South East Strategic Reservoir Option

Preliminary Environmental Information Report

Appendix 12.2 - Potential for fog and frost technical note

Date: October 2025

Contents

1 Potential for frost and fog formation as a result of the Project

1.1 Introduction

1.1.1 The potential impact of the South East Strategic Reservoir Option (referred to as 'the Project') on the local micro-climate has been raised by stakeholders as an issue of concern, particularly regarding the potential for an increased likelihood of frost and fog formation and the associated risk of traffic accidents related to those weather conditions increasing.

1.1.2 Previous studies and reviews have been undertaken to assess the potential for frost and fog development linked to the reservoir. The findings and conclusions from these investigations are detailed in the Technical Note: Micro-climate review at Annex A.

1.1.3 This Technical Note provides a summary of the key findings from the Technical Note (Annex A) and presents a high-level review to determine whether any developments since the original research (conducted in 2022) affect those conclusions. This includes a review of the most recent literature and relevant studies to ensure the findings remain valid in light of any new evidence.

1.2 Summary of previous studies

Previous studies 2005-2008

1.2.1 The potential impact of the Project on the local micro-climate was previously considered in studies conducted between 2005 and 2008. A summary of findings is provided in the Technical Note at Annex A.

1.2.2 The Technical Note (Annex A) summarises those earlier investigations as follows :

> *"The impact of the development on the micro-climate was considered in previous reservoir studies (2005–2008), which included assessments of how the proposed reservoir and its embankments might alter wind speed, humidity, temperature and shading in the local vicinity, and the potential to increase fog and frost-related incidents. Modelling and engineering studies involving an analysis of wind characteristics, predictions of wave generation and an assessment of their possible effects were carried out and the outputs used to inform the embankment design. These were Thames Water investigations completed to support a potential EIA that was not submitted at that time and therefore these studies were not published. Preliminary findings from the previous reservoir studies suggested the impact of the reservoir on micro-climate will be minimal, however mitigation may be required to improve road safety in areas where fog/frost-related incidences may increase once the reservoir was constructed, a point that was included in more recent WRMP documents."*

Micro-climate review

1.2.3 Annex A details further work which evaluated the potential micro-climate impacts of the Project, with a focus on concerns about fog and frost formation. It specifically:

- Reviewed baseline climate conditions and future climate change projections.
- Assessed existing evidence on how the reservoir might affect the local micro-climate.
- Explained key atmospheric processes influencing micro-climate.
- Synthesised findings and offers recommendations for further study.

1.2.4 Key findings from the study on frost and fog formation were:

- Frost: The reservoir's heat storage capacity is likely to reduce overnight frost risk on nearby land during spring and autumn. However, climate change is expected to have a much greater influence, with overall frost days already showing a downward trend. There is medium confidence in the conclusion.
- Fog: The risk of fog formation around the reservoir is considered low due to the flat terrain and steady local wind conditions, which are not conducive to fog development. However, raised embankments could lead to cold air drainage, potentially causing localised radiation fog. Landscape features such as buildings and vegetation may further influence fog and frost patterns by obstructing airflow. While the reservoir may contribute moisture to the atmosphere, its overall impact on fog formation is uncertain and likely to be minimal. There is low confidence in this conclusion.

1.2.5 The research found that advanced modelling tools, such as the Weather Research and Forecasting (WRF) model and the Met Office Unified Model could be used to simulate the potential micro-climate effects of the Project. However, due to the complexity, cost, and limited resolution of current models – particularly in capturing fog formation – these approaches may not provide significantly more insight. Observational studies, including the LANFEX project, highlight the ongoing challenges in accurately predicting fog due to the many interacting atmospheric variables involved.

1.2.6 The work concluded that the proposed reservoir is expected to have only minor effects on the micro-climate. Climate change, rather than the reservoir itself, is likely to be the dominant factor influencing future local climate conditions. As such, further modelling may offer only limited additional value.

1.3 Further review

1.3.1 A further review of expected microclimatic impacts aligns with the conclusions of the Technical Note in Annex A. However, with specific reference to modelling impacts on fogging, it was considered prudent to establish whether any scientific progress has been made in the intervening years that may have altered this conclusion.

Modelling advances since 2022

1.3.2 A significant factor in the conclusion reached by in the Technical Note (Annex A) was that the impact could only be assessed via Numerical Weather Prediction models, which at the time were typically run at resolutions greater than 1km. This would have made predictions of the weather processes local to the Project highly uncertain.

1.3.3 At the time, the highest resolution model in operational service within the UK Met Office's (UKMO) Unified Model framework was the 1.5km resolution UKV model. From 2022 onwards, a series of "city scale" regional models have been developed by the UKMO, with typical resolutions of 300m. This represents a significant step forward in the use of high-resolution weather models, capable of resolving local microclimatic effects and improving the possibility of accurate fogging predictions at the reservoir scale.

1.3.4 The use of these models is still in its infancy and we are not aware of a model that currently covers the Abingdon area. It would be feasible to commission the development of such a model, either by the UKMO or a third party using the open source Weather Research and Forecasting code. However, while the use of a higher resolution model would improve the possibility of accurate fogging predictions, this would not sufficiently mitigate for model uncertainties and biases would be difficult to quantify due to lack of empirical validation. Any conclusions reached through such a study could therefore not be considered robust.

Additional literature review (Post-2023)

1.3.5 A review of recent literature has identified several new studies published since 2023 that provide further insight into the potential micro-climate impacts of reservoirs. These studies reinforce the understanding that while reservoirs can influence local temperature, humidity, and atmospheric dynamics, the effects are typically localised and often secondary to broader climate change trends. Some noteworthy studies include:

- Zhao et al. (2021) conducted a global observational study on the climatic effects of large reservoirs, finding that surface area and storage capacity are key drivers of local temperature and precipitation changes. However, the study also highlighted significant variability depending on geography and reservoir characteristics, limiting direct applicability to the Project.
- Qin et al. (2023) used high-resolution WRF modelling to assess the impact of the Miyun Reservoir in China on heatwave dynamics. The study found that reservoirs can induce daytime cooling (up to −5°C) and night-time warming (up to +3°C) within a 20 km radius. The modelling was calibrated against observational data and found high correlation for the temperature variable but less confidence for relative humidity and wind speed. Frost or fog was not investigated in this study. While the modelling approach is sophisticated and validated, it is resource-intensive and based on a real reservoir, making it challenging to replicate for the Project without significant investment.
- Li et al. (2023) explored how reservoirs influence the coupling between temperature and precipitation. The study confirms that reservoirs can influence local climate, particularly with respect to temperature and precipitation patterns. Although it does not directly address variables such as frost or fog, it is reasonable to infer that changes in temperature and humidity could indirectly affect the likelihood of their occurrence. However, the research is based exclusively on observational data collected from areas near and distant from existing reservoirs worldwide. It does not incorporate modelling or simulation techniques and therefore does not offer a methodology that could be directly applied to assess the potential impacts of the Project. Furthermore, the data presented are not sufficiently detailed to draw conclusions about the Project's specific influence on local temperature, precipitation, or the formation of frost and fog. As such, while the findings suggest there may be some degree of climatic influence, they cannot be used to determine whether these effects would be beneficial or adverse in the context of the Project.

1.3.6 These studies collectively suggest that while reservoirs can have measurable effects on local climate variables, the magnitude and direction of these effects depend heavily on local topography, reservoir design, and broader climatic context. Importantly, most studies rely on either observational data from existing reservoirs or high-resolution modelling that is not easily transferable to a proposed scheme like the Project without empirical calibration.

1.4 Conclusions

1.4.1 The work presented in the Micro-climate Technical Note (Annex A) offers a comprehensive review of the potential influence of the Project on the local micro-climate. It draws on climate observations, climate change projections, and relevant research to assess the likelihood of increased frost and fog formation due to the reservoir.

1.4.2 A further high-level review of literature published since 2022 indicates that while there have been advances in high-resolution modelling – such as the development of sub-kilometre scale models using the WRF framework – these methods remain resource-intensive and require significant expertise. Moreover, the inherent uncertainties in fog modelling, particularly in the absence of site-specific observational data, mean that such approaches would still yield only medium confidence at best.

1.4.3 Recent studies (e.g. Zhao et al., 2021; Qin et al., 2023; Li et al., 2023) have explored the influence of large reservoirs on local climate. However, these studies often focus on reservoirs in different climatic zones, with significantly larger surface areas and different hydrological characteristics than the Project. Additionally, many of these studies do not directly address fog or frost formation, and their findings are based on observational data from existing reservoirs, limiting their applicability to the Project.

1.4.4 Overall, the conclusion that the value of micro-climate modelling for the Project is limited remains valid. The potential impacts are expected to be minor and further modelling would not significantly improve confidence in the outcomes.

References

Li, Y., Wang, J., Zhang, H., & Liu, Y. (2023). Impact of reservoirs on local precipitation–temperature coupling relationships. Geophysical Research Letters, 50(18), e2023GL103453. https://doi.org/10.1029/2023GL103453

Qin, Y., Zhang, Y., Wang, H., Liu, J. and Chen, X. (2023). Modelling analysis of the potential impact of large reservoir on heatwave events. Ecological Indicators, 154, p.110024. https://doi.org/10.1016/j.ecolind.2023.110024

Li, J., Zhang, S., Obulkasim, O., Lu, X., Wei, Z., Yuan, H., Li, L., Zeng, J., Yang, D. and Dai, Y. (2023). Impact of reservoirs on local precipitation–temperature coupling relationships. Geophysical Research Letters, 50(18), e2023GL103453. https://doi.org/10.1029/2023GL103453

Annex A Technical Note: Micro-Climate Review

Technical Note: Micro-climate review

1. Introduction

1.1. Background

The South East Strategic Reservoir Option (SESRO) is a raw water storage option in the upper catchment of the River Thames. The SESRO project is being developed by Thames Water and Affinity Water with the aim of delivering a new reservoir to store water abstracted during periods of high flow in the River Thames for use during periods of low river flow or high demand for water[1]. As well as providing a resilient water supply for the South East, the reservoir also provides opportunities to create new habitats and increase biodiversity, as well as provide new leisure and recreation facilities[2].

Figure 1-1 shows the site location and proposed site layout, including a number of features that may influence interactions between the land and atmospheric conditions, including the water body itself, raised embankments, screening mounds and the creation of wetland areas.

The impact of the development on the micro-climate was considered in previous reservoir studies (2005-2008), which included assessments of how the proposed reservoir and its embankments might alter wind speed, humidity, temperature and shading in the local vicinity, and the potential to increase fog and frost related incidents. Modelling and engineering studies involving an analysis of wind characteristics, predictions of wave generation and an assessment of their possible effects were carried out and the outputs used to inform the embankment design. These were Thames Water investigations completed to support a potential EIA that was not submitted at that time and therefore these studies were not published.

Preliminary findings from the previous reservoir studies suggested the impact of the reservoir on micro-climate will be minimal, however mitigation may be required to improve road safety in areas where fog/frost related incidences may increase once the reservoir was constructed, a point that was included in more recent WRMP documents[3].

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[1] Ofwat (2023) Strategic regional water resource solutions: standard gate two final decision for South East Strategic Reservoir Option. Available online: https://www.ofwat.gov.uk/wp-content/uploads/2023/03/SESRO-Gate-Two-Final-Decison-Document.pdf

[2] A new reservoir – the South East Strategic Reservoir Option (SESRO) - Thames Water Resources Management Plan (thames-wrmp.co.uk)

[3] Revised draft Water Resources Management Plan 2019 Statement of Response No 2 – Main Report April 2019

Figure 1-1 - Proposed site layout showing indicative location for SESRO along with main features

Source: [South East Strategic Reservoir Option (SESRO) – a new reservoir for the south east - Thames Water Resources Management Plan (thames-wrmp.co.uk)]

1.2. Aims and objectives

The aim of this Technical Note is to summarise the existing evidence on the potential impacts of the proposed reservoir on the local micro-climate, particularly in response to concerns around fog and frost formation.

Its objectives are to:

- Provide contextual information on the baseline climate and future climate change
- Summarise existing evidence on the scale of potential impacts of the proposed reservoir on the micro-climate
- Provide an overview of the fundamental atmospheric processes that influence micro-climate
- Synthesise the evidence and provide recommendations for further work

The Technical Note presents an initial opinion on the likelihood of impacts of SESRO on local climate in East Hanney, Drayton and Steventon, in the context of natural climate variability and climate change.

1.3. Structure of the report

The technical note is structured as follows:

- Section 2 provides a review of available climate observations and future climate change scenarios to provide an objective baseline climatology.
- Section 3 provides a literature review covering the key processes that influence micro-climate, relevant research literature and the relevant SESRO and Upper Thames Major Reservoir Development (UTMRD) studies completed to date.
- Section 4 provides a synthesis of the evidence, summarising micro-climate features, potential impact of the development on local receptors.

2. Baseline climate and future climate change

The baseline climate was described in previous EIA documents but is also updated here, based on the best available climate information available from the Met Office and other sources. This update provides an objective baseline, as well as evidence on trends over the last 40 years.

Potential changes in future climate are presented based on the UK Climate Projections 2018 (UKCP18) Local Climate Model (LCM) data for the site, UKCP18 probabilistic climate extremes and relevant indicators from the UK Climate Resilience programme. It is notable that South Oxfordshire has already warmed by 1.2 ˚C since the late 19th century and is expected to warm by approximately 3 to 4 °C by the 2070s under the high-end RCP8.5 climate scenario.

2.1. Climate data sources

A number of data sources are available to characterise the regional climate in South Oxfordshire, but very few site-specific observations are available. This section describes the available data sources.

