APPENDIX 14-1

Vulnerability Assessment

14 APPENDIX 14.1

14.1.1 VULNERABILITY ASSESSMENT FINDINGS

14.1.2 This appendix presents the detailed assessment and findings of Step2.

STEP 2: CLIMATE VULNERABILITY ASSESSMENT

SENSITIVITY

14.1.3 Based on relevant guidance[1], the climate variables which roads, bridges and cycle and footways (including crossings, signage, etc.) are typically sensitive to are indicated with a tick in **Table 14.1**. Blank cells in the table indicate where the climate variable or climate-related hazard is not relevant to the scheme components.

Table 14.1 - Sensitivity of scheme components

COMPONENT	VARIABLE										
	Rainfall			Temperature			Wind		RH	Soil	
	Annual average	Extreme rainfall	Drought	Annual average	Extreme temp	Solar radiation	Gales	Storms	Annual average	Moisture	Stability
Road	✓	✓	✓		✓	✓	✓	✓		✓	✓
Bridge		✓			✓	✓	✓				✓
Pedestrian and cycle	✓	✓	✓		✓	✓	✓	✓		✓	✓

14.1.4 These variables are used throughout the assessments of sensitivity, exposure and vulnerability. Given the inland location of the scheme, variables associated with sea level and sea temperature are not included in the assessment.

PRECIPITATION

- Roads and cycle/footways are sensitive to high rainfall. An average increase in winter rainfall may cause roads and footways to become flooded due to flooding of local watercourses (fluvial flooding) or surface water flooding (pluvial flooding). Flooding may mean that roads and footways are impassable and cause loss of amenity. Flooding may also cause damage to paved surfaces (leading to increased maintenance requirements).

- Roads, bridges and footways are also sensitive to extreme rainfall events which, in addition to flooding, may also lead to destabilisation of soils and earthworks, potentially leading to temporary or permanent loss of amenity. Any electronic control equipment associated with the bridge will also be sensitive to flooding.
- Roads and footways are also sensitive to low rainfall or drought. Prolonged dry periods may lead to drying out and cracking of earthworks and soils.

TEMPERATURE

- Roads, bridges and footways are sensitive to extreme temperatures. High temperatures may cause damage to paved surfaces, including potential melting and deformation. An increase in solar radiation can also cause more rapid deterioration of materials and associated infrastructure such as signage. Bridges are sensitive to high temperatures which affect thermal expansion joints and increase earth pressures. Fewer incidences of low temperatures will reduce hazards associated with snow and ice such as road damage from freeze thaw events.

WIND

- Bridges are sensitive to high winds which increase wind loading on the structure. High winds and storms can affect the stability of above-ground infrastructure and hasten material degradation. High winds can also cause wind-driven rain infiltration into building materials and surfaces which can increase maintenance costs and operational disruption. High winds also increase risk to bridge users (particularly high sided vehicles) and may lead to temporary closure. Road and footway users may also be sensitive to high winds. Associated infrastructure such as signage or signals could also be damaged by high winds.
- Bridges are also sensitive to storms, particularly the risk of lightning strike. Electronic control equipment associated with bridges is likely to be highly sensitive to lightning strike.

SOILS

- Roads, bridges and footways are all sensitive to soil stability. Soil stability can be reduced as a result of extreme rainfall or prolonged periods of rainfall which can lead to waterlogging, as well as extreme temperatures and drought which can causes soils to dry out and crack. Earthworks and embankments associated with roads, bridges and footways are particularly sensitive to changes in soil stability.
- Water availability can cause a number of impacts to water quality and soils. For example, greater water volumes can increase the mobilisation of pollutants in soils whilst water scarcity can increase the accumulation of chemicals and pollutants which may cause increased salinity and acidification. Sea level rise could also lead to increasing soil salinity. More acidic soils and/or water will increase the deterioration of building materials.

14.1.5 Based on the information described above, literature review and expert opinion, **Table 14.2** outlines the climate sensitivity of the scheme.

