PR24 Climate Resilience Assessment

Phase B - Technical assessments

October 2022

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1 Introduction

As part of the development of their Price Review (PR)24, Northumbrian Water is looking to produce a climate resilience enhanced business case for submission to Ofwat. This enhanced business case requires a justification of the need, established as the additional expenditure that the utility is likely to incur as a result of future climate conditions and their impact on the operation and integrity of their networks and assets. Mott MacDonald has been commissioned to undertake detailed technical assessments of risks that have been highlighted as high and very high in a previous preliminary risk assessment.

1.1 Contextualisation of climate risks

An initial contextualisation phase (Mott MacDonald 2022c) was conducted prior to this work, which identified and ranked the future climate risks that are of the foremost relevance to Northumbrian Water geographies and operations. These are summarised in Table 1.1 and Table 1.2 respectively for the north-east (Northumbria) and the south-east (Essex and Suffolk) areas of Northumbrian Water operations.

The expected trend towards more frequent and extreme rainfall events is likely to increase the risk of flooding to water and wastewater assets. Particularly, floods will become significantly more extreme in the north-east associated with large scale storms, whereas in the south-east, summer convective rainfall will increase, potentially leading to localised flooding. The south-east of England will also suffer from higher increases in sea level and is thus at greater risk of coastal flooding. Increases in extreme wind, with impacts like those recorded during Storm Arwen, are another major risk for both supply areas. An increase in rainfall intensity is also likely to drive greater spikes in contaminants along watercourses with potential threat to the operation of river intakes and the effectiveness of treatment processes.

Droughts will intensify, above all in the south-east, where the increase in temperatures will be greater. Annual rainfall is expected to decrease in both areas, slightly more in the north-east, with drier summers and autumns anticipated. These mechanisms will affect soil moisture deficits with likely impacts on summer pipe bursts. Additionally, heatwaves like the ones experienced in summer 2018 and summer 2022 will become more frequent and hotter, especially in the south-east. Subsequent decrease in water availability and water quality, together with an increase in demand can pose considerable strain on the networks and the ability to move water around the system to maintain the supply-demand balance. Wastewater discharges to waterbodies with lower dilution capacity as a result of longer and hotter dry spells will risk achieving compliance, thus requiring additional treatment.

Table 1.1: Summary of key climate risks to Northumbrian Water- Northumbria

Hazard	Magnitude of consequences	Future likelihood of the hazard	Future risk level	Comment
Flooding	High	Greater	Very high	The risk is assessed as very high for Northumbrian given expected changes in peak flood flows and summer rainfall.
Wind	High	Greater	Very high	The North-East will see an intensification of winter windstorms like storm Arwen and Desmond
Drought and water scarcity	Moderate	Greater	High	The risk is assessed as high as decreases in summer rainfall and increases in temperatures are likely to be smaller than in Essex and Suffolk, leading to lower impacts, and because the system has considerable resilience.
Soil moisture deficits	Moderate	Greater	High	The risk is assessed as high as decreases in summer rainfall and increases in temperatures are likely to be smaller than in Essex and Suffolk, leading to lower impacts.
Water quality deteriorations	Moderate	Greater	High	The risk is expected to increase in the future and be more widespread.
Heat	Low	Greater	Medium	The risk is assessed as moderate given that the increase in temperatures is likely to be lower than in Essex and Suffolk.
Cold and freeze thaw	High	Lower	Medium	This risk will decrease progressively during the century with global warming.
Lightning	Low	Stable	Low	
Earthquake	Low	Stable	Low	
Coastal erosion	Low	Stable	Low	
Wildfire	Low	Stable	Low	
Snow	Low	Lower	Low	

Table 1.2: Summary of key climate risks to Northumbrian Water- Essex and Suffolk

Hazard	Magnitude of consequences	Future likelihood of the hazard	Future risk level	Comment
Drought and water scarcity	High	Greater	Very high	The risk is assessed as very high given that decreases in summer rainfall and increases in temperatures are likely to be greater than that in the North-East.
Wind	High	Greater	Very high	The risk is assessed as very high due to the projected intensification of windstorms and the possibility of cascading failures.
Soil moisture deficits	High	Greater	Very high	The risk is assessed as very high given that decreases in summer rainfall and increases in temperatures are likely to be greater than that in the North-East.
Flooding	Moderate	Greater	High	The risk is assessed as high given the absence of wastewater assets. To note that the risk of coastal flooding is likely to be greater in the South-East due to higher increases in sea-level and the low-lying nature of the area.
Heat	Moderate	Greater	High	The risk is assessed as high given that the increases in temperatures are likely to be greater than that in the North-East.
Water quality deteriorations	Low	Greater	Medium	The risk is assessed as medium in absence of wastewater systems that are more likely to be impacted by lower river dilution.
Cold and freeze thaw	High	Lower	Medium	This risk will decrease progressively during the century with global warming.
Lightning	Low	Stable	Low	
Earthquake	Low	Stable	Low	
Coastal erosion	Low	Stable	Low	
Wildfire	Low	Stable	Low	
Snow	Low	Lower	Low	

1.2 Aims and objectives

The objective of this second phase is a more detailed quantification of some of the risks highlighted in Section 1.1, together with an evaluation of the physical and financial impacts that future climate conditions will lead to. In line with Ofwat requirements, these evaluations are undertaken for both RCP2.6 and RCP8.5, a low and high emission scenario respectively, to encompass the range of possible futures. Following Ofwat guidance on long-term delivery strategies, the work has focussed on investigating impacts for the 2050 time horizon for the two scenarios and across both NW and ESW supply areas.

Particularly, the focus of the technical work has been on quantifying the following risks:

- Fluvial, surface water and coastal flooding driven by changes in rainfall and sea level rise;
- Summer pipe bursts resulting from increased temperatures and drought conditions and increases in soil moisture deficits;
- Water quality deterioration from increased storm events and sea level rise;
- Water quality deterioration from extreme heat and drought conditions;
- Impacts of extreme heat on wastewater and clean water assets; and,
- Winter pipe bursts driven by freeze thaw events.

These assessments aim to inform on the level of changes (positive or negative) of the different risks, and in particular, to provide a range of additional costs that climate change could provoke by mid-century across both supply areas so that optioneering on adaptation measures can take place.

1.3 Structure of the report

The report is structured as follows:

- Section 2 summarises the data gathered and used for the definition of baseline conditions and future climate trends;
- Section 3 details the pipe bursts assessment conducted in relation to future changes in summer and winter conditions;
- Section 4 presents the water quality investigations undertaken for extreme rainfall, extreme heat and long dry spells events;
- Section 5 summarises the outcomes of extreme heat assessments and the additional impacts on asset operations;
- Section 6 highlights the likely changes in flood risk across both supply areas and associated potential damages; and
- Section 7 compiles the main findings and provides recommendations for future work.

2 Data gathering

Data was gathered and processed to obtain the necessary information for the definition of baseline and future conditions. These include a set of climatological, hydrometric and water quality data combined with asset-specific and cost information.

2.1 Baseline data

2.1.1 Meteorological and hydrometric data

Met Office HadUK data[1] was used for developing an understanding of baseline rainfall and temperature conditions across the two supply areas. The data was extracted from gridded datasets at 12km resolution for a suite of point locations:

- Daily maximum temperature was extracted at five locations in Northumbria (Berwick upon Tweed, Alnwick, Newcastle, Consett and Middlesbrough) and three locations across Essex and Suffolk (Southend, Lowestoft, Chelmsford) for the conduct of the extreme heat analysis;
- Daily maximum and minimum temperature and daily rainfall was extracted at the same eight locations and used for summer and winter pipe bursts investigations. The datasets were post-processed to derive Standardised Precipitation Evapotranspiration Index (SPEI) metrics at those same locations; and,
- Daily maximum temperature was extracted at Hanningfield and Fontburn reservoirs for the associated algal blooms and THM investigations.

The selected locations for extreme heat and pipe burst investigations aimed to provide a good spatial coverage of rainfall and temperature patterns across the areas of services, while being close to main assets.

Catchment rainfall series, post-processed from HadUK gridded data for the delivery of regional rainfall- runoff models (Mott MacDonald 2021a, 2021b) to support WRMP24, were used for undertaking investigations on turbidity and sulphates that needed to consider patterns across a wider area. Rainfall series for catchment draining to the following locations were used in this regard:

- Tees at Darlington Broken Scar;
- Tyne at Bywell;
- Wear at Chester-le-Street; and,
- Coquet at Morwick.

Flow data was collated at the same locations from the Environment Agency Hydrology Data Explorer[2]. In addition, flow series at Ellingham Mill were obtained from the same source and combined with tidal gauged series at Lowestoft downloaded from the BODC repository[3] to evaluate the impact of high flows and sea level on turbidity at Barsham.

Finally, water temperature data was further accessed from EA[4] records at Fontburn Reservoir over the 1998-2007 period and used for the delivery of Trihalomethane (THM) investigations.

[1] HadUK-Grid - Met Office
[2] Hydrology Data Explorer
[3] Download UK Tide Gauge Network data from BODC
[4] Surface Water Temperature Archive up to 2007 - data.gov.uk

2.1.2 Water quality data

Water quality monitoring data was received from NWL for intake locations across both supply areas. Data was received and reviewed for Barsham, Broken Scar, Horsley, Ormesby, Mosswood, Lumley and Warkworth as river intake locations as well as Hanningfield, Abberton and Fontburn as reservoir locations. Of particular relevance for the analysis, records of turbidity, iron, nitrate, sulphate and algal counts were reviewed. However, the absence of correlation between water quality and rainfall and/or flow data prevented the use of turbidity, iron and nitrate measurements. The Environment Agency WIMS records[5] for turbidity were instead used for the conduct of baseline investigations at the following locations:

- River Tees at Broken Scar – records between 2000 and 2021;
- River Waveney at Ellingham Mill – records between 2004 and 2015;
- River Tyne at Bywell (Horsley) – records between 2000 and 2021;
- River Wear at Chester New Bridge (Lumley) – records between 2000 and 2022; and,
- River Coquet at Warkworth Dam – records between 2000 and 2022.

Algal counts in Hanningfield Reservoir recorded by NWL between 2004 and 2021 were used for the conduct of algal bloom assessments. Similarly, sulphate levels at Lumley obtained from NWL for the 2000-2022 baseline period were used to investigate increasing levels during low flow conditions. Discontinuous records of THM levels during summer 2018 in Fontburn reservoir were finally used for high-level investigations of the impact of extreme heat events on THMs.

Results from the SAGIS water quality modelling feeding into the WINEP investigations carried out by Mott MacDonald and Stantec teams were analysed to determine current levels of phosphate at 40 sewage treatment work (STW) locations and ammonia at 4 STW locations across NW area (3 of those STWs being the same sites as for phosphate), where effluent discharges occur. Current baseloads of phosphorus and ammonia as well as Q95 data were extracted alongside At Permit levels for phosphorus and ammonia and At Permit levels after Environment Act reductions for phosphorus only. Output target load for Good WFD status in each receiving water body were used in the climate analyses to evaluate the possible impact of future climate conditions on the discharge of effluents.

2.1.3 Flood risk data

Publicly available flood maps and information have been used by Stantec in their preliminary Climate Change Flood Risk Assessment, which is reported separately. They include:

- Fluvial Flood Risk (undefended): Environment Agency Flood Map for Planning Flood Zones 2 and 3 (1 in 1000-year and 1 in 100-year, respectively)
- Fluvial Flood Risk (defended): Environment Agency 'Long term flood risk maps for rivers and the sea' including layers associated with High (up to 1 in 30yr), Medium (30yr to 100yr), Low (100yr to 1000yr) and Very Low (>1000yr) risk.
- Pluvial Flood Risk: Environment Agency 'Long term flood risk maps for surface water', including layers associated with High (1 in 30yr), Medium (1 in 100yr) and Low (1 in 1000yr) risk.
- Tidal Flood Risk (undefended): Environmental Data WMS Service layers for "Costal Flood Boundary Extreme Sea Levels", including present day 1 in 200 year and 1 in 1000 year levels.
- Tidal Flood Risk (defended): Environment Agency 'Areas Benefitting from defences' dataset and "NCERM-2018 Tidal Defence" layer.

[5] Open WIMS data

2.1.4 Asset deterioration/failure data

2.1.4.1 Pipe bursts

Two sets of historical records - pipe bursts and leakage - were provided by NWL to inform the pipe burst analyses. The received pipe burst dataset with records from 2004 to 2021 is the one used by NWL deterioration modelling team and gives details on date, soil type, pipe material, age and diameter for each burst. The information provided suitable granularity and length of record to undertake the technical assessments. Weekly leakage values were also obtained but the short length of records (only starting in 2017) prevented its use for the definition of robust baseline conditions. The total length of different pipe materials across ESW and NW areas and more specifically the length of asbestos cement and cast iron pipelines in clay and non-clay soils were also provided by NWL deterioration modelling team (2021 statistical data).

2.1.4.2 River intakes limit of actions

Thresholds and limit of actions can be put in place at river intakes to monitor the need for altering operations in response to high levels of turbidity or other chemicals in the river stream. These were obtained from NWL operatives at a number of locations:

- At Ellingham Mill (Barsham), two action limits are set at 75 NTU and 150NTU respectively. While the first threshold is typically escalated as a warning, the second threshold signals the need to stop or reduce abstraction for a better blending;
- At Horsley, the limit for the new process is set at 50 NTU. Previous records of incidents showed that the raw water can reach up to 150 NTU;
- At Lumley, a limit of 250mg/l on sulphate is in place for compliance. Furthermore, there is an action limit at 20 NTU (turbidity) to start sampling for cryptosporidium. From the SCADA in place at the river intake, a high alarm is set at 30 NTU and very high at 50 NTU although these are not set as shut-down triggers; and,
- At Warkworth, the trigger limit is set at 100NTU.

To note that no turbidity limits are specified for Broken Scar intake as the works can cope with high levels of turbidity with sufficient chemical dosing applied.

2.2 UKCP18 data extraction

2.2.1 Probabilistic projections

Probabilistic projections of monthly changes in rainfall, maximum and minimum temperature were extracted from the UKCP18 user interface[6] for RCP2.6 and RCP8.5 for use in the rainfall-runoff modelling undertaken for the water quality assessments. Projections were extracted for both the North-East of England and East of England and for the 2040-2069 epoch relative to a 1981-2010 baseline. In line with Ofwat's recommendation, the 50th percentile of each projection was adopted. While rainfall anomalies were used directly in the modelling, maximum and minimum temperature anomalies were used to estimate changes in Potential evapotranspiration (PET) using Penman-Monteith equation. Associated monthly factors are presented in Table 2.1 and Table 2.2, showing a trend towards wetter winters and drier summer and an increase in PET more accentuated during the summer months.

[6] Welcome to UKCP (metoffice.gov.uk)

Table 2.1: Monthly factors for rainfall and PET in North East England for the 2050s

	RCP2.6		RCP8.5	
Month	**Rainfall**	**PET**	**Rainfall**	**PET**
Jan	4.8%	4.2%	7.6%	7.3%
Feb	7.6%	1.1%	9.8%	3.2%
Mar	-2.2%	1.2%	-3.0%	3.4%
Apr	-2.1%	4.0%	-4.2%	6.5%
May	-0.8%	3.6%	-2.5%	7.1%
Jun	-6.3%	4.1%	-8.0%	6.0%
Jul	-11.2%	6.9%	-15.8%	10.1%
Aug	-9.5%	8.0%	-13.0%	10.0%
Sep	-7.5%	7.4%	-8.9%	10.4%
Oct	2.8%	3.5%	5.8%	6.6%
Nov	7.1%	3.0%	9.3%	5.8%
Dec	2.0%	2.2%	5.4%	3.6%

Table 2.2: Monthly factors for rainfall and PET in the East of England for the 2050s

	RCP2.6		RCP8.5	
Month	**Rainfall**	**PET**	**Rainfall**	**PET**
Jan	5.4%	3.6%	9.0%	7.5%
Feb	8.1%	1.9%	10.1%	4.6%
Mar	-0.3%	4.4%	-1.2%	8.3%
Apr	-1.2%	4.8%	-3.2%	7.7%
May	1.8%	5.9%	-6.0%	9.9%
Jun	-10.5%	4.3%	-13.2%	6.9%
Jul	-12.0%	8.2%	-17.7%	13.0%
Aug	-16.5%	8.8%	-20.6%	11.9%
Sep	-13.4%	9.1%	-14.8%	12.9%
Oct	2.3%	4.3%	6.1%	7.5%
Nov	7.7%	4.1%	12.7%	7.9%
Dec	3.6%	1.8%	7.4%	3.4%

2.2.2 Regional projections

Regional projections at 12km spatial resolution were extracted from UKCP18 using the files stored in the CEDA archive[7] to support the assessments where daily projections are required, in particular:

- Maximum and minimum temperature for analysing changes in freeze thaw events;
- Maximum and minimum temperature, wind speed and daily rainfall for analysing changes in soil moisture deficit leading to summer pipe bursts;
- Maximum temperature for analysing changes in extreme heat leading to algal blooms, THM spikes and other impacts to water and wastewater assets;
- Daily rainfall for analysing changes in extreme rainfall leading to turbidity incidents.

[7] Dataset Record: UKCP18 Regional Projections on a 12km grid over the UK for 1980-2080 (ceda.ac.uk)

They corresponded to 2050 (2036-2065) and were compared to a 1991-2020 baseline. In all cases, raw projections were bias corrected using Scaled Distribution Mapping[8] and HadUK observations. This correction is required to remove modelling biases so that absolute projections values can be adopted.

Regional projections are only available for RCP8.5. In order to estimate changes associated with RCP2.6 in 2050, the global warming level method recommended by the Met Office[9] was followed, where the timing of reaching the global warming level associated to RCP2.6 and 2050 was identified within the RCP8.5 trajectory, and RCP8.5 projection at that time used to characterise RCP2.6 future.

Average level of global warming in 2050 for RCP2.6 is 1.7°C compared to preindustrial levels. This increase in global temperature is expected to happen in 2030 following the RCP8.5 trajectory and therefore RCP8.5 projections for 2016-2045 (centred in 2030) were used for RCP2.6.

2.2.3 Marine projections

UKCP18 marine projections of sea level anomaly (relative to the baseline of 1981-2000) for the coastal grid-cell including Lowestoft were processed to derive the change in 2050 for the 50th percentile and the two emission scenarios, indicating seal level rises of 0.24m and 0.30m for RCP2.6 and RCP8.5 respectively.

2.3 Cost information

2.3.1 NWL costs

2.3.1.1 Pipe repair and replacement

Pipe mains repair and replacement costs have been obtained from NWL exploratory data analysis models which were compiled in 2016 and are currently under the process of being updated to account for more recent costing information.

Repair costs per burst were provided for three bands of pipe diameters and separately for the three Essex, Suffolk and North areas. Costs increase for larger pipe diameter and remain overall lower in the north-east area in comparison to those applied in the south-east (Table 2.3 and Table 2.4).

Pipe mains replacement costs per meter were provided for each supply zone within the three service areas and for each pipe diameter. These include an allowance for comms pipes, boundary boxes and ferrule connections. Similarly, replacement costs are overall higher for the south-east area and larger pipe diameters.

Updated costs have not been received to date however, the 2016 costs have been uplifted in the analyses to reflect the total observed repair/replacement costs of the 2018 heat wave. To not that these do not consider costs for loss of service.

[8] HESS - Scaled distribution mapping: a bias correction method that preserves raw climate model projected changes (copernicus.org)

[9] UKCP18-Derived-Projections-of-Future-Climate-over-the-UK.pdf (metoffice.gov.uk)

Table 2.3: Historical mains repair costs

Repair cost/burst	Essex	North	Suffolk
0-150mm diameter	£1,289	£720	£1,819
150-300mm diameter	£1,999	£2,008	£2,417
>300mm diameter	£2,965	£1,661	£2,965

Table 2.4: Average historical mains replacement costs

Replacement cost/m	Essex	North	Suffolk
38-50-63mm diameter	£195	£122	£150
75-80-90mm diameter	£213	£147	£160
100-110-125mm diameter	£213	£150	£165
150-180mm diameter	£273	£219	£202
200-225mm diameter	£348	£245	£239
250mm diameter	£459	£364	£365
300-315mm diameter	£550	£369	£371
>315mm diameter	£676	£460	£613

2.3.1.2 Outages and price of water

The reporting of planned and unplanned outages between April 2019 and March 2022 across both Northumbria, Essex and Suffolk areas were received from NWL. The data was reviewed to filter those recent outages linked to high levels of turbidity, algae or other contaminant at all relevant surface water sites. All relevant water quality outages are reported as exclusions to the regulator and thus do not fall within the unplanned outage category that comes with penalty costs. For each reporting event, the number of days and associated megalitre of water lost per day during the outage have been used to feed into the assessment of physical impacts of recent extreme weather events driving spikes in certain water quality parameters.

The outage data was correlated with unit cost details provided for surface water sites across the Northumbria, Essex and Suffolk areas for the year 2022 (up to August). The data gives the details of actual fixed, variable and total costs associated with the operation of a given site and was used to estimate the costs (in £/Ml) resulting from a given outage.

2.3.1.3 Extreme heat events

Cost data was supplied by NWL, summarising expenditure that occurred on the clean water assets and networks throughout 2022 as well as during the 2018 summer months (July to September). These include total costs associated to a range of paid overtime, fuel, contractors, plant hires, traffic management, materials, chemicals and tankering expenditures. In addition, total annual costs for operations and capital recharge costs were provided by NWL and these are broken down by areas of expenditure. No long-term financial data was provided on a monthly basis, restricting the ability to understand the additional costs of operating under heat wave conditions such as those that occurred during summer 2018 and summer 2022.

