# The Norfolk County Council (Norwich Northern Distributor Road (A1067 to A47(T))) Order

# 6.2 Environmental Statement: Volume II: Chapter 16. Climate Change Risk Assessment

Planning Act 2008

Infrastructure Planning

The Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009

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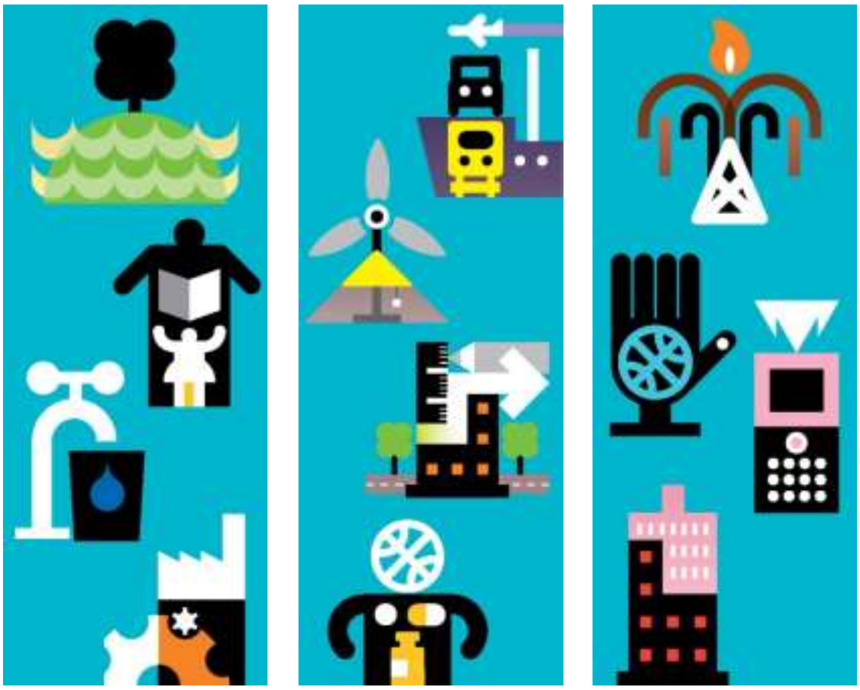
*This document is submitted in relation to the application for a proposed development by Norfolk County Council to the Planning Inspectorate, under the Planning Act 2008.*

*The application is for the Norfolk County Council (Norwich Northern Distributor Road (A1067 to A47(T))) Order, to grant development consent for the construction of a new highway running west-east between the A1067 Fakenham Road and the A47 Trunk Road at Postwick, including improvements to the existing highway network to the north and north east of Norwich.*

*This document comprises part of the application documents and relates to Regulation 5(2)(a) of the Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009.*

# Table of Contents

## A. Climate Change Risk Assessment



# NDR Climate Change Risk Assessment

December 2013

Norfolk County Council

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# Contents

# Executive Summary

In support of the Environmental Impact Assessment (EIA) process Mott MacDonald has undertaken a Climate Change Risk Assessment (CCRA) of the NDR scheme. The CCRA process identifies and appraises significant climate risks that are expected to affect the proposed development to determine the scheme's climate resilience and its impact on the wider environment's vulnerability and capacity to adapt to climate risks (Section 1.2). This supports the requirements of the Scoping Opinion to address climate change issues (Section 1.3.1).

The mainstreaming and consideration of climate change issues in the EIA process supports best practice. This is also in line with the proposed revision to the European EIA Directive and national and sub-national planning policy, where climate change issues will need to be addressed in project assessments (Section 1.3.2).

The assessment of current and projected future climate (Section 1.5) has identified a number of medium and low risks to the scheme (Table 1.1).

Table 1.1: Climate Risk to the NGT Scheme

| Variable | Current Risk | Future Risk |
|---|---|---|
| Heatwaves and high temperature extremes | Medium | Medium |
| Coldwaves and low temperature extremes | Medium | Medium |
| Flooding and heavy precipitation events | Medium | Medium |
| Drought | Low | Low |
| Snow and ice | Medium | Medium |
| Gales | Medium | Medium |

Current UK design standard provide a high degree of resilience to climate risks (Section 1.6). The resilience of the road surfaces to temperature extremes is, however, highlighted as an area where resilience can be improved (Table 1.2).

Table 1.2: Scheme resilience

| Structural features | Key Climate Risks | Scheme resilience |
|---|---|---|
| Road carriageway | • Heatwaves and high temperature extremes<br>• Coldwaves and cold temperature extremes<br>• Snow and ice | Moderate |
| Bridges | • Flooding and heavy precipitation events<br>• Drought<br>• Heatwaves and high temperature extremes<br>• Gales<br>• Snow and ice | High |
| Embankments and cuttings | • Drought<br>• Flooding and heavy precipitation events | High |
| Drainage | • Flooding and heavy precipitation events | High |
| Landscaping and ecology | • Gales<br>• Heatwaves and high temperature extremes | High |
| Other structural features | • Gales<br>• Heatwaves and high temperature extremes<br>• Snow and ice | High |
| Asset management/maintenance | • n/a | High |
| Construction | • Drought<br>• Flooding and heavy precipitation events<br>• Heatwaves and high temperature extremes<br>• Snow and ice<br>• Gales | High |
| Public utilities | • Coldwaves and low temperature extremes<br>• Drought | High |

# 1 Climate change resilience

## 1.1 Introduction

Climate change will have significant implications for proposed new infrastructure assets, particularly those with long design lifetimes. Decisions made now will shape the resilience of design and development of infrastructure systems. Action is therefore needed to ensure that new infrastructure is robust and resilient to climate conditions in the long term, through considered planning and design.

In support of the Environmental Impact Assessment (EIA) process Mott MacDonald has undertaken a Climate Change Risk Assessment (CCRA) of the NDR scheme. The CCRA process identifies and appraises significant climate risks that are expected to affect the proposed development to determine the scheme's climate resilience and its impact on the wider environment's vulnerability and capacity to adapt to climate risks.

In line with the requirements of the Scoping Opinion to address climate change issues (Section 1.3.1.1), the CCRA has informed the consideration of issues in the relevant topic chapters of the Environmental Statement (ES). Also in support of the Scoping Opinion, this chapter uses the findings of the CCRA to determine the scheme's climate resilience through an evaluation of the design or incorporated climate change adaptation measures. Recommendations for supplementary climate change adaption measures to build resilience are not considered in this assessment.

The process adopted for this assessment aims to provide a robust assessment of climate change issues in support of Development Consent Order (DCO) application process. This has been achieved through the identification of the scheme's resilience to climate risks over its operational life.

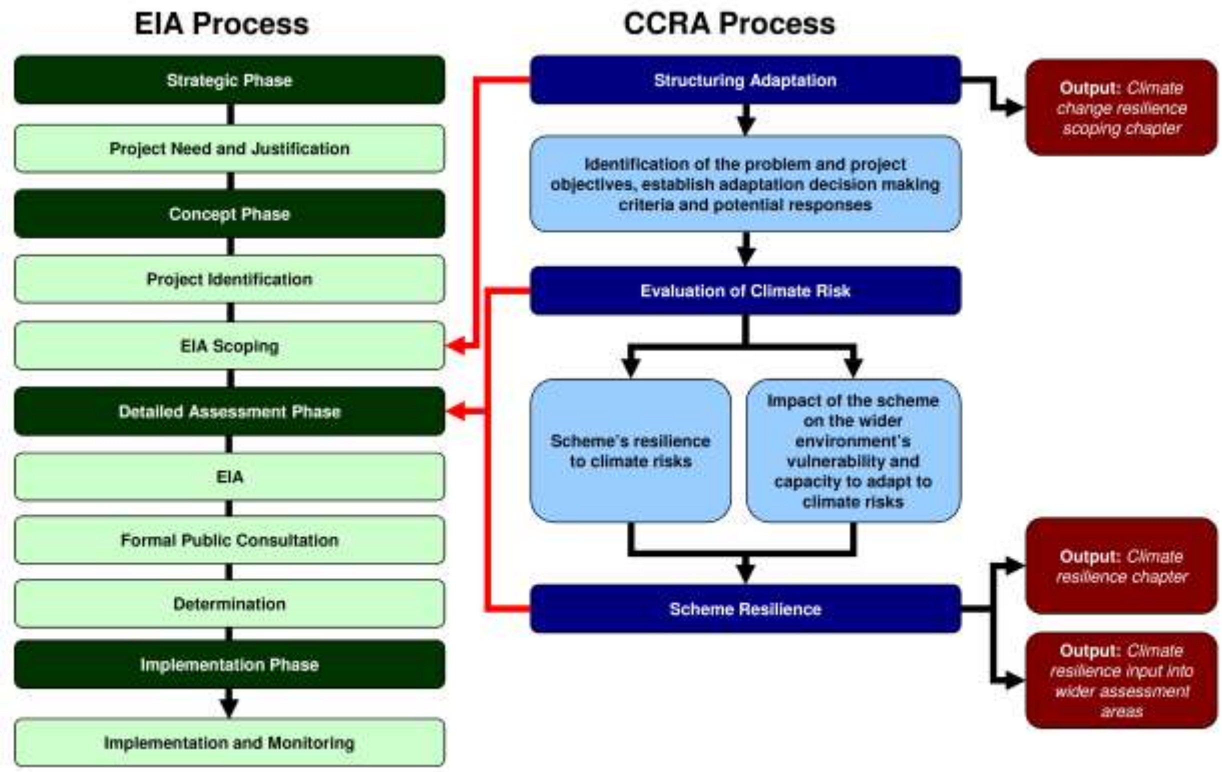
The mainstreaming and consideration of climate change issues in the EIA process supports best practice. This is also in line with the proposed revision to the European EIA Directive, where climate change issues will need to be addressed in project assessments. This is subject to the EIA directive being adopted, which is likely to occur in the next couple of years.

