of climate modeling, the results obtained are more sensitive to these assumptions. This is often called the 'cascade of uncertainty' as different visions of the social and economic future of the world, different global and regional climate models, different downscaling techniques and different ways of thinking about impacts will all increase the uncertainty of results at the local scale. For many entirely justifiable reasons, this particular study has chosen one particular route through this cascade. However, it is important to recognise that this one route cannot, and does not try to, encompass the total range of uncertainty.

Confidence in Variables

Due to the nature of the processes being simulated in climate models, and the large natural variability in some weather parameters, climate modelers attach very different reliability to estimates of change in different parameters. Broadly, there is most confidence in long term or seasonal averages of quantities (e.g. summer mean temperatures), and least in estimates of extremes or short time resolution variables (e.g. hourly extreme rainfall).

The UKCIP02 Scientific Report outlines the reliability for different weather variables, with most confidence cited in mean temperature, followed by mean rainfall. Projections of wind, especially, are less reliable due to the highly variable nature of wind gusts, and dependence on land surface roughness.

UKCP09

During 2009 a new set of results were published which are referred to as the UKCP09 projections. These results are not based on just the HadRM3 model, but on runs from a wide range of other climate models, from the UK and other countries. This was done because there are processes in our climate that are poorly understood and running many models using different parameters allows some of this uncertainty to be captured. The 2009 results have considerable continuity with the previous projections, however a key difference between the two sets of results, is that the 2009 projections have a range of probabilities attached to them. This allows for some of the uncertainty inherent in modeling future climate to be assessed.

Overall it was found that the UKCP09 projections are broadly similar to the findings of this study in both the direction and magnitude of changes for rainfall and temperature. However, for projected changes in droughts, heatwaves and extreme heavy rainfall, UKCP09 suggests substantially larger futures changes. This means that the conclusions of this study (based on UKCIP02 and EARWIG) remain valid, however for those variables where UKCP09 projections are more severe than the ones found by this study, the adaptation actions need to be implemented sooner.

Further key findings from UKCP09 for the Yorkshire and Humber region (for the 2080s) can be found on the UKCP09 website at: http://ukcp09.defra.gov.uk/content/view/42/6/.

Stage 2

This stage assessed the impacts of the projected climate changes on the communities, services, infrastructure, and businesses within Yorkshire and Humber.

Assessing the Impacts

Information relating to flooding, erosion, landslips, groundwater and minewaters in the region was collated and the technical expertise of a range of professionals applied, in order to assess the likely impacts of projected climate changes. These professional experts included climatologists, hydrologists, river, coastal and drainage engineers, environmental scientists, economics specialists, mast and tower engineers, transport and highways engineers, structural engineers, geomorphologists and geotechnical engineers. This analysis was supplemented with local expertise and knowledge from technical officers working for various organisations across the region through a series of workshops.

The first phase of workshops addressed the five core themes within the study. These are; infrastructure and utilities, business and the economy, health and welfare, public and voluntary services, and biodiversity. Details of the workshops are available on the website, including distilled but unprocessed outputs, which include additional comments submitted post-event.

Following on from the sectoral workshops, a larger cross-sectoral workshop was held at the Leeds Hilton on January 21st 2009. This whole-day event attracted about 100 delegates who developed earlier discussions and investigated interactions between both impacts and adaptation measures to make sure that tackling one did not inadvertently create negative impacts elsewhere (a spillover effect). These discussions allowed an initial list of adaptations to be prioritised into a top ten list of actions. Reasons why these actions had not already been carried out were also discussed to identify “blockers” and “enablers” (i.e. factors which either prevented or encouraged adaptation actions).

The list of prioritised actions and the blockers and enablers can be found in the adaptation section.

Stage 3

This stage identified suitable adaptation measures to counter the impacts across the region that are anticipated from the projected climate changes by the 2050s.

Identifying Adaptation Actions

Adaptation actions were identified by reviewing the latest research into adaptation in specific sectors. These included the UKCIP Adaptation Wizard and outputs from Building Knowledge for a Changing Climate (BKCC) and the more recent Sustain Knowledge for a Changing Climate (SKCC).

The adaptation actions identified from the literature were supplemented with the professional expertise of the project team and local expertise and knowledge from technical officers working for various organisations across the region.

3. Results

This section of the report contains the key climate changes that are projected to affect the region by the period 2040 to 2070 (the 2050s). The projections are based on the outputs from EARWIG and UKCIP02 and are compared with a baseline period of 1960 to 1990 (the 1970s). All of this data and more can be found on the website: www.adaptyh.co.uk. Local authority factsheets with results for each district in the region can also be found on the website.

Results Summary

The principal climate changes projected for the region by the 2050s are:

Average daily temperatures are projected to increase in all seasons with a region-wide annual average daily temperature change of just below 2°C. Average daily temperatures will increase across the region throughout all seasons. The greatest net increases will be in summer of around 2.1°C to 2.5°C and the lowest in winter of around 1.3°C to 1.5°C. The current regional trend in temperature shows that the coast and southern inland areas are the warmest in the region, with temperatures reducing progressively towards the northern and upland areas.

Extreme hot temperatures will increase by around 3.4°C. With an expected increase of up to around 3.4°C in extreme hot temperatures we can more regularly expect the summer daily average temperatures to reach around 34°C in many parts of the region, especially for the more southern parts of the region.

The number of hot days with a maximum temperature of 28°C or more is likely to increase. There will be a greater tendency for daily temperatures to exceed the 28°C threshold, with some areas of the region experiencing over six days in the summer where this threshold is exceeded.

There will be a very slight increase in incidences of heatwaves. Despite the increase in hot days (over 28°C) there is only a very small chance that these days will occur consecutively, resulting in only the central areas of the region experiencing increases in heat waves.

Annual rainfall is projected to reduce throughout the region by up to approximately 6 per cent. The pattern of rainfall across the region varies geographically, with patterns being influenced by topography. Inland areas see the greatest reduction in rainfall (up to around 5.8 per cent) while the reduction in upland areas is only around 2 per cent.

Rainfall is projected to show increased seasonality with increases of up to 17 per cent in winter and reductions of around 25 per cent in summer. The region should expect greater seasonal variation of rainfall with increases in winter rainfall combined with summer decreases. The greatest percentage changes occur at the coast, however some of the greatest net changes will occur in the uplands due to the much greater baseline rainfall.

There is a projected variability in extreme rainfall events, with an increase of up to around 10 per cent felt in some areas. There will be considerable variability in extreme rainfall events across the region. Some locations will show an extremely small increase in extreme rainfall or none at all, while others areas will show a small reduction. In the northern and upland areas, extreme rainfall events will increase, by up to around 10 per cent in the worst case.

There will be a considerable increase in the number of dry spells. The number of occurrences of 10 and 20 consecutive days without rainfall is expected to increase by up to three additional occurrences per year. The greatest actual increases occur in the centre of the region while the greatest relative increases are located at the north of the region.

There is projected to be a major reduction in winter snowfall of between 54 and 68 per cent across the region. The increases in winter temperature and especially the increases in average daily minimum and severe winter temperatures nearing or in many cases rising above 0°C will mean a reduction in the number of days witnessing snowfall throughout the region. The largest relative reductions will occur in the autumn.

There will be up 50 per cent fewer days of frost per year. The region-wide increase in temperatures will result in winter severe temperatures moving closer to the melt point but still remaining below zero. Across the region there will be between a 35 per cent and 50 per cent reduction in the number of frost days per year.

Mean wind speeds will marginally increase in winter. There will be marginal increases in mean winter wind speeds across the region. However, summer and autumn will see a small decrease in mean wind speed especially in northern and upland areas.

There is projected to be a decrease in relative humidity of about 15 per cent (in summer) in some areas. The average annual relative humidity is expected to reduce by 10 per cent in all areas. During the winter the relative humidity is projected to reduce by up to 8 per cent, with the largest reduction of up to 15 per cent in summer.

Soil moisture content is set to decrease by up to 11 per cent with greatest decreases in summer and autumn. There will be a reduction in annual average soil moisture content throughout the region. The number of days when the soil is either saturated or above field capacity will significantly reduce, but conversely the number of days when the soil is dry will significantly increase.

Sea levels will increase by around 0.35m. Guidance from central government recommends allowances to be made in the design of coastal protection and sea defence works of around 4mm per year up to 2025 and then 8.5mm per year up to 2055 south of Flamborough Head.

Results detail

Temperature

Annual and seasonal daily averages

Average daily temperatures are projected to increase in all seasons with a region-wide annual average daily temperature change of just below 2°C.

Table 1. Annual average daily mean temperature

Annual Average Daily Mean Temperature The arithmetically averaged mean temperature for each day recorded during a calendar year					
Location	Baseline (°C)		2050s (°C)		Absolute Change (°C)
	Mean	Standard Deviation	Mean	Standard Deviation	
Stapleton (Darlington)	8.6	0.3	10.4	0.3	+1.8
South Pennines/Yorkshire Dales	6.6	0.4	8.4	0.4	+1.8
North York Moors	7.4	0.4	9.2	0.4	+1.8
Scarborough	8.7	0.3	10.5	0.3	+1.8
York	9.3	0.3	11.2	0.3	+1.9
Leeds/Bradford	9.0	0.4	11.0	0.4	+1.9
Hull	9.4	0.3	11.3	0.3	+1.9
Sheffield	8.9	0.4	10.9	0.4	+1.9

Table 2. Spring average daily mean temperature

Spring Average Daily Mean Temperature The arithmetically averaged mean temperature for each day recorded during March, April and May					
Location	Baseline (ºC)		2050s (ºC)		Absolute Change (ºC)
	Mean	Standard Deviation	Mean	Standard Deviation	
Stapleton (Darlington)	7.3	0.6	8.9	0.6	+1.6
South Pennines/Yorkshire Dales	5.3	0.7	6.9	0.7	+1.5
North York Moors	6.0	0.7	7.6	0.6	+1.6
Scarborough	7.3	0.6	8.8	0.6	+1.6
York	8.0	0.6	9.6	0.6	+1.6
Leeds/Bradford	7.9	0.7	9.5	0.7	+1.6
Hull	8.0	0.6	9.6	0.6	+1.6
Sheffield	7.7	0.7	9.4	0.7	+1.6

Table 3. Summer average daily mean temperature

Summer Average Daily Mean Temperature The arithmetically averaged mean temperature for each day recorded during June, July and August					
Location	Baseline (ºC)		2050s (ºC)		Absolute Change (ºC)
	Mean	Standard Deviation	Mean	Standard Deviation	
Stapleton (Darlington)	14.1	0.5	16.3	0.6	+2.2
South Pennines/Yorkshire Dales	12.2	0.6	14.3	0.7	+2.1
North York Moors	12.9	0.5	15.1	0.6	+2.2
Scarborough	14.2	0.5	16.4	0.5	+2.2
York	14.9	0.5	17.3	0.6	+2.4
Leeds/Bradford	14.9	0.6	17.3	0.6	+2.4
Hull	15.0	0.5	17.3	0.5	+2.3
Sheffield	14.8	0.6	17.3	0.7	+2.5

Table 4. Autumn average daily temperature

Autumn Average Daily Mean Temperature The arithmetically averaged mean temperature for each day recorded during September, October and November					
Location	Baseline (ºC)		2050s (ºC)		Absolute Change (ºC)
	Mean	Standard Deviation	Mean	Standard Deviation	
Stapleton (Darlington)	9.4	0.6	11.4	0.6	+2.0
South Pennines/Yorkshire Dales	7.4	0.6	9.4	0.7	+2.0
North York Moors	8.3	0.6	10.3	0.6	+2.1
Scarborough	9.6	0.6	11.7	0.6	+2.0
York	10.0	0.6	12.2	0.6	+2.2
Leeds/Bradford	9.6	0.6	11.8	0.7	+2.2
Hull	10.3	0.6	12.4	0.6	+2.1
Sheffield	9.5	0.6	11.7	0.7	+2.2

Table 5. Winter average daily temperature

Winter Average Daily Mean Temperature The arithmetically averaged mean temperature for each day recorded during December, January and February					
Location	Baseline (ºC)		2050s (ºC)		Absolute Change (ºC)
	Mean	Standard Deviation	Mean	Standard Deviation	
Stapleton (Darlington)	3.5	0.9	4.9	0.9	+1.3
South Pennines/Yorkshire Dales	1.6	0.9	2.9	0.9	+1.4
North York Moors	2.3	0.9	3.6	0.9	+1.4
Scarborough	3.5	0.8	4.9	0.8	+1.4
York	4.0	0.9	5.4	0.9	+1.4
Leeds/Bradford	3.7	1.0	5.1	1.0	+1.4
Hull	4.2	0.9	5.6	0.8	+1.4
Sheffield	3.6	1.0	5.0	0.9	+1.5

The greatest net increases will be in summer of around 2.1°C to 2.5°C and the lowest in winter of around 1.3°C to 1.5 °C. The current regional trend in temperature shows that the coast and southern inland areas are the warmest in the region, with temperatures reducing progressively towards the northern and upland areas.

Annual and seasonal daily maximum and minimum

Annually, the long-term average maximum temperature is projected to rise by 2.9ºC. The greatest increases are to be in the southern and greater urban areas of the Yorkshire and Humber region.

Table 6. Annual average daily maximum temperature

Annual Average Daily Maximum Temperature The long-term average daily maximum air temperature observed over the calendar year					
Location	Baseline (ºC)		2050s (ºC)		Absolute Change (ºC)
	Mean	Standard Deviation	Mean	Standard Deviation	
Stapleton (Darlington)	25.6	1.5	28.4	1.6	+2.8
South Pennines/Yorkshire Dales	24.5	1.7	27.2	1.8	+2.7
North York Moors	24.5	1.6	27.2	1.6	+2.7
Scarborough	25.3	1.4	28.1	1.5	+2.7
York	26.9	1.5	29.9	1.6	+3.0
Leeds/Bradford	27.8	1.6	30.7	1.7	+3.0
Hull	26.4	1.5	29.3	1.5	+2.9
Sheffield	27.9	1.7	31.0	1.8	+3.1

Minimum average daily temperatures are projected to increase by, on average, 1.6ºC across the region. The greatest increase in annual average minimum temperatures is seen in the urban areas around Leeds, Sheffield and Hull of around 1.7ºC. The lowest increase in minimum temperature is in the upland areas which see an increase of 1.5ºC.

Table 7. Annual average daily minimum temperature

Annual Average Daily Minimum Temperature The long-term average daily minimum air temperature observed over the calendar year					
Location	Baseline (ºC)		2050s (ºC)		Absolute Change (ºC)
	Mean	Standard Deviation	Mean	Standard Deviation	
Stapleton (Darlington)	-1.5	2.0	0.1	1.8	+1.6
South Pennines/Yorkshire Dales	-3.8	2.0	-2.3	2.0	+1.5
North York Moors	-2.7	1.9	-1.2	1.8	+1.5
Scarborough	-1.2	1.7	0.4	1.7	+1.6
York	-1.3	2.0	0.5	2.0	+1.7
Leeds/Bradford	-2.0	2.2	-0.4	2.2	+1.6
Hull	-0.7	1.9	0.9	1.8	+1.6
Sheffield	-2.2	2.3	-0.6	2.2	+1.6

Seasonal predictions indicate that the greatest increase in long term average maximum temperatures will be in the summer and autumn months. The change is predicted to be up to 3.1ºC. The lowest change will be during the winter months in the upland and barren areas of the region with an average of 1.2ºC. Summer minimum temperatures will see the greatest increase compared to other seasons. The change will be up to 2.1ºC. Autumn minimum temperatures will also experience a similar increase to those in summer. Those in spring and winter will increase but at a lower range of 1.5ºC to 1.7ºC. Charts of seasonal daily maximum and minimum averages are available on the website.

Extreme cold and hot

Fifth percentile extreme cold temperatures (5 per cent of days have colder temperatures than this) will increase by around 1.6 to 2.1ºC in winter but will still remain below freezing. For example in Leeds the current fifth percentile temperature is -6.0ºC which will rise to -4.3ºC by the 2050s, which is an absolute change of 1.7ºC.

Fifth percentile extreme hot temperatures (5 per cent of days have hotter temperatures than this) will increase by around 2.8ºC to 3.2ºC in summer, reaching values of 33.6ºC in Leeds.

Charts of data for the 5th, 10th, 90th and 95th percentile temperatures for each season (spring, summer, autumn and winter) are available on the website.

Annual average hot days

The number of days when the daily maximum air temperature is above 28ºC has a significant range throughout the region. The upland areas see an increase in the average number of days but not above one day. However, the southern and lowland areas will see a greater increase in the number of hot days, with up to 5.5 extra hot days per year occurring in Sheffield.

