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Raw water deterioration

Protecting our customers from deteriorating raw water quality

Executive summary

This proposal outlines our 'no-regrets' plan to meet our statutory obligations at sites where raw water quality is deteriorating, or where there is a change in standard, in order to provide our customers with a reliable supply of wholesome drinking water.

Case for change

Delivering safe, clean drinking water to our customers' taps is the most fundamental aspect of the services we provide, and we carry out detailed monitoring and analysis across Severn Trent's 136 water sources to ensure compliance with drinking water standards.

Investment in AMP8 is required for the following reasons:

- **Raw water deterioration.** Through the Drinking Water Inspectorate (DWI), water companies are required to monitor, assess and take steps to manage risks to water quality as a result of raw water deterioration. This can be caused by pollution and environmental changes, many of which are legacy impacts from former industrial discharges or land management practices;
- **The emergence of new contamination risks.** The DWI has requested water companies' support to inform and comply with guidance on new water quality standards for poly and perfluorinated alkyl substances (PFAS), also known as 'forever chemicals', alongside other emerging contaminants; and
- **The need to protect the environment through sustainable abstraction.** Through the Water Industry Environmental Improvement Programme (WINEP) we are required to limit abstraction from unsustainable water sources in alignment with the Water Framework Directive (WFD) and the Environment Agency's (EA) 'environmental destination' requirements for 2050. This means we now have to change some of our current ways of mitigating raw water deterioration (such as blending good and poorer sources) simply because some sources will no longer be available.

Our analysis indicates that 12 of our water sources will require intervention in AMP8 to secure them against raw water deterioration and to comply with statutory obligations – doing nothing could cause the loss of 338Ml/d of sustainable resource.

Solution

Our AMP8 proposal is for an investment of £317m, which will deliver the following benefits:

- **Protect customers.** Deliver priority activities at 12 sites (338Ml/d resource) to comply with drinking water standards, and continue five catchment management schemes which will also deliver wider social and environmental benefits; and
- **Prepare for future legislation.** Investigate PFAS and other emerging contaminants to inform the development of future drinking water standards.

The proposed activities (summarised in Table 0.1) have been through our rigorous adaptive planning process to balance certainty with cost efficiency, and the DWI has confirmed its support for this investment, as set out in its PR24 Decision Support Letters (31 August 2023).

Table 0.1: Proposed activities in AMP8

Raw water driver	Activity	Water resource protected(1)	AMP8 Cost
Cryptosporidium and bacteria – pathogens	Install treatment plants (ultraviolet inactivation or ultrafiltration membrane removal) at six groundwater sites, in tandem with catchment management measures.	[✂]Ml/d	£77.1m
Nitrate	Install treatment plants (Ion Exchange) at two groundwater sites, in tandem with catchment management measures.	[✂]Ml/d	£40.1m
Algae	New treatment process (Dissolved Air Floatation) at one site at which levels of reservoir algae are increasing, preventing the effective removal of pathogens.	[✂]Ml/d	£67.3(2)
Lead	Enhanced treatment process (next generation ceramic membrane) at one site where lead levels in raw water are higher than average.	[✂]Ml/d	£74.9m(2)
PFAS and other emerging contaminants	Advanced carbon-based adsorption treatment processes to remove PFAS at two sites, catchment investigations to reduce future treatment costs, and specialist laboratory capability to determine PFAS removal and to inform long-term planning for emerging contaminants.	[✂]Ml/d	£56.2m
Catchment management	Continuation of five AMP7 catchment management schemes for cryptosporidium and bacteria risks.	[✂]Ml/d	£1.1m
Total		**338.4Ml/d**	**£316.7m**

We have considered a wide range of options to meet our drinking water standards obligations, prioritising nature-based solutions (such as catchment management and floating wetlands). Where our proposed activities involve the construction of new treatment plants and processes, we have confirmed that a nature-based approach would not deliver the benefits required in AMP8.

We are confident that this proposal represents the best option for customers, and that it will deliver best value overall in terms of costs, risks, affordability of customers' bills, and wider environmental and social benefits. We have proposed a price control deliverable to track delivery of our obligations and return money to customers in the event of late or under delivery.

[1] Average licence or WRMP24 sustainable capacity.
[2] Proportion allocated to enhancement investment. The remaining cost met through base expenditure.

Content

Note: Annexes referred to sit within separate PR24 documents whereas Appendices are contained within this document.

1. The need for investment

1.1 We have legal statutory obligations to meet drinking water compliance

The DWI, the regulator for drinking water quality, has shown in its recent annual report (2022) that, overall, drinking water in England is of an excellent standard and this is demonstrated through a continuing high standard of 99.97% compliance with standards – consumers should therefore have confidence in their supply. However, the Chief inspector in their forward also states that:

> *"We cannot stand still, be complacent, or assume drinking water remains of such high quality that no investment above base expenditure or no action is required, because this will result in our failure to protect public health and we consequently won't be in the top six countries in the world for drinking water quality."*

Our statutory obligations are set out in the Water Supply (Water Quality) Regulations 2016, which require drinking water to be 'wholesome' – as defined by standards for a wide range of substances, microorganisms and properties of water. The DWI is the statutory enforcement authority for these regulations.

The standards cover:

- Microorganisms including pathogens;
- Chemicals such as nitrate and pesticides;
- Metals such as lead and copper; and
- The way water looks and how it tastes.

Other key parts of the regulations driving our activity and plans are Regulation 26, specifying disinfection requirements, and Regulation 27, specifying the requirement for Drinking Water Quality Risk Assessments – a 'source to tap' approach. Our Drinking Water Safety Plans (DWSPs) meet this requirement. Since the implementation of our DWSPs, just before PR14/AMP5, we significantly improved our understanding of catchment risks and raw water deterioration.

There are two triggers for enhancement investment as a result of our statutory obligations. We explain each one in more detail below:

- We are obligated to take action where there is evidence of deteriorating raw water quality that puts treated water compliance at risk; and
- Where there is a change in standard, or where we are required to take steps to monitor and understand emerging pollutants (specifically PFAS) that could lead to new standards.

We submitted our AMP8 water quality improvement schemes to the DWI for technical support on 31 March 2023, evidencing the need for action, our preferred solutions, and cost estimates that were subject to change before final business plan submission. On 31 August, the DWI issued Final Decision Letters to us, supporting all our proposals – they will be putting in place the relevant legal instruments for statutory schemes by February 2024.

1.1.1 Deteriorating raw water sources

To ensure high standards for drinking water quality continue, we carry out detailed monitoring and analysis across all our 136 water sources and we are required to identify and mitigate deteriorating trends in raw water quality. These raw water quality changes have been brought about by pollution and environmental changes, many of which result from actions taken many decades earlier that are outside of our direct control. This introduces a risk of non-compliance against the existing legal standards and, if left unchecked, could impact our ability to supply wholesome, safe drinking water.

The DWI's long term planning guidance (September 2022) clearly sets out their expectation that we monitor, assess, and then take steps to manage emerging risks to water quality as a result of changing raw water quality. The definition provided in the DWI guidance is:

> *"Failure or a likelihood of failure to supply wholesome water because of a deterioration or a change in raw water quality... Deterioration in this context means a measured reduction/change in raw water quality over time, or demonstrable unmitigated volatility in quality brought about by pollution changes within the catchment, and most frequently arising from diffuse pollution, but also from changing weather patterns for example"*

This business case puts forward the investment needs and solutions that meet this criteria for raw water deterioration. We have five areas of compliance risk driving investment in AMP8: nitrate, cryptosporidium/pathogens, algae, lead, and PFAS. Table 1 summarises the first four of these drivers and explains why they are a problem.

Table 1: Summary of our raw water deterioration drivers in AMP8

Raw Water Driver	Why they are a problem?
Cryptosporidium and bacteria in groundwater	Cryptosporidium is a parasite that can result in a diarrhoeal disease called cryptosporidiosis. Most people will recover within four to six weeks but individuals with a compromised immune system may be more seriously affected. Raw water contamination sources are most commonly from agricultural land, sewage treatment works, or cesspits. The cryptosporidium bodies, or 'oocysts', are resistant to chlorine disinfection – unsuitable treatment can result in their presence in drinking water. Effective treatments are conventional coagulation, clarification, and filtration (at surface WTWs), membrane filtration (groundwater sites), and ultraviolet (UV) treatment, which is a cheaper and chemical free process that inactivates the cryptosporidium rather than removes it. Other bacteriological contaminants include faecal coliforms (such as Escherichia coli, *E. coli*), enterococci, and clostridium perfringens – pathogenic bacteria of concern that can cause vomiting, diarrhoea, and other sickness. Their presence is generally measured by coliform 'indicator organisms' which can indicate the presence of faecal contaminants in raw water or potential ineffective disinfection in final drinking water supplies. • Coliform bacteria and *E. coli* have a prescribed concentration value (PCV) of zero (numbers/100 ml); and • Cryptosporidium does not have a PCV as its presence can be indicated by other, more measurable bacteriological parameters – although Regulation 26 does state it is necessary to remove or inactivate all pathogens. If a detection is deemed to be of concern, it is considered a likely DWI event.
Nitrate in groundwater	Nitrate in drinking water can cause oxidation of haemoglobin in the blood which inhibits the transportation of oxygen. This is a particular risk for children under three-months-old, and so the PCV of 50mg/l in drinking water is based on this age group. Nitrate can reach both surface water and groundwater via excess application of inorganic nitrogenous fertilizers and manures in agriculture, from wastewater treatment, and from oxidation of nitrogenous waste products in human and animal excreta, including septic tanks. Nitrate loading and land use changes in catchments over time can take years to migrate to groundwater abstraction sources. Our modelling shows aquifer travel times for nitrate pollution plumes can be many years, even decades, in our Permo-Triassic sandstone aquifers. This contrasts with aquifers in other parts of the country, such as those found in limestone, that are far more responsive.
Algal blooms in reservoirs	Algal blooms occur when conditions are optimal for algal growth in water, which include high concentrations of nutrients (mainly phosphorous and nitrogen) and warm, light, and calm weather conditions – known as eutrophication. During blooms when algal density is high, coagulation and clarification, the first stage of conventional treatment, is not able to remove all the material. This can lead to carryover of algae to downstream filters which in turn can become blocked or fissured. This ultimately poses a risk to compliance as crypto/pathogenic bacteria can pass through these filters that are supposed to be barriers. This problem also leads to increased filter backwashing to

	the point where the wastewater system is overloaded and/or the filter backwash process cannot wash the filters fast enough. Algal blooms are becoming an increasing problem year-on-year at most of our reservoir sites, and this could get worse as climate change encourages favourable conditions: • Periods of excessive rainfall and nutrient runoff, followed by prolonged drought and heatwave conditions; and • Earlier spring warming and later autumn cooling results in a longer growing season, enabling blooms to develop early and persist for longer.
Lead in raw water	Lead in drinking water is harmful to humans, particularly affecting brain development in babies and infants. Current UK regulations set a PCV of 10µg/l which came into effect in 2013 after a previous revision to the standard in 1998 which moved from 50µg/l to 25µg/l. The EU Drinking Water Directive (DWD) has lowered the value even further to 5µg/l. We acknowledge the need to protect customers from the harmful effects of lead. The sector and society need to do more to reduce lead in drinking water as there is no safe level of human exposure to it, as confirmed by the World Health Organisation. We recognise that the 10µg/l lead standard is set on practical achievability given the prevalence of customer lead pipes – if there were no lead pipes then the standard would be set at the health level of zero. The most challenging source of lead in drinking water is lead supply pipes. Despite new installations being banned in the UK since 1970, legacy lead pipes still present a health and compliance risk. We are considering a long-term programme for this problem (refer to our 'Lead Reduction' business case), starting with lead supply pipe replacement trials and activities prioritised by risk to customers. Our ultimate ambition is to reduce chemically intensive and costly phosphate dosing, which we currently rely on to prevent the leaching of lead into drinking water supplies. Another, more easily, tackled problem is lead that is naturally found in raw water sources, which is the subject of this business case.

1.1.2 Emerging pollutants

In addition to understanding current risks, the DWI require companies to take action to understand emerging risks and better understand parameters that have previously not been monitored e.g. new pesticides such as metaldehyde during AMP6.

In October 2021, the DWI issued a letter to companies to request additional analysis and monitoring for 47 Poly and Perfluorinated Alkyl Substances (PFAS aka 'Forever Chemicals', a description of which is provided in Table 2). The intention was that data provided would be used to inform the introduction of science-based PFAS drinking and environmental water quality standards into water quality regulations. In July 2022 the DWI followed up with a letter providing precautionary guideline values and expectations, and in June 2023 we submitted to them our AMP8 strategy for investigating PFAS risks and identifying actions – a requirement for all water companies in England and Wales.

More recently, in July 2023, the DWI issued a legal instrument to include PFAS mitigation at Cropston WTW, upon us applying for use of a new source of water from Thornton Reservoir/Rothley Brook – this is a very recent and unexpected requirement that came late to our planning for this business case.

Table 2: Explanation of PFAS and emerging contaminants

Substance	Explanation
PFAS (forever chemicals)	Per and polyfluoroalkyl substances (PFAS) are a group of more than 4,700 synthetic chemicals with the ability to easily repel water and grease – used widely for a range of purposes, from industrial to household products and have been, or continue to be, in widespread use in England and Wales. PFAS have caught the attention of regulatory agencies and the media worldwide because of their persistence, toxicity, and widespread occurrence in the blood of humans and of wildlife. They were dubbed 'forever chemicals' as the carbon fluorine bond in PFAS is one of the strongest bonds in organic chemistry, giving them an extremely long environmental half-life. Currently, there are no specific standards listed in the water quality regulations for any PFAS compounds. However, the DWI has issued guidance based on a precautionary, tiered approach to risks which requires actions relating to a subset of PFAS chemicals, based on their potential toxicity and given the uncertainty or absence of specific treatment technologies to reliably remove/reduce PFAS. This will be reviewed periodically for each individually named PFAS compound and we understand that:

	• Tier 1 (<0.01 µg/l) low risk: No action is to be taken; • Tier 2 (<0.1 µg/l): Enhanced monitoring required. Notify DWI/health professionals; and • Tier 3 (≥0.1 µg/l): Water is considered 'unwholesome' if exceeded in final water and is a reportable Water Quality (WQ) event. Emergency contingency required.
Other Emerging contaminants	Since leaving the EU, the EU Drinking Water Directive (DWD) no longer drives the UK water quality regulations. The 2021 revision of the DWD has left UK regulations behind in some areas. In response to this, the DWI is establishing a standards board in 2023 to help inform future changes to UK regulations, and this is likely to lead to the inclusion of new standards for emerging risk parameters such as: • PFAS – currently has guidance in place; • Haloacetic acids (HAAs) – toxic disinfection by products, five of these have an EU DWD PCV of 60µg/l; • Endocrine disruptors – Bisphenol A has a DWD PCV of 2.5µg/l; • Pharmaceuticals and personal care products; and • Persistent mobile toxic substances (PMTs). The first three are likely but the latter two will be further in the future as they are not as well understood and are on the DWD watchlist until further research is undertaken.

1.1.3 Government policy on abstraction reductions

Another driver supporting this investment case relates to the implications of the Government's long-term policy of reducing abstraction to prevent damage to the environment. Our ability to continue to meet water quality standards is exacerbated by our statutory Water Industry Environmental Improvement Programme (WINEP) which includes a reduction of 187Ml/d of groundwater abstraction licences in AMP8/9. We have ambitious plans to meet this challenge (refer to our 'Meeting Our Future Water Needs' business case) but as a result of these changes it means the remaining uncapped licenced sources will have to operate under different source water quality blending regimes – so previously managed raw water deterioration can no longer be tolerated with these existing controls.

1.2 Responding to customer expectations

Over many years, our customer research has shown that delivering safe drinking water is our customers' highest priority and a fundamental part of their expectations of us. They rightly expect us to be able to deliver a good quality and consistent product every time they turn on the tap.

More recent PR24 research, including our comprehensive affordability and acceptability testing of our plan, has shown our customers want us to maintain a consistent, high quality and reliable source of water now and in the future, and tackling raw water deterioration is a fundamental part of delivering that. Customers also expect us to deliver our statutory obligations.

For more details about our PR24 customer and stakeholder engagement programme, including how we meet Ofwat's tests and standards for high quality research, see Annex 3a 'Customer and Stakeholder engagement, challenge and assurance' and associated appendices.

In summary, we know that:

- Our region has traditionally scored well in the 'Water on Tap' quality measures in CCWater's annual Water Matters survey, with scores aligned with the WaSC average;
- As part of our 2022 research into perceptions of tap water quality, 91% of customers considered their tap water to be safe and the majority said they were happy to drink it. Across our region we find that the majority of customers are satisfied with the appearance, taste and smell of their tap water, although there are areas where smell, taste and latherability are a source of dissatisfaction;
- Throughout our extensive PR24 research, as well as research undertaken by Ofwat and CCW, on customer needs and priorities, we find that maintaining water quality is a key priority for

customers. While awareness of the specifics of water quality regulation is low, there is an assumption that water quality is regulated and therefore not something that customers need to worry about;

- Customers expect us to be planning to meet current and future challenges, including investing in resilience to climate change, new standards and emerging issues……including raw water deterioration; and
- When it comes to solutions, customers tend to trust Severn Trent to make the right technical solution choices. Catchment management solutions are supported in principle, although customers question how easy engaging with farmers will be given the challenges they face.

