PR24

NORTHUMBRIAN WATER *living water* | ESSEX&SUFFOLK WATER *living water*

A3-10
CLIMATE CHANGE RESILIENCE WTW PROCESS ENHANCEMENTS

NES24

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1. INTRODUCTION

Climate change is disrupting UK weather patterns and changing the operating context for some of our key water treatment assets. The outputs of our climate scenario modelling show that the effects of climate change, including increasing temperatures and greater sunlight intensity, will increase the operational challenge and impact our ability to maintain current levels of resilience.

This case sets out our plans for protecting vulnerable WTW (Water Treatment Works) from the effects of climate change - specifically the impact of rising temperatures on our existing water treatment processes. The case addresses three specific risks where increasing average temperatures and hotter summer periods threaten resilience. These are summarised below:

1.1. HYPOCHLORITE DEGRADATION RISK

- There is a need for safe and resilient storage and control of Sodium Hypochlorite chemicals used for multiple applications at many of our water treatment sites.
- Sodium Hypochlorite in storage degrades and forms Chlorate which can impact water quality. The rate of Chlorate formation is proportional to the temperature of the chemical and the number of days of storage at that temperature.
- At higher temperatures, and during heatwave events, the resilience of our water treatment process can be compromised by limitations on our ability to dose due to higher Chlorate levels and significantly reduced storage times.
- In January 2020, the DWI proposed a target PCV for Chlorate of 0.25 mg/l. Ahead of the new target, we have reviewed our Hypochlorite dosing and storage facilities to ensure our ability to achieve the required concentration at each point will not be compromised as a function of climate change while still being able to comply with levels of 0.25 mg/l Chlorate at the customer’s tap.
- Through a site risk assessment process, we have identified 44 vulnerable dosing points.
- Our solution to mitigate the risk and maintain resilience is to switch from 15% to 10% Hypochlorite at 9 smaller network booster sites where dose rates are lower, and to install chilling units at 36 larger sites.

1.2. DISSOLVED OXYGEN DEPLETION IN SLOW SAND FILTER BEDS

- There is a need to monitor Dissolved Oxygen (DO) levels within our Slow Sand-filter (SSF) process units at five sites in the Essex & Suffolk Water region, and to provide Run-To-Waste facilities to minimise water quality impacts.
- The majority of our SSF sites were built circa 1930 to a design that limits skim frequency below levels now considered necessary to maintain filter health.
- Blanket weed growth and DO depletion is a significant risk, particularly in higher temperatures during summer months. Our climate change modelling shows increasing temperatures as well as greater intensity and frequency of heat wave weather patterns.

- To ensure ongoing resilience in the face of rising temperatures, we need to be able to monitor the health of individual filter beds and have the ability to respond rapidly to mitigate the risk.
- Our solution is DO monitoring on each SSF bed, and addition of Run-To-Waste facilities to enable more frequent skimming without impacting water quality into supply.

1.3. RAPID GRAVITY FILTER (RGF) BED EXPANSION

- There is a need to enhance the capacity of our backwash systems at six sites across our Northumbrian Water and Essex & Suffolk Water areas.
- The RGF processes at these sites were built to outdated design standards which now limit backwash capacity and provide inadequate headroom above the filter media to allow sufficient bed-expansion during the filter backwash cleaning cycle.
- If filters are not cleaned effectively, the headloss at the beginning of a filter run deteriorates over time leading to a requirement for more frequent cleaning and an increased risk of solids breakthrough. There is an increasing risk that filter performance will not recover after cleaning without frequent media replacement. This impacts site output and resilience.
- Rising temperatures exacerbate this resilience risk. Bed expansion at fixed backwash flowrates is greater at lower raw water temperatures, and as temperatures increase, a greater backwash volume is required to achieve the same target bed expansion. Bed expansion is required to release solids trapped within the media and regrade filter bed media as required to achieve adequate filter cleaning and maintain filter health and performance.
- To maintain resilient RGF backwash at these sites we need to significantly increase backwash rates and modify the filter structures to increase the distance between the top of the filter media and the launder position, thus allowing optimum bed expansion without loss of filter media.
- Higher washwater volumes also need to be treated appropriately and recovered without impact on site performance.
- Our solution is to ensure that the backwash is optimised such that each filter bed can be returned to a clean condition after each wash. This will require upgrades to the position of the filter launders, enhanced launder design, modified filter floors, new backwash and air scour systems and enhanced wash water treatment systems.

This case presents the evidence from our climate change analysis and scenario modelling alongside site specific risk data to illustrate the need for investment during AMP8. Our options appraisal process has considered an appropriate range of solutions to address the risks and provide value for customers, while ensuring resilient supply and safeguarding water quality.

1.4. SUMMARY OF COSTS

Table 1 below summarises the costs included in this enhancement case.

TABLE 1: SUMMARY OF AMP8 ENHANCEMENT COSTS

	Capex (£m)	Opex (£m)	Total (£m)
Hypochlorite degradation			
Northumbrian Water	27.425	0.089	27.514
Essex & Suffolk Water	6.838	0.000	6.838
Slow Sand Filter DO depletion			
Northumbrian Water	N/A	N/A	N/A
Essex & Suffolk Water	11.855	0.328	12.183
Rapid Gravity Filter Backwash degradation			
Northumbrian Water	15.282	1.585	16.867
Essex & Suffolk Water	16.118	1.146	17.264
Total	**77.518**	**3.148**	**80.666**

We include these costs in lines CW3.118 to CW3.120 of Table CW3, along with our other resilience enhancement case for water, flooding and power resilience (NES32).

2. NEED FOR ENHANCEMENT INVESTMENT

2.1. ALIGNMENT WITH RISK AND RESILIENCE PLANNING FRAMEWORK

Table 2 below displays the expectations for plans to enhance resilience as outlined in PR24 guidance. We have developed our plan for resilience in accordance with our company risk and resilience planning framework and our approach for resilience in the round. We have comprehensively reviewed our resilience framework to make sure it remains fit for purpose into the future (as described in Appendix A8 – Resilience, NES09).

TABLE 2: EXPECTATIONS FOR PLANS ENHANCING RESILIENCE FROM PR24 GUIDANCE

Expectation	How this has been met
Clear line of sight between organisational objectives, resilience planning framework, planned level of service and requested investment	Maintaining a resilient water supply is a central aspect of our long-term strategy. The investment set out in this case is required to ensure we can mitigate the effects of climate change and provide a greater level of resilience to current (observed) and future (predicted) climate trends.
Clear systematic risk assessment with corporate risk management process and drinking water safety plans Risk assessments should assess relevant hazards	Through our climate change modelling we have assessed the risk of increasing temperatures on our operations in both our NE and SE areas and identified where the resilience of some of our critical water treatment assets is vulnerable. Climate change risk is a key risk highlighted both in our corporate risk management process and also highlighted in our risk and compliance statement and resilience framework. Our appendix A8 – resilience (NES09) explains this in more detail.
Investments should be cost beneficial and represent best value	Our options development and screening process identified a range of potential solutions that are both technically feasible and would provide an appropriate level of risk mitigation. Short-listed options have been scored and loaded into our Copperleaf investment appraisal tool, where a cost-benefit analysis has been undertaken.
Optioneering should cover all types of mitigations including resistance, reliability, redundancy, respond and recovery	Our option framework considers the 4Rs of Resilience in the context of a Totex hierarchy.
Companies should be clear how solution options and the preferred option have been robustly assessed and selected Investments should be prioritised and promoted based on an understanding of the current level of risk and how this changes under the proposed investment and compares to risk appetite of customers and the company's board	Our options development and screening process, and the assessment of cost, risk and benefit for alternative solutions in our Copperleaf investment optimisation tool enable us to robustly evaluate investment decisions. Copperleaf allows us to assess a baseline level of risk ('do nothing' scenario) against the level of benefit provided by each alternative option. Benefits are determined by scoring against our value models which include models that align to performance commitments as well as others that align to related objectives and regulatory standards.
Consideration of partnership approaches to establish that the overall management of the system of risk is efficient and financial contributions appropriately set	We considered Partnership as part of our Totex hierarchy approach. However, as this case relates to impacts of climate change that are beyond our control and have a direct impact on the effectiveness of our water treatment processes, no viable opportunities for partnership were identified.
Potential impacts on common performance commitments should be assessed and where none can be determined material investments should have a customer protection mechanism based on either outcomes or outputs.	The potential impact on common performance commitments has been assessed where there is a forecast reduction in risk this has been and the included in the benefits assessment.
Companies should be clear on how any resilience enhancement investments interact with other aspects of its long-term plan and common planning scenarios, and evidence that it has fully explored any synergies. Robust sensitivity analysis should be undertaken	The company has considered how each investment aligns with long term investment strategy, the water resource management plan, and system resilience.

Interventions could reduce the likelihood of a hazard or reduce its consequence. Investments to reduce the consequence can be more efficient as they can reduce the risk to multiple hazards (e.g. remove single point of failure from WS networks can reduce impact of loss of water treatment works due to a variety of hazards – companies should look at this and proportionally allocate costs between base and enhanced)	1. The interventions proposed in this case reduce the consequence of rising temperatures and increased frequency and intensity of heat wave weather patterns on our water treatment processes.

2.1.1 Link to long term strategy

This investment is needed as part of the 'maintaining resilience' investment area under our Long-Term Strategy (LTS) core pathway.

One of our key themes for PR24 is that we will invest in the resilience of our water supply assets, to protect our customers from the impact of climate change on water quality and security of supply. This business case covers our approach to address water treatment risks caused by climate change and therefore outside our control.

In particular, this enhancement case builds on our **Climate Change Adaptation Report** to look at the hazards from climate change and how these will affect our assets in future. We are tackling the risks to water quality and security of supply now, in 2025-30, because:

- These hazards have the potential to impact on service levels now. The heatwaves and higher average temperatures experienced in recent summers are already impacting on stored hypochlorite degradation and dissolved oxygen content in sand filters.
- Although uncertainty remains about future temperature changes, it is unlikely that these investments would be unnecessary given current and expected temperatures in the near future (rather than in the long-term).
- These enhancements could provide an immediate reduction in risk to service levels.

Customers told us that they were cautious about spending money before it is necessary (as the future is uncertain), and that bills need to be kept affordable. However, they wanted us to invest in climate change adaptation when there is a high likelihood that climate change would have an impact on our services in the short or medium term (under any future climate change scenario); and where this is likely to have an immediate impact on services (see our **line-of-sight report**, NES45, on climate change adaptation).

These actions are necessary to prevent costs and problems escalating in future years and to ensure a safe, clean, reliable supply of water which is the highest customer priority.

We consider the investment in interventions to address these two issues is low / no regret because it is needed under both the benign and adverse Ofwat common reference scenarios for climate change. We need to make this investment in the

2025-30 period to maintain resilience now and over the long term. So, we consider this investment is necessary in 2025-30 to deliver our LTS.

2.2. RESILIENCE INVESTMENT IN AMP7

During AMP7, we are delivering a water resilience enhancement programme covering the following areas:

- Abberton to Hanningfield Raw Water Transfer – to enable Hanningfield to benefit from the expansion of Abberton.
- New Mecana Filtration Treatment at Layer WTW – to provide resilience against increasing algae and related turbidity risk.
- Barsham Service Reservoir and Water Pumping Station and North Suffolk strategic mains resilience
- Springwell Service Reservoir and South Tyneside strategic mains resilience
- New UV treatment at Mosswood WTW – to mitigate raw water deterioration and provide resilience against cryptosporidium levels
- Lartington Mains and Tees strategic mains reinforcement – combining water quality, base spend on legacy assets and some resilience. The resilience element is focused on Whorley to Shildon strategic main.
- Assets Too Critical to Fail – resilience measures at 14 sites to protect against the hazards flooding and power interruptions

The investment set out in this business case does not overlap with or duplicate activities funded in AMP7 or other previous price reviews. Our **independent assurance of AMP7 schemes** (NES62) assesses how we are delivering these.

2.3. CLIMATE CHANGE RISK ASSESSMENT

2.3.1 Background

In 2022, we carried out an assessment of climate change impacts and the resilience of our operations in the Northumbrian Water and Essex & Suffolk Water regions. The scope of the study includes the following aspects:

A review of past weather events and their impacts on our assets and operations, including a review of cost impacts

- An investigation into future weather patterns and climate trends based on UKCP18 projections
- A high-level climate change risk assessment to evaluate vulnerability against a range of climate related hazards.

Of particular relevance to this case are future projections of temperature increase based on the UKCP18 scenarios, in terms of increase in both average and peak temperatures, and also with regard to an increasing risk of heat wave events.

In addition, for each of the three areas of vulnerability addressed in this business case, we have assessed the risk posed by increasing temperatures on the performance and resilience of the relevant assets: Sodium Hypochlorite storage and control facilities at all our water treatment sites, and slow sand filter processes present at five of our WTWs in our Essex & Suffolk Water region.

We have published this assessment with our business plan in two parts:

- **A8-01 Climate Resilience Phase A – Mott MacDonald** (NES52)
- **A8-02 Climate Resilience Phase B – Mott MacDonald** (NES53)

We describe our approach to assessing resilience in our **Appendix A8 – Resilience** (NES09), and discuss the relevant findings for this enhancement case below.

2.3.2 UKCP18 predictions for temperature increase and heatwave frequency

We have analysed UKCP18[1] projections of weather patterns for the UK from general circulation models (GCMs) for the baseline period (1991-2020) and for 2050 (2036-2065) for the North-East and South-East regions. In addition, we assessed correlation between weather patterns and:

- Daily maximum temperature during summer months
- Daily minimum temperature during winter months

Analysis centred around a 12km square area in both the Newcastle and Southend region as representative of weather patterns in our North-East and South-East operational areas respectively. We developed regional projections in each case, and corrected bias against observations. We identified the weather patterns leading to the most extreme weather conditions and added these to historical events for a more comprehensive assessment. We estimated changes in the frequency of weather patterns and in the magnitude of resulting extreme weather variables.

Figure 1 below shows UKCP18 probabilistic projections of average and maximum temperatures for 2050 for both the RCP2.6 and RCP8.5 climate change scenarios (these represent "low" and "high" climate change scenarios, as set out in UKCP18). We generated these based on data at a 25km^2 resolution.

Overall, our projections show an increase in mean temperature in all seasons for both the North-East and South-East regions. Future increases are greater in summer than in winter. For example, for the North-East region under RCP8.5, winter temperature would increase by 1.5°C compared to 2˚C in summer (Figure 1). The South-East region is facing higher increases in annual, winter and summer temperatures. For example, under RCP8.5 winter temperature is projected to increase by 1.7°C and by 2.4°C in summer (Figure 2). The RCP8.5 scenario shows higher increases (between 0.5°C and 1°C more) compared to RCP2.6. While the North-East region is forecast to experience temperature increases in line with the UK average, the South-East region would experience larger increases than the UK average, as shown in Figure 3.

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[1] MetOffice UKCP18 climate projections (www.metoffice.gov.uk)

FIGURE 1: UKCP18 TEMPERATURE CHANGES BY 2050 IN OUR NORTHUMBRIAN WATER REGION

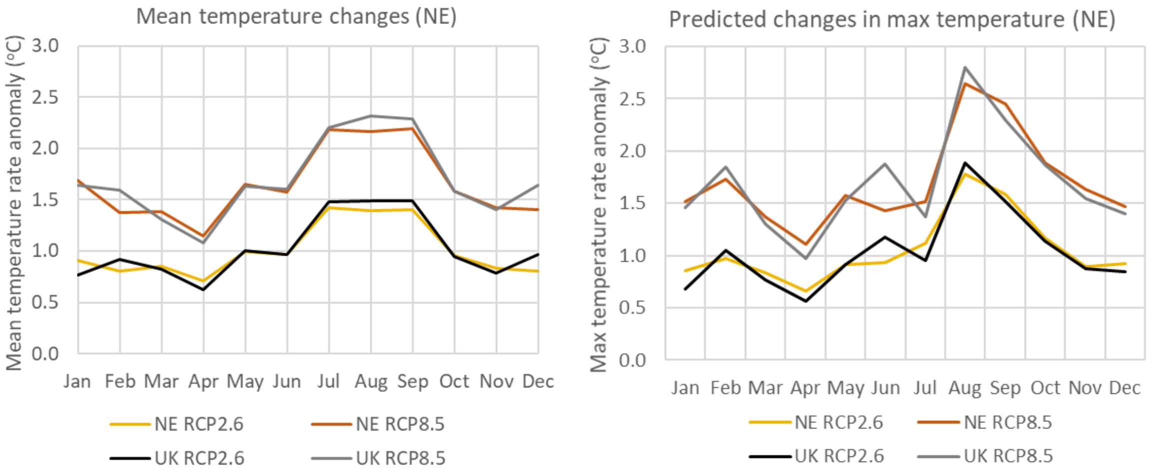


FIGURE 2: UKCP18 TEMPERATURE CHANGES BY 2050 IN OUR ESSEX AND SUFFOLK WATER REGION

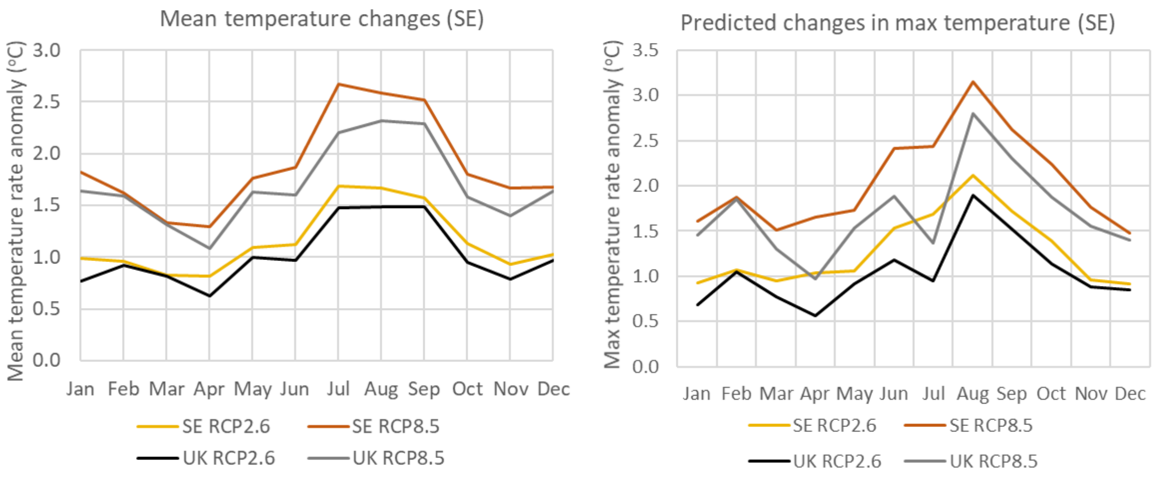
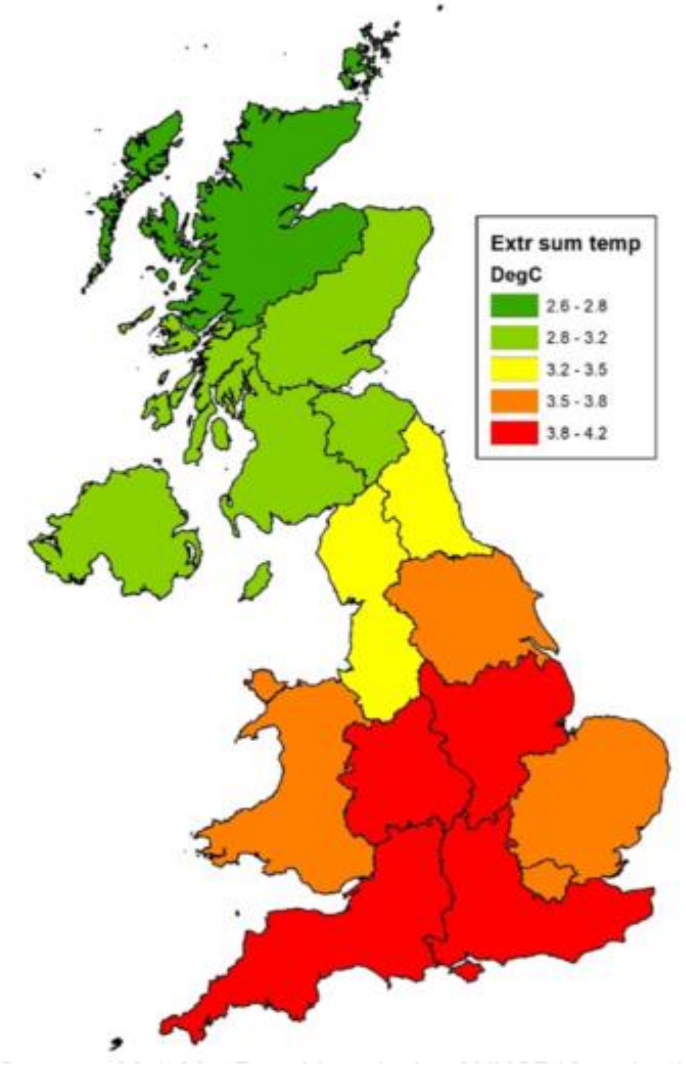


FIGURE 3[2]: UKCP18 EXTREME SUMMER TEMPERATURE CHANGES BY 2050



In addition to increases in average and maximum temperature, the modelling forecasts an increase in extreme weather events, including heatwaves such as experienced in 2018, and in July 2022 (as shown in Figure 3 above). We have identified and forecast the weather conditions and patterns linked to such historical heatwave events, and the results show that heat waves like the one experienced in 2018 are likely to occur more frequently and intensify in the future. Other weather patterns leading to high maximum temperatures are likely to occur less frequently, but the overall effect is a net increase in heatwave events.