The determination of the scheme's carbon emissions and climate change mitigation actions is considered separately in the Environmental Statement.

## 1.2 Methodology

This section outlines the approach undertaken to evaluate climate risk issues for the NDR scheme. A outline of the technical methodology used is provided in Appendix A: CCRA Methodology. A 'Climate Change Risk Assessment' (CCRA) process has been used to evaluate current and future climate risks in relation to how they affect project specifications and the scheme design, as a means of assessing the long term climate resilience of the scheme. This approach is based on guidance from the Organisation for Economic Co-operation and Development (OECD) and the European Commission (EC) for incorporating climate change impacts and adaptation into Environmental Impact Assessments, shown below (Figure 1.1).

Figure 1.1: Climate Change Risk Assessment Process




Source: Adapted from Agrawala et al (2010) Incorporating climate change impacts and adaptation in Environmental Impact Assessments: Opportunities and Challenges. OECD

#### 1.2.1 Review of literature and evidence

Mott MacDonald undertook a review of evidence and literature to scope and formulate the issue of climate change adaptation in the context of the NDR scheme. These issues have been further explored in the assessment phases.

The evidence and literature review that supported this assessment included a review of the following key references:

- NDR Scheme Layout April 2013 Rev B
- NDR Utility Works Locations October 2013
- Draft NDR Plans for Public Utilities: Key Plan
- European Commission (2013) Guidance on Integrating Climate Change and Biodiversity into Environmental Impact Assessment;
- Defra (2012) UK Climate Change Risk Assessment for the Transport Sector;
- HM Government (2011) Climate Resilient Infrastructure: Preparing for a Changing Climate ;
- Engineering the Future (2011) Infrastructure, Engineering and Climate Change Adaptation: ensuring services in an uncertain future;
- DEFRA (2011) Climate Resilient Infrastructure: Preparing for a Changing Climate;
- Wider PEIR chapters
- NSIP Application Construction Methodology
- Jenkins, G. J et al (2008) The Climate of the United Kingdom and Recent Trends. Met Office Hadley Centre, Exeter, UK;
- Murphy, J. M et al (2009) UK Climate Projections Science Report: Climate change projections. Met Office Hadley Centre, Exeter, UK;
- UK Climate Projections 2009 (UKCP09); available at http://ukclimateprojections.defra.gov.uk/
- Norfolk Local Climate Impacts Profile (2009); available at [http://www.ukcip.org.uk/wordpress/wp-content/LCLIP/Norfolk_LCLIP.pdf](http://www.ukcip.org.uk/wordpress/wp-content/LCLIP/Norfolk_LCLIP.pdf)

### 1.3 Context

#### 1.3.1 Technical

##### 1.3.1.1 Scoping Opinion

The Scoping Opinion for the scheme outlines that in relation to inclusion of Climate Change within the ES Contents:

*Climate Change (see Scoping Report Section 14): The SoS welcomes the intention to include this chapter within the ES as a summary of the proposed adaptation and mitigation measures within the specialist topic chapters. … [T]he aspect of climate change should be addressed in each topic chapter where relevant.*

*As indicated in Paragraph 14.2.1.1 of the Scoping Report, the SoS agrees that the topic of climate change should be addressed from the point of view of maintenance of the highway structure, and from the point of view of the effect the proposed scheme may have on the local environment's response to climate change effects. The Applicant is referred to comments from NE in this regard (Appendix 2).*

In line with the scoping opinion a CCRA has been undertaken to enable climate change (adaptation) issues to be addressed in the context of this Environmental Impact Assessment. This is broken down into an assessment of the effects of climate change on the scheme (the focus of this chapter) and the effect the proposed scheme may have on the local environment's capacity to response to climate change. The latter is considered in each relevant topic chapter of the ES.

### 1.3.2 Relevant Legislation, Policy and Strategies

The EIA process has an important role in ensuring that future developments respond to the issue of climate change and that the developments do not exacerbate the effects of climate change on the environment, society or the economy. The current EIA Directive contains a number of principles that provide the basis for considering climate change in EIA, even though it does not refer to the term explicitly. In 2012, the revised EIA Directive strengthened the provisions related to climate change. It introduced clear references to 'climate change' and 'greenhouse gases'. It also provided detailed descriptions of climate change issues to be addressed in project screening and in the EIA report in detail[1]:

- **Climate Change Mitigation** - Impacts of the project on climate change in terms of greenhouse gas emissions and mitigation potential, including from land use, land-use change and forestry.
- **Climate Change Adaptation** - Impacts relevant to adaptation including the impacts of climate change on the project and the contribution of the project to wider resilience.

The Institute of Environmental Management and Assessment (IEMA) currently anticipate that proposed regulations will be adopted into UK regulation in 2015/16. Given that approval for the NDR is not likely to be given until 2014, this means that the provisions of the revised directive may affect this scheme, and therefore, climate change issues have been considered in this assessment.

Climate change is also an important consideration in planning development, with international, national and sub-national policy a primary driver in the UK. The objectives set out within the UK's climate change legislation inform the development of planning policy, as well as regional and local strategies on climate change. The following sub-sections also summarise existing national, regional and local policy, as well as legislation and strategies in the UK. These key policy drivers highlight that climate change should be considered as part of the EIA for the proposed development, however direct compliance is not required.

[1] European Commission (2013) Guidance on Integrating Climate Change and Biodiversity into Environmental Impact Assessment

#### 1.3.2.1 Climate Change Act 2008

The UK has passed legislation that introduces the world's first long-term legally binding framework to tackle the risks posed by climate change. The Climate Change Act 2008 creates a new approach to managing and responding to climate change in the UK, by:

- Setting ambitious, legally binding emission reduction targets;
- Taking powers to help meet those targets;
- Strengthening the institutional framework;
- Enhancing the UK's ability to adapt to the impact of climate change; and
- Establishing clear and regular accountability to the UK Parliament and to the devolved legislatures.[2]

Key provisions of the act in respect to climate change adaptation include:

- A requirement for the Government to report, at least every five years, on the risks to the UK of climate change, and to publish a programme setting out how these will be addressed. This Act also introduces powers for Government to require public bodies and statutory undertakers to carry out their own risk assessment and make plans to address those risks.
- The Adaptation Sub-Committee of the Committee on Climate Change, will provide advice to, and scrutiny of, the Government's adaptation work.

#### 1.3.2.2 National Planning Policy Framework (NPPF)

The Climate Change Act has strengthened the institutional framework in respect of planning policy and managing the impact of climate change.

The NPPF was published on 27th March 2012 replacing the majority of the Planning Policy Statements and Planning Policy Guidance. It states that local authorities should adopt proactive strategies to mitigate and adapt to climate change (in line with the objectives and provisions of the Climate Change Act 2008), taking into account flood risk, coastal change and water supply and demand considerations.