Table 14.2 - Sensitivity Assessment

CLIMATE VARIABLE		SENSITIVITY OF SCHEME COMPONENTS		
		ROADS	BRIDGE	PEDESTRIAN AND CYCLE
Precipitation	Annual average rainfall	Low	Not applicable	Low
	Extreme rainfall	Medium	Medium	Medium
	Drought	Medium	Not applicable	Medium

CLIMATE VARIABLE		SENSITIVITY OF SCHEME COMPONENTS		
		ROADS	BRIDGE	PEDESTRIAN AND CYCLE
Temperature	Extreme temperature	Medium	Medium	Medium
	Solar radiation	Low	Low	Low
Wind	Gales and extreme wind events	Medium	High	Medium
	Storms	Low	Not applicable	Low
Soil	Soil moisture	Medium	Not applicable	Medium
	Stability	Medium	Medium	Medium

EXPOSURE

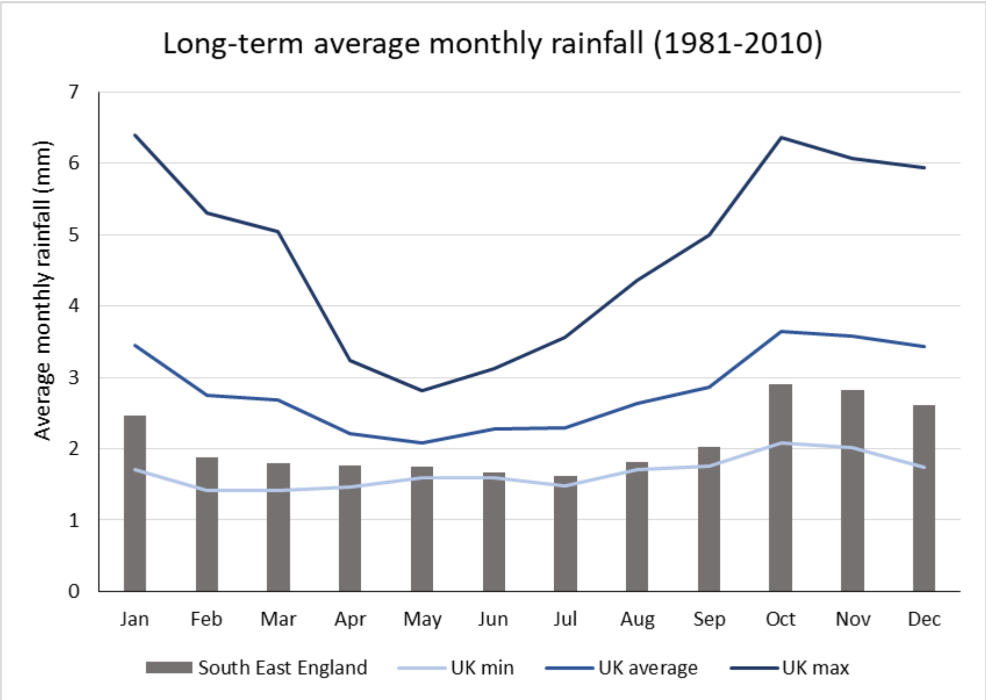
14.1.6 This section considers the exposure of the scheme to current climate and climate change/changes in extreme weather.

CURRENT CLIMATE

14.1.7 The scheme is located in the south east of England which has a warm, dry climate, compared to UK average. Information on long term average observed climate variables over the period 1980 – 2010 is presented below. This information is taken from the UKCP09 report, The Climate of the United Kingdom and Observed Trends[2].

