Amberley Wild Brooks SSSI

Climate change vulnerability assessment and adaptation planning report

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Foreword

Natural England is undertaking a Site of Special Scientific Interest (SSSI) Future Reforms (SSSIFR) project to investigate whether the statutory framework for SSSIs supports adaptation to climate change, or if the legal framework needs to evolve to better protect habitats, species and geological features during a time of rapid change.

Natural England commissioned this report to start to create an evidence-base of how climate change might affect a SSSI, and to identify potential options for adaptive management, using Amberley Wild Brooks SSSI as a case study.

The outputs of this project will be used as the basis of further conversations with stakeholders about long term management objectives for the site and to develop future adaptive management plans. The findings of this project will inform Natural England’s SSSIFR project, and whether the statutory framework has the flexibility to enable site managers to adapt to change, and if not, what are the obstacles. The approach developed for this pilot will potentially be rolled out to further case studies.

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Executive summary

Climate change is placing additional pressures on the natural world as well as directly affecting landscapes, habitats, species, geological features and ecological functioning. Designated features within Sites of Special Scientific Interest (SSSIs) may be particularly vulnerable to the physical risks of climate change due to their unique and often vulnerable or endangered status. For SSSI land managers, understanding how climate is projected to change and what this means for ecological future baselines and changes is necessary to develop and deliver effective management plans.

Natural England is undertaking a SSSI Future Reforms (SSSIFR) project to investigate whether the statutory framework for SSSIs supports adaptation to climate change, or if the legal framework needs to evolve to better protect features during a time of rapid change.

The aim of this project is to create an evidence-base of how climate change might affect a SSSI, and to identify potential options for adaptive management, using Amberley Wild Brooks SSSI as a case study.

Climate hazards and risks

Climate projections indicate that southern England is likely to continue to experience changes in seasonal and annual average rainfall and temperature patterns, with warmer and wetter winters, and hotter and drier summers, as well as an increase in the frequency and intensity of extreme climate events such as floods, heatwaves, and storms.

As a result of changing climate and hydrological conditions, there are a range of climate risks to features at the site. The direct risks from climate change that have been identified for Amberley Wild Brooks SSSI are relate to:

- Increased flooding
- reduced water quality
- droughts and reduced water levels
- changes to growing seasons
- invasive non-native species
- higher water temperatures
- increased nutrient release
- saline intrusion
- heatwaves
- wildfire risk
- changes in prey
- reduced breeding success

As well as direct risks, climate change is likely to exacerbate existing pressures on site, such as water level management challenges, pressure on groundwater resources from abstraction, deer trampling, shading of plant features and pollution.

Site risk assessment

A risk assessment was conducted under two greenhouse gas scenarios for the 2060s – a Medium-High scenario and a High Scenario, considering the vulnerability of each feature.

The assessment identified that under the Medium-High scenario, all features face medium and high risks meaning more than 50% of each feature may be adversely affected or lost, and some more than 75% of that feature.

Under the High Scenario, all features are at high risk, meaning that more than 75% of each feature may be adversely affected or lost by the 2060s.

The main effects of climate change that could result in feature loss and damage are loss or decline of principle habitats or breeding and feeding habitats due to climatic and hydrological conditions. Ultimately, these impacts may lead to population decline, changes in distribution of designated features and to assemblage types, and habitat succession.

Options for adaptive management

Supporting the adaptation of ecosystems to the impacts of climate change will require working with ecological transformations, rather than working to maintain a static set of habitat conditions or features. To explore potential adaptation strategies and options, the Resist Accept Direct (RAD) framework has been used. The RAD framework is simple and flexible, allowing site managers to explore options that may seek to ‘Resist’ change and strive to maintain existing ecosystems, ‘Accept’ transformation when it is not feasible to resist, or ‘Direct’ changes to a future ecosystem configuration for desirable outcomes.

Deciding which approaches to use at different locations and habitats will depend on identifying desired outcomes by determining what ‘good’ could look like for that location. From these desired outcomes, the most appropriate adaptation actions can be decided.

For Amberley Wild Brooks SSSI, the key adaptation options identified include updated and increased water level management and embankment protection to resist changing flood levels and preserve water quality, as well as other management to maintain ditch quality and control invasive species. Accept options include allowing of overtopping, flooding and sedimentation processes, resulting in a naturally functioning wetland, requiring a review of SSSI designated features. Direct approaches may include a change in site governance and actions to alter the embankment and ditch network to allow site flooding and creation of a naturally functioning wetland.

Next steps

The outputs of this project will be used as the basis of further conversations with stakeholders about long term management objectives for the site and to develop future adaptive management plans. Further work is needed to explore what ‘good’ could look like for this site over specified time horizons. This should include developing further understanding of features that may thrive under future non-stationary climate and hydrology and natural ecosystem functioning at the site. Networks of sites will need to be considered to risk and management responses at a landscape scale. Legal and financial constraints as well as implementation challenges of options will also need to be explored.

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Project introduction and aims

Project background

Across the globe, climate change is placing additional pressures on the natural world, transforming ecosystems, endangering biodiversity, and altering hydrological and geological features. Designated features within Sites of Special Scientific Interest (SSSIs) may be particularly vulnerable to the physical risks of climate change due to their unique and often vulnerable or endangered status.

For land managers of SSSIs, the impacts of climate change are profound, leading to a shift of ecological baselines from baselines that are known and agreed upon, to new baselines that are non-stationary, uncertain and contestable (Williams, 2022). Management plans based on assumptions of stable ecological baselines driven by historical climatic conditions are unlikely to deliver required outcomes as the climate continues to change.

Supporting climate adaptation of SSSIs requires an understanding of how features within a site may react directly to climate change, and how climate change influences from the wider landscape, particularly hydrological will indirectly moderate (exacerbate or ameliorate) pressures. As well as understanding these impacts at the site scale, decisions about future management and adaptation actions also require an understanding of the impacts of climate change across a network of sites at the landscape scale. Identification of adaptation measures may require a more dynamic approach in future as priorities change, depending on species and habitat response to climate change.

Natural England is undertaking a SSSI Future Reforms (SSSIFR) project to investigate whether the statutory framework for SSSIs supports adaptation to climate change, or if the legal framework needs to evolve to better protect habitats, species and geological features during a time of rapid change.

Project aims

The aim of the project was to create an evidence-base of how climate change might affect a SSSI, and to identify potential options for adaptive management, using Amberley Wild Brooks SSSI as a case study.

The scope of the project was to:

- Identify the current climate and projected climate change at the site
- Undertake a climate change vulnerability assessment for the monitored features, non-designated features at the site and wider landscape influences
- Identify potential options for long term management of the site in light of projected climate change, using the Resist Accept Direct (RAD) framework.

The outputs of this project will be used as the basis of further conversations with stakeholders about long term management objectives for the site and to develop future adaptive management plans. The findings of this project will inform Natural England's SSSIFR project, and whether the statutory framework has the flexibility to enable site managers to adapt to change, and if not, what are the obstacles, with the approach developed for this pilot potentially being rolled out to further case studies.

Site description

Site overview

Amberley Wild Brooks is a 327.5 ha SSSI within the Arun Valley Special Protection Area (SPA) and Special Area of Conservation (SAC), contributing significantly to the wildlife and landscape interest of the Arun Valley catchment. The land was designated as a SSSI in 1985 for its range of biological features, particularly invertebrate and plant species, and importance as a habitat for assemblages of breeding waders and wintering wildfowl. The site lies on greensand and river alluvium although there is an area of peat in the north which represents the only sizeable example of a relict raised bog in the south east. Southern parts of the site are fed by calcareous springs whose influence declines to the north. This variation in the chemical status of the water gives rise to the rich diversity of flora and fauna on the site, highlighting the importance of wider catchment influences on the condition of the site.

The land is owned by multiple stakeholders including the RSPB (who own 133 ha of the SSSI and manage a further 81 ha on behalf of Sussex Wildlife Trust), as well as various other private landowners (who undertake agricultural practices), with the Environment Agency acting as the Internal Drainage Board (IDB) for the entire site.

Amberly Wild Brooks SSSI contains a range of habitats and features as depicted in Figure 1.

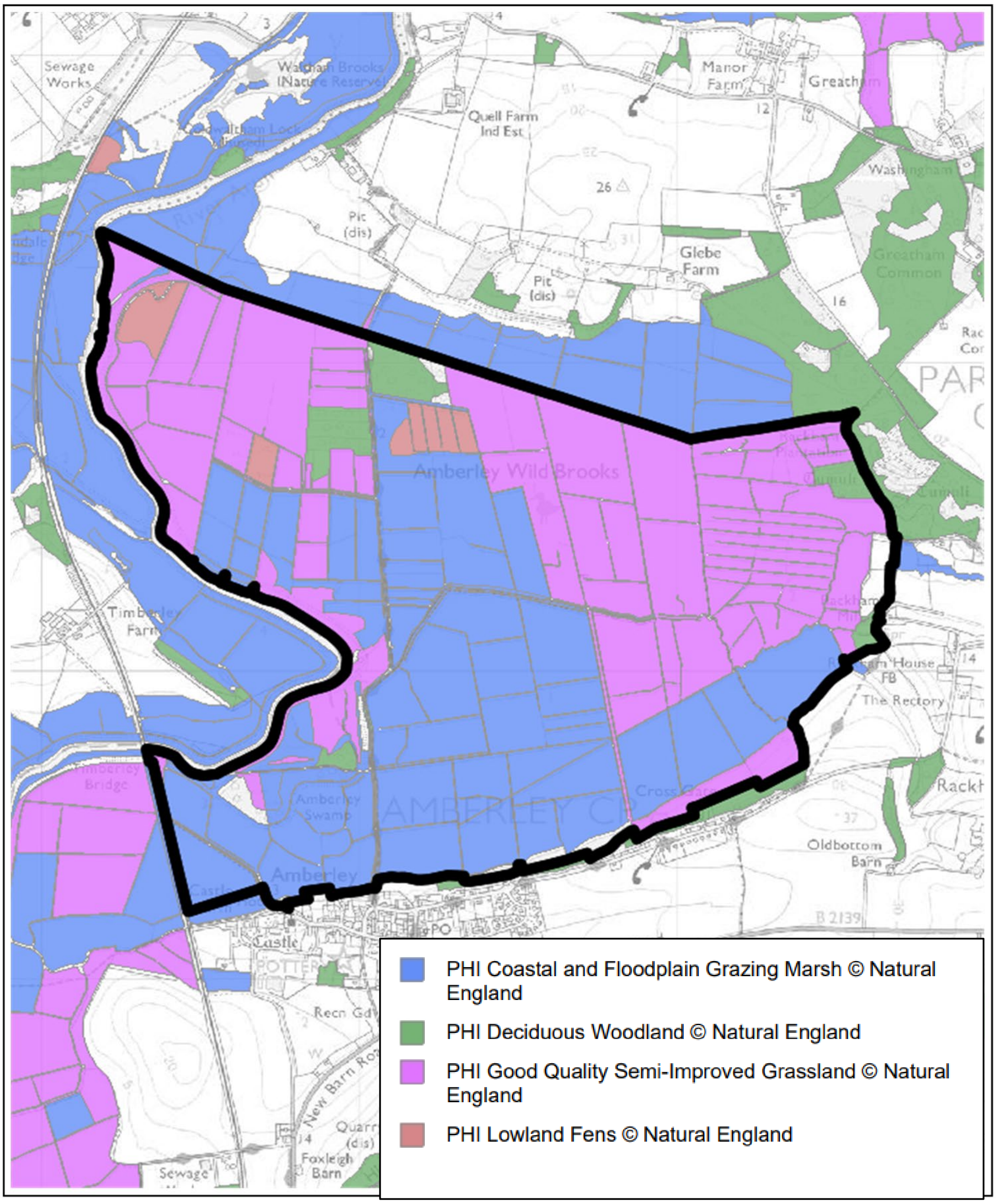

Figure 1 Map of Amberly Wild Brooks SSSI showing the variety of habitats: coastal and floodplain grazing marsh, deciduous woodland, good quality semi-improved grassland and lowland fens. The extent of the SSSI is outlined in black. Contains, or is derived from, information supplied by Ordnance Survey. © Crown copyright and database rights 2023. Ordnance Survey 100022021. Map Scale at A4: 1:16,470.

