Adaptation Committee




Research to review and update indicators of climate-related risks and actions in England

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1 INTRODUCTION

1.1 Background

In order for the Adaptation Committee of the Committee on Climate Change (CCC) to report to parliament on progress in adapting to climate change in England, the Adaptation Committee uses an evaluation method based on a two-part framework. The first part relates to the assessment of analysis of trends in indicators of change that relate to climate change risks and adaptation. The second part assesses the extent to which planning for climate change is taking place, including whether climate-sensitive plans and policies are adequately considering the risks and opportunities from climate change.

The Adaptation Committee applies this framework across a number of defined 'adaptation priorities' to understand if there is a plan in place; whether actions are being implemented; and effects of actions in managing vulnerability. The Adaptation Committee use a set of metrics and indicators to assess and track changes in climate change risks and adaptation, whereby observed changes are monitored through time (using key data and information) across three core components of adaptation: indicators of risk, indicators of adaptation action, and indicators of climate impact.

There are a number of 'types' of indicator the Adaptation Committee use for their assessment of adaptation progress in England. These comprise indicators to assess trends in risk factors (hazard, vulnerability and exposure), as well as indicators to assess trends in adaptation action (input and output), and impacts.

To enable the Adaptation Committee to comprehensively apply this framework and provide up-to-date information in the next report to Parliament in 2021 assessing the government's progress on the second National Adaptation Programme (NAP), a number of metrics and indicators that form the basis of this assessment require updating.

1.2 Research purpose

This research reviews a subset of the Adaptation Committee's full indicator set. The subset of indicators updated in this study were identified by the Adaptation Committee as part of the procurement process for this project. ADAS were not involved with the selection of indicators chosen to be updated. It is recognised that there may be alternative indicators that could also be suitable to demonstrate progress in adaptation, however these were not considered within the scope of this project.

The subset of indicators assessed by ADAS in this project provides supporting evidence to inform current understanding of adaptation progress being made in England. It is expected that these indicators will be used by the Adaptation Committee, alongside other indicators within the full indicator set, to inform the Adaptation Committee's 2021 report to government. The purpose of this research is not to provide a comprehensive or representative overview of adaptation progress in England, rather it is intended to provide updated indicators (within the context of climate resilience) to inform the Adaptation Committee of the current evidence base.

1.3 Approach

In total, nine indicators of climate-related risk and actions are assessed in this report, which may be of relevance to various sectors including the built environment, infrastructure, the natural environment (including agriculture, forestry and fisheries), people and health, and business. The data and information obtained came through a range of sources through consultation with stakeholders and industry representatives, and web-based searches.

For each indicator, a high-level description is provided and reference to the 'type of indicator it is categorised as under the Adaptation Committee's assessment.

1.3.1 Updated indicators

Where robust datasets were available, with suitable metrics to demonstrate change over time, indicators have been updated or developed to provide trends and allow interpretation of the data for climate resilience. For each updated indicator, we provide detail on the data sources and methods used, outline the trends and implications for climate resilience, and assess the robustness of the indicator as a measure of assessing climate-related risks and actions.

1.3.2 Updated evidence bases

Where datasets or suitable metrics were not available to update or develop an indicator, the evidence base was updated instead. For this, we provide detail on the available information, which may include industry insight, ad hoc data, grey literature, maps etc.

1.4 Scope and interpretation of climate

The project scope was for England only. However, for some indicators and evidence bases, disaggregated data was not available. In these instances, the data represented will include England, but not be completely attributable at a regional level (e.g. if data is for England and Wales, or the United Kingdom).

In this study we provided analysis of the available data and information. It is noted that some indicators are not purely climate driven, may not have a high (or any) sensitivity to climate change, and in fact require other drivers. Subsequently, indicators should be interpreted with caution and not used in isolation or out of context.

2 INDICATORS UPDATED

The indicators in this section are part of the Adaptation Committee's indicator set and were updated with new data and analysis as part of this study.

2.1 Rate of development of properties in areas at risk of flooding

Description: *Rate of development of residential and non-residential properties in areas at risk of flooding*

Type: *Exposure*

Time series: *2018 to 2020*

Region: *England*

2.1.1 Introduction

This indicator was last updated by ADAS (2019). The indicator provides an assessment of the development of residential and non-residential properties that are being carried out within areas of flood risk to understand changes and trends in exposure and vulnerability of property to flooding. This update provides new data for 2020.

2.1.2 Data source and method

This method examines the impact of two different sources of flooding on properties, following on from work previously carried out by HR Wallingford (2015). The 'Risk of Flooding from Rivers and Sea' (RoFRS) and 'Risk of Flooding from Surface Water' (RoFSW). Both these datasets identify areas of High (each year, there is a chance of flooding of greater than 1 in 30), Medium (each year, there is a chance of flooding of between 1 in 30 and 1 in 100) and Low (each year, there is a chance of flooding of between 1 in 100 and 1 in 1000) flood risk.

Property data was provided by the latest OS AddressBase layer. This layer provides a classification code for each property, which provides information on the property type. Previous studies of properties at risk have classified properties into multi-coloured manual (MCM) codes: dwelling, retail, offices, warehouses, leisure, public buildings, industry and miscellaneous. Therefore, in order to maintain consistency with previous studies, the AddressBase codes were matched to an MCM code: dwelling (MCM_0), retail (MCM_2), offices (MCM_3), warehouses (MCM_4), leisure (MCM_5), public Buildings (MCM_6), industry (MCM_8) and miscellaneous (MCM_9). Spatial analysis was then carried out to identify which (if any) flood risk area each property was within, and the local authority it was within, enabling summaries by local authority, MCM code and flood risk.

It is recognised that this analysis used different property data to that used previously; with AddressBase Premium used in ADAS (2019), while this analysis was carried out using AddressBase Plus. The main difference between the two datasets is the level of content provided.

- AddressBase Premium provides the most detailed view of an address and its life cycle for England, Wales and Scotland, including all the information relating to an address or property from creation to retirement. This level of data requires more processing than that of other products in the AddressBase product range.

- AddressBase Plus is a more refined and smaller product than AddressBase Premium and was used to reduce the size of the data that needed to be sent and processed. AddressBase Plus contains current properties including addresses sourced from Local Authorities, Ordnance Survey and Royal Mail, all provided with an UPRN (Unique Property Reference Number) for England, Wales and Scotland.

Consequently, this resulted in differences in the categories of properties included in the analysis (e.g. AddressBase Premium incudes pre-build and historic addresses, whilst AddressBase Plus does not). Due to the differences in these datasets, it was therefore not possible to robustly evaluate an ongoing trend for this report. However, future updates of this indicator using AddressBase Plus will be comparable.

2.1.3 Trends and implications for climate resilience

2.1.3.1 *Risk of flooding from rivers and sea*

Changes in the number of properties at risk from flooding is likely to be a combination of changes to the flood risk extents, and changes in property numbers resulting from the underlying datasets used (see 2.1.2).

The percentages of the total numbers of properties per local authority that are in high, medium and low flood risk areas are shown on maps in Figure 1. The total number of properties in each risk area are reported in Table 1.

Table 1. Number of properties at risk from flooding from rivers and sea for England by property type. Source: ADAS for the CCC.

Property type	High Likelihood of flooding	Medium Likelihood of flooding	Low Likelihood of flooding	Very low Likelihood of flooding	Total
Dwelling	132,625	472,915	842,798	580,215	2,028,553
Retail	8,446	22,616	33,342	17,773	82,177
Offices	5,674	14,734	20,769	17,767	58,944
Warehouses	9,983	23,583	30,309	11,412	75,287
Leisure	8,867	7,655	13,764	4,991	35,277
Public Buildings	2,284	5,702	8,407	4,172	20,565
Industry	3,034	6,381	5,469	2,224	17,108
Miscellaneous	12,952	17,447	26,410	17,214	74,023

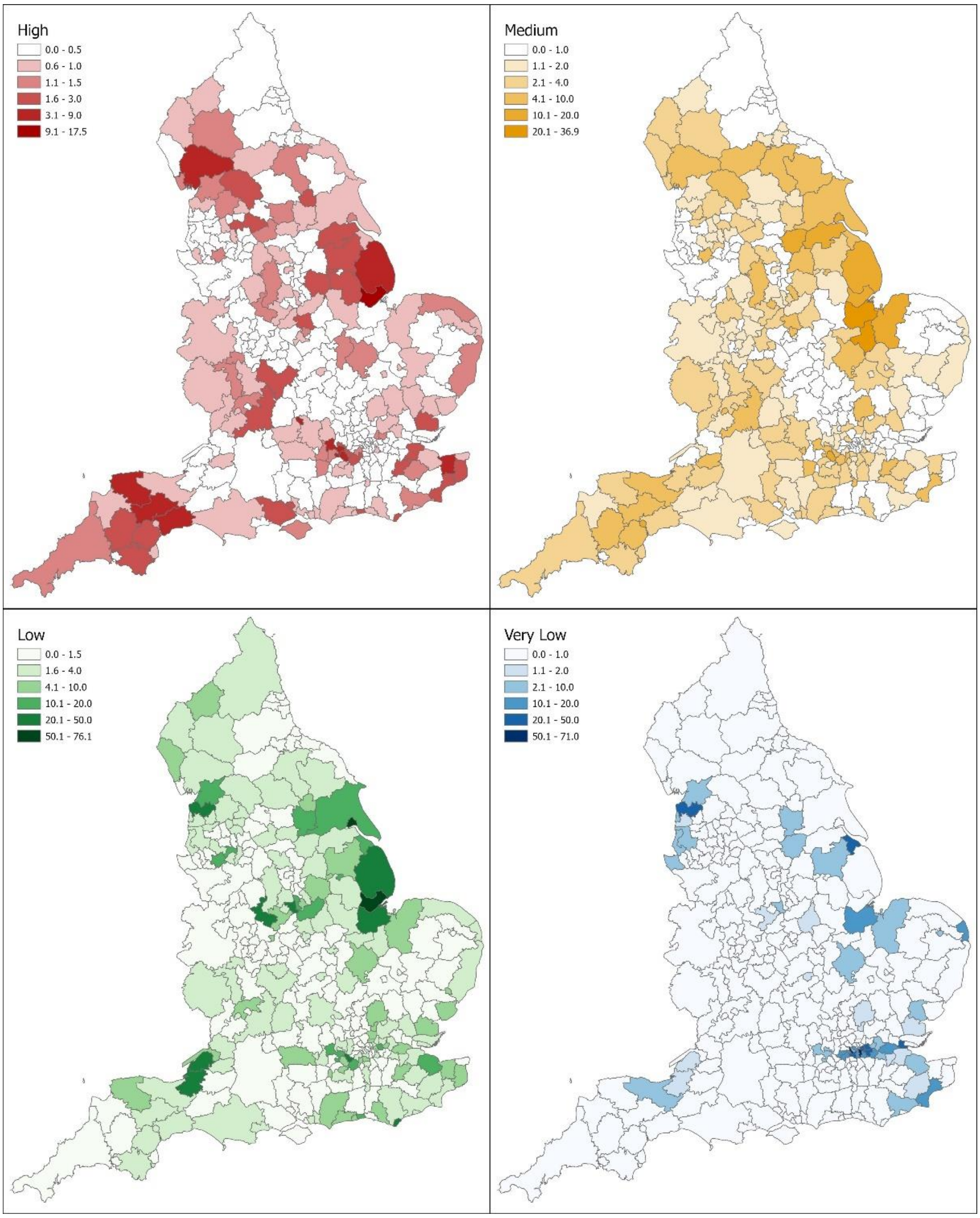

Figure 1. Percentage of properties in each Local Authority at High (a), Medium (b) Low (c) and Very low (d) risk of flooding from rivers and sea in England. Source: ADAS for the CCC.

2.1.3.2 *Risk of flooding from surface water*

As with the analysis for the risk of flooding from rivers and sea, the analysis for the risk of flooding from surface water is likely to yield different results to those in previous analysis, due to differences in the AddressBase data used, therefore an assessment of trend was not undertaken. Table 2 shows the number of properties at risk at each risk level.

Table 2. Number of properties at risk from flooding from Surface Water for England by property type. Source: ADAS for the CCC.

