artesia

Collaborative Study

The impact of COVID-19 on water consumption during February to October 2020 – Final report

Project reference: 2463

Report number: AR1403

2021-05-21

Report title:	The impact of COVID-19 on water consumption during February to October 2020 – Final report
Project reference:	2463
Report number	AR1403
Date:	2021-05-21
Client:	Collaborative Study
Client lead:	Paul Merchant – South West Water
Collaborators:	Affinity Water, Anglian Water, Dwr Cymru Welsh Water, Environment Agency, Northumbrian Water Ltd, Severn Trent Water & Hafren Dyfrdwy, South East Water, South Staffordshire & Cambridge Water, South West Water & Bournemouth, SES Water, Thames Water, United Utilities, Wessex Water, Yorkshire Water
Project manager:	Kayleigh Powell
Technical leads:	Dene Marshallsay, Sarah Rogerson
Contributors:	Francesca Cecinati, Daniele Di Fiore, Aidan Gibbons, Robert Mayger, Shana Meeus, Cristina Munilla, Jamie Urwin

Version	Author(s)	Reviewed by:	Description	Date
1	Dene Marshallsay	Sarah Rogerson	First draft	8/2/2021
2	Dene Marshallsay	Kayleigh Powell	Final draft	27/4/2021
3	Dene Marshallsay	Kayleigh Powell	Final	21/05/2021

Any enquiries relating to this report should be referred to the authors at the following address:

Artesia Consulting Ltd, Unit 2 Badminton Court, Yate, Station Road, Bristol, BS37 5HZ.

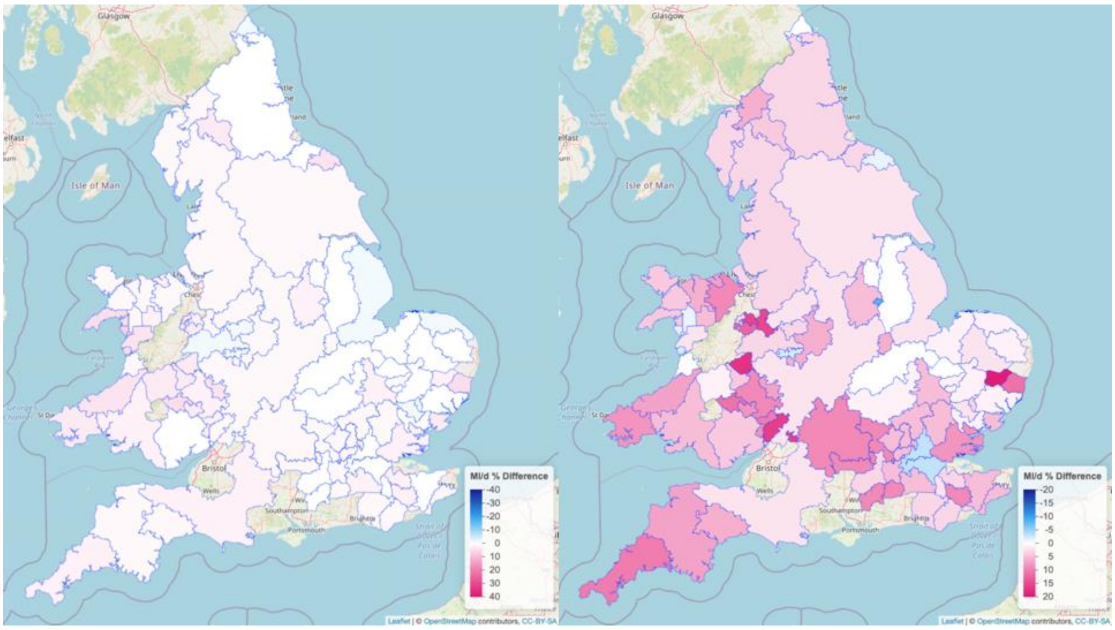
Telephone: + 44 (0) 1454 320091 Website: www.artesia-consulting.co.uk

Executive summary

On the 23rd March 2020 people throughout the UK were told they must stay at home and were only allowed to leave their homes for a small number of purposes to control the spread of COVID-19 from the novel coronavirus SARS-CoV-2. Lockdown had started. What we couldn't have foreseen at the time was the huge impact on water consumption in homes and businesses, which when combined with the hot and dry weather resulted in some of the highest peaks in water demand that water companies have ever seen.

Within this study we wanted to quantify the impact of COVID policies on the consumption of water around England and Wales throughout the period from February through to the end of October 2020. The collaborating companies provided us with a range of different consumption data from distribution input data through to data from individual households and non-household properties. We also collated data from other sources on local weather, Google mobility data and Government policy data.

To illustrate the overall impact from January to October 2020, we can look at distribution input data at water resource zone (WRZ) level. The figure below shows the change in total demand from pre-COVID on the left, to during COVID up to October on the right. Blue shading indicates a reduction in total demand, pink shading indicates an increase in total demand. For the majority of WRZs in England and Wales there is an increase in total demand during 2020 that we believe is due to COVID-19 and the policies implemented to control the spread of the virus.



We have been able to quantify the impact on total demand, household consumption and non-household consumption due to COVID-19 policies and measures from February through to the end of October 2020. This is the impact over and above that we would expect to have seen given the weather in 2020 under non-COVID conditions.

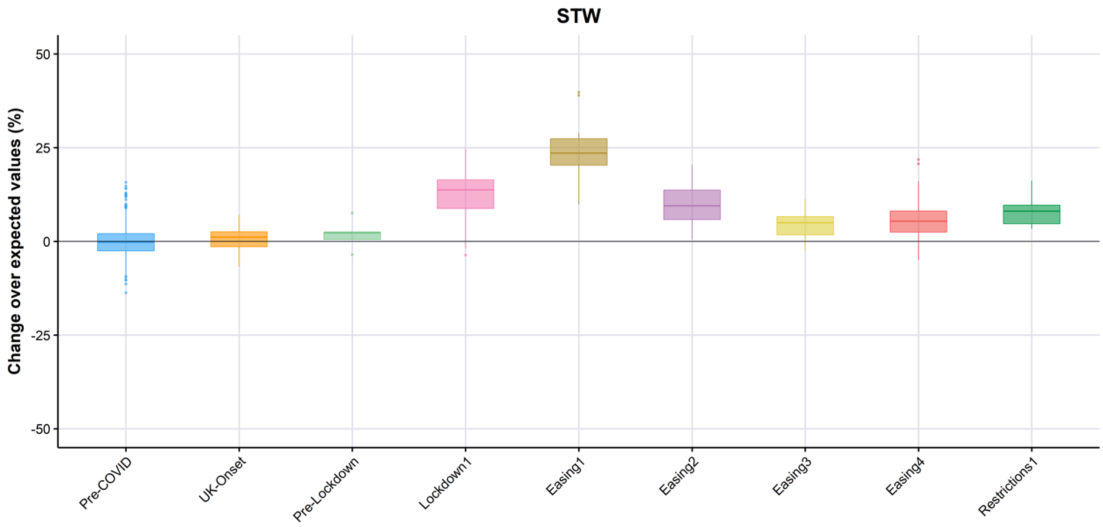
During this period, the impact from COVID-19 policies and measures has been:

- An increase in total demand of about 2.6%.
- An increase in total household consumption of around 9% and 13%.
- A decrease in non-household consumption of about 25%.

There are regional and temporal variations in these numbers. The biggest increases in total demand are in the south (with the exception of London – see below), then the midlands/west, with the lowest increases in the north and east.

Using total demand data, we have observed a redistribution of demand during the COVID pandemic. This is most clearly visible in the London resource zone which experienced a reduction in total demand, with total demand increasing in the zones surrounding London. This is probably due to fewer people commuting into London for work or study.

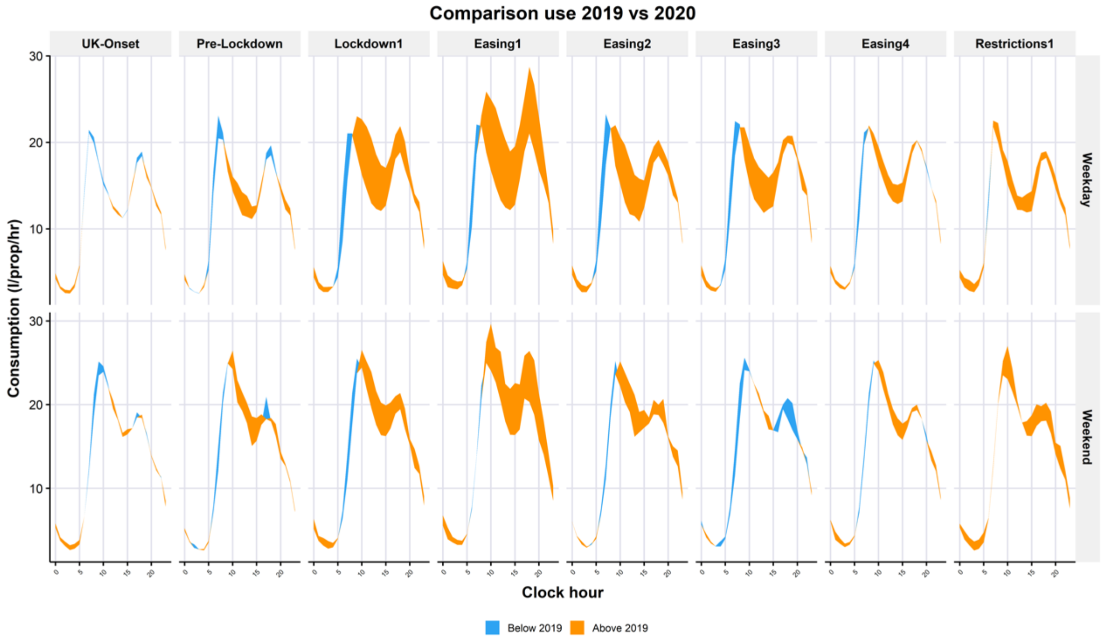
The increase in household consumption (PHC) was greatest during the hotter and drier periods. Peak increases in PHC (20% to 30%) were observed during easing 1 (mid-May to June) where most lockdown measures were still in place, and we saw a two-week period of hot weather at the end of a long (6-week) dry spell. This indicates that there was a combinational impact from lockdown measures and hot-dry weather (greater than would have been observed with the weather factors alone). Over the period from lockdown to the end of easing 4 (March to September) the average increase in PHC was between 8% and 10%. One dataset extended to early November and this area saw an increase in PHC of about 6% during the restrictions phase in October. An example of this can be seen in the figure below.



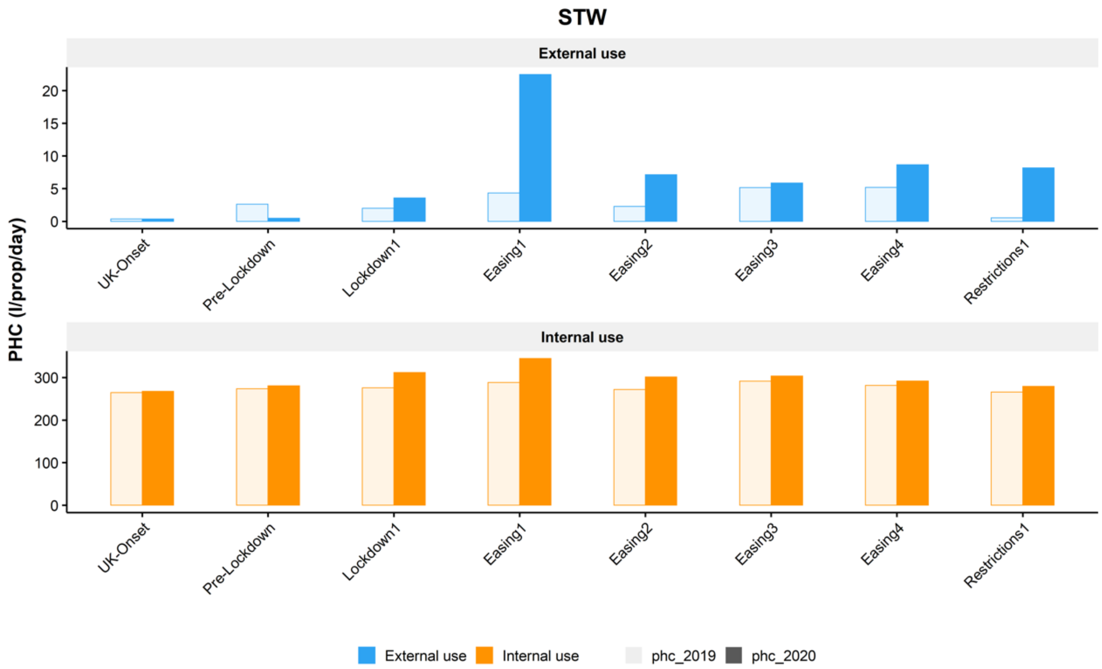
A social science study with the University of Manchester carried out during this study suggests that there was a change in the value and meaning attached to domestic gardens, which has fueled an already growing popular interest in gardening as a leisure activity resulting in a rise in water consumption. There were also changes in daily patterns of indoor water usage related to wider changes in the organisation of life and work, as people have more time to invest in activities within the household and have more flexible routines.

We were able to observe these changes in household water consumption patterns through the day. We saw a clear change in use after lockdown starts, with more water being used through the day with the morning peak becoming less dominant. The biggest changes are during easing 1 as expected given the increase in PHC, and during this period we see the evening peak during weekdays becoming the dominant peak, suggesting outside use is a driver. We used the sub-daily flows to differentiate between internal use (water use by appliances and taps within the home) and external use, water use in the garden plant watering, filling of paddling pools, etc.

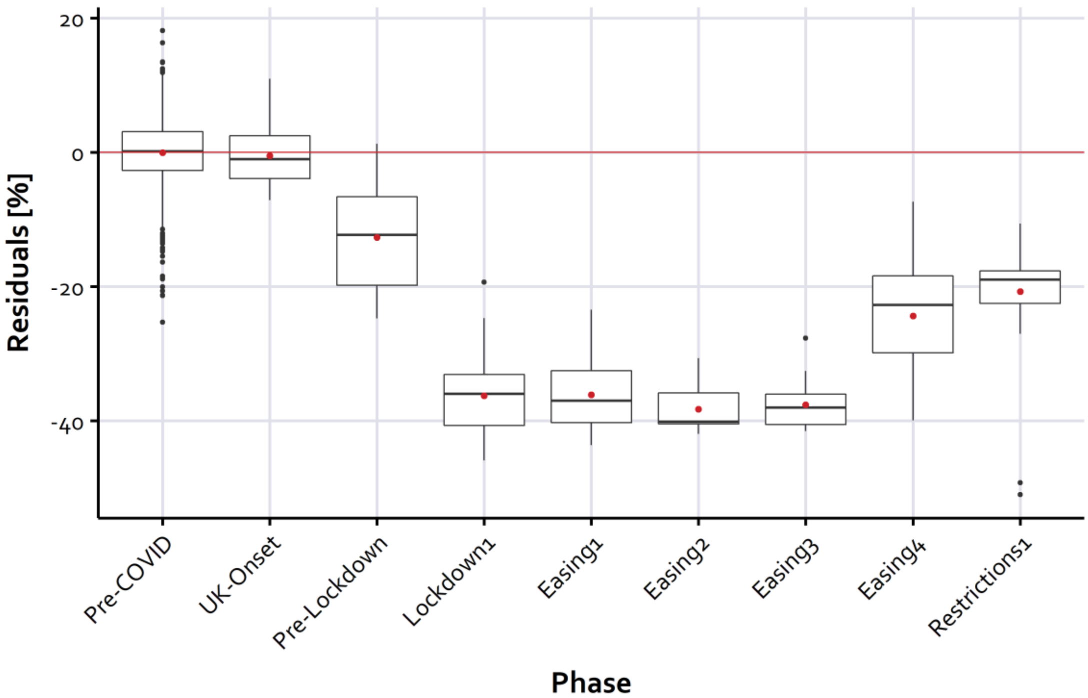
An example of the change in flow patterns during the day is shown in the figure below which shows the change for weekdays (top row) and weekends (bottom row) and shows the impact during each of the COVID phases. Each graph shows the consumption across the day, with orange areas showing an increase, and blue areas showing a decrease.



An example of the change in internal and external consumption is shown below. In this figure the top line is external use (blue) and the bottom line is internal use (orange). This clearly shows that the peak increase in consumption during easing 1 was driven by outside use, and we also see increased in internal use through the whole period.



For non-household consumption the temporal variations were different for different sectors, but in overview the changes in non-household consumption through each COVID period is shown below.



The commercial sectors behave differently over time. The hotel and restaurant sector started to see a reduction during the pre-lockdown phase, with a change in water consumption of about -30%, reached a minimum during the lockdown period of about -70% and did not recover much during the easing phases. The sport and recreational service sectors were significantly hit by the pandemic, with a decline in water consumption up to -60% during lockdown, and it has not recovered much, even considering a partial increase during the 4th easing. The education sector was impacted by school closures and remained lower than expected until the 4th easing. Other sectors were affected less, for example essential services such as food production, utilities and health and social work were not impacted as much as their water consumption was not changed significantly.

In terms of regulatory reporting, the increase in household consumption will impact the per capita consumption (PCC) performance commitment. This is because PCC is defined as the total household consumption (which has increased) divided by the total population (which has remained unchanged). Because the performance commitment is based on a 3-year rolling average, the increase in PCC during 2020 will impact the performance commitment for several years (bearing in mind we do not know yet how long household consumption will remain elevated).

A number of recommendations have been made for monitoring and further analysis of demand data during the latest periods of lockdown and the easing of these restrictions, and the emergence of any new water use behaviours.

Contents

Figures

Tables

1 Introduction

1.1 Background

On the 23rd March 2020 people throughout the UK were told they must stay at home and were only allowed to leave their homes for a small number of purposes to control the spread of COVID-19 from the novel coronavirus SARS-CoV-2. Lockdown had started. What we could not have foreseen at the time was the huge impact on water consumption in homes and businesses, which when combined with the hot and dry weather resulted in some of the highest peaks in water demand that water companies have ever seen. Whilst the foremost thoughts at the time were for the safety and health of everyone during the pandemic, water plays a key part in the country's health and sanitation and the industry's ability to maintain water and waste services during disruptive events like this is vital.

Soon after lockdown began, water companies realised that closing down businesses, putting workers on furlough schemes and asking office workers to work at home where possible, had the potential to change the patterns and scale of consumption in the water network. It became apparent that if the pandemic were to persist and if there emerged a "new normal" then water companies would need to quantify the impact from these changes in consumption on regulatory reporting, water network operations and water resource planning.

In July 2020 Artesia were asked to carry out a project where the following water companies collaborated, along with the Environment Agency to share data and resources to investigate the changes to water consumption arising from the pandemic:

- Affinity Water,
- Anglian Water,
- Dŵr Cymru Welsh Water,
- Environment Agency,
- Northumbrian Water Ltd,
- Severn Trent Water & Hafren Dyfrdwy,
- South East Water,
- South Staffordshire & Cambridge Water,
- South West Water & Bournemouth Water,
- SES Water,
- Thames Water,
- United Utilities,
- Wessex Water,
- Yorkshire Water.

1.2 Context

During the planning of this project in July 2020, it was widely anticipated that the pandemic would be under control by September 2020, schools would reopen and a "new normal" would emerge with a higher proportion of office workers working from home on a permanent basis. Therefore, the plan was to collate data up to the end of September to capture the new normal.

Little did we suspect that that by January 2021 the UK would be in another full lockdown, with schools closed until at least March 2021.

As it became apparent during the summer of 2020 that a return to a new normal was looking unlikely, the project plan was altered to collect data up to the end of November 2020 and then carry out the analysis and prepare a report in early 2021.

In addition to this collaborative consumption study, during the summer and autumn of 2020, WaterUK and Ofwat decided to work collaboratively to understand the impacts of COVID-19 on the water sector and produce a high-level view of the economic impact from COVID-19[1]. Their report identified the impact on consumption as significant.

This collaborative consumption study is more of a 'deep dive' into the data and evidence that the companies have collected pre and post-lockdown (up to the end of October 2020).

1.3 Objectives

The overall objectives of the project are to:

a. Quantify the observed variations in consumption through lockdown to the end of October 2020 in different regions,

b. Quantify the impacts on consumption during specific periods of lockdown,

c. Explain the impact on reported consumption components and potential regulatory challenges,

d. Model consumption under a range of potential future scenarios,

e. Explore the potential issues for water resource planning.

This report presents evidence and findings on objectives (a), (b) and (c), (d) and (e).

[1] Economic impacts of COVID-19 on the water sector. December 2020. Frontier Economics.

2 Approach

Within this study we wanted to quantify the impact of COVID policies on the consumption of water around England and Wales throughout the period from February through to the end of October 2020. The collaborating companies provided us with a range of different consumption data from distribution input data to through to data from individual households and non-household properties. We also collated data from other sources on local weather, Google mobility data and Government policy data. This section outlines the data and the approach to the study design.

2.1 Data used in the study

2.1.1 Distribution input data

All companies supplied daily distribution input data at Water Resource Zone (WRZ) level covering the COVID period and several preceding years. This data is the for total demand in each zone and this includes household consumption, non-household consumption, leakage and other minor components. Using this data we wanted to understand the impact on total demand, whether it increased or decreased as a result of the different COVID policies, and how this varied in different geographies.

2.1.2 District metered area data

In order to manage the water network, water companies create discrete areas of the network and monitor the flows into and out of these areas. Typically, these areas cover about 1,000 households, although this varies depending on the network configuration. These areas are known as DMAs (district metered areas), and some of these are areas supplied through a single meter with no outlets. These allow us to monitor total demand at a smaller scale. Data from these areas typically has a temporal resolution of 15 minutes (i.e. 96 flow readings over a 24-hour period).

2.1.3 Individual household data

Across England and Wales, just over 50% of households are supplied and billed through a domestic water meter. However, these are typically only read twice a year. For this study we needed to have data at a sub-daily resolution so that we could monitor changes in consumption at different times of the day. This was available primarily from "household monitors"[2], smart meter trial areas, or smart metered properties. Typically, these allow us to monitor households at 15-minute or hourly resolution (with the appropriate GDPR and data protection policies and procedures in place).

[2] Household monitors are samples of households which represent company socio-demographics that are monitored at a high flow resolution (15-mute or hourly).

2.1.4 *Individual non-household data*

Data from individual non-household (commercial, industrial, offices, shops, etc) properties. The dataset we used holds consistent data from 2016 to the current date and includes consumption data at 15-minute resolution.

2.1.5 *COVID policy data*

Information on the policies, and societal impacts during the COVID period were collated from three principal sources. The first is the "Oxford COVID-19 Government Response Tracker"[3]. From this we selected 13 indicators:

- School closing
- Workplace closing
- Cancel public events
- Restrictions on gatherings
- Close public transport
- Stay at home requirements
- Restrictions on internal movements
- International travel controls
- Income support
- Confirmed deaths
- Testing policy
- Contact tracing
- Facial coverings

Secondly, we selected 5 indicators from ONS for different commercial sectors[4]: furloughed staff, remote working, turnover change, self-isolating staff, and variation in job adverts.

We also selected the following from Google's mobility data[5]: visits (footfall) to shops (retail and recreation), essential shops (grocery and pharmacy), transport (transit) stations and workplaces.

2.1.6 *Social science study*

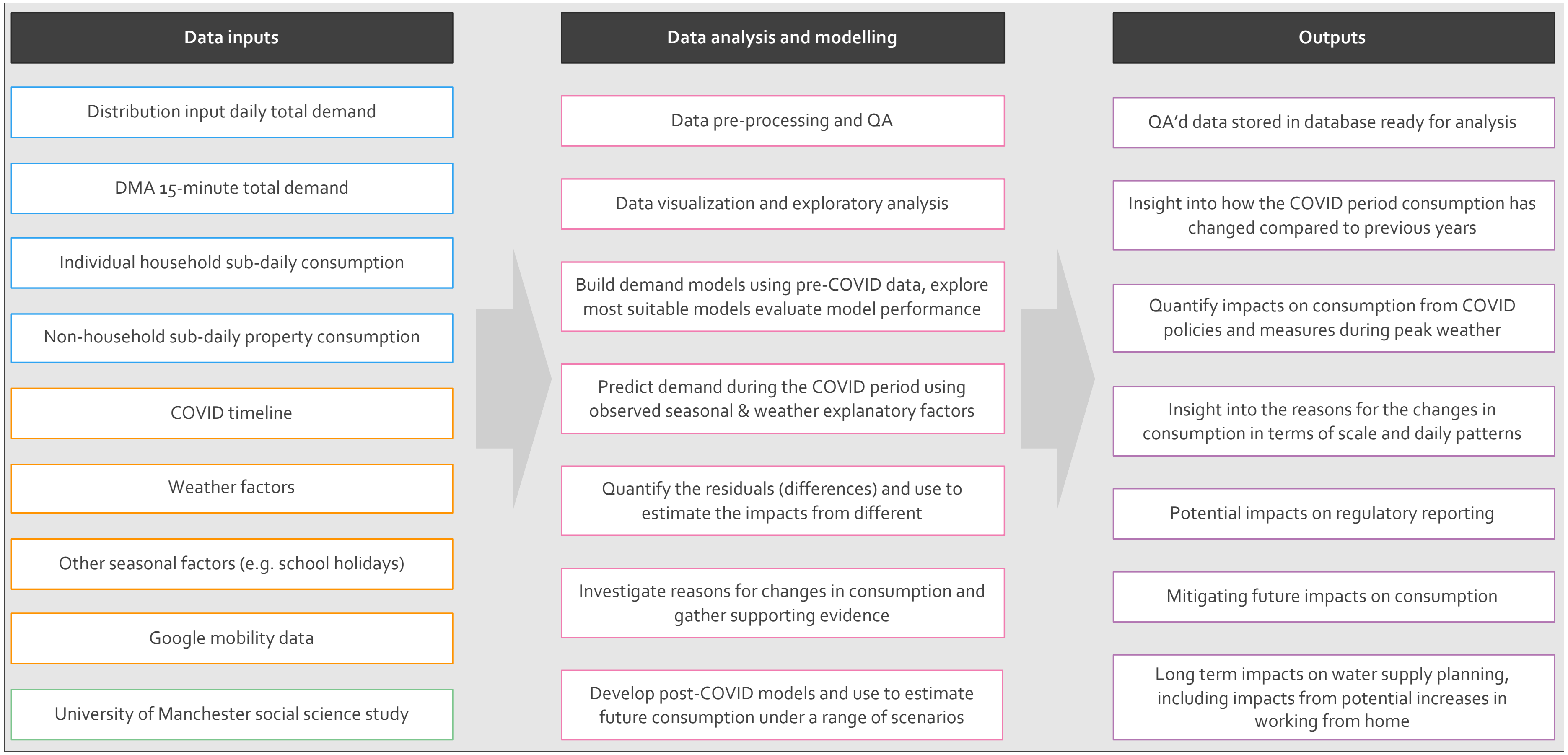
During the summer of 2020, Artesia collaborated with the University of Manchester to conduct a consultancy project on 'Understanding changes in domestic water consumption associated with COVID-19 in England and Wales'. The collaboration was through a framework of the University of Manchester's Collaboration Labs programme funded by the ESRC NPIF Accelerating Business Collaboration scheme. The full report is available to this collaborative project.[6] It is used in this study to help understand how water using practices have changed through the COVID period.

2.2 Overview of methodology

Figure 1 shows an overview of the approach to the data analysis. Each section of this report will include further details on the methodology used for each consumption component.

[3] https://www.bsg.ox.ac.uk/research/research-projects/coronavirus-government-response-tracker
[4] https://www.gov.uk/guidance/coronavirus-covid-19-statistics-and-analysis#business-and-the-economy
[5] https://www.google.com/covid19/mobility/
[6] The full report is available to this collaborative project and is downloadable here: https://artesia.shinyapps.io/Artesia-Reports/

Figure 1 Overview of data analysis plan



For water companies it is extremely important to understand how water consumption has quantitatively changed during the implementation of COVID-19 control policies such as lockdown and social distancing measures. However, it is not as simple as looking at the consumption during lockdown, as this is influenced by other factors, like the extremely dry and warm weather of April and May 2020 or the holiday periods.

Therefore, throughout this report we will use models to:

- separate what would be the consumption under "normal conditions", from the variations due to lockdown measures.
- understand what factors of lockdown influence the various components of water consumption (remote working, business closure, school closure, limited business capacity, etc).

Within this report we will use pre-COVID models to allow us to measure the impacts that the COVID-19 pandemic has had so far on water consumption, compared to what we believe would have been the consumption without COVID-19 policies.

Therefore, we need to understand what the consumption under "normal conditions" is: what factors influence the different components of consumption i.e. what would have been the consumption during the lockdown period only based on the influencing factors? We will test different pre-COVID modelling approaches to model consumption as a function of many known factors, such as:

- Property factors,
- Socio-demographic factors,
- School holiday periods,
- Religious holiday periods,
- Weather conditions (e.g. temperature, rainfall, sunshine hours)
- Long-term trends
- Location.

In the next report we will use models based on data during the post-COVID period to forecast how consumption will be impacted in the near future, considering different scenarios for different lockdown measures that could be introduced to fight the pandemic.

3 The Covid-19 timeline

From the time that the SARS-Cov-2 virus started to impact society in the UK, there have be a series of policies that have been implemented in an attempt to curtail the impact of the virus. These policies started in a consistent manner across the UK, but through the summer of 2020, the policies started to diverge between England, Wales, Scotland and Northern Ireland. Further into the summer we also started to see local variations within each of the regions.

To allow us to look at the impact on consumption through the COVID-19 period in a systematic and consistent way, all the graphs and data in this report have been aggregated into a consistent timeline based on the English Government's policies (as most of the areas we are assessing are in England). This timeline is shown in shown in Table 1. The table lists the name of each period, the date range, a description of the policies in place and a general description of the UK weather during the date range. The weather description is high level and taken from a graphic published by the Met Office and shown in Figure 2.

We include in our analysis some data from Dŵr Cymru Welsh Water. Wales started to vary policy decisions during Lockdown 1. The key variations are identified below:

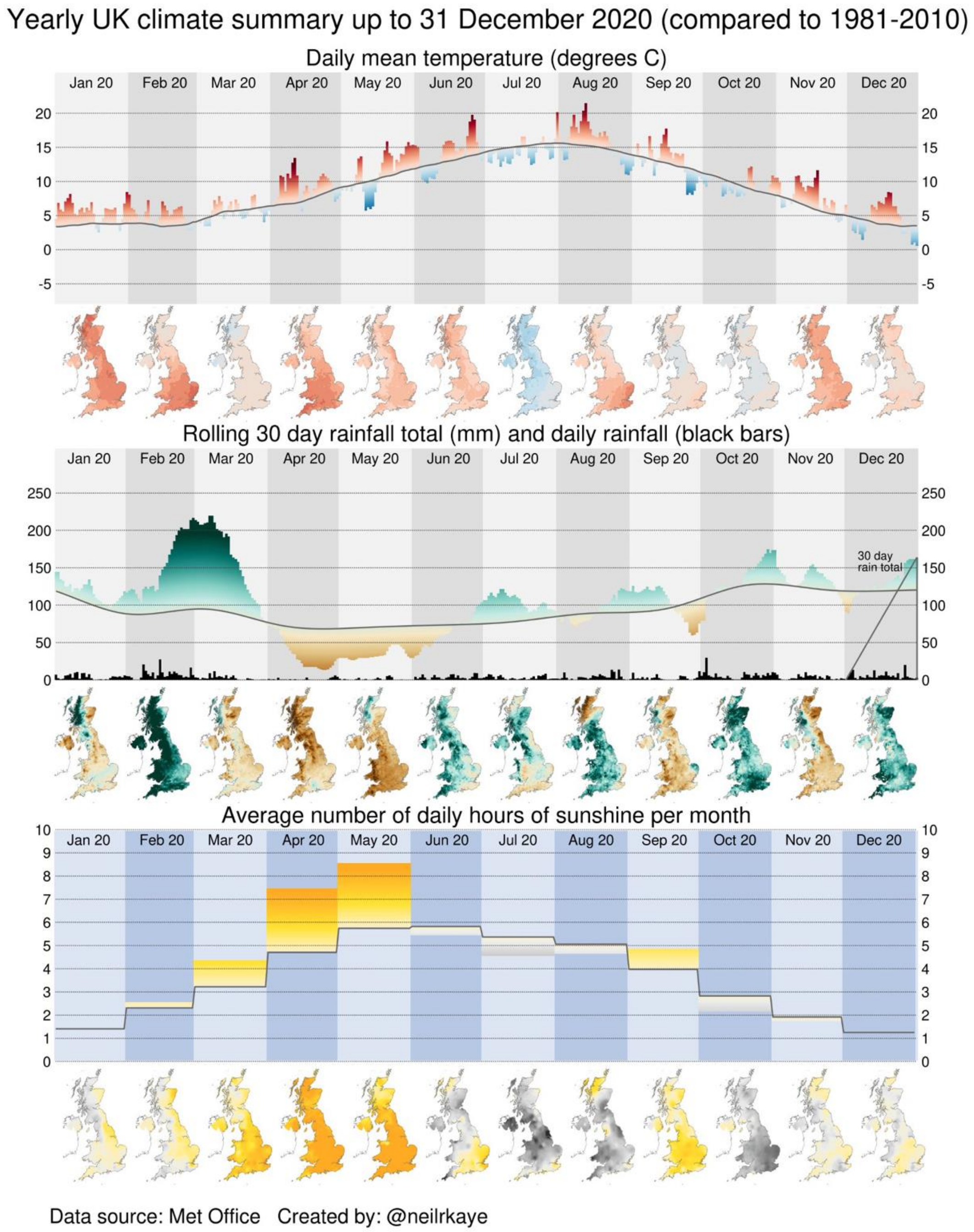
- Whilst the first easing of lockdown 1 in England started on the 13th May 2020, the first easing in Wales did not start until the 1st June 2020.
- Pubs and restaurants could open in England (indoors and out) with appropriate restrictions from 4th July, whereas in Wales pubs and restaurants could only open outdoors from the 13th July, and not open inside until 3rd August 2020. Stay local restrictions were lifted at this time allowing greater travel in Wales.
- England started to introduce local lockdowns (see below) 26th June (Leicester). In Wales, the first local lockdowns started on 7th September 2020, by the 27th September, approximately 66% of Wales' population were subject to lockdown measures.
- Wales introduced a "Firebreak" lockdown on 23rd October 2020 for 3 weeks, whereas England introduced a second 4-week lockdown on the 5th November 2020.

Local restrictions started in England on 26th June in some areas around Leicester. On the 20th July 2020 lockdown measures were introduced in Greater Manchester, East Lancashire and Yorkshire. Other areas were then added to this list during August, September and October until on the 5th November 2020 when the second lockdown started in England.

Table 1 COVID timeline England

COVID-period	Date range	Description	Weather
Pre-COVID	Before 2/02/2020	We can assume life as normal.	Warmer, average rainfall
UK-onset	2/02/2020 to 16/03/2020	Initial measures are taken by the Government: Handwashing advised, COVID-19 action plan published, Self-isolation measures.	Warm and very wet
Pre-lockdown	16/03/2020 to 23/03/2020	Initial business closures, more stringent Government regulations, schools are closed.	Average temperature and wet.
First Lockdown (Lockdown 1)	23/03/2020 to 13/05/2020	The UK government announces a lockdown, no one can leave their home unless for essential reasons. Only essential workers can continue working, all other businesses either to close or work from home.	Warm, dry and sunny
1st Easing	13/05/2020 to 2/06/2020	Housing market opens. Outdoor sports courts and other outdoor sporting activities are permitted to reopen if they can do so safely.	Hot, dry and sunny
2nd Easing	2/06/2020 to 15/06/2020	You can spend time outdoors for recreation with your household or in groups of up to six people from outside your household. Outdoor markets and car showrooms can open.	Cool start, then hot and dry
3rd Easing	15/06/2020 to 4/07/2020	Shops selling non-essential goods can open. Schools can open for years 10 and 12. Face coverings mandatory for public transport.	Hot, dry then some rain
4th Easing	4/07/2020 to 22/09/2020	Pubs, restaurants, hairdressers and cinemas can open, with appropriate measures. This period includes the "eat out to help out" scheme from 3/08/2020 to 31/08/2020.	Jul: Ave. temp. and wet Aug: Hot and dry Sep: Hot with some rain
New Restrictions (Restrictions 1)	22/9/2020 to 5/11/2020	Office workers are asked to work from home again if possible; all pubs, bars and restaurants restricted to table service and must close at 10pm; face masks mandatory in indoor businesses.	Average temperature and rain
Second Lockdown (Lockdown 2)	5/11/2020 to 5/12/2020	A second national lockdown is in place, but with less strict measures than the first lockdown (nurseries, schools and colleges remain open, no limit on outdoor exercising, parks and playgrounds remain open).	Warm and average rain

Figure 2 Overview of the weather in the UK during 2020



4 Social science study - understanding changes in domestic water consumption associated with COVID-19

During the summer of 2020, Artesia collaborated with the University of Manchester to conduct a consultancy project on 'Understanding changes in domestic water consumption associated with COVID-19 in England and Wales'. The research project takes an interdisciplinary perspective building on quantitative evidence of changes in water demand; a rapid evidence assessment of news articles, grey literature, and peer reviewed journal articles; and six focus group discussions conducted with a total of 21 participants.