"I believe the quality of our water is very important, as we need to drink it to keep us healthy, therefore it needs to be clean and purified to a high standard"

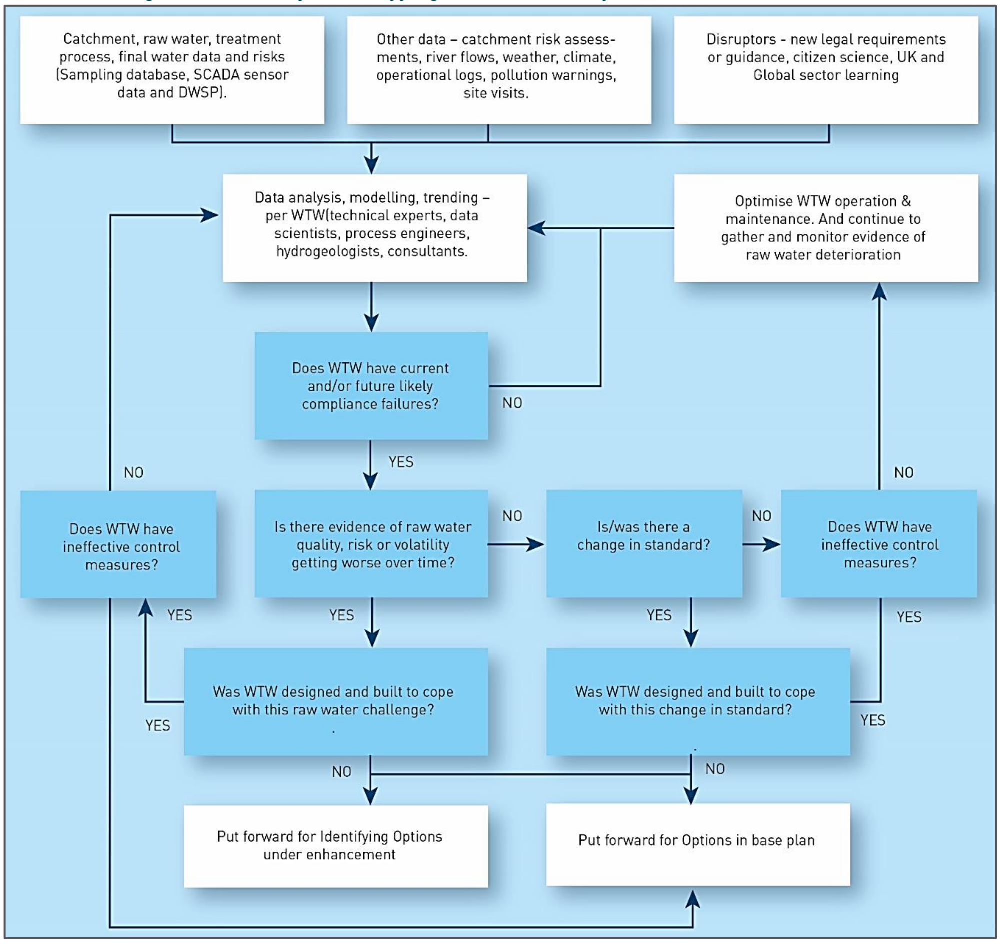
Household customer, Strategic Priorities research (2021)

This business case represents statutory driven investment within our PR24 plan. Our affordability and acceptability research has found that our plan is acceptable to 76% of customers.

1.3 Our process for identifying needs

As part of our strategic asset planning function, we analyse and review data from our Drinking Water Safety Plans (DWSPs), our sampling database (QUIS) and our online sensor data (SCADA). Together with external data sources, this feeds our process for identifying potential sources and water treatment works that are exposed to genuine raw water quality deterioration, as opposed to asset health deterioration (illustrated in Figure 1 below).

Figure 1: Process for Identifying Needs caused by Raw Water Deterioration



1.4 Where we need to mitigate deteriorating raw water quality

1.4.1 Groundwater – nitrate pollution

Groundwater makes up a third of our supply, and 40% of these sources exhibit a rising trend in nitrate concentrations – a clear deterioration in raw water quality. Many of these risks are currently managed by previous interventions, such as blending of source waters in our network, treatment at source, or through operational migration. Some are predicted to level off with adequate headroom.

We use a well-established linear trend analysis based on the methodology developed through UK Water Industry Research (UKWIR), and endorsed by the DWI, to determine a future forecast of nitrate concentration for each of our sources. We then apply these projections to models that include our treatment and blending controls and the future abstraction licence changes that will be made due to WINEP over the next 25 years. These then determine which of our drinking water supplies may exceed the Prescribed Concentration Value (PCV) over time.

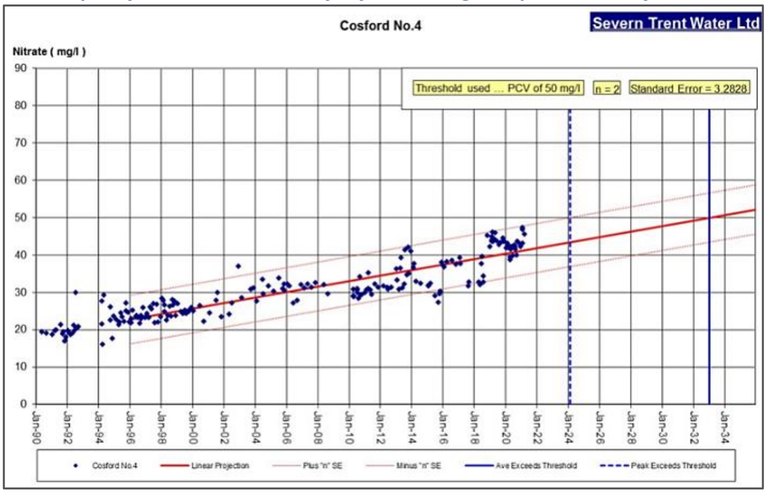
This analysis shows we have two sites that are predicted to fail the PCV (50 mg/l) from 2030-35 and are already likely to exceed the action trigger of 45 mg/l – a safety value needed to take account of sampling and sensor measurement accuracy. These sites require interventions in AMP8 to prepare for this.

Table 3: Summary of groundwater nitrate interventions required

Site/location	County	Licence – average (Ml/d)	Evidence of raw water quality deterioration or change in risk	Forecast PCV Failure
Nurton DSR (Cosford, Copley and Hilton sources)	Shropshire	[✂]	Deteriorating trends at Cosford and Copley causing issues with blend at Nurton DSR	2035
Nedge Hill DSR (Beckbury and Grindleforge sources)	Shropshire	[✂]	Both trends within blend are rising, however Beckbury is the greatest	2030

An example of one these sites' rising nitrate trend is shown in Figure 2 below – Cosford, one of the individual sources feeding Nurton Distribution Service Reservoir (DSR). Our PR24 DWI submissions provide more data and evidence of raw water deterioration at these sites.

Figure 2: Example of nitrate trend used for forecasting compliance - Cosford borehole no.4



Conclusion: we need new controls in place at Nurton DSR and Nedge Hill DSR to prevent exceedance of the nitrate limit in 2030-2035.

1.4.2 Groundwater – cryptosporidium and bacteria

As part of our statutory DWSP approach, all our operational groundwater sources have a catchment risk assessment undertaken for cryptosporidium and microbiological hazards. We look for sources of hazards in the catchment, e.g. livestock, and any hydrogeological features, such as fissuring or watercourses, that may provide a pathway for these contaminants to occur at our points of abstraction. We have identified sites where these catchment risks cannot be controlled effectively. These sites only have marginal chlorination in place, i.e. low level chlorine dosing that is only there to provide a residual in the network, not disinfection or inactivation of cryptosporidium or viruses. This is contrary to our disinfection policy, shown in Table 4. The sites requiring interventions in AMP8 are listed in Table 5, which also shows that there have been multiple bacteriological detections over the last five years – demonstrating that a source and pathway exists at these sites that needs mitigating.

Table 4: Summary of disinfection policy – DWSP catchment risk and treatment required

DWSP Catchment Risk - Cryptosporidium	DWSP Catchment Risk Microbiological (Faecal and/or Non-Faecal)		
	Green	Amber	Red
Green	'Disinfection' not required. Marginal chlorination needed for distribution residual.	Super chlorination or UV and chlorination to achieve a Ct >0.25mg/l.min^{-1} or ultrafiltration and marginal chlorination*	Super chlorination or UV and chlorination to achieve a Ct >0.25mg/l.min^{-1} or ultrafiltration and marginal chlorination*
Amber	N/A	UV and chlorination to achieve a Ct >0.25mg/l.min^{-1} or ultrafiltration and marginal chlorination* or cartridge filters and superchlorination	UV and chlorination to achieve a Ct >0.25mg/l.min^{-1} or ultrafiltration and marginal chlorination* or cartridge filters and superchlorination
Red			

**Marginal chlorination permitted where membranes are certified for a 4-log removal of viruses.*

Table 5: Groundwater sites with no treatment in place for cryptosporidium/bacteria risks - bacteriological indicator detections (Jan. 2016-Jan. 2023)

Source	Abstraction licence – average (Ml/d)	DWSP catchment risk		Raw water samples with bacteriological detections (%)	
		Bacteriological	Cryptosporidium	Non-faecal*	Faecal**
Edgmond Bridge, Shropshire	[✂]	Red	Amber	**16**	1.4
Far Baulker, Nottinghamshire	[✂]	Red	Amber	**13**	0.6
Rednal, Shropshire	[✂]	Red	Amber	**23**	0.4
Dunhamptomn, Worcestershire	[✂]	Red	Amber	**13**	0.5
Wildmoor, Worcestershire	[✂]	Red	Amber	**15**	0.2
Cresswell, Staffordshire	[✂]	Red	Red	**10**	0.3
All remaining marginal chlorination sites				***3***	*0*

**Non-Faecal: Non coliforms and colony counts*
**Faecal: Confirmed - Coliforms/E. coli, Enterococci or C. perfringens.*

Conclusion: we need appropriate treatment in place at six groundwater sites to prevent customers from ingesting disease-causing microorganisms – cryptosporidium and faecal bacteria.

1.4.3 Algal blooms – Whitacre WTW

All our reservoir-fed WTWs experience algal blooms every year, and we can currently just about manage this problem, except at Whitacre WTW where the situation has been getting worse over time.


Figure 3: Shustoke reservoir – toxic Algal bloom 2023

Whitacre WTW is situated on the River Blythe, in north Warwickshire and provides supplies to the Nuneaton and Coventry areas via Oldbury and Meriden DSRs. It has an abstraction licence of [✂]Ml/d (average). Its raw water pumping regime is relatively complex due to the nature of the raw water quality challenges that exist.

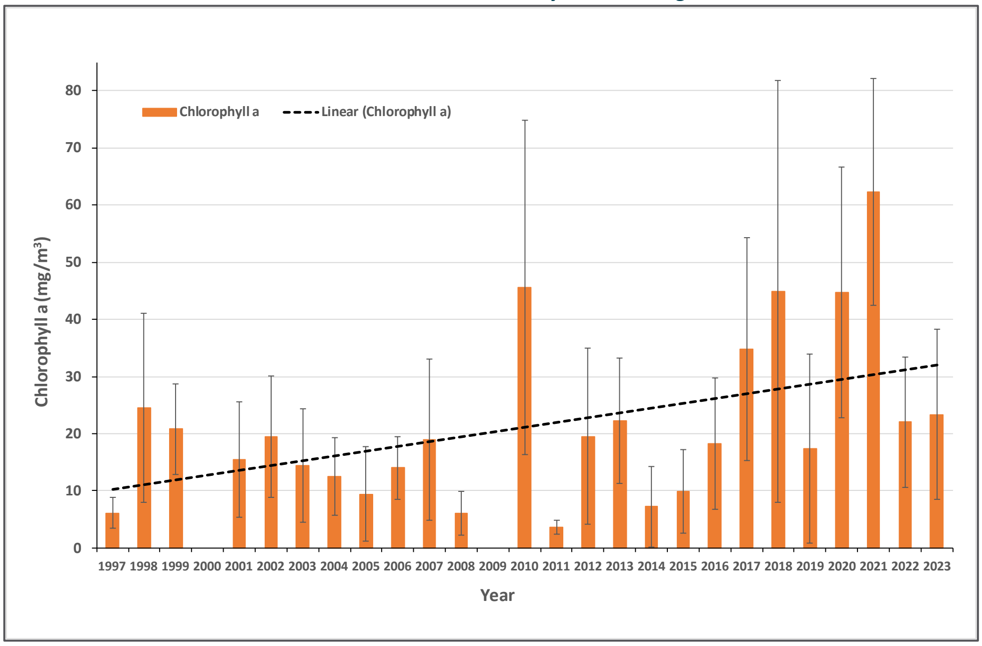
The works abstracts its water from two sources, both of which are tributaries of the River Tame:

1. The River Blythe, which can be high in pesticides and nitrates – we have catchment management schemes under WINEP Drinking Water Protected Areas to help manage this impact on the WTW. The Blythe intake has to be restricted at low flows due to the river being categorised as a Site of Specific Scientific Interest (SSSI); and

2. The River Bourne, which is pumped into the Upper and Lower Shustoke Reservoirs that feed Whitacre WTWs.

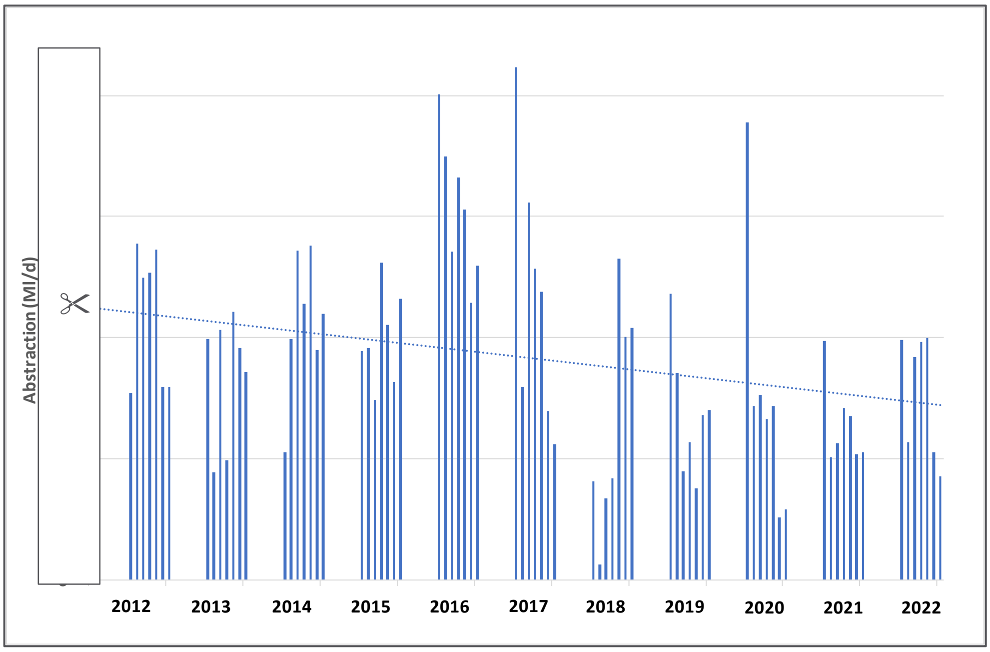
The Upper and Lower Shustoke reservoirs are prone to significant algal blooms every year from March to October – this goes back to at least the 1980s and has got progressively worse over time. Figure 4 shows the annual average of chlorophyll-a concentrations over time at Lower Shustoke reservoir – the key parameter highlighted in recent UKWIR research, as an indicator of how much algae are present in the water column.

Figure 4: Algae measurement – annual average Chlorophyll A concentrations at Lower Shustoke reservoir – January 1997 to August 2023



It is clear that preceding conditions for algal blooms are getting worse over time. We know this situation could get worse as climate change encourages favourable conditions for algal blooms. Over the last 15 to 20 years, our ability to abstract raw water from these reservoirs during the algal bloom season has declined – demonstrated in Figure 5 below.

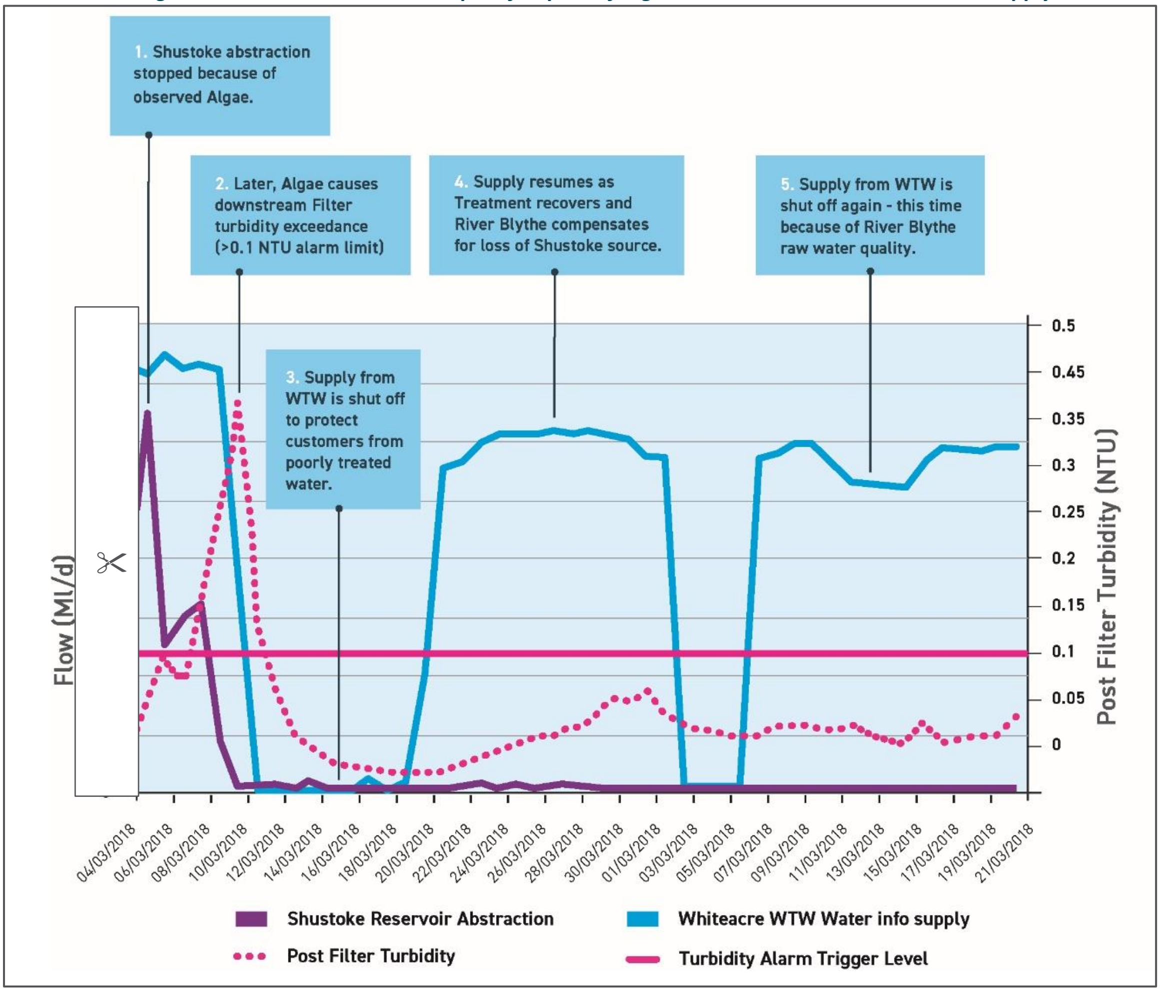
Figure 5: Shustoke Reservoir abstraction during the months of March to September representing algal bloom periods



In more recent years, algal loading from reservoir blooms has been very high (up to 350,000 cells/ml) and with little warning – leading to quick blocking of our filters which then causes two issues:

1. The effectiveness of filters as a control for hazards such as cryptosporidium is compromised – this presents a significant water compliance and safety issue. Whitacre WTW has had to shut down often due to algae blooms causing filtered water turbidity to exceed the safe process target for effective disinfection, downstream of the process. An example of this is shown in Figure 6; and
2. During these events, the amount of water used for such frequent backwashing of all the filters in quick succession means that output from the WTW starts to decrease – in some circumstances the WTW is not able to produce any water until the bloom passes, which can take weeks. More information on these two issues was provided in our DWI PR24 submissions and our response to DWI queries.