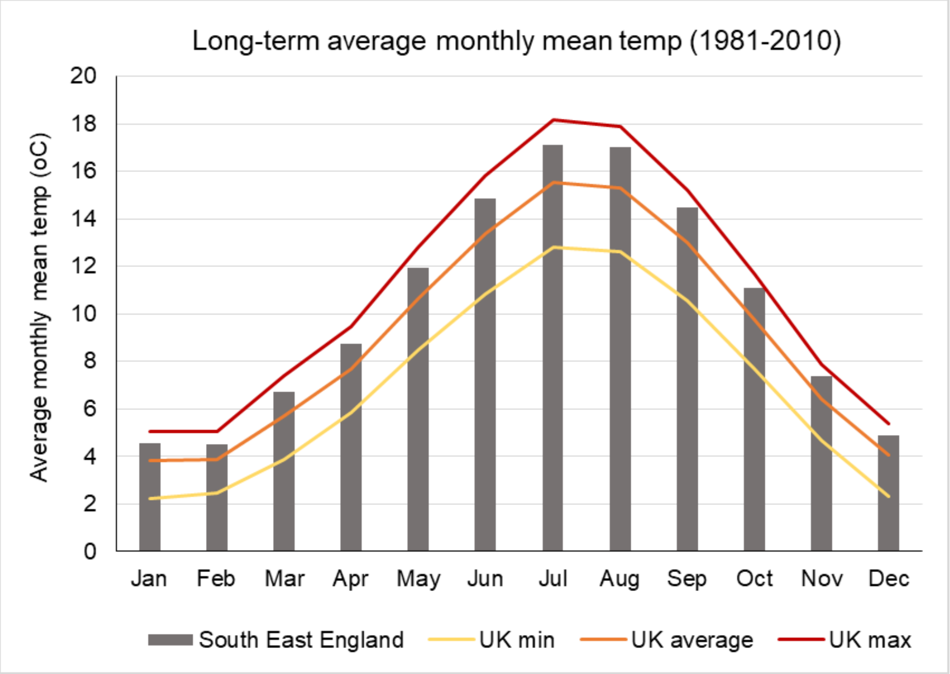
14.1.8 Graph 15.1 shows the long-term average monthly rainfall for the south-east region between 1981 and 2010. It shows that the region is considerably drier than most parts of the UK, with the lowest monthly rainfall in July and the highest in October.

Graph 15.1 - Long Term Average Mean Monthly Rainfall



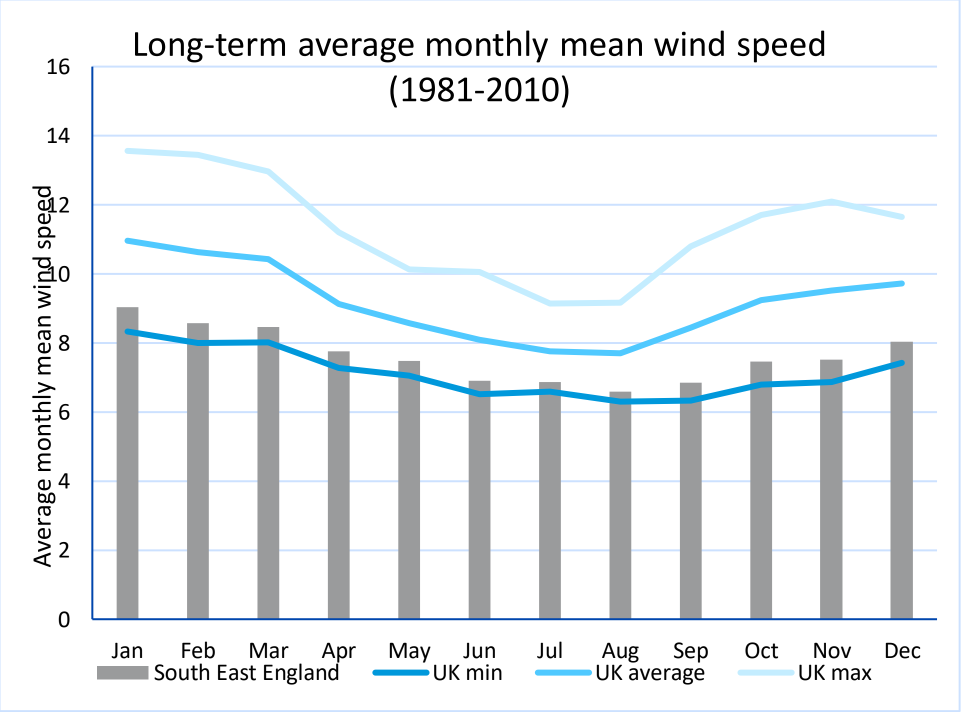
14.1.9 Graph 14.1 shows the long-term average mean monthly temperature for the south-east region between 1980 and 2010. It shows that the region is warmer than the UK average, with July being the warmest month and February being the coldest month.

Graph 14.1 - Long Term Average Mean Monthly Temperature



14.1.10 Graph 14.2 shows the long term average monthly mean wind speed in the south east region between 1981 and 2010. It shows that the region is less windy than the UK average, with highest wind speeds occurring in January and lowest wind speeds occurring in August.