According to the Amberley Wild Brooks SSSI citation detail (naturalengland.org.uk), the site contains 14 units and 13 monitored features. For the purposes of this study, in addition to the 13 monitored features, peat bogs were also analysed as being a feature of high interest for the site, plus the impact of climate change on the site's hydrological influences due to their impact on feature condition. Non-breeding birds were also aggregated and assessed as a single group due to ecological similarities and climate sensitivity. The (groups of) features that have been analysed in this vulnerability assessment are:

- Aggregations of breeding birds – Redshank (*Tringa tetanus*)
- Aggregations of non-breeding birds – Bewick's swan (*Cygnus columbianus bewickii*), Shoveler (*Anas clypeata*), Teal (*Anas crecca*), variety of wintering species
- Assemblages of breeding birds – Mixed: Lowland damp grassland, Woodland
- Ditches
- Invertebrate assemblage W211 open water on disturbed sediments
- Dragonfly assemblages
- Population of RDB mollusc – Little Ramshorn Whirlpool Snail (*Anisus vorticulus*)
- Population of RDB plant – True Fox-sedge (*Carex vulpine*)
- Population of Schedule 8 plant – Cut-grass (*Leersia oryzoides*)
- Vascular plant assemblage
- Raised peat bogs

Existing condition of Amberley Wild Brooks SSSI

The RSPB noted that current habitat and species condition of Amberley Wild Brooks has been largely declining over the past 30 years, with observed reductions in breeding waders, particularly snipe and redshank (RSPB, 2021). Although the ditches have generally maintained their floristic interest and are at a range of successional stages, the Little Whirlpool Ramshorn Snail (*Anisus vorticulus*) now has an extremely restricted distribution (one ditch on RSPB land on the eastern side of the site) (RSPB, 2021; NE, 2022). According to the latest Natural England condition assessment as well as discussions with stakeholders, grassland and woodland areas are largely in unfavourable condition. Invertebrate and ornithological assemblages' conditions vary but are largely in unfavourable condition (NE, 2011; NE, 2022). Ditch condition appears to have unfavourable water quality as well as channel form and succession. Peat habitats also appear to be in declining condition and, due to flooding, are sometimes inaccessible for survey or maintenance. Overall, the site appears to be experiencing a loss in species richness, particularly concerning declining rare plant species and bird species and water-dependant features such as the Little Whirlpool Ramshorn Snail.

There are several contributory factors, including climate change as a direct risk, to these unfavourable conditions and declines over time. The further factors have been identified as 'indirect risks', which are further exacerbated by climate change and will be considered within the climate change vulnerability assessment, including:

- Complex site hydrology and water level management challenges
- Invasive non-native species (INNS)
- Saline intrusion and polluted water breaching site
- Deer trampling of ground-nests

- Predator intrusion
- Shading of monitored plant features
- Changes to nearby groundwater and surface water sources
- National decline of populations and condition of other SSSIs, leading to population pressures at Amberley Wild Brooks.
- Escaped carp travelling upstream and increasing turbidity through sediment disturbance and remobilisation

Observed climate impacts at the site

Based on a site visit in December 2022 and discussions with stakeholders, overtopping of flood embankments has been increasing in frequency with small flood events (5-year return periods) happening particularly frequently. This is affecting water quality as flood waters contain pollutants including saline intrusion (as the tidal limit is moving further upstream due to sea level rise), increased sedimentation, as well as concerns regarding wastewater pollution due to combined sewer overflows (CSO) from sewage treatment works upstream of the site. Water level management plans are in place for the site (see below for further details) however are based on historical seasonal water levels and are not up-to-date regarding latest flood risk and extreme events. The site however is well drained and flood waters do not remain for prolonged periods (which would be beneficial to some flood sensitive features). In addition, it is understood that implementation of the water level management plans presents challenges due to the variety of land uses and different priorities and stakeholders needs across the site.

During the summer months, warmer temperatures and site drainage means that there are increasing signs of drying on the site leading to drying out of ditches and subsequent reduction in certain plant species, invertebrates and breeding birds. The cause of these changes, in addition to climactic, may also be attributed to changes in groundwater supplies outside of the SSSI due to abstraction practices as well as the site's water level management (Hicks and others, 2019).

The site visit identified site flooding (following recent heavy rainfall) that quickly dropped within roughly one week and ditch water levels that were lower than those at the River Arun. During the visit there was no observable flow from the river into the site, however it is understood that at the time, the flap valve at one of the sluice structures was broken and thereby allowing leakage into the site. There was also a wastewater smell, which could be indicative of CSO spills onto the site.

Current management

Current management practices include:

- Water level management through operation of sluices managed by the Environment Agency across the whole site (Environment Agency, 2006) as well as maintenance of ditches and embankments. Water level management principles (WLMP) were

partially agreed by some landowners across the site, and it is understood that they are not effectively implemented. The agreed principles are:
    - To achieve shallow flooding on between 25% to 30% of the SSSI with occasional larger natural flooding events on up to 70% of the SSSI for a total of 3 to 4 months from mid-November to late February, to reflect natural flooding patterns
    - To allow a gradual draw down of the water levels from winter levels in order to retain a number of wet pools to at least 5% of the SSSI by July
    - To facilitate grazing from spring with increasing stock numbers towards the end of June and remaining into late autumn
    - To allow natural drain-down between July and mid-October and raise water levels in increments from mid-October, aiming to return to winter levels by mid-November
    - Manage water levels on peat areas to achieve a similar regime, but accounting for increasing hydraulic conductivity of the peat and with special reference to management requirements for breeding snipe.
- Other habitat management measures (RSPB, 2017) include:
    - Vertebrate control
    - Sward and scrub management through grazing
    - Mechanical topping to manage sward height
    - Livestock and grazing management
    - Woodland management (sapling planting, non-native removals, deer control)
    - Ditch management.

Assessment methodology

The climate change vulnerability assessment was carried out using the following steps:

1. Desk-based review of site features and present condition.
2. Site visit with stakeholders to understand site features and condition as well as current pressures and potential climate change impacts.
3. Construction of a climate baseline, covering current climate and projected future climate change.
4. Identification of potential risks from climate change to site features and wider interest features such as raised peat bogs and hydrological processes including abstraction outside of the SSSI and calcareous springs groundwater sources.
5. Vulnerability assessment: determination of a vulnerability rating for each feature, against each climate hazard, based on consideration of the sensitivity of the feature to climate change, the exposure of the feature to climate change and the adaptive capacity of the feature.
6. Risk assessment: determination of a risk rating, based on the vulnerability of the feature and the likelihood of the impact occurring under the climate change outcomes of two greenhouse gas (GHG) emissions scenarios.
7. Identification of potential adaptation options to address the risks, based on the Resist-Accept-Direct (RAD) framework.
8. A stakeholder workshop to gather feedback on the vulnerability assessment and RAD options, which was fed back into the assessment and reporting.

Feature condition identification

Firstly, an understanding of the site, the wider influences on the site and current condition of the features of interest was ascertained through desk-based review of available site information as well as review of available literature on the potential impacts of climate change to features of interest, though not necessary specific to Amberley Wild Brooks SSSI (Burton and others, 2020; Gillingham, 2013; Smart and Jill, 2003; Forestry Commission, 2020; Evans and others, 2011; Thompson and others, 2009; Environment Agency, 2013).

Site visit

A site visit supported by discussions with RSPB and Natural England stakeholders was conducted to understand the existing site condition (outlined above), direct climate hazards and related risks, as well as other, indirect risks facing the site. Contextual insights obtained during the site visit were used to inform the expert judgement applied during the vulnerability assessment. Findings from the site visit are captured within the above Site description section and site notes are available in Appendix A.

Climate baseline

A climate baseline was constructed using data from the UK Met Office Climate Projections 2018 (UKCP18), covering both observed and projected climates. Information on present-day weather and climate was established based on historic, regional data for Southern England (UK Met Office, 2016).

Future climate projections from the Met Office UKCP were used in this study (UK Met Office, 2018a). Information on projected change in climate variables for temperature and precipitation at a 25km resolution have been obtained for the relevant grid square containing Amberley Wild Brooks SSSI [512500, 112500]. Due to uncertainty over future (GHG emissions, the Met Office have produced four future scenarios representing different trajectories of GHG emissions and overall global warming over the 21st Century (UK Met Office, 2018b). Two of these future scenarios have been used for this risk assessment:

1. **RCP6.0 – 'Medium-high scenario'** - broadly representative of a scenario where global temperature increase is mitigated to a moderate degree, leading to temperatures around +3°C above pre-industrial temperatures.
2. **RCP8.5 – 'High scenario'** - represents a pathway where greenhouse gases continue to grow unmitigated, leading to global temperatures above +4°C above pre-industrial temperatures.

For each scenario, the future climatic projections were identified for the 2060s (2050-2069) to provide a mid-future understanding of climate change to help inform longer term conservation goals and management plans.

From these climate projections, a range of climate hazards that may impact site features were identified. Climate change alters the frequency and intensity of both acute and chronic climate hazards. Acute climate hazards refer to sudden-onset and usually short-lived events. These include heavy rainfall events, storms, high winds, humidity, thunderstorms and lightning as well as hydrological events such as drought, pluvial and fluvial flooding, and rapid changes in ground conditions such as landslip or subsidence as a result of intense periods of precipitation change. Chronic climate hazards refer to longer-term events or changes in climate such as rising average temperatures and changing seasonal patterns such as warmer, wetter winters and hotter, drier summers, as well as effects that build up gradually over a period of months or years such as depleted aquifers or significant changes in vegetation as a result of prolonged and repeated droughts, or more frequent or permanent inundation of coastal zones due to sea level rise.

Identification of potential risks and impacts

Using information on both the site features and future climate hazards we identified risks and potential impacts to each feature. These risks included both direct risks (risks that occur as a result of the climate hazard affecting the feature) and indirect risks, where climate change is likely to exacerbate existing pressures (i.e., where climate change is likely to act as a risk multiplier).

Vulnerability assessment

For each impact identified, the vulnerability of affected features was determined by considering the combination of feature sensitivity and its adaptive capacity.

Sensitivity

Sensitivity of each feature to each climate hazard is a measure of how much a habitat or species is susceptible to be adversely affected by the change in climate hazard. Table 1 shows the definitions associated with the sensitivity scores. These are based on the sensitivity scores used in Natural England's National Biodiversity Climate Change Vulnerability Model (NBCCVM), modified to create a 5-point scale, consistent with the other scales used in the assessment.

Table 1 Sensitivity ratings

Sensitivity rating	Sensitivity value	Description
1	Not sensitive	Habitats/species that will be negligibly affected by disturbances in climate conditions or a perturbation in feature condition.
2	Not sensitive / sensitive	Habitats/species that will be slightly affected by disturbances in climate conditions or a perturbation in feature condition. Species that will quickly re-colonise disturbed areas, particularly following habitat restoration and rehabilitation.
3	Sensitive	Habitats/species that naturally recover quickly following disturbance. Species that will re-colonise disturbed areas, particularly following habitat restoration and rehabilitation but perhaps at a slower rate that other commonly occurring species. Species that can rely on an assemblage of other species for prey.
4	Sensitive/Very Sensitive	Habitats/species that have a slow rate of recovery following disturbance. Habitats used by medium value species as important feeding or breeding areas (or migration routes). Species that usually rely on specific species for prey but can also rely on other species in the assemblage.
5	Very Sensitive	Habitats/species that are highly unlikely to naturally recover following disturbance. Habitats supporting an assemblage of unique or important species as important feeding or breeding areas (or migration routes). Species that rely on a specific species for prey.

Adaptive capacity

Adaptive capacity is qualitatively captured using expert judgement and stakeholder consultation, with a short narrative being used to determine the extent to which a feature is able to adapt to changing conditions.

Vulnerability rating

A vulnerability rating is calculated based on a combination of sensitivity and adaptive capacity using expert judgement as well as literature review. The vulnerability rating assigned describes the propensity of a feature to be adversely affected by an impact under current climate conditions. The vulnerability ratings are identified in Table 2.

