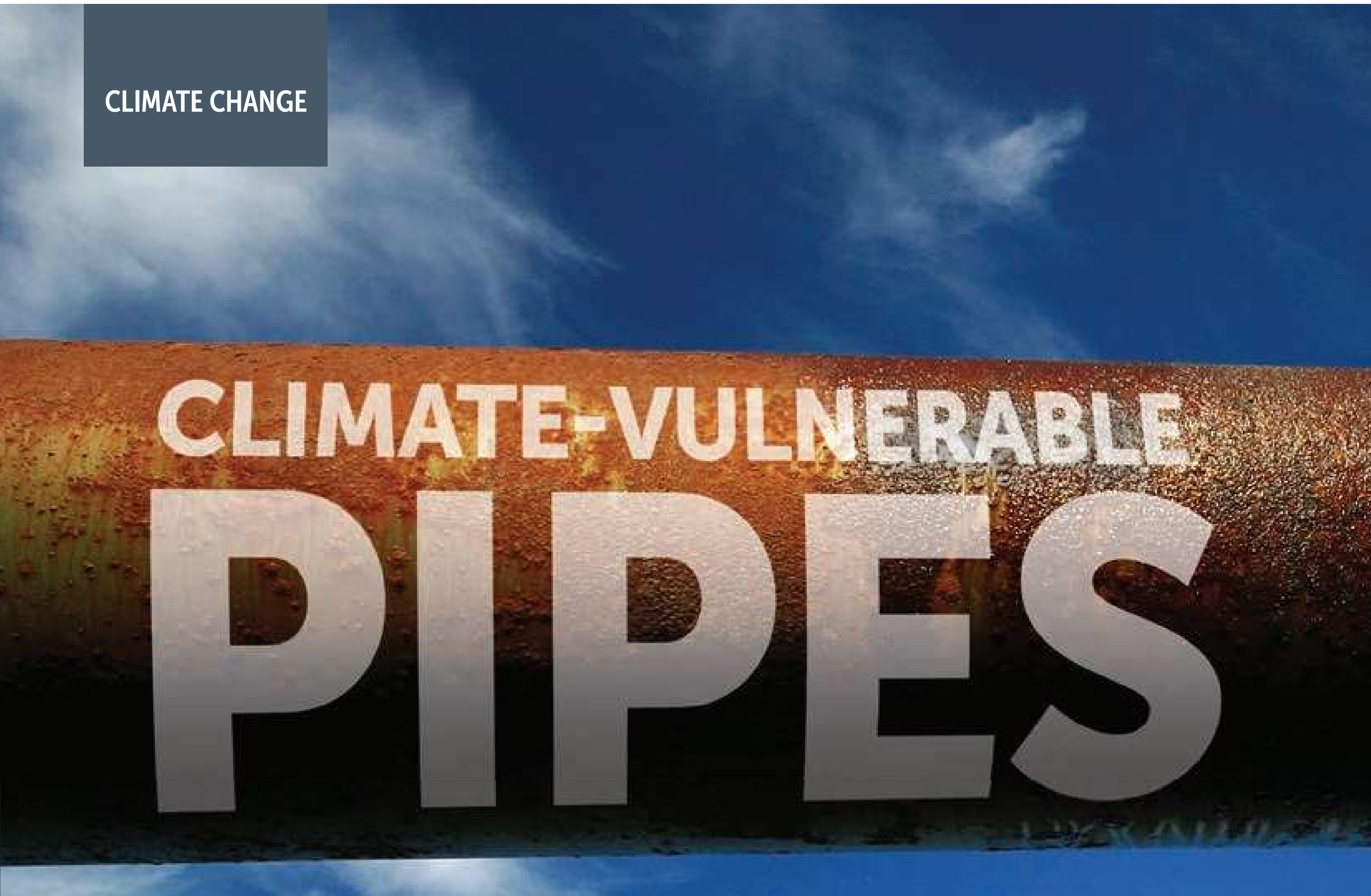

# CLIMATE-VULNERABLE PIPES

## TIMOTHY FAREWELL DISCUSSES THE IMPACT OF CLIMATE CHANGE ON UK WATER NETWORKS

**CLIMATE CHANGE** is arguably the greatest challenge facing our world today.

As scientists, we like to speak in nuanced tones, and love to qualify our statements. We have been reluctant to use emotive language to communicate to the wider public the impacts of our current way of life. Yet to most geoscientists, it is now becoming increasingly apparent that many of Earth's natural systems are becoming destabilised.