Figure 6: Whitacre WTW – example of impact of algae on abstraction, treatment and supply



The treatment stream at Whitacre WTW includes Hopper-bottomed Clarifiers (HBCs), Rapid Gravity Filters (RGFs), Granular Activated Carbon (GACs), and super and de-chlorination (chlorine gas). Conventionally, HBCs are not generally suited to algal-laden waters and, 30 years after their installation, it has become very evidently so at Whitacre – technologies such as DAF and membranes are more appropriate.

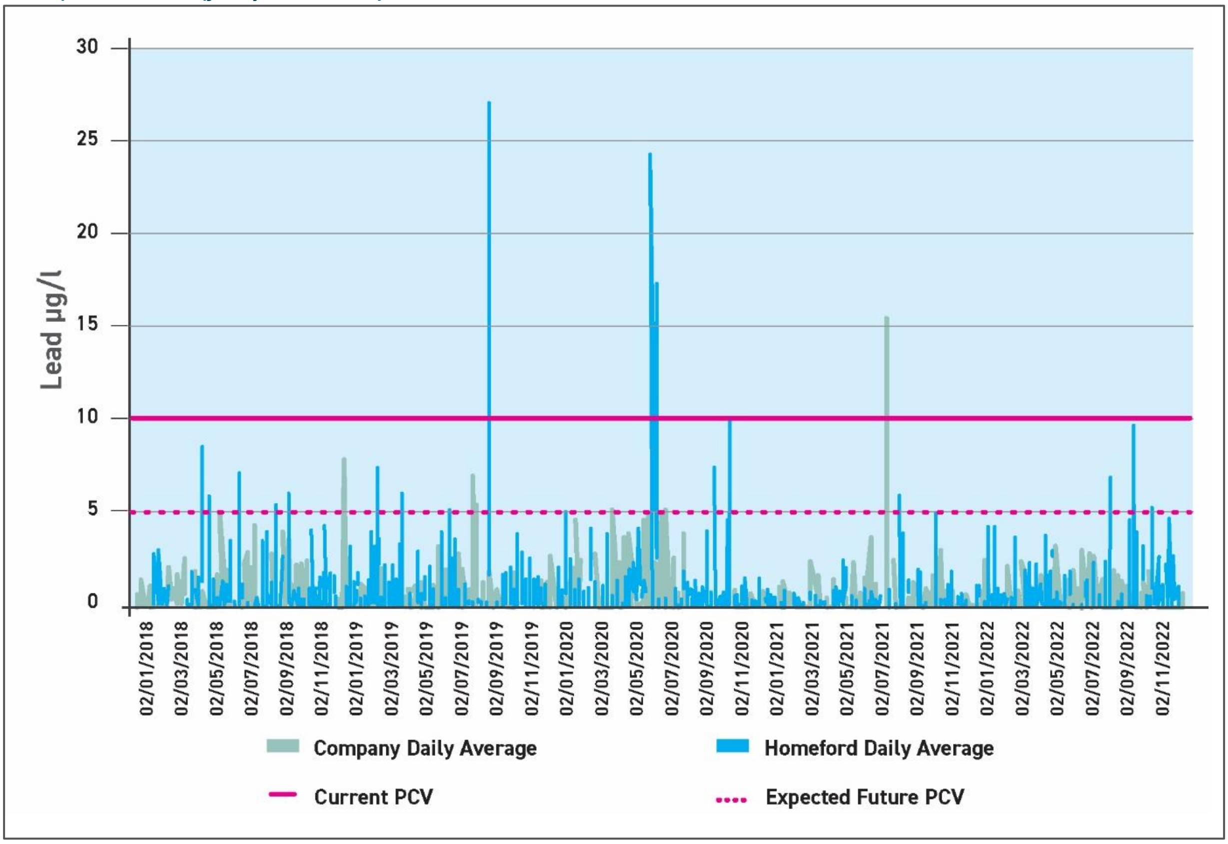
Conclusion: the existing treatment process at Whitacre is not appropriate for the increasing levels of algae that have been occurring over the last 20 years – preventing effective removal of pathogens, and at times when peak summer demand is high.

1.4.4 Raw Water Lead – Homesford WTW

Of our 136 sources of water, only Homesford WTW raw water contains levels of lead that are causing us a challenge with compliance and public health risk. The works is in Derbyshire and treats water from Meerbrook Sough, which is an underground channel that carries drainage water out of a disused lead mine into the River Derwent. We have a licence to abstract water from the Sough at [✂]Ml/d average and [✂]Ml/d peak. This is one of our most sustainable sources of water and a key source for our strategic grid.

Given the nature of the source of water, it contains high levels of lead: generally around 15-20µg/l, with peaks above 40µg/l – the PCV for lead is 10µg/l. Despite some lead removal taking place at our treatment works at Homesford, the area it supplies has elevated levels of lead which increases the risk/lead burden to customers who will also have lead pipes in their supply area. Figure 7 illustrates this by comparing final drinking water quality in predominantly Homesford supplied zones compared to the rest of our area.

Figure 7: Lead exceedances and daily average concentrations for Homesford supplied WQZs compared with rest of Severn Trent (2018 to 2022 (five-year dataset), WQZs based on 2022 Blue Book



Homesford WTW supplied zones have exceeded, or came very close to exceeding, the PCV six times on average since 2018, compared to once for the company-wide daily average, and exceeded the trigger limit (5 µg/l) 24 times since 2018 (compared to 16 times for company average). Our analysis also shows that lead in drinking water is on average up to 42% greater in areas predominantly supplied by Homesford, compared to the rest of our customer's supply.

Conclusion: Drinking water supplied from Homesford WTW has lead levels that are higher than average; a risk on top of that already posed by lead supply pipes which we cannot easily replace in the short term. Lead levels could be reduced further, and more easily in the short term, by removing it at source with appropriate treatment – this will also reduce compliance failures.

1.4.5 PFAS & Emerging Contaminants

<u>Witches Oak WTW – River Trent</u>

In AMP7 we are building a new water treatment works at Long Eaton, Derbyshire, called Witches Oak. This is one of our Green Recovery projects and seeks to deploy the River Trent abstraction licence we bought from Rugeley Power Station in 2020 – [✂]Ml/d annual average and [✂]Ml/d peak. The works will be located on operational land at our Church Wilne WTW (Figure 8) and will be capable of treating to the Rugeley licence volumes and feeding directly into the Derwent Valley Aqueduct (DVA).

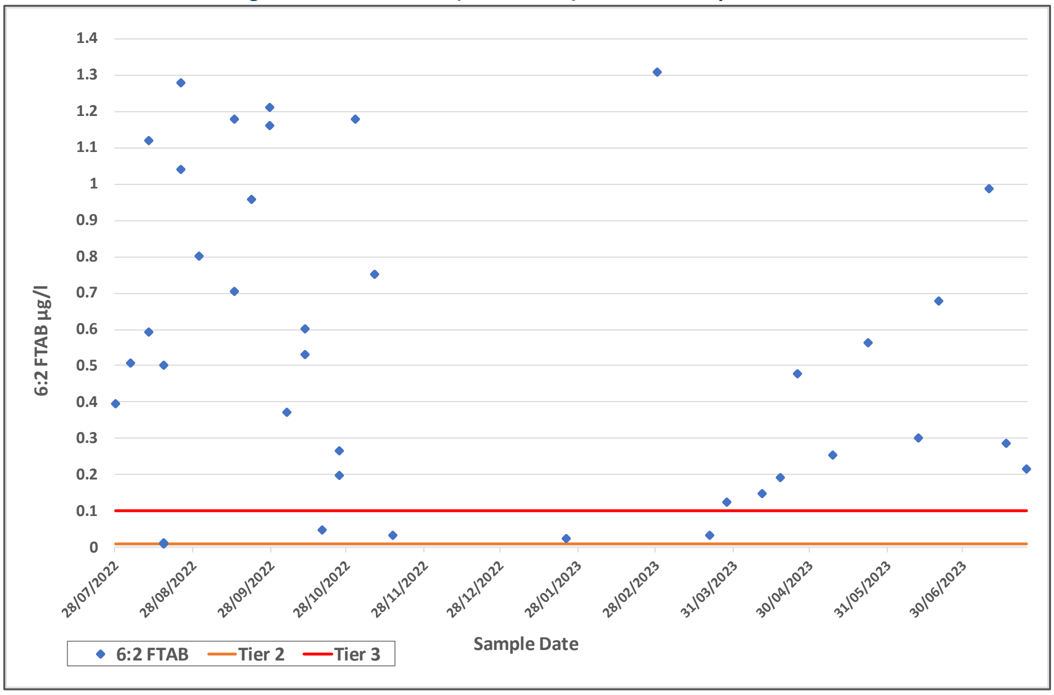
Figure 8: Supply arrangements for the proposed Witches Oak abstraction point (using new Rugeley licence), new WTW and provision of resilience to Melbourne WTWs

The project also seeks to deliver our AMP7 commitment to provide resilience to Melbourne WTW to protect customers from its single points of failure that we identified in our PR19/AMP7 plan. This will be achieved by providing a cross connection from the DVA to Melbourne WTW supplied areas, so allowing a second source of supply in the event of 'losing' Melbourne WTW.

In July 2021 we received Final Determination approval from Ofwat for the project. Our original plan put commissioning water into supply in February 2025, so we were expecting to be submitting a Regulation 15 DWI approval for the new source around August 2024. However, given new regulatory PFAS requirements, and monitoring capability, we have detected consistent non-compliant PFAS concentrations at the new abstraction point.

- From July 2021 we started testing for the 20 PFAS compounds specified in previous DWI guidance. All our WTWs were within DWI's Tier 1 – the lowest risk at <0.01µg/l – not considered to be "unwholesome";
- By July 2022, the industry had developed an accredited method for analysis of the new 47 PFAS compounds required by DWI's updated guidance – all our sites are within Tier 1;
- ALS, our laboratory contractor, also provide us with results for a 48th PFAS compound called 6:2 FTAB;
- 6:2 FTAB (48th) and 6:2 FTSA (one of the 47) are both present at Tier 3 levels in the River Trent at the new abstraction point planned for our new Witches Oak WTW – this means the DWI would consider the water as "unwholesome" if the water was in supply, and concentrations would trigger a reportable event. Emergency contingency required; and
- Extensive sampling has identified consistently elevated levels of 6:2 FTAB above the Tier 3 threshold of 0.1µg/L (Figure 9).

Figure 9: Witches Oak (River Trent) 6:2 FTAB sample results



Since these detections we have been carrying out the following actions:

- Liaising with UKHSA about any research on 6:2 FTAB toxicity and engaging with Dr Sarah Bull from TARA for a toxicity review of 6:2 FTAB;
- Engaging with Jacobs to learn from PFAS risks and mitigations used worldwide;
- Recently established good links with Singapore's PUB which has expertise in PFAS science;
- Catchment risk assessments - identified a high risk from PFAS and PFOS at the Witches Oak abstraction point on the River Trent, verified through water quality sampling;
- Catchment surveys to try and establish PFAS sources and more immediate catchment investigations to support scheme feasibility. This has included more catchment-specific sampling programme at key points to try to better understand the PFAS source locations, as well as catchment walkovers. The data is presented in Section 2.2.5 below;
- Working on proposals for an AMP8 permanent treatment solution for the new Witches Oak WTW – including organising a pilot plant to trial PFAS removal technologies; and
- Increasing our monitoring for PFAS at these sites and updating our DWSP – although our contractor ALS has had issues with their method since November 2022 so there was a backlog for us and other water companies.

<u>Cropston WTW – Rothley Brook (Thornton Reservoir)</u>

Since our PR24 proposal submissions to the DWI, they issued a legal instrument (Regulation 28 notice) in July 2023 to include PFAS mitigation at Cropston WTW, upon us applying for use of a new source of water from Thornton Reservoir/Rothley Brook. This is a very recent and unexpected requirement that came late to optioneering and planning stages for this business case, as all sample data showed levels all below Tier 3 (see Table 6 below).

Rothley Brook (Thornton Reservoir) is a raw water source supplying Cropston WTW that ceased to be used in 2012 (due to Invasive Non Native Species). We submitted a Regulation 15 application on 28 April 2023 to start using this source again (as part of our planned AMP7 water resource scheme – Thornton to Cropston). This was not approved based on the "No Deterioration" principle under the Water Industry Act – Rothley Brook (Thornton Reservoir) has Tier 2 levels (6:2 FTAB, the 48th PFAS), meaning that Cropston Reservoir would deteriorate from a Tier 1 to Tier 2 source, following Thornton import. We are currently considering how best to bring this source online while controlling PFAS risk, and we will ensure adequate monitoring is in place.

Table 6: PFAS sampling results for Rothley Brook (Thornton Reservoir) and Cropston WTW – 6:2 FTAB

Rothley Brook				Cropston WTW			
PFAS sample location	Date	6:2 FTAB result (µg/l)	PFAS tier	PFAS sample location	Date	6:2 FTAB result (µg/l)	PFAS tier
Raw	18/10/2022	*method not available*		Final	20/04/2021	*method not available*	
Raw	25/10/2022	0.0093	1	Raw	20/04/2021		
Raw	31/10/2022	0.0581	2	Final	23/02/2022		
Raw	15/11/2022	0.0299	2	Raw	23/02/2022		
Raw	*20/03/2023*	*0.0053*	1	Final	15/08/2022	< 0.001	1
Raw	28/03/2023	0.0043	1	Raw	15/08/2022	< 0.001	1
Raw	*04/04/2023*	*0.0031*	1	Raw	27/03/2023	< 0.001	1
				Final	27/03/2023	< 0.001	1

Conclusion: PFAS removal is required at Witches Oak WTW and Cropston WTW for legal compliance with recent, and potentially upcoming, changes to water quality guidance. In-house laboratory capability is required to confirm PFAS removal and to inform longer-term planning for emerging contaminants that may have legal standards to come over the next 10 to 20 years.

1.5 Management control

The following section explains:

- How we have historically managed the needs set out in the previous section;
- Any relevant, previous decisions around risk management and strategy;
- Current control measures we have had in place; and
- Why these needs are outside of our direct control.

1.5.1 Groundwater – nitrate pollution

We have known for decades that our groundwater sources are suffering from rising concentrations of nitrate. We monitor them regularly and choose to intervene at the optimum time to minimise cost.

As part of PR09, the rate of nitrate concentration increase at Cosford warranted an AMP5 scheme to remove customers who were directly supplied from the source. It moved those customers onto pure Nurton DSR supplied water – where the rising nitrate at Cosford would be blended with the lower nitrate sources at the time: namely Copley and Hilton. This blending scheme was approved based on a 10-year solution life for direct fed customers which has now ended. Nitrate concentrations at all three sources have continued to rise (as predicted) to a point where a new scheme is now needed to protect all customers supplied by Nurton DSR for at least the next 25 years.

1.5.2 Groundwater – cryptosporidium and bacteria

Since adopting the statutory DWSP approach in the lead up to PR14, which includes catchment risk assessments, we discovered that the majority of our sites were not low risk "pristine" sources as thought pre-2010. This is represented by the first pie chart in Figure 10. These sites only had/have marginal chlorination in place, i.e. low level chlorine dosing that is only there to provide a residual in the network, not disinfection or inactivation of cryptosporidium or viruses. For many of these sites, installation of appropriate treatment (disinfection, removal or inactivation) was required to match this risk. This needed to be phased over subsequent AMP periods based on site criticality, starting with AMP6 schemes that were supported at PR14.