Additional ad-hoc evidence was provided for impact costs specifically on the wastewater system; including data for Brand Sands, Howdon and Sherburn sites. The data however do not give the necessary long-term records for conducting a detailed financial analysis for the future. Four-years of quantities and subsequent cost data for the supply of septicity control chemicals was further provided; showing an upward trend between 2019 and 2022. A monthly review of the data however could not demonstrate a specific increase in the quantities during the 2018 and 2022 summer months when heat waves occurred.

2.3.2 Flood damage costs

In the absence of a flood damage curve specific to Northumbrian Water assets, standard flood damage costs have been extracted from the Multi Coloured Manual[10]. Non-residential properties (NRP) weighted annual average damage (WAAD) costs have been used to allow for an assessment of flood damages. The WAAD method was adopted in the absence of flood depth information at the flooded site. A single value of damage cost was thus applied for a given standard of protection (assumed to be 50 years for baseline conditions) and generic values for sub-stations were used. The other industry sub-group was found to be too generic and not sufficiently representative of the nature of water and wastewater assets. Applied WAAD values are summarised in Table 2.5.

Table 2.5: NRP WAAD 2022 values

		Standard of Protection						
MCM code	**Sector Type**	**None**	**5**	**10**	**25**	**50**	**100**	**200**
960	Sub-station	260.74	158.16	113.18	61.88	27.99	7.00	3.50

Source: Multi Coloured Manual – WAAD method (2022)

[10] MCM-Online – The Multi Coloured Manual – Online

3 Investigation of pipe bursts

The outcomes of the contextualisation work highlighted an increase in drought conditions in catchments across both the south-east and the north-east. Dry conditions in soils are known to cause additional bursts through shrink-swell processes that exert extra pressure on the pipes. Additionally, a review of freeze-thaw events also known to cause pipe bursts during winter was conducted as a sense-check of the initial conclusions about a reducing trend drawn during the previous contextualisation work.

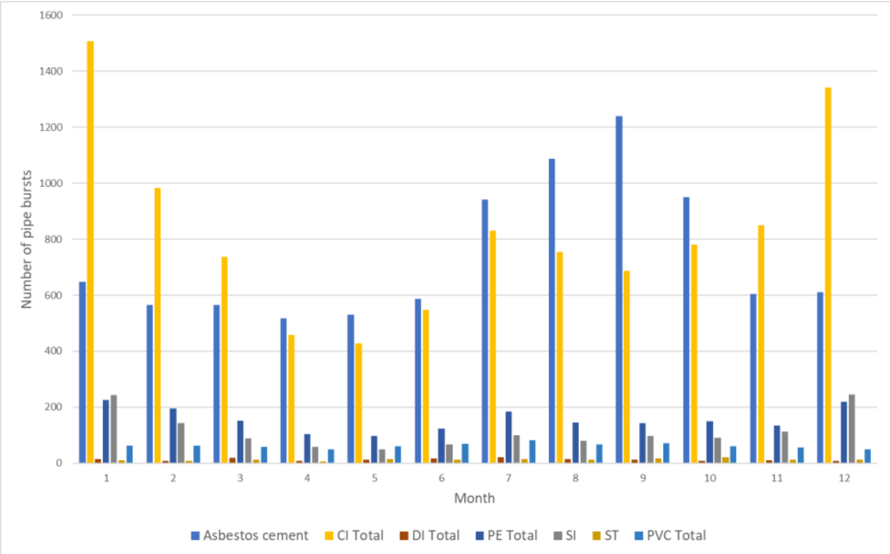
3.1 Summer pipe bursts

3.1.1 Definition of baseline conditions

A review of the data provided shows that asbestos cement (28%), cast iron (27%) and polyethylene (26%) pipes cover most the ESW network whilst across NW area, cast iron (31%), polyethylene (30%) and PVC (23%) pipes are prevalent. Volumes of pipe bursts across the network however vary with regards to differing soil types, material and diameter. An analysis of the deterioration modelling data shows that:

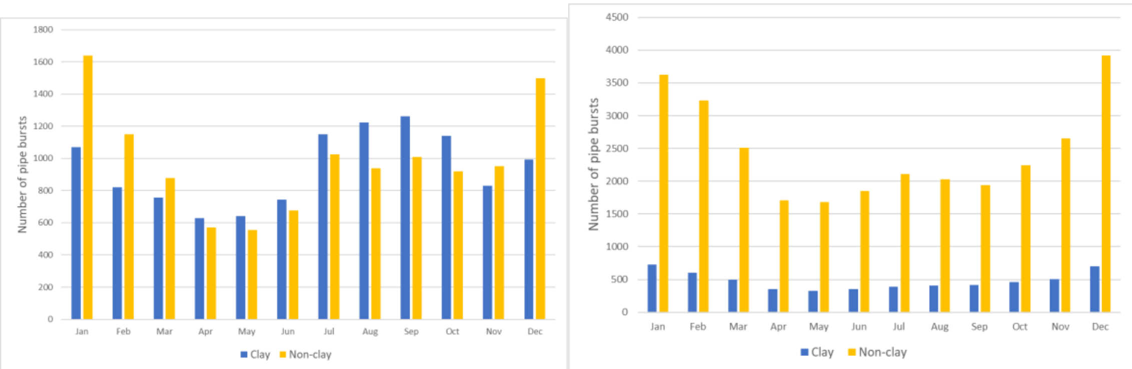
- The majority of pipe bursts across the ESW network occurs on asbestos cement and cast iron pipes whilst bursts are prevalent on cast iron, UPVC and asbestos cement pipes in NW area. On this basis, polyethylene pipes are excluded from the analysis for both areas;
- Increases in asbestos cement bursts occur mainly between July and October whilst cast iron bursts increase during the winter months (November to February) across both ESW (Figure 3.1) and NW areas;
- More than 80% of the asbestos cement and cast iron pipe bursts occur for diameters ranging between 70 and 150mm in ESW. Similarly, 90% of the cast iron bursts across NW occur on 75mm-100mm and 150mm diameters (volume of asbestos cement bursts in the north-east is comparatively small);
- Higher volumes of bursts occur in non-clay soils across NW with spikes during the winter months. In ESW, similar volumes are recorded overall with spikes between July and October in clay soils and between December and February in non-clay soils (Figure 3.2); and,
- A small portion of asbestos cement pipes are present in clay soils across NW which correlate with the small number of pipe bursts historically recorded. Reversely, more than double the length of cast iron pipes in NW sits on non-clay soils in comparison to ESW.

Figure 3.1: Seasonal variations in number of pipe bursts for different materials in ESW



Source: Mott MacDonald based on NWL data

Figure 3.2: Seasonal variations in number of pipe bursts for different soil types in ESW (left) and NW (right) areas



Source: Mott MacDonald based on NWL data

Pipe networks are susceptible to cracks and bursts under specific conditions when soil moisture deficits increase and lead to the shrink-swell of soils. Building on the understanding of this failure mechanism, a correlation between the number of summer pipe bursts and the SPEI metric was sought. SPEI was calculated from rainfall, temperature and wind speed data and represent a good proxy to soil moisture deficit, with negative values signalling drier conditions than average. It is a well-known drought index used worldwide to determine the onset, duration and magnitude of drought conditions. For this particular assessment, it was calculated for different durations – 1, 3, 6 and 12 months (SPEI-1, SPEI-3, SPEI-6 and SPEI-12) that could lead to summer soil moisture deficit.

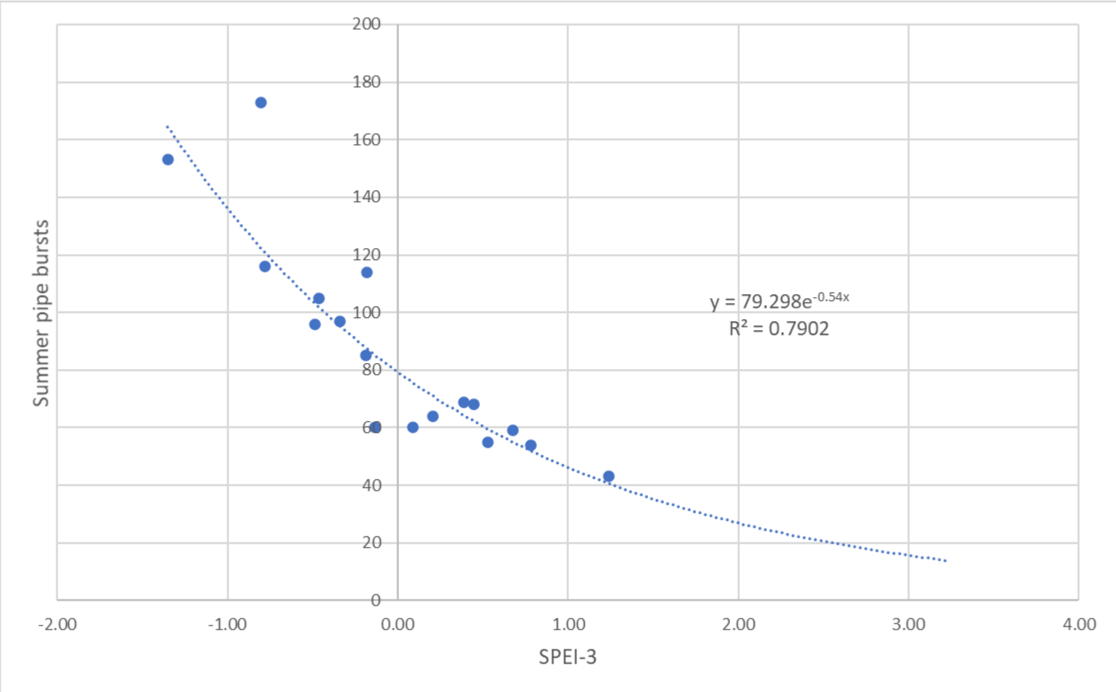
Pipe bursts between July and October were reviewed against the different SPEI metrics and best correlations were found with SPEI-3. Thus, decreases in SPEI-3 below zero, representing increases in soil moisture deficit, correlate well with increases in pipe bursts over the drier/hotter months. In the south-east, different correlations were adopted for cast iron and asbestos cement pipes, recognising the differential volume of bursts as a function of material. Similarly, different correlations were adopted for clay and non-clay soils, recognising that clay soils are more susceptible to the shrink-swell process. Adopted correlations are presented in Figure 3.3 to Figure 3.6.

Over the 2004-2021 baseline period, the 95th percentile (high) volumes of pipe bursts between July and October are:

- 157 bursts of asbestos pipes in non-clay soils equivalent of 0.12 burst/km;
- 294 bursts of asbestos pipes in clay soils;, equivalent of 0.21 burst/km
- 146 bursts of cast iron pipes in non-clay soils, equivalent of 0.08 burst/km; and,
- 123 bursts of cast iron pipes in clay soils, equivalent of 0.21 burst/km.

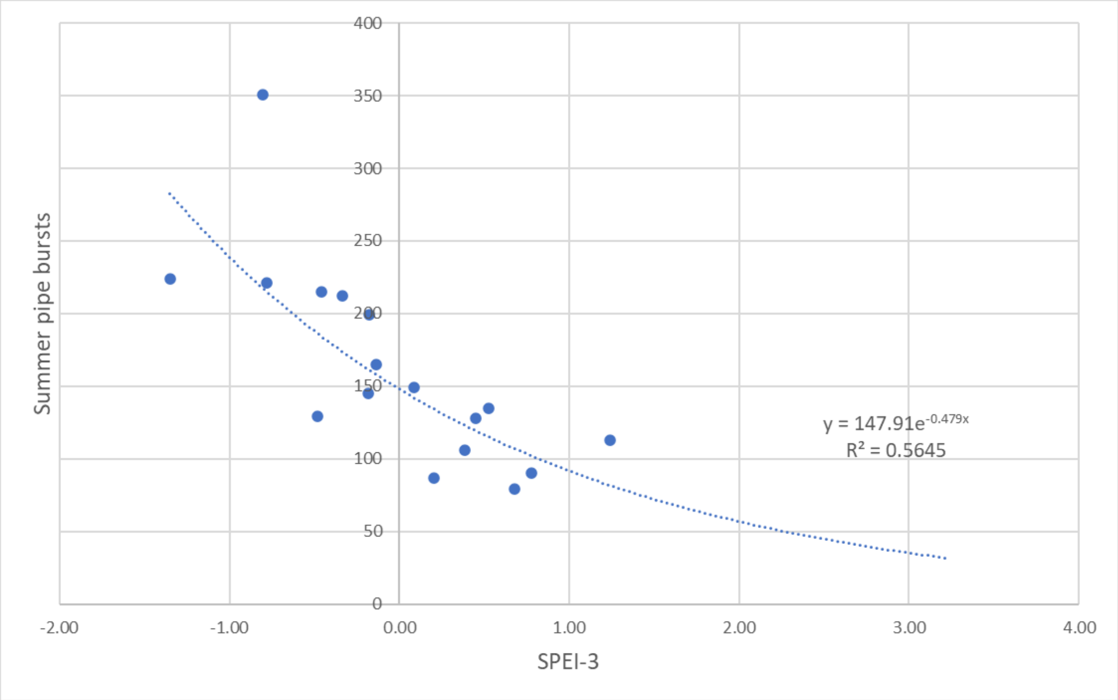
Normalised values demonstrate a higher rate of bursts in clay soils.

Figure 3.3: South-east correlation for asbestos cement pipes on non-clay soils



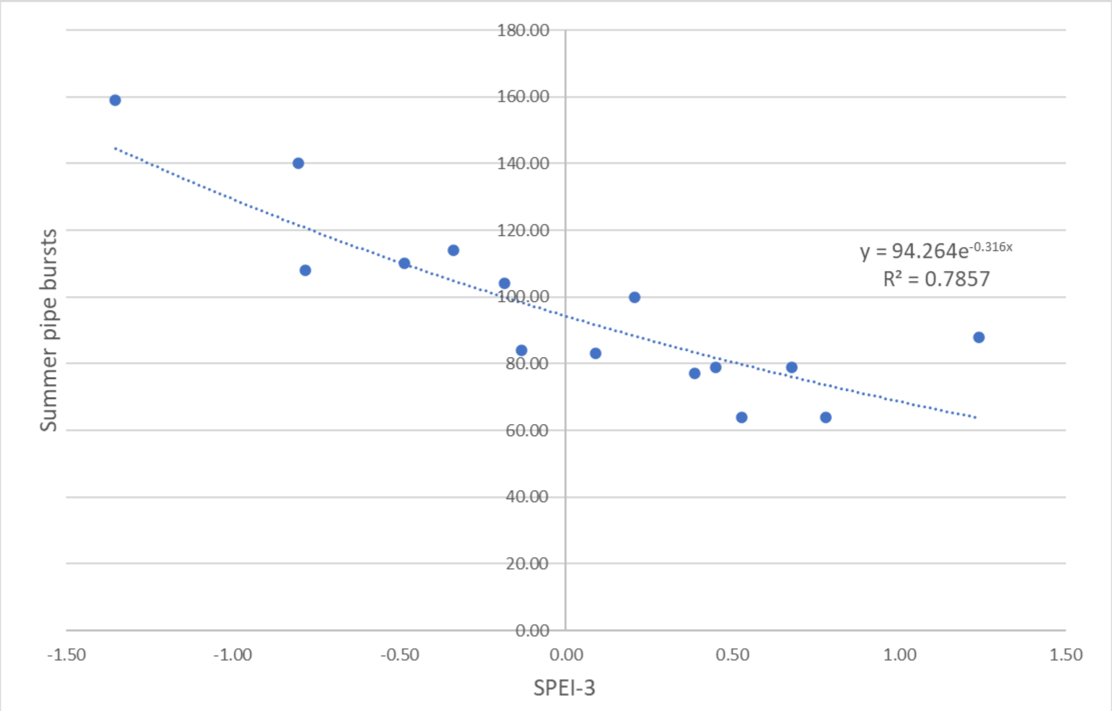
Source: Mott MacDonald

Figure 3.4: South-east correlation for asbestos cement pipes on clay soils



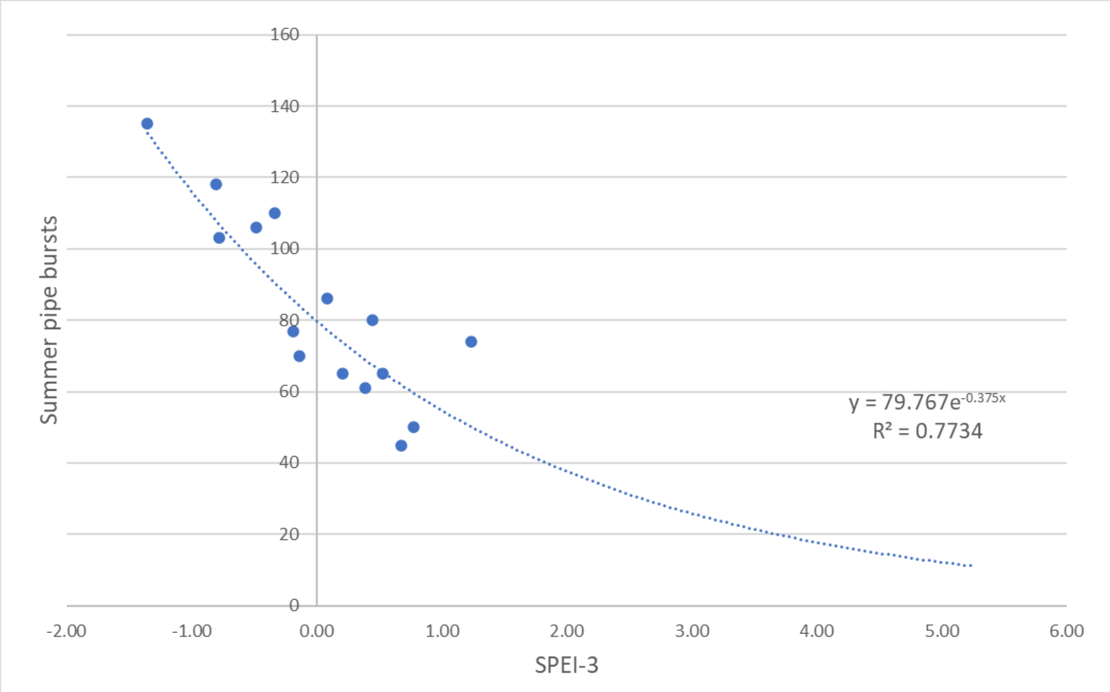
Source: Mott MacDonald

Figure 3.5: South-east correlation for cast iron pipes on non-clay soils



Source: Mott MacDonald

Figure 3.6: South-east correlation for cast iron pipes on clay soils



Source: Mott MacDonald

The absence of correlations in the north-east for cast iron and asbestos cement pipes reflects current conditions where soil moisture deficits are not as pronounced as in the south-east. Nonetheless, over the 2004-2021 baseline period, the 95th percentile (high) volumes of pipe bursts occurring during those summer/autumn months are:

- 62 bursts of asbestos pipes in non-clay soils, equivalent of 0.07 burst/km;
- 3 bursts of asbestos pipes in clay soils, equivalent of 0.08 burst/km;
- 277 bursts of cast iron pipes in non-clay soils, equivalent of 0.06 burst/km; and,
- 78 bursts of cast iron pipes in clay soils, equivalent of 0.08 burst/km.

Despite slight increases in UPVC pipe bursts during summer and winter, volumes remain largely constant throughout the year. Furthermore, similarly to asbestos cement and cast iron pipes, no correlation could be found against SPEI metrics under current conditions. In light of these, UPVC pipes were excluded from further analysis.

3.1.2 Prediction for future summer pipe bursts

3.1.2.1 Essex and Suffolk

Projections from twelve UKCP18 Regional Climate Models (RCM) for temperature, wind speed[11] and rainfall were processed to derive future regional averages of SPEI-3 values using the same locations as those considered for definition of the baseline. Applying the four correlations presented in Section 3.1.1 to SPEI-3 projected values, the range of future number of pipe bursts by 2050 was estimated (Table 3.1 to Table 3.4). A revised baseline period was used for comparison with future conditions to consider the standard 1991-2020 period, with

[11] Maximum and minimum temperature and wind speed were used to derive PET

values found to be in the same range as those derived from observed pipe burst data. Similarly, 30-year periods centred in 2030 and 2050 were adopted for characterising future conditions.

In both RCP2.6 and RCP8.5 scenarios, results indicate increases in the number of pipe bursts between July and October, by 2050. Increases are more pronounced in a high emission scenario, associated with higher increases in temperatures and expected drier conditions across the catchments. A greater number of asbestos cement pipes sitting on clay soils is at risk of bursts, reflective of the sensitivity of this material to the shrink-swell process.