For example, in the Northumbrian Water area, the total number of weather types with max temperature exceeding 25ºC (the heatwave threshold defined by the Met Office) 5% of the time (Q95) increases from 9 in the baseline period to 26 in

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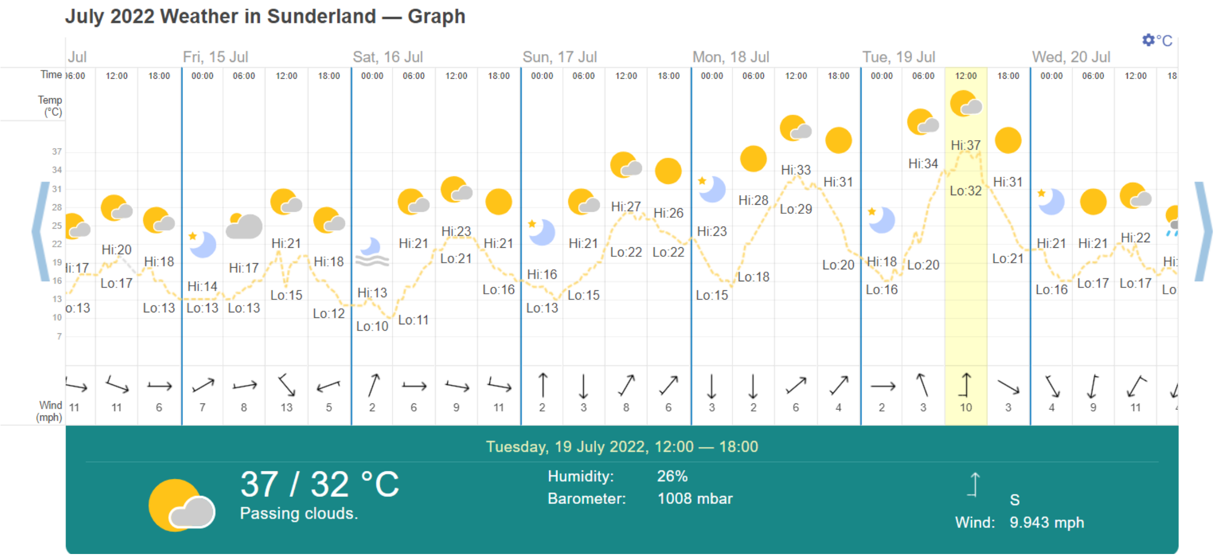
[2] Source: NES52

the 2050s, indicating that more weather types would result in heatwaves. Likewise, an average increase in Q95 maximum daily temperatures is modelled at 3.2ºC over the same period.

FIGURE 4: JULY 2022 EXTREME TEMPERATURES IN SUNDERLAND


July 2022 Weather in Sunderland — Graph

Tuesday, 19 July 2022, 12:00 — 18:00

37 / 32 °C

Passing clouds.

Humidity: 26%

Barometer: 1008 mbar

S

Wind: 9.943 mph

Figure 4 shows an example of such an extreme weather event in the North East in July 2022.

Table 3 and Table 4 below show the model results for % change in heatwave event frequency and increase in maximum temperature for the weather patterns identified as driving heatwave conditions. Overall, these projections indicate more frequent and more intense heatwaves in both of our operational areas. The weather patterns described in these tables are shown in more detail in A8-01 Climate Resilience Phase A – Mott MacDonald (NES52).

TABLE 3: NORTHUMBRIAN REGION - EXPECTED CHANGES IN HEATWAVE FREQUENCY AND TEMP

Weather pattern	No. events per year			Associated Q95 max daily temperature		
	Baseline	2050s	% change	Baseline	2050s	Change (ºC)
3	7.5	6.4	-15	26.0	28.7	+2.7
5 (summer 2018)	7.6	8.3	+10	25.9	29.9	+3.0
6 (summer 2018)	8.5	10.8	+28	25.6	29.0	+2.4
12	3.4	2.0	-41	26.9	29.7	+1.8
22	2.0	1.1	-46	26.2	29.3	+3.1

TABLE 4: ESSEX AND SUFFOLK - EXPECTED CHANGES IN HEATWAVE FREQUENCY AND TEMP

Weather pattern	No. events per year			Associated Q95 max daily temperature		
	Baseline	2050s	% change	Baseline	2050s	Change (ºC)
3	7.5	6.4	-15	30.2	33.4	+3.2
5 (summer 2018)	7.6	8.3	+10	29.8	34.1	+4.3
6 (summer 2018)	8.5	10.8	+28	29.5	33.0	+3.5

Weather pattern	No. events per year			Associated Q95 max daily temperature		
	Baseline	2050s	% change	Baseline	2050s	Change (°C)
12	3.4	2.0	-41	30.0	32.7	+2.7
22	2.0	1.1	-46	30.2	32.7	+2.5

2.3.3 Climate risk assessment

We carried out an assessment of the level of risk posed by different climate change impacts on our North East and South East operational regions, linking the climate scenario modelling to analysis of the impact of past significant climate events on our operations. Weather events that have affected our systems during the recent past have led to significant extra-costs to respond, mitigate an ongoing event and undertake post-event repair and maintenance works to restore the performance of the whole system to pre-event levels. In the future, projections show that some events are likely to increase in frequency and/or intensity (such as storms Desmond and Arwen, or the 2018 heat wave).

In addition to the weather patterns currently affecting the networks, it is likely that, in the future, other patterns would also lead to an increase in summer heatwaves, winter extreme rainfall in the north and summer extreme rainfall in the south. This will increase the risk to the integrity of our assets and our ability to supply water to our customers. These findings tie in with the predicted future changes in temperature and precipitation, pointing towards drier and hotter summers as well as wetter winters, across both the North-East and South-East.

The trend towards more frequent extreme rainfall events, together with more frequent and longer droughts is also likely to reduce the resilience of the system in areas where resilience is not currently an issue. Water quality deterioration risks are likely to be amplified in the future. At present, impacts have been localised and limited to specific works where WTW outage could be mitigated by increasing output from other WTW works. Future weather conditions affecting multiple works could stretch the ability of the system to shift demand to other works with direct impacts on customer supply.

Our review of recent incidents and work to model changes in weather conditions within our service areas has highlighted two Very High, three High and two Moderate risks in the North-East (Table 5), and three Very High, two High and two Moderate risks in the South-East (

Table 6). While the South East is at greater risk of the impacts of heatwaves and drought conditions, both regions will be affected by increasing temperatures and changing weather patterns.

TABLE 5: SUMMARY OF KEY CLIMATE RISKS - NORTHUMBRIAN WATER (NORTH EAST)

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 6: SUMMARY OF KEY CLIMATE RISKS – ESSEX & SUFFOLK WATER (SOUTH EAST)

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	

As set out in A8-01 Climate Resilience Phase A – Mott MacDonald (NES52), the risks in the tables above have been ranked in relative terms within Northumbrian Water operational areas and cannot be compared with similar risk categorisations done by other water companies and included in their Adaptation Reports. As the category of the risk is a function of the magnitude of the hazard but also how exposed/vulnerable assets are to it, a cross company comparison is not possible without understanding the level of resilience currently built-in to each water company's systems. However, assuming the same level of resilience, our regions would experience a greater change in the magnitude of several hazards compared with the UK average. In particular:

- The North-East would be particularly susceptible to climate change impacts on winter windstorms and extreme summer rainfall. Extreme winter rainfall would increase as well, and the EA has derived higher allowances for peak flood flows than in other areas of England. Finally, annual rainfall is expected to decrease significantly, above all in autumn compared with the rest of the country.
- The South-East would be significantly impacted by extreme summer rainfall associated with convective storms and sea level rise is likely to affect this region more than others. Droughts and heatwaves are a particular concern in an area already under water stress.

As an extension to our climate risk assessment, we have assessed the vulnerability of our WTWs to the impacts of **rising temperatures** and have identified and investigated three specific aspects where there are immediate impacts on service levels now:

1. Chlorate formation due to increased Sodium Hypochlorite degradation at higher ambient temperatures (see 2.4).
2. Dissolved Oxygen (DO) depletion in our slow sand filter (SSF) beds in the Essex & Suffolk Water region due to rising temperatures (see 2.5).
3. Capacity for backwash at rapid gravity filters under higher temperatures (see 2.6).

We have looked at the impacts of wind and flooding separately in our enhancement case for flooding and power resilience (NES32).

The sections below outline the need to address these challenges in 2025-30 (in each of sections 2.4, 2.5, and 2.6).

2.4. SODIUM HYPOCHLORITE DEGRADATION RISK

At many of our WTW sites, we rely on dosing Sodium Hypochlorite as an essential part of our treatment process. The chemical is used for primary disinfection as well as a range of other applications from source to tap, as shown in Table 7 below.

TABLE 7: SODIUM HYPOCHLORITE – APPLICATION AND DOSE RATES

Application	Typical dose rate
Removal of or protection against mussel growth	1.5 to 3+ mg/l, intermittent dosing for periods of hours to several days
Oxidation of iron or manganese	1 to 3+ mg/l, continuous dosing
Breaking ammonia	1 to 4 + mg/l, continuous dosing when ammonia present in raw water
Pre oxidation to enhance coagulation and particle removal	1 to 2+ mg/l, intermittent or continuous dosing
Primary Disinfection	0.7 to 2.5+ mg/l, continuous dosing
Secondary or emergency disinfection	0.7 to 2.5+ mg/l, intermittent dosing
Network Booster Chlorination	0.2 to 0.7 mg/l, intermittent or continuous dosing

2.4.1 Chlorate formation

Sodium Hypochlorite degrades over time. This weakens the concentration and therefore the efficacy of the dose and can lead to operational challenges – but more importantly, degradation also results in the formation of chlorate as an undesirable by-product. Chlorate is a disinfection by–product (DBP) that can arise where sodium hypochlorite, calcium hypochlorite, chlorine dioxide or onsite electrolytic chlorination (OSEC) are used for disinfection. The rate of degradation is linked to the temperature of the chemical, which is impacted by ambient temperature and the number of days of storage at that temperature.

The British Standard for storage of Sodium Hypochlorite[3] highlights the influence of temperature as a key factor in chemical degradation and the production of chlorate, and the importance of managing temperature to maintain chemical stability:

> *6.5.2 Long term stability*
> *The stability is greatly affected by heat, light, pH, and the presence of heavy metal ions. The solution gradually decomposes resulting in the reduction of the concentration of the active chlorine and in the liberation of oxygen gas.*

Most of our liquid disinfection processes are designed for 15% Hypochlorite, which decays more rapidly than 10% solution and therefore forms chlorate at a faster rate under high temperatures. As there is a direct relationship between temperature and chlorate formation, increasing ambient temperatures and prolonged exposure to elevated temperatures associated with climate change increase the rate at which chlorate is formed.

Chlorate is not desirable in drinking water and should be minimised. The DWI, in its paper in January 2020 (Chlorate in Drinking Water, DWI ref:70/2/316), outlined a proposed move to introduce a regulatory PCV target of 0.25 mg/l for chlorate to protect drinking water supplies.

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[3] BS EN 901:3013 Chemicals used for treatment of water intended for human consumption. Sodium Hypochlorite

While there is currently a legal requirement for water companies to minimise DBP formation, there is no prescribed concentration or trigger value for chlorate in drinking water, which is a gap the proposed DWI standard of 0.25 mg/l is intended to address.

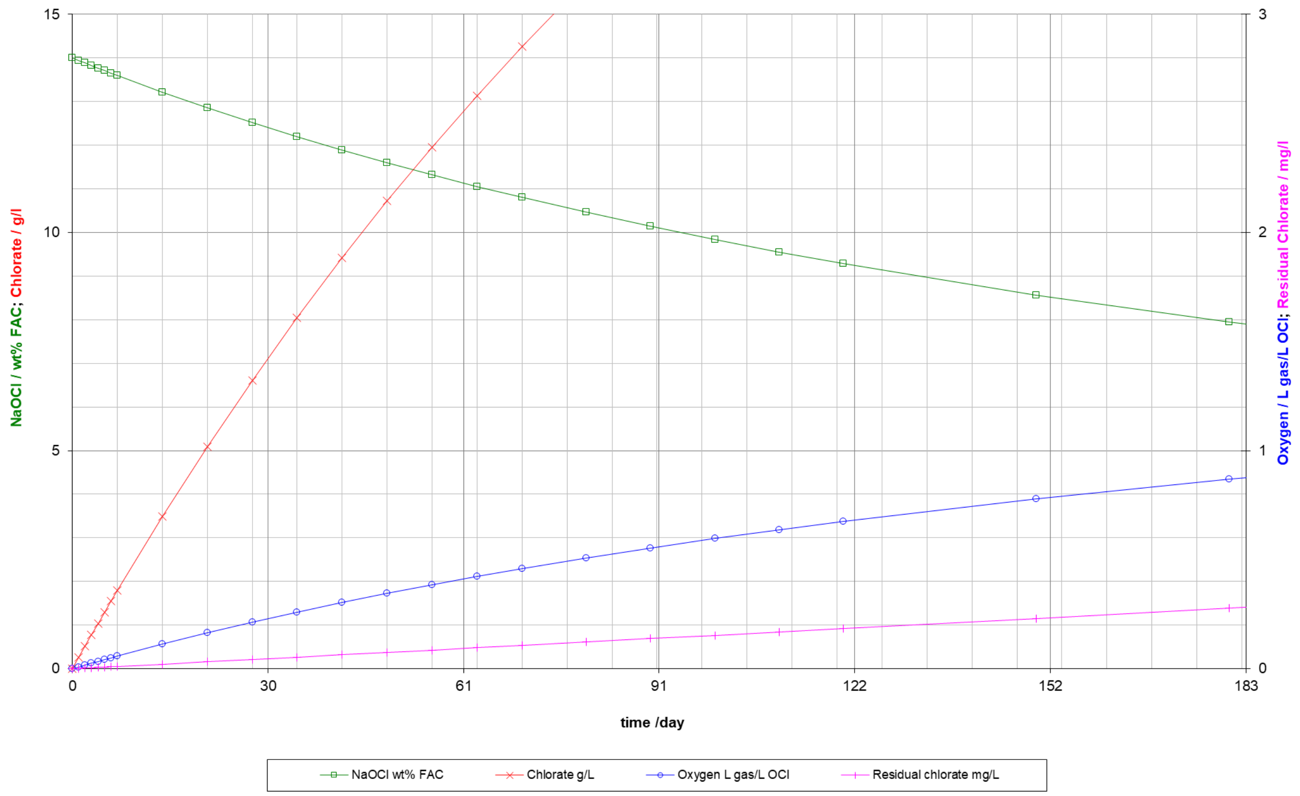
In 2022, Southern Water was prosecuted for elevated chlorate in drinking water networks. The charges were brought by the DWI for supply of water containing sodium chlorate above the World Health Organisation assigned level of 700 µg/l (or 0.7 mg/l). The Chief Inspector of Drinking Water said that "…consumers rightly expect their water to be good, clean and wholesome… The requirements for processes, standards and materials, including storage of chemicals used in disinfection, do not just stop at a point or instance in time."

Predicted increases in temperature and incidence of heatwaves is likely to increase the rate of chlorate formation to the point where our existing chemical storage arrangements would be unable to dose sufficient chemical to achieve appropriate disinfection without breaching the new Chlorate PCV standard. We show this in Table 8 and 9 below.

2.4.2 Oxygen release

A secondary risk of Hypochlorite degradation is the release of oxygen gas. This can cause gas-locking of dosing pumps and pipework, particularly where chemical storage tanks are not elevated and therefore the head available to clear a gas blockage is minimal, especially at low level. Figure 5 shows the relationship between chemical storage times and rates of chlorate and oxygen formation at ambient temperatures of 20°C.

FIGURE 5[4]: SODIUM HYPOCHLORITE – APPLICATION AND DOSE RATES



Without intervention, rising temperatures are also likely to result in increasing air-locking of dosing pumps and pipework leading to disinfection failures.

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[4] WRC portfolio research project P4006

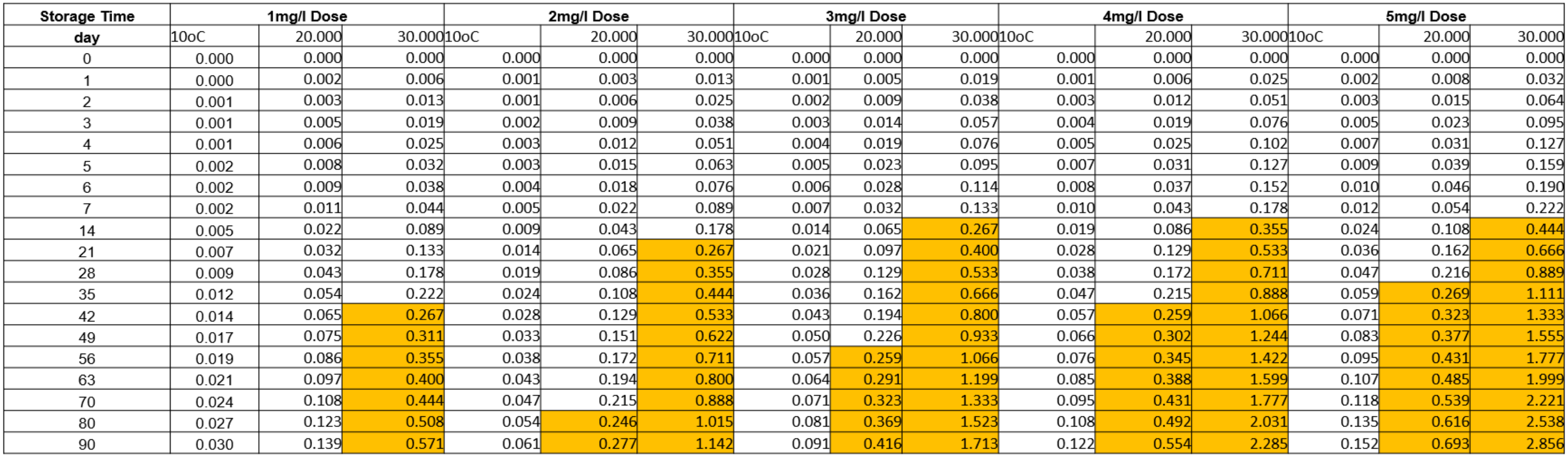
2.4.3 Risk Analysis

We have reviewed our Sodium Hypochlorite chemical dosing and storage requirements for different dosing points within our treatment works and networks. The aim is to ensure we can maintain the ability to dose the required concentration of chlorine at each dosing point within the supply system as temperatures increase while complying with the proposed DWI target of 0.25 mg/l final water chlorate at the customers tap.

Unless we make significant changes to our existing Sodium Hypochlorite storage and dosing systems, the forecast temperature increases outlined in section 2.1 are likely to materially reduce the amount of liquid chlorine we can dose, for any application between source and customers tap, to circa 1 mg/l. This would not allow us to meet standards for water quality and so we need to make changes before regulatory changes or further temperature increases.

Based on WRc research (WRc Portfolio P4006) we have calculated chlorate residual values for 15% Hypochlorite storage times at a range of temperatures (10°C, 20°C and 30°C) and dose rates (1 – 5 mg/l). The tables below show the rate of degradation of Hypochlorite in each scenario. We predominantly use 15% Hypochlorite where liquid rather than gas dosing is used. Depending on the dose rate and application, expected chemical storage times can range from less than a week to more than 90 days.