The focus group discussions aimed to get participants to reflect about how their domestic water practices have changed in the months following the government's 'stay-at-home' order in England and Wales. This included questions about changes in routines, schedules, patterns of mobility, hygiene meanings and expectations, ways of spending free time and the implications of those for household water usage. Participants were also asked to reflect on future trajectories of water consumption as restrictions are eased up.

The project has been shaped by a practice-based approach to water demand. The full report can be downloaded[6]. The research findings show:

- The main changes in daily patterns of indoors water usage are related to wider **changes in the organisation of life and work**. For those working from home, water consumption has relocated from public spaces (e.g. offices, gyms, canteens) into the home (e.g. drinking, flushing the toilet or washing dishes), as people have more time to invest in activities within the household (e.g. time saved from long commutes used in cooking or gardening) and have more flexible routines (e.g. showers are taken throughout the day instead of early morning).
- At the beginning of the lockdown people **adopted water intensive practices to protect themselves from contracting the virus.** The majority of these practices were not new but what changed was the frequency and intensity with which they were undertaken (i.e. more frequent and conscious washing of hands, frantic personal and clothes washing, thorough washing of groceries and home deliveries). However, most of these hygiene practices have quickly faded (or are fading) as people are getting used to living with the virus.
- Outdoor water consumption has been importantly underpinned by a **change in the value and meaning attached to domestic gardens**. Prior to the lockdown, gardens were used on an occasional basis and this was often weather-dependent, however now they have gained importance for the everyday life of people in the months following the 'stay-at-home' order. With restrictions to mobility and reduced opportunities for other leisure activities, gardens have become **key spaces for socialization and mental health in challenging times, to take breaks from work, to get privacy from other household members, to entertain oneself, or for food production.** This has fuelled an already growing popular interest in gardening as a leisure activity resulting in a rise in water consumption.
- As people go back to their pre-lockdown lives, it is likely that some water- intensive domestic practices will disappear while others will remain. Findings show that **water consumption related to hygiene practices that are undertaken for health reasons are likely to recede as people get used to living with the virus.** The exception to this is handwashing which is likely to be sustained over a longer period. It is expected

that many people will continue working from home in the coming months, with some participants expressing the desire to continue with flexible working arrangements post-COVID-19. As a result, it is likely that at least some patterns of water consumption that started during the lockdown **become an important part of the new normality in terms of domestic water demand** (e.g. longer showers throughout the day instead of a short one in the early morning). Other water consuming activities related to new ways of spending free time, such as gardening or taking long relaxing baths, will likely remain as they have now become a part of the everyday lives of people.

5 The impact on distribution input

All companies supplied daily distribution input (DI) data at Water Resource Zone level covering the COVID period and several preceding years. This data is the for total demand in each zone and this includes household consumption, non-household consumption, leakage and other minor components. Using this data we wanted to understand the impact on total demand, whether it increased or decreased as a result of the different COVID policies, and how this varied in different geographies.

5.1 Distribution input analysis methodology

5.1.1 *Data*

The DI data provided by all companies in the project was daily consumption data at water resource zone level the current year (2020) and as many historic years as possible (whilst maintaining consistent data).

Additional data was collated for:

- **Weather data** – temperature, precipitation, and sun-exposure variables, at daily granularity.
- **COVID-19 timeline data** – dataset describing different government policy phases in response to COVID-19.
- **Holidays** – dataset describing local school holidays, bank holidays, Ramadan, and other holiday events, at daily granularity.

5.1.2 *Exploratory analysis and seasonal decomposition*

When we look at the DI data for 2020 compared to previous years, we see that in some areas DI is at the upper end of the DI range and in some at the lower end. An example for a selection of South East Water (SEW) water resource zones is shown in Figure 3. The DI timeseries contain annual cyclical patterns and longer-term trends.

The cyclical patterns are caused by predictable events like school holidays, Christmas holidays and normal weather patterns. The long-term trends are caused by gradual changes in the population, metering and leakage trends within the WRZ. These components of the signal need to be removed to make the DI readings more comparable over the years. To do this we use the R package "anomalize" that contains a function called "time_decompose" which decomposes a signal into separate "trend", "season" and "remainder" components.

An example of this is shown in Figure 4 for Haywards Heath WRZ. The top line of the graph shows the raw DI signal, the bottom line shows the long-term trend that is removed, the third line down shows the regular seasonal pattern that has been removed, this leaves the 'remainder' in the second line down, which is the observed signal with the trend and seasonality removed. This remaining signal is influenced by abnormal seasonal events such as the peak summer of 2018 (highlighted in blue), or the COVID-19 period (highlighted in orange). The remainder is the component that we are interested in for the rest of the DI analysis.

Figure 3 Raw DI signal in 2020 (red) overlayed onto historic DI (green)

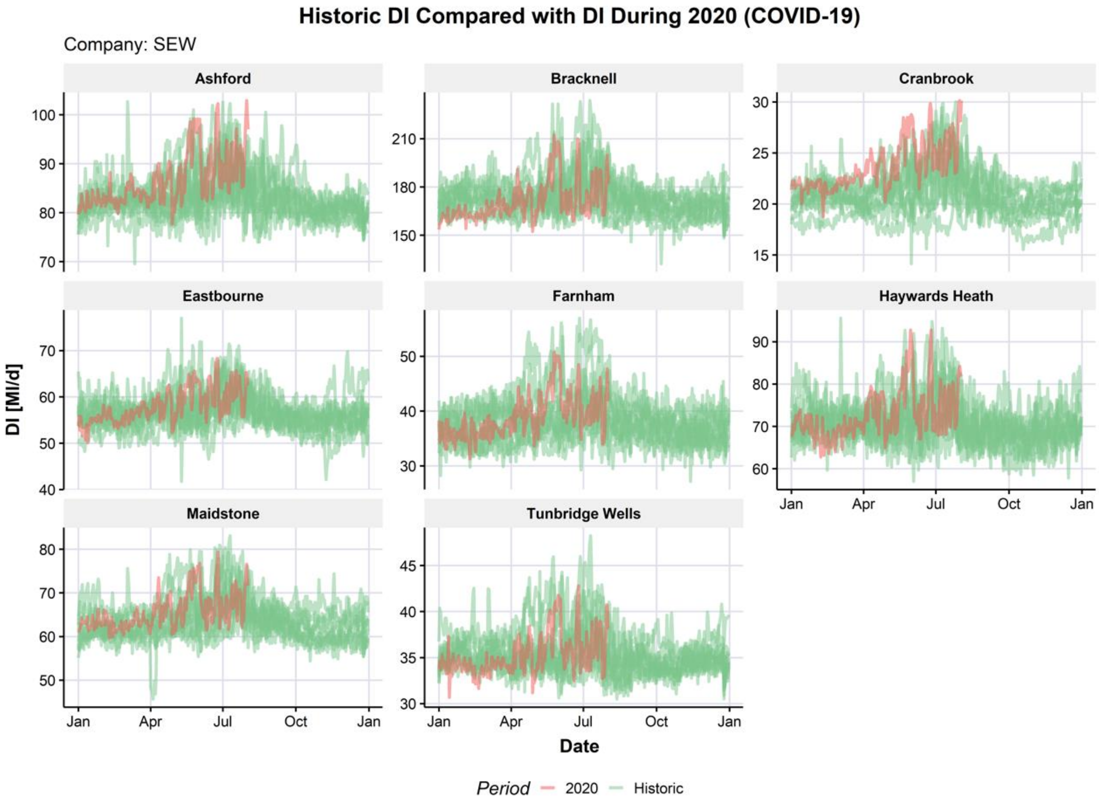
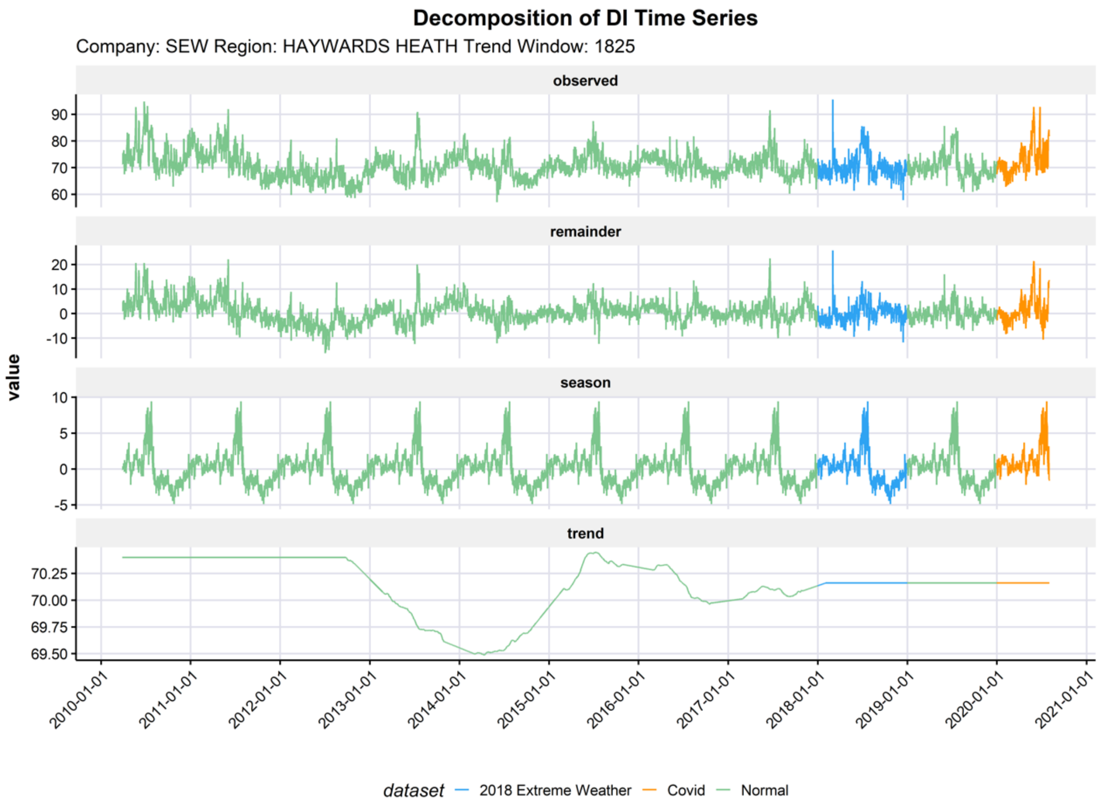


Figure 4 Example of a decomposition of a DI signal



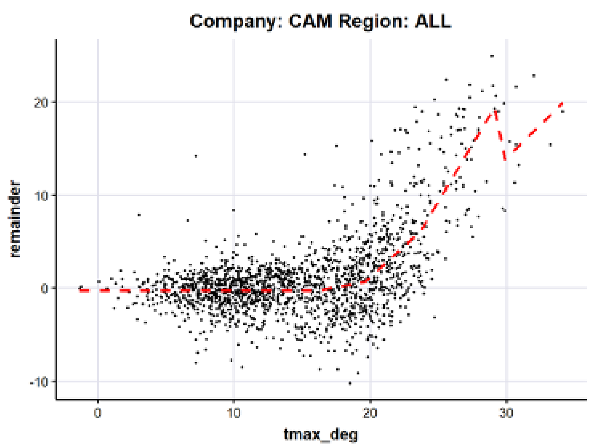
Subtracting the trend eliminates the influence of long-term gradual changes, this may be changes in WRZs geography or economy, technological developments, improvements in leakage reduction, metering of domestic customers or other factors. Subtracting the seasonality removes the impact of events that occur reliably at a certain time in the year, such as holidays, normal weather patterns, tourism, and others. This leaves short-term sporadic drivers of water consumption evident in the remainder signal.

One of these factors in 2020 will be the COVID-19 impact, but there will also be influences from the hot and dry weather observed during the summer of 2020. To separate out the factors driving changes in DI in 2020 we need to model the remainder signal. The DI pre-2020 remainder is therefore mapped onto variables describing the drivers of consumption (weather parameters, school holidays, etc).

It was observed that many of the variables that required modelling had a non-linear relationship with DI. Elbow patterns were often observed, where there is a sharp change in trajectory of the trend.

One model that is particularly suited to this kind of non-linearity is the multivariate adaptive regression splines (MARS) model. As the name suggests, MARS is a regression model, meaning that it attempts to fit a line through a series of datapoints. MARS can be considered as an extension of the standard linear model. However, the MARS model introduces non-linearity by stitching together multiple linear models to introduce changes in gradient, see Figure 5. These changes in gradient allow it to approximate elbow-shaped data with much more accuracy than any linear model. With increased model complexity comes the concern of overfitting, however, multiple years of daily DI readings are available, so the abundance of data will be enough to mitigate this issue.

Figure 5 Demonstration of the non-linear fit of a MARS model



The MARS model is then used to perform feature selection (features are included if they make an improvement to R^2 greater than or equal to 0.01) and return an adequate model.

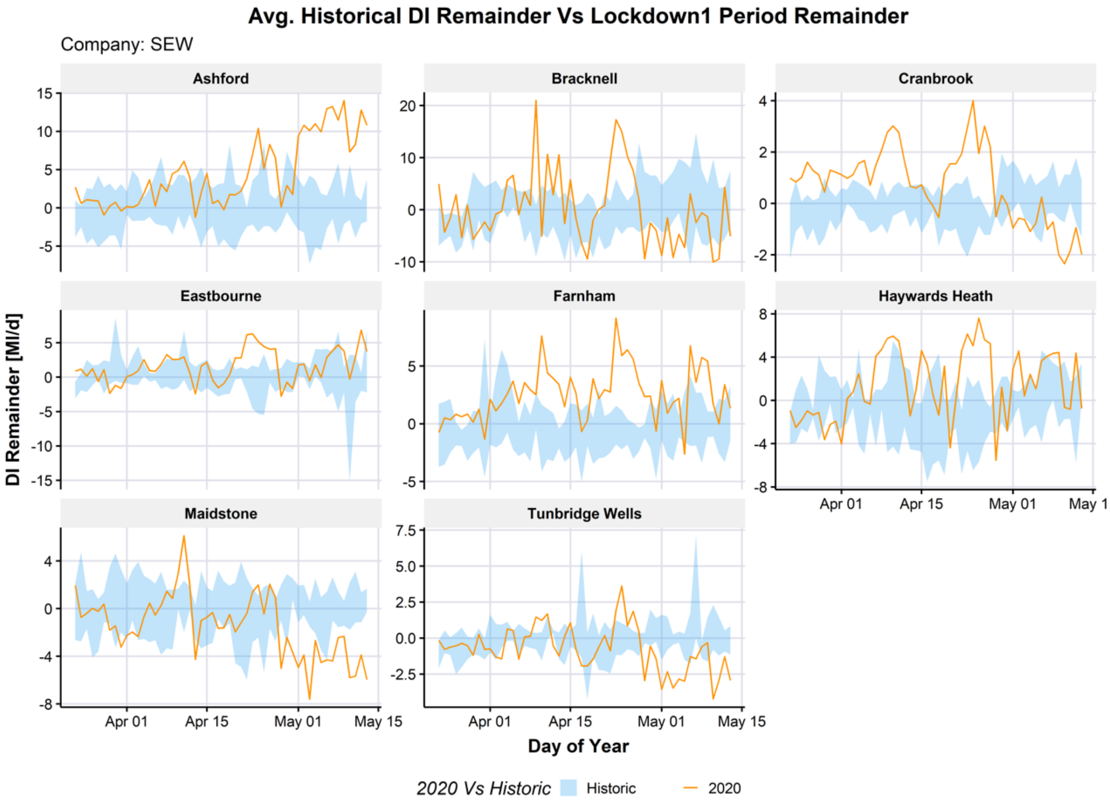
An example of the model outputs is shown in Figure 6 for the Haywards Heath WRZ. The remainder signal is in red and the modelled signal is in green. The model was built using pre-2020 data, so we would expect a reasonable fit for data from 2016 through to the end of 2019, which is what we observe in Figure 6.

Figure 6 Example of the comparison of model outputs (green line) and actual remainder (red line)

For 2020 the model has been applied to the observed weather and normal holiday periods, and therefore any deviations in the observed remainder signal compared to the modelled values will be due to other factors not in the pre-2020 data, for example the impacts from various COVID-19 policies. In this example (Figure 6), the model suggests that there will a small increase in DI during April to June, whereas the observed signal is much higher. Therefore, we conclude, in this example that the COVID-19 policies are directly increasing DI during April, May and June, whereas in August the model predicts that the combination of high temperature and low rainfall would have led to an increase in DI, and therefore the observed peak (at the end of the 2020 timeseries in this example) is partly due the observed weather – but there is also an additional smaller increase due to COVID-19.

If we look at this period in more detail, we can see in Figure 7 that during 'Lockdown 1' (23rd March to 13th May) the Haywards Heath zone shows the DI remainder component to be higher than expected during April. It is also worth noting that some of the other zones show similar increases (e.g. Cranbrook, Bracknell, Eastbourne and Fareham), but other zones (Ashford and Maidstone) show different behaviour.

Figure 7 Example of the 2020 DI remainder compared to historical DI remainder for Lockdown 1



If we look at the next period 'Easing 1' (14th to 30th May), see Figure 8, the Haywards Heath zone continues above the expected level, with a large increase towards the end of May. As in Figure 7 some zones have a similar profile, and others follow a different trend. What is emerging is a complex set picture with different trends in different WRZs within a single company. This can be seen for the whole period in Figure 9, which shows how the unexplained DI (blue line) varies during the COVID-19 timeline compared to the historic remainder (orange line).

Figure 8 Example of the 2020 DI remainder compared to historical DI remainder during Easing 1

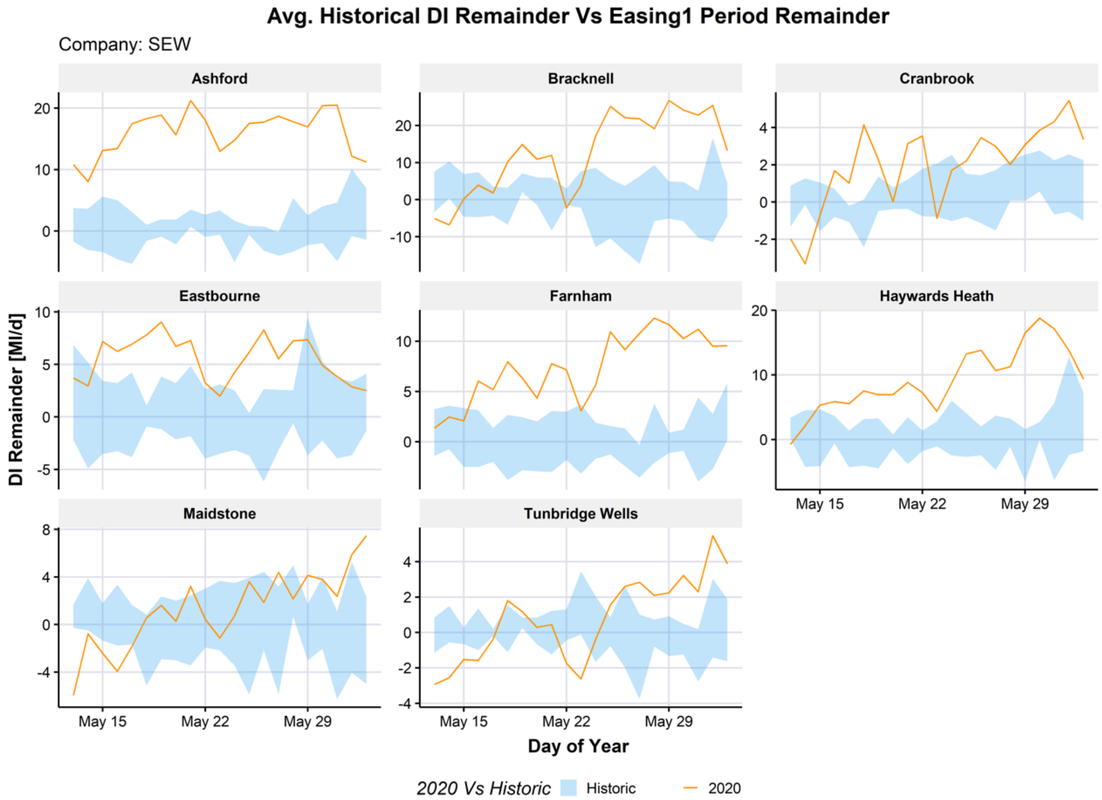
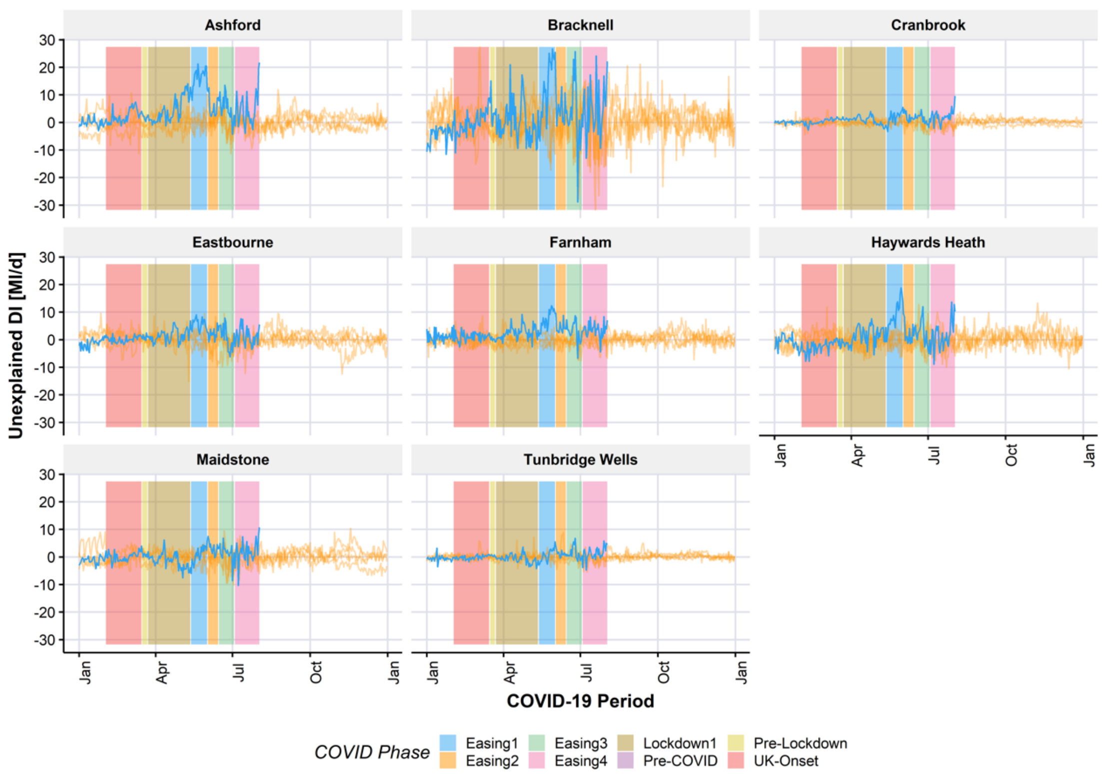
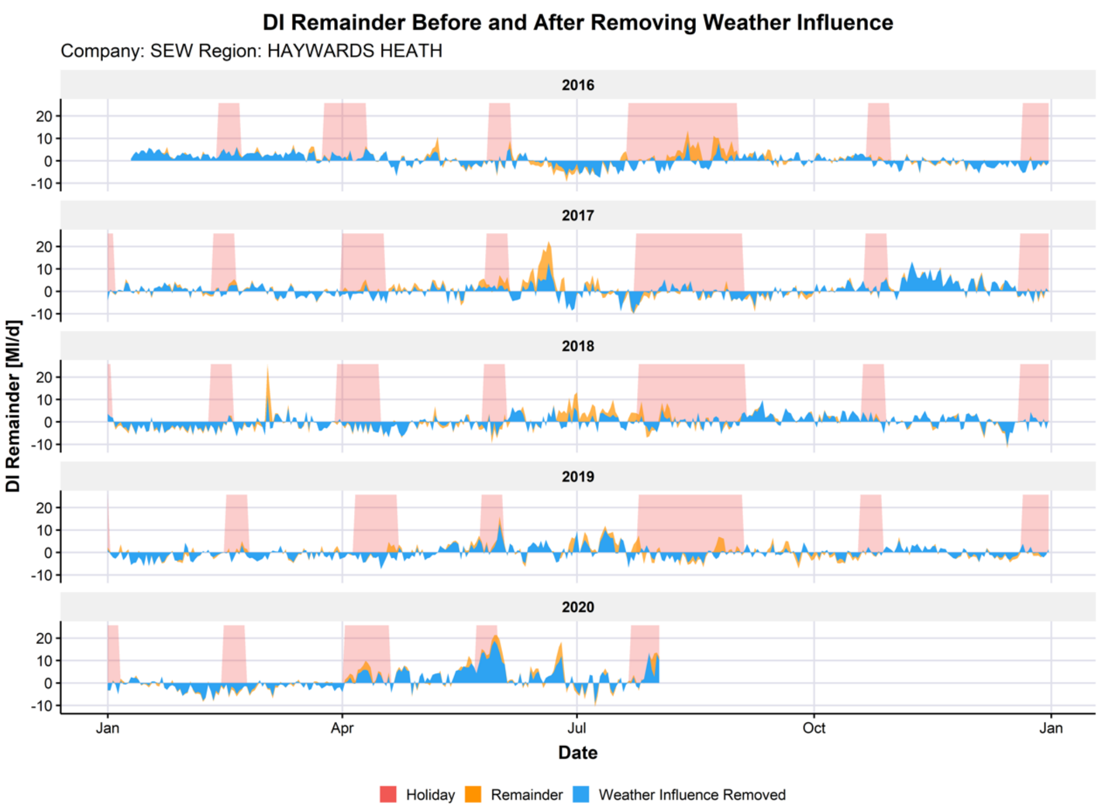


Figure 9 Unexplained DI by WRZ and COVID-19 period



We can quantify the unexplained DI (remainder) through time after removing the influence of weather using the modelling described above. This is shown in Figure 10 where the blue shaded area is the DI remainder after removing the influence of weather. We can see that during April 2020 most of the unexplained DI cannot be explained by weather and is most likely associated with changes due to COVID-19 impacts on society.

Figure 10 DI remainder after removing the influence of weather (blue area)



We have applied this modelling approach to every WRZ for which we have data (there are 103 WRZs, each has been modelled separately). The unexplained DI remainder with the weather influence removed (blue shaded areas in Figure 10) provides us with our best estimate of the impact of COVID-19 polices on DI in each of the WRZs.

Therefore, we can quantify the likely impact of COVID-19 on total demand during each of the COVID-19 timeline stages (see section 3). These results are shown in the next section.

5.2 Distribution input results

We have presented the results from each WRZ on a map of England and Wales using a colour graded scale showing the proportion of the unexplained DI remainder that has had the influence of weather removed (section 5.1.2). This is shown on the maps as a percentage difference in the total DI volume (Ml/d) for each COVID-19 period that is due to COVID-19 policies. Blue shading indicates a reduction in DI, pink shading indicates an increase in DI.

Figure 11 Overview of the impact of COVID-19 on DI from January to October 2020

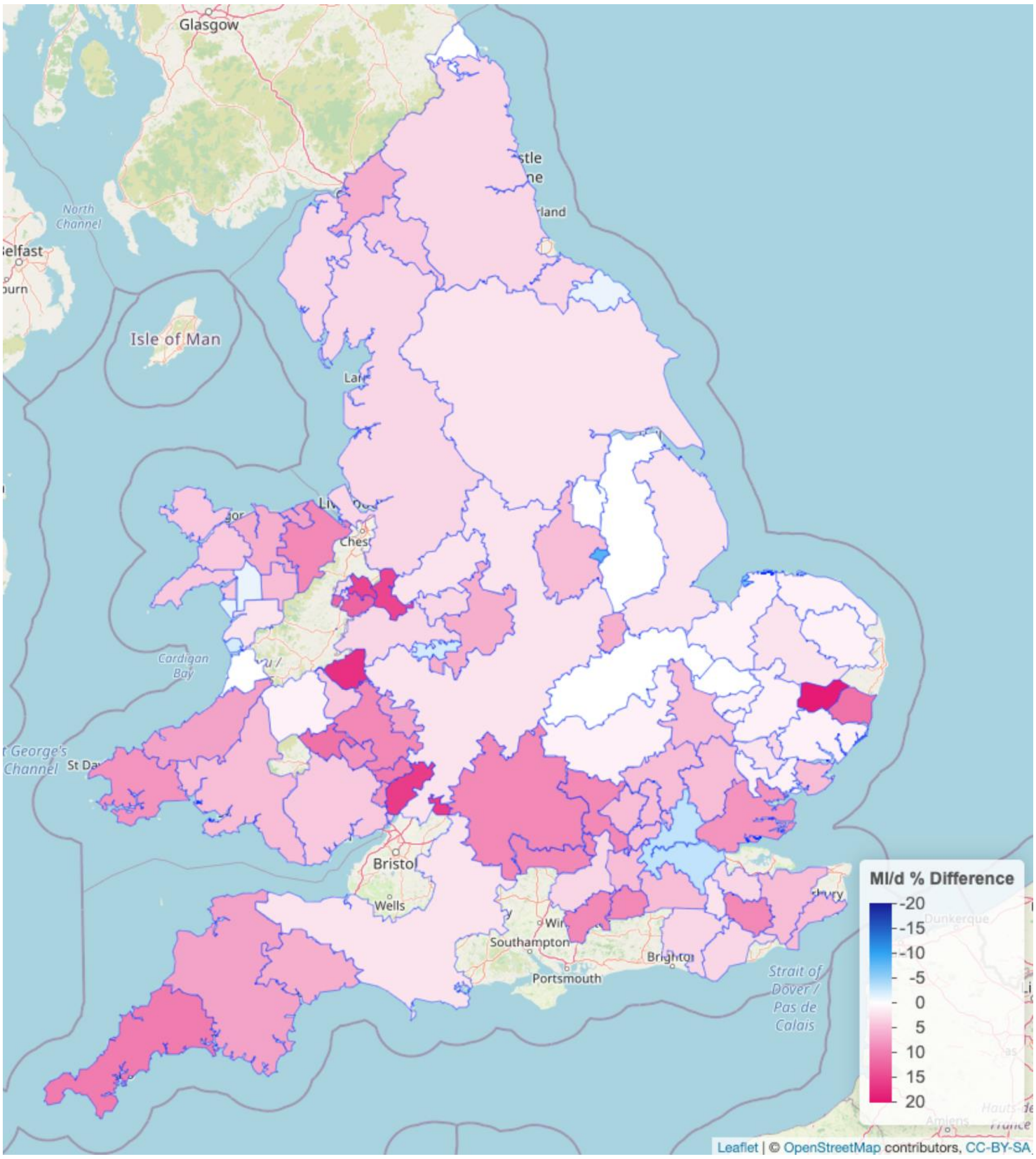


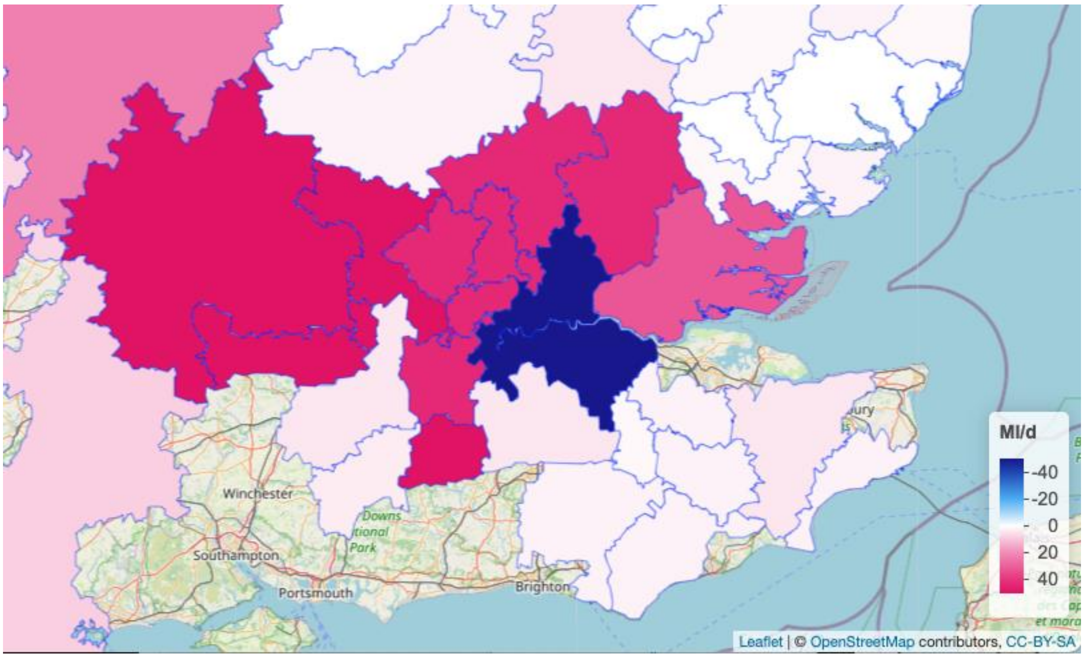
Figure 11 shows the impact on DI from COVID over the period from January to the end of October 2020, i.e. an aggregate of the whole period during which COVID-19 could have impacted total demand (up to the start of the second lockdown). There are some areas for which we have no data and these are left un-shaded.

For the majority of WRZs in England and Wales there is an increase in total demand during 2020 that we believe is due to COVID-19 and the policies implemented to control the spread of the virus. There are some exceptions and these are explained below:

The most notable (due to its geographic size and the change in volume) is London. Referring to Figure 11, we see that London's DI dropped whilst the surrounding areas all increased. In Figure 12 we have presented the WRZ map showing the absolute change in total demand (Ml/d), so the darker colours show the larger total volume change due to COVID. London' total demand decreased by an estimated 50 Ml/d (across this period), whereas all the surrounding areas increased. This is most likely to be due to:

- Fewer people commuting into London for work. This would lead to a reduction in water used in offices and the commercial premises that serve those offices, such as cafes, restaurants, pubs, hotels, entertainment and shopping centres. Those people would be spending their time in other places of residence outside London (increasing consumption in other WRZs where commuters live).
- Students moving back home to study remotely.
- Fewer tourists and day visitors to London.
- Potential a migration of transient workers out of London back to their countries of origin[7].

Figure 12 Increase in total demand (Ml/d) during 2020 to October due to COVID-19 policies



The data underpinning Figure 12 is shown in Table 2; this shows the change in DI due to COVID-19 polices (i.e. over and above the impact we would have expected given the weather in 2020), the total DI for the areas during the same period and the percentage change. There are two further columns that provide the population and the potential minimum increase in PCC (per capita consumption); this last column applies to areas where the change in DI is positive. We know (see section 8) that non-household consumption will have decreased due to the reasons given above, therefore any increase will be due to an increase in household consumption and/or leakage. We know companies have a clear focus on reducing leakage, and whilst there may be some increases in leakage, the biggest increase is likely to be in household consumption. The last column in the table is therefore calculated from the increase in DI divided by the population. It presents an estimate, to illustrate that although the percentage increase in DI is (relatively) small, the increase in PCC is potentially significant.

[7] https://www.escoe.ac.uk/estimating-the-uk-population-during-the-pandemic/

Table 2 Movements in DI in London and surrounding areas

Company / region	Estimated change in DI due to COVID (Ml/d)	Total DI over the same period in 2020 (Ml/d)	Percentage change (%)	Population	Potential minimum increase in PCC (l/head/day)
Thames: London	-60.8	2019	-3.0	-	-
Thames: Other WRZs	+49.8	611	+8.2	2,184,000	22.8
Affinity: Central plus Dour	+46.9	939	+5.0	3,548,000	13.1
SES Water	+12.3	176	+7.0	735,000	16.3
South East Water	+20.4	553	+3.7	2,196,000	9.3

Note: the London area does not have an estimated change in PCC as we believe that the reduction here in DI is largely due to a reduction in non-household consumption. we will see later (section 7) that household consumption in the resident population has increased.

Referring back to Figure 11, we also see some other areas where DI decreases during the COVID-19 period. These include smaller WRZs on the west coast of Wales and in the North East of England. We know from previous work on peak demand during the summer of 2018[8], that total demand in these areas during holiday periods can be dominated by demand from tourism. In the spring and summer periods of 2020, we may be seeing the opposite effect, i.e. the expected tourism is greatly reduced and the impact from COVID-19 policies is to reduce demand during these periods. In smaller water resource zones the reduction during holiday periods can be seen across the extended period of time from January through to October in 2020.