Table 3.1: Change in ESW asbestos cement pipe bursts in non-clay soils

Number of pipe bursts/year	Baseline (1991-2020)	2050s – RCP2.6 [% change]	2050s – RCP8.5 [% change]
Median	81	108 [33%]	149 [84%]
5th percentile	45	55 [23%]	76 [69%]
95th percentile	138	195 [41%]	266 [92%]

Table 3.2: Change in ESW asbestos cement pipe bursts in clay soils

Number of pipe bursts/year	Baseline (1991-2020)	2050s – RCP2.6 [% change]	2050s – RCP8.5 [% change]
Median	151	194 [29%]	258 [71%]
5th percentile	89	106 [20%]	141 [59%]
95th percentile	242	327 [35%]	431 [78%]

Table 3.3: Change in ESW cast iron pipe bursts in non clay soils

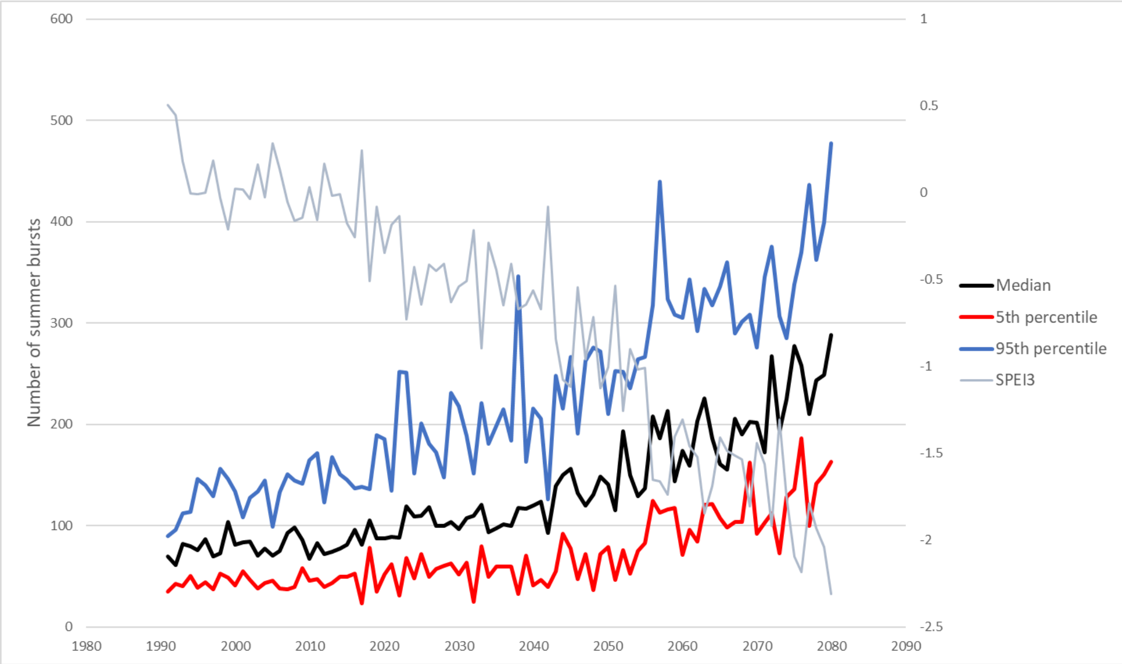
Number of pipe bursts/year	Baseline (1991-2020)	2050s – RCP2.6 [% change]	2050s – RCP8.5 [% change]
Median	95	112 [18%]	135 [42%]
5th percentile	67	75 [12%]	90 [34%]
95th percentile	130	158 [22%]	190 [46%]

Table 3.4: Change in ESW cast iron pipe bursts in clay soils

Number of pipe bursts/year	Baseline (1991-2020)	2050s – RCP2.6 [% change]	2050s – RCP8.5 [% change]
Median	81	98 [22%]	123 [52%]
5th percentile	53	61 [15%]	76 [42%]
95th percentile	117	148 [27%]	183 [57%]

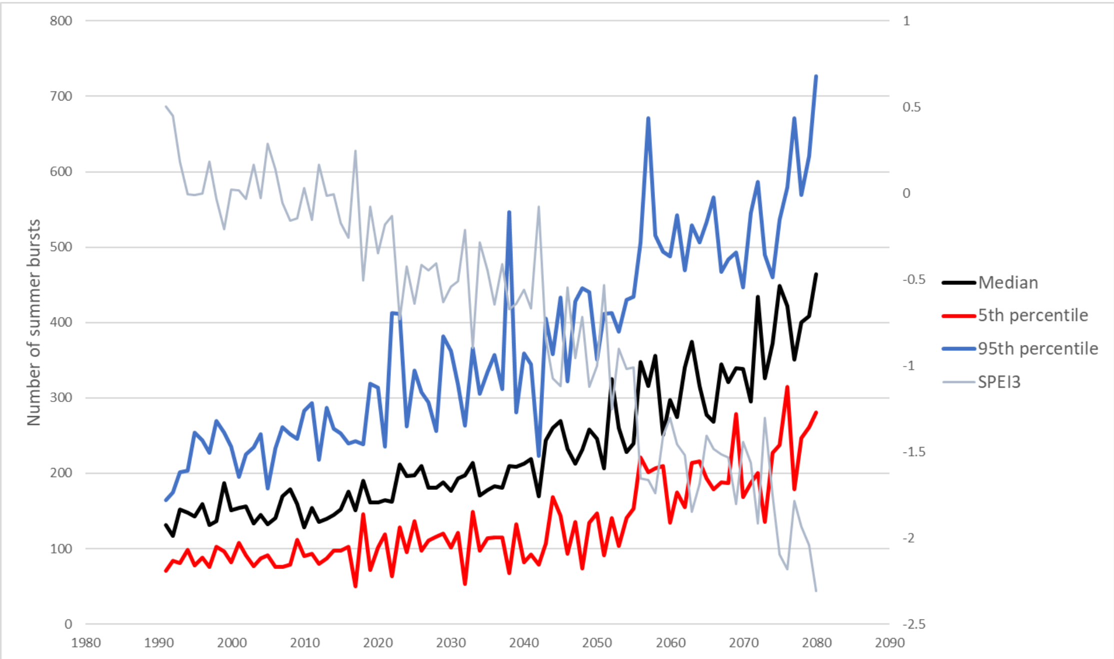
Figure 3.7 to Figure 3.10 present the long-term evolution of pipe bursts up to 2080 in a RCP8.5 scenario and for the four pipe material/soil type configurations considered in the baseline. In line with the results for the 2050 time horizon, pipe bursts are likely to continue increasing in the second half of the century. Figures also demonstrate the continuous reduction in SPEI-3 metric as a result of more frequent and intense drought conditions in the south-east. To note that these projections assume no change in the configuration of ESW and NW networks. Further vulnerability analyses would be needed if PVC becomes the main material deployed across the ESW network.

Figure 3.7: Projected changes in pipe bursts of asbestos cement pipes in ESW non-clay soils



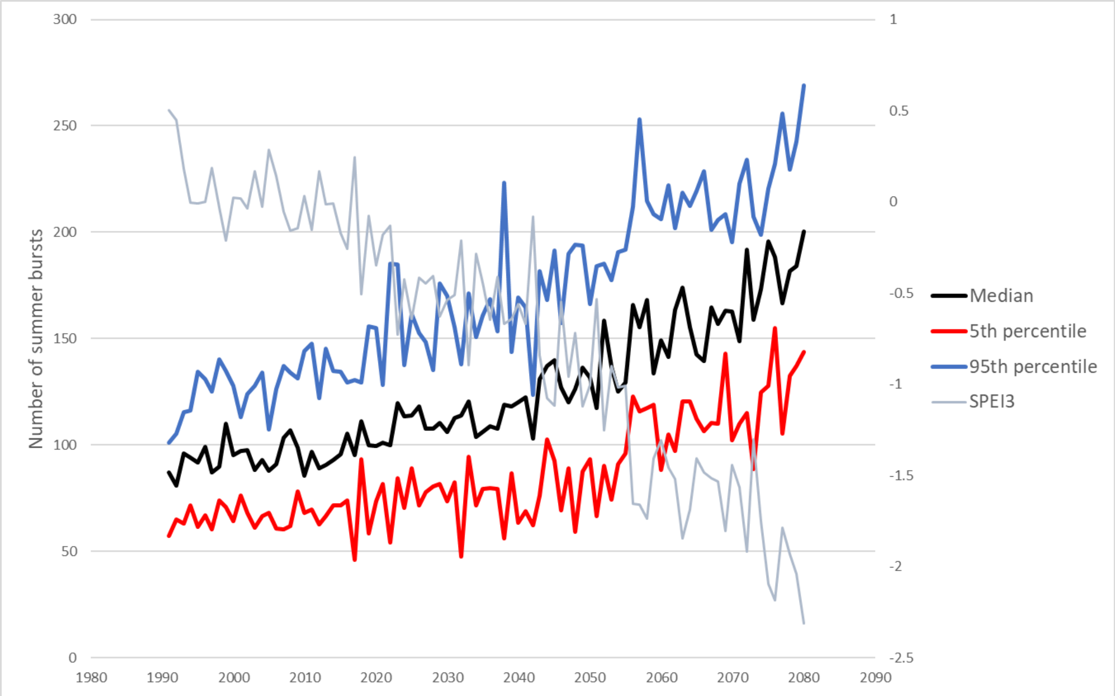
Source: Mott MacDonald

Figure 3.8: Projected changes in pipe bursts of asbestos cement pipes in ESW clay soils



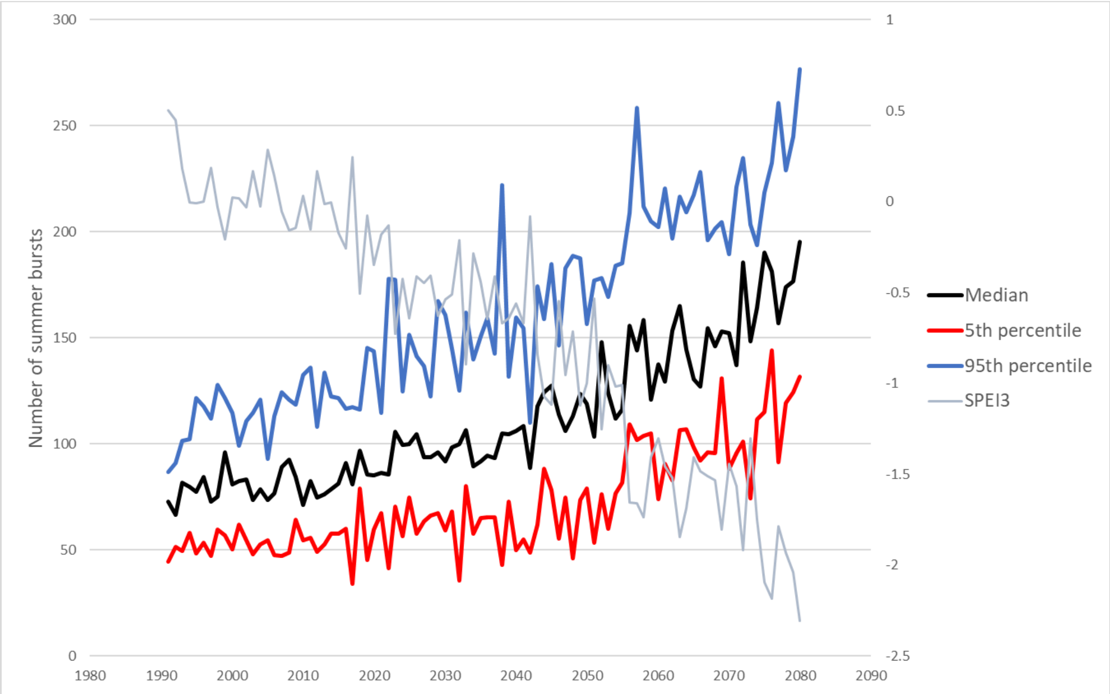
Source: Mott MacDonald

Figure 3.9: Projected changes in summer bursts of cast iron pipes in ESW non clay soils



Source: Mott MacDonald

Figure 3.10: Projected changes in summer bursts of cast iron pipes in ESW clay soils



Source: Mott MacDonald

3.1.2.2 Northumbria

In the absence of a climate signal for current conditions, the correlations obtained for the south-east were further applied to the north-east. This is in recognition that, with increasing temperatures and drier summer, soil moisture deficits in Northumbria are likely to increase in the future to match those currently occurring in the south-east, thus affecting the number of pipe bursts. This aligns with the findings documented in the contextualisation report, with an expected increase in drought conditions in the north-east.

Projections from the twelve UKCP18 RCMs were processed for temperature, wind speed and rainfall to derive future regional averages of SPEI-3 values using the same locations as those considered for definition of the baseline. The application of the south-eastern correlations to the north-east necessitated, however, standardising the future SPEI values to the baseline climate conditions in the south-east. This implies that adopted SPEI-3 values in the north-east will not be relative to average conditions there but to those in the south-east. This results in more positive SPEI-3 values for current conditions, and hence, no increase in summer pipe bursts when south-eastern correlations are used. However, SPEI-3 values progressively turn more negative with time until a point when the south-eastern correlation will indicate an increase in burst.

In addition, the number of pipe bursts was calculated with adjustment factors (Table 3.5) to:

- Consider differences in pipe length between ESW and NW areas (e.g. fewer asbestos pipes in Northumbria) through application of a **scaling factor** based on that pipe length difference; and,
- Consider other differences in network configuration (e.g. pumped versus gravity) and calibrate the regression model to observed baseline conditions in the north-east, through application of a **calibration factor**. This factor ensures that baseline pipe bursts are in line with observations.

Table 3.5: Applied pipe bursts adjustment factors

	ESW length (km)	NWL length (km)	Scaling factor	Calibration factor
Asbestos cement pipe in clay soil	1,199	40	0.03	0.9
Asbestos cement pipe in non-clay soil	1,276	831	0.65	1.75
Cast iron pipe in clay soil	576	948	1.65	0.75
Cast iron pipe in non-clay soil	1,825	4,499	2.46	1.4

Similar to the method adopted for ESW, the 1991-2020 period was used as baseline alongside 30-year periods centred in 2030 and 2050 for future projections. Results are presented in Table 3.6 to Table 3.9. Lower increases than for ESW are reported and this aligns with lower decreases in SPEI-3 values reflective of lower soil moisture deficits.

Asbestos cement pipe bursts in clay soils will remain minor in comparison to those sitting in non-clay soils due to respective lengths of pipeline. A greater number of cast iron pipes is at risk of summer/autumn bursts, particularly those sitting in non-clay soils. Whilst clay soils are more prone to the shrink-swell process, baseline conditions have shown that bursts also increase in non-clay soils during the summer/autumn months. Although not having sufficiently high clay content to be categorised otherwise, a portion of non-clay soils still bear moderate to very high shrink swell potential. Out of the total number of observed bursts occurring between July and

October in non-clay soils, over half occur in soils that have a moderate to very shrink-swell potential.

Table 3.6: Change in NW asbestos cement pipe bursts in non clay soils

Number of pipe bursts/year	Baseline (1991-2020)	2050s – RCP2.6 [% change]	2050s – RCP8.5 [% change]
Median	47	60 [29%]	80 [71%]
5th percentile	26	29 [9%]	38 [46%]
95th percentile	93	118 [27%]	145 [57%]

Table 3.7: Change in NW asbestos cement pipe bursts in clay soils

Number of pipe bursts/year	Baseline (1991-2020)	2050s – RCP2.6 [% change]	2050s – RCP8.5 [% change]
Median	2	3 [25%]	4 [61%]
5th percentile	1	2 [8%]	2 [39%]
95th percentile	5	6 [23%]	7 [49%]

Table 3.8: Change in NW cast iron pipe bursts in non clay soils

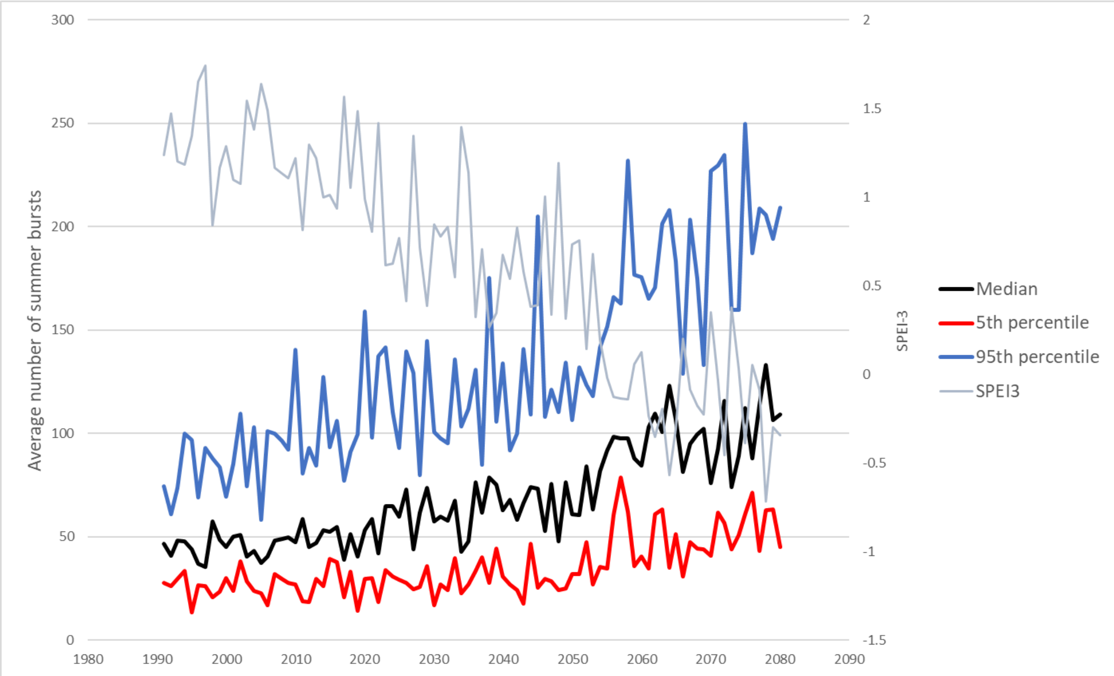
Number of pipe bursts/year	Baseline (1991-2020)	2050s – RCP2.6 [% change]	2050s – RCP8.5 [% change]
Median	220	255 [16%]	300 [36%]
5th percentile	157	164 [5%]	193 [23%]
95th percentile	327	375 [15%]	425 [30%]

Table 3.9: Change in NW cast iron pipe bursts in clay soils

Number of pipe bursts/year	Baseline (1991-2020)	2050s – RCP2.6 [% change]	2050s – RCP8.5 [% change]
Median	62	74 [19%]	90 [45%]
5th percentile	42	44 [6%]	53 [29%]
95th percentile	99	117 [18%]	136 [36%]

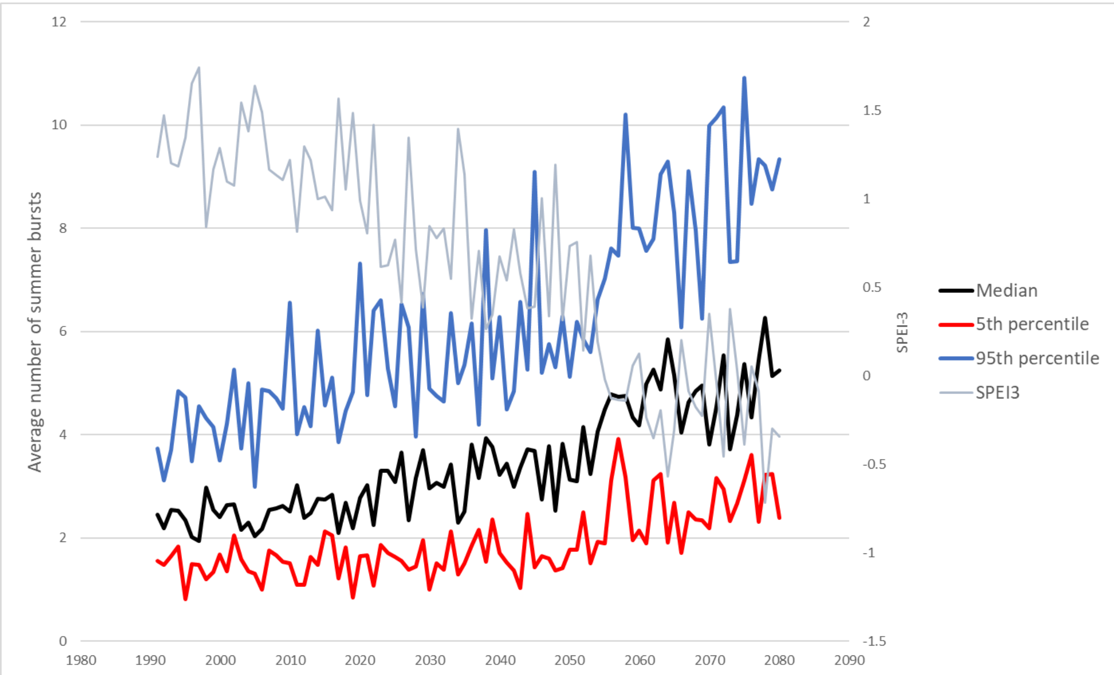
Figure 3.11 to Figure 3.14 present the long-term evolution of pipe bursts up to the end of the century in a RCP8.5 scenario and for the four pipe material/soil type configurations considered in the baseline. In line with the results for the 2050 time horizon, increases in pipe bursts are likely to continue increasing in the second half of the century. Figures also demonstrate the continuous reduction in SPEI-3 metric as a result of more frequent and intense drought conditions in the north-east with values becoming negative relative to south-eastern baseline conditions around 2050. To note that these projections assume no change in the configuration of ESW and NW networks and a monitoring of UPVC pipe bursts with increasing soil moisture deficits is needed to evaluate the vulnerability of the material to future climate conditions.