Table 8. Annual average of hot days

Annual Average of Hot Days *(with Tmax > 28ºC)* The average number of days in a calendar year when the daily maximum air temperature is more than 28 °C					
Location	Baseline (Days)		2050s (Days)		Absolute Change (Days)
	Mean	Standard Deviation	Mean	Standard Deviation	
Stapleton (Darlington)	0.1	0.3	1.2	1.4	+1.1
South Pennines/Yorkshire Dales	0.0	0.2	0.5	0.9	+0.4
North York Moors	0.0	0.2	0.4	0.8	+0.4
Scarborough	0.1	0.2	0.9	1.2	+0.8
York	0.3	0.6	3.5	2.5	+3.2
Leeds/Bradford	0.7	1.0	5.5	3.4	+4.8
Hull	0.2	0.4	2.3	2.0	+2.1
Sheffield	0.8	1.1	6.3	3.7	+5.5

Seasonal average hot days

Winter and spring months will see no change in the average number of hot days from the baseline until the 2050s. Autumn will see a small increase in the number of hot days in the southern part of the region, but by less than one day. In summer however, there will be an increase in the number of hot days across the region, with a greater increase being seen in the southern and lowland areas than in the upland areas. The greatest increase will be in Sheffield with a change of +5.2 days between the baseline and 2050s.

Table 9. Spring average hot days

Spring Average of Hot Days *(with Tmax > 28ºC)* The average number of days in the months of March, April and May when the daily maximum air temperature is more than 28 °C					
Location	Baseline (Days)		2050s (Days)		Absolute Change (Days)
	Mean	Standard Deviation	Mean	Standard Deviation	
Stapleton (Darlington)	0.0	0.0	0.0	0.1	0.0
South Pennines/Yorkshire Dales	0.0	0.0	0.0	0.1	0.0
North York Moors	0.0	0.0	0.0	0.0	0.0
Scarborough	0.0	0.0	0.0	0.0	0.0
York	0.0	0.0	0.0	0.1	0.0
Leeds/Bradford	0.0	0.1	0.0	0.2	0.0
Hull	0.0	0.0	0.0	0.1	0.0
Sheffield	0.0	0.1	0.1	0.3	0.0

Table 10. Summer average hot days

Summer Average of Hot Days *(with Tmax > 28ºC)* The average number of days in the months of June, July and August when the daily maximum air temperature is more than 28 °C					
Location	Baseline (Days)		2050s (Days)		Absolute Change (Days)
	Mean	Standard Deviation	Mean	Standard Deviation	
Stapleton (Darlington)	0.1	0.3	1.1	1.4	+1.1
South Pennines/Yorkshire Dales	0.0	0.2	0.5	0.9	+0.4
North York Moors	0.0	0.2	0.4	0.8	+0.4
Scarborough	0.1	0.2	0.9	1.2	+0.8
York	0.3	0.6	3.3	2.5	+3.0
Leeds/Bradford	0.7	1.0	5.2	3.3	+4.6
Hull	0.2	0.4	2.2	1.9	+2.0
Sheffield	0.8	1.1	6.0	3.6	+5.2

Table 11. Autumn average hot days

Autumn Average of Hot Days *(with Tmax > 28ºC)* The average number of days in the months of September, October and November when the daily maximum air temperature is more than 28 °C					
Location	Baseline (Days)		2050s (Days)		Absolute Change (Days)
	Mean	Standard Deviation	Mean	Standard Deviation	
Stapleton (Darlington)	0.0	0.0	0.0	0.2	0.0
South Pennines/Yorkshire Dales	0.0	0.0	0.0	0.1	0.0
North York Moors	0.0	0.0	0.0	0.1	0.0
Scarborough	0.0	0.0	0.0	0.2	0.0
York	0.0	0.1	0.2	0.5	+0.2
Leeds/Bradford	0.0	0.1	0.3	0.6	+0.3
Hull	0.0	0.1	0.1	0.4	+0.1
Sheffield	0.0	0.1	0.3	0.7	+0.3

Table 12. Winter average hot days

Winter Average of Hot Days *(with Tmax > 28ºC)* **The average number of days in the months of December, January and February when the daily maximum air temperature is more than 28 °C**					
Location	Baseline (Days)		2050s (Days)		Absolute Change
	Mean	Standard	Mean	Standard	(Days)
Deviation		Deviation			
Stapleton (Darlington)	0.0	0.0	0.0	0.0	0.0
South Pennines/Yorkshire Dales	0.0	0.0	0.0	0.0	0.0
North York Moors	0.0	0.0	0.0	0.0	0.0
Scarborough	0.0	0.0	0.0	0.0	0.0
York	0.0	0.0	0.0	0.0	0.0
Leeds/Bradford	0.0	0.0	0.0	0.0	0.0
Hull	0.0	0.0	0.0	0.0	0.0
Sheffield	0.0	0.0	0.0	0.0	0.0

Heatwaves

Heatwaves (two consecutive days with a maximum daytime temperature greater than 28ºC and a minimum nighttime temperature greater than 15ºC) will marginally increase in the south of the region. On average, there will be a 0.3 increase in the number of two day heat waves for these locations.

Table 13. 2 day heatwaves

2 Day Heatwaves (Tmax > 29°C, Tmin > 15°C) **The average number of consecutive 2 day periods in a calendar year when the daily maximum air temperature is more than 29 °C and the daily minimum air temperature is more than 15 °C**					
Location	Baseline (Occurences)		2050s (Occurences)		Absolute Change
	Mean	Standard Deviation	Mean	Standard Deviation	(Occurences)
Stapleton (Darlington)	0.0	0.0	0.0	0.3	0.0
South Pennines/Yorkshire Dales	0.0	0.0	0.0	0.2	0.0
North York Moors	0.0	0.0	0.0	0.2	0.0
Scarborough	0.0	0.0	0.0	0.3	0.0
York	0.0	0.1	0.2	0.6	+0.2
Leeds/Bradford	0.0	0.1	0.4	0.8	+0.4
Hull	0.0	0.0	0.1	0.5	+0.1
Sheffield	0.0	0.1	0.5	1.0	+0.4

Precipitation

Annual average rainfall

Rainfall currently shows a fair amount of variability across the region, with Darlington experiencing almost twice as much annual rainfall as York. The drier southern sites will experience even less rainfall in the future. York will experience 5.8 per cent less annual rainfall whereas the upland regions will see a much smaller decrease of around 2 per cent.

Table 14. Annual average rainfall

Annual Average Rainfall The arithmetically averaged total amount of rainfall recorded during a year in mm.						
Location	Baseline (mm)		2050s (mm)		Absolute Change (mm)	Relative Change (%)
	Mean	Standard Deviation	Mean	Standard Deviation		
Stapleton (Darlington)	659.8	96.5	627.4	93.1	-32	-4.9
South Pennines/Yorkshire Dales	1179.6	152.9	1162.4	153.0	-17	-1.5
North York Moors	950.5	123.3	926.5	122.9	-24	-2.5
Scarborough	689.1	96.2	664.8	94.8	-24	-3.5
York	620.5	85.1	584.9	82.2	-36	-5.8
Leeds/Bradford	700.0	98.1	669.8	95.1	-30	-4.3
Hull	654.2	90.4	631.6	91.4	-23	-3.5
Sheffield	771.4	108.4	740.1	105.4	-31	-4.1

Seasonal average rainfall

While annual average rainfall shows a decrease across the whole region, seasonal rainfall shows much greater variability. Winter rainfall will increase by 2050 at all sites by about 15 per cent while summer rainfall will decrease by up to 25 per cent.

Table 15. Spring average rainfall

Spring Average Rainfall The arithmetically averaged monthly rainfall recorded during March, April and May in mm						
Location	Baseline (mm)		2050s (mm)		Absolute Change (mm)	Relative Change (%)
	Mean	Standard Deviation	Mean	Standard Deviation		
Stapleton (Darlington)	49.2	15.1	48.5	15.7	-0.7	-1.4
South Pennines/Yorkshire Dales	81.4	21.0	80.4	22.3	-1.0	-1.2
North York Moors	68.5	18.7	69.3	19.2	+0.9	+1.3
Scarborough	50.0	13.2	50.1	13.5	+0.0	+0.0
York	45.7	11.9	44.6	12.0	-1.1	-2.5
Leeds/Bradford	53.0	14.4	51.7	13.5	-1.3	-2.4
Hull	48.5	13.1	48.4	13.2	-0.1	-0.2
Sheffield	58.7	16.3	57.1	16.0	-1.6	-2.8

Table 16. Summer average rainfall

Summer Average Rainfall The arithmetically averaged monthly rainfall recorded during June, July and August in mm						
Location	Baseline (mm)		2050s (mm)		Absolute Change (mm)	Relative Change (%)
	Mean	Standard Deviation	Mean	Standard Deviation		
Stapleton (Darlington)	55.7	15.9	41.6	13.5	-14.1	-25.3
South Pennines/Yorkshire Dales	71.5	18.1	55.5	16.1	-16.0	-22.4
North York Moors	69.8	19.1	53.8	16.5	-16.0	-22.9
Scarborough	55.8	16.7	43.2	15.3	-12.5	-22.5
York	54.0	15.9	40.2	13.6	-13.8	-25.6
Leeds/Bradford	54.0	15.9	41.2	14.5	-12.8	-23.7
Hull	55.3	15.7	41.8	14.9	-13.5	-24.4
Sheffield	57.3	18.0	42.9	17.4	-14.3	-25.0

Table 17. Autumn average rainfall

Autumn Average Rainfall The arithmetically averaged monthly rainfall recorded during September, October and November in mm						
Location	Baseline (mm)		2050s (mm)		Absolute Change (mm)	Relative Change (%)
	Mean	Standard Deviation	Mean	Standard Deviation		
Stapleton (Darlington)	59.1	17.3	54.7	15.7	-4.4	-7.5
South Pennines/Yorkshire Dales	111.9	27.5	107.7	26.7	-4.1	-3.7
North York Moors	90.6	23.5	84.0	23.5	-6.7	-7.4
Scarborough	65.5	18.4	60.6	18.0	-5.0	-7.6
York	55.9	14.4	51.2	13.6	-4.7	-8.4
Leeds/Bradford	64.4	16.7	59.4	17.3	-5.0	-7.8
Hull	59.4	16.1	56.1	16.2	-3.3	-5.6
Sheffield	69.1	18.2	64.6	18.1	-4.5	-6.6

Table 18. Winter average rainfall

Winter Average Rainfall The arithmetically averaged monthly rainfall recorded during December, January and February in mm						
Location	Baseline (mm)		2050s (mm)		Absolute Change (mm)	Relative Change (%)
	Mean	Standard Deviation	Mean	Standard Deviation		
Stapleton (Darlington)	55.9	13.8	64.3	16.3	+8.4	+15.0
South Pennines/Yorkshire Dales	128.3	31.2	143.7	32.9	+15.4	+12.0
North York Moors	87.8	18.9	101.6	21.2	+13.8	+15.7
Scarborough	58.3	13.5	67.7	15.1	+9.4	+16.1
York	51.2	13.2	58.9	14.0	+7.7	+15.1
Leeds/Bradford	61.9	16.6	71.0	16.6	+9.0	+14.6
Hull	54.9	14.2	64.3	15.3	+9.4	+17.2
Sheffield	72.0	17.9	82.0	18.5	+10.0	+14.0

Extreme rainfall events

Extreme rainfall events show variability across the region, with some locations experiencing increases of up to 10 per cent for some extreme events, others showing similar decrease, and others exhibiting negligible change.

Charts of 5 and 50 per cent annual exceedance probabilities (AEP) for one, two, five and ten day duration events are available on the website, as are data tables for 10 and 50 per cent AEPs for extreme rainfall events for one, three, six and 12 hour duration events. The annual exceedence probability (AEP) is the probability of a particular event for a specified duration (e.g. one hour, two days, a week etc) being equaled or exceeded in any one year period.

Dry spells

The number of occurrences of 10 consecutive days without rainfall is expected to increase by up to three additional occurrences per year by 2050. The greatest actual increases occur in the centre of the region while the greatest relative increases will be seen in the north of the region. For longer dry spells of 20 consecutive days with less than 0.2mm rainfall there will be an average increase of 0.6 extra occurrences by 2050. There will also be an increase in the number of dry spells of 10 and 20 days where less than 1mm of rain falls. For these types of events, there will be an increase in 10 day dry spells of around two additional occurrences per year and for 20 day dry spells, around 0.6 extra occurrences per year.

Table 19. Dry spells - 10 consecutive days of rainfall below 0.2mm

Dry Spells - 10 consecutive days of rain fall below 0.2 mm

The number of independent occasions where 10 consecutive days with less than 0.2 mm of rainfall is recorded during the calendar year

Location	Baseline (Occurences)		2050s (Occurences)		Absolute Change (Occurences)	Relative Change (%)
	Mean	Standard Deviation	Mean	Standard Deviation		
Stapleton (Darlington)	5.6	2.3	7.8	2.5	+2.2	+39.5
South Pennines/Yorkshire Dales	1.9	1.3	3.7	1.8	+1.8	+96.0
North York Moors	2.3	1.5	4.1	1.9	+1.8	+80.6
Scarborough	3.8	1.9	6.3	2.2	+2.5	+66.7
York	4.1	1.9	6.5	2.2	+2.4	+57.2
Leeds/Bradford	4.0	1.9	7.0	2.3	+3.0	+76.4
Hull	4.2	1.9	6.8	2.3	+2.7	+64.8
Sheffield	4.0	1.9	6.6	2.2	+2.7	+67.2

Table 20. Dy spells - 20 consecutive days of rainfall below 0.2mm

Dry Spells - 20 consecutive days of rain fall below 0.2 mm The number of independent occasions where 20 consecutive days with less than 0.2 mm of rainfall is recorded during the calendar year						
Location	Baseline (Occurences)		2050s (Occurences)		Absolute Change (Occurences)	Relative Change (%)
	Mean	Standard Deviation	Mean	Standard Deviation		
Stapleton (Darlington)	0.7	0.8	1.2	1.1	+0.5	+72.9
South Pennines/Yorkshire Dales	0.1	0.3	0.4	0.6	+0.3	+351.1
North York Moors	0.1	0.3	0.4	0.6	+0.2	+195.0
Scarborough	0.2	0.5	0.8	0.8	+0.6	+227.2
York	0.2	0.5	0.8	0.8	+0.6	+232.2
Leeds/Bradford	0.3	0.5	1.1	1.0	+0.8	+327.1
Hull	0.3	0.5	1.0	0.9	+0.7	+252.2
Sheffield	0.3	0.6	1.0	0.9	+0.7	+208.9

Snowfall and frost

The number of days on which snow falls is expected to decrease dramatically across the region with 54 to 68 per cent fewer snowy days than currently. Annual average snow depth (measured as water depth equivalent) will reduce by 51 to 67 per cent. Almost no snow will fall in spring, summer and autumn, except in the Yorkshire Dales and, to a lesser extent, the North York Moors, but even in these locations there will be a big reduction in snowfall.

Table 21. Annual average days snowfall

Annual Average Days of Snowfall per year (Tmean ≤0°C) **The average number of days in a calendar year when the daily mean air temperature is less than or equal to 0 °C**						
Location	**Baseline (days)**		**2050s (days)**		**Absolute Change (days)**	**Relative Change (%)**
	Mean	**Standard Deviation**	**Mean**	**Standard Deviation**		
Stapleton (Darlington)	4.4	3.2	1.6	1.7	-2.8	-64.3
South Pennines/Yorkshire Dales	19.6	7.6	9.0	5.0	-10.6	-54.1
North York Moors	12.5	5.9	5.3	3.7	-7.1	-57.2
Scarborough	4.9	3.5	1.7	1.9	-3.2	-65.7
York	3.3	2.7	1.1	1.5	-2.2	-66.0
Leeds/Bradford	4.5	3.2	1.7	1.8	-2.8	-62.9
Hull	2.9	2.5	0.9	1.3	-1.9	-67.6
Sheffield	5.3	3.5	2.0	2.0	-3.3	-62.1

Seasonal average days of snowfall

The Yorkshire Dales and the North Yorkshire Moors currently experience 14.5 and 10 days of snowfall respectively during the winter months (Dec, Jan and Feb). By 2050 this is expected to decrease to 7.4 and 4.7 days respectively. These sites currently experience between 3.5 and 1.6 days of spring snowfall (Mar, Apr, May) which will decrease to 1.5 and 0.8 days by 2050. Autumn snowfall is currently negligible across the region (0.2 to 1.6 days) and this will decrease to between zero and 0.5 days of snowfall by 2050. Unsurprisingly there are even fewer occurrences of summer snowfall in the Yorkshire and Humber region, with only the Yorkshire Dales ever experiencing any summer snowfall at 0.002 days per year. By 2050 this will reduce to zero.

Annual average days of frost

The Yorkshire Dales and area just south of the North Yorkshire Moors have the most frost days per year in the baseline period, with 96.6 and 78.8 days respectively. These areas also have the lowest relative change, with a fall of 37 per cent combined. Hull will see the number of frost days reduce by almost half, from 43.5 days currently to 22.1 days by 2050.