#### 1.3.2.3 Greater Norwich Development Partnership Joint Core Strategy

The Joint Core Strategy for Broadland, Norwich and South Norfolk was adopted in March 2011. One of the 'grand challenges' that the Strategy aims to address between 2008 and 2026 is 'Environment: enhancing our special environment and mitigating against any adverse impacts of growth'. The spatial vision also states, under 'Climate change and sustainability', that:

*'Regeneration, development and growth will create sustainable places and revitalise areas of deprivation, while minimising the use of global resources, supporting the development of good waste management practices, maximising the use of brownfield land and mitigating and adapting to the effects of climate change.'*

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[2] DECC (2012) Climate Change Act 2008

Objective one of the spatial planning objectives is to minimise the contributors to climate change and address its impact. It states that *'throughout Broadland, Norwich and South Norfolk, high standards of design and sustainable access will be promoted to reduce greenhouse gases and adapt to the impact of climate change'.*

Policy 1: Addressing climate change and protecting environmental assets builds on this, by requiring that, to address climate change and promote sustainability:

*'all development will be located and designed to use resources efficiently, minimise greenhouse gas emissions and be adapted to a changing climate and more extreme weather.'*

The Joint Core Strategy makes reference to the Norwich Area Transportation Strategy including the construction of the NDR.

#### 1.3.2.4 'Connecting Norfolk' - Norfolk's Local Transport Plan for 2011 – 2026

The strategy reflects the importance of 'having a resilient highway network and responding to the likely impacts of climate change'.

One of the priorities in the strategy for managing and maintaining the transport network is 'a network that is resilient to the impacts of climate change'.

Policy 3 of the strategy (Network Resilience) states that *'The likely impacts of climate change on the highway network should be addressed, with a risk based approach taken to determining the priority for action. Network resilience should form a key part of the Transport Asset Management Plan to ensure there is preparation for future impacts.'*

#### 1.3.2.5 New Anglia Local Enterprise Partnership

The New Anglia region's Local Enterprise Partnership is a national 'Green Economy Pathfinder'. As part of this role it has created a Manifesto showcasing local businesses which are demonstrating a cutting edge approach to the green economy, setting out the barriers and opportunities around sustainable economic growth, and highlighting New Anglia's aspirations for the future.

Leading The Way, the Green Economy Pathfinder manifesto 2012–15 includes climate change under 'Priority objective 3' (Enable innovative, entrepreneurial and radical solutions to business challenges and opportunities). It states that 'as the region on the frontline of climate change, the LEP commits to being the test-bed for innovative solutions that respond to climate change challenges'. One of the 'Challenges and Barriers' identified in the manifesto is the impacts of climate change, which states that:

*The New Anglia region is particularly vulnerable to the impacts of climate change: temperature rise, the potential reduction in summer rainfall, lower available water resources, increased flood risk and rising sea levels. The impact of hotter, drier summers, combined with a growing population, will increase the demand for water, while coastal and low-lying assets face an increased risk of flooding.*

## 1.4 Baseline[3]

The following section outlines the current and future climate baseline for the scheme for key climate variables. Data and information supporting this section can be found in Appendix B.

### 1.4.1 Temperature

July and August are the warmest months, with mean daily maximum temperature around 22°C. The record temperature for the region is 37.9°C[4]. By the 2050s, an increase in mean daily maximum temperature to between 22°C and 27°C (Figure 1.2) and an increase in temperature on the warmest day to between 37°C and 46°C is 'likely'[5] (Figure 1.3). By the 2050s, an increase in mean daily minimum temperature to between 2°C and 5°C is 'likely' (Figure 1.4).

February is currently the coldest month in Norfolk, with a mean daily minimum temperature around 0.7°C. Minimum temperatures are usually recorded in January or February. From December 2009 to January 2010 there was a widespread and very severe frost across the UK including Norfolk, with temperatures recorded around -8˚C. The lowest recorded temperature for the region was -20°C in January 1963. Cold extremes of this magnitude have, however, not been experience in the recent climatological record. By the 2050s an increase in temperature on the coldest day to between -7°C and -2°C is 'likely' (Figure 1.5).

### 1.4.2 Precipitation

Precipitation is generally well-distributed throughout the year within the region, although there are seasonal patterns. Precipitation from Atlantic depressions, or with convection, is more vigorous in autumn and winter, resulting in higher precipitation. In summer, sporadic thunderstorms can produce very intense precipitation events. The highest recently recorded 24-hour rainfall is 77.8mm[6], although many localised precipitation events are unrecorded. There is more uncertainty in future changes in precipitation patterns, although precipitation intensities are expected to increase. By the 2050s, precipitation on the wettest day of between 70m and 104mm is likely (Figure 1.6).

East Anglia is currently one of the driest parts of the UK with areas receiving a total annual precipitation of 500mm or lower. The area currently receives an average total annual precipitation of 652.5mm. Winter and spring are the driest seasons in Norfolk, with around 150mm of rainfall over each three month period. By the 2050s total average precipitation is likely to change to between:

- 146mm and 188mm in winter (Figure 1.7)
- 134mm and 155mm in spring (Figure 1.8)
- 95mm and 170mm in summer (Figure 1.9), currently 170mm (1990 to 2010)

[3] An evolving baseline over time

[4] http://www.metoffice.gov.uk/public/weather/climate-extremes/

[5] There is an 80% chance of change to between these figures

[6] http://www.metoffice.gov.uk/public/weather/climate-extremes/

### 1.4.3 Gales

Average wind speed currently ranges between 4m/s and 5.4m/s, with gust of up to 44.8m/s recorded during extreme events. There is, however, considerable uncertainty associated with projected changes in wind in the region.

## 1.5 Climate risk

Climate variability, weather extremes and changes in these over time have the potential to generate significant risks or opportunities for the Norwich NDR scheme. The following section identifies and evaluates the risks from climate variables to the Norwich NDR scheme in relation to an evolving baseline operational life of the scheme. Information supporting this assessment can be found in Appendix B.

### 1.5.1 Temperature

Extreme temperatures can result in thermal loading of structures and surfaces which can cause expansion, buckling and stresses including road surface softening, ‘bleeding’ and pot holes. Temperature extremes can also damage to natural landscape features. These impacts primarily result in an increased requirement for the maintenance of assets, although high temperature extreme can cause structural damage. Operational loss can also occur as road lanes need to be closed to carry out this maintenance. For example, heat waves and high temperature extremes have historically impacted road maintenance costs in the Norfolk with a number of significant impacts recorded (See box below). In extreme cases cold temperature extremes can also cause the failure of utility pipelines within the vicinity of the scheme.

Recent records of high temperature impacts

- In July 2013, daily maximum temperatures exceeded 28 °C for prolonged periods across East Anglia.
- July 2006 saw days with maximum temperatures exceeding 30°C to 32 °C in eastern areas of England, which placed large amounts of pressure on water and utility companies, road and rail links, and health and fire services.
- Hot weather in the summer of August 2003 (up to 30°C) generated excessively high road surface temperatures of 50-55°C causing road surfaces to melt.

The current frequency and severity of temperature extremes is expected to present a medium level of risk to the NDR scheme (Table 1.1). Projected changes in temperature will increase the frequency and magnitude of future heatwaves and high temperature extremes, although the overall level of risk is expected to remain the same. The frequency and magnitude of low temperature extremes is projected to reduce although, again, the level of risk will remain constant as a result of natural variability in winter temperatures.

Table 1.1: Climate Risk to the NDR Scheme: Temperature

| Variable | Current Risk | Future Risk |
|---|---|---|
| Heatwaves and high temperature extremes | Medium | Medium |
| Coldwaves and low temperature extremes | Medium | Medium |

### 1.5.2 Precipitation

Current and future changes in precipitation patterns will generate risks to the NDR scheme as a result of flooding, droughts and snow and ice (Table 1.2).

Flooding can cause temporary road closure in dangerous conditions (major operational loss). The majority of climate risks in Norfolk are from heavy rainfall and localised flooding, although many of these events occurred in coastal areas. A number of significant heavy rainfall events have occurred in the region (See box below). As the scheme is largely located in Flood Zone 1 (defined as having a low probability of flooding together with no recent records of historical flooding[7]) there is limited risk from fluvial flooding.

Recent records of flooding and heavy rainfall events

- In April and June 2012, East Anglia experienced 367mm of rainfall, 186% above the average. Flooding caused widespread problems, particularly to the transport network.
- From May to July 2007, record levels of rainfall were seen in the East Anglia (173.8mm) 171% above average.
- In October 2002, long periods of rainfall of up to 12 hours at stations in Norfolk resulted in over 40mm rain.
- A front over the east of the UK in October 2001 was responsible for heavy rain resulting in high surface water depths.
- In Autumn 2000, rivers rose to record levels and burst their banks across the country. Norfolk was one of the wettest areas, experiencing 24 hours of heavy rainfall.