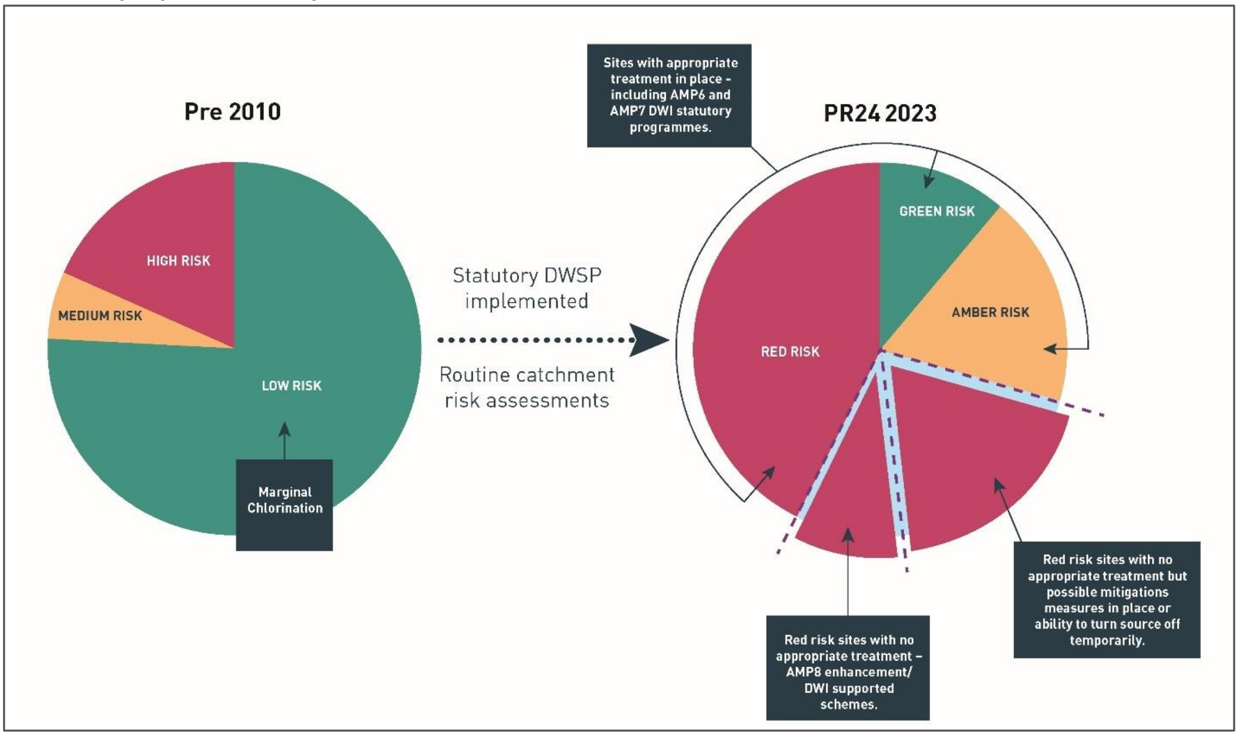
At PR19, our updated catchment risk assessment showed more raw water red risks that had no appropriate control – these identified the supported schemes for AMP7.

The second pie chart in Figure 10 shows our current raw water risk position at PR24, the enhancements that we made in AMPs 6 and 7, and the next group of sites that now require treatment to mitigate raw water risk in AMP8.

The remaining 18 sites (not included for AMP8) out of all 115 either have appropriate mitigation in place or the ability to take the supply out of service temporarily if risk is realised, i.e. cryptosporidium or bacteriological detections. These detections could impact our industry Compliance Risk Index (CRI) score, hence the need for either a Performance Commitment (PC) deadband or an investment step change in this area.

Essentially, Figure 10 shows how we set out on a long-term multi-AMP programme to move away from marginal chlorination, prioritised by risk to allow a manageable and affordable delivery programme. Now, given the pressures from abstraction licence reductions, the need to secure supplies as per our WRMP and resilience challenges, we need to progress to the next set of sources in AMP8.

Figure 10: Multi-AMP phasing of treatment for Cryptosporidium/Microbiological risks at our groundwater sites following the statutory implementation of DWSP



1.5.3 Algae – Whitacre WTW

There have been a series of measures used in the Whitacre system to control the development of algal blooms, with research starting around 1987. Between 1995 and 2001, water from the River Bourne was treated by dosing ferric chloride as it entered Upper Shustoke reservoir, to strip out phosphorous, with precipitated floc settling out on the reservoir bed. This ended due to environmental permit limits imposed by the EA. After ferric chloride dosing stopped, biological control techniques were then investigated.

In 2021 we commissioned APEM to develop a nutrient budget, to consider managing the nutrient concentrations in the Whitacre system effectively. This identified sources of nutrients, pathways by which nutrients are added to a water body, and sinks (methods by which they are removed from the water body). The study clearly showed that, although the rivers Bourne and Blythe are the dominant sources of nutrients to the system, there is a risk from legacy nutrients being re-released into the water (high concentrations of phosphorus were measured in sediment samples at all three reservoirs). This limits the effect catchment management can have.

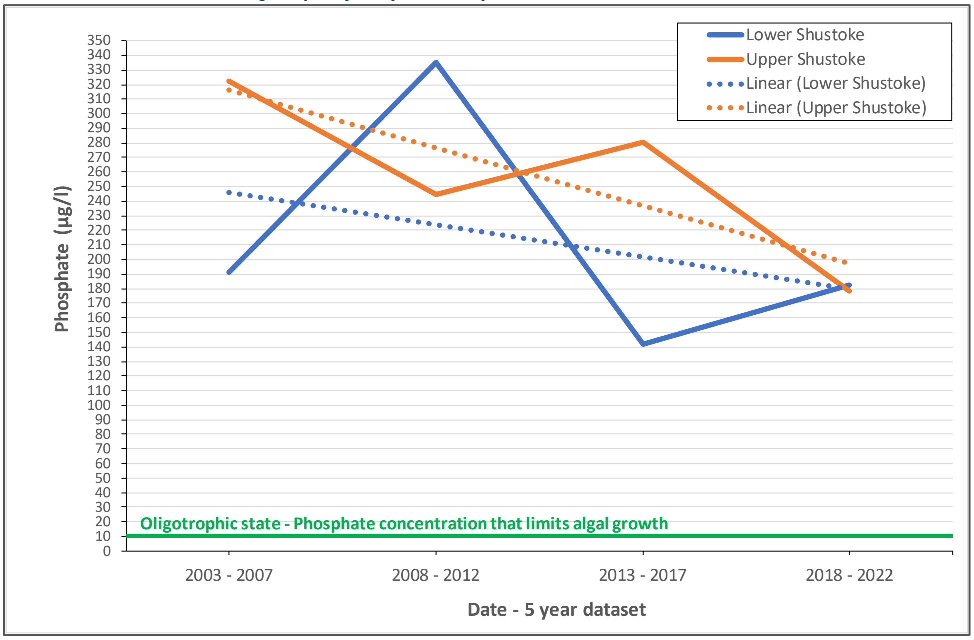
There are several initiatives to improve catchment management to reduce nutrient inputs. During AMP6, the Whitacre catchment was designated as a drinking water safeguard zone for pesticides and nitrates, with an associated package of catchment management measures under WINEP. For AMP7, phosphate has been added as a priority substance – benefits are not expected to be realised until the mid- to long-term (10 to 25 years). More detail on catchment management was provided in our PR24 DWI submissions and response to queries.

Impact of our Wastewater Treatment works investment

For the rivers Blythe and Bourne, our statutory WINEP AMP7 and AMP8 programmes (including Catchment Nutrient Balancing (CNB)) will deliver our fair share of phosphate reduction to get to WFD good status for those rivers. Barston Wastewater Treatment Works (WwTW) is the largest WwTW discharging to the Blythe catchment. In 2020 we completed £24m of investment at the site to ensure removal of phosphate to the technically achievable permit limit of 0.2mg/l, compliance with a 1.0mg/l ammonia permit limit and to enable a total nitrogen permit in May 2026 (15mg/l max and minimum removal of 50%). In addition to Barston, investment has been, or will be, undertaken at the other five sewage treatment works discharging to the River Blythe, together with a programme of storm overflow improvements. For the River Bourne catchment, the largest WwTWs is at Arley which is being upgraded to a 0.3mg/l P-limit in AMP7, followed by Ridge Lane WwTW (0.1Ml/d) which is being upgraded to a 0.45mg/l P-limit in AMP8. There are also a couple of very small works and our Whitacre CNB scheme is also covering the Bourne catchment.

With the investment in these catchments we have undertaken over the last 20 years, combined with removal of phosphorous from household detergents, there has been a dramatic reduction in phosphorous input to our rivers. However, Figure 11 below demonstrates how slow recovery from a eutrophic to an oligotrophic state (approx. 10µg/l P) can/will be for the reservoirs, i.e. much smaller concentrations are required to limit algal growth.

Figure 11: Long term trends of Phosphate at Lower and Upper Shustoke reservoirs – grouped five-year sample data – 2003 to 2022



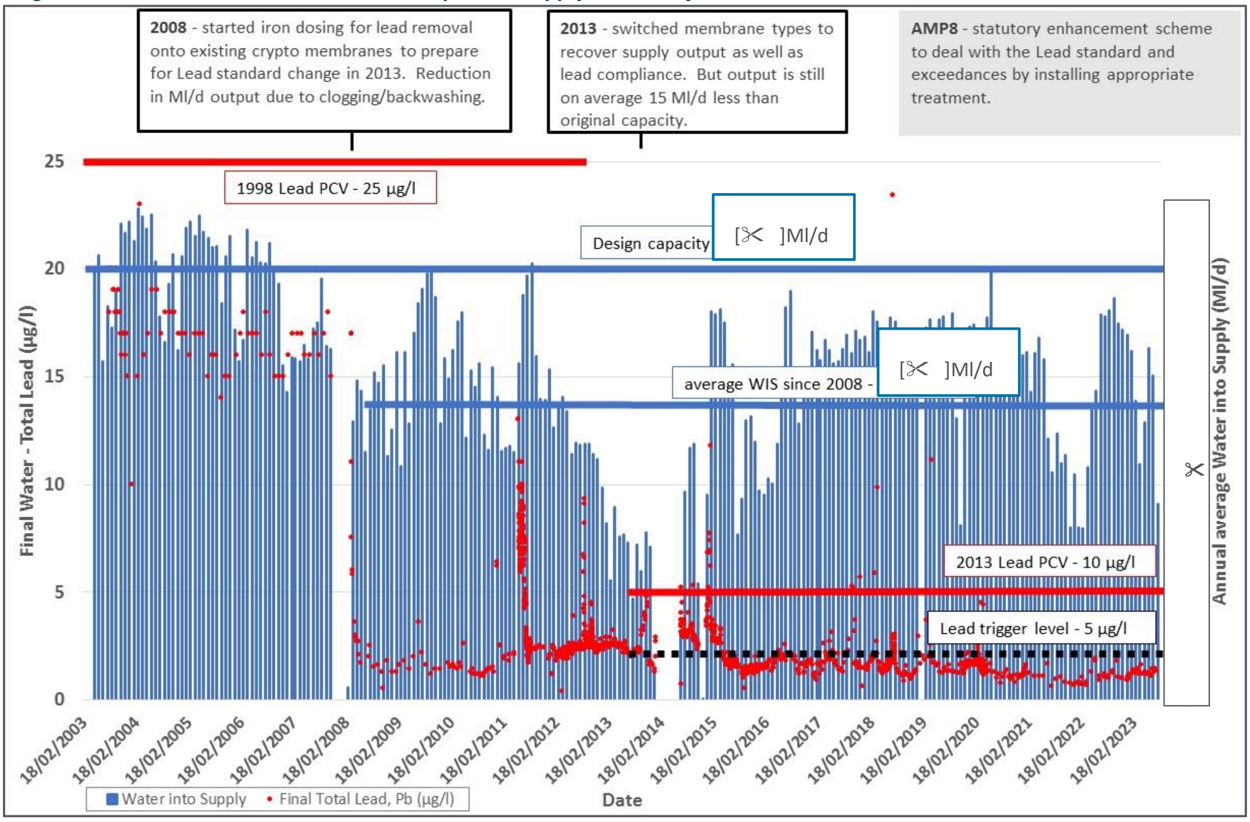
1.5.4 Raw Water Lead – Homesford WTW

- In March 2005, we received a DWI Undertaking in respect of remedial actions at Homesford WTW to secure compliance with the lead standard at the time;
- Based on pilot trials, in 2008 we started iron dosing (to remove lead by coagulation) onto the existing ultrafiltration (UF) membrane that was installed in 2000 for the removal of cryptosporidium;
- In 2009 we confirmed we had completed all steps associated with the Undertaking;
- The DWI was subsequently satisfied in 2011 with the efficacy of the remedial action as monitoring showed no exceedance of the 25µg/l standard in the final water for the duration of the Undertaking;
- The remedial action also improved compliance against the new 10µg/l standard that came into force later in 2013. However, this was at the expense of a significant reduction in output of the works as the existing membranes became clogged, requiring much greater backwashing than expected. The expected five to seven year life of membrane filters had also not been achieved due to the increased rate of deterioration caused by iron dosing;
- In 2013 we tried to rectify the problem by switching to using a different type of membrane within existing plant – low pressure backwash membranes which were deemed to be more resistant to the iron dosing and increased backwashing/cleaning required;
- These had to be replaced five years later, in 2018; and
- In 2022, the membranes were replaced again due to significant flow restrictions in Spring 2021, caused by membrane deterioration.

Overall, we have invested a large amount from base spend (£6.8m) on membrane replacements at Homesford because of iron dosing for limited lead removal. We now need enhancement investment to ensure we have more appropriate treatment in place for this statutory requirement.

Figure 12 shows flow and quality data over time and a history of changes made to the site. The dips in Water into Supply (blue line) are caused by managing lead and the retrofit changes to works that originally came in 2008.

Figure 12: Historical lead treatment and impact on supply at Homesford WTW

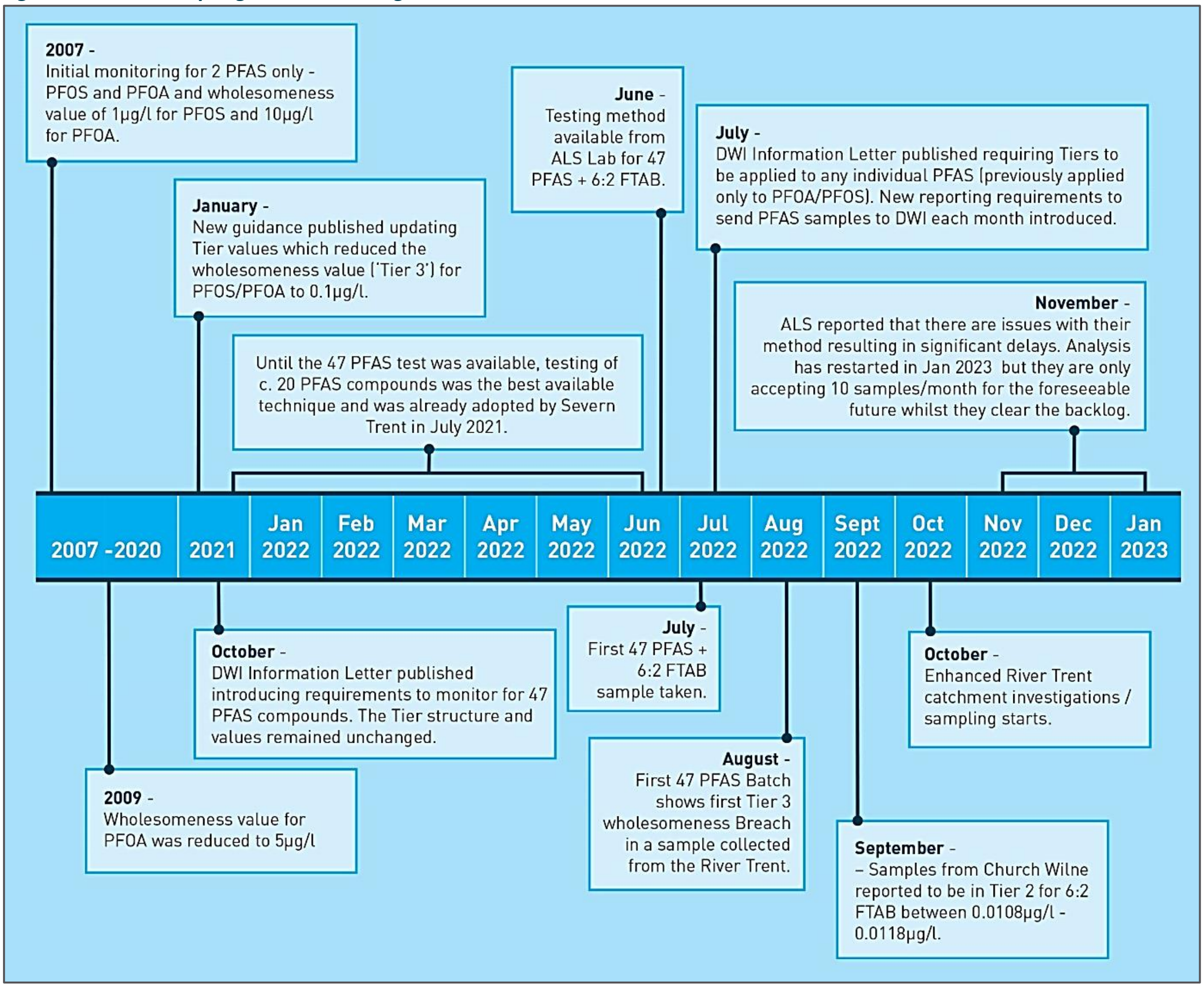


1.5.5 PFAS & emerging contaminants

The PFAS regulatory timeline below (Figure 13) shows that we tested for the original PFAS listed in regulatory guidance and all our sites were at low risk. We then went the extra mile to work out how to analyse the newly required PFAS, and we now need to invest more.

Unfortunately, the PFAS regulatory requirements, analytical capability and results (illustrated in the Figure 13 timeline below), came too late to inform the confirmation of our Witches Oak WTW solution to Ofwat in August 2022 regarding our Green Recovery 2025 commitment. The solution proposed did not allow for PFAS removal, meaning additional investment is required for the works in AMP8.

Figure 13: PFAS sampling and monitoring timeline



1.5.6 Our track record with raw water deterioration interventions

The water quality changes described here have been brought about by pollution within catchments outside our control and we have confirmed these changes are not due to the poor performance of our treatment works, as these are operating within their normal existing design parameters.

In the past, we have invested in managing raw water deterioration – we are not putting forward enhancement needs identified and funded in previous price reviews.