Figure 3.11: Projected changes in pipe bursts of asbestos cement pipes in NW non-clay soils



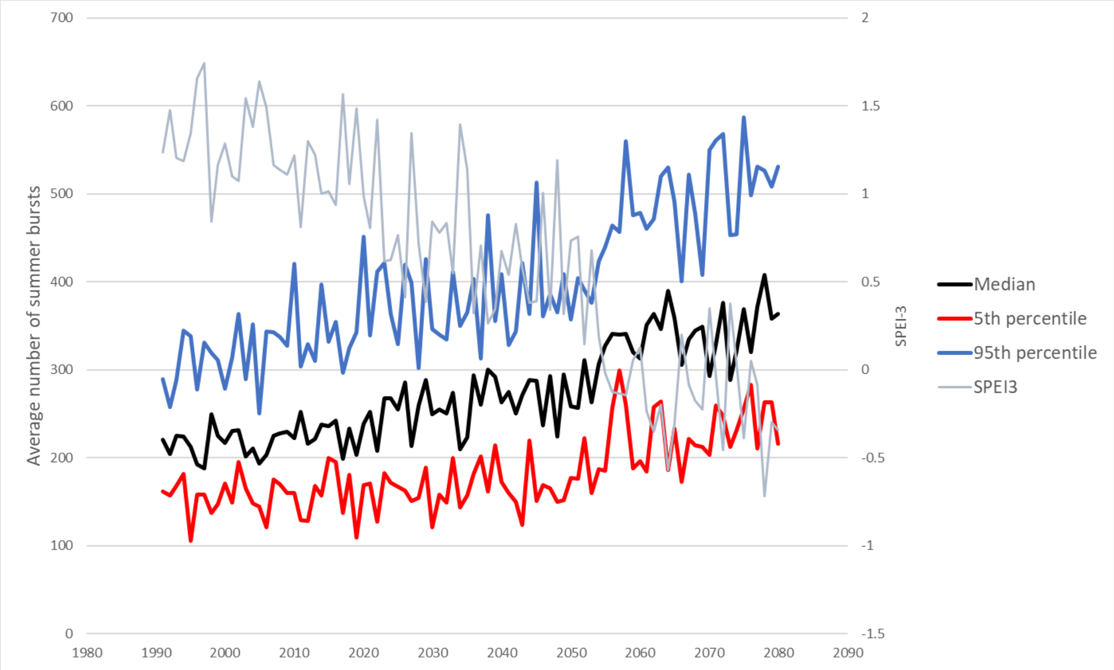
Source: Mott MacDonald

Figure 3.12: Projected changes in pipe bursts of asbestos cement pipes in NW clay soils



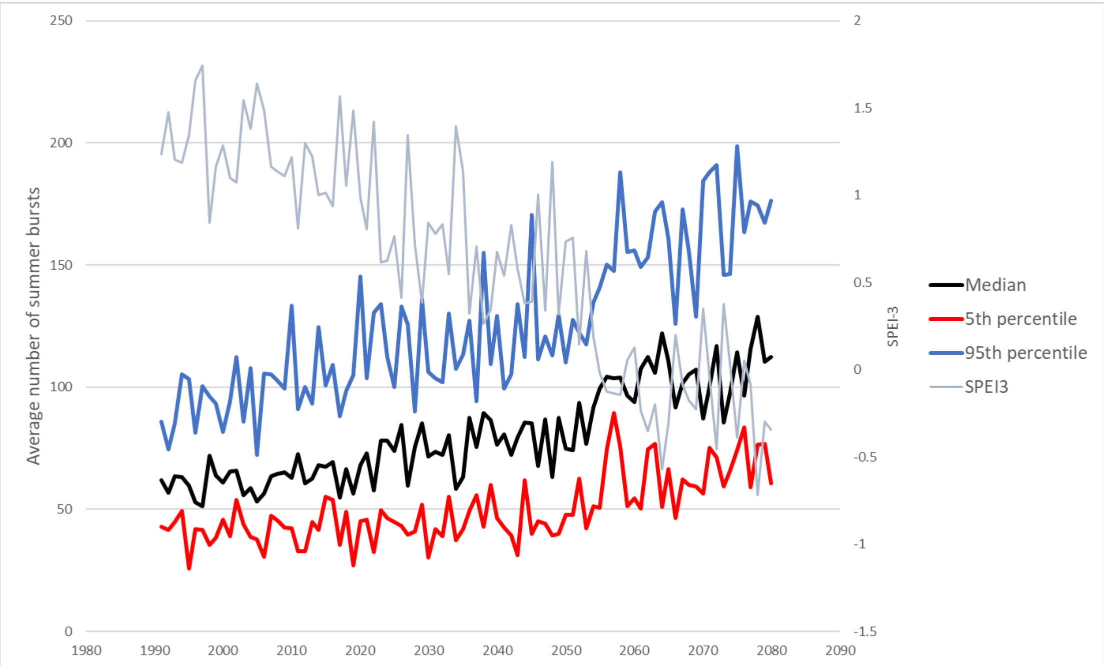
Source: Mott MacDonald

Figure 3.13: Projected changes in pipe bursts of cast iron pipes in NW non-clay soils



Source: Mott MacDonald

Figure 3.14: Projected changes in pipe bursts of cast iron pipes in NW clay soils



Source: Mott MacDonald

3.1.3 Cost impacts

Building on the results of pipe bursts presented in Section 3.1, the range of pipe burst related expenditure by 2050 was estimated for a low and high emission scenario. The 2016 repair and replacement costs provided by NWL and included in Section 2.3.1.1 were adjusted to reflect the observed costs of the 2018 heat wave reported in the Contextualisation report (Mott MacDonald 2022c) as they included additional related expenditure on top of repairs and replacement . The baseline cost models were then increased by applying a factor of 3 and a factor of 2 respectively in the north-east and the south-east in order to obtain baseline total costs reflective of those observed during the 2018 heat wave.

Repair and replacement costs were used respectively for cast iron and asbestos cement bursts, recognising that the former is usually addressed by installing a ring around the crack whilst the latter requires replacement of a given length as well as the pipe disposal off-site. For each configuration of soil type/pipe material considered, the proportion of bursts for pipes of different diameters was factored in to calculate weighted total costs by 2050, assuming the same split in pipe bursts between diameters as that observed in baseline conditions.

In the case of asbestos cement pipes and after discussion with NWL stakeholders, a 4 meter length of replacement was assumed for each burst and a nominal charge of £90/burst was added to consider costs of disposal to an appropriate waste facility.

3.1.3.1 Essex and Suffolk

Additional expenditure estimated for the two emission scenarios as a result of cast iron and asbestos cement predicted pipe bursts is summarised in Table 3.10. Based on the median value, the total additional costs **estimated** by 2050 are respectively of **£588,267** and **£241,072** per annum for the RCP8.5 and RCP2.6 scenarios. These are reflective of the additional costs that would be incurred from increased soil moisture deficits in the context of global warming in a Do Nothing scenario. To note that those additional bursts might incur service impacts to customers that are not accounted for in this analysis.

Table 3.10: Pipe bursts additional expenditure (per annum) by 2050 for ESW

Configuration	Emission scenario	Median	5th percentile	95th percentile
Asbestos cement – non clay	RCP8.5	£123,353	£56,458	£231,479
	RCP2.6	£48,528	£18,505	£102,590
Asbestos cement - clay	RCP8.5	£194,951	£94,742	£343,184
	RCP2.6	£78,478	£31,604	£154,959
Cast iron – non clay	RCP8.5	£131,864	£75,330	£196,054
	RCP2.6	£56,315	£26,225	£92,910
Cast iron –clay	RCP8.5	£138,099	£74,388	£218,199
	RCP2.6	£57,751	£25,518	£101,636

3.1.3.2 Northumbria

Similarly, additional expenditure estimated across NW supply area is summarised in Table 3.11. Based on the median value, the total additional costs **estimated** by 2050 are respectively of **£319,277** and **£133,839** per annum for the RCP8.5 and RCP2.6 scenarios. These are reflective of the additional costs that would be incurred from increased soil moisture deficits in the context of global warming in a Do Nothing scenario. To note that those additional bursts might incur service impacts to customers that are not accounted for in this analysis.

Table 3.11: Pipe bursts additional expenditure (per annum) by 2050 for NW

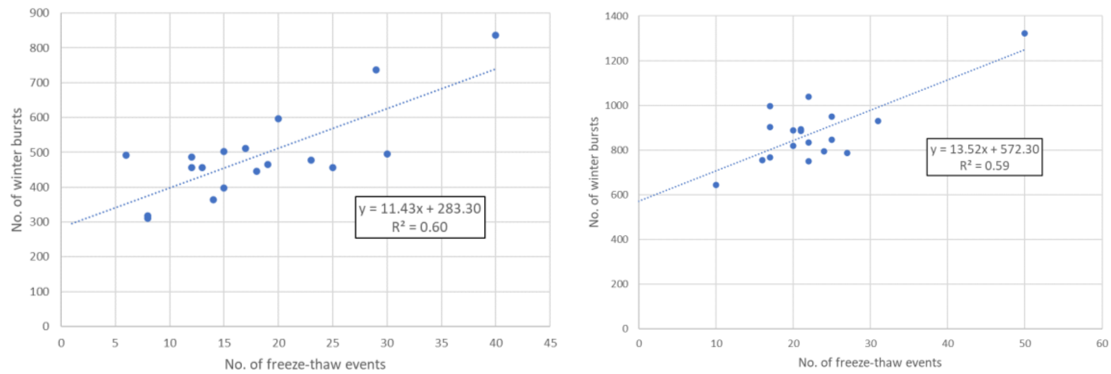
Configuration	Emission scenario	Median	5th percentile	95th percentile
Asbestos cement – non clay	RCP8.5	£65,664	£23,793	£104,595
	RCP2.6	£26,751	£4,703	£49,382
Asbestos cement - clay	RCP8.5	£8,786	£4,170	£14,275
	RCP2.6	£1,231	£229	£2,095
Cast iron – non clay	RCP8.5	£181,862	£83,014	£221,761
	RCP2.6	£78,960	£17,075	£108,778
Cast iron –clay	RCP8.5	£62,966	£27,017	£82,324
	RCP2.6	£26,898	£5,507	£39,974

3.2 Freeze thaw events

3.2.1 Definition of baseline conditions

Pipes are further susceptible to freeze-thaw events whereby the fluctuation of temperatures above and below freezing levels exert extra pressure and can lead to winter bursts. In the present analysis, different climate representations of freeze-thaw events were tested based on daily maximum and minimum temperate with a best match achieved when on a single day minimum temperature is below -1°C and maximum temperature is above 0°C. Correlations were then found for both the ESW and NW areas between the number of freeze-thaw events with the number of pipe bursts occurring during the winter months (December to March) (Figure 3.15).

Figure 3.15: South-east (left) and north-east (right) correlations for winter pipe bursts



Source: Mott MacDonald

Under baseline conditions, the number of bursts occurring as a result of freeze thaw events during the winter months are summarised in Table 3.12 for ESW and NW areas. Higher numbers are recorded in the north-east, reflection of lower temperatures and greater occurrences of freeze-thaw events.

Table 3.12: Pipe burst occurrences from freeze thaw events

Number of pipe burst/year	NW	ESW
Median	866	472
95th percentile	1080	752
5th percentile	734	316

3.2.2 Prediction of future winter pipe bursts

Projections from twelve UKCP18 Regional Climate Models (RCM) for minimum and maximum temperature were extracted, averaged to obtain regional estimates and processed to derive freeze thaw occurrences in a similar fashion to that done for the observed baseline. The standard baseline 1991-2020 period and 30-year periods centred in 2030 and 2050 were adopted for obtaining future values. Results are presented in Table 3.13 and Table 3.14.

The number of winter pipe bursts associated with freeze-thaw events is expected to decrease in both emission scenarios as a result of increased temperatures and fewer occurrences of freeze-thaw conditions. Slightly higher decreases are expected in the south-east as a result of warmer temperatures in comparison to the north-east of England.

Table 3.13: Changes in NW pipe burst occurrence from freeze-thaw events

Number of pipe bursts/year	Baseline (1991-2020)	2050s – RCP2.6 [% change]	2050s – RCP8.5 [% change]
Median	847	737 [-13%]	649 [-23%]
5th percentile	704	618 [-12%]	580 [-18%]
95th percentile	1079	941 [-13%]	844 [-22%]

Table 3.14: Changes in ESW pipe burst occurrence from freeze-thaw events

Number of pipe bursts/year	Baseline (1991-2020)	2050s – RCP2.6 [% change]	2050s – RCP8.5 [% change]
Median	462	391 [-15%]	325 [-30%]
5th percentile	356	307 [-14%]	286 [-20%]
95th percentile	641	542 [-15%]	466 [-27%]

A reduction in repair and replacement costs is anticipated from the reduced incidence of freeze-thaw events. This is summarised in Table 3.15 for NW and Table 3.16 for ESW areas.

Table 3.15: Estimated reductions in winter bursts related expenditure by 2050 for NW

Emission scenario	Median	5th percentile	95th percentile
RCP2.6	-£227,444	-£176,106	-£285,326
RCP8.5	-£408,470	-£255,247	-£484,223

Table 3.16: Estimated reductions in winter bursts related expenditure by 2050 for ESW

Emission scenario	Median	5th percentile	95th percentile
RCP2.6	-£155,972	-£108,679	-£217,483
RCP8.5	-£300,235	-£154,592	-£385,581

Overall, a decrease in winter bursts from freeze thaw events in the NW area could compensate increases in summer bursts and the associated costs. In the ESW area, those decreases will however not be sufficient to compensate increases in soil moisture deficits and the costs associated to the resulting increases in pipe bursts.

3.3 Implications for performance commitments

A change in the number of summer and winter bursts can impact two performance commitments as set out in the PR19 final determinations Northumbrian Water outcomes performance commitment appendix[12]:

- Leakage, defined as the percentage reduction of three year average leakage in megalitres per day (Ml/d) from the 2019-20 baseline.
- Main repairs, reported as the number of mains repairs per thousand kilometres of the entire water main network (excluding communication and supply pipes).

Projections included in sections 3.1 and 3.2 indicate changes in the number of bursts as shown in Table 3.17 for the median estimate. They would imply a reduction in the number of main repairs and replacements across both Northumbria and Essex and Suffolk for the low emission scenario and an increase for the high emission scenario.

Table 3.17: Estimated changes in the number of main repairs in 2050

	RCP2.6			RCP8.5		
	Summer	**Winter**	**Annual**	**Summer**	**Winter**	**Annual**
Essex and Suffolk	+104	-71	+33	+257	-137	+120
Northumbria	+61	-110	-49	+143	-198	-55
Total	+165	-181	-16	+400	-335	+65

If standardised by the total length of the network (in thousands of kilometres), potential change in performance commitment metric would be -0.61 and +2.47 for RCP2.6 and RCP8.5 respectively, which depending on the baseline performance could mean an incentive of £59,700 per year in 2050 for RCP2.6 assuming the standard outperformance payment, or a penalty of £368,742 for RCP8.5 assuming the standard underperformance payment.

As regards leakage, correlations between recorded leakage and pipe bursts for the period April 17 – Mar 21 point towards the additional leakage per pipe burst presented in Table 3.18, indicating that summer bursts would generally lead to a greater leakage as they tend to occur on larger pipes.

Table 3.18: Average leakage (Ml/d) per additional pipe burst

	Summer	**Winter**
Essex and Suffolk	0.083	0.072
Northumbria	0.064	0.034

Applying these values to the changes in the number of bursts shown in Table 3.17 results in the additional leakage and associated penalty assuming the standard underperformance payment presented in Table 3.19 and Table 3.20. The impact is greater in Essex and Suffolk due to greater number of summer bursts and the greater associated leakage compared with baseline value.

[12] https://www.ofwat.gov.uk/wp-content/uploads/2019/12/PR19-final-determinations-Northumbrian-Water-Outcomes-performance-commitment-appendix.pdf

Table 3.19: Impact on leakage performance commitment by 2050 in Essex and Suffolk

Emission scenario	Additional leakage (Ml/d)	2019-2020 baseline (Ml/d)	Change	Penalty
RCP2.6	3.5	64.3	5.5%	£985,381
RCP8.5	11.5		17.8%	£3,210,047

Table 3.20: Impact on leakage performance commitment by 2050 in Northumbria

Emission scenario	Additional leakage (Ml/d)	2019-2020 baseline (Ml/d)	Change	Penalty
RCP2.6	0.2	130.8	0.1%	£21,942
RCP8.5	2.4		1.9%	£323,777

4 Water quality analysis

Water quality deterioration can result from extreme rainfall or flood events leading to the wash-off of contaminants and sediments into watercourses, as well as from extreme heat and dry conditions, with lower flows implying lower dilution of contaminants and warmer waters benefiting algal growth whilst also affecting the performance of chemical dosing.

4.1 Extreme rainfall analysis

4.1.1 Turbidity

Following concerns that high turbidity events have led in the recent years to an increasing number of outages at clean water sites and also with consideration of the criticality of surface water streams to feed major water treatment works, a review of NWL and EA WIMS water quality monitoring data (refer to Section 2.1.2) and subsequent assessments were undertaken for a suite of four river intake locations in NW service area; namely Broken Scar, Horsley, Lumley and Warkworth. The specific case of Barsham intake is discussed in Section 4.1.2.

4.1.1.1 Definition of baseline conditions

Turbidity level vary throughout the year. During winter, high turbidity levels occur alongside high flows resulting from less intense but more prolonged periods of rainfall, when sediments are progressively added to the surface water system. In the rest of the year, high turbidity levels are more associated with extreme rainfall events, washing out sediments from the land close to the river network at a time with lower flows.

EA WIMS turbidity data was thus correlated:

- Between December and February against daily flow; and,
- Between March and November against daily catchment rainfall (adopting a one-day lag to consider the concentration time down to the intake).

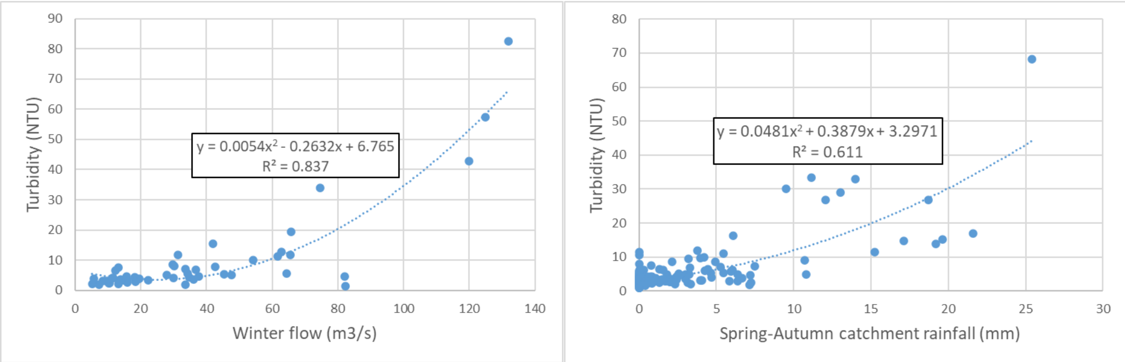
Correlations are presented in Figure 4.1 to Figure 4.4.

The observed 95th percentile (high) turbidity levels in the surface water system at the various intake locations in baseline conditions (2000-2021/2022[13]) are:

- 23.2 NTU at Broken Scar;
- 32.4 NTU at Horsley intake;
- 59.6 NTU at Lumley intake; and,
- 42.6 NTU at Warkworth intake.

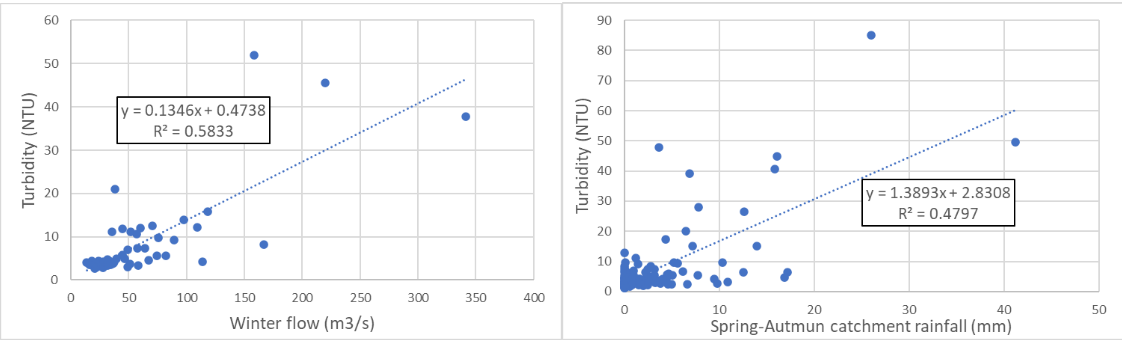
[13] This varies with the length of turbidity records at the different river intakes

Figure 4.1: Adopted correlations on turbidity levels at Broken Scar



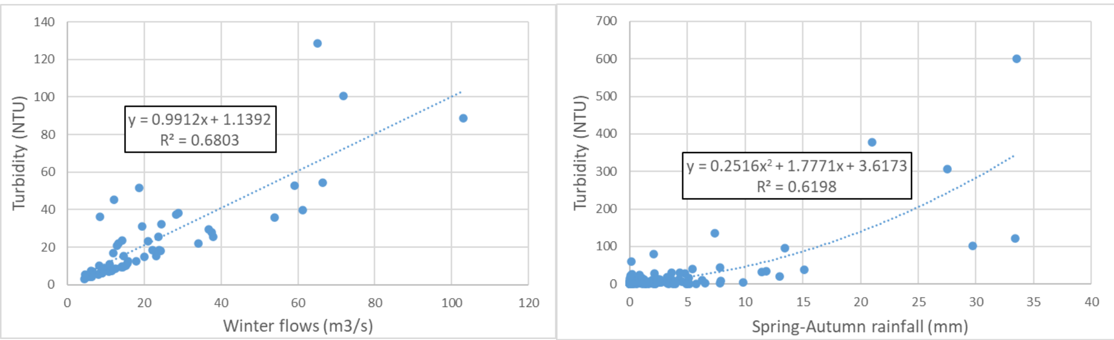
Source: Mott MacDonald

Figure 4.2: Adopted correlations on turbidity levels at Horsley



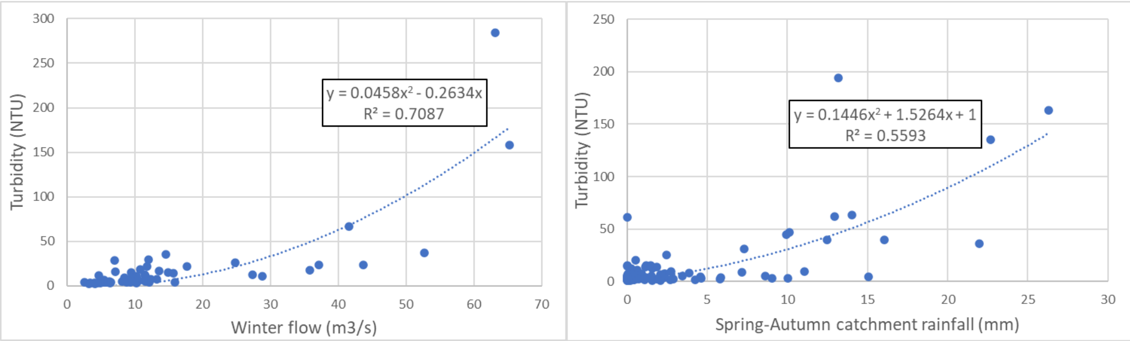
Source: Mott MacDonald

Figure 4.3: Adopted correlations on turbidity levels at Lumley



Source: Mott MacDonald

Figure 4.4: Adopted correlations on turbidity levels at Warkworth



Source: Mott MacDonald

4.1.1.2 Recent outages and associated costs

High turbidity levels have resulted in outages at a number of treatment works across both Northumbria and Essex and Suffolk supply areas in the past three years. A summary of these is presented in Table 4.1. All outages were reported as exclusions on the basis of being water quality exceptions in line with Ofwat's PR19 methodology. Large outages were recorded at Langford, Langham in the south-east as well as Horsley and Lumley in the north-east.