TABLE 8: CHLORATE RESIDUAL VS HYPOCHLORITE STORAGE TIME AT A RANGE OF TEMPERATURES AND DOSE RATES (15% HYPOCHLORITE)



Storage Time	1mg/l Dose			2mg/l Dose			3mg/l Dose			4mg/l Dose			5mg/l Dose		
day	10oC	20.000	30.000	10oC	20.000	30.000	10oC	20.000	30.000	10oC	20.000	30.000	10oC	20.000	30.000
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.000	0.002	0.006	0.001	0.003	0.013	0.001	0.005	0.019	0.001	0.006	0.025	0.002	0.008	0.032
2	0.001	0.003	0.013	0.001	0.006	0.025	0.002	0.009	0.038	0.003	0.012	0.051	0.003	0.015	0.064
3	0.001	0.005	0.019	0.002	0.009	0.038	0.003	0.014	0.057	0.004	0.019	0.076	0.005	0.023	0.095
4	0.001	0.006	0.025	0.003	0.012	0.051	0.004	0.019	0.076	0.005	0.025	0.102	0.007	0.031	0.127
5	0.002	0.008	0.032	0.003	0.015	0.063	0.005	0.023	0.095	0.007	0.031	0.127	0.009	0.039	0.159
6	0.002	0.009	0.038	0.004	0.018	0.076	0.006	0.028	0.114	0.008	0.037	0.152	0.010	0.046	0.190
7	0.002	0.011	0.044	0.005	0.022	0.089	0.007	0.032	0.133	0.010	0.043	0.178	0.012	0.054	0.222
14	0.005	0.022	0.089	0.009	0.043	0.178	0.014	0.065	0.267	0.019	0.086	0.355	0.024	0.108	0.444
21	0.007	0.032	0.133	0.014	0.065	0.267	0.021	0.097	0.400	0.028	0.129	0.533	0.036	0.162	0.666
28	0.009	0.043	0.178	0.019	0.086	0.355	0.028	0.129	0.533	0.038	0.172	0.711	0.047	0.216	0.889
35	0.012	0.054	0.222	0.024	0.108	0.444	0.036	0.162	0.666	0.047	0.215	0.888	0.059	0.269	1.111
42	0.014	0.065	0.267	0.028	0.129	0.533	0.043	0.194	0.800	0.057	0.259	1.066	0.071	0.323	1.333
49	0.017	0.075	0.311	0.033	0.151	0.622	0.050	0.226	0.933	0.066	0.302	1.244	0.083	0.377	1.555
56	0.019	0.086	0.355	0.038	0.172	0.711	0.057	0.259	1.066	0.076	0.345	1.422	0.095	0.431	1.777
63	0.021	0.097	0.400	0.043	0.194	0.800	0.064	0.291	1.199	0.085	0.388	1.599	0.107	0.485	1.999
70	0.024	0.108	0.444	0.047	0.215	0.888	0.071	0.323	1.333	0.095	0.431	1.777	0.118	0.539	2.221
80	0.027	0.123	0.508	0.054	0.246	1.015	0.081	0.369	1.523	0.108	0.492	2.031	0.135	0.616	2.538
90	0.030	0.139	0.571	0.061	0.277	1.142	0.091	0.416	1.713	0.122	0.554	2.285	0.152	0.693	2.856

For each scenario, the highlighted values show the point at which storage times would result in residual chlorate levels that would exceed 0.25 mg/l. The analysis for 15% Hypochlorite shown in Table 8 highlights the following:

- At ambient temperatures of 10°C, storage times greater than 90 days are possible, at all dose rates, without exceeding the 0.25 mg/l recommended limit for Chlorate residual.
- At ambient temperatures of 20°C, maximum storage times are limited to between 28 and 70 days depending on the dose rate.
- For ambient temperatures of 30°C, maximum storage times are limited to between 7 and 14 days for all dosing applications where greater than 1 mg/l dose rate is required. For dose rates greater than 2 mg/l, storage times are limited to 7 days.

This means that at high temperatures (30°C), storage times are greatly decreased.

TABLE 9: CHLORATE RESIDUAL VS HYPOCHLORITE STORAGE TIME AT A RANGE OF TEMPERATURES AND DOSE RATES (10% HYPOCHLORITE)

Storage Time	1mg/l Dose			2mg/l Dose			3mg/l Dose			4mg/l Dose			4mg/l Dose		
day	10oC	20.000	30.000	10oC	20.000	30.000	10oC	20.000	30.000	10oC	20.000	30.000	10oC	20.000	30.000
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.000	0.001	0.003	0.000	0.002	0.007	0.001	0.002	0.010	0.001	0.003	0.013	0.001	0.004	0.017
2	0.000	0.002	0.007	0.001	0.003	0.013	0.001	0.005	0.020	0.001	0.006	0.026	0.002	0.008	0.033
3	0.001	0.002	0.010	0.001	0.005	0.020	0.002	0.007	0.030	0.002	0.010	0.040	0.003	0.012	0.050
4	0.001	0.003	0.013	0.001	0.006	0.026	0.002	0.010	0.040	0.003	0.013	0.053	0.004	0.016	0.066
5	0.001	0.004	0.017	0.002	0.008	0.033	0.003	0.012	0.050	0.004	0.016	0.066	0.004	0.020	0.083
6	0.001	0.005	0.020	0.002	0.010	0.040	0.003	0.014	0.059	0.004	0.019	0.079	0.005	0.024	0.099
7	0.001	0.006	0.023	0.002	0.011	0.046	0.004	0.017	0.069	0.005	0.022	0.092	0.006	0.028	0.116
14	0.002	0.011	0.046	0.005	0.022	0.092	0.007	0.034	0.139	0.010	0.045	0.185	0.012	0.056	0.231
21	0.004	0.017	0.069	0.007	0.034	0.139	0.011	0.050	0.208	0.015	0.067	0.277	0.019	0.084	0.346
28	0.005	0.022	0.092	0.010	0.045	0.185	0.015	0.067	0.277	0.020	0.090	0.370	0.025	0.112	0.462
35	0.006	0.028	0.115	0.012	0.056	0.231	0.018	0.084	0.346	0.025	0.112	0.462	0.031	0.140	0.577
42	0.007	0.034	0.139	0.015	0.067	0.277	0.022	0.101	0.416	0.030	0.134	0.554	0.037	0.168	0.693
49	0.009	0.039	0.162	0.017	0.078	0.323	0.026	0.118	0.485	0.035	0.157	0.647	0.043	0.196	0.808
56	0.010	0.045	0.185	0.020	0.090	0.370	0.030	0.134	0.554	0.039	0.179	0.739	0.049	0.224	0.924
63	0.011	0.050	0.208	0.022	0.101	0.416	0.033	0.151	0.624	0.044	0.202	0.831	0.055	0.252	1.039
70	0.012	0.056	0.231	0.025	0.112	0.462	0.037	0.168	0.693	0.049	0.224	0.924	0.062	0.280	1.155
80	0.014	0.064	0.264	0.028	0.128	0.528	0.042	0.192	0.792	0.056	0.256	1.056	0.070	0.320	1.320
90	0.016	0.072	0.297	0.032	0.144	0.594	0.047	0.216	0.891	0.063	0.288	1.188	0.079	0.360	1.485

We conducted the same analysis for 10% Hypochlorite, shown in Table 9, which highlights the following:

- At ambient temperatures of 10°C, storage times greater than 90 days are possible, at all dose rates, without exceeding the 0.25 mg/l recommended limit for Chlorate residual.
- At ambient temperatures of 20°C, maximum storage times are reduced to between 60-70 days but only for dose rates higher than 4 mg/l.
- At ambient temperatures of 30°C, maximum storage times between 35 and 63 days are still achievable where dose rates are no higher than 2 mg/l. However, for dose rates greater than 3 mg/l, maximum storage times are limited to 14 days. This means that for smaller sites, where dose rates are low, a shift to use of 10% Hypochlorite may provide adequate mitigation.

The analysis shows that at sustained ambient temperatures > 20ºC, the rate of Chlorate formation is significantly increased and impacts on site storage times, and therefore operational resilience. At sustained summer temperatures approaching or greater than 30°C, the rate of degradation results in a level of risk that is untenable to manage operationally, both in terms of logistics of chemical delivery/renewal and the ability to effectively optimise dosing for all dosing applications.

2.4.4 Vulnerable dosing points

We are undertaking a programme of work reviewing risks that have the potential to affect the quality or quantity of drinking water at our WTW sites. We have identified several sites using hypochlorite which are at risk of failing the proposed 0.25mg/l water treatment standard for chlorate, which is significantly lower than the World Health Organisation value of 0.7mg/l.

We reviewed our initial list of vulnerable sites and categorised dosing points by type. We added a further category of 'Logistical stores for deployment' to cover protection of sites where chemical is stored before distribution to other sites. These categories are listed below, and the list of dosing points shown in Table 10:

- Primary disinfection (6 dosing points)
- Network booster chlorination (12 dosing points)
- Marginal Chlorination (6 dosing points)
- Logistical stores for deployment (3 sites where chemical is stored centrally for distribution to smaller rural sites)
- Interstage treatment - Manganese oxidation (3 dosing points)
- Mussel control dosing – required for compliance with Invasive Non-native Species regulations (INNS) (7 dosing points)
- Emergency disinfection (7 dosing points)

TABLE 10: OUR VULNERABLE HYPOCHLORITE DOSING SITES BY TYPE

No	WTW / Supply Zone	Dosing point / Application
1	Abberton RWPS	INNS (mussel) control
2	Allenheads	Primary disinfection
3	Barsham Waveney Intake RWPS	INNS (mussel) control
4	Bolton WPS	Network booster chlorination
5	Brantham RWPS	INNS (mussel) control
6	Carrshields	Primary disinfection
7	Charlton WPS	Network booster chlorination
8	Chigwell	INNS (mussel) control
9	Cockershields WPS	Network booster chlorination
10	Dalton	Marginal chlorination
11	Ferry Hill WPS	Network booster chlorination
12	Fir Tree WPS	Network booster chlorination
13	Fontburn	Emergency disinfection
14	Ford WPS	Network booster chlorination
15	Fulwell	Marginal chlorination
16	Hawthorn	Marginal chlorination
17	Honey Hill	Emergency disinfection
18	Horsley	Emergency disinfection
19	Horsley	Interstage (metals oxidation) treatment
20	Langham lowlift RWPS	INNS (mussel) control
21	Lound	INNS (mussel) control
22	Lumley	Emergency disinfection
23	Lumley	Logistical stores for deployment
24	Mindrum WPS	Network booster chlorination
25	Mosswood	Emergency disinfection
26	Mosswood	Interstage (metals oxidation) treatment
27	Murton	Logistical stores for deployment
28	New Winning	Marginal chlorination
29	North Dalton	Marginal chlorination
30	Ormesby WPS	Network booster chlorination
31	Ormesby WTW	INNS (mussel) control
32	Pennyhill WPS	Network booster chlorination
33	Peterlee	Primary disinfection
34	Rainton MS	Network booster chlorination
35	Redcar WPS	Network booster chlorination
36	Roding	Primary disinfection

37	St Andrews WPS	Network booster chlorination
38	Stoneygate	Marginal chlorination
39	Thorpe	Primary disinfection
40	Tosson	Primary disinfection
41	Wear Valley	Emergency disinfection
42	Whittle Dene	Emergency disinfection
43	Whittle Dene	Interstage (metals oxidation) treatment
44	Whittle Dene	Logistical stores for deployment

Our climate change analysis shows that increasing ambient temperatures, and the increased frequency of high temperatures sustained for even relatively short periods, pose a significant risk of Chlorate formation that would restrict or prohibit the use of 15% Hypochlorite in our treatment processes against the 0.25 mg/l PCV target at the selected dosing points. Regardless of whether the DWI proposed PCV target comes into effect during AMP8, rising temperature and its effect on Chlorate formation remains a significant issue. Under climate change, control of Chlorate levels will increasingly impact our ability to provide a resilient supply, and there is a clear need for us to invest in solutions to maintain resilience.

2.5. DISSOLVED OXYGEN DEPLETION IN SLOW SAND FILTERS

2.5.1 Slow Sand Filter vulnerability to rising temperatures

Slow sand-filter sites are vulnerable to the effects of increasing temperature and sunlight intensity which result in accelerated blanket weed or algae growth and oxygen depletion. While slow sand filters are a highly effective biological process (and an efficient treatment process), the biology requires oxygen levels to be maintained to ensure the health and sustainable function of the filter.

We operate five WTW sites with slow sand filtration, shown in Table 11 below, all of which are in our Essex & Suffolk Water region.

TABLE 11: SLOW SAND FILTER SITES IN OUR ESSEX & SUFFOLK WATER REGION

Site	Output (MLD)	No. of SSF beds	SSF Capacity	Date of installation
Chigwell	118	18	2600	1963
Langham	55	12	1600	1930's
Layer	145	20	2500	late 1930's to early 1940’s
Lound	18	6	900	predates 1930
Ormesby	36	6 (3 smaller and 3 larger)	2250 and 2700	predates 1930

The majority of our slow sand filter sites were built in the period just before or after 1930, except for Chigwell which was commissioned in 1963. Due to their age and the design philosophy of the time, the filters were designed to be skimmed at a frequency of approximately 100 to 120 days. Depending upon temperature and sunlight conditions, blanket weed growth can occur at rates that require skimming frequencies between 30-70 days. During April – September, algal growth can reach material levels after 30 days, while during October – March algal growth is limited to >70 days. As both summer and winter temperatures increase due to climate change, rates of algal growth within our slow sand filter beds will also increase, impacting the levels of Dissolved Oxygen (DO) within the bed structure affecting the biological performance and driving the need for more frequent skimming to mitigate water quality risk.

2.5.2 DO levels and filter health

There are many different recommendations for the minimum DO concentration required to maintain an aquatic biological community for effective water treatment. The following research is relevant to the risk of DO depletion in slow sand filters:

- The World Health Organisation has recommended that values should be maintained as close as possible to saturation, which equates to approximately 9mg/l at a water temperature of 20°C (WHO, 1996[5]).
- Chapman (1996[6]) stated that values below 5mg/l are likely to adversely affect the survival of biological communities
- Huisman & Wood (1974[7]) evidenced that DO levels in slow sand filters should be maintained above 3 mg/l to avoid anaerobic conditions.
- Den Blanken (1982[8]) reported that in order to "keep the useful bacteria in filters in good condition it is important to flush them continuously with oxygen-rich water so as to prevent low DO contents (less than 3-4mg/l) occurring in the filtrate".
- Results of a study by Chen (1996[9]) which developed a model for predicting the critical bulk DO concentration for onset of oxygen limitation in a biofilm, indicated that the bulk DO level strongly influenced removal when the dissolved oxygen was less than approximately 3mg/l.
- Haarhoff and Cleasby (1991[10]) stated that: "anaerobic filter conditions lead to severe water quality problems and should be avoided at all costs".

In 2003, Thames Water sponsored a PhD to determine the effective optimisation of slow sand and GAC sandwich filters (Melissa Steele, 2003) and set operational minimum values for DO for individual filter outlets and combined filtrate water.

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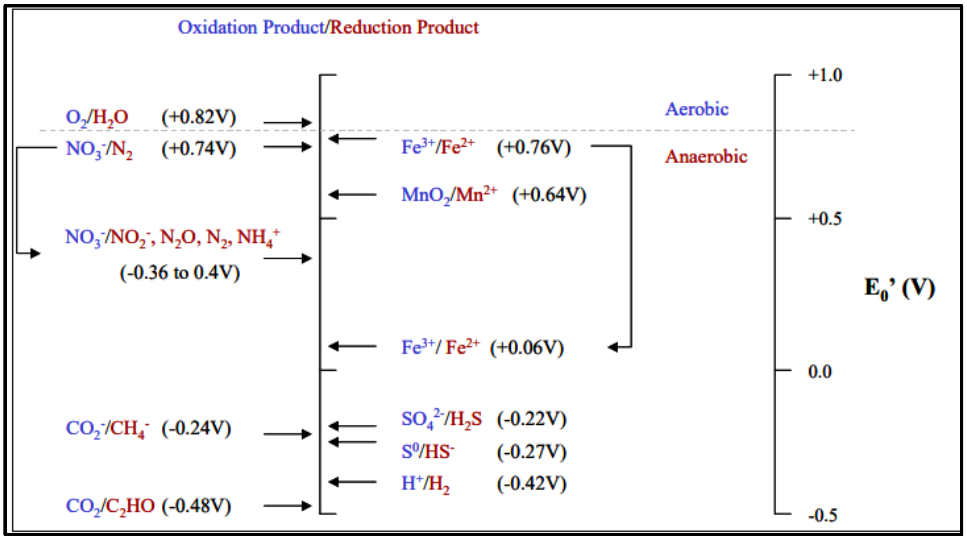
[5] Muhammad, N., Ellis, K.V., Parr, J. and Smith, M.D., 1996. Optimization of slow sand filtration.
[6] Chapman, P.M., 1996. Presentation and interpretation of sediment quality triad data. Ecotoxicology, 5, pp.327-339.
[7] Huisman, L. and Wood, W.E., 1974. Slow sand filtration. World Health Organization.
[8] den Blanken, J.G., 1982. Microbial activity in activated carbon filters. Journal of the Environmental Engineering Division, 108(2), pp.405-425.
[9] Chen, G.H., 1996. Prediction of oxygen limitation in an aerobic biofilm reactor. Journal of Environmental Science & Health Part A, 31(10), pp.2465-2475.
[10] J Haarhoff, Report of a site investigation conducted at the Goreangab water treatment plant from 1991-07-08 to 1991-07-16. Submitted to the City Engineer, City of Windhoek, (1991).

The study found that anaerobic respiration will begin to dominate in a slow sand filter when oxygen becomes limiting and will result in chemical reactions releasing noxious by-products. Figure 6 below, from Steele's paper, shows the risk of low oxygen levels in the bed triggering anaerobic conditions and associated reactions and elevated levels of toxic substances including ammonia, iron, nitrite and sulphides.

FIGURE 6[11]: THE IMPACT OF ANEAROBIC CONDITIONS WITHIN SLOW SAND FILTER BEDS



Levels of DO within sand filter beds are subject to a natural diurnal pattern due to the plants or algae within the bed stripping oxygen out of the water as they respire during the night. This can lead to very low dissolved oxygen concentrations overnight, which recover slowly during the day, as illustrated in Figure 7 below.

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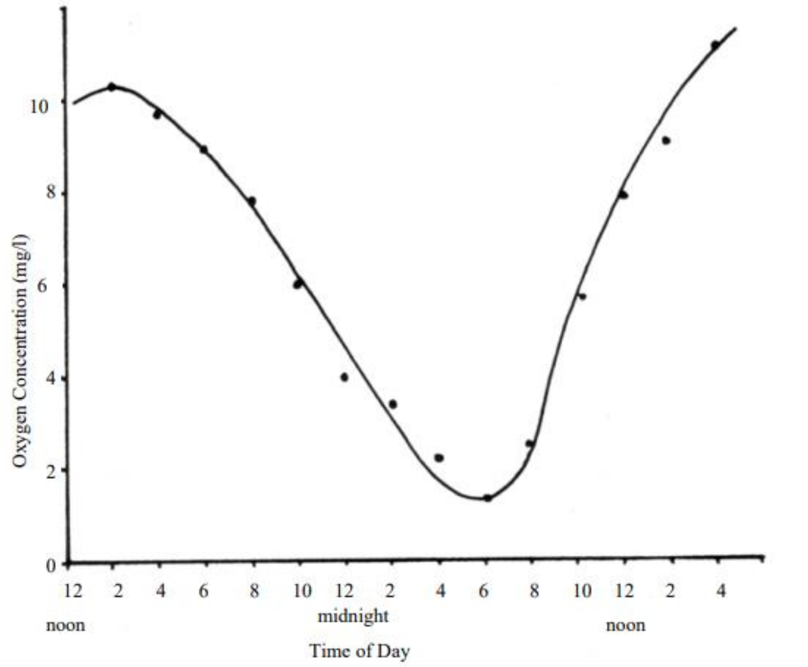
[11] Source: Steele, M.E.J., Evans, H.L., Stephens, J., Rachwal, A.J. and Clarke, B.A., 2006. Dissolved oxygen issues with granular activated carbon sandwich (TM) slow sand filtration. *Recent Progress in Slow Sand and Alternative Biofiltration Processes*, pp.83-94.