2.1.1. Met Office gridded data sets

The Met Office produces 1 km gridded observation data sets for a number of climate variables[4]. The 'HadUK' data set provides suitable data to construct a baseline climatology for the site, as well as detect changes in the baseline climatology due to climate change. The following climate variables are available as part of the 1 km gridded data:

- Maximum air temperature
- Minimum air temperature
- Precipitation
- Wind speed
- Number of days with ground frost

This report uses the HadUK data to provide a baseline climatology representative of the period 1981 - 2000 inclusive for the SESRO site. The 1981-2000 period chosen is the same as the standard 20-year baseline period used by the Met Office to reflect changes in climate in UKCP18. The data presented are from the 1 km cell in the centre of the site at 51°38'6.36"N 1°21'29.97"W.

2.1.2. Data from weather stations

i. Climate observations in Oxfordshire are managed primarily by the Met Office. Data from a number of synoptic weather stations are made publicly available through the "Open MIDAS" system.[5] The closest long-term record, which is accessible on public archives is from the Radcliffe Meteorological Station in Oxford approximately 15 km north of the site of the proposed reservoir. A synoptic weather station was also operated at the former Abingdon Airfield in Shippon, 7 km north of the site. Some sub-daily and daily data are available between 1957 and 1973 including air temperature, pressure and further basic climate variables.

In addition, previous assessments by Cascade Consulting[6] made use of 15-minute data from the following sources:

- Upper Thames Major Resource Development automatic weather station (UTMRD AWS): from August 2005 to June 2006.
- Benson and Brize Norton weather stations; note that the available data files contain solely wind speed and wind direction data from February to May 2007.
- Orchard Farm: October 2006 to January 2007, March to July 2007, January 2008 to January 2009.

[4] HadUK-Grid Gridded Climate Observations on a 1km grid over the UK, v1.0.3.0 (1862-2020)

[5] Met Office (2019): Met Office MIDAS Open: UK Land Surface Stations Data (1853-current). Centre for Environmental Data Analysis, 10/06/2022. http://catalogue.ceda.ac.uk/uuid/dbd451271eb04662beade68da43546e1

[6] It is noted our review has been limited to the Cascade Consulting files made available to us by Ricardo and Thames Water.

2.1.3. Met Office UK Climate Projections 2018

The UK Climate Projections 2018 (UKCP18)[7] provide information on the future climate of the UK, under a range of Representative Concentration Pathways (RCPs) from 'high-end' scenarios (RCP8.5) to very low-end scenarios (RCP2.6). This study makes use of the UKCP Local Projections (a very high-resolution Regional Climate Model product) for RCP8.5 to assess potential future changes in climate. Lower warming and lower impact scenarios can be derived through scaling the results of these models. Changes in climate are relative to the 1981-2000 20-year baseline period. Full details of the data used for this assessment are provided in Appendix A.

2.2. Baseline climate

2.2.1. Temperature

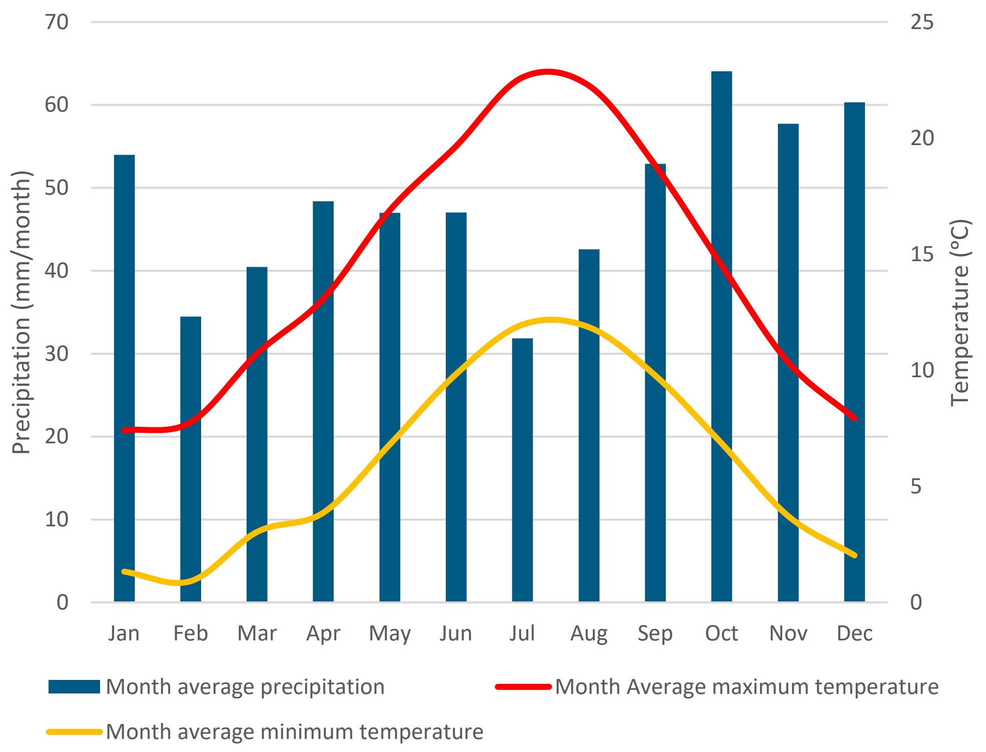
2.2.1.1. Seasonal data

Figure 2-1 shows the annual average observed minimum and maximum temperatures in South Oxfordshire for 1981-2000 vary from 0.9 °C in the winter to 22.6 °C in the summer[4]. Figure 2-2 shows the 1981-2020 timeseries of daily minimum and maximum temperatures and that very low minimum temperatures are rare, with the coldest observed temperatures in the 1981-2020 period reaching -17.9 °C in January 1982. Higher maximum temperatures are becoming more frequent. As shown in Figure 2-3 by the climate stripe changes in annual average daily temperatures that all top ten observed temperatures from 1981 to 2020 occurred from 1990 onwards. The highest maximum daily temperature of 35.7 °C was recorded in July 2019. This high temperature was exceeded on the 19/7/22 as much the region experienced temperatures of more than 38 °C and Heathrow airport recorded 40.2 °C.

Temperature data from Abingdon Airfield just north of the site and north of the A415, show a similar seasonal pattern. Figure 2-4 shows sub-daily temperatures observed in 1963, which had a particularly cold period in January. These data indicate a daily cycle with the lowest temperatures at 3 am and warmest temperatures at 3 pm in the afternoon.

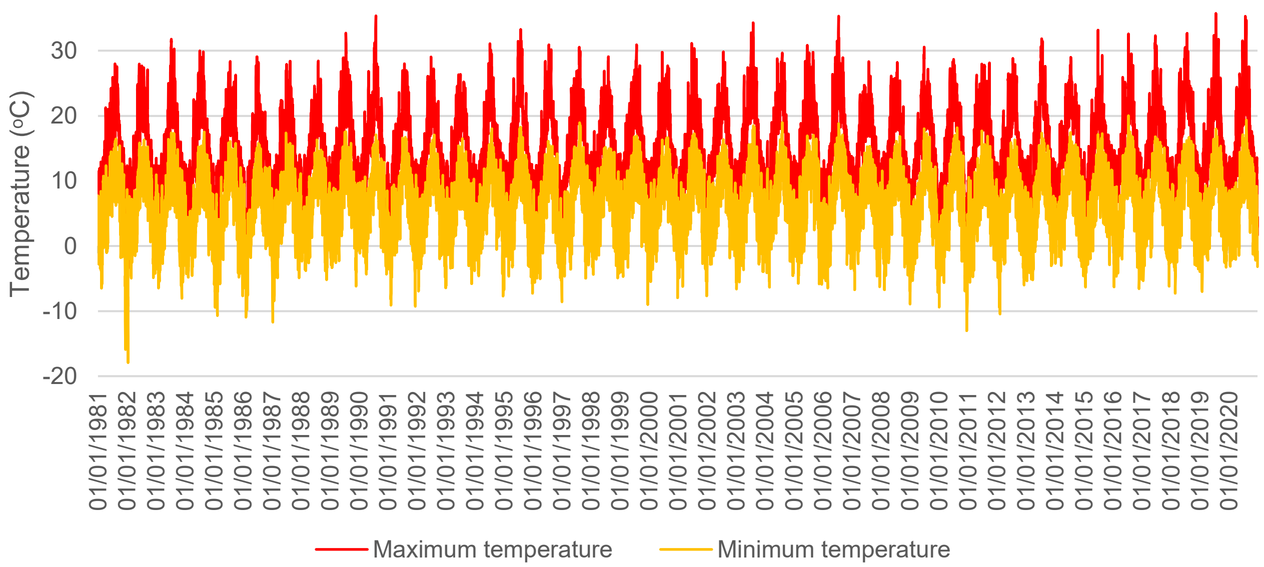
[7] Data obtained from the UKCP User Interface. Data: Variables from local projections (2.2km) regridded to 5km over UK for daily data. Gohar G, Bernie D, Good P and Lowe JA, 2018. UKCP18 Derived Projections of Future Climate over the UK, Met Office.

Figure 2-1 - Annual average maximum and minimum temperatures and monthly precipitation from 1981 to 2000 inclusive



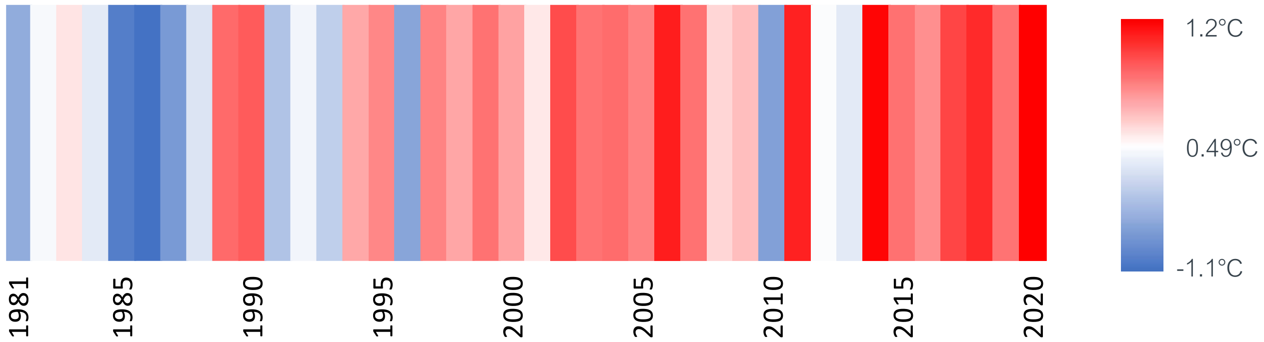
Source: HadUK 1 km gridded data[4]

Figure 2-2 - Annual average daily maximum and minimum temperature time series from 1st January 1981 to 31st December 2020



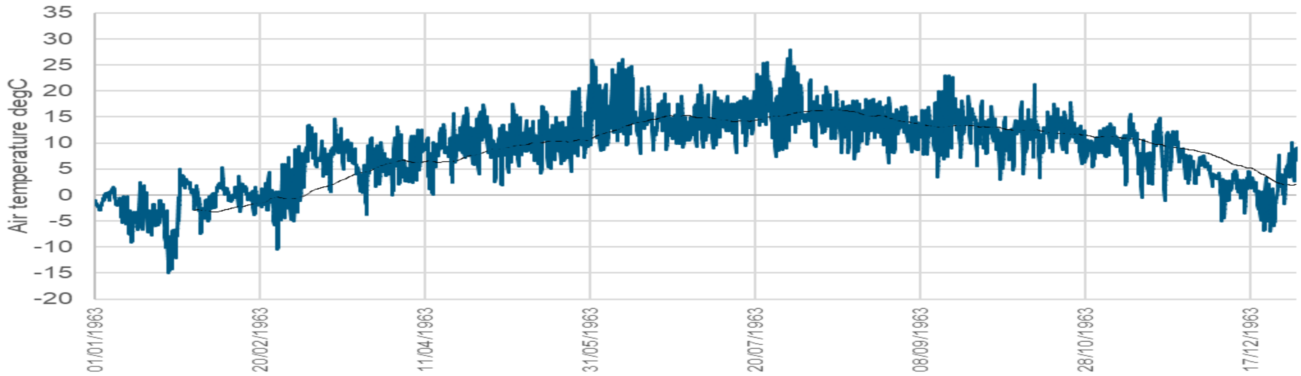
Source: HadUK 1 km gridded data (SESRO) [4]

Figure 2-3 - Climate stripes of changes in annual temperature relative to the 1981-2000 period. Blue (red) colours represent cooler (warmer) years than average.



Source: HadUK 1 km gridded data[4]

Figure 2-4 – Sub-daily (3 hour) temperature time series for Abingdon Airfield, Shippon in 1963.