Table 2 Vulnerability ratings

Vulnerability Rating	Value	Description	Proportion of feature affected
1	Low	A small proportion of the habitat/species is vulnerable but without the loss of viability / function of the habitat	<10% (1 – 10%)
2	Low-Medium	A moderate proportion of the habitat/species is vulnerable but without the loss of viability / function of the habitat	<25% (11 – 25%)
3	Medium	A significant proportion of the habitat/species is vulnerable such that the viability and function of part of the habitat/species or the entire habitat/species is reduced but does not threaten the long-term viability of the habitat or species dependent on it	<50% (26 - 50%)
4	Medium-High	A significant proportion of the habitat/species is vulnerable such that the viability and function of part of the habitat/species or the entire habitat/species is reduced but does not threaten the long-term viability of the habitat or species dependent on it	<75% (51 - 75%)
5	High	The entire habitat/species or significant proportion of the habitat/species is vulnerable, where the viability / function of the entire habitat/species is reduced and the long-term viability of the habitat and the species dependent on it are threatened	>75%

In addition to this case study, Natural England is carrying out research into the effectiveness of agri-environment scheme (AES) options in adapting to the impacts of climate change and increasing the resilience of protected sites. The AES project uses geographic information systems (GIS) to develop an automated approach to climate vulnerability assessment. GIS is used to calculate vulnerability of monitored features to climate hazards, based on their sensitivity to the hazard, their exposure to the hazard and the adaptive capacity of the feature (based on condition). The preliminary output of the AES project for the Amberley Wild Brooks SSSI site is included within Appendix C of this report, and the two should be considered in conjunction, noting however that the AES project was carried out using a different methodology and that the results are not directly comparable. This report is the more detailed of the two for Amberley Wild Brooks SSSI.

Risk assessment

A risk score was determined based on the vulnerability rating (described above) and the likelihood of the impacts occurring under the two climate change scenarios used in this assessment (i.e., the Medium-high GHG emissions scenario and the High GHG emissions scenario). Under both climate scenarios, the likelihood of the impact occurring was estimated using the definitions presented in Table 3.

Table 3 Likelihood ratings

Rating	Value	Description	Likelihood percentage
1	Low	Circumstances are such that the impact could occur, but it is not certain even in the long term that it would occur. The impact is less likely to occur in the short term.	(<10%) 1 - 10%
2	Low-medium	It is somewhat probable that the impact will occur possibly in the short term and is quite likely over the long term.	(<25%) 11 - 25%
3	Medium	It is probable that the impact will occur possibly in the short term and likely over the long term.	(<50%) 26 - 50%
4	Medium-high	Impact appears likely in the short term and very likely over the long term.	(<75%) 51 - 75%
5	High	Impact appears very likely in the short term and almost inevitable over the long term, or there is evidence of the impact already happening.	>75%

The overall risk rating for each climate impact was then calculated as the combination of future likelihood combined with feature vulnerability to that impact using the matrix identified in Table 4. A risk rating was calculated against each impact, for each climate scenario.

Table 4 Risk assessment matrix. Risks are assigned a percentage to reflect the proportion of habitats that are vulnerable.

Likelihood	Vulnerability				
	1	2	3	4	5
5	<25%	<50%	<75%	>75%	>75%
4	<25%	<50%	<50%	<75%	>75%
3	<25%	<25%	<50%	<50%	<75%
2	<10%	<25%	<25%	<50%	<50%
actioned1	<10%	<10%	<25%	<25%	<25%

Identification of adaptation options

Potential options for managing the risks were identified using the Resist-Accept-Direct (RAD) Framework. Under the RAD framework, options are classified into one of the three categories:

- **Resist** – adaptation options that seek to resist or slow the trajectory of change by mitigating the risks and working to maintain or restore the ecological baseline where existing biological conditions are important.
- **Accept** – allowing an ecosystem to change without intervention or through continued existing interventions, which are not ramped up or altered based on evolving climate conditions. Accept options may be temporary, and management may shift to Resist or Direct options after a period of acceptance in order to reach a maintainable desired condition.
- **Direct** – adaptation actions that actively shape ecosystem change toward preferred new conditions along a faster and preferred timescale.

The adaptation options were identified through stakeholder discussion, desk-based review and expert knowledge.

Assumptions and limitations

A list of assumptions and limitations associated with the use of climate projection data can be found in Appendix B.

Climate baseline

Current climate conditions

Southern England is subject to both continental influences that can bring both warm and humid weather in summer as well as cold spells in the winter. It is also furthest in the UK from the paths of most Atlantic depressions, which bring associated cloud, wind and rain, so the climate of southern England is relatively quiescent (UK Met Office, 2016).

Average annual temperatures in Southern England are around 9-11°C with average maximum temperatures during summer of around 24°C and average minimum temperatures of roughly 3°C in winter (according to baseline Met Office climate data averages from 1981-2010). Extreme maximum temperatures based on historic data from 1957-2014 can approach 40°C. For example, in 2022 the UK experienced an unprecedented extreme heatwave with temperatures reaching up to 40°C recorded across England. The heatwave was also accompanied by a period of severe drought across England with the Met Office declaring the driest July since 1935.

In winter temperatures can be as low as -12°C and there are approximately 12 days per month of ground frost (where ground temperature is at or below 0°C), and approximately 7-8 days per month of air frost (when air temperatures at 1.25m reach 0°C).

The average maximum daily temperatures at North Heath weather station (West Sussex), approximately 6 miles from Amberley Wild Brooks SSSI, range from 8°C in the winter, to 23°C in the summer, as shown in Figure 2.

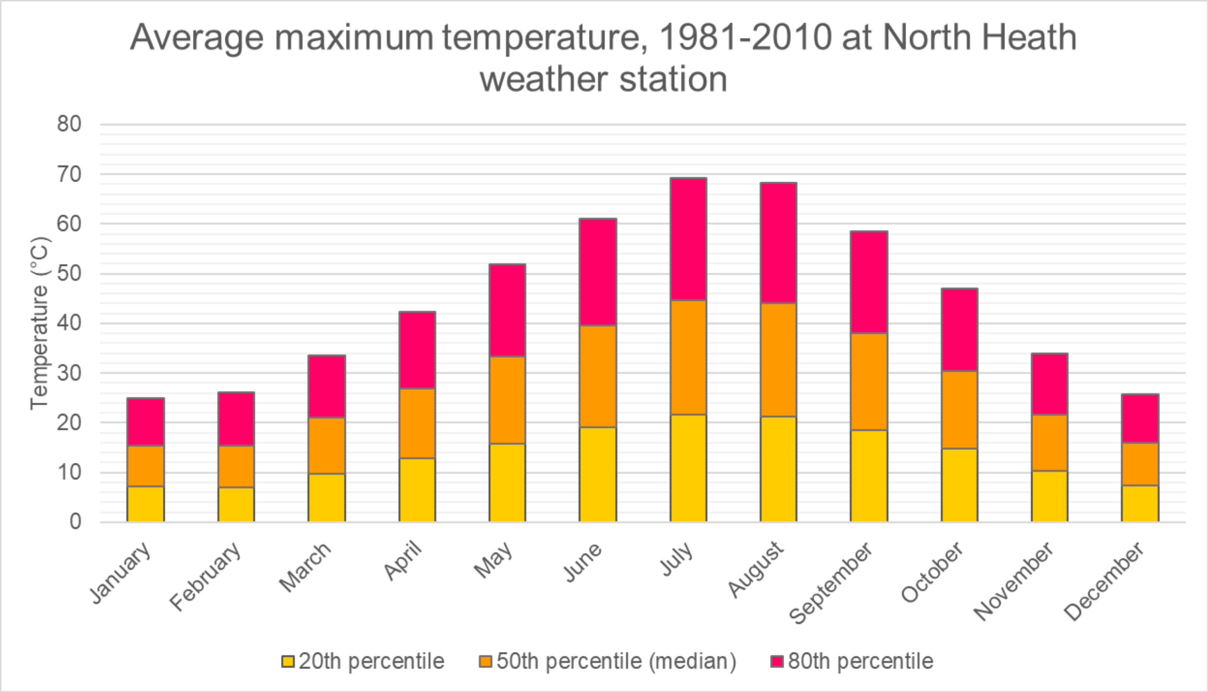

Figure 2 Average daily maximum temperature (°C) (1981-2010). Data from UK Met Office, contains public sector information licensed under the Open Government Licence v3.0. The bar height depicts the monthly average maximum temperatures at North Heath weather station for the 20th percentile, 50th percentile (median) and 80th percentile. The height of the fuchsia bar (the top section) represents the 80th percentile value, the height of the orange bar (the middle section) depicts the average value (50th percentile) and the yellow bar (bottom section) depicts the 20th percentile.

Southern England includes the sunniest places in mainland UK, with average annual sunshine duration of between 1550-1600 hours, with as many as 300 hours per month during summer and less than 100 hours per month in winter.

Rainfall in England tends to be associated with Atlantic low-pressure depressions or with convection. The Atlantic Lows are more vigorous in autumn and winter and bring most of the rain that falls in these seasons. In summer, convection caused by solar surface heating sometimes forms shower clouds and a large proportion of rain falls from showers and thunderstorms in heavy rainfall events.

Southern England is much drier than other parts of the country, with an annual average of 826mm of rainfall per year at North Heath (West Sussex) weather station. Figure 3 shows the average monthly rainfall at North Heath weather station. The majority of rainfall occurs between October and January. The wettest month is November with an average of 103mm and the driest month is May with an average of 46mm rainfall.

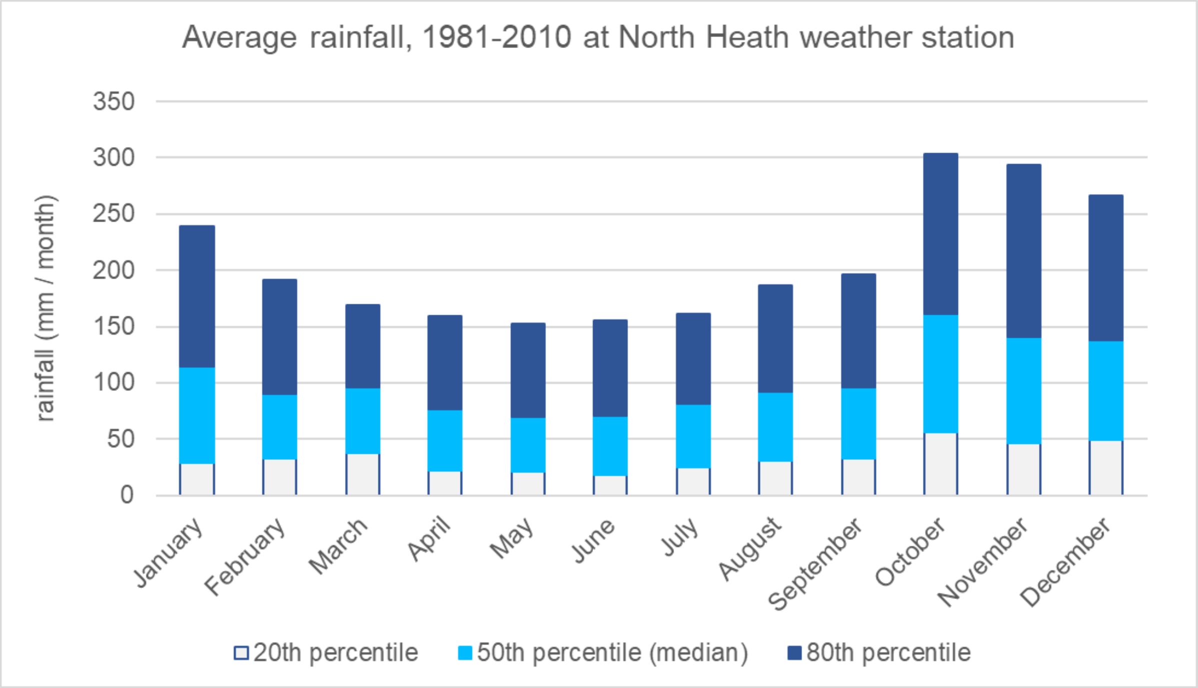

Figure 3 Average monthly rainfall (mm) 1981-2010. Data from UK Met Office, contains public sector information licensed under the Open Government Licence v3.0. The graph depicts the monthly average rainfall (mm) at North Heath weather station. The height of the dark blue bar (top section) represents the 80th percentile value, the height of the pale-blue bar (middle section) depicts the average value (50th percentile) and the white bar (bottom section) depicts the 20th percentile.

Although ground and air frost occur more regularly, snowfall is rare in southern England with only 7-8 days per year of snow lying (UK Met Office, 2016).

Average wind speeds across southern England are generally slower than the rest of the country as the coast is more sheltered from the Atlantic. The strongest winds are associated with the passage of deep areas of low pressure close to or across the UK. The frequency and strength of these depressions is greatest in the winter half of the year, especially from December to February, and this is when mean speeds and gusts (short duration peak values) are strongest. Average wind speeds are around 8-10 knots whilst wind gusts can range from 42 -78 knots, with higher gust speeds generally occurring in winter (UK Met Office, 2016).