Volumes lost over past incidents were combined with 2022 Actual Year To Date unit production costs to quantify the level of monetised costs of these events for all relevant water treatment works. The total outage costs were estimated in the order of **£1,452,638** over the April 2019 to March 2022 period, and associated with the need to replenish the lost production.

Table 4.1: Outages for high turbidity between April 2019 and March 2022

	Site	Counts of incidents	Total number of days	Total outage (Ml)	Total outage (£)
ESW	Chigwell	7	85	836	£97,052
	Hanningfield	1	10	300	£28,773
	Langford	1	15	**434**	£119,714
	Langham	9	225	**3,222**	£416,126
	Layer (Abberton Reservoir)	6	12	75	£8,359
NW	Horsley	9	109	**1,667**	£535,320
	Lumley	5	62	650	£224,107
	Mosswood	3	30	289	£22,883
	Gunnerton	1	1	2	£304

4.1.1.3 Predictions of future turbidity levels

The regional rainfall-runoff models produced by Mott MacDonald and used for the derivation of climate change and stochastic flow series for Northumbrian Water and Essex and Suffolk Water WRMP24s (Mott MacDonald 2022a, 2022b) were rerun for this specific application. Baseline and future flow series were obtained, the latter by applying rainfall and PET factors to historical sequences as indicated in Section 2.2.1. The baseline period and 30-year periods centred in 2030 and 2050 were adopted. Correlations derived from observed data were further used to obtain the range of future turbidity levels under each emission scenario. Results presented in Table 4.2 show an overall increase in high turbidity values at all four intakes, reflective of wetter winters and increases in extreme rainfall in the rest of the year.

Table 4.2: Changes in high turbidity levels (95th percentile) at river intakes

% change from baseline	2050s – RCP2.6	2050s – RCP8.5
Broken Scar	4%	8%
Horsley	6%	7%
Lumley	13%	15%
Warkworth	16%	24%

Further analysis was undertaken to investigate the frequency of exceedance of specific turbidity thresholds that would trigger actions to adapt to these high levels at the intakes:

- At Horsley, thresholds of 50, 100 and 150 NTU are respectively exceeded on average 4.6, 1.5 and 1.2 days per year during the observed baseline period. In future conditions, exceedance of the 50 NTU limit is expected to increase to 5.8 and 6.1 days/year respectively in an RCP2.6 and RCP8.5 scenario. The exceedance of the 100 NTU limit is expected to increase to 2.1 and 2.6 days/year while the 150 NTU limit is expected to be exceeded 1.7 and 2.0 days/year on average in a low and high emission scenario respectively.
- At Warkworth, the 100 NTU limit of action is exceeded on average 8.1 days/year in baseline conditions. This is expected to increase in the future to 9.9 and 11.4 days/year respectively in an RCP2.6 and RCP8.5 scenario.
- At Lumley, the 50, 30 and 20 NTU limits are exceeded on average 20.8, 35 and 63.1 days/year in baseline conditions. The upper limit exceedance is expected to increase in the future to 25.9 and 24.9 in a low and high emission scenario, whilst the middle limit exceedance frequency is expected to rise to 42.3 and 40.9 days/year respectively. Finally, the lower limit is anticipated to be exceeded 72.6 and 70.1 days/year in RCP2.6 and RCP8.5. To note that the above thresholds are exceeded quite often, thus not being associated with significantly extreme rainfall and flow events. This explains why greater increases in exceedance frequency are projected for a low emission scenario as this will experience lower decreases in rainfall throughout the year compared to a high emission scenario.

No exceedance frequency analysis was conducted for Broken Scar given the high elasticity of operations of the works.

On average, increases in the frequency of high turbidity events known to pose issues to the operations of the works are estimated to be around 13% and 20% by 2050 (averaged across Horsley, Warkworth and Lumley) in an RCP2.6 and RCP8.5 scenario respectively. To note that these values were obtained compared with a more recent 2010-2019 baseline period for consistency with the one covered by outage data. Together with the number of outage days as well as daily averages of lost volumes, yearly additional costs were estimated by 2050 as presented in Table 4.3.

Table 4.3: Increase in costs from outages resulting from high turbidity events (per annum)

£/year	**RCP2.6**	**RCP8.5**
Chigwell	£3,779	£5,687
Hanningfield	£1,248	£1,878
Langford	£3,667	£5,519
Langham	£17,137	£25,791
Layer	£292	£439
Horsley	£21,832	£32,857
Lumley	£10,756	£16,187
Mosswood	£1,133	£1,706
Gunnerton	£13	£20
Total	**£59,858**	**£90,084**

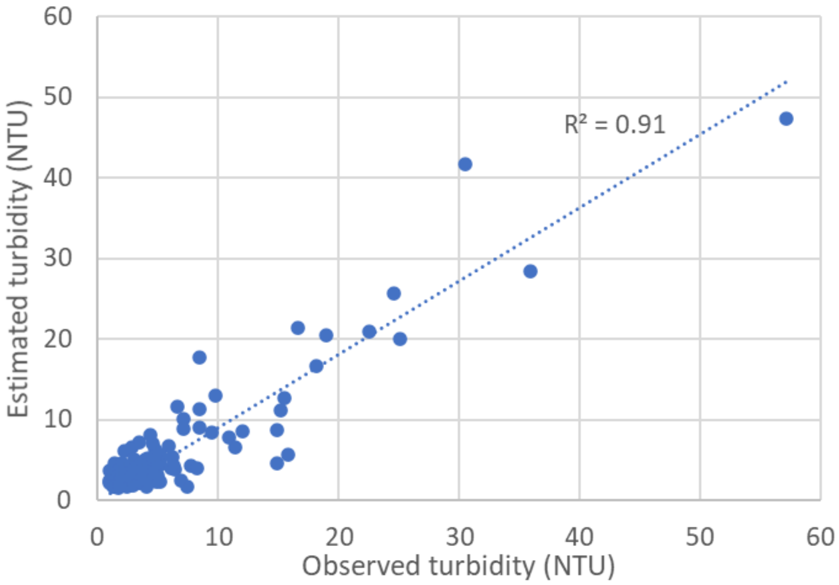
It is possible that upscaling costs based on a three-year recent period introduces some bias as they could incorporate a stronger climate change signal that the usually adopted 30-year baseline. However, using a most recent baseline instead of 1991-2020 should counteract this. In any case, estimated costs should be considered with caution.

4.1.2 Case with sea level rise

4.1.2.1 Definition of baseline conditions

Previous records of tide locking conditions on the River Waveney required further investigations of the impact of sea levels on the operation of the Barsham river intake. A review of turbidity levels at Ellingham Mill highlighted increases with higher river flows as well as maximum tide levels. A multivariate regression model was subsequently fitted between observed turbidity, river flows and maximum tide levels, achieving a good correlation to observed turbidity levels (see Figure 4.5). Under observed baseline conditions (2004-2015), the 95th percentile (high) turbidity level at Barsham intake is 17.9 NTU.

Figure 4.5: Outcomes from statistical model applied for Barsham intake



Source: Mott MacDonald

4.1.2.2 Predictions of future turbidity levels

Similar to the analysis conducted at the four north-east river intakes, the regional rainfall-runoff model produced by Mott MacDonald for the Waveney catchment was rerun to obtain baseline and future flow series, the latter using uplifted rainfall and PET factors. The standard baseline 1991-2020 period and 30-year periods centred in 2030 and 2050 were adopted.

The statistical model fitted for baseline conditions was used to obtain the range of future turbidity levels under each emission scenario. Further to future flow series, baseline series for maximum tide levels were adjusted to account for sea level rise.

Changes in high turbidity levels (95th percentile) by 2050 are respectively 18% and 28% for the RCP2.6 and RCP8.5 scenarios.

The two limits of actions in place at Barsham river intake - 75 and 150 NTU - are exceeded on average less than 1 day per year during the observed baseline period. In future conditions, the exceedance of the first action limit is expected to increase by 0.5 and 1 day/year respectively in an RCP2.6 and RCP8.5 scenario. The second limit is expected to remain exceeded less than 1 day/year in both emission scenarios.

4.1.2.3 Impacts

The river intake at Barsham is operated as run to waste post-clarifiers when turbidity levels reach beyond operating limits. Abstraction therefore does not cease and treatment chemicals continue to be applied until the quality returns within limits. The run to waste flow goes through the next stages of treatment but does not feed into supply stream until levels come back within limits which can take from a few hours to several days. Bore streams are turned on to mitigate any supply loss.

The process costs of the river stream remain similar to normal conditions; the slight difference being that the process is run at its minimum base load to minimise chemical costs. However, the associated chemical and power costs cannot be recovered through supply to customers revenues. Additional costs would also incur in the bore stream, through increased power costs of having all bores as well as the emergency chalk bore turned on. In the absence of sub metering of assets for power costs and a dashboard recording chemical and power costs with live process data, no quantification of financial impacts could be conducted to date.

4.2 Extreme heat analysis

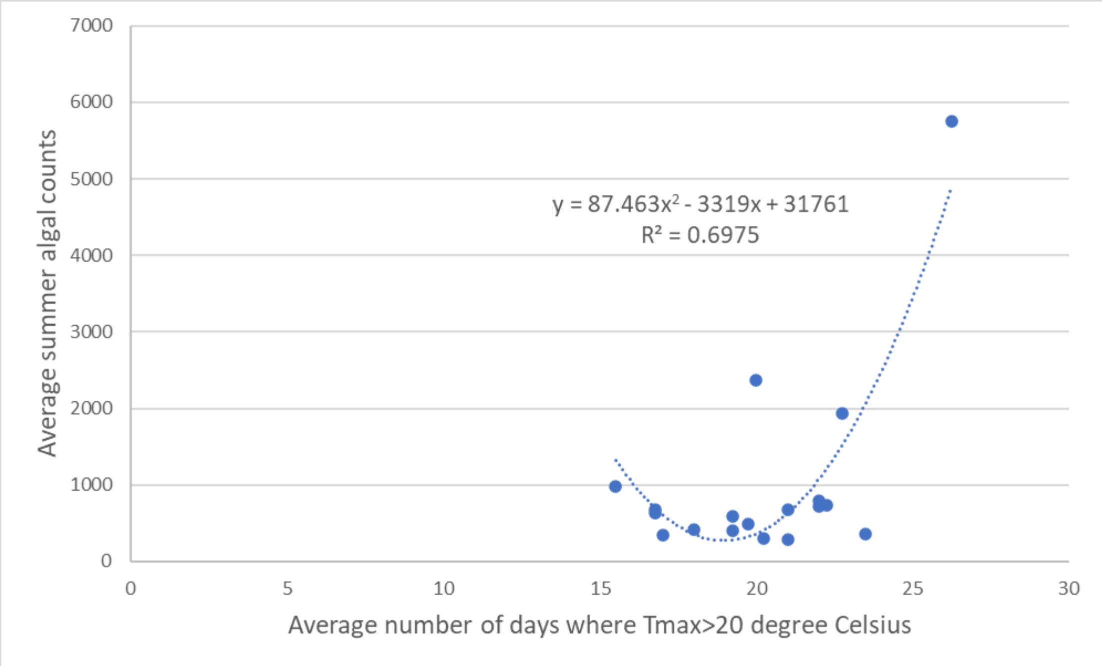
4.2.1 Algal blooms

4.2.1.1 Definition of baseline conditions

Algal blooms in reservoirs and rivers can disturb the operations of intakes by clogging filters and deteriorating raw water quality requiring additional treatment. Algal growth is dependent on temperature, sunshine and nutrient levels (nitrogen and phosphorus) and achieving an optimal balance between these parameters will lead to algal blooms in waterbodies.

The assessment has been conducted at Hanningfield Reservoir, where a correlation was found between algal monthly counts averaged over the summer months (June to September) and the average number of days per month when maximum temperatures exceed 20°C (Figure 4.6). Attempts to fit a multi-variate regression model incorporating sunshine hours did not offer an improvement, given its high correlation with maximum temperature. In addition, the absence of nitrogen and phosphorus data in water quality records prevented the inclusion of nutrient levels in the analysis. Nonetheless, an acceptable regression was obtained for the 2004-2021 baseline period using maximum temperature data, which was then used to predict future levels of algae in the reservoir. Under observed baseline conditions (2004-2021), the 95th percentile (high) value of algal counts is 2,871.

Figure 4.6: Correlation on algal counts for Hanningfield Reservoir



Source: Mott MacDonald analysis
Note: A constant value is adopted below 20 days to correct the upward trend of the adopted regression

4.2.1.2 Recent outages and associated costs

Algal blooms in water bodies will cause increases in operational costs, including increases in coagulant and acid dosing, higher rates of washing primary filters (especially slow sand filters) and subsequent reduction in throughput due to increased load.

A review of outage incidents between April 2019 and March 2022 was undertaken to identify those caused by algal blooms. Recent incidents were recorded mainly at Hanningfield and Abberton (Layer) reservoirs in Essex and Suffolk but outage was also recorded in Northumbria at Whittle Dene and Lumley in Essex and Suffolk. All recent events were reported as exclusions on the basis of being water quality exceptions, in line with Ofwat's PR19 methodology. To note that whilst this could not be included in the present analysis due to a lack of data, communication from Northumbrian operatives pointed out high algae levels at Hanningfield Reservoir following summer 2022 heatwaves, also leading to significant outages.

Similar to the analysis done on turbidity, volumes lost over past incidents were combined with 2022 Actual Year To Date unit production costs to quantify the level of monetised costs resulting from recent high algae events for all relevant water treatment works. The total outage associated costs were estimated to be in the order of **£1,216,404** over the April 2019 to March 2022 period.

Table 4.4: Outages for high algae levels between April 2019 and March 2022

	Site	Counts of incidents	Total number of days	Total outage (Ml)	Total outage (£)
ESW	Hanningfield	5	98	1,949	£86,892
	Layer (Abberton Reservoir)	3	147	5,145	£574,697
NW	Lumley	1	21	210	£72,404
	Whittle Dene	1	65	2,795	£382,412

4.2.1.3 Predictions of future algal blooms

UKCP18 data for maximum temperature extracted for the grid encompassing Hanningfield Reservoir was obtained and analysed to derive future trends in the number of days when maximum temperature exceeds 20°C. By 2050, an extra 4.3 day and 5.4 day per month on average will see maximum temperatures beyond that limit between June and September, in a RCP2.6 and RCP8.5 scenario respectively.

Using the correlation fitted for baseline conditions, high algal counts (95th percentile value) will increase by 40% and 46% respectively in a low and high emission scenario by 2050 (in comparison to the 1991-2020 baseline). These changes correspond to seasonal algal counts of 4,015 and 4,195 respectively.

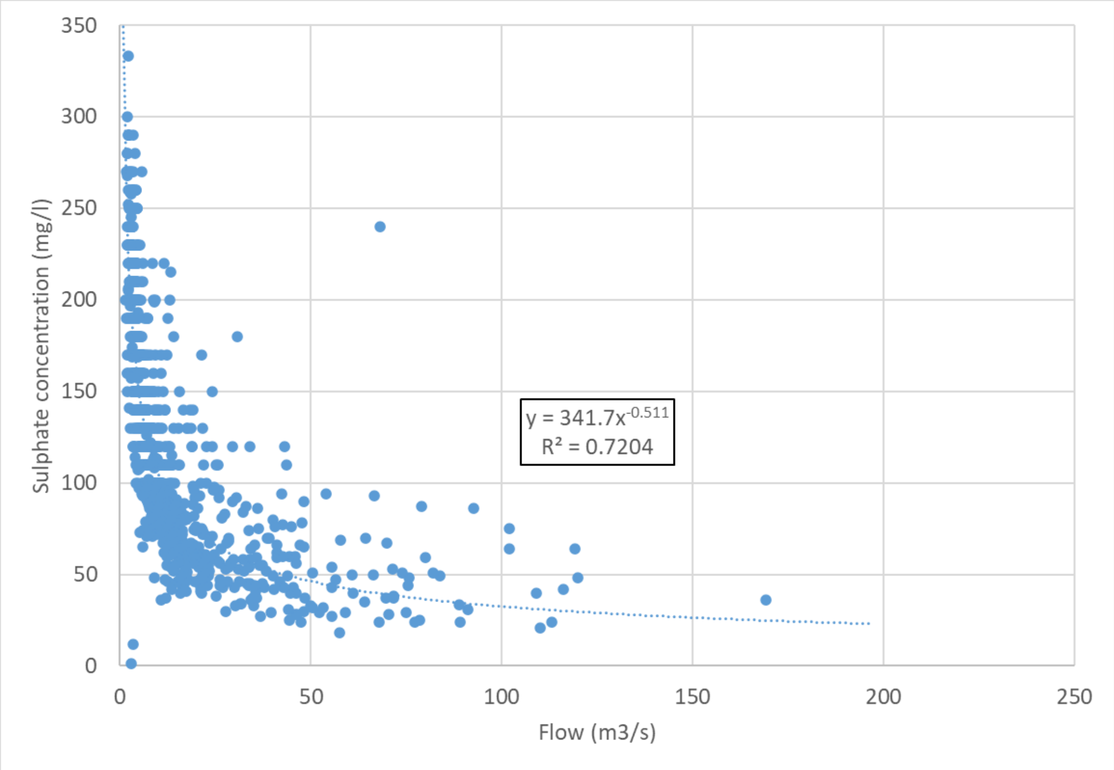
The data obtained is not sufficient to build an understanding of levels known to cause problems to operations. Furthermore, derived uplifts cannot be applied to the number of outages since they correspond to changes in seasonal levels of algae levels. Further data is needed to refine the model as well as to undertake an analysis of financial impacts. Nevertheless, in both climate scenarios, algae levels are likely to increase as a result of increased temperatures and longer periods of hot weather, thus extending periods of disrupted treatment operations and outages. These would be concurrent with periods of dry weather that have an impact on treatment outputs as well as periods of increased demand, thus exacerbating supply-demand balance challenges. Whilst in current conditions, these issues are localised and can be mitigated by moving water around the region; under future conditions, increases in heat wave frequency (as demonstrated in Section 5.1) affecting the whole region is likely to extend algal bloom challenges to other reservoirs or river intakes. Together with other regional water availability challenges, this could pose considerable strain on the network and limit the ability to shift to other sources and reconfigure the network to maintain supply.

4.2.2 Sulphate

Low flow conditions in watercourses have a bearing on the dilution of contaminants which can in turn drive a deterioration of water quality below raw water quality standards. The presence of coal mining activities in the Wear catchment have been shown to affect sulphate levels in the watercourse at Lumley during low flow periods.

Flows at Chester-le-Street were correlated with sulphate concentrations at Lumley river intake (Figure 4.7). Results demonstrate a spike in concentration during low flows with a 95th percentile value of 240 mg/l.

Figure 4.7: Correlation on sulphate levels at Lumley



Source: Mott MacDonald

The regional rainfall-runoff model produced by Mott MacDonald for the Wear catchment and used for deriving climate change and stochastic flow series to Northumbrian Water WRMP24 (Mott MacDonald 2022b) was rerun for this specific application. Baseline and future flow series were obtained, the latter by applying rainfall and PET factors as indicated in Section 2.2.1. The standard baseline period and 30-year periods centred in 2030 and 2050 were adopted. The correlation derived from observed data was further used to obtain the range of future sulphate levels under each emission scenario.

Increases in high sulphate values (95th percentile) during low flows are respectively 3% and 4% in a RCP2.6 and RCP8.5 scenario, reflective of drier conditions in the catchment and a reduction in low flows.

Moreover, the limit of 250mg/l in place at Lumley is exceeded on average 9.5 days/year nowadays and exceedance is expected to increase to 13 and 14.4 days/year respectively in a low and high emission scenario.