Table 22. Annual average days of frost per year

Annual Average Days of Frost per year *(Tmean ≤0°C)*

The average number of days in a calendar year when the daily minimum air temperature is less than 0 °C

Location	Baseline (Days)		2050s (Days)		Absolute	Relative
	Mean	Standard Deviation	Mean	Standard Deviation	Change (Days)	Change (%)
Stapleton (Darlington)	55.8	12.9	31.3	9.9	-24.5	-43.9
South Pennines/Yorkshire Dales	96.6	14.4	63.0	12.9	-33.7	-34.8
North York Moors	78.8	14.1	47.9	12.3	-30.9	-39.2
Scarborough	52.9	12.3	28.6	9.8	-24.3	-45.9
York	49.7	11.9	26.6	9.2	-23.1	-46.5
Leeds/Bradford	58.1	12.7	33.2	10.5	-24.9	-42.9
Hull	43.5	11.6	22.1	8.6	-21.4	-49.2
Sheffield	60.4	12.9	35.0	10.4	-25.3	-42.0

Soil moisture

EARWIG does not directly model soil moisture so instead meteorological results such as rainfall, wind and temperature from EARWIG were used as input to a hydrological model called the Arno Distribution Model (ADM).

The ADM model produces outputs of catchment-averaged values and does not account for the differences between soil types. For this reason simple indicators of soil moisture have been considered, using arbitrary thresholds.

The following parameters were considered using the ADM:

Saturation	This is the point at which the soil cannot hold any more water. This has arbitrarily been set here at 80 per cent of the available water content.
Field Capacity	This is the point at which the soil is at its natural capacity. This has arbitrarily been set here at 60 per cent of the available water content.
Wilt Point	The wilt point has arbitrarily been set here at 40 per cent of the total available water content. Definitions of wilt point vary and actual values are dependent upon soil type and crop.

Soil moisture is measured by a number of parameters:

- Annual average soil moisture content is projected to decrease by between 5 and 11 per cent
- Greatest decreases will be in summer and autumn, of up to 20 per cent reductions.
- There will be a reduction of between 5 and 19 per cent in mean available water content throughout the region.
- The number of days when the soil is either saturated or above field capacity will significantly reduce throughout the region, but the converse of this is that there will be a significant increase in the number of dry soil days.

Mean Available Water Content

Results indicate that overall, significant drying is projected, with decreases in mean available water content throughout the region. Changes in this parameter range from reductions of 5 to 19 per cent.

Number of Days Saturated Soil (at arbitrary saturation point or above)

There will be large decreases in the number of days when soils are saturated and in some locations this problem will not be experienced by the 2050s.

Number of Days Wet Soil (at field capacity or above)

There will be a reduction of between 11 and 30 per cent in the number of days of wet soil.

Number of Days Dry Soil (at arbitrary wilt point or below)

There are projected to be significant increases in the number of days with available water content at the arbitrary wilting point or below. Changes are projected to be greatest at Stapleton (Darlington), Scarborough, York and Hull, but remain very high at all other locations.

A full table of results from the Arno Distribution Model is available on the website.

Wind speeds

Modeling projections of future wind climate across the region are based on mean wind speed, and not extreme wind speeds or wind direction. Results show variability across the region. Key findings are:

- Annual average wind speed will marginally decrease (by around one per cent).
- Winter average wind speeds, which have the greatest background values and presently cause considerable damage across the region, will marginally increase (by less than around one per cent) throughout the region.
- Average wind speeds in spring, summer and autumn are projected to decrease.

Sea level rises and storm surges

The Yorkshire and Humber region meets the North Sea along its eastern margins and the Humber is a major tidally-influenced estuary. These parts of the region are therefore exposed to marine processes including tides, surges and waves.

Climate change has the potential to alter the marine processes in three principal ways of interest to the present study. First, the mean sea level could change through an increase in the volume of water within the oceans and a rising of sea levels relative to the land mass (which in parts of the UK is sinking). Second, extreme sea levels caused by atmospherically-induced surges or wind set-up could change in magnitude or frequency, or both. Third, the wind-generated wave climate could change should there be any changes to the track, magnitude or frequency of storms across the UK.

Each of these issues is discussed in turn in the following sub-sections.

Mean sea levels

Climate change has the potential to affect mean sea levels in three principal ways:

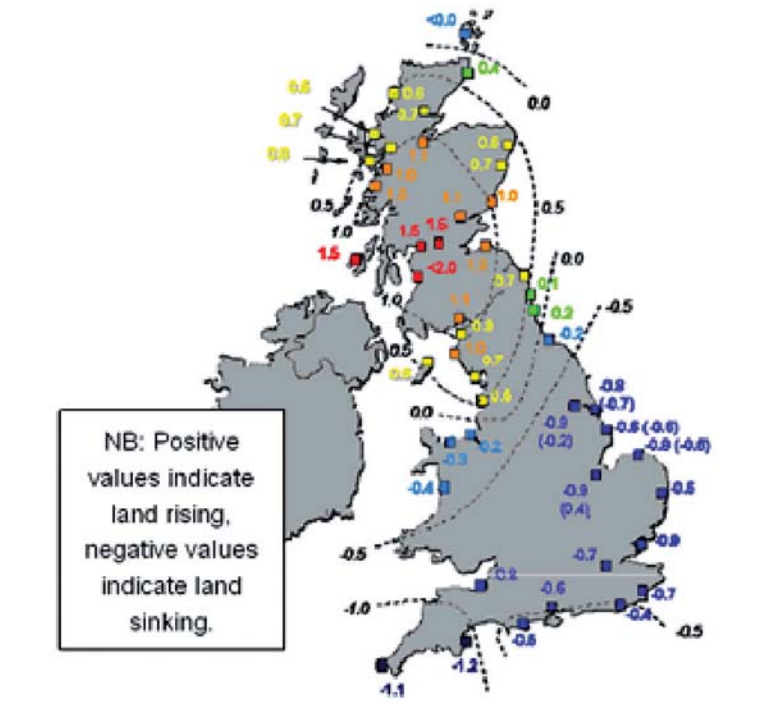
- Melting of glaciers following the last Ice Age has led to a long-term slow and progressive re-adjustment of the land mass of Great Britain (this process is known as isostatic rebound);
- Ice caps and ice sheets globally are melting which is leading to a physical increase in the volume of water in the world's oceans (glacio-eustacy); and
- As water warms up, it expands. Because global temperatures are rising, the volume of water in the oceans is increasing.

It is important to note that even if greenhouse gas emissions were stabilised or reduced now, the earth's climate is "locked-in" to the changes caused by the emissions already in the atmosphere. This is because there is such a long time-lag inherent in global-scale system response between global warming and thermal expansion of the oceans.

Isostatic rebound

The first change is the result of a very long-term process that operates over geological timescales (i.e. many hundreds of thousands of years). During the last Ice Age, northern and central parts of the land mass of Great Britain were covered with glacial ice. As this ice melted, the amount of weight pressing down on the land mass altered. The result of this is the gradual and long-term re-adjustment of the land mass, with the north of Great Britain lifting up, and the south sinking as a consequence.

Figure 4. Rates of isostatic rebound in Great Britain



Source: UKCIP

The scientific literature suggests that the fulcrum of this re-adjustment is (very approximately) along an imaginary line drawn from just north of Tees Bay in the east to the Dee estuary in the west (pictured, above). The mechanisms involved in this isostatic rebound involve a considerable time-lag between the melting of the glaciers and completion of the land mass movements. The existing literature suggests that the rate of uplifting of northern England is beginning to demonstrably slow. This means that the eustatic components of global sea level rise will start to become more pronounced in the north of England and in Scotland.

Eustatic component

The second (ice caps melting) and third (thermal expansion) effects of climate change on sea level, combine to cause a change in absolute water levels due to an increase in volume or mass. This is known as eustatic sea level rise and such changes are felt on a relatively uniform basis around the UK coast. The largest contributor to sea level rise, out of these effects of climate change, is the thermal expansion of ocean waters.

Relative sea level change

The combination of these isostatic and eustatic changes results in a change in sea level that we can directly observe at the coast. The combined effect is known as the relative sea level change (i.e. the net effect of eustatic change relative to isostatic adjustment). This is why sea level rise is a particularly severe problem in southern England: the absolute sea level has been rising and the land mass has been sinking. In northern Great Britain, while the sea level has been rising so has the land mass, meaning that the relative effect is less marked than in southern England, although it obviously remains an important consequence of climate change. In the future, the relative effect will become more pronounced as the isostatic adjustment slows down.

Rates of sea level rise

In order to compare past sea level rise with what will happen in the future, two datasets can be examined. First, geological evidence can be examined to identify isostatic changes, and second, actual tide gauge records can be analysed to reveal relative sea level trends.

Shennan and Horton (2002) compiled data regarding the relative rate of land uplift around Great Britain, including data for two stations within the Yorkshire and Humber region. Their best estimates for the current rate of land uplift at these stations are presented below.

Table 23. Late holocene relative land-/sea-level changes in the North East region

Station	Relative Change Value (mm/year)	Description
Humber (Inner Estuary)	-0.86	Land sinking
Humber (Outer Estuary)	-0.78	Land sinking

This analysis shows that the land mass in Yorkshire and Humber is sinking (due to isostatic rebound).

Because of the volumes of carbon dioxide already released into the atmosphere, scientists believe that sea levels will rise faster in the future than they have in the past. Defra recommends that up to the year 2025, and allowance of 2.5mm/year be made north of Flamborough Head and 4.0mm/year be made south of Flamborough. This rises to 7.0mm/year north of Flamborough and 8.5mm/year south of Flamborough between 2025 and 2055.

Extreme sea levels

Extreme sea level conditions typically arise when a particularly high or particularly low astronomical tide combines with a storm-related surge. A surge is a positive or negative deviation of the observed tide from the routine, predictable astronomical tide. It can be caused by high (or low) atmospheric pressure depressing (or elevating) the level that the tide reaches, or caused by the wind set-up of waters. Extreme sea levels can happen if there is an area of low pressure over the sea, which causes the tide level to be higher than normal. When combined with on-shore winds and a high tide (e.g. a spring tide) this can cause unusually high sea levels which can overtop defences and cause flooding.

The North Sea has historically been subject to positive surge events that have led to widespread flooding (see Box A).

Box A: Historic records of surge events in the North Sea

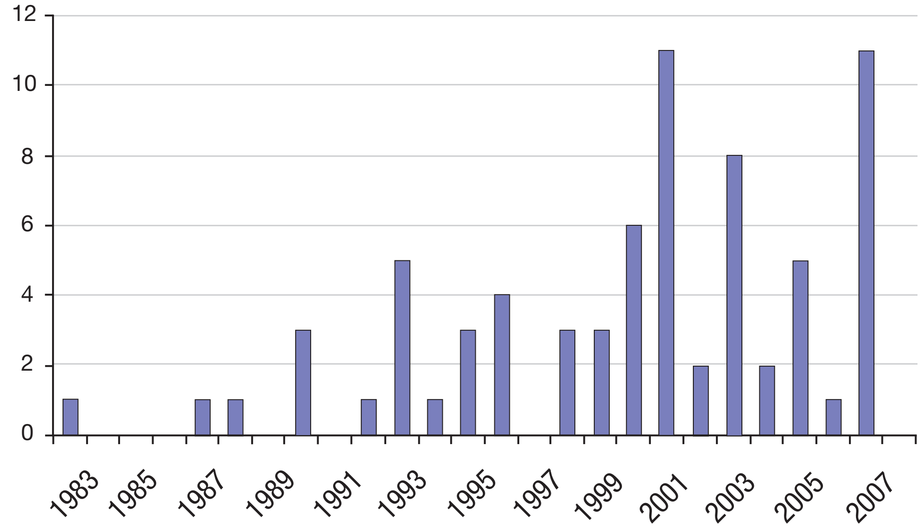
In the Netherlands on 18 November 1421, water from the North Sea breached sea defences and swept through 72 villages killing over 10,000 people. Similar disastrous breaches on the Dutch coast occurred in 1570, 1825, 1894, 1916 and 1953. During the infamous 1953 event, for example, it was estimated that 1,800 people were drowned in the Netherlands. These events prompted the Dutch Government to adopt a 'defend at all costs' policy to protect their country as over 40% of it lies below mean sea level.

The 1953 storm surge also devastated the east coast of England, particularly between the Humber and the Thames estuaries. The worst affected areas were Suffolk, Essex and Kent, including Canvey Island in the Thames where 58 people died. During the storm, wind speeds exceeding 80mph were recorded. The event resulted in the loss of over 300 lives, flooding of 100,000 hectares and caused damage to assets worth over £5 billion (in present value).

In response to this event, a massive programme of maintenance and capital works on flood defences was instigated, including the construction of the Thames Barrier. In addition, the Storm Tide Forecasting Service was introduced, which is operated on behalf of Defra by the Met Office. The service provides the Environment Agency (in England and Wales) and the Scottish Environment Protection Agency with regular coastal flooding, surge and wave activity forecasts.

As mentioned in Box A, the Thames Barrier was designed with the purpose of reducing the risk of flooding to London from surge events that build up in the North Sea and propagate up the Thames estuary. Construction of the barrier commenced in 1974 and it became operational in 1983. As can be seen from this graph, the barrier is being closed an increasing number of times per year. Whether this trend can be explained as being entirely attributable to the effects of increasing North Sea surge frequency associated with climate change is questionable, since natural fluctuations in the lunar tidal cycle and isostatic re-adjustment could both be affecting the need for barrier closures. However, this frequency of barrier closure is far greater than was anticipated during its inception, planning and design in the 1960s and 1970s.

Figure 5. Thames Barrier Closures, 1983-2007

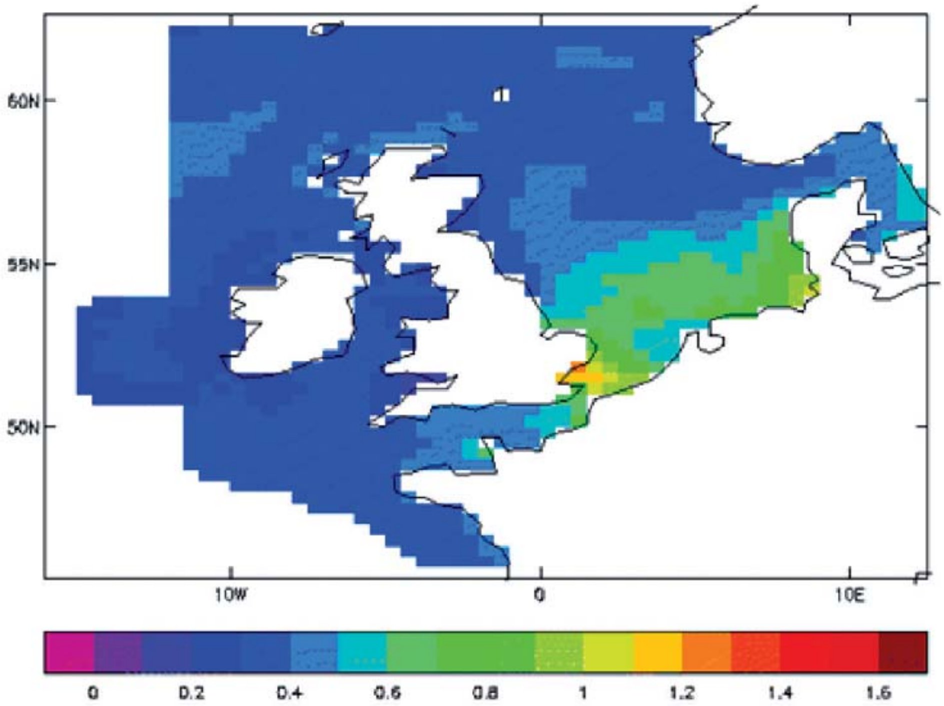


Source: Environment Agency

Recent research has investigated whether climate change could alter the occurrence of storm surges around the UK. The results indicated that a discernable increase in surge heights could be expected as a result of climate change along many parts of the UK coast, although interestingly the increase was smallest in the southern North Sea (where the present surge levels are greatest).

Modeling work was undertaken to inform the production of the UKCIP02 report using the Hadley Centre's third-generation regional climate model, HadRM3, to predict changes to the 1 in 50 year return period surge height by the 2080s for the Low, Medium-High and High emissions scenarios. This modeling took into account the combined effects of global average sea level rise, changes in storminess and vertical land movements. For the medium high scenario (below), the predicted increase in the 1 in 50 year return period surge height was 0.3 to 0.4m.