Each month we see dramatic news stories of floods, fires and famines. These are all being made more common, and more extreme, because of the ever-increasing greenhouse gas pollution from our lifestyles. We may recognise these climate impacts on other people and in other places. Often, they seem quite far removed from us, but some climate impacts are already starkly visible in data here in the UK too (Fig. 1). In the summer of 2022, there were an estimated 2,803 excess heatwave-related deaths just from those aged over 65 (UKHSA, 2022). Wildfires broke out in various places across the UK including one in London which destroyed 20 houses. There are other less visible impacts as well.

As an applied geoscientist, I use predictive numerical models to help organisations identify and reduce their hidden, yet costly risks from climate change. For the past two decades, much of my research has focused on interactions between natural and human-made systems in the built environment, for example the impacts of weather and ground conditions on pipe networks in Eastern England. While not as dramatic as human deaths, the impacts of climate change on our critical national infrastructure systems are already evident in our data. These impacts are proving hugely expensive to infrastructure operators and disruptive to us all.

### Failure mechanisms

By their nature, buried infrastructure networks are hidden from our sight, so most of us are unaware of the complexity of these systems. Our water networks have grown and developed since Victorian times. While most of the earliest pipes were made of cast iron, later metallic pipe materials, such as spun iron, ductile iron and steel were developed. Cement-based pipes were often installed in the post-war period, before polyvinyl chloride (PVC) and eventually polyethylene (PE) pipes became commonplace. Each of →

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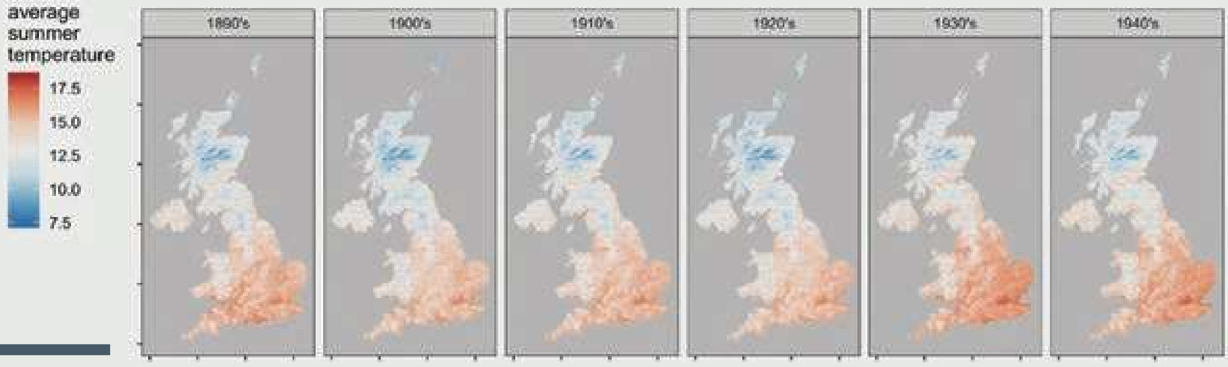


**Figure 1 |** Average summer temperature (°C) by decade in the UK between the 1890s and 2020s. Uses HadUK-Grid data (Met Office, 2022).

Note: 2020's data only includes complete years (2020-2021).

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A burst water main erupts from beneath a road surface in Garforth, Leeds, West Yorkshire