Property type	3.3% probability	1% probability	0.1% probability	Total
Dwelling	116,860	259,775	938,122	1,314,757
Retail	4,172	9,769	38,113	52,054
Offices	2,110	5,616	20,444	28,170
Warehouses	2,518	5,604	22,662	30,784
Leisure	1,441	2,786	9,527	13,754
Public Buildings	2,119	4,907	16,365	23,391
Industry	2,335	4,550	12,572	19,457
Miscellaneous	11,829	23,589	66,231	101,649

Across all of the risk levels, the south-east consistently has a high percentage of properties at risk of surface water flooding (Figure 2).

Flood Map for Planning (Rivers and Sea)

Analysis was also carried out to calculate the number of properties within the Environment Agency 'Flood Map for Planning' zones. These results are displayed in Table 3 for each property type, as defined by the relevant multi-coloured manual (MCM) reference code. The percentage of properties in the planning flood map remained roughly similar to 2018. The greatest increase in percentage of properties in flood zones 2 & 3 was in MCM_5 (Leisure) and MCM_4 (Warehouses). It is anticipated that this is partly due to differences in the underlying dataset (i.e. AddressBase Plus being used instead of AddressBase Premium). Most other property types saw a decrease in the percentage of properties inside flood zone 2 and flood zone 3 between 2018 and 2020.

Table 3. Percentage of properties in each flood zone (numbers for each zone have been calculated individually) for each property type, as defined by the relevant multi-coloured manual reference code. Source: ADAS for the CCC.

	Percentage of properties (%)		Change (2018-2020)	
Property type	Zone 3	Zone 2	Zone 3	Zone 2
Dwelling	5.6	8.0	-0.1	-0.2
Retail	8.0	12.5	-0.5	-0.4
Offices	9.3	14.6	-0.2	-0.2
Warehouses	10.9	16.5	1.3	2.0
Leisure	14.4	18.7	1.4	2.2
Public Buildings	6.8	9.8	-0.3	-0.5
Industry	9.7	13.2	0.1	0.0
Miscellaneous	9.5	13.5	-0.6	-0.6

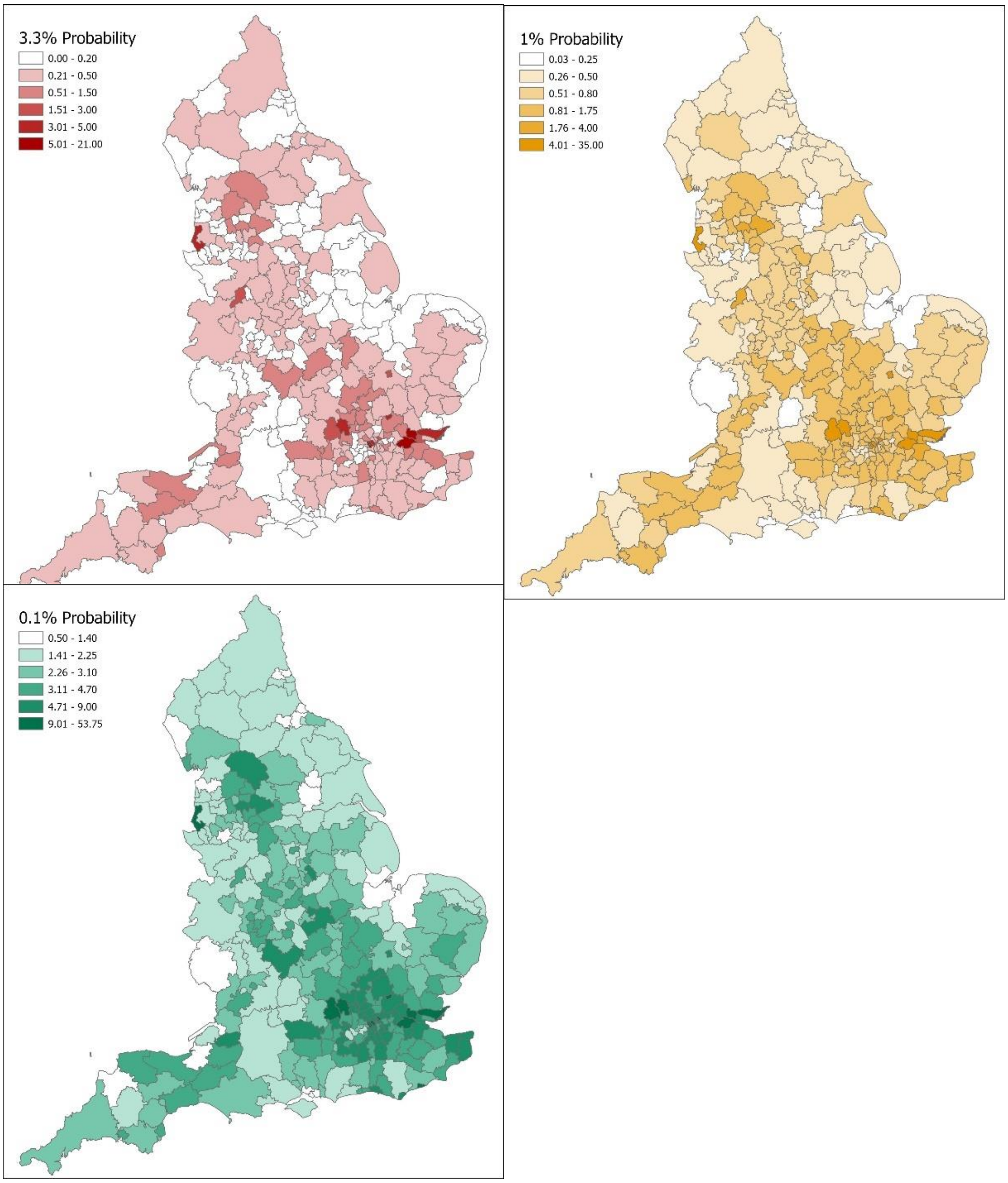

Figure 2. Percentage of properties in each Local Authority with a 3.3% (a), 1% (b) and 0.1% (c) probability of flooding from surface water in England. Source: ADAS for the CCC.

2.1.4 Robustness of indicator

In this analysis, AddressBase classification codes had to be converted to MCM codes; used in the original analysis by HR Wallingford (2015). This amalgamation into MCM categories may have some differences to the methods used previously, since details on the MCM classification used by HR Wallingford was not available.

Furthermore, as previously mentioned, the use of different Addressbase data (Plus rather than Premium) will lead to some differences in property numbers and the types of properties included in the analysis. Additional properties are included in the Addressbase Premium product, which leads to an apparent decrease in most property types for 2020 where the Addressbase Plus product has been used. Additional analysis could be carried out to reanalyse the 2018 data to match the latest Addressbase (Plus) data. This would allow for a better comparison between the years to be carried out.

2.2 Area of impermeable surfacing in urban areas

Description: *Area of impermeable surfacing in urban areas*

Type: *Vulnerability*

Time Series: *2001 to 2020*

Region: *England*

2.2.1 Introduction

This indicator was last updated by ADAS (2019). The indicator provides the relative proportions of manmade and natural surfaces in the urban environment, in England, between 2001 and 2020. This update provides new data and analysis for 2020.

2.2.2 Data source and method

The 'Topography' layer of Ordnance Survey's MasterMap product (the most detailed digital mapping available nationally) records the surface material of each land parcel as "Natural", "Manmade" or "Multiple". The area categorised as "Manmade" is assumed to be impermeable. The "Multiple" category represents domestic gardens, which is assumed to be a mixture of permeable and impermeable surfaces. A methodology was developed by HR Wallingford (2012) to estimate the impermeable fraction of this category based on urban creep research under the assumption that estimated urban creep rates could be applied to these areas to determine the potential likely increase in intra-urban impermeable areas. The same method has been used for this indicator update.

Data was sourced from HR Wallingford (2012) for 2001, 2008 and 2011 data, and ADAS (2019) for 2016 and 2018 data. 2020 data is new analysis as part of this project.

To define the urban (built-up) area, up-to-date OS AddressBase Plus data was used to calculate the property density per 1km grid cell. Two methods were used to define the urban area:

- Method 1: Uses the method first developed by HR Wallingford (2012) that uses a property density of >500 properties per 1km cell to identify the urban area. This method is comparable to previous impermeable calculations dating back to 2001.
- Method 2: Improved to include larger areas of greenspace within cities and towns, which are not captured in method 1. This improved approach takes account of the values of the neighbouring cells by taking an average of the central cell and its surrounding eight cells. This smooths the values, better defines the edge of urban areas and accounts for city centre greenspace. The original mask using > 500 properties per 1km cell was added to the revised mask to ensure inclusion of smaller settlements that would be missed by the revised method. This method is comparable to previous impermeable calculations carried out in 2016 by ADAS (2017).

The urban creep method (Gill et al., 2008) used the property density to assign a housing class to each grid cell (Table 4). The impervious fractions of the "Multiple" areas were then estimated per housing class by adding the annual creep (quantified at differing housing densities by Gill et al. (2008)) to the impervious flat fraction of the 2001 baseline (Table 5) and then adding this the impervious pitched fraction to get a total impervious fraction.

Table 4. Mean address points per hectare for each housing class. Source: Gill et al. (2008).

Urban classification	Mean address points/ ha	Class break
High density residential	47.3	37.1
Medium density residential	26.8	20.8
Low density residential	14.8	-

Table 5. Baseline data for surface type percentages of domestic gardens by housing class in 2001. Source: Gill et al. (2008).

Classification	Pervious	Impervious pitched	Impervious flat
Low density	57.3%	16.3%	26.4%
Medium density	42.7%	29%	28.3%
High density	15.6%	50%	34.4%

2.2.3 Trends and implications for climate resilience

The area of built-up areas covered by impermeable surfaces is outlined for both methods of urban area calculation.

2.2.3.1 Method 1

The area of impermeable surfaces in urban areas is shown in Table 6 and Figure 3 for the current analysis (2020), alongside previous updates of this indicator in 2001, 2008 and 2011 (HR Wallingford, 2012), 2016 (ADAS, 2017) and 2018 (ADAS, 2019).

The total impermeable area (manmade and multiple (impermeable)) has increased by 143,000 hectares, from 477,000 hectares in 2001 to 621,000 hectares in 2020. The impermeable fraction of the total urban area has increased from 37% in 2001 to 45% in 2020.

Since 2018, the total impermeable area has remained consistent at 621,000 hectares. The manmade area however has increased by 10,000 hectares, whilst the multiple (impermeable) area has decreased by 10,000 hectares. The impermeable fraction of the total urban area (1,383,000 hectares in 2020) has remained stable at 45%.

Table 6. Area of built-up urban areas covered by impermeable surfaces as estimated using OS MasterMap and using assumptions of urban creep (Method 1). Data sourced from HR Wallingford (2012) for 2001, 2008 and 2011 data and ADAS (2019) for 2016 and 2018 data. 2020 data is new analysis as part of this project. Source: ADAS for the CCC.