Projected climate

Climate projections indicate that southern England is likely to continue to experience changes in seasonal and annual average rainfall and temperature patterns, as well as an increase in the frequency and intensity of extreme climate events such as floods, heatwaves and storms. Key messages from the UKCP18 projections are that the region will experience:

- Hotter, drier summers

- Warmer, wetter winters
- An increase in extreme weather events such as heatwaves and intense rainfall events
- An increase in windspeeds
- A decrease in the frequency and severity of snowfall and ice
- A decrease in the number of fog days
- An increase in the frequency and magnitude of storms with some possibility for an increase in lightning events.

Increased temperatures and reduced summer rainfall may also increase variance in soil moisture and thereby associated risks of ground movements such as shrink-swell, desiccation and subsidence.

Increased extreme rainfall volumes (i.e., heavy rainfall events) may also increase the risk of pluvial and fluvial flood risk at the site, as well as saline intrusion due to sea level rise and increased tidal range of the River Arun.

The following set of graphics outline the projected changes (by the 2060s) in key climate variables under both the medium-high (RCP6.0) and high (RCP8.5) emissions scenarios. Changes are presented as an anomaly from a modelled 1981-2000 baseline value. The UKCP18 probabilistic projections dataset has been used and the below figures provide the 50th percentile values for each variable, representing an ‘as-likely-as-not’ value from the projections data range.

Temperature changes

Figure 4 and Figure 5 show that temperatures are projected to rise, with winter average daily temperatures (December, January, February) projected to rise to between 6.3°C or 7°C by the 2060s. Average summer (June, July, August) temperatures may increase to between 18.3°C or 19.4°C by the 2060s.

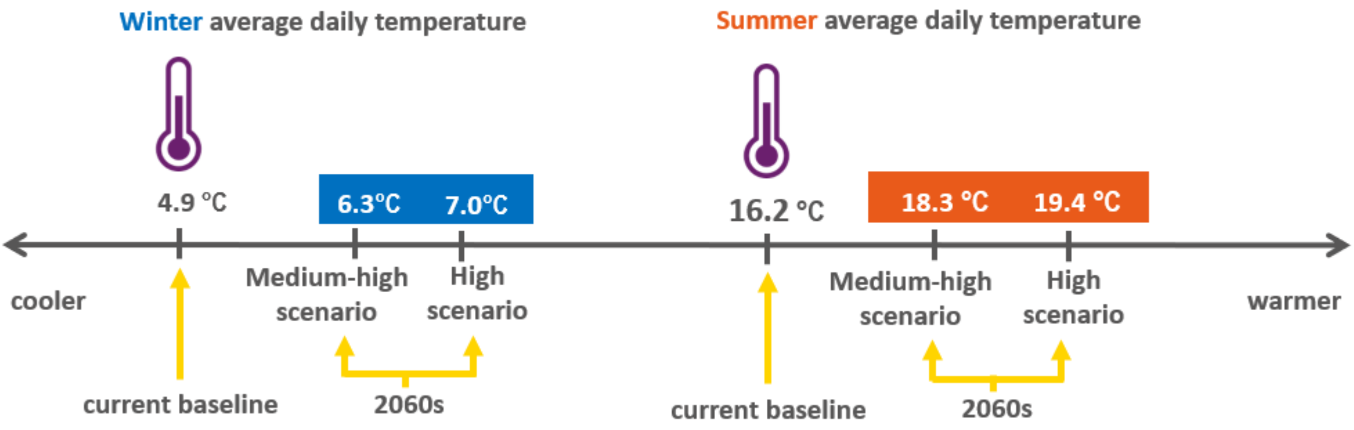

Figure 4 Average daily temperature (°C). Source Mott MacDonald, using data from UK Met Office (UK Met Office, 2018a). Contains public sector information licensed under the Open Government Licence v3.0. Current baseline values indicate the average seasonal temperature during the period 1981-2010 and the projected future temperatures are shown as departures from the baseline. For the Medium-high scenario average temperatures by the 2060s may be 6.3°C in winter and 18.3°C in summer. Under the High scenario temperatures may average 7.0°C in winter and 19.4°C in summer.

Whilst average daily temperatures are projected to rise, extreme temperatures may increase even more. For the site location, maximum daily temperatures are projected to increase 1.8-2.8°C, reaching 35.4 to 36.4°C (Figure 5). It should be noted however that extreme temperatures even outside of the 50th percentile projections data may occur, resulting in maximum temperatures higher than those projected. For example, the heatwave of 2022 saw temperatures reach over 40°C in the south of England (UK Met Office, 2021), during heatwaves (prolonged periods of significantly higher than average temperatures). A special report on UK climate extremes identified that on average between 2008-2017, warm spells lasted twice as long as they did in the period 1961-1990 (UK Met Office 2018c).

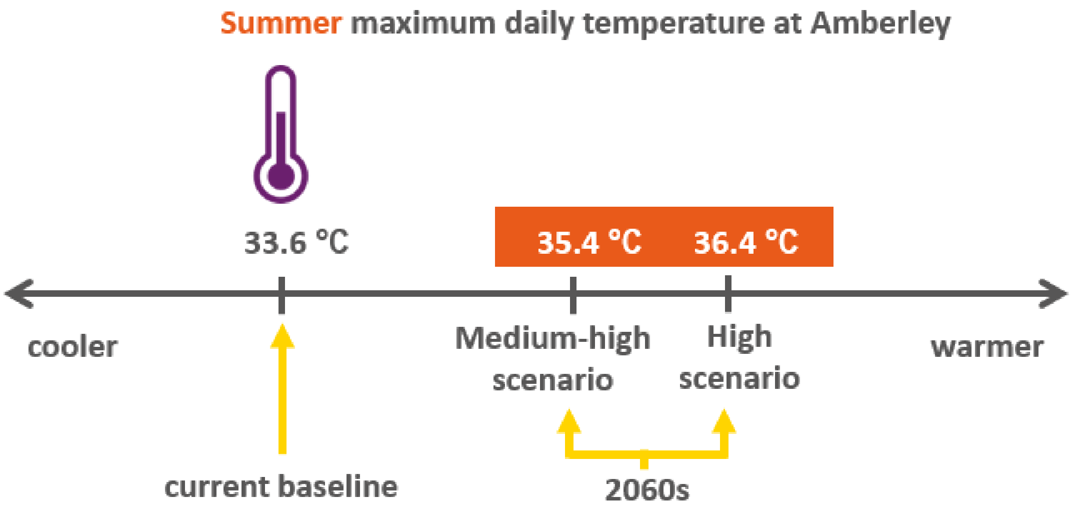

Figure 5 Summer maximum daily temperature (°C). Source Mott MacDonald, using data from UK Met Office (UK Met Office, 2018a). Contains public sector information licensed under the Open Government Licence v3.0. Current baseline values indicate the average maximum temperature during the summers of 1981-2010 were 33.6°C. The projected future maximum summer temperature by the 2060s is projected to be 35.4°C under the Medium-high scenario, or 36.4°C under the High scenario.

Precipitation changes

Figure 6 shows that winter average daily precipitation is projected to increase to between 9.0mm/day (medium-high scenario) and 9.4mm/day (high scenario). Summers are projected to become drier, with reductions in summer average daily rainfall down to 4.5mm/day (medium-high scenario) or to 4.1mm/day (high scenario).

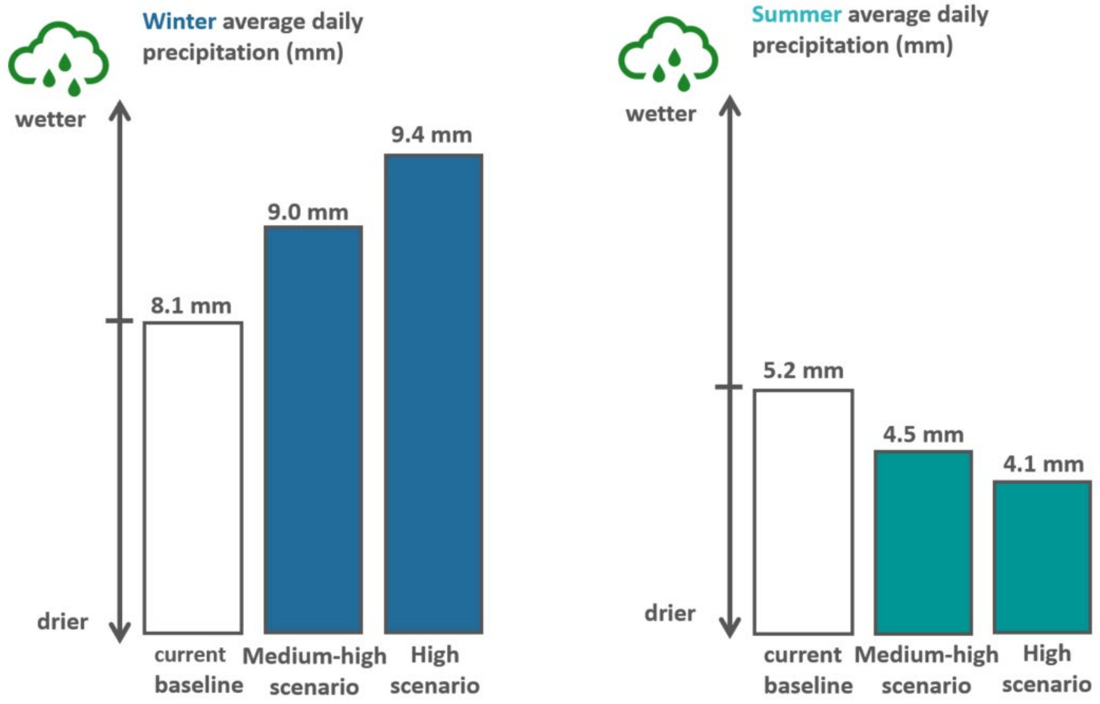

Figure 6 average daily precipitation (mm). Source Mott MacDonald, using data from UK Met Office (UK Met Office, 2018a). Contains public sector information licensed under the Open Government Licence v3.0. The first white bars indicate baseline values (averaged over 1981-2010) showing a daily precipitation of 8.1mm in winter and 5.2mm and in summer. The second and third bars indicate potential future precipitation levels under the Medium-high and High scenarios. Future daily rainfall in the 2060s under the Medium-high scenario may increase to 9.0mm in winter and decrease to 4.5mm in summer. Under the High scenario, rainfall may increase to 9.4mm in winter and decrease to 4.1mm in summer.

As well as changes to average daily precipitation, climate change and hotter air are able to carry more moisture, which may mean that heavy rainfall events are more frequent and higher in intensity. Table 5 outlines projected future extreme precipitation intensities (mm).

Table 5 Future total rainfall volumes (absolute value) for extreme rainfall events.

Variable	Season	Medium-high scenario		High scenario	
		20-year return period	100-year return period	20-year return period	100-year return period
5-day total precipitation (mm)	**Winter**	86.3	93.9	88.2	95.7
	Summer	75.1	86.7	74.6	86.3
1-day total precipitation (mm)	**Winter**	40.4	51.5	41.6	53.2
	Summer	45.1	59.7	45.3	60

Sea level rise

By 2060, marine projections for mean sea level rise (using the marine simulations UKCP18 product, 50th percentile value for coastal grid square [50.72, -0.58]) project rises of between +31.7 to +38.4cm as shown in Figure 7. Note that due to limitations of the UKCP18 dataset, RCP6.0 data was not available and so RCP4.5 data has been used as an alternative for the medium emissions scenario, though this represents a lower level of GHG emissions than RCP6.0.

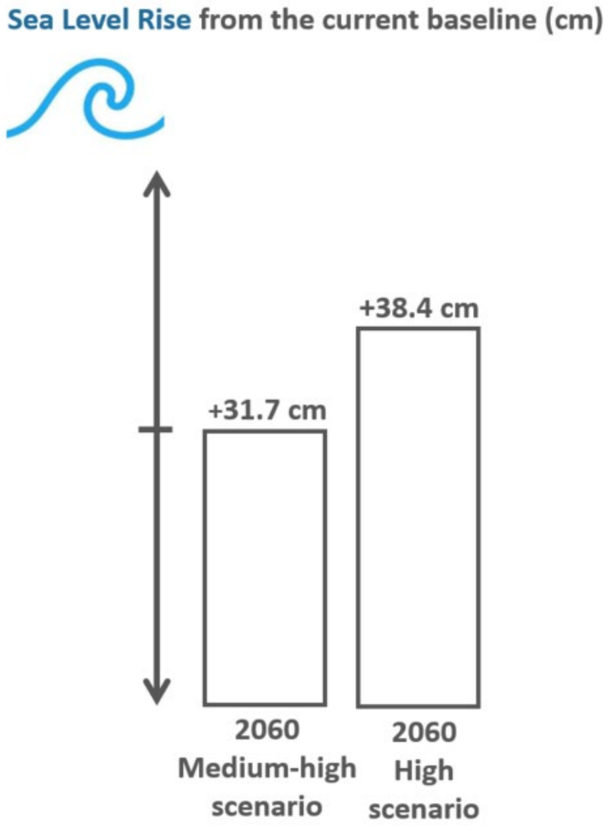

Figure 7 Projected sea level rise by 2060. Source Mott MacDonald, using data from UK Met Office (UK Met Office, 2018a). Contains public sector information licensed under the Open Government Licence v3.0. The columns indicate the potential increase in sea level by the 2060s, from current levels. Under the Medium-high scenario, mean sea levels at the southern coast of England at the mouth of the river Arun could be 31.7cm higher. Under the High scenario, mean sea level could be 38.4cm higher.