The risk to the scheme from pluvial flooding is currently medium. This level of risk is expected to remain over time. Precipitation intensities are projected to increase, although there some uncertainty regarding the change in the frequency of these events.

Drought conditions can present landscape maintenance issues and in extreme cases cause subsidence and slope instability in embankments and cuttings, although UK design standards will provide a high level of resilience. Subsidence can also cause the failure of utility pipelines within the vicinity of the scheme. A number of significant drought events have occurred in the region (See box below).

[7] The scheme would pass through a very limited area of Flood Zone 2 and Flood Zone 3 forming the floodplain at Dobbs Beck. The flow in Dobbs Beck will be maintained under the NDR through a culvert of adequate size to prevent additional flooding elsewhere or impede flood flows.

Recent records of drought events

- 2005 was the 4th driest year on record and the driest since 1973.
- A dry period from 2010 to March 2012 resulted in renewed concerns for farming, water resources and the environment with eastern counties the worst affected.
- The spring of 2011 is the driest in the series from 1910 across East Anglia and south-east England.

Drought currently presents a low risk to the scheme and the level of risk is expected to remain over time. Average precipitation in winter is 'very likely' to increase, thus reducing the frequency and magnitude of winter dry periods. A decrease in spring average precipitation is 'as likely as not' (an increase), although summer average precipitation is 'likely' to reduce to become the driest season in comparison to current trends. Although seasonal precipitation patterns are expected to change, annual total precipitation is 'as about as likely as not' to change.

Snow and ice generates a requirement for maintenance, for example in the form of gritting and snow clearance, to avoid accidents and increases in journey times. A number of snow and ice events have occurred recently in the region (See box below). The build-up of snowfall and ice can cause mechanical loading of overhead lines within the vicinity of the scheme. In extreme cases this can result in line failure.

Recent records of snow and ice events

- In March and April 2013 the UK experienced a prolonged spell of below average temperatures and snowfalls
- December 2010 - widespread and prolonged spell of this type across the UK
- December 2009 to January 2010 - Transport was particularly badly affected with snowfalls causing numerous road closures
- February 2009 - heavy snowfalls in many parts of eastern England

Snow and ice currently presents a medium risk to the scheme and the level of risk is expected to remain. Projected increases in winter precipitation has the potential to raise the risk of ice and snow, however, this is expected to be limited by projected increases in mean winter temperature.

Table 1.2: Assessment of Climate Risk to the NDR Scheme: Precipitation

| Impact | Current Risk | Future Risk |
|---|---|---|
| Flooding and heavy precipitation events | Medium | Medium |
| Drought | Low | Low |
| Snow and ice | Medium | Medium |

### 1.5.3 Gales

Gales can damage structures as a result of windborne debris and the loading of structures. UK design standards will provide resilience, although landscape features such as trees can be vulnerable and cause impacts and disruption to the operation of the scheme. High winds or gusts can cause mechanical loading of overhead lines within the vicinity of the scheme. In extreme cases this can result in line failure. A number of significant gales have occurred in the region (See box below).

Table 1.3: Recent records of gales

- October 2013 - Autumn storm brought damaging winds (70 to 80 knots) across much of southern England
- January 2012 - Winter storm brought storm force winds, with maximum gusts of 50 to 60 knots
- December 2011 - Winter storm brought gales with maximum gusts of 40 to 50 knots, many trees downed
- March 2008 - Strong winds cause some disruption to transport, with maximum gusts of 50 to 60 knots
- January 2005 – Wind causes disruption to transport with maximum gusts of 40 to 50 knots

Gales present a medium of risk to the NDR scheme (Table 1.4). There is significant uncertainty in respect to changes in the frequency and manganite of gales. As a result the level of risk is assumed to remain the same.

Table 1.4: Assessment of Climate Risk to the NGT Scheme: Gales and Wind

| Impact | Current Risk | Future Risk |
|---|---|---|
| Gales | **Medium** | **Medium** |

## 1.6 Mitigation - Climate Resilience

This section provides an overview of the expected resilience of the scheme to key climate risks. Each of the primary elements and features of the NDR Scheme have been appraised to provide an indication of expected resilience to the climate change risks identified (Table 1.5). This assessment also informs the consideration of the scheme’s impact on the wider vulnerability of the environment to climate impacts and its capacity to adapt to changes in climate, which is covered within each of the relevant receptor chapters of the ES.

**Road carriageway** – The NDR will be constructed mainly from a combination of standard asphalt alternatives[8]. Current UK road and surface design standards can be vulnerable to temperature extremes, although the relatively short design life (10--12 years[9]) of road surfaces builds in flexibility, allowing for adaptation. Snow and ice will continue to present operational risks to the scheme over time, although maintenance regimes can provide an appropriate level of resilience to these risks.

**Bridge** – UK design standards provide a high degree of resilience to climate risks such as thermal loading, expansion and wind and ice loading, including projected changes in risk resulting from climate change. The proposed bridges do not cross any surface water bodies, meaning that the risk to bridge structures from flooding, scouring and corrosion will be low. The proposed green bridges at Marriott's Way and Middle Road may be at risk from slope instability during drought conditions or heavy rainfall. Robust structural design will limit this, but there may be an increased maintenance requirement.

**Embankments -** Slope instability presents a risk to embankments, although robust structural design will limit this risk. As the climate changes there may be increased requirement for maintenance of these structures.

**Drainage** – Drainage systems have been designed to incorporate Sustainable Drainage Systems (SuDS). The drainage has been designed to cope with an increase in peak intensity rainfall of 30% to ensure that surface water flows are not increased from current levels. This will be achieved through soakaway systems, culverts and drainage lagoons. Soakaway systems and culverts under the road will be installed to control and direct overland flow. Drainage lagoons are proposed to regulate discharge rates to surface water at the existing greenfield runoff rates. Discharges of routine runoff to surface water and groundwater will flow through a three tiered treatment system[10]. This will have benefits for the wider environment through protection of water quality and habitat creation.

**Landscaping** – Landscaping will include native, locally present species of woodland, scrub and grassland habitats, hedgerows and wetland areas. Hardy species will be included in the landscape design, meaning that overall resilience will be good. Maintenance will, however, need to be employed to during drought conditions. Landscaping may also be vulnerable to gales.

**Other structural features -** This includes noise fencing, road signs, 25km of new links with some improved surfacing (suitable for use by pedestrians, cyclists and equestrians where permitted) and lighting.[11] Gales can damage lighting columns and signage, although robust design will provide a high degree of resilience. New footpaths and cycleways can be vulnerable to temperature extremes and snow and ice although maintenance regimes can respond to these risks.

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[8] Hydraullically-Bound Mixture (HBM), bituminous binder and surface course, with sub-base of a Course Bound Granular Mixture (CBGM)

[9] http://assets.highways.gov.uk/about-us/climate-change/HA_Climate_Change_Risk_Assessment_August_2011_v2.pdf

[10] Grassed swales, lined settlement pond, infiltration pond (if discharges to groundwater) or surface flow wetland (if discharged to surface water)

[11] Majority of the scheme will not be lit. The exception to this is the Postwick Hub area.

**Asset management/maintenance** – Maintenance of structures and surfaces will help maintain a degree of resilience to climate risks. These activities provide the opportunity to assess vulnerability and risks over time and make improvements or to incorporate retrofitting measures in response to the risks. This can be undertaken as part of maintenance, modification or replacement regimes, such as:

- gritting and snow ploughing
- unblocking of drains
- watering and general maintenance of landscape features
- maintenance of structural features such as embankments, cuttings, bridges and road
- maintenance of bridges
- repairs to road surfacing

**Construction** – The construction site will be vulnerable to current climate variability and extremes. Following appropriate construction codes of practice and developing an adherence to a Construction Environmental Management Plan will reduce this risk.

**Public utilities** – Public utilities have the potential to affect the operation and maintenance of the NDR scheme, for example from burst water and waste water pipes and overhead line failure. Underground utilities are more resilient to climate risks than exposed utilities, although, design standards for public utilities generally provide a high degree of resilience to climate risks. The proposed rerouting of overhead lines and diversion of other public utilities within the scheme will further reduce the potential for impacts.