*© Alamy*

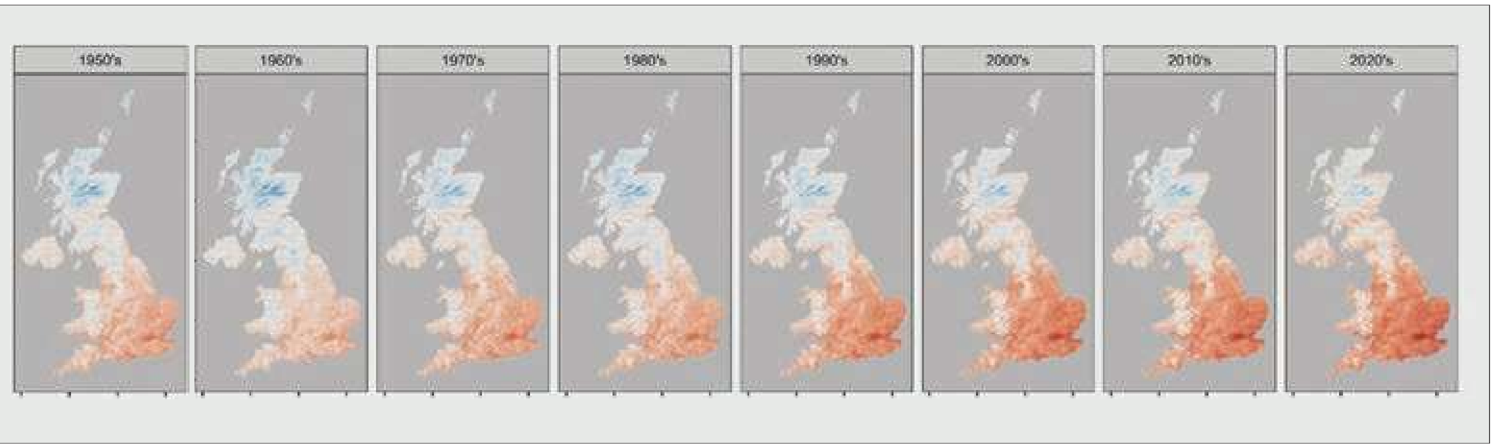
these materials respond in varying ways to environmental stresses and, as a result, different seasonal patterns of failures can be seen in the various pipe materials.

Most pipes respon badlky to changes and extremes in environmental conditions. Extreme temperatures (both hot and cold) lead to increased pipe failures, that is, bursts (whereby physical repairs are required on water mains) and the associated leakage (the volume of water lost). Soils that are corrosive or highly shrinkable can also increase pipe failure rates, particularly in some of the older cement-based and iron pipes (which is what we are seeing in East Anglia; Fig. 2)

## Building a climate-model for pipe failures

Victorian iron pipes currently fail most in cold winters, but also show increased failure rates in hot, dry summer months. Cement-based pipes, installed in the UK in the 1950s and 60s, are now deteriorating.

These pipes fail most in the summer, when fen peats and clay-rich soils dry out and shrink (Figs. 2 & 3). The resulting differential ground movement dislodges weakening joints and can even circumferentially fracture the pipe. In addition, when temperatures soar, so does demand for water. These changes in water usage patterns (and associated changes in pipe pressure) increase failure rates on early PVC pipes.




So, for water companies in Eastern and Southeast England, it is typical to see a large spike in pipe failure rates during the cold winter months, the lowest failure rates in the spring, and an increase in failures in the summer and early autumn months, primarily because of ground movement.

To improve service levels, Anglian Water had been using some predictive models that I created to help them understand the impact of weather and soil conditions on the burst rates of their water pipes. Then in 2020, as an industry first, they asked me to build some innovative, forward-looking models to predict the coming impacts of climate change on their networks.

My colleagues and I at MapleSky Ltd. aimed to create a suite of data-driven statistical models (Poisson Generalised Linear Models), so it was vital that we trained the models on the best available data. Data cleaning (that is, the process of identifying and correcting errors, inconsistencies, and inaccuracies within a dataset) is one of the most important parts of model building because poor-quality data will give poor-quality outputs. We therefore spent significant time cleaning the pipe and failure data to ensure that the reported failures were allocated to →