Sea level rise will cause the tidal upper limit of the River Arun to move upstream, affecting saline intrusion at the site.

In addition to rises in mean sea level, the maximum wave height during storm surges and resultant tidal extent of the River Arun may vary however there is high uncertainty in the extent of impacts of climate change upon storm surge levels. However, projections suggest that changes in storm surge levels due to climate change may be relatively small compared to variation in mean sea levels (UK Met Office, 2018d).

Hydrological changes

Changes in rainfall patterns locally as well as across the wider catchment can have an impact on the hydrology of the site and affect water levels in the drains and ditches as well as flooding conditions.

Wetter winters and increases in the frequency and intensity of extreme rainfall will affect river flows and water levels with the potential to increase the frequency and magnitude of flooding across the site. This can be directly from pluvial (i.e., rainfall falling directly onto the site and ponding or causing localised flooding), groundwater or fluvial sources:

- More frequent overtopping of the River Arun which has the potential to drive prolonged periods of flooding and increase the risk of pollution from introducing water of degraded quality onto the site.
- Increases in rainfall, which will drive increased flows entering the Wild Brook Stream from its intermediate catchment, bringing higher inflows to the site and higher water levels as it flows east to west towards the embanked River Arun. Water quality deterioration may occur from higher runoff rates draining sediments, nutrients, pesticides from the upstream catchment, which can pose an additional risk of pollution to the site.
- Higher groundwater recharge during the winter, which could lead to increased groundwater levels. The Wild Brook Stream takes its source from the South Downs aquifer and is thus susceptible to higher springs flow rates, bringing more alkaline waters onto the site.
- The connection of the Wild Brook Stream with the underlying Folkestone Beds, which may also lead to increased water levels at the site.

Conversely, drier summers (reduced average daily rainfall) together with increases in the frequency and intensity of high summer temperatures may lead to increased soil moisture deficits, driving lower water levels in drains and ditches and increased drought conditions across the site. Summer recharge rates may be further reduced in summer as heavy downpours on compacted soils following drought conditions may not infiltrate as effectively in the future. The vulnerability of chalk aquifers to drought conditions may have an impact onto water levels at the site, from decreased flows in the Wild Brook Stream during the summer period.

Furthermore, increases in sea levels may lead to more frequent tide-locking conditions, where drainage of flood waters experience restrictions due to high river levels, particularly during winter due to higher water levels in the River Arun. Sea level rise is also causing the tidal prism to move further upstream, increasing the residence time of salt water and other pollutants at the site and affecting the ability to drain water out of the site.

There is anecdotal evidence of saline intrusion onto the site. Whilst this needs to be supported by monitoring of salinity across the site, sea level rise and lower flows during the summer have the potential to push the saline interface further upstream and increase the risk of saline intrusion through seepage under the embankment and through the sluice structures.

Climate proxies

In addition to identifying potential future climate baseline values, examples of other regions where these climates are already being experienced were identified to provide evidence of the types of natural habitats that are able to function under such climates. Through desk-based review of climate and ecological data, two regions in France were identified with having similar climates to the potential future climate at the site.

Under the Medium-high scenario, in 2060 the climate at Amberley Wild Brooks SSSI may be similar to the present day (1981-2000) climate at Pays-de-la-Loire; with the region currently experiencing an annual average temperature of 12.0°C. The region contains multiple Special Areas of Conservation (SACs) as part of the Natura 2000 network, a network of Community areas for the protection of priority habitats and species (French Republic, 2023; INPN, 2023). One of them is the Erdre Marshes SAC which contains an assemblage of habitats including marshes/peatland (40%) and waterbodies (e.g., pools and streams) (35%) within a wide floodplain. Species present on site include *Myotis, Rhodeus amarus, Euplagia quadripunctaria, Luronium natans, Unio crassus, Coenagrion mercurial, Lucanus cervus, Cerambyx cerdo, Triturus cristatus, Rhinolophus ferrumequinum, Barbastella barbastellus,* and *Myotis emarginatus*. Other species present can be found on the designation specification of the site (Natura 2000, 2023a, Section 3.3).

Under the High scenario, in 2060 the climate at Amberley Wild Brooks SSSI may resemble the present day (1981-2000) climate at Poitou Charentes which has an average annual temperature of 12.47°C. The Poitou Charentes region is home to multiple SACs and protected species including birds, invertebrates, molluscs and plants (INPN, 2023). One of those sites are the Brandes of Montmorillon, characterised by nearly 50% of lowland heath, 20% of arable land and 20% meadows as well as localised peatland (<1%). Some species of interest include *Myotis myotis, Luronium natans, Caldesia parnassifolia, Leucorrhinia pectoralis, Coenagrion mercuriale, Lycaena dispar, Euphydryas aurinia, Leucanus cervus, Cerambyx cerdo, Triturus cristatus, Emys orbicularis, Rhinolophus hipposideros, Rhinolophus ferrumequinum, Barbastella barbastellus, Myotis emarginatus* and *Myotis bechsteinii*. Other species present can be found on the designation specification of the site (Natura 2000, 2023b, Section 3.3).

Figure 8 shows the geographical location of these climate proxy sites. It must be noted that whilst the selected sites represent climate proxies, there are other factors such as historical land use, water management strategies and local geology that will affect the assemblage of species and habitats present.

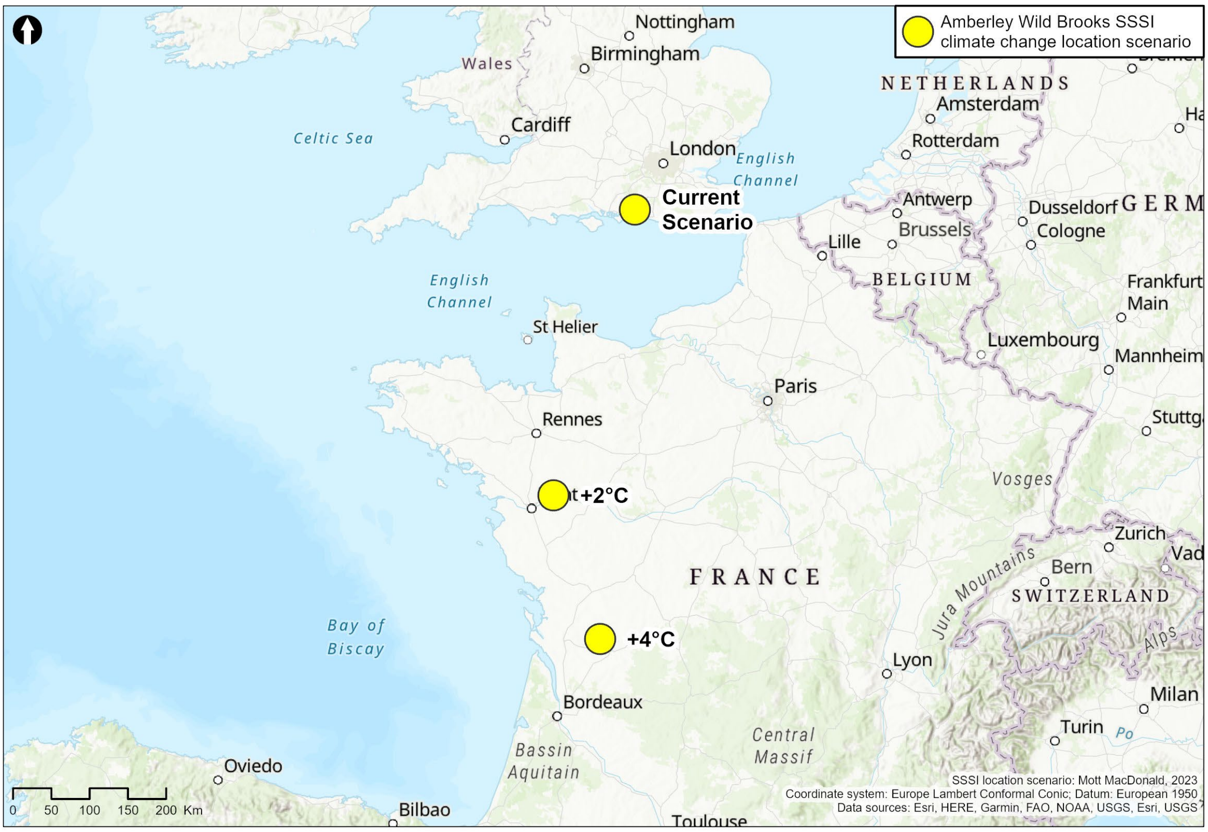

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Figure 8 Geographical locations of climate proxies. Source: Mott MacDonald. The small circles indicate the geographical location of the climate proxies for the current climate (Amberley Wildbrooks), a +2°C scenario (Pays-de-la-Loire) and a +4°C scenario (Poitou Charentes). Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors and the GIS User Community.

Climate hazards

As a result of changing climate and hydrological conditions in the future, there are a range of climate risks to features at the site. The direct risks from climate change that have been identified are:

- Increases in river levels and flow, leading to:
    - Increase in frequency and magnitude of bank overtopping and flooding of site
    - Introduction of contaminants to site and deterioration in water quality
    - Higher water level on site – unable to discharge
- Increased risk of drought, leading to:
    - Reduced water levels and increased frequency of drought conditions
    - Concentration of pollutants and deterioration in water quality
    - Soil moisture deficit and Increased peat oxidation and erosion
- Higher average winter temperatures, leading to:
    - Increase in length of growing season

    - Colonisation by INNS
    - Increased incidence of pests and diseases
    - Loss of wintering birds which may remain closer to breeding grounds
    - Increased release of nutrients from sediments
    - Increased water temperature affecting water quality
- Increased saline intrusion due to sea level rise and increased overtopping, leading to:
    - Sea level rise causing tidal prism to move further upriver
    - Increased frequency of flood bank overtopping
    - Increase in brackish water on site
    - Change in invertebrate and flora community composition
    - Deterioration in water quality
- Increased frequency and intensity of storms (combined high winds and heavy rainfall), leading to:
    - More intense and frequent storms – high winds and intense rainfall
    - Intense rainfall – surface compaction and reduced infiltration
    - Increase in direct rainfall on the site
    - Increased frequency of flood bank overtopping
    - Higher water level on site – unable to discharge
- Increased frequency and intensity of heatwaves, leading to:
    - Increasing frequency of eutrophic conditions
    - Extreme temperatures exceed tolerance of some species
    - Heatwave coupled with drought could lead to drying out of site, potentially increasing the risk of wildfire
- Higher average summer temperatures leading to:
    - Increase in length of growing season
    - Colonisation by INNS
    - New arrivals and loss of species as species range shift north
    - Increase in release of nutrients from sediments

Risk Assessment

Climate change impacts on site features and vulnerability assessment

Table 6 provides a summary of the identified impacts on each of the site features against the Medium-high and High scenarios

Risk assessments for the impacts identified against each individual climate hazard are available in the vulnerability assessment supplementary information (NECR504 Supplementary Information)

Table 6 Summary of potential climate impacts and overall vulnerability rating of each feature to climate hazards

Feature	Hazard							Risk Rating for 2060s	
	Increase in river levels and flows	Drought	Higher winter temperatures	Saline intrusion	Storms (high intensity and volume of rainfall)	Heatwaves	Increase in average summer temperatures	Medium-high scenario	High scenario
Breeding birds (Redshank, *Tringa totanus*)	Displacement of breeding to drier sites outside SSSI in early spring. However, potential for land use change in the wider landscape creating potential habitat creation. Lower reproductive success as nesting habitat and feeding area compromised. Changes to groundwater and surface water supply (e.g., chalk and green sands springs).	Lower reproductive success as not suitable conditions for nests. Lower survival rate of broods due to limited access to water and invertebrates. Habitat succession. Changes to groundwater and surface water supply (e.g., chalk and green sands springs).	Sward height causing a loss in feeding habitats for breeding waders, leading to a change in species abundance and/or distribution.	Change in prey assemblage Change in vegetation community - impact on sward height	Loss of foraging habitat leading to decline in redshank population.	Sward height causing a loss in feeding habitats for breeding waders, leading to a change in species abundance and/or distribution	Increase in food availability for chick rearing. Sward height causing a loss in feeding habitats for breeding waders, leading to a change in species abundance and/or distribution	**<75%**	**>75%**