Source: MIDAS Open Data, Abingdon Airfield[8]

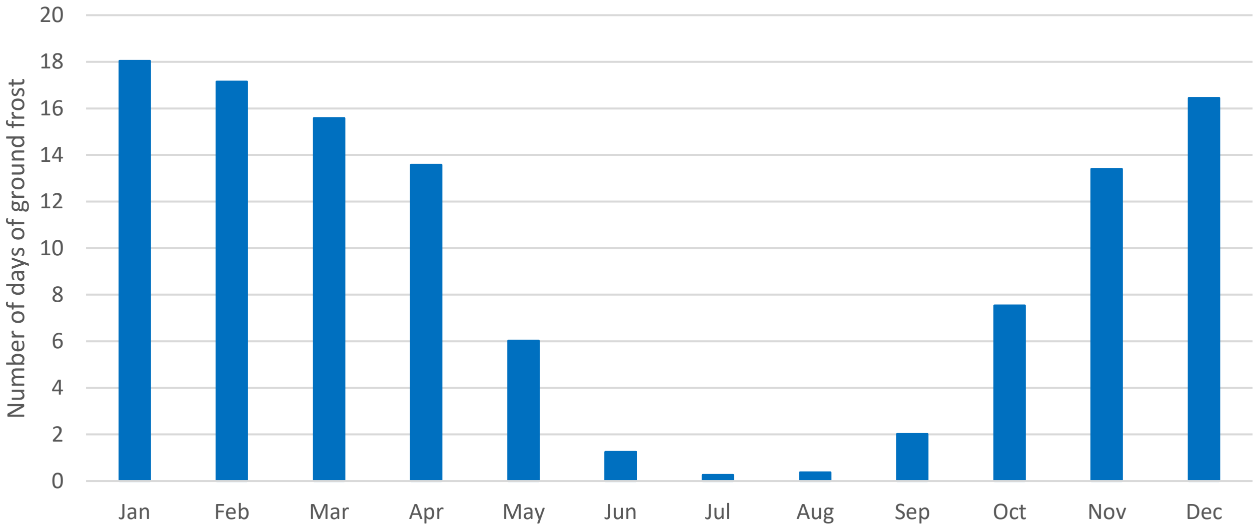
[8] Met Office (2006): MIDAS: UK Hourly Weather Observation Data. NCAS British Atmospheric Data Centre, 10/06/2022. https://catalogue.ceda.ac.uk/uuid/916ac4bbc46f7685ae9a5e10451bae7c

2.2.1.2. Frost days

Figure 2-5 shows that for 1981-2000 on average the number of ground frost days per month ranges from 0 to 18 days. Figure 2-6 shows a time series from 1981-2020 of the total number of days per year with ground frost per year. There is a slight negative trend in the average number of ground frost days per year, with the average number of days with ground frost decreasing from 118 days in the period 1981-1990 to 104 days in the period 2011-2020[4]. Research from Kendon et al. (2021)[9] states:

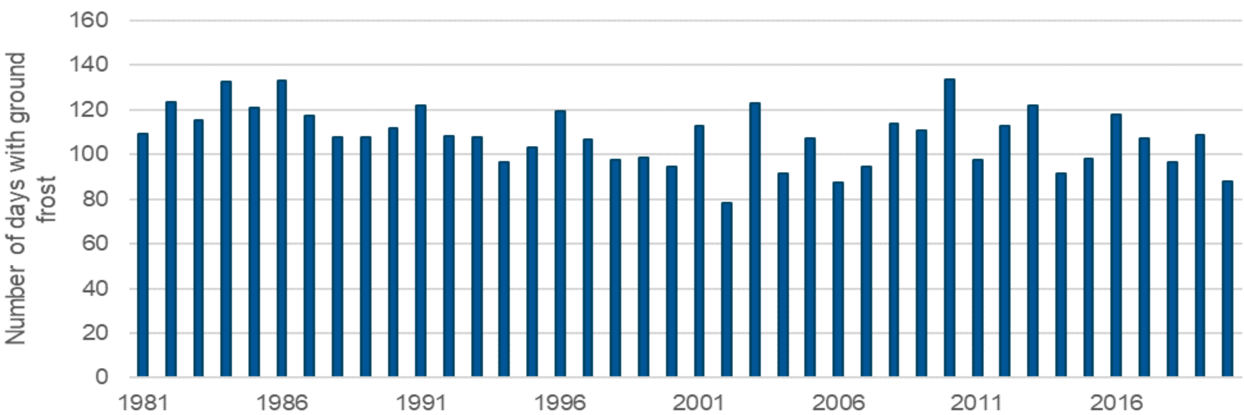
- 2020 was the seventh consecutive year where the number of air and ground frosts was below the 1981–2010 average. The number of air and ground frosts were both fourth lowest in the series from 1960/1961.
- The most recent decade (2011–2020) has had 16% fewer days of air frost and 14% fewer days of ground frost compared to the 1981–2010 average, and 25%/20% fewer compared to 1961–1990."

Figure 2-5 – Average number of ground frost days (1981-2000)



Source: HadUK 1 km gridded data[4]

Figure 2-6 – Time series (1981-2020) of the total number of days with ground frost per year



Source: HadUK 1 km gridded data[4]

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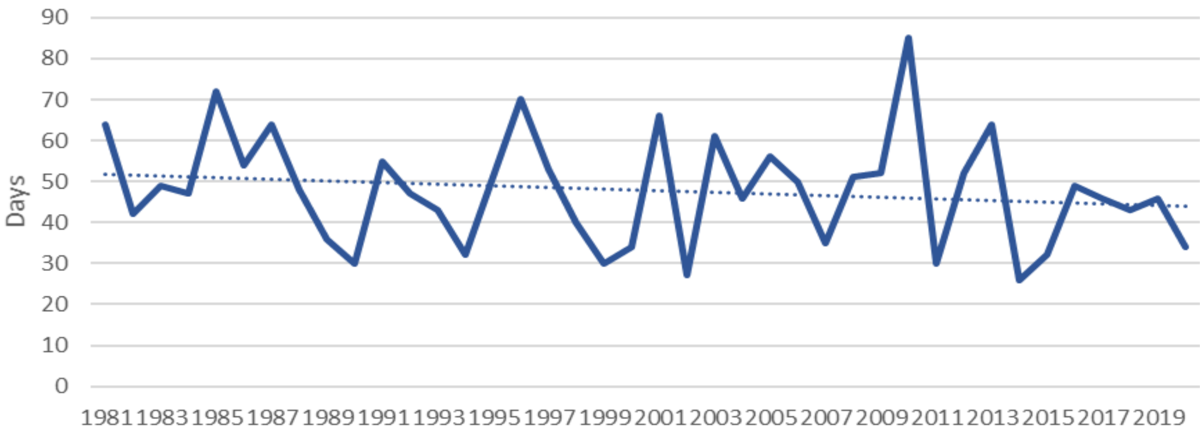
[9] Kendon, M., McCarthy, M., Jevrejeva, S., Matthews, A., Sparks, T., & Garforth, J. (2021). State of the UK Climate 2020. International Journal of Climatology, 41 (Suppl. 2), 1– 76. https://doi.org/10.1002/joc.7285

2.2.1.3. Cold snaps

Ground frost typically forms if the ground surface temperature falls below 0 °C and below the dew point temperature. Air frost forms when the air temperature falls to or below the freezing point of water[10]. Due to local variation in topography ground frost may occur on marginal nights when temperatures are anywhere between plus and minus 5 °C. The HadUK data[4] provides air temperature and the number of days per month that frost is observed and recorded. From 1981 to 2020, there are 1912 days where the minimum air temperature falls to, or below, 0 °C; there are 70 days where the maximum air temperature falls to, or below, 0 °C.

Figure 2-7 shows that the number of days with a minimum air temperature of 0 °C and below each year fluctuates from 1981 to 2020, however, there is a general decline over the decades. The average number of days per year with a minimum temperature at, or below, the freezing point decreases from approximately 50 days per year to 42 days per year for the time ranges 1981-1990 and 2011-2020, respectively. A similar trend can be seen for the maximum air temperature, with the average number of days per year with a maximum temperature at, or below, 0 °C decreasing from approximately 4 days to 0 days for the same time ranges.

Figure 2-7 – A time series (1981-2020) showing the average number of days per year with a minimum temperature at, or below, the freezing point



Source: HadUK 1 km gridded data[4]

2.2.1.4. Cold weather events

The Met Office issues a Cold Weather Alert service if one of two thresholds are breached[11]:

- Mean temperatures below 2 degrees Celsius for 48 hours or longer
- Heavy snow and/or widespread ice may occur

Mean air temperature was calculated by averaging the maximum and minimum air temperatures measured on a day. During the timeseries period from 1981 to 2020 there were 160 instances where mean temperature was below 2 °C for 48 hours or longer, hereinafter called a "cold weather event". The longest cold weather event lasted for 29 days, starting on the 3rd February 1986.

All cold weather events from 1981 to 2020 occurred in the months between November to March, inclusive. In total, 13 cold weather events occurred in March while 47 events occurred in December.

2.2.2. Precipitation

The annual average precipitation recorded in South Oxfordshire was 500 mm from 1981-2000, which is low rainfall compared to the Thames catchment as a whole. Figure 2-1 shows that the wettest month is October, 64.0 mm/month, and driest month is February, 34.5 mm/month. The maximum precipitation experienced on a single day was 45.1 mm on 22/09/1992[4] during the 1981-2000 baseline period. Outside of the baseline period 52.8 mm was experienced on a single day on 20/07/2007, and 45.6 mm on 03/10/2020.

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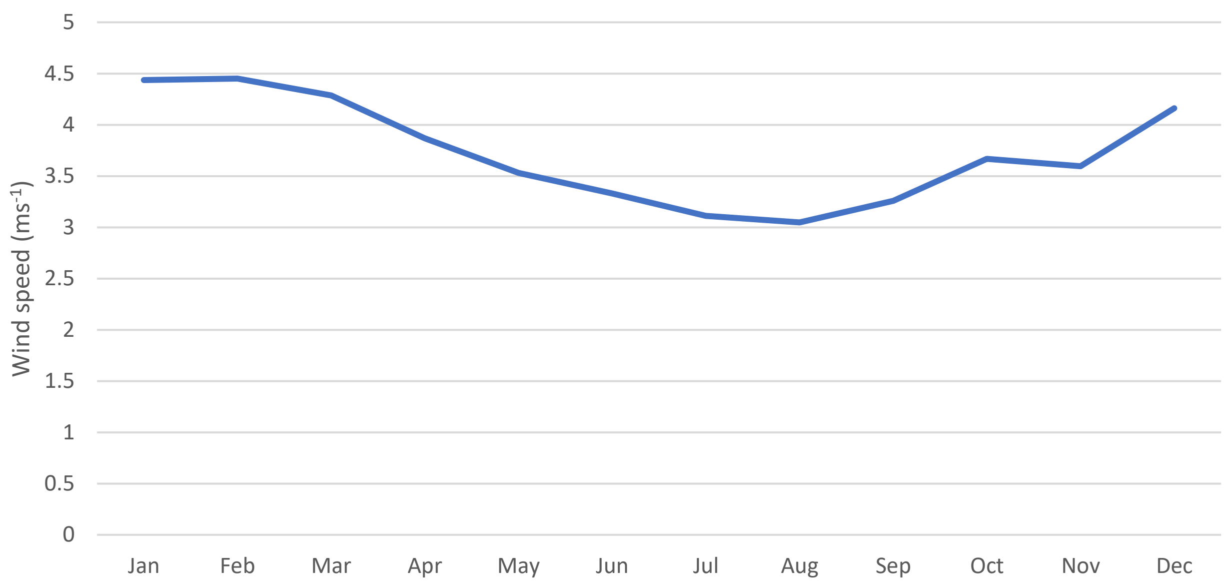
[10] https://www.metoffice.gov.uk/weather/learn-about/weather/types-of-weather/frost-and-ice/frost
[11] https://www.metoffice.gov.uk/public/weather/cold-weather-alert/?tab=coldWeatherAlert&season=normal

2.2.3. Windspeed

Figure 2-8 shows that the average monthly wind speed for 1981-2000 in south Oxfordshire ranges from 3.04 ms^{-1} (August) to 4.43 ms^{-1} (January). During a longer timeseries period from 1981 to 2020, the maximum average wind speed at 10 m in the HadUK data was 6.60 ms^{-1} which occurred in February 1990[4].

Figure 2-8 - Average monthly wind speed for 1981-2000

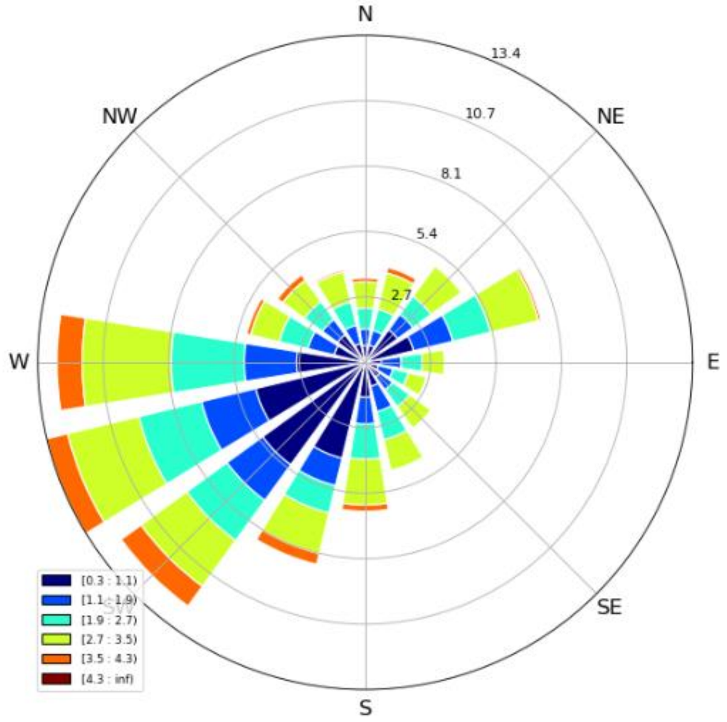


Source: HadUK 1 km gridded data[4]

Figure 2-9 presents a wind rose from August 2005 to June 2006 data collated onsite from the UTMRD AWS to provide a snapshot of local windspeeds and direction. In that time period, the site predominantly experienced west to south-westerly winds with wind speeds between 2.7 to 3.5 ms^{-1}. There is a lack of very low windspeeds on site, showing the site is prone to steady winds. However, the windspeeds are similar to other locations on Oxfordshire[12].