Thousand ha	2001	2008	2011	2016	2018	2020
Manmade	384	398	401	429	451	461
Multiple (impermeable)	94	142	163	160	170	160
Total impermeable area	**477**	**540**	**565**	**589**	**621**	**621**
Total urban area	1,298	1,297	1,296	1,332	1,383	1,383
Impermeable fraction	0.37	0.42	0.44	0.44	0.45	0.45

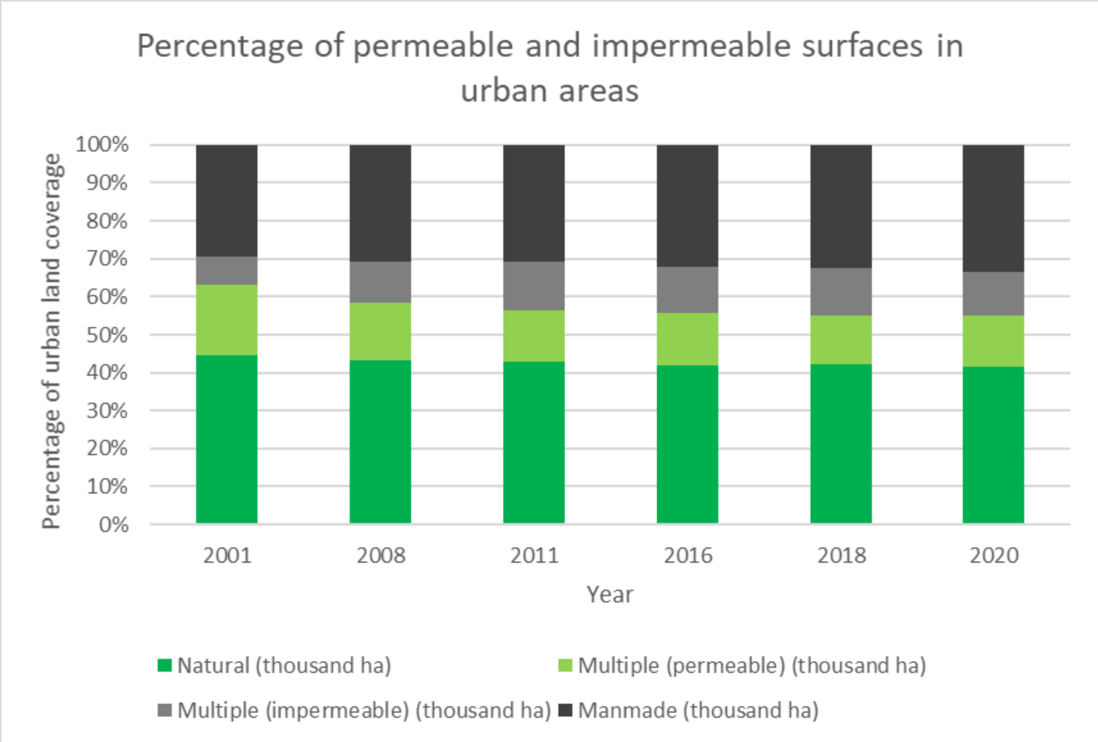

Figure 3. Changes in the proportion of permeable and impermeable surfaces in built-up urban areas in 2001, 2008, 2011, 2016, 2018 and 2020 (urban areas defined using method 1). Data sourced from HR Wallingford (2012) for 2001, 2008 and 2011 data and ADAS (2019) for 2016 and 2018 data. 2020 data is new analysis as part of this project. Source: ADAS for the CCC.

2.2.3.2 Method 2

Area of impermeable surfaces is shown for the current analysis (2020) and previous analyses of this indicator in 2016 (ADAS, 2017) and 2018 (ADAS, 2019). Results are shown in Table 7 and Figure 4.

Table 7. Area of built-up urban areas covered by impermeable surfaces as estimated using OS MasterMap and using assumptions of urban creep (Method 2). Data sourced from ADAS (2019) for 2016 and 2018 data. 2020 data is new analysis as part of this project. Source: ADAS for the CCC.

Thousand ha	2016	2018	2020
Manmade	498	509	520
Multiple (impermeable)	184	180	170
Total impermeable area	**682**	**689**	**690**
Total urban area	1,772	1,730	1,720
Impermeable fraction	0.38	0.40	0.40

As with the first method (2.2.3.1), the overall impermeable area fraction has remained stable at 40% of the total urban area. The impermeable fraction is lower in all years compared to Method 1 due to the inclusion of more urban greenspace.

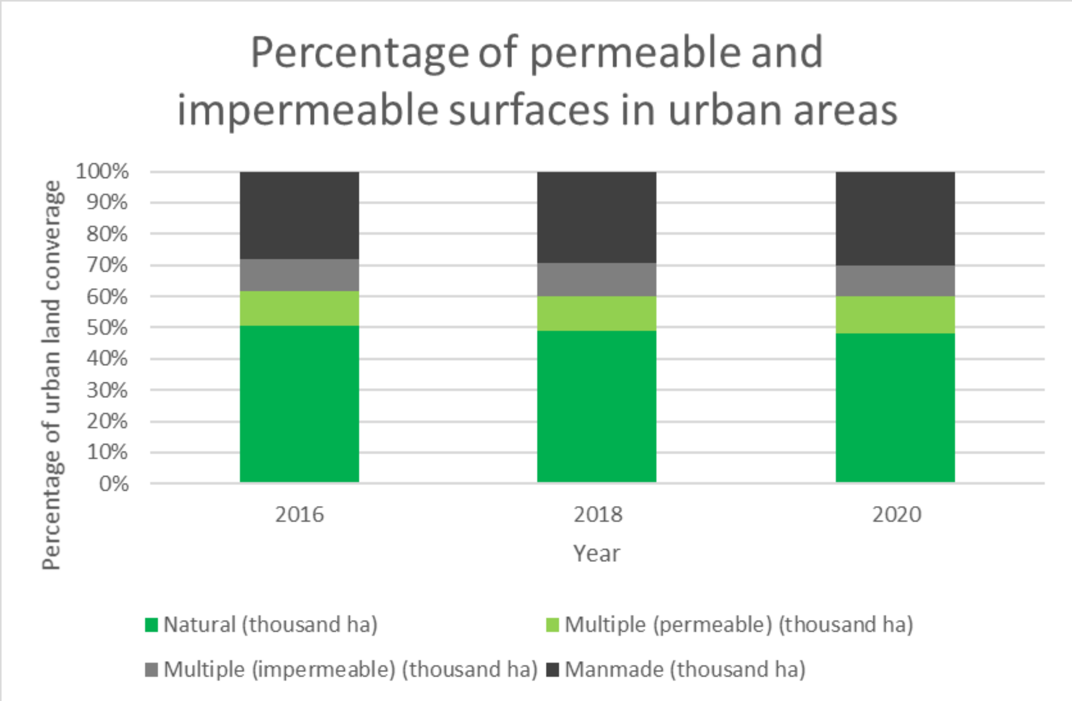

Figure 4. Changes in the proportion of permeable and impermeable surfaces in built-up urban areas in 2016, 2018 and 2020 (urban areas defined using method 2). Data sourced from ADAS (2019) for 2016 and 2018 data. 2020 data is new analysis as part of this project. Source: ADAS for the CCC.

2.2.4 Robustness of indicator

Ordnance Survey MasterMap is considered to be the definitive source for detailed geographic data of Great Britain. This indicator is therefore robust in terms of the mapping used to represent impermeable surfaces; however, an estimate has to be made of the impermeable fraction of the 'Multiple' surface type based on research into urban creep. This may lead to under- or over-estimation of impermeable area but should be consistent across years.

Different products in different years have been used to estimate the number of properties, The Address point data used prior to 2016 was superseded by OS AddressBase. Furthermore, OS Addressbase Premium was used in 2018 while OS Addressbase Plus was used in this analysis. The property data is used to identify housing densities which is used to identify urban areas and density classes. Therefore, changes in the product used impact on these calculations.

2.3 Area of urban greenspace

Description: *Area of urban greenspace*

Type: *Vulnerability*

Time Series: *2001 to 2020*

Region: *England*

2.3.1 Introduction

This indicator was last updated by ADAS (2019). The indicator provides the relative proportions of natural and semi-natural areas (greenspace) within towns and cities in England between 2001 and 2020. This update provides new data and analysis for 2020.

2.3.2 Data source and method

The method used was equivalent to that used for 'the area of impermeable surfacing in urban areas' (see section 2.2), except that the area of greenspace in urban areas was estimated from the area of the "Natural" material plus the permeable fraction of "Multiple".

The 'Topography' layer of Ordnance Survey's MasterMap product (the most detailed digital mapping available nationally) records the surface material of each land parcel as "Natural", "Manmade" or "Multiple". The area categorised as "Natural" is assumed to be Greenspace. The "Multiple" category represents domestic gardens, which is assumed to be a mixture of permeable and impermeable surfaces. A methodology was developed by HR Wallingford (2012) to estimate the impermeable fraction of this category based on urban creep research under the assumption that estimated urban creep rates could be applied to these areas to determine the potential likely increase in intra-urban impermeable areas. The same method has been used for this indicator update.

See section 2.2 for the full method applied in this analysis.

Data was sourced from HR Wallingford (2012) for 2001, 2008 and 2011 data, and ADAS (2019) for 2016 and 2018 data. 2020 data is new analysis as part of this project.

2.3.3 Trends and implications for climate resilience

The area of built-up urban areas covered by permeable surfaces (greenspace) is shown for both methods of urban area calculation.

2.3.3.1 *Method 1*

The area of permeable surfaces (greenspace) in urban areas is shown in Table 8 for the current analysis (2020), alongside previous updates of this indicator in 2001, 2008 and 2011 (HR Wallingford, 2012), 2016 (ADAS, 2017) and 2018 (ADAS, 2019).

The total permeable area (natural and multiple (permeable)) has decreased by 58,000 hectares, from 821,000 hectares in 2001 to 763,000 hectares in 2020. The permeable fraction of the total urban area has decreased from 63% in 2001 to 55% in 2020.

Since 2018, the permeable fraction of the total urban area (1,383,000 hectares in 2020) has remained stable at 55%.

Table 8. Area of built-up areas covered by permeable surfaces (greenspace) as estimated using OS MasterMap and using assumptions of urban creep (Method 1). Data sourced from HR Wallingford (2012) for 2001, 2008 and 2011 data and ADAS (2019) for 2016 and 2018 data. 2020 data is new analysis as part of this project. Source: ADAS for the CCC.

Thousand ha	2001	2008	2011	2016	2018	2020
Natural	581	559	554	558	583	574
Multiple (permeable)	240	198	178	185	179	189
Total permeable area	**821**	**757**	**732**	**743**	**762**	**763**
Total urban area	1,298	1,297	1,296	1,332	1,383	1,383
Permeable fraction	0.63	0.58	0.56	0.56	0.55	0.55

See Figure 3 for a graph showing the percentage split between permeable and impermeable surfaces in the built-up urban area using Method 1.

2.3.3.2 Method 2

The area of permeable surfaces (greenspace) is shown for the current analysis (2020) and previous analyses of this indicator in 2016 (ADAS, 2017) and 2018 (ADAS, 2019). Results are shown in Table 9.

As with the first method, the overall permeable area fraction has remained stable, at 60% of the total urban area. The impermeable fraction is higher in all years compared to Method 1 due to the inclusion of more urban greenspace.

Table 9. Area of built-up areas covered by permeable surfaces (greenspace) as estimated using OS MasterMap and using assumptions of urban creep (Method 2). Data sourced from ADAS (2019) for 2016 and 2018 data. 2020 data is new analysis as part of this project. Source: ADAS for the CCC.

Thousand ha	2016	2018	2020
Natural	899	849	828
Multiple (permeable)	191	192	202
Total permeable area	1090	1041	1030
Total urban area	1772	1730	1720
Permeable fraction	0.62	0.60	0.60

See Figure 4 for a graph showing the percentage split between permeable and impermeable surfaces in the built-up urban area using Method 2.

2.3.4 Robustness of indicator

Ordnance Survey MasterMap is considered to be the definitive source for detailed geographic data of Great Britain. This indicator is therefore robust in terms of the mapping used to represent permeable surfaces; however, an estimate has to be made of the permeable fraction of the 'Multiple' surface type based on research into urban creep. This may lead to under- or over-estimation of the permeable area but should be consistent across years.

Different products in different years have been used to estimate the number of properties, The Address point data used prior to 2016 was superseded by OS AddressBase. Furthermore, OS Addressbase Premium was used in 2018 while OS Addressbase Plus was used in this analysis. The property data is used to identify housing densities which is used to identify urban areas and density classes. Therefore, changes in the product used impact on these calculations.

2.4 Wildfire incidents and area burnt

Description: *Number of wildfire incidents and total area burnt*

Type: *Realised impact*

Time Series: *2009-10 to 2016-17; and 2015 to 2019*

Region: *England, and the UK*

2.4.1 Introduction

This indicator was last updated by ADAS (2019). The indicator provides an assessment of the number of wildfire incidents and the total area burnt by land cover class from two different datasets:

- The Forestry Commission dataset covering wildfires in England, between 2009-10 and 2016-17. This update does not provide new data for this series.
- The European Forest Fire Information System dataset covering wildfires in the UK. This update provides new data for 2015 to 2019.

2.4.2 Data source and method

Forestry Commission dataset

The Forestry Commission published a report in 2019 (Forestry Commission, 2019), which was used to extract key statistics on wildfires in the natural environment (see ADAS, 2019). New data was not available within the timeframes of this project due to unforeseen circumstances in the Forestry Commission. Instead, a summary of the previous analysis is provided.