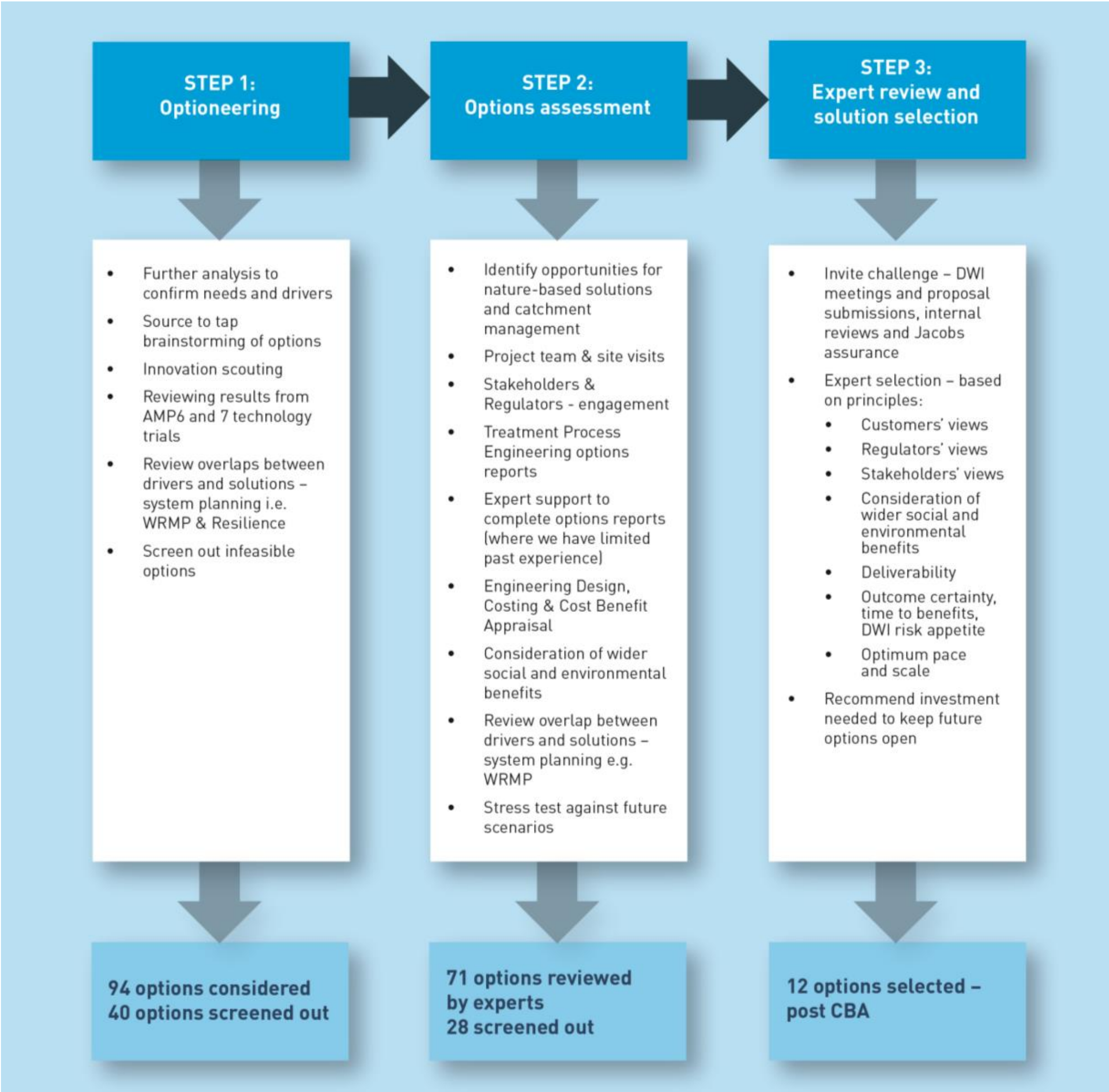
Over the last three AMP cycles we have operated, and invested in, our catchments and assets responsibly to manage drinking water quality compliance and have delivered all our statutory obligations. Our long-term drinking water quality plans came to fruition in 2020 when we were moved out of the DWI's transformation programme, which the Chief Inspector noted in their 2020 annual report as being:

> *"... a highly significant occurrence since it endorses the strategic action at the highest level in a company, to invest and drive action to prioritise their consumers and public health by maintaining and improving drinking water quality as a central strategy. This is a commendable approach and serves as an example to the industry of the necessary qualities in water company leadership"*

2. Identifying and assessing the best option for customers and the environment

In this section we set out our process for identifying options to manage the raw water deterioration described in Section 1.

Figure 14: Our Process for Identifying Options to deal with raw water deterioration



2.1 STEP 1 - Optioneering

2.1.1 Source to tap brainstorming

Having developed a list of potential investment needs, totalling more than £500m, we ran brainstorming workshops and activities with our internal technical experts to confirm these needs and to identify several solution options, from source to tap. In summary, we started with 84 options which included:

- Abandonment;
- Site relocation;

- Centralised treatment;
- Bankside storage;
- Alternative raw water intakes;
- Catchment management;
- Nature-based solutions;
- Conventional treatment;
- Innovative treatment;
- Distribution network solutions;
- Water Resources Management Plan scheme solutions ('Meeting our future water needs' business case); and
- Resilience scheme solutions ('Resilient Water Networks' business case).

As we probed more into data and analysis, we were able to screen out needs and solution options, realising they either had:

- Appropriate existing control measures in place;
- Overlaps with our wider system plans for WRMP and Resilience and our base plan; or
- More data required to better quantity risk.

Needs and solutions that were discounted altogether during optioneering included the following in Table 7:

Table 7: Example of needs and solutions discounted during optioneering step

Early Need/Solution identified	Rationale for screening out	Approximate investment removed (£m)*
Groundwater nitrate – treatment at Amen Corner, Nottinghamshire	We decided that the site will most likely need to be abandoned in 2030 due to the statutory WINEP licence changes in the area (refer to Water WINEP business case).	30
Groundwater nitrate – treatment at Boughton, Nottinghamshire	Although very close to PCV, the trend has been stable for decades so we decided that, instead, we could save customers money and manage the risk. We also confirmed that an AMP7 WRMP scheme and proposed AMP8 resilience scheme (Resilient Water Networks business case) would allow the Boughton system to be less restricted by current nitrate blending arrangements.	42
Groundwater cryptosporidium – treatment at Astley and Lee Brockhurst	We drilled into our catchment risk assessments and found that risks at these sites were being driven more by our own on-site sources/activities, rather than off-site risks in the catchment. So we decided to look at instigating other control measures before pursuing UV schemes.	8
Water quality risk at Strensham WTW – bankside storage, alternative raw water source or additional treatment	Strensham is our worst performing WTW in terms of the DWI's Compliance Risk Index (CRI) measure, mainly due to bacteriological (coliform) detections – we have carried out extensive investigations. Our data science investigations (Appendix A) could not establish any clear evidence of raw water deterioration to appear in this business case. Much of this was to do with the limited data record for climate change predictions, something recognised by collaborative research we carried out with WRc and other companies as part of PR24. At this early optioneering stage we had considered bankside storage and using the River Avon as alternative source to the River Severn. The latter will now feature in our WRMP24 ('Meeting our future water needs') business case. We plan to carry out catchment management in this area to reduce cryptosporidium and bacteriological risks, and we made the decision to invest £20m in base spend to solve potential asset related causes (potentially UV treatment).	20 to 100
Cryptosporidium risk at Boughton WTW, Chester	In September 2021 cryptosporidium was detected in our final treated water and there was some evidence in recent years of a	20

	step-up in raw water cryptosporidium detections (DWSP red risk). Further investigations and data analysis on the River Dee could not establish whether raw water quality had deteriorated over time or had become more volatile. At this early optioneering stage we had considered additional treatment (i.e. UV) but optimisation of the WTW has improved performance – there have been no further detections since November 2021. We also plan to carry out catchment investigations in AMP8 for the River Dee in partnership with United Utilities and DWC/WW, EA and Natural Resources Wales.	

**Approximate estimate as part of early optioneering stage that had lower scope and cost certainty compared with later solution selection stages.*

2.1.2 Innovation – scouting and reviews of trials

All the needs and solutions being looked at for this business case have brought in innovation and learning from inside and outside our organisation and will continue to do so. Some examples are described in Table 8 below.

Table 8: Summary of key learning and innovation for solution options

Needs	Summary of key learning in innovation for solutions
Groundwater nitrate	• We are undertaking a global horizon scan of best practice for nitrate removal. The aim is to identify processes that avoid the need for nitrate treatment waste disposal which conventionally requires new sewers laid to large WwTW. The horizon scan will also consider options for the in-situ treatment of the nitrate waste to enable alternative disposal/reuse options; and • We have previously explored technologies such as biological treatment and in-situ destruction of nitrate in treatment waste streams. Historically, these technologies have had issues with the robustness of the process, However, we believe the market/technology may have developed sufficiently to make these solutions worthy of consideration for schemes in AMP8. Our evaluation of these potential solutions will include: totex, robustness/suitability for use in UK, current regulatory approvals, and the availability of reference sites to assess asset operator experience.
Groundwater cryptosporidium – UV	• LED technology: We approached Typhon to find out the latest on the developments in LED UV technology. It is expected to be a much more energy efficient technology than conventional UV lamps, and we were keen to see if it could be applied to our AMP8 proposals. For the site capacities we looked at, significantly more LED UV reactors would be required than conventional reactors, meaning higher capex, and, although opex estimates were slightly lower, this did not offset the higher capex. There is also a risk with current systems as there is no lamp wiper mechanism to prevent iron and manganese deposition which would prevent effective treatment. Taking these into account, we did not consider this to be a viable option for AMP8 but we will continue to monitor developments. During AMP7 we explored a joint industry collaboration with Typhon, via the Ofwat Innovation Fund, to validate these findings; • Offsite manufacturing: Learning from AMP7 efficient programmes – our UV solutions are based on offsite manufacturing/skid mounted to reduce construction costs; and • Interceptor tanks: Use of interceptor tanks to deal with UV lamp breakage – although very uncommon, it has happened. New design allows much faster site recommissioning time and waste containment.
Algae – Whitacre	• We have considered the latest UK research on managing algal blooms: *UKWIR – Developing Management Strategies for increasingly frequent algal blooms in source waters - Report Ref. No. 20/DW/07/10;* • In 2020 we commissioned the global environmental consultancy APEM to examine the available data from the Whitacre system identify options for managing and controlling algal blooms to reduce impacts on the operation of the WTW; and • For the last two years we have had an Innovation project underway which looks to understand causes and short-, medium- and long-term control options for algae specifically in the Whitacre/Shustoke Reservoir system. A key component of this includes piloting the use of Mecana pile cloth filter for algae removal. The project includes assessing treatability of filtered water. • In 2022 we commissioned Mott MacDonald to look at the feasibility for nature-based solutions at Whitacre, which included floating wetlands – taking learnings from our Green Recovery project at Witches Oak;

	• Working with LG Sonic, which has global expertise in managing algal blooms using ultrasonic technology and satellite imagery. A trial has been underway since 2022 to inform solution options; • Working with Doosan, a supplier which is offering a new more efficient, cheaper DAF technology which avoids the need for air saturators; • We submitted an Ofwat Innovation Fund project proposal which aims to use a digital twin of water systems to allow more predictive management of abstraction, including when reservoirs are restricted; and • At all our reservoir sites we are rolling out the use of new algal probes and sondes following one of our innovation projects – these give immediate warnings of algal bloom development so sites can draw-off at different reservoir levels to avoid algae. However, this is of no use at Shustoke/Whitacre as there is only one draw-off level due to it being such a shallow reservoir.
Lead – Homesford	• Next generation of ceramic membranes – a segmented membrane that is patented by Nanostone, a world-leading supplier of ceramic membranes. Compared to conventional ceramic membranes, their product claims to have higher surface area, higher yield, and lower manufacturing costs as no machining is required in production. It is more robust and reliable, giving a broader range of applications, which is good for Homesford; • We have been working with Nanostone and have purchased a pilot plant which we aim to have up and running in 2023; and • We are aiming for a six-month trial to prove design flows used and to look at whole life cost to choose the best flux rate options.

PFAS – Witches Oak, River Trent	• Our Green Recovery project at Witches Oak is employing a wide range of innovation that we are learning from to inform AMP8:
	  ○ Ceramic membrane treatment;
	  ○ Use of wetlands (i.e. floating wetlands) as a pre-treatment process;
	  ○ Use of Witches Oak as bankside storage;
	  ○ UV as part of the disinfection process replacing the need for a contact tank; and
	  ○ Installing in-line coagulation units at half the height to reduce the lift required by the abstraction pumps.
	• To prepare for the PFAS design challenge, we have been engaging with Veolia on installing a pilot plant to trial new technologies for PFAS removal – due to run from November 2023 to November 2024;
	• A concern for any treatment process is returning PFAS to the environment via disposal of treatment waste into sewage treatment processes. So, we have started working with Warwick University on exploring a high energy Advanced Oxidation Process (AOP) that uses boron doped diamond electrodes to bind destroy large and short chain PFAS molecules;
	• This research will complement trials of PFAS treatment technologies currently being undertaken by Cranfield University (commissioned by the DWI with additional funding from UKWIR). These trials will identify options to remove PFAS from potable water but do not include the treatment/disposal of any residual waste streams;
	• To support our catchment investigation to control PFAS at source we have investigated novel detection/monitoring systems that can help assess the occurrence of PFAS compounds. We are planning to trial passive sampler that will provide a more reliable assessment of PFAS occurrence the spot samples; and
	• We also recently visited PUB – Singapore's National Water Agency – to start sharing and learning on innovation initiatives. PFAS expertise is one of these themes.

Emerging risks – monitoring and laboratory equipment	We have been developing an accredited method to analyse the full suite of the 47 PFAS compounds – we will be submitting our method and validation to UKAS in August 2023. We are the only laboratory in our sector, other than ALS, with a method for the analysis of an additional PFAS that was identified from a screening method used for the CIP 6:2 FTAB which is a precursor to some of the other PFAS in the suite of 47. We are aware that many of the other water company laboratories have been setting up PFAS analysis, some more successfully than others, and many have now postponed their development programme due to the technical challenges.
	• To better understand the impact of climate change on raw water quality deterioration to inform and develop our long-term plan we:
	  ○ Joined a WRc Portfolio project with five other water companies: CP621 – Water Quality in Water Resource planning, summarised in Appendix A; and
	  ○ Employed our recently recruited data scientists in Asset Intelligence and Innovation to use various big data sources to look for an indication of future needs and solutions – summary in Appendix A.

2.2 STEP 2 - Options assessment

After our optioneering stage, we had 71 options for further assessment. Having clearly established the need for interventions with our planning and operational teams, we started early feasibility and high-level design on solution options with our innovation, process design, engineering, and commercial teams and our supply chain. Our process closely follows our capital design and delivery process for feasibility and high-level design. Site visits and engagement with teams across the asset management cycle and outside our organisation have been carried out to identify these solutions, along with key stakeholders and regulators see (Table 9).

Table 9: Activities and engagement undertaken during options assessment stage

Need	Site visits & activity	Teams involved	Engagement with Stakeholders and Regulators
Groundwater nitrate	Catchment visits and investigations at Beckbury and Cosford	Catchment, Hydrogeology, Customer Operations (site team), Engineering Design and Delivery	EA confirmation through WINEP plus EA local teams, DWI PR24 meetings, farmers in the catchment, National Farmers Union (NFU), Industry/consultants – for best practice for NEP nitrate investigations and treatment solutions.
Groundwater cryptosporidium	Site level Catchment Risk Assessment visits. Engineering desk-based reviews of our groundwater site surveys carried out by our Integrated Programme Team for AMP7 delivery, e.g. borehole surveys, previous scheme reviews, MCCs, etc.	Catchment, Hydrogeology, Customer Operations (site team), Hydraulic engineers, Engineering Design and Delivery	EA confirmation through WINEP plus EA local teams, DWI PR24 meetings, farmers in the catchment, NFU Industry/consultants – for best practice for cryptosporidium investigations and treatment solutions.
Algae – Whitacre WTW	10 detailed site visits specifically about scheme solutions.	Severn Trent: Catchment, Customer Operations (site team), Treatment Process Engineering design team, Engineering Design and Delivery, Innovation team, Asset Strategy and Planning External suppliers: LG sonics (ultrasonics), Doosan (DAF), Elique Hydro (Mecana filter), and Mott MacDonald (floating wetlands)	EA confirmation through WINEP, plus local EA teams, DWI PR24 meetings, Natural England, Warwickshire Wildlife Trust, NFU, farmers in catchment, large estates in the catchment (e.g. Packington), Arden Farmer Facilitation Fund Network, Warwickshire Rural Hub, Harworth Group (Large commercial landowner) Shustoke Sailing Club, and Shustoke Fly Fishers (fishing club).
Lead – Homesford WTW	Four detailed site visits specifically about scheme solutions.	Severn Trent: Customer Operations (site team), Engineering Design and Delivery, Treatment Process Engineering design team, Innovation team, Asset Strategy and Planning. External supplier: Nanostone (ceramic membrane)	DWI PR24 meetings. Historically we have engaged with the EA on the structural integrity of the Meerbrook Sough, which is the source of Homesford WTW.
PFAS – Witches Oak WTW, Cropston WTW	We currently have a pilot plant and live project delivery team on site for our Green Recovery scheme at Witches Oak – the same team has been working on PFAS solution options for AMP8	Severn Trent: Catchment team, Customer Operations (site team) – water/wastewater/biosolids/trade effluent, Engineering Design and Delivery, Treatment Process Engineering design team, Innovation team, External supplier: Veolia	EA local teams – water and wastewater, Fire Service, East Midlands Airport, landfill operators, local authorities, UKHSA.

Emerging risks – monitoring and laboratory	Visits to Bridgend chemistry laboratories to confirm equipment and costs required.	Laboratory: Labs Manager and Principal Scientist, Strategy and Planning, Water Quality Regulations team,	Labs Liaison Forum, as well as other groups such as "Laboratory Mutual Aid – chaired by DWQR (Scotland) and with DWI in attendance", and the Standing Committee of Analysts (SCA).

For all options, we completed Process Options Reports, which is our standard approach for all our live capital projects. We self-funded these knowing that several options would not proceed but needed high calibre work for this business case. These technical reports considered feasible options and outlined advantages, disadvantages, risks, and certainty of outcome. They are summarised in Tables 11 to 19, and highlight which ones we screened out, and those we put forward for preliminary design, costing and benefits assessment using our standard tools (our approach to costs is set out in Section 5). In most cases our preferred and most feasible option has the lowest whole life and carbon costs.