FIGURE 7[12]: DAILY DO VARIATION IN SLOW SAND FILTER BEDS



The diurnal variation in DO is greater in slow sand filters constructed to a 'GAC Sandwich' design, where the bed consists of a layer of Granulated Activated Carbon media, sandwiched between two layers of sand media (Figure 12). Slow sand filters at Chigwell, Langham and Layer WTW sites in Essex are all constructed to a GAC sandwich design. DO levels are impacted by filtration rate and the length of time that filters are in service between washing/skimming, as well as rates of algal and blanket weed growth.

Aeration prior to SSF will increase dissolved oxygen but is not a guarantee that SSF will remain aerobic. Diurnal variation in DO levels needs to be established and managed for each site.

Low DO levels could lead to anaerobic conditions and present a water quality risk in terms of the potential for discolouration, biofilm shedding, metal dissolution and coliform breakthrough. If anaerobic conditions occur, even in a limited portion of a slow sand filter bed, the filtrate and final water quality can be compromised. Effects include:

- Shedding a large mass of particles.
- Release of coliforms, e-coli and potentially cryptosporidium.
- Reduced pathogen and organics removal.
- Elevated dissolved substances such as ammonia, iron, manganese, elevated nitrite and sulphides due to changes in redox.

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[12] Source: Steele, M.E.J., Evans, H.L., Stephens, J., Rachwal, A.J. and Clarke, B.A., 2006. Dissolved oxygen issues with granular activated carbon sandwich (TM) slow sand filtration. *Recent Progress in Slow Sand and Alternative Biofiltration Processes*, pp.83-94.

These effects can jeopardise the disinfection process (either chlorine disinfection or UV disinfection) resulting in disinfection failures and an increased risk of taste and odour impacts. The microbiological threat under anaerobic conditions can be extremely high as a result of the shedding of micro-organisms from the media.

The risk of oxygen depletion is greatest when high concentrations of algae are present in the top water, or there is significant blanket week growth and large biological communities exist within the SSF media. Elimination of algal growth or proliferation could be achieved by the exclusion of sunlight, such as covering the beds, but otherwise, the stabilisation of DO concentrations must be achieved by monitoring and management.

If large amounts of algae or blanket weed are present in the top water of a SSF, the demand for oxygen during the night may exceed the volume of oxygen present in the raw water. As this deoxygenated water passes through the bed, the biological community within the media can die off, reducing the efficiency of the biological filtration process. Given the right conditions, algal growth can be exponential. After an initial period of approximately 30 days, the mass of blanket weed growth above the filter bed can double every 10-days depending on sunlight levels and ambient conditions.

Recovery of an anoxic bed is a slow process, requiring filter drain-down, a deep skim or complete removal of the media, significant work to refill the media and ripen the filter, during which time a prolonged run to waste operation is necessary. Therefore, the process of recovering an anaerobic slow sand filter will lead to prolonged and material outage and loss of supply to customers.

Other water companies have had slow sand filters turn anaerobic. In some cases, sites have been unrecoverable, leading to abandonment due to prolonged outage and cost to recover. Companies have also reported bacteriological failures, taste and odour incidents and discolouration events as a result of slow sand filter performance. Increasing DO stability will significantly reduce the risk of ammonia and nitrite peaks and the associated potential for future taste and odour problems. This will prevent any future associated large increases in chlorine demand that can be caused by peaks in the levels of ammonia and nitrite.

2.5.3 Link between temperature and DO levels

The solubility of oxygen in water will reduce as temperature increases. This is an established principle known as Henry's law (Metcalf & Eddy, 5th Edition p99[13]). This relationship is shown in Figure 8 between temperature and surface DO levels for a generic body of water.

Low DO conditions are therefore more likely to develop in a slow sand filter bed during the warmer seasons and as temperatures increase due to climate change. It is also well documented that microbial communities increase more rapidly at higher temperatures. Temperature affects the size and activity of the microbiological community in the filter bed,

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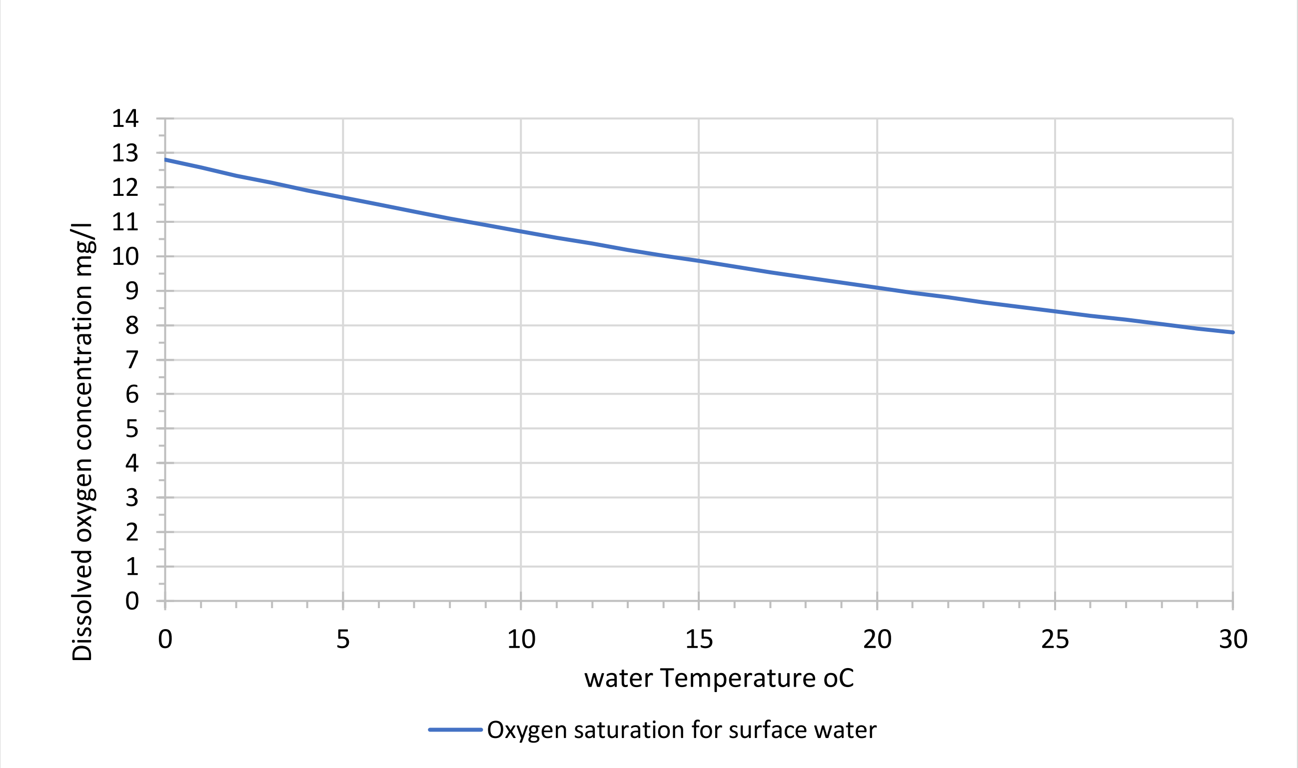
[13] Metcalf, L., Eddy, H.P. and Tchobanoglous, G., 1991. Wastewater engineering: treatment, disposal, and reuse (Vol. 4). New York: McGraw-Hill.

impacting the respiratory demand for oxygen (Labouyrie et al, 1997[14], den Blanken, 1982[15]). Goddard (1980[16]) reported that ciliate populations in slow sand filter media increased at a rate of only 18%/day at 4°C compared to 36%/day when temperatures reach 36°C.

FIGURE 8[17]: RELATIONSHIP BETWEEN DO AND SURFACE WATER TEMPERATURE



Rates of photosynthesis will also be affected by temperature, with rates increasing as temperature rises. The exact relationship is dependent on factors including taxonomy, light intensity and light dose, which increase under climate change scenarios. While the temperature impact on photosynthetic oxygen production will be restricted to daylight hours, the increased respiratory demand caused by high temperatures is expected to be more influential on slow sand filter DO levels (M. Steel pHD Thesis).

Therefore, the combination of reduced DO solubility and higher respiratory demand for DO heightens the risk of an anaerobic environment developing when ambient temperatures are higher.

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[14] Labouyrie, L., Le Bec, R., Mandon, F., Sorrento, L.J. and Merlet, N., 1997. Comparaison de L'Activite Biologique de Differents Charbons Actifs en Grains Comparison of Biological Activity of Different Types of Granular Activated Carbons. Environmental Technology, 18(2), pp.151-159.

[15] den Blanken, J.G., 1982. Microbial activity in activated carbon filters. Journal of the Environmental Engineering Division, 108(2), pp.405-425.

[16] Goddard, M.R., 1980. The ecology of protozoan populations of slow sand filters with particular reference to the ciliates. University of London, Royal Holloway College (United Kingdom).

[17] Metcalf, L., Eddy, H.P. and Tchobanoglous, G., 1991. Wastewater engineering: treatment, disposal, and reuse (Vol. 4). New York: McGraw-Hill. Henry's Law, data for 20°C.

2.5.4 Slow Sand Filter Site Analysis

As described above, DO is a critical indicator of the health of slow sand filters, and a leading indicator for water quality leaving the water treatment works and in the network. As environmental conditions change, it is important to be able to monitor DO levels and their impact on our treatment processes. In common with other water companies, we do not currently measure DO concentrations on individual slow sand filter beds. We have limited historic samples which are taken during the day and represent periods where any plants within the slow sand filters are photosynthesising and therefore producing oxygen. While these allow us to trend DO levels over time, they do not capture minimum overnight DO levels and therefore do not accurately reflect the level of risk. The day-time sampling to date indicates that concentrations lower than 5mg/l will be occurring overnight.

We have analysed our data for both raw water temperature (2010 – 2022) and filter bed DO levels (2018 – 2022) and the results are summarised in Table 12 below.

TABLE 12: SUMMARY OF ANALYSIS

Site	Filter type	Raw water temperature trend	Minimum DO levels <3 mg/l
Chigwell	GAC sandwich construction	Increasing	Yes
Langham	GAC sandwich construction	Increasing	Yes
Layer	GAC sandwich construction	Increasing	Yes
Lound	Sand only	Increasing	Yes
Ormesby	Sand only	Increasing	Yes

The results for all 5 sites are highly consistent, and the data analysis for Langham WTW is shown below. We have 13 years of raw water temperature data which shows the annual temperature profile and the range between 1°C and 23.4°C, as shown in Figure 9. The annual 95%ile temperature since 2013, shown in Figure 10, demonstrates an increasing trend with raw water temperatures increasing by approximately 1°C over the period. The climate change modelling predicts an increase of between 1.5 and 2.6°C in average summer temperatures by 2050 in the South East, which will sustain the rising trend in raw water temperatures.

FIGURE 9: LANGHAM WTW RAW WATER TEMPERATURE DATA SINCE 2010

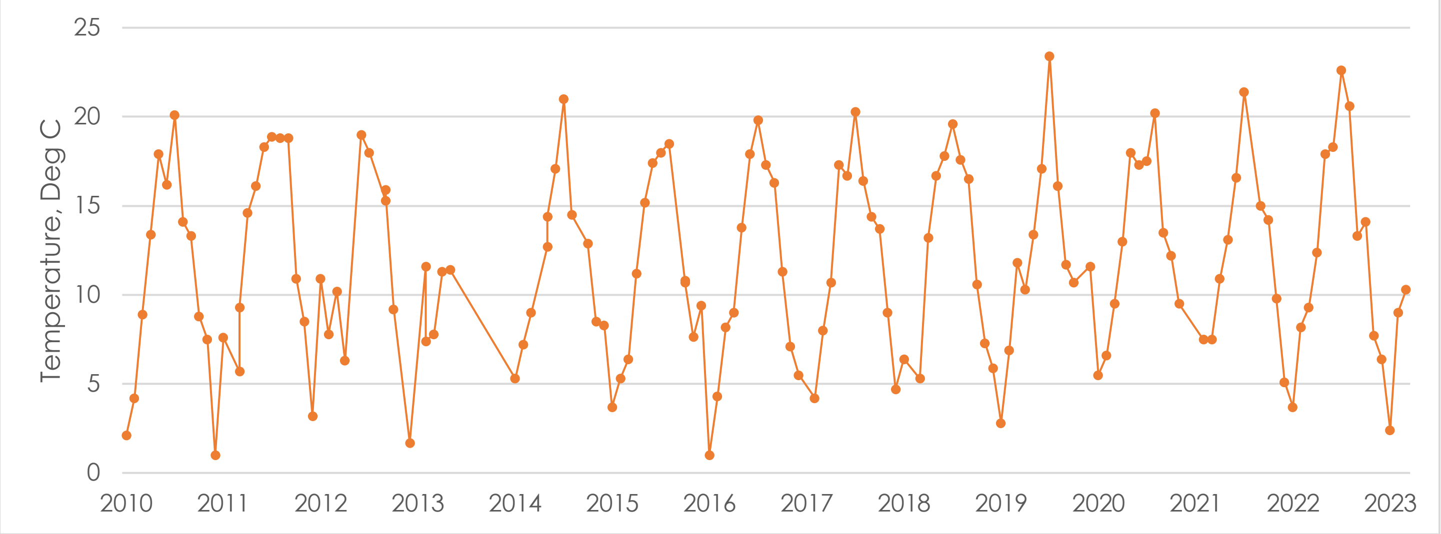
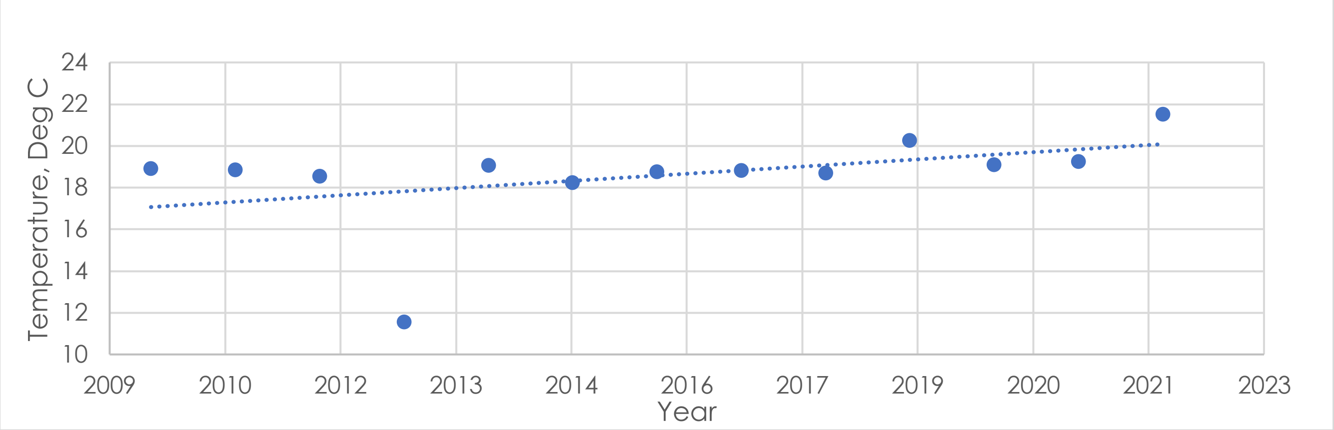


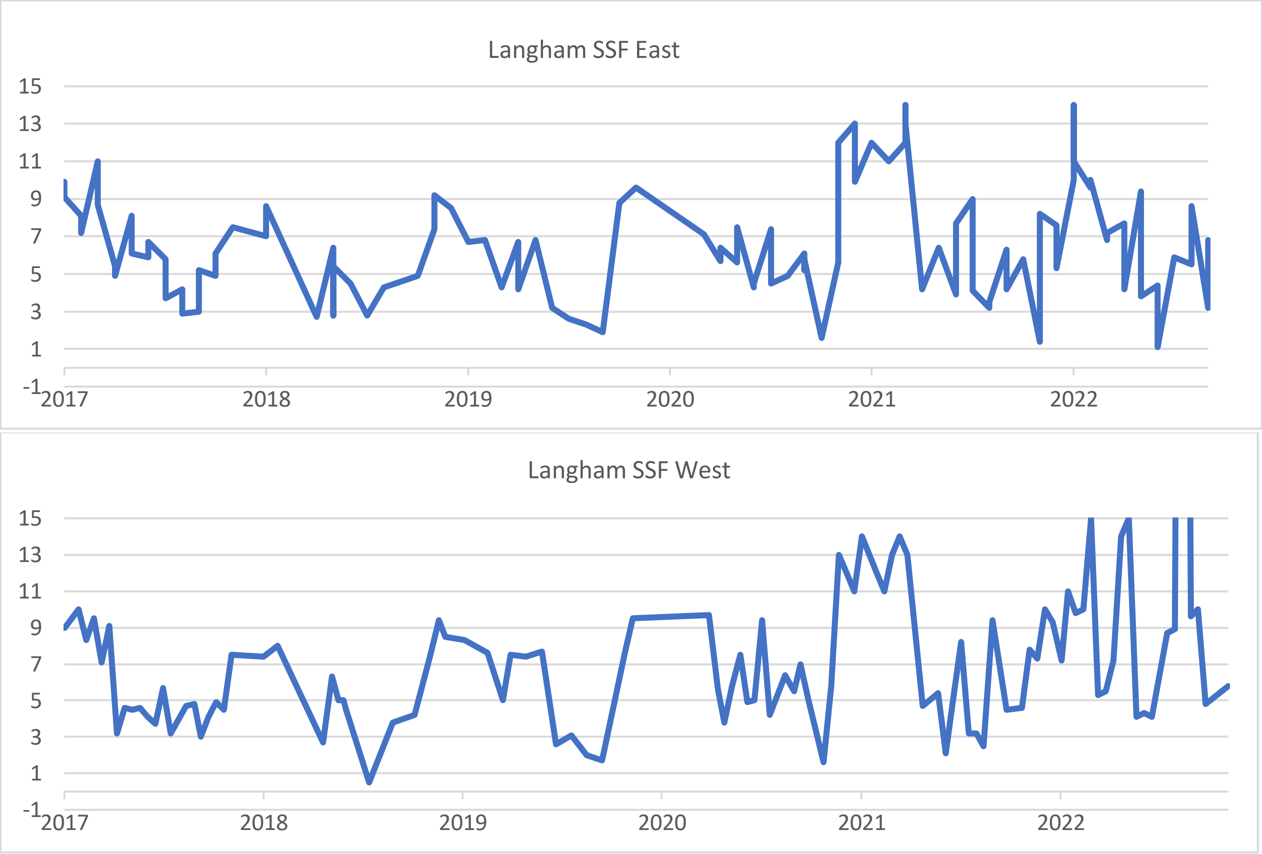
FIGURE 10: LANGHAM WTW 95%ILE RAW WATER TEMPERATURE SINCE 2010



As noted previously, we do not have DO monitors installed and our sample data is limited to monthly spot samples taken by our operational teams. While this data has its limitations, Figure 11 shows data for the outlets of 2 banks of slow sand filters at Langham WTW. A clear annual DO profile is evident with lower DO levels during summer months as temperatures increase. In addition, recorded DO levels during summer months are frequently <3mg/l. As all our samples have been taken during daytime hours, the actual DO levels overnight are likely to be lower still, for reasons outlined in 2.5.2.

Our climate change analysis and assessment of site vulnerability highlight the need to invest to ensure ongoing resilience in the face of rising temperatures. We need to be able to monitor the health of individual filter beds and be able to respond rapidly to mitigate the risk of anaerobic bed conditions. DO monitoring at an individual filter level is required to inform operational optimisation, and more frequent skimming of filter beds is required to enhance filter health and provide resilience to increasing temperatures. Sites do not currently have the facility to run-to-waste flows from filter skimming operations, and therefore skim frequency is currently limited by the need to manage impact of skimming on final water quality. Provision of run-to-waste facilities is therefore required to allow more frequent skimming and protect the biological health of our slow sand filter processes.

FIGURE 11: LANGHAM WTW - DO LEVELS (2017- 2022) IN EAST & WEST SLOW SAND FILTER STREAMS



2.6. RAPID GRAVITY FILTRATION – BACKWASH DEGRADATION

Many of our surface and ground water treatment plants employ rapid gravity filters (RGFs) as a key barrier against particles including pathogens, indicator organisms, suspended matter and turbidity entering the treated water. Rapid gravity filters treat water at a relatively high filtration rate and the resultant clogging of media (headloss development) leads to the requirement for regular and effective backwashing. If the filters are not backwashed, eventually the headloss through the media will equal the available head (water pressure above the media) and the filter will cease to function effectively. Therefore, as the clogging through the filter increases during a filter run, the flow through the filter can reduce significantly. If multiple filters are in this condition at the same time, the treatment plant would not be able to consistently produce its required output.

