Infrastructure Transitions Research Consortium

Report

ITRC WS2 IUK infrastructure hazard and data report

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ITRC WS2 IUK Infrastructure Hazard and Data Report

SECTION 1: INTRODUCTION

National infrastructure (NI) forms the backbone of our modern communities[1] and provides the foundations for economic productivity and social wellbeing[2]. NI includes the five economic infrastructure sectors of: (1) energy, (2) transport, (3) water, (4) waste, and (5) information and communication technology (ICT). These five systems are interdependent, relying on the service provided by each other to function normally. They support and underpin our communities by providing the energy and resources needed to function and enable people, information and goods to move efficiently. However, in the UK as well as other advanced nations, NI is continually threatened by natural disasters, man-made accidents and malicious attacks[3]. These threats have the potential to damage our NI systems, which can result in devastating effects to the communities which rely upon them. For example, hurricane Katrina (2005) flooded 80% of New Orleans causing 'unprecedented damage' to the electricity system[4] and 'devastating' communications infrastructure which incapacitated emergency service dispatch centres[5]. Several large hospitals were also destroyed, the majority of health care facilities were closed and hundreds of patients became stranded inside dark and flooded hospitals that lacked basic supplies – some of these patients succumbed to these conditions before they could be evacuated. Fortunately, such large scale natural hazards are extremely rare in the UK; however, smaller scale events can still have devastating consequences. For example, the summer 2007 floods in England flooded approximately 55,000 homes and businesses and left half a million people without mains water or electricity[6,7]. To better protect our communities and the people within them from the effects of a natural hazard we must ensure that our NI systems are resilient to these risks. To achieve this, we must first gain an understanding of the risks and their potential impacts to our vital NI systems.

To identify the risks to the UK, the government developed the first National Risk Register (NRR) in 2008, which was '*intended to capture the range of emergencies that might have a major impact on all, or significant parts of, the UK*'[8]. This report identified hazards that were likely to affect the UK over the next 5 years and gave an assessment of the relative likelihood and impact of each hazard. This report has been reviewed and updated in recent years (initially in 2012[9] and again in 2013[10]) to reflect the changing threat from risk to the UK.

This report identifies potential risks/threats to NI from both natural and man-made sources, and incorporates many of the risks identified in the 2013 NRR. An assessment of both the impact and likelihood of occurrence of each risk is made, along with locations particularly likely to be affected, where possible. This information is used to assess the likely impacts to five NI sectors from each risk, and also incorporates a review of past events and their impacts. The final section of this report

[1] Institution of Civil Engineers (2009) *The State of the Nation: Defending Critical Infrastructure*.
[2] Hall, J.W., Henriques, J.J. and Nicholls, R.J. (2012) *A Fast Track Analysis of strategies for infrastructure provision in Great Britain: Technical Report*.
[3] Cabinet Office (2010) *A Strong Britain in an Age of Uncertainty: The National Security Strategy*. London.
[4] U.S. Department of Energy (2005) *Department of Energy's Hurricane Response Chronology*.
[5] U.S. Government (2006) *The Federal Response to Hurricane Katrina: Lessons Learned*.
[6] Cabinet Office (2008b) *The Pitt Review: Learning Lessons from the 2007 Floods*.
[7] Environment Agency (2007) *Review of 2007 summer floods*.
[8] Cabinet Office (2008a) *National Risk Register*. London.
[9] Cabinet Office (2012) *National Risk Register of Civil Emergencies*. London.
[10] Cabinet Office (2013) *National Risk Register of Civil Emergencies*. London.

considers the availability of datasets that can be used to analyse the current resilience of UK NI systems and also the availability of datasets quantifying the disruption to NI systems when exposed to risk.

SECTION 2: REVIEW OF RISKS IN THE UK AND THEIR POTENTIAL IMPACT TO NATIONAL INFRASTRUCTURE

2.1: NATURAL HAZARDS

The majority of the natural hazards threatening UK NI today can be broadly placed into one of two categories, those caused by weather related impacts and those resulting from geotechnical conditions. As such, this section has been split into three sub-sections, one for each of these main areas of risk and one further section other detailing all other risks. It is worth noting that some of these risks can be placed into two categories, for example coastal erosion is caused by weather related impacts but the severity of these impacts is linked to the rock/soil structure (geotechnical). These risks have been placed into the category which is deemed to have the most influence over the likelihood and impact of the risk. It is also worth considering that many of the natural hazard risks outlined in this section can cause other natural hazard risks. For example, flooding can occur due to a period of heavy rainfall, but can also be caused by severe storms and gales and the melting of an extensive snowfall which are both natural risks themselves, and pose their own threat to UK NI[11].

2.1.1: WEATHER RELATED RISKS

2.1.1.1: FLOODING

Flooding has been identified to be the greatest risk to the UK, both currently and in future climate change exacerbated scenarios[12,13]. This type of event can have devastating effects to our NI systems and can therefore also impact the communities they support[14]. These effects are illustrated in many past events, including the flooding across England in summer 2007 (Figure 1). This event was caused by a period of extreme rainfall (the wettest since rainfall records began in 1766[15]) and resulted in the flooding of over 55,000 homes and businesses[16,17]. The event also caused flash flooding in the immediate rainfall areas and subsequent downstream flooding, which caused resulted in significant damage to many NI systems. The damage to energy infrastructure systems included the closure of electricity substations which were affected by floodwaters, including the closure of the Castle Meads substation which left 42,000 people without power for up to 24 hours. Water infrastructure was also badly affected, with the closure of water treatment works due to flooding (including, the closure of the Mythe water treatment works which caused 350,000 people to be without access to mains water supply for 17 days[18],[19]). There was also significant structural damage to the dam at Ulley Reservoir (South Yorkshire) caused by the overtopping of water after a period of heavy

[11] Cabinet Office (2011) *Keeping the Country Running: Natural Hazards and Infrastructure*.
[12] Institution of Civil Engineers (2009) *The State of the Nation: Defending Critical Infrastructure*.
[13] Institution of Mechanical Engineers *Climate Change: Adapting to the Inevitable?*
[14] Environment Agency (2011) *Understanding the risks, empowering communities, building resilience: The national flood and coastal erosion risk management strategy for England*.
[15] Stuart-Menteth, A. (2007) *U.K. Summer 2007 Floods*.
[16] Cabinet Office (2008b) *The Pitt Review: Learning Lessons from the 2007 Floods*.
[17] Environment Agency (2007) *Review of 2007 summer floods*.
[18] Cabinet Office (2008b) *The Pitt Review: Learning Lessons from the 2007 Floods*.
[19] OFWAT (2007) *Water and sewerage services during the summer 2007 floods*.

rainfall[20]. This damage required emergency action to prevent major downstream flooding and also forced the closure of parts of other infrastructure sectors, including the M1 for over 40 hours[21]. This event also directly impacted transport infrastructure, forcing the closure of roads and railways (due to flooding); however the direct impact to ICT and waste infrastructure are less recorded. Although, these sectors were affected due to their interdependency with other infrastructures; for example, much of ICT requires an energy supply in order to operate normally. It was estimated that the insurance industry expected to pay out over £3 billion and economic losses to NI systems was estimated at £674 million, with the water sector the worst affected[22]. This flood event also showed that these events are not necessarily confined to one small geographic area and have the potential to affect large areas of the UK; with surface water flooding affected many towns, villages and individual properties from Bristol to Newcastle.

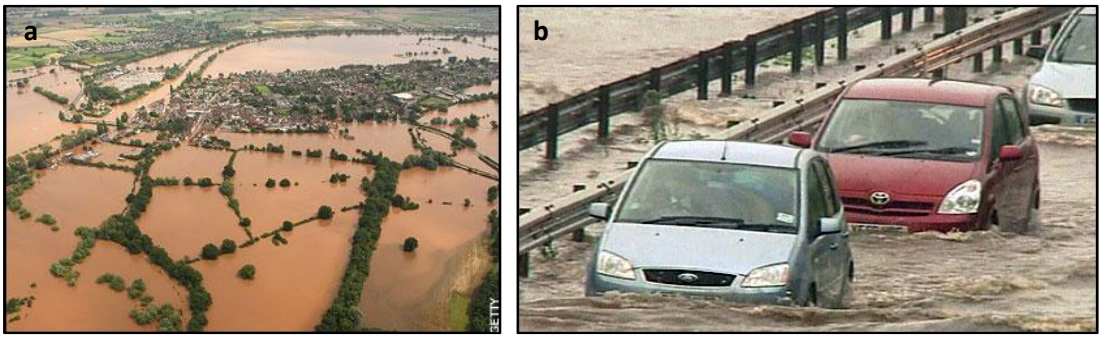

Figure 1: Showing the impacts of the 2007 flood event to the UK, showing (a) Upton on Severn surrounded by water[23] and (b) motorists in Hull[24].

Other recent notable flood events in the UK include the flooding in Cumbria in November 2009 (which notably '*cut in half*'[25] communities through severe damage to bridges (Figure 2(a)) and also caused disruption to energy and water infrastructure[26]) and the summer 2012 floods (which included a flash flood event in Newcastle, where a month's rainfall fell in 2 hours, causing major disruption to transport infrastructure and flooding 1,200 properties many for the first time[27]). These past events highlight not only the significant impact on people, businesses and NI that flooding can cause, but also the geographically widespread nature of these events.

[20] Environment Agency (2013e) *Impact on reservoirs of 2007 summer floods*. Available at: http://www.environment-agency.gov.uk/research/library/publications/40515.aspx (Accessed: 24 September).
[21] Environment Agency (unknown) *2007 Summer Floods: Reservoir Safety - Learning from Ulley*.
[22] Environment Agency (2010b) *The Costs of the Summer 2007 Floods in England*.
[23] The Telegraph (2007) *Upton on Severn, Worcs, is surrounded by water*. [Online] Available at: http://www.telegraph.co.uk/news/uknews/1558232/Floods-worsen-as-rivers-continue-to-rise.html.
[24] BBC (2007b) *Drains fail in Hull*. [Online] Available at: http://news.bbc.co.uk/1/hi/uk/7449188.stm.
[25] Met Office (2012) *Heavy Rainfall/Flooding in the Lake District, Cumbria - November 2009*. Available at: http://www.metoffice.gov.uk/climate/uk/interesting/nov2009 (Accessed: 9 August).
[26] The Guardian (2010) *Cockermouth, a year on from the floods*. Available at: http://www.theguardian.com/society/2010/nov/16/cockermouth-cumbria-floods-first-anniversary (Accessed: 9 August).
[27] Newcastle City Council (2013) *Summer 2012 Flooding*. Available at: http://www.newcastle.gov.uk/environment/environment/june-28-recent-flooding.

Figure 2: Showing (a) a collapsed bridge due in the November 2009 Cumbrian floods[28] and (b) the flooding in Newcastle as a resulting of flash flooding in 2012[29].

These events were all primarily caused by periods of intense rainfall; however, in the UK there are several other events/conditions which can trigger a flood event. For example, the 1953 east coast flooding emergency was caused by a combination of high tides and a major sea surge which breached flood defences[30] and was the last occasion that a national emergency was formally declared in the UK[31]. This event caused widespread damage to many NI systems, including the loss of 2 power stations, 12 gas works and over 100 miles of road and 200 miles of railway became impassable due to flooding[32]. In urban areas the flood waters became contaminated with sewage and water pumping stations unable to operate (as they were inundated with water) and underground water resources became contaminated with salt water. It was estimated that the damage from this event was £50 million (approximately £1 billion today).

In the UK, there are different types of flooding[33,34] and it is possible that different forms of flooding can occur in a single event:

- *coastal flooding* (or *tidal flooding*)- caused by sea and/or river defences being overtopped or breached;
- *fluvial flooding* – arises on floodplains when the capacity of a river is exceeded, possibly as a result of high levels of rainfall or snow and ice melts within a catchment area;
- *ground water* - occurs when a rising water table reaches the ground surface, typically in low lying areas;

[28] The Telegraph (2009) *Cumbria Floods*. [Online] Available at: http://www.telegraph.co.uk/topics/weather/6616396/Cumbria-floods-wife-of-hero-policeman-killed-in-flood-says-he-died-helping-others.html.

[29] Mail Online (2012b) *Thunderstorms in Newcastle upon-Tyne*. [Online] Available at: http://www.dailymail.co.uk/news/article-2165944/UK-floods-153-lightning-strikes-minute-hailstones-size-GOLF-BALLS-hits-Midlands.html.

[30] Risk Management Solutions (2003) *1953 U.K. Floods: 50 Year Retrospective*.

[31] Cabinet Office (2013) *National Risk Register of Civil Emergencies*. London.

[32] BBC (2003) *1953 Floods - Facts and Figures*. Available at: http://www.bbc.co.uk/lincolnshire/asop/places/floods/floods_facts.shtml (Accessed: 24 September).

[33] Royal Institute of British Architects (2013) *Flooding: Flooding Explained*. Available at: http://www.architecture.com/findoutabout/sustainabilityandclimatechange/flooding/floodingexplained.aspx#.UftxXb5wa1s.

[34] Natural Environment Research Council *FREE: Flood Risk from Extreme Events*.

- *pluvial flooding (*or *surface water flooding)* - caused by excess surface water from intense rainfall that cannot drain away quickly enough;
- *flooding from sewers* - occurs when the capacity of combined storm and foul sewers are exceeded by large amounts of surface water run-off over a short time period;
- *flooding from man-made infrastructure* - caused by the failure of a man-made structures for example the failure of a dam or canal.

Coastal (or tidal) flooding has been identified as the form of flooding that has the greatest potential to cause the most widespread impact in a single event[35,36]. However, this type of flood event can be predicted to some accuracy (and therefore mitigated to some extent), which is not the case with other forms of flooding; for example, flash floods (caused by fluvial flooding), pluvial flooding and flooding from sewers are hard to predict and can occur with little, or no, warning.

The Environment Agency (EA) '*plays a central role in managing flood risk from rivers and the sea*' and coordinates the many different public and private bodies involved in managing flood risk, as defined in a recent report[37]. The EA also plays a key role in providing detailed flood risk maps for England (for example Figure 3(a)) and provides estimates for the number of properties that are at risk of flooding. In the report, the EA estimated that there were 2.4 million properties in areas that are at risk of flooding from rivers and the sea in England. The flood risk maps (Figure 3(a)) can be combined with an assessment of the number of properties likely to be exposed to the flood event to identify the proportion of buildings in the floodplain that have more than a 1 in 75 chance of being flooded, shown in Figure 3(b). This map shows the areas where the local authorities and the EA face the greatest challenges. The EA also produces flood maps for other sources of flooding (Figure 3(b) showing surface water flooding for example).

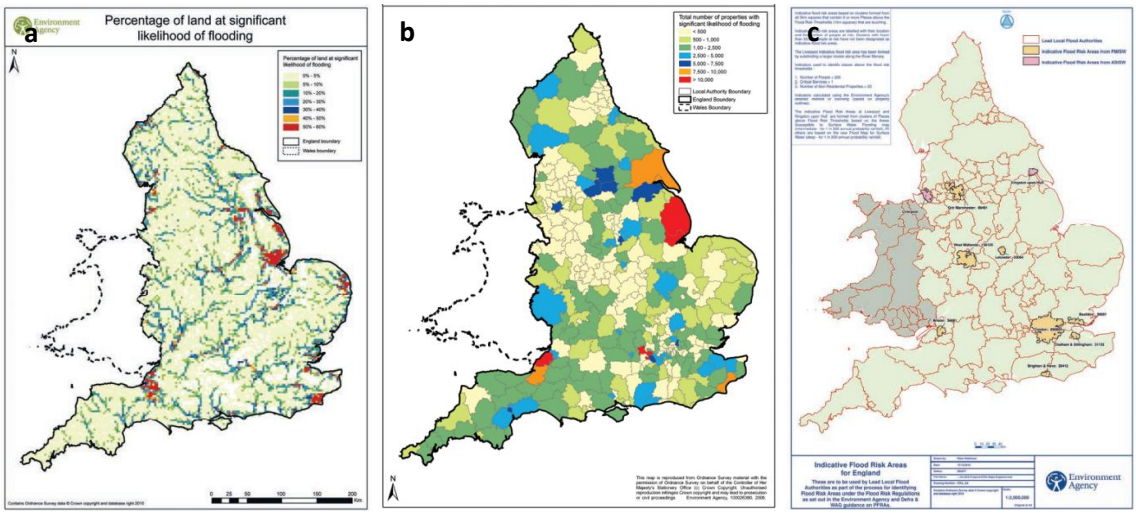

Figure 3: Showing (a) the proportion of land at significant likelihood of flooding in England[38], (b) the number of properties, in each local authority boundary in England, with significant likelihood of flooding[39] and (c) the main urban areas at risk of surface water flooding in England[40].

[35] Cabinet Office (2010) *A Strong Britain in an Age of Uncertainty: The National Security Strategy*. London.
[36] Cabinet Office (2013) *National Risk Register of Civil Emergencies*. London.
[37] Environment Agency (2009) *Flooding in England : A National Assessment of Flood Risk*.
[38] Environment Agency (2011) *Understanding the risks, empowering communities, building resilience: The national flood and coastal erosion risk management strategy for England*.

The report also highlighted that there were '*significant risks to important national infrastructure*' from flooding; with over 55% of water and sewage pumping station/treatment works, 20% of railways, 10% of major roads, 14% of electricity and 28% of gas infrastructure located in areas at risk from flooding (Figure 4). The high percentage of water-related infrastructure at risk of flooding is a result of many of these structures (including treatment works) needing to be close to rivers in order to function. If these assets do become inoperable, due to a flood event, they may not only cause a loss of service in the immediate flood area, but also have knock on effects to the wider community (affecting those not in the flooded area). Flooding has the potential to affect all of the five areas of NI included in this report, either directly or indirectly (through cascading failures).

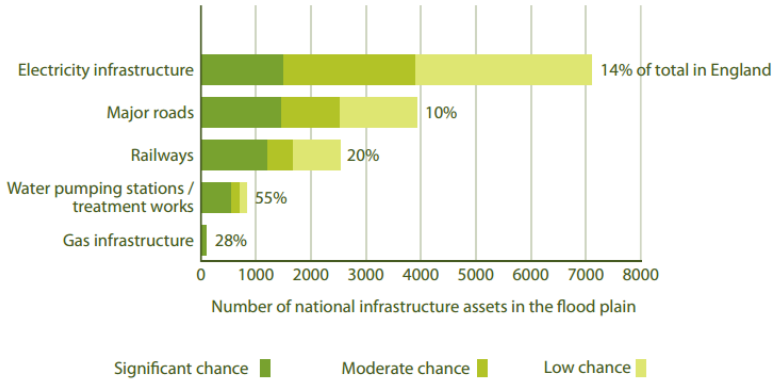

Figure 4: The proportion of National Infrastructure assets located in flood risk areas[41].

Whilst the EA produces flood maps showing the likelihood of areas to flood, it does not appear to make publically available the detailed return periods for these flood events. However, an indication of the relative likelihood of coastal and inland flooding events occurring within the next five years is given in the NRR:

- Coastal flooding – between 1 in 2,000 and 1 in 200
- Inland flooding – between 1 in 200 and 1 in 20

Climate change is expected to increase the frequency of flood events within the UK, caused by potential rises in sea level and increased precipitation[42]. For example, in England and Wales, there are currently around 50,000 hectares that are classed as at risk of frequently flooding (at least once in every three years) which is projected to increase to around 200,000 hectares by the 2080s.

2.1.1.2: WINDSTORMS AND GALES

Windstorms and gales are the *'most common cause of damage and disruption in the* UK'[43] and they have the potential to affect widespread areas. The average cost of damage to the UK each year is estimated to be at least £300 million.

[39] Environment Agency (2009) *Flooding in England : A National Assessment of Flood Risk*.
[40] Environment Agency (2011) *Understanding the risks, empowering communities, building resilience: The national flood and coastal erosion risk management strategy for England*.
[41] Environment Agency (2009) *Flooding in England : A National Assessment of Flood Risk*.
[42] HM Government (2012) *UK Climate Change Risk Assessment: Government Report*. London: The Stationary Office.
[43] Met Office (2013f) *Severe Gales*. Available at: http://www.metoffice.gov.uk/weather/uk/advice/storm.html.

One of the most notable past windstorm events, to affect the UK, occurred on 16 October 1987. This storm, which affected southern England, was poorly forecast and was unusually strong, with losses estimated around £1.4 billion[44]. The storm brought down around 15 million trees, which caused damage to power lines and disrupted power supply and telephone communications to Gatwick airport as well as thousands of homes. Transport infrastructure was also badly affected, as debris closing many roads and railways, with Kent, Surrey and Sussex the worst affected counties.

Windstorms have the potential to affect a wide range of NI systems, with perhaps the energy sector the most vulnerable to damage caused by falling trees severing power cables. The majority of distribution faults to the UK power grid, resulting from weather-related effects, occur due to windstorms and gales[45]. Indeed, severe windstorms and hurricanes have caused extensive damage to power systems; for example, the power system in the central Gulf Coast region of the USA has previously been significantly impacted by hurricanes Ivan (2004) and Katrina (2005))[46]. The damage to these systems also causes loss of services to other critical infrastructures, through their interdependent connections (including water and ICT infrastructures). This can lead to significant delays in post-storm recovery for the impacted area[47]. Debris from windstorms can also cause direct impact to transport infrastructures, by blocking roads and rail. Due to the direct impacts to these two sectors, communications and ICT infrastructure can also experience disruption due to their interdependence.

The NRR gives a relative likelihood of wind storms and gales occurring within the next 5 years to be between 1 in 20 and 1 in 2. However, information regarding which locations within the UK are more likely than others to be affected does not appear to publically exist.

2.1.1.3: SEVERE WINTER WEATHER (INCLUDING LOW TEMPERATURES, HEAVY SNOW AND ICE STORMS)

Severe winter weather can consist of low temperatures, heavy snowfall and ice storms. All of these events have the potential to affect NI systems, with heavy snowfall causing the most disruption to UK NI in recent years. For example, the winter of 2009-10 was '*the most severe in the UK for over 30 years*' with a mean UK temperature of 1.5°C for the whole winter[48]. Significant snowfalls were recorded from mid-December until the end of February and were the most widespread of a winter for 30 years[49]. There were snowfalls of over 20cm recorded in southern England and over 30cm in central and northern Scotland[50,51]. This snowfall caused '*extensive disruption*' to the UK's transport

[44] Risk Management Solutions (2007) *The Great Storm of 1987: 20-Year Retrospective*.
[45] McColl, L., Palin, E.J., Thornton, H.E., Sexton, D.M.H., Betts, R. and Mylne, K. (2013) 'Assessing the potential impact of climate change on the UK's electricity network', *Climate Change*, 14(1), pp. 821-835.
[46] Han, S.-R., Rosowsky, D. and Guikema, S. (2013) 'Integrating Models and Data to Estimate the Structural Reliability of Utility Poles During Hurricanes.', *Risk analysis : an official publication of the Society for Risk Analysis*.
[47] Ibid.
[48] Met Office (2011a) *Case Study: Winter 2009/10*. Available at: http://www.metoffice.gov.uk/about-us/who/how/case-studies/winter09-10 (Accessed: 12 August).
[49] Transport Committee (2011) *Keeping the UK moving: The impact on transport of the winter weather in December 2010*. London: The Stationary Office.
[50] Met Office (2013b) *Climate Change: Winter 2009/10*. Available at: http://www.metoffice.gov.uk/climate/uk/2010/winter.html (Accessed: 12 August).
[51] Met Office (2013g) *Snow and low temperatures - December 2009 to January 2010*. Available at: http://www.metoffice.gov.uk/climate/uk/interesting/jan2010.

infrastructure[52], with Heathrow airport closed between 18th and 20th December after 7cm of snow fell within one hour[53]. Another event, in Northern Ireland February 2011, saw a period of heavy snowfall which was combined with strong north-easterly winds and resulted in deep snow drifts, bringing down power lines, which resulted in power cuts to 70,000 homes[54]. Heavy snowfall is most likely to directly affect energy infrastructure (through damage to power lines), communications infrastructure (due to damage to telephone masts) and transport infrastructure (due to closed roads and rail links and disruption to airport operations). Although, this can cause knock on effects to other infrastructure systems due to their interdependence (for example, deliveries to business may be disrupted due to blocked roads).

Ice storms also have the potential to disrupt energy infrastructure, with power lines and transmission towers particularly susceptible to damage (Figure 5). During these storms ice can accumulate on power lines, initially causing them to lose efficiency (due to sagging, Figure 5(a)) and can eventually snap the power cables leading to a total loss of power. These storms can also cause total failure of transmission towers (Figure 5(b)), which can result in a lengthy repair time and a high cost of repair. A notable example of this type of failure is the January 2008 Ice Storm which damaged 1196km of transmission lines and 4017 transmission towers in China, causing transmission systems in some areas to become '*completely dysfunctional*'[55].

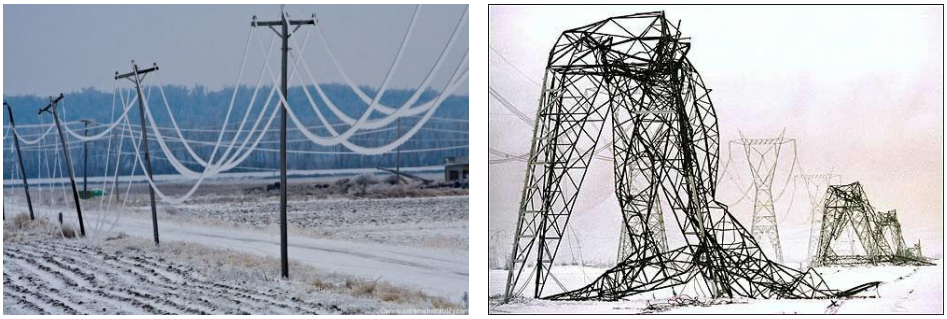

Figure 5: Damage to (a) power lines[56] and (b) transmission towers due to ice storms[57].