Catchment management is always our first line of defence for drinking water quality and brings wider social and environmental benefits. However, our studies show that it can take decades for these schemes to take effect due to the nature of the sandstone aquifers in our region. We have strong, industry-leading catchment management plans in place and much of it is delivered through our WINEP under Drinking Water Protected areas. We fully acknowledge the DWI's long-term planning guidance that companies will be required to adopt a twin track approach that includes treatment and/or other operational control measures in addition to catchment management actions to mitigate the risks to consumers from raw water deterioration (more detail on Catchment Management options considered were provided in our DWI PR24 submissions).

Although these proposals are supported by the DWI, we have attempted to judge their benefit in terms of CRI – the most relevant performance commitment for raw water deterioration. The proposals would avoid future failures (not AMP8 targets) that would lead to a potential CRI impact, or, in the case of cryptosporidium, an Event Risk Index (ERI) failure.

For CRI we have looked at root cause failures and estimated the potential CRI impact of failure for a given water quality parameter and site. All solution options put forward have the same CRI benefit – expressed as CRI failure avoided (see Table 10). The total package of options could be viewed as avoiding a total of 2 CRI points in future AMPs, although only 0.18 was seen or realised so far in AMP7 for these sources.

Table 10: Summary of avoided CRI impact based on 2023 CRI calculator

Raw Water Driver	Source	Potential future AMP CRI Score	AMP7 actual CRI score
Cryptosporidium and bacteria – groundwater	Edgmond Bridge and Lilleshall	0.12	0
	Far Baulker and Rufford	0.12	0
	Rednal	0.00	0
	Westwood and Dunhampton	0.05	0
	Wildmoor	0.08	0
	Cresswell	0.08	0.18
Nitrate – groundwater	Nurton DSR blend (Cosford, Copley and Hilton)	0.19	0
	Nedge Hill blend (Beckbury and Grindleforge)	0.15	0
Algal blooms* – reservoir	Whitacre WTWs	0.34	0
Lead – raw water**	Homesford WTW	n/a	0
PFAS – Emerging contaminants***	Witches Oak WTW	0.98	0
	Cropston WTW	0.17	0
	Total	2.28	0.18

**Based on bacteriological failures caused by ineffective treatment.*
***WTW final water Lead is not part of CRI score methodology – Lead has minimal impact on CRI due to low prescribed sample frequencies, and point of compliance is at customer tap – scoring at DMA level not WQZ.*

****PFAS is not yet part of CRI (no PCV) so no impact on AMP7 CRI.*

2.2.1 Nitrate options

Table 11: Summary of options considered to treat nitrate

Groundwater nitrate	Overview of option	Certainty of outcome	Put forward for CBA?
Catchment	For the two proposals in AMP8 we have nitrate catchment schemes in place – the costs of which are part of WINEP	Low	No
Treatment – ion exchange (IX) and waste sewer main	Ion exchange is a reliable conventional process for removing nitrate, and we have lots of experience delivering and operating them. Solution generates waste that requires careful disposal and treatment.	High	Yes
Treatment – electrolytic dialysis reversal (EDR) and waste sewer main	EDR is a treatment process that we have little or no experience of delivering and operating. Solution also generates waste that requires careful disposal and treatment.	High	Yes
Treatment – reverse osmosis (RO) and waste sewer main	We have some experience of designing, delivering and operation RO plants for hardness reduction and nitrate. This will be a technology looked at more as part of next generation options for our WRMP. Solution generates a highly concentrated waste that requires disposal and treatment, and is energy intensive.	High	Yes
Blending	For our two sites we have considered longer term WRMP solutions to bring more low nitrate water into the area from Hampton Loade WTW. However, working with South Staffs Water we have confirmed that this extra water is not available or reliable enough to maintain nitrate compliance in this area. This option would also leave these sites as non-resilient.	Low	No
Site abandonment	Given the WRMP24 supply demand assumptions in this zone we have no option to abandon this source as it could create new localised supply shortfalls over and above the material deficit challenges being addressed in our WRMP.	High	No

Table 12: Summary of outputs from Cost-Benefit Analysis for shortlisted options considered to treat nitrates

Site	Solution option	Financial cost and risks – 25yr Ofwat compliant (£m)	Total carbon costs (£m)
Cosford	IX (preferred)	23.87	0.747
	EDR	33.85	1.21
	RO	29.09	0.82
Beckbury	IX (preferred)	24.65	0.36
	EDR	27.10	0.57
	RO	24.98	0.40

Our preferred option for nitrate has the lowest whole life cost and carbon cost of options assessed.

2.2.2 Cryptosporidium and bacteria options

Table 13: Summary of considered options for cryptosporidium/bacteriological risk intervention

Groundwater cryptosporidium	Overview of option	Certainty of outcome	Put forward for CBA?
Catchment	For all our cryptosporidium/bacteriological risk sites identified for AMP8 intervention, we have proposed groundwater catchment investigations. These will inform whether catchment management is a viable option. Such solutions could include providing agricultural advisors and influencing changing farming practices.	Low	No
Treatment – UV conventional	UV is a reliable, robust and chemical free treatment with no waste – we have lots of experience delivering and operating them efficiently.	High	Yes

(preferred)			
Treatment – UV LED	We approached Typhon to find out the latest on the developments in LED UV technology. It is expected to be a much more energy efficient technology than conventional UV lamps, and we were keen to see if it could be applied to our AMP8 proposals. For the site capacities we looked at, significantly more LED UV reactors would be required than conventional reactors, meaning higher capex and, although opex was slightly lower, this did not offset the higher capex. Given this, we did not consider this to be a viable option for AMP8, but we will continue to monitor developments.	Low	No
Treatment – emergency UV rigs/connection points	Taking the learnings from previous programmes, we considered purchasing emergency UV rigs and installing connection (plug and play) points at our AMP8 proposed sites. However, this does not protect our customers from cryptosporidium, only ensuring we can get potentially failed sites back up and running more quickly if a failure occurs	Low	Yes
Treatment – Ultrafiltration (UF) membrane.	UF is as effective as UV disinfection with the added benefit of posing less bromate risk. We have experience of delivering and operating these cryptosporidium solutions. They are more energy intensive than UV and require chemicals for cleaning, and produce a waste stream.	High	Yes
Treatment – filters and conventional chlorination disinfection	We have experience of installing replaceable cartridge filters for turbidity issues and this could be a solution for cryptosporidium removal but requires super- and de-chlorination (S&D) downstream. Not a standard approach in our design manual.	Med	Yes
Site abandonment	We have confirmed that all five sites are required in our WRMP24 and WINEP programme and so abandonment is not a feasible option.	High	No

Table 14: Summary of outputs from CBA for shortlisted options considered for cryptosporidium/bacteria

Site	Solution option	Financial cost and Risks – 25yr (£m)	Total carbon costs (£m)
Dunhampton/Westwood	UV (preferred)	2.45	0.39
	UF	34.27	0.38
	Cartridge filters with S&D disinfection	10.11	51.75
	Emergency UV connection points	1.08	0.34
Edgmond Bridge/ Lilleshall/Redhill	UV (preferred)	3.22	0.39
	UF	43.61	0.38
	Cartridge filters with S&D disinfection	7.16	51.75
	Emergency UV connection points	1.55	0.34
Rufford/Far Baulker	UV	9.17	0.39
	UF (preferred)	62.84	0.38
	Cartridge filters with S&D disinfection	28.41	51.75
	Emergency UV connection points	6.51	0.34
Rednal	UV (preferred)	4.45	0.39
	UF	31.97	0.38
	Cartridge filters with S&D disinfection	9.14	51.75
	Emergency UV connection points	2.64	0.34
Wildmoor	UV (preferred)	6.02	0.39
	UF	39.50	0.38
	Cartridge filters with S&D disinfection	11.72	51.75
	Emergency UV connection points	2.56	0.34
Cresswell	UV and iron and manganese removal (preferred)	17.66	0.39
	UF	37.76	0.38
	Cartridge filters with S&D disinfection	21.31	51.75
	Emergency UV connection points	1.18	0.34
Emergency UV plants		5.23	0.34

Generally our preferred option for cryptosporidium/bacteria has the lowest whole life cost and difference in carbon costs between UF and UV are negligible. Emergency UV is shown as an option but does not provide the outcome required.

2.2.3 Algae options

Table 15: Summary of options considered to deal with algae at Whitacre WTW

Algae – Whitacre	Overview of option	Certainty of outcome	Put forward for CBA?
Removal of nitrogen and phosphorus from wastewater treatment works discharges	For the Blythe and Bourne, our AMP7 and AMP8 wastewater programmes will deliver our fair share of phosphate reduction to get to WFD good status for those rivers. Refer to Section 1.5 for more information on management control. Despite dramatic reduction in phosphorous input to our rivers already and planned, data shows how slow recovery to an oligotrophic state (approximately 10 µg/l P) can/will be for the reservoirs, i.e. much smaller concentrations are required to limit algal growth.	Low	No
Catchment management	Catchment management around Whitacre began with an AMP5 investigation, which led to an AMP6 WINEP catchment scheme focussing on Bourne and Blythe – the catchment became designated as a drinking water safeguard zone for pesticides and nitrate, with an associated package of catchment management measures. For AMP8, the Whitacre programme will expand its scope to include nutrients (particularly phosphates), via a WINEP Catchment Nutrient Balancing scheme but this will have a mid- to long-term material benefit (15-25 years) for the Shustoke and Whitacre reservoirs based on what we see with river improvements – *our PR24 DWI submissions provided more detail on catchment management and other mid- to long-term options we commissioned APEM to look into*.	Low	No
Nature-based solutions – floating wetlands	Biomatrix produce a floating wetland system, which is comprised of planted islands created on a floating platform, with the root systems feeding into the water – these systems can act as a coagulant surface, and remove nutrients that algae feed on. In 2022 we commissioned Mott MacDonald to undertake a feasibility study into this option for Whitacre and concluded this could not be a standalone solution; the impact of predicted nutrient removal rates was uncertain and we felt we could not justify the c.£3m to £5m installation cost that would be required. The likely coverage of the reservoirs would also significantly impact the local sailing club and other users. We will continue to assess the solution we are currently working on as part of our Green Recovery project at Witches Oak WTW.	Low	No
Solar panel coverings	We are aware that some water companies are using solar panels to cover open reservoirs to control algae growth with the added benefit of generating renewable energy. We considered this as part of the feasibility project above. Similarly to floating wetlands, the likely coverage required was thought to be too disruptive for the sailing club, anglers, and visitors to this locally important place for wildlife.	Low	No
Nature-based solutions – ultrasonics	We are already trialling the use of ultrasonics at Whitacre (since summer 2022) but do not have enough data or evidence yet to determine its effectiveness. It is not likely to be a standalone solution and, similar to wetlands, could be useful for peak lopping of very high algal blooms.	Low	No
Pre - treatment/removal – pile cloth filter	We are already trialling this as part of our innovation portfolio and still require more data to determine whether this will be a reliable enough solution in terms of algae removal rate and treatability downstream. We have costed this solution for CBA on the assumption it could be a standalone solution.	Med	Yes
New dissolved air floatation (DAF) plant and pumping	For any source waters at risk from algae, the conventional treatment approach would be DAF as opposed to hopper bottom clarifiers that are currently at Whitacre, which are more suited to lowland river fed WTWs. DAF air bubbles are particularly good at attaching and	High	Yes

arrangements (preferred)	removing algal cells. At most of our works we have a mix of HBCs and DAFs to cope with algal periods as they arise – Whitacre has never had these; most likely as back in the 1980s/1990s, ferric dosing of the reservoirs took place as the main control (and this has since been banned by the EA). Innovation wise we have been working with Doosan, a supplier which is offering a new efficient, cheaper DAF technology that avoids the need for air saturators.		
New ceramic membrane plant	Ceramic membranes can completely replace the clarification and filtration process at a works and theoretically provide a cheaper and lower chemical solution – as is being delivered by our green recovery project at Witches Oak.	High	Yes
Continued use of Frankley WTW treated water – backfill lost water with new source	We have considered a WRMP scheme option for an additional 15Ml/d from Birmingham Canals (surplus) to River Severn to Lick Hill/Frankley WTW – this could replace the lost water at Whitacre caused by managing algae. The scheme would cost £30.7m AMP totex (£2.05m per ML) versus the £67.3m AMP totex (£4.2m per ML) we currently propose for the raw water quality component of the proposed DAF/raw water pumping scheme. However, the WRMP solution would neither eliminate the drinking water quality risk at Whitacre nor provide synergy with our base maintenance plan at Whitacre WTW.	Med	No
Site abandonment	We had considered this option by looking at two of our WRMP24 solution options (non-preferred) to backfill the water: Minworth effluent re-use schemes which ranged from 30Ml/d (c.£205m) and 90Ml/d (c.£472m). These were considerably more expensive than treatment options and a draft WRMP24 solution to expand Whitacre WTW. There was also a non-preferred WRMP24 option for Ogston WTW expansion by 50Ml/d at c.£83m but this is further north in our strategic grid and it was deemed to be very difficult to get water to the areas currently supplied by Whitacre.	High	No

Table 16: Summary of outputs from CBA for shortlisted options for Whitacre WTW – Algae

Solution option	Financial cost and risks – 25yr Ofwat compliant (£m)	Total carbon costs (£m)
Pile cloth (Mecana) filter	58.65	5.58
DAF (preferred)	80.17	10.91
Ceramic membrane	109.11	13.74

The pile cloth filter has the lowest whole life cost and carbon cost, however the solution does not yet guarantee the drinking water quality required – so the next lowest cost option is our preferred solution.

2.2.4 Raw Water Lead options

Removing lead supply pipes and lead from customers' homes is a complex long-term activity that we have a strategy for and have submitted alongside our scheme proposals. Removing the additional lead burden from Homesford raw water will be much more of a certain "quick win" in relative terms, and achievable in AMP8, and is far more within our direct control. Hence the options we put forward for treatment options.

Table 17: Summary of options considered to treat lead at Homesford WTW

Lead - Homesford	Overview of option	Certainty of outcome	Put forward for CBA?
Ceramic Ultrafiltration (UF) membrane plant – replace existing plant (preferred)	We have been exploring a solution with Nanostone which supplies a next generation of ceramic UF membrane that is suitably robust enough for iron dosing directly onto membranes for coagulation. The benefit is that the UF membrane also continues to meet the original cryptosporidium	High	Yes

	barrier driver at this site. We have already purchased a pilot plant to begin detailed feasibility and design.		
Conventional filtration – super- and de-chlorination – new contact tank	This option replaces the existing polymeric membrane altogether with conventional filters, e.g. RGFs, that we have at most of our large water treatment works, and would provide a cryptosporidium barrier. Lead removal would be achieved by iron dosing directly onto filters. New downstream disinfection would be required by super- and de-chlorination and a new contact tank.	High	Yes
Conventional filtration and UV disinfection/inactivation	As above but using UV as an alternative to conventional disinfection.	High	Yes
Conventional filtration and continued use of existing polymeric membrane plant	As above but retaining existing membrane plant for disinfection stage and some potential polishing for any particulate lead breakthrough.	Med	Yes
Ferric hydroxide media	Installation of enhanced water treatment media that we use for arsenic removal, contained in pressure vessels. Option would require keeping the existing membranes and smaller contact tank for disinfection and virus inactivation. Likely to be short media life and generates a hazardous landfill waste.	Med	Yes

Table 18: Summary of outputs from CBA for shortlisted options considered to treat lead at Homesford WTW

Solution option	Financial cost and risks – 25yr Ofwat compliant (£m)	Total carbon costs (£m)
Ceramic membrane (preferred)	91.67	3.97
Filtration and disinfection (Contact Tank)	96.43	3.65
Filtration and disinfection (UV)	94.08	3.77
Filtration and existing polymeric membranes	117.06	1.78
Ferric hydroxide and existing polymeric membranes	117.22	1.77

Our preferred option for lead is the lowest whole life cost option assessed – although the carbon costs come out as third highest, they are minimal over a 25 year period/asset life.

2.2.5 PFAS and Emerging contaminants – options

Witches Oak WTW is not yet built or supplying water and has yet to go through Regulation 15 approval. We understand from previous conversations with the DWI at PR24 meetings that this would not be approved if no effective control was put in place for the PFAS concentrations we have detected. We are currently assuming treatment options would be based on achieving compliance within Tier 3 (<0.1 µg/l) for the 47 individual compounds named in the current guidance as well 6:2 FTAB.

<u>Catchment Options</u>

Although we have been engaging with regulators and stakeholders (Table 9, Section 2), we are not currently sure what catchment interventions would be, or whether they would be feasible – these would come from the information and data discovery part of the investigation we intend to implement for the new Witches Oak WTW catchment. We will be undertaking a longer and more detailed investigation than we have done so far to ensure we can target and implement an effective catchment scheme for PFAS and related compounds.

This would involve:

- A more detailed programme of catchment sampling, and data interpretation, e.g. reviewing ratios of PFAS compounds to help identify potential sources;
- Better site-specific identification of PFAS risks;

- Stakeholder engagement to both help identify risks and create options that target risk reduction that are suitable in scale given the risk and surrounding circumstances; and
- Engagement, alongside other stakeholders, with landowners and businesses on a local level to raise awareness of PFAS.

Our cost estimates for this scheme are set out in Table 19. We propose a two-year investigation, which involves a greater level of stakeholder engagement to that of our standard catchment investigations to date.

Table 19: Cost estimate breakdown of proposed PFAS catchment investigation

Activity	Description	CAPEX estimate (£k)
Desk-based investigation	Desk-based catchment investigation that incorporates sampling data, catchment walkovers, and feeds outputs to better inform the DWSP.	86.1
Investigative sampling (two-year)	Catchment sampling on a recurring monthly basis for two years, plus ad-hoc during high risk times or at high risk sites (bespoke designed sampling programme to help understand transport pathways and risk movements). Also includes costs for PFAS/PFOS fingerprinting to better understand sources.	168.9
Stakeholder engagement	Extensive plan for stakeholder engagement of industry, regulators and other users/source producers.	15.0
	Total	**270**

<u>Treatment options and waste stream consideration</u>

In terms of treatment technologies, we are considering a range of options. There are several recognised forms of treatment for PFAS, including ion exchange or carbon technologies (i.e. Powdered Activated Carbon (PAC), Granular Activated Carbon (GAC), and Actiflo Carb). From what we can see so far, the only technology which removes all PFAS compounds is Reverse Osmosis, which brings significant waste and cost challenges.