The Joint Research Centre

The European Forest Fire Information System (EFFIS) consists of a modular web geographic information system that provides near real-time and historical information on forest fires and forest fire regimes in the European, Middle Eastern and North African regions. Data was sourced from the annual reports produced by the Joint Research Centre (JRC) based on EFFIS information and supplemented by qualitative information submitted by representatives from the four devolved UK countries, for the years 2015 (San-Miguel-Ayanz et al., 2016), 2016 (San-Miguel-Ayanz et al., 2017), 2017 (San-Miguel-Ayanz et al., 2018), 2018 (San-Miguel-Ayanz et al., 2019) and 2019 (San-Miguel-Ayanz et al., 2020).

The Rapid Damage Assessment module of EFFIS provides reliable and harmonized estimates of the areas affected by forest fires during the fire season. EFFIS Rapid Damage Assessment is based on the analysis of the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery. The methodology and the spatial resolution of the satellite sensor data used for this purpose allows the mapping of all fires of about 30 ha or larger. Statistics on the burnt area by land cover type use data from the European CORINE Land Cover (CLC) 2016 database, which is overlaid with the burnt mapped burned areas (San-Miguel-Ayanz et al., 2020).

Data for this analysis was extracted on the number of wildfires greater than 30 hectares, and the area burnt, from the annual reports.

2.4.3 Trends and implications for climate resilience

2.4.3.1 Statistics for England (Forestry Commission)

The majority of wildfire incidents that occurred in England between 2009-10 and 2016-17 were associated with improved grassland (34%), arable (25%) and broadleaved woodland (19%); averaged for the whole period (ADAS, 2019). In terms of the area burnt (hectares) by land cover class between 2009-10 and 2016-17 (averaged across the whole period), the largest area lost was associated with mountain heath and bog (48%), improved grassland (18%), arable (11%) and semi-natural grassland (11%), shown in Figure 5. However, it is noted that there is considerable variation year-to-year. For example, the area burnt of mountain heath and bog ranged from 4% of the total area in 2009-10 to 82% in 2011-12.

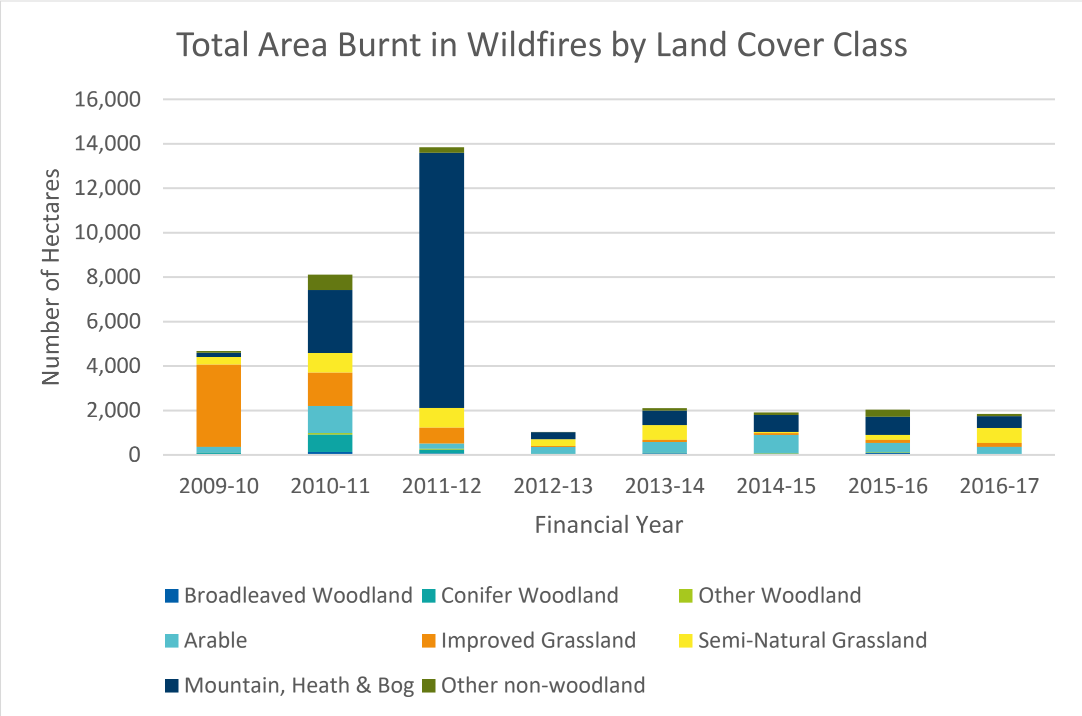

Figure 5. Area burnt in wildfire incidents, recorded each year by the Fire and Rescue Services, split by land cover class. Data sourced from the Forestry Commission (2019) report on wildfire statistics. Source: ADAS, 2019.

Research by ADAS (2019) showed that both the number of wildfire incidents and the total area burnt were notably lower between 2012-13 to 2016-17, compared with the three years prior to this (2009-10 to 2011-12). No new data for England was available from the Forestry Commission for the period 2017-18 to 2019-20, due to delays in the dataset being produced because of the coronavirus pandemic.

2.4.3.2 Statistics for the UK (The Joint Research Centre)

Statistics from the Joint Research Centre show that the number of wildfires (larger than 30 hectares in size) have increased over the last few years, from less than 20 in 2015, 2016, and 2017, increasing to 79 in 2018 and 137 in 2019, shown in Figure 6. The relatively low number of wildfire incidents observed in the UK between 2015 and 2016 concur with analyses of Forestry Commission data for England during the same period (see ADAS, 2019).

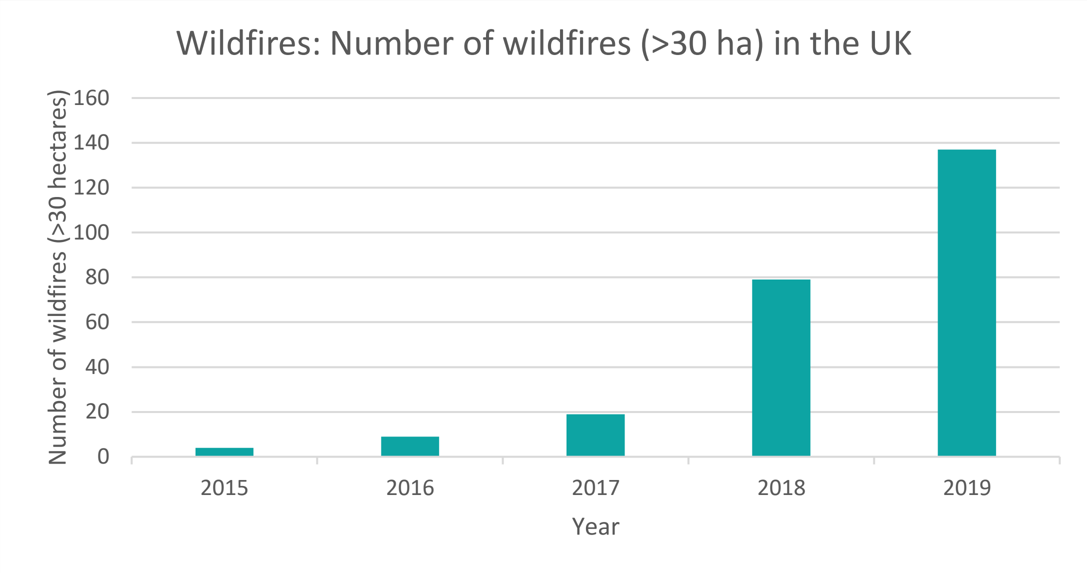

Figure 6. The number of wildfires larger than 30 hectares in size in the UK between 2015 and 2019. Data sourced from the Joint Research Centre (San-Miguel-Ayanz et al., 2016; 2017; 2018; 2019; 2020). Source: ADAS for the CCC.

In terms of the area burnt by wildfires, this has increased significantly in the last few years, from around 2,000 ha in 2015 and 2016, increasing to 5,000 ha in 2017, 18,000 ha in 2018 and 29,000 ha in 2019, shown in Figure 7. The relatively small burnt area observed in the UK between 2015 and 2016 concurs with analysis of Forestry Commission data for England in the same period (see Figure 5 and ADAS, 2019).

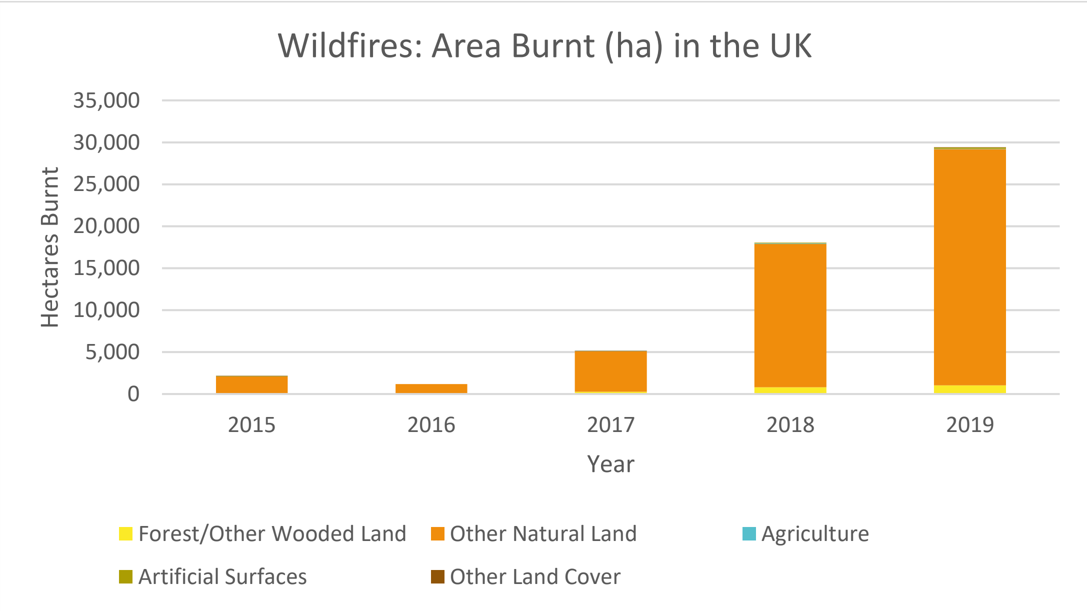

Figure 7. The area burnt (hectares) by wildfires larger than 30 hectares in size in the UK between 2015 and 2019. Data sourced from the Joint Research Centre (San-Miguel-Ayanz et al., 2016; 2017; 2018; 2019; 2020). Source: ADAS for the CCC.

The majority of the area burnt each year was classified as 'other natural land', with this land cover type accounting for between 94.7% and 96.7% of the total burnt area in each of the five years. The land cover categories are based on CORINE Land Cover 3.2, which is very broad and includes different land cover types for different countries. In the UK, the other natural land category largely includes fires on natural grassland, and moors and heathland, defined as:

- **Natural grassland**; grasslands under no or moderate human influence. Low productivity grasslands. Often situated in areas of rough, uneven ground, steep slopes; frequently including rocky areas or patches of other (semi-)natural vegetation.
- **Moors and heathland**; vegetation with low and closed cover, dominated by bushes, shrubs, dwarf shrubs and herbaceous plants, forming a climax stage of development. Including for example, wet heath distributed on humid or semi-peaty soils (peat depth < 30 cm); and dwarf-shrub covered areas with <30 cm peat and without visible sign of morphological features typical of bogs (e.g. pools, peat hags, peatland gullying).

Most large wildfires in the UK occur in the UK have occurred on land associated with these land cover types. For example, recent wildfires have included the Saddleworth Moor fire in July 2018 that burnt over 1,000 ha; the Pauls Hill/Morayshire grassland fire in April 2019 that burnt over 2,800 ha; and the Sutherland peatland wildfire in May 2019 that burnt over 5,500 ha (San-Miguel-Ayanz et al., 2019; 2020). The second most prevalent land cover type was 'forest/other wooded land', accounting for between 3.2% and 5% of the total burnt area in each of the five years. Whilst it is noted that the dataset only covers wildfires greater than 30 hectares, it suggests that the majority of large wildfires (>30 ha) occur in natural habitats, rather than agriculture, artificial surfaces or other land cover types.