Feature	Hazard							Risk Rating for 2060s	
	Increase in river levels and flows	Drought	Higher winter temperatures	Saline intrusion	Storms (high intensity and volume of rainfall)	Heatwaves	Increase in average summer temperatures	Medium-high scenario	High scenario
	Currently in unfavourable condition								
Non-breeding birds (Bewick's swan, *Cygnus columbianus bewickii*, Shoveler, *Anas clypeata*, Teal, *Anas crecca*, variety of wintering species)	Loss of foraging habitat leading to a decline in populations	Habitat succession due to changes in foraging habitat	Loss of sensitive species due to migratory short stopping	Change in prey assemblage	Loss of foraging habitat leading to a decline in populations	Loss of foraging habitat due to INNS dominance	N/A	**<50%**	**>75%**
Dragonfly	Changes in physico-chemical qualities (e.g., oxygenation, nutrients and poisonous chemicals). Lower reproductive success as	Conversion to 'Litter-rich fluctuating wetland' or 'Grassland and scrub matrix' assemblage types. Lower reproductive success and	Conversion to 'Litter-rich fluctuating wetland' or 'Grassland and scrub matrix' assemblage types. Loss of sensitive	Loss of sensitive species. Reduced breeding success and potential species loss as a result of changes in salinity	Changes in physico-chemical qualities (e.g., oxygenation, nutrients and poisonous chemicals). Reduced breeding	Changes in physico-chemical qualities (e.g., oxygenation, nutrients and poisonous chemicals). Reduced breeding success	Change in prey assemblage composition and availability	**<75%**	**>75%**

Feature	Hazard							Risk Rating for 2060s	
	Increase in river levels and flows	Drought	Higher winter temperatures	Saline intrusion	Storms (high intensity and volume of rainfall)	Heatwaves	Increase in average summer temperatures	Medium-high scenario	High scenario
	larvae are washed away and prey concentrations are reduced by flood events. Potential increased larval dispersal due to higher river flows	potential species loss as breeding water bodies dry up, larvae perish, and adults seek alternative breeding ponds.	species. Reduced breeding success as water bodies become choked with vegetation and the rate of succession increases.	within breeding habitat.	success and potential species loss because of reduced flying time during adult stages leading to reduced hunting/ feeding time, lower chance of finding a mate and less egg-laying time.	because of INNS dominance leading to lower prey biomass.		🟧	🟥
RDB Mollusc	Changes in physico-chemical qualities (e.g., oxygenation, nutrients and poisonous chemicals). Potential beneficial impacts due to increased oxygenation and increased dispersal from higher flows	Loss of principal habitat	Population decline due to changes in the winter water quality	Population decline as a result of changes in salinity within habitat.	Extreme intensive rainfall causing disturbance to population	Changes in physico-chemical qualities (e.g., oxygenation, nutrients and poisonous chemicals)	Population decline	**>75%**	**>75%**

Feature	**Hazard**							**Risk Rating for 2060s**	
	Increase in river levels and flows	Drought	Higher winter temperatures	Saline intrusion	Storms (high intensity and volume of rainfall)	Heatwaves	Increase in average summer temperatures	Medium-high scenario	High scenario
RDB plant (*Carex vulpina*, True Fox-sedge)	Flooded winter conditions are suitable for Carex vulpina, which can sometimes persist in areas of standing water.	Plants likely to die off in unsuitable dry conditions, especially where droughts were repeated in successive years without water level management, over time plants would likely not recover and disappear from site.	Greater encroachment of taller and denser sward causing Carex vulpina to be shaded out. Plant thrives in well-lit conditions. This could cause loss in Carex vulpina abundance and distribution at the site.	Change in species assemblage. Carex vulpina not tolerant to salt (across UK it is absent from saline sites).	Possible decline in Carex vulpina presence and distribution.	Decrease in Carex vulpina presence on site due to unsuitable temperatures, increased dry and unsuitable site conditions and uncreased shading through encroachment of other taller plants and shrubs.	Decrease in Carex vulpina presence on site due to unsuitable temperatures, increased dry and unsuitable site conditions and uncreased shading through encroachment of other taller plants and shrubs.	**<75%**	**>75%**
Schedule 8 plant (*Leersia oryzoides*, Cut-grass)	N/A	Plants unable to survive in consistent dry conditions, especially if conditions persisted in successive years, resulting in reduction in population and distribution across site.	Greater encroachment of taller and denser sward causing Leersia oryzoides to be shaded out. Plant thrives in well-lit conditions. This could cause loss in abundance and distribution at the site.	Change in species assemblage. Leersia oryzoides not tolerant to salt (across UK it is absent from saline sites).	Extreme intensive rainfall causing disturbance to population	Decrease in population and distribution across site due to unsuitable temperatures, increased dry and unsuitable site conditions and increased shading through encroachment of other taller	Grazing and mowing regime to reduce encroachment of other species. Water level management to compensate for increase in drier conditions.	**<50%**	**>75%**

Feature	Hazard							Risk Rating for 2060s	
	Increase in river levels and flows	Drought	Higher winter temperatures	Saline intrusion	Storms (high intensity and volume of rainfall)	Heatwaves	Increase in average summer temperatures	Medium-high scenario	High scenario
						plants and shrubs.			
Invertebrate assemblage W211 open water on disturbed sediments	Changes in physico-chemical qualities (e.g., oxygenation, nutrients and poisonous chemicals). Lower reproductive success as aquatic life stages are washed away by flood events.	Conversion to 'Litter-rich fluctuating wetland' or 'Grassland and scrub matrix' assemblage types. Lower reproductive success and potential species loss as breeding water bodies dry up.	Conversion to 'Litter-rich fluctuating wetland' or 'Grassland and scrub matrix' assemblage types. Loss of sensitive species.	Reduced breeding success and potential species loss as a result of changes in salinity within breeding habitat.	Changes in physico-chemical qualities (e.g., oxygenation, nutrients and poisonous chemicals). Lower reproductive success as aquatic life stages are washed away by flood events.	Changes in physico-chemical qualities (e.g., oxygenation, nutrients and poisonous chemicals)	Change in assemblage composition	**<75%**	**>75%**
Ditches	N/A	Hydrological disconnection causing ditches to dry out and loss of vital habitat	N/A	N/A	N/A	Poor ecological status (water quality)	Poor ecological status (water quality)	**<75%**	**>75%**

Feature	Hazard							Risk Rating for 2060s	
	Increase in river levels and flows	Drought	Higher winter temperatures	Saline intrusion	Storms (high intensity and volume of rainfall)	Heatwaves	Increase in average summer temperatures	Medium-high scenario	High scenario
Vascular plants	Flooded winter conditions will be suitable for many wet habitat species, but not in minority of site with dry habitat (particularly woodland), and even in wet habitats, some species may not persist in areas of standing water.	Plants dying off in unsuitable dry conditions, especially where droughts were repeated in successive years without water level management - wetland habitats particularly vulnerable. Smaller dry woodland habitats will be less resilient to heat and drought than larger woodlands.	Changes in species composition, possible encroachment of taller and denser sward.	Change in species assemblages (and eventually habitat types). Many species will be intolerant to saline conditions and will have reduced survival and growth.	Possible changes in habitat composition and richness. Some plants will not be tolerant of standing water conditions. But increase in water table could be beneficial.	Changes in species composition and habitat type over time, particularly in hydrological sensitive habitats - wet grassland, wet woodland, ditches, raised peat bog. Potential loss of sensitive habitats over successive years of prolonged drought.	Changes in species composition and habitat type over time, particularly in hydrological sensitive habitats - wet grassland, wet woodland, ditches, raised peat bog. Resulting in loss of sensitive habitats over successive years of drought.	**<75%**	**>75%**
Assemblages of breeding birds (Mixed: Lowland damp grassland, Woodland)	Displacement of breeding to drier sites outside SSSI in early spring	Lower reproductive success as not suitable conditions for nests. Lower survival rate of broods due to limited access	Sward height causing a loss in feeding habitats for breeding waders, leading to a change in species abundance	Change in prey assemblage (grassland abundance decreases)	Damage to prey assemblage and breeding areas leading to a loss of sensitive species	Sward height causing a loss in feeding habitats for breeding waders, leading to a change in species abundance	Habitat succession	**<50%**	**>75%**

Feature	Hazard							Risk Rating for 2060s	
	Increase in river levels and flows	Drought	Higher winter temperatures	Saline intrusion	Storms (high intensity and volume of rainfall)	Heatwaves	Increase in average summer temperatures	Medium-high scenario	High scenario
		to water and invertebrates	and/or distribution			and/or distribution		🟨	🟥
Raised peat bog	Potential increase in suitable water-logged conditions, though high nutrient levels can disaggregate peat structure. Possible erosion of peat.	Soil moisture deficit Drying out and compacting of soil structure and oxidising existing peat. Reducing likelihood of raised bog habitat recovery.		Altered nutrient status, effecting species assemblage for any potential peat bog recovery.	May effect peat bog recovery, depending on condition of peat, causing erosion of peat.	Conditions slowing any potential recovery of peat bog habitat through loss of water and peat, the latter of which would take a long time to replace.	Conditions slowing any potential recovery of peat bog habitat through loss of water and peat, the latter of which would take a long time to replace.	**<75%**	**>75%**

Adaptation Options – how to respond to change

Resist – Accept – Direct (RAD) framework

Supporting the adaptation of ecosystems to the impacts of climate change will require working with ecological transformations, rather than working to maintain a static set of habitat conditions or features. The RAD framework can be used to help decision makers to strategically identify and select viable adaptation options to support conservation efforts (US NPS, 2022).

The RAD framework is simple and flexible, allowing managers to identify and select climate adaptation approaches to support healthy ecological transformation and pursue a desired outcome. These future outcomes could be natural ecological functions, or a different form of managed natural environment and set of conserved features, if this is the desired outcome.

Adaptation options can seek to Resist change and strive to maintain existing ecosystem composition, structure, and function; Accept transformation when it is not feasible to resist change or when changes are deemed acceptable; or Direct change to a future ecosystem configuration that would yield desirable outcomes (Thompson and others, 2020).

Deciding which approaches to utilise at different site locations and time horizons will depend on identifying desired outcomes by determining what ‘good’ could look like for that habitat. From these desired outcomes, the most appropriate approach and range of adaptation actions can be determined.

Options for the site

Table 7 outlines a menu of possible adaptation actions identified under the RAD framework. This summary includes the main options identified for each feature but also includes options that may be applicable at site level, affecting all features of the SSSI.

The menu of identified options are non-prescriptive and are intended to be used as guidance for future decision-making regarding achievable, desired future condition and function and the adaptation actions required to support this. The menu can be used by stakeholders to understand available options and to support decisions around whether to pursue a Resist, Accept or Direct approach and then the most applicable adaptation options to achieve viable future desired conditions for the site. Different approaches may be appropriate in different locations and on different time horizons and the overall management of the site should be flexible and may require switching between approaches. For example, adaptation approaches may focus on resisting change for a period of time, and then shifting to a Direct approach once a set of tipping points are reached, to help move the site into a new state, which once reached is maintained under a new set of Resist actions.

The adaptation approach may also vary spatially across the site for the different units / habitat types and features, based on their differing vulnerability ratings. Site managers should consider local context and trade-offs to decide what is best for their site.

In this way, future management actions accept and can work within ongoing environmental change and ecosystem evolution, which will ideally lead to supporting a naturally functioning site that is more resilient to continuously evolving climatic, hydrological and ecological conditions.

A more detailed breakdown of adaptation options for each feature, against each potential impact of climate change are available in NECR(SI).

Selection of options

When selecting viable, desirable future states and selecting adaptation approaches, costs, benefits and trade-offs should be considered for each approach, as well as the available actions under each approach.

Legal considerations and funding availability to pursue different approaches and specific adaptation options will also need to be considered. Tactical / practical challenges will also need to be identified and addressed. Knock-on impacts on other sustainability drives, such as carbon mitigation and ecosystem services at the site or across networks of sites must also be considered.