Severe winter weather can be predicted with some accuracy and is usually forwarded by a Met Office early warning which gives an indication of the location and severity of the event[58]. However, these extreme events still have the potential to cause widespread damage and disruption to the UK, particularly in Scotland where the majority of snowfall occurs[59]. The NRR considers the relative likelihood of a heavy snow event affecting the UK, within the next 5 years, to be between 1 in 20 and

[52] Transport Committee (2011) *Keeping the UK moving: The impact on transport of the winter weather in December 2010*. London: The Stationary Office.
[53] Heathrow Winter Resilience Enquiry (2011) *Report of the Heathrow Winter Resilience Enquiry*.
[54] NNR
[55] Yang, H., Chung, C.Y., Zhao, J. and Dong, Z. (2013) 'A Probability Model of Ice Storm Damages to Transmission Facilities', *IEEE Transactions on Power Delivery*, 28(2), pp. 557-565.
[56] Hollingshead, M. (2007) *Northwest Missouri Ice Storm* [Photograph]. [Online] Available at: http://www.extremeinstability.com/faves/slides/wi-d9530.html (Accessed: 25 September 2013).
[57] Canadian Energy Issues (2012) *Ice-ravaged electricity transmission towers* [Photograph]. Available at: http://canadianenergyissues.com/2012/11/08/cities-and-power-revisiting-smiths-division-of-labour/.
[58] Met Office (2013e) *National Severe Weather Warnings - United Kingdom*. Available at: http://www.metoffice.gov.uk/public/weather/warnings/?regionName=uk (Accessed: 12 August).
[59] Met Office (2013i) *UK Snow*. Available at: http://www.metoffice.gov.uk/learning/snow/snow-in-the-uk (Accessed: 12 August).

1 in 2. However, due to climate change effects winters in the UK are expected to become milder and wetter (on average) and therefore extreme snowfall events may become less frequent, particularly in the south of the UK in the future[60]. This could also reduce the impact of the hazard, by reducing the amount of snowfall for each event. Currently, the NRR does not assess the likely risk of ice storms to the UK and there appears to be no reports of this risk causing disruption to UK NI.

2.1.1.4: HEATWAVE

Heatwaves are another form of extreme weather event that has the potential to affect NI systems within the UK. Whilst, there is no actual definition of what constitutes a heatwave in the UK[61], UKCP09 defines a summer heatwave as more then 3°C above the 1961-90 daily normal for ≥ 5 consecutive days (May-Oct)[62]. The Met Office don't have a definition, though do define threshold temperatures, for day and night, which '*could have significant impact on health if reached on at least two consecutive days and the intervening night*'[63]. These temperatures are highest in London, at 32°C (day) and 18°C (night) and are lowest in the north east of England at 28°C (day) and 15°C (night). There have only been several occasions of temperatures being recorded above 32°C in half, or more, of the UK occurring in 1911, 1976, 1990 and most recently in 2013.

This type of risk can put a strain on our NI systems and cause a disruption to service provision, with energy infrastructure particularly susceptible to disruption. In the event of a heatwave it is likely that customers will operate an increased number of air conditioners, which can dramatically increase the demand for power. This could lead to demand potentially outstripping supply causing power blackouts. This problem can also be exacerbated by the drop in efficiency from some power grid components; for example, extreme heat can cause power lines to sag, resulting in a drop in their performance, and can also cause transformers to become less efficient. Heatwaves also have the potential to directly affect transport infrastructure, through the deterioration of road and runway services[64] which can lead to lengthy transport delays. Water infrastructure can also be directly affected by this risk, as heatwaves can occur during periods of drought where there is often a reduction in the water supply available. Coupled with the increase in customer water usage, due to the high temperatures, this can put a strain on the available resources.

Whilst heatwaves occur in the UK they can occur more severely (for a prolonged period of time, with higher temperatures) in other countries. For example, in 2009 Melbourne (Australia) the maximum daily temperatures were 12-15°C above the seasonal average of 28-32°C for many consecutive days[65]. This caused a relatively minor impact to water and ICT infrastructures, however some transportation systems were more badly affected (including rail and road transport). Although, it

[60] NRR

[61] Met Office (2013k) *What is a heat wave?* Available at: http://metofficenews.wordpress.com/2013/07/04/what-is-a-heat-wave/ (Accessed: 5 August).

[62] UK Climate Projections (2012) *UKCP09: Annual data sets*. Available at: http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/available/annual.html (Accessed: October 14).

[63] Met Office (2013c) *Heat-Health Watch*. Available at: http://www.metoffice.gov.uk/public/weather/heat-health/ (Accessed: 5 August).

[64] Cabinet Office (2013) *National Risk Register of Civil Emergencies*. London.

[65] McEvoy, D., Ahmed, I. and Mullett, J. (2012) 'The impact of the 2009 heat wave on Melbourne's critical infrastructure', *Local Environment*, 17(8), pp. 783-796.

was the electricity system which showed the most vulnerability to the event, due to cascading failures within the system.

Whilst heatwaves on the scale of the 2009 Melbourne event do not occur in the UK, the NRR assesses the relative likelihood of a heatwave affecting the UK, in the next five years, to be between 1 in 20 and 1 in 2. However, climate change forecasts show that the maximum higher temperatures are likely to increase and therefore the impact of these events could increase in future years[66].

2.1.1.5: DROUGHT

Droughts are regular events in the UK, occurring in varying magnitudes and intensities depending largely on their location. In the UK, there is currently no single definition of a drought[67] and although droughts are caused by a lack of rainfall, they can be exacerbated by demands upon the available water supply (by the public, industry and agriculture). In a similar manner to other extreme weather events, droughts can be predicted to a reasonable level of accuracy. The indicators of a drought can be assessed by monitoring river and groundwater levels, which is coordinated by the EA[68].

Droughts tend to only directly impact upon water infrastructure in the UK, however, due to the interdependency of NI systems these effects also impact upon the other sectors. For example, parts of the energy network require a constant water supply in order to function normally. Droughts also pose little threat to the majority of transportation systems (posing a risk only to water transportation after a severe drought) and little direct risk to ICT systems.

The most recent drought in the UK occurred in 2010-12, where some parts of the south-east and eastern England recorded the lowest 18 month rainfall for at least 100 years. Within this severe dry spell water companies ran water saving campaigns and managed to restrict the imposed water saving measures to domestic customers only (i.e. there was no impact to industry or agriculture)[69,70].

The NRR considers the relative likelihood of a drought event affecting the UK, within the next 5 years, to be between 1 in 200 and 1 in 20. However, it is thought that climate change could increase the frequency of droughts in the UK. Although, this may not result in the more frequent use of restrictions, due to continually developing water resource and drought planning.

2.1.2: GROUND CONDITION RISKS

2.1.2.1: COASTAL EROSION

Coastal erosion is defined as '*the removal of material from the coast by wave action, tidal currents and/or the activities of man, typically causing a landward retreat of the coastline*'[71]. Erosion is dependent upon the resilience/erodibility of the coastline and the strength/erosivity of the

[66] Benzie, M., Harvey, A., Burningham, K., Hodgson, N. and Siddiqi, A. (2011) *Vulnerability to heatwaves and drought: Case studies of adaptation to climate change in south-west England*.
[67] Environment Agency (2013c) *Drought explained*. Available at: http://www.environment-agency.gov.uk/homeandleisure/drought/31783.aspx (Accessed: 5 August).
[68] Environment Agency (2013d) *Environment Agency: our role in managing drought*. Available at: http://www.environment-agency.gov.uk/homeandleisure/drought/138333.aspx (Accessed: 13 August).
[69] Cabinet Office (2013) *National Risk Register of Civil Emergencies*. London.
[70] Environment Agency (2012) *Review of the 2010-2012 drought and prospects for water resources in 2013*.
[71] British Geological Survey (2012a) *Coastal Erosion*.

waves/tides. As such, the rate of coastal erosion varies at regional, national and international scales. In England and Wales, it has been estimated that of the 6,251km coastline, 3,327km (53%) are cliffs subject to instability and erosion[72]. Figure 6 shows the distribution of these erodible cliffs in England; from this figure it can be seen that there are only a few areas of the English coastline that are not vulnerable to this type of risk.

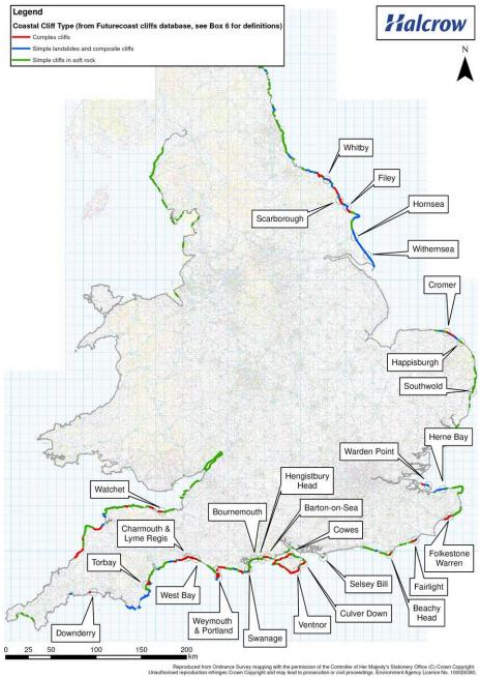

Figure 6: The distribution of erodible cliffs in England[73].

There are many examples of coastal erosion threatening our communities in the UK; for example the village of Hallsands (Devon) collapsed into the sea during a storm in January 1917[74,75], destroying all but two homes. These two properties are still threatened by cliff collapses and landslides; most recently in May 2012 when they were evacuated amid fears that they could collapse after a landslide nearby. Another notable example is the village of Happisburgh (Norfolk), which is now a coastal village where it used to be some distance from the sea[76]. The coastline in this area has retreated 105m between 1992 and 2004 (averaging around 8m per year)[77] and is now threatening to destroy homes and businesses in the village[78].

[72] Environment Agency (2010a) *Assessment of Coastal Erosion and Landsliding for the Funding of Coastal Risk Management Projects*.
[73] ibid.
[74] BBC (2004) *The Village the Collapsed into the Sea*. Available at: http://www.bbc.co.uk/insideout/southwest/series1/hallsands.shtml (Accessed: 15 August).
[75] British Geological Survey (2013j) *Hallsands landslide, South Devon*. Available at: http://www.bgs.ac.uk/landslides/hallsands.html (Accessed: 15 August).
[76] British Geological Survey (2013d) *Coastal erosion at Happisburgh, Norfolk*. Available at: http://www.bgs.ac.uk/landslides/happisburgh.html (Accessed: 15 August).
[77] British Geological Survey (2012a) *Coastal Erosion*.
[78] Hurrell, A. (2013) *Dramatic photograph of Happisburgh's erosion timebomb*. Available at: http://www.edp24.co.uk/news/environment/dramatic_photograph_of_happisburgh_s_erosion_timebomb_1_1985929 (Accessed: 15 August).

Whilst, coastal erosion is a major issue for those living in these communities and can leave local councils facing multi-million pound repair bills[79], the overall threat to our NI systems remains small. However, some major infrastructure components must be located close to the coast and therefore have the potential to be affected by this threat. This mainly affects energy infrastructure, as nuclear power stations must be located close to an area of guaranteed continuous water supply and gas terminals which import fuel from other countries. There are some reports of coastal erosion threatening these components, such as the Bacton Gas Terminal[80]; however, this risk is known, can be predicted to some degree and can be mitigated through the use of coastal defences.

Considering future climate change predictions coastal erosion is likely to increase in some areas over the next hundred years[81]. A recent study suggests that under current climatic conditions the coast of England and Wales could experience an average of 67m of erosion over the next 100 years, however, climate change may increase this figure to around 175m[82].

2.1.2.2: LANDSLIDES AND EMBANKMENT FAILURES

A landslide is the movement of soil, rock or debris down a sloped section of land. The frequency and occurrence of landslides are dependent upon the geology, climate, vegetation and hydrology of an area and the impact of a landslide can range from slight to very high depending upon the exact location of the event and its proximity to infrastructure (e.g. local communities, major roads, etc.). For example, a landslide in the Phillippines in 2006, caused by heavy rainfall, resulted in 1,100 deaths and destroyed 375 homes and schools[83].

These events can be both natural and man-made. A natural landslide is usually caused after extreme weather events, including periods of heavy rainfall or earthquakes (e.g. the 2010 landslide in Uganda was caused by a period of heavy rainfal[84]). Whereas a man-made landslide can be caused by intense deforestation or construction in landslide prone areas for example[85] (e.g. the 1966 Aberfan disaster caused by the collapse of a coal tip[86]). Landslides are '*responsible for considerable greater economic and casualty losses than is generally recognised*'[87] and can occur during other major disasters. For example landslides frequently occur during an earthquake, destroying whole communities and causing significant loss of life, but their impacts can be overlooked by news media (who tend to focus on the impacts of the earthquake).

[79] The Geological Society (unknown) 'The Earth in our Hands: How Geoscientists Serve and Protect the Public - Coastal Erosion'.
[80] Dickson, M., Walkden, M. and Hall, J. (2006) *Modelling the impacts of climate change on an eroding coast over the 21st Century*.
[81] British Geological Survey (2013c) *Climate Change and Coastal Erosion*. Available at: http://www.bgs.ac.uk/discoveringGeology/climateChange/general/coastalErosion.html (Accessed: 15 August).
[82] Environment Agency (2013f) *Is climate change causing an increase in coastal erosion?* Available at: http://www.environment-agency.gov.uk/homeandleisure/107550.aspx (Accessed: 15 August).
[83] U.S. Geological Survey (2013) *Worldwide Overview of Large Landslides of the 20th and 21st Centuries*. Available at: http://landslides.usgs.gov/learning/majorls.php (Accessed: 15 August).
[84] Ibid.
[85] World Health Organisation (2013) *Landslides*. Available at: http://www.who.int/hac/techguidance/ems/landslides/en/ (Accessed: 15 August).
[86] McLean, I. (2007) *Aberfan: No End of a Lesson*.
[87] U.S. Geological Survey (2001) *Socioeconomic and Environmental Impacts of Landslides in the Western Hemisphere*. Available at: http://pubs.usgs.gov/of/2001/ofr-01-0276/ (Accessed: 15 August).

In the UK landslides on this scale are rare; however, we do experience smaller scale landslides that can have lasting impacts. Landslides mainly affect transportation infrastructure, with a significant proportion of slope failures occurring on man-made railway embankments, potentially leading to train delays and cancellations for extended periods of time. This can be exemplified by the disruption experienced at the end of June 2012 where landslides shut both the east coast main line in north eastern England and the west coast main line at Tebay (Cumbria) simultaneously[88] as well as on the Newcastle to Carlisle line[89]. The landslides were caused by a period of intense rainfall on the afternoon of Thursday 28th which led to the closures of the lines for the remainder of the day. It also resulted in disruption over the weekend on the east coast mainline and the Newcatsle-Carlilse line where major repairs were required for train to operate a normal service again. Road infrastructure can also be affected, for example, a landslide in Rothbury (Northumberland) in December 2012 forced the closure of a road which has still not reopened, due to continuing ground movement in the area[90]. However, landslides also have the potential to affect other infrastructure sectors, by causing damage to electricity pylons (energy infrastructure) and uncovering, or damaging, buried pipelines (energy and water infrastructure). All of these effects could lead to significant disruption to the levels of service provided by these systems to our communities, which have the potential to propagate to areas unaffected by the initial landslide.

The British Geological Survey (BGS) has formed a National Landslide Database[91] which maps the locations of all previous known landslides in the UK and from this is it possible to determine the 'at risk' areas. However, climate change is thought to be increasing the number of landslides that occur in the UK, due to an increase in rainfall[92], and these 'at risk' areas could be subject to change in future years.

2.1.2.3: SUBSIDENCE

Subsidence is the gradual sinking of an area of land, caused by the shrink-swell behaviour of soil and is estimated to have cost the UK economy £3bn in the last 10 years making it the most damaging geohazard in the UK today[93]. Subsidence is most problematic on clay, as it is a cohesive soil and changes in volume when wetted or dried (causing the shrink-swell behaviour).

[88] The Telegraph (2012) *England cut off from Scotland as rail lines shut off by flooding and landslides*. Available at: http://www.telegraph.co.uk/topics/weather/9362927/England-cut-off-from-Scotland-as-rail-lines-shut-off-by-flooding-and-landslides.html#disqus_thread (Accessed: October 14).

[89] Network Rail (2012) *North east rail repair continues over weekend*. Available at: http://www.networkrailmediacentre.co.uk/News-Releases/NORTH-EAST-RAIL-REPAIR-CONTINUES-OVER-WEEKEND-1af2.aspx (Accessed: October 14).

[90] Northumberland Gazette (2013) *Landslide road will not re-open for a year*. Available at: http://www.northumberlandgazette.co.uk/news/local-news/landslide-road-will-not-re-open-for-a-year-1-5432455 (Accessed: 15 August).

[91] British Geological Survey (2013b) *BGS National Landslide Database*. Available at: http://www.bgs.ac.uk/science/landUseAndDevelopment/landslides/NLD.html (Accessed: 15 August).

[92] British Geological Survey (2013k) *Increased Incidence of Landslides in 2012*. Available at: http://www.bgs.ac.uk/landslides/November2012.html (Accessed: 15 August).

[93] Landmark (2013) *A Guide to Subsidence: Risk Assessment and Risk Management against Soil Shrinkage*.

The BGS has produced a potential shrink-well hazard map which identifies areas most at risk of subsidence issues (as well as other potential ground instability risks)[94]. A section of this hazard map is shown in Figure 7, where it can be seen that the majority of areas at risk of subsidence are in the south and east of England.

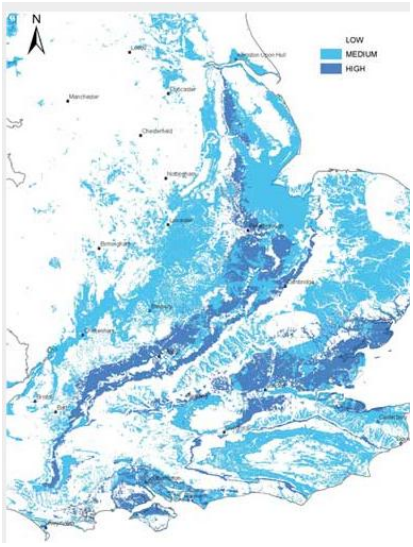

Figure 7: A sample of the shrink-swell hazard map[95].

All structures built in these vulnerable areas face the threat of subsidence, which includes many of our NI components. The potential impact to our NI, compared to other hazards, is fairly small; however, subsidence still has the potential to cause a loss of supply for some NI sectors (e.g. water and electricity) due to damage to power stations, water treatment works or electricity substations for example; whilst, other NI sectors could also see disruption, for example increased journey times due to damaged rail lines.

In the long term future it is thought that climate change may exacerbate the shrink-swell effects on clays and increase the problem of subsidence within the UK, due to the increases in both rainfall and temperature[96].

2.1.3: OTHER RISKS

2.1.3.1: SPACE WEATHER

In 2011 the UK recognised, for the first time, extreme space weather events as rare but potentially high impact hazards[97]. The term *space weather* refers to '*changes in the near-Earth space Environment*'[98] and is caused by varying conditions within the Sun's atmosphere, specifically relating to the ejection of radiation and particles[99]. This solar activity changes according to 11-year cycles, in

[94] British Geological Survey (2013o) *Shrink-Swell Hazard Potential Mapping*. Available at: http://www.bgs.ac.uk/science/landUseAndDevelopment/shallow_geohazards/hazardPotentialMapping.html (Accessed: 15 August).
[95] Ibid.
[96] Ibid.
[97] Royal Academy of Engineering (2013) *Extreme space weather : impacts on engineered systems and infrastructure* (1903496969).
[98] Houses of Parliment (2010) *Space Weather*.
[99] MITRE (2011) *Impacts of Severe Space Weather on the Electric Grid*.

which solar storms are at their highest magnitude and intensity around solar maximum (the peak of the cycle) due to happen again in 2012-13[100]. Space weather includes a wide range of different phenomena, such as: solar flares, coronal mass ejections and solar energetic particle events[101].

Space weather has the potential to directly, or indirectly, affect the majority of our NI in the UK (Figure 8). The majority of these effects are related to the operations of satellites and the power grid; though due to the interdependency of our NI the loss of the power grid could affect the supply of clean water, communications and transport, for example[102]. Space weather can cause the failure of power grids, due to geomagnetically induced currents which overload parts of the system[103,104]. To date, space weather has not greatly affect the UK, but has had a significant impact to the power grids in other nations; notably, causing the entire province of Quebec (Canada) to suffer an electrical blackout affecting 6 million people[105,106] until power was restored 9 hours later.

Scientists have found it difficult to provide an accurate forecast for these events, as the effects of solar weather travel at, or close to, the speed of light[107]. However, it is possible to monitor solar activity and provide a forecast for some space weather events (specifically, coronal mass ejections) with an accuracy of around ±6-8 hours[108]. Whilst, this is not precise it is useful for notifying the operators of power grids so they can prepare for any possible disruption. Currently, the majority of space weather monitoring is undertaken by the Space Weather Prediction Centre[109] (in Boulder, USA), however the Met Office is currently working to expand its facilities to include the forecasting of space weather[110].

The NRR rates this risk at relatively high likelihood of occurrence in the UK within the next 5 years (between 1 in 20 and 1 in 2)[111]. However, due to our growing dependence upon technology, which is vulnerable to space weather, the impact of these events could worsen in future years.

[100] National Oceanic and Atmospheric Administration (2013) *Solar Cycle Progression*. Available at: http://www.swpc.noaa.gov/SolarCycle/ (Accessed: 9 August).
[101] Cabinet Office (2013) *National Risk Register of Civil Emergencies*. London.
[102] Lloyd's (2010) *Space Weather: Its impact on Earth and implications for businesses*.
[103] Government of Canada (2012) *Geomagnetic Storms - Reducing the Threat to Critical Infrastructure in Canada*. [Online]. Available at: http://www.solarstorms.org/CanadaPipelines.html.
[104] Wik, M., Pirjola, R., Lundstedt, H., Viljanen, A., Wintoft, P. and Pulkkinen, A. (2009) 'Space weather effects in July 1982 and October 2003 and the effects of geomagnetically induced currents on Swedish technical systems', *Annales Geophysicae*, 27, pp. 1775-1787.
[105] NASA (2009) *The Day the Sun Brought Darkness*. Available at: http://www.nasa.gov/topics/earth/features/sun_darkness.html (Accessed: 9 August).
[106] Marusek, J.A. (2007) 'Solar Storm Threat Analysis', *Impact*.
[107] Royal Academy of Engineering (2013) *Extreme space weather : impacts on engineered systems and infrastructure* (1903496969).
[108] Ibid.
[109] National Weather Service (2013) *Space Weather Prediction Centre*. Available at: http://www.swpc.noaa.gov/ (Accessed: 12 August).
[110] Met Office (2013h) *Space Weather*. Available at: http://www.metoffice.gov.uk/publicsector/emergencies/space-weather (Accessed: 9 August).
[111] Cabinet Office (2013) *National Risk Register of Civil Emergencies*. London.

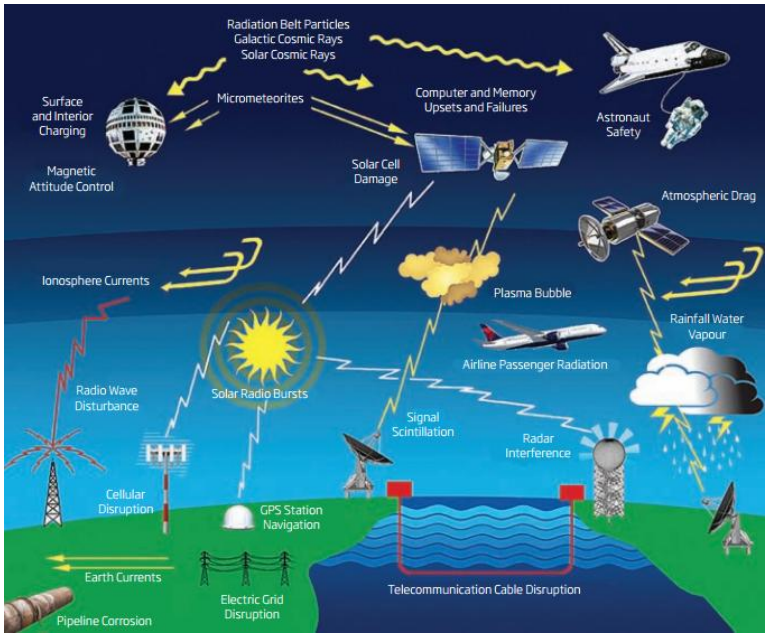

Figure 8: The potential impacts of space weather[112].

2.1.3.2: METEOR STRIKES

Meteor strikes are extremely rare and there currently exists very in little literature surrounding the likelihood or impact of these hazards occurring on Earth. NASA is currently working towards identifying all possible near-Earth-objects (including, asteroids and comets) that have the potential to strike the Earth. To date NASA astronomers have identified more than ten thousand asteroids near to the Earth, finding that none of these pose a threat, however, they do state that there is no way of knowing when or where the next strike may come from[113].

The 2013 Russian meteor strike is the most documented event in recent years. The meteor was estimated to have weighed 10,000 tonnes, be 55 feet wide and caused a 50-foot hole in a frozen lake near Chelyabinsk on impact[114]. The event injured more than 1,000 people, mainly due to breaking glass from windows[115].

The impacts to infrastructure from meteor strikes could range from minor (e.g. temporary loss of services) to catastrophic (e.g. the loss of a major power station) and is dependent entirely upon the size of the meteor and the impact location.

[112] Royal Academy of Engineering (2013) *Extreme space weather : impacts on engineered systems and infrastructure* (1903496969).
[113] NASA (2013) *Asteroid and Comet Impact Hazards*. Available at: http://impact.arc.nasa.gov/intro_faq.cfm (Accessed: 15 August).
[114] Mail Online (2013b) *Meteor that crashed in Russia was part of a 656-foot wide asteroid that broke off during its orbit around Earth*. Available at: http://www.dailymail.co.uk/sciencetech/article-2387639/Meteor-crashed-Russia-656-foot-wide-asteroid-broke-orbit-Earth.html (Accessed: 15 August).
[115] Mail Online (2013a) *Fireball from outer space: 1,000 injured as 40-ton meteor travelling at 33,000mph explodes over a terrified town*. Available at: http://www.dailymail.co.uk/news/article-2279020/Russian-meteor-shower-Fireball-outer-space-1-000-injured-40-ton-meteor-travelling-33-000mph-explodes-terrified-town.html (Accessed: 15 August).

2.1.3.3: VOLCANIC ERUPTION

There are no active volcanoes within the UK, although that does not mean that the UK is unaffected by the effects of volcanic eruptions as shown by the 2010 eruption of the Eyjafjallajökull volcano in Iceland.