2.4.4 Robustness of indicator

Forestry Commission dataset

The data used within the FC report was sourced from the Home Office's online Incident Recording System. Fire and Rescue Services provide records about wildfires (and other) incidents on the Incident Recording System. This includes a wildfire element of the Incident Recording System that provides a record of the nature of incidents requiring a response by the Fire and Rescue Services, in line with the UK Vegetation Fire Standard. The FC report is deemed to be robust with a consistent methodology applied to calculate the number of wildfire incidents, and area burned, each financial year. It is not known when the FC will publish its next report on wildfires.

Joint Research Centre dataset

The Joint Research Centre note that, due to the significant processing periods for fire statistics, it is not possible to gain access to Incident Recording System data for Great Britain, gathered from Fire and Rescue Services. The data is therefore based on qualitative information submitted by representatives from the four developed UK Countries (San-Miguel-Ayanz et al., 2020).

The Joint Research Centre analysis; based on EFFIS data and qualitative information, is considered to be less robust than the analysis conducted by the Forestry Commission (2019); which did have access to and used data sourced from the Home Office's online Incident Recording System. However, in the absence of the Forestry Commission data, the Joint Research Centre analysis provides a comparable indication (between years) of the number of large wildfires (i.e. >30 hectares) and area burnt in the UK each fire season.

2.5 Area under vine and volume of wine produced

Description: *Area of vines planted, and the volume of wine produced in England and Wales*

Type: *Realising Opportunity*

Time Series: *1989 to 2020*

Region: *England and Wales*

2.5.1 Introduction

This indicator was last updated by ADAS (2019). The indicator provides an assessment of the area of vines planted and volume of wine produced, in England and Wales, between 1989 and 2020. This update provides new data for 2019 and 2020.

2.5.2 Data source and method

Data on the area under vine and volume of wine produced for this analysis was sourced from English Wine, for the period 1994 to 2020. These datasets are predominantly based on values supplied by the Wine Standards Branch of the Food Standards Agency (FSA). The Wine Standards Branch produce the official record of vintage production for DEFRA, based on annual harvest and production declarations provided to the FSA from commercial vineyards. The exception is data on the area under vine for 2019 and 2020, which is based on industry expert estimations due to Wine Standards Branch not collecting this data in these years. However, these estimated values are considered to be the accepted industry figures and are used in industry publications in the absence of Wine Standards Branch data, for example, the Wines of Great Britain 2020 Industry Report (WineGB, 2020). Data for 1989-93 has not been included in this analysis due to the Wine Standards Branch figures including hectares from hobby vineyards and abandoned vineyards. Wine Standards Branch data for 1994 onwards includes the commercial area only and therefore provides a more consistent and representative time series. The commercial area is split between hectares in production and hectares not in production.

2.5.3 Trends and implications for climate resilience

<u>Area of vines planted</u>

The total commercial area under vine in England and Wales has more than doubled in the last decade from 1,384 hectares in 2011, to an estimated 3,380 hectares in 2020, shown in Figure 8. These values are for commercial vineyards only and exclude 'hobby vineyards' and 'abandoned vineyards, which in 2020 accounted for an estimated additional 66 hectares and 54 hectares respectively.

Approximately 81% (2,738 hectares) of the total commercial area under vine in 2020 was in active production. Of the 19% of the planted area not in production, the majority is attributed to newly planted crops that have not yet been fully established, and thus not growing high quality fruit in the quantities required for active harvesting.

There is no indication in the datasets as to whether this increase in area is being driven by improving climatic conditions for the vines, or whether there are other economic reasons for the increase in area. However, it anticipated that the climate is becoming more suitable for vine production and thus allowing the opportunity to be capitalised upon by growers interested in wine production.

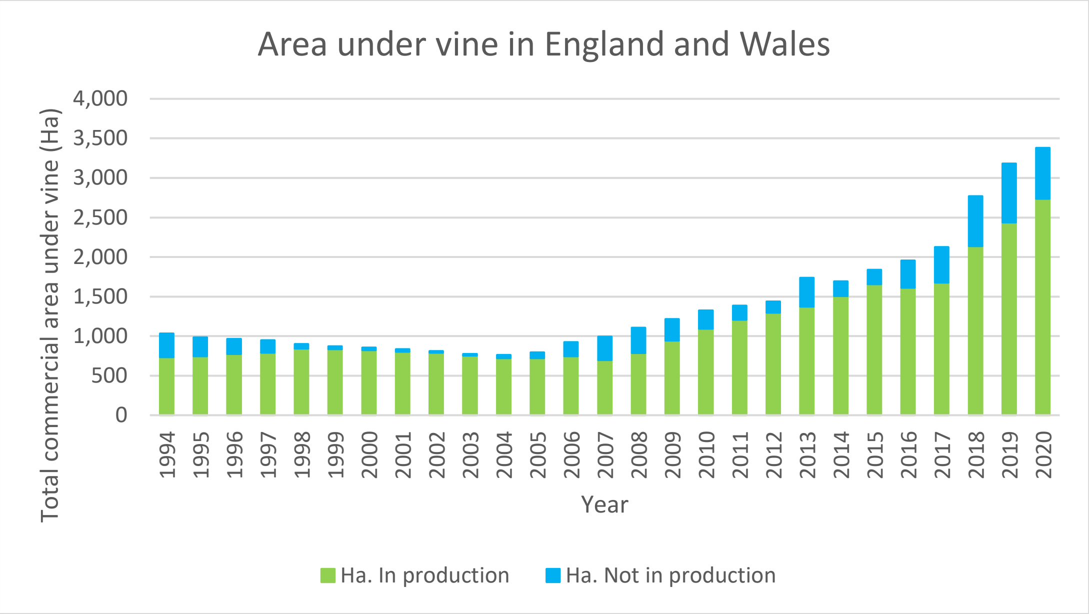

Figure 8. Total commercial area (hectares) under vine each year, excluding 'hobby vineyards' or 'abandoned vineyards', split between area in production (green), and not in production (blue), for England and Wales from 1994 to 2020. Data sourced from English Wine, based on data supplied by the Wine Standards Branch of the Food Standards Agency for the period 1994-2018 and industry estimations for 2019-2020. Source: ADAS for the CCC.

Volume of wine produced

The total volume of wine produced each year (i.e. number of 75cl bottles produced) is highly variable depending on the weather conditions experienced during the growing season. Figure 9 shows how the volume of wine produced has changed year on year.

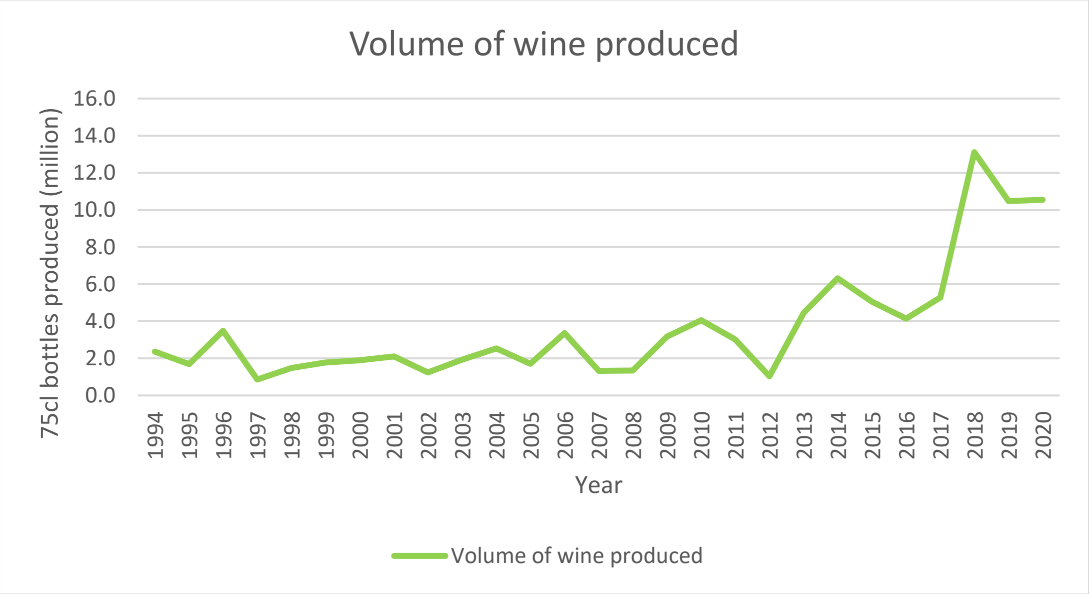

Figure 9. Wine production (millions of 75cl bottles produced) in the UK from 1994 to 2020. Data sourced from English Wine, based on data supplied by the Wine Standards Branch of the Food Standards Agency. Source: ADAS for the CCC.

It is evident that, despite the area in active production typically increasing year on year since 2004 (Figure 8), the volume of wine produced (Figure 9) has been much more variable, with large peaks and troughs.

Years with particularly poor production volumes include 2012 and 2016. The 2012 growing season was considered to be particularly poor with extremely unfavourable growing conditions that included the wettest June since 1988, the coldest summer since 1988 and the dullest summer since 1987 with just 403 hours of sunshine across the UK (Met Office, 2012). The 2016 growing season also exhibited poor conditions, due to a combination of cool conditions during the summer, followed by a lack of moisture in the later part of the growing season; to swell the grapes (Skelton, 2016). Climate projections suggest that the UK will experience hotter, drier summers in the future (Met Office, 2019). As a result, the irrigation of some crops during periods of low precipitation may become an increasingly significant adaptation practice. However, water scarcity and competing demand for water resources will limit the extent to which this is possible. The UK's second Climate Change Risk Assessment (CCRA2) (CCC, 2017; Defra, 2017) recognises that water restrictions will have potential consequences for agricultural businesses, particularly those specialising in crops that are (or become) dependent on supplementary irrigation (CCC, 2019).

The 2018 growing season was exceptional with high quality grapes and favourable weather conditions, associated with a prolonged spell of hot weather, followed by a period with very little rain, enabling the grapes to fully ripen on the vine (Skelton, 2019). The 2019 and 2020 growing seasons were also very good with high volumes of production. The 2020 growing season exhibited a warmer and drier than average spring that led to an early budburst, whilst a warmer than average August brought ripening on quickly, resulting in one of the earliest harvests in modern times (Skelton, 2020).

2.5.4 Robustness of indicator

The data sourced from English Wine, originally supplied by the Wine Standards Branch of the FSA is considered to be fairly robust and consistent over the time series, providing a good indicator for the total area of commercial vineyards (both in and out of production), as well as robust estimations of the volume of wine produced. WineGB also hold a dataset, based on Wine Standards Branch data. Whilst there are some minor inconsistencies between the English Wine dataset and WineGB dataset, the majority of values match and any differences are considered to be materially insignificant to the larger trends shown. There is some uncertainty around the 2019 and 2020 figures for the area under vine from English Wine due to the Wine Standards Branch not collecting this data in these years. However, the accepted industry estimations used in the absence of this data are considered to be representative of the current area planted.

The original source of the Wine Standards Branch data comes from annual declarations on a survey, completed by commercial vineyard growers. It is anticipated that the Wine Standards Branch and/or English Wine or WineGB will continue to collect this data year-on-year, allowing for future updates of the indicator.

3 INDICATORS AND EVIDENCE-BASES DEVELOPED

The indicators and evidence-bases in this section are new to the Adaptation Committee's indicator set and were designed and developed as part of this study.

3.1 Average field size (grassland and arable) in England

Description: *Changes in the average field size (grassland and arable) in England.*

Type: *Exposure*

Time Series: *2015*

Region: *England*

3.1.1 Introduction

The mean size of agricultural fields in a landscape is a major driver of diversity and abundance of farmland biodiversity taxa including plants, arthropods, and vertebrates. Agricultural intensification in Europe from the 1930s–1940s onward has been associated with the removal of field margins, including grass strips, hedgerows and ditches, in order to create larger fields (Kirchweger and Kantelhardt, 2020).