For each approach (Resist, Accept, Direct), managers should first identify what ‘good’ could look like and relevant conditions / functions that might indicate this positive outcome. From this desired end-goal, a menu of possible adaptation options can then be implemented to support transformation to this outcome, with the proviso for flexible management approaches and periodic review of outcomes in future as climate change impacts and risks to habitats and species become more certain.

It should be recognised that resisting ecological change under future climate conditions may become untenable and increasingly costly in the future and so resisting adaptation may need reviewing and adjusting over time or be used in tandem with other approaches. Accepting change may be the most easily achievable approach however risks losing some or all features on the site. Accept and Direct options also need to consider not only resultant changes at Amberley Wild Brooks SSSI but other vulnerabilities and adaptation approaches nationally, reflecting that protected sites sit in a wider landscape, and management approaches across the network of sites within that landscape determine the specific approaches taken at individual sites.

As migration patterns change and species distributions shift north and to higher altitudes, SSSI designations and features may choose to accept this trend. These decisions need to be embedded in national and regional planning, to make sure that species are not lost entirely, and translocation can be managed, for example, by creation of compensatory habitats outside of Amberley Wild Brooks SSSI. Less mobile species, with lower adaptive capacity under this approach may be benefit less from this approach and may need alternative consideration.

The outputs of the AES project and their effectiveness in reducing vulnerability of SSSIs to climate change may also be useful in guiding the choice of measures to be adopted at Amberley Wild Brooks SSSI. That project has reviewed SSSI vulnerability and assessed AES options to identify the extent to which they may reduce vulnerability to climate hazards. The spatial potential of the project may additionally be beneficial on a landscape scale. The preliminary output of the GIS for Amberley Wild Brooks SSSI is in Appendix C.

Monitoring

Under any approach, monitoring will be essential to understand the impact of the adaptation options upon condition, while taking into account the effects of climate change on condition. Comparative monitoring for similar habitats and sites may form part of this to identify the response of species and habitats to the changing climate.

Monitoring will support flexibility of approach, allowing a shift from one approach to another, which may be required to support reaching a defined desired outcome or to decide a change of outcome.

Determining what ‘good’ looks like

For a species, habitat or functional ecosystem, stakeholders must identify and agree on what the future intended desired state is, the timeline for which this outcome should be achieved, with periodic review built into the adaptive management plan to allow for reassessment as confidence in future conditions increases, before then identifying the suite of options to be implemented across years and decades that will support sites to transition onto this path.

Decision making may involve further studies into what future features / colonizers at the site could potentially be before identifying actions to develop these new ecosystems and natural functions. Agreement amongst landowners is needed for what ‘good’ may look like and what indicators should be used to assess progress. Indicators may include presence and condition of species and habitats or consider ecosystem functioning. Negative indicators should also be identified and monitored under all scenarios e.g., INNS and water quality.

Resist

Following a Resist approach, a desirable future state might be the return and maintenance to favourable condition of current designated features through increased investment and effective implementation of flood embankment maintenance and WLMP agreements by all stakeholders. This may be appropriate, for example, to facilitate stable breeding bird assemblages with successful reproduction rates.

In the face of increasing environmental change, the extra resource required to Resist change would need to be justified by the Adaptive (RAD) Management Plan.

Accept

Under an Accept approach, a desired future state may allow changes in the features as hydrology and other climatic factors and effects alter under climate change, leading to a new natural state with a different ecosystem and functional features.

This approach may mean accepting loss of the most sensitive species such as the RDB Mollusc (*Anisus vorticulus*) and other bird and plant species. In place, new colonisers may be encouraged such as species that thrive under different flood conditions and which are less sensitive to changes in water quality and salinity levels.

Reproduction rates of breeding birds may be allowed to diminish, focusing instead on certain species, incoming species, or by accepting species loss at the site coupled with creation of compensatory habitats created at other sites in order to reduce national decline.

Additional research would be required to explore the viability of such an approach, at a landscape scale, with likely negative consequences for many species even with translocation mitigations.

This approach may support the conservation of raised peat bogs, which are currently not a designated feature, through gradual restoration of the hydrological integrity of the site. Additional research will be required to understand not only ecological implications of an

Accept approach, but the legal requirements and monitoring options for the site if it is agreed that features will be lost.

Direct

Under a Direct approach, a desired future state may also look like a different set of habitats and ecosystem functions that can be achieved under a quicker timescale to reduce stress on those features that are to be conserved.

For the Amberley Wild Brooks SSSI, an example desired outcome could be to enhance natural functioning of the site. This may allow the site to have greater adaptive capacity to further climate change and create the most sustainable long-term outlook.

Water level management plans could be altered, ditches infilled, and flood banks removed to support site flooding by brackish water and a quicker transition to a new naturally functioning water level. This outcome would increase the resilience of a wide range of site features, including incoming species, to climate change impacts, but would result in the loss of some current features (which are at high climate change risk under current management). Further research into what these natural functions could be under future climate conditions will be required to support decision-making, as well as the legal and practical requirements to enable ecosystem transformation.

Spatial RAD

Considering the network of SSSIs across the landscape, it may be decided that Amberley Wild Brooks SSSI should focus on a Resist approach to conserve certain functions and features important at a landscape scale, whilst other features are encouraged to follow an Accept or Direct approach.

This may include, for example, accepting the loss of some species that are less regionally scarce in order to focus on creating favourable conditions for others for which Amberley Wild Brooks SSSI is regionally an important site. These decisions would be part of the considerations of financial, practical and legal restraints for landowners and managers, and the overall consideration of natural functioning of the site.

Temporal RAD

An adaptive management plan needs to be adaptable, however as the effects of climate change and response of the natural environment become more apparent over time given time and experience, outcomes may need to be reviewed and change. Resisting change may become untenable in the future economically, so key is to have a preferred outcome (for example Resist), supported by a Plan B (Accept or Direct) supported by monitoring and periodic reviews.

Table 7 Summary of potential adaptation options.

Climate Hazard	Intervention			Recommended monitoring
	Resist	Accept	Direct	
Increase in river levels and flows	1) Update and agree the WLMP and winter water level management with landowners, including buy-in to WLMP from all stakeholders. 2) Increase standard of protection of the flood embankment or changes to flood embankment footprint itself. 3) Increased maintenance of ditches to remove sedimentation.	1) Let the site flood and not maintain the WLMP. 2) Accept arrival of new features and review SSSI designated features. 3) Still maintain the site to reduce negative pressures on the natural ecosystem function (soil pollution, water pollution, INNS). 4) Set and manage new water quality requirements based on more regular flooding, saline intrusion and sedimentation. 5) Combine accept options with creation of compensatory habitats (at Amberley or other sites nationally).	1) Review current site governance to update the traditional management practices. 2) Alter the mosaic flooding of the site by filling in ditches, enabling creation of a naturally functioning wetland floodplain and lowland damp grassland habitat. This may impact species population, leading to a change in conservation management and increase in compensatory habitats elsewhere. 3) Review SSSI designated features to determine if a new ecosystem is suitable for species. 4) Maintain a higher water table through control of valves to allow flooding. 5) If new habitat does not support species population, provide compensatory wetland habitat. Identify opportunities for freshwater habitat creation adjacent to the SSSI. 6) Alter INNS management due to anticipated increase in INNS due to new flood levels.	1) Monitor species population size, abundance and reproductive success, and winter water levels. 2) Monitor known and potential new INNS. 3) Monitoring of water quality and water levels

Climate Hazard	Intervention			Recommended monitoring
	Resist	Accept	Direct	
Drought	1) Update and agree the WLMP and review management of summer water levels with land owners. 2) Create low lying scrapes to maintain wetted areas for longer periods. 3) Use grazing management on Phragmites (common reed) in late successional ditches/fen (whilst avoiding overgrazing and trampling). 4) Work with stakeholders to restore groundwater to natural states to support wetland function through reductions to abstraction rates.	1) Provide no remediation for drought and do not maintain any summer water levels in the site. 2) Allow ditch hydrological disconnections to occur. 3) Accept prolonged winter flooding to assist in remediating the wetland. 4) Accept arrival of new features and review SSSI designated features. 5) Still maintain the site to reduce negative pressures on the natural ecosystem function (soil pollution, water pollution, INNS). 6) Combine Accept options with creation of compensatory habitats (at Amberley or other sites nationally).	1) Review current site governance to update the traditional management practices. 2) Review SSSI designated features to determine if a new ecosystem is suitable for species. 3) Alter the hydrological connection of the site by filling in the ditches to enable the creation of a wetland floodplain. This may impact the species population, leading to a change in conservation management and increase in compensatory habitats elsewhere. 4) If new habitat does not support species population, provide compensatory wetland habitat to accommodate the impacted species and ensure the biological communities are able to translocate to a suitable nearby location. Identify opportunities to protect/create “Ark sites” within SSSI and/or freshwater habitat creation adjacent to the SSSI.	1) Monitor species population size, abundance and reproductive success; and summer and winter water levels (suitable conditions are in combination of winter and summer conditions). 2) Monitoring of water quality and water levels
Higher winter temperatures	1) Increase over-winter grazing, mowing and weed-wiping to minimise sward and maximise wet grassland distribution. 2) Carry out removal	1) Accept habitat succession, sward growth and vegetation change. 2) Cease grazing and mowing targeted at sward growth on the site.	1) Review current site governance to update the traditional management practices. 2) Engage with landowners to optimise a new vegetation structure and density. This may impact the species population, leading to a change in conservation management	1) Monitor species population size, abundance and reproductive success, and vegetation characteristics.

Climate Hazard	Intervention			Recommended monitoring
	Resist	**Accept**	**Direct**	
	works of the invasive species to eradicate future growth. 3) Update and agree the WLMP and winter water level management with land owners to minimise shallow water, increases in water temperatures and release of nutrients from sediments. Effective implementation of WLMP.	3) Do not maintain the WLMP - allow the site to naturally flood/dry and accept higher water temperatures. 4) Accept arrival of new features and review SSSI designated features. 5) Still maintain the site to reduce negative pressures on the natural ecosystem function (soil pollution, water pollution, INNS). 6) Combine Accept options with creation of compensatory habitats (at Amberley or other sites nationally).	and increase in compensatory habitats elsewhere. 3) If new habitat does not support species population, provide compensatory wetland habitat to accommodate the impacted species and ensure the biological communities are able to translocate to a suitable nearby location. Identify opportunities to protect/create "Ark sites" within SSSI.	2) Monitor changes in the species to determine if invasive species are forming or taller/scrub species encroaching and need further management. 3) Monitor water quality and winter water levels.
Saline intrusion	1) Increase standard of protection of the flood embankment and maintenance of downstream structures to prevent inflow from river onto the site. 2) Update the WLMP to control sluice levels and tidal flaps,	1) Accept increasingly saline conditions and growth of habitats that flourish under saline conditions. 2) Accept arrival of new features and review SSSI designated features. 3) Still maintain the site to reduce negative pressures on the natural ecosystem function (soil pollution, water pollution, INNS).	1) Review current site governance to update the traditional management practices. 2) Encourage soil invertebrates/plants that thrive on higher saline conditions which may impact the species population, leading to a change in conservation management and increase in compensatory habitats elsewhere. 3) If new habitat does not support species population, provide compensatory wetland habitat to accommodate the impacted	1) Monitor the water quality to determine salinity levels in the site. 2) Monitor species assemblage composition. 3) Monitoring of key prey species (food availability) and

Climate Hazard	Intervention			Recommended monitoring
	Resist	Accept	Direct	
		4) Combine accept options with creation of compensatory habitats (at Amberley or other sites nationally),	species and ensure the biological communities are able to translocate to a suitable nearby location. Identify opportunities to protect/create "Ark sites" within SSSI.	tree/grassland abundance and health.
Storms (high intensity and volume of rainfall)	1) Manage sluices during/after a storm to allow flood waters to drain. 2) Increase standard of protection of the flood embankment and update WLMP.	1) Do not manage storm water levels and allow the site to remain flooded after storm rainfall. 2) Do not remediate areas/species that are damaged due to high winds. 3) Accept arrival of new features and review SSSI designated features. 4) Still maintain the site to reduce negative pressures on the natural ecosystem function (soil pollution, water pollution, INNS). 5) Combine Accept options with creation of compensatory habitats (at Amberley or other sites nationally).	1) Review current site governance to update the traditional management practices. 2) If new habitat does not support species population, provide compensatory wetland habitat that can be managed post-storm (grasslands recuperated) to accommodate the impacted species and ensure the biological communities are able to translocate to a suitable nearby location. 3) Where woodland/trees are felled due to high winds and/or saturated ground, leave woodland to naturally regenerate, and/or reinstate lost habitats at location less susceptible to flooding.	1) Monitor species population size, abundance and reproductive success. 2) Monitor flooding frequency and winter/summer storm water levels.