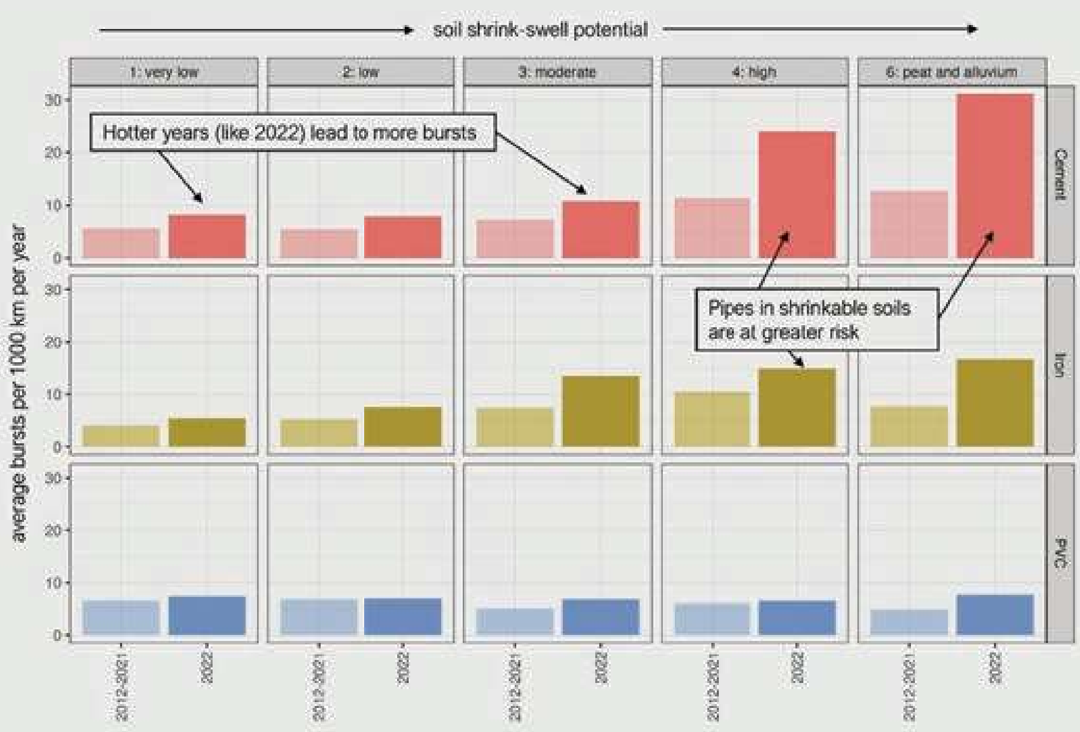



**Figure 2 |** The average summer burst rate of three water main materials in East Anglia, comparing the short-term average (summers in 2012 – 2021) and the hot, dry summer of 2022. Extreme temperatures and corrosive or highly shrinkable soils can increase pipe failure rates. *Data sources: Pipe and burst data: Anglian Water; Soil shrink-swell data: Cranfield University. © Dr Tim Farewell, MapleSky Ltd..*