Effective backwashing causes expansion of the media bed. Expansion is governed by the fluidising velocity which is media specific, and the temperature of the water. As water temperature increases, the minimum fluidising velocity required to achieve bed expansion also increases. Therefore, with climate change and increasing seasonal raw water temperatures, filters with already limited filter wash capability as a result of legacy design and site constraints, will deteriorate.

FIGURE 12[18]: TYPICAL STAGES OF A RAPID GRAVITY FILTER RUN

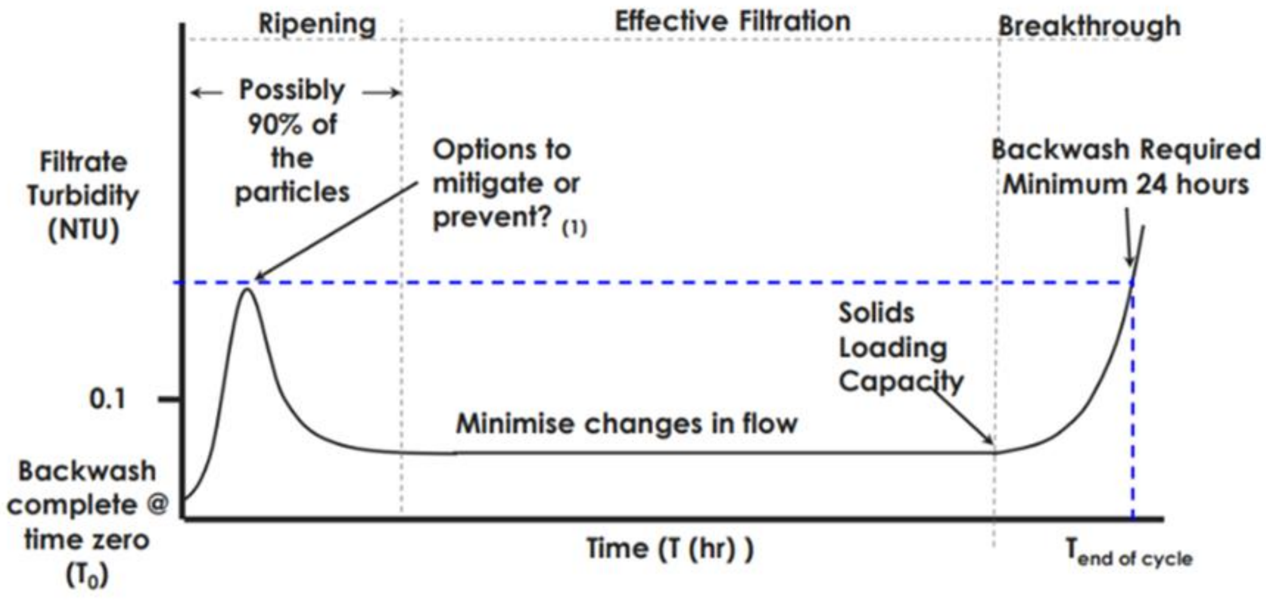


Figure 12 shows the stages of an RGF cycle. When the backwash is complete at ‘time zero’, the filter should return to a clean bed condition. If the filter wash is effective for all filters units, then all filters will return to the same clean bed condition following each backwash. The filter then completes a ripening phase, where an initial peak in turbidity is caused by particles

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[18] Stantec Water Treatment Training – Module C – Particle Removal 2, Filtration

loosened by the backwash cycle, before turbidity and quality of the filtered water improves. There follows an effective filtration period, before the solids loading capacity of the filter (its ability to retain solids) is exhausted and particles begin to breakthrough.

In instances where the filter backwash is ineffective – i.e. where the starting bed headloss is higher – effective filtration time is reduced and the ripening period can be erratic or prolonged. This results in unpredictable filter performance and increases the risk of solids breakthrough.

In order to mitigate the water quality risk, operational changes are required to increase backwash frequency, which also increases process losses, and reduces plant output and supply resilience, especially during periods when raw water quality is reduced. Each filter can have a different media condition and therefore different threshold for premature particle breakthrough, resulting in an increased risk of breakthrough and potential compliance failures. The operational response is typically to reduce filtration rates and flow through the treatment plant to protect customers from the risk of unwholesome water.

Replacement of media with new media is a very short-term solution as it does not address the root cause of filter bed deterioration, and new media quickly becomes clogged due to the poor backwash performance.

2.6.1 Rapid Gravity filter health and backwash

We have an ageing filter estate. Specific backwash rates, air wash rates, and design of filter shells and launders differs from site to site according to when the filter was designed, the media that was selected, the raw water quality and the industry design recommendations at that time. Since some of our plants were built, raw water challenges have changed and expectations for treated water quality, resilience and expected outputs from each site have increased significantly.

Therefore, best practice for filter operation, management of backwash and returning filters to service has changed materially since some of our treatment sites were built. Our older RGF structures have limited washwater capacity, but the physical limitations of the civil structures, and the lack of capacity to deal with increased washwater volumes, preclude simple backwash upgrades (e.g. increasing backwash pump size in isolation).

Key issues associated with RGF performance, and their consequences, are listed below in Table 13.

TABLE 13: FILTER PERFORMANCE

Issue	Consequence
Insufficient Bed Expansion	Dirt is not released or washed from filter bed
Inadequate backwash volume	Wash is incomplete, filter ripening and return to service compromised
Inadequate treatment of filter ripening filtrate	No capability for slow-start, delayed start, filter to waste
High starting bed headloss	Premature particle / pathogen breakthrough Increased process losses Reduced Deployable Output
Non uniform normalised starting bed headloss	Individual filters in different conditions Unpredictable short filter runs Unpredictable increased process losses Reduced Deployable Output Poor operational confidence in plant Higher likelihood of pathogen / particle breakthrough
Media Loss	Reduced efficacy of pathogen barrier Short filter run times Reduced output
Poor media condition	Dirt content Mud-balling etc Cracks in filters – pathogen breakthrough Floor over-pressurisation and failure

2.6.2 Backwash vulnerability to rising temperatures

Significant research has been undertaken on the impact of bed expansion on the effectiveness of a filter backwash. Modern filtration plants would typically be built with temperature compensated backwash systems designed to achieve 10-15% bed expansion. Where mixed media filtration beds are utilised, which applies to all our priority sites included in this case, it is important that the filter wash is capable of re-stratifying the layers of media (layers of different size and density). Mixed media beds have a higher capacity for solids retention which supports longer filter run times, whilst maintaining treated water quality targets. However, if a mixed media bed is not re-stratified effectively, the smaller size media clogs the voids in the larger media layer at the beginning of the filter run, leading to shorter filter runs and poorer water quality performance.

Different media types have different wash requirements. Figure 13 illustrates the relationship between temperature and backwash rates, showing that higher rise rates were required to fluidise the media under warm water conditions (20°C) compared to cold water conditions (10°C). This is because the viscosity of water decreases at higher temperatures, leading to a greater flow being required to exert sufficient force on the surfaces of the media grains to oppose the downward force of their mass acting under gravity. At warmer temperatures the minimum fluidising velocity (velocity of water required to achieve any bed expansion during backwash) is increased.

At temperatures greater than 20°C which now routinely occur and will occur with increasing frequency and duration under our modelled climate change scenarios, the minimum fluidising velocity is further increased.

FIGURE 13[19]: IMPACT OF TEMPERATURE ON RGF MINIMUM BED FLUIDISING VELOCITY

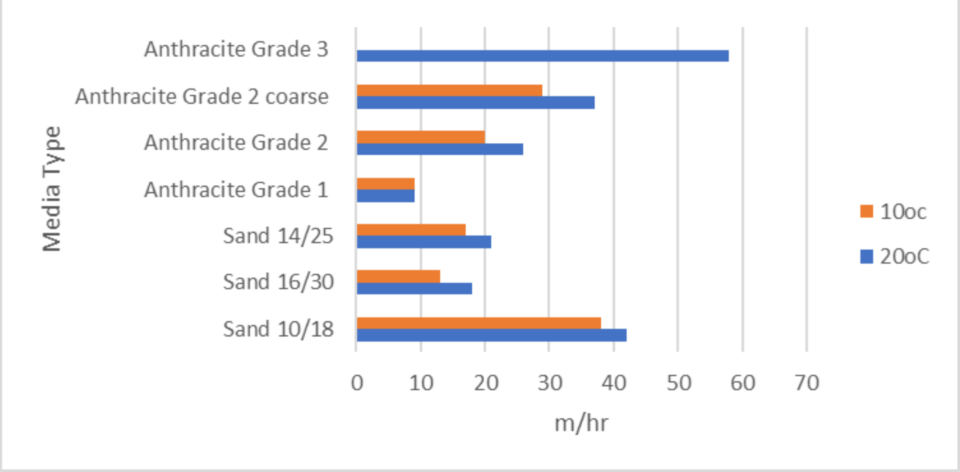

FIGURE 14[20]: RGF BED EXPANSION AT DIFFERENT BACKWASH RATES AT 20°C

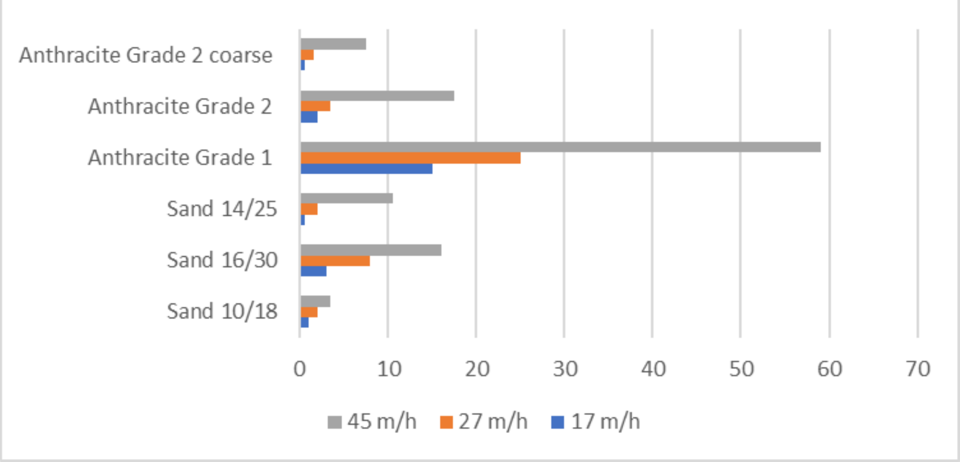

Figure 14 shows the effectiveness of different backwash rates for different media types in warm weather conditions (20°C). With the exception of Grade 1 Anthracite media, bed expansion is minimal at 17m/hr at 20°C for all other media types. At standard wash rates of 27m/hr (which aligns with our current standard of 28 m/hr) bed expansion rates are very low or in the case of 16/30 sand, well below 10%.

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[19] Chipps, M.J., Bauer, M.J. and Bayley, R.G. Achieving enhanced filter backwashing with combined air scour and sub-fluidising water at pilot and operational scale. Filtration and Separation Vol 32, part 1, pp55-62. 1995.

[20] Chipps, M.J., Bauer, M.J. and Bayley, R.G. Achieving enhanced filter backwashing with combined air scour and sub-fluidising water at pilot and operational scale. Filtration and Separation Vol 32, part 1, pp55-62. 1995.

Notably, coarse cut Anthracite Grade 2 which is commonly used in dual media filters, requires velocities in excess of 45 m/hr to achieve expansion rates of 15% in warmer water temperatures. At rates of 27 m/hr the expansion rate will be very small and inadequate to regrade the media bed, leading to poorer filtration performance and potential reduced plant output.

Normalising headloss at a standardised flow, water viscosity and media depth enables effective monitoring of filter media condition over time. Part of our proposed solution is to ensure upgraded filters have normalised headloss performance and media depth trends stored and recorded on SCADA, so that it is clear when filters have recovered from a water quality challenge or where performance is deteriorating over time and will not recover.

2.6.3 Prioritisation

Our prioritisation of sites for AMP8 is focused on WTWs that have material strategic importance, rank highest in our criticality classification, and show an increasing trend in raw water temperature. We are also currently monitoring additional sites in detail, and investigations are ongoing to assess filter performance, backwash efficacy and climate change resilience.

Our priority sites for AMP8 are shown in Table 14 below. Criticality is scored between 1 and 5, where 1 is most critical. Raw water temperature trend is derived from analysis of site temperature data since 2009 for maximum, minimum and 95%ile results (see example analysis for Broken Scar in Section 2.6.4):

TABLE 14: AMP8 PRIORITY SITES

Site	Region	Design Output (Ml/d)	Population	Criticality	Raw water temperature trend
Broken Scar	NW	180	417,901	1	Increasing
Fontburn	NW	19	67,815	1	Increasing
Hanningfield	ESW	220	588,475	1	Minimum reducing, maximum & 95%ile increasing
Layer	ESW	145	425,013	1	Increasing
Langford	ESW	56	135,635	1	Minimum reducing, maximum & 95%ile increasing
Mosswood	NW	152	525,597	1	Increasing

The individual site legacy design issues are highlighted in Section 2.6.4 below.

2.6.4 Rapid Gravity filter site analysis

The following figures summarise the current process limitations and challenges for each site. In many cases poor backwash capability results in extended washing periods. Therefore, even though wash rates are low, wash volumes produced can be high. As detailed in Section 2.6.2 above, dual media filters designed to use Anthracite grade 2 media are particularly vulnerable due to the high wash velocities required to effectively backwash and achieve adequate regrading of media. Table 15 shows that all our priority sites have dual media filters utilising Anthracite grade 2 media. In addition, Layer Treatment Works also has a bank of single media filters.

TABLE 15: FILTER BACKWASH PERFORMANCE ASSESSMENT

Site	Backwash rate (m/hr)	Media A			Media B		
		Type	Bed fluidisation	Bed expansion at 20°C	Type	Bed fluidisation	Bed expansion at 20°C
Broken Scar	34	16/30	Yes	3.6%	Anthracite	Yes	3.6%
Fontburn	14	16/30	No	0%	Anthracite	No	0%
Hanningfield	28	16/30	Yes	<10%	Anthracite	Yes	<5%
Layer (Patterson stream)	7	14/25	No	<1%	N/A	N/A	N/A
Layer BOBY stream	29	16/30	Yes	<10%	Anthracite	Yes	<5%
Langford	18	16/30	borderline	<5%	Anthracite	No	<3%
Mosswood	23	16/30	Yes	<5%	Anthracite	No	<3%

Table 16 provides a summary of the issues identified at each of the sites.

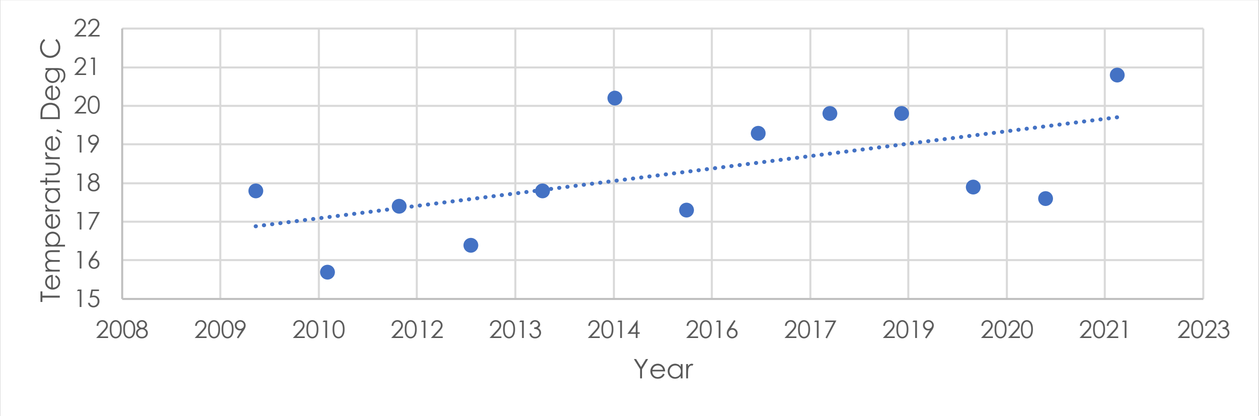
TABLE 16: FILTER ASSESSMENT SUMMARY

Site	Issues
Broken Scar	• Insufficient media expansion • Dual media not adequately regraded following backwash • Uneven Air Scour Distribution • Insufficient clean wash water storage
Fontburn	• Insufficient media expansion • Dual media not adequately regraded following backwash • Insufficient headroom above media for adequate expansion without risk of media loss. Overflow during air scour. • Insufficient air scour rate • No Temperature Compensation backwash • Insufficient clean wash water Storage • Uneven air scour distribution
Hanningfield	• Insufficient bed expansion (Block 3 - no bed expansion) • Insufficient headroom above media for adequate expansion without risk of media loss. Overflow during air scour. • Dual media not adequately regraded following backwash • No Temperature Compensation backwash • Uneven Air Scour Distribution

Layer	• Insufficient media expansion • Dual media not adequately regraded following backwash • No Temperature Compensation backwash control • Uneven air scour distribution
Langford	• Inadequate filter launder channel arrangement • Insufficient media expansion • Insufficient air scour • Dual media not adequately regraded following backwash • No Temperature Compensation backwash control • Visible Solids Above Filter After Wash • Filter freeboard is insufficient when wash is changed
Mosswood	• Inadequate filter launder channel arrangement • Insufficient media expansion • Insufficient air scour • Dual media not adequately regraded following backwash • No Temperature Compensation backwash control

Consistent with the climate change risk assessment and the conclusions of our future climate scenarios outlined in Section 2.3, our sites are showing a clear trend in increasing maximum and 95%ile raw water temperature. Figure 15 shows data from Broken Scar WTW raw water inlet, taken since 2009.

FIGURE 15: BROKEN SCAR MAXIMUM RAW WATER TEMPERATURE TREND



All of our AMP8 priority sites show the same increasing trend for maximum and 95%ile raw water temperature. With the exception of Langford and Hanningfield in our ESW region, sites also show an increasing trend in minimum raw water temperature.

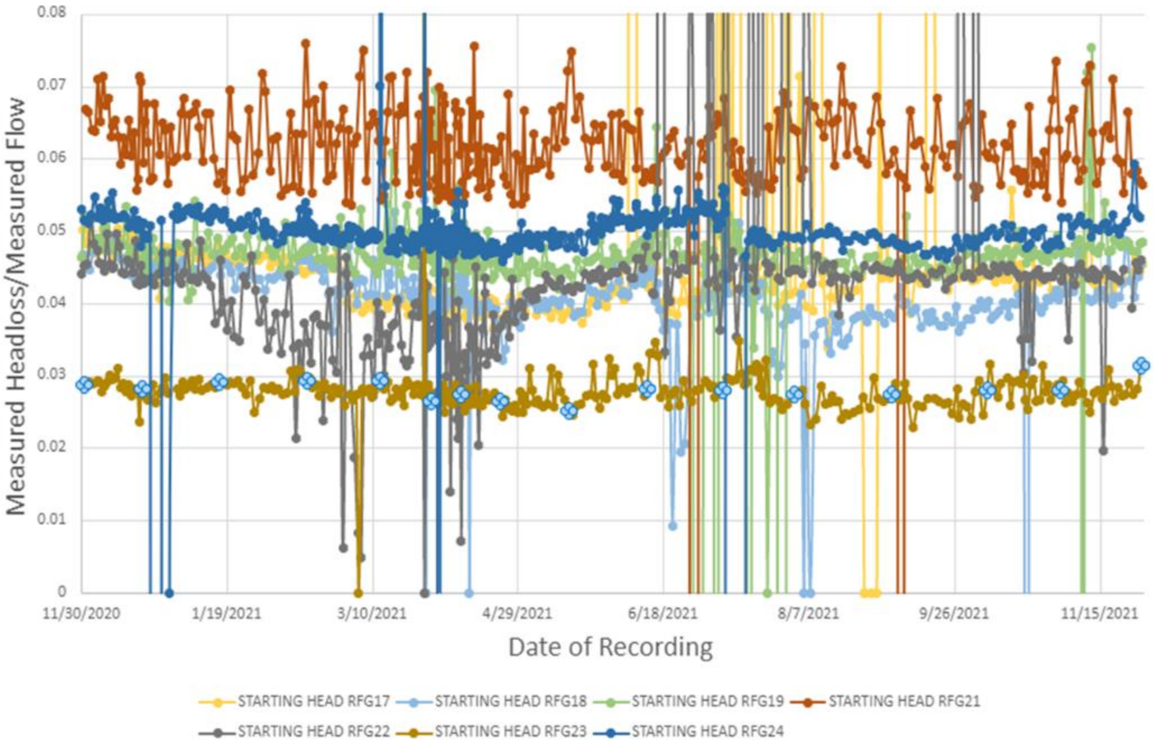
Figure 16 illustrates some of the consequences of the limitations on RGF backwash at our priority sites. The image on the left shows RGFs at Fonburn during a backwash cycle with quiescent areas at the side of the filter indicative of inadequate backwash rates. The image on the right shows an RGF at Langford WTW, post-backwash, with evidence of high turbidity caused by inadequate backwash capacity, resulting in turbidity spikes on return to service.