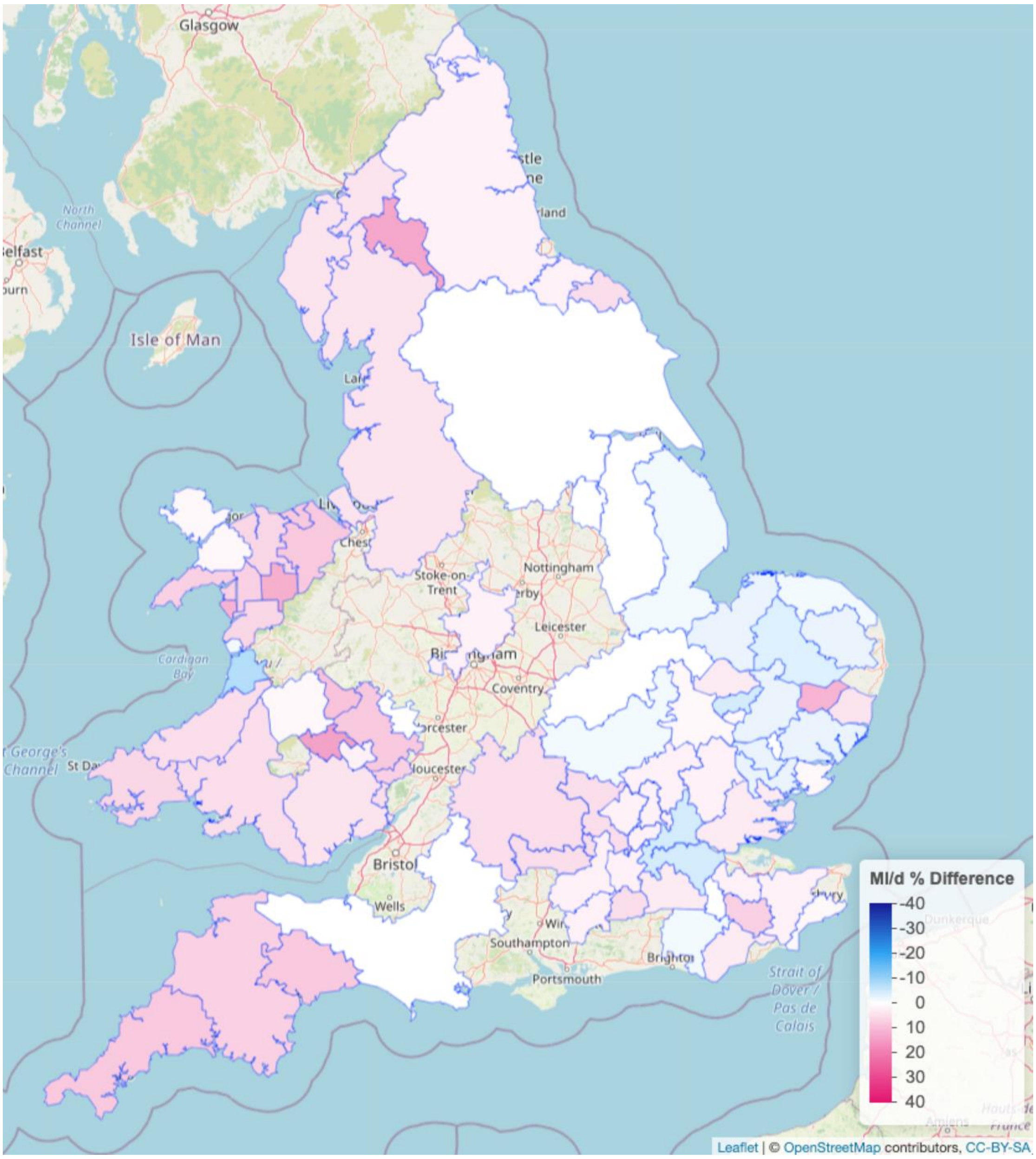
Table 3 provides the values for the percentage change in DI from COVID over the period from January to the end of October 2020 for each company (with the exception of Thames Water, which is split into London and the sum of the remaining Thames Water WRZs). The values represents the impact from COVID over and above the DI we would have expected in 2020 without COVID being present.

[8] Water demand insights from summer 2018 – Final Technical Report. Artesia Collaborative Report AR1313. June 2020.

Table 3 Change in DI summarised at Company level

Company	Change in DI (%) from January to the end of October 2020 due to COVID
Affinity Water	+5.70%
Anglian Water	+0.84%
Cambridge Water	+4.93%
Dŵr Cymru Welsh Water	+4.95%
Essex and Suffolk Water	+7.85%
Northumbrian Water	+2.66%
SES Water	+7.48%
South East Water	+3.82%
South Staffs Water	+5.94%
Severn Trent Water	+2.82%
South West Water	+7.52%
Thames Water – London	-2.94%
Thames Water – Other WRZs	+4.93%
United Utilities	+2.91%
Wessex Water	+2.18%
Yorkshire Water	+1.06%

Figure 13 The impact of COVID on DI during pre-lockdown (16-03-2020 to 23-03-2020)



If we look at Figure 13, which is the impact on DI during the pre-lockdown period (16/03/2020 to 23/03/2020) we see that there is a mixed response, there may be some evidence of changes in DI, but it may just be noise in the data and models, it does however provide a benchmark against which to view subsequent COVID periods.

Figure 14 show the impact on DI during the COVID lockdown 1 period (24/3/2020 to 13/05/2020). There is a general increase in areas around London (as discussed earlier). There is evidence that some of the smaller tourist WRZs in the west coast of Wales, and the North east of England see a reduced DI. Comparing Figure 13 and Figure 14 there appears to be more of an increase in DI in the south than in the north, which may be symptomatic of the greater initial impact from COVID-19 in the south of England. Although the weather was dry for most of this period, it was not excessively hot, and so we would not expect to see much impact from hot and prolonged dry weather.

Figure 14 The impact of COVID on DI during lockdown 1 (24-03-2020 to 13-05-2020)

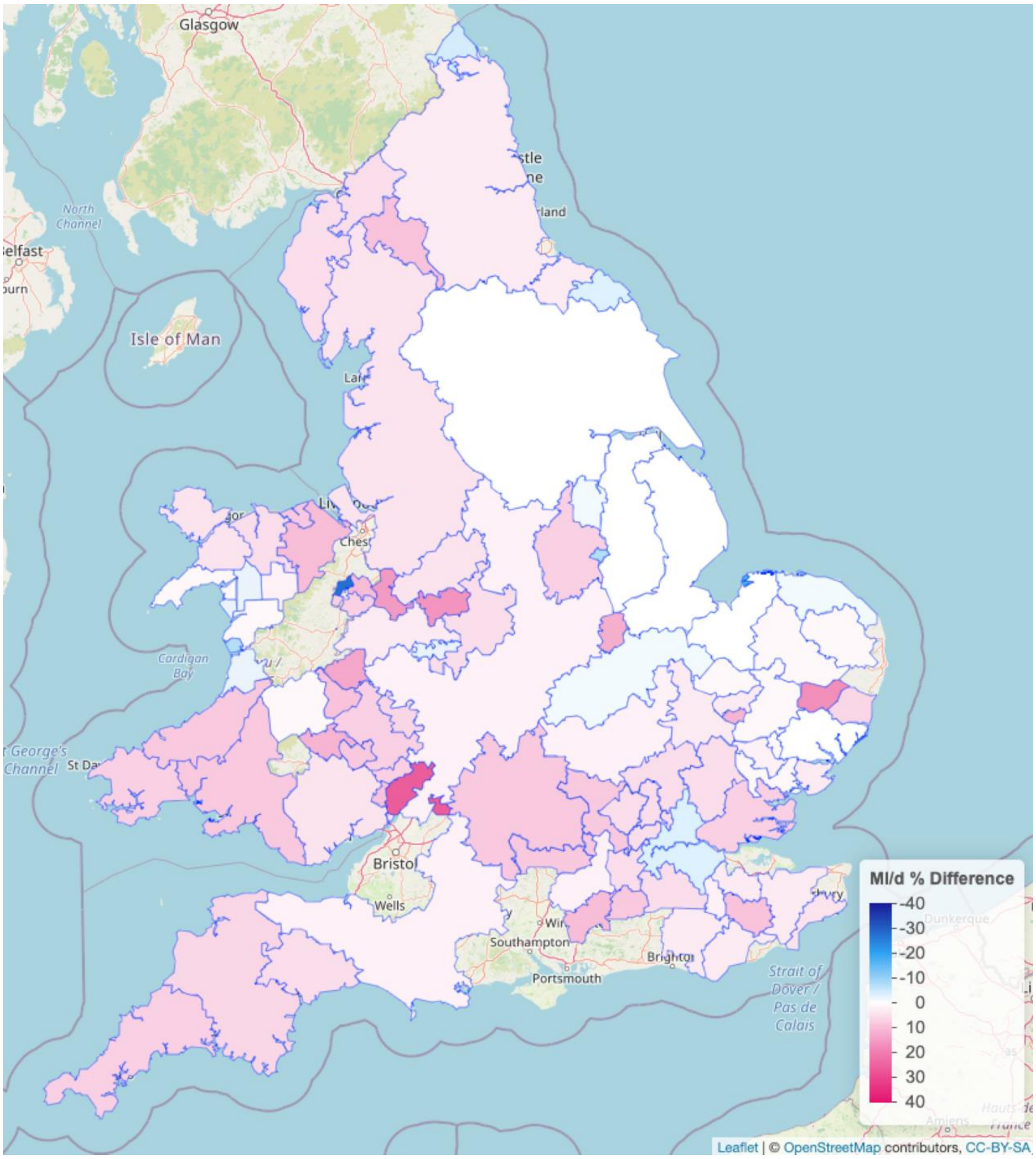


Figure 15 shows the impact on DI during the first easing (13/05/2020 to 2/06/2020). This first easing of restrictions was fairly minor (see Table 1). However, during this period we saw an increase in temperatures at the end of a prolonged dry spell that started at the beginning of April. We see that DI is increased significantly across the whole country, with the exception of London and some of the small tourist zones (although these zones have increased DI compared to the Lockdown 1 period).

The expected influence of weather from pre-COVID behaviours has been removed from this data, and therefore we think this is a combined demand response from weather and COVID policies. This backs up the social science study findings that a change in the value and meaning attached to domestic gardens has fuelled an already growing popular interest in gardening as a leisure activity resulting in a rise in water consumption. This will be explored in more detail in the analysis of household consumption in section 6.

Figure 15 The impact of COVID on DI during easing 1 (13-05-2020 to 2-06-2020)

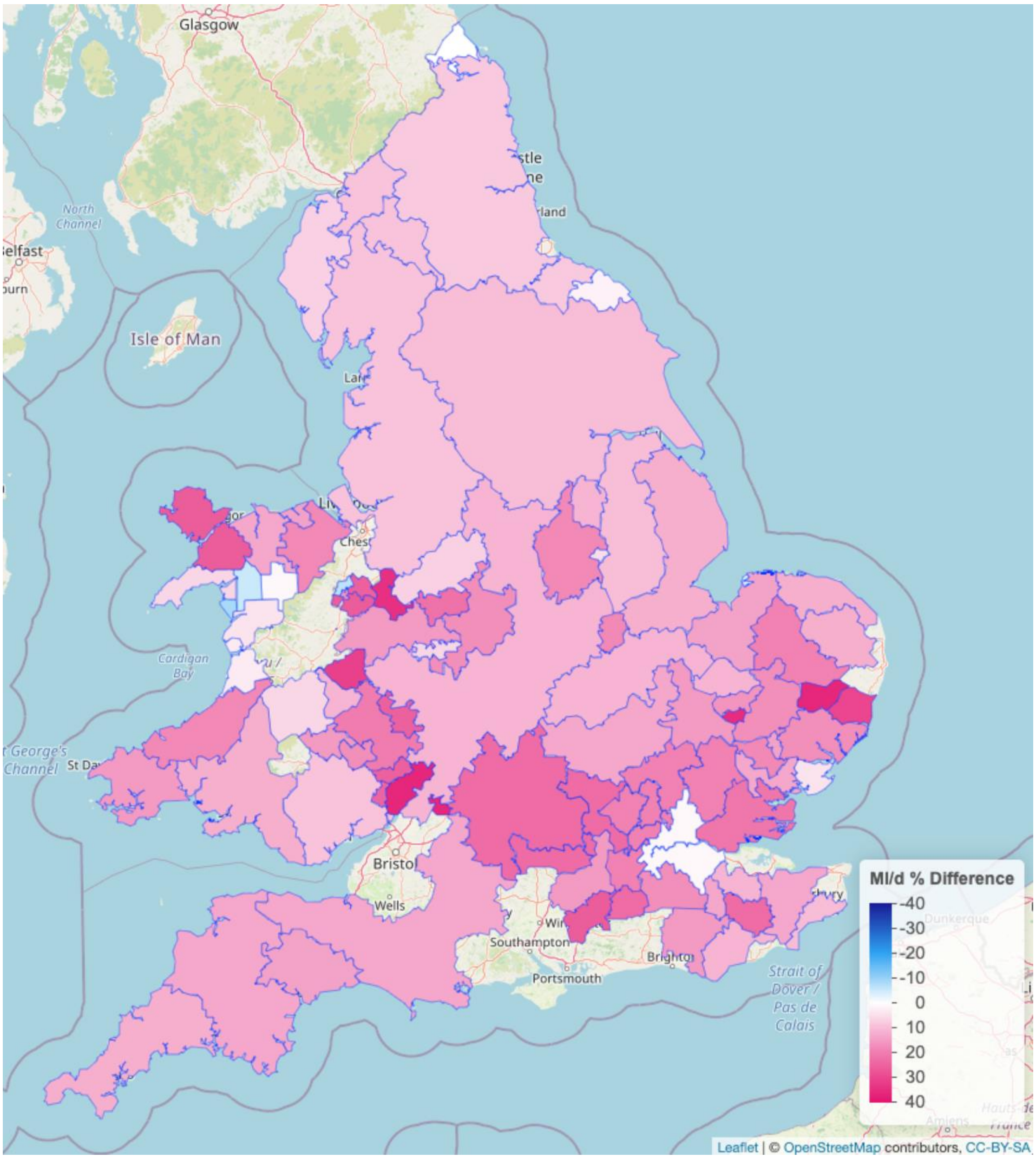


Figure 16 shows the impact on DI during the second easing (2/06/2020 to 15/06/2020). DI is still increased for this time of year across most areas. The tourist WRZs in west Wales and the north east and east of England are showing some significant reductions in total demand, presumably because normally the tourist visitors are increasing at this time of year under normal conditions.

Figure 16 The impact of COVID on DI during easing 2 (2-06-2020 to 15-06-2020)

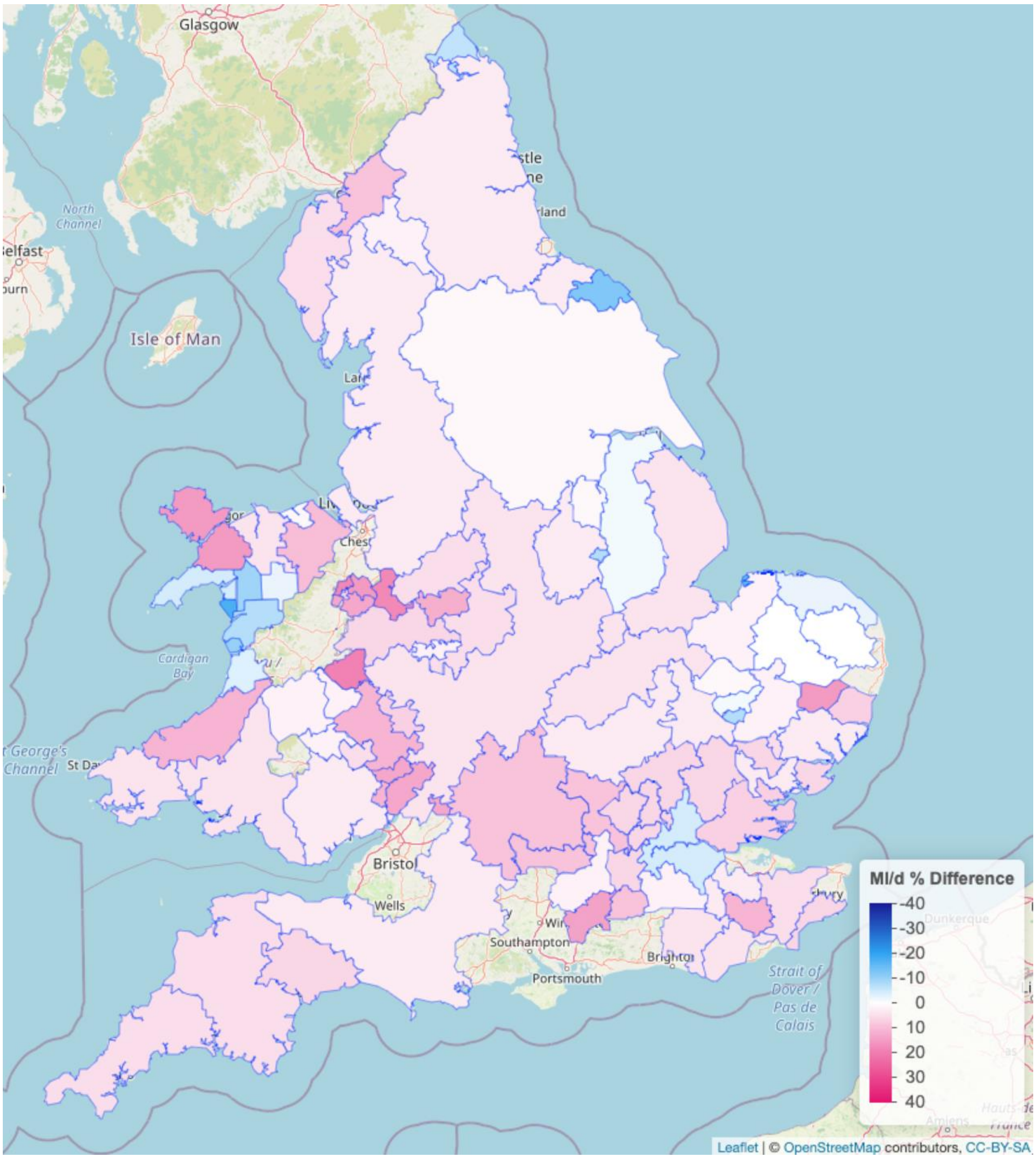


Figure 17 (the third period of easing through the remainder of June) shows a similar picture to the second period of easing, but with more zones showing a lower-than-expected DI, which may be indicative of a wider impact from lack of tourism.

Figure 17 The impact of COVID on DI during easing 3 (15-06-2020 to 4-07-2020)

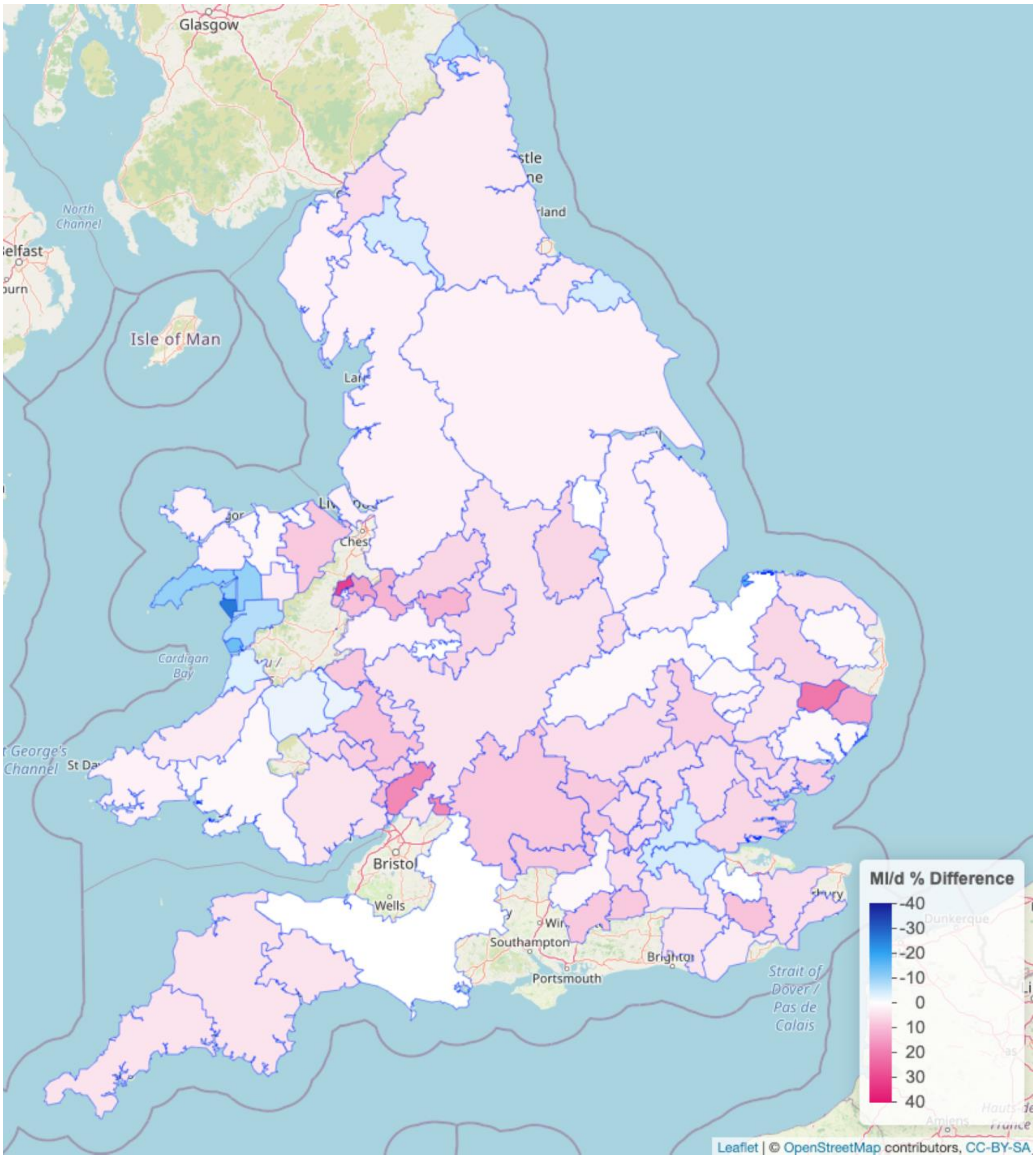


Figure 18 shows the impact from COVID on DI during the 4th period of easing (4/07/2020 through to 22/09/2020). During this period the weather was mixed with a wet and cool July then a very hot and dry August period, followed by a reasonably average September. We also saw the lifting of travel restrictions in Wales, and the introduction of the 'eat out to help out' scheme, all of which encouraged an increase in local tourism. If you contrast the west of Wales between Figure 17 and

Figure 18 it is clear that the DI was depressed during the easing 3 period but has increased during the easing 4 period, which may be indicative of a resurgence of tourism in these areas. Other areas continue to see higher than expected DI, especially in the south of England. London's DI continues to be lower than expected, indicating that commuters and tourism is well below normal levels for this time of year.

Figure 18 The impact of COVID on DI during easing 4 (4-07-2020 to 22-09-2020)

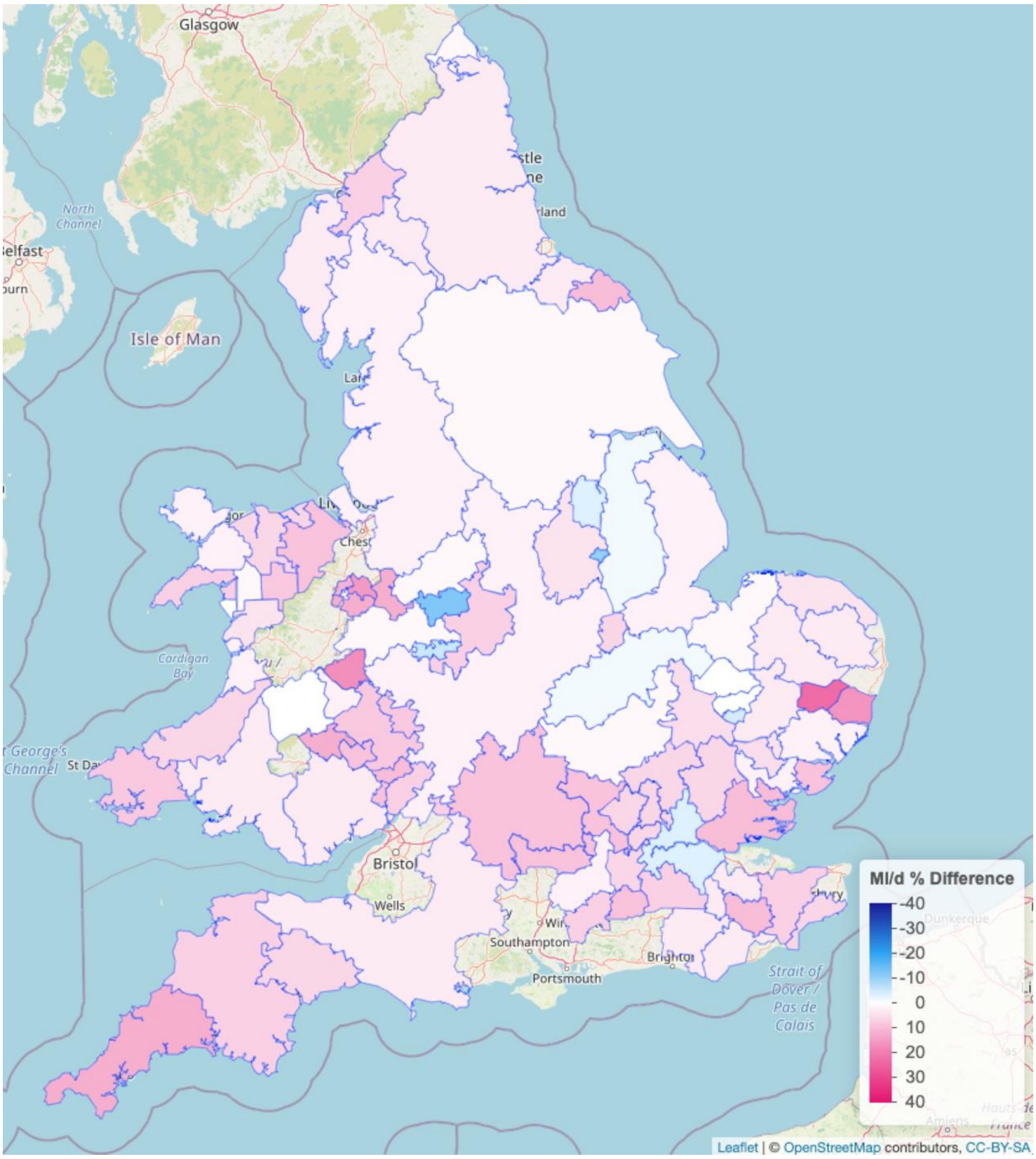
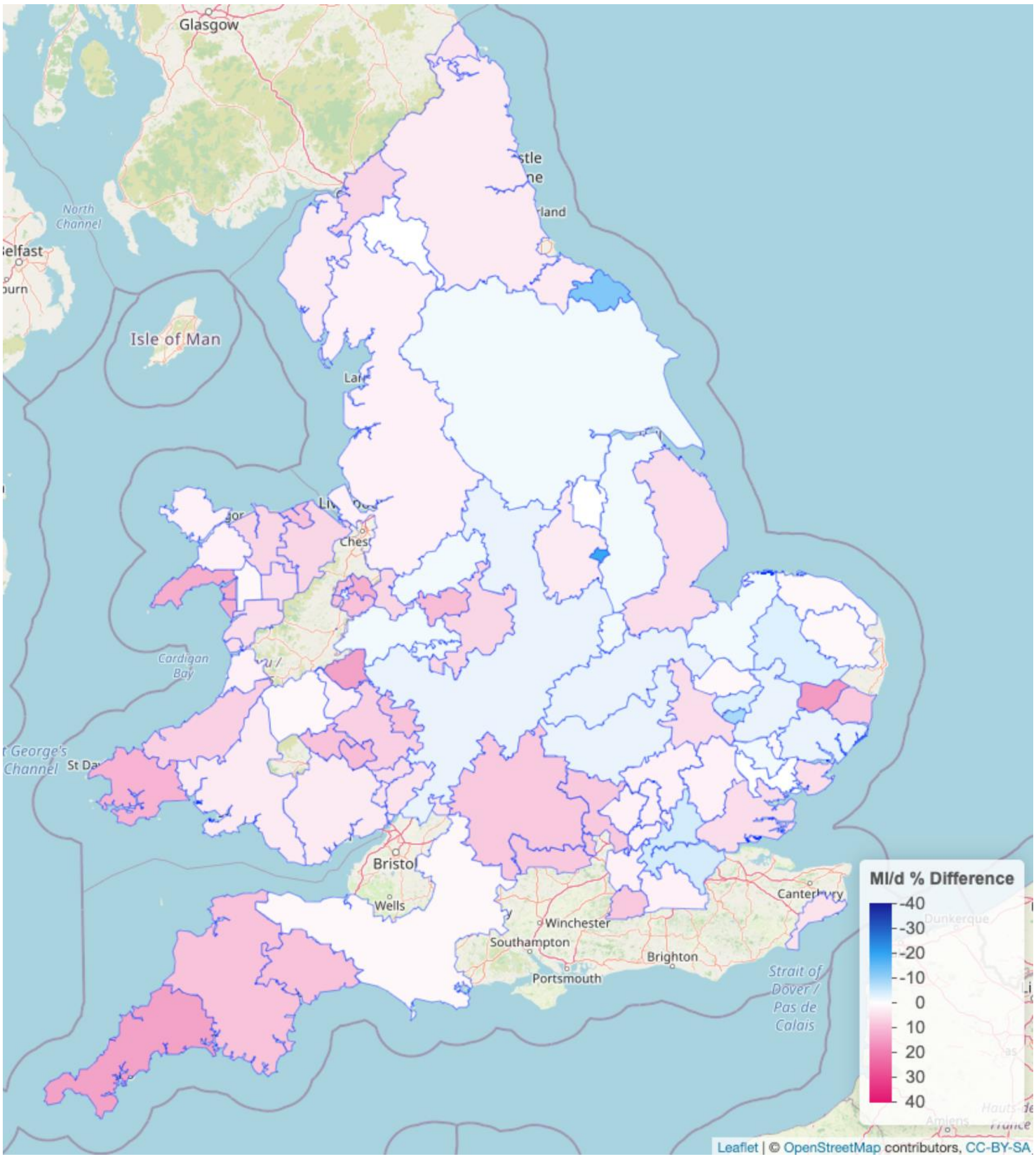


Figure 19 shows the impact on DI during the period when new restrictions started in England, with office workers encouraged to stay at home and restrictions on pubs and restaurants. It was notable in Wales that internal travel and tourism within Wales was permitted and this may be evidence in the increase in DI figures in the west of Wales during this period. London continues to experience lower than expected DI levels, with the continuing message to work at home if possible. Areas around London still show higher than expected DI and this may be the higher number of commuters staying at home in these surrounding areas.

Figure 19 The impact of COVID on DI during restrictions 1 (22-09-2020 to 5-11-2020)



5.3 Distribution insights

For the majority of WRZs in England and Wales there is an increase in total demand during 2020 that we believe is due to COVID-19 and the policies implemented to control the spread of the virus.

There is clear evidence of some areas experiencing lower DI levels than expected.

One area is London which has lower than expected DI during the whole of the COVID period up to the end of October. This will largely be due to commuters and student residents outside London working from home during these periods. This will have a knock-on impact on supporting services such as hospitality and retail premises. There is also likely to be a reduction of tourism into London.

The other areas that show a lower-than-expected DI during COVID are coastal tourist areas with small WRZs. West Wales is a good example of this, and we can see evidence in the sequence of plots through the COVID timeline, where these areas have depressed DI due to lack of tourism, and then DI picks up as travel restrictions in Wales are relaxed.

It is clear that there is an overall increase in DI during the COVID period. We expect that household consumption will have increased as more people are spending more hours in homes each day (as opposed to going to places of employment or education centres). We also expect to see non-household consumption to fall, due to shops closings, people working from home, and commercial premises closing down or putting staff on furlough schemes whilst their business are impacted by COVID control policies.

However, there appears to be a resulting increase in total demand, and evidence that total demand has been 'moved' between water resource zones. It appears that the weather had a compounding impact on increased water use at home, but there may also be other changes of behaviour or water using practices.

The DI data analysed during 2020 (from January through to the end of November) should not have been impacted by any winter breakouts in leakage as the winter months January to March 2020 did not see any extreme freeze thaw events. These were seen in January and February 2021, and any analysis of data in 2021 should take this into account.

We will explore in more detail the impact on water use in the home and in the non-household sectors in sections 7 and 8. But first we take a closer look at total demand at DMA level.

6 Total demand at DMA level

6.1 Data and methodology

We collected data from a range of the collaborators from single feed DMAs. Single feed DMAs are small areas of the network with anywhere between a few hundred and a few thousand properties, that are closed systems with one point of water supply monitored by flow meter sending back data at 15-minute intervals. Therefore, the flow into these DMAs is an aggregate of household consumption, non-household consumption, leakage from the network, and any other water consumed from the network such as the use of fire hydrants etc. We have found that they can provide a consistent data set over time to monitor total demand and can be used to derive information like how much water is consumed by properties at night.

For this COVID study we have used this data to provide a picture of the change in total demand during the COVID period compared to previous years. This gives us a better view of total demand throughout the day from the 15-minute data (as opposed to the daily aggregate flows, we looked at for DI in the previous section).

In this report we are using them to look at how the patterns of flow have changed over time and how they vary from region to region. In the second report we will use some of the areas to look at how night use has been impacted during COVID.

We have developed a way to visualise the flows that can show the changes in flow at a 15-minute resolution for each day over several many years in a single graphic. To do this we first quality check the flows from all the single feed DMAs we want to look at in an area or company. Then we aggregate the flows every 15-minutes and normalise by total DMA property count.

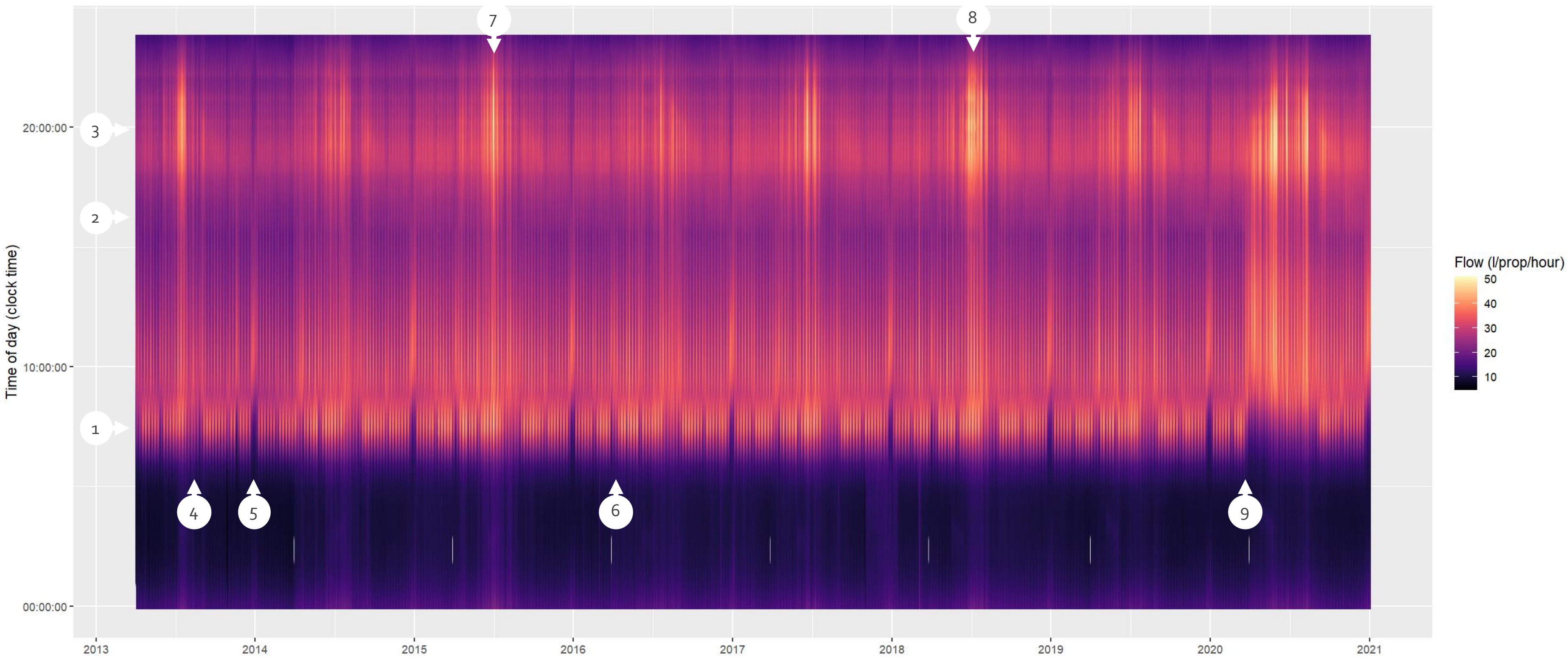
We then create a 'spectrogram' plot which plots flow values for every day along the horizontal axis and time of day up the vertical axis, the scale of the flow is then represented by a colour scale, which in the examples shown in this report range from zero which is black to high flows which are bright yellow. This kind of plot makes it possible to view a huge amount of information quickly and look for changes in the scale and patterns of flow.