We are planning to trial two technologies on the pilot plant at Witches Oak: Actiflo®Carb and Suspended Ion Exchange (SIX). Working with Veolia, we are aiming to have the pilot plant operational by November 2023 and we will trial for a year, ready to commence detailed design in December 2024. We estimate that construction of a PFAS solution may start in July 2025

Our pilot trials will aim to determine this technology's effectiveness, size, dose rates, and likely capex and opex – and will also provide additional monitoring and data to better quantify risk and inform future plans. Determining the effect of background organic matter is also important as it could influence the efficiency of the process. So far, Actiflo Carb looks be the lowest cost option – the process is similar to Actiflo (used for our Birmingham Resilience Project) but using carbon instead of sand. There are many reference sites overseas for Actiflo Carb, particularly in France. SIX is a relatively new technology with fewer reference sites.

Whatever the selected option for PFAS removal we need to avoid putting PFAS back into the water cycle and the wider environment. This means either separating the PFAS from the waste stream by concentrating it into a solid form or chemically separating it. Options that include a waste discharge to our nearby Derby wastewater treatment works (WWTWs) would need to remove the PFAS from its discharge. An Ion Exchange or Reverse Osmosis option would result in large volumes of waste being discharged to Derby WWTWs and would require a c.13km pipeline. The existing sewer network does not have the capacity for transporting such large volumes of waste to Derby WwTWs.

Another challenge is that Derby WwTWs discharges to the River Derwent upstream of the existing Draycott intake which supplies Church Wilne WTW. So any increase in PFAS discharge to the Derwent could create a PFAS compliance issue for Church Wilne WTW, if appropriate controls are not in place.

One of the main concerns about this PAC/GAC process is the disposal route for the spent carbon. From the literature it is not clear if GAC can be regenerated without the risk of releasing PFAS breakdown products into water or air via the exhaust gases during thermal destruction. We are planning laboratory scale studies to explore this further. In addition, we will explore the potential for safe incineration of the PAC/GAC.

In our pilot plant studies we will also consider the use of ion exchange resins to remove PFAS compounds. While these are known to be effective (from studies in North America) it is not clear what the best solution is to deal with ion exchange regeneration waste containing concentrated PFAS compounds. We intend to explore this in conjunction with Warwick University using a high energy Advance Oxidation Process (AOP) that uses boron dipped diamond electrodes to bind and destroy large and short chain PFAS molecules. These batch treatment processes offer an alternative to returning PFAS to the environment via disposal into sewage treatment processes.

Our research will complement trials of PFAS treatment technologies currently been undertaken by Cranfield University (commissioned by the DWI with additional funding from UKWIR). Our understanding is that these are identifying options to remove PFAS from potable water but not options for treatment/disposal of any residual waste streams.

We also recently visited PUB – Singapore's National Water Agency – to start sharing and learning on innovation initiatives. PFAS expertise is one of these themes.

Our current estimate for our preferred option at Witches Oak, ActiFlo Carb, is c.£31m capex and £730k per year in additional opex. Given that PFAS is such a new parameter we are not able to carry out CBA on multiple options at this stage.

As Cropston WTW is such a recent requirement, we are not able to carry out CBA on multiple options at this stage but will do so as part of AMP8 early work. For PR24, we have produced a preliminary design based on PAC dosing and downstream risk mitigation, based on similar plant we have installed – our CAPEX estimate is £18m. At this stage, we are unable to quantify opex as we do not know yet what PAC dose rate is required for PFAS removal. We will establish this in tests running from September 2023 to January 2024, as part of the DWI legal notice. We have made an assumption based on Witches Oak projected opex.

2.3 STEP 3 – Expert review and solution selection

2.3.1 inviting challenge, review and assurance

Regulatory challenge and collaboration

We have sought independent challenge at every stage of this process to test the rigour of our assessment and the prioritisation of our AMP8 activities. We have considered all possible options and have fully engaged with the DWI throughout the PR24 process, paying close attention to the guidance they developed with Ofwat – Long Term Planning Guidance for the Quality of drinking water supplies (July/September 2022). The guidance explains that water quality proposals will be supported if we can demonstrate there is a need driven by a change in regulatory standards or a deterioration in raw water quality. We have considered a wide range of solution options. These consider whole life costs and risks and benefits, and align with our longer-term system plans for meeting future water demand (refer to 'Meeting our future water needs' business case) and the customer-supported need to be more resilient at times when our system is under the most pressure (refer to our 'Resilient water networks' business case).

We provided updates to the DWI at technical meetings on 12 October and 15 December 2022, to gauge support and to seek their views on the evidence supporting the need for action and the solutions we had been working on.

In March 2023 we submitted our comprehensive scheme proposals, and updated risk assessment, using the detailed templates they provided, covering i) background information, ii) details of water treatment works and supply systems, iii) hazard identification and risk characterisation, and iv) control measures required, short, medium, and long-term, including costs and benefits that clearly stated were subject to change prior to final business plan submission.

In May we received the following queries/challenges from our submissions, and promptly provided detailed responses. For example:

- Cryptosporidium/bacterial – we confirmed we would commence regular cryptosporidium monitoring prior to scheme delivery, as an interim measure;
- Homesford lead – challenge on making sure that any changes in future volumetric output of the site would not increase the mass flow of lead to customers – we provided a mass balance that confirmed this would not be the case;
- Whitacre algae – we supplied more sensor data to show the impact of poor raw water quality on water treatment processes (filtration) and more information on the time limitations of Catchment Management in this area; and
- Witches Oak PFAS – confirmation that AMP8 PFAS treatment would be retrofitted to the new WTWs currently being delivered as part of the AMP7 Green Recovery initiative.

All proposals have been supported, as set out in their PR24 Decision Letters on 31 August 2023. These letters refer to the cost estimates submitted in March that were subject to change as scope and costs matured – hence differences to those presented in this business case.

<u>Internal and external assurance</u>

Prior to our DWI submissions we carried out assurance, similar to that we undertake for our annual DWI submissions for water quality performance. Our teams have processes in place to comply with the requirements and the technical knowledge to assure the information. Relevant technical knowledge is required to carry out assurance as this information is specialist in nature. The assurance followed our established Assurance Framework, with Table 20 summarising our actions.

Table 20: Overview of Assurance Processes undertaken for our DWI PR24 submissions

Activity	Carried out by	Aim
First line	SMEs within teams working on PR24 proposals	• Perform checks on the completeness and accuracy of information provided and ensure commentary is clear and explains context; • Confirm consistency with previous submissions and our PR24 plans; • Document outputs of the assurance checks; and • Ensure sign off from relevant senior manager/business lead.
Second line	Technical experts/SME outside core PR24 team	• Provide critical challenge to the content of the proposals to confirm accuracy; • Read and understand the relevant regulator guidance and ensure the submission complies with these guidelines; • Confirm the submission (text and data) has been prepared carefully and diligently, and that commentary (if applicable) is clear and explains the context; • Provide independent critical challenge of the technical content of the submission and confirmation that, overall, it is accurate, reliable, complete, and transparent; • Ensure consistency of the messaging with previous submissions; an • Document outputs of the assurance checks.
Third line	Independent third party	• Perform an independent, critical friend review to assess the evidence against the expectations in Ofwat's methodology (Appendix 9 of the PR24 final methodology) (Oct 2022 and again in March 2023); • To highlight areas where the evidence was not compelling or hard to follow to enable us to improve the articulation of our analysis; and • Formal assurance in July 2023 to review the accuracy and completeness of the business case, to report to the Severn Trent Board to inform their Board Assurance Statement.

The following sections describe in more detail the solutions we have finally selected.

2.3.6 Nitrate option selection

Historically for groundwater, “blending” of sources has been a cheaper, shorter-term solution to manage rising concentrations of nitrate. Given how our WRMP24 is dominated by the requirement to reduce groundwater supplies (418 Ml/d by 2050 which is equal to 25% of our total supply today) we can no longer rely on this as a resilient enough solution going forward. The sources that are left, including surface water treatment works, become even more critical and we need to ensure they can operate fully independent of each other so peak output is not restricted by blending, especially during extreme weather/peak demand events which we know are becoming more frequent.

For AMP8, all of this directs us to treatment as the main solution for compliance over the next 25 years, although we will continue catchment management for longer-term benefits. We have considered a wide range of solution options. These consider whole life costs, risks and benefits and align with our longer-term system plans for meeting future water demand reductions (i.e. the WRMP) and the customer-supported need to be more resilient at times when our system is under the most pressure.

Ion exchange is our preferred treatment option as it is the lowest whole life cost and is considered to be the most reliable option at this stage. We propose this treatment because these sources require a greater level of nitrate control over the next 25 years which is the assumed general asset life of a treatment plant. It is expected that, after this point, the benefits of catchment management and overall reductions in nitrate at the boreholes will begin to be realised. The DWI PR24 submissions provide more detail on addressing the risk of hazard within the required timescales.

2.3.7 Cryptosporidium option selection

Conventional UV is our preferred treatment option for most sites as it is lowest whole life cost and we considered it to be the most reliable option at this stage.

We have taken the learning from our current AMP7 UV programme:

- Offsite manufacturing – our UV solutions are based on offsite manufacturing/skid mounted to reduce construction costs; and
- Installing Interceptor tanks – to deal with potential UV lamp breakage (although very uncommon). New design allows much faster site recommissioning time and waste containment.

UV disinfection is a proven technology for microbiological and cryptosporidium inactivation. The treatment will be installed to the required standard, delivering a dose of at least $40mJ/cm^2$ at a wavelength of 254nm to achieve at least the minimum required inactivation. Water to be treated will comply with Regulation 26 requirements for disinfection. In particular, the turbidity of the water presented to disinfection will be maintained below 1 NTU. Fail safe shut down will be activated in line with our disinfection policy requirements.

Cresswell differs to the other UV schemes as it requires iron and manganese removal to avoid fouling of the UV lamps, which would render treatment ineffective.

UV has not been selected for Rufford and Far Baulker, as raw water bromide is high and much greater than the levels experienced at our existing sites with UV plants. Installing UV treatment would pose a risk of transforming bromide to bromate, which is a carcinogen and has a PCV of 10µg/l under water quality regulations, so we require an alternative. We chose UF over cartridge filters/super- and di-chlorination, as it a more robust and sustainable solution.

2.3.8 Algae option selection

We have carefully considered a wide range of options for Whitacre. Given the uncertainty around the timing and effectiveness of nature-based solutions, such as catchment management, we are proposing a new treatment process and raw water pumping configuration to be delivered in AMP8, to ensure safe compliant drinking water.

Of the three higher certainty options, DAF is our preferred treatment option as it is considered the most reliable, offering lower process risk and better removal rates. We need to gather more data from our trials to inform our final decision as we move through our gated process for projects.

All solution options have been sized to allow for improved flexibility of raw water pumping to better handle raw water deterioration challenges. This, coupled with consideration of future capital maintenance that would otherwise be required, leads us to currently proposing the following proportional allocation scheme costs for our preferred option:

Table 21: Breakdown of proportional allocation of preferred option costs for Whitacre algae – DAF

Driver	Proportional allocation (%)	AMP8 capex (£m)
Raw water quality – appropriate treatment for algae: new DAF plant and enabling including major pipework, washwater/sludge treatment, HV electrical	95	67.0
Base capital maintenance – identified disinfection plant maintenance needs	5	3.5

2.3.9 Lead option selection

Of the three higher certainty options, the ceramic membrane option currently has slightly higher whole life costs and carbon. However, it is our preferred treatment option at this stage as it is considered the most reliable option, offering lower process risk and better lead removal rates. The option is also better suited to the base capital maintenance needs of the site.

All solution options have been sized to allow for the need identified. This, coupled with consideration of future capital maintenance that would otherwise be required, leads us to propose the following proportional allocation scheme costs for our preferred option:

Table 22: Breakdown of proportional allocation of preferred option costs for Homesford lead – Ceramic membrane

Driver	Proportional allocation (%)	AMP8 capex (£m)
Raw water quality – appropriate treatment for lead removal based on current work capacity	83	74.9
Base capital maintenance – identified disinfection plant maintenance need and future replacement of existing polymer plant that is more than 20 years old	17	15.8

2.3.10 PFAS and Emerging contaminants – option selection

In summary, we have selected a programme of work estimated at c.£56.23m to address PFAS risks at Witches Oak WTW, Cropston WTW and surrounding catchments, and new analytical capability to measure removal and to identify contaminants for the longer term.

Table 23: Summary of AMP8 PFAS proposal and capex estimates

AMP8 PFAS proposals	CAPEX estimate (£m)
Catchment – investigation scheme	0.27
Treatment – new process at Witches Oak WTW – activated carbon based technology (ActiFlo Carb)	34.64
Treatment – new process at Cropston WTW – (Powdered Activated Carbon)	18.93
Specialist Laboratory equipment Liquid Chromatograph High Resolution Accurate Mass (LC-HRAM); Liquid Chromatography Triple Quadrupole Mass Spectrometry (LC-QQQ); and Specialist supporting items for PFAS and other emerging contaminants.	2.39
Total	**56.23**

Our AMP8 strategy for investigating PFAS risks and identifying actions that we submitted to the DWI in June 2023, recognised PFAS as a serious, complex and emerging challenge for us and the industry, and our commitment to working with regulators to find out more about this problem so we can best protect our customers. Unlike other water companies that we have talked to and heard from, our groundwater sources seem not to be problematic – our current challenge appears to be with large river sources.

Our approach consists of the following key components:

- **Analytical capability** – sufficient for current and future watchlist parameters, and measuring removal;
- **Monitoring** – risk-based and going beyond minimum regulatory requirements;
- **Risk characterisation** – benchmarking sites against international or potential new standards;
- **Catchment management** – risk assessments and investigations to determine potential control measures in high-risk areas, collaborating with stakeholders and regulators;
- **Research, development and innovation** – into monitoring, treatment and waste streams;
- **Operational measures** – optimising our existing assets in readiness; and
- **Identifying investment needs and solutions** – our PR24 proposals and the long term.

Investment for analytical capability is a top priority. We have been developing an accredited method to analyse the full suite of the 47 PFAS compounds and will be submitting our method and validation to UKAS in August 2023. We are the only laboratory in our sector, other than ALS, with a method for the analysis of an additional PFAS that was identified from a screening method used for the CIP 6:2 FTAB which is a precursor to some of the other PFAS in the suite of 47.

We are aware that many of the other water company laboratories have been setting up PFAS analysis, some more successfully than others, and many have now postponed their development programme due to the technical challenges.

The current lack of capacity in the supply chain for PFAS and other emerging contaminant testing poses a risk to wholesomeness and compliance as control measures cannot be verified. These parameters have typically not been previously monitored or not at the required level of detection, and we are currently too reliant on limited external laboratory services for PFAS and other emerging contaminant risks. This is a new field in analytical services for the industry.

To deal with this challenge, we are proposing additional laboratory capability in AMP8, which was part of our PR24 submission in March. Our internal laboratory service is looking to develop an in-house UKAS accredited method for the 48 PFAS compounds highlighted earlier, and we are preparing for the need to investigate compounds beyond the 47 prescribed in current guidance. To do this we propose purchasing more in-house laboratory equipment.

The challenge presented to UK laboratories by the guidelines is greater than in the EU. The EU range of PFAS are smaller molecules than in the UK suite, with the larger molecules tending to be difficult to keep in solution for analysis. Challenges remain with the heavier PFAS being absorbed in the analytical system – modifications of the method may require that the suite of 47 compounds are analysed by two processes.

Our proposed increase in capacity will also help to investigate, manage and develop a plan for other emerging contaminants in the long term that could have new legal standards put in place over the next 10 to 25 years, as described in Section 1.1.2. With this proposed investment, combined with our in-house expertise, we would also be able to support the industry in detecting emerging risks, i.e. helping other water companies if needed on a mutual aid basis, not commercial.

2.3.7 DWSP risk reduction – DWI concerns and expectations

Table 24 is the official DWSP/Regulation 28 risk status agreed with the DWI which ultimately reflects their concerns with the sources we have identified for investment, i.e. no adequate effective controls are currently in place. The table also shows the expected risk reduction for each selected solution, as confirmed with DWI.