FIGURE 16: FONTBURN RGF – DEADSPOTS DURING BACKWASH

Figure 17 shows the performance of all filters in Bank 3 at Hanningfield WTW. The data shows normalised starting filter headloss following a wash cycle for each filter, illustrating the difference in backwash efficacy both between subsequent washes in the same filter, and across seven individual filters. Each data point is taken 30 minutes after the start of each filter run, plotted over time and normalised for flow. The variability in starting bed headloss and filter media condition translates to uncertainty in how long a filter can be run before the risk of breakthrough increases. This leads to:

- uncertainty in treatment plant capability and output;
- reduced output due to operational intervention required to run the plant within safe boundaries to protect water quality;
- remaining risk of unwholesome water as performance can be unpredictable; and
- reduced resilience to raw water quality events (e.g. algal events).

FIGURE 17: HANNINGFIELD WTW – NORMALISED FILTER HEADLOSS AFTER BACKWASH CYCLE



As our climate change analysis and site data show, raw water temperatures are already increasing and are predicted to continue to rise. We need to invest in enhancing our priority RGF processes at our critical WTW sites in AMP8. To maintain resilient RGF backwash at these sites we need to:

- Significantly increase backwash rates and modify the filter structures to increase the distance between the top of the filter media and the launder position, thus allowing optimum bed expansion without loss of filter media.
- Ensure increased washwater volumes can be appropriately treated and recovered without impact on site performance.
- Optimise backwash control such that each filter bed can be returned to a clean condition after each wash. This will require upgrades to the position of the filter launders, enhanced launder design, modified filter floors, new backwash and air scour systems and enhanced wash water treatment systems.

2.7. BASE VS ENHANCEMENT

Table 17: sets out the rationale for base and enhancement included in the case. We have excluded all base expenditure from this investment case.

TABLE 17: SUMMARY OF BASE VS ENHANCEMENT RATIONALE

Base	Enhancement
Refurbishment of assets • No refurbishment of existing assets included in the scope **Factors inside our control** • Investment driven by need for resilience to climate change risk	**New assets/equipment providing a greater level of protection** • Sodium Hypochlorite chilling/mixing and enhanced storage & control • SSF DO monitoring and Run-to-waste facility to enhance filter performance and increase resilience to DO depletion • RGF backwash enhancements to provide resilience to the impact of rising temperature and filter design limitations on backwash performance **Factors outside of our control** • Increasing raw water and ambient temperatures and increased sunlight intensity caused by climate change, accelerating both DO depletion in slow sand filters, reduction in backwash efficacy in RGFs and formation of Chlorate in Hypochlorite chemical storage

We also note that South West Water was funded under enhancement at PR19 for replacement of Knapp Mill and Alderney WTW[21]. Both are slow sand filter sites that were deemed to require enhancement intervention following water quality and taste and odour incidents.

2.7.1 Factors outside our control

Climate change trends, evidenced by the climate scenario modelling outputs are outside the control of water and wastewater companies. When our water treatment processes are impacted, whether because of significant high-intensity events such as heatwaves, or simply driven by a steady incremental increase in raw water or ambient temperatures, our customers are at greater risk of experiencing an impact on service. As temperatures rise in line with predictions, customers want us to invest to ensure climate impacts are mitigated (see 2.8).

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[21] PR19 final determinations: South West Water final determination, December 2019 (Ofwat.gov.uk)

2.8. CUSTOMER SUPPORT

Water quality is the highest priority for customers, and they expect us to continue to meet their expectations on this in the face of increasing risks from climate change. We asked our customers about the specific risks from climate change, and the solutions (installing refrigeration to stabilise liquid chlorine, and improve slow sand filters to reduce downtime) in our “pre-acceptability” research in February 2023. This included asking when we should carry out this work and discussing the risks of reducing water quality if we do not carry out this work.

We estimated that this work would cost around £2 on the average water bill in the North East and £3 in Essex and Suffolk, and asked customers if we should start this work in 2025 or 2030.

Our customers have mixed views on adaptation to climate change, with younger customers and customers in our Essex & Suffolk Water area being more supportive of investment in this area (**enhancements and other service area summaries**, NES43).

These mixed views continued through the development of our business plan. In our qualitative affordability and acceptability testing, many felt this was important to avoid future issues and protect future generations. Others questioned if the investment was required, or if other investments would do enough to protect water supplies and quality anyway – and how much impact climate change would have in the UK. The majority of respondents in Essex and Suffolk, and around half of respondents in the North East, selected the “medium” phasing option (used in our business plan).

Some customers wanted a higher phasing option, with a perception that investment in this area was happening too late.

We developed our plan for climate change adaptation by looking at where:

1. There was a high likelihood that climate change would have an impact on our services in the short or medium term (under any future climate change scenario).
2. This is likely to have an immediate impact on services – in our customer research, we identified supply interruptions from water treatment works and pollution incidents from sewage pumping stations as two of the key areas.

We set these criteria in line with customer views, as they wanted to be sure that the investment was really needed and that we could be confident that the impact of climate change would mean increased risks to services (see our **line-of-sight document**, NES45, on climate change adaptation).

In our pre-acceptability testing, customers preferred a business plan package that included these investments, saying that this was not a high bill increase compared to the “must do” statutory requirements. However, they remained concerned about affordability of all of our enhancement and service packages. When asked specifically about these enhancement items, the majority of customers in these groups thought that we should invest in these issues now. This is consistent with previous discussions about resilience and climate change adaptation, where customers have told us they want to invest now if there are immediate service impacts or risks.

We therefore included this enhancement case in our affordability and acceptability testing, drawing out this (alongside our flooding and power climate change resilience case) as a specific item to discuss with customers.

In our qualitative affordability and acceptability testing (NES49), our customers supported our “medium” option (as included in our business plan). This includes investments in flooding and power resilience, as well as process enhancements for water treatment to address specific heat risks that are already happening now.

We considered if we should go further on tackling the impacts of heat. We asked our customers about higher investment in 2025-30, to tackle potential future risks – for example, addressing algae growth which can have impacts on water quality, filter performance, and sludge systems at water treatment works. We said that these were less certain, and that we did not think these effects would be seen in the next few years. Some customers did support these investments, but as there were mixed views, we have not included these in our plans for 2025-30.

Most of the effects from increasing temperatures are not likely to be seen in the next few years, particularly where these are effects that build over a long time from higher temperatures (rather than being as a result of a short period of unusually high temperatures). These forecasts also vary considerably, with lower climate change scenarios not necessarily requiring so much work and the potential for updated climate change assessments to indicate a different risk profile. There are likely to be further unknown mitigations that might reduce the impacts across the wider system, such as: reducing abstraction and restoring river flow; improving river water quality; or improvements in technology. The Water Forum noted that long-term climate change scenarios still had considerable uncertainty and described for example the impact of possible shifts in the Gulf Stream.

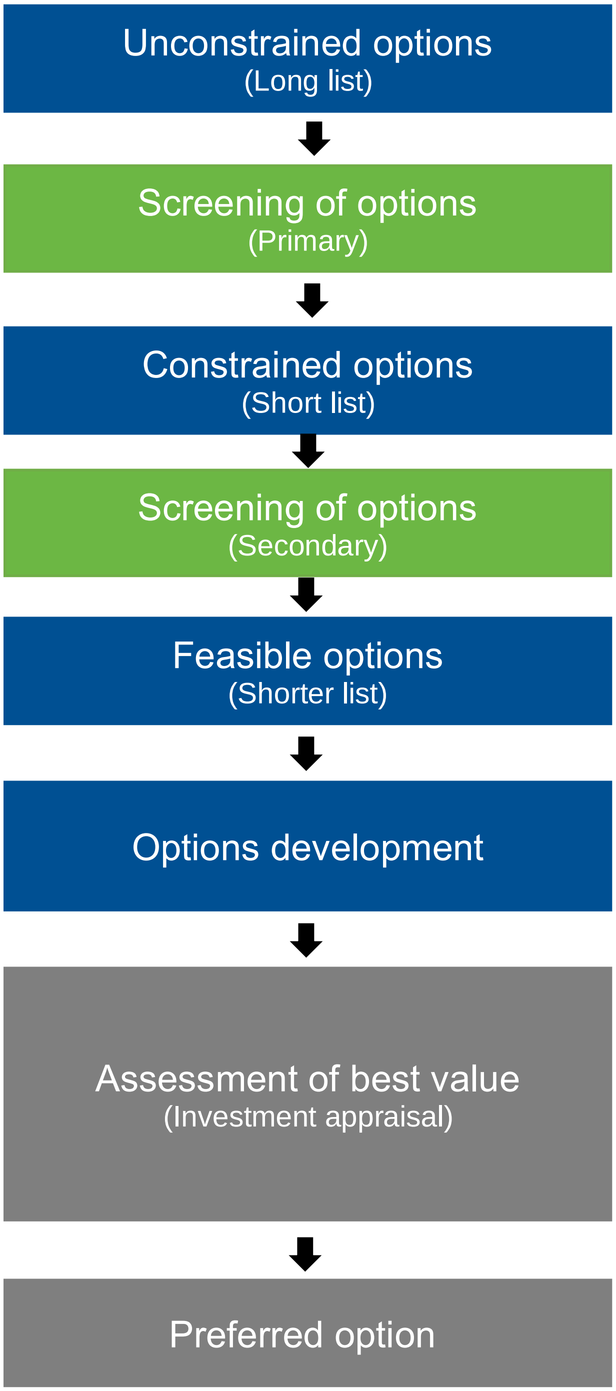
This uncertainty suggests that a large investment programme to tackle increases in heat during 2025-30 is not necessary – we have too much uncertainty about the threats from climate change; we do not yet know what specific mitigations would be required; and there has been limited focus on technology to tackle the wider impacts of increasing temperatures on water and wastewater networks. Instead, we will need to focus on understanding these threats and the potential mitigations that will be required, as well as strengthening our innovation focus on this issue. Our appendix A8 – resilience (NES09) looks at the impacts of different climate risks in more detail, including heat and raw water quality.

3. BEST OPTION FOR CUSTOMERS

3.1. OPTIONEERING APROACH

To determine the best option for customers to address the need, we followed an options identification and screening process as outlined in Figure 18. The first step identified an unconstrained long list of options which we reviewed in a ‘Primary Screening’) exercise to determine whether the options were technically feasible to implement, and capable of addressing the Need. The resulting short list was subject to a ‘Secondary Screening’ to define a list of feasible options. These were developed by a team of process engineers to define a scope to allow cost estimation and cost-benefit analysis.

FIGURE 18: OUR OPTIONEERING PROCESS



Unconstrained list of options (Section 3.2)

We have developed a range of options to address the Hypochlorite degradation, slow sand filter DO depletion and RGF backwash risks. Options were identified using a Totex hierarchy approach and based on our understanding of the nature and scale of the risks, issues and opportunities.

Constrained list of options (Section 3.2)

To identify a constrained list of feasible options capable of meeting the need, we have screened the unconstrained list of options against two criteria:
1) Technically feasibility, and
2) Degree of resilience provided to address the risk of rising temperatures and increased frequency and intensity of heatwave weather patterns.

Options development (Section 3.3)

We have developed engineering scopes for the short-listed options to allow costing in our iMOD system.

Assessment of best value (Section 3.3)

We have undertaken an assessment of costs and benefits for each option to identify which is considered best value.

We have also assessed each option against the Wider Environmental Outcomes Metrics and a deliverability assessment as part of our benefits assessment.

Preferred option (Section 3.3.2)

We have identified preferred options based on the outcomes of the best value assessment to maximise value for customers while achieving the resilience required to protect future water supply in the face of rising temperatures.

3.2. RANGE OF OPTIONS

We have developed a broad range of options categorised according to the 4Rs of resilience:

- Resistance – prevent disruption by providing measures to resist the impacts of climate change on our operations and mitigate any impact on our WTWs.
- Reliability – solutions designed to ensure our assets have the capacity and capability to address the risks posed by climate change.
- Redundancy - provide backup measures that can be implemented during periods when climate change impacts are most intensive to ensure continuity of service.
- Response and recovery – Fast and effective response to, or recovery from, disruptive events caused by climate change impacts.

We developed an unconstrained long list of options for each need through a series of workshops involving Stantec process scientists and engineers, and our asset management and operational colleagues. In line with our Totex Hierarchy approach, and in addition to the 4 Rs of resilience, we categorised options as follows:

- Eliminate - identification of processes or practices that eliminate the need indirectly. In this case, the cause of the resilience risk is rising temperature which is beyond our control. Therefore, options to mitigate the risk are limited to those we can implement on-site to counter the effects of rising temperature on our water treatment processes.
- Collaborate - working with stakeholders to share costs and realise a broad range of benefits for all parties.
- Operate – improving our operational management practices to reduce the impact of increasing temperatures on our treatment processes. This includes installation of DO monitoring on our slow sand filter sites to inform operational decisions and optimisation of skim frequency to mitigate DO depletion risk.
- Invigorate – enhancing existing assets to improve performance, these include options to provide an increased level of benefit but perhaps at a lower cost than fabricate options. In this case, options include addition of chemical chilling to address Chlorate formation risk, enhancement of RGF backwash capacity and addition of run-to-waste facilities on our slow sand filter sites to allow more frequent bed washing and ripening without impacting water quality.
- Fabricate - investing in new assets to augment or replace existing to meet the need. These options are likely to have the highest costs. Green options will have lower carbon and potentially higher biodiversity and amenity benefits. Traditional grey options are likely to have highest certainty that service-related benefits will be realised. In this case, we have considered options to replace our priority RGF and slow sand filter process with alternative treatment, as well as covering slow sand filter beds to eliminate exposure to sunlight.

The Totex Hierarchy for each risk is shown below in Figure 19, Figure 20 and Figure 21.