6.2 Results

Figure 20 shows an example spectrogram from about 200 of Affinity Water's DMAs which represents about 200,000 households from April 2013 through to the end of December 2020. It shows how consistent network flows are from day to day and year to year with the major influences for changes in patterns being weekdays and weekend, school holidays, Christmas, and summer weather. This set of DMAs contain mostly domestic properties with a few small commercial premises within them. They therefore give a good insight into household consumption patterns.

Figure 20 has a number of labels on it to explain some of the key features visible on the spectrogram. The biggest disruptor to both the scale and the normal patterns of network flows is the start of the COVID period marked by the label "9".

Figure 20 DMA flow spectrogram for approximately 200 DMAs in Affinity Water representing about 200,000 households from 2013 to 2021



1. The typical morning peak in flows.
2. Mid-afternoon is normally lower.
3. There is normally an increase in the evening.
4. Summer school holidays, later morning peak.
5. Flows change dramatically each Christmas.
6. Other school breaks (e.g. Easter).
7. Summer peaks dependent on weather.
8. The peak demand seen in the summer of 2018.
9. Start of lockdown 1

Figure 21 DMA flow spectrogram for approximately 200 DMAs in Affinity Water representing about 200,000 households from 3/12/2019 to 3/01/2021

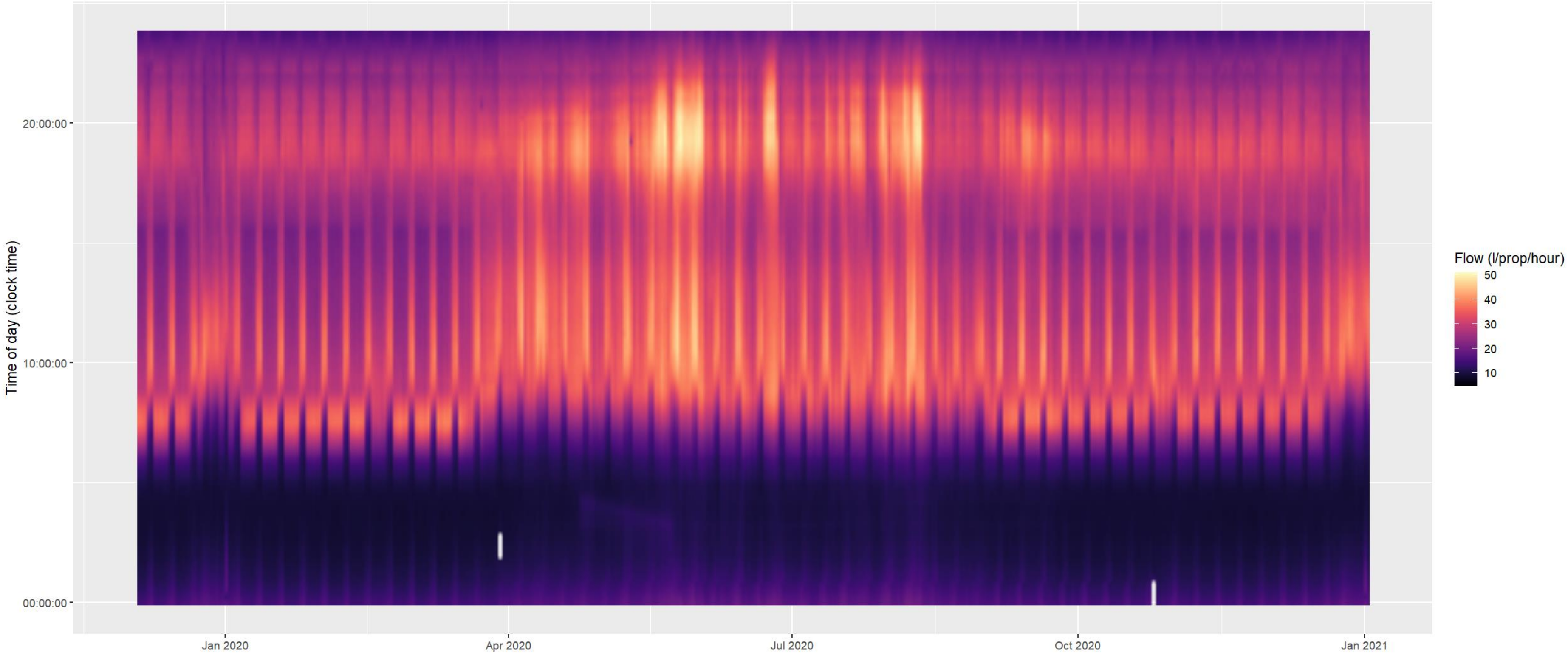


Figure 21 zooms into the past 13 months and shows some of the features in more detail. Pre-COVID (before March 23rd) the regular weekday/weekend pattern can be seen in the morning peak period, also the Christmas / New Year at the end of 2019. After the 23rd March the patterns and scale of water flows change dramatically. Immediately the increase in morning flows starts later in the day, flows are higher through the morning period, and water use is higher in the evening period than in the morning period. As we progress through the summer there are significant peak flows during hot dry periods (referring to Figure 20, these are higher than was seen in the peak summer of 2018).

Figure 21 shows the pre-COVID regular pattern of weekends/weekdays starts to become apparent around the beginning of September 2020 when schools start to reopen. However, during weekdays the flows during the 'working day' (8am through to 5pm) are higher than in pre-COVID times, possibly driven by more people working at home or still on furlough schemes. A greater understanding of why these changes have occurred will emerge in section 7 when we investigate consumption in individual households.

We have collated flows from single feed DMAs from a range of companies and these are shown in Figure 22 for the period from January 2018 through to the end of October 2020. Not all datasets cover the whole period, but all include the period from at least November 2019 through to September 2020. The start of Lockdown 1 is highlighted with the white vertical line. These groups of DMAs are from Affinity Water, Anglian Water, Cambridge Water, Welsh Water, Severn Trent Water and Hafren Dyfrdwy, SES Water, South Staffs Water, Wessex Water and Yorkshire Water. The flow data has been normalised to allow direct comparison between the different areas.

There are a lot of similarities during the pre-COVID period, notably the impact of the peak summer weather in 2018, the Christmas breaks, the regular weekday/weekend patterns. After the start of lockdown, all areas show similar changes in patterns of flow. The scale of the changes in flows are different. All show responses to hotter drier weather around May, although we start to see a more muted response through August in some areas, particularly in the north, which corresponds to some of the regional variations we saw in the DI data. The biggest response is seen in SES Water, which always shows a strong response to summer weather.

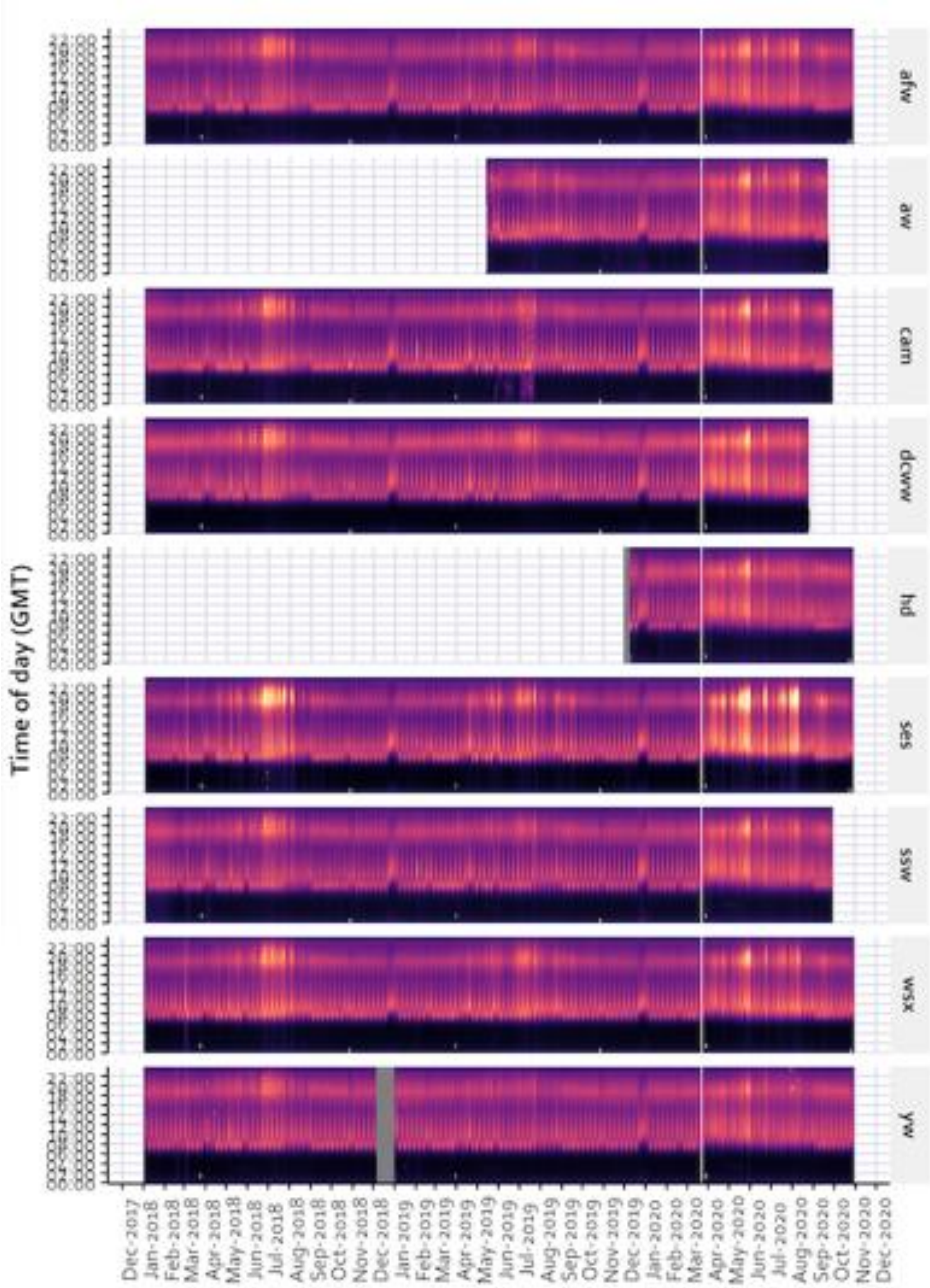
6.3 DMA insights

The analysis of the DMAs shows during the pre-COVID period how consistent network flows are from day to day and year to year with the major influences for changes in patterns being weekdays and weekend, school holidays, Christmas, and summer weather.

Post COVID-19, after the 23rd March 2020, the patterns and scale of water flows change dramatically. Immediately the increase in morning flows starts later in the day, flows are higher through the morning period, and water use is higher in the evening period than in the morning period. As we progress through the summer there are significant peak flows during hot dry periods (higher than was seen in the peak summer of 2018).

We see similar patterns across DMAs from different geographic areas of the country: south, east, west and north, showing that the total demand in these areas has been increased during extended periods of the COVID-19 pandemic. There are regional variations in scale of increases in demand, with some of the highest impacts in the south east, which may be related to higher residential population density, plus warmer and drier weather. We need to drill down into the individual components of consumption (domestic and non-household) to understand why we see these increases, which we will do in the next two sections.

Figure 22 Spectrograms of DMA total demand from different regions



7 The impact on daily household consumption

7.1 Household consumption analysis methodology

Data was checked using the following quality assurance process:

- The format of data was checked for consistency.
- The presence of duplicates, negatives, and incomplete records was checked.
- Ensured all selected meters were reporting at the same intervals (1-hour or 15-minutes)
- Checked the minimum and maximum datetimes available for the complete dataset and evaluated the number of meters that were reporting per day.
- Evaluated the number of records that were available and ensure that this was representative of the period under analysis.
- Evaluated the missing values for each time series, and the size of gaps.
- Imputed missing values where necessary to fill short periods of missing data.
- Evaluated the presence of continuous flows and removed data which potentially contained customer supply pipe losses (note there was a risk that some properties with internal plumbing losses could have been removed).

Figure 23 Household consumption datasets evaluated in the QA process

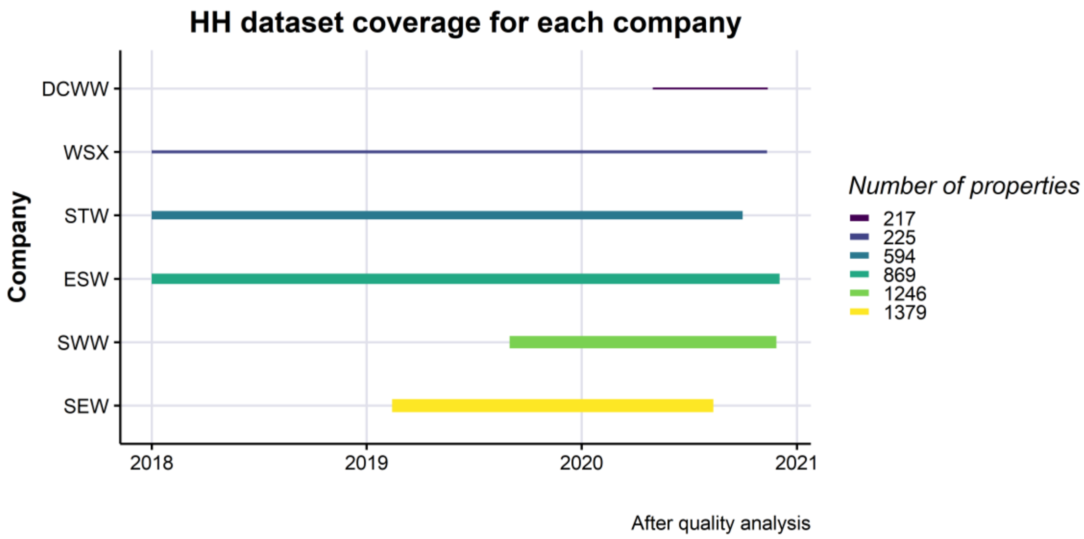
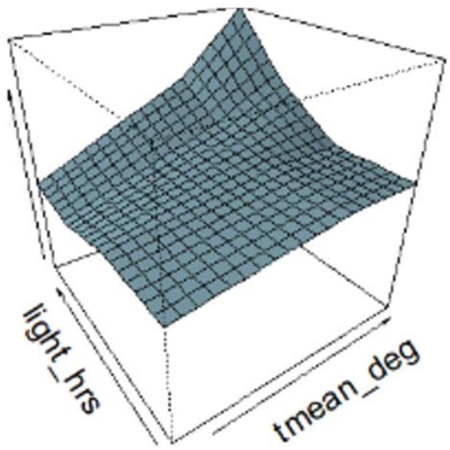


Figure 23 shows the datasets that were assessed for this report. In order to be able to evaluate the increase in per household consumption (PHC) due specifically to COVID-19 policies, we were particularly interested in removing the influence of weather-related increases PHC. i.e. increases in PHC that would have been observed under normal conditions in 2020. In order to do this we required sufficient consistent data prior to 2020. From the datasets above we selected household data from Wessex, Severn Trent and South East Water for the analysis in this report.

We have also been provided with results that Thames Water have carried out on their smart metered households in the London area, and this is also included in this section.

For the Wessex, Severn Trent and South East data we have been able to build a pre-COVID consumption model to predict the level of household consumption that we would expect to have seen with the observed weather conditions. To do this we have built pre-COVID models using Multivariate Adaptative Regression Splines (MARS). This is a form of regression analysis with the advantage that we can capture non-linear relationships and the interaction between variables automatically. The interpretation of the outputs from the MARS model, such as the interaction and the non-linear relationships are intuitive. For instance, the plot in Figure 24 shows the PHC response based on the interaction between the terms "Hours of light" and "Average temperature"; where we can see that the increase in PHC reaches the highest point for a specific combination of these two terms.

Figure 24 Example of the interactions in a MARS model



The terms in the resulting regression models for SEW, Severn Trent and Wessex models are shown in Table 4.

Table 4 Household consumption models

Company household model	Regression terms
South East Water	Maximum temperature Hours of light Rain Weekend flag Bank holiday flag
Severn Trent Water	Weekend flag Weekday Sunday Maximum temperature Rainfall Hours of light
Wessex Water	Mean temperature Maximum temperature Rain Hours of light Ramadan flag Weekend_flag

7.2 Household consumption results

We apply the pre-COVID models to each dataset and predict the daily per household consumption (PHC) to the observed post-COVID model variables in Table 4, and then compare the predicted PHC (under pre-COVID behaviour) to the PHC observed during the COVID periods.

Figure 25 and Figure 26 show the results for Severn Trent Water. Figure 25 presents the expected (modelled) PHC in orange and the observed PHC in blue. This clearly shows an increase in PHC immediately after lockdown starts that extends to the start of Easing 2 when the difference decreases, but is still above that expected.

Figure 25 Observed vs modelled PHC for STW

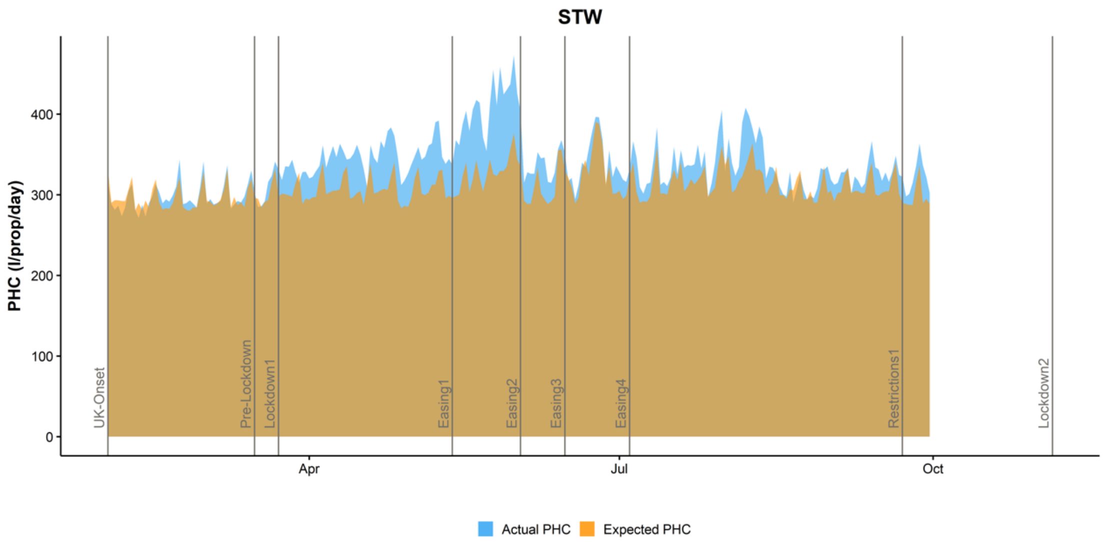


Figure 26 Change in PHC due to COVID-19 during each lockdown period for STW

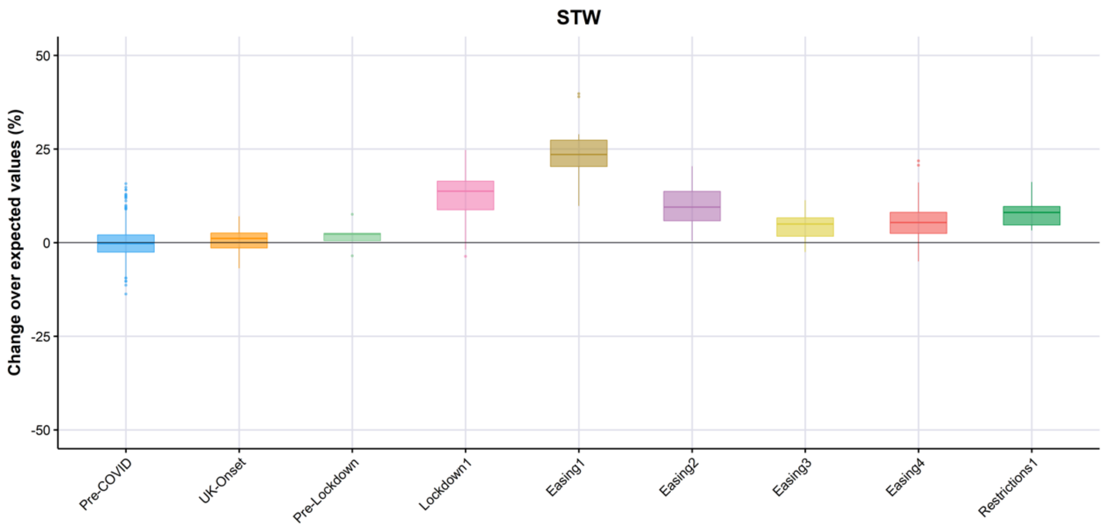


Figure 26 shows the percentage change in PHC for each of the COVID-19 periods, showing the mean increase with the horizontal line, the interquartile range with the box, and extreme values with vertical lines and dots. The peak increase is during the first easing when lockdown measures were mostly still in place and we had a hot and dry period, and the increase was about 24%. Lockdown was the second highest period at about 12% and easing 2 was at 10%. Across the period to easing 4 the PHC has increased by about 7.8%.

Figure 27 and Figure 28 show the results for South East Water. Figure 27 presents the observed PHC against the modelled, and the pattern is similar to that seen in STW (Figure 25). Interestingly, South East Water also shows some increase in PHC during the pre-lockdown period.

Figure 27 Observed vs modelled PHC for SEW

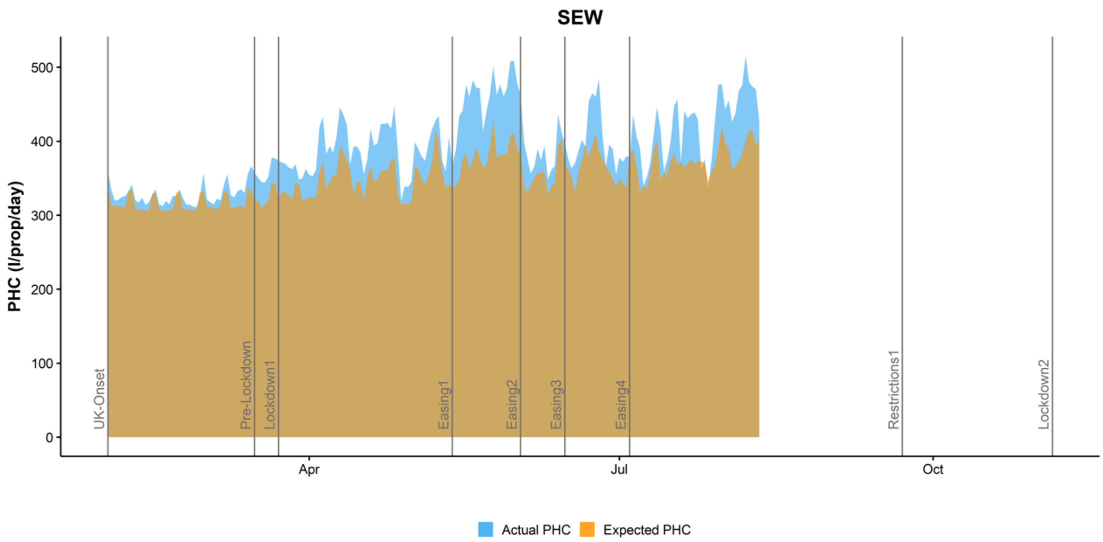


Figure 28 Change in PHC due to COVID-19 during each lockdown period for SEW

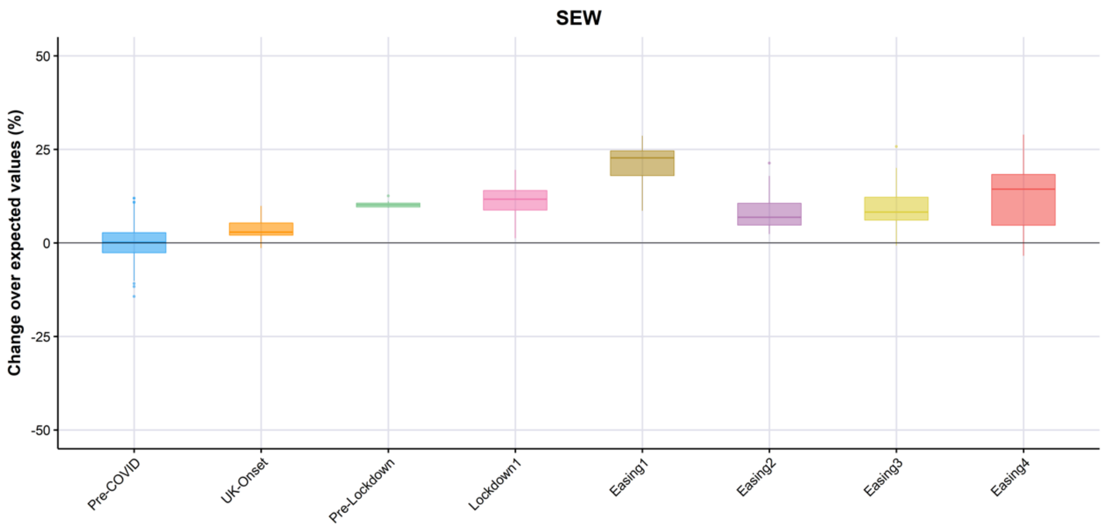


Figure 28 shows the percentage change in PHC for each of the COVID-19 periods. The peak increase is again during the first easing when lockdown measures were mostly still in place and we had a hot and dry period, and the increase was about 21%. Lockdown was the second highest period at about 12% and the easing 4 at 12%. Across the whole period PHC has increased by about 10.6%.

Figure 29 and Figure 30 show the results for Wessex Water (WSX). Figure 29 presents the observed PHC against the modelled, and the pattern is similar to that seen for the previous two companies.

Figure 29 Observed vs modelled PHC for Wessex Water

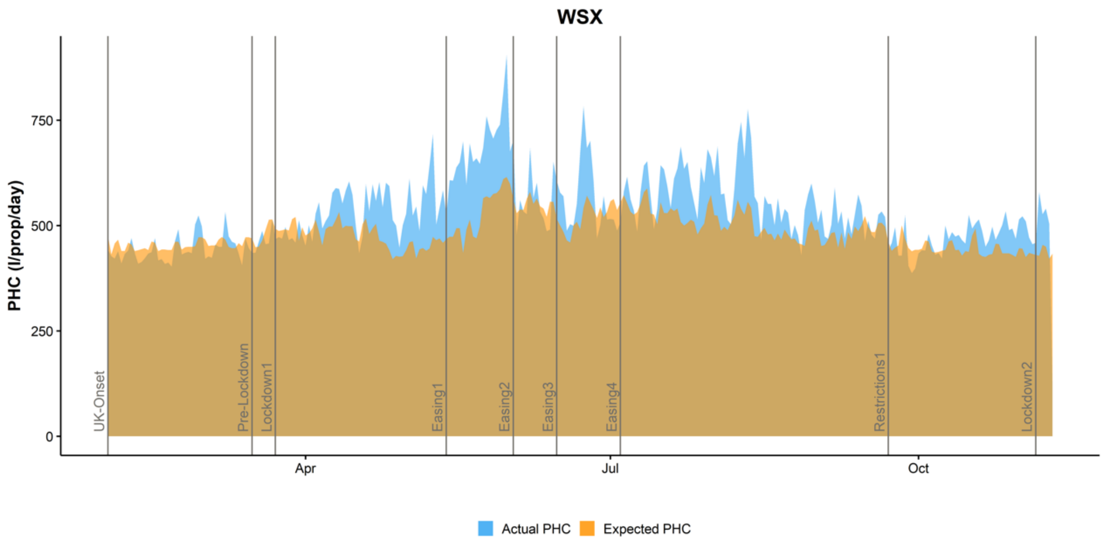


Figure 30 Change in PHC due to COVID-19 during each lockdown period for Wessex Water

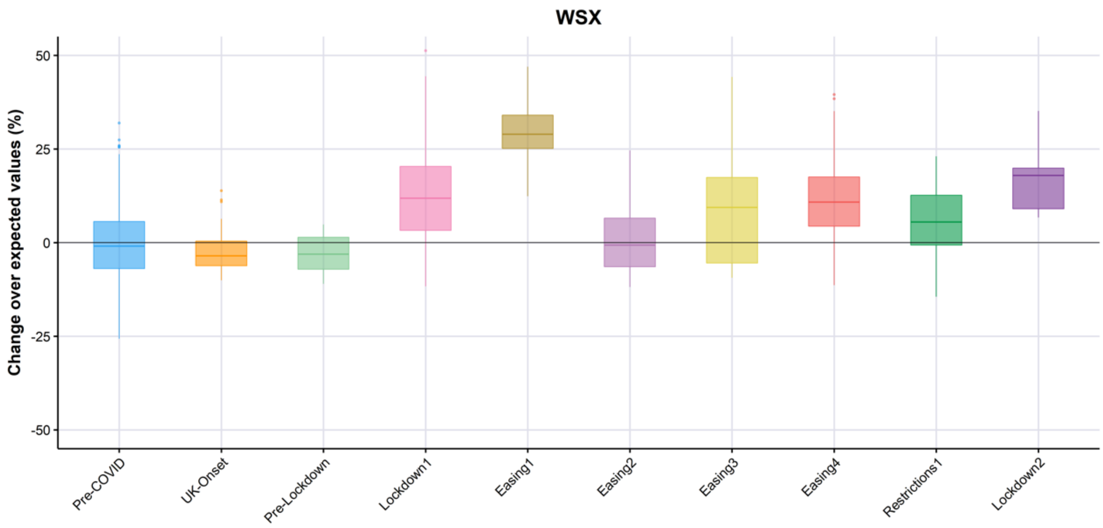


Figure 30 shows the percentage change in PHC for each of the COVID-19 periods. The peak increase is again during the first easing when lockdown measures were mostly still in place and we had a hot and dry period, and the increase was about 30%. Lockdown was the second highest period at about 12% and the easing 4 at 11%. Across the period to Easing 4 the PHC has increased by about 9.7%. This dataset has data extending through Restrictions 1 to early November and during this period the increase in PHC is about 5.6%.

Despite the geographical separation of the three areas, the patterns and scale of PHC changes due to the COVID-19 policy periods is fairly consistent. There is a slight difference in the scale of the increase during the driest and hottest period (Easing 1), 21%, 24% and 30%. Only South East Water shows significant increase in PHC during the pre-lockdown period and this may be due to commuters who normally travel into London staying away during the early COVID period as London was the first city to see COVID spreading. Table 5 shows the mean increases for each of the three areas during the COVID periods.

Table 5 PHC changes during each of the COVID-19 periods for STW, SEW and WxW PHC monitors

	Change in PHC (%)		
COVID phase	**Severn Trent**	**South East**	**Wessex**
Pre-lockdown	1.7	10.4	-3.0
Lockdown 1	12.5	11.5	12.7
Easing 1	24.3	21.1	30.3
Easing 2	9.9	9.1	2.4
Easing 3	4.2	9.5	9.3
Easing 4	5.7	12.2	11.4
Restrictions 1	8.1	-	5.6
Lockdown 2	-	-	3.8

Next, we look at the changes in PHC through the COVID-19 periods for different property types. We have this data from the Severn Trent and South East datasets, along with data from Thames Water from their smart meter data.

Figure 31 shows the observed PHC against the modelled PHC for each property type for Severn Trent, and Figure 32 shows the same for SEW. The property types with least change in both areas are 'flats', although they also show increases through the COVID period. The other property types show much bigger differences, and this may be due to the number of occupants and the presence of gardens, which we will look at next.

Figure 31 Observed vs modelled PHC for STW by property type

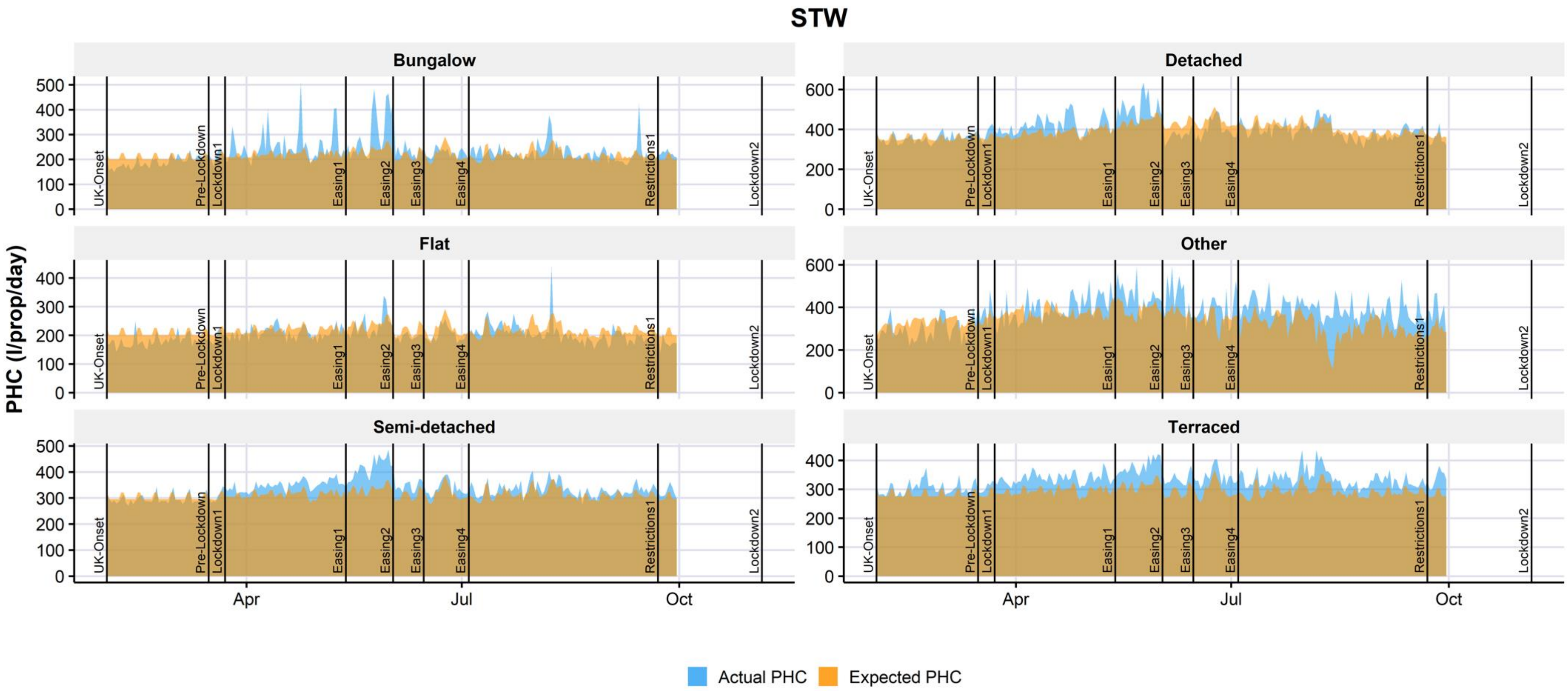
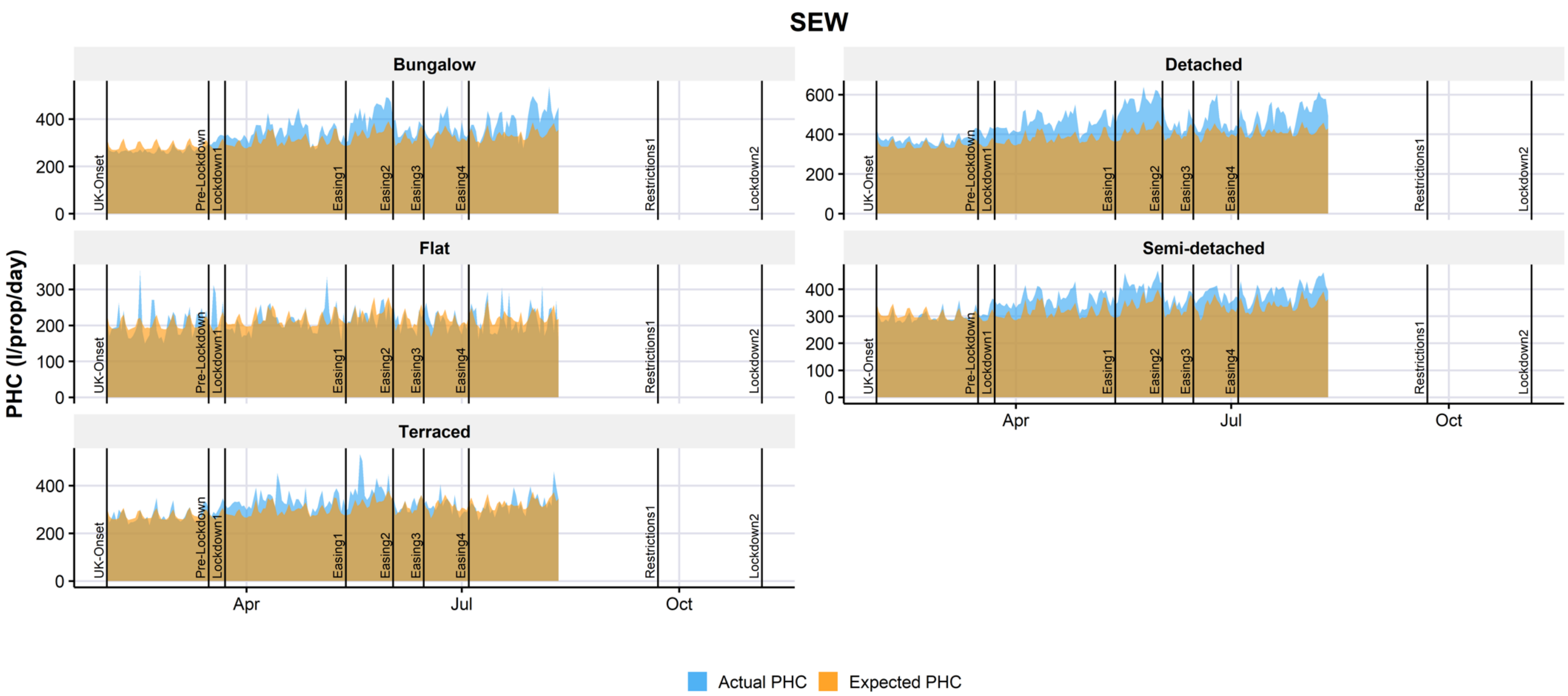
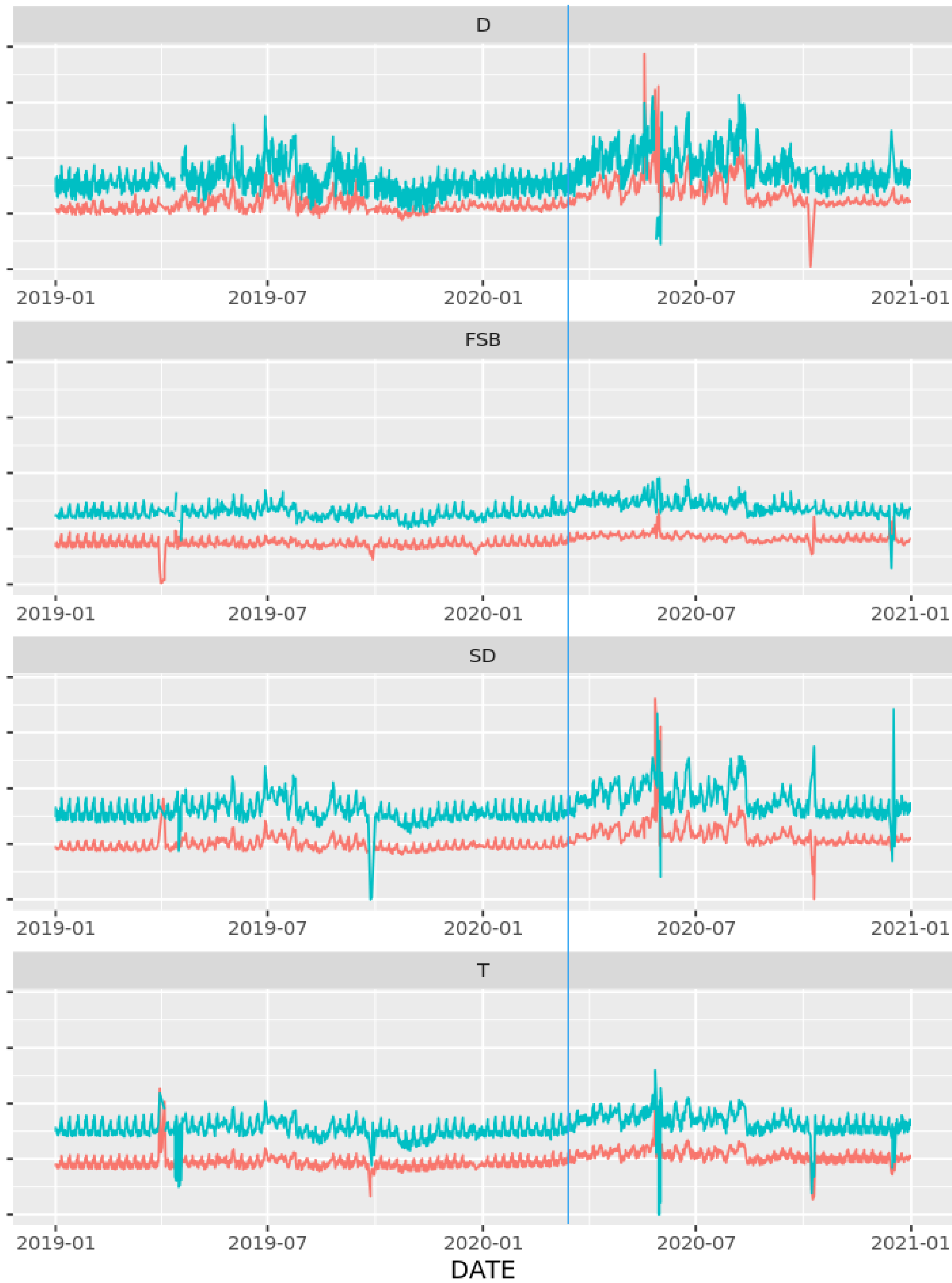


Figure 32 Observed vs modelled PHC for SEW by property type



Thames Water were also able to supply analysis from about 150,000 smart metered properties in the London area. This data provided (Figure 33) shows consumption from 2019 and 2020 for smart metered properties paying on a metered bill (red line) and smart metered properties paying on a rateable value bill (green line). Data is presented at daily household level for detached (D), small blocks of flats (FSB, typical buildings with 6 or less flats), semi-detached (SD) and terraces (T). The blue line marks the start of lockdown.