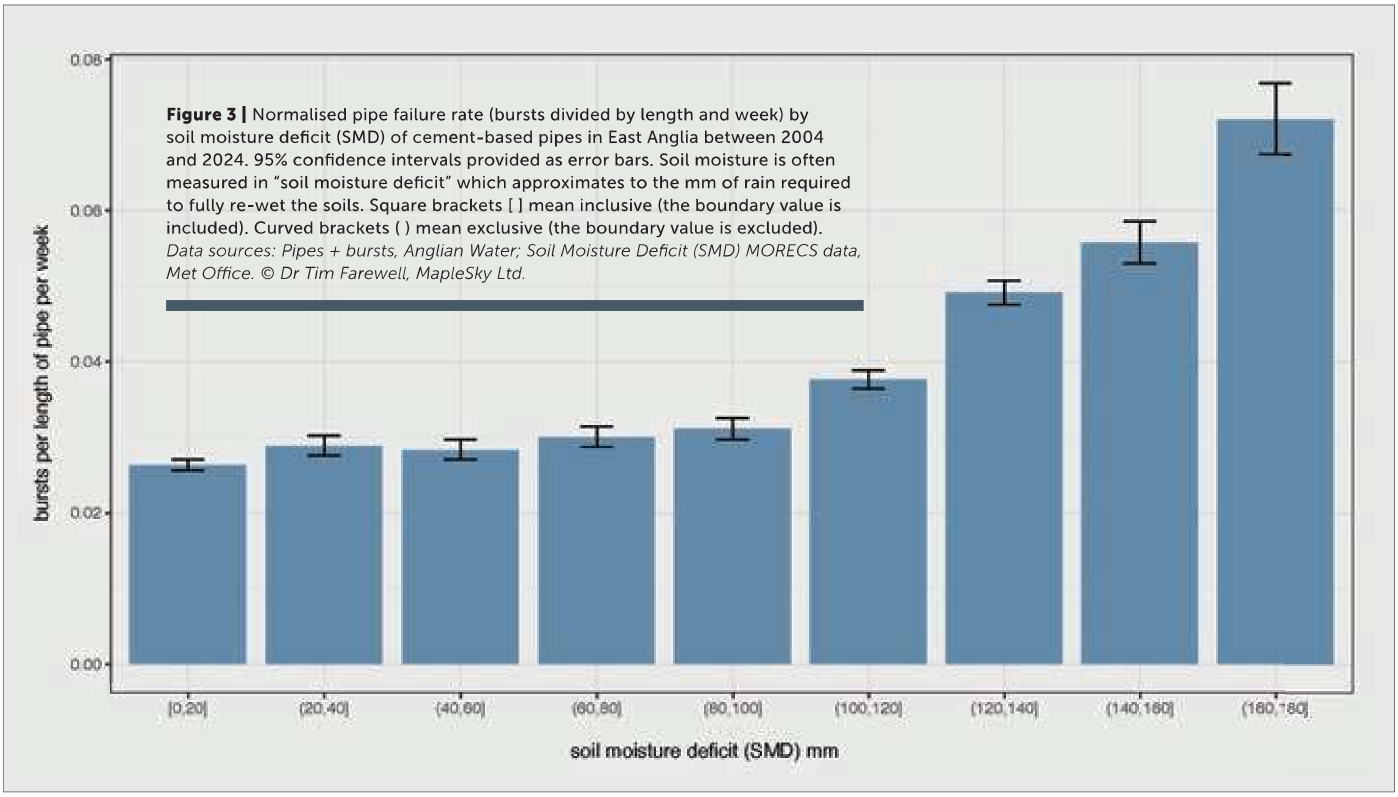



**Figure 3 |** Normalised pipe failure rate (bursts divided by length and week) by soil moisture deficit (SMD) of cement-based pipes in East Anglia between 2004 and 2024. 95% confidence intervals provided as error bars. Soil moisture is often measured in "soil moisture deficit" which approximates to the mm of rain required to fully re-wet the soils. Square brackets [ ] mean inclusive (the boundary value is included). Curved brackets ( ) mean exclusive (the boundary value is excluded). *Data sources: Pipes + bursts, Anglian Water; Soil Moisture Deficit (SMD) MORECS data, Met Office. © Dr Tim Farewell, MapleSky Ltd.*

the correct pipes, and attributes such as material and diameter were as complete and correct as possible.

We acquired and reviewed a range of UK Climate Projections (UKPC18, a suite of climate models from the Met Office Hadley Centre). We settled on a set of probabilistic projections for every decade to the end of the century under four emissions scenarios, or "representative concentration pathways" (RCPs; Fig. 4) These can be approximated as ranging from "low emissions" to "high emissions" scenarios.

To match the available weather variables in the UKCP18 future climate models, we acquired historic gridded weather data for the period 2006 – 2019 (Had-UK Grid data; a collection of data interpolated from weather stations). We gathered spatial data on the soil and ground conditions and combined all the data together into our spatio-temporal data science models.

We split the combined pipe, failure, weather and ground condition data into random



A burst water pipe in Slough in June 2021 training and testing subsets and built initial models to capture the response of six main pipe materials (cast and spun iron, cement, PVC, steel and ductile iron, polyethylene and "other") to monthly environmental conditions. Once we were happy that the models were performing well and predicting the response of the infrastructure to the changing weather patterns, we then replaced the historic weather data with the forward-looking climate models.

For the purposes of our models, we assumed no further deterioration of the pipes in the water network and simply applied future weather conditions to today's infrastructure. Because we know buried assets are deteriorating, our model results underestimate the number of pipe failures that should be expected to occur.

### Model predictions

All four climate scenarios showed the same overall patterns for seasonal changes in temperature and rainfall, but with different magnitudes. Even under RCP 2.6/ RCP 3PD, which assume a rapid transition to a low-carbon economy, winters in the UK are set to become warmer and wetter, and summers will become hotter and drier than today. Under the RCP 8.5 scenario (where we carry on eating, flying and heating as we are) or even the RCP 6.0 scenario, the UK summers become unrecognisably hot and dry (Fig. 5).

The response of the built environment to climate change is rarely simple, and this complexity was reflected in our model results as well. We found that there was some (initial) good news for the water networks: the coming warmer winters will lead to a reduction in the average number of winter failures on old iron pipes – at least until a particularly harsh winter arrives.