Table 1.5: Scheme resilience to climate risks

| Structural feature | Key Climate Risks | Scheme resilience |
|---|---|---|
| Road carriageway | • Heatwaves and high temperature extremes<br>• Coldwaves and cold temperature extremes<br>• Snow and ice | Moderate |
| Bridges | • Flooding and heavy precipitation events<br>• Drought<br>• Heatwaves and high temperature extremes<br>• Gales<br>• Snow and ice | High |
| Embankments and cuttings | • Drought<br>• Flooding and heavy precipitation events | High |
| Drainage | • Flooding and heavy precipitation events | High |
| Landscaping and ecology | • Gales<br>• Heatwaves and high temperature extremes | High |
| Other structural features | • Gales<br>• Heatwaves and high temperature extremes<br>• Snow and ice | High |
| Asset management/maintenance | n/a | High |

| Structural feature | Key Climate Risks | Scheme resilience |
|---|---|---|
| Construction | • Drought<br>• Flooding and heavy precipitation events<br>• Heatwaves and high temperature extremes<br>• Snow and ice<br>• Gales | High |
| Public utilities | • Coldwaves and low temperature extremes<br>• Drought | High |

## 1.7 Conclusion

This chapter has assessed the climate change (adaptation) issues associated with the NDR scheme to determine its resilience to climate risks. The main findings of this assessment process are summarised below. The assessment of current and projected future climate has identified a number of medium and low risks to the scheme (Table 1.6).

Table 1.6: Climate Risk to the NGT Scheme

| Variable | Current Risk | Future Risk |
|---|---|---|
| Heatwaves and high temperature extremes | Medium | Medium |
| Coldwaves and low temperature extremes | Medium | Medium |
| Flooding and heavy precipitation events | Medium | Medium |
| Drought | Low | Low |
| Snow and ice | Medium | Medium |
| Gales | Medium | Medium |

Under the assumption that the infrastructure will be designed and built to robust standards, it is expected that the scheme will be resilient to the range of climate risks. The resilience of the road surfaces to temperature extremes is, however, highlighted as an area where resilience can be improved (Table 1.7).

Table 1.7: Scheme resilience

| Structural features | Scheme resilience |
|---|---|
| Road carriageway | Moderate |
| Bridges | High |
| Embankments and cuttings | High |
| Drainage | High |
| Landscaping and ecology | High |
| Other structural features | High |
| Asset management/maintenance | High |
| Construction | High |
| Public utilities | High |

# Appendices

# Appendix A. CCRA Methodology

### 1.7.1 Evaluation of climate risk

This section outlines the calculation method which is used to determine the level of risk associated with current and future climate impacts to the NDR Scheme. The calculation method used is as follows:

***Probability of impact x Severity of impact = Risk***

#### 1.7.1.1 Probability

The probability of impacts to the NDR Scheme determined by an evaluation of current and projected (future) climate data. Using this data, a quantitative representation of the likelihood of impacts is established. Current climate impact is based on an estimated impact return period (Table 1.8). Future climate impact is based on a combination of the estimated future impact return period (Table 1.9) and the confidence in a future direction of climate change (Table 1.10). A combination of Met office data[12] and data from UKCP09[13] was used to evaluate the current climate and likely future changes as a result of climate change respectively to determine these probability values.

Table 1.8: Probability of current climate impact

| Score | Probability (Current or Future Climate) |
|---|---|
| 5 | An estimated return period of less than 1 year |
| 4 | A return period of at most 1 in 1 years |
| 3 | A return period of at most 1 in 3 years |
| 2 | A return period of at most 1 in 5 years |
| 1 | A return period of at most 1 in 10 years |

Table 1.9: Confidence in a future direction of change for a climate risk variables

| Score | Confidence (Future Climate) | Rating |
|---|---|---|
| 5 | 90 to 100% probability | Very Likely |
| 4 | 66 to 90% probability | Likely |
| 3 | 33 to 66% probability | About as Likely as Not |
| 2 | 10 to 33% probability | Unlikely |
| 1 | 0 to 10% probability | Very Unlikely |

[12] Met Office (accessed July 2013) UK Climate http://www.metoffice.gov.uk/climate

[13] UK Climate Projection 2009 - http://ukclimateprojections.defra.gov.uk/

Table 1.10: Future climate impact

| Probability | | | | | |
|---|---|---|---|---|---|
| **5** | 3 | 3.5 | 4 | 4.5 | 5 |
| **4** | 2.5 | 3 | 3.5 | 4 | 4.5 |
| **3** | 2 | 2.5 | 3 | 3.5 | 4 |
| **2** | 1.5 | 2 | 2.5 | 3 | 3.5 |
| **1** | 1 | 1.5 | 2 | 2.5 | 3 |
| | **1** | **2** | **3** | **4** | **5** |
| | Confidence | | | | |

Current weather and climate data, for the Marham weather station, covered the following periods:

- 1970s (1961 to 1990 dataset) represents the 'Baseline' climate from which future climate change projections are determined.
- 1990s (1981 to 2010 dataset) is referred to as the 'Current' climate.

The following climatic fluctuations or trends were identified for Norfolk over that period:

- Increasing maximum temperatures
- Increasing minimum temperatures
- Slight increase in average rainfall and number of days rainfall
- Variations in seasonality of rainfall

Projections of future climate were obtained from UKCP09[14] for the 2020s (2010 to 2039), 2050s (2040 to 2069) and 2080s (2070 to 2099) for the high emissions scenario.[15] Projected change factors in climatic variables were applied to a climate baseline to determine an absolute projected change. In response to the range of uncertainty generated from outputs from the climate model ensemble used in UKCP09, this assessment focuses on the 'likely range' (the 10th and 90th percentiles) of outcomes. This is based on the understanding that projected changes outside of this range are considered 'Unlikely'. Where possible the likelihood of a direction of change in climate variables is expressed using the information given in Table 1.11. This approach for communication of the uncertainty associated with projected changes in climate is expressed in Table 1.12.

[14] http://ukclimateprojections.defra.gov.uk/21678

[15] This scenario has been chosen in respect to current emission pathways, which as are currently exceeding the high (SRES – A2) and the higher (A1F) emission scenario. Although, the changes associated with other emission scenarios have also been considered in analysis.

Table 1.11: Communicating likelihood

| Term | Likelihood of an outcome |
|---|---|
| Virtually certain | 99-100% probability |
| Very likely | 90-100% probability |
| Likely | 66-100% probability |
| About as likely as not | 33 to 66% probability |
| Unlikely | 0-33% probability |
| Very unlikely | 0-10% probability |
| Exceptionally unlikely | 0-1% probability |

Source: IPCC [16]

Table 1.12: Projected changes in key climate variables in Norfolk by the 2080's

| Climate variable | Future trend (likelihood) | The 'likely' range of change from baseline |
|---|---|---|
| Annual mean temperature | Increase (virtually certain) | 2.7ºC to 5.9ºC |
| Annual mean daily maximum temperature | Increase (virtually certain) | 2.3ºC to 6.8ºC |
| Annual mean daily minimum temperature | Increase (virtually certain) | 1.8ºC to 6.6ºC |
| Annual temperature on the warmest day | Increase (likely) | -2.38ºC to 10.69ºC |
| Annual total precipitation[17] | Decrease (About as likely as not) | -7.2% to 9% |
| Annual mean temperature | Increase (virtually certain) | 2.7ºC to 5.9ºC |

Source: UKCP09

This assessment is based on an observational climate data set and the accompanying UKCP09 projections. Modelled data for the future are not predictions of climate, but simulations of future climate under a range of hypothetical emissions scenarios. Any further research, analysis or decision-making should take account of the accuracies and uncertainties associated with these projections. It is also important to note that the analysis is based on chosen observed data, the results of climate model ensemble experiments and a selected range of existing climate change research and literature at the time. Any future decision-making based on this analysis should consider the range of literature, evidence and research available and any recent developments in these.

[16] Mastrandrea, M.D. et al, 2010: Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties. Available at www.ipcc.ch

[17] With significant season variations

### 1.7.1.2 Severity

The following scales were used to quantify the potential severity of climate impacts to the NDR scheme (Table 1.13) which are rated from 0 (no impact) to 5 (structural failure), with minor (+) or major (++) ratings for positive impacts. The appraisal of the severity of impacts was determined based on a combination of expert review of available evidence and literature.

Table 1.13: Potential severity of impact to the scheme

| Score | Impact on the scheme | Rating |
|---|---|---|
| 5 | Structural failure | Very High |
| 4 | Structural damage | High |
| 3 | Major operational loss | Moderate |
| 2 | Minor operational loss | Low |
| 1 | Increased maintenance | Very Low |
| 0 | No impact | No impact |
| + | Minor positive impact | Minor positive impact |
| ++ | Major positive impact | Major positive impact |

### 1.7.1.3 Risk

The combination of the probability and severity scores can be used to determine the current and future level of risk to the NDR Scheme. This is calculated using Table 1.14. A 40 year design life for the NDR Scheme is planned. The projections used as the basis for the future level of risk were therefore the 2050s, however projections for the 2020s and 2080s are also used, to allow for the consideration of risk associated with early operation and longer-term impacts to the scheme as the scheme is likely to be operational beyond its design life.