[12] https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-averages/gcpn7mp10

Figure 2-9 – Average wind direction and speed (ms^{-1}) on site – the plot shows a histogram i.e. the number of windspeed events that fall within a specified wind speed range and given direction



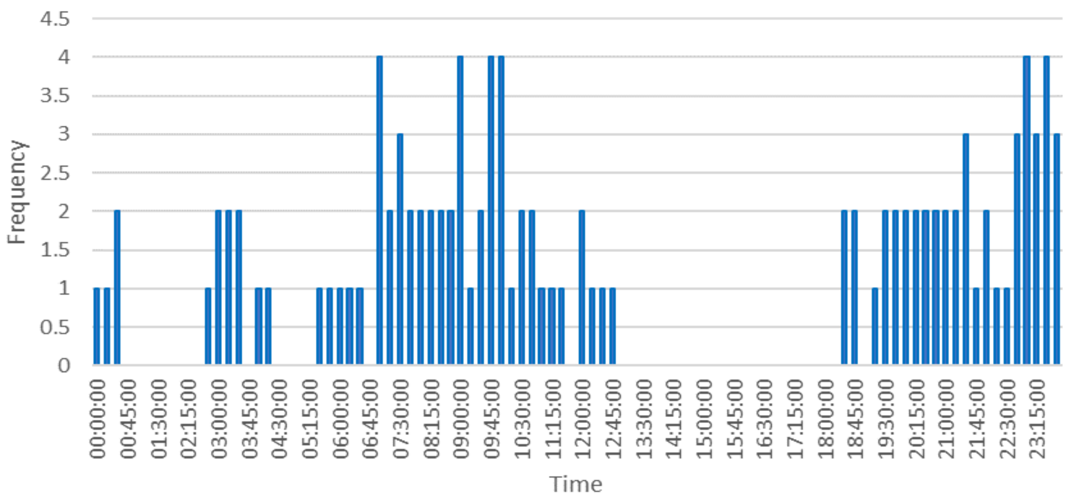
Source: Data from the UTMRD AWS (August 2005 – June 2006), from Cascade Consulting

2.2.4. Fog

From 19th August 2005 to 18th June 2006, there are 32 unique days where fog or ice fog patches were recorded at the UTMRD AWS at some point during the day or night.

Figure 2-10 shows the frequency that fog or ice fog was detected at UTMRD AWS at each 15 minute interval of a 24 hour day. Fog was typically detected from 7:00 am to 12:45 pm and from 6:30 pm to 00:30 am.

Figure 2-10 – Frequency that fog or ice fog was detected at a particular time of day from August 2005 to June 2006



Source: Data from the UTMRD AWS (August 2005 – June 2006), from Cascade consulting

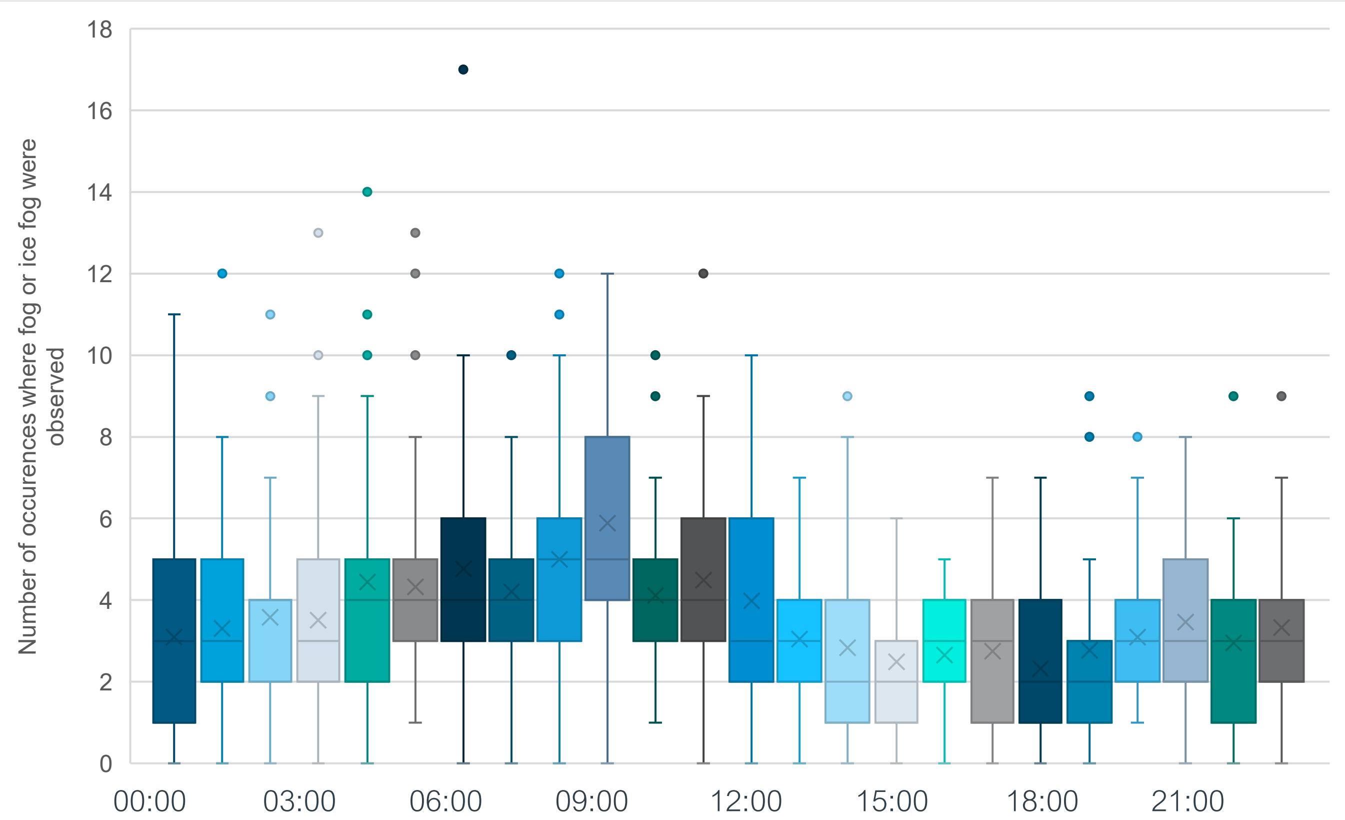
Number of days with fog determined by visibility:

An analysis of the Cascade UTMRD AWS data reveals that the number of fog days, where visibility was 1000 m, at UTMRD AWS was 10 days between 19th August 2005 to 18th June 2006. Only one of the fog days occurred in 2006.

Brize Norton

Additionally, to provide a nearest neighbour context the number of occurrences where fog or ice fog were observed at Brize Norton were reviewed. Figure 2-11 shows a box plot showing for each hour of the day the range of occurrences where fog or ice fog were observed during 1st January 1980 to 31st December 2022 inclusive. Mist which is defined as 'when there is such obscurity and the associated visibility is equal to or exceeds 1000 m',[13] was not included. The box plot shows that fog mostly occurs during the early hours of the morning and disperses during the morning after sunrise as the ground warms. This provides guidance on what time of day fog will likely occur and when it will likely disperse, it cannot be used as a direct comparison for number of occurrences due to the different geographies on the edge of the Wolds.

Figure 2-11 - Number of occurrences at Brize Norton where fog or ice fog were observed each hour between 1980 and 2022. The box shows the upper and lower quartiles, and the median, whilst the 'X' marks the mean. The tails represent the minimum and maximum, whilst the dots represent outliers.



Source: MIDAS Open Data, RAF Brize Norton.[14]

2.2.5. Relative Humidity

From 1981 to 2000 relative humidity was approximately 85% in the winter months, reducing to 74% over the summer months[4].

[13] What is the difference between mist, fog and haze? - Met Office

[14] Met Office (2023): MIDAS Open: UK hourly weather observation data, v202308. NERC EDS Centre for Environmental Data Analysis, 03 October 2023. doi:10.5285/c9663d0c525f4b0698f1ec4beae3688e. https://dx.doi.org/10.5285/c9663d0c525f4b0698f1ec4beae3688e

2.3. Future climate

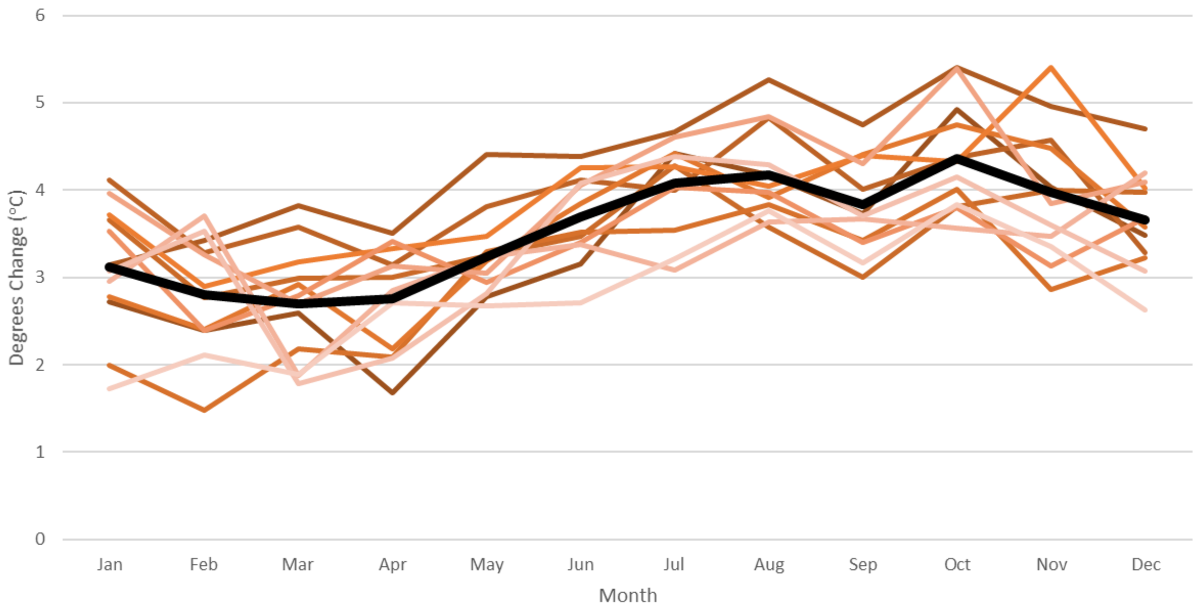
2.3.1. Climate change scenarios

The climate change scenarios presented in this technical note derive from the high-end RCP8.5 scenario, which is associated with high atmospheric carbon concentrations and primarily from the UKCP18 local projections. These are based on a very high-resolution Regional Climate Model (RCM), which is promoted by the Met Office as providing the best data for local extremes and potential changes in summer rainfall. There are 12 members of the RCM, which provide a spread of results for this specific model, but the full range of potential outcomes is far wider.

2.3.2. Temperature change

Figure 2-12 shows the average uplift in average minimum temperature for each month of the year, ranging from around 2 °C in spring to around 4 °C in summer compared to 1981-2000. Some individual models indicate minimum temperatures may increase by more than 5 °C in the 2070s[15].

Figure 2-12 - Temperature change for minimum temperature (°C) for the 2070s (2061-2080) relative to the 1981-2000 baseline, for RCP8.5 models (orange) and average change (black)



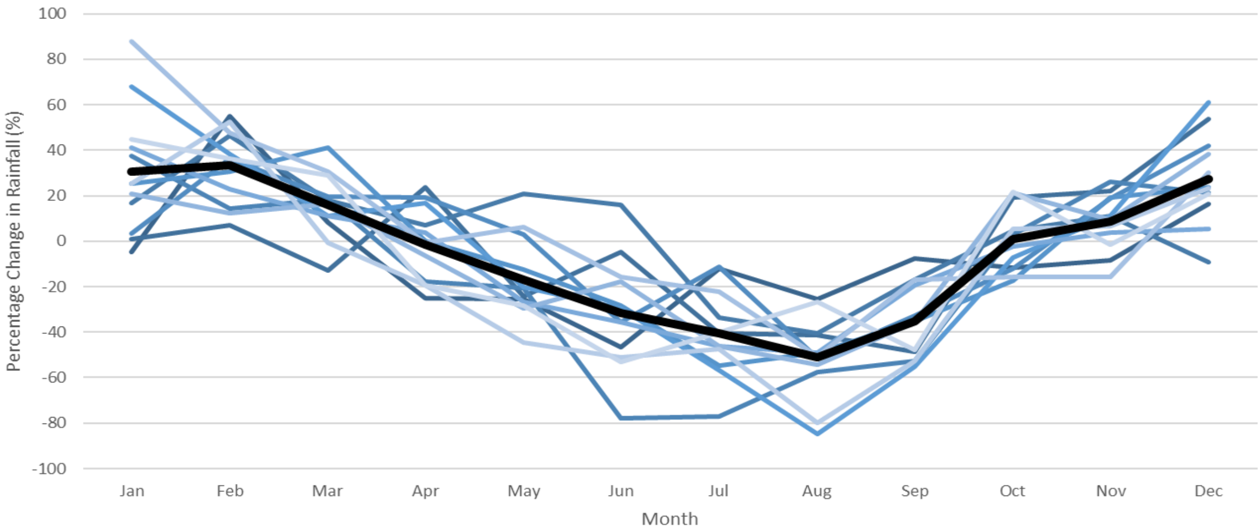
Source: Met Office UKCP Local[15]

2.3.3. Precipitation changes

Figure 2-13 shows there is widespread variation in the potential changes in average monthly rainfall throughout the year, with an average increase of 33% in February and an average decrease of 50% in August. Some modelling scenarios depicted an increase in precipitation as much as 88% in January and a decrease by up to 85% in August[15].