This eruption of the Eyjafjallajökull volcano occurred on the 14th March and disrupted transportation infrastructure within the UK, through the closure of airspace around Europe[116]. This event resulted in the delay of 10 million air passengers and was estimated to have caused 1.7 billion US dollars in loss of revenue[117]. This volcanic eruption was classified as an 'explosive eruption' and is one of two types of eruption that have the potential to affect the UK[118,119]:

- *effusive* -these eruptions are not violent and include the outpouring of lava from vents in the volcano and can emit large volumes of gases and aerosols into the atmosphere for months or even years;
- *explosive* - are characterised by a violent, explosive eruption which usually emits a large ash cloud.

These eruptions could affect the UK through the emission of volcanic ash and aerosols. At high altitude the effects are generally limited to aircraft, potentially causing engine failure and high concentrations could also pose health risks to air passengers. However, if present at ground level the impacts could directly affect human health, contaminate water supplies and affect electricity infrastructure[120].

The NRR identifies several volcanoes in Europe which have the potential to affect the UK (Vesuvius (Italy), Santorini (Aegean Sea)) and also provides the relative likelihood for these events within the next 5 years:

- Effusive – between 1 in 200 and 1 in 20;
- Explosive – between 1 in 20 and 1 in 2.

All locations within the UK could be affected by volcanic eruptions, with northern areas most likely to be affected by Icelandic eruptions, although this very much depends on the atmospheric conditions (the wind direction and speed) at the time[121].

2.1.3.4: EARTHQUAKE

The UK is in an area of low seismicity, where even moderate earthquakes are rare, but can occur. The BGS monitors the earthquake activity in the UK and has recorded 20 significant earthquakes

[116] Brooker, P. (2010) 'Fear in a Handful of Dust: Aviation and the Icelandic Volcano', *Significance* 3, pp. 112-115.
[117] Mazzocchi, M., Hansstein, F. and Ragona, M. (2010) 'The 2010 Volcanic Ash Cloud and its Financial Impact on the European Airline Industry', *CESifo Forum* 11, pp. 92-100.
[118] Cabinet Office (2013) *National Risk Register of Civil Emergencies*. London.
[119] The Geological Society (2013) *Effusive and Explosive Eruptions*. Available at: http://www.geolsoc.org.uk/ks3/gsl/education/resources/rockcycle/page3599.html (Accessed: 12 August).
[120] British Geological Survey (2012b) *Volcanic Hazards*.
[121] Ibid.

(Magnitude 4.0 or greater) between June 1970 and February 2008[122]. This included the Magnitude 5.2 event on 27 February 2008 which was felt across large parts of the country, but caused only minimal damage to structures[123].

Earthquakes have the potential to cause devastation affecting widespread areas and all NI sectors, for example the 2011 earthquake in New Zealand, which killed 65 people, caused water mains to burst, destroyed many power lines, disrupted communications and also disrupted transport services[124]. To this day many there is still extensive work underway to repair many of the horizontal infrastructures in and around the city of Christchurch[125]. However, the likelihood of a devastating earthquake is rare in the UK; the BGS has assessed the risk of earthquake in the UK for a 2,500 year return period (Figure 9). Therefore, in the UK earthquakes have the potential to cause some damage to structures and cause disruption to services, but are unlikely to have a major impact to our NI systems.

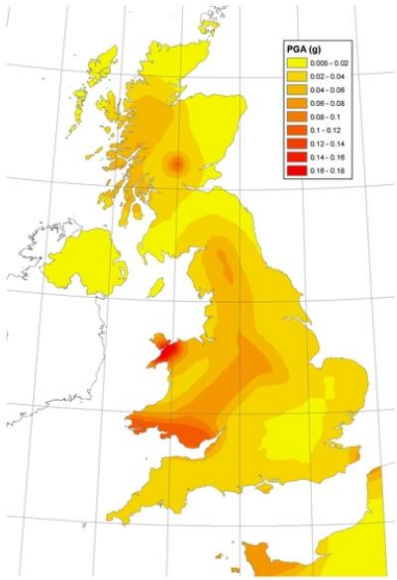

Figure 9: Hazard map for a 2,500 year return period seismic event in the UK[126].

2.1.3.5: TSUNAMI

The 'Boxing Day' earthquake in 2004, which initiated a devastating tsunami, has led to many governments assessing the likelihood, and potential impacts, of similar events occurring in other parts of the world[127]. This earthquake occurred off the west coast of northern Sumatra (Indonesia) and measured M_W9.3 (moment magnitude scale), making it the second biggest earthquake ever

[122] British Geological Survey (2013p) *Significant British Earthquakes*. Available at: http://www.earthquakes.bgs.ac.uk/earthquakes/UKsignificant/index.html (Accessed: 20 August).
[123] BBC (2008) *Earthquake felt across much of UK*. Available at: http://news.bbc.co.uk/1/hi/7266136.stm (Accessed: 20 August).
[124] BBC (2011b) *New Zealand earthquake: 65 dead in Christchurch*. Available at: http://www.bbc.co.uk/news/world-asia-pacific-12533291 (Accessed: 20 August).
[125] SCRIPT (2013) *Repairing the city's state highway network*. Available at: http://strongerchristchurch.govt.nz/work/roads/repairing-the-city-state-highway-network (Accessed: October 14).
[126] British Geological Survey (2013n) *A Revised Seismic Hazard Map for the UK*. Available at: http://news.bbc.co.uk/1/hi/7266136.stm (Accessed: 20 August).
[127] Defra Flood Management (2005) *The threat posed by tsunami to the UK*.

recorded. The resulting tsunami caused loss of life in 11 countries[128], with an estimated total death toll of more than 230,000[129]. This event also had a devastating impact to all infrastructure systems, breaking water and sewage pipes, contaminating water and food sources, damaging coastal assets for all infrastructures and washing away roads. This damage led to disruption to the water and electricity systems, which hampered rescue efforts in immediate aftermath of the disaster[130] and caused longer term problems with disease[131].

Whilst events on this scale are rare there is historical and geological evidence that tsunamis have affected the UK in the past[132], and as such there is a potential for this risk to pose a threat to our NI systems in the future. The two most notable tsunamis to affect the UK are the 6100BC tsunami in Scotland, which was caused by a massive landslide in Norway, and the tsunami caused by the 1755 earthquake in Lisbon (Portugal), which had an estimated wave height of 1-2m and affected the south-west coast of England[133]. However, the impacts that these tsunamis had to NI within the UK is unclear, as the majority of data has been gathered from historical and geological records.

Today there are several potential events that have been identified as posing a tsunami risk to the UK, and are mainly triggered by earthquakes in other countries and underwater landslides. In the 1990s, geologists discovered that the Cumbre Vieja volcano (La Palma, North Africa) could pose a tsunami threat to the UK and concluded that an eruption from the volcano would cause part of the rock formation to collapse into the sea as part of a massive landslide. This in turn would generate a huge tsunami (in the Atlantic Ocean) affecting Spain, Portugal, France, the south coast of England and the east coast of the USA. It was estimated that the wave would take around 6 hours to reach southern England and have a possible wave height of 10-13m, however this is dependent upon the actual mass of the collapsing rock formation[134]. It has been estimated that this wave could '*cause enormous damage to London and other UK cities*'[135], although the specific damage to NI is not stated in published reports. Other tsunamis which could affect the UK may originate from the Caribbean, Mid-Atlantic Ridge, Canary Islands and the plate boundary west of Gibraltar. The possible impacts of these tsunamis varies from very low (with a consequence of probability of less than 0.1%) to very high (with a consequence of probability greater than 90%) as outlined in a report by DEFRA[136]. Therefore, it can be concluded that tsunamis pose a threat to the UK and our NI, although the potential damage could be minimal (e.g. a temporary loss of service due to slight damage to

[128] Earthquake Engineering Field Investigation Team (2006) *The Indian Ocean Tsunami of 26 December 2004: Mission Findings in Sri Lanka and Thailand*.
[129] Synolakis, C., Okal, E. and Bernard, E. (2005) 'The Megatsunami of December 26, 2004', *The Bridge*, 35(2), pp. 26-35.
[130] Think Quest (2005) *Tsunami: Magnitude of Terror - Damage to Infrastructure*. Available at: http://library.thinkquest.org/04oct/01724/effects_infra.html (Accessed: 16 August).
[131] World Health Organisation (2005) *Three months after the Indian Ocean earthquake-tsunami report*. Available at: http://www.who.int/hac/crises/international/asia_tsunami/3months/report/en/ (Accessed: 16 August).
[132] Defra Flood Management (2005) *The threat posed by tsunami to the UK*.
[133] British Geological Survey (2013e) *Could a Tsunami hit the British Isles?* Available at: http://www.bgs.ac.uk/research/earthquakes/BritishTsunami.html (Accessed: 2 September).
[134] Ward, S.N. and Day, S. (2001) 'Cumbre Vieja Volcano - Potential Collapse and Tsunami at La Palma, Canary Islands', *Geophysical Research Letters*, 28(17), pp. 3397-3400.
[135] Gurney, I. (2004) *A Wave of Destruction Will Destroy America's East Coast*. Available at: http://rense.com/general56/tsu.htm (Accessed: 16 August).
[136] Defra Flood Management (2005) *The threat posed by tsunami to the UK*.

individual infrastructure components) or devastating (e.g. complete loss of NI within the impact area).

2.2: MAN-MADE HAZARDS

Man-made hazards are, by their nature, more difficult to predict than natural hazards as they cannot be predicted to the same level of accuracy and often require an assessment of human behaviour. This section outlines the likelihood and potential impact from large-scale man-made hazards to NI systems within the UK. There are many smaller scale man-made hazards which have not been included, for example road traffic accidents and house fires, whilst these events have the potential to cause loss of life they are not likely to cause disruption to critical NI systems.

This section has also been split into two further sub-sections, one detailing the hazards which are caused by deliberate actions and the other by accidental actions.

2.2.1: DELIBERATE

2.2.1.1: CATASTROPHIC TERRORIST ATTACK

Catastrophic terrorist attacks in the UK are unlikely, however, events both at home and abroad have shown that this risk cannot be ruled out and terrorist attacks are one of the highest priority national security risks to the UK[137]. The most notable large-scale terrorist attack in recent memory is the 9/11 attack on the Twin Towers and the Pentagon, which occurred on the 11th September 2001 and resulted in over 2,700 deaths[138,139]. Within the UK the 7/7 bombings in July 2005 are the only recent event of a terrorist attack actually occurring[140].

Considering these, and other, past terrorist attacks it is clear that they are not focused towards critical NI systems, but are seemingly targeted to create the most disruption or highest death toll. Whilst the 7/7 bombings did target the London underground system, this is not considered a critical infrastructure system (unlike the water and power sectors) and it was still possible to travel in London using other means.

The NRR has assessed the relative likelihood of attacks on critical NI systems happening in the UK, in the next 5 years, to be medium to low. Due to the nature of these events it is not possible to give a specific location within the UK that will be affected by this type of risk. However, considering past events it is possible to form estimates of possible future targets. The UK Government's counter-terrorism strategy (CONTEST) is currently concerned with identifying, pursuing, preventing, protecting and preparing the UK from future terrorist threats[141].

[137] Cabinet Office (2013) *National Risk Register of Civil Emergencies*. London.
[138] CNN (2003) *New York reduces 9/11 death toll by 40*. Available at: http://edition.cnn.com/2003/US/Northeast/10/29/wtc.deaths/ (Accessed: 19 August).
[139] National Commission on Terrorist Attacks upon the United States (2004) *The 9/11 Commission Report*.
[140] HM Government (2006) *Report of the Official Account of the Bombings in London on 7th July 2005*.
[141] HM Government (2011) *CONTEST: The United Kingdom's Strategy for Countering Terrorism*.

2.2.1.2: CYBER ATTACKS

Today cyberspace is an integral part of our economy, security and national infrastructure systems and whilst cyberspace provides the UK with many opportunities, the risks of using this source are increasing with the number of global attacks on these systems on the rise[142]. In these attacks, information is either; stolen, altered or destroyed, usually from an anonymous source. As cyberspace is used by both the Government and the military amongst others, the potential impacts of this risk could be devastating. Whilst cyber attacks occur on ICT infrastructure, they have the potential to cause large scale supply disruption to water and electricity infrastructures. However these attacks can originate from anywhere in the world due to the nature of cyber space and thus make identifying and defending against the culprits increasingly more difficult.

UK NI systems have previously been targeted by cyber attacks[143,144], but there have (as yet) been no known and recorded attacks affecting these systems. For example, in June 2010 'stuxnet' a computer worm seemingly designed to target industrial control equipment was discovered and destroyed[145].

The NRR currently assesses the risk to the UK from this risk as 'medium low'. However, it is possible that this likelihood could rise in the future, particularly if terrorists change from 'traditional' attack methods (e.g. suicide bombers) to attacks on cyber controlled infrastructure.

2.2.1.3: PUBLIC DISORDER

The impacts of public disorder hit the news headlines in August 2011 when a public protest in Tottenham quickly escalated into widespread violent disorder. Over the next four days disorder spread first to London, then to Manchester, Salford, Birmingham and other towns in England[146]. This event included looting, violence directed at police officers and damage to property (mainly through smashed windows and arson)[147]. This is the worst case of public disorder in recent years in the UK, but other events have included the 2010 protest against student tuition fees[148] and the G20 protests in 2009[149].

This type of event can be difficult to predict as there can be many different trigger events which can result in widespread public disorder, such as the public protest which lead to the August 2011 riots,

[142] Industrial Control Systems Cyber Emergency Response Team (2011) *Incident Response Summary Report*.
[143] The Independent (2012) *UK's power and water infrastructure 'at risk of cyber attacks'*. Available at: http://www.independent.co.uk/news/uk/home-news/uks-power-and-water-infrastructure-at-risk-of-cyber-attacks-8375958.html (Accessed: 19 August).
[144] The Guardian (2012) *Hostile states using cyberwarfare to attack UK infrastructure*. Available at: http://www.theguardian.com/technology/2012/dec/03/hostile-states-cyberwarfare-uk-infrastructure (Accessed: 19 August).
[145] Cabinet Office (2013) *National Risk Register of Civil Emergencies*. London.
[146] BBC (2011a) *England riots: Maps and timeline*. Available at: http://www.bbc.co.uk/news/uk-14436499 (Accessed: 19 August).
[147] National Centre for Social Research (2011) *The August riots in England: Understanding the involvement of young people*.
[148] BBC (2010) *Student tuition fee protest ends with 153 arrests*. Available at: http://www.bbc.co.uk/news/education-11877034 (Accessed: 19 August).
[149] The Guardian (2009) *Man dies during G20 protests in London*. Available at: http://www.theguardian.com/world/2009/apr/02/g20-protests-man-dies-london (Accessed: 19 August).

but the majority of these events are peaceful and pass without incident. These events can also manifest in several ways, including: rioting, looting, arson, violence and vandalism.

Whilst this risk poses a threat to UK NI past events have shown that these systems are not specifically targeted. The damage to property in these events appears to be concentrated around town centres and local businesses, rather than specific infrastructure components (e.g. electricity sub-stations and water treatment plants). The NRR assesses the likelihood of this risk occurring, within the next 5 years, to be between 1 in 20 and 1 in 2. Therefore, this is a risk that does need to be considered when assessing the risk to infrastructure, but could be mitigated through a series of simple measures (e.g. increased security).

2.2.1.4: DISRUPTIVE INDUSTRIAL ACTION

Disruptive industrial action usually occurs when members of a trade union are involved in a dispute with their employer which cannot be solved by negotiation and involves either the employees refusing to work entirely or refusing to work in the way stated in their employer contract. These disputes normally arise over pay, working hours, working conditions or redundancy.

In recent years, there have been many industrial action disputes in the UK, for example: school teachers took strike action in 2012 over pay and conditions[150] and are planning further strike action later this year[151]. Other examples include the continuing strike by post office workers[152],[153]and the 2013 civil servant strike[154].

By law employers must be given at least 7 days prior notice of impending strike action by their employees, which must outline the category of employee to strike (e.g. school teacher) and the number of employees affected[155]. This allows the employer to mitigate the impacts of the strike, particularly if it affects critical NI services. For example, in 2002-03 the Fire Brigade Union took strike action over a pay dispute and the armed forces were drafted in to provide essential fire fighting and rescue capability[156,157].

The NRR assesses the relative likelihood of this type of risk occurring within the next 5 years to be between 1 in 20 and 1 in 2. It is difficult to predict the location of potential disruptive industrial

[150] BBC (2012b) *Teachers to strike over pay and conditions*. Available at: http://www.bbc.co.uk/news/education-19519839 (Accessed: 20 August).
[151] The Telegraph (2013a) *Teachers to strike over pay, pensions and workload*. Available at: http://www.telegraph.co.uk/education/10175654/Teachers-to-strike-over-pay-pensions-and-workload.html (Accessed: 20 August).
[152] Mail Online (2001) *Massive main backlog after postal strikes end*. Available at: http://www.dailymail.co.uk/news/article-48994/Massive-mail-backlog-postal-strikes-end.html (Accessed: 20 August).
[153] BBC (2013c) *Post Office workers strike over bank holiday weekend*. Available at: http://www.bbc.co.uk/news/business-23732088 (Accessed: 20 August).
[154] The Guardian (2013a) *Civil servants strike over cuts*. Available at: http://www.theguardian.com/politics/2013/jun/02/civil-servants-strike-over-cuts (Accessed: 20 August).
[155] Local Government Employers (2010) *Industrial action ballots and notice to employers*. Available at: http://www.lge.gov.uk/lge/core/page.do?pageId=119721 (Accessed: 20 August).
[156] BBC (2002b) *Firefighters go on strike*. Available at: http://news.bbc.co.uk/1/hi/uk/2465745.stm (Accessed: 20 August).
[157] BBC (2002a) *Fire strike's embers burn on*. Available at: http://news.bbc.co.uk/1/hi/uk/2577465.stm (Accessed: 20 August).

action, but it has the potential to affect the whole of the UK. This risk also has the potential to impact upon critical NI within the UK; for example, the strike action of fuel drivers in 2000 '*resulted in direct and indirect impacts on critical infrastructure in the* UK'[158]. The energy sector was directly affected by the strike (and was the most severely affected sector) as tankers were not able to leave oil refineries and fuel depots to transport gasoline to stations for public distribution. This in turn affected the transportation sector as the public could not gain access to fuel and it was estimated that 29% of private motorists were forced to stop driving[158]. The limited access to fuel encouraged panic buying[159],[160] which only increased the magnitude of the consequences of the strike with respect to the availability of both fuel and basic food supplies[158]. This strike also had an impact upon health care, as the NHS relies on the transportation of staff, patients and supplies[158]. Therefore, disruptive industrial action has the potential to affect the whole of the UK and also impact upon all NI sectors; however, as notice must be given before strike action commences the impacts this action can be mitigated.

2.2.1.5: AGING INFRASTRUCTURE

'*Over the centuries, the UK has had a great record of investing in world class infrastructure to underpin economic growth*'[161]. However, in recent decades this approach to infrastructure investment has changed to become uncoordinated and insufficiently targeted to support sustainable development and economic growth. Many infrastructure assets within the UK are reaching the end of their design life, becoming outdated[161] and will need replacing, refurbishing or face higher maintenance to order to continue to function[162]. This presents an opportunity to upgrade assets and systems to meet future challenges, but will require significant investment to ensure that NI is able to meet the required demands with reliable, cost-effective and high quality services[163].

Ageing infrastructure presents an increased risk in terms of potential failure and also poor environmental performance. This risk is a key concern for water and energy utilities around the world[164]. To give an example, the majority of the UK's existing infrastructure was constructed during the 19th Century[161] and 44% of London's water mains are over 100 years old and 12% are more than 150 years old[165]. This problem causes a high number of water leaks and burst water mains which have the potential to not only affect localised communities[166] but can also close main roads[167]

[158] IWS (2005) *Impact of September 2000 Fuel Price Protests on UK Critical Infrastructure*. Available at: http://www.iwar.org.uk/cip/resources/PSEPC/fuel-price-protests.htm (Accessed: 20 August).
[159] BBC (2000) *Ration warning over fuel panic*. Available at: http://news.bbc.co.uk/1/hi/uk/932207.stm (Accessed: October 14).
[160] The Telegraph (2000) *Panic buyers start to strip supermakets*. Available at: http://www.telegraph.co.uk/news/uknews/1355259/Panic-buyers-start-to-strip-supermarkets.html (Accessed: October 14).
[161] HM Treasury and Infrastructure UK (2010) *National Infrastructure Plan 2010*.
[162] Environment Agency (2009) *Flooding in England : A National Assessment of Flood Risk*.
[163] Hall, J.W., Henriques, J.J. and Nicholls, R.J. (2012) *A Fast Track Analysis of strategies for infrastructure provision in Great Britain: Technical Report*.
[164] Black and Veatch (2013) *Risks of Aging Infrastructure*. Available at: http://bv.com/Home/news/thought-leadership/security-and-risk-management-issues/risks-of-aging-infrastructure (Accessed: 14 August).
[165] Thames Water (2013) *Why we are replacing pipes*. Available at: http://www.thameswater.co.uk/about-us/2690.htm (Accessed: 14 August).
[166] BBC (2013b) *Herne Hill properties flooded after burst water main*. Available at: http://www.bbc.co.uk/news/uk-england-london-23598335 (Accessed: 19 August).

affecting communities and other NI sectors (due to their interdependency and close spatial proximity). The number of leaks are increasing year on year, for example in 2001-02 Thames Water lost 865Ml/d which is an increase of over 30% on the 1999-2000 figure[168]. Therefore, an '*on-going investment in aging infrastructure to reduce leakage and improve resilience is required*'[169].

In the US the fragility of ageing infrastructure has been brought to the attention of global audiences through the numerous bridge collapses in the country. To give an example, the 40-year old I-35W bridge collapse in Minneapolis caused 1,000 feet of the deck truss to collapse and resulted in 13 deaths and 121 injuries[170]. This collapse was due to a design error in the calculation of the load capacity of the bridge, but also in the lack of attention to areas of the bridge in routine inspection / maintenance checks[171]. The condition of bridges in the US formed part of an assessment of the country's infrastructure, forming the 2009 and 2013 Report America's Infrastructure from the American Society of Civil Engineers[172]. In these Report Cards each category is evaluated on the basis of capacity, condition, funding, future need, operation and maintenance, public safety and resilience[173]. Table 1 shows a section of the assessed infrastructure assets, where it can be seen that virtually all assets earned near failing grades in both the 2009 and 2013 Report Cards. This highlights that ageing infrastructure is a major issue and not only within the UK and also has the potential to affect all components of all NI sectors.

Table 1: A selection of the grades given to US infrastructure in the 2009 and 2013 Report Cards from the American Society of Civil Engineers[174,175].

Asset	Score	
	2009	2013
Bridges	C	C+
Dams	D	D
Drinking Water	D-	D
Energy	D+	D+
Rail	C-	C+
Roads	D-	D
Solid Waste	C+	B-
Wastewater	D-	D

[167] BBC (2012a) *North Circular partially reopens after burst main flood*. Available at: http://www.bbc.co.uk/news/uk-england-london-19499571 (Accessed: 19 August).
[168] London Assembly (2003) *London's Water Supply*.
[169] Institution of Civil Engineers (2012) *The State of the Nation: Water 2012*.
[170] FEMA (2007) *I-35W Bridge Collapse and Response*.
[171] National Transportation Safety Board (2007) *Collapse of I-35W Highway Bridge Minneapolis, Minnesota*.
[172] Black and Veatch (2013) *Risks of Aging Infrastructure*. Available at: http://bv.com/Home/news/thought-leadership/security-and-risk-management-issues/risks-of-aging-infrastructure (Accessed: 14 August).
[173] American Society of Civil Engineers (2013) *2013 Report Card for America's Infrastructure*. Available at: http://www.infrastructurereportcard.org/ (Accessed: 14 August).
[174] Ibid.
[175] American Society of Civil Engineers (2009) *Report Card for America's Infrastructure*. Available at: https://apps.asce.org/reportcard/2009/grades.cfm (Accessed: 14 August).

2.2.2: ACCIDENTAL

2.2.2.1: MAJOR INDUSTRIAL ACCIDENTS

Major industrial accidents can take a variety of forms, including fire, contamination and technical failure, and as such they have variable impacts to NI; although, all NI sectors have the potential to be directly and indirectly impacted by this type of risk. In the majority of cases this impact does not extend outside the industrial plant where the accident occurred; however, in a few extreme cases this impact can extend to the wider community and affect a number of NI sectors. For example, the explosion at the West Fertiliser plant in Texas (USA) in 2013, initially started by a fire in the plant, killed 15 people and badly damaged many nearby buildings[176,177]. In December 2005 a fire at the Buncefield Oil Storage Terminal in Hemel Hempstead caused injuries to over 40 people, resulted in evacuations of the surrounding area and caused significant damage to nearby residential and commercial properties[178]. Other instances have had direct impacts to critical NI sectors, for example in 2006 water supply areas used by South West Water were contaminated with diesel, affecting 2,500 properties[179].

The NRR assesses the relative likelihood of this type of risk occurring within the next 5 years to be between 1 in 20,000 and 1 in 2,000. Due to the nature of this risk it is not possible to predict potential locations or assess the potential impacts to wider society and NI sectors. However, it should be noted that this type of risk is connected with any form of industry and does have the potential to affect our critical NI systems as displayed by past events.

2.2.2.2: SEVERE WILDFIRES

Severe wildfires could be placed in any of the main categories included in this report, as they could be classed as a natural hazard (caused by lightening for example) or could be started accidentally (man-made accidental hazard); however, it is deemed that the 'worst case' scenario for this hazard is to be deliberately started (where specific sites could be targeted) therefore they have been placed in this category.

The term 'wildfire' refers to any '*unplanned and uncontrolled vegetation fire which may require suppression*'[180]. Heath, moorland and forests are particularly at risk from this hazard, but wildfires can also occur on agricultural land. These events can be predicted, to some extent, as they usually triggered by drought and possibly strong winds. However, these conditions tend to be short lived and predominantly occur in spring and summer in the UK.

The impacts of wildfires economically are most significant if they occur close to urban areas, however the environmental impacts are equal no matter the location and can affect all NI sectors

[176] BBC (2013d) *Texas Waco fertiliser plant causes many casualties*. Available at: http://www.bbc.co.uk/news/world-us-canada-22195495 (Accessed: 20 August).
[177] The Dallas Morning News (2013) *Analysis: West Fertilizer report details sequence of a catastrophe*. Available at: http://www.dallasnews.com/news/west-explosion/headlines/20130516-analysis-west-fertilizer-report-details-sequence-of-a-catastrophe.ece (Accessed: 20 August).
[178] BBC (2005) *Massive blaze rages at fuel depot*. Available at: http://news.bbc.co.uk/1/hi/uk/4517962.stm (Accessed: 20 August).
[179] South West Water (2007) *Exeter contamination incident of February 2006*. Available at: http://www.southwestwater.co.uk/index.cfm?articleid=3894 (Accessed: 20 August).
[180] Knowledge for Wildfire (2012) *What are wildfires?* Available at: http://www.kfwf.org.uk/ (Accessed: 20 August).

within the affected area in both rural and urban locations. For example, wildfires can force the closure of roads and rail (transport infrastructure), contaminate water supplies (water infrastructure) and damage transmission towers (energy infrastructure). Whilst the UK can be affected by wildfires (for example, the 2011 Swinley Forest fire resulted in road, school and local business closures[181]) other countries are more severely affected (including, Australia[182], USA[183] and China[184]).