Table 1.14: Future climate risk

| Probability | | | | | | |
|---|---|---|---|---|---|---|
| | 5 | 5 | 10 | 15 | 20 | 25 |
| | 4 | 4 | 8 | 12 | 16 | 20 |
| | 3 | 3 | 6 | 9 | 12 | 15 |
| | 2 | 2 | 4 | 6 | 8 | 10 |
| | 1 | 1 | 2 | 3 | 4 | 5 |
| | | 1 | 2 | 3 | 4 | 5 |
| | | | | | | Severity |

| Risk |
|---|
| Low |
| Medium |
| High |

### 1.7.2 NDR Scheme resilience and recommendations for climate change adaptation

In response to the climate risks profiled in the previous stage, the NDR scheme's resilience (Figure 1.5) is reviewed and identified. These stages of the assessment are based on expert opinion supported by evidence and literature. The schemes impact on the wider environment's vulnerability to climate impacts or capacity to adapt to climate change is considered in the corresponding environmental chapter, taking account of the climate risks raised in this assessment.

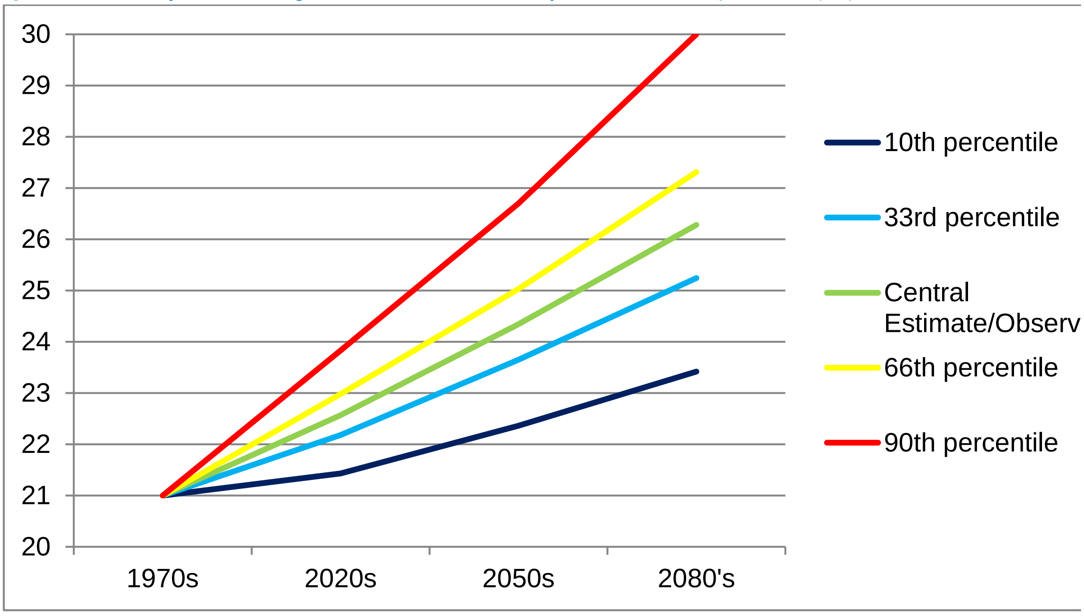
Table 1.15: Scheme resilience

| Rating |
| --- |
| Low Resilience |
| Moderate Resilience |
| High Resilience |

# Appendix B. Climate Change Risk

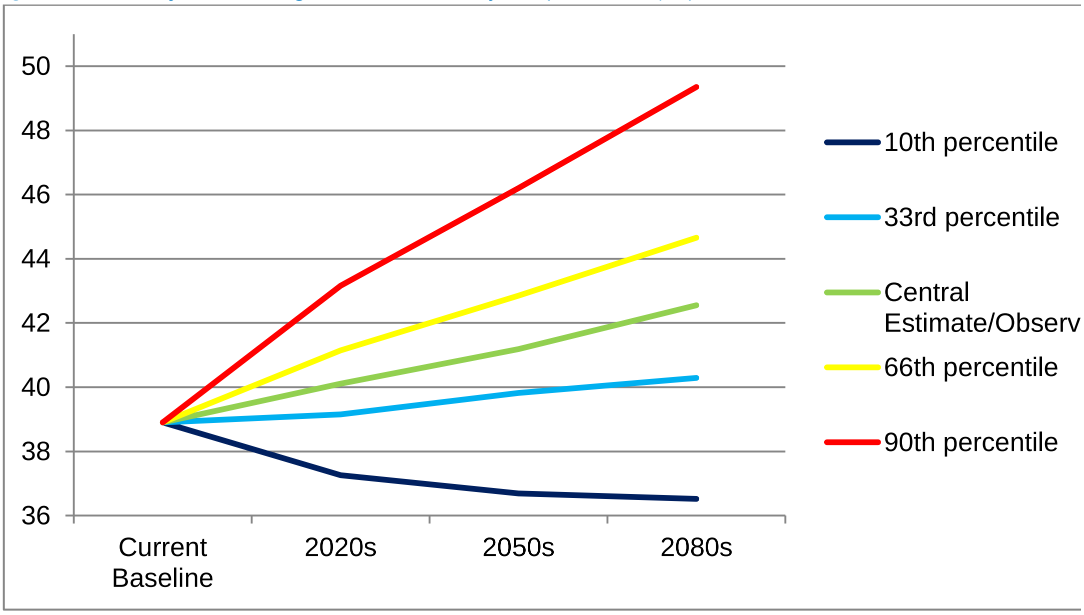
## B.1 Temperature

Figure 1.2: Projected change in summer mean daily maximum temperature (˚C)



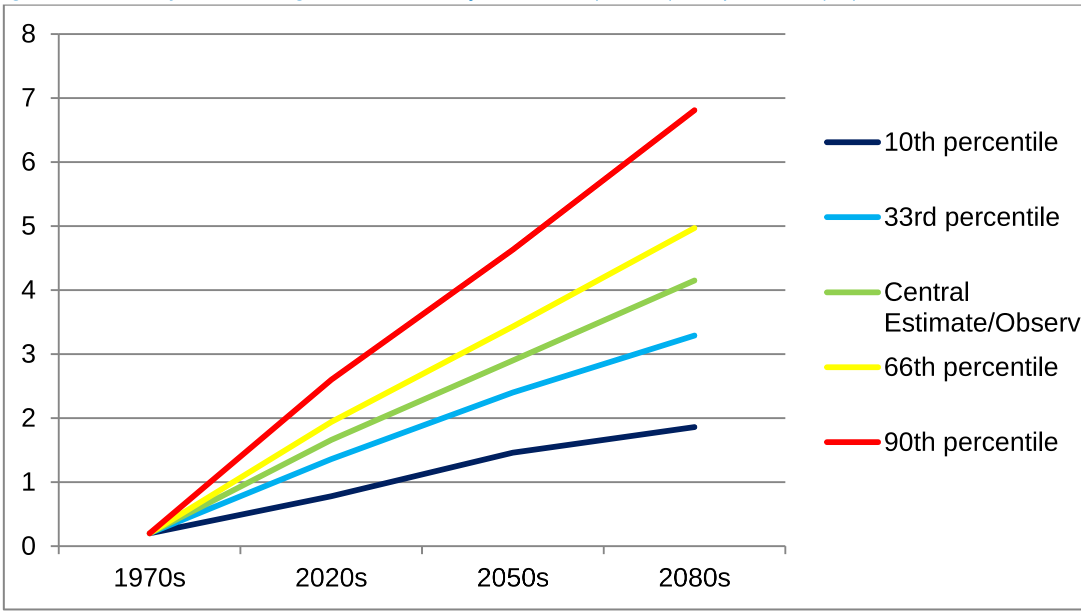

Source: UKCP09/Met Office

Figure 1.3: Projected changes in warmest day temperatures (˚C)