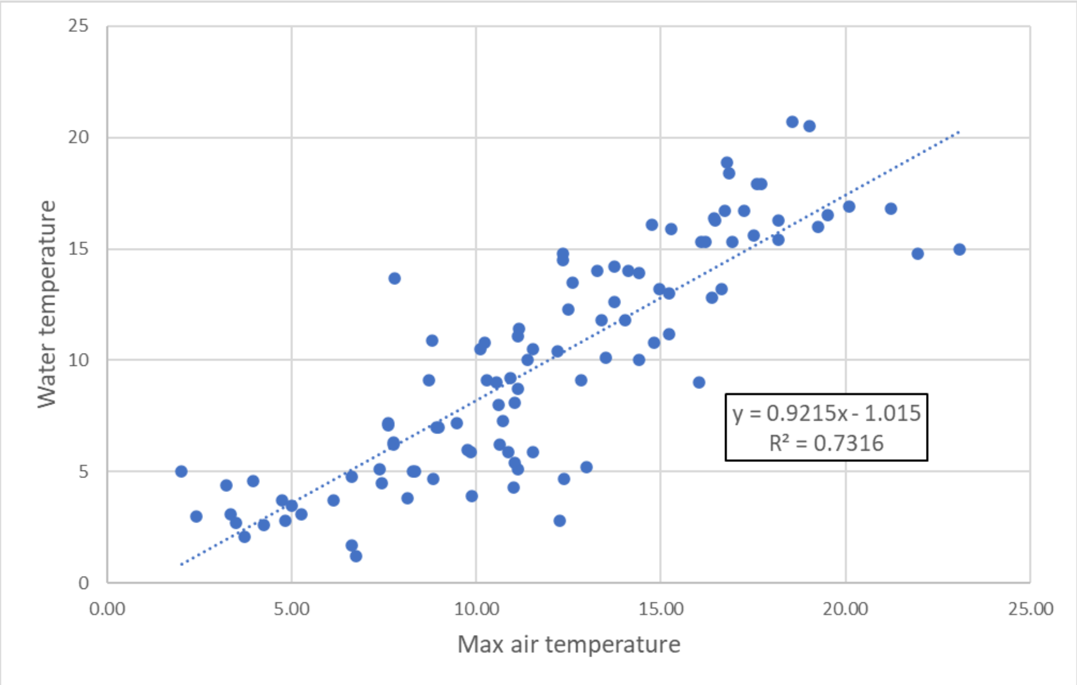
No additional costs for running Lumley on high sulphate levels could be evidenced to date. To note that the works run with blended water from different sources. During summer 2022, levels were recorded above 230mg/l most of the summer months and release of water from Frosterley Impounding reservoir was put in place by the catchment team.

4.2.3 Trihalomethanes (THMs)

THMs are found in water as by-products of the disinfection process when chlorine is added to the water and when elevated levels of organics matter are present. This is exacerbated in regions where specific landcover such as peatlands is particularly sensitive to increased temperatures that would drive increases in organic matter degradation and subsequently, in dissolved organic carbon. For example, correlations between high levels of THMs in drinking water have been derived with increasing water temperature and levels of dissolved organic carbon in Scotland (Valdivia-Garcia, M., Weir, P., Graham, D.W. et al., 2019[14]).

At Fontburn Reservoir, high levels of THMs were recorded in June and July 2018 when extreme high temperatures were recorded. Monthly averages of maximum temperatures were found to be then 1.6 and 2.4 degree higher than the long-term averages during the baseline 1991-2020 period. A correlation was sought between maximum air temperature and water temperature data (Figure 4.8) and average water temperature during June and July 2018 were similarly 1.5 and 2.2 degree higher than the long-term averages of 13.8 and 15.9 degrees.

Figure 4.8: Correlation between air and water temperature in Fontburn Reservoir



Source: Mott MacDonald

UKCP18 projections for maximum temperature were extracted for Fontburn Reservoir and an evaluation of changes in average monthly temperatures for the summer months was carried out. The correlation derived for baseline conditions was applied to future maximum temperatures and changes in monthly water temperature for the summer months were derived (Table 4.5).

Results indicate an increase in monthly water temperatures during the summer months in both emission scenarios, with greater increases expected in late summer. Increases experienced during June 2018 could become the new normal in a RCP2.6 scenario whilst those experienced during July 2018 could become the new normal in a RCP8.5 scenario. It is thus likely to see more frequent incidents of THMs spikes in the Fontburn Reservoir by 2050.

To note that no additional costs for running Fontburn on high THMs levels could be evidenced to date. However, a prescribed concentration is set for the sum of concentrations of the four THMs measured at the consumer tap and increases in THM levels in chlorinated water could pose a compliance risk.

[14] Predicted Impact of Climate Change on Trihalomethanes Formation in Drinking Water Treatment - https://doi.org/10.1038/s41598-019-46238-0

Table 4.5: Changes in water temperature by 2050 in Fontburn Reservoir

Change from 1991-2020 baseline (degree Celsius)	2050s – RCP2.6	2050s – RCP8.5
June	1.2	2.3
July	1.3	2.4
August	1.5	2.8
September	1.3	2.8

4.2.4 Phosphate and Ammonia

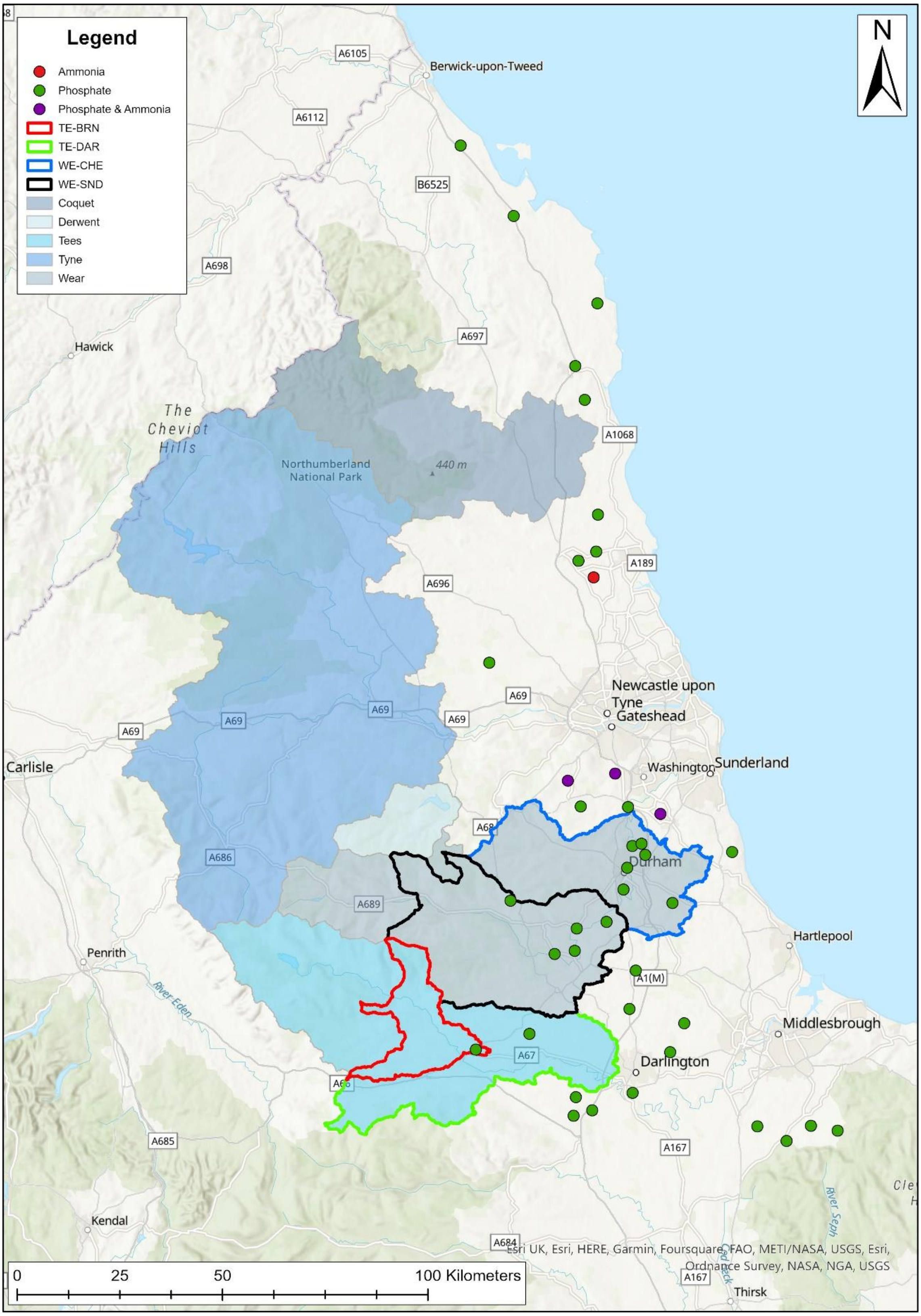
Phosphate and ammonia levels in watercourses can impact the ecological conditions of aquatic ecosystems. Outcomes from the SAGIS modelling provided by Stantec to Mott MacDonald and undertaken for the delivery of PR24 WINEP investigations have been used to characterise the baseline conditions for ammonia and phosphate in receiving waterbodies. The present climate resilience work builds on the outcomes of the baseline and at permit models to investigate changes in future concentrations of ammonia and phosphate in the two investigated climate scenarios.

The regional rainfall-runoff models produced by Mott MacDonald and used for the derivation of climate change and stochastic flow series for Northumbrian Water and Essex and Suffolk Water WRMP24s (Mott MacDonald 2022a, 2022b) were rerun for this specific application. Baseline and future flow series were obtained, the latter by applying rainfall and PET factors to historical sequences as indicated in Section 2.2.1. The baseline period and 30-year periods centred in 2030 and 2050 were adopted. Flow series at intermediate points (where available) as well as at the outlet of the Wear, Tees, Tyne and Coquet catchments were obtained and percentage changes in Q95 corresponding to low flow conditions were calculated and applied to the Q95 values output from the SAGIS models at all 41 STW locations (Figure 4.9). Where site locations fall outside of the regional rainfall runoff modelling catchments, changes in flows in the upstream or nearest catchment were used.

Future loads have been assumed to remain the same as in current conditions and adopting three scenarios: baseline, At Permit without reductions and At Permit with Environment Act reductions. Future concentrations have then been estimated using post-processed future Q95 values for low flow conditions. These were in turn compared with the equivalent WFD Good Status concentrations to investigate potential changes in status. To note that the phosphate results presented in this version are not based on the latest version of the SAGIS model and will need to be revisited once these are made available. It could result in changes to the conclusions presented in this version of the report.

In the absence of target loads output from the SAGIS models for ammonia, a different approach was taken to investigate compliance against target concentrations in the future. River Quality Planning (RQP) models were run for current and future scenarios and for both baseline and At Permit scenarios. Models were run assuming the same output flow and load from the works whilst changing low flow conditions in the upstream waterbody to investigate changes in concentrations downstream.

Figure 4.9: Location of investigated STWs discharges in NW catchments



Source: Mott MacDonald

Results demonstrate that current phosphate loads in the waterbody are beyond those prescribed in the At Permit with Environment Act reductions model for 32 out of 40 receiving waterbodies and good status is only achieved in three receiving waterbodies, respectively Bishop Auckland, Low Wadsworth and Morpeth STWs (Table 4.6). For all others, high concentrations of phosphate currently prevent achieving the WFD Good Status. In the future and without improvements, higher concentrations during low flows would further degrade quality and prevent meeting prescribed levels. This would in turn push some of those waterbodies to lower bands:

- From moderate to poor downstream of Carlton and Ingleby Greenhow STWs under RCP2.6;
- From moderate to poor downstream of Aldbrough, Carlton, Hustledown and Ingleby Greenhow STWs under RCP8.5; and,
- From poor to worse than poor downstream of Windlestone STW under RCP2.6 and RCP8.5.

A comparison between the two At Permit scenarios demonstrates improvements to the WFD status for phosphate for a number of receiving waterbodies after implementation of Environment Act reductions (Table 4.7 and Table 4.8). In future emission scenarios however, results show that these reductions will not be sufficient to maintain improvements and degradation in WFD status would occur:

- From good to moderate downstream of Bishop Auckland and Stamfordham STWs under RCP2.6;
- From good to moderate downstream of Alnwick, Bishop Auckland, Stamfordham, Stressholme and Wllington STWs under RCP8.5;
- From moderate to poor downstream of Bishopton, Carlton, Great Broughton, Hutton Rudby, Ingleby Greenhow and Pegswood STWs under RCP2.6; and,
- From moderate to poor downstream of Aldbrough, Bishopton, Carlton, Great Broughton, Hutton Rudby, Ingleby Greenhow, Pegswood and Stainton Camp STWs under RCP2.6.

These could in turn trigger further reductions in discharge permits from the works to improve water quality in a greater number of waterbodies, with potential additional investment to upgrade the works.

Table 4.6: WFD status for phosphate in receiving waterbody downstream of investigated sewage treatment works (baseline model)

STW Name	Baseline	RCP2.6	RCP8.5
Aldbrough	Moderate	Moderate	Poor
Alnwick	Moderate	Moderate	Moderate
Aycliffe	Poor	Poor	Poor
Barkers Haugh	Moderate	Moderate	Moderate
Barton	Poor	Poor	Poor
Belford	Worse than poor	Worse than poor	Worse than poor
Belmont	Poor	Poor	Poor
Birtley	Poor	Poor	Poor
Bishop Auckland	Good	Good	Good
Bishopton	Moderate	Moderate	Moderate
Brasside	Worse than poor	Worse than poor	Worse than poor
Carlton in Cleveland	Moderate	Poor	Poor
Cassop	Moderate	Moderate	Moderate
Chester Le Street	Moderate	Moderate	Moderate
East Tanfield	Poor	Poor	Poor
Embleton	Poor	Poor	Poor
Great Broughton	Poor	Poor	Poor
Haggerston Castle	Moderate	Moderate	Moderate
Hawthorn	Poor	Poor	Poor
Hustledown	Moderate	Moderate	Poor
Hutton Rudby	Poor	Poor	Poor
Ingleby Greenhow	Moderate	Poor	Poor
Leamside	Moderate	Moderate	Moderate
Low Wadsworth	Good	Good	Good
Melsonby	Poor	Poor	Poor
Morpeth	Good	Good	Good
Pegswood	Poor	Poor	Poor
Sadbergh	Poor	Poor	Poor
Sedgeletch	Poor	Poor	Poor
Shilbottle	Moderate	Moderate	Moderate
Staindrop	Moderate	Moderate	Moderate
Stainton Camp	Poor	Poor	Poor
Stamfordham	Moderate	Moderate	Moderate
Stressholme	Moderate	Moderate	Moderate
Tow Law	Poor	Poor	Poor
Tudhoe Mill	Moderate	Moderate	Moderate
Ulgham	Moderate	Moderate	Moderate
University	Worse than poor	Worse than poor	Worse than poor
Willington	Moderate	Moderate	Moderate
Windlestone	Poor	Worse than poor	Worse than poor

Table 4.7: WFD status for phosphate in receiving waterbody downstream of investigated sewage treatment works (at-permit without reductions)

STW Name	Baseline	RCP2.6	RCP8.5
Aldbrough	Moderate	Poor	Poor
Alnwick	Moderate	Moderate	Moderate
Aycliffe	Worse than poor	Worse than poor	Worse than poor
Barkers Haugh	Moderate	Poor	Poor
Barton	Poor	Poor	Poor
Belford	Worse than poor	Worse than poor	Worse than poor
Belmont	Worse than poor	Worse than poor	Worse than poor
Birtley	Poor	Poor	Poor
Bishop Auckland	Moderate	Moderate	Moderate
Bishopton	Poor	Poor	Poor
Brasside	Worse than poor	Worse than poor	Worse than poor
Carlton in Cleveland	Moderate	Poor	Poor
Cassop	Poor	Poor	Poor
Chester Le Street	Poor	Poor	Poor
East Tanfield	Poor	Poor	Poor
Embleton	Poor	Poor	Poor
Great Broughton	Poor	Poor	Poor
Haggerston Castle	Moderate	Moderate	Moderate
Hawthorn	Poor	Poor	Poor
Hustledown	Poor	Poor	Poor
Hutton Rudby	Moderate	Poor	Poor
Ingleby Greenhow	Moderate	Poor	Poor
Leamside	Moderate	Poor	Poor
Low Wadsworth	Moderate	Moderate	Moderate
Melsonby	Poor	Poor	Poor
Morpeth	Good	Good	Good
Pegswood	Poor	Poor	Poor
Sadbergh	Poor	Poor	Poor
Sedgeletch	Worse than poor	Worse than poor	Worse than poor
Shilbottle	Moderate	Moderate	Moderate
Staindrop	Moderate	Poor	Poor
Stainton Camp	Poor	Poor	Poor
Stamfordham	Moderate	Moderate	Moderate
Stressholme	Moderate	Moderate	Poor
Tow Law	Poor	Poor	Poor
Tudhoe Mill	Moderate	Moderate	Moderate
Ulgham	Moderate	Moderate	Moderate
University	Worse than poor	Worse than poor	Worse than poor
Willington	Moderate	Moderate	Moderate
Windlestone	Poor	Poor	Poor

Table 4.8: WFD status for phosphate in receiving waterbody downstream of investigated sewage treatment works (at-permit with reductions)

STW Name	Baseline	RCP2.6	RCP8.5
Aldbrough	Moderate	Moderate	Poor
Alnwick	Good	Good	Moderate
Aycliffe	Poor	Poor	Poor
Barkers Haugh	Moderate	Moderate	Moderate
Barton	Good	Good	Good
Belford	Worse than poor	Worse than poor	Worse than poor
Belmont	Poor	Poor	Poor
Birtley	Poor	Poor	Poor
Bishop Auckland	Good	Moderate	Moderate
Bishopton	Moderate	Poor	Poor
Brasside	Poor	Poor	Poor
Carlton in Cleveland	Moderate	Poor	Poor
Cassop	Moderate	Moderate	Moderate
Chester Le Street	Moderate	Moderate	Moderate
East Tanfield	Poor	Poor	Poor
Embleton	Poor	Poor	Poor
Great Broughton	Moderate	Poor	Poor
Haggerston Castle	Moderate	Moderate	Moderate
Hawthorn	Moderate	Moderate	Moderate
Hustledown	Poor	Poor	Poor
Hutton Rudby	Moderate	Poor	Poor
Ingleby Greenhow	Moderate	Poor	Poor
Leamside	Moderate	Moderate	Moderate
Low Wadsworth	Good	Good	Good
Melsonby	Good	Good	Good
Morpeth	Good	Good	Good
Pegswood	Moderate	Poor	Poor
Sadbergh	Poor	Poor	Poor
Sedgeletch	Poor	Poor	Poor
Shilbottle	Good	Good	Good
Staindrop	Good	Good	Good
Stainton Camp	Moderate	Moderate	Poor
Stamfordham	Good	Moderate	Moderate
Stressholme	Good	Good	Moderate
Tow Law	Moderate	Moderate	Moderate
Tudhoe Mill	Moderate	Moderate	Moderate
Ulgham	Moderate	Moderate	Moderate
University	Poor	Poor	Poor
Willington	Good	Good	Moderate
Windlestone	Poor	Poor	Poor

Results from the RQP modelling highlighted that current ammonia concentrations in the receiving waterbodies are below prescribed concentrations in the at-permit model for Hepscott, East Tanfield and Sedgeletch STWs whilst concentrations at Birtley STW are above at-permit levels in low flow conditions. In the future, minor increases in ammonia concentrations in downstream waterbodies will not result in additional exceedance of prescribed levels. Furthermore, in low flow conditions:

- For Hepscott STW, downstream concentrations will be within the range to achieving good status in all three current, RCP 2.6 and RCP8.5 scenarios.
- For East Tanfield STW, downstream concentrations are higher than those required to achieve WFD good status in all three scenarios. However, the waterbody overall (i.e. under mean annual flow conditions) achieves good status and minor changes in future concentrations during low flows are unlikely to affect that status.
- For Birtley STW, downstream concentrations are higher than those required to achieve WFD good status in all three scenarios as well as in the at-permit model. Overall, under mean annual flow conditions, the waterbody also fails to achieve good status (i.e. only reaching moderate status) and in the future, this is likely to remain the case.
- For Sedgeletch STW, downstream concentrations are higher than those required to achieve WFD good status in all three scenarios. However, the waterbody overall (i.e. under mean annual flow conditions) achieves good status and minor changes in future concentrations during low flows are unlikely to affect that status.

4.3 Implications for performance commitments

A change in raw water quality and dilution capacity can impact two performance commitments as set out in the PR19 final determinations Northumbrian Water outcomes performance commitment appendix:

- Unplanned outage, defined as the temporary loss of peak week production capacity (PWPC) in the reporting year weighted by the duration of the loss (in days), normalised based on overall company peak week production capacity, and reported as a percentage.
- Treatment works compliance, reported as the number of failing sites (as a percentage of the total number of discharges) and not the number of failing discharges. A discharge can be confirmed as failing for different breaches of a numeric permit, including nutrients (eg P) and sanitary parameters (eg NH_3).

An increase in turbidity levels as presented in section 4.1.1 would imply an additional 24 days and 36 days of unplanned outage across Northumbria and Essex and Suffolk for RCP2.6 and 8.5 respectively. Multiplying by the lost production, this results in 308Ml and 463Ml of unplanned outage or 0.85 and 1.27Ml/d. Normalising by a total company deployable output of 1348Ml/d (according to WRMP19), the unplanned outage metric would increase by 0.06 and 0.09%. Assuming the standard underperformance payment, this would lead to an additional penalty of £103,200 and £154,800 per year for RCP2.6 and RCP8.5 respectively.

As regards the discharge consent compliance, even with permit reductions there will be WFD deterioration downstream several STWs (see Table 4.8) due to the impact on climate change on low flows. This will likely lead to further permit reductions in future AMPs that would require investment to improve treatment process. Otherwise the likelihood of breaching the new permits would be high, and this would imply a penalty of £597,000 per year for each % of discharges not complying over total number below a dead band of 99%. In addition, Ofwat in their PR24 draft methodology are proposing to introduce a new river water quality performance commitment[15] that measures the reduction in phosphorous from water company activities, covering both the reduction in the amount of phosphorus discharged at wastewater treatment works and also the phosphorous stopped from entering rivers from wider partnership working. The actual mechanism to measure the performance commitment and the magnitude of the associated penalty is still unclear, but compliance might be affected by climate change.