Figure 33 Change in PHC by property type from 2019 to 2020 from smart meter data in London



A similar pattern is seen in Thames Water to the other areas (Severn Trent and South East) in that the largest increases in PHC are seen in detached and semi-detached properties during the COVID period. However, household consumption has increased across all property types including flats. This is an interesting observation, given that the distribution input data (section 5.2) shows that total demand in London decreased. This suggests that the resident domestic population in London have increased their consumption during lockdown like other areas of the country and that it is the non-household or commercial sector driving the consumption down in London.

We then start to look at how the consumption varies during the day in households. Figure 34, Figure 35 and Figure 36 show how patterns of consumption changed. The graphs show the change for weekdays (top row) and weekends (bottom row) and show the impact during each of the COVID phases. Each graph shows the consumption in litres/prop/hour across the day, with orange areas showing an increase, and blue areas showing a decrease. We need to do the comparisons of the observed data in 2020 against 2019 as we do not model consumption at hourly intervals.

We see a clear change in patterns of use after lockdown starts with more water being used through the day with the morning peak becoming less dominant. The biggest changes are during easing 1 as expected given the increase in PHC, and during this period we see the evening peak during weekdays becoming the dominant peak (in all three areas), suggesting outside use is a driver.

We see the increase in use through the day extending through to the end of the data period in November for weekdays and weekends.

Figure 34 Analysis of consumption changes during the day at COVID periods - STW

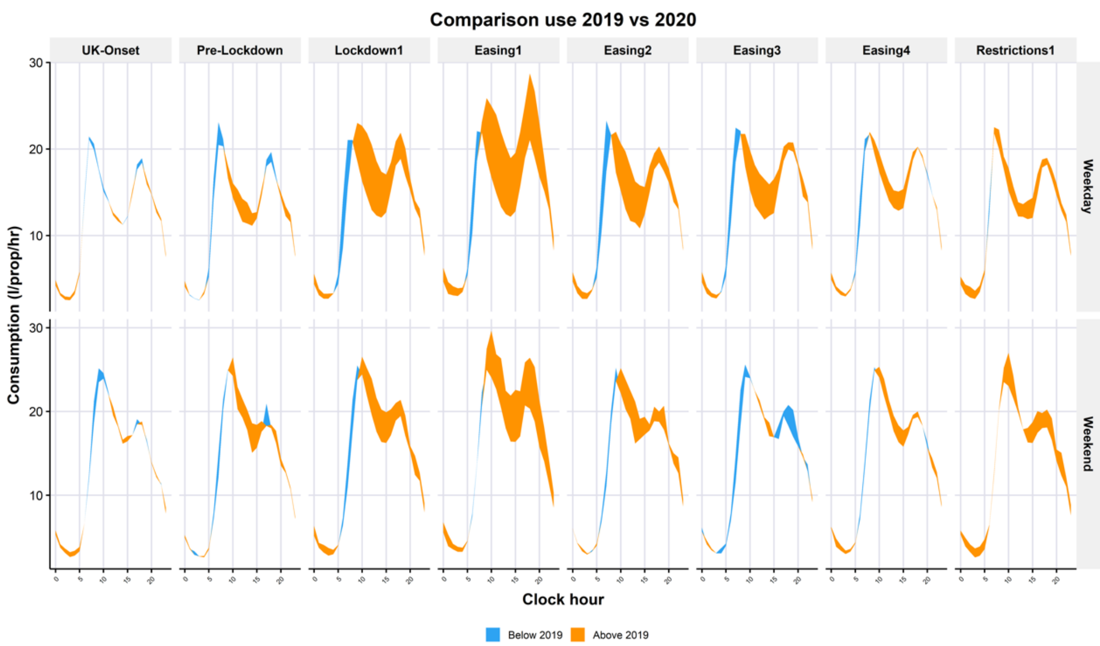


Figure 35 Analysis of consumption changes during the day at COVID periods - SEW

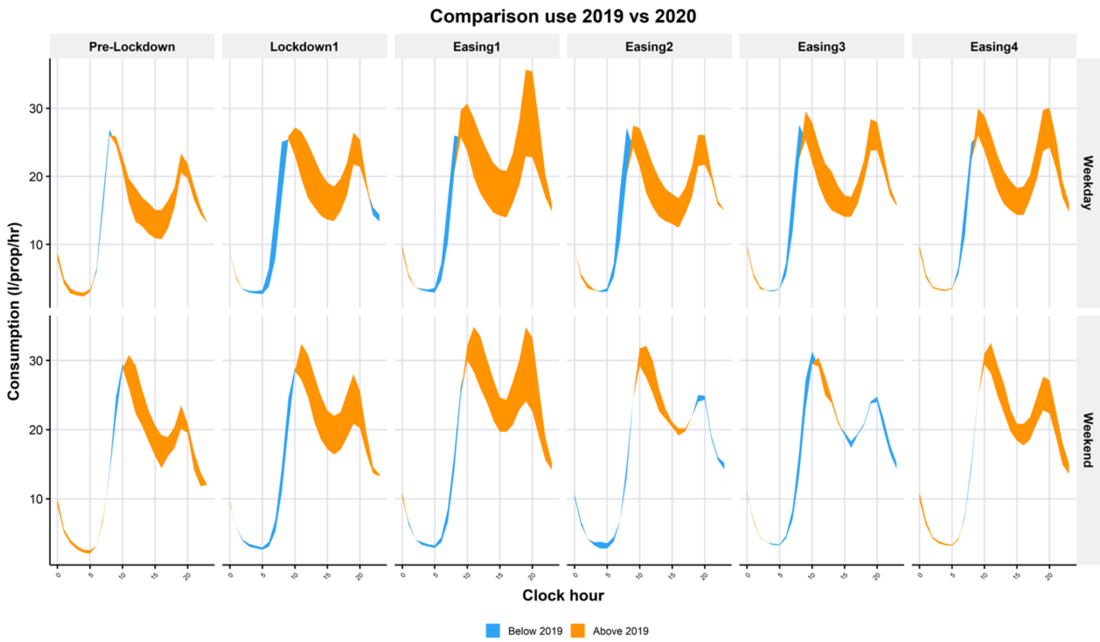
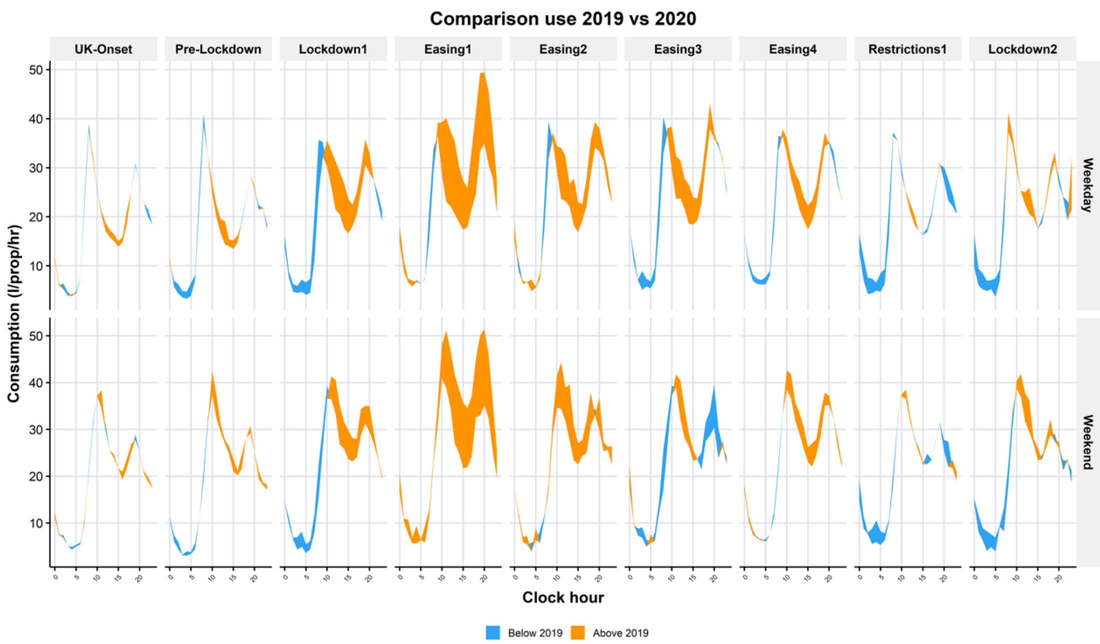


Figure 36 Analysis of consumption changes during the day at COVID periods- WxW



We can use the sub-daily flows to differentiate between internal use (water use by appliances and taps within the home) and external use (water use in the garden plant watering, filling of paddling pools, etc.). We were able to do this for the monitors in Severn Trent, South East and Wessex, and these are shown in Figure 37, Figure 38, and Figure 39. In these graphs the top line is external use (blue) and the bottom line is internal use (orange). Again, we need to do the comparisons of the observed data in 2020 against 2019 as we do not model consumption at hourly intervals. Data from 2019 is in the light shaded columns, and 2020 in the dark shaded columns.

Figure 37 Analysis of internal use and external use during COVID periods - STW

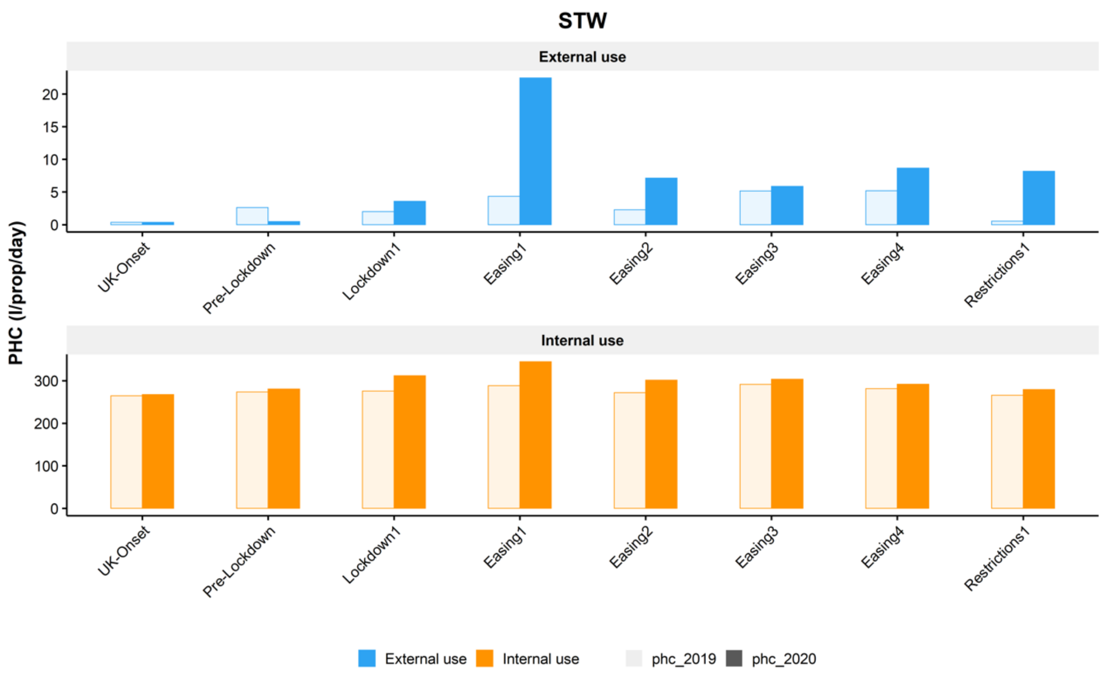


Figure 38 Analysis of internal use and external use during COVID periods - SEW

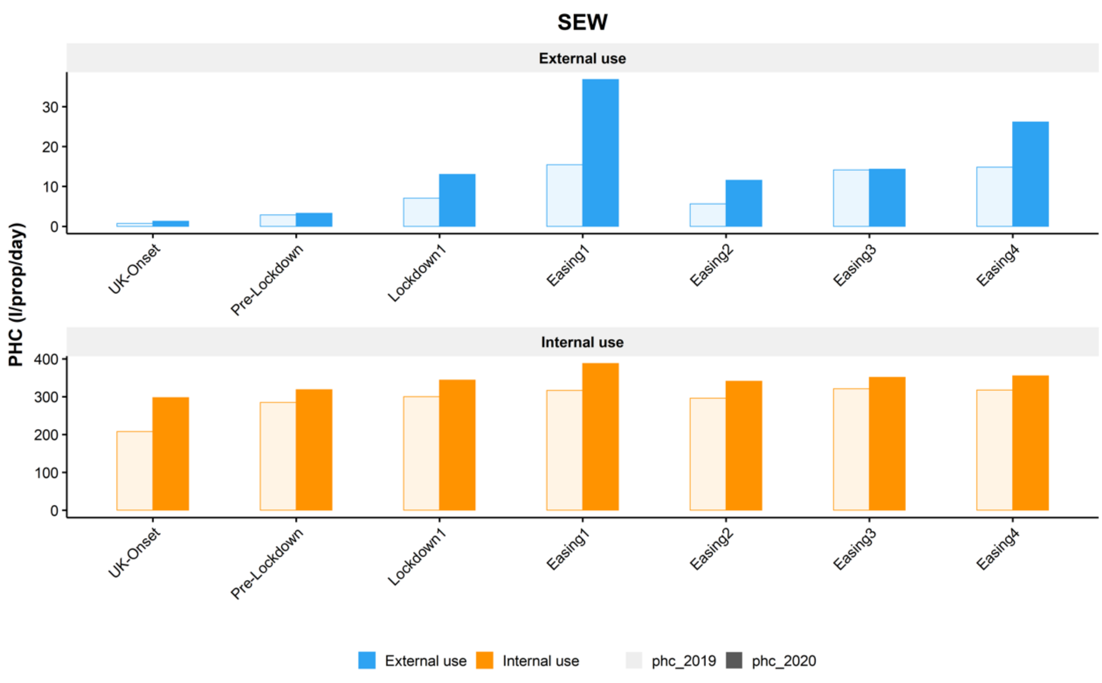
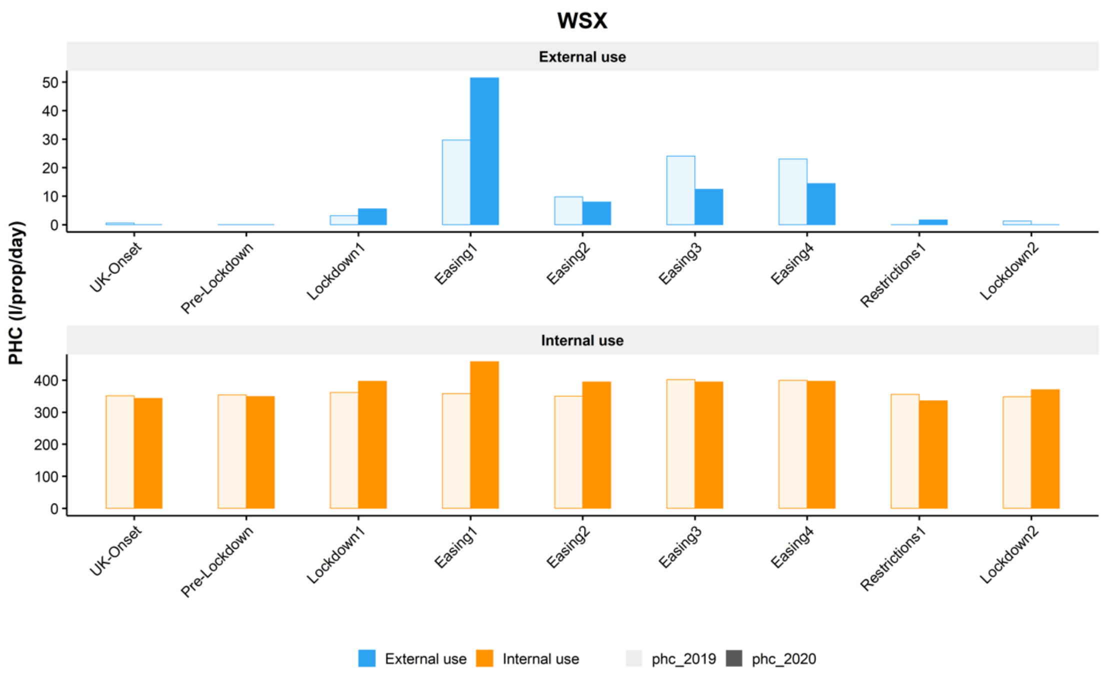


Figure 39 Analysis of internal use and external use during COVID periods - WxW



We start to see some differences between the regions. All three areas show a clear increase in external use during the easing 1 period (the second half of May) when there was an extreme hot and dry period. Severn Trent and South East show increased external use through more of the easing periods. Wessex Water's outside use is not increased during these periods, and this may be because of a warm, dry late summer period in this area in 2019.

In all areas there is also increased internal use during the COVID-19 periods, most pronounced for South East Water, which may be driven by a greater proportion of commuters working from home or more furloughed staff staying at home. All areas would have seen school children staying at home during this period.

7.3 Scenario modelling of the impact on PHC due to COVID measures

7.3.1 Scenario definitions

A set of scenarios were defined using COVID indicators that have proven to be relevant to model household consumption, from the Oxford COVID-19 Government Response Tracker[3]. These are shown in Table 6.

Table 6 Variables used to define the scenarios for different COVID futures

Indicator	Level of application	Description
Schools closing	0	No measures
	1	Recommend closing or all schools open with alterations resulting in significant differences compared to non-Covid-19 operations
	2	Require closing (only some levels or categories, e.g. just high school, or just junior schools)
	3	Require closing all levels
Work-place closing	0	No measures
	1	Recommend not to travel between regions/cities
	2	Internal movement restrictions in place
Stay at home requirements	0	No measures
	1	Recommend not leaving the house
	2	Require not leaving the house with exceptions for daily exercise, grocery shopping, and `essential` trips
	3	Require not leaving house with minimal exceptions (e.g. allowed to leave once a week, or only one person can leave at a time, etc)
Restrictions on internal movement	0	No measures
	1	Recommend not to travel between regions/cities
	2	Internal movement restrictions in place
	0	No measures

Using these indicators, plus modelling for normal and peak consumption, three different scenarios were produced:

- **New Normal (1)**: this scenario considers that the pandemic is no longer an imminent threat and people can resume normal lives. However, the new normal does include more working from home, less use of public transportation (as a consequence of increased working from home), and non-compulsory use of face masks.
- **Partial lockdown (3)**: this scenario considers that the pandemic is still ongoing, but under control, thanks to partial shop closing, working from home whenever possible, limits to internal and international movement, facial covering and testing. However, schools are open and many commercial activities can operate in a limited way.
- **Full lockdown (5)**: this scenario considers the pandemic an imminent threat that needs to be fought with stricter means: schools are mostly closed, only essential shops and commercial activities can remain open, the majority of the population

either works from home or is furloughed, internal and international movement is limited to the essential travels, households cannot mix.

The three scenarios were defined using the indicators (Table 6), as shown in Table 7.

Table 7 Definition of future scenarios

Scenario	Full lockdown 5		Partial lockdown 3		New normal 1	
Weather	Peak	Normal	Peak	Normal	Peak	Normal
Stay at home	2	2	1	1	0	0
Schools closing	1	1	0	0	0	0
Workplaces closing	3	3	2	2	1	1
Restrictions on movement	2	2	1	1	0	0

7.3.2 Future scenarios

Post COVID models were derived from the household consumption data in section 7.2 using the indicator variables in Table 6, weather variables and property type. Property was used for this model as there is a readily available dataset from ONS that describes these across England and Wales. These were then applied for the year 2021-2022 for each company.

A typical plot is shown in Figure 40 for normal weather, and typical plot is shown in Figure 41 for peak weather.

Figure 40 and Figure 41 show the percentage increase over a monthly profile for a normal year, i.e. the normal year monthly profile can be uplifted by these values. This allows a number of different scenarios to be mapped out, for example you could use this to predict a month of full lockdown in normal weather, followed by 5 months of partial lockdown under peak weather, followed by 6 months of a new normal under normal weather. Note the scenario for 'old normal' is set to mimic pre-COVID behaviour.

Tables of the percentage values for each company will be provided under a separate report.

Figure 40 Future scenario impact of COVID on PHC during normal weather by month

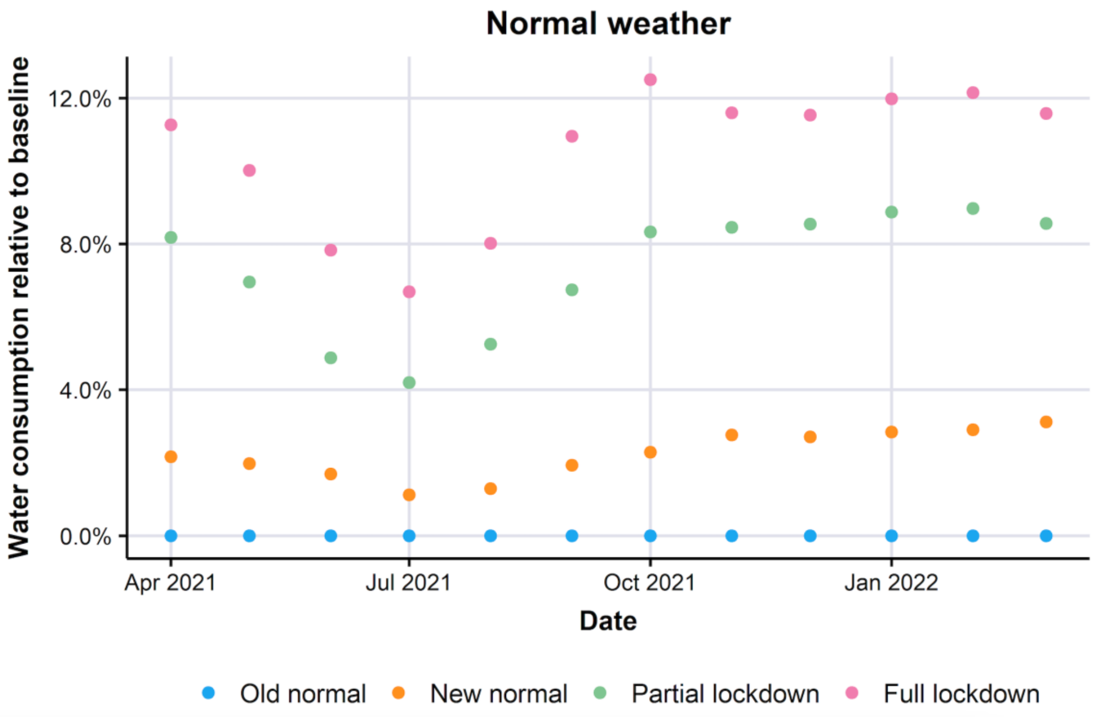
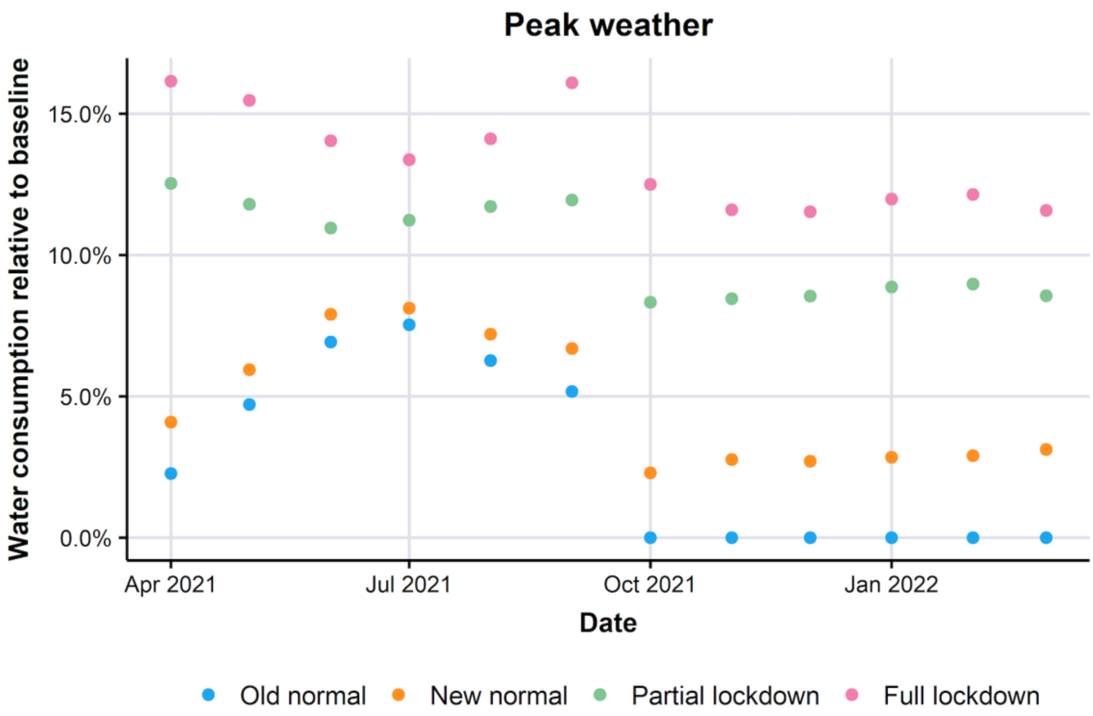


Figure 41 Future scenario impact of COVID on PHC during peak weather by month



7.3.3 Predicting the impact in 2020

We have used the same approach to predict the impact on PHC in the year 2020-21. This has been necessary because the data provided to the project only goes up to the end of October 2020. To do this we defined the alert level for England (Figure 42) and Wales (Figure 43) separately, using the same indicators as in section 7.3.1 mapped on to alert levels from 5 (full lockdown) to zero (no impact).

Figure 42 Average alert level fo the housheold explanatory factors for 2020-21 for England

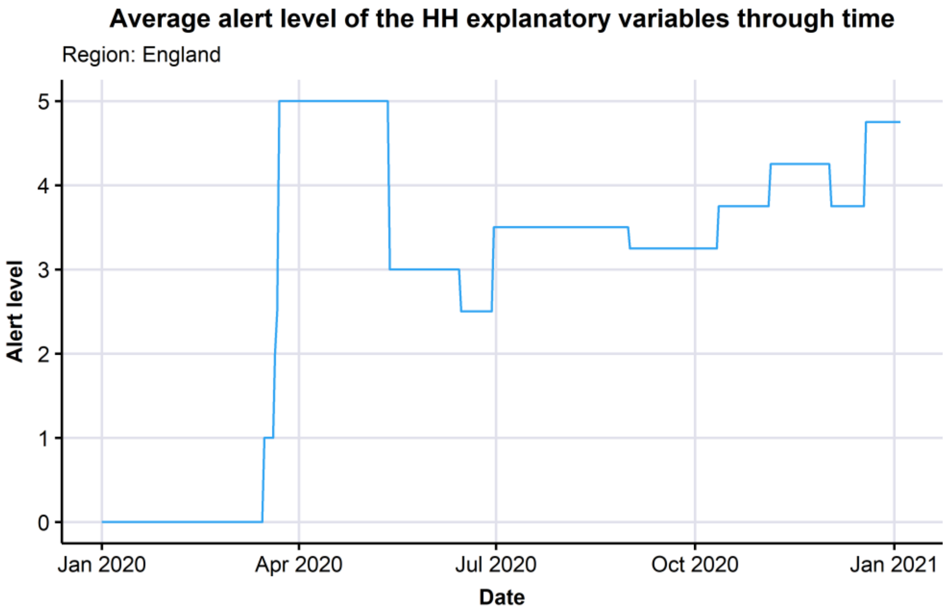
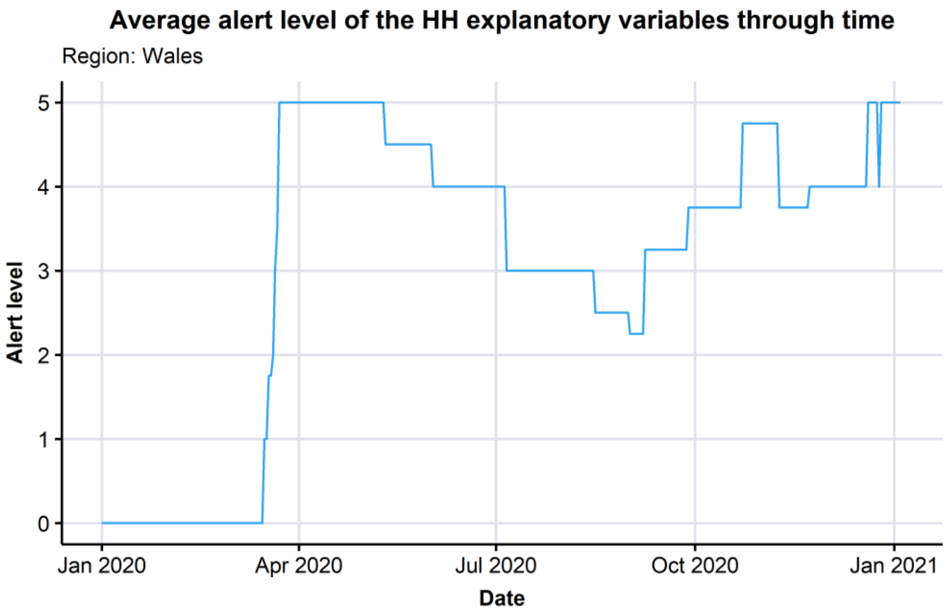
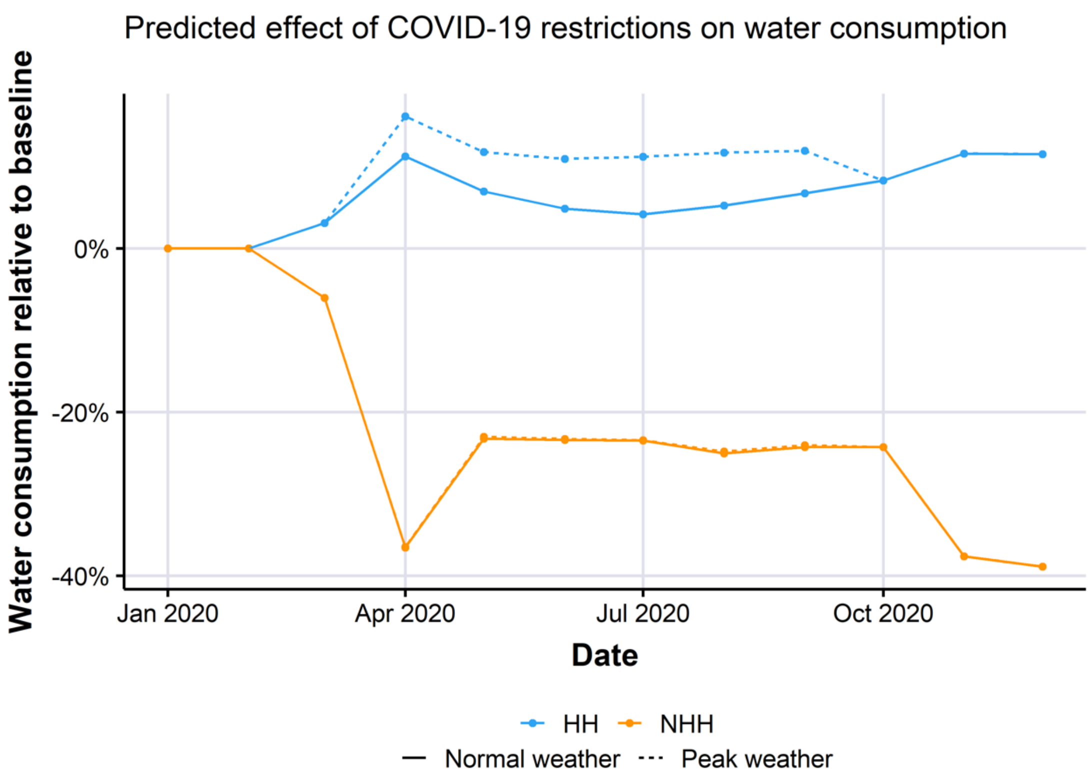


Figure 43 Average alert level fo the housheold explanatory factors for 2020-21 for Wales



Using these alert levels and applying the post COVID models we have predicted the impact during each month of 2020. An example is shown in Figure 44 for a typical company, note that this graph also shows the impact on non-household consumption. These are the percentage change from a normal year.