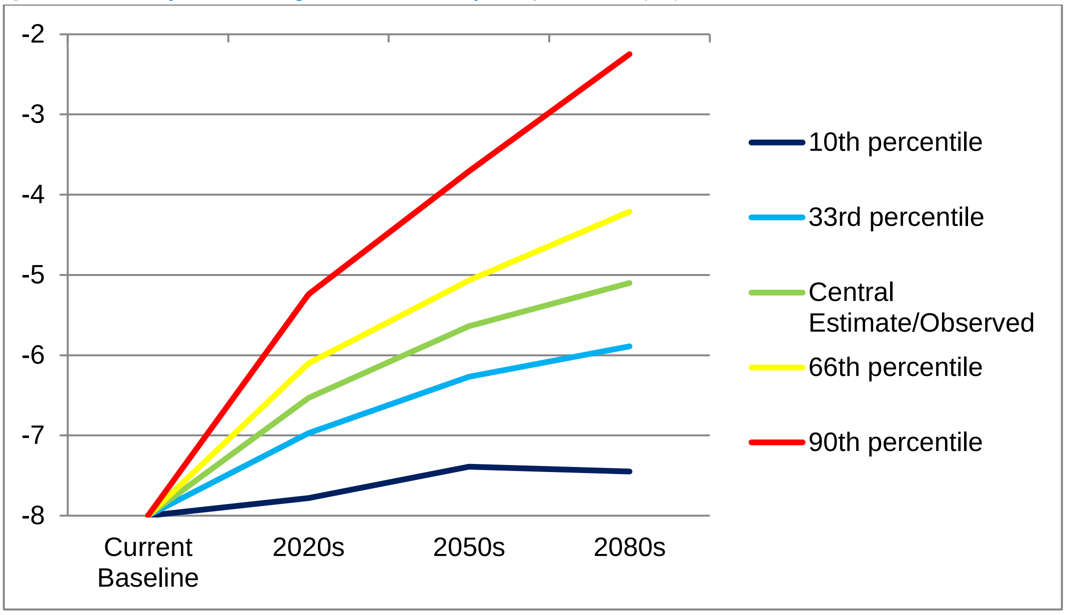

Source: UKCP09/Met Office

Figure 1.4: Projected changes in mean daily minimum (Winter) temperature (˚C)




Source: UKCP09/Met Office

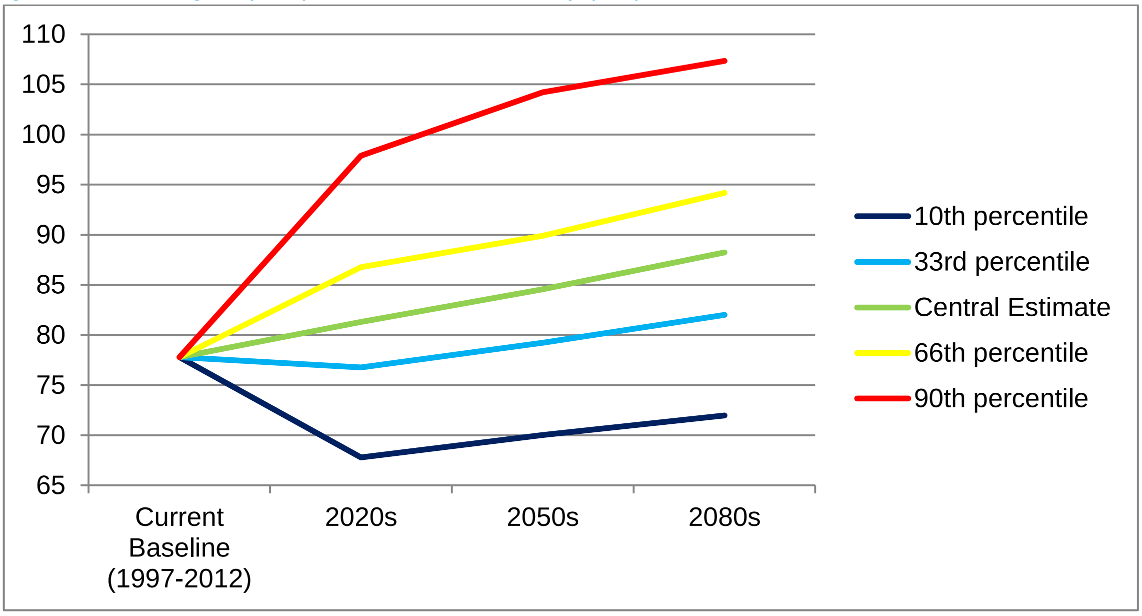
Figure 1.5: Projected changes in coldest day temperatures (˚C)




Source: UKCP09/Met Office

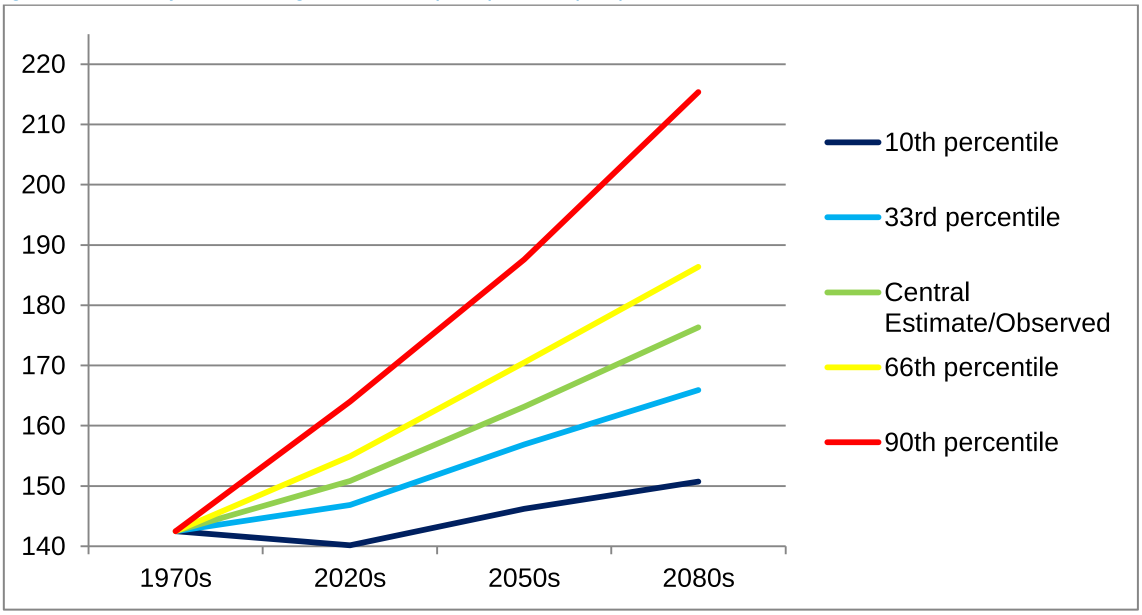
### B.1.1 Precipitation

Figure 1.6: Change in precipitation on the wettest day (mm)



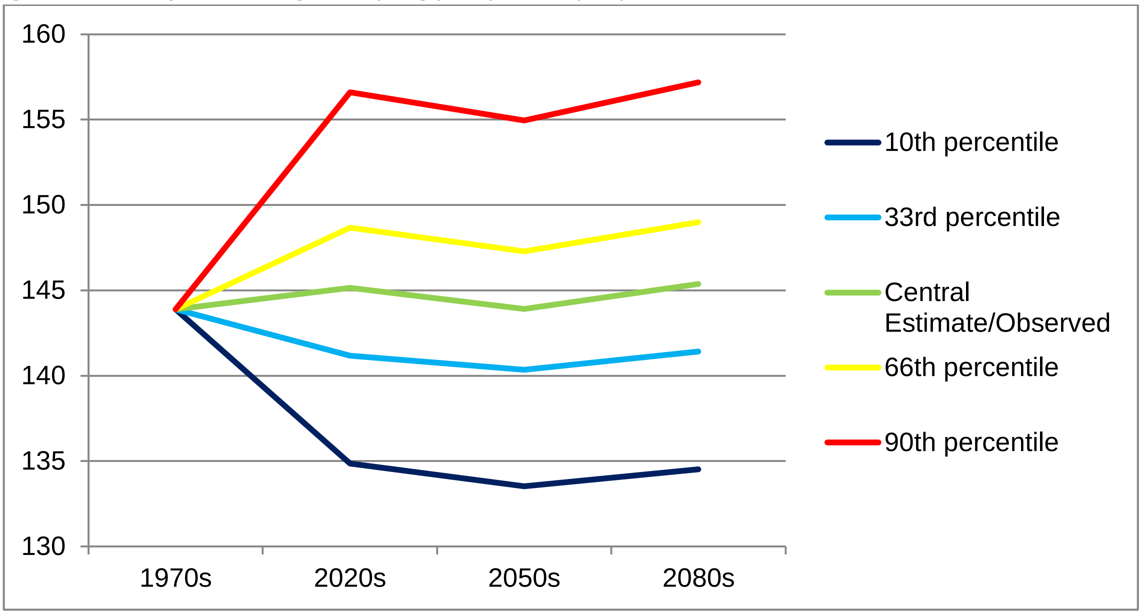

Source: UKCP09/Met Office

Figure 1.7: Projected changes in winter precipitation (mm)