This is a newly assessed risk in the 2013 NRR and the relative likelihood of this type of risk occurring within the next 5 years is deemed to be between 1 in 200 and 1 in 20. However, climate change is likely to lead to longer, drier summers this therefore results in a higher risk of more frequent and larger wildfires in the future[185].

[181] BBC (2011c) *Swinley Forest fire 'largest in Berkshire's history'*. Available at: http://www.bbc.co.uk/news/uk-england-berkshire-13292400 (Accessed: 20 August).
[182] Australian Geographic (2011) *The worst bushfires in Australia's history*. Available at: http://www.australiangeographic.com.au/journal/worst-bush-fires-in-Australias-history.htm (Accessed: 20 August).
[183] BBC (2007a) *Californians flee as fires rage*. Available at: http://news.bbc.co.uk/1/hi/7055721.stm (Accessed: 20 August).
[184] The New York Times (1988) *The Breath of the Black Dragon in Russia and China*. Available at: http://www.nytimes.com/1988/10/01/opinion/the-breath-of-the-black-dragon-in-russia-and-china.html?pagewanted=1 (Accessed: 20 August).
[185] Met Office (2011c) *Meterological factors influencing forest fire risk under climate change mitigation*.

SECTION 3: REVIEW OF CURRENT HAZARD DATASETS

Unless stated otherwise, it is presumed that there is currently no data held within the ITRC hazard database for each respective hazard.

Where data/evidence for a hazard has been found it is included in the respective table with the associated metadata or description. Where evidence has been found which can be used to assess the risk of a critical infrastructure network to a hazard, information is included; otherwise the infrastructure is omitted from the list and does not mean that the omitted infrastructures are not affected.

3.1: NATURAL HAZARDS

3.1.1: WEATHER RELATED HAZARDS

3.1.1.1: FLOODING

Table 2 lists the current datasets held by the ITRC database with respect to flooding. To supplement this data, a list of further datasets which extend the coverage of the data geographically as well as in the types of flooding, is provided in Table 3. Further to this the impacts of flooding on some of the UK's critical infrastructures are provided in Table 4.

Table 2: Data held within the ITRC Database currently.

Table prefix/table name	Description
Flood Zone 2	National Flood Zone Data Supplied by the Environment Agency – England and Wales Coverage Only. Best estimate of those areas with between zone 3 and the extents of a 1000 to 1 chance extents for river and sea flooding.
Flood Zone 3	National Flood Zone Data Supplied by the Environment Agency – England and Wales Coverage Only. Estimate of those areas of land which are at a 100 to 1 or greater chance of flooding from rivers, or a 200 to 1 chance or greater of flooding from the sea.
Flood Zone 2	National Flood Zone Data Supplied by the Environment Agency – England and Wales Coverage Only – update 2013. Best estimate of those areas with between zone 3 and the extents of a 1000 to 1 chance extents for river and sea flooding.
Flood Zone 3	National Flood Zone Data Supplied by the Environment Agency – England and Wales Coverage Only – update 2013. Estimate of those areas of land which are at a 100 to 1 or greater chance of flooding from rivers, or a 200 to 1 chance or greater of flooding from the sea.
Flooding extents	Cranfield supplied NSRI Natural Perils Flood Extent Dataset. This shows those areas where water is likely to flow when levels exceed current river tops/flooding defences. Based on those areas where soils have been laid down by water[186].
Flooding likelihood	March 2013 Update of Environment Agency Flood Likelihood. A Grid for England and Wales with flooding likelihood category based on a flood risk assessment.

[186] Cranfield University (2013a) *Subsidence and flooding data for the UK insurance industry*. Available at: http://www.landis.org.uk/npd (Accessed: October 14).

Flooding likelihood	November 2012 Update of Environment Agency Flood Likelihood. A Grid for England and Wales with flooding likelihood category based on a flood risk assessment.
Flood water storage features	Environment Agency-supplied data showing those areas that act as a balancing reservoir, storage basin or balancing pond, with the purpose of attenuating an incoming flood peak to a flow level that can be accepted by a downstream channel.
Area which defences may benefit	Environment Agency-supplied data showing those areas that would benefit from the presence of defences in a 1% fluvial / 0.5% tidal flood event
Area which defences may benefit	Environment Agency-supplied data showing those defences constructed during the last five years with a standard of protection equal to or better than 1% for rivers and 0.5% from the sea.

Table 3: Suggested additional datasets for the assessment of flooding as a hazard.

Dataset	Details	
Flooding extents for Scotland	**Description:**	Flood extent maps for Scotland. See Figure 10 for an example of the data.
	Age:	Unknown
	Resolution:	NA
	Coverage:	Scotland
	Data type:	Polygons
	Availability:	Viewable on an interactive map. Not downloadable.
	License:	Unknown
	Source:	SEPA (Scottish Environment Agency)
	URL:	http://www.sepa.org.uk/flooding/flood_extent_maps.aspx
	Email	Via an online form. http://www.sepa.org.uk/about_us/contacting_sepa/by_email.aspx
Risk of areas to flooding in Scotland	**Description:**	Risk of areas to flooding, see Figure 11.
	Age:	Unknown
	Resolution:	$1km^2$
	Coverage:	Scotland
	Data type:	Gridded
	Availability:	Not downloadable.
	License:	Unknown
	Source:	SEPA
	URL:	http://www.sepa.org.uk/flooding/flood_risk_management/national_flood_risk_assessment.aspx
	Email:	Via an online form. http://www.sepa.org.uk/about_us/contacting_sepa/by_email.aspx
Flooding extents	**Description:**	Extent of areas likely to flood from inland and coastal flooding. An example is shown in Figure 12.
	Age:	Unknown
	Resolution:	NA
	Coverage:	Britain
	Data type:	Polygons

	Availability:	Downloadable to registered users.
	License:	Unknown
	Source:	British Geological Society (BGS)
	URL:	http://www.promap.co.uk/pro_geodata_geological.php
	Email:	customerservice@promap.co.uk
Groundwater flooding	**Description:**	Those areas which are most vulnerable to ground water flooding.
	Age:	Unknown
	Resolution:	NA
	Coverage:	Britain
	Data type:	Polygons
	Availability:	Downloadable to registered users
	License:	Unknown
	Source:	BGS
	URL:	http://www.promap.co.uk/pro_geodata_geological.php
	Email:	customerservice@promap.co.uk
Surface water flooding	**Description:**	Extent of areas likely to flood from surface water, as shown in Figure 13. Produced using a model incorporating predicted rainfall volumes for extreme events and a surface model.
	Age:	Unknown
	Resolution:	NA
	Coverage:	Britain
	Data type:	Polygons
	Availability:	Downloadable to registered users
	License:	Unknown
	Source:	BGS
	URL:	http://www.promap.co.uk/pro_geodata_rms.php
	Email:	customerservice@promap.co.uk
Storm surge height projections	**Description:**	Projected storm surge heights can be calculated through the UKCP09 model[187,188], with Figure 13 showing a set of results for the change in storm surge heights around the coasts of the UK.
	Age:	Unknown
	Resolution:	25km^2
	Coverage:	Britain
	Data type:	CSV file
	Availability:	Downloadable to registered users (25km^2 cell at a time).
	License:	Data can be used for non-commercial purposes. For details see http://ukclimateprojections.defra.gov.uk/23476
	Source:	UKCP09 (UK Climate Projections 2009)
	URL:	http://ukclimateprojections-ui.defra.gov.uk/ui/manual/manual.php?id=6.5
	Email:	enquiries@environment-agency.gov.uk

[187] UK Climate Projections (2013e) *Request Pathway - Storm surge height projections for UK waters*. Available at: http://ukclimateprojections-ui.defra.gov.uk/ui/manual/manual.php?id=6.5 (Accessed: 11 September).
[188] UK Climate Projections (2013a) *Marine and coastal Storm surge projections*. Available at: http://ukclimateprojections.defra.gov.uk/22569/ (Accessed: 11 September).

Sea level rise	**Description:**	Results from modelling the changing climate and the effects on sea level rise around Britain. An example output is shown in Figure 14.
	Age:	Unknown
	Resolution:	5km^2
	Coverage:	Britain
	Data type:	CSV file
	Availability:	Downloadable to registered users.
	License:	Data can be used for non-commercial purposes.
	Source:	UKCP09
	URL:	http://ukclimateprojections-ui.defra.gov.uk/ui/manual/manual.php?id=6.6.1
	Email:	enquiries@environment-agency.gov.uk
Dam breaks	**Description:**	No data found

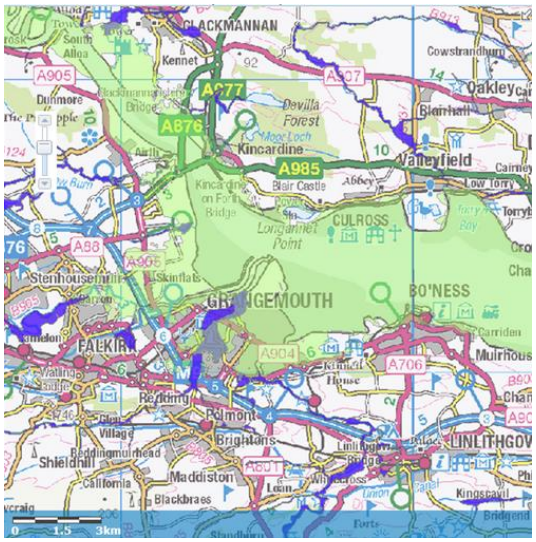

Figure 10: Areas at risk of flooding from the Sea (Green) and from rivers (Purple)[189].

Figure 11: An extract of the flood risk assessment results at a resolution of 1km^2, produced for the whole of Scotland[190].

[189] Scottish Environment Protection Agency (2013) *Indicative River and Coastal Flooding Map*. Available at: http://www.sepa.org.uk/flooding/flood_extent_maps/view_the_map.aspx (Accessed: 11 September).

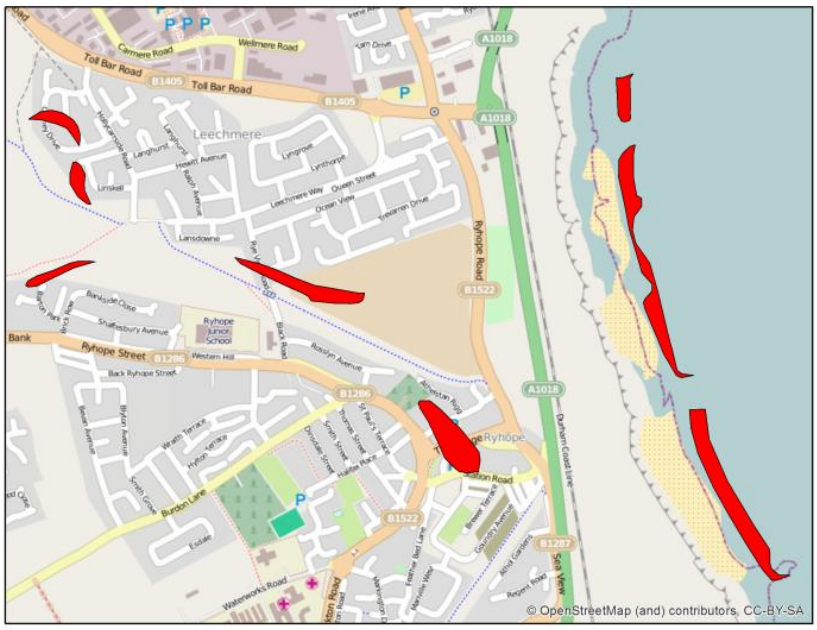

Figure 12: Area susceptible to coastal or inland flooding based on geological data[191].

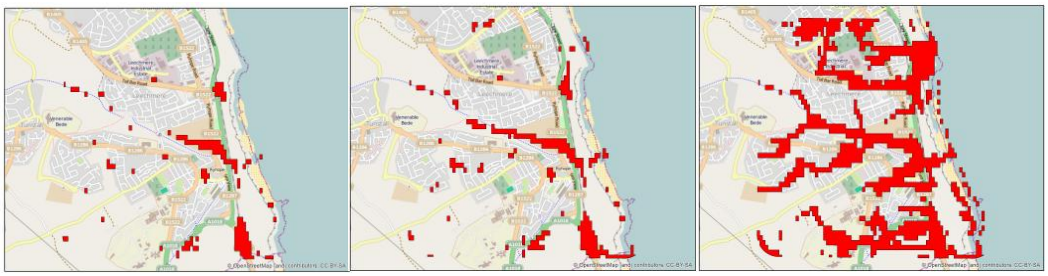

Figure 13: Example of images showing the extent of surface flooding in an area of Sunderland over three extreme precipitation events. From left to right; 1 in 75years, 1 in 100 years and 1 in 1000 years[192].

[190] Scottish Environment Protection Agency (2011) *The National Flood Risk Assessment*.
[191] Promap (2013a) *British Geological Society Flood Data*. Available at: http://www.promap.co.uk/pro_geodata_geological.php (Accessed: 11 September).
[192] Promap (2013b) *RMS Flood Data*. Available at: http://www.promap.co.uk/pro_geodata_rms.php. (Accessed: 11 September).

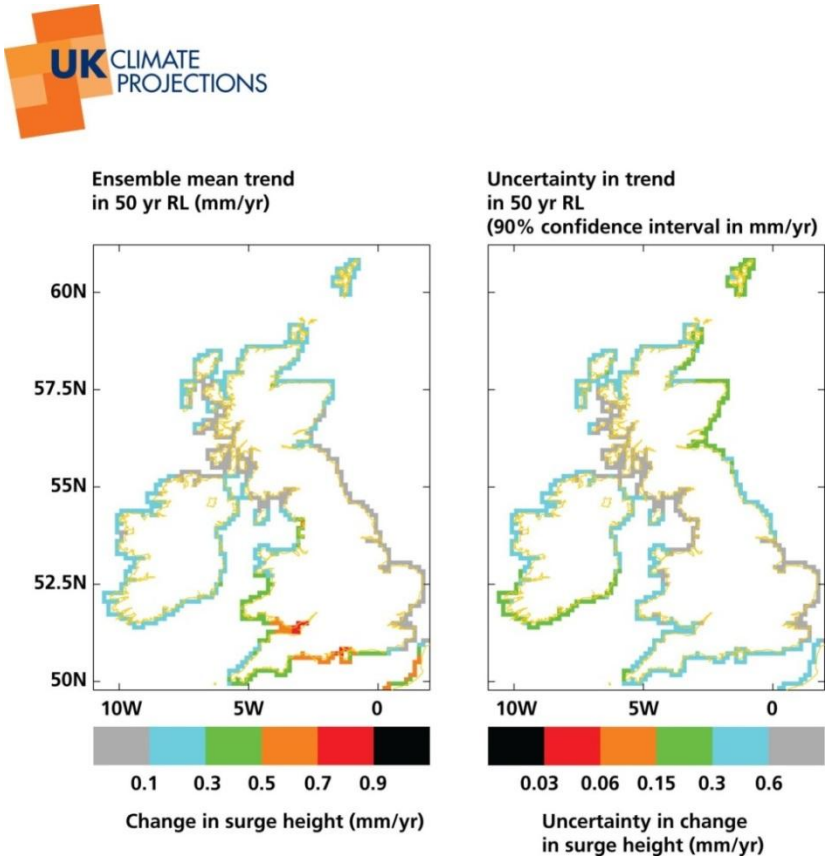

Figure 14: Images showing the projected change in storm surge heights around the coastline of the UK, generated through the UKCP09 model[193].

[193] UK Climate Projections (2013b) *Online Breifing report 6.3.2 Changes in storm surge*. Available at: http://ukclimateprojections.defra.gov.uk/22907 (Accessed: 1 October).

Table 4: A list of the main critical infrastructures which can be directly affected by flooding and how they are affected. From here after the relevant companies/agencies will be referred to by name only.

Infrastructure	Assessment
Power – generation	The flooding of sites and access routes to power stations is assessed as one of the greatest vulnerabilities of electric generation sites, especially to those on the coast which can be vulnerable to see level rise as well[194,195]. The risk of flooding affecting the operation of power plants is assessed as very low[196]or low[197], with all the main generators agreeing on an increase in the level of risk by the 2040s if not the 2020s.
Power – transmission network	National Grid has identified 13 sites as being at risk from a 1:100 year flood event using Environment Agency data, and thus work is being undertaken to protect these sites, with further work to protect all sites which would be affected by a 1:200 year event[198]. The locations of these sites have not been provided.
Gas – transmission network	National Grid report that flooding is not considered a considerable threat to the supply of gas as compression stations, akin to substations for electricity, can be bypassed if flooded with minimal effect on supply[199].
Gas – distribution network	One of the main components in the gas distribution network, pressure reduction stations, are acknowledge by Wales and West Utilities as being susceptible to flooding in a number of locations, with the risk likely to increase[200], though National Grid report that it is unlikely that this will result in a loss of supply in all but long term flooding scenarios. For example at a regional level, Northern Gas Networks identified 45 stations which are vulnerable to flooding on their distribution network[201]. Wales and West Utilities assess the risk from higher river levels damaging pipes across rivers which can lessen the connectivity of the network and potentially cut off supplies, as increasing in the future[202]. Further to this if IT data centres where the gas networks are managed from flood a significant impact including the loss of service would be incurred[203].
Rail	Network Rail have identified flooding as hazard with the likely impacts including failure of line side equipment, scour at bridges and embankment scour[204]. The likely source of the flooding is said to be from rivers, though the hazard from coastal flooding and extreme rainfall scenarios is also mentioned as lesser hazard.

[194] Centrica Energy (2011) *Climate Change Adaption Report*.
[195] EDF Energy (2011) *Report on Adaptation Under the Climate Change Act 2008*.
[196] Centrica Energy (2011) *Climate Change Adaption Report*.; Drax Power Limited (2011) *Climate Change Adaption Report*.; RWE npower (2011) *Climate Change Adaptation Report*.
[197] EDF Energy (2011) *Report on Adaptation Under the Climate Change Act 2008*.; E.ON UK Generation (2011) *Climate Change Adaptation*.; InterGen (2011) *Climate Change Adaptation Report*.; International Power plc (2011) *International Power Climate Change Adaptation Report*.; ScottishPower (2011) *ScottishPower Generation Climate Change Adaption Report*.; Scottish and Southern Energy Group (2011) *SSE Generation Climate Change Adaptation Report*.;
[198] National Grid Electricity Transmission plc (2010) *Climate Change Adaptation Report National Grid Electricity ransmission plc*.
[199] National Grid Gas plc (2010) *Climate Change Adaptation Report National Grid Gas*.
[200] Wales and West Utilities (2011) *Adaptation to Climate Change*.
[201] Northern Gas Networks (2011) *Northern Gas Networks Climate Change Adaptation Report*.
[202] Wales and West Utilities (2011) *Adaptation to Climate Change*.
[203] Southern Gas Networks and Scotland Gas Networks (2011) *Southern Gas Networks and Scotland Gas Networks Climate Change Adaptation Report*.
[204] Network Rail (2011) *Network Rail Climate Change Adaption Report*.

Road	A National Flood Register has been developed by the Highways Agency which stores all motorways and trunk roads which have been identified as being vulnerable to flooding[205]. It is unclear if this includes those assets which are vulnerable to a rise in sea levels however or how this was compiled. For more information on this potential data set use the following email address ha_info@highways.gsi.gov.uk. The impact of flooding on highways includes the closure of lanes or entire stretches of roads due to standing water, reducing capacity.
Air	The threat of extreme rainfall events increasing in frequency has been assessed as a low[206,207,208] or medium[209,210] risk to airfields around the UK as these can force an airport to close due to dangerous surface conditions in the short (up to 2020). In the long term (up to 2050) most assess the risk as medium.

3.1.1.2: WINDSTORMS AND GALES

The required data sets for the assessment of windstorms and gales as a hazard to critical infrastructure networks in the UK are listed in Table 5. Where possible sources of data have been found, appropriate metadata has also been provided. Following from this the infrastructures directly affected by windstorms and gales are summarised in Table 6 along with some of the consequences.

Table 5: Required datasets for the assessing windstorms and gales as a hazard to infrastructure networks.

Data	Details	
Historic wind speeds	**Description:**	Wind speeds as recorded by the Met Office from recording stations located across Britain[211].
	Age:	Current and historical
	Resolution:	Daily to hourly observations from sites around Britain.
	Coverage:	Britain
	Data type:	Unknown (likely to be CSV)
	Availability:	Access must be applied for using the email below.
	License:	Only eligible for use in academic research where each researcher using the data is registered of access.
	Source:	Met Office
	URL:	http://badc.nerc.ac.uk/view/badc.nerc.ac.uk__ATOM__dataent_ukmo-midas.
	Email:	enquiries@metoffice.gov.uk
Future projections of wind speeds	**Description:**	No data found
Likelihood of wind storms	**Description:**	No data found

[205] Highways Agency (2011) *Highways Agency Climate Change Risk Assessment*.
[206] Heathrow Airport Limited (2011) *Heathrow Airport Climate Change Adaption Reporting Power Report*.
[207] London Luton Airport (2011) *Climate Change Adaptation Report*.
[208] Glasgow Airport Limited (2011) *Climate Change Adaptation Report for Glasgow Airport*.
[209] Stansted Airport Limited (2011) *London Stansted Airport Climate Change Adaptation Plan*.
[210] Gatwick Airport Limited (2011) *Climate Change Adaptation Report at Gatwick Airport*.
[211] Centre for Environmental Data Archival (2013) *Met Office Integrated Data Archive System (MIDAS) Land and Marine Surface Stations Data (1853-current)*. Available at: http://badc.nerc.ac.uk/view/badc.nerc.ac.uk__ATOM__dataent_ukmo-midas (Accessed: 11 September).

Table 6: Those critical infrastructures which have been reported as having some vulnerabilities to windstorms and gales.

Infrastructure	Assessment
Power - generation	It has been assessed by a number of energy generators that strong winds and gales are a hazard, though the risk is generally assessed as very low or low[212], with little change across the assessment period up to the 2040s. Many of the generators also report that the assessment is limited by the availability of reliable data of how mean and extreme wind speeds will change over the period.
Power – transmission network	Given the mixed evidence supporting either an increase or decrease in extreme wind speeds and the frequency of such events, National Grid have concluded that no action is necessary as the overhead lines are built to withstand gusts up to 131mph[213].
Road	The Highways Agency expect that exposed structures will be closed to, if not have speed restriction in place for vulnerable traffic (HGV's and motorcyclists). They also report that the increase in frequency of stronger winds may affect the structural integrity of some signs and signals and in extreme cases some larger structures such as overhead gantries.
Rail	Network Rail currently imposes speed restrictions when winds exceed 60-69mph over a 4hr period (or gusts between 70 -89mph) of 50mph to reduce the impact/frequency of incidents involving trees or branches on the lines. Further to this, if the wind speeds exceed 90mph, all services are suspended. Their modelling suggests an increase in the frequency of the speed limits being imposed, but no change in the frequency of occurrence for the threshold for suspension of services being met.
Air	The risk posed to the air industry by changes in winds as the climate changes has been assessed as low[214] up to the 2050s. Due to the lack of reliable wind forecasts up to 2050, this assessment is static throughout the period.

3.1.1.3: SEVERE WINTER WEATHER

Table 7 provides a list of possible data sources for assessing severe winter weather as hazard to infrastructure networks (for windstorms and gales see page 37). Where possible data sources have been identified, metadata has been provided for the evaluation of this data. The affect severe winter weather such as snow and ice can have on our critical infrastructures is summarised in Table 8.

[212] EDF Energy (EDF) label this as a very low risk. Those who assess this as a low risk are Drax Power Limited (Drax), E.ON UK Generation (EON), InterGen, InternationalPower, Scottish and Southern Electricity (SSE), Scottish Power.

[213] National Grid Electricity Transmission plc (2010) *Climate Change Adaptation Report National Grid Electricity ransmission plc*.

[214] Stansted Airport, Heathrow Airport, Glasgow Airport, Gatwick Airport

Table 7: Suggested data sets, where possible, for assessing severe winter weather as a hazard.

Data	Details	
Historic snow fall	**Description:**	The number of days where snow has been lying on the ground at the station. The data is averaged and interpolated[215]. See Figure 15 for an example of how this data can be used.
	Age:	Data from 1971 to 2011
	Resolution:	5km^2
	Coverage:	Britain
	Data type:	CSV, gridded
	Availability:	Users must register for free before downloading from http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/download/monthly/gridded_monthly.html#SnowFall
	License:	Allowed to use the data for most purposes apart from commercial gain. Falls under Non-Commercial Government Licence (http://www.nationalarchives.gov.uk/doc/non-commercial-government-licence/).
	Source:	Met Office
	URL:	http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/download/index.html
	Email:	enquiries@metoffice.gov.uk
Historic snow cover	**Description:**	The number of days snow/sleet has fallen. See Figure 15 for an example of this data can be used.
	Age:	Data from 1971 to 2011
	Resolution:	5km^2
	Coverage:	Britain
	Data type:	CSV, gridded
	Availability:	Users must register for free before downloading from http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/download/monthly/gridded_monthly.html#SnowLying
	License:	Allowed to use the data for most purposes apart from commercial gain. Falls under Non-Commercial Government Licence (http://www.nationalarchives.gov.uk/doc/non-commercial-government-licence/).
	Source:	Met Office
	URL:	http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/download/index.html
	Email:	enquiries@metoffice.gov.uk
Future snow fall predictions	**Description:**	No data sources found. It is predicted that in future decades winters will be warmer, but that precipitation levels will increase[216]. It is

[215] Met Office (2006) *The generation of monthly gridded datasets for a range of climatic variables over the United Kingdom*. [Online]. Available at: http://www.metoffice.gov.uk/climatechange/science/downloads/Monthly_gridded_datasets_UK.pdf.
[216] Met Office (2011b) *Climate : Observations , projections and impacts*.

		though the warmer weather will reduce snow fall levels, though extreme snow fall events may increase in severity.
Locations of ice storms	**Description:** **Age:**	No data source found.
Likelihood of ice storms	**Description:**	No data source found.
Severity of ice storms	**Description:**	No data source found.