When a future severe winter does occur (following a run of warmer winters), a large outbreak of iron pipe failures is likely. This is because the population of weakened ageing pipes grows over time and is primed to fail at the first cold snap. We have seen examples of this pattern: the colder winter of 2008 – 2009 led to a large outbreak of pipe failures after more

**❝ Failures will tend to occur more in the summer and early autumn months, when demand for water is already at its greatest ❞**

than a decade of mild winters. Similarly, the winter of 2016 – 2017 had a large outbreak of pipe failures following just three mild winters.

Of greater concern, however, is the impact that the coming hotter and drier summers will increasingly have on the water network. Anglian Water has over 40,000 km of pipes across East Anglia, which is home to the largest area of lowland and fen peat in the UK. Peats are highly shrinkable when they lose water – either through pumping or the action of evapotranspiration. Also, there are large amounts of highly shrinkable clay soils across the region, which not only cause houses to subside, but also lead to markedly increased pipe failure rates in the hotter summers. Another challenge in East Anglia is that many of the pipes running through the most shrinkable and corrosive peat soils are in rural areas, which means that pipe failures are less likely to be detected by the public, and more proactive asset management strategies are required.

Our climate-adjusted pipe failure models show increased rates of summer failures on the old iron, and cement-based pipes due to these →

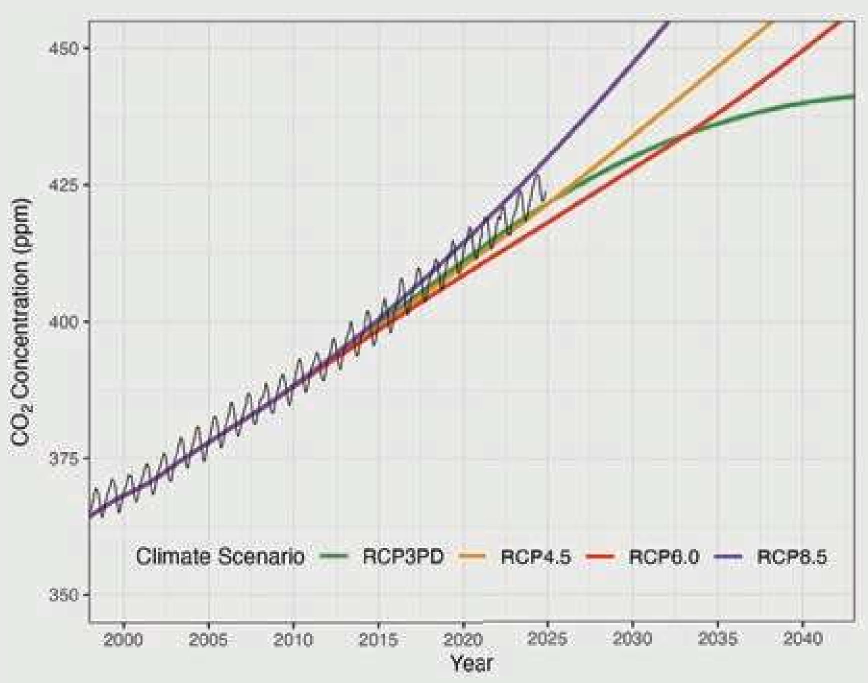



**Figure 4 |** Atmospheric $CO_2$ concentrations over time. Monthly observed atmospheric $CO_2$ concentrations (in parts per million) from NOAA GML, Mauna Loa, Hawaii (thin black line) and four potential climate scenarios or "representative concentration pathways" (RCPs). Each RCP represents the radiative forcing (additional energy retained by the Earth system due to increased greenhouse gases), predicted until the year 2100, but here shown until 2040. RCP 3PD (which is very similar to RCP 2.6), represents future climates under the most ambitious mitigation efforts, while RCP 8.5 represents high emissions under a business-as-usual scenario. © *Dr Tim Farewell, MapleSky Ltd., 2025*