[15] Data obtained from the UKCP User Interface. Data: Variables from local projections (2.2km) re-gridded to 5km over UK for monthly, seasonal or annual data. Gohar G, Bernie D, Good P and Lowe JA, 2018. UKCP18 Derived Projections of Future Climate over the UK, Met Office.

Figure 2-13 – Precipitation percentage change (%) for the 2070s (2061-2080) relative to the 1981-2000 baseline for RCP8.5 models (blue) and average change (black)



Source: Met Office UKCP Local[15]

2.3.4. Wind

The UKCP18 projections show no compelling trends in storminess, as determined by maximum gust speeds, from the UK wind network over the last four decades.

The global projections over the UK show an increase in near surface wind speeds over the UK for the second half of the 21st century for the winter season when more significant impacts of wind are experienced. This is accompanied by an increase in frequency of winter storms over the UK. However, the increase in wind speeds is small compared to natural variability[16] and users generally assign very low confidence to climate change impacts on wind variables.

2.3.5. Cold snaps

UKCP18 RCP8.5 local projections show that by the 2030s (2021-2040) an average year will experience less than 1 day where the minimum temperature falls to, or below, 0 °C. By the 2070s (2061-2080) there may be no days where minimum temperature falls to, or below, 0 °C. This is a large decrease from the annual average numbers of days experience sub-zero temperatures in the 1981 to 2000 baseline, approximately 9 days per year. These projections suggest that the observed downward decline in cold snaps will continue and accelerate under climate change. With the number of days experiencing temperatures at, or below, 0 °C projected to decrease over the century, the appropriate conditions for ground frost to form will also decrease.

2.3.6. Cold weather event

The Met Office issues a Cold weather alert service if one of two thresholds are breached[1]:

- Mean temperatures below 2 degrees Celsius for 48 hours or longer
- Heavy snow and/or widespread ice

Figure 2-14 shows the 10th, 50th and 90th percentile of the potential number of occurrences of a public cold weather alert event per year over the 21st century in a 12kmx12km grid around Abingdon. On average, the number of cold weather events per year is expected to decrease from approximately 3 events from 1981-2010 to 1 event per year by the 2080s (2071-2100).

Reviewing the UKCP18 local projections that are localised to the site, under RCP8.5 it is projected that there could be no cold weather events in the 2030s (2021-2040) and in the 2070s (2061-2080).

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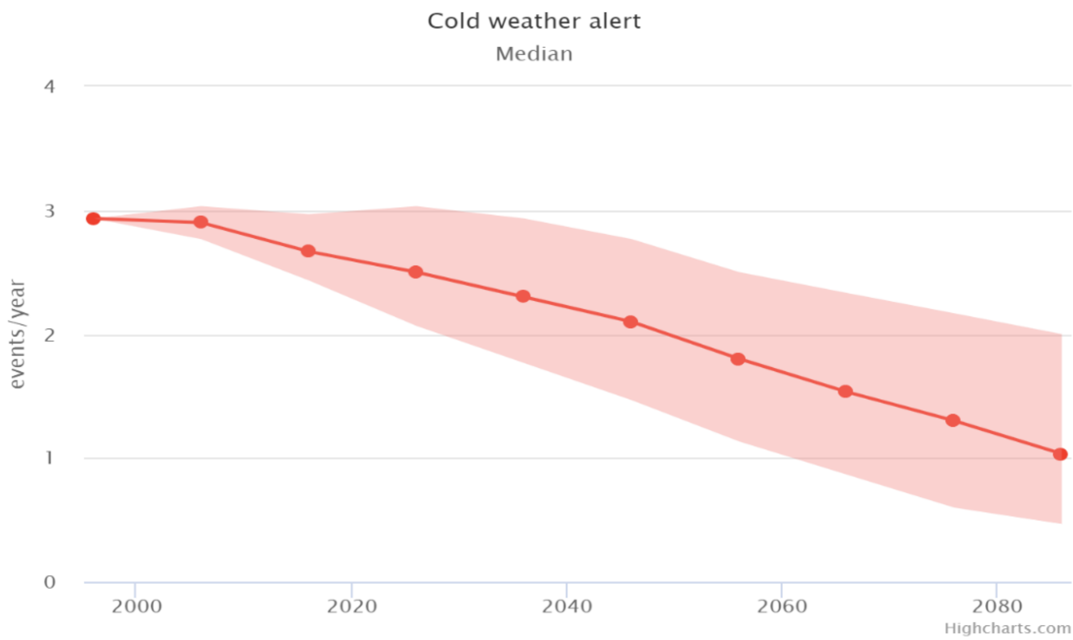
[16] https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-fact-sheet-wind_march21.pdf

Figure 2-14 – Number of cold weather alert events per year

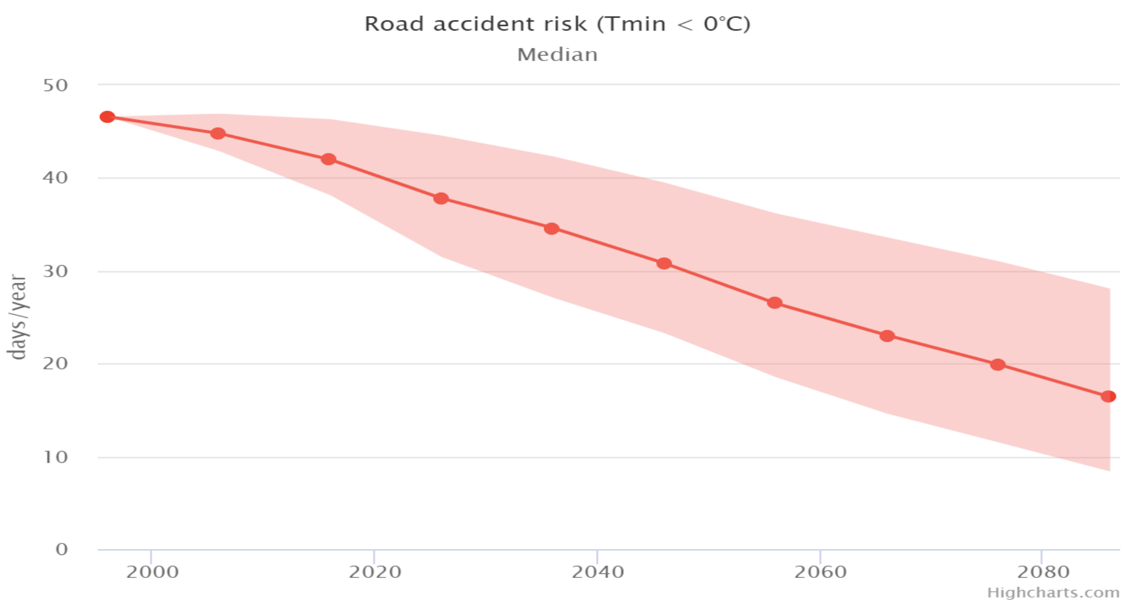


ii.

Source: UK Climate Risk Indicators[17]

Figure 2-15 shows the potential 10th, 50th and 90th number of days with a risk of road accidents, where minimum temperature is below 0 °C, per year in a 12 x 12 km grid around Abingdon. The number of days per year with a risk of road accidents from cold weather is expected to decrease from approximately 47 in 1981-2010 to 16 in the 2080s (2071-2100).

Figure 2-15 - Number of road accident risk days per year



Source: UK Climate Risk Indicators[17]

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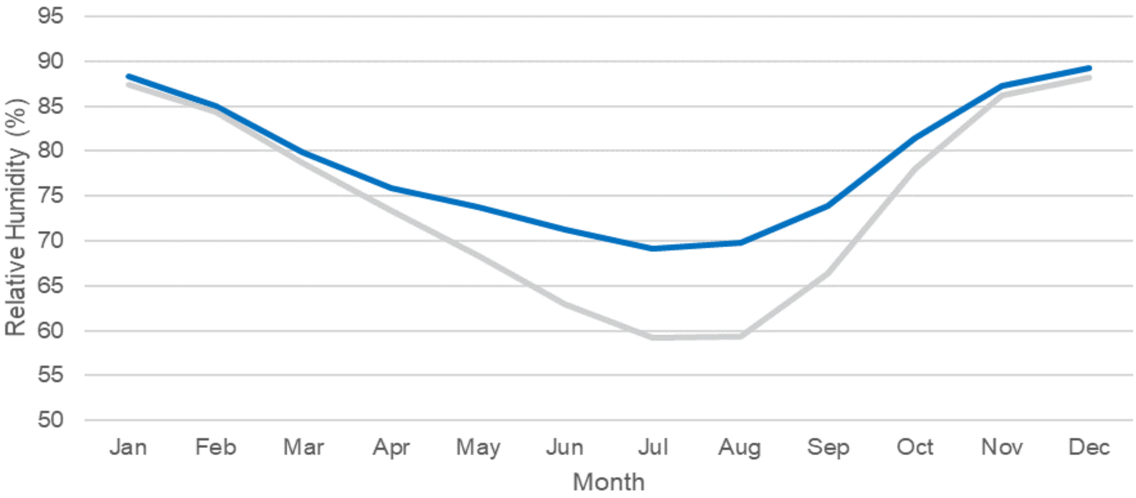
[17] Graph from https://uk-cri.org/ under the Creative Commons Attribution 4.0 International License. The data used is from the UKCP18 Climate Projections, see Footnote 7 for more detail.

2.3.7. Relative humidity

The relative humidity projection in Figure 2-16 shows that overall relative humidity is expected to decrease and there will be a greater variation in relative humidity throughout the year in the 2070s compared to the 1981-2000 baseline. The largest change (around 10%) will be seen in summer[15].

Figure 2-16 – Average monthly relative humidity (%) in 1981-2000 (blue) and 2061-2080 (grey)



Source: Met Office UKCP18 Local[15]

2.4. Fog

Fog is very challenging to model on future climate projection timescales. In the UKCP09 climate projections (forma to UKCP18) future changes in frequency of fog days were supplied as an additional technical note[18]. The UKCP09 projections are even coarser (~25km) than the UKCP18 projections. The methodology used a visibility threshold of 1000m and is interpreted upon a constant value of aerosol and changes in relative humidity. The UKCP09 projections for fog days indicated a small percentage increase (+2 to +8%) in number of fog days by the 2080s when compared to 1961 to 1990. There are large amounts of uncertainty with this methodology and no firm conditions can be drawn, because most notably it only relies on relative humidity alone, the scale of the modelling at 25km and the effects of local topography, no change in aerosols, and that radiation fog is also controlled by radiative cooling, stable atmospheric boundary layer (calm weather conditions), and low winds.

UKCP18 did not include any climate projections on fog, nor did it provide any update on UKCP09 methodology. This is primarily due to the complexity of modelling fog and the many different components required for its formation. What we can deduct from the review of UKCP18 variables is that relative humidity will decline, the number of cold weather events (often can be related to calm conditions) will decline, minimum temperatures are set to increase, all of which are less favourable for radiation fog formation.

Additionally for fog to form it requires small particles or aerosols (Cloud Condensation Nuclei - CCN) of dust and other air pollutants for water vapour to condense onto them. Semi-rural and rural environments are typically pollution free, and where typically if fog forms it is less dense when compared to industrial areas or near the sea (sea salt particles). Air quality is only set to improve in the UK with various air quality strategies and frameworks and under the Environment Act 2021, therefore it is possible to hypothesise that fog formation events could become fewer, and the density (thickness) of any event could become less.

[18] Boorman, P., Jenkins, G., Murphy, J. (2010) Future Changes in fog Frequency from the UKCP09 ensemble of regional climate model projections. Available online: https://webarchive.nationalarchives.gov.uk/ukgwa/20181204111026/http:/ukclimateprojections-ukcp09.metoffice.gov.uk/22530. Accessed: 06/06/2024.

2.5. Summary of local climate conditions

Based on the available evidence the SESRO site has a typical climate for Oxfordshire with the potential for very hot days in summer and cold snaps during the winter. Winds are predominantly from the south-west but despite the relatively flat and open landscape, windspeeds are similar to elsewhere in the county, including Oxford. Recent warming trends also reveal a slight reduction in the number of days with ground frost.

There is limited data available for fog monitoring at the SESRO site. As described in the next section fog formation is due to a variety of contributing factors. Under climate change it is unclear and there is limited confidence on the impacts it might have on fog formation at the SESRO site and local region.

Under future climate change scenarios warmer conditions are expected to lead to a significant reduction in the number of Met Office Cold Weather Alerts and “Road Accident Days” by the end of the century, as well as lower humidity in the summer months. Cold snaps and ground frost can’t be ruled out, but the evidence suggests a strong downward trends due to climate change. These impacts are likely to be a similar magnitude or greater than meso- and micro-climate variations due to topographic and land use changes[19] (see Section 4).

[19] Opinion of the author, discussed further in Section 4.

3. Literature Review

Local climate conditions are influenced by site characteristics and the regional context including micro-climate and meso-climate factors, such as:

- Radiation balance and heating and cooling related to topography (aspect), land, water and plant-soil-water processes.
- Windspeeds due to the length of undisturbed 'fetch'[20] and shelter or tunnelling effects of trees, embankments and buildings.
- Elevation due to adiabatic lapse rates (ALRs)[21] and cooler temperatures at height, although that is not expected to be significant here.
- Differences between land and water temperatures throughout the year and higher rates of evaporation from open water.
- Cold air drainage, i.e. the ability of colder air to 'drain' away from the site and not to become trapped forming frost hollows.