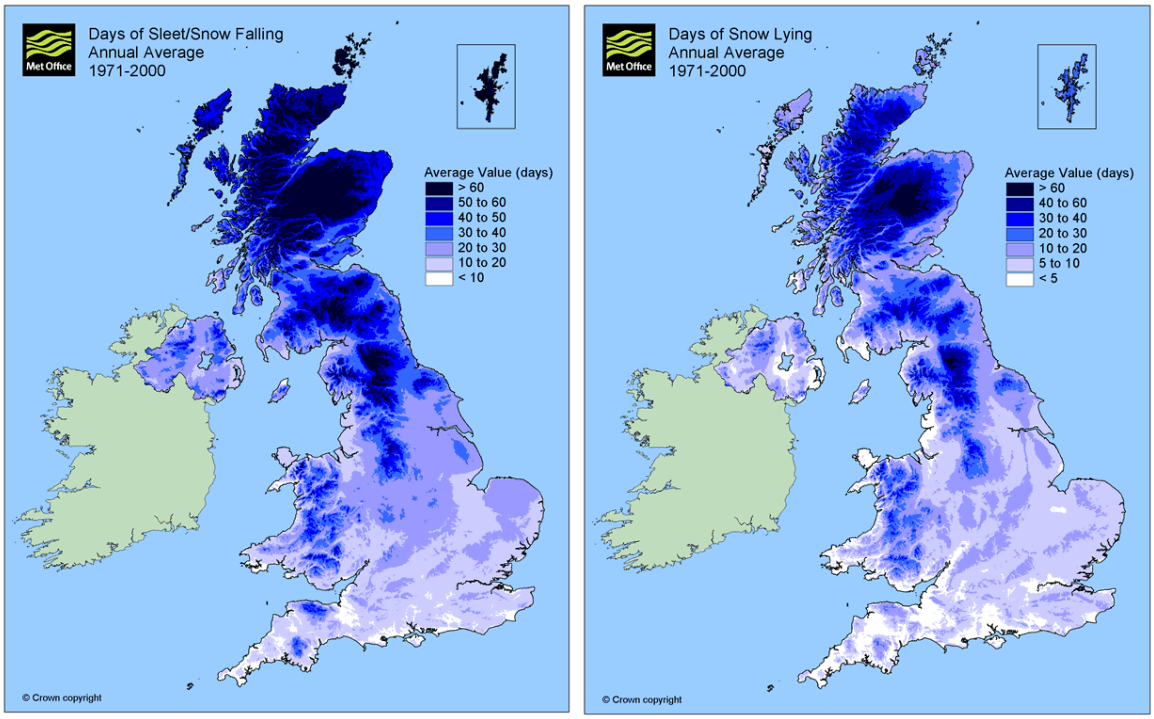

Figure 15: Left: Map produced by the Met Office showing the annual average number of days of snowfall between 1971 and 2000. Right: Map produced by the Met Office showing the annual average of number of days annually where snow has been recorded as lying between 1971 and 2000 [217].

[217] Met Office (2013a) *Climate - Average maps*. Available at: http://www.metoffice.gov.uk/public/weather/climate/newcastle-upon-tyne-youth-hostel#?tab=climateMaps&region=uk (Accessed: 10 September).

Table 8: Critical infrastructures and how they are mainly affected by severe winter weather.

Infrastructure	Assessment
Power – generation	Extreme low temperatures are calculated as posing a very low risk to the operation of power station sites or no risk at all[218]. This is one of the few hazards which shows a decrease in risk over the assessment period (up to 2030s-2040s). Snow fall is assessed as a very low risk or a low risk[219]. Again as a hazard, the risk has been assessed as decreasing by all operators on average across their sites.
Power – transmission network	From the experience of the National Grid and the predictions from the Met Office, it is believed that there will be no increase in the frequency of ice build-up on overhead cables and thus no action is needed improve resilience to this hazard.
Road	The Highways Agency feel that larger snow fall levels from more extreme events will not only lead to a requirement for a greater capacity within the associated equipment such as snow ploughs, but may also lead to localised flooding and its associated consequences.
Rail	National Rail report that cold weather, between 0^{o} and -5^{o}, affects the performance of breaks on trains, increasing stopping distances and thus affecting services. Currently, and in the future the most likely locations for the -5^{o} threshold to be broken include Scotland, Northern England and Central Wales. For example the percentage change for the 2040's from the baseline average for North West England is -43%. As this suggests the frequency of the threshold being broken is expected to decrease, thus also reducing problems of snow and ice on overhead power lines and third rails.
Air	Due to climate forecasts predicting an increase in temperatures the risk from cold weather is static/reduces slightly up to 2050, remaining low[220].

3.1.1.4: HEATWAVES

As a result of climate change heatwaves are predicted to increase in frequency[221] along with the mean temperatures across the UK[222]. Possible data sources allowing for heatwaves to be characterised as a hazard are given in Table 9 where identified, and a summary of the impact of heatwaves on critical infrastructures is provided in Table 10 where appropriate.

[218] Npower assess extreme cold as no risk to their power generation operations. Those which assess extreme cold as a low risk are EON, EDF, Drax, Centrica, InterGen, International Power, SSE and Scottish Power.
[219] EON, EDF, Drax, Centrica, InterGen, International Power and SSE assess snowfall as a very low risk which decreases in the future slightly, whereas Scottish Power address snow fall as a low risk.
[220] Stansted Airport, London Luton, Heathrow, Glasgow and Gatwick.
[221] Beniston, M. (2004) 'The 2003 heat wave in Europe: A shape of things to come? An analysis based on Swiss climatological data and model simulations', *Geophysical Research Letters*, 31.
[222] Benzie, M., Harvey, A., Burningham, K., Hodgson, N. and Siddiqi, A. (2011) *Vulnerability to heatwaves and drought: Case studies of adaptation to climate change in south-west England*.

Table 9: Data required to assess heatwaves as a hazard.

Data	Details	
Likely locations of future heatwaves and their likelihood	**Description:**	No data sources found.
Changes in temperature	**Description:**	The predicted summer mean, maximum and minimum temperatures can be predicted using UKCP09[223]. These values then can be used as inputs to estimating the likelihood of heatwaves, which are based on regional temperature thresholds[224].
	Age:	NA
	Resolution:	5km^2
	Coverage:	Britain
	Data type:	CSV
	Availability:	Free to download for registered users
	License:	Data can be used for non-commercial purposes. For details see http://ukclimateprojections.defra.gov.uk/23476
	Source:	UKCP09
	URL:	http://ukclimateprojections.defra.gov.uk/22787
	Email:	enquiries@environment-agency.gov.uk

Table 10: Critical infrastructures where their operations/effectiveness are affected by heatwaves.

Infrastructure	Assessment
Power - generation	Increased mean temperatures and higher maximum temperatures will affect the operation of power stations, and as a hazard the risk has been assessed as very low, low or medium[225]. The trend between operators is for the risk to increase slightly by the 2030s/2040s.
Power – transmission network	The National Grid expect an annual rise in mean temperature of 8^o will reduce the capacity of some of the national grid transmission equipment marginally, though the extent is unclear due to a lack of understanding in the area.
Gas – transmission network	The National Grid have reported that the current rise in mean ambient temperatures is already affecting some equipment (such as compression stations), and future rises may cause further issues.
Road	The Highways Agency have identified a number of impacts as a result of the increase in temperatures (not just heatwaves) which include possible damage to road surfaces, greater growth rate of roadside vegetation and possible increase in accidents due to poorer levels of visibility due to heat haze according to the Highways Agency. This mainly applies to areas in Southern England but is not limited to these areas. The undertaking of maintenance work will also be affected as working conditions deteriorate in warmer conditions and the materials being used can become more

[223] UK Climate Projections (2013d) *Online climate change projections report Table 1.1*. Available at: http://ukclimateprojections.defra.gov.uk/22914 (Accessed: 11 September).
[224] Met Office (2013d) *Heatwave*. Available at: http://www.metoffice.gov.uk/learning/learn-about-the-weather/weather-phenomena/heatwave (Accessed: 13 September).
[225] Assessed as very low by SSE and Npower. Low by EON, Drax, Centrica, InterGen, International Power and Scottish Power. EDF assess the hazard as a low risk.

	difficult to work with.
Rail	Network Rail report the effect on rail is threefold; damage to tracks and overhead power cables as well as less effective maintenance work. Higher temperatures cause power lines to sag and rails to buckle, resulting in speed restrictions in the affected areas. The number of occurrences where the threshold temperature before power lines are expected to start to sag is expected to increase but not dramatically. The frequency in which the threshold (31^{o}) where it is predicted that tracks may start buckling is expected to increase by 494% for South West England. Secondly, higher temperatures affect when track maintenance can be carried out. Network Rail estimates that for the South East, the most vulnerable area that the number of heat-related non-work days will increase from the current baseline average by 74% in the 2040s. Transport for London also believe there is an increased chance of trains becoming too hot for both passengers and staff if they are stationary for a prolonged amount of time, potentially requiring better management of services or other mitigation methods to keep the services running[226].
Air	The increase in mean temperatures as well as heatwaves are predicted to cause many issues, however the risk to the operation of airports is assessed as low up to 2020, but medium by the 2050s[227].

3.1.1.5: DROUGHT

Droughts are predicted to increase in frequency over the next 100 years[228] and thus will pose a greater hazard to our infrastructures. Figure 16 shows the current human water security threat in the UK, which was calculated on a global scale and as such the results are relative to the rest of the world[229]. This shows that the south east is most vulnerable to droughts, a trend which is expected to continue, if not get worse while the rest of the UK experiences little change over time[230]. Data for assessing droughts as a hazard is presented in Table 11, including changes in precipitation and change in temperatures which are the key drivers for droughts[231]. Those critical infrastructures affected directly by drought conditions are shown in Table 12.

[226] Transport for London (2011) *Providing Transport Services Resilient to Extreme Weather and Climate Change*.
[227] Stansted, London Luton, Heathrow, Glasgow and Gatwick.
[228] Met Office (2010) *Number of droughts likely to increase under climate change*. Available at: http://www.metoffice.gov.uk/news/releases/archive/2010/droughts-to-increase (Accessed: 18 September).
[229] Met Office (2011b) *Climate : Observations , projections and impacts*.
[230] Ibid.
[231] Centre for Ecology and Hydrology (2013) *What is a drought?* Available at: http://www.ceh.ac.uk/data/nrfa/nhmp/whatisadrought.html (Accessed: 24 September).

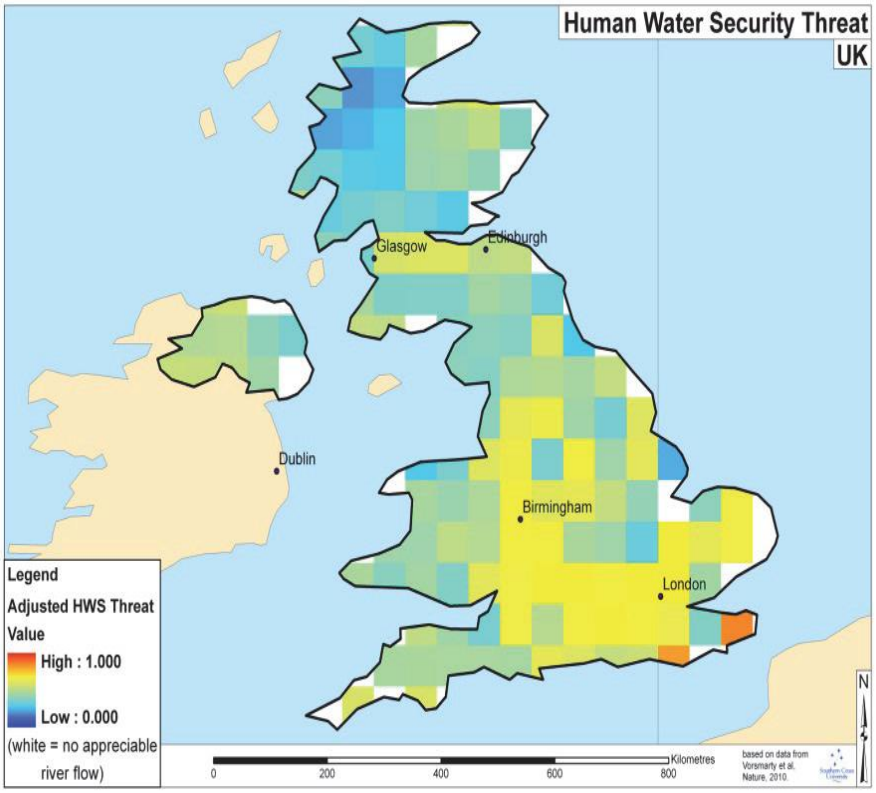

Figure 16: Adjusted water security threat (HWS) at present for the UK at a 50km resolution[232].

Table 11: Suggested data for the assessment of droughts as a hazard to UK infrastructures.

Data	Details	
Location and likelihood of future droughts	**Description:**	No data source found.
Changes in temperature	**Description:**	The predicted summer mean, maximum and minimum temperatures can be predicted using UKCP09[233]. These can then be used for helping to forecast those areas most vulnerable to droughts.
	Age:	NA
	Resolution:	5km^2
	Coverage:	Britain
	Data type:	CSV
	Availability:	Free to download for registered users
	License:	Data can be used for non-commercial purposes. For details see http://ukclimateprojections.defra.gov.uk/23476
	Source:	UKCP09
	URL:	http://ukclimateprojections.defra.gov.uk/22787

[232] Met Office (2011b) *Climate : Observations , projections and impacts*.
[233] UK Climate Projections (2013d) *Online climate change projections report Table 1.1*. Available at: http://ukclimateprojections.defra.gov.uk/22914 (Accessed: 11 September).

	Email:	enquiries@environment-agency.gov.uk
Changes in precipitation	**Description:**	Precipitation levels are predicted to change in both winter and summer with a large variability across the UK[234]. This data can be seen in maps or generated through the UKCP09 model.
	Age:	NA
	Resolution:	5km^2
	Coverage:	Britain
	Data type:	CSV
	Availability:	Free to download for registered users
	License:	Data can be used for non-commercial purposes. For details see http://ukclimateprojections.defra.gov.uk/23476
	Source:	UKCP09
	URL:	http://ukclimateprojections.defra.gov.uk/22787
	Email:	enquiries@environment-agency.gov.uk

Table 12: The critical infrastructures primarily affected by droughts.

Infrastructure	Assessment
Power – generation	The risk of droughts affecting power stations has been calculated as being very low, low or medium, increasing from the current risk level towards the 2040s[235]. It is thought of being one of the more major hazards for power stations, especially to those located in regions which have a higher risk of suffering from droughts.
Road	The Highways Agency believe there may be in increase in the likelihood of vehicles skidding as during periods of no precipitation debris/dirt can build up on road surfaces. During the first significant rainfall after such a period, grip levels may be reduced to less than normal under wet conditions due to the dirt which has accumulated generating a greater risk to road users as well.
Air	The impact of droughts on the aviation industry include the build-up of dirt on the tarmac surfaces, possible water supply issues, increased chance of vegetation fires within the airfield and possible ground movement, leading to the risk predominately being assessed as low[236] in the short term and long term.

[234] UK Climate Projections (2013c) *Online Briefing report 5.4 Changes in precipitation*. Available at: http://ukclimateprojections.defra.gov.uk/22751 (Accessed: 22 September).
[235] Assessed as very low by Drax, low by Centrica, InterGen, Npower, SSE and Scottish Power and EON, EDF and International Power all assess it as a medium risk.
[236] Stansted, London Luton, Heathrow, Glasgow and Gatwick.

3.1.2: GROUND CONDITION HAZARDS

3.1.2.1: COASTAL EROSION

The data required to assess coastal erosion as a hazard to critical infrastructures is presented in Table 13 alongside the associated metadata where sources were identified.

Table 13: Suggested data for the assessment of coastal erosion as a hazard.

Data	Details	
Areas of erosion	**Description:**	Data showing the areas of erosion along with the locations where the erosion is managed are shown on an interactive map[237], Figure 17, which is provided by the Environment Agency.
	Age:	Unknown
	Resolution:	NA
	Coverage:	England and Wales
	Data type:	Unknown
	Availability:	Not available to download.
	License:	Unknown
	Source:	Environment Agency
	URL:	http://www.environment-agency.gov.uk/homeandleisure/134808.aspx
	Email:	enquiries@environment-agency.gov.uk
Areas of erosion	**Description:**	Figure 18 shows the vulnerability of the Scottish shoreline to erosion has been assessed. In summary it is reported that 75% is broadly stable, with 12% erosional, 8% accretional and the rest yet to be assessed[238]. However the data behind this cannot be downloaded and the source of data has not been identified.
	Age:	
	Resolution:	
	Coverage:	Scotland
	Data type:	
	Availability:	
	License:	
	Source:	
	URL:	
	Email:	
Rate of erosion	**Description:**	Shoreline management plans are held by the Environment Agency which detail the condition of the coastlines[239]. The rate of erosion over short stretches

[237] Environment Agency (2013a) *Coastal Erosion*. Available at: http://maps.environment-agency.gov.uk/wiyby/wiybyController?topic=coastal_erosion&ep=map&scale=7&lang=_e&layerGroups=default&layerGroupToQuery=1&x=401212.6538&y=651439.0717000004&textonly=off#x=435009&y=567672&lg=1,&scale=7 (Accessed: 17 September).

[238] Transport Scotland (2013) *Environmental Assessment (Scotland) Act 2005 Scottish Ferry Services Draft Plan for Consultation Strategic Environmental Assessment*. Available at: http://www.transportscotland.gov.uk/strategy-and-research/publications-and-consultations/j210731-07.htm (Accessed: 26 September).

[239] Environment Agency (2013g) *Shoreline Management Plans*. Available at: http://www.environment-agency.gov.uk/research/planning/104939.aspx (Accessed: 17 September).

		which combine into a shoreline management plan zone is recorded, as shown by the example in Table 14. However no single dataset appears to exists, with a separate document for each few km's of coastline. However it is unclear if the Environment Agency has a national data set.
	Age:	Unknown
	Resolution:	NA
	Coverage:	England and Wales
	Data type:	Text
	Availability:	Can be downloaded freely
	License:	Free to use.
	Source:	Environment Agency
	URL:	http://www.environment-agency.gov.uk/homeandleisure/134834.aspx
	Email:	enquiries@environment-agency.gov.uk
Rate of erosion	**Description:**	No data source found (for Scotland). It has been reported that the range in coastal erosion rates is between <1mm and 4m in a single year[240]. There is no geographic aspect however to this data to show how the rates vary geographically.
Assets vulnerable to coastal erosion	**Description:**	No data source found.

[240] Scottish Natural Heritage (1997) *Coastal erosion and defence*. Available at: http://www.snh.org.uk/publications/on-line/advisorynotes/73/73.html (Accessed: 11 September).

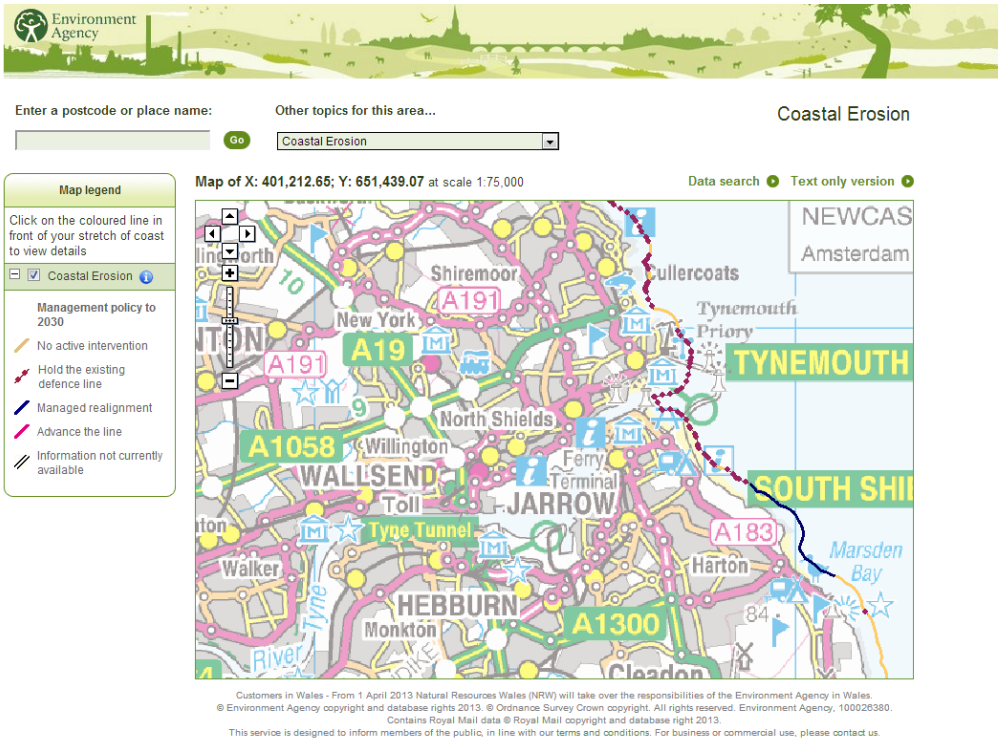

Figure 17: Screen shot of environment agencies online viewer displaying information on the current management of the coastline with England and Wales[241].

[241] Environment Agency (2013a) *Coastal Erosion*. Available at: http://maps.environment-agency.gov.uk/wiyby/wiybyController?topic=coastal_erosion&ep=map&scale=7&lang=_e&layerGroups=default&layerGroupToQuery=1&x=401212.6538&y=651439.0717000004&textonly=off#x=435009&y=567672&lg=1,&scale=7 (Accessed: 17 September).

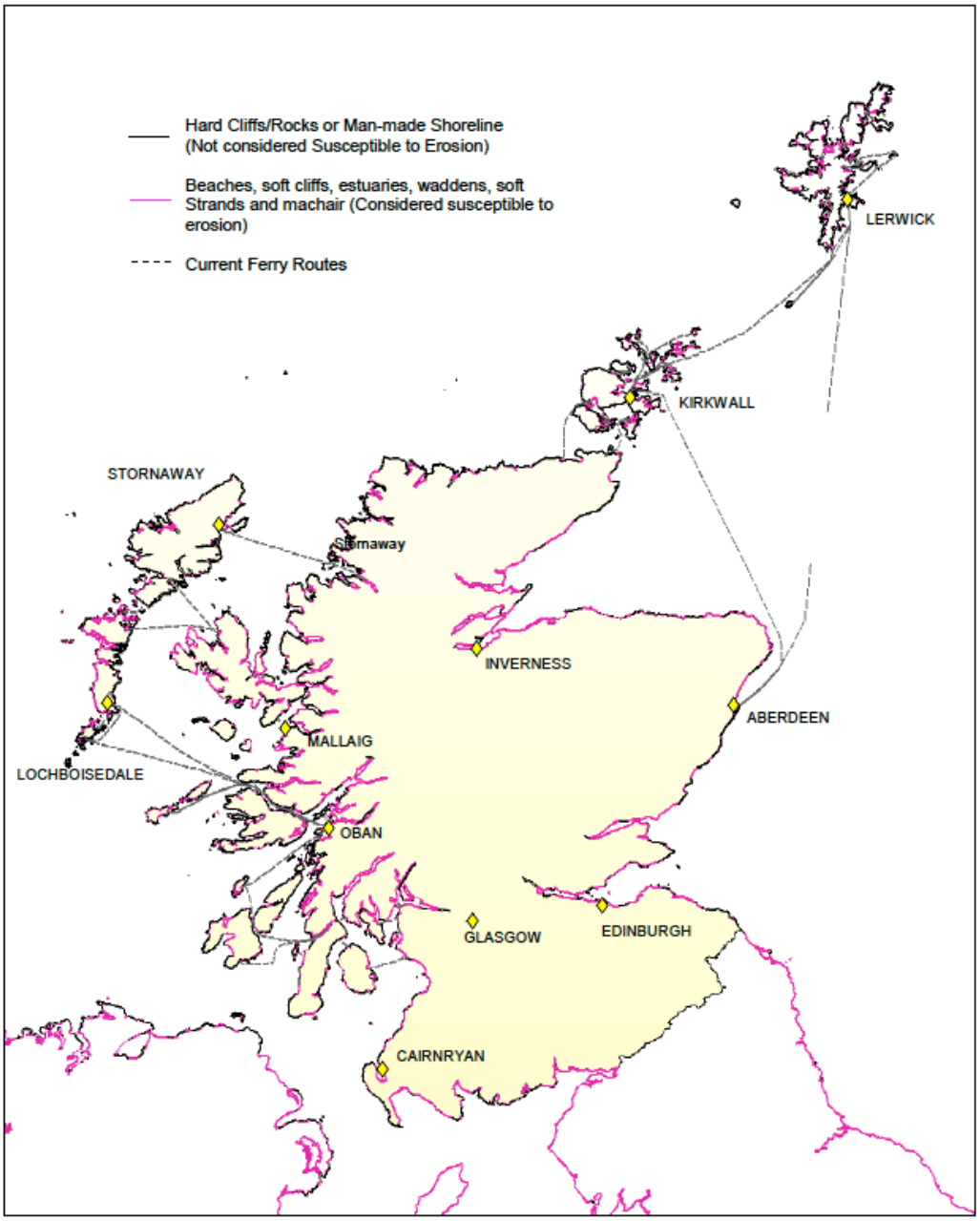

Figure 18: Showing the vulnerability of the coastal of Scotland to coastal erosion[242].

[242] Transport Scotland (2013) *Environmental Assessment (Scotland) Act 2005 Scottish Ferry Services Draft Plan for Consultation Strategic Environmental Assessment*. Available at: http://www.transportscotland.gov.uk/strategy-and-research/publications-and-consultations/j210731-07.htm (Accessed: 26 September).

Table 14: Table from the environment agency detailing location 650 where they provide information on the rate of erosion along this specific section of coastline[243].