For farmers, benefits have included decreased working time in the field and fuel expenses when fields are larger (e.g. due to economies of scale), whilst the uptake of larger machinery and subsidies favouring larger farms have provided incentives to manage land in larger units However, the loss of field margins has resulted in the loss of important farmland habitats for biodiversity, with a lower diversity of plant and animal farmland species reported where cropland has been aggregated into larger fields (Kirchweger and Kantelhardt, 2020).

Across Europe, field sizes are still increasing, facilitated by increasing farm sizes and land consolidation (Kirchweger and Kantelhardt, 2020). It is not clear if this trend is also prevalent in the UK.

This indicator provides an assessment of average field size in England in 2015.

3.1.2 Data source and method

The analysis used the UK Centre for Ecology and Hydrology (CEH) Land Cover Map for 2015 dataset, LCM2015 (CEH, 2017).

LCM2015 is a parcel-based land cover map for the UK, created by classifying satellite data into 21 land cover classes. This data was used to estimate field sizes in England. The 'Arable and horticulture' and 'Improved Grassland' land cover classes were selected from the dataset and the areas of these parcels were averaged to provide an estimate of average field size across England.

3.1.3 Trends and implications for climate resilience

Analysis of the LCM2015 dataset provided an estimation of the average field size in England, outlined in Table 10.

Table 10. Average field size (ha) in England by land cover type (arable and horticulture, and improved grassland) using the CEH (2017) LCM2015 dataset. Source: ADAS for the CCC.

Land Cover Type	Average field size (ha) in 2015
Arable and horticulture	6.34
Improved Grassland	2.57
Average of both land cover types	**3.74**

The results show that the average field size for arable and horticultural land is more than double the average field size for improved grassland, illustrated in Figure 10.

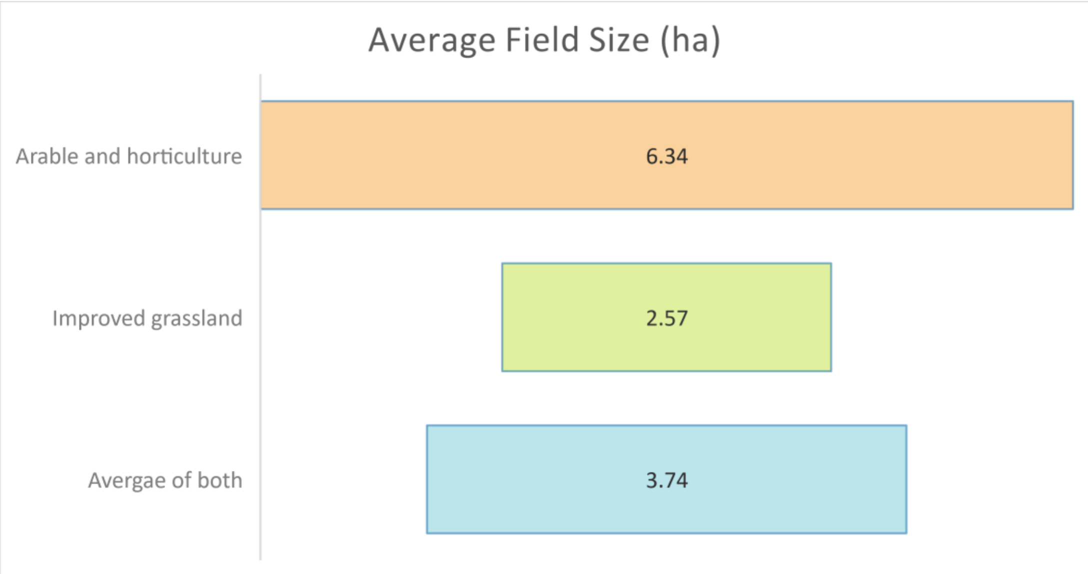

Figure 10. Average field size (ha) in England by land cover type (arable and horticulture, and improved grassland) using the CEH (2017) LCM2015 dataset. Source: ADAS for the CCC.

Due to only one point of reference in the time series, it was not possible to assess whether the average field size has changed over time. However, this analysis will provide a baseline to compare against future analyses of this indicator.

3.1.4 Robustness of indicator

The land parcels in LCM2015 were derived by generalising national cartography and are designed to represent discrete real-world units of land such as fields, parks, urban areas, woodlands, lakes and so forth. The land cover classes selected ('Arable and horticulture' and 'Improved Grassland') are a best representation of land that is most likely to cover current agricultural land parcels. Other land cover classes may also include agricultural land parcels (such as 'Neutral Grassland', 'Calcareous Grassland', 'Acid Grassland') but it is difficult to know whether these are still under current agricultural land management or instead under other land management (e.g. parks, nature conservation, nature reserves etc.).

It is expected that this indicator can be updated in the future to provide an assessment of changes in average field size at specific time points. For example, whilst not available within the timeframes of this study, additional CEH Land Cover Map datasets (CEH, n.d.) could provide a second reference point in the time series. Future updates to the Land Cover Map would provide subsequent reference points.

3.2 Change in total hedgerow length

Description: *Length of hedgerows in England*

Type: *Exposure*

Time Series: *1984 to 2007*

Region: *GB and England*

3.2.1 Introduction

Hedgerows are an important landscape feature which deliver numerous biodiversity benefits by providing food and shelter for a range of birds, insects and mammals. Hedgerows also facilitate movement through the landscape by providing respite for organisms such as flying insects (Wolton, 2012). Additionally, there are over 100 priority species associated with hedgerows, and although few of them are wholly dependent on these, the deterioration or loss of hedgerows would result in a significant decrease of their populations (Wolton, 2012). In 2006, it was estimated that only 22% of the UK's hedgerows were in a favourable state (Defra, 2007).

Most hedges were originally planted to enclose livestock or define boundaries, with many hedgerows considered a historical interest in their own right (Hedgelink, n.d.). Hedgerows provide wider environmental benefits and regulatory services such as increasing water quality and regulation, increasing air quality, reducing flood risk, reducing soil erosion, maintaining climate regulation through carbon sequestration, and promoting pollination and pest control by providing habitat for pollinators and predators of crop pests. By acting as a physical barrier at a field edge, hedgerows are able to reduce the amount of fertilisers, pesticides and sediment, which may be included in surface water run-off, from reaching watercourses. They can also contribute to managing the flow of water run-off, which can support in reducing peak flows and the risk of flooding across the catchment (Wolton, 2012).

'Managed' hedgerows provide the greatest value, both to farmers and wildlife, however, if these are neglected the value can greatly reduce or become negligible (Countryside Survey, 2007). Similarly, where hedgerows are lost, the benefits associated with the hedgerows are lost alongside this, which can have negative impacts for biodiversity and regulatory services, and also result in an increase in carbon emissions.

This indicator provides an assessment of the change in hedgerow length in England and Great Britain, between 1984 and 2007. In addition, comment is made around more recent estimates.

3.2.2 Data source and method

Data used within this analysis was sourced from the Countryside Survey. Grants associated with hedgerows are included within Countryside Stewardship agreements (Defra, 2020). This includes grants for laying hedges, hedge coppicing, hedge gapping up, and hedgerow trees. Data for the years 1984, 1990, 1998 and 2007 were available for direct download; however, differences in linear feature classification prevent direct analysis of this data. The supporting report for the 2007 data (Countryside Survey, 2007) collated the timeseries on hedges across these four years in a comparable format. It is this data, cited within the 2007 report, that has been used for this analysis. Unfortunately, this data has not been collected since 2007 within this particular data collection programme.

In addition, commentary is provided around more recent estimations of total hedgerow length in Great Britain.

3.2.3 Trends and implications for climate resilience

Countryside Survey Statistics

The length of managed hedgerows decreased by 6.2% in Great Britain between 1998 and 2007, shown in Table 11. There was a decline in hedgerow length in Great Britain between 1984 and 1990. In all regions apart from Wales, hedgerow length then increased slightly between 1990 and 1998, before further reducing to equal or below the lengths seen in 1990 in 2007. Overall, between 1984 and 2007, there was a 24% decrease in the length of 'managed' hedgerows in GB.

Table 11: 'Managed' hedgerow length (000's km) in Great Britain (England, Wales and Scotland) from 1984 to 2007. Source: Countryside Survey (2007).

Region	Managed' hedgerow length (000's km) per year			
	1984	1990	1998	2007
England	511	426	428	402
Wales	86	58	57	54
Scotland	28	21	23	21
GB	624	506	508	477

In England specifically, the length of 'managed' hedgerows decreased by 6% between 1998 and 2007 (in line with the GB figure) and reduced by 21% between 1984 and 2007. This represents a loss of 109,000 km of 'managed' hedgerows in England, from 511,000 km in 1984 to 402,000 km in 2007, with a further 145,000 km of linear features such as relict hedges and lines of trees (Countryside Survey, 2007; Hedgelink, n.d.).

This data is presented graphically in Figure 11.

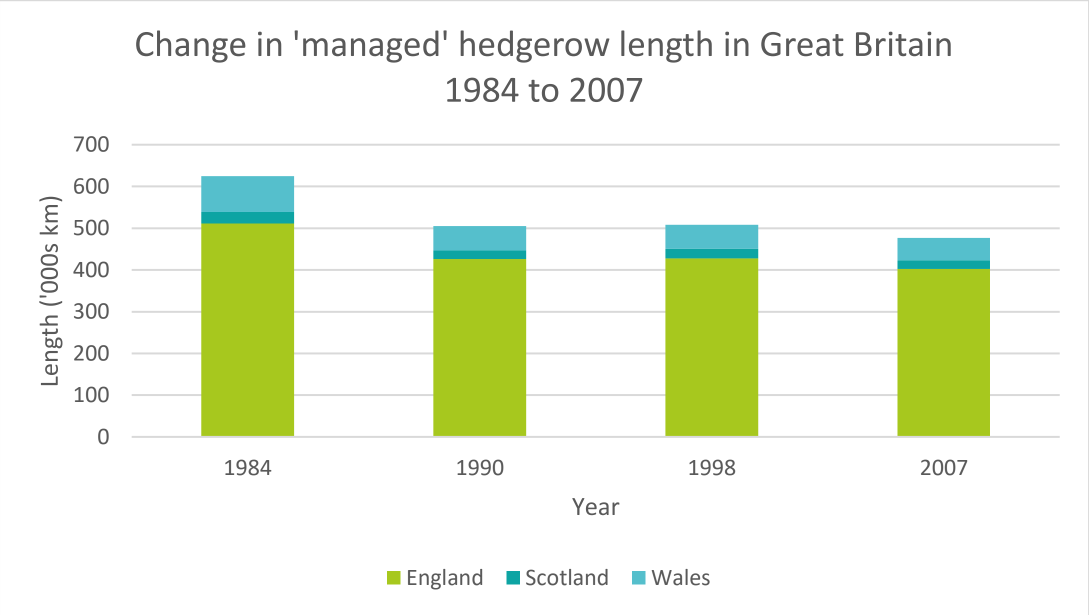

Figure 11. Change in 'managed' hedgerow length in Great Britain (England, Scotland and Wales) between 1984 and 2007, using Countryside Survey data (Countryside Survey, 2007). Source: ADAS for the CCC.

Whilst it is recognised that the reduction in 'managed' hedgerow length will reduce the benefits provided by hedgerows, including the ability to sequester carbon; some of the observed hedgerow decline is due to 'managed' hedges turning into lines of trees and relict hedges due to a lack of management, rather than full hedgerow removal (Countryside Survey, 2007). This can be accounted for somewhat in the increase in length of trees, shrubs and relict hedge over the same timeframe, as shown in Table 12. Therefore, the reduction in 'managed' hedgerow length does not necessarily translate to a direct increase in carbon emissions as in some cases the hedges will not have been removed entirely. However, where hedgerow length is reducing due to hedgerow removal, this will have consequences on carbon emissions.

Table 12. Lines of trees/shrubs/relict hedge length (thousand km) in Great Britain (England, Wales and Scotland) from 1984 to 2007. Data sourced from Countryside Survey (2007).