Graph 14.2 - Long Term Average Monthly Mean Wind Speed



PROJECTED CLIMATE

14.1.11 Information on projected climate is taken from the UK Climate Projections 2009. The UK Climate Projections 2009 (UKCP09) are the most up-to-date projections of climate change for the UK. Probabilistic projections of a range of climate variables are presented for different emissions scenarios[3] and for a range of timeslices[4] to the end of the 21st Century. The projections are provided at a resolution of 25 km over land, and as averages for administrative and river basin regions.

14.1.12 Climate change is projected to lead to wetter winters and drier summers, with more extreme rainfall events. UKCP09 suggests that by the 2050s, mean winter precipitation is expected to increase by 19% (50th percentile) and by the 2080s, increase by 30% (50th percentile) under the High emissions scenario. For the summer, by the 2050s, mean summer precipitation is expected to decrease by 19% (50th percentile) and by the 2080s, decrease by 29% (50th percentile), under the High emissions scenario. **Table 14.3** summarises changes in mean winter and summer precipitation for the 2050s and 2080s under the Low, Medium and High emissions scenarios.

Table 14.3 - Projected change in mean summer and winter precipitation (mm) for the 2050s and 2080s under Low, Medium and High emissions scenario

PERIOD		**EMISSIONS SCENARIO**								
		LOW			MEDIUM			HIGH		
		10TH	50TH	90TH	10TH	50TH	90TH	10TH	50TH	90TH
Summer	2050s	-37	-14	+9	-41	-19	+7	-43	-19	+9
	2080s	-39	-15	+13	-48	-23	+7	-57	-29	+5
Winter	2050s	+1	+13	+30	+2	+16	+36	+3	+19	+40
	2080s	+4	+18	+40	+4	+22	+51	+7	+30	+67

14.1.13 In addition to projected changes in seasonal rainfall (i.e. wetter winters and drier summers), it is likely that more rainfall will be delivered by 'intense' events, particularly in winter.

14.1.14 Table 14.4 show the UKCP09 projections for changes in extreme precipitation in the south-east region in the 2050s and 2080s under Low, Medium and High emissions scenarios.

Table 14.4 - Projected change in extreme precipitation variables for the 2050s and 2080s under Low, Medium and High emissions scenario

CHANGE IN VARIABLE		EMISSIONS SCENARIO								
		LOW			MEDIUM			HIGH		
		10TH	50TH	90TH	10TH	50TH	90TH	10TH	50TH	90TH
Wettest day in winter (%)	2050s	-10	+10	+30	+10	+30	+40	+10	+30	+50
	2080s	-10	+30	+50	+10	+30	+50	+10	+30	+60
Wettest day in summer (%)	2050s	-30	-10	+30	-40	-10	+20	-40	-20	+10
	2080s	-30	-10	+30	-50	-20	-10	-50	-20	+20

14.1.16 Snowfall is closely linked with temperature, with falls rarely occurring if the temperature is higher than 4 °C. For snow to lie for any length of time, the temperature normally has to be lower than this. With regards to future changes, rising winter temperatures are likely to reduce the amount of precipitation that falls as snow in winter. UKCP09 projects a reduction of mean snowfall, the number of days when snow falls and heavy snow events by the end of the 21st century. UKCP09 does not provide projections for the nearer-term for snow.

14.1.17 Climate change is projected to lead to hotter summers and warmer winters and fewer extreme low temperate events. UKCP09 suggests that by the 2050s, mean winter temperature in the south-east region is expected to increase by 2.5 ºC (50th percentile) and by the 2080s, increase by 3.7 ºC (50th percentile), under the High emissions scenario. For the summer, by the 2050s, mean summer temperature is expected to increase by 3.1 ºC (50th percentile) and by the 2080s, increase by 4.9 ºC (50th percentile), under the High emissions scenario. **Table 14.5** summarises changes in mean winter and summer precipitation for the 2020s, 2050s and 2080s under the Low, Medium and High emission scenarios.