The literature on micro-climate and potential impacts of landscape changes on micro-climate includes fundamental and applied atmospheric physics literature describing land-atmosphere interactions, empirical studies of the variation in climate variables across landscapes and studies specifically commissioned for this reservoir.

Most applied research is focused on very specific impacts, such as fog formation at airports or on roads, or the influence of micro-climate on ecological conditions for specific species. The climatic effects of very large lakes or reservoirs such as the Great Lakes of North America have been well studied and are known to modify the climate from the microscale to the synoptic scale.[22] The most recent example of the effects of reservoirs on local climate is that of the Alqueva reservoir, Portugal, which was built in the early 2000s and where the impacts on fog, lake breeze and effects on air temperature, moisture, and electrical field were investigated (see Section 3.2.2). The size of this artificial lake is an order of magnitude larger than this proposed reservoir, with a surface area of 250 km^2, where any impacts are likely amplified by the much larger and deeper body of water and the differing Mediterranean climate. However, there is very little literature on the influence of smaller sized surface water reservoirs on the climatic conditions with most investigating the impacts of climate or climate change on the lake or reservoir itself.

Section 3.1 sets out the characteristics of the atmospheric boundary layer and highlights how a body of water, such as a reservoir will interact and impact the microclimate. Section 3.2 reviews the previous studies on fog and frost, and wind effects. Section 3.3 reviews the latest peer-reviewed science on the impacts of reservoirs or lakes on the atmosphere and local microclimate.

3.1. Characteristics of the atmospheric boundary layer

The boundary layer is the lower part of the atmosphere that is directly influenced by the earth's surface. Its depth can range from a few metres to several kilometres depending on the local meteorology.[23] The atmosphere exchanges heat, moisture and momentum with the earth's surface. Turbulence is also generated in the boundary layer as the wind blows over the earth's surface and by thermals such as those associated with land heating.[24] This turbulence redistributes heat, moisture and the drag on the wind within the boundary layer. The roughness of the surface affects the intensity of turbulence and the fluxes of the exchanges above the surface.

A considerable proportion of all solar radiation passes straight through the atmosphere to the earth's surface, which it warms on absorption, and in turn emits terrestrial radiation upwards. The energy balance at the surface requires that the energy gained from net radiation be balanced by fluxes of sensible and latent heat to the atmosphere and storage of heat at the earth's surface (e.g., ocean, land, lakes, rivers etc). Sensible heat is the

[20] Fetch is the length of water (or flat land surface) over which a given wind has blown without obstruction.
[21] ALR is the rate at which atmospheric temperature decreases with increasing altitude in conditions of thermal equilibrium.
[22] Eichenlaub V.L. (1987) Lakes, effects on climate. In: Climatology. Encyclopaedia of Earth Science. Springer, Boston, MA. https://doi.org/10.1007/0-387-30749-4_103
[23] Met Office (2021) The atmospheric boundary layer. Available online: https://www.metoffice.gov.uk/research/foundation/parametrizations/boundary-layer accessed: 27/04/2022.
[24] Met Office (2021) The atmospheric boundary layer. The representation of turbulence in the atmosphere. Available online: https://www.metoffice.gov.uk/research/foundation/parametrizations/boundary-layer Accessed: 27/04/2022

exchange of heat through convective processes, for example the warmth you can feel from the sun on a hot day. Latent heat is the heat that causes the changes between a solid (e.g. ice) to liquid (e.g. water) to gas (e.g. water vapour). Surface temperatures and these energy fluxes are regulated by the surface albedo (its reflectivity), surface conductance to evapotranspiration, and thermal conductivity. The surface energy balance is written:

$$R_n = H + \lambda E + G$$

Where the net radiation (R_n) absorbed by the surface is balanced by the sensible heat (H), latent heat (λE) and change in heat storage (G). Heat at the surface can also be dissipated by evapotranspiration where this heat is transferred from the evaporating surface to the air, where it is stored in water vapor as latent heat.

Land use changes can have both immediate and long-lasting impacts on hydrological and microclimatic processes within the boundary layer. The proposed reservoir will replace a large area of what is presently arable and pastureland with a large area of surface water covering an area of approximately 6.5 km^2. The remainder of this area will be landscaped embankment (due to the existing topography it will range from between 15m and 25m above the current ground level).[25] Lakes and reservoirs, either natural or manmade are known to modify the climates of their surroundings. These are known as lake effects that extend from the microscale to the synoptic scale dependant on its surface area, depth, configuration of the lake or reservoir, the wind speed and its direction, the general climatic environment within which it interacts, and the season. Large deep lakes or reservoirs are likely to have greater modifications than smaller shallower equivalents. Therefore, it is important to consider that reservoirs can have an important role in determining very localised climate, primarily because of large differences in albedo, heat capacity, surface roughness and energy exchange. The potential impacts are described below, based on the fundamental atmospheric physics and synthesis of literature (noting that the literature is mostly focussed on much larger reservoirs, and the physics and any impacts will be similar, however the area of influence away from the reservoir impacted will be reduced):

- The reservoir will lead to a **reduction in albedo**, the reflection of shortwave radiation; water has a greater ability to absorb and store solar radiation as heat, leading to an increase in sensible heat and an increase of the evaporation process (latent heat).
- The **heat budget** for a reservoir is controlled by interactions with the boundary layer. These interactions are affected by the boundary layer stability which can be empirically indicated by the difference in air and surface water temperature. An unstable boundary layer can be associated with warmer surface water temperatures than the air. When the boundary layer is unstable (stable) heat loss by sensible and latent heat transfer is enhanced (reduced). The stability of the boundary layer is affected by wind speed and the changes in temperature and humidity above the surface of the water. Lakes and reservoirs can experience large amounts of variability in boundary layer stratification (e.g., stable layers to unstable) due to the greater heating and cooling by the surrounding land. [26] Wind speed changes can also be related to the differences between the temperature of the land and water surface.
- The reservoirs' ability to store and release heat energy can be responsible for **daytime cooling during summer, warming during winter nights**, and the formulation of local breeze patterns that would be characteristic to this area only.[27] **Under certain conditions such heat energy transfer can cause fog formation** when a cold moist air mass passes over the warmer reservoir surface. The presence of the body of the water and its heat storage capacity in the spring and autumn will also likely **reduce the risk of frosts overnight for adjacent land.**
- The effect of the reservoir on **air temperature** will decline with distance, dependent on the underlying surface characteristic (e.g. soil type) and the reservoir capacity. A study of 12 reservoirs in the Pearl River Delta area, China, found that temperatures across the distances 0-100 m and 0-200 m away from the reservoir had a linear relationship with distance.[28] The effect on temperature gradually declined beyond 200 m. This type of linear temperature relationship would typically occur during periods of calm weather.

[25] Strategic regional water resource solutions: Preliminary feasibility assessment. Gate one submission for South East Strategic Reservoir Option (SESRO), 5th July 2021.
[26] Verburg, P., and J. P. Antenucci (2010), Persistent unstable atmospheric boundary layer enhances sensible and latent heat loss in a tropical great lake: Lake Tanganyika, J. Geophys. Res., 115, D11109, doi:10.1029/2009JD012839.
[27] Lakunin, M., Abreu, E.F.M., Canhoto, P., Pereira, S., and Salgado, R. (2021) Impact of a large artificial lake on regional climate: A typical meteorological year Meso-NH simulation results, Int J Climatology, 42, 1231-1252, doi: 10.1002/joc.7299.
[28] Wu, D., Wang, Y., Fan, C., Xia, B., (2018) Thermal environment effects and interactions of reservoirs and forests as urban blue-green infrastructures, Ecological Indicators, 91, 657-663, doi: https://doi.org/10.1016/j.ecolind.2018.04.054

- Warm and cool air caused by the reservoir can also be advected further afield by large-scale breezes or more localised wind flows. A high resolution numerical weather modelling study for Alqueva reservoir demonstrated that night-time north-west winds can transport warm air from the lake up to 2 km away, and with large-scale sea-breezes the impact can be found up to 10-12 km away.[29]
- The **roughness length z_o** describes the amount of exchange between the atmosphere and the surface, a low number implies less exchange and greater surface wind speeds. This exchange and distribution of heat, moisture and momentum plays a crucial role in the weather (e.g., temperature, humidity, wind strength, fog, cloud cover, frost) we experience on the surface. A reservoir with a fetch greater than 3 km has a roughness length of 0.0002 m. This implies less exchange and greater surface wind speeds. The effect of the change in roughness from a shoreline or embankment towards the lake and vice versa can be the acceleration and deceleration of wind speed and changes in its direction (due to wind stress curl caused by frictional drag changes). It is also important to consider raised embankments and their potential to increase wind speed.

The **adiabatic lapse rate** is described as an air parcel rising into regions with lower pressure where it expands and cools, and there are no losses in heat by any kind of exchange between the parcel and its environment. [30] Air temperatures decrease with height, and typically if a parcel of air follows an adiabatic lapse rate in a cloudless environment it is cooled in the order of 10°C per km (1°C per 100m). On partly to cloudy days the lapse rate ranges from 5°C per km in the clouds to the clear sky limit. This is important to consider for reservoirs with raised embankments and any impact it would have on air temperatures above the original surface level.

Cold air drainage is best observed in a hilly region during clear and still nights. As a result of radiative cooling (long wave cooling) from the surface a cold layer of air forms in close proximity. As the cold layer is more dense than warm air it flows to lower ground levels displacing warmer air. [31] This is also known as katabatic winds that lead to the pooling of cold air. This can lead to the development of fog and lead to potential frost pockets. The impact of frosts is described in Section 3.2. Cold air drainage can occur on slopes with less than 1% gradient [32] but is most notable with the advection of colder dense air with much steeper slopes.

3.2. Review of previous studies

3.2.1. Fog and frost

Fog is defined by the World Meteorological Organization (WMO) as a weather phenomenon that causes a reduction in horizontal visibility to less than 1 km. Fog is formed when air approaches saturation by adding moisture or by removing heat. Attributes such as synoptic conditions, climatology of the area, time of the year, thermal characteristic of air, stability of boundary layer, vertical and horizontal wind speed, dew point depression, terrain or topography, and characteristics of the condensation nuclei are important for fog occurrence and its prediction.

In the context of this study, we consider radiation fog events that typically occur during high pressure synoptic situations and its associated clear skies, a temperature inversion (increasing air temperature with height) and low wind speeds (e.g., 0.27 to 1.39 ms^{-1}).[33] In the UK it is particularly common in autumn and winter and commonly forms near sources of moisture such as lakes, rivers and reservoirs. Radiation fog usually forms overnight and dissipates during the day, however in mid-winter it has the potential to stay all day, particularly in latitudes where the sun is low in the sky (e.g. central England). Radiation fog is often more localised and is the result of local microclimate variations accompanied by favourable meteorological conditions.

The number and percentage of reported road collisions by contributory factor for Local Authorities from 2013 to 2022 are provided by the Department for Transport. The percentage of collisions per year that were contributed to rain, sleet, snow or fog that impacted vision that were reported across Oxfordshire are shown in Table 3-1. Contributory factors provide some insight into why collisions may have occurred. There are often more than one contributory factor and when police officers attend the scene, they can select up to 6. Of the many different

[29] Lakunin, M., Salgado, R., Potes, M. (2018) Breeze effects at a large artificial lake: summer case study, Hydrol. Earth Syst. Sci., 22, 5191–5210, doi:
https://doi.org/10.5194/hess-22-5191-2018
[30] McIlveen, R. (1992) Fundamentals of weather and climate, Chapman & Hall, London.
[31] Levenson, J. and P.E. Matthiae. (1975), Cold air drainage: a field experiment, Field Station Bulletin 8(2): 20-26
[32] Stull, R.B. (1988) An Introduction to Boundary Layer Meteorology. Kluwer Academic Publishers, Boston.
[33] Met Matters (2020) 'I tried to catch the fog… but I mist!'. Available online: https://www.rmets.org/metmatters/i-tried-catch-fog-i-mist Accessed: 26/04/2022.