650	
Location reference	650
Local Authority	Northumberland County Council
Shoreline Management plan	SMP 1 (Northumberland and North Tyneside)
Type of defence	No defences are maintained
Note	In some areas the SMP Policy is 'Hold the existing defence line' and erosion is considered negligible. However, this may be dependent on the policy being funded and implemented and defences being improved and maintained to prevent erosion.
20 year SMP management policy	No active intervention
Erosion predicted over 20 years	0.7 - 1.3 metres
50 year SMP management policy	No active intervention
Erosion predicted over 50 years	1.7 - 3.3 metres
100 year SMP management policy	No active intervention
Erosion predicted over 100 years	3.4 - 6.6 metres
Timescales are approximate	

[243] Environment Agency (2013b) *Coastal Erosion - Shoreline Management Plans*. Available at: http://maps.environment-agency.gov.uk/wiyby/wiybyController?topic=coastal_erosion&x=401751.68715&y=650777.356000001&scale=7&layerGroups=1&location=X:%20401,751.69;%20Y:%20650,777.36&textonly=off&ep=query&lang=_e&page=2 (Accessed: 17 September).

3.1.2.2: LANDSLIDES AND EMBANKMENT FAILURES

Table 15 shows a list of suggested data required to assess the hazard posed by landslides and embankment failures towards critical infrastructure networks in the UK. This is followed by Table 16 which lists those critical infrastructures where it has been assessed that landslides/embankment failures are potentially a hazard to them.

Table 15: Possible data sets for the assessment of landslides and embankment failures as a hazard to critical infrastructure networks.

Data	Details	
Historical landslide data	**Description:**	A national landslide database is held by the BGS to hold data on recorded landslides[244].
	Age:	Current
	Resolution:	NA
	Coverage:	Britain
	Data type:	CSV/Point
	Availability:	License required for use
	License:	Unknown
	Source:	BGS
	URL:	http://www.bgs.ac.uk/science/landUseAndDevelopment/landslides/NLD.html
	Email:	landslides@bgs.ac.uk
Slope stability data	**Description:**	The BGS GeoSure product includes a slope stability dataset, with the stability ranked in one of five categories[245]. An example of this dataset for an area in Derbyshire is presented in Figure 19.
	Age:	Unknown
	Resolution:	1:50000
	Coverage:	Britain
	Data type:	Polygons
	Availability:	Licence must be obtained.
	License:	Non-commercial use permitted with a set number of users. For more details see http://www.bgs.ac.uk/about/copyright/digital_availability.html
	Source:	BGS
	URL:	http://www.bgs.ac.uk/products/geosure/home.html
	Email:	digitaldata@bgs.ac.uk
Change in frequency of landslides	**Description:**	No data source found.

[244] British Geological Survey (2013m) *National Land Slide Database*. Available at: http://www.bgs.ac.uk/science/landUseAndDevelopment/landslides/NLD.html (Accessed: 16 September).

[245] British Geological Survey (2013l) *Landslides (slope instability)*. Available at: http://www.bgs.ac.uk/products/geosure/landslides.html (Accessed: 24 September).

Figure 19: Areas at risk from landslides in a 70km^2 area in Derbyshire (North of Buxton) as in the BGS GeoSure product. There are five levels of susceptibility ranging from the light colours to the dark, with most severe those areas where 'instability problems are almost certainly present'[246].

Table 16: Some of the infrastructures most at risk from landslides and how this has been assessed.

Infrastructure	Assessment
Power - generation	As a risk to pipelines/infrastructure, the risk caused by landslides, embankment failure and subsidence have been assessed as very low[247]. In most cases the risk has been assessed as decreasing very slightly over the next few decades.
Rail	It is suggested that there is no clear evidence either way to state weather there will be in increase, decrease or no change in the number of landslides which affect the rail network. The greatest frequency of landslides as it stands are in the South East due to the geology being predominately clay.

3.1.2.3: SUBSIDENCE

Table 17 shows a selection of data which can be used for assessing the risk to infrastructures from subsidence. Those infrastructures which have been deemed most vulnerable to subsidence are listed in Table 18 along with some brief details of their vulnerabilities.

[246] Ibid.
[247] EON, EDF, Drax, Centrica, InterGen, International Power and Scottish Power.

Table 17: Suggested data for assessing subsidence as a hazard to infrastructure networks.

Data	Details	
Subsidence from shrink swell action	**Description:**	The Natural Peril Directory contains a risk assessment for subsidence from the swell and shrinkage of the soil[248]. Figure 20 provides an example of this data for a small area (5km^2) in Northampton.
	Age:	Unknown
	Resolution:	Exit-level postcode unit
	Coverage:	Britain
	Data type:	Unknown (likely to be polygons)
	Availability:	License required. Use email below.
	License:	Required, details unknown.
	Source:	LandIS – National Soils Research Institute - Cranfield University
	URL:	http://www.landis.org.uk/services/npd.cfm
	Email:	t.s.farewell@cranfield.ac.uk
Subsidence from mining	**Description:**	Subsidence from old mine workings can occur unexpectedly[249], and thus the Coal Authority store details of previous areas of mining, as shown in the map in Figure 21.
	Age:	Unknown
	Resolution:	NA
	Coverage:	Britain
	Data type:	Unknown
	Availability:	Not available to download
	License:	Unknown
	Source:	Coal Authority – Department for Energy and Climate Change
	URL:	http://coal.decc.gov.uk/en/coal/cms/services/reports/mining_report/mining_report.aspx
	Email:	See http://coal.decc.gov.uk/en/coal/cms/contact/contact.aspx
Subsidence from ground movement	**Description:**	The BGS GeoSure product maps the likelihood of ground movement from six different hazards including shrink swell, exemplified in Figure 22, as well as collapsible deposits and compressible ground[250].
	Age:	Unknown
	Resolution:	1:50000
	Coverage:	Britain
	Data type:	Polygons
	Availability:	Licence must be obtained.
	License:	Non-commercial use permitted with a set number of

[248] Cranfield University (2013b) *Subsidence and flooding data for the UK insurance industry*. Available at: http://www.landis.org.uk/services/npd.cfm (Accessed: 16 September).
[249] The Coal Authority (2013b) *Protecting the Public in Coal Mining Areas*. Available at: http://coal.decc.gov.uk/en/coal/cms/services/safety/safety.aspx (Accessed: 16 September).
[250] British Geological Survey (2013i) *GeoSure*. Available at: http://www.bgs.ac.uk/products/geosure/ (Accessed: 16 September).

	users. For more details see http://www.bgs.ac.uk/about/copyright/digital_availability.html
Source:	BGS
URL:	http://www.bgs.ac.uk/products/geosure/home.html
Email:	digitaldata@bgs.ac.uk

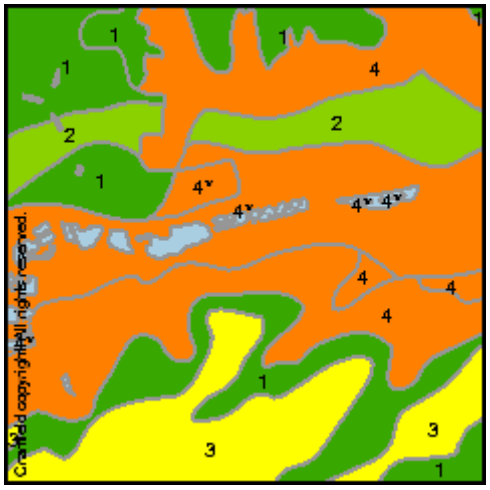

Figure 20: An example of a map of ground movement potential for a 5km by 5km area in Northampton[251].

Figure 21: Map showing the subsidence from mining activities in the UK[252].

[251] National Soil Resources Institute (2008) *Sample Soil Report*. [Online]. Available at: http://www.landis.org.uk/services/downloads/Full_5km.pdf.

Figure 22: An example of the shrink swell data available through the BGS GeoSure data product. The area shown lies north of Buxton in Derbyshire covering an area of approximately 70km^2. The lighter blue areas show those which are classed as no-plastic, and the darker blue those which have a low plasticity[253].

Table 18: Infrastructures which are assessed to be vulnerable to subsidence and the risk caused by this hazard to those affected.

Infrastructure	Assessment
Power - generation	See Table 16, page 52 (landslides and embankment failures).
Gas – distribution network	The National Grid report that further data is required to assess the extent of change in the frequency of ground movement of all forms, which inevitably can affect gas distribution networks and thus the supply to users. The risk is assessed to increase slightly for pipelines[254], but change over the shorter time scale 2020[255]. Some other providers have not addressed subsidence as a risk to their infrastructure[256].

[252] The Coal Authority (2013a) *Mining and Ground Stability in Britain*. Available at: http://coal.decc.gov.uk/en/coal/cms/services/reports/mining_report/mining_report.aspx (Accessed: 16 September).

[253] British Geological Survey (2013g) *Edale Valley, Derbyshire*. Available at: http://www.bgs.ac.uk/products/geosure/derbyshire_example.html (Accessed: 16 September).

[254] ESO Gas Group Limited (2011) *Climate Change Act Adaptation Risk Assessment and Adaptation Policy*.

[255] Northern Gas Networks.

[256] Wales and West Utilities along with Southern Gas Networks and Scotland Gas Networks.

3.1.3: OTHER RISKS

3.1.3.1: SPACE WEATHER

Space weather is considered a rare, but high impact hazard[257], though very little data exists to quantify what impact a major solar storm would have on UK infrastructure systems. It is agreed that it would have a greater impact than the last major storm given the large increase in the number of earth orbiting satellites and our reliance upon them however[258]. Table 19 displays the data required for assessing space weather as a hazard to critical infrastructure networks in the UK. As the effect of a solar storm hitting Earth is understood, a number of infrastructures are known to be directly vulnerable to such an event, Table 20.

Table 19: Data sets for assessing space weather as a hazard to infrastructure networks in the UK.

Data	Details	
Likelihood and severity of a solar storm	**Description:**	No data found. However, the BGS have recently started recording the surface electric field through a small number of monitoring stations around the UK which is directly affected by solar storms[259] .

Table 20: The critical infrastructure assessed as being vulnerable to space weather and how it might affect them.

Infrastructure	Assessment
Power - transmission	The risk posed by a solar storm to the power distribution network varies with the scale of the storm. National Grid believes that no disruption should be noticed by users unless a 1 in 30 year event or greater occurs. From a 1 in 30 year event or greater some substations may fail due to an increase in demands due to reactions by customers on news of the storm. It is also forecast that for a 1 in 100 event between 10-20 stations may fail as a result of the storm directly.
Air	The Royal Academy of Engineering have reported that a strong solar storm would cause planes which fly at a higher altitude to decrease their height to reduce the risk of exposure to those on-board. Where the storm was particularly strong, flights would be grounded in the affected area.

[257] Royal Academy of Engineering (2013) *Extreme space weather : impacts on engineered systems and infrastructure* (1903496969).
[258] Parllamentary Office of Science and Technology (2010) *Space Weather*.
[259] British Geological Survey (2013h) *Geoelectric Field Monitoring*. Available at: http://www.geomag.bgs.ac.uk/research/electric_field.html (Accessed: 24 September).

3.1.3.2: METEOR STRIKES

The threat from meteor strikes comes in two forms, the first being direct impacts from meteors falling to Earth, and the second from meteors striking Earth orbiting satellites upon which we rely upon[260]. A similar threat to meteorites comes from space debris and thus will also be addressed in this section[261]. A list of data required to assess the risk that meteorites pose to infrastructures in the UK is given in Table 21 with appropriate metadata given where possible.

Table 21: Data for assessing meteor strikes as a hazard to infrastructures.

Data	Details	
Historical meteor strikes	**Description:**	All recorded meteor strikes within the UK are held within the meteoritical database[262], a global database for such data. Figure 23 shows those meteors strikes recorded in the UK.
	Age:	Current
	Resolution:	NA
	Coverage:	Britain
	Data type:	Points/CSV
	Availability:	Free to download: https://www.google.com/fusiontables/DataSource?docid=1vHSvjNgCIl6kRhFXPHhvESnnYx_ShToJWtWdjm8#rows:id=1 or http://www.lpi.usra.edu/meteor/metbull.php
	License:	Non-commercial use.
	Source:	Meteoritical Society
	URL:	http://www.lpi.usra.edu/meteor/about.php
	Email:	jgrossman@nasa.gov
Future likelihood of meteor strikes	**Description:**	No data has been found.
Meteorite strikes on earth orbiting satellites	**Description:**	No data has been found.
Collision between space debris/satellites and satellites	**Description:**	No data found. Space debris as well as other satellites pose a hazard to orbiting satellites, though as shown in Figure 24, currently there have been very few incidents. However, as space debris continues to accumulate, and more satellites are put into orbit[263], the chance of future collisions naturally rises, as shown in the plot.

[260] Parllamentary Office of Science and Technology (2010) *Space Weather*.
[261] European Commission (2013) *Avoiding damage from space debris*. Available at: http://europa.eu/rapid/press-release_MEMO-13-149_en.htm (Accessed: 21/09/2010).
[262] The Meteoritical Society (2013) *The Meteoritical Society*. Available at: http://meteoriticalsociety.org/ (Accessed: 11 September).
[263] Parllamentary Office of Science and Technology (2010) *Space Weather*.

Figure 23: Recorded meteor strikes in the UK since 2300BC[264].

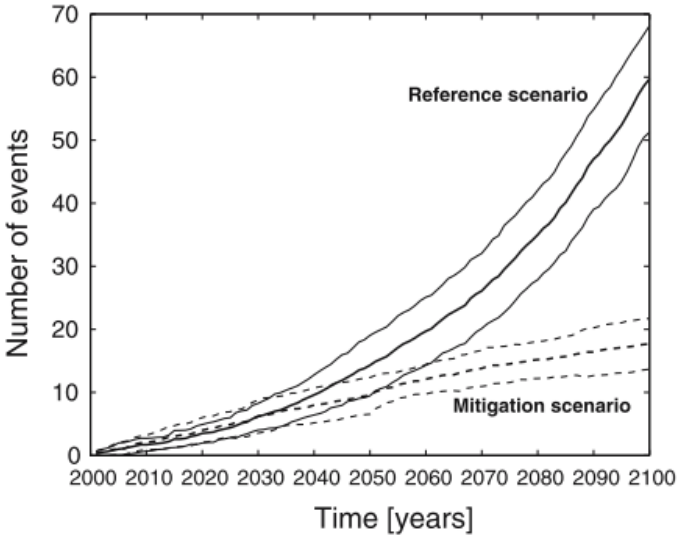

Figure 24: The prediction of the number of collisions between space debris and satellites[265].

[264] The Guardian (2013b) *Every meteorite fall on earth mapped*. Available at: http://www.theguardian.com/news/datablog/interactive/2013/feb/15/meteorite-fall-map (Accessed: 11 September).

3.1.3.3: VOLCANIC ERUPTION

As no volcanoes are found within the UK, the main threat from eruptions is from ash clouds which can stop flights due to the damage which can be caused to the engines of aircrafts[266] and the threat from a gaseous eruption, which is considered a more significant threat as it can destroy crops amongst other things[267]. A further hazard from volcanoes is the potential for tsunamis, however the risk if considered low, see page 63. Table 23 lists the required data for an assessment of the hazard volcanic eruptions pose to UK critical infrastructure networks. Those infrastructure networks most likely to be affected by the hazards caused by volcanic eruptions are shown in Table 23.

Table 22: Possible data for the assessment of volcanoes as hazards to UK infrastructure networks.

Data	Details	
Likely areas affected by ash clouds	**Description:**	No data source found. The Met Office is one of nine VAAC (Volcanic Ash Advisory Centres) which provides forecasts for ash plumes within their area of responsibility[268], and thus may be able to provide further information on this hazard.
Likelihood of future ash clouds affecting the UK	**Description:**	No data source found. It has been reported that the metrological conditions which were in place, and required to cause problems for the UK, when the Eyjafjallajokull volcano erupted are only so for 6% of the year[269]. The same report has located a number of volcanoes which could cause similar problems given the correct metrological conditions, Figure 25.
Likelihood of an eruption causing a tsunami	**Description:**	No data source found.
Likelihood of a gaseous eruption affecting the UK	**Description:**	No data source found.

[265] Rossi, A. and Valsecchi, G.B. (2006) 'Collision risk against space debris in Earth orbits', *Celestial Mechanics and Dynamical Astronomy*, 95, pp. 345-356.

[266] Civil Aviation Authority (2013) *Assessing the dangers of volcanic ash*. Available at: http://www.caa.co.uk/default.aspx?catid=2011&pagetype=90&pageid=12641 (Accessed: 24 September).

[267] Mail Online (2012a) *Solar storms raised to 'high priority' risk in Britain as concerns mount over dangers to communications and power grids*. Available at: http://www.dailymail.co.uk/sciencetech/article-2117192/Solar-storms-volcanoes-added-official-list-threats-Britain-alongside-floods-flu-terrorism.html (Accessed: 24 September).

[268] Met Office (2013j) *Volcanic Ash Advisory Centres*. Available at: http://www.metoffice.gov.uk/aviation/vaac (Accessed: 23 September).

[269] UCL Institute for Risk and Disaster Reduction (2010) *Volcanic Hazard from Iceland: Analysis and implications of the Eyjafjallajokull eruption*.

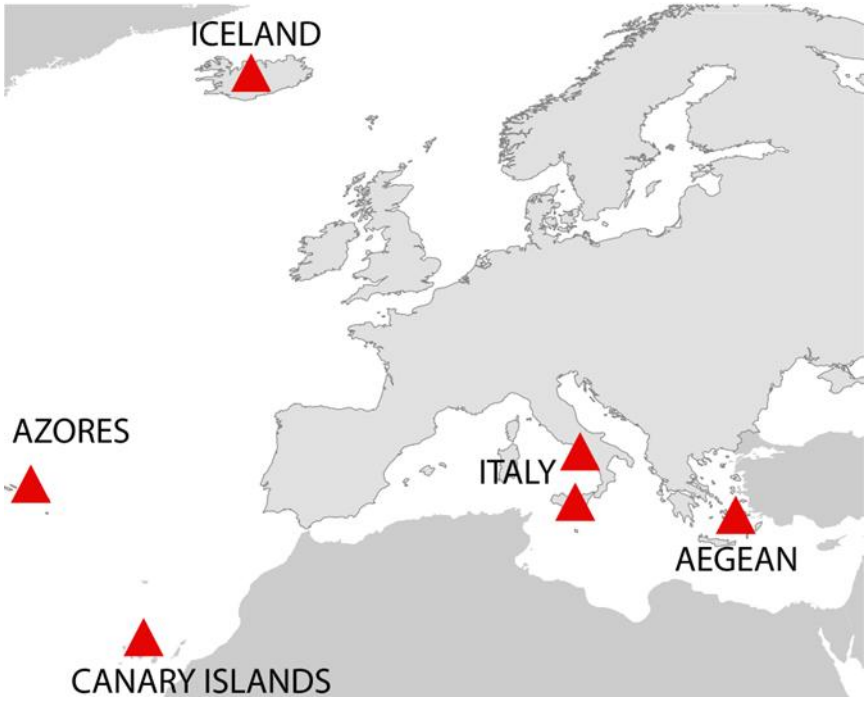

Figure 25: Western Europe/African volcanoes which are most likely to generate ash clouds which can affect the UK[270].

Table 23: Those critical infrastructures assessed as being vulnerable to volcanic eruption events.

Infrastructure	Assessment
Air	The threat from ash clouds to the continued operational ability of airports is acknowledged by many[271], however the risk and probability of such events is not addressed in any case.

3.1.3.4: EARTHQUAKE

The required data sources for an assessment of earthquakes as a hazard to UK critical infrastructure networks are presented in Table 24 with appropriate metadata on the suggested data where a suitable source was identified.

[270] Ibid.
[271] Stansted, Gatwick, Glasgow and Heathrow

Table 24: Suggested data sets for assessing the hazard caused by earthquakes.

Data	Details	
Likely location and magnitude of earthquakes	**Description:**	The BGS have already began the development of a database to store all records of earthquakes in the UK region[272]. Currently the location, time and magnitude of an earthquake can be downloaded. Figure 26 shows those earthquakes which have been recorded in the UK and their size which have a magnitude of 3.0 and over. Further to this Table 25 shows the expected frequency according to magnitude of earthquakes in the UK.
	Age:	2001 (more current data may be available)
	Resolution:	NA
	Coverage:	Britain
	Data type:	CSV/points
	Availability:	Free to download. http://quakes.bgs.ac.uk/earthquakes/dataSearch.html or http://quakes.bgs.ac.uk/historical/query_eq/
	License:	No information apparent
	Source:	BGS
	URL:	http://quakes.bgs.ac.uk/historical/
	Email:	ukeqs@bgs.ac.uk

[272] British Geological Survey (2013q) *UK Historical Earthquake Database*. Available at: http://quakes.bgs.ac.uk/historical/index.html (Accessed: 18 September).

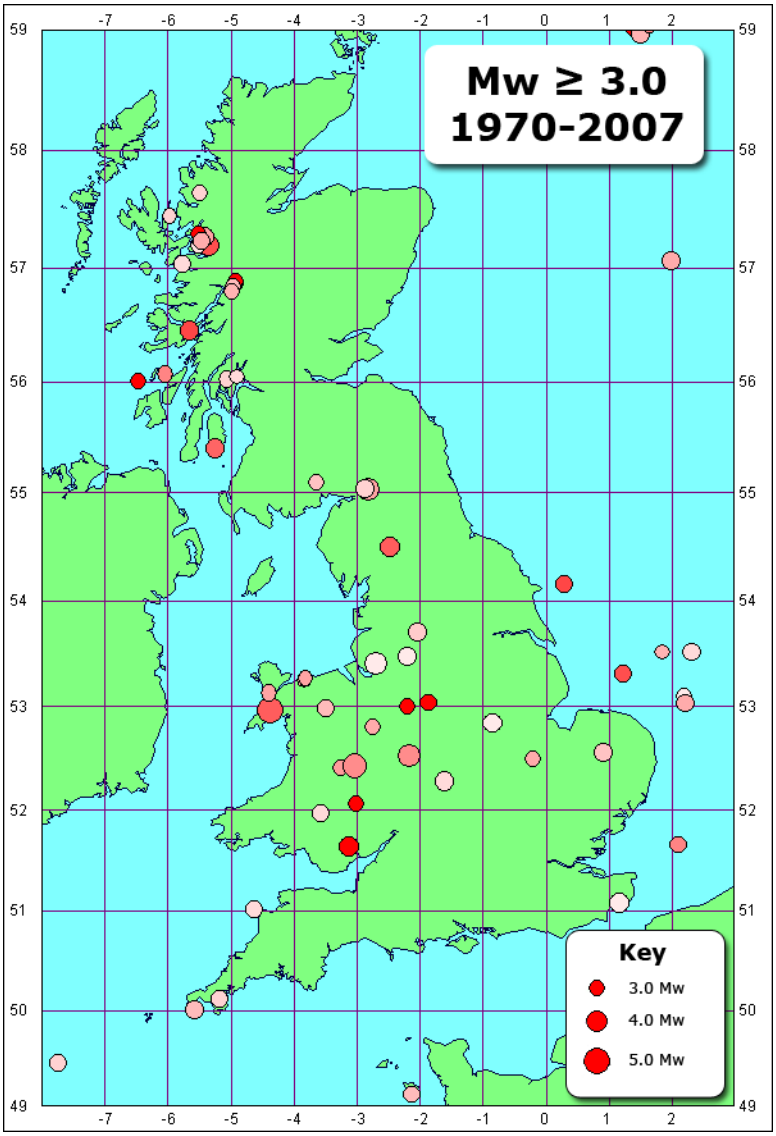

Figure 26: Recorded UK earthquakes equal to and greater than 3MW between 1970 and 2007[273].

Table 25: Frequency of earthquakes by strength occurring each year in the UK[274]. An earthquakes of magnitude 5 is described as 'causing small objects to fall over'[275] .

Magnitude	UK earthquake frequency
5	1 every 20 years
4	1 every 3–4 years
3	3 each year
2	25 each year
1	100s each year

[273] Musson, R.M.W. and Sargeant, S.L. (2007) *Eurocode 8 seismic hazard zoning maps for the UK*.
[274] British Geological Survey (2013a) *Aye yesterday's earthquakes tomorrow's disasters?* Available at: http://www.bgs.ac.uk/research/earthquakes/yesterdaysearthquakes.html?src=sfb (Accessed: 18 September).
[275] British Geological Survey (2013f) *Earthquake intensity*. Available at: http://www.bgs.ac.uk/discoveringGeology/hazards/earthquakes/intensity.html (Accessed: 2 September).

3.1.3.5: TSUNAMI

The risk of a tsunami hitting the UK is low due to its geographic location being a significant distance from a subduction zone which tend to cause the largest tsunamis[276]. However there are other causes of tsunamis which can affect the UK such as volcanic activity and sub-marine landslides. The suggested data required to assess these as a hazard to UK critical infrastructure networks is listed in Table 26 with metadata provided where datasets have been found. Table 27 shows those infrastructures which are most likely to be affected by tsunamis where evidence was found.

Table 26: Possible data for assessing tsunamis as a hazard to infrastructure networks in the UK.

Data	Details	
Areas at most risk from tsunamis caused by earthquakes	**Description:**	No data source found. Recent reports have linked the south coast of England as being vulnerable to tsunamis originating from a subduction zone off the Portuguese coast where there would be approximately a 5hour advanced warning for a tsunami here in the UK[277,278]. There is also a seismically active area to the north west of Europe, however this has been assessed as a low risk in terms of generating tsunamis[279].
Areas at most risk from tsunamis caused by ground movements	**Description:**	No data source found. Landslides caused by volcanoes or subsea activity can cause tsunamis which might affect the UK. The south coast of England witnessed a 2ft tsunami in 2011 which caused little damage, though it was thought to have been caused by a sub-marine landslide, though the cause of which is unknown[280,281], highlighting the unpredictability of these events.

Table 27: Critical infrastructures which are most vulnerable to tsunamis.

Infrastructure	Assessment
	EDF report that a report form 2007 by the British Energy New Build team address the risk of a tsunami as 1 in 1000yrs, and that predicted wave heights do not exceed those greater than a storm surge[282]. Further to this the EDF report also adds that the current level of defence at nuclear sites is for a 1:10000year event.