Table 14.5 - Projected change in mean summer and winter mean temperature (°C) for the 2050s and 2080s under Low, Medium and High emissions scenario

PERIOD		EMISSIONS SCENARIO								
		LOW			MEDIUM			HIGH		
		10TH	50TH	90TH	10TH	50TH	90TH	10TH	50TH	90TH
Summer	2050s	1.4	2.6	4.3	1.3	2.8	4.6	1.4	3.1	5.2
	2080s	1.4	3.0	5.1	2.0	3.9	6.5	2.6	4.9	8.1
Winter	2050s	0.9	2.0	3.1	1.1	2.2	3.4	1.4	2.5	3.8
	2080s	2.0	2.6	4.0	1.6	3.0	4.7	2.0	3.7	5.7

14.1.18 In addition to changes in seasonal average temperatures, it is likely that there will be more extreme temperature events. By the 2050s, projections for daily maximum summer temperature for the south-east region suggest increases of between 4 and 6ºC, depending on emissions scenario (central estimate). By the 2080s, projections for daily maximum summer temperature suggest increases of between 4 and 8ºC, depending on emissions scenario (central estimate). The UKCP09 projections depict a wide spread of future changes in mean surface wind speed, however, there is large uncertainty in projected changes in circulation over the UK and natural climate variability contributes much of this uncertainty[5]. It is therefore difficult to represent regional wind extreme winds and gusts within regional climate models[6].

14.1.1 Central estimates of change in mean wind speed for the 2050s are small in all ensemble runs (<0.2ms^{-1}). A wind speed of 0.2 ms^{-1} (~0.4 knots) is small compared with the typical magnitude of summer mean wind speed of about 3.6–5.1 ms^{-1} (7–10 knots) over much of England[7]. Seasonal changes at individual locations across the UK lie within the range of –15% to +10%. Results suggest that there could be a future reduction in the summer westerly wind flows over the southern half of the UK. There may be an increase in westerly flows in the north during summer and an increase in southerly flows over the UK in winter.

14.1.2 Relative Humidity is the most common measure of humidity. It measures how close the air is to being saturated. By the 2050s, projections for winter mean relative humidity in the south-east region suggest a decrease of up to 5% under the high emissions scenario (central estimate). By the 2080s, winter mean relative humidity could increase by up to 5% (high emissions scenario, central estimate. The projection for summer mean humidity in the 2050s under the high emissions scenario is a decrease of up to 10% (central estimate). By the 2080s the decrease could be as much as 15% (high emissions scenario, central estimate).

14.1.3 A range of 'extreme' climate change scenarios (produced by Wade et al., 2015 have also been reviewed. Wade et al., (2015) considered a range of climate variables including heatwaves, cold snaps, low and high rainfall, droughts, floods and windstorms. The H++ scenarios represent the margins or beyond the 10th to 90th percentile range of the 2080s UKCP09 High emissions scenario as presented in the UKCP09 projections and reported here. These scenarios provide a high-impact, low-likelihood event to compare against more likely outcomes.

14.1.4 The H++ scenarios suggest that average summer maximum temperatures will exceed 30°C across most of the UK, with temperatures of the hottest days are also likely to exceed 40°C[8]. The H++ scenarios for heavy daily and sub-daily rainfall suggest that, for the same period, there is a 60% to 80% increase in rainfall for summer or winter events based on a consideration of new high resolution modelling and physical processes. This is within the UKCP09 distribution range for the 2080s High emissions "wettest day of the winter" variable but higher than uplifts previously considered for summer.

14.1.5 Based on the climate change projections for the south-east region, **Table 14.6** indicates the level of exposure of the scheme to changes in climate variables.

Table 14.6 - Exposure Assessment

CLIMATE VARIABLE		EXPOSURE RATING
Precipitation	Annual average rainfall	Medium
	Extreme rainfall	Medium
	Drought	High
Temperature	Annual average temperature	Medium
	Extreme temperature	High
	Solar radiation	Medium
Wind	Gales and extreme wind events	Medium
	Storms	Medium
Soil	Soil moisture	High
	Stability	Medium

14.1.6 The sensitivity and exposure analyses are combined to provide an overall assessment of vulnerability of the scheme. **Table 14.7**, **Table 14.8** and **Table 14.9**Error! Reference source not found. presents the assessment of vulnerability for the road, bridge and cycle/footway components of the scheme respectively.