Figure 3. 1 in 50 year return period surge height, 2080s



Source: Hadley Centre

Waves

Waves are generated by wind-stresses acting over the surface of water and the maximum height a wave can reach is physically limited by either fetch (the distance across which the wind blows) or time (the duration for which the wind blows). Consequently, future changes in the generated wave climate will be governed by any change in (wind) storm track, frequency or intensity that results from climate change. Once generated, waves become transformed by a number of processes, such as refraction, reflection, diffraction, shoaling and breaking. Waves shoal and break as they approach the shore because the sea bed (and therefore the depth of water) becomes shallower (known as a depth-limiting effect). Under future rising sea levels, the depth-limiting effect will be progressively reduced and therefore waves will break slightly closer to shore, potentially leading to increased erosion of coastal landforms (such as shore platforms, beaches, sand dunes and sea cliffs) and increased overtopping of existing coastal defence structures.

The common perception is that offshore and near shore wind and wave conditions will worsen under climate change. Looking more specifically at the available wind and wave data cited in previous literature, anemometer data from 1977 to 1987 at Spurn Point shows an increase in annual mean wind speed of 4cm per second per year (4cm/s/yr), while wave data measured from 1978 to 1986 off the coast from Humber and Lincolnshire shows an increase in annual mean significant wave height of 1.5cm per year (National Rivers Authority, 1994). However, these data records cover only relatively limited durations (<15 years) and longer time-series are required before more meaningful results are yielded. Furthermore, these data relate to annual mean conditions and it is of course extreme events that are most damaging to the coastline.

The projection of winds is very difficult to achieve, particularly when considering long-term future conditions associated with climate change. Consequently, the projection of future wave climates, which is dependent on the future wind climate, is equally uncertain. Recent research (Sutherland and Wolf, 2002) did attempt to use a climate model to predict future wind conditions for 2075 and then use these conditions as an input to a wave model to assess the changes in wave height at five locations around the UK. In general terms, this revealed that changes in the wave climate are likely to be small (<5 per cent of present wave height values).

Due to the uncertainties with projecting future wind and wave climates, UKCIP has not presented any quantified information on wave height or direction changes associated with climate change (UKCIP, 2002). Instead qualitative hypotheses have been presented, such as the likely future tendency for the North Atlantic Oscillation (NAO), which influences wave heights, to create higher and more westerly index values in the future.

Other previous research on changes in future wave climates has mostly focused on 'what-if' scenarios, rather than definitive predictions. For example, the Futurecoast study (Defra, 2002) considered what the effect would be on the rate and direction of littoral sediment transport of different hypothetical future wave climate scenarios (i.e. existing predominant wave direction ±1° or 2°, existing significant wave height ±10 per cent). This assessment revealed, in general terms, that small changes in wave direction had little effect on energy or sediment transport rates at the shoreline, increased water levels associated with sea level rise had a modest effect, but increased or decreased wave heights by a hypothetical ±10 per cent had the greatest effect, increasing or decreasing wave energy at the shoreline by up to 10 per cent.

Output from the workshops

During this study a number of workshops were held to allow broad engagement with regional and local professionals working in and across the sectors addressed by the study. The first phase of workshops addressed the five core themes within the study. Following the conclusion of the sectoral element of the study, and building on areas identified through it, a larger cross-sectoral workshop was held at the Leeds Hilton on 21st January 2009. This whole day event attracted about 100 delegates who developed earlier discussions and investigated interactions between both impacts and adaptation measures to ensure that tackling one does not inadvertently create negative impacts elsewhere (a 'spillover effect'). Details of the workshops and distilled but unprocessed outputs, incorporating any additional comments submitted post-event, are available on the website. The prioritised list of adaptation actions, and both a summary of factors which are blocking the uptake of such actions, and factors which will enable change, are found in the Adaptation section of this report.

Impacts

This section provides a summary overview of the key impacts in the Yorkshire and Humber region by 2050. Further information for each of the study themes can also be found on the website. The detailed flooding section has been included in this report (see the Adaptation section) due to its potential to impact on all parts of the region and every sector, and should be read in conjunction with any of the theme sections.

Summary

Increased flooding from rivers and sea

Increases in the magnitude and intensity of rainfall events will increase river flows and flooding. Properties currently at risk will be at an increasing risk of more frequent flooding, and the number of properties at risk will rise. An increase in high intensity events will result in more 'flashy' flood events. In extensive river systems across the region, including the Ouse, Aire and Don, both intense summer rainfall, and increased winter saturation of the moorland areas of the Dales and North York Moors, will increase the likelihood of floods. Increasing flood levels and frequency are likely to put additional strain on critical defences. Rising sea levels and increased storminess will also increase tidal flooding problems around the Humber estuary due to overtopping and bypassing of the defences.

Increased surface water and drainage flooding

The majority of the existing urban network carries the combined flows of household waste and rainwater. Older systems are not usually designed for increased future flows and foul sewers may well become overloaded during large or intense rainfall events. This could lead to flooding of properties and roads. Any blockages within the system due to general debris, for example from storms, will also exacerbate problems and could lead to additional flooding. Drainage problems are exacerbated by high tide or river levels, when drainage outfalls may become restricted or tide-locked (causing flows to back-up and flood). This is a particular problem in Hull, where 90 per cent of the area is below high tide level.

Increased erosion

A range of existing weather impacts at the coast are likely to be exacerbated by climate change, including overtopping of coastal defences by waves leading to more frequent flooding of promenades, properties and other assets. Increased erosion of softer areas, due to higher wave and tidal energy particularly during storms, will lead to loss of land, assets and habitats. Over time a changing profile of the coastline may alter sediment movement and other coastal processes, and increase coastal habitat 'squeeze'.

Declining groundwater levels and decreased water resource in some areas

Reductions in groundwater levels due to reduced recharge rates could have important implications for river flow, particularly in summer, in areas towards the south of the region underlain by the Chalk and Corallian Limestone aquifers. This could have implications for some sensitive wetlands reliant on groundwater flows. Higher storage in the other principal aquifers (the Magnesian Limestone and the Sherwood Sandstone) means they are likely to be relatively robust to climate change.

Possible increase in groundwater derived floods, slope failures and subsidence

Increased winter rainfall and higher short-term recharge rates mean there is some risk of groundwater derived floods from the Chalk aquifer. Localised exacerbation of natural slope failures, particularly around river and stream banks, cannot be ruled out under the future climate. Some risks associated with historic spoil heaps may remain in remote areas of the Yorkshire Pennines. Risks are considered negligible in areas overlying the Limestone and Sandstone aquifers.

Possible increased risk of minewater outbreak

Recent outbreaks have occurred at Sheephouse Wood and Jackson Bridge (both South Yorkshire), associated with intense multi-day rainfall events. The projected increase in the number of these rainfall events in the future could lead to damage to infrastructure and significant pollution to water courses. The most likely locations for these are from shallower workings around Sheffield and Wakefield. Existing pumping schemes may also require greater capacity. A risk of outbreak is also suspected in the headwaters of the rivers Nidd, Wharfe and Swale.

Impacts on business premises and other built assets

These can be both positive and negative, are not sector dependent, and can apply across different sizes and types of organisation. Business premises, schools, places of worship and heritage sites and visitor attractions are likely to be impacted in similar ways. Changes in climate will affect both existing buildings and the requirements of new buildings. Particular impacts are expected to include increased internal temperatures; increased water penetration through weaknesses in the building fabric leading to the increased potential for rot and fungal attack; overloaded guttering and drainage; increased flood risk from river, sea and surface water flooding; and increased storm damage and wind-related disruption. Where urban flooding occurs, contamination will be a concern. Localised instances of subsidence also cannot be ruled out, although most of the vulnerable zones are in sparsely populated areas.

Impacts on employees, customers and students

Future comfort and safety are an issue for many industries and within the built environment issues such as increased temperature, and the potential for fungal growth, could affect health, comfort, and employee /pupil performance. Employees and customers in outdoor environments could also suffer greater incidence of heat stress, and where working practices and behaviour change in response to warmer temperatures there is potential for greater exposure to UV light with further implications for health. The effects of transport disruption on commuting, and on customer access, are also secondary impacts.

Changing yields and crops in agriculture and forestry

Climate change will extend the growing season and, combined with increased fertilisation from elevated carbon dioxide levels, crop and tree yields can be expected to increase. There is also potential for growing new and in particular more specialist crops. However over the longer term more significant adaptation to heat resilient cultivars or species may be required as current economic species become unviable. This is especially of concern in longer-term industries such as forestry. Fisheries will also experience changing yields as traditional catch species are replaced by new, warmer water species.

Opportunities to diversify the agricultural economy
Opportunities are likely to include diversification of farmland and woodland management to provide woody biomass for energy production, timber for use in more sustainable timber-framed buildings, and UK-based carbon sequestration (offset) schemes. The region is also well-placed to respond to an increased focus on issues such as locally-sourced or organic production. As climate change affects growing conditions overseas, other opportunities may become available to farmers and growers in the region.

Water shortages affecting agricultural practices
Increased summer temperatures, reduced summer rainfall, and more erratic rainfall patterns are expected to reduce the amount of water available for crop irrigation and for livestock. This will increase the demand for piped water for intensively farmed animals, and irrigation, and may increase competition between agricultural needs, domestic and industrial requirements, and the wider needs of the region's biodiversity.

Changes and disruption to land management practices
Changing weather patterns will potentially limit access to land and increase disruption around key farming periods such as sowing and harvesting, with consequences for yields. Animal movements between upland and lowland, or between sheds and fields, and other farm practices such as lambing and calving may need to occur at different times to make the most of forage growth and suitable temperatures. Wider changes in many managed areas will require altered maintenance and intervention regimes.

Loss of, and damage to, productive soils
Periods of drought alternating with more intense rainfall are likely to exacerbate problems with soil management and increase the occurrence of challenging farming conditions, such as waterlogged land. Animals may also require supplementary feeding or housing to prevent them trampling fields.
Greater erosion of soil from fields as a result of heavy rain or wind could also reduce topsoil cover, particularly on friable sandy soils (for example parts of the Vale of York) affecting productivity over time. Farming and forestry practices (such as clear-felling) could exacerbate this. Salinisation of soils may also occur, particularly in low-lying areas, as a result of drought conditions and increased irrigation.

Flooding of agricultural land and the potential for contamination
Increased flooding, inundation of coastal agricultural areas, and increased storminess and storm surge heights, can reduce land quality and spread contamination with implications for both animal and human health. In the shorter term, tidal flooding impacts may increase risks to livestock or crops in susceptible areas, and over the medium to long term may render some areas (in particular around the Humber) unsuitable for continued cultivation.

Changing pests and diseases affecting agriculture, forestry, parkland and gardens, and biodiversity
Changes to temperature, flooding frequency and other climate parameters could have an indirect effect through increasing the range or virulence of pests, and vectors of diseases such as bluetongue.
Larger pest populations can develop as they survive warmer winters, and new 'exotic' pests may also be introduced. Climate-related stresses will also increase susceptibility to pests and diseases and in

extreme situations there could be increased transmission of diseases to humans. Areas attracting large numbers of visitors (including tourists) will be more susceptible to the import and spread of pests and disease, also increasing pressure on the region's biodiversity.

Increases in uncontrolled fires and the need for emergency response
Drought conditions combined with an expected increase in outdoor leisure is projected to increase the occurrence of fires in forests, parks and moorlands. As well as direct economic impacts this also has implications for Fire and Rescue Services, and in particular on resourcing. Tackling rural fires will also be more challenging in areas experiencing water shortage.

Potential for greater tree cover and woodland expansion
There are opportunities for woodland expansion and extension across the region. Strategically positioned woodland can significantly increase floodplain storage and reduce downstream flood flows. In urban areas trees can limit local climatic variations, especially through reducing local temperatures and providing shelter from wind. Where trees are close to buildings and significant infrastructure, dealing with risks of damage and disruption from falling trees and debris will require close management.

Increased tourism
Higher summer temperatures are likely to increase demand for outdoor leisure and recreation, representing an opportunity for the region's tourism sector. UK destinations are expected to become more attractive to tourists from the UK and abroad, and this may be further enhanced by legislation enacted to tackle climate change (e.g. personal carbon allowances). Warmer temperatures may also increase visitation in the 'shoulder' periods reducing the seasonality of incomes associated with this sector.

But greater pressure on tourism centres and some increased vulnerability
Although increasing revenue for services including shops, hotels and parking, higher levels of visitation could increase conflict between recreational and other demands, including stressing transport and water treatment/supply infrastructure. Path erosion (through overuse) and loss during extreme rainfall events and floods are other possible impacts, and changes to the natural environment may affect the attractiveness of particular areas (e.g. landscapes suffering drought, may reduce visitation).
Sea-level rise and storm surges are also likely to have a greater impact on tourism due to the number of resorts and other attractions – such as the wildlife habitats of the Humber - at the coast. Losses due to flooding, inundation or storm damage, and in particular reductions in beach bathing space and coastal habitat integrity will have dramatic effects. Increases in flooding could also affect the quality of bathing waters (e.g. Blue Flag status), and affect the attractiveness of tourist areas.

Challenges for grounds and venue operation and maintenance
Golf clubs and other professional and amenity sports and leisure venues will find it increasingly difficult maintaining conditions during the summer when irrigation water may be limited. Conversely winter water logging of pitches and courses will be another concern, and the alternating wet and dry periods will require adapted management regimes. At heritage and amenity sites fine lawns may well demand year-round mowing and lawn care, raising maintenance costs or requiring changes to public expectation.

Outdoor events and festivals may become increasingly vulnerable to disruption and cancellation due to extreme weather, and crowd welfare, particularly during periods of extreme heat or storms, may require changes in safety procedures.

Opportunities for advanced manufacturing and Research and Development

The need for technological solutions to elements of climate mitigation, and adaptation as identified in this study and elsewhere, suggest an increasing role for the research and development sector. With a strong base in, and future focus on, manufacturing, as well as existing and developing links with universities, the Yorkshire and Humber region, is well placed to respond. This may offset any more negative effects on larger industrial processes.

Disproportionate impact on Small and Medium Enterprises (SMEs) and Digital Industries

By far the largest proportion of businesses across all sectors in the region are SMEs and although impacts will be felt across sectors, there is expected to be more of an influence on smaller companies. SMEs often operate from a single or small number of sites and as such they are often more vulnerable to any disruptions and changes in markets. Disruption to IT infrastructure will also particularly affect heavily-reliant industries. The large data storage centres associated with digital media and the creative industries (both of which are priority economic growth sectors for the region) are susceptible both to hot temperatures and particularly to flooding. The common location of servers and data storage in ground floor and basement locations creates a significant vulnerability.

Changing markets affecting retail and manufacturing

The retail sector is well-used to responding to changing demands due to weather events. The implications for manufacturers, suppliers and retailers, are well understood. Since most climate changes will occur over longer timescales the retail sector is expected to be reasonably resilient, although increased volatility may mean that more diverse ranges will need to be stocked.

Altered pressures on emergency services

Reductions in ice and snow could lead to fewer road accidents, although these impacts are unclear. Increasing summer and extreme temperatures are however likely to increase the need to respond to people suffering the effects of drought and heat stress. Increased storminess could also lead to increases in call-outs for rescue from floods and fallen trees.

Increasing challenges for waste management

Although increasing composting rates, increased temperatures could have an impact on the future operation and development of waste management facilities. Biodegradable waste may require more collections due to increased decomposition rates, odour and pests, and increased storminess could lead to increased dispersal of particulates and bioaerosols. Enhanced wet-dry cycles could increase the risk of slope instability on existing and closed waste management sites. Management and treatment processes will also need to be reviewed to deal with increased flood risk and more variable waste moisture content. Health risks to workers from increased temperatures, and pathogen and vermin activity also cannot be ruled out.

Disruption to transport infrastructure

Increased temperatures will have an effect on materials such as road surfaces, rail tracks, and overhead cables resulting in disruption and enforced safety speed limits. Parts of both the road and rail network are already vulnerable to windthrown trees, poles etc causing disruption. Wind-blown debris can also lead to blockages that exacerbate localised flooding. Increased winter and extreme rainfall will trigger more slippages in road cuttings and embankments, exacerbating scour around bridge abutments. Although lower snowfall may reduce the demand for snow clearance, an increase in marginal temperatures may increase the need for precautionary and post-event gritting and salting of roads. The region will also continue to experience sub-zero temperatures and relatively heavy snowfall. Inland rail tracks, trans-Pennine roads and rural roads, particularly in upland areas, will all continue to be affected. Transport infrastructure is also critically vulnerable to flooding, and its networked nature means that there are significant knock-on effects on all other areas covered by this study.

Rainfall and temperature will affect water supply and wastewater treatment

Increased winter and extreme rainfall will increase pressure on piped wastewater networks, as design capacities are more frequently exceeded with pollution and public health consequences. Conversely, reduced summer rainfall will affect river flows and water volumes in reservoirs. However the region is particularly well supplied with water and Yorkshire Water does not project a resource deficit despite increased demand on water supply for drinking and other domestic uses, and for agricultural use and livestock. Despite this, specific reservoirs, especially smaller ones in South Yorkshire, will be vulnerable to drought and some rivers may face tighter controls on abstraction.