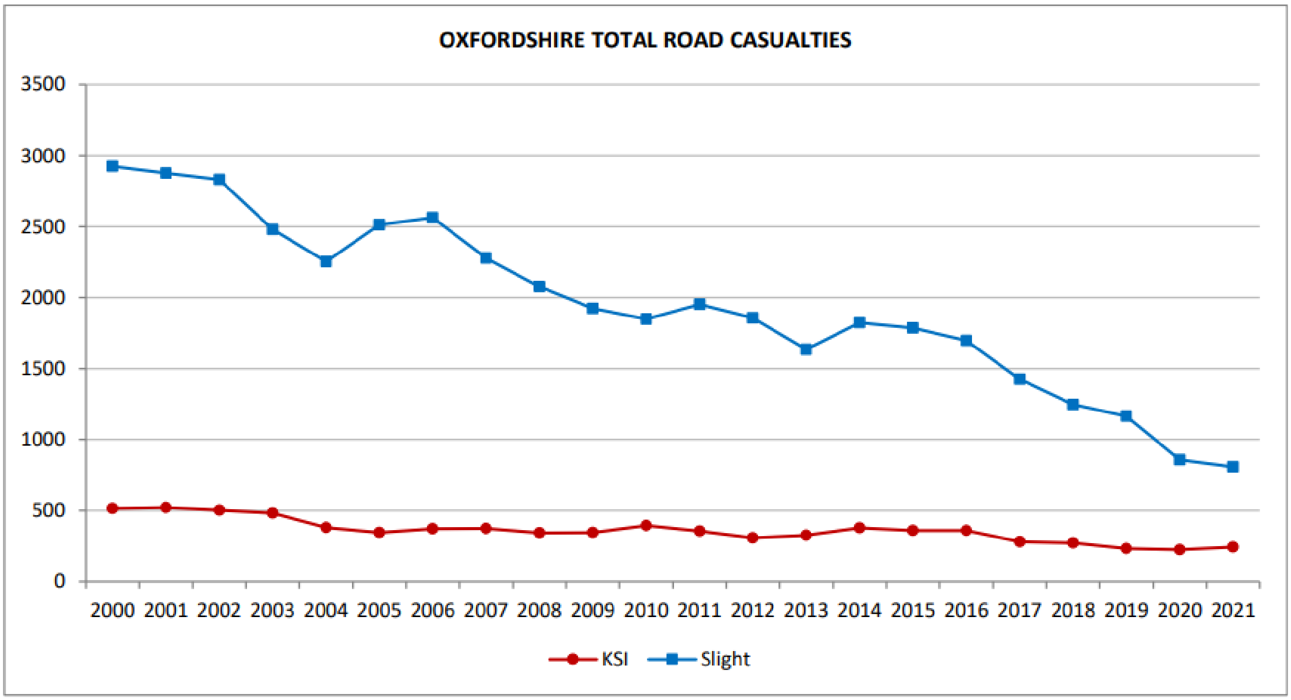
types of categories and contributory factors visibility affected by rain, sleet, snow or fog is considered a minimal factor each year across the county of Oxfordshire. As shown in the bottom row of Table 3-1 a far greater contributory factor is slippery roads due to weather, additionally they are decreasing year-on-year. As shown in Figure 3-17 from the year 2000 to 2021 the total number of casualties has declined.

Table 3-1 - Percentage of reported road collisions where the contributory factor reported in the collision is rain, sleet, snow, or fog that affected vision

Category/Impact	Contributory factor reported in collision	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Vision affected by external factors	**Rain, sleet, snow, or fog**	3%	2%	2%	1%	1%	1%	1%	2%	0%	1%
Road environment contributed	**Slippery road (due to weather)**	15%	12%	11%	12%	9%	8%	7%	9%	6%	5%

Source: Department for Transport, RAS0706, https://www.gov.uk/government/statistical-data-sets/reported-road-accidents-vehicles-and-casualties-tables-for-great-britain#factors-contributing-to-collisions-and-casualties-ras07

Figure 3-17 - Total Road casualties by year for Oxfordshire. "KSI" stands for killed or seriously injured, and 'slight' injuries include sprains, neck whiplash injury (not necessarily requiring medical treatment), bruises and slight shock requiring roadside attention.



Source: Oxfordshire County Council Road Traffic Collisions: Casualty Data Summary 2021. [OCC Road Traffic Accident Data Summary 2014 (oxfordshire.gov.uk)]

3.2.2. Wind effects

Wind speed, direction, fetch length, and duration can all have important effects on reservoirs. Fetch length is the distance over water the wind flows over in a single direction, and acts to constrain the growth of waves. The wind applies a horizontal stress to the surface of the water and as an example can act to raise the level on the leeward bank and lower the level on the windward bank. This is important to consider in the amount of freeboard allowance required on embankments. Wind can also generate waves, and these can range in height and period that increase as the waves travel over the fetch length.

The raised banks of the reservoir between 15m and 25m will affect winds locally, the orographic or topographic effect caused by this embankment will act to deflect, channel, block or accelerate. The reduction in roughness length changing from a shoreline or embankment towards the lake and vice versa will accelerate and decelerate wind speed and cause changes in its direction.

HR Wallingford (2006)[34] were commissioned by Jacobs to model extreme wind flows around the proposed reservoir to confirm the influence of the embankments on wind speed and to review the over-water speed-up factors. This study builds upon previous studies carried out by HR Wallingford (2004)[35] that reviewed wind data from RAF Benson and then expanded to Oxford, Harwell and Orchard Farm (HR Wallingford, 2005)[36]. In these previous studies the effects of reduced frictional drag due to decreased roughness length was also taken into account to derive wave conditions.

The HR Wallingford (2006) report reviewed a previous study carried out by Entice Technology Limited (2006)[37] that were commissioned to review the impact of the topography on far field wind speeds in the vicinity of the proposed reservoir. This study reviewed high winds associated with two storm events on the 16/10/1987 and 25/01/1990. The model predicted that the wind speeds around the site of the reservoir would be approximately 6-7% less than those at the Harwell weather station due to land use types (effects of roughness length and frictional drag) and topography. Although dated the storm events provide useful context as significant wind events.

3.3. Latest science

As previously mentioned, there is very little literature on the influence of smaller sized surface water reservoirs (the same scale as the proposed reservoir) on the climatic conditions with most investigating the impacts of climate or climate change on the lake or reservoir itself. Most studies are on very large lakes or artificial reservoirs and often in regions of the world where the climatology is very different to that of the site. However there have been some step changes in the ability to observe, predict and study fog which is summarised in section 3.3.1. The findings from the Alqueva reservoir study where the impacts on fog, lake breeze and effects on air temperature, moisture, and electrical field were investigated are described in section 3.3.2.

3.3.1. LANFEX fog experiment UK

The Local and Nonlocal Fog Experiment (LANFEX) field campaign was a collaborative effort to better understand the behaviour of fog, including its formation and the development of radiation fog (in a stable boundary layer) into much deeper adiabatic fog.[38] The experiment ran over an 18-month period from September 2014 to March 2016 in Shropshire and Bedfordshire. The Shropshire region chosen is characterised by a network of valleys (1 to 4 km in width) and small hills (heights 100 to 150m) and Cardington, Bedfordshire is in a wide shallow valley characterised by arable fields and low hedges (somewhat similar to that of the proposed reservoir location). LANFEX consisted of a number of studies with the ultimate motive to improve the predictions of numerical weather prediction (NWP) models. This latest study indicated that at scale of sub-km's (around 100 m in horizontal grid length) can reasonably reproduce the meteorological conditions that leads to the development of fog in a network of shallow valleys. However, it must be caveated that there are also potential notable limitations, for example with regards to soil temperatures which impacts fog formation.[39]. A further fog modelling study carried out that was inspired by LANFEX [40] concluded that fog remains a significant forecasting challenge because there are still large gaps in the NWP model's ability to produce fog, get the timing and location, and its dissipation. The study concluded that there is a "continued

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[34] HR Wallingford (2006) Upper Thames Reservoir Planning: Local Wind Modelling. HR Wallingford Technical Note MAR3770 TN04

[35] HR Wallingford (2004) Upper Thames Reservoir: Wind, waves, run-up / overtopping and slope protection. HR Wallingford Technical Note MAR3645 TN01

[36] HR Wallingford (2005) Upper Thames Reservoir: Wind, waves and overtopping of reservoir embankment. HR Wallingford Technical Note MAR3770 TN01

[37] Entice Technology (2006) Potential Impact of Topography on Wind Speed in the Vicinity of the UTMRD.

[38] Price, J. D., Lane, S., Boutle, I. A., Smith, D. K. E., Bergot, T., Lac, C., Duconge, L., McGregor, J., Kerr-Munslow, A., Pickering, M., & Clark, R. (2018) LANFEX: A Field and Modeling Study to Improve Our Understanding and Forecasting of Radiation Fog, Bulletin of the American Meteorological Society, 99(10), 2061-2077, doi: https://doi.org/10.1175/BAMS-D-16-0299.1

[39] Smith, DK, Renfrew, IA, Dorling, SR, Price, JD, Boutle, IA. (2021) Sub-km scale numerical weather prediction model simulations of radiation fog. QJR Meteorol Soc., 147: 746– 763, doi: https://doi.org/10.1002/qj.3943

[40] Boutle, I., Angevine, W., Bao, J-W., Bergot, T., Bhattacharya, R., Bott, A., Ducongé, L., Forbes, R., Goecke, T., Grell, E., Hill, A., Igel A.L., Kudozotsam I., Lac, C., Maronga, B., Romakkaniemi, S., Schmidli, J., Schwenkel, J., Steeneveld, G-J., Vié, B. (2022) Demistify: a large-eddy simulation (LES) and single-column model (SCM) intercomparison of radiation fog. Atmo. Chem. Phys., 22, 319-333.

investment need for observational understanding of real fog events, particularly to understand the high-frequency (in time and space) variability that exists in fog". Additionally, programmes such as this are intensive and expensive and often not leading to conclusive resolutions.

3.3.2. Alqueva reservoir Portugal

The Alentejo Observation and Prediction systems (ALOP) project was a very recent study (2016 to 2019) that like the proposed reservoir wanted to understand the impacts of the reservoir on the local microclimate. The specific objective was to 'improve knowledge of the state of the atmosphere and reservoirs in the region with special emphasis on the study about Alqueva – the strategic water reservoir of Alentejo'.[41] The project also included a measurement campaign on and around the reservoir monitoring meteorological data including evaporation, visibility, and water temperature. To investigate the weather impact of the Alqueva reservoir a numerical modelling study was carried out to simulate a 'typical' 12-month meteorological year. Simulations were generated with and without the reservoir where results showed a decrease of air temperatures and night time increases, in nearby towns daily maximum temperature decreased and daily minimum temperature increased (which refers to milder weather conditions), and Alqueva mainly showed a reduction in fog formation in the nearby area.[42] It should be noted that the climate of the region is of Mediterranean type where temperatures in summer average 23°C with maximums exceeding 45°C, winters are mild (average 10°C) and wet, temperatures can often reach 24°C in January during stable periods of high pressure, and total solar radiation (that consists of direct radiation, that is the earth's of radiation that reaches the earth's surface without being scattered by the atmosphere, and diffuse that reaches the surface after a change in its direction due to scattering e.g. clouds act to diffuse) at the surface is some the highest in Europe (mean daily values of 300 Wm^{-2}, with max daily of 1000 Wm^{-2} in summer). In comparison to the proposed region in Oxfordshire temperatures are milder in winter and hotter in summer, and mean daily total solar radiation ranges between 110 to 120 Wm^{-2}.[43] The study also observed a lake breeze effect (where the land heats up and warm air rises and is replaced by cooler air over the lake, generating a lake breeze circulation) with its greatest effect in summer with warm favourable conditions, the scale of this reservoir with a surface area of 250 km^2 will generate far greater lake breeze effects than a smaller reservoir.

iii. Overall this modelling study was able to demonstrate how simulations can demonstrate the impacts of reservoirs on the local microclimate, and in this instance up to 20 km away from its shores. Which demonstrates future potential investigations for the proposed reservoir site. However there are also noted limitations including the ability to model fog and sub grid scale meteorological processes, and the short period of one representative year therefore missing potential extreme events and the year-to-year variability.

3.4. Summary

The fundamental atmospheric physics literature indicates that changing land use is likely to have local effects on micro-climate due to changes in the radiation balance, topography and differences in land and water temperatures. The LANFEX study at Cardington, Bedfordshire was carried out in a somewhat similar site to that of the proposed location. It was able to reasonably reproduce the meteorological conditions that leads to the development of fog in a network of shallow valleys using high resolution NWP models. However, there are also notable limitations with such studies that demonstrate a continued investment need for observational understanding of fog events. Additionally, the LANFEX study did not include the micro-climate impacts of reservoirs on fog formation. There is a lack of literature on the micro-climate impacts of reservoirs and most examples are for bigger, deeper lakes in very different climate conditions where the impacts are expected to be more significant. Previous studies on the site indicated the potential for more radiation fog formation (based on empirical indices only) and changes in windspeed over the reservoir and its implication for significant wave heights. The only similar study, noting that it is a Mediterranean climate, Portugal revealed changes in day and night-time temperature, due to cooling and warming effects, and a reduction in fog formation.

[41] Alentejo Observation and Prediction systems, available online: https://www.alop.ict.uevora.pt/index.php/objectivos/?lang=en, accessed: 23/05/2022

[42] Iakunin, M., Abreu, E. F. M., Canhoto, P., Pereira, S., & Salgado, R. (2022) Impact of a large artificial lake on regional climate: A typical meteorological year Meso-NH simulation results. International Journal of Climatology, 42(2), 1231– 1252, doi: https://doi.org/10.1002/joc.7299

[43] Burnett, D., Barbour, E., Harrison, G.P. (2014) The UK solar energy resource and the impact of climate change. Renewable Energy, 71, 333-343, doi: https://doi.org/10.1016/j.renene.2014.05.034

4. Synthesis of available evidence

4.1. Introduction

This section synthesises the evidence from baseline climate, future climate change scenarios and the literature to provide an assessment of the likely micro-climate effects of the reservoir. As some evidence is conflicting it includes an assessment of confidence in the evidence (low to high) and clearly sets out factual information (F) from the opinion of the author (O). Our synthesis of the evidence is provided in Table 4-1.