FIGURE 19: TOTEX HIERARCHY FOR HYPOCHLORITE DEGRADATION RISK

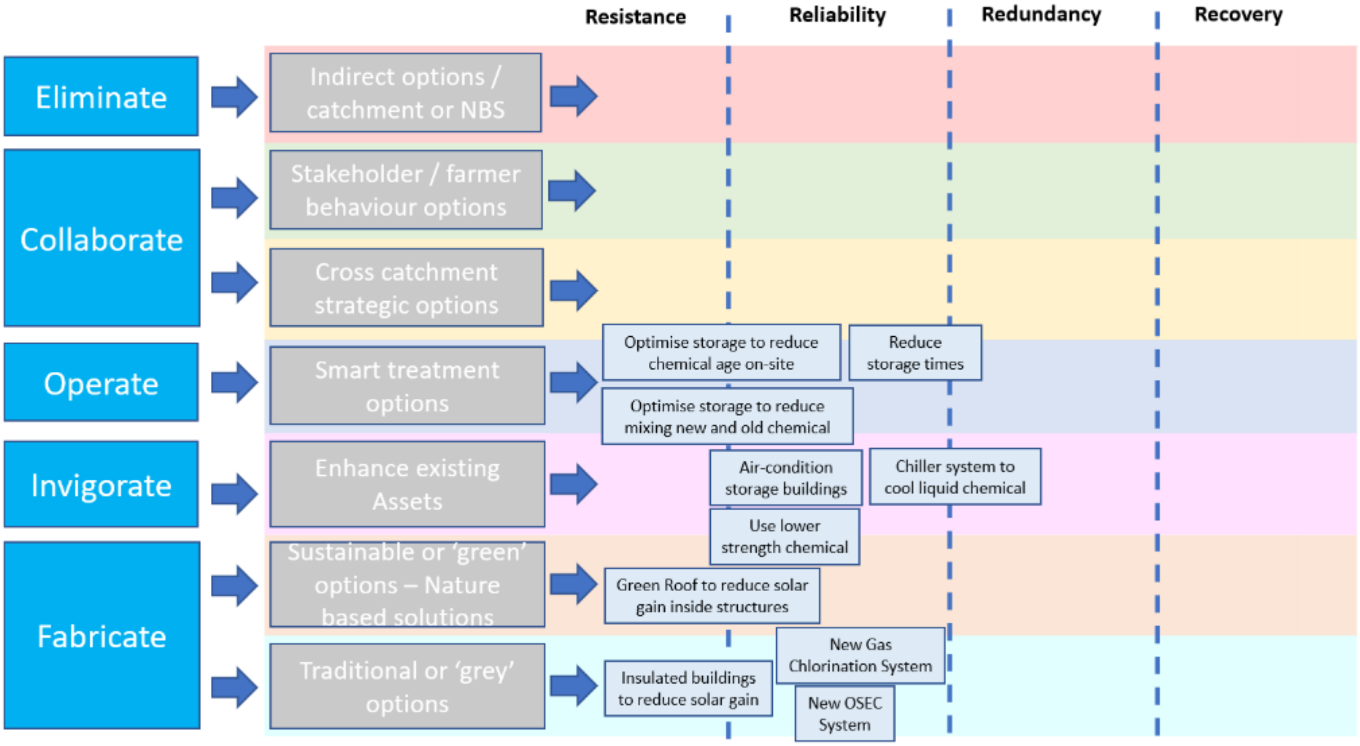


FIGURE 20: TOTEX HIERARCHY FOR SLOW SAND FILTER D.O. DEPLETION RISK

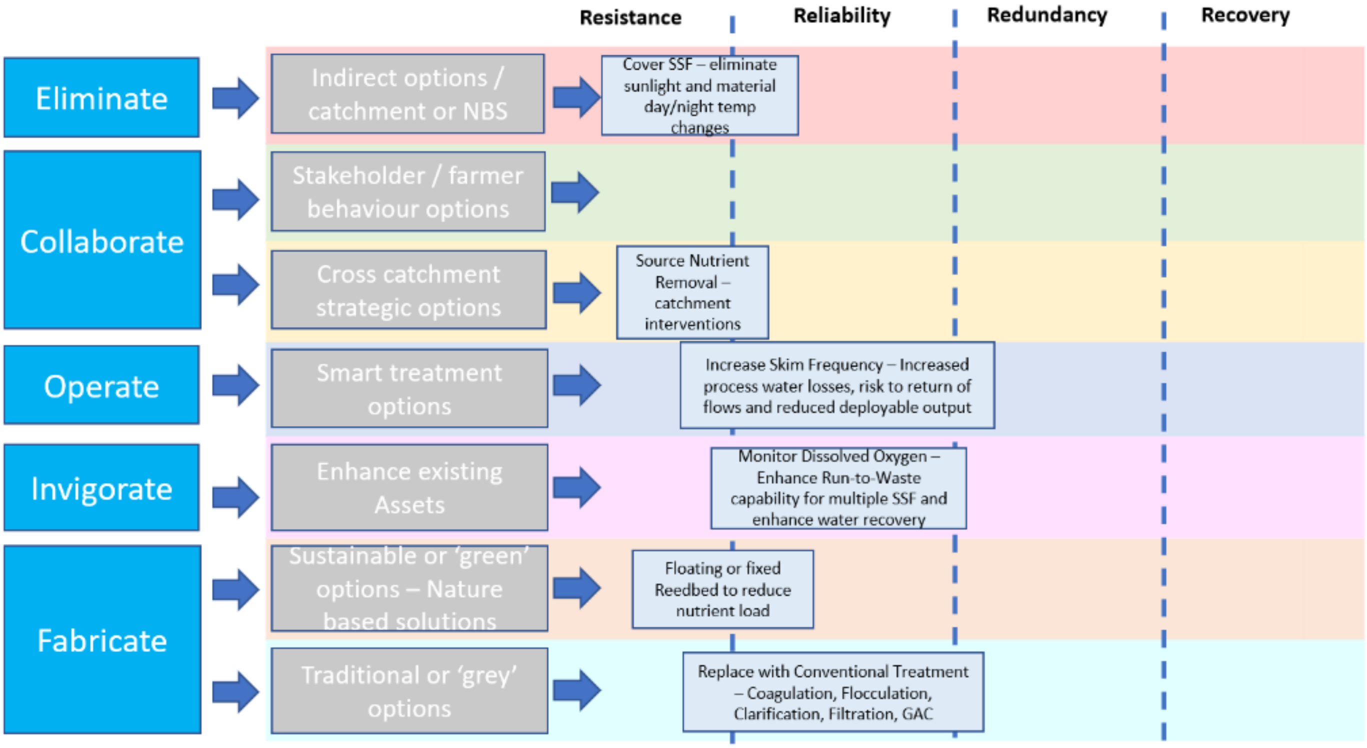
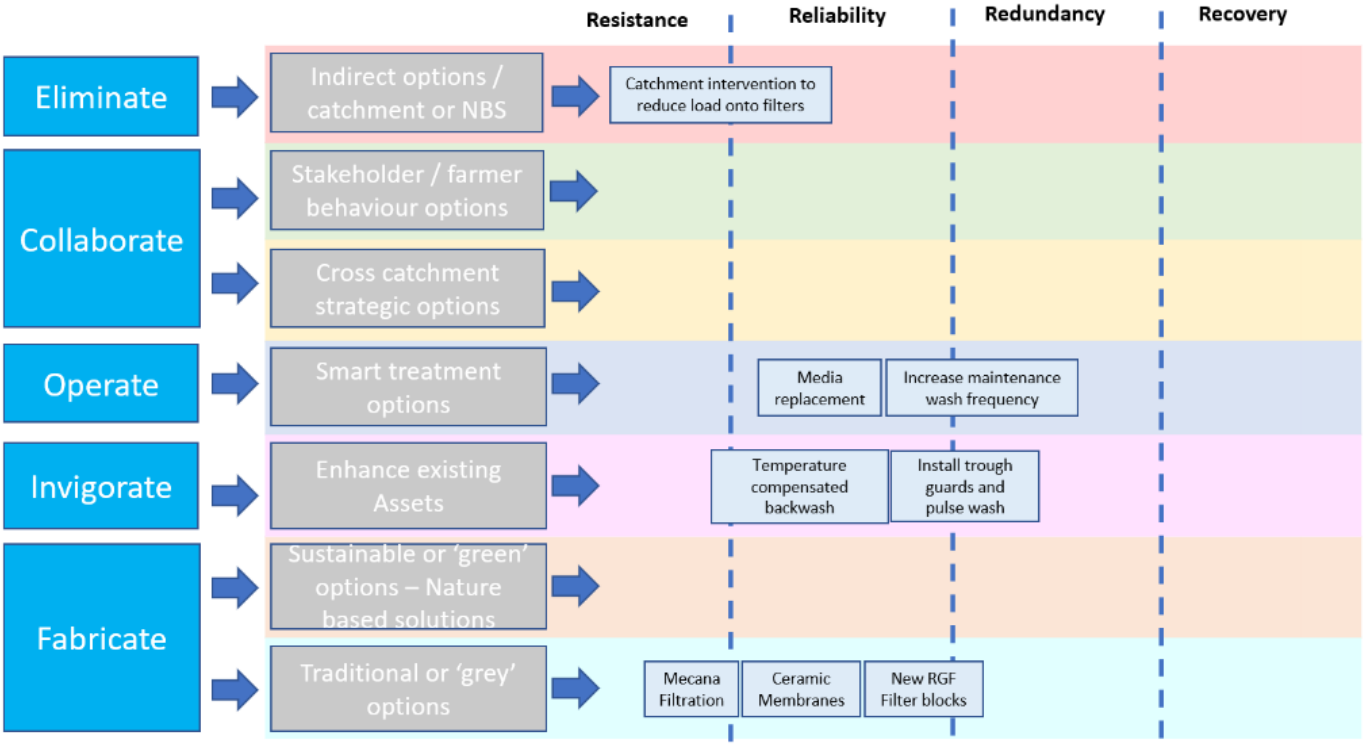


FIGURE 21: TOTEX HIERARCHY FOR RAPID GRAVITY FILTER BACKWASH DETERIORATION RISK



3.2.1 Hypochlorite degradation options

Based on the unconstrained list reflected in the Totex Hierarchy, we screened each option for technical feasibility and risk mitigation. A summary of the screening output is shown in Table 18 below. The options carried forward for further solution development and cost-benefit analysis are highlighted in green.

TABLE 18: OPTIONS SCREENING – HYPOCHLORITE DEGRADATION

Totex Hierarchy	Options		Technically Feasible	Addresses the risk in AMP8	Primary Screening Outcome	Resilience Approach
Operate	1	Reduce chemical storage times	Yes	No	Rejected: While technically feasible, reduced chemical storage times would have a material impact on the logistics and cost of chemical delivery. It would also reduce resilience, as smaller volumes of chemical would be held on site.	Reliability
	2	Optimise storage to reduce mixing of new and old chemical	Yes	No	Rejected: separate storage tanks to segregate different chemical deliveries would have some benefit in preventing the mixing of fresh chemical with older chemical with a higher Chlorate	Resistance

					content but would not address the degradation risk.	
Invigorate	3	Air condition storage buildings	No	No	Rejected: Air conditioning would be required to cool a significant internal area	Reliability
	4	Chiller system to cool liquid chemical	Yes	Yes	Carried Forward: addition of chilling units would allow direct cooling of the chemical and address the risk of accelerated degradation in higher temperatures	Reliability
	5	Use lower strength chemical	Yes (small sites only)	Yes (small sites only)	Carried Forward: Switch from 15% to 10% Hypochlorite chemical for small sites where dose rates are limited. Upsized storage and dosing pumps required	Resistance
Fabricate	13	Green roof to reduce solar gain inside storage buildings	No	No	Rejected: Existing storage buildings not suitable for retrofit of green roof. Limited impact in high temperature/heatwave conditions.	Resistance
	14	Upsize Gas chlorination system	Yes (sites with existing Gas dosing)	Yes (sites with existing Gas dosing)	Carried Forward: For larger WTWs with existing Gas dosing systems, upsizing the capacity to offset the need for liquid Hypochlorite dosing would address the risk.	Reliability
	15	New OSEC system	Yes	Yes	Rejected: Technically feasible but would introduce new risks associated with containment, security and safe operation. Would fall under SEMD, requiring a self-contained (possibly fortified) building.	Reliability

Development of screened options was carried out by Stantec process engineers in line with our optioneering process. Further details of the principles, scope and benefits of the 3 options taken forward are set out below in Table 19.

TABLE 19: OPTIONS SHORTLIST – HYPOCHLORITE DEGRADATION

Option	Scope	Benefits
Chiller system to cool liquid chemical	• Chemical tanks with mixing and refrigeration/chilling units. • Analysers and Scada interface • Pipework and lagging to maintain temperature • Options considered for:	• Addresses risk of chemical heating and therefore minimises rate of Chlorate formation and maximises storage time • Chiller units directly maintain low chemical temperatures and are therefore an efficient solution compared to maintaining low temperatures within a building

Use lower strength chemical	• Applicable only at smaller Network Booster sites where storage and dosing requirements are minimal, and risk can be mitigated through dosing increased volumes of 10% Hypochlorite • Additional chemical storage capacity and larger dosing pumps to facilitate a switch from 15% to 10% Hypochlorite chemical. • Analysers and chemical mixing	• No refrigeration required due to lower rate at which 10% Hypo degrades
Upsize Gas chlorination system	• Applicable only at larger sites with both Gas and Liquid systems, where Gas capacity could be increased to eliminate use of liquid Hypochlorite • Install additional Gas disinfection system	• Eliminates the Chlorate formation risk associated with liquid dosing at sites with existing Gas dosing capacity

In the case of the Hypochlorite risk, not all of the options listed above can be applied to all of the 44 dosing points on our list of risk sites. For example, moving to 10% Hypochlorite dosing is only viable at smaller sites, and upsizing gas chlorination systems is only an option for sites with existing gas dosing capacity. Therefore, further workshops were carried out to establish a range of investment options that would address the risk based on appropriate combinations of options for different sites. These are shown in Table 20 below:

TABLE 20: INVESTMENT OPTIONS DERIVED FROM OPTIONS SHORTLIST – HYPOCHLORITE DEGRADATION

Option	Scope
1	• Installation of chilling systems at 44 dosing points
2	• Installation of chilling systems at 35 dosing points • Switch to 10% Hypochlorite at 9 Network Booster dosing points (9 of the 12 Booster sites identified)
3	• Increase capacity of Gas disinfection at 9 dosing points (where sites have existing Gas systems) • Installation of chilling systems at 26 dosing points • Switch to 10% Hypochlorite at 9 Network Booster dosing points

3.2.2 Slow sand filter DO depletion options

Based on the unconstrained options list, we screened each slow sand filter option for technical feasibility and risk mitigation. The output of the screening in Table 21 below. The options carried forward for further solution development and cost-benefit analysis are highlighted in green.

TABLE 21: OPTIONS SCREENING – SLOW SAND FILTER DO DEPLETION

Totex Hierarchy	Options		Technically Feasible	Addresses the risk in AMP8	Primary Screening Outcome	Resilience Approach
Eliminate	1	Cover slow sand filter beds to eliminate sunlight and reduce temperature impacts	Yes	Yes	Carried Forward: Technically feasible to house filters within a building and would be highly effective in mitigating the risk through eliminating the effects of sunlight on blanket weed growth and temperature.	Resistance
Collaborate	2	Source Nutrient Removal	No	No	Rejected: Level of achievable benefit is uncertain and unlikely to be delivered before AMP10. Solution may limit blanket weed growth but does not allow increased bed skimming.	Resistance
Operate	3	Increase SSF skim frequency	Yes	No	Rejected: Existing units not designed to support skimming at the frequency required to mitigate the risk. Return flows would have material impact on process performance. Significant reduction in deployable output would be required to manage water quality risks.	Reliability
Invigorate	4	Enhance existing assets. DO monitoring and enhanced Run-to-waste capability	Yes	Yes	Carried Forward: DO monitoring would inform optimisation of skim frequency and Run-To-Waste capability would allow increased skimming without causing a process impact.	Reliability
Fabricate	5	Reedbed or alternative NBS to reduce nutrient load	Yes	No	Rejected: Level of achievable benefit is uncertain. Solution may limit blanket weed growth but does not allow increased bed skimming.	Resistance
	6	Build alternative treatment process to replace SSF	Yes	Yes	Carried Forward: Both technically feasible and effective in addressing the risk. Capex, Opex and Carbon costs likely to be high. Solution would require coagulation, flocculation, clarification, filtration and possibly GAC for some sites.	Reliability

Development of screened options was carried out by Stantec process engineers in line with our optioneering process. Further details of the principles, scope and benefits of the 3 options taken forward are set out below in Table 22:

TABLE 22: OPTIONS SHORTLIST – SLOW SAND FILTER DO DEPLETION

Option	Scope	Benefits
Cover slow sand filter beds to eliminate sunlight and reduce temperature impacts	• Construction of a building or canopy structure to house the slow sand filter beds. • Access and lighting • Would require initial pilot to establish the operational benefits and appropriate skim frequencies	• Exclusion of sunlight would effectively prevent in situ growth of algae and blanket weed but would not protect against river or reservoir algae that may pass through the upstream process • Some protection from extremes of temperature • Protection from wildlife contamination
Enhance existing assets. DO monitoring and enhanced Run-to-waste capability	• Continuous DO monitors installed on individual slow sand filter beds and pre-disinfection sampling point. • Monitors linked to alarms to flag when combined outlet flow from the slow sand filters <5mg/l DO and when individual filters drop below 3 mg/l as a minimum trigger level. • Run-to-waste facilities of sufficient capacity to allow multiple filter beds to be skimmed and ripened in succession	• DO monitoring allows operations to mitigate by increasing filtration rate or scheduling beds for skimming • Run-to-waste supports increased filter health through frequent skimming with waste returned to the head of the site to mitigate water quality impacts
Build alternative treatment process to replace SSF	• New or increased capacity for coagulation, flocculation, clarification and filtration processes. • Some sites would require additional GAC	• Modern treatment process would mitigate climate and process risks • This option has been implemented by other water companies following water quality incidents at slow sand filter sites – e.g. Thames Walton WTW. South West Water was funded under enhancement in AMP7 for replacement of Knapp Mill and Alderney WTW.

3.2.3 Rapid Gravity Filter backwash options

Based on the unconstrained list reflected in the Totex Hierarchy, we screened each RGF option for technical feasibility and risk mitigation. A summary of the screening output is shown in Table 29 below.

The options carried forward for further solution development and cost-benefit analysis are highlighted in green.

TABLE 23: OPTIONS SCREENING – FILTER BACKWASH DEGRADATION

Totex Hierarchy	Options		Technically Feasible	Addresses the risk in AMP8	Primary Screening Outcome	Resilience Approach
Eliminate / Collaborate	1	Catchment management	Limited	No	Rejected: While raw water improvements may have a marginal benefit in reducing the requirement for backwashing, this option does not address the root cause of the risk	Resistance
Operate	2	Replace media	Yes	No	Rejected: While technically feasible, replacing media is a short-term fix which would recover performance for a short period only (~ six months) and would result in outage due to media cleaning on replacement. It would not address the root cause.	Reliability
	3	Maintenance washes	Yes	No	Rejected: Technically feasible, but a short-term partial fix. It would only have any benefit if a short collapse pulse wash was viable, which is not the case for the sites assessed. Significant risk of excessive media loss due to filter design.	Reliability
Invigorate	4	Temperature Compensated Backwash	Yes	Yes	Carried Forward: Enhancement of existing assets to enable climate change proof temperature-compensated backwash	Reliability
	5	Trough guards and pulse wash	Yes	Yes	Carried Forward: Enhancement of existing assets including novel media, trough guards and enhanced or prolonged collapse pulse washes that reduce water losses while sustaining climate change proof temperature compensated backwash	Reliability
Fabricate	6	New filter blocks	Yes	No	Carried Forward: While the cost of the programme is significant, it involves less operational risk during the construction phase than enhancing existing assets as new units would be built offline.	Reliability
	7	Ceramic membranes	No	Yes	Rejected: Prohibitive cost and programme	Reliability
	8	Mecana	Yes	No	Rejected: Mecana filtration. Doesn't address the root cause, only mitigates individual raw water issues such as algal blooms.	Reliability

Development of screened options was carried out by Stantec process engineers in line with our optioneering process. Further details of the principles, scope and benefits of the 3 options taken forward are set out below in Table 24:

TABLE 24: OPTIONS SHORTLIST – FILTER BACKWASH DEGREDATION

Option	Scope	Benefits
Invigorate Existing Assets	• Review media • Enhance launders • Consider trough guards • Upgrade backwash • Upgrade air scour • Incorporate collapse pulse • Incorporate new floors where existing filter shell & floors leave insufficient room to adequately backwash • Upgrade clean washwater tanks • Upgrade washwater treatment – where required.	• Climate change proof – temperature compensated backwash • Sustainable – low water loss backwash • Assure deployable output • Assure treated water quality on filter return to service • Reduce risk of unwholesome water going into supply • Reduce CRI and ERI risk • Enhance resilience
Fabricate New Assets	• Build New Filter Block which can be backwashed sustainably • Include slow start and delayed start, filter to waste as required.	• Climate change proof – temperature compensated backwash • Sustainable – low water loss backwash • Assure deployable output • Assure treated water quality on filter return to service • Reduce risk of unwholesome water going into supply • Reduce CRI and ERI risk • Assets are built off-line and commissioned without risk to existing supply.

3.3. BEST VALUE

3.3.1 Benefit Scoring

For each option carried forward to this stage we have completed a benefits assessment using our Value Framework which contains a wide range of benefits which reflect measures that relate to performance commitments or other social and environmental values. Our Value Framework is embedded into our portfolio optimisation tool, Copperleaf. Table 25 shows the range of benefits (value measures), including their quantification and monetisation values, we have used for the assessment of the shortlisted options. These include improved water aesthetics, unplanned outage and carbon emissions.

For the benefits assessment, first we score the impact of continuing business as usual and then we score each of the relevant options. Benefits are scored over time for a 30-year time horizon. This scoring considers the certainty of benefits being realised for different types of options.

TABLE 25: VALUE MEASURES APPLIED TO CLIMATE CHANGE RESILIENCE OPTIONS

Value measures	Description	Unit	Value	Performance Commitment
Improved Water Aesthetics	Cost of improving appearance, taste and smell of water	£/Number of Customer Contacts (Banded)	£41,766[22] £6,661[23]	Yes
Reduced Unplanned Outage	Cost of reducing the number of unplanned outages	£/Ml	Non-monetised	
CRI Score	Reduction of instances of Drinking Water Inspectorate (DWI) noncompliance	CRI Score	Non-monetised	
Water Quality Compliance	Number of water quality non-compliance events	£/Non-compliance event	£5,770[24]	
Operational Emissions	tCO_2e / year	tCO_2e	£256.20[25]	Yes
Embedded Emissions	tCO_2e / year	tCO_2e	£256.20[22]	Yes

We have assessed the benefit of our short-listed options to address our need to prevent sodium hypochlorite degradation by using our CRI Score value measure. To do this, we have assumed that the short-listed options will be 100% effective from date of commissioning as they are engineered interventions. This has meant that we assumed that the frequency of water quality events relating to sodium hypochlorite risk will drop to zero following intervention. As a result, the short-listed options are expected to deliver the same benefit at each site, in terms of reduced risk of sodium hypochlorite degradation. Therefore, the differentiator between options will be option cost.

We have assessed the benefit of our short-listed options to address our need to reduce DO reduction in SSFs by using our Embedded Emissions and Operational Emissions value measures. These have helped us to determine that the 'Enhance existing assets' options will result in the least amount of embodied carbon emissions at the majority of sites, between 212-344 tCO_2e, except at Lound WTW where the least amount of embodied carbon is associated with the option to 'Build alternative treatment process to replace SSF' (161 tCO_2e). These same options also have the lowest whole life carbon emissions, over a 30-year time period.

To measure the benefit of the RGF short-listed options, we have focused on the benefit of having an enhanced filter backwash which will reduce the risk of solids breakthrough and associated water quality risks. We know that the short-listed options will deliver benefits beyond this, however as the enhanced backwash is the key element that will address the risk that filter performance will not recover after cleaning and lead to solids breakthrough, we have focused our benefits

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[22] £ value for appearance category with 0-1000 customers affected.
[23] £ value for smell category with 0-1000 customers affected.

[24] £ value for PVC failure category for turbidity.
[25] £ value per tonne of CO_2e in 2025/26, annual increase (varying rate) reaching £378.6/t CO2e in 2054/55.

assessment on this element. We have also applied all the value measures in Table 25 to assess benefits. To do this, we have assumed that the short-listed options will be 100% effective from date of commissioning as they are engineered interventions. This has meant that we have made the assumptions that the frequency of water quality events caused by lack of adequate backwash will drop to zero, in our CRI Score and Water Quality Compliance value measures, and that the frequency of unplanned outage events related to backwash deficiencies will drop to zero, in our Reduced Unplanned Outage value measure. As a result, both options are expected to deliver the same benefit at each site, in terms of reduced risk. Therefore, the differentiator between options will be option cost.

3.3.2 Cost benefit appraisal to select preferred option

For each of the feasible options we have undertaken a robust cost benefit appraisal within our portfolio optimisation tool to select the preferred option. This calculates an NPV over 30 years, in accordance with the PR24 Guidance, and the cost to benefit ratio for each option. The ratio is calculated by dividing the present value of the profile of benefits by the present value of the profile of costs over the appraisal period of 30 years.

Costs and benefits have been adjusted to 2022-23 prices using the CPIH[26] Index financial year average. The impact of financing is included in the benefit to cost ratio calculation. Capital expenditure has been converted to a stream of annual costs, where the annual cost is made up of depreciation/RCV run-off costs and allowed returns over the life of the assets. Depreciation (or run-off) costs are calculated using the straight-line depreciation over the appraisal period. To discount the benefits and costs over time, we have used the social time preference rate as set out in 'The Green Book'.