[276] British Geological Survey (2013e) *Could a Tsunami hit the British Isles?* Available at: http://www.bgs.ac.uk/research/earthquakes/BritishTsunami.html (Accessed: 2 September).
[277] British Geological Survey (2013e) *Could a Tsunami hit the British Isles?* Available at: http://www.bgs.ac.uk/research/earthquakes/BritishTsunami.html (Accessed: 2 September).
[278] The Telegraph (2013b) *Tsunami could swamp Cornwall, scientists warn*. [Online]. Available at: http://www.telegraph.co.uk/science/science-news/10184443/Tsunami-could-swamp-Cornwall-scientists-warn.html.
[279] Musson, R.M.W. (2008) 'The Case for Large M> 7 Earthquakes Felt in the UK in Historical Times', p. 24.
[280] Owen, B. (2011) 'UK tsunami risk: an overview of the evidence'.
[281] British Geological Survey (2011) *Tsunami or meteotsunami?* Available at: http://www.bgs.ac.uk/research/highlights/2011/tsunamiSWEngland2011.html (Accessed: 18 September).
[282] EDF

3.2: MAN-MADE HAZARDS

3.2.1: DELIBERATE

3.2.1.1: CATASTROPHIC TERRORIST ATTACK

Ranked by the UK government as one of the most significant threats to the UK, terrorist attacks pose a hazard to UK infrastructure networks[283,284]. However, the nature of these events makes assessing the hazard challenging as the targets can range from railway stations to government buildings to shopping centres. The data required to assess terrorist attacks as a hazard to critical infrastructures in the UK is listed in Table 28, however due to the nature of the hazard very little data has been found. Table 29 shows the critical infrastructures which might be impacted by a terrorist attack event where supporting evidence of the risk was found.

Table 28: Data required for assessing terrorist attacks as a hazard to infrastructures.

Data	Details	
Likely targets	**Description:**	No data source found.
Likelihood of attacks	**Description:**	No data source found. Data on the number of arrests and convictions for terror related activities can be found in reports from HM Government[285], however these do not allow for a full assessment of the likelihood of an attack.

Table 29: Infrastructures most likely directly affected by a terrorist attack.

Infrastructure	Assessment
Air	It is clear that there is a threat to air networks, with reducing the vulnerability to a terrorist attack in the aviation sector a priority[286]. The risk to the UK network cannot be easily quantified due to the many factors including the global nature and interconnectedness of air networks.
Rail	The rail network is also vulnerable to a terrorist attack, especially around hub stations on the network where the greatest impact can be caused. For this reason much work is being done to reduce the threat to key assets both on the National network and on the London underground system[287]. Assessing the risk of this and how it might change however if difficult, especially in the longer term.

[283] HM Government (2011) *CONTEST: The United Kingdom's Strategy for Countering Terrorism*.
[284] Cabinet Office (2010) *A Strong Britain in an Age of Uncertainty: The National Security Strategy*. London.
[285] HM Government (2011) *CONTEST: The United Kingdom's Strategy for Countering Terrorism*.
[286] Ibid.
[287] Ibid.

3.2.1.2: CYBER ATTACKS

Ranked in the top tier of threats as a priority risk to the UK alongside international terrorism, large scale natural hazards and an international military crisis, the threat of cyber attacks is clearly a significant hazard[288]. IT has been reported that 93% and 87% of large companies and small businesses respectively have reported a cyber breech on some scale within the previous 12 months of the survey[289]. However the scale of these attacks/breeches is often hidden and thus assessing the extent of this as a hazard is challenging, though the sort of data required to do so is listed in Table 30. Following this, Table 31 shows infrastructures most likely to be affected directly by cyber attacks.

Table 30: Data for assessing cyber attacks as a hazard to infrastructure networks.

Data	Details
Impact of attacks	**Description:** No data source found.
Likely locations/sites of attacks	**Description:** No data source found.

Table 31: Those critical infrastructures most likely directly affected by cyber attacks.

Infrastructure	Assessment
Electricity transmission	It is known that some of our critical infrastructures have been targeted by cyber attacks and it is thought that this includes the electricity transmission network as well as the gas and water distribution networks[290,291].
Gas transmission	See Electricity transmission above.
Water distribution	See Electricity transmission above.

[288] Cabinet Office (2010) *A Strong Britain in an Age of Uncertainty: The National Security Strategy*. London.
[289] HM Government (2013) *Keeping the UK safe in cyber space*. Available at: https://www.gov.uk/government/policies/keeping-the-uk-safe-in-cyberspace (Accessed: 18 September).
[290] The Independent (2012) *UK's power and water infrastructure 'at risk of cyber attacks'*. Available at: http://www.independent.co.uk/news/uk/home-news/uks-power-and-water-infrastructure-at-risk-of-cyber-attacks-8375958.html (Accessed: 19 August).
[291] The Guardian (2012) *Hostile states using cyberwarfare to attack UK infrastructure*. Available at: http://www.theguardian.com/technology/2012/dec/03/hostile-states-cyberwarfare-uk-infrastructure (Accessed: 19 August).

3.2.1.3: PUBLIC DISORDER

By their nature predicting the locations of public disorder is very difficult, and thus the possible risk this causes to infrastructure networks is consequently even more difficult to quantify. Listed in Table 32 is the data which would help to quantify the extent which public disorder is a hazard to infrastructures.

Table 32: Suggested data for assessing public disorder as a hazard to infrastructures.

Data	Details	
Likelihood of disorder	**Description:**	No data source found.
Locations of previous disorder	**Description:**	Partial data source found. The locations of all the incidents reported during the 2011 riots in the UK can be downloaded[292]. Obviously data from other incidents is required to fully assess the likely locations of public disorder.
	Age:	Current
	Resolution:	NA
	Coverage:	UK
	Data type:	CSV/point
	Availability:	Free to download: https://docs.google.com/spreadsheet/ccc?key=0AonYZs4MzlZbdDFMMmRSSWFvTnU3Q2EyaWFNMzlFX2c&hl=en_US#gid=0
	License:	Unlicensed
	Source:	The Guardian
	URL:	http://www.theguardian.com/news/datablog/2011/aug/09/uk-riots-incident-listed-mapped
	Email:	data@guardian.co.uk

3.2.1.4: DISRUPTIVE INDUSTRIAL ACTION

Strikes in the UK[293] as well as outside the UK[294] can affect our critical infrastructures on different scales and through different reasons. However assessing these as a hazard over a long term scale to infrastructures is difficult due to the nature of industrial action, though suggested datasets are given in Table 33.

[292] The Guardian (2011) *UK riots: every verified incident.* Available at: http://www.theguardian.com/news/datablog/2011/aug/09/uk-riots-incident-listed-mapped (Accessed: 16 September).

[293] Mail Online (2011) *Railway services across Britain close down for Christmas as strike action begins*. Available at: http://www.dailymail.co.uk/news/article-2078409/Railway-services-Britain-close-Christmas-strike-action-begins.html (Accessed: 4 October).

[294] BBC (2013a) *France air traffic control strike hits Europe flights*. Available at: http://www.bbc.co.uk/news/world-europe-22870781 (Accessed: 1 October).

Table 33: Data for assessing the hazard to infrastructures caused by industrial action.

Data	Details	
Likelihood/frequency of strikes within the UK	**Description:**	Data reporting the frequency of strikes in the UK has been found, though the data is only broken down to industrial sectors, a scale which is not fully suitable for a detailed analysis of this as a hazard. Table 34 shows a snap shot of this data for strikes between 2006-2012.
	Age:	Current
	Resolution:	National/Regional
	Coverage:	Britain
	Data type:	CSV
	Availability:	Free to download http://www.ons.gov.uk/ons/publications/re-reference-tables.html?edition=tcm%3A77-308802
	License:	Covered under the Open Government License making it free to use for most purposes (commercial or non-commercial.
	Source:	Office for National Statistics
	URL:	http://www.ons.gov.uk/ons/rel/bus-register/labour-disputes/annual-article-2012/index.html
	Email:	mark.williams@ons.gsi.gov.uk
Likelihood/rate of strikes outside the UK	**Description:**	Strike data similar to that provided by the ONS (see above) is also available for most countries in Europe.
	Age:	Current
	Resolution:	National
	Coverage:	World
	Data type:	CSV/Excell
	Availability:	Free to download: http://www.ilo.org/ilostat/faces/home/statisticaldata/bulk-download?_adf.ctrl-state=1cl4tdf1sp_105&clean=true&_afrLoop=330325145642573
	License:	A license must be request for reproduction and commercial use of the data/website content.
	Source:	International Labour Organisation
	URL:	http://www.ilo.org/global/lang--en/index.htm
	Email:	inform@ilo.org
Impact of strikes	**Description:**	No data source found.

Table 34: An extract of data from the Office for National Statistics strike data between 2006 and 2012[295].

Year	Working days lost (000s)	Working days lost per 1,000 employees	Workers involved (000s)	Stoppages	Stoppages involving the loss of 100,000 working days or more
2006	755	28	713	158	1
2007	1,041	38	745	142	4
2008	759	28	511	144	2
2009	455	17	209	98	1
2010	365	14	133	92	1
2011	1,390	53	1,530	149	3
2012	249	9	237	131	1

3.2.1.5: AGING INFRASTRUCTURE

Infrastructures which are aging become more susceptible to failures and capacities become reduced as components deteriorate, thus becoming a hazard. To assess the extent of this hazard Table 35 lists those datasets which would typically be required to quantify the risk posed to infrastructure networks by aging infrastructure.

Table 35: Data for assessing aging infrastructure as a hazard.

Data	Details	
Impact of failure	**Description:**	No data source found.
Location of aging infrastructure components	**Description:**	No data source found.
Likelihood of failure	**Description:**	No data source found.

3.2.2: ACCIDENTAL

3.2.2.1: MAJOR INDUSTRIAL ACCIDENTS

Table 36 lists the data required to assess the hazard which major industrial accidents can have on UK infrastructure networks.

Table 36: Data sets for assessing industrial accidents as a hazard to infrastructures.

Data	Details	
Impact of industrial accidents	**Description:**	No data sources found.
Likelihood of industrial accidents	**Description:**	No data sources found.
Location of hazardous industries	**Description:**	No data sources found.

[295] Office for National Statistics (2013) *Labour Disputes - Annual Article , 2012*. [Online]. Available at: http://www.ons.gov.uk/ons/rel/bus-register/labour-disputes/annual-article-2012/art---labour-disputes--annual-article-2012.html#tab-Review-of-1993-–-2012.

3.2.2.2: SEVERE WILDFIRES

Table 37 lists the data which is suggested as being required for assessing the hazard from wildfires for UK critical infrastructure networks, and Table 38 shows the infrastructures which may be affected by these events.

Table 37: Suggested data for assessing the hazard posed by severe wildfires.

Data	Details	
Historic locations of wildfires	**Description:**	Data is available on the types of fires recorded since 2000, though a regional breakdown is only available for more recent years. Figure 27, has been produced by the Office for National Statistics which shows the number of fires per 100000 people[296] exemplifying the type of data available.
	Age:	2011-2012
	Resolution:	County
	Coverage:	Britain
	Data type:	CSV/Spreadsheet
	Availability:	Free to download: https://www.gov.uk/government/publications/fire-statistics-great-britain-2010-to-2011 (see fire statistics Great Britain 2011 to 2012: tables 17a-24, then see table 23b).
	License:	Open Government license – free to use most purposes
	Source:	Office for National Statistics
	URL:	https://www.gov.uk/government/organisations/department-for-communities-and-local-government/series/fire-statistics-great-britain
	Email:	info@ons.gsi.gov.uk
Future likelihood of wildfires	**Description:**	No data sources were found. It is widely reported that there is a direct correlation between drought like conditions and an increase in the frequency of wildfires as seen in Wales[297] and Scotland in 2010-11[298]. Thus the likelihood of wildfires will increase in those areas where the likelihood of droughts increases, though in general their occurrence is expected to increase[299] due to climatic changes.
Disruption caused by wildfires	**Description:**	No possible data sources found.

[296] Statistics for Wales (2013) *Statistical Bulletin: Grassland fires , 2011-12*.
[297] Ibid.
[298] The Scottish Government and Office for National Statistics (2012) *Statistical Bulletin - Fire Statistics Scotland*.
[299] Department for the Environemnt Food and Rural Affairs (2013) *The national adaptation programme: Making the country resilient to a changing climate* (9780108512384).

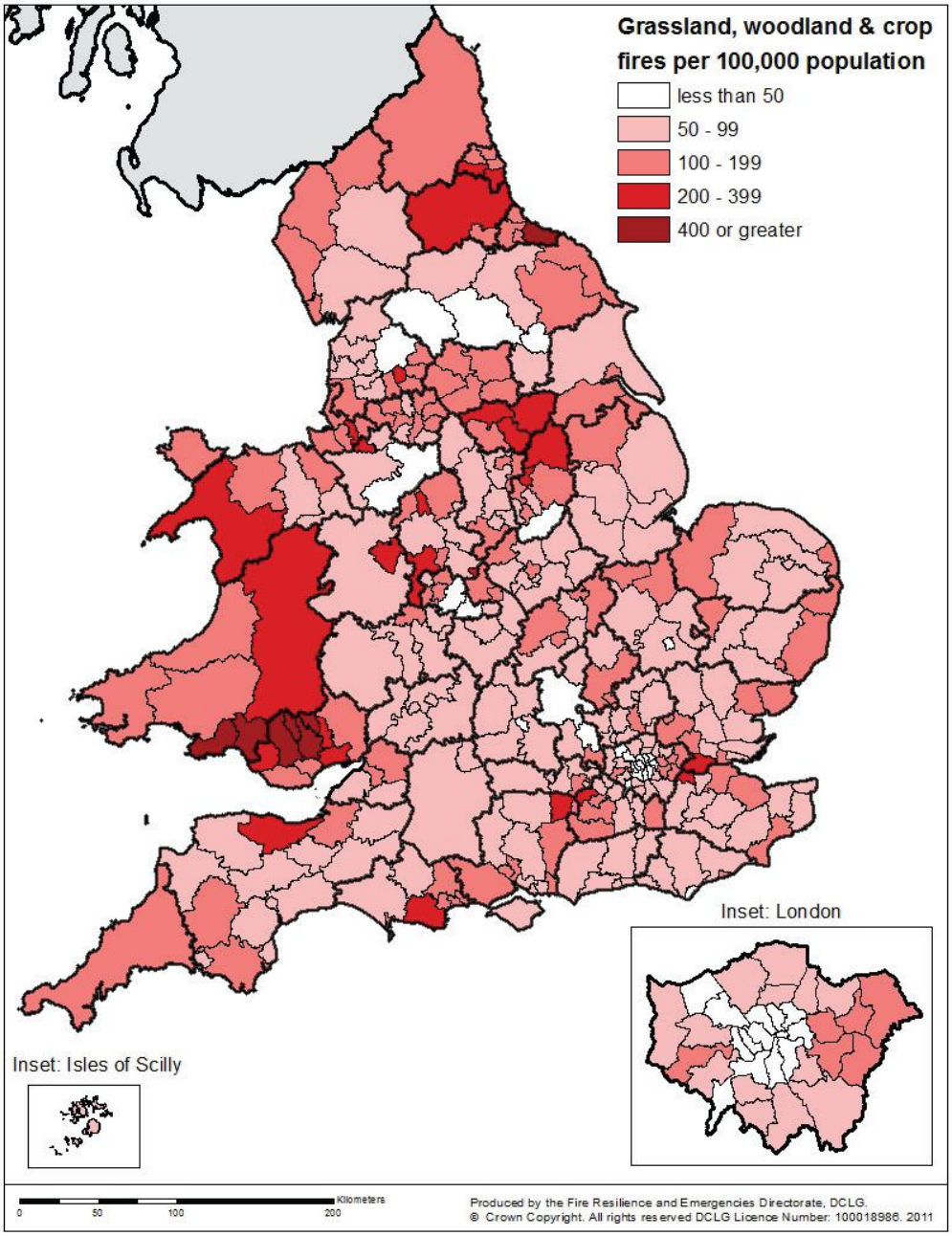

Figure 27: Map showing the distribution of grassland, woodland and crop fires per 100,000 people in England and Wales[300].

[300] Department for Communities and Local Government and Office for National Statistics (2011) *Fire Statistics Great Britain, 2010 - 2011*.

Table 38: Infrastructures likely to be affected directly by severe wildfires.

Infrastructure	Assessment
Gas – distribution network	Southern Gas Networks and Scotland Gas Networks are one of only a minority to specifically address wildfires as a hazard to their network systems[301]. They predict a significant increase in the risk wildfires cause to network components towards the 2050s using current climate projections, more so in southern England than Scotland though. It is expected that wildfires in locations where gas distribution network components are located, particularly installations such as pressure reducing stations, will cause '*considerable damage to major assets and security of supply issues*'. To a lesser extent Wales ad West Utilities acknowledge that wildfires may pose a risk to infrastructure assets, but have only briefly addressed them due to a lack of guidance on the most vulnerable locations to such events[302].
Electricity -	Scottish Power don't explicitly address wildfires as a separate risk, though do acknowledge that such events may cause damage and/or restrict access to parts of the network which are in need of repair[303]. This may then lead to longer outages for customers than expected. However as this is not assessed as hazard to the network as with other climate change impacts, little thought has been given to how these extreme events may change in scale or frequency over time.
Roads	The Highways Agency predict that there may be an increase in the number of incidents due to smoke from wildfires drifting across they managed motorway network, though no scale is given[304].

[301] Southern Gas Networks and Scotland Gas Networks
[302] Wales and West Utilities
[303] ScottishPower Engery Networks (2011) *Climate Change Adaption Report*.
[304] Highways Agency

SECTION 4: REFERENCES

American Society of Civil Engineers (2009) *Report Card for America's Infrastructure*. Available at: https://apps.asce.org/reportcard/2009/grades.cfm (Accessed: 14 August).

American Society of Civil Engineers (2013) *2013 Report Card for America's Infrastructure*. Available at: http://www.infrastructurereportcard.org/ (Accessed: 14 August).

Australian Geographic (2011) *The worst bushfires in Australia's history*. Available at: http://www.australiangeographic.com.au/journal/worst-bush-fires-in-Australias-history.htm (Accessed: 20 August).

BBC (2000) *Ration warning over fuel panic*. Available at: http://news.bbc.co.uk/1/hi/uk/932207.stm (Accessed: October 14).

BBC (2002a) *Fire strike's embers burn on*. Available at: http://news.bbc.co.uk/1/hi/uk/2577465.stm (Accessed: 20 August).

BBC (2002b) *Firefighters go on strike*. Available at: http://news.bbc.co.uk/1/hi/uk/2465745.stm (Accessed: 20 August).

BBC (2003) *1953 Floods - Facts and Figures*. Available at: http://www.bbc.co.uk/lincolnshire/asop/places/floods/floods_facts.shtml (Accessed: 24 September).

BBC (2004) *The Village the Collapsed into the Sea*. Available at: http://www.bbc.co.uk/insideout/southwest/series1/hallsands.shtml (Accessed: 15 August).

BBC (2005) *Massive blaze rages at fuel depot*. Available at: http://news.bbc.co.uk/1/hi/uk/4517962.stm (Accessed: 20 August).

BBC (2007a) *Californians flee as fires rage*. Available at: http://news.bbc.co.uk/1/hi/7055721.stm (Accessed: 20 August).

BBC (2007b) *Drains fail in Hull*. [Online] Available at: http://news.bbc.co.uk/1/hi/uk/7449188.stm.

BBC (2008) *Earthquake felt across much of UK*. Available at: http://news.bbc.co.uk/1/hi/7266136.stm (Accessed: 20 August).

BBC (2010) *Student tuition fee protest ends with 153 arrests*. Available at: http://www.bbc.co.uk/news/education-11877034 (Accessed: 19 August).

BBC (2011a) *England riots: Maps and timeline*. Available at: http://www.bbc.co.uk/news/uk-14436499 (Accessed: 19 August).

BBC (2011b) *New Zealand earthquake: 65 dead in Christchurch*. Available at: http://www.bbc.co.uk/news/world-asia-pacific-12533291 (Accessed: 20 August).

BBC (2011c) *Swinley Forest fire 'largest in Berkshire's history'*. Available at: http://www.bbc.co.uk/news/uk-england-berkshire-13292400 (Accessed: 20 August).

BBC (2012a) *North Circular partially reopens after burst main flood*. Available at: http://www.bbc.co.uk/news/uk-england-london-19499571 (Accessed: 19 August).

BBC (2012b) *Teachers to strike over pay and conditions*. Available at: http://www.bbc.co.uk/news/education-19519839 (Accessed: 20 August).

BBC (2013a) *France air traffic control strike hits Europe flights*. Available at: http://www.bbc.co.uk/news/world-europe-22870781 (Accessed: 1 October).

BBC (2013b) *Herne Hill properties flooded after burst water main*. Available at: http://www.bbc.co.uk/news/uk-england-london-23598335 (Accessed: 19 August).

BBC (2013c) *Post Office workers strike over bank holiday weekend*. Available at: http://www.bbc.co.uk/news/business-23732088 (Accessed: 20 August).

BBC (2013d) *Texas Waco fertiliser plant causes many casualties*. Available at: http://www.bbc.co.uk/news/world-us-canada-22195495 (Accessed: 20 August).

Beniston, M. (2004) 'The 2003 heat wave in Europe: A shape of things to come? An analysis based on Swiss climatological data and model simulations', *Geophysical Research Letters*, 31.

Benzie, M., Harvey, A., Burningham, K., Hodgson, N. and Siddiqi, A. (2011) *Vulnerability to heatwaves and drought: Case studies of adaptation to climate change in south-west England*.

Black and Veatch (2013) *Risks of Aging Infrastructure*. Available at: http://bv.com/Home/news/thought-leadership/security-and-risk-management-issues/risks-of-aging-infrastructure (Accessed: 14 August).

British Geological Survey (2011) *Tsunami or meteotsunami?* Available at: http://www.bgs.ac.uk/research/highlights/2011/tsunamiSWEngland2011.html (Accessed: 18 September).

British Geological Survey (2012a) *Coastal Erosion*.

British Geological Survey (2012b) *Volcanic Hazards*.

British Geological Survey (2013a) *Aye yesterday's earthquakes tomorrow's disasters?* Available at: http://www.bgs.ac.uk/research/earthquakes/yesterdaysearthquakes.html?src=sfb (Accessed: 18 September).

British Geological Survey (2013b) *BGS National Landslide Database*. Available at: http://www.bgs.ac.uk/science/landUseAndDevelopment/landslides/NLD.html (Accessed: 15 August).

British Geological Survey (2013c) *Climate Change and Coastal Erosion*. Available at: http://www.bgs.ac.uk/discoveringGeology/climateChange/general/coastalErosion.html (Accessed: 15 August).

British Geological Survey (2013d) *Coastal erosion at Happisburgh, Norfolk*. Available at: http://www.bgs.ac.uk/landslides/happisburgh.html (Accessed: 15 August).

British Geological Survey (2013e) *Could a Tsunami hit the British Isles?* Available at: http://www.bgs.ac.uk/research/earthquakes/BritishTsunami.html (Accessed: 2 September).

British Geological Survey (2013f) *Earthquake intensity*. Available at: http://www.bgs.ac.uk/discoveringGeology/hazards/earthquakes/intensity.html (Accessed: 2 September).

British Geological Survey (2013g) *Edale Valley, Derbyshire*. Available at: http://www.bgs.ac.uk/products/geosure/derbyshire_example.html (Accessed: 16 September).

British Geological Survey (2013h) *Geoelectric Field Monitoring*. Available at: http://www.geomag.bgs.ac.uk/research/electric_field.html (Accessed: 24 September).

British Geological Survey (2013i) *GeoSure*. Available at: http://www.bgs.ac.uk/products/geosure/ (Accessed: 16 September).

British Geological Survey (2013j) *Hallsands landslide, South Devon*. Available at: http://www.bgs.ac.uk/landslides/hallsands.html (Accessed: 15 August).

British Geological Survey (2013k) *Increased Incidence of Landslides in 2012*. Available at: http://www.bgs.ac.uk/landslides/November2012.html (Accessed: 15 August).

British Geological Survey (2013l) *Landslides (slope instability)*. Available at: http://www.bgs.ac.uk/products/geosure/landslides.html (Accessed: 24 September).

British Geological Survey (2013m) *National Land Slide Database*. Available at: http://www.bgs.ac.uk/science/landUseAndDevelopment/landslides/NLD.html (Accessed: 16 September).

British Geological Survey (2013n) *A Revised Seismic Hazard Map for the UK*. Available at: http://news.bbc.co.uk/1/hi/7266136.stm (Accessed: 20 August).

British Geological Survey (2013o) *Shrink-Swell Hazard Potential Mapping*. Available at: http://www.bgs.ac.uk/science/landUseAndDevelopment/shallow_geohazards/hazardPotentialMapping.html (Accessed: 15 August).

British Geological Survey (2013p) *Significant British Earthquakes*. Available at: http://www.earthquakes.bgs.ac.uk/earthquakes/UKsignificant/index.html (Accessed: 20 August).

British Geological Survey (2013q) *UK Historical Earthquake Database*. Available at: http://quakes.bgs.ac.uk/historical/index.html (Accessed: 18 September).

Brooker, P. (2010) 'Fear in a Handful of Dust: Aviation and the Icelandic Volcano', *Significance* 3, pp. 112-115.

Cabinet Office (2008a) *National Risk Register*. London.

Cabinet Office (2008b) *The Pitt Review: Learning Lessons from the 2007 Floods*.

Cabinet Office (2010) *A Strong Britain in an Age of Uncertainty: The National Security Strategy*. London.

Cabinet Office (2011) *Keeping the Country Running: Natural Hazards and Infrastructure*.

Cabinet Office (2012) *National Risk Register of Civil Emergencies*. London.

Cabinet Office (2013) *National Risk Register of Civil Emergencies*. London.

Canadian Energy Issues (2012) *Ice-ravaged electricity transmission towers* [Photograph]. Available at: http://canadianenergyissues.com/2012/11/08/cities-and-power-revisiting-smiths-division-of-labour/.

Centre for Ecology and Hydrology (2013) *What is a drought?* Available at: http://www.ceh.ac.uk/data/nrfa/nhmp/whatisadrought.html (Accessed: 24 September).

Centre for Environmental Data Archival (2013) *Met Office Integrated Data Archive System (MIDAS) Land and Marine Surface Stations Data (1853-current)*. Available at: http://badc.nerc.ac.uk/view/badc.nerc.ac.uk__ATOM__dataent_ukmo-midas (Accessed: 11 September).

Centrica Energy (2011) *Climate Change Adaption Report*.

Civil Aviation Authority (2013) *Assessing the dangers of volcanic ash*. Available at: http://www.caa.co.uk/default.aspx?catid=2011&pagetype=90&pageid=12641 (Accessed: 24 September).

CNN (2003) *New York reduces 9/11 death toll by 40*. Available at: http://edition.cnn.com/2003/US/Northeast/10/29/wtc.deaths/ (Accessed: 19 August).

Cranfield University (2013a) *Subsidence and flooding data for the UK insurance industry*. Available at: http://www.landis.org.uk/npd (Accessed: October 14).