Figure 44 Typical example of the imapct of COVID on housheold and non-household consumption during 2020



Tables of the percentage values for each company will be provided under a separate report to allow companies to apply these to their previous normal year data.

7.4 Household consumption insights

We have examined three different sets of individual household monitor data to drill down into household use during the COVID-19 period. These datasets have sufficiently good quality data to allow us to build pre-COVID models to predict the level of consumption we would expect to see under normal conditions with weather patterns we saw during 2020; we then compared the modelled to predicted household consumption to determine the direct impact of COVID-19 during the various periods of lockdowns, easings and further restrictions.

We observed a fairly consistent response to COVID across the three sets of modelled and observed data in the southeast, midlands and west of the country. We saw an increase in PHC immediately after lockdown starts (23rd March) that extends to the start of Easing 2 (2nd June), impact on PHC then decreases but an increase is still observed right the way through to the end of the data in November (before lockdown 2 started).

Peak consumption increases in PHC (20% to 30%) were observed during easing 1 (mid-May to June) where most lockdown measures were still in place, and we saw a two-week period of hot weather at the end of a long (6-week) dry spell. This indicates that there was a combinational impact from lockdown measures and hot-dry weather (greater than would have been observed with the weather factors alone).

Over the period from lockdown to the end of easing 4 (March to September) the average increase in PHC was between 8% and 10% from the sample data we have. When we build a post COVID model and predict the impact across 2020 the range increase to between 9% and 13%, depending on weather and region when the samples are extrapolated by property type.

With the data that we currently have we were not able to assess whether measured and unmeasured households had a different change in water use behaviour during the COVID measures.

Interestingly, South East Water shows a significant increase in PHC during the pre-lockdown period and this may be due to commuters who normally travel into London staying away during the early COVID period as London was the first city to see COVID spreading. This corresponds to the findings we observed in the distribution input data for those areas surrounding London.

Looking at the different property types (bungalows, detached, semi-detached, terraced, and flats) we see that flats had the lowest increase in consumption, and detached/semi-detached properties the highest. Suggesting that occupancy and garden use might be significant drivers for post-COVID increases in consumption.

We also observed domestic properties in London increasing their consumption during the COVID period. This suggests that the resident domestic population in London have increased their consumption during lockdown like other areas of the country and that it is the non-household or commercial sector driving the consumption down in London.

Drilling down into the patterns of water use during the day, we see a clear change in use after lockdown starts with more water being used through the day with the morning peak becoming less dominant. The biggest changes are during easing 1 as expected given the increase in PHC, and during this period we see the evening peak during weekdays becoming the dominant peak (in all three areas), suggesting outside use is a driver. We also see the increase in use through the day extending through to the end of the data period in November for weekdays and weekends.

We used the sub-daily flows to differentiate between internal use (water use by appliances and taps within the home) and external use (water use in the garden plant watering, filling of paddling pools, etc.). From this analysis, we start to see some differences between the regions.

All three areas show a clear increase in external use during the easing 1 period (the second half of May) when there was an extreme hot and dry period. Severn Trent and South East show increased external use through more of the easing periods. Wessex Water's outside use is not increased during these periods, and this may be because of a warm dry late summer period in this area in 2019.

In all areas there is also increased internal use during the COVID-19 periods, most pronounced for South East Water, which may be driven by a greater proportion of commuters working from home or more furloughed staff staying at home. All areas would have seen school children staying at home during this period.

8 The impact on non-household consumption

8.1 Non-household data and quality assurance

This section is based on a dataset provided by Severn Trent Water (STW), who have a unique non-household (NHH) monitor recording data at 15-minute resolution for 3,686 commercial properties, with data from 2016 to the present. STW have provided a sample of NHH data covering the whole period from 2016 to lockdown, to benefit the whole UK water industry. This dataset has been joined with historic records and analysed to help understand the COVID-19 impact on NHH water consumption in the UK.

The STW NHH sample is comprised of more than 3000 properties. However, the dataset used in this work is made joining historic data and more recent updates covering the COVID-19 period. This results in a smaller sample of properties, covering the study period. The sample is representative of STW commercial property distribution. The data has been subject to the following checks and pre-processing steps:

- Eliminate files with no flow records.
- Eliminate files with only zero flow.
- Sum up consumption from properties with multiple meters.
- Check that data is of the correct data type (dates as dates, flow as numeric).
- Remove records without log number or date.
- Correct for clock shifts in summer/winter.
- Check for duplicate readings and resolve them.

The resulting dataset is subject to a quality assurance (QA) test, which is reported in Table 8

Table 8 Results of QA checks on the dataset, after pre-processing

Check	Result
Number of Properties	821
Number of Records	132367367
Missing Logger Numbers	0
Missing Dates	0
Starting Date	2016-04-01 01:00:00
Ending Date	2020-11-05 10:30:00
Minimum Flow	0
Maximum Flow	1310.6 l/prop/hour
Number of Absolute Duplicates	0
Number of Partial Duplicates	0
Result	Pass

This is an incredible dataset, which allows us to study "regular" commercial consumption over multiple years and compare it to the "exceptional" consumption patterns that occurred after the COVID-19 lockdown. We tracked the response of businesses along all the different COVID-19 response phases described in section 3.

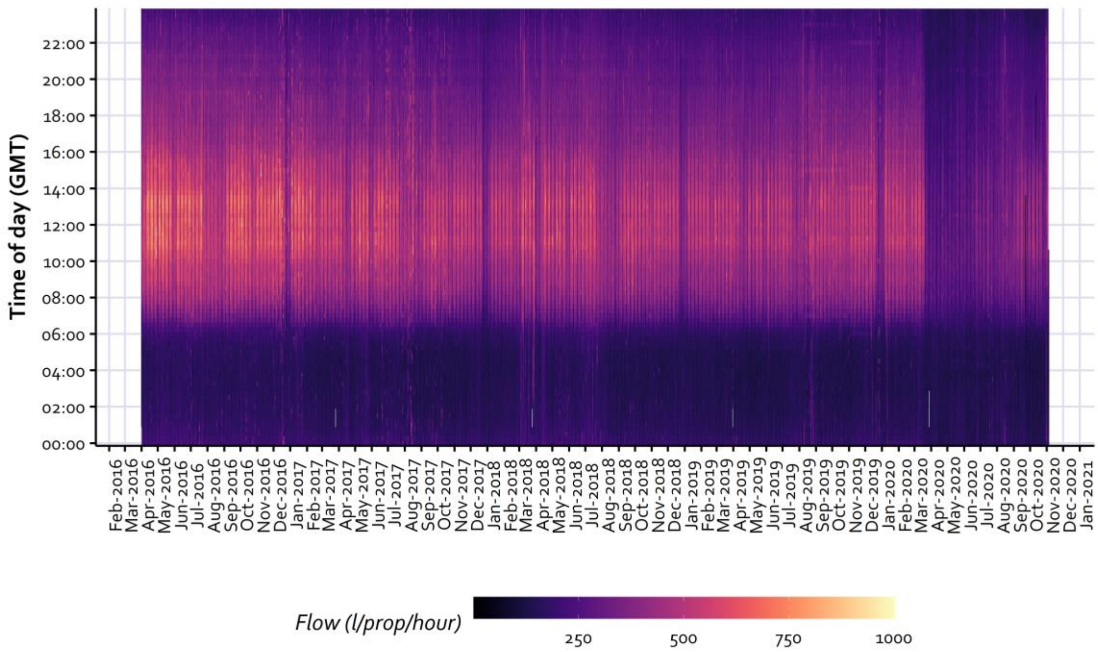
8.2 Non-household consumption visualisation

8.2.1 Spectrograms

Before starting a quantitative evaluation of the COVID-19 impact on NHH consumption, we observe the data. This step helps us getting a sense of what to expect, and therefore guides us toward the best modelling approach.

Spectrograms are a powerful tool to visualise data with a very fine temporal resolution. On the x-axis we have the date, while on the y-axis we have the time of the day. The plot is fully coloured according to the average consumption across all properties at each specific date and time. Although individual properties may have erratic behaviours, the average across all considered properties is an accurate representation of trends. Figure 45 shows the spectrogram from the 1/04/2016 to the 15/11/2020; Figure 46 zooms on the most recent years, starting on the 01/01/2019; Figure 47 zooms on the pandemic period, reporting phases as well.

Figure 45 Spectrogram of consumption for whole study period



Although some variability remains from random behaviours, the spectrograms show an incredible amount of detail. To start we can observe the daily pattern: usually consumption starts increasing around 7-8 am and reduces after 4pm in a more gradual way, reflecting the variety of businesses that can be more or less active in the evening hours. Weekends are visible as darker vertical lines occurring frequently and regularly.

Holiday periods are clearly visible: the Christmas break is the darkest of the consumption reduction periods, summer holidays are longer in time, but the reduction in consumption is less intense, while Easter and the May bank holidays are both short and not very intense.

The consumption is a little higher in 2016 than in the following years. However, the daily, weekly, and seasonal patterns are the same of the following years. The reason for this is not known currently, it could be due to a real reduction in consumption after 2016 due to regulations, economic slow-down, or other factors, or it could be an artefact in the data, possibly due to a different data collection and manipulation system.

Figure 46 Spectrogram of consumption from the 01-01-2019

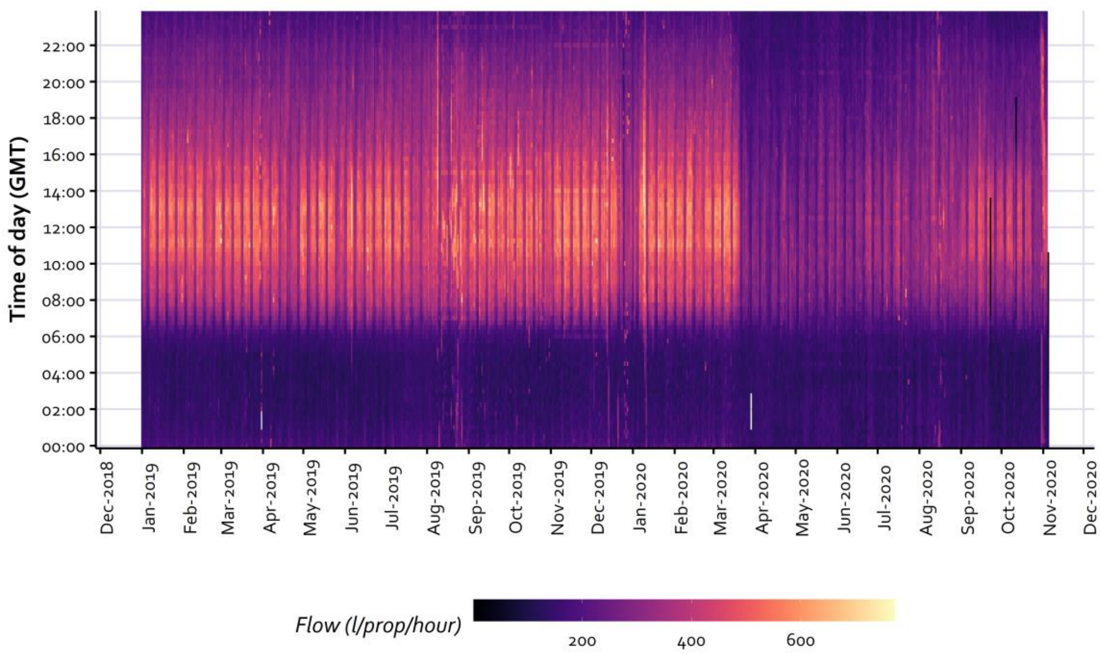
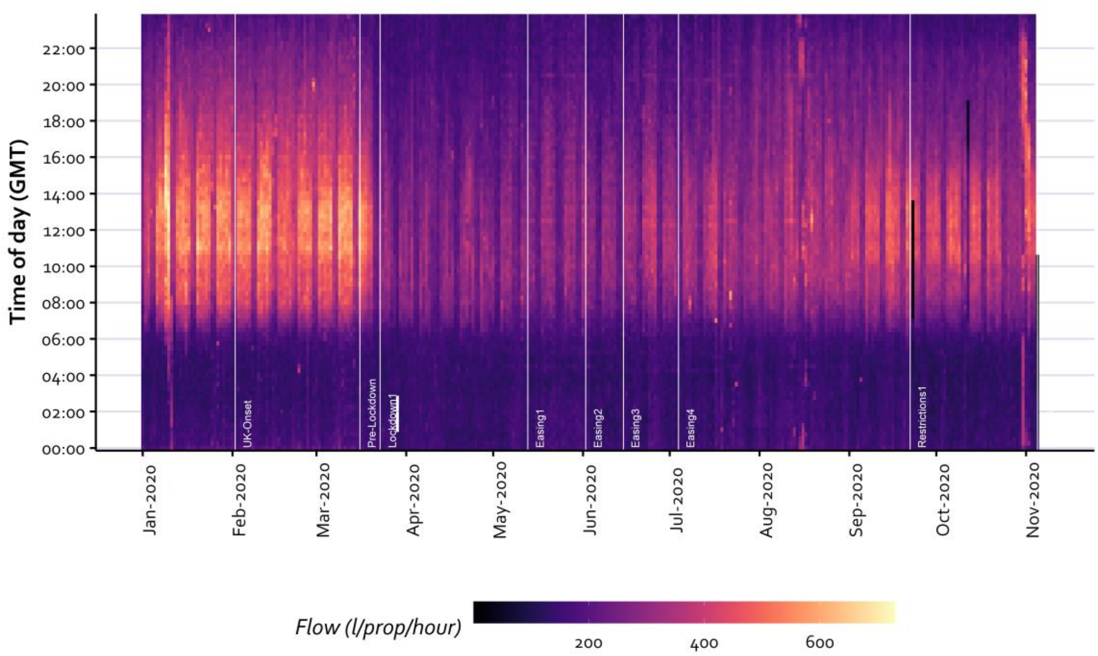


Figure 47 Spectrogram of consumption from the 01-01-2020 with phases



Finally, as expected, we can clearly see a drastic decline in consumption from the end of March 2020, due to the lockdown measurements that the UK government passed to contain the COVID-19 pandemic on the 23rd March 2020. The lockdown forced many businesses to close, others moved to a working-from-home arrangement, and others could only operate in a limited capacity. Some consumption can still be observed between 7am and 4pm, but most of the evening consumption, in large part corresponding to restaurants, pubs, and entertainment businesses has disappeared.

Consumption has gradually recovered after July, with gradual lockdown easing measures adopted over the summer 2020. However, consumption patterns are still different from what they used to be and overall consumption continues to be lower than pre-COVID levels.

8.2.2 Non-household consumption per sector

Considering only the data from November 2019, we can check the monthly variation between commercial sectors, to observe if the lockdown measures impacted some sectors more than others or in different ways. This is shown in Figure 48.

We can observe that the lockdown has not affected all sectors equally: some sectors seem almost unaffected, some other only had a drop during the central lockdown phase (March and April 2020), some other sectors still have not fully recovered from the drop in consumption. It must be considered that so far, the analysis has not separated the weather effect: the lockdown period coincided with extremely sunny and dry weather, therefore some of the observed effects may be a mixed response to weather conditions and lockdown.

This is in line with the expectations, as the most affected sectors correspond to businesses that had to close during lockdown (hotels and restaurants, transport, washing and dry cleaning), while other essential sectors could continue almost unaffected (agriculture and health). Sectors that had a mixed response, like offices, wholesale retail, and manufacturing, include some essential services, but in many instances could close or work remotely, thus there is a general reduction in consumption during the central lock-down months, recovering after the summer.

This analysis highlights that we need to consider the effect of COVID on different commercial sectors separately, as business response to the different government measures is very different across sectors. We also need to consider that some sectors do not have a lot of representation in the sample, as shown in Table 9.

Figure 48 Monthly variation of NHH consumption across commercial sectors since Nov 2019

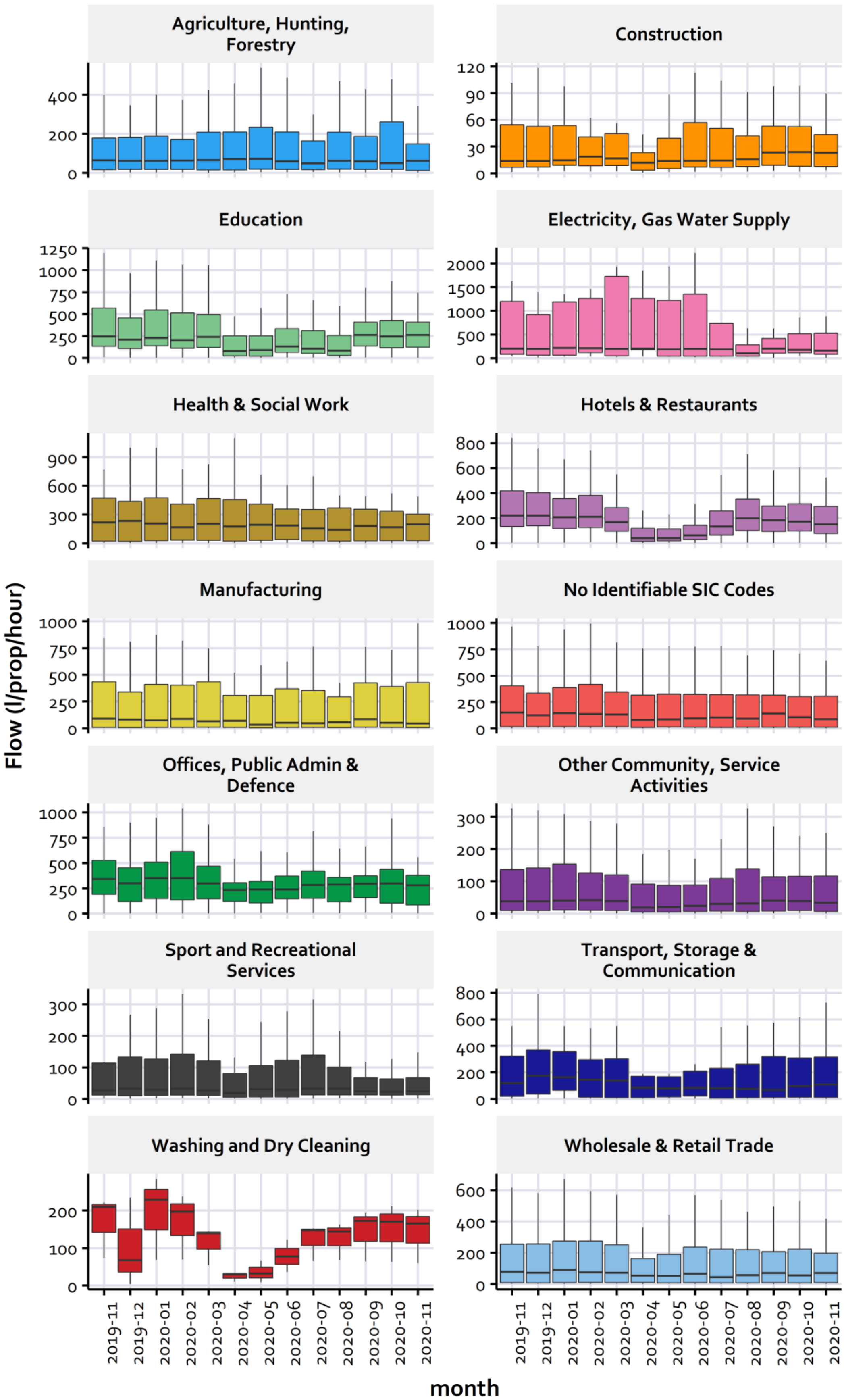


Table 9 Number of commercial properties per commercial sector

Sector	Number Properties
Agriculture, Hunting, Forestry	73
Construction	24
Education	87
Electricity, Gas Water Supply	5
Health & Social Work	26
Hotels & Restaurants	134
Manufacturing	27
No Identifiable SIC Codes	137
Offices, Public Admin & Defence	33
Other Community, Service Activities	91
Sport and Recreational Services	44
Transport, Storage & Communication	20
Washing and Dry Cleaning	3
Wholesale & Retail Trade	117

8.2.3 Non-household daily patterns

Finally, we want to check if there has been a change in daily pattern after the beginning of the COVID-19 lockdown. A change of patten has been observed in households, showing that people start using water later (as when working from home or not working at all there is no need to wake up early for the commute) and reducing differences between weekdays and weekends. To do so, we also consider the different phases of COVID-19 response, as listed in section 3.

To start we can check how the daily profiles have changed through the different stages, during weekdays and weekends. As expected, Figure 49 shows that the daily consumption during lockdown is drastically reduced, both during weekdays and during weekends. Lockdown weekdays and weekends show a much more similar profile. Consumption has not recovered to the pre-COVID time. It is interesting to notice that consumption for post-lockdown has increased relatively more during the weekend than during the week. This is probably due to the fact that the type of businesses operating during the weekend (restaurants and hotels, hospitals, transportation, sport, etc...) usually cannot be performed from home, while a more significant part of the weekday jobs can be performed remotely, so water is not consumed in the workplace, even when businesses are operative. Similarly, we observe that the pre-lockdown restrictions had affected the weekend businesses more than the weekday ones. Interestingly, during both weekends and weekdays we observe that there has been slightly more water consumed after the first easing of lockdown than after the second easing of lockdown, which can be due to businesses flushing stagnant water from pipes after weeks of inactivity to avoid sanitary hazards, as recommended by the government. Finally, we observe that the restrictions re-introduced in September 2020 do not seem to have had a significant effect on reducing demand, possibly due to the fact that the Government preferred to target household behaviour rather than businesses, to avoid another hard hit on the UK economy.

Figure 49 Daily profiles of water consumption through the different lockdown stages, during week days and weekends

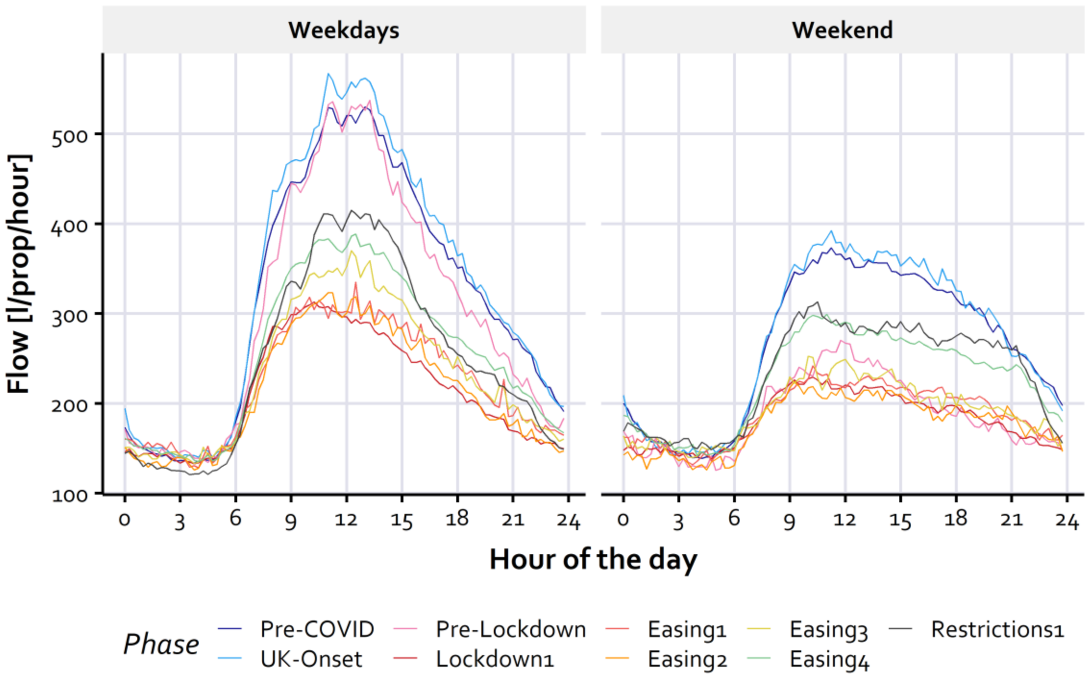


Figure 50 shows that the daily profiles are expected to be very different from sector to sector. Again, we observe that the COVID lockdown journey has been very different for the different business categories.

Agriculture, hunting, forestry - The consumption does not seem to be affected by the lockdown, with the exception of a rise after the first easing of lockdown measures and a decrease during the UK onset. We need to consider that the weather effect is not separated from the lockdown effects at this stage. This could mean that in reality there could have been an effect of lockdown, counterbalanced by the higher demand due to the exceptionally hot and sunny weather that occurred in April and May 2020, which is then evident after the first easing. Alternatively, the increase in consumption after the first easing could be due to a specific large user, or to specific hygienic and washing measurements: for example it was recommended to flush water systems to remove any contamination risk from standing water - e.g. legionella.

Construction - the construction sector was partially affected already during the pre-lockdown phase and has now only partially recovered. Interestingly the night use has also dropped compared to pre-lockdown levels. The only exception is a relatively high consumption after the second easing of lockdown measurements, including a high night use. We need to consider that the construction sector is highly variable, due to its project-based nature.

Education - the education sector is probably the most regular, as all schools tend to follow a similar schedule. Consumption has drastically dropped during lockdown and recovered gradually. The flow increased in response to the third lockdown easing (schools reopening for years 10/12, and primary reception/Y1 started to go back at the same time) and more after the fourth easing. During the UK onset, the pre-lockdown and the restriction phases consumption seem to have increased beyond the pre-COVID level. This could be due to a different account of holidays in the considered periods, but also to a higher level of hygiene and handwashing.

Energy, Gas, Water Supply - This sector needs to be considered carefully, because only five businesses are present in the sample. However, it is interesting to note that during lockdown and the first three lockdown easings daily consumption has marginally dropped, but night use has gone up. Interestingly, after the fourth easing of lockdown restrictions consumption has significantly dropped across the 24h.

Health and social work - the health sector has been on the first line fighting to save every COVID patient, and this is reflected by the fact that there has been a very little reduction in consumption during lockdown. Water consumption has also increased at night and early in the morning, with just a marginal reduction in the afternoons. After the emergency, in coincidence with the subsequent phases of lockdown easing, water consumption reduces as many non-essential services are reduced or offered remotely.

Hotels and restaurants - This sector has been strongly affected by lockdown, with a significant drop in water consumption already in the pre-lockdown phase and through most of the post-lockdown phases. It has only marginally recovered after the fourth lockdown easing.

Manufacturing - water consumption for the manufacturing sector has not dropped much during lockdown. However, there has been an increase in flow in pre-lockdown, especially in the evenings, possibly due to increased hygiene/cleaning or maybe to fulfil high demand for NHS supply or due to the stockpiling effect. Lockdown and post-lockdown flows are quite similar - perhaps reflecting a reduced demand, or economic impact of lockdown on this type of industry. Consumption has dropped more drastically after the September 2020 restrictions, which may be due to regulation, but also to the fact that some factories may be closing because of the economic crisis.

Offices, public admin and defence - this sector has not been affected by pre-lockdown much, with the exception of some increased night use, possibly for cleaning. However, since lockdown there has been a significant drop in demand, only starting to recover after the third and the fourth lockdown easings, due to many businesses adopting remote working. It is evident the change in Government guidance regarding homeworking: for a period during the summer (Easing 4) people were asked to return to office if safe, while during the second restriction phase people were asked to work from home where possible.

Other community service activities - Interestingly this sector shows a very particular demand profile during lockdown, with almost unvaried demand in the early morning and a decline during the day. Demand drops drastically in the following lockdown easing phases. This effect could be due to the provision of essential services during lock-down.

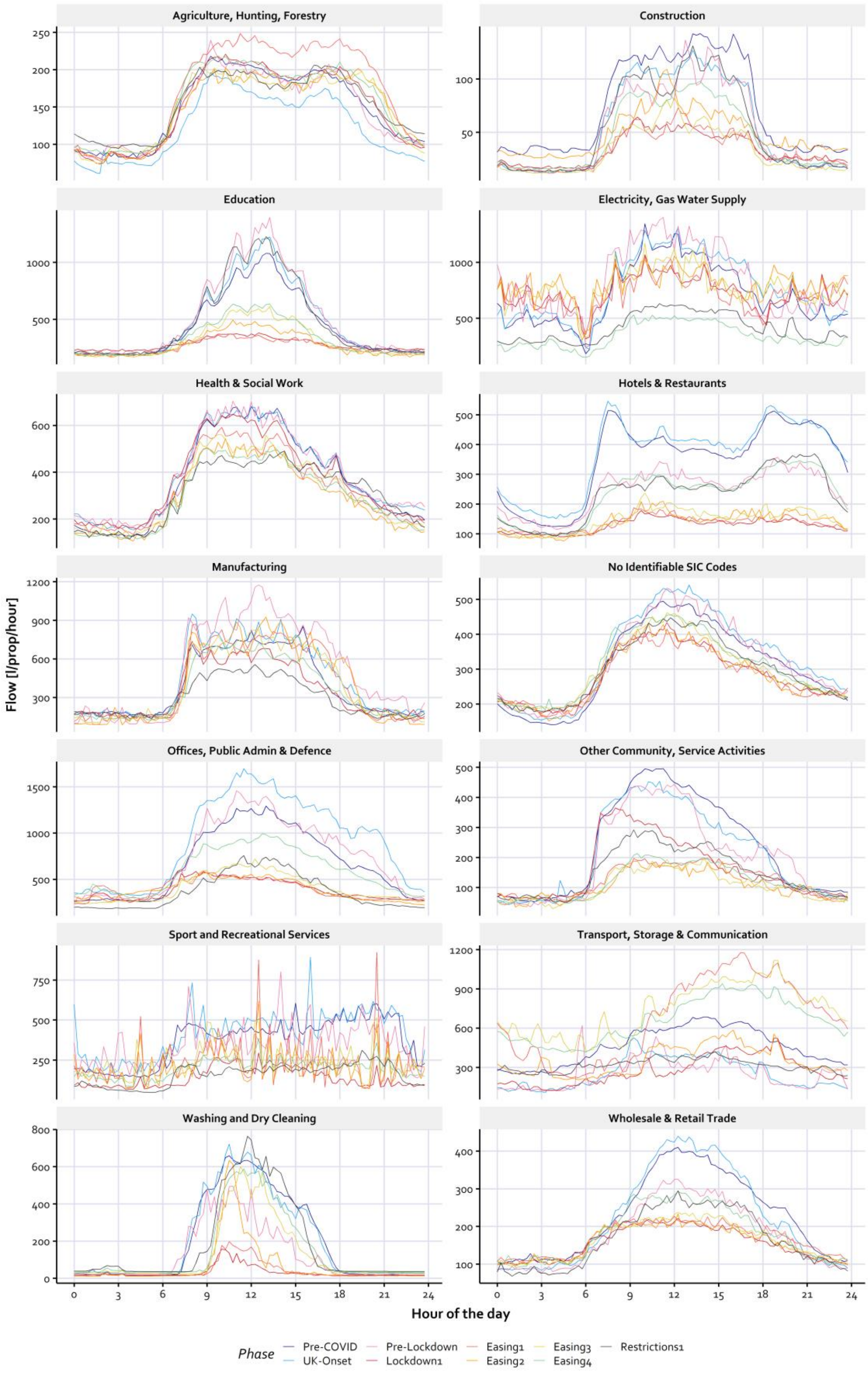
Sport and recreational services - the sport sector has a variable profile after lock-down. There are significant spikes, likely to be due to increased/altered cleaning and pitch irrigation regimes, as well as possibly an automatisation of irrigation. Demand after lockdown easing has dropped, possibly influenced by weather as well.

Transport, storage and communication - demand profile for the transport, storage and communication sector are very interesting and variable. Without doubt the travelling sector is strongly driven by the airports, which are affected by seasons, holidays and, in 2020, by travelling restrictions and flight cancellations. Demand has dropped during lockdown to then jump much higher than pre-lockdown levels with the first easing, then dropped down again after the second easing, to then jump up again with the third and more modestly after the fourth easing, while the new restrictions caused another drop. A separate time scale of travelling regulations should be considered. Besides airports, the high demand may also be driven by the high demand of home-delivery during and after lock-down.

Washing and dry-cleaning - this sector is represented by only three businesses, therefore it cannot be considered representative. However, we observe an expected profile, with a drastic drop in demand during lockdown and a gradual recover after. Interestingly the demand after lockdown has a different profile, with demand starting later in the morning and dropping more quickly in the afternoon, suggesting either a reduced opening schedule or a decrease in demand that does not require to work outside opening time anymore.

Wholesale and retail trade - this sector was strongly affected already in the pre-lockdown phase, as many shops were asked to close and has only marginally recovered after the fourth phase of lockdown easing.

Figure 50 Difference between daily NHH water consumption through the different phases of lockdown by sector



8.2.4 The impact of local lockdowns

The national lockdown in 2020 has caused a dramatic impact on the UK economy. For this reason, after the suppression of the first COVID wave, the government has decided to target the fight to COVID with local lockdowns in areas where infections are higher.

Leicester was the first case of local lockdown, basically never fully getting out of the national lockdown and keeping a different set of rules, while the rest of England moved to lockdown easing phases.

This is a short timeline of the lockdown decisions in Leicester:

- 30th June 2020: Lockdown is extended in the city of Leicester, meaning that non-essential shops that reopened on June 15 had been asked to close again; bars, restaurants and hairdressers did not reopen; schools closed from Thursday July 2 until the September term except to vulnerable children and children of key workers; vulnerable people had to extend the shielding.

- 16th July 2020: government announces that Leicester and Oadby and Wigston would remain in lockdown for another fortnight, but restrictions were relaxed in other county areas that were originally within the red line, from the 18th July.

- 24th July 2020: non-essential shops and schools (despite most in Leicester already being closed for the summer holidays) would be allowed to reopen, but confusion as people are recommended to go out only for essential travel.

- 1st August 2020: Places of worship and pubs, restaurants, cafes and hairdressers were now told they could open. Limitations on household visits would remain. Leicester residents were told that holidays were now permitted but only with members of their own household or support bubble.

- 17th August 2020: beauty salons, nail bars and tattoo studios opened.

- 1st September 2020: the majority of county and city children are back in school in line with the rest of the country.

- 4th September 2020: gyms and swimming pools are among businesses being allowed to reopen.

Birmingham, Sandwell and Solihull were also affected by a local lockdown:

- 11th September 2020: Birmingham, Sandwell, and Solihull were subject to a local lockdown. However, the lockdown was mostly affecting household interactions, as people were not allowed to mix indoors, but most shops, pubs and restaurant remained open.

- 14th October 2020: The area moves from a local lockdown to a Tier 3 region, after the introduction of the tier system. This means that it is a very high alert area. Households cannot mix indoors. Hospitality businesses remain open only for takeaway, drive-through, or delivery. Retail shops remain open. Where possible, people are recommended to work from home.

We can check whether water NHH demand in Leicestershire shows a slower recover post-lockdown, compared to the other areas in the Severn Trent basin, and if the Central region of STW (where Birmingham is) shows signs of the local lockdown.

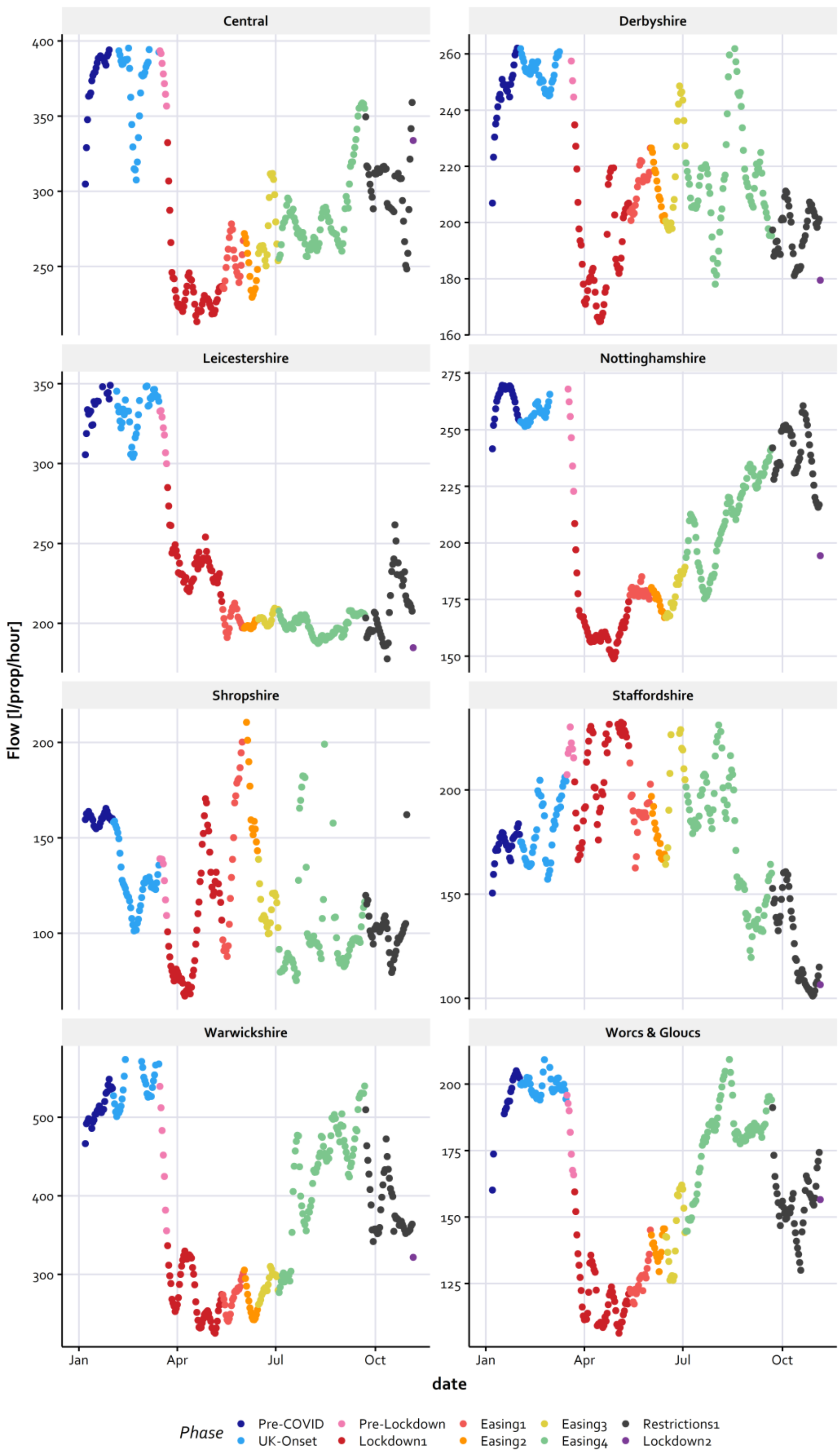
In Figure 51 the effect of the Leicester lockdown is evident, if we compare the Leicestershire profile to the one of areas like Central, Derbyshire, Nottinghamshire, Warwickshire and Worcestershire & Gloucestershire: all other areas have a drop during the lockdown phase and gradually recovered their water demand, although not always to reach the pre-COVID levels. Leicestershire instead had a further drop after the national lockdown, with further restrictions put into place.