Positive and negative effects on water treatment

Increases in temperature are likely to accelerate chemical and biological treatment processes for both water and sewage treatment. However sustained high temperatures could increase incidences of cryptosporidium in water, particularly if temperatures rise soon after intense rainfall events which have contaminated watercourses. More variable river flows will also affect effluent dilution, and higher treatment standards may be required.

Disruption to electricity and telecommunication networks, and wider knock-on effects

Increases in winter average wind speeds (and also extreme wind speeds) would make steel lattice towers and transmission lines more susceptible to failure. Energy and telecommunications infrastructure is also extremely vulnerable to flooding. A major consequence of any failure is the effect on other sectors, including supply disruptions to pumping stations, hospitals and water and sewage treatment works, as well as to businesses and households, and loss of communications during emergency responses.

Positive and negative effects for the region's biodiversity

Climate change models predict different outcomes for biodiversity, which is not surprising given the complexity of interactions between different species and habitats. However it is clear that those species which can disperse and colonise different areas easily will have the advantage over those which cannot. In general the direct impacts are likely to be:

- Changes in the timings of seasonal events (phenology), potentially leading to loss of synchrony between species and their food;

- Shifts in suitable climate conditions for individual species affecting both abundance and range;
- Changes in habitat composition.

Increased fragmentation of sensitive habitats
Upland hay meadows are unique to northern England and, although losses to date are not related to climate, future distribution is likely to be restricted to higher parts of the Pennines. This fragmentation will also be exacerbated by the likely encroachment of generalist species into habitats (for instance an increased range of grassland species and insects, and consequent decline in more specialist species).

Significant changes to upland and lowland wetlands
Increased winter rainfall may increase waterlogging, but although high rainfall does help sustain bog habitats, more intense rainfall is likely to increase runoff into streams and could enhance erosion. This is particularly the case when combined with other pressures such as recreation. Lowland wet meadow, already under threat from drainage, is likely to deteriorate further due to drought and enhanced abstraction. Changes in coastal processes may also have a detrimental impact as sea levels rise and changes in erosion could increase habitat loss, with knock-on impacts on species which use these habitats.

Varying conditions in surface waters
Rising temperatures in streams will increase biological respiration and may result in periods of anoxia (no oxygen). More variable seasonal flows are likely to affect habitats which have adapted to less volatile conditions, in particular as high summer temperatures are also likely to reduce stream flow but increased rainfall is likely to flush sediments and other pollutants through the system. As water availability, flow and quality are all likely to change, the viability of some freshwater habitats and species may be affected.

Exacerbation of existing health conditions
Air pollution episodes, especially during extreme heat events in urban areas, are expected to increase the incidence of complications associated with respiratory illnesses such as asthma, and Chronic Obstructive Pulmonary Disease. More frequent intense rainfall, and flooding affecting housing, is expected to worsen mental health concerns such as stress and depression. Acute and chronic impacts on mental wellbeing are especially evident during and following flood events and often persist far beyond the flood itself. There is also expected to be an increase in acute health problems, including heat stress, exhaustion and dehydration, particularly during extreme heatwaves. As climate change is expected to exacerbate current problems, those in areas already identified as deprived, or people/communities identified as vulnerable, will be most severely affected.

Changing nature of health needs
Fuel poverty and cold-related conditions, injuries and mortality may decline during winter due to milder temperatures. However summer heat waves will make homes uncomfortable, particularly for the elderly and vulnerable, and as temperatures rise, conditions associated with insects, vermin, and vector- and water-borne diseases will be more widespread. Behavioural change in response to warmer temperatures, and more outdoor leisure and working, could potentially increase the number of skin cancer cases from UV exposure.

Challenges to health care delivery

Hospitals and care homes across the region may find it increasingly difficult to provide core services due to rising summer temperatures and associated conditions. If buildings have difficulty maintaining comfortable temperatures, patients will be placed under additional stress, possibly exacerbating their conditions. Increased volatility and severe weather may impact mobile care and support services (e.g. home help and meals-on-wheels) with serious implications for vulnerable individuals, particularly in rural areas.

5. Adaptation

The need for adaptation

In combating climate change there is a need for regional action in terms of both adaptation and mitigation.

Adaptation focuses on ensuring services, assets, communities, businesses, infrastructure and the economy are resilient to the realities of a changing climate.

Mitigation focuses on reducing the emission of greenhouse gases through energy efficiency measures, the Kyoto Protocol, regulation and control, etc in an attempt to reduce the rate of climate change.

There is considerable inertia in the earth's climate system and we are locked into the inevitable consequences of the greenhouse gasses that have already been (and continue to be) released into the atmosphere. This is why adaptation is needed now.

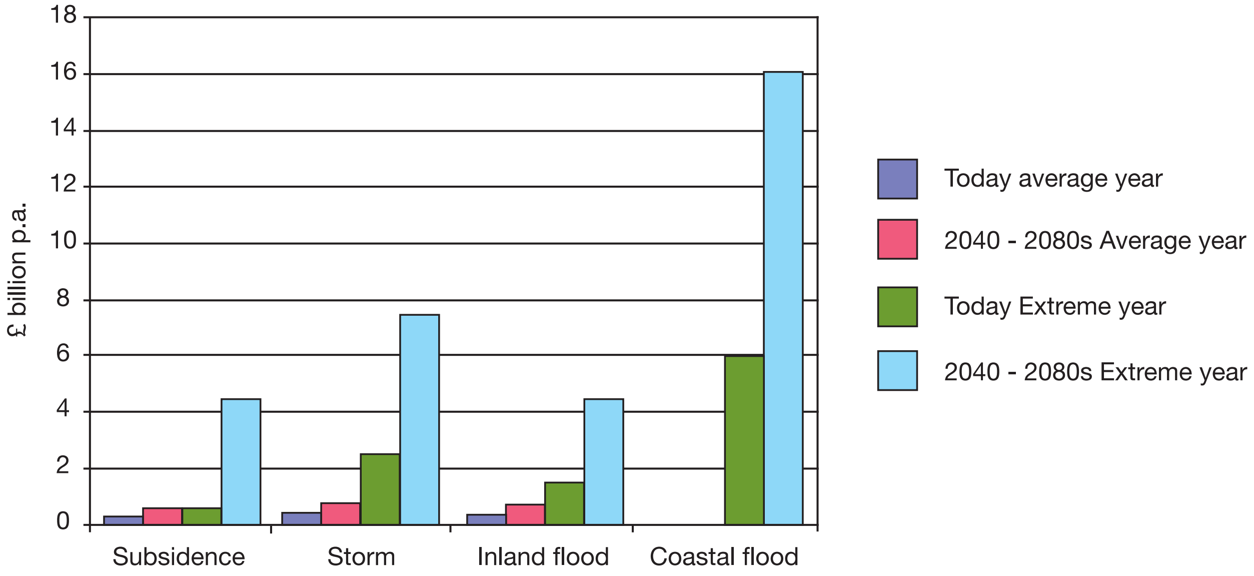
Mitigation is also important now, but for a different reason. To ensure that climate changes remain manageable beyond the next 50 years, there is a need for immediate reductions in greenhouse gas emissions. The inertia in the earth's climate system means that the benefits of reducing emissions will not be immediate and therefore the earlier mitigation action is taken, the earlier the benefits will be realised. In the absence of appropriate mitigation, the earth's climate system may accelerate towards a tipping point, beyond which changes may be irreversible.

Cost of Inaction versus Cost of Adaptation

Current weather events cause considerable economic loss due to direct damage and disruption, which in itself causes indirect damage and consequential loss. In an average year, around £800million is paid out by insurers in weather-related claims. In a year with exceptional events, this can rise to around £10.5billion. During the summer 2007 floods, it has been estimated that around £5billion of economic damage was caused nationally. The principal causes of weather-related damages are subsidence, storm-damage, inland flooding and coastal flooding.

In its publication, "Insuring Our Future Climate: Thinking for Tomorrow, Today", the Association of British Insurers (ABI) has estimated that by the 2050s, the payouts during an average year will rise to around £2.2billion and payouts during years with exceptional events will increase nearly three-fold to around £29.2billion, due to the effects of climate change alone (i.e. not taking into consideration other changes such as new buildings, more material possessions in homes, etc.) The figure below illustrates this.

Figure 7. Insurance Pay-outs.



Source: ABI

This research provides, at an indicative level, the broad scale of the cost of inaction against climate change for the UK, as measured by insurance payouts. Additionally, the high profile Stern Review on the Economics of Climate Change suggests that if no action is taken, the overall costs and risks of climate change will be equivalent to losing at least five per cent, and possibly as much as 20 per cent, of global Gross Domestic Product (GDP) each year, now and into the future. In contrast, the cost of action (here measured through the benefits of mitigation and adaptation, rather than adaptation alone) are around one per cent of global GDP each year.

The European Environment Agency has recently published a technical report entitled Climate Change: The Cost of Action and the Cost of Adaptation in which it is identified that:

adaptation has an extremely important role in reducing the economic costs of climate change; and while adaptation has a cost, it significantly reduces the residual costs of climate change.

All of these previous studies highlight the importance of adaptation actions now in more than offsetting the economic consequences of inaction later.

Adaptation Tools

To assist organisations in identifying suitable adaptation approaches, a number of adaptation tools are available.The UKCIP Adaptation Wizard is one such tool that provides information from the latest research projects and covers a wide range of sectors. Other industry guidance documents are also available relating to best practice in adaptation for specific sectors, such as business or flood and coastal defences. Adaptation can best be achieved by linking appropriate measures into planned maintenance activities and all capital investment projects.

A large number of sector-specific adaptation mechanisms have been identified throughout this study and are laid out in the sectoral/thematic pages available on the website. However there are also a number of common overarching themes and adaptation actions which will bring benefits for all. These are set out below, along with a list of the factors which are currently blocking the uptake of adaptation measures, and factors which will enable or facilitate adaptation actions.

Overarching themes

In order to address the current low levels of specific information relating to climate vulnerability there is a need to encourage and develop processes to monitor, assess, and respond to change. Many adaptation actions will rely initially on identifying vulnerability through monitoring. Early identification and assessment of weaknesses in particular services, buildings or activities means that appropriate and necessary action can be built into routine upgrade and maintenance programmes, rather than relying on more expensive reactive actions. This is a more cost effective means of adapting to future change and reducing the risks associated with the future climate.

Guidance and dissemination. Information relating to the nature of climate change, impacts on different areas, and adaptation activities available, is being released regularly. Successful actions must be based on the best available information but mechanisms for ensuring the wide circulation and awareness of this information, within sectors to ensure it is of most relevance, are crucial. Information is relevant at the local, regional, global and sectoral levels, and identifying trusted sources of information is critical.

Innovation. Many sectors can build resilience and adapt to climate change through moving away from traditional techniques, markets and crops or products. While early movement has the potential to gain market advantage, it is perceived as carrying an element of risk. These risks can be reduced through the application of research findings, pilot studies, and from adopting any learning from experiences elsewhere.

Opportunity. Climate change brings opportunities as well as potential challenges. Early identification of these opportunities, and positioning to maximise them, will bring advantages to the region and allow it to align future growth in a climate-adapted way. As well as looking to reduce risks, actions should also be designed to maximise these benefits.

Staged adaptation. Not all impacts require an immediate response, and a single big change is not always the safest or most cost-effective means of adapting to the gradual changes in climate. A more staged approach enables regular review of markets and assets, but also of developing knowledge and best practices. Coordination of actions is key to this, but introducing changes incrementally also builds in flexibility. As such even long-term decisions do not lock the region into an unadapted future.

Cross sectoral adaptation actions

Strategically-delivered activities, identified as having the potential to bring wide-ranging benefits across a number of sectors, and which could be integrated into a resourced regional action plan, include:

- Better manage all land to address drainage, water storage and flooding
- Facilitate greater uptake of green infrastructure
- Develop and encourage new crops and land management methods
- Stimulate private sector involvement
- Ensure climate change and regional priorities are aligned
- Improve co-ordination with the region, within and between sectors, to raise awareness of resilience and develop approaches to climate adaptation
- Optimise the use of existing building stock, including encouraging retro-fitting for climate adaptation

Blocking delivery

A number of factors have been identified as potentially blocking effective delivery of climate change adaptation.

Political and private sector understanding and will. Although tackling climate change is attractive, some necessary actions can be less so. Drive at the highest levels can vary, and in particular, there is a strong perception of low private sector engagement within the region, despite business vulnerabilities and a potentially key role in delivering adaptation. Linked with this there is also felt to be a general resistance to innovation which, although playing a role in adaptation, can be high-risk. There are further concerns about inconsistent application of regulations, including in the planning system, standing in the way of climate adaptation.

Lack of coordination, responsibility and communication at a specific level. The nature of climate change means that it will affect almost everyone, within most sectors of society. Due to the number of stakeholders, the cross sectoral nature of many of the issues, and potentially competing objectives between stakeholders, there is a strong role for coordination at the regional, and at the sub-regional or sectoral/thematic levels.

Lack of communications, integration and engagement. Linked with coordination and understanding are perceived poor levels of communication about climate change challenges to many sectors within Yorkshire and Humber. Low levels of information sharing between different sectors and networks are of concern, and are associated with insufficient advocacy at the appropriate level (regional, sub-regional and sectoral) to raise awareness, to make the case for action, and to drive adaptive action.

A lack of incentive has also been identified as affecting delivery. Due to the lower levels of understanding of the benefits and risks associated with climate change, incentives may be required to encourage action that might be perceived as a risk. This may not necessarily be financial incentives, as business support and appropriate encouragement may also enable greater drive by organisations to address these issues.

Enabling change

To address the above points and to enable delivery of more focused, thematic climate change adaptation in a coherent and efficient way, we suggest that five overarching enabling factors are addressed.

1. Centralised coordination of climate change adaptation activity in the region. Operating at the regional level this should drive the consolidation of climate change work in Yorkshire and Humber, and delivery of actions against a prioritised and resourced climate change adaptation plan. This regularly-reviewed plan should encompass the other areas of enabling work. Further to this, a workshop carried out as part of the study discussed actions which can bring cross-sectoral benefits (these are the cross sectoral actions listed above).

2. Wider education and engagement of stakeholders and the public to ensure adaptive capacity is built into organisations and wider political structures. Stronger engagement could be facilitated through sectoral groups, established along the lines of this study or within existing structures. These will help ensure climate change impacts and adaptation measures are made relevant to all sectors. They can also ensure appropriate communication and information sharing, and coordinate delivery within and between sectors where appropriate, contributing to progressing the regional adaptation plan.

3. Collation and dissemination of an improved evidence base to support and enable greater engagement by businesses and organisations in particular. This evidence base should be made widely available and be used to support greater advocacy for change, coordinated through sectoral groups and aimed at building political and board level will, including lobbying for change at the national level. As well as drawing together existing and emerging guidance and information at the national and sectoral levels this evidence base should be augmented by targeted research including regional vulnerability/opportunity mapping. This can then enable adequate risk assessment, and allow a risk-based approach to prioritisation within the regional adaptation plan.

4. Identify, and fund where necessary, pilot schemes within the region but linked with national, European and international initiatives to trial innovative approaches to climate change adaptation. This would further contribute to the evidence base and such schemes can be used to overcome perceptions of risk associated with innovation, facilitating further change. They could also help in positioning the region as a leader in climate change adaptation across a range of sectors.

5. Delivery of climate change resilience through long-term planning, including infrastructure and spatial planning, will require greater integration of climate change awareness and understanding into planning structures and planners' toolkits. Although linked with wider education, this reflects the importance with which delivering tangible climate change adaptation immediately is seen by regional stakeholders. The ongoing Regional Spatial Strategy review and regeneration activity offer means for delivery. However, flexibility is critical so that approaches can be amended in the light of emerging information in what remains a developing field.

Flooding

The Flooding section which follows contains information that is pertinent to every sector and every part of the region and which has overarching impacts and adaptation requirements. It is especially important that the Flooding section is read in conjunction with any of the other thematic sections.

Context and background

Over recent years there have been an increasing number of extreme rainfall and flooding events that seem to be occurring on a more frequent basis.

Previous major flooding has impacted across the region with two significant events in recent years. In October 2000, prolonged heavy rainfall led to major flooding across several of the main rivers causing widespread impacts on the Wharfe, Nidd, Ouse, Ure, and Swale, including 550 properties around York, 370 properties on the Aire near Keighley, and extensive flooding around Selby and Barlby. The River Ouse reached its highest level ever recorded.

In summer 2007 the worst flooding seen in decades hit areas around York and the Humber, as well as the Midlands, Gloucestershire and the South East. Several people died, and over 55,000 homes and businesses were flooded across England and Wales, totaling an approximate £3billion in insured losses alone, with four years worth of claims being made during the two months of June and July. Water supplies to 140,000 homes in Gloucestershire were cut off for up to two weeks, and almost 300 schools in Yorkshire and Humber suffered damage.