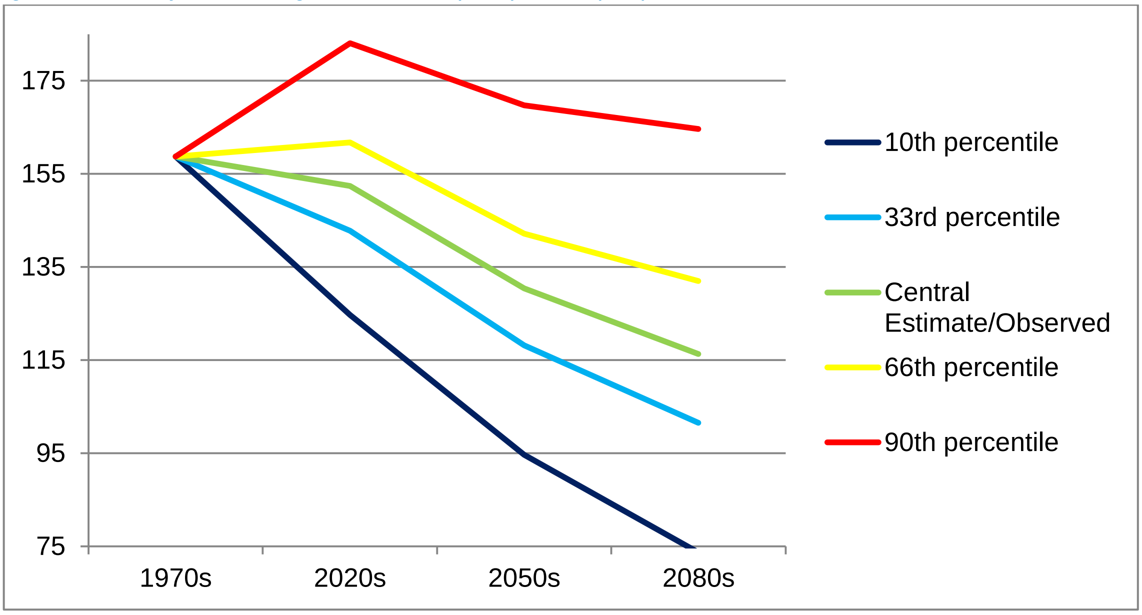

Source: UKCP09/Met Office

Figure 1.8: Projected changes in spring precipitation (mm)




Source: UKCP09/Met Office

Figure 1.9: Projected changes in summer precipitation (mm)




Source: UKCP09/Met Office

## B.2 Climate risk

### B.2.1 Temperature

Table 1.16: Assessment of Climate Risk to the NDR Scheme: Temperature

| Variable | Impact | Current Probability | Current Risk | Future Probability | Future Risk |
|---|---|---|---|---|---|
| Heatwaves and high temperature extremes | Minor operational loss (2) | A return period of at most 1 in 3 years (3) | Medium (6) | Increase - Very Likely (4) | Medium (8) |
| Coldwaves and low temperature extremes | Minor operational loss (2) | A return period of at most 1 in 1 years (4) | Medium (8) | Increase - Very Unlikely (2.5) | Medium (5) |

### B.2.2 Precipitation

Table 1.3: Assessment of Climate Risk to the NDR Scheme: Precipitation

| Impact | Impact | Current Probability | Current Risk | Future Probability | Future Risk |
|---|---|---|---|---|---|
| Flooding and heavy precipitation events | Major operational loss (3) | A return period of at most 1 in 3 years (3) | **Medium (9)** | Increase - Likely (3.5) | **Medium (10.5)** |
| Drought | Higher levels of maintenance (1) | A return period of at most 1 in 3 years (3) | **Low (3)** | Increase (Summer) - Likely (3.5) | **Low (3.5)** |
| Snow and ice | Minor operational loss (2) | A return period of at most 1 in 1 years (4) | **Medium (8)** | Increase - Very Unlikely (2.5) | **Medium (5)** |

### B.2.3 Gales

Gales present a degree of risk to the NDR scheme (Table 1.4).

Table 1.17: Assessment of Climate Risk to the NGT Scheme: Gales and Wind

| Impact | Impact | Current Probability | Current Risk | Future Probability | Future Risk |
|---|---|---|---|---|---|
| Gales | Minor operational loss (2) | A return period of at most 1 in 1 years (4) | **Medium (8)** | Increase - About as Likely as Not (3.5) | **Medium (7)** |

# Glossary

| | |
|---|---|
| **Adaptation (climate change)** | Actions to reduce the vulnerability of a system to the negative impacts of anticipated human-induced climate change. |
| **Adaptation action measures** | Practical actions to either reduce vulnerability to climate risks, or to exploit positive opportunities |
| **Adaptive capacity building measures** | Developing the institutional capacity to respond effectively to climate change |
| **Adaptive capacity or capacity to adapt** | Inherent capacity of a system or population to adjust to climate impacts or climate change, to moderate potential damages, exploit opportunities, and cope with the consequences. |
| **Baseline** | The baseline period defines the climate against which future changes are projected. |
| **Climate** | Climate is typically defined as the average weather (or more rigorously a statistical description of the average in terms of the mean and variability) over a period of time, usually 30 years. Climate in a wider sense is the state, including a statistical description, of the climate system. |
| **Climate Change Mitigation** | Reducing greenhouse gas emissions in order to slow or stop global climate change. |
| **Climate model** | A simplified mathematical representation of the climate system based on the physical, chemical, and biological properties of its components, their interactions and feedbacks between them. |
| **Climate resilience** | The ability of a system to absorb impacts from climatic and extreme weather events while retaining the same basic structure and ways of functioning, the capacity of self-organisation and the capacity to adapt to stress and change. |
| **Climate risk** | Additional risk to investments (such as buildings and infrastructure) and actions from potential climate change impacts. |
| **Climatic variables** | Measurable or observable climate and weather factors that provide an indication of the occurrence of climatic conditions and weather events. |
| **Coldwave** | An onset of unusually cold weather within a given period of time (usually 24 hours). |

**Extreme weather event** Extreme weather describes weather phenomena that are at the extremes of the historical distribution, especially severe or unseasonal weather.

**Heatwave** An onset of unusually cold weather within a given period of time (usually 24 hours).

**High temperature extreme** Extreme weather describes weather phenomena that are at the extremes of the historical distribution, especially severe or unseasonal weather.

**Gales** A very strong wind. Defined by the Met Office as being winds of at least Beaufort force 8 (34–40 knots) or gusts reaching 43–51 knots.

**Low regret measures** Measures that perform well under present-day climate with some uncertainty regarding future climate scenarios.

**Maladaptation** Action or investment that enhances vulnerability to climate change impacts rather than reducing them.

**No regret measures** Measures that perform well under present-day climate, and under all future climate scenarios.

**Projected climate** A description of climatic variables in the future, or how they have changed relative to a baseline. This is usually based on modelling of the response of the climate system to emission or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios.

**Return Period** The average time between events of a given magnitude. A 100-year return period is the equivalent of the event that has a 1 per cent probability of occurring in any given year.

**Robust** The term used to refer to the ability to cope with or recover from a range of inputs and situations in a given environment.

**Scenario** A description of a plausible future state which is not associated with an ascribed likelihood. In the context of UKCP09 climate projections, scenarios are generally based around future greenhouse gas emissions.

**Seasonal** One of the averaging periods for which climate changes projections are provided in UKCP09, based on projected changes to seasonal average conditions. Winter is the average for the three months December, January and February; Spring is the average for March, April and May; Summer is the average for June, July and August; and Autumn is the average for September, October and November.

| | |
|---|---|
| **Uncertainty** | Uncertainty refers to a state of having limited knowledge. Uncertainty can result from lack of information or from disagreement over what is known or even knowable. Uncertainty may arise from many sources, such as quantifiable errors in data, or uncertain projections of human behaviour. Uncertainty can be represented by quantitative measures or by qualitative statements. |
| **Weather** | Weather refers to the state of the atmosphere with regard to temperature, cloudiness, rainfall, wind, and other meteorological conditions. |