[15] Appendix-6-Performance-commitments-1.pdf (ofwat.gov.uk)

5 Extreme heat assessments

The risk of extreme heat was highlighted as high and medium respectively for ESW and NW areas in the contextualisation report. Further investigations are undertaken to quantify the changes in extreme heat conditions and the physical as well as the financial impacts of those on asset operations.

5.1 Changes in heatwave events

Heatwaves are characterised by the number of days every year where daily maximum temperatures reach above a certain threshold. Across NW and ESW, heatwave thresholds are set by the MetOffice respectively at 3 consecutive days with maximum temperature exceeding 25 and 27 degree Celsius[16], recognising that higher temperatures are generally recorded across the south-east of England.

Changes in heatwave occurrences by 2050 have been investigated by reviewing UKCP18 RCM projections for maximum temperatures against HadUK data used to obtain baseline conditions at the same seven locations across the south-east and north-east service areas. Results presented in Table 5.1 and Table 5.2 show increases in heatwave frequency at all locations in both a low and high emission scenario with higher occurrences overall across the ESW supply area. Higher occurrences of heatwaves in Middlesbrough in the north-west reflect its location further south in the region, where temperatures are expected to be higher. Similarly, in the south-east, lower frequency of heatwaves at Lowestoft reflects both its position further north as well as its coastal location, influenced by the cooling air of the open North Sea.

Table 5.1: Changes in heat wave frequency across NW

Number of heat waves/year	Baseline (1991-2020)	2050s – RCP8.5	2050s – RCP2.6
Berwick upon Tweed	0.17	1.11	0.49
Alnwick	0.17	1.22	0.5
Consett	0.3	1.44	0.75
Newcastle	0.27	1.67	0.74
Middlesbrough	0.97	3.61	2.12

Table 5.2: Changes in heat wave frequency across ESW

Number of heat waves/year	Baseline (1991-2020)	2050s – RCP8.5	2050s – RCP2.6
Chelmsford	1.03	3.69	2.23
Lowestoft	0.13	1.16	0.45
Southend	2.23	5.23	3.99

5.2 Impacts on clean water system

Engagement with multiple stakeholders within NWL organisation was carried out to better understand the range of physical impacts that are known to affect assets and networks during extreme heat events. They can be summarised as follows:

- Increases in pipe bursts and leakage from increased soil moisture deficits (reported in Section 3.1) but also due to fluctuations in customer demand causing pressure oscillations,

[16] What is a heatwave? - Met Office

particularly on high diameter pipes, leading to increases in manpower hours and in turn has an impact on ODIs.

- Increases in algae levels (reported in Section 4.2.1) with impacts on water quality, filter performance and the downstream sludge system that is slowed down. Particularly, algae increases have been reported in the north-east in the last 2-3 years, with Hallington and Derwent reservoirs being of concern. Whilst high algae levels can be treated, it increases processing and treatment costs.
- Changes in network configuration as a result of changes/reductions in resource availability in certain areas (ie upland reservoirs being depleted and needing to be replaced by downstream river intakes). This leads to additional pumping of water through the network. Further network configuration is needed to meet increased demand in different areas during dry conditions.
- Increases in sulphate levels in places, particularly at Lumley, from lower dilution in watercourses (reported in Section 4.2.2).
- Increases in THM levels at Fontburn, with repercussion along the Tyne network (reported in Section 4.2.3).
- Tripping of electrical/mechanical equipment, particularly in environments that lack ventilation or cooling systems.
- Temporary stoppage of flushing activities required to condition the mains with impact on colour. Flushing activities had to stop during the summer months in the last two years due to high demand.

5.3 Impacts on wastewater system

Similar engagement to that conducted with clean water experts within NWL was carried out to investigate the physical impacts of extreme heat on the wastewater system, highlighting:

- Increases in effluent concentrations putting a strain on sites when reaching beyond the range of treatable loads. Increases in chemical dosing becomes required to treat more concentrated effluents.
- Built in effluent septicity along the network and in concrete structures at the works, with associated corrosion issues and difficulties in treatment processes.
- Lower dilution in receiving waterbodies with possible impact on the discharge of effluents and on treatment compliance, particularly ammonia levels would pose a risk. Tertiary treatment becomes required to maintain compliance. Increases in pollutant concentrations in receiving waterbodies could lead to tighter discharge consents.
- First flush effects following prolonged dry periods putting a strain on the networks and the pumps.
- Susceptibility of plastic media to heat. Issues are particularly triggered when high fluctuations in temperatures occur between day and night times, with bacteria retreating from media and associated reduction in treatment capacity.
- Tripping of electrical/mechanical equipment, particularly in environments that lack ventilation or cooling systems.
- Disruption to gas exports during high temperature events necessitating releases to atmosphere with the associated loss of revenue.
- Increased temperatures of sludge effluents causing issues along the sludge system and requiring extra time for cooling.

5.4 Costs

The costs recorded between July and September 2018 totalled up to £3,624,000 while costs reached £5,821,790 over the June to August 2022 period. No comparative analysis could be drawn to date to quantify how much the heat wave that affected assets and networks during those periods contributed to the total expenditure. This is due to a lack of monthly profiles of expenditure for non-heat wave years. To note that the above costs would also incorporate costs associated to other impact mechanisms such as pipe bursts, whose associated financial impacts have been reported in other sections of this report.

6 Flood resilience assessments

6.1 Representation of future flood conditions

Hydrological analyses were undertaken to enable investigating future flood conditions at Northumbrian and Essex and Suffolk Water assets for the 1% Annual Exceedance Probability (AEP) event. The approach has assumed that the Environment Agency Flood Maps for Planning and Risk from Surface Water Flooding 0.1% AEP flood extents are reasonable proxies for the 1% AEP plus climate change (CC) - 1% AEP +CC - flood extent. To validate this assumption, flood flow estimates were derived at five peak flow rated gauging stations contained within the National River Flow Archive (NRFA) Peak Flow Database; two sites in the North-East of England and three in the South-East as shown in Figure 6.1 and Figure 6.2.

Figure 6.1: Location of Tyne at Bywell and Tees at Darlington Broken Scar catchments

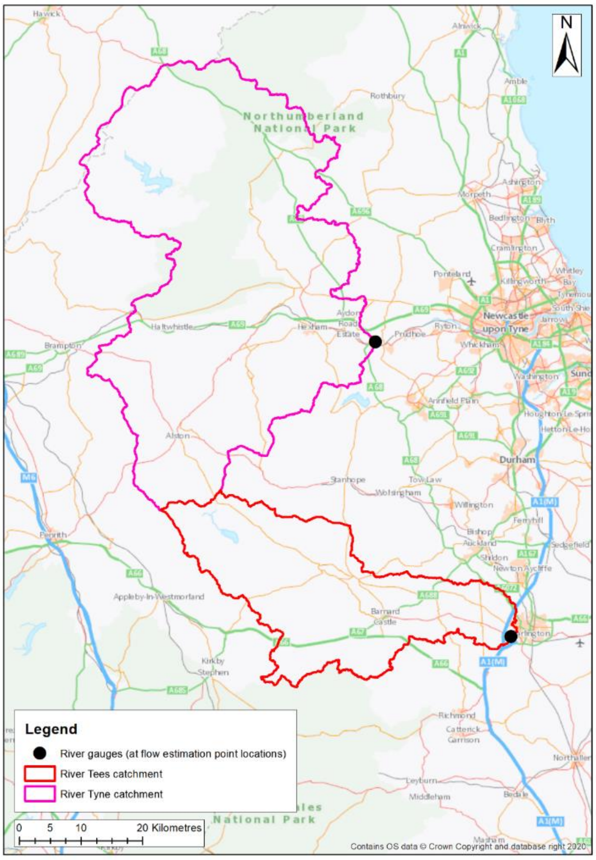
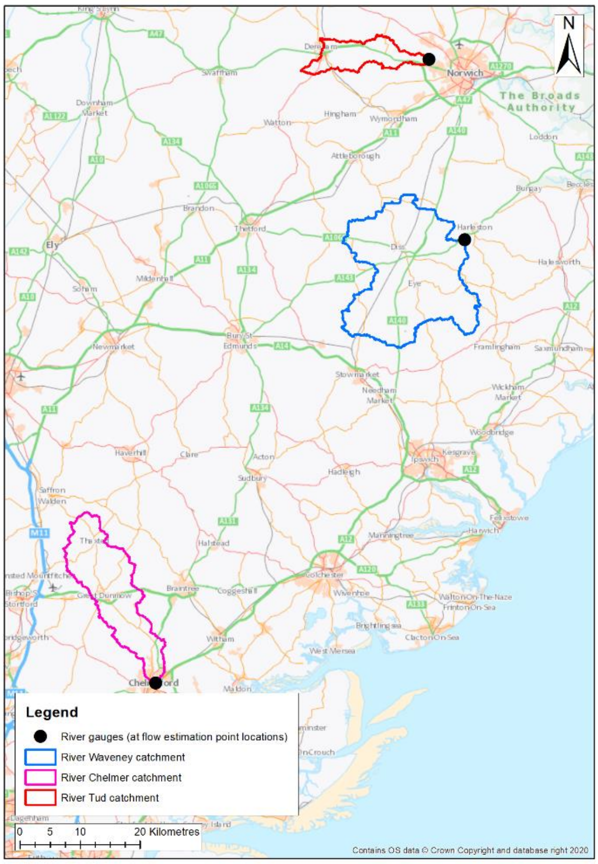


Figure 6.2: Location of Tud at Costessey Park, Chelmer at Springfield and Waveney at Needham Mill catchments



Stations were selected on the basis of the length of the period of record, suitable quality of peak flow data for applying Flood Estimation Handbook (FEH) procedures and proximity to critical assets.

The 1% AEP and 0.1% AEP peak flows in this assessment were derived based on the FEH Enhanced Single Site (ESS) statistical analysis and the Revitalised Flood Hydrograph 2 (ReFH2) methods. Given that the sites are NRFA peak flow rated gauging stations with suitable periods of record (>14 years), QMED (associated with a 50% AEP) was calculated directly from the Annual Maxima (AMAX) series at each station. WINFAP v5 was used to derive pooling groups for each subject site. The initial pooling groups were reviewed for suitability and amendments made as necessary. The generalised logistic (GL) distribution was adopted as it is reported by the FEH that on average, the GL distribution is considered to perform better than the GEV for pooled growth curve derivation.

Peak flow estimates were also derived using catchment descriptors in the ReFH2 software. Table 6.1 shows the final adopted 0.1% AEP estimate, derived by scaling the 1% AEP statistical estimate by the ratio of the ReFH2 0.1% AEP peak flow estimate over the ReFH2 1% peak flow estimate as standard procedure. This approach acknowledges that confidence is greater in rainfall growth curves than in flood growth curves for longer return periods[17]. Also presented are the 0.1% AEP estimates derived by extrapolating the FEH Statistical derived growth curves. Note that the peak flow values for Waveney have been taken from a recent study conducted on the River Waveney at Mill Lane[18].

Table 6.1: Final FEH Statistical peak flow estimates

Site code	Flood peak (m^3/s) for the following return periods (in years)									
	2	**5**	**10**	**30**	**50**	**75**	**100**	**200**	**1000 (Stat.)**	**1000 (Ratio)**
	Flood peak (m^3/s) for the following AEP (%) events									
	50	**20**	**10**	**3.33**	**2**	**1.33**	**1**	**0.5**	**0.1**	**0.1**
Tyne	842	1054	1198	1438	1559	1660	1736	1929	2456	2693
Tees	390	495	571	700	768	826	870	984	1311	1345
Tud	3.1	4.6	5.7	7.4	8.3	9.1	9.7	11.2	15.4	17.1
Chelmer	13.9	20.8	25.5	33.2	37.1	40.3	42.7	48.9	65.6	81.2
Waveney	-	-	-	-	-	-	68.9	-	118	118

To derive the 1% AEP +CC flow estimates, probabilistic projections for extremes of 1% AEP maximum daily rainfall for RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 were obtained for the present day (2020) and 2050s epochs from the UK Climate Projections 2018 (UKCP18) data. The relative uplifts based on these projections were calculated and applied to the 1% AEP storm profile used in REFH2 to estimate the impact on 1%AEP peak flow. This resulted in:

- Tyne at Bywell: the estimate of the 0.1% AEP peak flow is up to 37% and 50% greater than the estimate of the 1% AEP +CC.
- Tees at Darlington: the estimate of the 0.1% AEP peak flow is up to 47% and 51% greater than the estimate of the 1% AEP +CC.
- Tud at Costessey Park: the estimate of the 0.1% AEP peak flow is up to 51% and 68% greater than the estimate of the 1% AEP +CC.
- Chelmer at Springfield: the estimate of the 0.1% AEP peak flow is up to 47% and 82% greater than the estimate of the 1% AEP +CC.

The Environment Agency climate change allowances for rainfall in England[19] were also adopted. The reported upper allowances for the 2050s were considered for each catchment (see Table 6.2). These uplifts are for rainfall and were therefore applied to the rainfall storm profile in ReFH2. The resultant percentage change in peak flow was used to adjust the FEH statistical estimates.

[17] Environment Agency (2022). Flood Estimation Guidelines Instruction: LIT 11832 Published: 07/07/2022

[18] Mott MacDonald, 2021. *PDU4 – River Waveney and Tributaries Hydrology Report.* 393325WV | 02i | B

[19] Department for Environment, Food & Rural Affairs. *Climate Change Allowances.* [Online]. Available at: https://environment.data.gov.uk/hydrology/climate-change-allowances/river-flow [Accessed 27/07/2022]

Table 6.2: Peak rainfall uplifts for 2050s upper end

Site code	% uplift to 2050s (Upper)
Tyne	40
Tees	40
Tud	45
Chelmer	45
Waveney	45

The results are shown in Table 6.3, demonstrating that the Environment Agency climate change allowances for peak rainfall provide a good approximation of the 0.1% AEP peak flood flow by application of the upper allowances to the 1% AEP estimates at all sites. In particular for the 0.1% AEP peak flow derived by extrapolation of the enhanced single site derived growth curve, the absolute percentage difference is shown to be 1% or 13% for the smallest and largest differences. While for the 0.1% AEP peak flow estimates derived using the ratio of the ReFH2 0.1% AEP estimate over the 1% ReFH2 estimate, the absolute minimum and maximum difference is 4% and 27%, respectively.

Table 6.3: Peak flow estimates based on EA rainfall uplifts

Allowance	Site	From ReFH2				From FEH Statistical			
		1% AEP	1% AEP +CC	Flow increase between 1% AEP and 1% AEP +CC	0.1% AEP	1% AEP	1% AEP +CC	0.1% AEP (FEH Stat.)	0.1% AEP (ReFH2 ratio)
2050s Upper End	Tyne	1279	1872	46.4%	1984	1736	2542	2456	2693
	Tees	580	859	48.1%	896	870	1289	1311	1345
	Tud	15.6	24.9	59.8%	27.6	9.7	15.5	15.4	17.1
	Chelmer	41.9	62.7	49.6%	79.6	42.7	63.9	65.6	81.2
	Waveney	98.3	148	50.2%	164	68.9	104	118	118

Finally, the Environment Agency climate change allowances for peak river flow in England[20] were also applied directly to the 1% AEP FEH statistical estimates. The central, higher, and upper allowances for the 2050s were considered for each catchment (Table 6.4).

Table 6.4: Peak flow uplifts for 2050s

Site code	% uplift to 2050s		
	Central	**Higher**	**Upper**
Tyne	22	28	42
Tees	21	27	41
Tud	3	10	27
Chelmer	8	16	37
Waveney	3	10	27

Only the Upper End results are shown in Table 6.5, as this allowance resulted in the closest match between the 1% AEP +CC and 0.1% AEP estimates.

[20] Department for Environment, Food & Rural Affairs. *Climate Change Allowances.* [Online]. Available at: https://environment.data.gov.uk/hydrology/climate-change-allowances/river-flow [Accessed 27/07/2022]

Table 6.5: Peak flow estimates based on EA flow uplifts

Allowance	Site	From ReFH2			From FEH Statistical			
		1% AEP	1% AEP +CC	0.1% AEP	1% AEP	1% AEP +CC	0.1% AEP (FEH Stat.)	0.1% AEP (ReFH2 ratio)
2050s Upper End	Tyne	1279	1816	1984	1736	2465	2456	2693
	Tees	580	818	896	870	1227	1311	1345
	Tud	15.6	19.8	27.6	9.7	12.3	15.4	17.1
	Chelmer	41.9	57.4	79.6	42.7	58.5	65.6	81.2
	Waveney	98.3	125	164	68.9	87.5	118	118

This demonstrates that overall, the Environment Agency climate change uplifts provide a better justification of using the 0.1% AEP peak flow estimates as a proxy for the 1% AEP+ CC peak flow. For the Tees, Tud, Chelmer and Waveney, the Environment Agency allowances for peak rainfall provide a closer match, with the difference for the Tees being only 2% or 4% based solely on the enhanced single site growth curve or ReFH2 0.1% AEP/1% AEP ratio, respectively. While for the Tyne, the fluvial allowances give a difference of <1% and 9% based solely on the enhanced single site growth curve or ReFH2 0.1% AEP/1% AEP ratio, and the peak rainfall allowances a difference of 3% and 6%, respectively.

The UKCP18 probabilistic projections of maximum daily rainfall are significantly lower than fluvial and peak rainfall allowances reported by the Environment Agency. This is due to a number of factors, namely:

- The Environment Agency allowances have been derived based on a high emissions scenario only (RCP8.5);
- They are based on a 1981-2000 that does not account for the initial stages of climate change impact already realised (although still not noticeably observed in the flow record);
- They offer estimates accounting for higher uncertainty in climate projections; and,
- They (in the case of peak flows) consider the combined effect of changes in rainfall intensity and soil saturation during winter.

Given the findings of the hydrological assessment, the 0.1%AEP flood extents can be considered to be a good proxy for the 1%AEP+CC flood extents assuming the most conservative emission scenario and uncertainty band. They can then be used to determine the maximum potential impact.

Depending on the evolution of greenhouse gases emissions and how the climate evolves to them, future impact is likely to not exceed this maximum. Therefore, costs estimated below should be adjusted down to account for lower emissions (i.e. RCP2.6) and a median projection. The Environment Agency peak flow allowances can be used for this purpose as they provide uplifts for the central scenario corresponding to a 50th percentile that can be compared with the upper end to define a suitable scaling factor for RCP8.5. This central allowances for 2050s can then be further compared with those associated to 2020s to establish an additional scaling factor for RCP2.6.

Table 6.6 presents the comparison between peak flow allowances. It points towards adjustment factors in the north-east of 0.52 and 0.45 for RCP8.5 and RCP2.6 respectively, whereas in the south-east they will be 0.17 and 0.23 for each scenario. To note that there will be a greater risk of flooding in the south-east for the lower emission scenario, which can be explained by the interaction between the trend towards wetter winters and drier summer/autumns. Although in RCP8.5 rainfall will intensify in winter more than in RCP2.6, the drier antecedent conditions will imply less saturated soils leading to less pronounced floods.

Table 6.6: Adjustments factors for fluvial flooding

Site code	RCP8.5 % uplift to 2050s		95th to 50th percentile	RCP8.5 % uplift to 2020s	RCP8.5 to RCP2.6 factor
	Central	Upper		Central	
Tyne	22	42	0.52	18	0.82
Tees	21	41	0.51	19	0.90
Tud	3	27	0.11	8	2.67
Chelmer	8	37	0.22	7	0.88
Waveney	3	27	0.11	8	2.67

In addition, to changes in peak rainfall and peak flows, sea level rise will impact coastal flooding. Comparison in this case has been made between the 0.5%AEP tidal levels for baseline conditions as reported in the Environment Agency "Costal Flood Boundary Extreme Sea Levels" dataset, and those corresponding to future conditions in the 2050s assuming the Upper End and H++ allowances indicated by the Environment Agency. Similar to fluvial flooding costs, coastal flooding costs should be adjusted to reflect a central scenario corresponding to a 50th percentile for RCP8.5 and to estimate damages associated to RCP2.6. EA sea level allowances can be used for this, although they are not available for a central scenario but for a higher central one only. Associated adjustment factors are shown in Table 6.7

Table 6.7: Adjustments factors for coastal flooding

Area	RCP8.5 sea level rise to 2050 (cm)		95th to 70th percentile	RCP8.5 sea level rise to 2030 (cm)	RCP8.5 to RCP2.6 factor
	Higher Central	Upper		Higher Central	
Northumbria	27	35	0.77	14	0.52
Anglia	33	41	0.80	17	0.52

6.2 Future impact analysis

The analysis draws on the outcomes of the flood modelling undertaken by Stantec and reported in a separate technical report[21], in particular on the estimation of the number of priority sites that would be flooded for 1%AEP and 0.1%AEP in current conditions from different sources of flooding: fluvial, pluvial and tidal (in this case the 1%AEP event is replaced by 0.5%AEP), and on the quantification of the area of structures flooded in each of them.

A list of 836 priority sites, excluding 101 sites where investment needs were identified and delivered in PR19, have been included in the analysis. For pluvial and fluvial flood risk, the number of sites flooded are presented in Table 6.8, noting that future scenarios refer to the present 0.1%AEP flood event considered as a good proxy for the 2050s 1% AEP flood extent in an RCP8.5 Upper end scenario. Some discrepancies between the fluvial defended and undefended scenarios exist, whereby an increase in flooded assets occur in a defended scenario. This could be associated with differences in the resolution and modelling method adopted to produce each flood dataset. An envelope of the two scenarios have been considered when investigating sites for future investments as a precautionary approach.