May to July 2007 was the wettest period since records began in 1766. The ground became saturated during May and early June followed by several periods of extreme rainfall, with some locations experiencing up to a month's rainfall falling in a few hours. This produced some of the highest river levels on record and extensive flooding from the Rivers Don, Severn and Thames, as well as widespread surface water flooding, notably around South Yorkshire and Humber.

Across the Yorkshire and Humber region, approximately 25,000 homes and 4,000 businesses were flooded, as well as 248 schools, 65km of A-roads, 149 electricity substations and 23 sewage treatment works, affecting the service provided to more than 2.5 million people. This produced an estimated £2,100 million of overall damages, including £1,100 million in Sheffield and Rotherham, £650 million in Hull, £280 million in Doncaster, and £80 million across Leeds, Wakefield and York.

The extensive flooding events of summer 2007 also showed the impacts of key infrastructure such as water treatment works and electricity sub-stations being flooded, which in turn affected a significant number of the surrounding population. As well as residents, many organisations rely heavily on constant power and water supply to support the local population, which highlights the criticality of these services to the wider community than that directly affected by flooding.

The Government instigated a review into the summer 2007 floods. The Pitt Review reports on the extents and impacts of the flooding, and makes recommendations for the regulation and organisation of flood risk management, the management of surface water flooding and drainage, emergency response to extreme events and the identification and protection of critical infrastructure. The Environment Agency also produced a Review of 2007 Summer Floods which makes further recommendations for improvements.

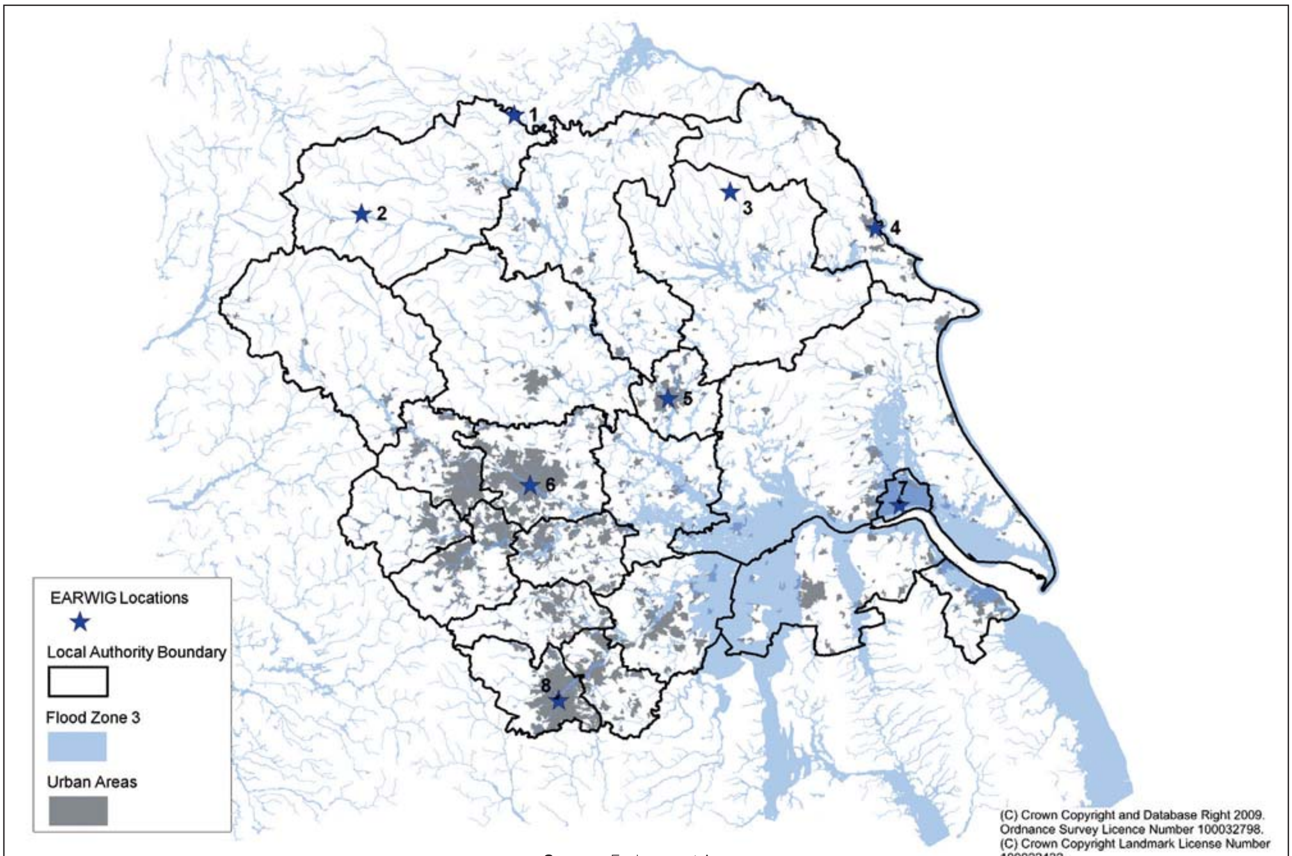
The following sections assess how flooding may affect the region by the 2050s, based on the projected climate changes, and what adaptation actions may be taken.

Sources of flooding

The predominant flood risk across the region, based on the Environment Agency's indicative Flood Zones, is related to tidal flooding in the Humber estuary. (The Flood Zones present the 'undefended' situation, assuming that the currently provided flood defences are not in place). The Humber is the largest area at risk from tidal flooding in England, with the greatest value of assets at risk outside of the Thames estuary. There are currently 90,000 hectares of land and 400,000 people within the identified flood risk areas, in addition to major industries, the country's largest port complex (Immingham), and other businesses.

Significant areas on all of the major rivers and tributaries are also at risk of flooding, including York (River Ouse), Leeds and Castleford (River Aire), Dewsbury and Wakefield (River Calder), Sheffield, Rotherham and Doncaster (River Don), Beverley and Hull (River Hull). In addition to this there is likely to be extensive flood risk related to surface water/drainage across the region, particularly in heavily urbanised areas, although the key risk locations are not defined. There is limited coastal flooding due to the natural protection provided by high cliffs along much of the open coast.

Figure 8. Areas at Risk of Flooding from Rivers and Sea.



Source: Environment Agency

Future flooding

Despite the general trend for less annual rainfall and drier summers, the Met Office warns that in the future there could be an increase in extreme rainfall events, similar to those high intensity storms that were prevalent during summer 2007. In addition, winter rainfall is projected to increase by up to 17 per cent by the 2050s, with the magnitude of individual extreme rainfall events increasing by up to 10 per cent.

A recent paper from Newcastle University showed that there has been a change in the timing of extreme rainfall with the majority now occurring during the autumn months. The paper also determined that the magnitude of recent extreme rainfall events has increased two-fold over parts of the UK since the 1960s, and that intensities previously experienced every 25 years now occur at approximately six year intervals.

There is further evidence that winters during the 1990s were wetter than ever before, with a threefold increase in the number of wet winter days recorded at Whitby. Some climate predictions indicate a potential fourfold increase in the frequency of future wet winters with 60 per cent more rainfall than the current average.

In addition, mean sea levels within the Humber estuary and along the Yorkshire coast are estimated to have risen at rates of between 1.5 and 3.6mm per year over the last 80 years. Future mean sea levels may rise by a total of 0.3m by the year 2050, based on current guidance from Defra, and extreme sea surge levels are likely to be even more exaggerated.

The Office of Science and Technology's Foresight Flood and Coastal Defence report estimates that, at a national level, the risk of flooding from rivers and the sea will at least double by the 2080s, and could increase by up to 20 times. The number of people at high risk of flooding across the UK could rise from 1.5 million to between 2.3 and 3.5 million over this period, with the cost of flooding rising from the current £1 billion a year to between £1.5 billion and £21 billion. This clearly represents a significant threat to the lives of many communities and the way the country operates as a whole.

Impacts from flooding from rivers and the sea

Increases in the magnitude and intensity of rainfall events will produce increasing river flows and therefore increased flooding across the flood plain areas. With larger rainfall events, the volume of surface runoff will typically be greater which will increase river flood flows and raise river levels throughout the system. The extents of flooding will increase putting a greater number of properties at risk. Additionally, properties currently at risk will be at an increasing risk of more frequent flooding. Higher intensity rainfall events over extended periods will mean the ground becomes more saturated than usual. This will exacerbate the problem of increased magnitude individual rainfall events, with increased levels of wetness meaning that a greater proportion of rainfall will runoff into the watercourses, and more quickly.

Increased 'seasonality' of rainfall will produce further flooding problems. As described above, any greater volume rainfall during the winter months will produce increased runoff. Also, future summer rainfall events are likely to be shorter, and of higher intensity, which will cause more frequent short, sharp, 'flashy' flooding events. With rising summer temperatures and lengthening periods of dryness, it is likely that areas, particularly clay-based ground, will harden and not be as permeable to rainfall.

This will have the likely effect of increasing the volume and speed of runoff during summer storm events. For extensive river systems such as the Ouse, Aire, Calder, Don, and other main river catchments across the region, intense summer events are likely to have adverse impacts for downstream areas with the input of fast runoff flows from a number of steep tributaries.

Greater seasonality of rainfall will lead to heightened groundwater levels and saturation during the winter months, and produce an increased flood season that may last for several weeks or months. Increased winter rainfall is likely to cause larger, longer duration floods during this period. In upland catchment areas, increased winter wetness will mean that the moorland areas of the Dales and North York Moors become more saturated. This will in turn increase the likelihood of sheet run off from the saturated ground surface and flashy catchment flows. Also higher groundwater recharge rates, particularly in the chalk aquifers across East Riding, will produce raised baseflows and groundwater levels. Increases in flashy events are likely to increase the frequency and impacts of small watercourse and surface water flooding, as heavy rainfall produces high volumes of runoff from the surrounding saturated hillsides.

Rising sea levels and increased storminess will increase the height of tides which will increase the chance of overtopping, bypassing and breaching of tidal defences around the Humber estuary. Higher tide levels will also restrict the capacity of rivers to discharge into the sea (this is known as tide-locking). If heavy rainfall and extreme high tides occur at the same time, there will be increased river levels and a greater chance of flooding.

With the average temperatures set to rise, if significant amounts of snow were to accumulate, then the magnitude and speed of snow melt events would be likely to increase. This would impact on river base flows, and potentially flooding, in upland areas, particularly on smaller watercourses in the Dales, Pennines and North York Moors.

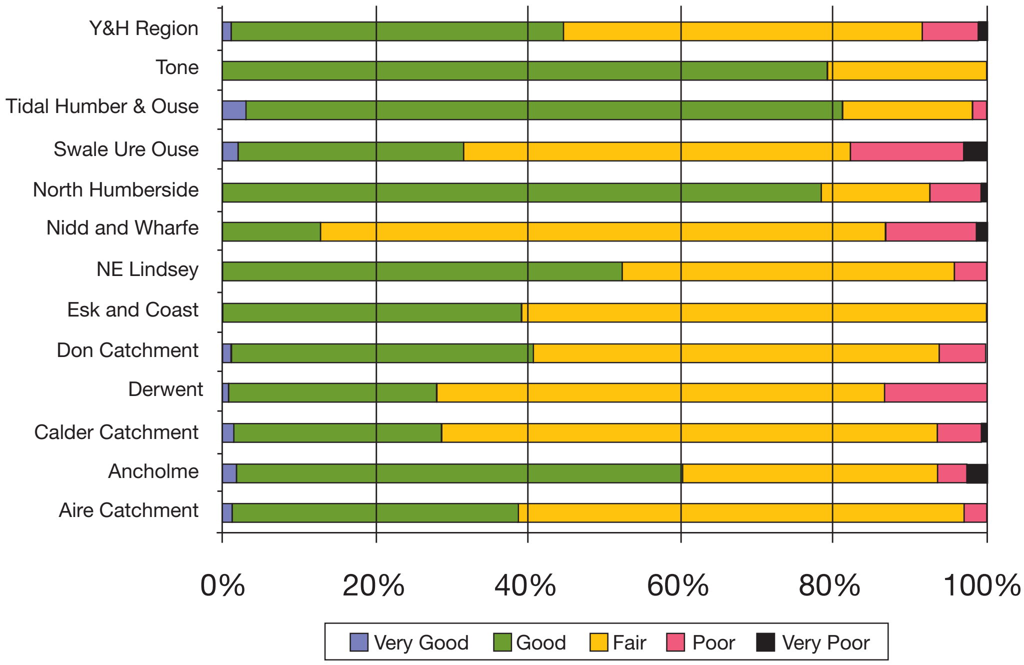
Impacts on flood defences

With regards to our flood defences, the maintenance of watercourses and the management of flood risk across the region, key impacts will include:

- Greater flood flows and increased flood levels leading to a reduction in the standard of protection provided by defences
- Increased scour and undermining of defence embankments
- More silt being washed into watercourses reducing the channel flow capacity
- The growing season starting earlier and lasting longer will increase the amount of channel maintenance and vegetation clearance needed to retain flow capacity
- More debris blocking in-flow structures and greater maintenance of culvert trash screens (because of higher river or flood flows washing debris into watercourses)
- Increasing populations of rabbits and vermin (with warmer temperatures), likely to produce more adverse affects to defence embankments from burrowing.

The Environment Agency maintains around 4,400km of flood defences in the Yorkshire and Humber region, many of which are ageing and were constructed during the 1950s/60s to a lower standard of protection than new defences are built to today. These are regularly inspected to assess their condition on a scale of one (very good) to five (very poor). In 2008, 91 per cent of the flood defences in the region were fair (grade three) or better, with 8.4 per cent being poor or very poor. The 2000 floods caused £2.5 million of damage to flood defences and with increasing flood levels and frequency in the future, the cost of maintaining and repairing flood defences is likely to rise.

Figure 9. Condition of Flood Defences Owned and Maintained by the Environment Agency, 2008.



Source: Environment Agency

Changing rainfall and weather will influence the geomorphology of the river networks, influencing the condition and durability of existing flood defences. Erosion, deposition and the transport of sediment are influenced by the flow regime of the river and the volume of sediment supplied to the river system. Changes in these processes, and increasing speed of river and flood flows from intense rainfall events, will have significant effects on the erosion of river banks and the integrity of the river flood defences.

Sedimentation from increased surface water and sediment runoff during intense rainfall events will reduce the capacity of river channels and culverts, increasing the potential risk of flooding in certain areas. Increased in-channel sediment supply through erosion and more frequent transport of greater volumes of sediment of a coarser grain size may also have consequences for sediment management and channel maintenance, for example where sediment is deposited within reservoirs and upstream of in-channel structures.

A greater number of high flow events will also result in more frequent out-of-bank flows and an increased exchange of sediment between the channel and the floodplain. This will be limited where flood embankments remain intact, but may contribute to the undermining of flood embankments if they are overtopped. Sediment supply through the weathering of hill slopes and channel banks is directly influenced by weather, including temperature differences, wetting and drying and freeze-thaw processes. Changes in temperature and rainfall will therefore result in changes in sediment supply and consequently changes in the river geomorphology.

A further indirect impact on river geomorphology may result from changes in flood plain land uses and vegetation. Changes in vegetation cover within the catchment and riparian zone resulting from climatic change may affect soil erosion and fine sediment delivery to rivers through runoff and the field drainage network. These changes could lead to changes in the flow regime and route of the watercourse.

Impacts on surface water/drainage

Historically, urban sewer systems carried both household waste and rainwater. Drainage systems built during the last 30 years have generally been constructed to carry these flows separately, however in our major cities much of the drainage networks were built in the 19th century and are now old and decrepit and not able to cope with the worsening 21st century conditions. Newer systems were constructed with ageing rainfall data which did not take into account climate change increases in future rainfall. Therefore, foul sewers become overloaded during large rainfall events leading to the flooding of properties and roads. Debris can often block sewers, further exacerbating problems or causing additional flooding.

Although the extreme and devastating flood event in summer 2007 was caused by surface water flooding, ordinarily, surface water floods tend to happen in very localised areas, particularly heavily urbanised low-lying ones, and although they occur with a fairly high frequency, they are generally of lower impact (in terms of risk and extent) than river or tidal flooding. However, problems can be made worse with high tide or river levels, when drainage outfalls may become tide-locked. This restricts the discharge from the outfalls and causes flows to back-up within the system and can lead to localised flooding. This is known to be a particular problem in Hull where 90 per cent of the area is below the high tide level.

In addition, direct flooding from surface water runoff can occur where drainage provision is insufficient or non-existent, when rainfall directly runs off from the surrounding ground and does not issue from a watercourse and is not able to enter a local drainage system (often referred to as unconnected flooding). Surface runoff can be a significant cause of flooding, especially across urban areas and the steeper upland areas.