The impact of the Birmingham lockdown on the Central region is not evident. This is probably due to the different nature of the restrictions, maintaining businesses as open as possible.

All areas show a slow down due to the new restriction phase.

Interestingly we also observe that Shropshire and Staffordshire have a profile that seems driven by Agriculture, and therefore not affected as much by lockdown measures.

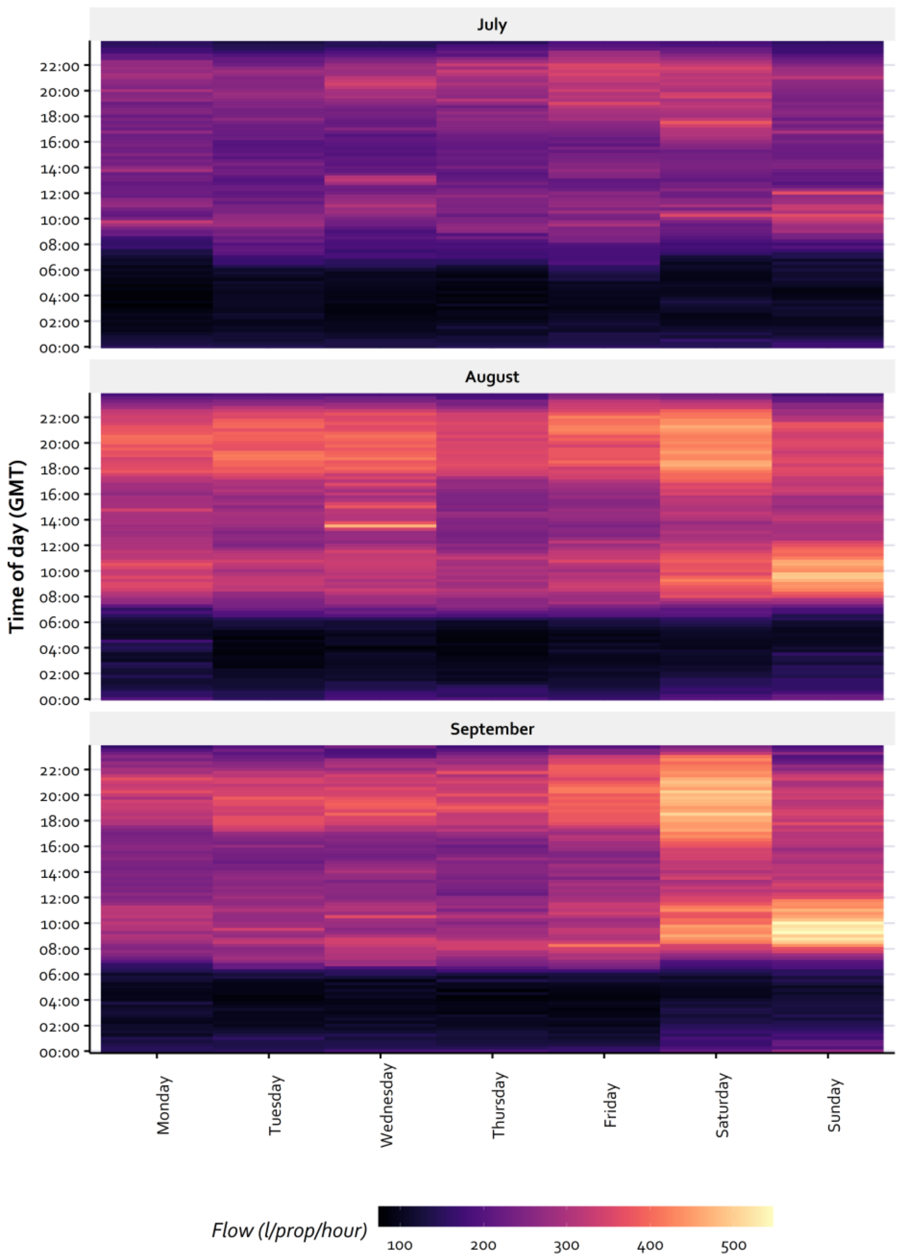
Figure 51 Weekly rolling average water demand by area in 2020. Colours denote the England lockdown phases, which are different from the Leicester lockdown phases



8.2.5 The 'eat out to help out' scheme

In August 2020 the government promoted an initiative named "Eat Out to Help Out", aiming at offering a 50% discount on food or non-alcoholic drinks to eat or drink in participating restaurants, Monday to Wednesday. The scheme was active between the 3rd August to the 31st August. We can observe if we see a variation in water consumption in the Restaurant and Hotels sector due to the scheme. We can check a spectrogram of the post-lockdown phase for the Hotels and Restaurants sector, by month and by day of the week.

Figure 52 Spectrogram of the Hotels and Restaurant sector during the post-lockdown phase, by month and day of the week



In Figure 52 the effect of the "Eat Out to Help Out" scheme is clearly visible in August: Mondays, Tuesdays and Wednesdays are brighter especially at dinner time, compared to the same days in September and compared to Thursdays in August, meaning a higher water demand. July still has lower demand over all compared to following months, meaning that the restart of the Hotels and Restaurants sector has not only been dictated by regulations, but also by people's behaviour and sense of safety, which grew over the summer.

8.3 Modelling pre-COVID NHH consumption

The pre-COVID model aims at defining the relationship between NHH consumption and explanatory variables in normal conditions. We have tested numerous types of models, including various multiple linear regression models (MLR), random forest (RF) models and generalised linear models (GLM). The different types of models were tested and refined and ultimately the GLM approach was used to build a separate model for each of the commercial sectors we had for the non-household data (see Table 9).

The model coefficients make sense as we expect: holidays and weekends usually have a negative effect on consumption, as do rainfall, and the days since 2016 (which represent an overall declining trend in consumption throughout the years), while maximum temperature and hours of sun have a positive impact. Some sectors (like the transport and hospitality) instead respond positively to holidays and weekends. Other variables are more complicated to interpret: the location coefficients signify that on average we can expect higher consumption on the East/West and the North/South part of Severn Trent. However, the interpretation can be more complex, as the variables can interact with each other. The area coefficients are difficult to interpret because they depend on how the GLM model transformed the categorical variables into numeric ones.

The chosen model is quite good at estimating the overall trends, but it is not extremely precise in estimating the absolute volumes, as outliers were removed when training the model. Therefore, when applying the model, a rebase is applied, so that the mean modelled value consumption during the pre-COVID phase for each sector is forced to be equal to the actual consumption. The rebasing factor is calculated as a multiplicative factor so it can be proportionally applied to businesses with great variability of consumption.

Now that we have a good model, we can predict what consumption would have been like in 2020 if the COVID-19 pandemic had not occurred, and compare the predictions with what actually happened in terms of observed consumption. The analysis was performed:

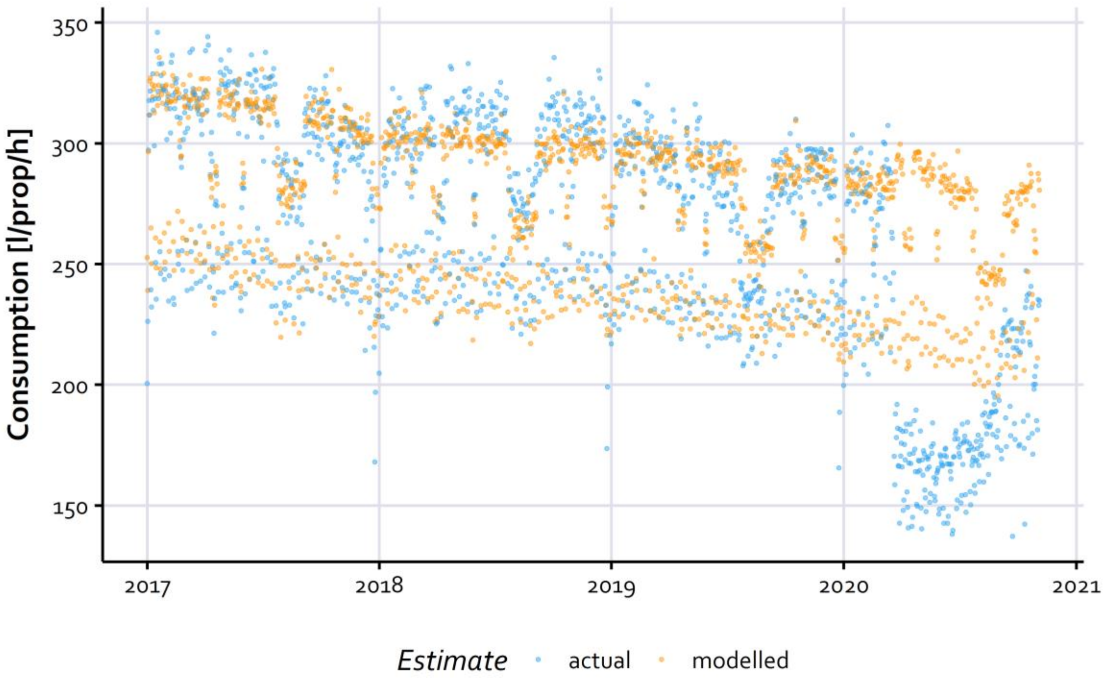
1. Considering consumption at daily level

2. Considering consumption for each COVID-19 response phase

3. Considering consumption for each COVID-19 response phase by sector.

Aggregating the data at daily level is useful to see the time series of predicted vs actual observed non-household consumption, as shown in Figure 53.

Figure 53 Predicted vs actual NHH consumption for the whole study period at daily resolution



The chosen model overall predicts the NHH consumption quite well. Three modes for weekdays, weekends, and holidays are well captured as three levels of frequent points, and the drops for holiday periods are overall well captured. Weather responses and the overall trends are well followed. The effect of the 2020 pandemic are evident: a sudden drop occurs in spring 2020 and slowly recovers afterwards. We can zoom on 2020 to evaluate some COVID-19 effects more in detail in Figure 54.

The following features can be observed:

- At the end of the UK onset period, just before the pre-lockdown phase, we observe a rise in consumption. This could be linked to the stockpiling effect: customers and other businesses buying more than usual due to the uncertainty on products availability during lockdown has forced many businesses to work more than usual to produce, transport, and sell the required products. This applies to services that would become unavailable during lockdown as well.

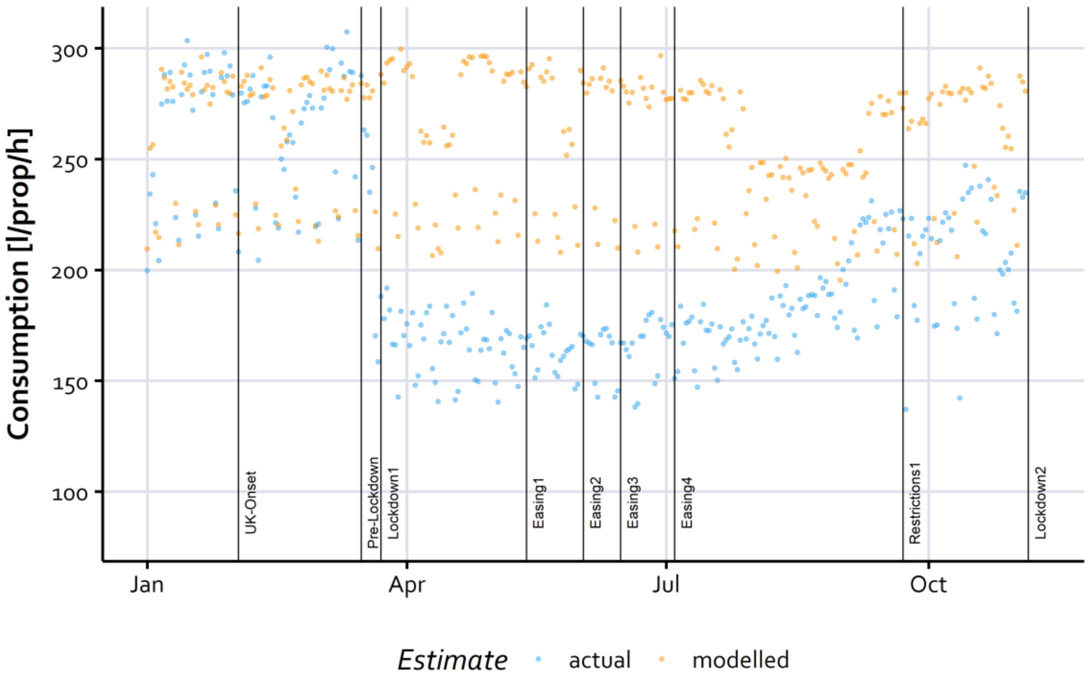
- The pre-lockdown phase, instead shows a drop in consumption, meaning that the measures adopted in this phase already had an impact on businesses and therefore their water consumption.

- The recovery is more gradual than one would expect, meaning that, together with the changes of policy, NHH water consumption may be influenced by the change of attitude and sense of risk, which may be more difficult to capture in a model. However, this may also be due to the impossibility to track on the plot other minor changes in policy, especially at local level.

- There is no sign of the Easter break and only partially of the May bank holiday and the summer break. Businesses that are closed do not have any different consumption during working days or holidays. Additionally, the impossibility of travelling, together with the need of recovering business losses may have made businesses remain open and active, when possible, during times of the year that are normally less busy.

- The difference between weekdays and weekends is reduced. This can be noticed as the spread between the more dense upper line of points and the less dense lower line of points. Again, this is due to many businesses being closed, but also to the fact that the majority of jobs that can be performed from home (and therefore cause a drop in NHH consumption even when the business is operative) are weekdays' jobs.

Figure 54 predicted vs actual NHH consumption for 2020 at daily resolution



As observed, the difference between expected and actual NHH consumption is variable in time, predominantly driven by regulation changes. Therefore, quantifying the overall effect of COVID-19 on NHH consumption is of limited usefulness. Figure 55 shows instead the decrease in NHH consumption for each phase. Residuals are the differences between the modelled, i.e. the expected, and the actual consumption, and are expressed as a relative percentage. The boxplot shows the mean as a red dot, the median as the central line in the box, the 25th and 75th percentiles as the top and bottom hinges, the whiskers extend to 1.5 the interquartile values, while the black dots can be considered outlier values. The difference between mean and median is an indicator of the distribution skewness.

Table 10 quantifies the changes observed in Figure 55, which represent very well what we observed qualitatively, i.e. water consumption plummeted in the pre-lockdown and lockdown phases, it then gradually recovers, but the recovery is slowed down in the first easing phases due to local lockdowns.

Figure 55 NHH residuals (modelled, i.e. expected, minus actual) by phase

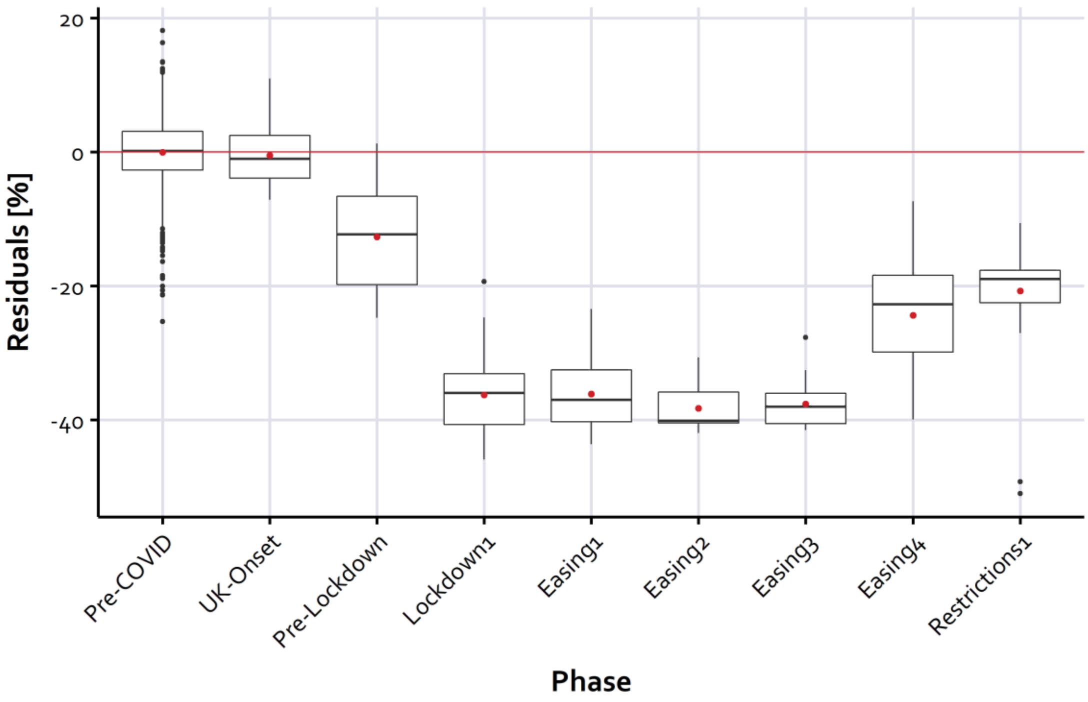
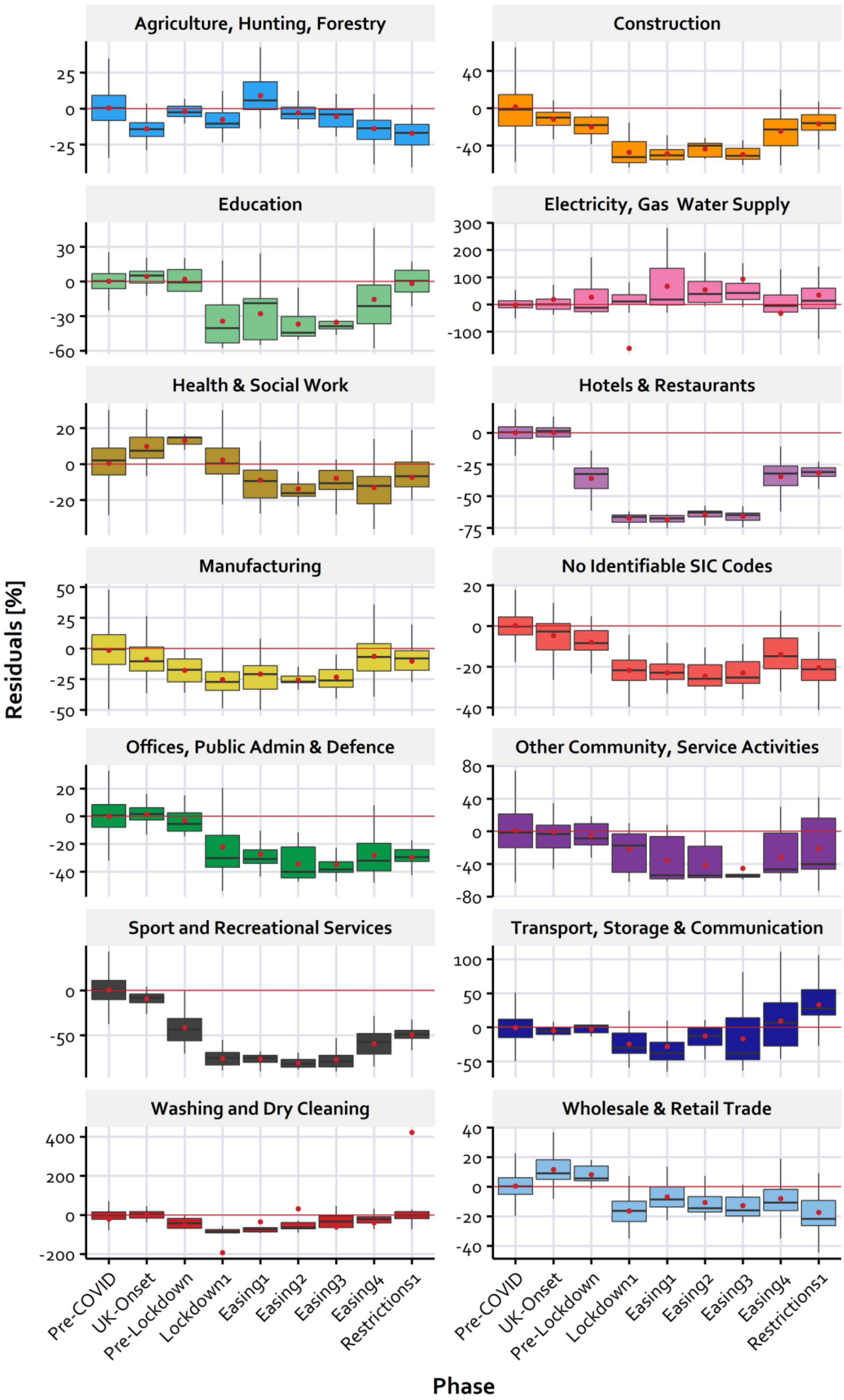


Table 10 Statistics of NHH consumption change [%] compared to expected conditions by phase

Phase	Mean	Median	Q25	Q75
Pre-COVID	-0.0	0.1	-2.7	3.1
UK-Onset	-0.5	-1.0	-3.9	2.5
Pre-Lockdown	-12.7	-12.3	-19.8	-6.6
Lockdown1	-36.2	-36.0	-40.7	-33.1
Easing1	-36.1	-37.0	-40.3	-32.5
Easing2	-38.2	-40.1	-40.4	-35.9
Easing3	-37.6	-38.0	-40.5	-36.0
Easing4	-24.4	-22.7	-29.9	-18.4
Restrictions1	-20.8	-19.0	-22.5	-17.7

Finally, we want to check how different commercial sectors were affected by the COVID-19 lockdown by phase. Figure 56 shows the boxplots of NHH consumption for each sector.

Figure 56 NHH consumption change compared to expected conditions by phase and sector



8.4 Non-household consumption insights

There is a lot of variability in how much different sectors have been affected by the lockdown:

The Agriculture, Hunting, Forestry sector shows oscillations that are unlikely to be linked to the COVID-19 regulation phases. Oscillations are probably due to weather conditions that have not been fully depicted by the model.

The Construction sector slowed down already during UK onset and pre-lockdown, and remain low until the 4th easing, but has not recovered fully.

The Education sector was not affected by the UK onset and the pre-lockdown, remained lower than expected until the 4th easing and has recovered to normal level during the restriction phase, as schools continued to operate at normal level.

The Electricity, Gas, and Water supply sector is based only on 5 properties and shows a high variability. Overall, it does not seem to be affected by the COVID-19 pandemic, but we cannot draw conclusions on such a small sample.

The Health and Social Work sector saw a rise in water consumption during UK Onset, pre-lockdown and lockdown, due to the increased activity to fight the pandemic and the improved hygiene measures. After the peak of the emergency consumption decreased a bit, as many unessential services have been cancelled, postponed or offered remotely (e.g. many GP practices operate mainly by phone unless a visit is necessary).

The Hotel and Restaurant sector was badly hit by the COVID-19 pandemic. It already suffered drastically during the pre-lockdown phase, with a decrease in water consumption of about -30%, and reached a minimum during the lockdown of about -70%. It did not recover much during the easing phases until easing 4. It still has not fully recovered.

The Manufacturing sector experienced a gradual decrease in water consumption until lockdown, then a gradual recovery, but seem to still operate slightly under their normal regime.

The Office, Public Admin, and Defence sector has slowed down slightly during pre-lockdown and reached about -30% of the expected consumption during lockdown. Differently from other sectors, it has not recovered, as most of the office work can be performed remotely. However, we have to keep in mind that this sector experienced an increase in water consumption between the second half of 2019 and the beginning of the pandemic, which could have continued into 2020, if the pandemic was not a factor, operating above expectation. Therefore, our estimate of water consumption reduction could be considered conservative.

The Other Community Service Activities had a stronger decline in water consumption during the easing phases than during the lockdown itself. This may be due to essential and emergency services being carried out during lockdown.

The Sport and Recreational Services sector was significantly hit by the pandemic, with a decline in water consumption up to -60% during lockdown. It has not recovered much, even considering a partial increase during the 4th easing. However, this could be partially due to the cut of water-related services: any sport centres do not allow clients to have showers in the premises, closed saunas and spa centres, and limited the swimming-pool services, but remained operative for gyms, courses, outdoor activities.

The Transport, Storage, and Communication sector has a very unusual profile. It shows a slight slowdown during the lockdown and the first easing phases, but then the recovery goes beyond the expected, with the sector consuming more water than expected in the 4th easing and the new restriction phases. This is probably due to a combination of things: on the one hand travelling restrictions have followed a particular schedule, especially as flights have been cancelled by airline companies due to their own expectation of demand and regulations in other countries too. On the other hand, the sector also includes storage and communication and there has been a boom of delivery services and postal services, as people avoided in-person shopping and good exchange. Therefore, it is likely that the variations of the travelling patterns have mixed up with the variations in the delivery sector.

The Washing and Dry-cleaning sector is based on 3 properties only, therefore it cannot be considered representative. Beyond a very high value in the restriction phase, that drives the mean very high, the pattern is as expected: initial reduction of water consumption during pre-lockdown, substantial decrease during lockdown, then slow recovery to almost-normal operation.

The Wholesale and Retail Trade sector had an increase in water consumption during the UK onset and pre-lockdown phase. As mentioned before, this is likely due to people stockpiling before the lockdown and to an increase in hygiene procedures in stores. Then there has been a decrease in water consumption during lockdown, as non-essential shops were asked to close. The recovery during the lockdown easing phases has not been steady and a decline occurred again in the new restriction phase. It must also be considered that due to the difficult economic situation some businesses may have closed and therefore the whole economic sector may have a long-lasting impact.

8.5 Scenario modelling the impacts on non-household consumption

A post COVID model was built using the SIC sectors and the variables shown in Table 11. Various modelling approaches were tested before selecting a Random Forest model with feature selection as the best performing model.

Table 11 Variable used for post COVID non-household consumption modelling

Variable	Full lockdown	Partial lockdown	New normal
School closing	2	0	0
Workplace closing	3	2	1
Close public transport	1	1	0

Stay at home requirement	2	1	0
Restrictions on internal movement	2	1	0
International travel controls	2	1	0
Testing policy	2	1	0
Facial coverings	2	2	1
Confirmed deaths (ONS)	700	300	0
Turnover change by sector (ONS)	April mean	October mean	0
Remote working by sector (ONS)	June mean	October mean	Minimum month
Furloughed staff by sector (ONS)	April mean	October mean	0
Self-isolating staff by sector (ONS)	April mean	October mean	0
Variation in job adverts by sector (ONS)	April mean	October mean	1
Shops' footfall (Google mobility)	April mean	October mean	0
Essential retail footfall (Google mobility)	April mean	October mean	0
Transport hub footfall (Google mobility)	April mean	October mean	Max month
Workplace footfall (Google mobility)	April mean	October mean	Max month

The model was used to derive the percentage change of a normal year's non-household consumption under the following scenarios:

- Full lockdown (5),
- Partial lockdown (3),
- New normal (1),
- Old normal (0) – this represents pre-COVID behaviours.

The outputs were predicted for each company for a normal year and a peak year. An example is shown for a typical company in Figure 58 for normal weather and Figure 58 for peak weather.

Figure 57 Predicted change in non-household consumption for each scenario under normal weather

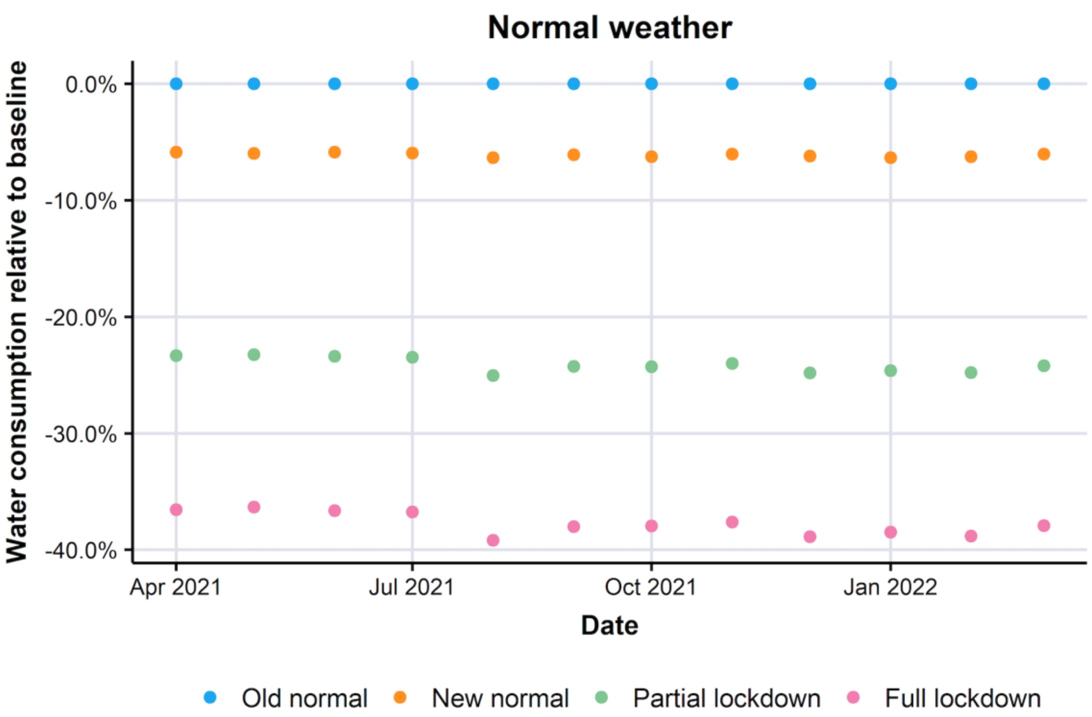
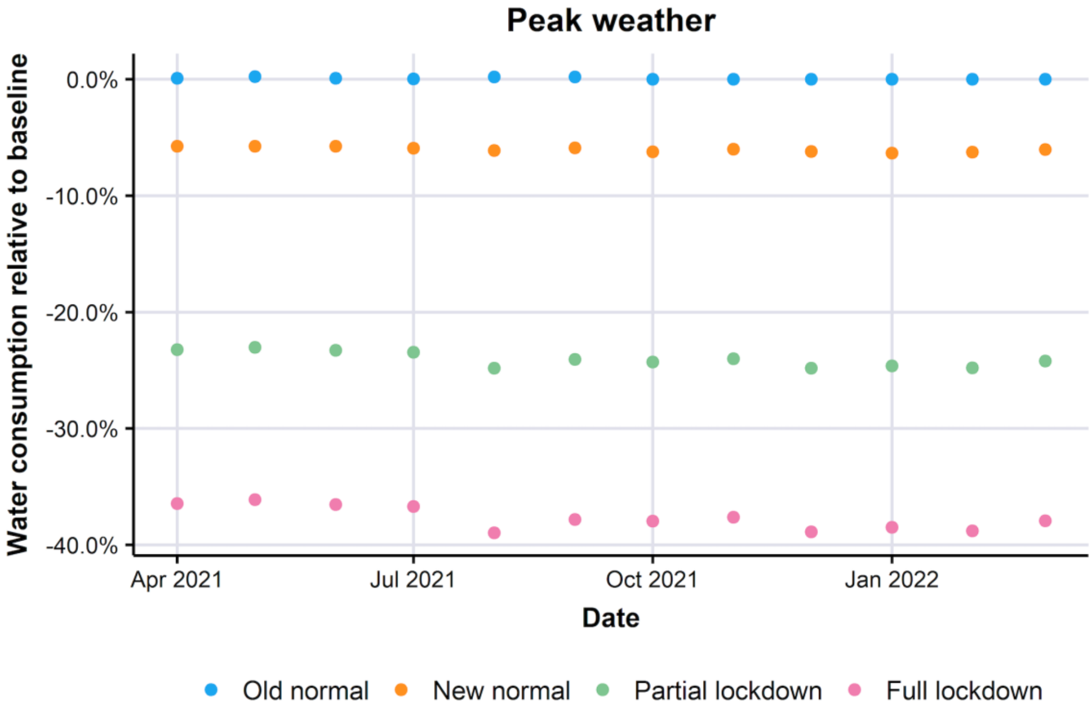
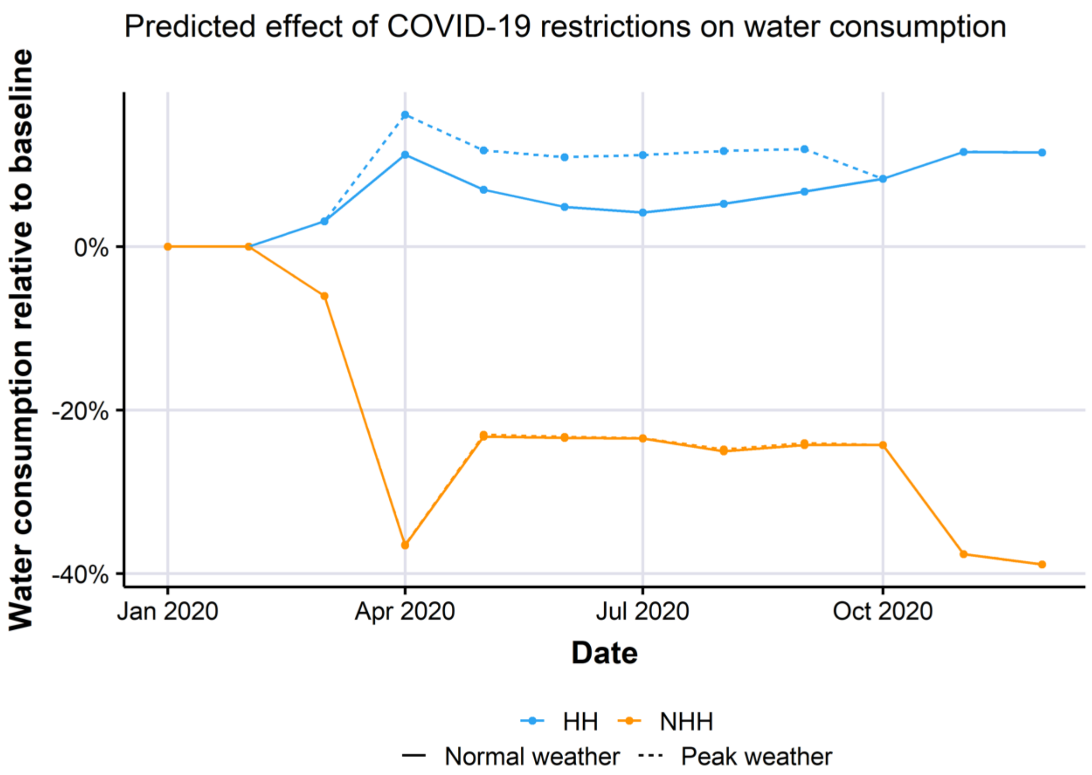


Figure 58 Predicted change in non-household consumption for each scenario under peak weather



Using the same approach, we have modelled the COVID impact for 2020 using the same alert levels used for households (see Figure 42and Figure 43 in section 7.3.3). The results of this for a typical company are shown in the lower half of Figure 61.

Figure 59 Typical example of the imapct of COVID on housheold and non-household consumption during 2020



Tables of the percentage values for each company will be provided under a separate report to allow companies to apply these to their previous normal year data.

9 The impact on night use

9.1 Introduction

A key part of determining leakage is removing legitimate usage from minimum night flow data. Leakage is quantified by measuring the flow into district metered areas DMAs, typically about 1000 properties in size and with flow meters measuring the net flow in each DMA. The minimum night flow is monitored during the night, typically between 3am and 4am, when domestic and commercial consumption (or night use) is at normally at its lowest. Companies use a variety of methods for quantifying the average night use from households and from non-households.