4.2. Conclusions

On the basis of the evidence available, the following conclusions are drawn:

- Occasional fog and ground frost conditions are already evident at the site, which forms a gentle depression across the Ock Valley and adjacent streams and are common in the Thames Valley where radiation fog may form in valley bottoms during periods with stable atmospheric conditions.
- The proposed development will have some impacts on micro-climate in the immediate vicinity of the reservoir, including positive and negative impacts, but changes are expected to be negligible or small.
- The introduction of a large reservoir introduces one of the many factors that influences fog formation, but other factors are unchanged or not favourable, e.g. steady wind conditions. Different factors may increase the chance of formation, while other factors will decrease the chance of formation.
    - The reservoir is located within a much larger rural area that has a strong cooling effect on the air that can promote the development of radiation fog when conditions are calm and favourable while other factors, including climate change, will decrease the chance of fog formation.
    - Radiation fog usually occurs in winter in calm favourable weather conditions. The reservoir will be warmer than the surrounding land, fog formation will more likely occur across the wider surrounding land area due to the stronger radiative cooling. A warmer surface and increased windspeed over the reservoir would promote fog dispersal.
    - The reservoir itself may introduce moisture as it will have a high heat storage capacity and the surface will evaporate into the near surface air. This may cause local evaporation fog under a very specific conditions with warm water, cold air and low wind speeds.
    - It is hard to be conclusive if the effect of the reservoir can be a direct cause of fog formation because there are a number of additional influencing factors; some meteorological studies have indicated reductions in fog formation due to reservoirs, whereas empirical methods suggest that the presence of water may increase the likelihood of fog.
- Numerical Weather Prediction (NWP) models can add value but do not necessarily offer a complete solution. There are limitations in NWP models to resolve and capture fog formation and dissipation processes. Higher resolution models are demonstrating benefits due to being able to capture the local topography and smaller scale physical processes, but they are still limited by the microphysics schemes that are linked to very small-scale water processes such as water droplet size and distribution. It was documented in the literature that fog remains a significant forecasting challenge. There is a need to improve observation programs for understanding of fog events.
- The reservoir is not large enough or deep enough to have the kinds of impacts on micro- and meso-climate observed in examples around the world where lakes or large reservoirs are known to affect the local and regional climate.
- In China the effects reservoirs on air temperature has been shown to decline with distance linearly, dependent on the underlying surface characteristic (e.g. soil type) and the reservoir capacity. In the research this was found to be around 100-200m, which would typically occur in calm weather conditions.
- The impacts of local land use changes, including the reservoir, on aspects of the micro-climate that concern local residents (e.g. frost) is less significant than the impacts of climate change on the same climate variables.

Table 4-1 - Synthesis of evidence on the impacts of SESRO on micro-climate for surrounding villages

Micro-climate effect	Climate change trend	SESRO impact	Confidence	Commentary
Fog formation	Unknown	Potential increase to the immediate surroundings The risk of a significant increase is considered **low** due to so many factors that contributing to fog formation	Low	Considering the surrounding area is relatively flat the risk of fog formation is regarded as low. The raised reservoir banks could lead to cold air drainage from the reservoir surface to its immediate surroundings leading to radiation fog (O) over both aforementioned areas. The local windspeed data shows steady and consistent winds, which does not provide the ideal conditions for fog formation (F). The 'damming' effects of local buildings, road embankments, woodlands and hedgerows could act to block this flow of cold air into depressions and lead to more patchy fog and frost development (O). The frequency of such events could also be investigated looking at the occurrence of suitable meteorological conditions (weather pattern types) and how this might evolve with climate change. It is also important to consider the ability for the boundary layer to store more water above the reservoir. It is enhanced over open water, where the heat and water vapor from the reservoir will act to warm the air and cause it to rise, in turn leading to cooler air being drawn in (F). Improved observations in the surrounding area could be used particularly to understand the high-frequency (in time and space) variability that exists in any fog patches that form locally and more broadly what drives fog formation over the region.
Frost formation	Decrease	Decrease	Medium	The presence of the body of the water and its heat storage capacity in the spring and autumn will likely reduce the risk of frosts overnight for adjacent land (O). Downward trends in frost days are already evident and climate change is expected to have a larger impact than the reservoir on the number and frequency of frost days (F).
Local winds	No significant change	Increase over water body Potentially reduced by tree/sound barriers	Low	The roughness length will reduce to 0.0002 m for a reservoir with a fetch greater than 3 km. This implies less exchange and greater surface wind speeds when compared to that at present where land use is primarily arable and a solar farm. This will impact very localised turbulence and the redistribution of heat, moisture and momentum. The effect of the change in roughness from a shoreline or embankment towards the lake and vice versa can be the acceleration and deceleration of wind speed and changes in its direction (due to wind stress curl caused by frictional drag changes). The impact of wind on the leeward side of the reservoir will be influenced by landscaping and tree planting; windspeeds can be reduced over distances of 5-20 times the height of trees and other barriers. Porous shelterbelts are more effective, but their aerodynamics are complicated[44] (F).

[44] Lawson et al., 2019. Gerry Lawson, Christian Dupraz, Jeroen Watté, Chapter 9 - Can Silvoarable Systems Maintain Yield, Resilience, and Diversity in the Face of Changing Environments?, Editor(s): Gilles Lemaire, Paulo César De Faccio Carvalho, Scott Kronberg, Sylvie Recous, Agroecosystem Diversity, Academic Press,

Micro-climate effect	Climate change trend	SESRO impact	Confidence	Commentary
				The wind study carried out by HR Wallingford in 2006 is clear that acceleration and deceleration zones will occur due to the embankments (F). The limitation of this study is that it is based upon 2 storm events and does not include events of the past decade. The reservoirs' ability to store and release heat energy may be responsible for formulation of local breeze patterns that would be characteristic to this area only. However, this is constrained by the size of the lake, its depth, and the shape of the shoreline. Any local lake breezes would likely be weak in nature and would have a cooling influence of summer air temperatures when temperature gradients between the reservoir and land would be large enough for any thermal breeze development (O). An unstable atmospheric boundary layer will likely be associated with warmer surface water temperatures than the air. This will be associated with free convection and localised updrafts, downdrafts and very small scale localized breeze formations (O).
Summer cooling effects	n/a	Increase	Medium	The reservoirs' ability to store and release heat energy will be responsible for very localised daytime cooling during summer (O). Any temperature effects are very localised. Advections affects further afield are unknown (O).
Winter warming effects	n/a	Increase	Medium	The reservoirs' ability to store and release heat energy will be responsible for very localised warming during winter nights (O). Any temperature effects are very localised. Advection affections further afield are unknown (O).
Adiabatic lapse rate and raised banks	n/a	Nil	Medium	The raising of embankments and water level to between 15m and 25m above the current ground level could potentially lead to marginally cooler air temperatures above the surface. The outcomes on temperature on still cloudless (1°C per 100m) and partly cloudy (0.5°C per 100m) nights or days is set to be minimal (F).

2019, Pages 145-168, ISBN 9780128110508, https://doi.org/10.1016/B978-0-12-811050-8.00009-1. (https://www.sciencedirect.com/science/article/pii/B9780128110508000091)

5. Conclusion

5.1. In summary

The impact of the reservoir on fog formation is considered low risk due to the many factors (e.g., low wind speeds, radiative cooling, stable boundary layer etc) that must happen in combination for radiation fog to form. Yes, the reservoir could add moisture, but it is inconclusive if the effect of the reservoir can be a direct cause of fog formation due to its size and depth and whether or not it increases the relative humidity of the air.

Shallow river basins have been shown to be more fog prone, but due to the raised nature and its size any fog formation would be local to the reservoir itself and within a very localised surrounding area due to katabatic drainage of cold moist air caused by the existence of a horizontal temperature differences. Studies in China have found that the effect of the reservoir on air temperature has been shown to decline linearly with distance of a few hundred metres, dependent on the underlying surface characteristic (e.g., soil type) and the reservoir capacity, this could potentially halt further radiation fog progression away from the reservoir.

In our opinion the value of micro-climate modelling is questionable because: (i) the potential impacts on the site are small; (ii) the complexity of modelling means that only certain conditions can be modelled, i.e. typical days or short periods in the summer and winter; (iii) there are a number of limitations due to their ability to resolve the finer microphysics detail that is critical for fog formation (e.g., water droplet size and distribution) (iv) with detailed modelling the level of confidence will still be “medium” at best because models may not represent fog processes very effectively. Additionally, due to this level of modelling complexity and the number of contributing factors for fog to form there are limited benefits to modelling under climate change.

5.2. Caveats

This assessment was based on the data available from previous studies and provided to AtkinsRéalis at the start of this project. If further monitoring data or modelling studies are available, these may change the overall recommendations.

Appendix A. Climate data sources and UKCP data

A.1. Data sets

A.1.1. HadUK-Grid Gridded Climate Observations on a 1km grid over the UK, v1.0.3.0 (1862-2020)

Met Office; Hollis, D.; McCarthy, M.; Kendon, M.; Legg, T.; Simpson, I. (2021): HadUK-Grid Gridded Climate Observations on a 1km grid over the UK, v1.0.3.0 (1862-2020). NERC EDS Centre for Environmental Data Analysis, 08 September 2021. doi:10.5285/786b3ce6be54468496a3e11ce2f2669c. http://dx.doi.org/10.5285/786b3ce6be54468496a3e11ce2f2669c

CEDA Data Catalogue Page for this dataset: http://catalogue.ceda.ac.uk/uuid/786b3ce6be54468496a3e11ce2f2669c

Licence:

Use of these data is covered by the following licence:

http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/

When using these data you must cite them correctly using the citation given on the catalogue record.

Access: Access to these data is available to any registered CEDA user. Please Login or Register for an account to gain access.

A.1.2. UCKP Data: Variables from local projections (2.2km) re-gridded to 5km over UK for daily data, monthly, seasonal or annual data

Gohar G, Bernie D, Good P and Lowe JA (2018). UKCP18 Derived Projections of Future Climate over the UK, Met Office.

Link to UKCP User Interface: https://ukclimateprojections-ui.metoffice.gov.uk/products

Licence:

iv. --------

The UKCP18 data was collated from the UKCP User Interface under the Open Government Licence v3.0. for public sector information. https://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/

A.1.3. Met Office Open MIDAS data for UK weather observations

Met Office (2006): MIDAS: UK Hourly Weather Observation Data. NCAS British Atmospheric Data Centre, 10/06/2022. https://catalogue.ceda.ac.uk/uuid/916ac4bbc46f7685ae9a5e10451bae7c

v. CEDA Data Catalogue Page for this dataset: https://catalogue.ceda.ac.uk/uuid/916ac4bbc46f7685ae9a5e10451bae7c

Met Office (2019) *UKCP18 Factsheet: Wind*. Accessed: https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-fact-sheet-wind_march21.pdf

Licence:

Use of these data is covered by the following licence:
http://licences.ceda.ac.uk/image/data_access_condition/ukmo_agreement.pdf.

The archives indicate some weather observations in Abingdon from 1957 – 1975, with a weather station located at the former Abingdon Airfield, Shippon (now Dalton Barracks), which is ca. 7km northwest of SESRO. The daily temperature data are not available on the open archive (CEDA returns an error). However, some sub-daily data are available during this period, including air temperature, wet-bulb temperature and dewpoint temperature for a range of conditions from the cold snap in 1963 through to drier and hotter periods in the mid-1970s.

archive / badc / ukmo-midas-open / data / uk-hourly-weather-obs / dataset-version-202107 / oxfordshire / 00822_abingdon / qc-version-1

MIDAS Open: UK hourly weather observation data, v202107

0 dirs 17 files	Description	Size	Actions
midas-open_uk-hourly-weather-obs_dv-202107_oxfordshire_00822_abingdon_qcv-1_1957.csv		918.4 KB	
midas-open_uk-hourly-weather-obs_dv-202107_oxfordshire_00822_abingdon_qcv-1_1958.csv		917.1 KB	
midas-open_uk-hourly-weather-obs_dv-202107_oxfordshire_00822_abingdon_qcv-1_1959.csv		913.1 KB	
midas-open_uk-hourly-weather-obs_dv-202107_oxfordshire_00822_abingdon_qcv-1_1960.csv		914.6 KB	
midas-open_uk-hourly-weather-obs_dv-202107_oxfordshire_00822_abingdon_qcv-1_1961.csv		911.1 KB	
midas-open_uk-hourly-weather-obs_dv-202107_oxfordshire_00822_abingdon_qcv-1_1962.csv		911.5 KB	
midas-open_uk-hourly-weather-obs_dv-202107_oxfordshire_00822_abingdon_qcv-1_1963.csv		910.1 KB	

Other well-known sites, such as Benson airfield or Oxford Radcliffe Observatory, are a significant distance from the site and offer no advantages over using 1km gridded data.

archive / badc / ukmo-midas-open / data / uk-daily-temperature-obs / dataset-version-202107 / oxfordshire

MIDAS Open: UK daily temperature data, v202107

10 dirs 0 files	Description	Size	Actions
00605_brize-norton			
00606_oxford			
00607_south-newington			
00608_banbury-grimsbury-p-sta			
00609_shirburn-model-farm			
00611_maidensgrove			
00613_benson			
00820_letcombe-regis			
00822_abingdon			
00825_wallingford			

A.1.4. UK Climate Risk Indicators

Link to data: https://uk-cri.org/ .The data used in the interface are the UKCP18 Climate Projections by the Met Office, see Section A.1.2 for full details on the UKCP18 Climate Projection data.

Licence:

The research used on the UK Climate Risk Indicators website is based on research undertaken in the Department of Meteorology at the University of Reading, led by Professor Nigel Arnell, and at the UK Centre for Ecology and Hydrology.

A.1.5. Cascade Consulting data

Data collated by Cascade Consulting on site from the Upper Thames Major Resource Development Automatic Weather Station, in Orchard Farm, in Benson and in Brize Norton, from 2005 to 2009 were provided.

A.1.6. Supporting data and code

https://www.metoffice.gov.uk/weather/learn-about/weather/types-of-weather/frost-and-ice/frost

Revised draft Water Resources Management Plan 2019 Statement of Response No 2 – Main Report April 2019

Source of code to create the wind rose diagram: Roubeyrie, Lionel & Celles, Sebastien (2018) *windrose, Notebook example*, Revision 977ff8cb, https://windrose.readthedocs.io/en/latest/usage.html; Copyright 2018, Lionel Roubeyrie & Sebastien Celles Revision 977ff8cb

A.2. Literature

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