[21] NWG PR24_Climate Change Risk Assessment_Flood Risk Technical Methods and Results (Stantec, Oct 2022)

Table 6.8: Number of water and wastewater assets flooded in 1% AEP present and future scenarios from fluvial and pluvial sources

	Fluvial Undefended Present	Fluvial Undefended Future	Fluvial Defended Present	Fluvial Defended Future	Pluvial Present	Pluvial Future
WTW	9	11	10	10	15	24
SR	3	3	2	2	10	15
STW	57	71	66	72	67	94
SPS	64	73	60	73	50	87
WPS	4	5	5	5	3	6

Note: Reported values for fluvial and pluvial scenarios are counts of assets scoring 5-A, 5-B, 5-C and 5-D respectively in present and future scenarios based on Stantec's scoring methodology.

A similar analysis was conducted for tidal flooding although on a shorter list of 550 priority sites that could be identified from the whole list of assets that underwent the tidal flood risk assessment. Results are presented in Table 6.9 indicating that no water assets in the list analysed are at risk of 0.5%AEP tidal flooding in both current and future scenarios.

Table 6.9: Number of wastewater assets flooded in 0.5%AEP present and future scenarios from fluvial and pluvial sources

	Tidal Undefended Present	Tidal Undefended Future	Tidal Defended Present	Tidal Defended Future
STW	3	5	1	3
SPS	8	21	6	19

Note: Reported values are counts of assets scoring 5 and 3-4-5 respectively in undefended and defended scenarios based on Stantec's scoring methodology.

By looking at the envelope across undefended/defended scenarios and all three sources of flooding:

- 249 sites are currently at risk of a 1% AEP fluvial/pluvial flood event and/or 0.5%AEP tidal events; and,
- 53 additional sites are at risk of a future 1% AEP fluvial/pluvial event and/or 0.5%AEP tidal flood event (equivalent to the current 0.1% AEP flood extent).

6.3 Cost impact analysis

Current and future flood damage costs to assets have been estimated using the flooded areas under each investigated scenario. In the absence of flooded area for tidal scenario, the total structure area was assumed to be flooded if the asset was scored at risk of flooding. This is a reasonable scenario for coastal flooding that mainly affect low-lying areas.

An average 2% AEP standard of protection (SoP) has been assumed across the water and wastewater asset base. In the absence of asset specific SoP, this was deemed a suitable typical value between the likely low SoP for small water and wastewater pumping stations and the high SoP for larger water and wastewater treatment works. As a result, the 2% AEP SoP damage rate was applied for assets at current risk of a 1% AEP fluvial and pluvial flood event and 0.5%AEP tidal flood event. In the future, assets at current risk from such events are likely to become flooded more often, in turn dropping the standard of protection and resulting in higher damages. A 4% AEP SoP damage rate was applied in future scenarios for those assets at risk in both current and future 1% AEP pluvial/fluvial event or 0.5%AEP tidal event. The differences indicated in Table 6.1 between peak flows suggest that applying a 10-year damage cost would be too conservative to represent the change in standard of protection in the future. For assets at risk from fluvial and pluvial sources in a future 1% AEP event only or those at risk from tidal sources in a future 0.5%AEP event, the 2% AEP SoP damage rate was applied.

Furthermore, adjustment factors were applied to total damage costs to scale these for a RCP8.5 and RCP2.6 scenario by the 2050s. Factors summarised in Table 6.6 were applied for fluvial and pluvial scenarios whilst factors summarised in Table 6.7 for tidal scenarios. Additional annual damage costs for the 2050s are presented in Table 6.10 and Table 6.11.

Table 6.10: Additional annual flood damage costs by 2050s from fluvial and pluvial sources

	Fluvial Undefended RCP2.6	Fluvial Undefended RCP8.5	Fluvial Defended RCP2.6	Fluvial Defended RCP8.5	Pluvial RCP2.6	Pluvial RCP8.5
SPS	£627,809	£726,999	£565,037	£654,329	£570,612	£664,978
SR	£185,730	£221,131	£159,882	£192,271	£161,893	£187,593
STW	£1,681,109	£1,935,843	£1,552,451	£1,785,276	£1,803,412	£2,068,550
WPS	£196,228	£239,204	£172,213	£209,891	£21,966	£26,616
WTW	£369,528	£382,322	£265,846	£228,953	£2,397,096	£2,893,708
Total	**£3,060,404**	**£3,505,499**	**£2,715,428**	**£3,070,719**	**£4,954,979**	**£5,841,444**

Note: Damage values are calculated for a 1% AEP flood event

Table 6.11: Additional annual flood damage costs by 2050s from tidal sources

	Tidal Undefended RCP8.5	Tidal Undefended RCP2.6	Tidal Defended RCP8.5	Tidal Defended RCP2.6
STW	£367,739	£191,224	£324,572	£168,777
SPS	£300,674	£156,351	£296,268	£154,060
Total	**£668,413**	**£347,575**	**£620,840**	**£322,837**

Note: Damage values are calculated for a 0.5% AEP flood event

7 Conclusion

7.1 Summary of impacts and monetised costs

Both clean and wastewater systems are susceptible to a range of impacts from climate changes. A range of physical as well as financial impacts have been quantified for those risks identified as high and very high to NWL assets and operations. The present investigations thus demonstrate the need for investment in climate resilience to avert the additional expenditure as well as compliance risks by 2050. This shall further ensure that the long-term delivery of performance commitments such as leakage/pipe bursts to the regulator are fulfilled.

Flooding

The likelihood of flooding from all three pluvial, fluvial and tidal sources is likely to increase in the future, driven by sea level rise, wetter winters and increases in extreme rainfall intensity. 251 sites have been highlighted at current risk of a 1% AEP flood event from pluvial and/or fluvial sources and/or at current risk of a 0.5% AEP flood event from a tidal source. In the future, this number is likely to increase, and an additional 51 sites would become at risk of flooding with the same probability of occurrence by 2050. This is considering an upper end estimate of future flooding conditions in RCP 8.5 emission scenario.

This increase in the risk of flooding across both NW and ESW areas would result in increases in annual flood damages in a 1% AEP pluvial/fluvial flood event and a 0.5% AEP tidal event. This would amount to an additional **£3,070,719** in a fluvial defended scenario, **£5,841,444** in a pluvial scenario and **£620,840** in a tidal defended scenario for the RCP8.5 scenario. In a lower RCP2.6 emission scenario additional annual flood damages would be lower but remain significant; **£2,715,428** in a fluvial defended scenario, **£4,954,979** in a pluvial scenario and **£322,837** in a tidal defended scenario. To note that this does not include a potential financial penalty from the regulator due to outage or costs associated with the loss of production.

Soil moisture deficits

A very likely increase in summer pipe bursts as a result of increased soil moisture deficits has been estimated in both NW and ESW areas and under both RCP2.6 and RCP8.5 scenarios. Across the ESW area, these could lead to an additional **£241,072** and **£588,267** each year (in a low or high emission scenario) for the repair and replacement of pipes by 2050. Across the NW area, lower additional total costs are expected due to lower drier conditions overall. These have been respectively estimated as **£133,839** and **£319,277** for each scenario. Additional pipe repair and replacement costs from increases in soil moisture deficits between spring and autumn will be only partly counteracted by a likely reduction in winter freeze-thaw events across the ESW area under both emission scenarios. To note that these costs do not include service impacts to customers.

An increase in the number of summer bursts can also have an impact on two performance commitments set out in the PR19 final determinations Northumbrian Water outcomes performance commitment appendix; being leakage and main repairs. This could result in additional penalties for underperformance as presented in Table 7.1. These would however be partly compensated by likely decreases in winter pipe bursts driven by decreases in freeze-thaw events. Overall this could result in an **incentive of £59,700** per year in 2050 for RCP2.6 or a **penalty of £368,742** for RCP8.5 assuming the standard underperformance payment for main repairs. As regards to leakage, this could come with a **penalty of £985,381** and **£3,210,047** for a low and high emission scenario in the south-east and **£21,942** and **£323,777** respectively in the north-east.

Water quality deterioration

In the recent years, significant outages and associated costs have occurred as a result of water quality deteriorations. For turbidity, these were estimated as £1,452,638 over the April 2019 to March 2022 period, whilst for algae estimated costs totalled £1,216,404 over the same period.

Under both emission scenarios, increases in extreme rainfall and winter flows across all catchments investigated in the NW area are shown to increase the frequency of high turbidity events known to pose issues to the operations of the works. The total additional expenditure for the works already affected has been estimated as **£59,858** and **£90,084** per annum under a low and high emission scenario. Further costs are anticipated for sites that would start experiencing outages. This could be the case for Barsham where further monitoring might start capturing more frequent high-turbidity events which could lead to outages not seen in current conditions. To note that only the most recent period of financial records was used to derive the range of future costs while a longer period is usually needed to define baseline conditions.

In the situation where weather events can no longer be excluded from the company's performance commitments for unplanned outage, increases in turbidity levels resulting in additional outages could drive an increase of 0.06 and 0.09% of the unplanned outage metric. Assuming the standard underperformance payment, this would lead to an additional penalty of **£103,200** and **£154,800** per year for RCP2.6 and RCP8.5 respectively.

An increase in temperatures during the summer months is likely to increase algal levels in reservoirs as has been demonstrated for Hanningfield. Whilst no cost analysis could be undertaken for the future because of data limitations, impacts recorded in the recent years, together with the trend in temperatures provide sufficient evidence to suggest an increase in the costs of operations across both the ESW and NW areas under both scenarios. Together with other stresses posed on treatment operations during dry periods (i.e. water availability) and increases in customer demand, these events could have a wider impact on the supply demand balance. This is especially important when considering that heat waves and prolonged periods of dry weather are not localised and affect an entire region. Where current incidents can be mitigated by the overall capacity of the network through reconfiguration, future stresses posed at a regional level, including algal bloom incidents at multiple reservoirs and river intakes, could prevent the application of such mitigation and have a direct impact on supply to customers. Similarly, such events could in the future be characterised as unplanned outage with associated penalty for underperformance.

Further analyses suggest a likely increase in the frequency of THM incidents, specifically at Fontburn Reservoir. This new challenge has the potential to start occurring in other places across the NW area where higher temperatures will drive increases in dissolved organic carbon from upland peat areas. Whilst no additional costs for running Fontburn on high THM levels could be evidenced to date, increases in THMs in treated water could pose a **compliance risk.**

A decrease in low flows as a result of drier conditions is likely to drive higher concentrations of contaminants as a result of a lower dilution capacity. This mechanism has been observed specifically at Lumley as regards sulphate levels, with climate change likely to trigger more frequent exceedance of the 250mg/l limit. Whilst no additional costs for running Lumley on high sulphate levels could be evidenced to date, increases in the frequency of incidents could lead to **compliance risks** and require action.

Analyses have further demonstrated that drier conditions in catchments under both emission scenarios would increase concentrations of phosphates in receiving waterbodies at certain times of year. Current phosphate loads in waterbodies downstream of effluent discharges are beyond those prescribed in the At Permit with Environment Act reductions model for 32 out of 40 receiving waterbodies and WFD good status is only achieved for three of them. In future emission scenarios, decrease in dilution potential would push some waterbodies to lower bands, even after implementation of Environment Act reductions. This demonstrates that proposed reductions would not be sufficient to maintain or improve water quality in receiving waterbodies by 2050 to the levels prescribed and that **tighter permits** could be put in place on discharges with potential financial implications. In the case of ammonia, analyses have not demonstrated a significant change in concentrations in future emission scenario, suggesting that climate change will have little bearing on that parameter for the receiving waterbodies investigated.

Extreme heat

Increases in heatwave frequency have been estimated at all locations across ESW and NW areas in both a low and high emission scenario with higher occurrences overall across ESW. Whilst this will likely trigger a range of impacts similar to those recently recorded across both the water and wastewater systems and with subsequent additional costs, more data is needed to investigate the full extent of financial impacts, beyond what has been showcased in the present investigations.

7.2 Summary of climate risks

The technical assessments presented in this report were used to review and refine the levels of risks for the different climate hazard introduced in the contextualisation report. This exercise was undertaken specifically for those risks highlighted as very high, high and medium. The final analysis of risks was undertaken combining both regions given than some cost metrics could only be calculated across the whole asset base.

Table 7.1: Summary of climate risks

Hazard	Magnitude of consequences	Future likelihood of the hazard	Future risk level
Flooding	**Major** - Additional costs for flood damages reaching £5m and £5.8m in a future 1% AEP pluvial event, £2.7m and £3.1m in a future 1% AEP fluvial event and £371k and £713k in a future 0.5% AEP tidal event, respectively for RCP2.6 and RCP8.5 scenarios. Interruption to supply is also likely to reach beyond 12 hours for flooding of major sites. Furthermore, major flooding of sites is likely to result in regulator penalties as well as major damage to asset infrastructures.	**Possible** - 251 sites assessed to be at risk for a 1% AEP fluvial/pluvial and/or a 0.5% AEP tidal event. Some of the sites are however likely to be at more frequent risk of flooding under current conditions, given the nature of operations and the location of assets in the immediate vicinity of watercourses. The probability of flooding is also likely to increase with climate change. To note that tidal flooding of sites is constrained to the wastewater assets and the north-east area.	**High**
Wind	**Major**- Storm Arwen that affected the north-east area resulted in 1,127 no water incidents, 127 low pressures, 83 appearance, 1 complaint of illness and 4 taste and odour contacts being reported in relation to this event. The event affected water supply across 15 water quality zones with a combined population of 295,255 although only a portion of these were affected by the issue. On the wastewater side, 55 instances of discharge incidents were recorded, most of them as a result of control system failure due to the loss of external power triggered by high winds. Emergency discharge of sewage materials led to water environmental impacts recorded as Category 3 and 4. The impacts resulted in an estimated cost of £1.86m	**Probable** - Weather patterns for extreme wind, similar to that driving Storm Arwen are likely to increase in both magnitude and frequency across both the north-east and south-east areas with high likelihood of occurrence each year.	**Very High**

Hazard	Magnitude of consequences	Future likelihood of the hazard	Future risk level
	including compensatory payments for failure to comply with standards of service		
Drought and water scarcity	Covered in WRMP24		
Water quality deteriorations	**Major** - Total outage costs for high turbidity events were estimated in the order of £1.5m over the April 2019 to March 2022 period, and associated with the need to replenish lost production. For algae, similar costs reached around £1.2m over the same period. In the future, increases in costs from lost production resulting from high turbidity event driven outages are estimated to be around £60k and £90k per year by 2050 in an RCP2.6 and RCP8.5 scenario. In the future, should such events be treated as unplanned outage in the company's performance commitments, it could result in an additional penalty of £103,200 and £154,800 per year for RCP2.6 and RCP8.5 respectively, assuming the standard underperformance payment. These events can also drive risks of prolonged interruptions to supply, particularly if impacts were to occur across large parts of the system (i.e. algal blooms). Furthermore, reductions in low flow dilutions would lead to WFD deterioration of some waterbodies downstream of effluent discharges. This will likely lead to further permit reductions in future AMPs that would require investment to improve treatment process. Otherwise, the likelihood of breaching the new permits would be high, implying a penalty of £597,000 per year for each % of discharges not complying over total number below a dead band of 99%.	**Probable** - Future rainfall and flow conditions in the catchments will likely drive increases in the frequency of exceedance of current limits of actions for water treatment works with threshold values being exceeded at least once every year. Changes dry conditions in catchments in also likely to drive lower flows with impacts on WFD status demonstrated for some waterbodies by 2050 in both RCP scenarios and measured on an annual basis.	**Very High**
Heat	**Moderate** - Costs recorded between July and September 2018 totalled up to £3.6m while costs reached £5.8m over the June to August 2022 period. These were associated to summer heat wave events that impacted water and wastewater networks. Values include expenditure associated to summer pipe bursts repair and replacement covered in the above soil moisture deficit category. Impacts of significant magnitude (i.e. pipe bursts, water quality deterioration) are covered in other risk items. Other heat related impacts would result in financial costs, potential interruptions to supply (tripping of key electrical equipment) or risk to water quality compliance (increased septicity of effluents).	**Probable** - Increases in heat wave frequency is likely to occur with at least one occurrence per year in an RCP8.5 scenario across both north-east and south east areas. In an RCP2.6 scenario, the frequency of occurrence in the north-east is likely to be slightly less than once a year but will remain above once a year in the south-east.	High
Cold and freeze-thaw	**Moderate** - Costs recorded during the Beast from the East event totalled up to £1.1m with £0.4m and £0.5m costs for material and contractors in the north-east and the south-east, respectively. This type of events can further lead to interruptions to	**Unlikely** - Events like the Beast from the East and other freeze-thaw events are likely to decrease in both intensity and frequency in both regions as result of significant increase in Q99 minimum daily temperatures.	**Medium**

Hazard	Magnitude of consequences	Future likelihood of the hazard	Future risk level
	supply and a risk to the company not meeting its performance commitments for pipe burst and leakage.	A decrease in the occurrence of winter pipe bursts is likely to occur across both the north-east and the south-east by 13% and 15% in an RCP2.6 scenario and by 23% and 30% in an RCP8.5 scenario.	

7.3 Recommendations

Whilst the present assessments provide good evidence on how climate risks are likely to affect assets and operations, gathering additional information in the future, together with the conduct of further modelling, will **improve robustness** and **allow for a quantification of additional risks** (including systemic risks).

For planning, this will help **strengthening the case for resilience investments** by quantifying further the financial risks that climate change will pose on business operations. These could be significantly greater for systemic risks. Other standard of protection information will further **support the prioritisation of investments**; targeting sites that are at most immediate risks. This will provide stronger evidence **for the development adaptive planning road maps.**

For operations, further monitoring will ensure that climate-related incidents are traceable. That can in turn inform the need for changes in operative procedures, thresholds or standards operations to **prevent future outages or additional costs** of operating assets and networks.

7.3.1 Data collection and further modelling

The provision and analysis of long-term and more granular records will allow the identification of long-term and systemic impacts beyond the more immediate ones that have been shown to affect single assets. Particularly, it is recommended to obtain:

1. Water quality data:
   - Monitoring of THMs alongside dissolved organic carbon levels between late spring and early autumn at Fontburn Reservoir as well as any additional reservoirs located in NW that are fed by upland waters running on peat soils.
   - Monitoring of nutrient levels alongside algae levels (including monitoring of species known to be problematic to treatment operations) in reservoirs and river intakes across the ESW and NW areas between late spring and early autumn.
2. Flood risk data:
   - Current SoP of priority sites to improve the quantification of annual average flood damages.
   - Repairment costs associated with historical flood incidents and the associated impact (flood extent and depth) to calibrate the cost model
3. Outage data:
   - More granular information for outage reported as exclusions, particularly to understand the levels of water quality parameters that triggered the incident.
   - Longer records of outages with full coverage across the NW and ESW areas.
4. Financial data
   - Cost of water for all relevant sites where outages are reported on a yearly basis.

- Long-term records of mechanical/electrical failures due to heat and subsequent repair/replacement costs. Those shall ideally be obtained during and following heatwave events as well as under more normal operating conditions to enable comparison.
- Long-term records of hot summer costs/quantities versus normal summer costs/quantities on a monthly basis with details of expenditure areas.
- Updated pipe repair/replacement data for different materials and pipe diameters.

The current assessments have utilised all existing data and generally applied regressions to link climate and impact information. While this approach is robust when good correlations are obtained, it is recommended to conduct further modelling when this is not the case. In particular:

- Raw water quality deterioration for different determinands can be estimated using catchment water quality modelling (eg, SWAT) able to simulate field runoff and in river water quality processes. Once calibrated to baseline conditions, it can be used to extrapolate future conditions by changing climate time series.
- The risk posed by algal blooms in the future can be investigated by undertaking dynamic reservoir water quality modelling (eg, PCLake+) based on the reservoir geometric, reservoir operation, nutrients inflows and climate conditions at present and in the future.
- The implication of varying loads for wastewater treatment processes and their ability to achieve discharge permits can be assessed for future conditions by using a process simulator (eg, BioWin) and estimating changes in loads due to longer dry spells, the first flush effect and wetter winters. Changes in water temperature can be considered too.

In addition, the Flood Risk Assessment undertaken is necessarily preliminary with the sole aim of identifying the magnitude need. For a more accurate estimate of annual flood damages, a better prioritisation of sites including the impact of more frequent flood events, and a more granular identification of additional sites at risk for different emission scenarios, large scale flood modelling can be conducted for different return periods and climate change scenarios.

7.3.2 Optioneering

The work presented in this report should support the identification of options requiring resilience investments to feed into the enhanced business case that NWL is planning to present to Ofwat.

- For flooding, it is recommended to first target investments during AMP8 on those sites that are currently at the 1% or 0.5% AEP risk of flooding from fluvial/pluvial and tidal sources respectively. That is investing in resilience at 249 sites. For future AMPs, it is recommended to target investments on 53 wastewater assets at future risk of 1% or 0.5% AEP from fluvial/pluvial and tidal flooding respectively;
- For pipe bursts, it is recommended to target investments in AMP8 on areas of the network where the greatest vulnerabilities to future drought conditions have been highlighted. This can be complemented by aging investigations to prioritise further the list of vulnerable assets;
- For other water quality and extreme heat risks, it is recommended to first target investments on areas/sites that have been recently affected by climate hazards and where it has resulted in additional expenditure.

To note that resilience measures that are investigated and proposed (i.e. replacement of vulnerable pipes) need to consider the vulnerability of the solution to climate hazards (i.e. pipe lining/material propensity to resist the shrinking and swelling of soils).

References

Mott MacDonald (2021a) *ESW rainfall-runoff modelling RevA*.

Mott MacDonald (2021b) *NWL rainfall-runoff modelling Rev B*.

Mott MacDonald (2022a) *ESW Stochastics and climate change Rev C*.

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