Foul and surface water drainage systems potentially are vulnerable to the following effects of climate change:

- Increases in rainfall intensities in winter months will produce increased incidents of flooding across the drainage network during these seasons or months. There is a finite capacity within the surface water drainage systems and excess flows will lead to surcharging and localised flooding, particularly in the major urban locations. Blockages in the network and ancillary structures will exacerbate problems.

- Increases in winter rainfall will increase the number of flooding incidents at known foul and surface water sewer flooding locations, and new flooding locations are likely to arise as drainage systems are put under greater pressure. Low gradient urban areas will be the most susceptible, especially as the current 30 year design standard will fail to provide the same level of protection under future climate conditions.
- Short duration, high intensity summer storms are likely to become more prevalent in the future and these types of events typically have the greatest impact on drainage systems, as water can quickly saturate or bypass permeable areas leading to fast runoff flows and overwhelming local drainage systems. This can be a particular problem in both steep urbanised areas and in upland areas where fast runoff from surrounding steep hillsides and moorlands causes flooding on reaching lower gradients.
- Significant impacts to the drainage systems would also arise from mid to long duration events due to high groundwater levels and saturation. This would exacerbate the problem of increased magnitude individual rainfall events, with increased levels of wetness meaning that a greater proportion of rainfall will runoff into the local drainage systems, and more quickly.
- The ageing nature of our sewer system coupled with increased demand (because of greater flows from more rainfall, and from new developments) will produce more foul sewer spills. Improvements to combined sewer overflows (CSOs) performance, capacity and storage will be required.
- Sea level rise and higher river flows will restrict the capacity of both CSOs and surface water systems to discharge which can produce flooding problems further up the system.
- Snow melt from the thawing of snowfall on the upland areas can produce significant runoff flows into local drainage systems. This can have particular impact where heavy snowfall thaws at a fast rate.

Impacts on people and businesses

As the previous recent major events have shown (York and Selby in 2000, Sheffield, Hull, Humber, etc in summer 2007) the impacts of flooding to the population and country's assets can be severe. The major impacts to the community are:

- Risk of fatalities
- Direct property damages
- Direct impacts to vulnerable communities and critical infrastructure
- Indirect damages, due to access and distribution routes being blocked, supply chains being affected, and widespread disruption to the local economy from people not flooded being unable to go to work (due to transport network flooding or having to look after children whose schools have been closed due to flooding)
- Health and safety issues due to the contamination of flood waters from sewer overflows or the flooding of treatment works
- Continuity of service provision from emergency, welfare and community services, particularly to support vulnerable communities during times of impacts
- Increasing tidal and fluvial flood risks may lead to 'insurance blight' for businesses and households within flood-affected areas.

With future climate change, there is projected to be an increase in the number of properties and assets at risk. The following critical infrastructure is estimated to be at risk of future flooding from rivers or the sea across the Yorkshire and Humber region:

- 22 Ambulance Stations, 90 Police Stations and 51 Fire Stations.
- 509 Schools, 161 Nurseries, and 63 College/University buildings.
- 33 Hospitals.
- 79 Railway Stations and 11 Bus Stations.
- 157 Sewage Treatment Works.
- Over 375,500 Residential properties.

….as well as numerous other businesses and industries.

From our discussions with various organisations within the region, one of the greatest threats posed by the weather on social wellbeing in the region is the serious potential for disruption to transport networks, as we have experienced during previous events. Also, the increased likelihood for vulnerable people and communities to be left without electricity, heating or water due to the flooding of critical infrastructure (as occurred during the summer 2007 floods), is a serious threat to wellbeing.

Adapting to flooding from rivers and the sea

Flooding from the rivers, streams and sea is generally pro-actively managed by the appropriate authorities as part of well-established flood risk management programmes. These include long-term and strategic planning, flood warning systems, and the development and maintenance of appropriate flood risk management solutions. More than 205,000 properties (70 per cent of those at risk) are currently covered by the Environment Agency's flood warning service (although not all of these are registered to receive warnings). Typically, these activities inherently consider the likely effects of future climate changes and are planned to continue into the future as part of central government's approach to flood risk management.

The Regional Flood Defence Committee and Environment Agency have various flood risk management projects in their current programme. Of particular note are the following:

- The Humber Strategy – considers the future management of flood defences along the estuary, to continue the protection provided to 99 per cent of inhabitants, and the development of managed realignment areas to create 1,000 hectares of additional inter-tidal habitat.
- Development of new strategies for flood management to return certain agricultural floodplain land to washlands, in order to provide increased protection to surrounding urban areas.
- Flood defence scheme through Leeds city centre to raise the current flood defences and provide additional upstream storage (£80 million, to start 2011).

There are many adaptation measures that should continue to be incorporated in this approach. These include measures at a strategic planning level down to flood defence provision and forecasting significant events.

Detailed hydrological and hydraulic modeling could be used to identify the numbers of properties at risk under future climate scenarios. This could involve identifying the criticality and vulnerability of key public infrastructure (electricity, gas, water supply, sewage works, telecommunications, transport, schools) and producing improved regulations for their ongoing protection from flooding. The risks need to be considered across organisations to identify key interdependencies.

Improved regulation and guidance should be provided across all sectors to ensure that the impacts of flooding due to climate change are considered. Many regulators are not currently engaged in the debate on climate change and its inclusion in their requirements and recommended guidance, i.e. OFWAT, Rail Regulator, Housing Corporation, would support adaptation.

Developments allowed within the flood plain corridor should continue to be tightly controlled and it may be necessary to relocate key industries and critical/vulnerable properties away from areas of potential flood risk, particularly in situations where it is inappropriate or unsustainable to provide defences. The protection of assets during a flood should be considered, with top priority given to critical infrastructure and key access routes, followed by vulnerable populations and then residential property.

Existing flood defences should be maintained in locations where this is economically justified and, where necessary and cost-effective, improved to raise standards of protection. More innovative and sustainable flood management approaches in some situations may provide a more effective solution, such as upstream storage of flood water, use of washlands and managed realignment areas. Partnership approaches and cross-sectoral responses to reduce potential flooding should be established, and these might provide multiple adaptation benefits, such as water stored in upland areas being used to fight potential fires caused by higher summer temperatures.

Changes to land management in rural areas could be used to reduce the rate of surface runoff, e.g. providing hedgerows and ditches and ploughing fields along contours to help reduce field runoff, retain nutrients and prevent sediment being washed into watercourses. (A Forestry Commission study in Pickering and some Natural England Higher Level Stewardship schemes are currently looking into these, and other aspects, of flood risk alleviation by land management techniques). Encouraging managed realignment also benefits farmers, with flood waters bringing nutrients onto the fields. Increased woodland creation up catchment or on the local flood plain should be considered, which may reduce flood risk and potential for channel erosion.

The current and future planning and management of caravan and camping sites, which are highly vulnerable to flooding impacts, should be improved. Low volume sites are not currently subject to planning permission due to their temporary nature and sites are often placed at high flood risk near watercourses and the sea. New developments should move away from sites deemed lowest cost to more adaptable and sustainable developments, with sufficient flooding resilience. Raised electrics and sub-floors (for post-event draining) could be incorporated into designs. Retrofitting older properties could be carried out during any refurbishment work.

Also, new roads and railway sections could be constructed at raised levels (on stilts or viaducts) in flood prone areas. Existing main routes already affected could be bypassed and then improved in a similar fashion.

Multi-agency response plans should be produced in order to co-ordinate responses during extreme events. The availability of response units and equipment such as high volume pumps and boats could be improved. Temporary or demountable flood defences could be made available to low impact areas frequently affected by flooding, with clear access routes permanently available for their installation. All agencies should look at ways to educate the wider public and promote the development of flood resilience measures for properties at risk.

The maintenance of watercourse channels to remove vegetation and blockages should be increased in order to retain flow capacity, where this is economically justified. Public campaigns could be used to reduce fly tipping and clear rubbish from watercourses, reducing flood impacts during flash summer events and increased winter rainfall.

Monitoring and flood warning particularly in upstream areas and on unpredictable permeable chalk catchments should continue to be improved upon to provide emergency warnings as much in advance as possible of flooding events.

Adaptation to flooding from surface water/drainage

Although new drainage schemes and improvements may take into account future climate changes, existing systems are generally managed in a more reactive way. The key adaptation action in terms of surface water and drainage flooding is to determine future areas of risk.

A clear co-ordinating framework between local government, water companies, the Highways Agency and the Environment Agency is required for better managing the flood risk from surface water drainage. This is currently being developed to some degree through Surface Water Management Plans, Integrated Urban Drainage projects, and Water Cycle Studies.

Current design standards should be appropriate and locally relevant so that they can accommodate future increases in rainfall and runoff. The current planning requirements for new sewer designs are outdated, and use old rainfall data which only provides for a 1 in 30 year standard, although Yorkshire Water often designs its new sewers in flood–prone areas to accommodate increased future flows. Improvements across the drainage network should be strategically planned and implemented on a risk-based approach. Drainage for new build developments should ideally follow sustainable drainage techniques to attenuate runoff at source, or where this is not appropriate, incorporate additional capacity within their design. Additionally, the capacity of existing systems should be improved where necessary to accommodate for predicted increases in rainfall.

Downstream impacts from new drainage systems should be limited by designing the systems with over-sized pipe diameters and manholes to deliver a limited maximum appropriate outfall discharge, equivalent to normal greenfield runoff, as is currently generally applied in highways improvements.

There should be wider application of source control techniques which attenuate flow volumes earlier in the system and so reduce the downstream impacts on ageing sewer networks. This would also have the added benefit of reducing the impacts of peak flood flows in problem watercourses.

There are ongoing questions over the practicability of implementing such methods which need to be resolved, due to ownership issues and planning policy guidance requiring increasing numbers of houses with less space between them.

There are two Defra Integrated Urban Drainage pilot schemes currently underway in the region - in Bradford and Garforth, Leeds, which are looking at how to manage flooding from different sources. Lessons from these pilots should be applied across the region.

SUDS (sustainable urban drainage systems) could be retrofitted which would reduce urban runoff, and reduce peak flow impacts in downstream watercourses. In addition, balancing tanks could be fitted in areas known to flood in order to accommodate excess flows when sewers reach full capacity.

Water butts could be provided to households, along with information about the importance of SUDS, controlling flooding at source, and the wider impacts of paving over gardens (known as "development creep").

Infrastructure and equipment at sewage treatment works and pumping stations should be flood-proofed to accommodate greater flows. Combined Sewer Overflows (CSOs), should be improved in environmentally sensitive locations where increased spills are likely to have detrimental effects. Outfall capacity should be improved, storage provision increased or pumping included, at any CSOs likely to be affected by climate changes due to sea level rise or raised flood depths. River flood defence designs should consider the impacts of raised water levels on adjacent CSOs. Remote vulnerable properties should be flood-proofed where improvements to drainage systems would be uneconomic.

As well as improving the current flood warning system, especially in fast-reacting catchments, a new system could be introduced to warn people about surface water flooding in areas that are at risk.

Thematic abstracts

The following section provides an overview of the impacts and adaptation actions for the remaining seven themes which have not been covered in detail in this report. The full text for each of these can be found on the website.

Erosion

The Yorkshire and Humber coast falls within the Humber and North Yorkshire subregions, and is a dynamic and highly energetic coastline. Parts of the coast currently experience very high rates of erosion and this will likely accelerate under future climate conditions. Landslips in certain areas will be more likely to occur given future increases in intense rainfall events. Sea level rise will mean that coastal defences have a greater chance of being overtopped, and greater wave energy and incidences of storm surges will undermine sea walls and damage structures such as piers, as well as resulting in loss of or damage to intertidal habitat. Adaptation actions to respond to these impacts will vary depending on the cost-benefit analysis – some places will not be economically viable to defend. Allowing natural coastal processes to occur avoids the unsustainable construction of defence schemes, however, there are currently no technical or financial mechanisms in place to relocate and compensate people who may lose their homes or businesses to the sea, and the abandonment of coastal towns and villages is a controversial and politically sensitive issue. Further details of adaptation actions along the Yorkshire and Humber coast can be found in the River Tyne to Flamborough Head Shoreline Management Plan 2, the Flamborough Head to Gibralter Point Shoreline Management Plan 2, and the Humber Flood Risk Management Strategy, and on the study website.

Ground and minewater

Investment in the Yorkshire Grid (an interconnected system of water resources) means that the region is well prepared for future climatic conditions, and regulation of the water industry requires that climate change is considered in water company's long term plans. However, there is already stress on water resources, particularly in the southern part of the region and in the future there will be increasing demand for water. Balancing the needs of domestic and industrial customers and ensuring there is sufficient flow for biodiversity will require careful monitoring and possible future restrictions on abstractions. Old mine workings are present throughout the region and under certain conditions, can be a source of heavily polluted water which suddenly bursts out. These workings will require careful monitoring and remediation measures as future increases in multi-day intense rainfall events will increase the risk of minewater outbreaks.

Biodiversity

The Yorkshire and Humber region contains some of the most diverse and important habitats and species in Britain, including the largest extent of upland heathland in the country and extensive areas of blanket bog, lowland heathland, and low lying floodplain, as well as smaller, but important areas of wetlands, chalk cliffs, limestone pavements, hay meadows, ancient woodland and other types of habitat. Current pressures on the natural environment, not related to climate change, include grazing, artificial drainage, burning, invasive species, habitat fragmentation and loss through intensive farming and inappropriate management. In addition to these pressures, climate change will have the following impacts on biodiversity:

- Changes in the timings of seasonal events (phenology) potentially leading to a loss of synchrony between species and availability of food and other resources.
- Shifts in suitable climate conditions for individual species, leading to changes in both abundance and range.
- Changes to habitats and ecosystems such as altered water regimes, increased rates of decomposition in bogs, higher growth rates in forests and changes in the composition of plant and animal communities.

Guiding principals have been developed by Defra to help take account of climate change and maximise the natural environment's capacity to adapt. These are:

1. Conserve existing biodiversity
2. Reduce sources of harm not linked to climate change
3. Develop ecologically resilient and varied landscapes
4. Establish ecological networks though habitat protection, restoration and creation
5. Make sound decisions based on analysis
6. Integrate adaptation and mitigation measures into conservation management, planning and practice.

Business and the economy

Despite the current economic downturn, the Yorkshire and Humber economy has grown rapidly in recent years, overcoming large-scale job losses in the manufacturing and mining industries in the late 20th century. Between 2001 and 2006 regional Gross Domestic Product (GDP) increased significantly, and now exceeds £81 billion, accounting for some 7 per cent of the total UK economy. Although a significant proportion of regional GDP is based in West Yorkshire, the region as a whole has a strong, mixed economy. Agriculture and forestry are key sectors especially in North Yorkshire and the East Riding. Fishing fleets still operate from Whitby, Scarborough, Bridlington, Hull and Grimsby. Financial services are particularly prevalent in Leeds. Tourism, manufacturing, distribution, hotels and restaurants, construction, aggregate extraction and the public sector are also all major contributors to the regional economy. Business planning needs to acknowledge that the climate is changing and it will affect almost all businesses, particularly if they are already affected by weather and/or make long-term investments (e.g. in buildings and infrastructure). Small and medium enterprises (SMEs) are likely to be more severely impacted than larger companies because they often operate from only one site and are least likely to have business continuity plans. There are opportunities as well as threats - e.g. increased crop yields, more tourism, opportunities for new goods and services. Impacts and adaptation actions for individual sectors are listed on the website, however impacts on premises, people and transport infrastructure are likely to affect most organisations.

1. Premises - increased internal temperatures, increased water penetration through the building fabric, a need for enhanced drainage to deal with rainfall intensity, increased flood risk, increases in storm damage and disruption, increased subsidence due to enhanced wet-dry cycles. Adaptation actions include adopting higher building standards for new buildings and retrofitting existing ones, using low energy, low carbon and decentralised technologies to increase future resilience and reduce costs, using green roofs, shade trees and water features to reduce temperatures and attenuate flood risk, and ensuring provision has been made for flood protection.
2. People - the future comfort and safety of staff, increased temperatures reducing productivity and affecting health, flood or storm related transport disruption affecting both staff and customers. Adaptation actions may include changes in uniforms and dress codes, and more flexible working arrangements.
3. Disruption to transport infrastructure due to flooding or storms - this will impact on supply chains, staff and customers.