Region	Lines of trees/shrubs/relict hedge length (000's km)			
	1984	1990	1998	2007
England	43	47	76	82
Wales	10	12	19	19
Scotland	5	12	14	13
GB	58	71	109	114

<u>Recent estimations of hedgerow length</u>

It is estimated that Britain has lost half of its hedgerows since the Second World War. The loss of hedgerows has been associated with agricultural intensification between the 1940s and 1970s (Woodland Trust, 2014), combined with government policy that, at the time, encouraged hedge removal to ensure that Britain was self-sufficient in food (RSPB, n.d.). However, the loss of managed hedges appeared to subside in the mid-1990s, with the net length of hedges stabilising or possibly increasing since (RSPB, n.d.).

Beyond the Countryside Survey (2007) dataset, ADAS were unable to identify any more recent estimations of total hedgerow length in England or Great Britain. This is supported by a recent article that suggests no detailed surveys of hedgerow length have been conducted for many years and it is therefore difficult to estimate the total length of hedgerows in Britain (Collins, 2020).

Given the absence of robust evidence, it is not possible to provide a current estimation of total hedgerow length beyond that provided in the Countryside Survey (2007) of 402,000 km of 'managed' hedgerows. However, it is understood that, under the 25-Year Environment Plan, there is a drive to increase hedgerow length in England over the coming years, with Government recognising that hedgerow trees and individual trees play an important role in breaking up monocultures of arable crops (Defra, 2018).

3.2.4 Robustness of indicator

Changes to the definitions of woody linear features between 1984 and 2007 have made it difficult to compare 'managed' hedgerow length between the different years. For this reason, the raw datasets from Countryside Survey were unable to be analysed directly. However, the supporting report to the 2007 data (Countryside Survey 2007) provides an indication of change over the four data points available. There are limited data sources available for comparison to provide commentary on the accuracy of this data.

It is recognised that there may be other datasets that could provide further insight on more recent hedgerow length estimates in England. For example, the Rural Payments Agency

(RPA)[1] is responsible for the Land Management System (LMS) which captures the parcels of land registered under the Common Agricultural Policy (CAP) and the Countryside and Environmental Stewardship schemes in England. Whilst there is potential for RPA data to provide useful insight on the length of hedgerows, it doesn't provide a complete picture as not all farmers claim subsidy so the RPA only hold land information (including hedgerow data) on land that is registered on LMS.

Other potential data sources include the CEH woody linear features framework,[2] the UK Status, Change and Projections of the Environment (UK-SCaPE) programme,[3] and the Great British Hedgerow Survey.[4] However, access to these resources were not available within the timescales of this study.

3.3 Tree losses as a result of extreme weather

Description: *Tree sapling and mature tree losses as a result of extreme weather*

Type: *Realised impact*

Time Series: *Not available*

Region: *UK and England*

3.3.1 Introduction

Extreme climate events (e.g. droughts, heatwaves, storms etc.) can result in tree sapling and mature tree losses. For example, storms and extreme wind can result in direct damage to trees, including stem breaks and fallen or uprooted trees, whilst droughts and heatwaves severely affect trees through changes in plant physiology and phenology, which can lead to increased tree mortality (Unmenhofer and Meehl, 2017).

Consultation with various bodies, including the Forestry Commission and National Trust, confirmed that there are currently no suitable datasets that regularly track trees losses in England as a result of extreme weather.

A key barrier to data collection in this field is the issue of attribution, particularly when assessing the impacts of tree sapling losses. For example, whilst a fallen tree during a storm could be attributed to the event, the susceptibility of the tree to fall may have greatly increased by factors leading up to the trigger event, such as disease, waterlogged ground, age of the tree etc. Similarly, the loss of a tree sapling following a period of extended hot and dry weather could be associated with soil conditions, water availability, pest and disease pressures etc. It is therefore difficult to attribute the loss of trees to particular extreme weather events. However, where large numbers of trees are lost or damaged during an extreme weather event in a short space of time (i.e. one or two days), assigning causality is much stronger.

[1] The Rural Payments Agency. Available at: https://www.gov.uk/government/organisations/rural-payments-agency [Accessed 23 Mar. 2021]

[2] CEH Woody linear features framework. Available at: https://catalogue.ceh.ac.uk/documents/d7da6cb9-104b-4dbc-b709-c1f7ba94fb16 [Accessed 23 Mar. 2021]

[3] CEH UK-SCAPE programme. Available at: https://www.ceh.ac.uk/ukscape [Accessed 23 Mar. 2021]

[4] The Great British Hedgerow Survey. Available at: https://hedgerowsurvey.ptes.org/ [Accessed 23 Mar. 2021]

This indicator provides an evidence-based assessment of tree sapling and mature tree losses as a result of extreme weather, using published literature and case study examples.

3.3.2 Tree sapling losses as a result of extreme weather

Trees have certain needs for growth and survival, including access to water, nutrients, and sunlight (for photosynthesis). If trees lack any of these three necessities, they may slow their growth or eventually die. Extreme weather events, such as droughts and heatwaves, can severely impact on tree sapling growth through reducing water and moisture from the soil.

As the climate changes, large parts of England are projected to experience hotter, drier summers along with an increase in the frequency and intensity of extremes (Met Office, 2019). These conditions are expected to result in decreased precipitation and increased soil moisture deficits, creating more difficult growing conditions for newly planted trees. CCRA2 recognises that forestry faces significant risks from pests, pathogens and invasive species; and extreme climate events (wind, drought, heat, fire) now and increasingly in the future (CCC, 2019). Where extreme weather events (e.g. heatwaves) occur, this will further exacerbate the susceptibility of tree saplings to experience reduced growth and even mortality. However, attributing sapling losses to particular weather events is difficult.

In the UK, there have been several reported instances of tree sapling losses associated with extreme weather events (although causality is not well-defined). We outline a couple of examples:

Case Study: HS2 tree sapling losses (summer 2018)

Extreme Weather Conditions: Drought and heatwave conditions

The summer of 2018 was the UK's warmest summer since 2006, the driest since 2003 and the sunniest since 1995 (Met Office, 2018), resulting in lower than average precipitation and water shortages across many regions.

Impact: 89,000 tree saplings died

The news media (BBC, 2019; Independent, 2019) reported in May 2020 that tens of thousands of tree saplings planted along the High Speed 2 (HS2) train line had died as a result of extreme weather conditions experienced in summer 2018. Approximately 234,000 saplings were planted along the HS2 route between November 2017 and March 2018. However, it is estimated that more than one-third (89,000) of these saplings died as a result of the conditions experienced in summer 2018 (Independent, 2019). A spokesman for HS2 (citied in the Independent, 2019) noted that the team estimated it would have cost around £2 million to water the trees during the drought, so replacing the plants was a much more cost-effective solution, as well as a more ethical use of resources during unprecedented conditions at the height of summer.

Case Study: Hackney Marshes tree sapling losses (spring 2020)

Extreme Weather Conditions: Drought and heatwave conditions

Spring 2020 was the sunniest spring on record in England, the fifth warmest on record, and one of the top five driest on record. May in particular was exceptionally dry, ranking as the driest May on record in England with 9.6mm average rainfall, the sunniest May on record, as well as the sunniest calendar month on record (Met Office, 2020).

Impact: 4,000 tree saplings died

The news media (Hackney Citizen, 2020) reported in August 2020 that thousands of newly planted trees died on Hackney Marshes, London. The local Council blamed extreme weather in May as the cause for the loss of fruit and nut trees, broadleaf specimens and shrubs that had been planted in February 2020 to create an edible woodland. Despite all planned aftercare for the trees taking place, it was evidently not enough to prevent the plant deaths in the extreme hot weather. Trees for Cities are responsible for replacing the saplings that did not survive, as part of a carbon offsetting scheme.

3.3.3 Mature tree losses as a result of extreme weather

The Database on Forest Disturbances in Europe contains an overview of reported forest disturbance events in Europe up to about the year 2000 (Gardiner et al., 2010). Analysis of the database by Schelhaas et al. (2003; cited in Gardiner et al., 2010) reported increasing levels of damage from storms to European forests from 1950 to 2000, largely attributed to winter storms between the months of November to January.

In the UK, there are several notable storms and winters associated with reported losses of mature trees. We outline several examples:

Case Study: Great Storm of 1987

Extreme Weather Conditions: Storm and high winds

The Great Storm of 1987 was a violent extratropical cyclone that occurred on the night of 15–16 October, exhibiting hurricane-force winds gusting at up to 100mph. Analysis of records of the hourly mean wind speeds and highest gusts indicates that such extreme conditions over land in south and south-east England were likely to occur, on average, only once in 200 years (Met Office, n.d.).

Impact: 15 million mature tree losses

An estimated 15 million trees were blown down across southeast England, with many trees falling onto roads and railways, whilst other trees took down electricity and telephone lines, (Met Office, n.d.; Smart et al., 2014). Whilst damage was locally severe; the extent of damage to trees were variable within the storm-track, resulting from context dependent interactions between topography, tree species, form, age, substrate and variation in wind strength (Smart et al., 2014).

Gardiner et al., (2010) estimate that 3.9 million cubic metres of timber were damaged in the storm in England, representing around 12% of the growing stock in the affected region. This was equivalent to 5 months of UK conifer production and 2 years of UK broadleaf production. The storm also affected a large number of amenity, urban and park trees, with approximately 800,000 non-forest trees blown or damaged in England with a further 500,000 orchard trees blown over (Gardiner et al., 2010).

Case Study: Burns' Day Storm (1990)

Extreme Weather Conditions: Storm and high winds

The Burn's Day storm of 25 January 1990 produced winds of a comparable magnitude to those of the October 1987 storm, but over a much wider area (McCallum, 1990). The intense depression tracked across southern Scotland on 25 January 1990, bringing severe gales and storm force winds to much of England and Wales.

Impact: 3 million mature tree losses

The strong winds affected a much larger area than in October 1987, and hit during daylight hours, causing widespread disruption. It is estimated that around 3 million trees were felled during the event. This was less than in October 1987 since the strongest winds occurred in less wooded areas and deciduous trees were bare of leaves (Met Office, 2016).

Case Study: Winter storms (2013-14)

Extreme Weather Conditions: Winter storms, December 2013 to January 2014

From mid-December to early January, the UK experienced a spell of extreme weather as a succession of major winter storms brought widespread impacts to the UK. Initially most of the weather impacts related to strong winds, although flooding later became the major impact as rainfall totals accumulated (Met Office, 2014).

Impact: >1,000 mature tree losses

The National Trust (cited in BBC, 2014 and The Guardian, 2014) reported that the winter storms of December 2013 to February 2014 caused the greatest loss of trees in a generation in some areas, with woodlands, parks and gardens (cared for by the trust) experiencing the worst damage for more than two decades, and in some cases since the "great storm" of 1987.

A survey was carried out at more than 50 National Trust sites and while the full number of trees that had gone was not known, they National Trust stated that it was the greatest loss of trees in two decades. This included old oak, ash and beech trees lost in woods, as well as specimen trees in parks and gardens. Some of the largest losses within National Trust estates included 500 trees blown over in Killerton Estate in Devon; hundreds of trees lost across three areas in Mottisfont and the New Forest in Hampshire; and 400 trees across the wider estate in Stourhead in Wiltshire.

3.3.4 Summary

Our research suggests that whilst there are a few examples of tree sapling losses as a result of extreme weather (e.g. drought and heatwaves), the number of reported examples remains low and attribution to specific events is not well-defined, given there are multiple factors that may contribute to the survival of newly-planted trees. These factors include when the saplings were planted and how established the plant was at the time of the weather event, local ground conditions (e.g. soil, water availability, topography, exposure etc.) and local weather conditions (e.g. temperature, rainfall etc.).

With regards to mature tree losses, typically associated with winter storms, the scale of impact tends to be across large geographic areas. It is expected that most storms will result in locally fallen trees, particularly where those trees have been previously weakened (e.g. disease, waterlogged soils, old age etc.). However, there are few events where significant numbers (tens of thousands) of trees have been downed, such as in the examples outlined in the case studies.

Due to issues with the attribution of tree losses to particular events, as well as few surveys being conducted after extreme weather events have occurred, it is not expected that a robust indicator can be developed to assess these trends in the short-term.

3.4 Uptake of natural flood management

Description: *Assessment of the uptake of natural flood management (NFM) practices.*

Type: *Action*

Time Series: *No time series available*

Region: *England and UK*

3.4.1 Introduction

Flood risk management can take several approaches. Firstly, hard engineering management involves using artificial structures, such as dams and embankments to create permanent solutions for reducing flood risk. These actions typically occur in built up areas and address the impact of high-water flows (e.g. overflow of rivers), rather than reducing the root cause (e.g. preventing high flows in the first place).