Table 14.7 - Vulnerability Assessment - Road

CLIMATE VARIABLE		SENSITIVITY RATING	EXPOSURE RATING	VULNERABILITY RATING
Precipitation	Annual average rainfall	Low	Medium	Low vulnerability
	Extreme rainfall	Medium	Medium	Medium vulnerability
	Drought	Medium	High	Medium vulnerability
Temperature	Annual average temperature	Low	Medium	Low vulnerability
	Extreme temperature	Medium	High	Medium vulnerability
	Solar radiation	Low	Medium	Low vulnerability
Wind	Gales and extreme wind events	Medium	Medium	Medium vulnerability
	Storms	Low	Medium	Low vulnerability
Soil	Soil moisture	Medium	High	Medium vulnerability
	Stability	Medium	Medium	Medium vulnerability

Table 14.8 - Vulnerability Assessment – Bridge

CLIMATE VARIABLE		SENSITIVITY RATING	EXPOSURE RATING	VULNERABILITY RATING
Precipitation	Annual average rainfall	Not applicable		

CLIMATE VARIABLE		SENSITIVITY RATING	EXPOSURE RATING	VULNERABILITY RATING
	Extreme rainfall	Medium	Medium	Medium vulnerability
	Drought	Not applicable		
Temperature	Extreme temperature	Medium	Medium	Medium vulnerability
	Solar radiation	Low	Low	Low vulnerability
Wind	Gales and extreme wind events	High	Medium	Medium vulnerability
	Storms	Not applicable		
Soil	Soil moisture	Not applicable		
	Stability	Medium	Medium	Medium vulnerability

Table 14.9 - Vulnerability Assessment – Cycle and Footway

CLIMATE VARIABLE		SENSITIVITY RATING	EXPOSURE RATING	VULNERABILITY RATING
Precipitation	Annual average rainfall	Low	Medium	Low vulnerability
	Extreme rainfall	Medium	Medium	Medium vulnerability
	Drought	Medium	High	Medium vulnerability
Temperature	Annual average temperature	Low	Medium	Low vulnerability
	Extreme temperature	Medium	High	Medium vulnerability
	Solar radiation	Low	Medium	Low vulnerability
Wind	Gales and extreme wind events	Medium	Medium	Medium vulnerability
	Storms	Low	Medium	Low vulnerability
Soil	Soil moisture	Medium	High	Medium vulnerability
	Stability	Medium	Medium	Medium vulnerability

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[1] Standards Australia (2013) Climate Change Adaptation for settlements and infrastructure – a risk based approach. SAI Global Limited

[2] Jenkins, G.J., Perry, M.C., and Prior, M.J. (2008). The climate of the United Kingdom and recent trends. Met Office Hadley Centre, Exeter, UK.

[3] UKCP09 shows data for 3 possible emissions scenarios: low, medium and high. These are the Intergovernmental Panel on Climate Change (IPCC) scenarios B1, A1B and A1FI respectively. More information on the nature of these emissions scenarios can be found in the IPCC's SRES report.

[4] UKCP09 projections are given for seven overlapping 30-year time periods. Each period steps forward by a decade, with the first time period being 2010-2039. For simplicity, these time periods

are referred to by the middle decade, starting with the 2020s (2010-2039) and ending with the 2080s (2070-2099).

[5] Brown, S., Boorman, P., McDonald, R., and Murphy. J. (2012) Interpretation for use of surface wind speed projections from the 11-member Met Office Regional Climate Model ensemble. Post-launch technical documentation for UKCP09. Met Office Hadley Centre, Exeter, UK. Crown copyright.

[6] Brown, S., Boorman, P., Buonomo, E., Burke, E., Caesar, J., Clark, R., McDonald, R. and Perry, M. (2008) A climatology of extremes for the UK: A baseline for UKCP09. Met Office Hadley Centre, Exeter

[7] Jenkins, G. J., Perry, M. C. and Prior, M. J. (2008) The Climate of the United Kingdom and Recent Trends, Met Office Hadley Centre, Exeter, UK. Crown copyright.

[8] Wade, S., Sanderson, M., Golding, N., Lowe, J., Betts, R., Reynard, N., Kay, A., Stewart, L., Prudhomme, C., Shaffrey, L., Lloyd-Hughes, B., Harvey, B. (2015). Developing H++ climate change scenarios for heat waves, droughts, floods, windstorms and cold snaps. Met Office Hadley Centre, Exeter, UK. Crown copyright