Public and voluntary services

This theme covers education and schools, emergency services, the military, public assets (such as council offices, jobcentres, prisons and libraries), social housing, waste management facilities, places of worship, parks and gardens, crematoria and cemeteries, National Parks and voluntary organisations. The impacts and adaptation actions listed above in relation to premises and people will be relevant to most public and voluntary services. There are likely to be increased demands placed on emergency services due to heat stress, flooding and storms, and also a significant rise in the number of wild fires. This in turn may increase the demand placed on the military to provide humanitarian assistance and logistical support (e.g. airlifting flood victims). There are likely to be multiple climate related impacts on waste management – including faster decomposition rates, a need for more frequent waste collections, and effects on landfill gas and leachate. Parks and gardens will require more grass cutting and weeding due to longer growing seasons and higher temperatures, there may be both drought and flooding impacts on trees and other plants, and pests and diseases may become more prevalent. Overarching adaptation actions relating to buildings and people are listed in the Business section. Other actions include reviewing emergency services training and staffing levels, formulating robust emergency response plans, reviewing/assessing waste collection and management, and providing leadership and education to empower communities to take adaptation actions and bring about behaviour change.

Infrastructure

This section covers transport, water and waste water and energy and telecommunications. The Yorkshire and Humber region is at the centre of the country's north-south and east-west transport corridors and is also home to the second largest ports complex in the UK. There are several large power plants in the region, notably Drax, which supplies 7 per cent of the nation's electricity. Yorkshire Water deals with both water supply and waste water treatment for most of the region, with small areas being covered by various other utility companies. Yorkshire Water has made significant investment in the Yorkshire Grid which is an interconnected water resources distribution system. Although in general water resources are currently fairly ample, the Environment Agency's Catchment Abstraction Management Strategies show that for much of the region, there is no further water available for abstraction during times of low flows.

The networked nature of most of the region's infrastructure means it is particularly vulnerable to impacts such as flooding and any disruption to critical infrastructure can have wide-ranging and long lasting impacts, as was seen during the summer 2007 floods.

As well as the obvious disruption that can be caused by floods, other impacts on transport infrastructure will include roads being more susceptible to melting and rail tracks to buckling, road and rail side vegetation will need cutting for longer, wind related damage e.g. from fallen trees, and rising temperatures in trains, coaches and cars will affect passenger comfort. There may also be insufficient flows to maintain navigation on the region's canals. Both Network Rail and the Highways Agency are already aware of and are adapting to the impacts caused by a changing climate, through a combination of measures ranging from Seasonal Preparedness Plans to pre-stressing of rail tracks. Assets with long life spans such as bridges and tunnels will require ongoing monitoring in case remedial engineering works are required e.g. providing scour protection around bridges to cope with increased flows.

Impacts on the water and waste water sector are primarily related to changes in rainfall and temperature. Increased rainfall may overload our ageing sewer network (as described in the flooding section). Changes in flows will have effects on effluent dilution and dispersal and may require higher treatment standards during times of low flows. Changes to rainfall patterns will also have implications for groundwater recharge rates and water volumes stored in reservoirs, and higher temperatures will increase demand for water. Water treatment is highly susceptible to temperature and higher temperatures will speed up the biological and chemical treatment of sewage. Regulation of the water sector means that adaptation is already occurring in a phased manner that is proportionate to the balance of risks and costs to the customer and which takes into account changes in climate, technology and demand.

As well as risks from flooding, electricity pylons and power cables are susceptible to wind damage which is projected to increase slightly under future climate conditions. Rising temperatures will lead to greater sagging of power cables and the gas terminal at Easington may be susceptible to coastal erosion. Ongoing monitoring and maintenance along with flood risk management activities are the main adaptation actions for this sector.

Health and welfare

Standards of health and welfare vary markedly across the region. There are large inequalities throughout the region, significant numbers of wards that are amongst the United Kingdom's most deprived and a large proportion of people deemed to be suffering from 'fuel poverty' when compared to England overall. There are also lower than average levels of physical activity, healthy eating and housing deemed suitable for habitation, a higher than average number of premature deaths and long-term preventable illness and an aging population that is migrating away from urban centres towards more rural areas.

The region includes a total of 14 Primary Care Trusts (PCTs), 22 NHS Trusts, 32 general hospitals and 33 community hospitals. One of the Trusts is the Yorkshire and Humber Ambulance Service NHS Trust which serves the whole region.

The impacts on human health and welfare from climate change will exacerbate many of the issues listed above, and are likely to particularly impact on poor and disadvantaged communities which already suffer from health and environmental inequalities. Health impacts will include:

- Greater incidences of respiratory illnesses such as asthma due to air pollution episodes from elevated levels of atmospheric ozone and other air quality pollutants, exacerbated by hotter drier summers.
- Higher risk of skin cancers due to increased exposure to UV radiation.
- More incidences of food poisoning and vector, insect and pest borne diseases.
- Mental health issues arising from people being flooded. Loss of property and possessions, prolonged periods of living in temporary accommodation, slow or incomplete insurance payments and fear of future events can lead to stress, anxiety and depression.
- Heat related stress, heat stroke, dehydration and exhaustion especially for vulnerable people (e.g. those with breathing difficulties, the elderly and the very young)
- Severe weather impacts on mobile care services such as home help, meals on wheels and community transport schemes. Restriction of such services, even over short times scales (i.e. hours) could have serious impacts upon those requiring care.

Tackling the root causes of deprivation and social inequality effectively will pay many dividends when it comes to adapting to climate change, by providing increased adaptive capacity even if this was not the key aim of the scheme.

The key adaptation actions that can be taken include:

- Cooling the urban environment by planting shade trees and providing water features.
- Investigating the out migration of elderly people and its impacts on service delivery in rural areas.
- Encourage a move to 'full life-cycle' housing (e.g. Lifetime Homes) whereby homes are sufficiently flexible to accommodate people's needs over their whole lives.
- Promote and encourage resilience in communities that will not only help residents to deal with climate change and extreme events, but which will also contribute towards a healthier lifestyle with improved wellbeing. The Transition Towns initiative (www.transitiontowns.org) is a good example of this. Voluntary sector groups could be engaged to help local people prepare for, and during, heatwave and other extreme weather conditions.
- Mechanisms should be introduced to ease compensation payments by insurers to home and business-owners who have been adversely affected by flooding.
- Widespread investment in and promotion of the uptake of more sustainable modes of transport.
- Retrofitting homes to reduce vulnerability to fuel poverty.
- A significant change in the way that society uses and values water and energy. Smart metering would help people to become aware of the amount of water and energy that they consume and the costs, which should drive improved efficiency.

Conclusion

Climate change is a rapidly moving field and there are potentially major shifts in the policy landscape ahead, pending the outcomes of the forthcoming Copenhagen negotiations, and the issue of a national carbon budget by the Committee on Climate Change, as required by the Climate Change Act. This report is intended to provide a snap shot of current evidence for the Yorkshire and Humber region, and should be read in conjunction with the website, where more detailed sector-specific, and local information is available, and which will be regularly updated in light of new scientific and policy developments.

References

ABI, Insuring our Future Climate, Thinking for Tomorrow, Today. 2007

AXA, Preparing for Climate Change – a Guide for Small Businesses
http://www.axa.co.uk/aboutus/corporate_publications/climatechange_docs/AXA%20Preparing%20for%20climate%20change.pdf

The Cabinet Office, The Pitt Review, Learning Lessons from the 2007 Floods, 2008
http://archive.cabinetoffice.gov.uk/pittreview/thepittreview.html

Defra, Futurecoast, 2002
http://www.foresight.gov.uk/OurWork/CompletedProjects/Flood/index.asp

Defra, Key Findings from UKCP09 for Yorkshire and Humber, 2009
http://ukcp09.defra.gov.uk/content/view/42/6/

Defra, Guidance for Operating Authorities on Flooding and Coastal Defences, 2006
http://www.defra.gov.uk/environ/fcd/guidance/pagn/Climatechangeupdate.pdf

The Environment Agency, Review of Floods, 2007
http://publications.environment-agency.gov.uk/pdf/GEHO1107BNMI-e-e.pdf

European Environment Agency Technical Report, Climate Change, the Cost of Inaction and the Cost of Adaptation. 2007
http://www.eea.europa.eu/publications/technical_report_2007_13

HM Treasury, The Stern Review Report on the Economics of Climate Change, 2006
http://www.hm-treasury.gov.uk/stern_review_report.htm

Hulme,M., Jenkins,G.J., Lu,X., Turnpenny,J.R., Mitchell,T.D., Jones,R.G., Lowe,J., Murphy,J.M., Hassell,D., Boorman,P., McDonald,R. and Hill,S. (2002) Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report. Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK. 120pp
http://www.ukcip.org.uk/index.php?id=353&option=com_content&task=view

Kilsby,C.G, P.D. Jones, A. Burton, A.C. Ford, H.J. Fowler, C. Harpham, P. James, A. Smith, R.L. Wilby. (2007) A daily weather generator for use in climate change studies. Environmental Modelling and Software, 22(12), 1705-1719.

National Rivers Authority (1994) A guide to the understanding and management of salt marshes - R&D Note 324

Shennan, I. and Horton, B. (2002) Holocene Land and Sea Level Changes in Great Britain. Journal of Quaternary Science 17: 511-526.

SKCC and BKCC
The aim of sustaining knowledge for a changing climate (SKCC) project was to disseminate the research from the successful Building Knowledge for a Changing Climate (BKCC), sustain the community of researchers and end users assembled during BKCC and help set the agenda for a new programme of research on climate impacts and adaptation.
http://www.k4cc.org/

Sutherland, J. S. and Wolf, J.: Coastal Defence Vulnerability 2075, HR Wallingford report SR590, 2002.

UKCIP Adaptation Wizard Online Tool
http://www.ukcip.org.uk/index.php?Itemid=273&id=147&option=com_content&task=view

Annex 1

Location - City of Kingston upon Hull

Description of District

The city is located on the northern banks of the Humber estuary. It is a small urban district surrounded by the larger, more rural East Riding of Yorkshire.

Future Climate Projections

The modelling carried out for the Yorkshire and Humber Regional Climate Change Adaptation Study suggest that the following changes are likely by 2050:

- Annual average daily mean temperature for the district will rise by 1.9°C;
- The long term average maximum winter temperature will increase from 14.4°C to 15.6°C;
- There will be an increase in the intensity of both short and longer rainfall events (1, 2, 5 and 10-day);
- Summer rainfall will reduce by 24% and winter rainfall will increase by 17%; and
- Winter average wind speeds will increase marginally.

These figures relate to the nearest modelled cell, which was Kingston-upon-Hull.

Key Impacts and Adaptation Actions

Although principally a regional / sub-regional study, there are a range of issues that are of particular relevance to the city of Kingston-upon-Hull. These are set out below, using the same thematic headings as the main report. These points are not the only issues for consideration, however, as sub-regional and regional reports, as well as the thematic sections of the website *www.adaptyh.co.uk*, cover other issues relevant to this local authority.

Flooding

Key Impacts

- Greater rainfall leading to larger and more frequent flood problems for local properties, businesses and infrastructure;
- Rising sea levels will increase tidal flood impacts;
- There will be more surface water flooding, both because much of the district is low-lying and because rising sea levels will cause more frequent tide-locking of drainage systems; and
- Increased flooding to critical infrastructure and services (ambulance, fire and police stations all at significant risk).

Key Adaptations

- Concentrate improvements to tidal flood defences to maintain an appropriate standard for local populations;
- Produce multi-agency response plans to co-ordinate responses during extreme events and ensure clear access routes are kept available;
- Improve current drainage design standards to incorporate future climate changes, and strategically plan and implement system improvements across the drainage network; and
- Protect critical infrastructure and emergency services to ensure continuation of service, or relocate away from flood risk areas;

Coastal Erosionn

Key Impacts

- Salt marsh habitat will erode more quickly at some locations within the Humber estuary, in many cases leading to the progressive 'squeezing' of inter-tidal habitats; and
- Increased risk of overtopping of the Hull Tidal Surge Barrier.

Key Adaptations

- Adaptation to inter-tidal salt marsh edge erosion within the Humber estuary is inextricably linked with flood risk management decisions. There are limited opportunities for salt marsh re-creation since flood risk management will mainly involve maintenance or improvements to existing flood defence structures due to the urban and industrial nature of the frontage, leading to continued coastal squeeze.

Groundwater and Minewater

Key Impacts

- Risk to Chalk groundwater resource due to declining groundwater levels and increased drought;
- Impact on river flows, particularly River Hull, due to reduction in spring flow from Chalk; and
- Risk of saline intrusion from the Humber estuary especially during periods of drought as over abstraction leads to migration of saline water further inland.

Key Adaptations

- Continued monitoring and careful exploitation of the Chalk aquifer; and
- Assessment of saline intrusion and possible constraint of groundwater abstractions during periods of drought.

Business and Economy

Key Impacts

- As fish species currently targeted by local boats become unavailable or uneconomic they are likely to be replaced by other warmer-water species, the attractiveness of which will depend upon market changes;
- Increased flooding in urbanised and developed areas, combined with increasing temperatures, will increase the risk of contamination within the food and drink industries (and in particular the fish processing sector); and
- Industrial processes, and in particular those requiring large amounts of water may be impacted by water shortages. Heavy users may find limitations imposed in order to balance industrial and other needs, which could reduce process efficiency and output and increase costs.

Key Adaptations

- Promote and circulate research into the likely effects of climate change on local fisheries species, and ensure long-term investment decisions account for a potentially changing catch. Drive and share research on changing markets to ensure and enable early adaptation. Require that development and support programmes, especially where publicly or industry-supported, are climate adapted;
- Although standards are very high already there may be an increased demand on audit and quality control, and new processes and equipment may be required for food and drink industries. The effect of urban heating and flooding can also be reduced through the use of shade trees in urban areas. Flooding impacts on distribution and retail parks should be addressed as a priority before development, with surface water management plans and sustainable drainage systems, designed to cope with future water flows;
- Build climate adaptation into regular process reviews, and programme any necessary adaptations (for instance to improve water efficiency) into maintenance and upgrade cycles; and
- To limit impacts on agriculture in the wider region, initiate, develop and review pest management strategies, in particular associated with the ports, to ensure the early identification and treatment of any species or conditions which may negatively affect the district's habitats, agriculture, or human health.

Public and Voluntary Services

Key Impacts

- Indoor air temperatures are likely to rise in the summer months, particularly in urban areas (urban heat island effect) where there is less cooling overnight, as materials that have absorbed the sun's energy throughout the day, release it back into the environment;
- The drying out of soils followed by heavy rainfall could lead to increased risk of subsidence and slope instability, together with inundation and/or erosion of low lying coastal facilities.

Key Adaptations

- A set-aside maintenance and repair budget for school buildings and public service offices, developed through adapting current budgetary mechanisms, would ease the costs of any damage that is incurred as a result of climate impacts;
- Review built assets and resource availability and location to ensure resilience to future demands; and

- Ensure full participation in regional resilience forums and regional flood groups and undertake precautionary as well as adaptive measures recommended, in addition to reviewing risk registers.

Infrastucture and Utilities

Key Impacts

- Increased number of traffic accidents delays on major highways caused by increased winter rainfall and winter average wind speeds;
- Increased frequency of flooding from urban drainage and sewer systems in Hull, especially in winter; Increased blockage of drains, culverts and gullies;
- Mechanical operations within the water distribution grid could be affected by climate-related disruption to power supplies;
- Loss of telecommunications during severe weather incidents due to lack of connectivity with national grid; and
- Increased frequency of flooding to sections of the rail line to/from Hull.

Key Adaptations

- Weather and travel warnings issued to users of principal roads during storm events and anticipate increased resource requirements for emergency responses;
- Capital programs should consider improved sewer and drainage design;
- Re-evaluate resources and approaches for inspection and clearance of drain, culvert and gulley blockages;
- Increased awareness of inter-dependencies between critical infrastructures, leading to improved resilience planning;
- Back-up telecommunications link with national grid; and
- Consider increased flood defence to rail line and/or relocation of sections of line in the longer-term.

Biodiversity

Key Impacts

- Urban green space, brown field sites, and features of the urban landscape are likely to become more important refuges for species with a loss of productive soil and shifts in climate space of species.

Key Adaptations

- Wherever possible allow natural processes to continue, and therefore adaptation to change to occur naturally; and
- An overall expansion in habitat types currently suffering from isolation or fragmentation, to improve habitat permeability and work towards a total increase and improved value of urban and industrial areas as refuges and sustainers of species.

Health and Welfare

Key Impacts

- Impacts upon mental and physical health due to increasing temperatures, particularly in areas of deprivation; and
- Coastal and river flooding because of rising sea levels and increased seasonality and intensity of rainfall.

Key Adaptations

- Urban design to minimise heat island effect as much as possible by planting shade trees, green roofs etc;
- Raising awareness, educating and building community resilience to climate change and its likely impacts; and
- Continuing to tackle social and economic inequalities throughout the city will greatly reduce vulnerability to the impacts of climate change.

yorkshirefutures

Yorkshire Futures
Victoria House
2 Victoria Place
Leeds
LS11 5AE

Tel: 0113 394 9694
Email: info@yorkshirefutures.com
Web: www.yorkshirefutures.com

We are grateful for the continued support from:

Supported by
YORKSHIRE FORWARD
The Region's Development Agency