Natural flood management (NFM) approaches use land management solutions or engineering to help protect, restore or emulate natural functions of the river, coast, floodplains or catchments (Environment Agency, 2017).

NFM can also be mimicked in urban environments, here these actions are more often called Sustainable Drainage Systems (SuDS) (Susdrain, n.d.). SuDS integrate the use of concrete structures alongside "soft" engineering approaches to mimic natural drainage processes to reduce the effect on the quality (i.e. toxicity or level of contaminants) and quantity of run-off from developments and provide amenity and biodiversity benefits. SuDS are designed to make urban areas more permeable to water.

NFM and SuDS approaches are considered more sustainable and natural approaches to flood risk management compared to hard engineering. NFM is used to increase infiltration rates, store water and slow flow rates (Environment Agency, 2017). Susdrain (n.d.) adds to this list, suggesting that NFM can be used to release water slowly from stores, harvesting and using rain close to where it falls, filtering out pollutants and allowing sediments to settle out of water through controlling the water flows.

NFM and SuDS are used in the UK to reduce flood risk; by storing water or slowing flow and filtering it through both natural and urban landscapes. The different pros and cons of each approach can be found in Table 13.

Table 13. **Pros and cons of natural flood management (NFM), sustainable urban drainage systems (SuDS) and hard engineering.**

Approach	Pros	Cons
Hard engineering	• Effective • Controls where water flows	• Expensive to install • Can damage local ecosystems • Can increase flood intensity
NFM	• Delivers flood risk management • Delivers environmental and socioeconomic benefits • Produces flexible, resilient solutions • Can reduce overall impact costs of floods • More resilient to extreme events • Better value for money overall • Can be used alongside traditional defences	• Potential large initial expense • Need upkeep
SuDS	• Filters pollutants • Prevent sewage overflows • Reduce flood risk • Restore groundwater storage • Improve aquatic ecosystem • Can be repurposed into recreational spaces	• Potential large initial expense • Need upkeep

3.4.2 Actions, practices, and approaches for NFM

3.4.2.1 Nature-based solutions and/or green infrastructure

NFM reduces the flood risk from smaller magnitude floods in small to medium catchments, and compliments traditional engineering of natural landscapes (Environment Agency, 2017). NFM can be applied to river systems, from source to sea, as well as coasts and estuaries, with the surround landscapes offering management potential in order to slow the infiltration rate of rainfall into water systems. Actions that are encompassed under NFM include (Environment Agency 2017; The Dales to Vale Rivers Network, 2019):

River and flood plain management:

- River restoration – adding meanders to rivers.
- Floodplain restoration – restores the hydrological connectivity between floodplains and rivers.
- Leaky barriers – using wood to intercept the flow of water in a river.

- Offline storage areas – adapted floodplains that can store water and release it back to the river in a controlled matter, using an inlet, output, spillway or containment bund.

Woodland management:

- Catchment woodland – woodland in the catchment can reduce flood peaks and flood flows by intercepting, slowing, storing and filtering water.
- Cross-slope woodland – woodland planed on slopes that intercepts the flow of water as it runs down a hill.
- Floodplain woodland – woodlands in floodplains can increase water depth of the floodplain and slow floodwaters.
- Riparian woodland – woodlands planted on land immediately next to a water course can slow flood flows, reduce sediment delivery to watercourses and reduce bankside erosion.

Run-off management:

- Soil and land management – different measures that reduce peak flow by slowing and storing surface water runoff and encouraging infiltration in soils. Soil and land management includes conservation tillage, cover crops, crop rotation, altering stocking density, changing vegetation cover, hedgerow management and buffer strip management.
- Headwater management – techniques such as creating flow paths or restoring peatlands can delay flooding and reduce peak flow for small, local flood events.
- Runoff management – these include techniques like man-made ponds and sediment traps that can delay water flows and filter surface water runoff.

Coast and estuary management:

- Saltmarshes and mudflats – these reduce and dissipate energy from waves and tides in front of flood defences.
- Sand dunes – beach-dunes act as natural barriers, protecting land from tidal surges.
- Beach nourishment – adding material to shorelines to ensure they are a sufficient width and level to act as a coastal defence.

3.4.2.2 *Sustainable urban drainage systems*

SuDS are environmentally beneficial drainage systems in urban environments (Susdrain, n.d.). SuDS are built to management water quality (e.g. pollution), biodiversity and amenity as well as water quantity (e.g. flooding) and typically manage water near to rainfall events, as opposed to next to water bodies. They can be designed to transport surface water, slow runoff before it enters watercourses, store water in natural contours, allow water to soak into the ground, evaporate surface water and allow water to be transpired by evapotranspiration. SuDS include the following techniques:

- **Source control actions:** green roofs, rainwater harvesting, permeable or porous paving, and other permeable surfaces (e.g. grass).
- **Swales and conveyance channels:** swales, and channels and rills.
- **Filtration:** filter strips, filter trenches, and bioretention area.
- **Infiltration:** soakaways, infiltration trenches, infiltration basins, and rain gardens.
- **Retention and detention:** detention basins, retention ponds, and geocellular drainage.

- **Wetlands: distinct ecosystem that is flooded by water, either permanently or seasonally.**
- **Inlets, outputs and control structures:** inlets, outlets and controls, and vortex control structures.

3.4.2.3 Short-term / emergency measures

In addition, short-term emergency actions (or longer-term planned land use change) can be taken to reduce the risk of flooding and/or control where flood waters are directed. For example, in some situations the flooding of farmland offers a solution to flooding elsewhere, such as in towns or local residential areas where the economic impact may be much greater.

The Environment, Food and Rural Affairs (EFRA) Committee pointed out in its inquiry into 'future flood prevention' that evidence supplied by the CCC suggested that the cost of a flood affecting an urban area was £2.5m/ha higher than for a flood affecting agricultural land (EFRA, 2016).

Whilst farming has a role to play in managing the impact of floods, the National Farmers Union (NFU, 2016) emphasise that actions taken must consider that farmers need to protect their businesses. Whilst this action can prevent large economic losses in urban environments, it must be planned and it must go hand-in-hand with producing food, as the action has its own costs and repercussions for farmers, including lost crops, damaged grassland and the risk of water contamination.

3.4.3 Uptake of NFM in England

The Environment Agency's 'Working with Natural Processes to Reduce Flood Risk' evidence directory (Environment Agency, 2017) collated current knowledge to improve scientific understanding of NFM. That document, combined with £15 m of UK government (DEFRA) funding announced in July 2017, has encouraged wider implementation of NFM in the UK (Wells et al., 2019).

NFM approaches have been used in a wide range of applications across sites in England and more widely within the UK. Table 14 outlines projects that have been captured in two data sources: JBA Trust (2021) and Susdrain (n.d.). It is expected that the true number of projects is considerably greater than this, although there is no known central database currently collating this information at an England or UK-level.

Table 14. Example NFM projects that have been recorded on the JBA Trust website, and case studies on SuDS that have been recorded on Susdrain website. Source: *JBA Trust, 2021 and **Susdrain, 2021.

Region	Operational NFM projects*	Planned or feasible NFM projects*	SuDS case studies**
England	152	43	87
Wales	8	6	8
Scotland	22	10	4
Northern Ireland	-	-	1
Totals	**182**	**59**	**100**

Dataset 1: JBA Trust

JBA Trust (2021) has an interactive mapping website that shows information about nature-based flood risk management projects, including NFM, to help build up a picture of what is being done across the UK. To date (January 2021), the interactive mapping website had recorded 152 different NFM projects in England, and 182 when data for Scotland and Wales is also included. In addition, the interactive mapping shows areas where different types of river and catchment management approaches have the potential to help reduce flood risk by working with nature. To date (January 2021), the interactive mapping website showed 59 planned or feasible NFM projects.

Dataset 2: Susdrain

Susdrain (2021) has an interactive map showing cases studies for SuDS projects. To date (January 2021), the map has over 100 case studies from across the UK, of which 87 are England specific. The website notes that: *the extent to which the case studies have embraced the SuDS principles and exemplary good practice will vary and will often reflect the availability of guidance, the brief from the client and the subsequent philosophy and design criteria. However, all examples demonstrate the advantages of SuDS and provide improvements in either water quality, water quantity and amenity/biodiversity compared to traditional drainage.* As case studies are developed voluntarily to be uploaded to the Susdrain website, it is expected that the true number of SuDS projects being undertaken around the UK is considerably greater.

3.4.4 Barriers and enablers to the uptake of NFM

Although the use of NFM is becoming increasingly common in the UK (Dadson et al., 2017), significant barriers still exist to its implementation and the uptake of NFM schemes can be perceived as costly and time consuming by local authorities, with the benefits for downstream locations often unclear. Dadson et al. (2017) note that while it is recognised that implementation of NFM can produce multiple co-benefits, it is not easy to establish the precise nature and extent of those benefits due to a complex set of trade-offs between costs and benefits that accrue to different stakeholder groups within and outside the catchment.

A number of studies have looked at the opportunities and limitations to the uptake of NFM projects. Research by Bark et al., (2020) explored the views of NFM held by a diverse set of 118 flood risk management (FRM) stakeholders in the UK. The researchers found that while there was widespread interest in NFM, 'if, how and who pays for NFM' was found to be the most contested topic. Furthermore, they highlighted a need to debate rights/responsibilities linked with land management.

Another study by Wells et al., (2019) conducted 23 semi-structured interviews with land managers and practitioners of FRM in Nottinghamshire, which sought to understand the barriers to the uptake and implementation of NFM. The researchers found that the top barriers to uptake were lack of scientific evidence (78% of stakeholders), lack of governance (78%), lack of funding (70%), financial constraints for land managers (70%), perceptions of NFM (70%), and policy challenges (65%). Other barriers that also scored relatively high (40-60%) included interactions with land managers, interactions between practitioners, actor lack of knowledge, land manager cultural challenges, and transboundary catchment challenges.

Interventions to increase uptake of NFM projects

A recent study conducted on behalf of Defra (project FD2713) looked at the enablers and barriers to the delivery of natural flood management projects (Ngai et al., 2020). The researchers found that, although there are many examples of successful NFM projects to date, NFM is not yet routinely adopted within the catchment management process with confidence or ease (Ngai et al., 2020).

A series of key barriers to the delivery of NFM were identified. Those barriers which are particularly important for policy development and effectiveness included: NFM maintenance costs; legal liability of maintenance responsibilities and ownership of features; managing expectations of the extent of effectiveness of NFM; limited current NFM policy and regulation and differing governance between local authorities preventing straightforward NFM delivery; and limited access to modelling due to high costs or limited skills (Ngai et al., 2020).

Findings from the research suggested that appropriate advice, guidance and funding, plus good stakeholder relationships and timely participation was required to enable successful NFM implementation (Ngai et al., 2020). The following actions were identified with stakeholders in the study, which would help to overcome some of the barriers and enable greater uptake of NFM:

- Early, appropriate engagement with stakeholders.
- An improved evidence base with examples of successful partnerships and scheme implementation.
- Improved guidance surrounding NFM maintenance costs and liability issues.
- Form filling and the planning and consents processes need tailoring to NFM for location-specific schemes and to work across geographical and governance boundaries.
- The need for sufficient cost and resources appropriately scaled for projects both during the short-term development stages and for associated long-term maintenance costs.

3.4.5 Summary

Natural flood management can increase flood resilience and deliver multiple other benefits. The practice works best when a ‘catchment-based approach’ is taken and where a plan is developed to manage the flow of water along the whole length of a river catchment from its source to sea; allowing natural processes to compliment engineered flood defences (Environment Agency, 2017).

There are some examples of successful NFM projects to date, although NFM is not yet routinely being adopted. The limited research available (e.g. JBA Trust, 2021 and Susdrain, 2021) suggest that natural flood management practices (including SuDS) are being implemented in England on individual project levels, although a precise level of uptake is unknown due to limitations in the datasets and the lack of a central database to record such activities. There is little evidence to confirm whether or not NFM is being actively considered at a catchment-level.

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