We were asked to investigate whether night use from households and non-households has been affected by the change in consumption during the COVID period. In order to do this, we require a long time series of data pre-COVID and data through the COVID period to allow us to investigate any change due to COVID, over and above any changes we would expect from weather. Therefore, we investigated any impact on household night use using data from Affinity Water's night use fast logging monitor, and the impact on non-household night use using Severn Trent Water's non-household monitor. These are described in the next two sections.

9.2 Household night use

Affinity Water's fast-logging night use monitor includes about 200 single feed largely domestic DMAs across their company's area, this includes about 200,000 households. The monitor has been used for reporting household night use (HHNU) for about 6 years.

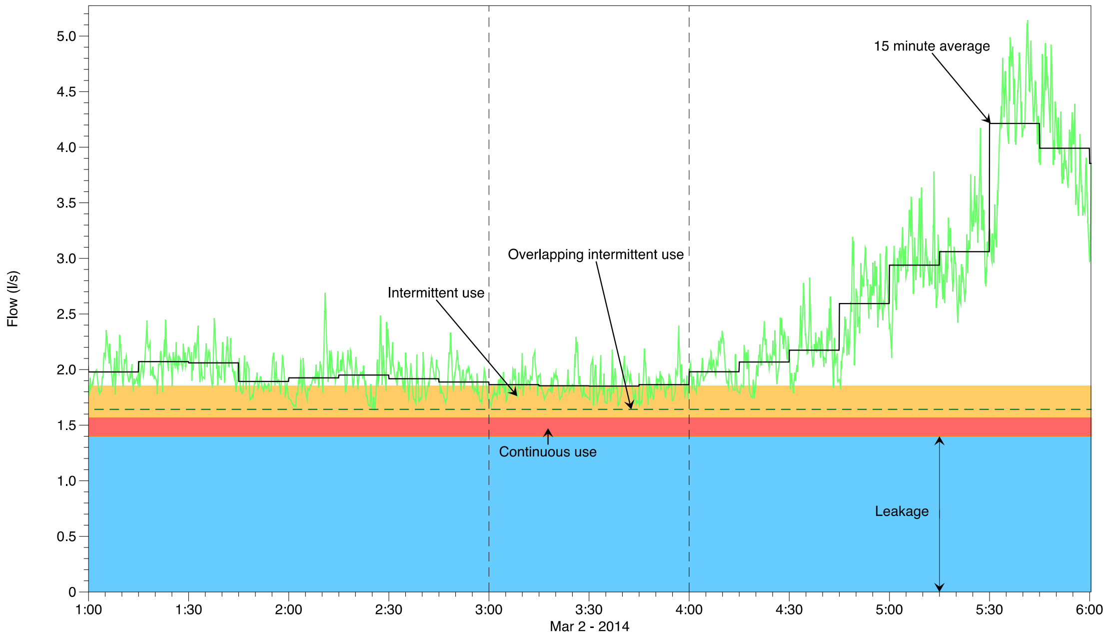
The term 'fast-logging' describes the process of measuring flow using high resolution data to estimate the continuous flow boundary, i.e. the level at which flow is continuous, providing an estimate of leakage. This value is typically recorded at night when flow is at its lowest. When combined with the 15-minute night flow value (coarse flow) an estimate of night use can be made, which is further corrected for influences such as commercial properties or area size.

The basis of the fast-logging[9] method is shown in Figure 60. the 15-minute average flow (MNF/coarse flow) in black, and the 1–second fine flow in green. The fine flow penetrates down through the minimum night flow (MNF) towards the boundary between leakage and household night use; it penetrates down to a level indicated by the green dotted line. This is the amount of intermittent night use that the fine flow can detect.

Below this level there are two further components of night use, and these are the continuous night use (flow from individual properties that is approximately constant during the minimum night flow period) and overlapping intermittent use (this is intermittent flow within properties that appears as continuous flow at the area level because the intermittent flows in each household overlap).

[9] Fast logging for improved estimation of household night use (17/WM/08/66)

Figure 60 The fast logging method for deriving night use from area monitors



The basis of fast logging is to measure the 15-minute average flow (demand plus leakage) and subtract a minimum fine flow value (leakage plus continuous use) to derive an estimate for intermittent night use, over-lapping intermittent night use, and continuous use.

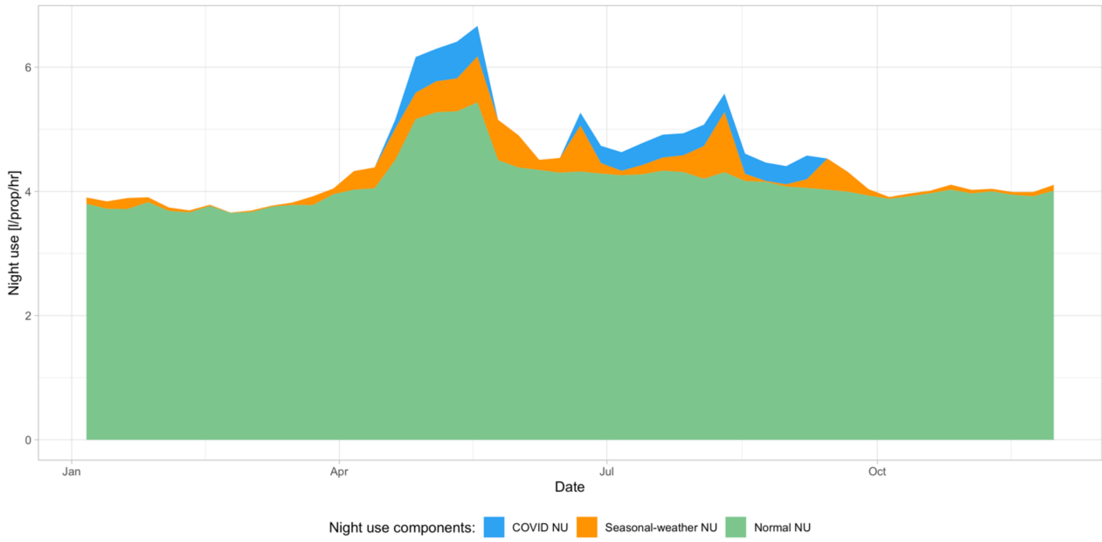
Because Affinity Water have a long time series set of data over many years, this is used to build a seasonal model for night use that assesses the influence of seasonal parameters such as the Ramadan period, holiday periods (schools, bank holidays, Easter and Christmas) and weather variables (temperature, rainfall and sunshine hours). The seasonal model assesses any change in over-lapping intermittent and continuous use.

Using the fast-logging data from 2016 to the end of November 2020, we started with the existing weather model and modified the model to include the COVID period. The modelling process was as follows:

- Take the fast logged consumption data for each of the monitor DMAs. 15-minute coarse flow and 10 second fine flow minima.
- Plot long term trend of 10 second minima per DMA and compute long term trend.
- Remove outlying points which may affect trend calculation (using standard deviations).
- Compute the minimum difference between the trend and the individual 10 second minima for each DMA.
- Import potential explanatory factors including: weather data, calendar events, seasonal metrics and the COVID timeline.
- Initial model exploratory analysis.
- Optimisation of model parameters and the introduction of transformations.
- Cross validation and resampling of the model. Examine model residuals to determine any unexplained variance and refine.
- Test model by comparing model metrics and reviewing HHNU outputs.
- Output model metrics and coefficients.
- Calculate final HHNU values.

The results of the modelling process are shown in Figure 61. This plot shows the normal night use (green) with the influence of seasonal factors including the weather experienced during the summer of 2020 (orange), and the impact from COVID (blue).

Figure 61 The impact from seasonal factors and COVID factors compared to normal night use



The peak we see from 23rd April to 23rd May is due to the Festival of Ramadan, during which night use behaviours can change significantly. This is a normal occurrence in Affinity Water's area and the impact varies from year to year depending on the timing of Ramadan and sunrise. In 2020 the period of Ramadan fell mostly within the COVID period Lockdown 1, with 10 days in the 1st Easing period. In addition, the weather was largely hot and dry during this period. We saw that over and above the increases due to hot weather, there was an increase which we can only attribute to COVID measures (shown in blue).

After Ramadan (from the 24th May to 22nd June), the models shows that the main influence was weather. After this period and into the first week of September, the model identifies a consistent period where there is an increase in night use from COVID measures. This is largely through the 2nd and 3rd Easing stages. The end of June and throughout August, which was hot and dry also shows a significant increase in night use from weather.

Table 12 shows for each week starting from the 20th April 2020, the increase in night use from COVID measures over and above the normal seasonally adjusted night use values (these are the blue areas shown in Figure 61). There was no detectable increase in night use due to COVID measures from the start of lockdown on 23rd March to the 20th April 2020.

This is data is from one data set, and each company's variation in household consumption could vary. Companies vary in their precise methods of deriving night use estimates households, but companies could use this data to explore the potential impact on their non-household estimates of night use.

Table 12 Increase in night use above normal seasonally adjusted figures due to COVID measures

Date (week beginning)	Increase in NU above normal seasonally adjusted values (%)	Comments
20/04/2020	2.88%	Ramadan
27/04/2020	10.27%	Ramadan
04/05/2020	9.08%	Ramadan
11/05/2020	10.15%	Ramadan
18/05/2020	7.96%	Ramadan
25/05/2020	0.00%	
01/06/2020	0.00%	
08/06/2020	0.00%	
15/06/2020	0.00%	
22/06/2020	4.11%	
29/06/2020	6.24%	
06/07/2020	6.91%	
13/07/2020	7.99%	
20/07/2020	8.12%	
27/07/2020	7.72%	
03/08/2020	7.28%	
10/08/2020	5.62%	
17/08/2020	7.60%	
24/08/2020	7.08%	
31/08/2020	7.13%	
07/09/2020	9.09%	

9.3 Non-household night use

This analysis uses the same data that we used in section 8, which covered the COVID impact on non-household daily consumption. Using this data, we have now looked at the consumption in the hour 3am to 4am and compared this with the use across the whole day (daily use).

For each sector we have aggregated the data into the COVID-19 phases (see section 3). We have also split the data into weekends and weekdays. We have used the following definitions in this analysis:

- Day use (DU) = mean flow across each 24 hour day aggregated by sector and phase.
- Night use (NU) = mean from 3am to 4am each day aggregated by sector and phase.
- NU to DU ratio = NU / DU
- All figures are reported in units of l/property/hour.

In Figure 62 we show the mean non-household day use and night use by sector and COVID phase for weekdays. Figure 63 shows the same for weekends.

Figure 64 then shows the night use to day use ratio by sector and COVID phase for both weekdays and weekends.

Both day use and night use have been impacted by COVID-19. The impact varies by commercial sector and is different for each phase of COVID-19 measures and policies. The pre-COVID phase can be used as a reference point for normal winter consumption.

The night use to day use ratios have changed significantly during the COVID-19 phases for some sectors, e.g. education, offices, hotels/restaurants and retail, and there are clear COVID measure and policies driving the change in consumption in these sectors. In other sectors the change is less clear.

This is data is from one dataset, and each company's variation in non-household consumption will vary, but all are likely to see a change in the relationship between day use and night, especially in the sectors highlighted. Companies vary in their precise methods of deriving night use estimates from non-household average daily consumption figures, but all will be impacted by the change in relationship between day and night use. Companies could use this data to explore the potential impact on their non-household estimates of night use.

Figure 62 Non-household day use and night use by commercial sector and COVID phase - weekday

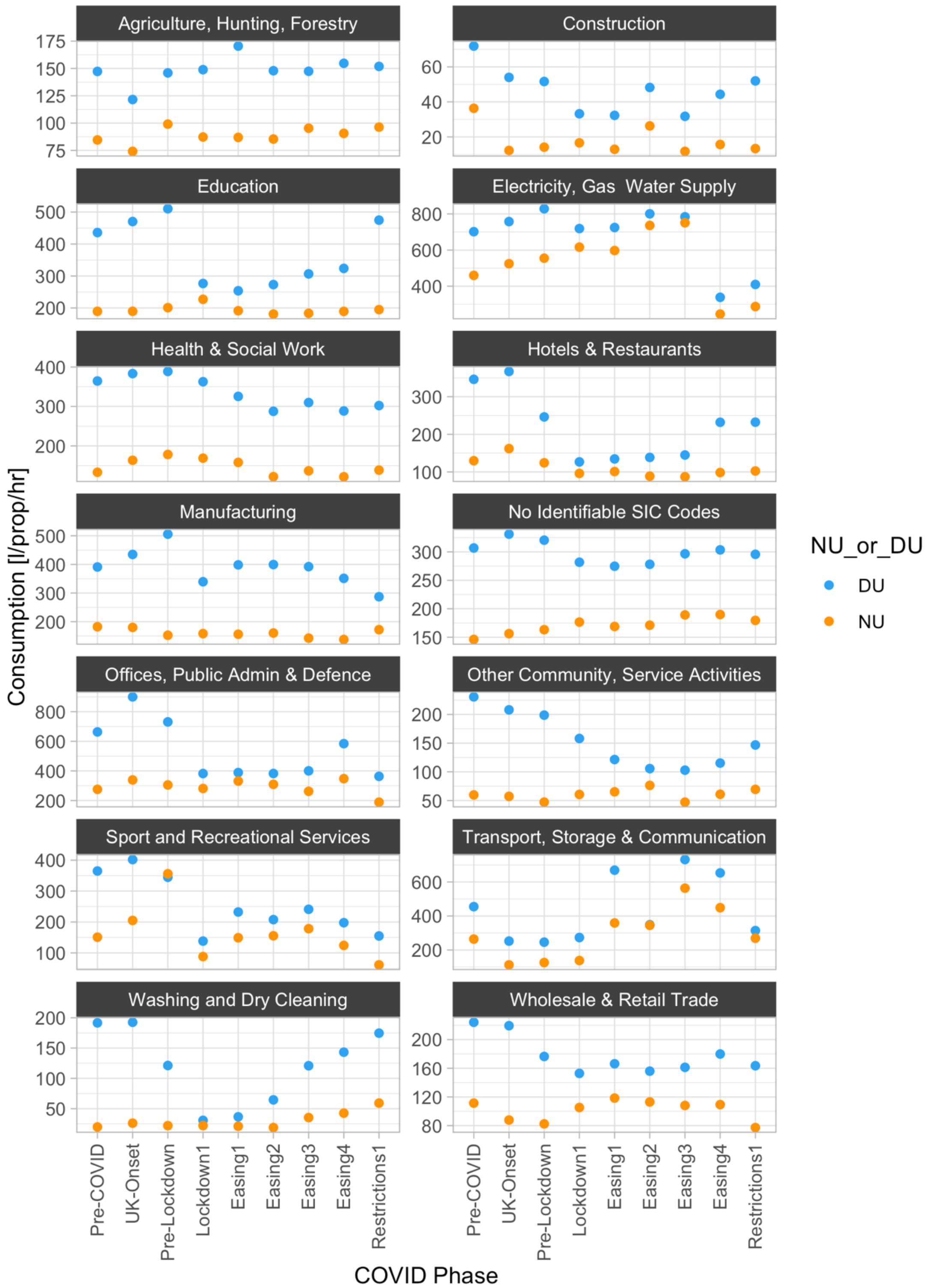


Figure 63 Non-household day use and night use by commercial sector and COVID phase - weekend

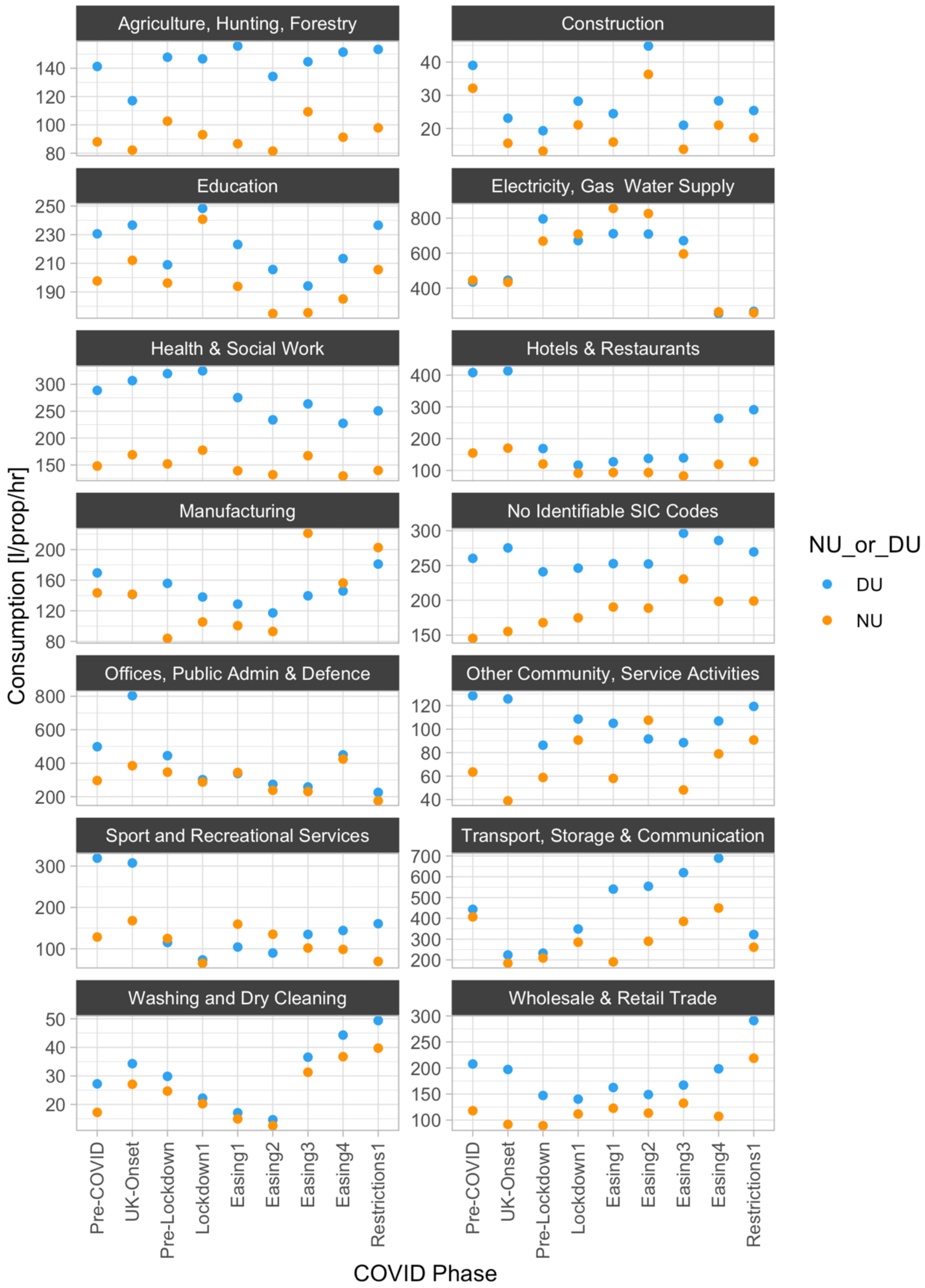
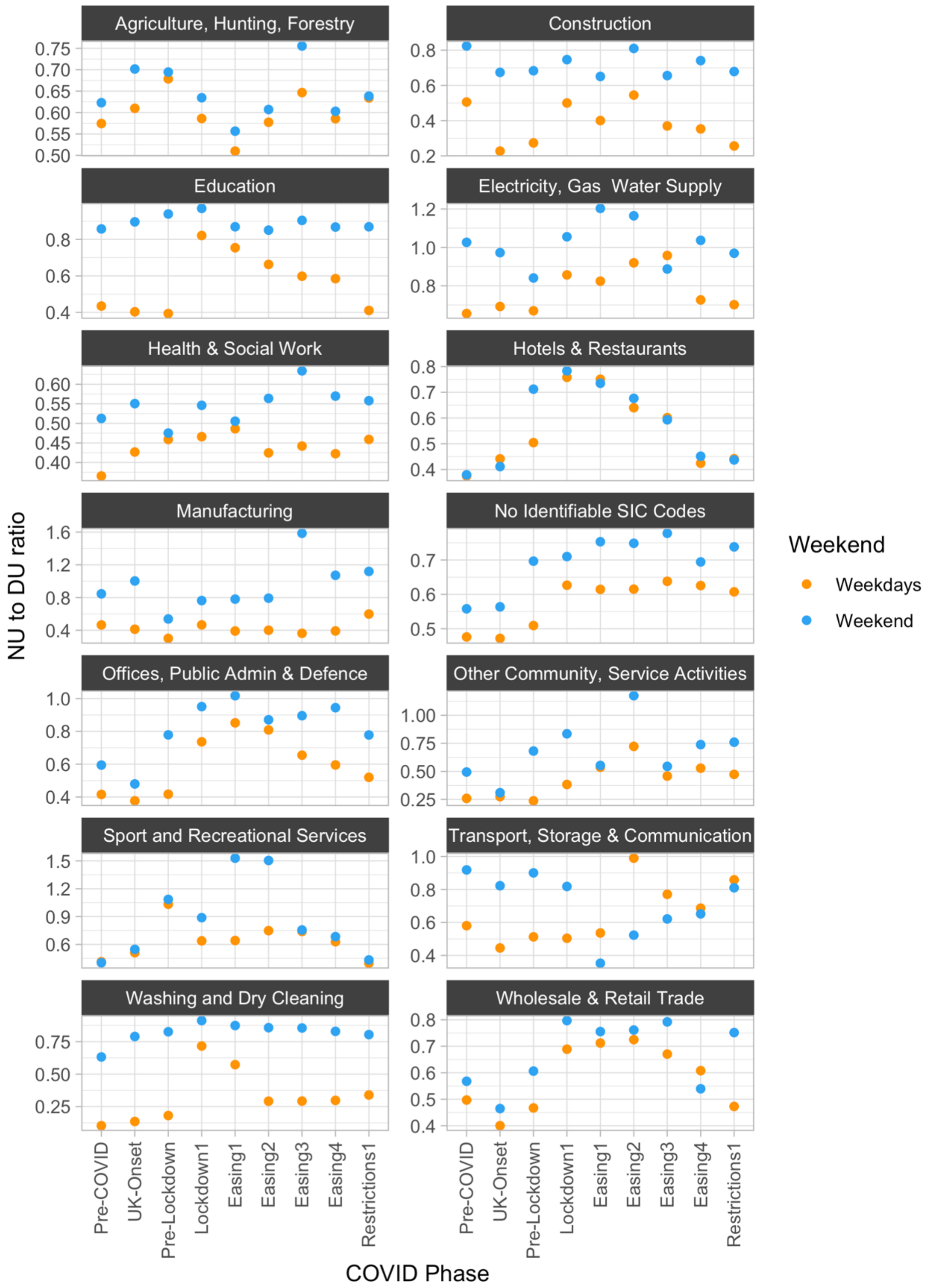


Figure 64 Non-household NU to DU ratio by commercial sector and COVID phase for weekdays and weekends



10 Impact on regulatory reporting

10.1 Impact on PCC

Water companies all have performance commitments to meet specific targets for per capita consumption (PCC) in AMP7. These are based on reductions from the average of PCC levels in 2017-18, 2018-19 and 2019-20. Performance against targets are assessed in each year of AMP7 based on a three-year rolling average.

COVID clearly had an impact on per household consumption (PHC) during 2020-21 as evidenced in this report. This will directly impact PCC as the population data has not changed and PCC is derived by dividing the total per household consumption by the total population. We do not know yet what will be the impact in 2021-22 and following years, but the first few months of 2021-22 will see COVID restrictions gradually eased. We do not know whether consumption behaviour will return to normal pre-COVID levels or whether a new normal will emerge (with more people working from home).

Due to the increases in consumption from COVID in 2020-21 companies will likely not meet the 2020-21 targets for PCC, but the increases in PCC in 2020-21 will impact the three-year rolling averages for 2021-22 and 2022-23, and possibly 2023-24 if consumption is higher in 2021-22 as well. However, if consumption returns to pre-COVID behaviours before the end of 2021-22 then companies could meet the end of AMP PCC target.

Under a scenario where a new normal emerges due to increased proportions of the population working at home and spending more hours in the home each day, this would present a challenge to companies in meeting their AMP7 PCC performance commitments in all years.

10.2 Impact on water resource planning

Under normal conditions, water companies would have used the year 2020-21 as the base year for household and non-household consumption forecasts. However, with the impact on both household and non-household consumption from COVID measures in 2020-21, then most companies will have to use 2019-20 as the base-year. This has been accommodated in the latest WRMP guidance, but places a responsibility on water companies to:

- assess the impacts on the water balance (such as from non-household use),
- describe how this affects the options companies have considered in their plans and consider scenario testing or adaptive planning,
- explain any uncertainty in PCC levels,
- describe how this affects the ability to meet any relevant planning assumptions in the national framework, regional plans and government aspirations to reduce PCC over the planning period,
- use improved and updated PCC data if it is available in your final WRMP,
- set out how forecasts will be reviewed during the planning period to monitor any short or long term changes and the impacts this could have on plans.

11 Discussion of findings

In this study we have gathered data from all the collaborators covering a timeline from before COVID up to the end of October 2020. This has included distribution input data, a selection of individual household monitor and smart meter data, a range of single feed DMA data, and a sample of non-household consumption data. This has been augmented with COVID policy data, data from the Office of National Statistics, and Google's mobility data to:

- Quantify the observed variations in consumption through lockdown to the end of October 2020 in different regions,
- Quantify the impacts on consumption during specific periods of lockdown,
- Explain the impact on reported consumption components and potential regulatory challenges.

It was important to understand how water consumption has quantitatively changed during the implementation of COVID-19 control policies such as lockdown and social distancing measures. Therefore, throughout this report we have used models to separate what would be the consumption under "normal conditions", from the variations due to lockdown measures. This will also allow us to understand what factors of lockdown influence the various components of water consumption to be able to predict future impacts (this will be addressed in the next report).

To allow us to look at the impact on consumption through the COVID-19 period in a systematic and consistent way, all the graphs and data in this report have been aggregated into a consistent timeline based on the English Government's policies, with differences in the Welsh governments response highlighted where necessary.

We were able to analyse the impact of COVID-19 measures on distribution input (DI) to over 80% of English and Welsh water resources zones from January through to the end of October 2020. During that period there was an estimated increase in total demand of about 360 Ml/d (1,000,000 litres a day) or about 2.6%. This is over and above that we would expect in 2020 due to the weather patterns through that period.

During this period, there were a few water resource zones that experienced a decrease in total demand. The most notable was the London zone, where the DI was reduced through the whole period. We think this was largely due to fewer people commuting into London for work or study, and also fewer tourists and visitors. This would lead to a reduction in water used in offices and the commercial premises that serve those offices, such as cafes, restaurants, pubs, hotels, entertainment and shopping centres. Those people would be spending their time in other places of residence outside London (increasing consumption in other WRZs where commuters live).

We were able to quantify the increase in DI in water resources zones around London and these numbers are provided in the report. This clearly shows that significant demand was redistributed between water resources zones and between companies during the COVID period.

One interesting point about the decrease in total demand in London, is that there is evidence that the resident domestic population increased their household consumption during this period.

The other zones that saw a decrease in total demand were smaller zones that have a large increase in tourist visitors at certain times of year. It was clear that visitors stayed away from these zones and consumption decreased at certain times in during the COVID period.

We also analysed total demand from much smaller areas of the water network known as DMAs (typically each DMA has about 1000 households in it). This allowed us to look at the changes in total demand at a much finer resolution (every 15 minutes during the day).

The analysis of the DMAs during the pre-COVID period demonstrates how consistent network flows are from day to day and year to year with the major influences for changes in patterns being weekdays and weekend, school holidays, Christmas, and summer weather.

Post COVID-19, after the 23rd March 2020, the patterns and scale of water flows change dramatically. Immediately the increase in morning flows starts later in the day, flows are higher through the morning period, and water use is higher in the evening period than in the morning period. As we progress through the summer there are significant peak flows during hot dry periods (higher than was seen in the peak summer of 2018).

We see similar patterns across DMAs from different geographic areas of the country: south, east, west and north, showing that the total demand in these areas has been increased during extended periods of the COVID-19 pandemic.

To understand what was driving these changes in total demand we looked at consumption in samples of household and non-household properties. In order to model the consumption during 2020 under non-COVID conditions we required at least daily data. In the end we analysed data from about 160,000 individual households and about 1,000 commercial properties (all anonymised). We also carried out a social science study with the University of Manchester which included focus group discussions aimed to get participants to reflect about how their domestic water practices have changed in the months following the government's 'stay-at-home' orders.

With more people staying in households for longer periods during the day due to working from home, being furloughed, or studying from home, it is not surprising that household consumption increased during the COVID period.

The increase in consumption was greatest during the hotter and drier periods. Peak increases in PHC (20% to 30%) were observed during easing 1 (mid-May to June) where most lockdown measures were still in place, and we saw a two-week period of hot weather at the end of a long 6-week dry spell. This indicates that there was a combinational impact from lockdown measures and hot-dry weather (greater than would have been observed with the weather factors alone).

There was evidence from the social science study that there was a change in the value and meaning attached to domestic gardens. With restrictions to mobility and reduced opportunities for other leisure activities, gardens have become key spaces for socialisation and mental health in challenging times, to take breaks from work, to get privacy from other household members, to entertain oneself, or for food production. This has fuelled an already growing popular interest in gardening as a leisure activity resulting in a rise in water consumption.

The social science study also highlighted that changes in daily patterns of indoor water usage are related to wider changes in the organisation of life and work. For those working from home, water consumption has relocated from public spaces (e.g. offices, gyms, canteens) into the home (e.g. drinking, flushing the toilet or washing dishes), as people have more time to invest in activities within the household (e.g. time saved from long commutes used in cooking or gardening) and have more flexible routines (e.g. showers are taken throughout the day instead of early morning).

We were able to observe changes in water consumption patterns through the day in individual properties during the COVID period. We saw a clear change in use after lockdown starts with more water being used through the day with the morning peak becoming less dominant. The biggest changes are during easing 1 as expected given the increase in PHC, and during this period we see the evening peak during weekdays becoming the dominant peak (in all three areas), suggesting outside use is a driver. We also see the increase in use through the day extending through to the end of the data period in November for weekdays and weekends.

We used the sub-daily flows to differentiate between internal use (water use by appliances and taps within the home) and external use (water use in the garden plant watering, filling of paddling pools, etc). All areas show a clear increase in external use during the easing 1 period (the second half of May) when there was an extreme hot and dry period. We also observed an increase in internal use during the COVID-19 periods.

Over the COVID period from March to October 2020 the average increase in household consumption (measured and unmeasured) from the household monitor samples was between 9% and 13%, but this figure will vary regionally.

Looking at the non-household or commercial consumption, we observed a lot of variability between different sectors during the COVID period. Some sectors saw a dramatic reduction in consumption during certain periods. The hotel and restaurant sector was badly hit by the COVID-19 pandemic. It started to see a reduction during the pre-lockdown phase, with a decrease in water consumption of about -30%, and reached a minimum during the lockdown period of about -70%. It did not recover much during the easing phases until easing 4. It still has not fully recovered. The sport and recreational services sector was significantly hit by the pandemic, with a decline in water consumption up to -60% during lockdown, and it has not recovered much, even considering a partial increase during the 4th easing. The education sector was impacted by school closures and remained lower than expected until the 4th easing and has recovered to normal level during the restriction phase (note our data for this report goes up to the end of October 2020 so does not include the latest, current, lockdowns).

Other sectors were affected less, for example essential services such as food production, utilities and health and social work were not impacted as much as their water consumption was not changed significantly.

The wholesale and retail sector was interesting. It saw an increase in water consumption during the UK onset and pre-lockdown phase; likely due to people stockpiling before the lockdown and to an increase in hygiene procedures in stores. Then there has been a decrease in water consumption during lockdown, as non-essential shops were asked to close. The recovery during the lockdown easing phases has not been steady and a decline occurred again in the new restriction phase.

Overall, the reduction in the consumption across the sample of non-household properties we analysed from March to October 2020 was about 25%.

Whilst there has been a reduction in non-household consumption, there has also been an increase in domestic household consumption. In the next report we will predict the overall change under a range of different COVID scenarios. However, what we observe from the total demand figures from distribution input data is that there has been in increase in total demand from March through to the end of October.

We have predicted the impact on household and non-household consumption during 2020, and this is presented in the relevant sections on household and non-households, along with predictions of future scenarios.

In terms of regulatory reporting, the increase in household consumption will impact the per capita consumption (PCC) performance commitment. This is because PCC is defined as the total household consumption (which has gone up) divided by the total population (which has remained unchanged). Because the performance commitment is based on a 3-year rolling average, the increase in PCC during 2020 will impact the performance commitment for several years (bearing in mind we do not know yet how long household consumption will remain elevated).

12 Conclusions

We have been able to quantify the impact on total demand, household consumption and non-household consumption due to COVID-19 policies and measures from February through to the end of October 2020. This is the impact over and above that we would expect to have seen given the weather in 2020 under non-COVID conditions.

During this period, the impact from COVID-19 policies and measures has been:

- An increase in total demand of about 2.6%.
- An increase in household consumption of around 9% to 13%, with the data we currently have we are unable to provide robust estimate for unmeasured and measured separately.
- A decrease in non-household consumption of about 25%.

There are regional and temporal variations in these numbers. The biggest increases in total demand are in the south (with the exception of London – see below), then the midlands/west, with the lowest increases in the north and east.

Using total demand data we have observed a redistribution of demand during the COVID pandemic. This is most clearly visible in the London resource zone which experienced a reduction in total demand, with total demand increasing in the zones surrounding London. This is probably due to fewer people commuting into London for work or study.

Temporal variations can be observed in each of the metrics.

- The increase in household consumption (PHC) was greatest during the hotter and drier periods. Peak increases in PHC (20% to 30%) were observed during easing 1 (mid-May to June) where most lockdown measures were still in place, and we saw a two-week period of hot weather at the end of a long (6-week) dry spell. This indicates that there was a combinational impact from lockdown measures and hot-dry weather (greater than would have been observed with the weather factors alone). Over the period from lockdown to the end of easing 4 (March to September) the average increase in PHC was between 8% and 10%. One dataset extended to early November and this area saw an increase in PHC of about 6% during the restrictions phase in October.
- For non-household consumption the temporal variations were different for different sectors. The hotel and restaurant sector started to see a reduction during the pre-lockdown phase, with a decrease in water consumption of about -30%, and reached a minimum during the lockdown period of about -70%, and did not recover much during the easing phases. The sport and recreational services sector was significantly hit by the pandemic, with a decline in water consumption up to -60% during lockdown, and it has not recovered much, even considering a partial increase during the 4th easing. The education sector was impacted by school closures and remained lower than expected until the 4th easing. Other sectors were affected less, for example essential services such as food production, utilities and health and social work were not impacted as much as their water consumption was not changed significantly.

A social science study with the University of Manchester carried out during this study suggests that there was a change in the value and meaning attached to domestic gardens, which has fuelled an already growing popular interest in gardening as a leisure activity resulting in a rise in water consumption. There were also changes in daily patterns of indoor water usage that are related to wider changes in the organisation of life and work, as people have more time to invest in activities within the household and have more flexible routines.

We were able to observe these changes in household water consumption patterns through the day. We saw a clear change in use after lockdown starts, with more water being used through the day with the morning peak becoming less dominant. The biggest changes are during easing 1 as expected given the increase in PHC, and during this period we see the evening peak during weekdays becoming the dominant peak, suggesting outside use is a driver. We also see the increase in use through the day extending through to the end of the data period in November for weekdays and weekends. We used the sub-daily flows to differentiate between internal use (water use by appliances and taps within the home) and external use (water use in the garden plant watering, filling of paddling pools, etc).

We have predicted the impact on household and non-household consumption during 2020, and this is presented in the relevant sections on household and non-households, along with predictions of future scenarios. These should allow companies to predict future impacts, until consumption over these periods can be quantified.

In terms of regulatory reporting, the increase in household consumption will impact the per capita consumption (PCC) performance commitment. This is because PCC is defined as the total household consumption (which has gone up) divided by the total population (which has remained unchanged). Because the performance commitment is based on a 3-year rolling average, the increase in PCC during 2020 will impact the performance commitment for several years (bearing in mind we do not know yet how long household consumption will remain elevated).

13 Recommendations

At the time of producing this report we have analysed data over the COVID period from January 2020 to the end of October 2020, and whilst we have predicted consumption beyond this, companies should put in place monitoring programmes to assess the impact from COVID as plans for easing restrictions develop during the current year 2021-22.

Further work is required to separate out the impact on measured and unmeasured household consumption.

Further work is required to improve the estimate of any changes to societal water use from the potential evolution in working practices, for example increased working from home.

More data and analysis is required to fully understand the difference in water consumption behaviours, and resulting PHC changes between measured and unmeasured households during COVID measures.

This report has demonstrated that there was a combinational impact from COVID measures and hot/dry weather. Further work is required to assess any potential impact on the security of supply index (SOSI) and on future peak demand factors.

Scenario modelling has been carried out for household and non-household consumption, further work could extend this to include future scenarios for distribution input.