The NPVs generated by our portfolio optimisation tool are included in Table 26. For our need to prevent hypochlorite degradation at multiple sites, there is a marginal difference in NPV between 2 of the options: installing chilling at 44 priority sites, and the alternative to install chilling at 35 of the 44 priority sites with an alternative approach for the 9 water pumping sites. Under this option, the 9 WPS are converted to use a lower concentration 10% Hypochlorite solution, instead of the higher concentration 15% solution currently utilised. While this reduces the Chlorate formation risk at the 9 sites, there is an additional Opex impact related to the more frequent chemical deliveries required to achieve the same water quality requirements when using the 10% solution. We have therefore opted for the solution to install chilling at all 44 sites.

For our need to address SSF DO depletion at five sites, the option expected to deliver the greatest benefit in all cases is the option to ‘enhance existing assets’. This is reflected in this option having the highest NPV (Table 26). These NPVs have been driven by the low carbon emissions of all the short-listed options, as discussed in Section 3.3.1, and lower costs associated with this option at each site. Therefore, our preferred option is to ‘enhance existing assets’ at the five sites, which will include DO monitoring and enhanced run-to-waste capability, in order to address SSF DO depletion and make our WTWs more resilient.

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[26] Consumer Prices Index including owner occupiers’ housing costs.

For our need to address RGF backwash at six sites, the option expected to deliver the greatest benefit in nearly all cases is the option to ‘invigorate existing assets’. This is reflected in this option having the highest NPV (Table 26). The exceptions are Fontburn WTW, where the greatest value (and therefore lowest NPV) is associated with the option to ‘fabricate new assets’, and Langford WTW, where the difference between the 2 options is very marginal. While the cost-differential between enhancing the existing assets and replacing the RGFs is significant for all other sites, Fontburn and Langford are the smallest of our priority RGF sites. As such, Fontburn’s yardstick of 19 Ml/d is below the normal range of the RGF cost model curve and therefore subject to more uncertainty and potential under-estimation. We believe it is highly unlikely that an RGF rebuild would be cheaper to construct or more cost-effective, and therefore our preferred option at all 6 sites, is to install temperature-controlled pulse-backwash and trough guards to prevent media loss. We believe this to be the more cost-efficient solution to address our RGF backwash need and make our WTWs more resilient.

The NPV for all options in Table 26 are negative – and in this case, we would normally not move ahead with these investments. However, we have concluded that we should still carry out this work because:

- Unplanned outage is not monetised in the benefits, because the impact is only seen in relatively rare high temperature events - but in the circumstances of high temperatures, we could see outages at all of these treatment works at once. This would be unacceptable, as customers and regulators expect us to maintain supplies even in the event of extreme weather – particularly when water is needed most to mitigate the impact of high temperatures.
- We could not capture this risk in our Copperleaf system, or the risk to public health of losing water supplies during hot weather periods. This system is new, and we are continuing to refine our value models to be able to capture risk.
- We have not been able to forecast a “tipping point” for high temperatures, or reliably measure the exact impact of different climate scenarios on these risks. This is still uncertain in the climate data, and so these risks are difficult to score. This investment is about addressing future risk in the event of increasing temperatures – and so the short-term benefits we could measure in the NPV are likely to increase greatly in the future in the face of this risk.

TABLE 26: NET PRESENT VALUE FOR ALL SHORT-LISTED OPTIONS

Risk	Site	Option	Net Present Value (30 years) (£)	Type of Option
Hypochlorite degradation	Multiple	Chiller system to cool liquid chemical (44 sites)	-28.396m	Preferred
		Chilling at 35 sites, convert to use lower strength 10% chemical at 9 WPS	-28.572m	Alternative
		Upsize gas chlorination system at 9 dosing points on sites with existing Gas systems. Chilling at 28 sites, convert to 10% at 9 WPS	-37.815m	Alternative
	Chigwell	Cover slow sand filter beds to eliminate sunlight and reduce temperature impacts	-62.712m	Alternative

Slow sand filter DO depletion		Enhance existing assets. DO monitoring and enhanced Run-to-waste capability	-2.683m	Preferred
		Build alternative treatment process to replace SSF	-55.908m	Alternative
	Langham	Cover slow sand filter beds to eliminate sunlight and reduce temperature impacts	-26.992m	Alternative
		Enhance existing assets. DO monitoring and enhanced Run-to-waste capability	-2.478m	Preferred
		Build alternative treatment process to replace SSF	-29.081m	Alternative
	Layer	Cover slow sand filter beds to eliminate sunlight and reduce temperature impacts	-66.788m	Alternative
		Enhance existing assets. DO monitoring and enhanced Run-to-waste capability	-3.491m	Preferred
		Build alternative treatment process to replace SSF	-38.693m	Alternative
	Lound	Cover slow sand filter beds to eliminate sunlight and reduce temperature impacts	-8.496m	Alternative
		Enhance existing assets. DO monitoring and enhanced Run-to-waste capability	-2.483m	Preferred
		Build alternative treatment process to replace SSF	-1.896m	Alternative
	Ormesby	Cover slow sand filter beds to eliminate sunlight and reduce temperature impacts	-21.267m	Alternative
		Enhance existing assets. DO monitoring and enhanced Run-to-waste capability	-1.821m	Preferred
		Build alternative treatment process to replace SSF	-8.709m	Alternative
RGF backwash degradation	Broken Scar	Enhance existing assets, upgrade backwash and upsize washwater capacity	-3.764	Preferred
		Build new RGF filter block which can be backwashed sustainably	-18.862	Alternative
	Fontburn	Enhance existing assets, upgrade backwash and upsize washwater capacity	-5.605m	Preferred
		Build new RGF filter block which can be backwashed sustainably	-2.827m	Alternative
	Hanningfield	Enhance existing assets, upgrade backwash and upsize washwater capacity	-9.911m	Preferred
		Build new RGF filter block which can be backwashed sustainably	-19.897m	Alternative

	Langford	Enhance existing assets, upgrade backwash and upsize washwater capacity	-6.498m	Preferred
		Build new RGF filter block which can be backwashed sustainably	-6.310m	Alternative
	Layer	Enhance existing assets, upgrade backwash and upsize washwater capacity	-3.423m	Preferred
		Build new RGF filter block which can be backwashed sustainably	-14.004m	Alternative
	Mosswood	Enhance existing assets, upgrade backwash and upsize washwater capacity	-9.161m	Preferred
		Build new RGF filter block which can be backwashed sustainably	-16.339m	Alternative

3.4. UNCERTAINTY

The solutions we propose are well established technology and known to effectively address the risk. We consider cost uncertainty as part of our cost methodology described in Section 4. Although climate change has some inherent uncertainty, our PR24 business plan is limited to tackling risks that are likely to be immediate and very likely.

3.5. THIRD PARTY FUNDING

We have identified no opportunities for third party funding for the chosen interventions, as these are solutions at treatment works.

3.6. DIRECT PROCUREMENT FOR CUSTOMERS

We assessed these investments against the DPC guidance (see our assessment report, NES38). We noted that they would not pass under the 'size' test, as they have a whole life cost of less than £200m. We considered how this could be bundled together with other improvements at treatment works across our business plan, but these are not discrete investments. We concluded that DPC was not appropriate.

4. COST EFFICIENCY

4.1. NORTHUMBRIAN WATER'S PR24 COSTING METHODOLOGY

To support the enhanced needs identification and optioneering, together with the least cost/best value approach, there has been a significant increase in the quantity of cost estimates required at PR24 when compared to previous price reviews. To support this, as well as maximising the benefit and efficiency of the costing effort, we have used a three-level estimating approach for developing PR24 costs:

- **Level 1** - Using iMOD Express or Costing Tools to develop order of magnitude estimating for rapid optioneering, elimination of non-beneficial solutions and aiding formulation of business cases.
- **Level 2** – Detailed cost estimates produced using Northumbrian Water's iMOD cost estimating system.
- **Level 3** – For complex and/or high value schemes to provide a traditional bottom-up cost estimate.

We carried out options costing for Hypochlorite and Slow Sand Filter interventions to Level 2, using the iMOD system. iMOD is an engineering scoping and cost estimating software system, developed for Northumbrian Water, which provides an integrated platform for project scope definition, whole life costing and tender evaluation.

There are two estimating approaches within the system, iMOD Express and iMOD engineering scoping and estimating. iMOD Express is an asset level cost triage system that provides high-level CAPEX and OPEX estimation based on a single overarching cost driver. iMOD Express is based on asset level cost curves, underpinned by full iMOD cost models, and has been extensively used for Level 1 estimation.

The full iMOD estimation package, used to cost the Hypochlorite, slow sand filter and RGF options to Level 2, comprises a suite of 50 engineering scoping models and a large and detailed cost database containing many thousands of costing data-points on a range of components and assets. With a minimum of input criteria that is readily known at project inception, the system can provide a detailed CAPEX, OPEX and whole life costing for a range of business issues by developing relevant cost curves for the investments in question. The iMOD system uses an Asset (referred to as 'Process') and Component costing hierarchy. The relevant processes are selected for each estimate, with the engineering scoping model run for each process. This produces a quantified Work Breakdown Structure (WBS), with detailed attribute tags, with costs applied via the iMOD cost database. The process models are then supplemented with individual components and/or unit rates to complete the estimate as appropriate. Contract overheads are then applied from a selection of 19 sub-categories chosen based on site specific or work type specific considerations. Each sub-category consists of a historical data cost curve and is generated using the value of the measured works. Project overheads are then applied to the combined value of the measured works and the contract overheads, based on a selection of 21 sub-categories. The iMOD engineering scoping models produce detailed OPEX calculations for Power, Operational labour, Chemical & Materials and Waste disposal.

The cost estimates have been produced using Asset Policy Group (APG) Water Treatment specific cost curves for Process, Component, Contract and Project Overheads.

4.2. PREFERRED OPTION COSTS

The iMOD costs generated for the preferred solutions are shown in Table 27. Capex includes the engineering scope cost and overheads. **The total AMP8 capex for this enhancement case is £77.518m.**

Table 27 also shows annual opex. This is the annual increase in operating costs applicable to each option following the delivery of interventions on each site. In the case of Hypochlorite, which is a programme of work across 44 sites, the opex is shown as the total annual opex impact once all 44 sites have been delivered. Where options enhance existing processes, for example, enhancement of RGF backwash capacity, opex shown is the uplift in operating cost (e.g. additional power for increased backwash rates). The total AMP8 opex, based on our estimated delivery programme is shown in Table 28 on the following page.

TABLE 27: IMOD COSTS FOR PREFERRED OPTIONS

Risk	Site	Preferred Option	Capex including OH & Risk (£m)	Opex (annual) (£m)
Hypochlorite – Chlorate formation	Multiple	Installation of chilling systems at 44 dosing points	34.263	0.101
Slow sand filter DO depletion	Chigwell	Enhance existing assets. DO monitoring and enhanced Run-to-waste capability	2.369	0.046
Slow sand filter DO depletion	Langham	Enhance existing assets. DO monitoring and enhanced Run-to-waste capability	2.442	0.059
Slow sand filter DO depletion	Layer	Enhance existing assets. DO monitoring and enhanced Run-to-waste capability	2.576	0.100
Slow sand filter DO depletion	Lound	Enhance existing assets. DO monitoring and enhanced Run-to-waste capability	2.653	0.016
Slow sand filter DO depletion	Ormesby	Enhance existing assets. DO monitoring and enhanced Run-to-waste capability	1.815	0.024
RGF backwash degradation	Broken Scar	Enhanced existing assets – install temperature-controlled pulse-backwash and trough guards to prevent media loss	4.491	0.056
RGF backwash degradation	Fontburn	Enhanced existing assets – install temperature-controlled pulse-backwash and trough guards to prevent media loss	3.355	0.213
RGF backwash degradation	Hanningfield	Enhanced existing assets – install temperature-controlled pulse-backwash and trough guards to prevent media loss	8.627	0.292
RGF backwash degradation	Langford	Enhanced existing assets – install temperature-controlled pulse-backwash and trough guards to prevent media loss	4.309	0.265
RGF backwash degradation	Layer	Enhanced existing assets – install temperature-controlled pulse-backwash and trough guards to prevent media loss	3.182	0.108
RGF backwash degradation	Mosswood	Enhanced existing assets – install temperature-controlled pulse-backwash and trough guards to prevent media loss	7.436	0.282
		Total	**77.518**	**1.562**

Table 28 summarises the AMP8 total opex for each option, based on our estimated delivery programme. Opex is calculated for each year within the AMP after the year delivery is completed. For the Hypochlorite option, we have programmed the work at the 44 sites across all 5 years, and the opex has been profiled for each year accordingly to derive the total. **The total AMP8 opex for this enhancement case is £3.148m.**

TABLE 28: AMP8 OPEX BASED ON DELIVERY PROGRAMME

Risk	Site	Delivery	Total AMP8 Opex
Hypochlorite – Chlorate formation	Programme of multiple sites	5-year programme for 44 sites	0.086
Slow sand filter DO depletion	Chigwell	Year 3	0.092
Slow sand filter DO depletion	Langham	Year 5	0.000
Slow sand filter DO depletion	Layer	Year 4	0.100
Slow sand filter DO depletion	Lound	Year 1	0.063
Slow sand filter DO depletion	Ormesby	Year 2	0.073
RGF backwash degradation	Broken Scar	Year 2	0.169
RGF backwash degradation	Fontburn	Year 1	0.853
RGF backwash degradation	Hanningfield	Year 4	0.292
RGF backwash degradation	Langford	Year 3	0.529
RGF backwash degradation	Layer	Year 2	0.325
RGF backwash degradation	Mosswood	Year 3	0.563
	Total AMP8 opex		**3.145**

4.3. COST BENCHMARKING

A sample of the cost estimates for slow sand filters, RGFs and Hypochlorite options produced as part of the PR24 costing process have been benchmarked against comparable water and wastewater companies. In each case, we have only benchmarked scope items where it is possible to draw a comparison with equivalent models from other water company data sets. As this is limited to a maximum of 3 elements per solution type, the benchmarking outputs do not fully reflect the total option cost. Our sample group of options includes 2 of the 5 slow sand filter sites, 2 of the 6 RGF sites, and 5 Hypochlorite options (>10% of sites). Models we were able to benchmark include static mixers, chemical tanks, in-trench pipework, exposed pipework, and chemical tanks.

The benchmarking compares Northumbrian Water generated estimates against 6 comparable water and wastewater companies in England and Wales. A mean average from company data has been used as the benchmark with a 25% percentile and 75% percentile provided as a suitable range. The costs comparisons have been calculated using the latest cost curve data from each company, and reflect the same data used by each company to build its PR24 submission. The costs generated by each cost curve are based on appropriate sizing metrics.

The benchmarked costs have been adjusted for inflation using CPIH and have a price base of Q2 2022.

Table 29 below shows the outcome of the cost benchmarking analysis for sample options. While there is variation at the option level, the total cost is 8% more efficient than comparator models for the option elements where a comparison was possible from the available data.

TABLE 29: PREFERRED OPTION COST BENCHMARKING OUTCOMES

Site	Northumbrian cost	Benchmark cost	25%ile	75%ile	Delta	Delta %
Ormesby	£522,974	£468,963	£368,847	£611,078	£54,011	12%
Layer	£763,665	£833,072	£661,780	£1,090,663	-£69,407	-8%
Fontburn	£700,123	£525,688	£420,551	£683,395	£174,435	33%
Langford	£828,380	£541,449	£433,159	£703,883	£286,931	53%
Abberton RWPS	£44,289	£23,708	£17,391	£30,502	£20,581	87%
Broken Scar	£44,450	£24,163	£17,755	£31,093	£20,287	84%
Peterlee	£5,489	£10,497	£8,618	£12,809	-£5,009	-48%
Wooler	£8,874	£10,686	£8,900	£12,904	-£1,812	-17%
Whittle Dene	£706,332	£1,503,552	£1,202,262	£1,953,636	-£797,220	-53%
Total	**£3,624,575**	**£3,941,778**	**£3,139,263**	**£5,129,964**	**-£317,203**	**-8%**

In addition to benchmarking project scope, we conducted analysis of client and contractor indirect costs, comparing our own project and contract overheads to data provided by the same 6 comparator water companies. Table 30 below shows that our indirect costs are calculated as 63.40% of direct costs compared to the industry benchmark of 73.86%. Our indirect costs are therefore 10.46% below the industry benchmark.

TABLE 30: INDIRECT COST BENCHMARKING OUTCOMES

Indirect cost type	Northumbrian cost	Benchmark cost	Delta
Total Contractor Indirect	36.88%	48.01%	-11.14%
Total Client Indirect	26.52%	25.84%	0.68%
Total Project Indirect	63.4%	73.86%	-10.46%

5. CUSTOMER PROTECTION

Customers are protected through performance commitments and ODIs on water supply interruptions, unplanned outage, and water quality – but only to some extent. This enhancement case addresses risks from climate change, and so will help to prevent these performance measures from deteriorating (rather than providing an increase in service performance). It is difficult to quantify the protection from these performance commitments, because if the risk of high summer temperatures did not materialise at all between 2025 and 2030 in practice, there would be no protection for customers at all from non-delivery.

5.1. PRICE CONTROL DELIVERABLE

Our approach to determining Price Control Deliverables (PCD) is outlined in section 12.3 of A3 – costs (NES04). Our assessment has highlighted that for these enhancements, customers will not be protected by performance commitments.

Therefore, we propose a PCD related to delivery of our 2025-30 climate change process enhancements, to make sure our customers are protected. In Table 31, we assess these enhancements to test if the benefits are linked to PCs; against Ofwat's materiality of 1%; and to understand if there are outcome measures that can be used.

TABLE 31: ASSESSMENT OF BENEFITS AGAINST THE PCD CRITERIA

Enhancement scheme	Benefits linked to PC?	Materiality	Possible outcomes?
Climate change resilience process enhancements (NES24)	Partial fail – impact on unplanned outage	Pass – 1.5%	The outcome would be to prevent increases in unplanned outage at WTWs – the contribution from these investments is difficult to measure and can vary greatly between years (as it relates to extreme heatwaves).

We propose a single **pooled scheme delivery** PCD for three of our water enhancement cases together – that is, water supplies (NES14); reservoir safety (NES22); and climate change resilience process enhancements (NES24, this case). These cases each have a few large schemes with variable costs, and no clear outcome measures. Our **pooled scheme delivery** PCD will be based on the delivery of individual schemes, with the assessment of the delivery of schemes to be done through external assurance reports to be provided at PR29 (including assessment of partial delivery).

TABLE 32: SUMMARY OF THE PRICE CONTROL DELIVERABLE FOR OUR WINEP PROGRAMME DELIVERY TO PROTECT CUSTOMERS

Description of price control deliverable	**Pooled scheme delivery** as set in our enhancement cases NES14, NES22, and NES24.
Measurement and reporting	We will report on the delivery of these schemes at the next price review (PR29), including specifying the individual schemes that have been delivered, not delivered, or that the Environment Agency or Defra has decided are no longer required (through any changes to WRMP or to reservoir safety).
Conditions on allowance	Projects must be delivered to the specification set out in WRMP including delivery of benefits (NES14). Projects must comply with reservoir safety notices (NES22). Projects must deliver the capacity described in the climate change resilience process enhancements case (NES24).
Assurances	We will provide external assurance, with a duty of care to Ofwat at PR29, that these schemes have been delivered to the specifications described above. Ofwat will set the timetable for this external assurance to be delivered (either for the PR29 business plan, or a later date if they determine this is more appropriate).
Price control deliverable payment rate	We will return funds back to customers for individual projects, as specified in Tables 28 and 29 above (for NES24) – 12 individual schemes to be delivered by the dates specified. For partial delivery, we will return partial funding as determined according to project completion by the external assurance.
Impact on performance in relation to performance commitments	There is no direct improvement to performance commitments from this enhancement case.

We propose a single PCD for our pooled scheme delivery. This should:

- Be set according to individual project costs, rather than a “per project” unit cost. This is because these costs vary considerably, and a single rate would create an incentive to deliver more of the cheapest projects (at the expense of more expensive projects). Ofwat’s guidance in IN23/05 identifies this incentive and expects us to set out scheme level deliverables where costs vary significantly across schemes (so our approach here is consistent with the guidance).
- Not include an automatic penalty for non-delivery (beyond returning the costs to customers). This is because each of these enhancement cases has other penalties that would apply in the case of non-delivery: for WRMP, we would not meet our statutory obligations to supply water; and for reservoir safety, we would not meet our statutory obligations for draw-down capacity. For climate change resilience process enhancements, we would continue to face ODI penalties in hot weather.

We have chosen to aggregate these PCDs because these share the same reporting, assurance, and conditions.