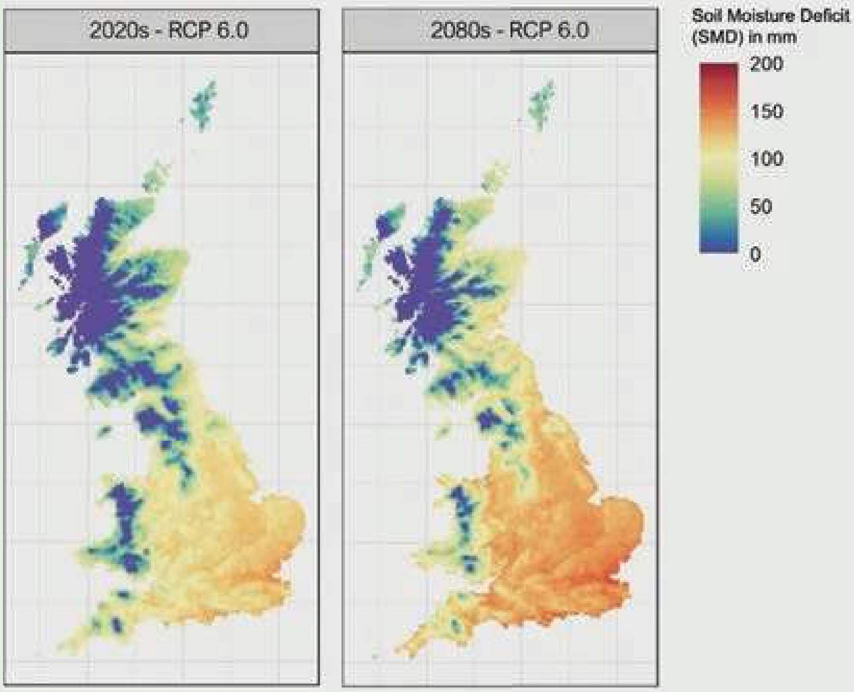



**Figure 5 |** Modelled average August soil moisture deficit (SMD) values for the 2020s and the 2080s under RCP 6.0. (© *Dr Tim Farewell, MapleSky Ltd., 2025*)

ground movements. In addition, early generation PVC pipes are also at increasing likelihood of failure from the hotter drier summers.

The greatest concern is not that the annual number of failures is markedly increasing, but rather that the failures will tend to occur more in the summer and early autumn months, when demand for water is already at its greatest. East Anglia is already classified as "severely water stressed", and the demand for water is always growing – this region has one of the highest rates of new housing development in the UK.

## Data-driven approach

As an applied geoscientist, it is wonderful to see our work being used to help address a real-world problem. Since our initial project to model the climatic risks to the water network in East Anglia, we have used these findings to help identify which specific pipes are most vulnerable to the hazards associated with our warming climate, and teams at Anglian Water are currently working to prioritise these pipes for replacement.

> **"Every megalitre of treated water saved from leakage can be used by the growing population"**

An additional, and unexpected benefit of the work came from the systematic data cleaning process we developed to clean the data sufficiently for our model building. With trustworthy datasets in a robust modelling environment, Anglian Water are now far more able to make rapid, informed, data-driven decisions as part of their triage and pipe replacement programmes. This allows them to save time and money, targeting these limited resources at the most critical assets.

## Collective response

I find it deeply rewarding when I see that my research has had an impact for good at a regional level. An individual research project and more resilient water network may not seem to make much difference to our global challenges. However, energy and chemicals are needed to treat our water, so every megalitre of treated water saved from leakage is not only water that can be used by the growing population but also saves hundreds of kilograms of greenhouse gases from being added to the atmosphere.

The climate crisis that we are collectively creating requires a collective response. As geoscientists, we are more aware than many of the changes in Earth's systems that we, as a species, have caused and continue to exacerbate. At the same time, we are also equipped with the critical skills and knowledge needed to create a more sustainable future. We geoscientists must show leadership in the informed collective action that is required to ensure our world remains fit to sustain our children and grandchildren. G

**DR TIMOTHY FAREWELL**
Director at MapleSky Ltd., UK

## FURTHER READING

**A full list of further reading is available at geoscientist.online.**

- National Emergencies Trust. Wildfires in the UK: Understanding the Growing Risk; nationalemergenciestrust.org.uk/wildfires-growing-risk
- UKHSA (2022) UK Health Security Agency and Office for National Statistics release estimates of excess deaths during summer of 2022; gov.uk/government/news/ukhsa-and-ons-release-estimates-of-excess-deaths-during-summer-of-2022
- Water Resources East; wre.org.uk