Climate Hazard	Intervention			Recommended monitoring
	Resist	Accept	Direct	
Heatwaves	1) Grazing can be considered later in season and more intensive or rotational grazing. 2) Carry out removal works of invasive species to eradicate future growth. 3) Sheltered areas (refugia) as protection from summer temperatures and sunshine intensity. 4) Update and agree the WLMP and review management of summer water levels with land owners to minimise shallow water and increases in water temperatures and decrease in water quality. 5) Block off some ditches and create scrapes in wet grassland to increase likelihood of water being maintained on site.	1) Accept habitat succession, sward growth and vegetation change. 2) Cease grazing and mowing targeted at sward growth on the site. 3) Do not maintain the WLMP - allow the site to naturally flood/dry and accept higher water temperatures. 4) Accept arrival of new features and review SSSI designated features. 5) Still maintain the site to reduce negative pressures on the natural ecosystem function (soil pollution, water pollution, INNS). 6) Combine Accept options with creation of compensatory habitats (at Amberley or other sites nationally)	1) Review current site governance to update the traditional management practices. 2) Engage with landowners to optimise a new vegetation structure and density that will be more resilient and adaptive to heatwaves and does not need increased maintenance. This may impact the species population, leading to a change in conservation management and increase in compensatory habitats elsewhere. 3) If new habitat does not support species population, provide compensatory wetland habitat to accommodate the impacted species and ensure the biological communities are able to translocate to a suitable nearby location. 4) Identify opportunities to protect/create "Ark sites" within SSSI.	1) Monitor species population size, abundance and reproductive success, and vegetation characteristics. 2) Monitor changes in the species to determine if invasive species are forming. 3) Monitor ditch water levels and water quality in summer.
Increase in average	1) Grazing can be considered later in season	1) Accept habitat succession, sward growth and vegetation	1) Review current site governance to update the traditional management practices.	1) Monitor changes in the species to

Climate Hazard	Intervention			Recommended monitoring
	Resist	Accept	Direct	
summer temperatures	and more intensive or rotational grazing. 2) Carry out removal works of invasive species to eradicate future growth. 3) Sheltered areas (refugia) as protection from summer temperatures and sunshine intensity. 4) Update and agree the WLMP and review management of summer water levels with land owners.	change. 2) Cease grazing and mowing targeted at sward growth on the site. 3) Provide no remediation for drought and do not maintain any summer water levels in the site. 4) Allow ditch hydrological disconnections to occur. 5) Accept arrival of new features and review SSSI designated features. 6) Still maintain the site to reduce negative pressures on the natural ecosystem function (soil pollution, water pollution, INNS). 7) Combine accept options with creation of compensatory habitats (at Amberley or other sites nationally).	2) Engage with landowners to optimise a new vegetation structure and density in parts of the SSSI with suitable habitat. This may impact the species population, leading to a change in conservation management and increase in compensatory habitats elsewhere. 3) Alter the hydrological connection of the site by filling in the ditches to enable the creation of a wetland floodplain. 4) If new habitat does not support species population, provide compensatory wetland habitat to accommodate the impacted species and ensure the biological communities are able to translocate to a suitable nearby location.	determine if invasive species are forming. 2) Monitor species and habitat composition and summer water ditch levels.

Conclusions and next steps

This report provides an initial evidence base to help land managers understand how climate is projected to change at Amberley Wild Brooks SSSI and how this might impact site features, both due to direct climate risks affecting the site as well as exacerbating existing pressures. The report also introduces the RAD framework for identifying and selecting management approaches and sets out options for management of the site under each of the Resist, Accept, Direct categories.

Prior to agreeing changes to management approach(es) for Amberley Wild Brooks SSSI, further research into a number of areas is recommended, which will help inform this decision making. Additional work is required to understand:

- Risks at a species level. This study has been conducted at the feature level. Since some species may be particularly sensitive to certain climate risks or indirect risks identified, further research into these species and their adaptive capacity may be required before deciding whether those features should Resist change, Accept change or be Directed to a new state.
- Potential change across a network of protected sites (i.e., landscape scale). SSSIs do not operate in silo but as a network of habitats, particularly for migratory species. As such, further research will be required across the SSSI network to develop a national picture of vulnerability to climate change and to help inform a national-level RAD strategy. From this, the adaptation approaches for Amberley Wild Brooks SSSI as well as other individual sites may be determined. Research should also seek to understand site dependencies and interactions between sites, for example, as species ranges shift and regional water resource management evolves, including water management and abstraction within sites and within the wider catchments.
- What ‘good’ could look like under different RAD approaches. When selecting RAD approaches, a common understanding of what ‘good’ could look like, will be required at both a national and regional level, as well as at the site level. Research into what natural functions and features may thrive under future, non-stationary climate and hydrological baselines and what future colonizers of the site may be under different approaches is required. Desired future states may look different for different stakeholders and stakeholder engagement and consensus building will be central to defining what ‘good’ will look like.
- What is needed to implement options under the different RAD approaches. Assessing the legal, policy, funding and stakeholder implications of potential options presented in this report was outside the scope of this study but would need further exploration before a management plan for the site can be developed.

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Glossary

Term	Definition
Adaptation	A change in natural or human systems in response to the impacts of climate change. These changes moderate harm or exploit beneficial opportunities and can be in response to actual or expected impacts.
Adaptive capacity	The ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, take advantage of opportunities, or cope with the consequences. Adaptive capacity can be an inherent property of the system, i.e., it can be a spontaneous or autonomous response. Alternatively, adaptive capacity may depend upon policy, planning and design decisions carried out in response to, or in anticipation of, changes in climatic conditions
Climate change scenario	A plausible description of the change in climate by a certain time in the future. These scenarios are developed using models of the Earth's climate, which are based upon scientific understanding of the way that the land, ocean and atmosphere interact and their responses to factors that can influence climate in the future, such as greenhouse gas emissions.
Climate variable	Surface variables such as temperature, precipitation, and wind.
Climate Hazard	The potential occurrence of a climatic or weather event or climatic trend that may cause impacts to exposed features such as damage, death or changes in condition.
Climate Risk	The potential for adverse consequences where something of value is at stake and where the occurrence and degree of an outcome is uncertain. In the context of the assessment of climate impacts, the term risk is often used to refer to the potential for adverse consequences of a climate-related hazard. Risk results from the interaction of vulnerability (of the affected feature), its exposure over

Term	Definition
	time (to the hazard), as well as the (climate-related) hazard and the likelihood of its occurrence.
Climate Impact	In the context of climate change, an effect of climate change on the environment. This may be detrimental or beneficial and may be either as a direct consequence of climate change, or as a result of a human response to climate change.
Ecosystem	A dynamic complex of plant, animal, and microorganism communities and their non-living environment, interacting as a functional unit.
Exposure	The presence of a feature in places and settings that could be adversely affected by a climate hazard.
Extreme weather	Unusual, severe or unseasonal weather, or weather at the extremes of the range of weather seen in the past.
Feature	Special geological or biological assets (such as habitats or species) within an area which are the cause for that area to be designated as a site of special scientific interest (SSSI).
Greenhouse gas emissions	A number of gases whose presence in the atmosphere traps energy radiated by the Earth, known as the greenhouse effect. These gases can be produced and emitted into the atmosphere through natural or human processes. Carbon dioxide is the most important greenhouse gas. Other gases are methane, fluorinated gases, ozone and nitrous oxide.
Invasive non-native species (INNS)	A species living outside its native distribution range, which has arrived there by human activity, either deliberate or accidental. Non-native species can have a variety of effects on the local ecosystem. Where that effect is negative, they are known as invasive.
Projection	A plausible description of the future and the pathway that leads to it. Projections are not predictions. Projections include assumptions, for example, on future socio-

Term	Definition
	economic and technological developments, which might or might not happen. They therefore come with some uncertainties.
Resilience	The ability of a social or ecological system to absorb disturbances while retaining the same basic ways of functioning, and a capacity to adapt to stress and change.
Special Protection Areas (SPAs)	Protected sites designated under the Conservation (Natural Habitats, &c.) Regulations 1994 in transposition of the EU Birds Directive. The Directive requires the identification and classification of Special Protection Areas (SPAs) for rare or vulnerable species listed in Annex I of the Directive, as well as for all regularly occurring migratory species, paying particular attention to the protection of wetlands of international importance. Together with SACs, these form the 'Natura 2000' series of sites. All terrestrial SPAs are also designated as SSSIs.
Sensitivity	The degree to which a system is affected, either adversely or beneficially, by climate variability or change.
Sites of Special Scientific Interest (SSSI)	Nationally important sites designated by Natural England under the Wildlife and Countryside Act 1981 for being 'of special interest by reason of any of its flora, fauna, or geological or physiographical features'. Legislation and policy provide a high level of protection for these sites.
Translocation	The deliberate movement of species' populations that are unable to move in response to climate change and would otherwise be 'stranded', to areas expected to be more suitable for their survival.
Vulnerability	In this context, the degree to which an individual, environmental feature or a system is susceptible to the adverse effects of climate change. Vulnerability is influenced by the system's sensitivity and its adaptive capacity, as well as the magnitude of the change

Appendix A

Limitations and assumptions

The assessment in this report is based on freely available information available from third parties for reporting purposes. This includes observational data from local weather stations, a number of readily available climate change projections and a range of existing climate change datasets and literature at the time of writing this assessment. The following limitations and disclaimer should be noted:

Climate change projections:

- Climate projections are not predictions or forecasts but simulations of potential scenarios of future climate under a range of hypothetical emissions scenarios and assumptions. The results, therefore, from the experiments performed by climate models cannot be treated as exact or factual, but projection options. They represent internally consistent representations of how the climate may evolve in response to a range of potential forcing scenarios and their reliability varies between climate variables. For a single emission scenario, projections can vary significantly as a function of the model used and how it is applied, so that there is a wide uncertainty band in the results. Scenarios exclude outlying “surprise” or “disaster” scenarios in the literature and any scenario necessarily includes subjective elements and is open to various interpretations. Generally global projections are more certain than regional, and temperature projections more certain than those for precipitation. Further, the degree of uncertainty associated with all climate change projections increases for projections further into the future. Climate models and associated projections are updated on a regular basis, implying changes in the forecasted future climate.
- Global Climate Models (GCMs) are averaged over a large spatial area and therefore come with data limitations related to extreme values. They do not adequately resolve extremes like storms, wind or changes in their characteristics. Statistical downscaling of climate models to a site-specific detail, as has been carried out by the UK Met Office for the UKCP18 probabilistic projections, has been undertaken using accepted procedures as published in the scientific literature. However, these techniques cannot remove all potential bias, in particular as regards extremes. They also rely on the stationarity of the derived statistical relationships, an assumption that cannot be verified.
- Reliability of the environmental modelling used to investigate the localised impact of climate change depends not only on the accuracy of the climate projections adopted but also on the existence of good quality calibration data and of detailed information to characterise the physical properties of the area. Even when this information exists, a model can never fully replicate the complexity in the natural environment and there will always be uncertainty about its performance when applied to different climate conditions to those used during calibration.

- Any environmental modelling exercise is an approximation of the real natural processes and has its own uncertainty related to the choice of model and its configuration, its spatial and temporal resolution, and the information used for its calibration. We follow accepted procedures in providing this modelling work, but results need to be interpreted in light of the related overall uncertainty.
- All climate scenarios are equally plausible. It is thus not possible to provide a definitive scenario for climate change and therefore ranges will be identified highlighting where there is confidence and where there is uncertainty.

Data validation:

- Climate modelling is beyond the scope of this Project. Reliance has been made solely on publicly available data on climate projections in this region, which in several cases is limited. Mott MacDonald has not independently verified the observational or projection data and does not accept responsibility or liability for any inaccuracies or shortcomings in this information. Should these information sources be modified by these third parties we assume no responsibility for any of the resulting inaccuracies in any of our reports. Issued reports are relevant to the project information provided and are not intended to address changes in project configuration or modifications which occur over time. The data is obtained to provide a general ‘sense check’ on the published literature on existing observational and climate projections for the region. Accordingly, any further research, analysis or decision-making should take account of the nature of the data sources and climate projections and should consider the range of literature, additional observational data, evidence and research available - and any recent developments in these.

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