Cranfield University (2013b) *Subsidence and flooding data for the UK insurance industry*. Available at: http://www.landis.org.uk/services/npd.cfm (Accessed: 16 September).

Defra Flood Management (2005) *The threat posed by tsunami to the UK*.

Department for Communities and Local Government and Office for National Statistics (2011) *Fire Statistics Great Britain, 2010 - 2011*.

Department for the Environemnt Food and Rural Affairs (2013) *The national adaptation programme: Making the country resilient to a changing climate* (9780108512384).

Dickson, M., Walkden, M. and Hall, J. (2006) *Modelling the impacts of climate change on an eroding coast over the 21st Century*.

Drax Power Limited (2011) *Climate Change Adaption Report*.

E.ON UK Generation (2011) *Climate Change Adaptation*.

Earthquake Engineering Field Investigation Team (2006) *The Indian Ocean Tsunami of 26 December 2004: Mission Findings in Sri Lanka and Thailand*.

EDF Energy (2011) *Report on Adaptation Under the Climate Change Act 2008*.

Environment Agency (2007) *Review of 2007 summer floods*.

Environment Agency (2009) *Flooding in England : A National Assessment of Flood Risk*.

Environment Agency (2010a) *Assessment of Coastal Erosion and Landsliding for the Funding of Coastal Risk Management Projects*.

Environment Agency (2010b) *The Costs of the Summer 2007 Floods in England*.

Environment Agency (2011) *Understanding the risks, empowering communities, building resilience: The national flood and coastal erosion risk management strategy for England*.

Environment Agency (2012) *Review of the 2010-2012 drought and prospects for water resources in 2013*.

Environment Agency (2013a) *Coastal Erosion*. Available at: http://maps.environment-agency.gov.uk/wiyby/wiybyController?topic=coastal_erosion&ep=map&scale=7&lang=_e&layerGroups=default&layerGroupToQuery=1&x=401212.6538&y=651439.0717000004&textonly=off#x=435009&y=567672&lg=1,&scale=7 (Accessed: 17 September).

Environment Agency (2013b) *Coastal Erosion - Shoreline Management Plans*. Available at: http://maps.environment-agency.gov.uk/wiyby/wiybyController?topic=coastal_erosion&x=401751.68715&y=650777.356000001&scale=7&layerGroups=1&location=X:%20401,751.69;%20Y:%20650,777.36&textonly=off&ep=query&lang=_e&page=2 (Accessed: 17 September).

Environment Agency (2013c) *Drought explained*. Available at: http://www.environment-agency.gov.uk/homeandleisure/drought/31783.aspx (Accessed: 5 August).

Environment Agency (2013d) *Environment Agency: our role in managing drought*. Available at: http://www.environment-agency.gov.uk/homeandleisure/drought/138333.aspx (Accessed: 13 August).

Environment Agency (2013e) *Impact on reservoirs of 2007 summer floods*. Available at: http://www.environment-agency.gov.uk/research/library/publications/40515.aspx (Accessed: 24 September).

Environment Agency (2013f) *Is climate change causing an increase in coastal erosion?* Available at: http://www.environment-agency.gov.uk/homeandleisure/107550.aspx (Accessed: 15 August).

Environment Agency (2013g) *Shoreline Management Plans*. Available at: http://www.environment-agency.gov.uk/research/planning/104939.aspx (Accessed: 17 September).

Environment Agency (unknown) *2007 Summer Floods: Reservoir Safety - Learning from Ulley*.

ESO Gas Group Limited (2011) *Climate Change Act Adaptation Risk Assessment and Adaptation Policy*.

European Commission (2013) *Avoiding damage from space debris*. Available at: http://europa.eu/rapid/press-release_MEMO-13-149_en.htm (Accessed: 21/09/2010).

FEMA (2007) *I-35W Bridge Collapse and Response*.

Gatwick Airport Limited (2011) *Climate Change Adaptation Report at Gatwick Airport*.

Glasgow Airport Limited (2011) *Climate Change Adaptation Report for Glasgow Airport*.

Government of Canada (2012) *Geomagnetic Storms - Reducing the Threat to Critical Infrastructure in Canada*. [Online]. Available at: http://www.solarstorms.org/CanadaPipelines.html.

Gurney, I. (2004) *A Wave of Destruction Will Destroy America's East Coast*. Available at: http://rense.com/general56/tsu.htm (Accessed: 16 August).

Hall, J.W., Henriques, J.J. and Nicholls, R.J. (2012) *A Fast Track Analysis of strategies for infrastructure provision in Great Britain: Technical Report*.

Han, S.-R., Rosowsky, D. and Guikema, S. (2013) 'Integrating Models and Data to Estimate the Structural Reliability of Utility Poles During Hurricanes.', *Risk analysis : an official publication of the Society for Risk Analysis*.

Heathrow Airport Limited (2011) *Heathrow Airport Climate Change Adaption Reporting Power Report*.

Heathrow Winter Resilience Enquiry (2011) *Report of the Heathrow Winter Resilience Enquiry*.

Highways Agency (2011) *Highways Agency Climate Change Risk Assessment*.

HM Government (2006) *Report of the Official Account of the Bombings in London on 7th July 2005*.

HM Government (2011) *CONTEST: The United Kingdom's Strategy for Countering Terrorism*.

HM Government (2012) *UK Climate Change Risk Assessment: Government Report*. London: The Stationary Office.

HM Government (2013) *Keeping the UK safe in cyber space*. Available at: https://www.gov.uk/government/policies/keeping-the-uk-safe-in-cyberspace (Accessed: 18 September).

HM Treasury and Infrastructure UK (2010) *National Infrastructure Plan 2010*.

Hollingshead, M. (2007) *Northwest Missouri Ice Storm* [Photograph]. [Online] Available at: http://www.extremeinstability.com/faves/slides/wi-d9530.html (Accessed: 25 September 2013).

Houses of Parliment (2010) *Space Weather*.

Hurrell, A. (2013) *Dramatic photograph of Happisburgh's erosion timebomb*. Available at: http://www.edp24.co.uk/news/environment/dramatic_photograph_of_happisburgh_s_erosion_timebomb_1_1985929 (Accessed: 15 August).

Industrial Control Systems Cyber Emergency Response Team (2011) *Incident Response Summary Report*.

Institution of Civil Engineers (2009) *The State of the Nation: Defending Critical Infrastructure*.

Institution of Civil Engineers (2012) *The State of the Nation: Water 2012*.

Institution of Mechanical Engineers *Climate Change: Adapting to the Inevitable?*

InterGen (2011) *Climate Change Adaptation Report*.

International Power plc (2011) *International Power Climate Change Adaptation Report*.

IWS (2005) *Impact of September 2000 Fuel Price Protests on UK Critical Infrastructure*. Available at: http://www.iwar.org.uk/cip/resources/PSEPC/fuel-price-protests.htm (Accessed: 20 August).

Knowledge for Wildfire (2012) *What are wildfires?* Available at: http://www.kfwf.org.uk/ (Accessed: 20 August).

Landmark (2013) *A Guide to Subsidence: Risk Assessment and Risk Management against Soil Shrinkage*.

Lloyd's (2010) *Space Weather: Its impact on Earth and implications for businesses*.

Local Government Employers (2010) *Industrial action ballots and notice to employers*. Available at: http://www.lge.gov.uk/lge/core/page.do?pageId=119721 (Accessed: 20 August).

London Assembly (2003) *London's Water Supply*.

London Luton Airport (2011) *Climate Change Adaptation Report*.

Mail Online (2001) *Massive main backlog after postal strikes end*. Available at: http://www.dailymail.co.uk/news/article-48994/Massive-mail-backlog-postal-strikes-end.html (Accessed: 20 August).

Mail Online (2011) *Railway services across Britain close down for Christmas as strike action begins*. Available at: http://www.dailymail.co.uk/news/article-2078409/Railway-services-Britain-close-Christmas-strike-action-begins.html (Accessed: 4 October).

Mail Online (2012a) *Solar storms raised to 'high priority' risk in Britain as concerns mount over dangers to communications and power grids*. Available at: http://www.dailymail.co.uk/sciencetech/article-2117192/Solar-storms-volcanoes-added-official-list-threats-Britain-alongside-floods-flu-terrorism.html (Accessed: 24 September).

Mail Online (2012b) *Thunderstorms in Newcastle upon-Tyne*. [Online] Available at: http://www.dailymail.co.uk/news/article-2165944/UK-floods-153-lightning-strikes-minute-hailstones-size-GOLF-BALLS-hits-Midlands.html.

Mail Online (2013a) *Fireball from outer space: 1,000 injured as 40-ton meteor travelling at 33,000mph explodes over a terrified town*. Available at: http://www.dailymail.co.uk/news/article-2279020/Russian-meteor-shower-Fireball-outer-space-1-000-injured-40-ton-meteor-travelling-33-000mph-explodes-terrified-town.html (Accessed: 15 August).

Mail Online (2013b) *Meteor that crashed in Russia was part of a 656-foot wide asteroid that broke off during its orbit around Earth*. Available at: http://www.dailymail.co.uk/sciencetech/article-2387639/Meteor-crashed-Russia-656-foot-wide-asteroid-broke-orbit-Earth.html (Accessed: 15 August).

Marusek, J.A. (2007) 'Solar Storm Threat Analysis', *Impact*.

Mazzocchi, M., Hansstein, F. and Ragona, M. (2010) 'The 2010 Volcanic Ash Cloud and its Financial Impact on the European Airline Industry', *CESifo Forum* 11, pp. 92-100.

McColl, L., Palin, E.J., Thornton, H.E., Sexton, D.M.H., Betts, R. and Mylne, K. (2013) 'Assessing the potential impact of climate change on the UK's electricity network', *Climate Change*, 14(1), pp. 821-835.

McEvoy, D., Ahmed, I. and Mullett, J. (2012) 'The impact of the 2009 heat wave on Melbourne's critical infrastructure', *Local Environment*, 17(8), pp. 783-796.

McLean, I. (2007) *Aberfan: No End of a Lesson*.

Met Office (2006) *The generation of monthly gridded datasets for a range of climatic variables over the United Kingdom*. [Online]. Available at: http://www.metoffice.gov.uk/climatechange/science/downloads/Monthly_gridded_datasets_UK.pdf.

Met Office (2010) *Number of droughts likely to increase under climate change*. Available at: http://www.metoffice.gov.uk/news/releases/archive/2010/droughts-to-increase (Accessed: 18 September).

Met Office (2011a) *Case Study: Winter 2009/10*. Available at: http://www.metoffice.gov.uk/about-us/who/how/case-studies/winter09-10 (Accessed: 12 August).

Met Office (2011b) *Climate : Observations , projections and impacts*.

Met Office (2011c) *Meterological factors influencing forest fire risk under climate change mitigation*.

Met Office (2012) *Heavy Rainfall/Flooding in the Lake District, Cumbria - November 2009*. Available at: http://www.metoffice.gov.uk/climate/uk/interesting/nov2009 (Accessed: 9 August).

Met Office (2013a) *Climate - Average maps*. Available at: http://www.metoffice.gov.uk/public/weather/climate/newcastle-upon-tyne-youth-hostel#?tab=climateMaps&region=uk (Accessed: 10 September).

Met Office (2013b) *Climate Change: Winter 2009/10*. Available at: http://www.metoffice.gov.uk/climate/uk/2010/winter.html (Accessed: 12 August).

Met Office (2013c) *Heat-Health Watch*. Available at: http://www.metoffice.gov.uk/public/weather/heat-health/ (Accessed: 5 August).

Met Office (2013d) *Heatwave*. Available at: http://www.metoffice.gov.uk/learning/learn-about-the-weather/weather-phenomena/heatwave (Accessed: 13 September).

Met Office (2013e) *National Severe Weather Warnings - United Kingdom*. Available at: http://www.metoffice.gov.uk/public/weather/warnings/?regionName=uk (Accessed: 12 August).

Met Office (2013f) *Severe Gales*. Available at: http://www.metoffice.gov.uk/weather/uk/advice/storm.html.

Met Office (2013g) *Snow and low temperatures - December 2009 to January 2010*. Available at: http://www.metoffice.gov.uk/climate/uk/interesting/jan2010.

Met Office (2013h) *Space Weather*. Available at: http://www.metoffice.gov.uk/publicsector/emergencies/space-weather (Accessed: 9 August).

Met Office (2013i) *UK Snow*. Available at: http://www.metoffice.gov.uk/learning/snow/snow-in-the-uk (Accessed: 12 August).

Met Office (2013j) *Volcanic Ash Advisory Centres*. Available at: http://www.metoffice.gov.uk/aviation/vaac (Accessed: 23 September).

Met Office (2013k) *What is a heat wave?* Available at: http://metofficenews.wordpress.com/2013/07/04/what-is-a-heat-wave/ (Accessed: 5 August).

MITRE (2011) *Impacts of Severe Space Weather on the Electric Grid*.

Musson, R.M.W. (2008) 'The Case for Large M> 7 Earthquakes Felt in the UK in Historical Times', p. 24.

Musson, R.M.W. and Sargeant, S.L. (2007) *Eurocode 8 seismic hazard zoning maps for the UK*.

NASA (2009) *The Day the Sun Brought Darkness*. Available at: http://www.nasa.gov/topics/earth/features/sun_darkness.html (Accessed: 9 August).

NASA (2013) *Asteroid and Comet Impact Hazards*. Available at: http://impact.arc.nasa.gov/intro_faq.cfm (Accessed: 15 August).

National Centre for Social Research (2011) *The August riots in England: Understanding the involvement of young people*.

National Commission on Terrorist Attacks upon the United States (2004) *The 9/11 Commission Report*.

National Grid Electricity Transmission plc (2010) *Climate Change Adaptation Report National Grid Electricity ransmission plc*.

National Grid Gas plc (2010) *Climate Change Adaptation Report National Grid Gas*.

National Oceanic and Atmospheric Administration (2013) *Solar Cycle Progression*. Available at: http://www.swpc.noaa.gov/SolarCycle/ (Accessed: 9 August).

National Soil Resources Institute (2008) *Sample Soil Report*. [Online]. Available at: http://www.landis.org.uk/services/downloads/Full_5km.pdf.

National Transportation Safety Board (2007) *Collapse of I-35W Highway Bridge Minneapolis, Minnesota*.

National Weather Service (2013) *Space Weather Prediction Centre*. Available at: http://www.swpc.noaa.gov/ (Accessed: 12 August).

Natural Environment Research Council *FREE: Flood Risk from Extreme Events*.

Network Rail (2011) *Network Rail Climate Change Adaption Report*.

Network Rail (2012) *North east rail repair continues over weekend*. Available at: http://www.networkrailmediacentre.co.uk/News-Releases/NORTH-EAST-RAIL-REPAIR-CONTINUES-OVER-WEEKEND-1af2.aspx (Accessed: October 14).

Newcastle City Council (2013) *Summer 2012 Flooding*. Available at: http://www.newcastle.gov.uk/environment/environment/june-28-recent-flooding.

Northern Gas Networks (2011) *Northern Gas Networks Climate Change Adaptation Report*.

Northumberland Gazette (2013) *Landslide road will not re-open for a year*. Available at: http://www.northumberlandgazette.co.uk/news/local-news/landslide-road-will-not-re-open-for-a-year-1-5432455 (Accessed: 15 August).

Office for National Statistics (2013) *Labour Disputes - Annual Article , 2012*. [Online]. Available at: http://www.ons.gov.uk/ons/rel/bus-register/labour-disputes/annual-article-2012/art---labour-disputes--annual-article-2012.html#tab-Review-of-1993-–-2012.

OFWAT (2007) *Water and sewerage services during the summer 2007 floods*.

Owen, B. (2011) 'UK tsunami risk: an overview of the evidence'.

Parllamentary Office of Science and Technology (2010) *Space Weather*.

Promap (2013a) *British Geological Society Flood Data*. Available at: http://www.promap.co.uk/pro_geodata_geological.php (Accessed: 11 September).

Promap (2013b) *RMS Flood Data*. Available at: http://www.promap.co.uk/pro_geodata_rms.php. (Accessed: 11 September).

Risk Management Solutions (2003) *1953 U.K. Floods: 50 Year Retrospective*.

Risk Management Solutions (2007) *The Great Storm of 1987: 20-Year Retrospective*.

Rossi, A. and Valsecchi, G.B. (2006) 'Collision risk against space debris in Earth orbits', *Celestial Mechanics and Dynamical Astronomy*, 95, pp. 345-356.

Royal Academy of Engineering (2013) *Extreme space weather : impacts on engineered systems and infrastructure* (1903496969).

Royal Institute of British Architects (2013) *Flooding: Flooding Explained*. Available at: http://www.architecture.com/findoutabout/sustainabilityandclimatechange/flooding/floodingexplained.aspx#.UftxXb5wa1s.

RWE npower (2011) *Climate Change Adaptation Report*.

Scottish and Southern Energy Group (2011) *SSE Generation Climate Change Adaptation Report*.

Scottish Environment Protection Agency (2011) *The National Flood Risk Assessment*.

Scottish Environment Protection Agency (2013) *Indicative River and Coastal Flooding Map*. Available at: http://www.sepa.org.uk/flooding/flood_extent_maps/view_the_map.aspx (Accessed: 11 September).

Scottish Natural Heritage (1997) *Coastal erosion and defence*. Available at: http://www.snh.org.uk/publications/on-line/advisorynotes/73/73.html (Accessed: 11 September).

ScottishPower (2011) *ScottishPower Generation Climate Change Adaption Report*.

ScottishPower Engery Networks (2011) *Climate Change Adaption Report*.

SCRIPT (2013) *Repairing the city's state highway network*. Available at: http://strongerchristchurch.govt.nz/work/roads/repairing-the-city-state-highway-network (Accessed: October 14).

South West Water (2007) *Exeter contamination incident of February 2006*. Available at: http://www.southwestwater.co.uk/index.cfm?articleid=3894 (Accessed: 20 August).

Southern Gas Networks and Scotland Gas Networks (2011) *Southern Gas Networks and Scotland Gas Networks Climate Change Adaptation Report*.

Stansted Airport Limited (2011) *London Stansted Airport Climate Change Adaptation Plan*.

Statistics for Wales (2013) *Statistical Bulletin: Grassland fires , 2011-12*.

Stuart-Menteth, A. (2007) *U.K. Summer 2007 Floods*.

Synolakis, C., Okal, E. and Bernard, E. (2005) 'The Megatsunami of December 26, 2004', *The Bridge*, 35(2), pp. 26-35.

Thames Water (2013) *Why we are replacing pipes*. Available at: http://www.thameswater.co.uk/about-us/2690.htm (Accessed: 14 August).

The Coal Authority (2013a) *Mining and Ground Stability in Britain*. Available at: http://coal.decc.gov.uk/en/coal/cms/services/reports/mining_report/mining_report.aspx (Accessed: 16 September).

The Coal Authority (2013b) *Protecting the Public in Coal Mining Areas*. Available at: http://coal.decc.gov.uk/en/coal/cms/services/safety/safety.aspx (Accessed: 16 September).

The Dallas Morning News (2013) *Analysis: West Fertilizer report details sequence of a catastrophe*. Available at: http://www.dallasnews.com/news/west-explosion/headlines/20130516-analysis-west-fertilizer-report-details-sequence-of-a-catastrophe.ece (Accessed: 20 August).

The Geological Society (2013) *Effusive and Explosive Eruptions*. Available at: http://www.geolsoc.org.uk/ks3/gsl/education/resources/rockcycle/page3599.html (Accessed: 12 August).

The Geological Society (unknown) 'The Earth in our Hands: How Geoscientists Serve and Protect the Public - Coastal Erosion'.

The Guardian (2009) *Man dies during G20 protests in London*. Available at: http://www.theguardian.com/world/2009/apr/02/g20-protests-man-dies-london (Accessed: 19 August).

The Guardian (2010) *Cockermouth, a year on from the floods*. Available at: http://www.theguardian.com/society/2010/nov/16/cockermouth-cumbria-floods-first-anniversary (Accessed: 9 August).

The Guardian (2011) *UK riots: every verified incident.* Available at: http://www.theguardian.com/news/datablog/2011/aug/09/uk-riots-incident-listed-mapped (Accessed: 16 September).

The Guardian (2012) *Hostile states using cyberwarfare to attack UK infrastructure*. Available at: http://www.theguardian.com/technology/2012/dec/03/hostile-states-cyberwarfare-uk-infrastructure (Accessed: 19 August).

The Guardian (2013a) *Civil servants strike over cuts*. Available at: http://www.theguardian.com/politics/2013/jun/02/civil-servants-strike-over-cuts (Accessed: 20 August).

The Guardian (2013b) *Every meteorite fall on earth mapped*. Available at: http://www.theguardian.com/news/datablog/interactive/2013/feb/15/meteorite-fall-map (Accessed: 11 September).

The Independent (2012) *UK's power and water infrastructure 'at risk of cyber attacks'*. Available at: http://www.independent.co.uk/news/uk/home-news/uks-power-and-water-infrastructure-at-risk-of-cyber-attacks-8375958.html (Accessed: 19 August).

The Meteoritical Society (2013) *The Meteoritical Society*. Available at: http://meteoriticalsociety.org/ (Accessed: 11 September).

The New York Times (1988) *The Breath of the Black Dragon in Russia and China*. Available at: http://www.nytimes.com/1988/10/01/opinion/the-breath-of-the-black-dragon-in-russia-and-china.html?pagewanted=1 (Accessed: 20 August).

The Scottish Government and Office for National Statistics (2012) *Statistical Bulletin - Fire Statistics Scotland*.

The Telegraph (2000) *Panic buyers start to strip supermakets*. Available at: http://www.telegraph.co.uk/news/uknews/1355259/Panic-buyers-start-to-strip-supermarkets.html (Accessed: October 14).

The Telegraph (2007) *Upton on Severn, Worcs, is surrounded by water*. [Online] Available at: http://www.telegraph.co.uk/news/uknews/1558232/Floods-worsen-as-rivers-continue-to-rise.html.

The Telegraph (2009) *Cumbria Floods*. [Online] Available at: http://www.telegraph.co.uk/topics/weather/6616396/Cumbria-floods-wife-of-hero-policeman-killed-in-flood-says-he-died-helping-others.html.

The Telegraph (2012) *England cut off from Scotland as rail lines shut off by flooding and landslides*. Available at: http://www.telegraph.co.uk/topics/weather/9362927/England-cut-off-from-Scotland-as-rail-lines-shut-off-by-flooding-and-landslides.html#disqus_thread (Accessed: October 14).

The Telegraph (2013a) *Teachers to strike over pay, pensions and workload*. Available at: http://www.telegraph.co.uk/education/10175654/Teachers-to-strike-over-pay-pensions-and-workload.html (Accessed: 20 August).

The Telegraph (2013b) *Tsunami could swamp Cornwall, scientists warn*. [Online]. Available at: http://www.telegraph.co.uk/science/science-news/10184443/Tsunami-could-swamp-Cornwall-scientists-warn.html.

Think Quest (2005) *Tsunami: Magnitude of Terror - Damage to Infrastructure*. Available at: http://library.thinkquest.org/04oct/01724/effects_infra.html (Accessed: 16 August).

Transport Committee (2011) *Keeping the UK moving: The impact on transport of the winter weather in December 2010*. London: The Stationary Office.

Transport for London (2011) *Providing Transport Services Resilient to Extreme Weather and Climate Change*.

Transport Scotland (2013) *Environmental Assessment (Scotland) Act 2005 Scottish Ferry Services Draft Plan for Consultation Strategic Environmental Assessment*. Available at: http://www.transportscotland.gov.uk/strategy-and-research/publications-and-consultations/j210731-07.htm (Accessed: 26 September).

U.S. Department of Energy (2005) *Department of Energy's Hurricane Response Chronology*.

U.S. Geological Survey (2001) *Socioeconomic and Environmental Impacts of Landslides in the Western Hemisphere*. Available at: http://pubs.usgs.gov/of/2001/ofr-01-0276/ (Accessed: 15 August).

U.S. Geological Survey (2013) *Worldwide Overview of Large Landslides of the 20th and 21st Centuries*. Available at: http://landslides.usgs.gov/learning/majorls.php (Accessed: 15 August).

U.S. Government (2006) *The Federal Response to Hurricane Katrina: Lessons Learned*.

UCL Institute for Risk and Disaster Reduction (2010) *Volcanic Hazard from Iceland: Analysis and implications of the Eyjafjallajokull eruption*.

UK Climate Projections (2012) *UKCP09: Annual data sets*. Available at: http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/available/annual.html (Accessed: October 14).

UK Climate Projections (2013a) *Marine and coastal Storm surge projections*. Available at: http://ukclimateprojections.defra.gov.uk/22569/ (Accessed: 11 September).

UK Climate Projections (2013b) *Online Breifing report 6.3.2 Changes in storm surge*. Available at: http://ukclimateprojections.defra.gov.uk/22907 (Accessed: 1 October).

UK Climate Projections (2013c) *Online Briefing report 5.4 Changes in precipitation*. Available at: http://ukclimateprojections.defra.gov.uk/22751 (Accessed: 22 September).

UK Climate Projections (2013d) *Online climate change projections report Table 1.1*. Available at: http://ukclimateprojections.defra.gov.uk/22914 (Accessed: 11 September).

UK Climate Projections (2013e) *Request Pathway - Storm surge height projections for UK waters*. Available at: http://ukclimateprojections-ui.defra.gov.uk/ui/manual/manual.php?id=6.5 (Accessed: 11 September).

Wales and West Utilities (2011) *Adaptation to Climate Change*.

Ward, S.N. and Day, S. (2001) 'Cumbre Vieja Volcano - Potential Collapse and Tsunami at La Palma, Canary Islands', *Geophysical Research Letters*, 28(17), pp. 3397-3400.

Wik, M., Pirjola, R., Lundstedt, H., Viljanen, A., Wintoft, P. and Pulkkinen, A. (2009) 'Space weather effects in July 1982 and October 2003 and the effects of geomagnetically induced currents on Swedish technical systems', *Annales Geophysicae*, 27, pp. 1775-1787.

World Health Organisation (2005) *Three months after the Indian Ocean earthquake-tsunami report*. Available at: http://www.who.int/hac/crises/international/asia_tsunami/3months/report/en/ (Accessed: 16 August).

World Health Organisation (2013) *Landslides*. Available at: http://www.who.int/hac/techguidance/ems/landslides/en/ (Accessed: 15 August).

Yang, H., Chung, C.Y., Zhao, J. and Dong, Z. (2013) 'A Probability Model of Ice Storm Damages to Transmission Facilities', *IEEE Transactions on Power Delivery*, 28(2), pp. 557-565.