Table 24: Pre- and Post-Treatment DWSP risks and DWI categories

Hazard / Site		Current status[1]					Expected Post-AMP8 solution completion status			
		Catchment DWSP Inherent Risk	Catchment DWI Category	WTW Overall DWSP Risk	WTW DWI Category		Catchment DWSP Risk	Catchment DWI Category	WTW Overall DWSP Risk[2]	WTW DWI Category[3]
NITRATE										
Nurton		Red	D	Red	D		Red	G	Green	A
Nedge Hill		Amber	D	Red	D		Amber	G	Green	A
CRYPTOSPORIDIUM/BACTERIOLOGICAL										
Cresswell		Red	D	Amber	D		Red	G	Green	A
Dunhampton		Red	D	Red	D		Red	G	Green	A
Far Baulker		Red	D	Amber	D		Red	G	Green	A
Redhill		Red	D	Amber	D		Red	G	Green	A
Rednal		Red	D	Amber	D		Red	G	Green	A
Wildmoor		Red	D	Amber	D		Red	G	Green	A
LEAD										
Homesford		Red	D	Amber	D		Red	G	Green	A
ALGAE/BACTERIOLOGICAL										
Whitacre		Red	D	Red	D		Red	G	Green	A

[1] Based on worst risk score for relevant parameters and sources.
[2] Overall DWSP risk expected outcome following delivery with the support of data (Realised risk) and validation of controls (Effectiveness of Controls).
[3] DWI Category change applies to risks where the control measures are operating effectively, their operation has been verified and validation indicates that control is maintained or where we have risks that are considered tolerated. The description for DWI category are given in the table below:-

Category	***Description***	***Guidance***
A	*Target risk mitigation achieved, verified and maintained*	• *The identified risk mitigation has been verified and is subject to continuous validation* • *The company does not require any additional control measures to reduce the residual risk at the time of the assessment* • *The company concludes that the mitigation measures and residual risk can be maintained until the next review is completed*
B	*Additional or enhanced control measures which will reduce risk are being validated*	• *New or enhanced control measures have been delivered, but are in a testing/commissioning phase* • *Validation data is being gathered* • *When related to a Legal Instrument, the category should remain B until revoked*
C	*Additional or enhanced control measures which will reduce risk are being delivered*	• *New or enhanced control measures that have been designed to reduce the residual risk are being delivered* • *Physical works have commenced*
D	*Additional or enhanced control measures are required to materially reduce risk*	• *The company has information which indicates the control measures are insufficient or will become insufficient within a time frame (includes breaching an internal trigger level)* • *Additional or enhanced control measures are being determined, designed or awaiting funding*
E	*Risk under investigation*	*Risk is being investigated to determine if additional or enhanced control measures may be required*
F	*Partial mitigation*	• *Partial mitigation occurs at this stage and further mitigation occurs at assets downstream; or*

		• *Mitigation is partial as not fully in the company's control*
G	*No mitigation in place: control point downstream*	*There is no mitigation at this asset there is mitigation at a downstream asset*
H	*No mitigation in place and none required*	*There is no mitigation at this asset and there is no mitigation at an upstream or downstream asset*
I	*Long-term mitigation required*	• *The company has information which indicates that there is likely to be a failure of the standards within the Regulations within a time frame* • *Immediate mitigation is not required* • *The company has future plans to carry out work to mitigate the risk*

2.3.8 Wider social and environmental benefits

Having considered customer views, and carefully selected with stakeholders the solutions we believe are the right ones for these statutory obligations and the risk reduction required, these solutions also have wider social and environmental benefits over those discounted (see Table 25 below).

Table 25: Social and Environmental benefits for each preferred option

Selected Option	Wider environmental and social benefits
UV for cryptosporidium and bacteria pathogens	Chemical-free treatment compared to other options that use chlorine or require chemical cleaning of membranes.
Ion exchange treatment for nitrate	The Reverse Osmosis option is very high in energy and carbon costs, so not selected. The downside of Ion Exchange is production of a waste stream – we will be pursuing a very new technology opportunity in the form of biological treatment which converts nitrate into nitrogen gas so reducing waste and risk to the natural environment.
DAF for Algae removal a Whitacre WTW	We had looked at floating wetlands and solar panel coverings as options for a better environmental outcome, and the lower carbon footprint solution which was a pile filter cloth. However, these are just not certain enough in terms of the drinking water quality required. The upside is the DAF option is of benefit to the well-established users of Shustoke reservoirs, i.e. the Sailing Club and anglers, and wildlife trusts. Catchment management and wastewater WINEP programmes are already in place to deliver more, longer-term environmental benefits – explained in Sections 2.1-2.2 earlier. In the meantime the asset life of DAF treatment will be enough to manage the problem until catchment and environmental solutions have made an impact.
Lead removal at Homesford	There is not much difference between the treatment solutions required for lead removal. However, continuing the use of this sustainable source of water manages flood risk in the area which is a key concern for the EA – continued abstraction manages the rising groundwater levels of this disused mine.
PFAS	PFAS pollution in the environment is a key concern, and wastewater monitoring of some PFAS is included in the England and Wales industry Chemicals Investigations programme. Removing it from drinking water quality and the water cycle also has a benefit for the wider environment. So too does our improved laboratory analytical capability and catchment management benefit our environmental and wastewater objectives.
Catchment Management – PFAS and AMP7 schemes continuation.	From our 13+ years of experience running these schemes, we know that, for every £1 we invest in catchment management, we save between £2 and £20 in water treatment costs and create £4 of wider environmental benefits.

3. A ‘no and low regrets’ strategy for the long term

In Annex 2 ‘LTDS’, we set out our single adaptive Long term delivery strategy. It provides details of our approach, the building blocks of our core pathway, details of how that has been shaped by customers, stakeholders and our Board and the evidence to show that it is no/low regrets investment against a wide range of plausible futures.

In this section we provide the specific evidence to show how we have applied adaptive planning principles described in Annex 2 to this investment case and how the investment proposed meets the definition of no-regrets investment choices.

In summary: All the investment by 2030 in this case is statutory driven and therefore meets the definition of no regrets. Added to this, our analysis shows the investment is not sensitive to the Ofwat common reference scenarios, which means our proposed investments remain the best value across all eight of them.

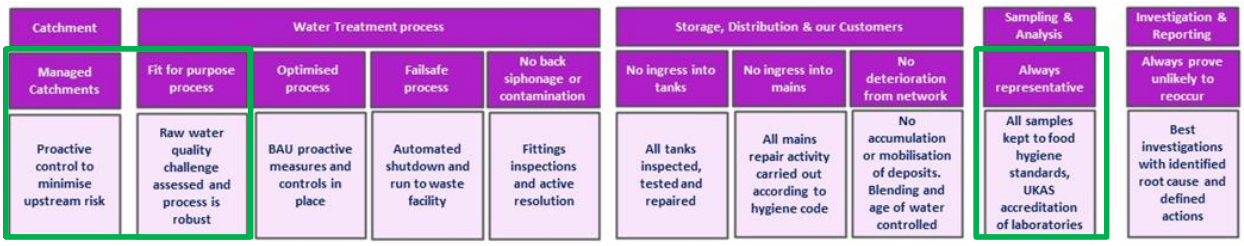
3.1 Our long-term ambition

Ensuring water is good to drink is one of our long-term outcomes, and we constantly strive to achieve its strategic goal which is:

- That supplies are continuously safe and 100% compliant with drinking water quality standards; and
- At a cost and quality that our customers find acceptable, while enhancing the environment.

Our good to drink plan identifies the key source to tap activities and outputs required to achieve this goal, now and in the future (Figure 15 below). Catchment management is our first line of defence – as explained in Section 2, we follow a twin track approach to try to get water collected in our catchment as cleanly as possible. Secondly, we need to match treatment processes to any raw water quality challenge or deterioration to get the optimum solution and therefore the most efficient cost to treat water – balancing quality and cost in every location. This also includes horizon scanning for future pollutants or where standards maybe tightened. These key things are the subject of this business case.

Figure 15: Our Good to Drink long term outcome – source to tap approach and relevant activities in this business case



3.1.1 What base buys

The first step to establishing enhancement needs to meet our long-term strategy is to consider what improvements can be made through our base service investments. Ensuring a consistently high quality of water requires the complete source to tap approach shown in Figure 15 and this is largely delivered through our business as usual processes (funded through BOTEX+ modelled allowance). As described in Section 1, this case relates solely to demonstrable changes in the raw water quality driven by external factors that need to be mitigated to ensure we continue to meet the expected high standards of water quality.

There are three aspects to driving improvements: performance commitment improvements delivered through our base plan (refer to Annex 5a 'Common performance commitments'), wider customer service improvements, and wider social and environmental benefits.

The measure that relates to this investment is CRI – improvement is funded exclusively from base spend. The investment set out in this business case is needed to offset the increased future risk of CRI failure – it is unacceptable to customers and our water quality regulators to allow a deterioration in this vital service area. We forecast that, without this investment, CRI could increase by 2 points in future AMPs – detailed in Section 2.2 above.

3.1.2 Challenges to overcome to meet this ambition

For our Strategic Direction Statement (SDS) we carried out research into key trends over the next 30 years. The key ones related to this business case for AMP8 include rising concerns over pollution to our watercourses. Given the fast-growing list of emerging contaminants such as PFAS compounds we will need at some point in the next 10 to 25 years to start to transition to more advanced treatment to ensure we can adapt. We also need to better understand the relationship between climate change and raw water quality, which we discuss in relation to the Common Reference Scenarios below.

3.2 Approach

To establish the most appropriate approach for defining the no-regrets programme we first considered the degree to which this investment is sensitive to the Ofwat common reference scenarios (CRS) and any other drivers of uncertainty. Table 26 summarises the relevance of the CRS for this business case.

Table 26: Assessment of investment sensitivity to common scenarios

Enhancement investment areas	Type of investment	Degree of Uncertainty (H,M,L)	Sensitivity to Ofwat common reference and bespoke scenarios					Robustness of data to understand relationship	Decision support needed
			Climate change	Tech-nology	Growth	Environ-ment	Other		
Raw water deterioration	Statutory	M	Possible	Possible	No	Possible	Legislation	L	No – CBA is appropriate

There are plausible relationships between climate change and environment CRS. However, the industry-wide limited availability of robust data and modelling for long term water quality, combined with the fact that this investment has a 2030 statutory driver resulted in us concluding that: i) the no regrets analysis could be best managed through sensitivity testing of the assumptions in our cost/benefit analysis; and ii) that it was not appropriate or necessary to use computational decision-making tools.

We do think there is scientific logic to suggest that climate change may impact raw water quality and treatability at some point in time:

- Changing rainfall patterns could increase the amount of sediment and pollutants being washed off the land and into our reservoirs and river sources, which could impact treatability; and
- Longer, drier summers and changes in rainfall patterns could increase the risk of algal blooms developing in reservoirs (an example being Whitacre WTW's Shustoke Reservoir which is covered by AMP8 investment in this business case).

To better understand this relationship we undertook a data science approach with WRc, jointly with other water companies, and using our own data scientists (summary in Appendix A). We were unable to establish a statistical relationship, mainly as we and the other companies do not have long enough data sets – it is only in the last 10 or 12 years that the industry has started to collect the right amount of water quality data and this is too short a period to consider for climate trends and predictive modelling.

The closest research linking climate change, raw water quality and treatability that we have found has been led by the Norwegian Meteorological Office (*Impacts of climate change on drinking water quality in Norway (2022) RG. Skaland et al. Journal of Water and Health Vol 20 No 3, 539*). In this study, associations between weather, surface water runoff and water quality were combined with climate change scenarios for the first time. Raw water quality (bacteria, turbidity and colour) was predicted to deteriorate by the end of the century, mainly due to increasing amounts of rainfall. However, they concluded that the concentrations predicted are relatively small and it is therefore likely that large waterworks will adapt to future conditions (although treatment processes at smaller waterworks might be challenged).

Therefore, we concluded the investment choices being made in the next five years typically have 30 year asset lives, which means they will be due for replacement before the impacts of climate change are observable and therefore we have not produced an alternative pathway for the climate CRS.

Similarly, there is a knock-on impact of the licence capping assumptions as part of the environment CRS. This is because changes to our abstraction regime mean that, where we currently blend groundwater sources to reduce concentration of some contaminants, this will no longer be possible. Our Water WINEP business case deals with this challenge. None of the drivers in this case are as a result of the current licence capping or future Environmental Destination (ED) and none of the investments we have proposed in AMP8 for raw water deterioration are affected by ED.

In addition to the CRS, we decided to manually consider the impact of potential future tightening of standards or inclusion of additional compounds to test if this would lead to investment regret for any of the AMP8 proposals. This data was input into the central repository of our decision support tool so that it could be combined with all other aspects of the plan to create our alternative adaptive pathways.

3.3 Creating our no-regrets core pathway

We are confident that the core pathway represents no regrets investment for the following reasons:

- All the investment for 2030 included in this case has been supported by the DWI and therefore by definition is no regrets, and 80% (by value) have statutory instruments (Regulation 28 notices) applied to them;
- The five schemes that have DWI support but without Regulation 28 notices are for the groundwater cryptosporidium/bacteria sites at risk. In their decision letters, the DWI supports these schemes, recognising the risk of faecal contamination of groundwater. They explained that formal enforcement action and putting in place legal instruments was inappropriate at this stage because the risk had not been realised in terms of sample failures – but that regulatory enforcement action could be taken subsequently, if considered necessary to protect public health. So any sample failure that does occur in AMP8, which is likely based on the information explained in sections 1.4.2 and 1.5.2, would lead to legal instruments being put in place, which would require enhancement expenditure for those new statutory requirement. Any failures would also seriously impact our water availability position as these sites would have to be put out of supply until schemes could be delivered;
- We recognise the need to give customers extra protection for these schemes that are currently without Regulation 28 notices and so we have included them in our Price Control Deliverable, set out in Section 6;

- As shown in Section 2, we have considered a wide range of options, which have been assessed using robust cost-benefit analysis, so we are confident we have identified the best possible solution;
- We have considered the impact of future changes in legislation (Section 3.4) but do not consider this to be certain enough to include in our core pathway. Instead, we have included low value interventions (laboratory capability and catchment investigations) to keep future options open to better monitor and track emerging pollutants and to better monitor the relationship between climate change and water quality; and
- The designs we complete for treatment solutions in AMP8 will aim to allow for modular future solutions, in case legislation does change for emerging contaminants.

3.4 Alternative adaptive pathway

In January 2023, as part of the DWI's PR24 requirements, we submitted our summary statement on future risk mitigating measures for drinking water quality – covering some of the themes in their long-term planning guidance relating to climate change such as efficacy of treatment and extreme weather.

We explained that we are not yet able to predict with any confidence the investment required for any raw water deterioration that might be caused by climate change over the next 25 years, due to the reasons outlined earlier. A summary of the analysis and data science we have done to attempt to do this is provided in Appendix A.

We have shared this work with the DWI as part of our PR24 engagement – they are keen for us to continue this approach with partners to better determine future needs by monitoring the relationship between climate change indicators, land use, and the impacts on our source to tap system. This is why our proposals for future laboratory capability and monitoring are so important and included in our core pathway, not an alternative one.

For our three alternative pathways, which are explained in LTDS Annex 2, Table 27 shows what we have assumed for this investment related to raw water deterioration or change in standards.

Table 27: Alternative adaptive pathways considered

Alternative adaptive pathway	By 2030	By 2035	By 2040	By 2045	By 2050
Adverse climate triggered change	No change	Legislation change for emerging contaminants	Better WTW construction materials		
Societal shifts	No change				Better WTW construction materials
Government-led legislative future	No change	Legislation change for emerging contaminants		Better WTW construction materials	

For 'Legislation Change for Emerging Contaminants' we assumed treatment would be needed at around 30 sites that could face non-compliance with new legalisation for emerging contaminants. As a proxy, this is based on the 30 sites we have currently identified that would not be compliant with existing USEPA and Danish PFAS standards – these are much stricter than current DWI PFAS guidance for England and Wales. Based on carbon absorption technology, a high-level estimate puts this at c.£500m totex which would need to phased across AMP9 and AMP10 to reflect supply chain deliverability and time for implementation of any legislation. This gives a sense of the cost and deliverability challenge we may be facing with emerging contaminants such as PFAS.

For 'Better WTW construction materials', we have assumed that, through the innovation set out in Section 2.1.2, the market has developed cheaper and more effective analytical and treatment technologies for emerging contaminants, leading to reduced costs of delivery once they become cost beneficial.

3.4.1 Trigger points

Analytical capability – with the laboratory investment proposed in this business case we will be able to assess risk under current and future potential/evolving regulatory conditions and "watchlist" parameters that could have new legal standards put in place over the next 10 to 25 years. We will then be able to plan accordingly to keep future options open. This includes the parameters explained in Section 1.1.2.

- PFAS – more than the those currently named in England and Wales guidance;
- Haloacetic Acids (HAAs) – toxic disinfection by products. Five have an EU DWD PCV of 60µg/l;
- Endocrine disruptors – Bisphenol A has a DWD PCV of 2.5µg/l;
- Pharmaceuticals and personal care products; and
- Persistent mobile toxic substances (PMTs).

Monitoring – throughout AMP8 we will be:

- Carrying out risk-based monitoring;
- Monitoring against other international standards to identify potential changes that could be transcribed into UK law;
- Continuing to participate in, and learn from, the industry's Chemical Investigations Programme to cover environmental water quality, which includes emerging contaminants;
- Reviewing sample data every quarter to identify whether any positive results have been reported that would require an increase in monitoring frequency at any site. We will undertake additional catchment sampling to target and support catchment investigations where required.

Risk characterisation – To be better prepared for any future changes, we plan to regularly risk assess our sites against the different standards that exist worldwide. As an example, Table 28 below presents the benchmarking we have started that uses current sample data for all sites against the EU DWD standards, the US EPA standards and the Danish standards for PFAS.

Table 28: Number of sites likely to require mitigation against PFAS in the future

Total number of sites	Sites exceeding US EPA PFOA/PFOS standard	Sites exceeding Danish standard (sum of PFOS/PFOA PFNA & PFHxS)	EU DWD Sum of 20 named PFAS 0.1µg/L	EU DWD total PFAS 0.5µg/L
121	11	30	0	0

For sites identified as potentially "Failing" we will review at a high level what future options could be applied to reduce risk so as to be prepared for any future potential evolution of regulatory standards.

Conclusion: We know this investment is no regrets because the requirements are a result of statutory drivers, with legal instruments in place where necessary for realised risks, that have to be completed by 2030. The investment to keep future options open is lower value and needed to help us efficiently plan for changes. We have considered future legislative changes to make sure that the choices we make now will continue to be best value in the long term.

4. Summary of the no or low regrets investment for AMP8

Table 29 presents our preferred solutions, costs and benefits for this DWI supported and statutory driven programme to address raw water deterioration or change in standards.

Table 29: Summary of outputs from CBA for preferred solutions – Enhancement expenditure Raw Water Deterioration

Raw water driver	Preferred solution & DWI scheme/notice Reference	Benefit: Water resource protected (Ml/d)	Benefit: CRI impact avoided	Whole-life carbon emissions (tCO2e)	AMP8 opex (£m)	AMP8 capex (£m)	AMP8 totex (£m)
Groundwater Crypto-sporidium and bacteria – pathogens	SVT4 – Westwood/ Dunhampton – UV treatment	[✂]	-0.049	1750	0.054	1.8	**1.9**
	SVT5 – Far Baulker/Rufford – UF membrane	[✂]	-0.117	432	0.114	51.6	**51.7**
	SVT6 – Wildmoor – UV treatment	[✂]	-0.078	1750	0.151	4.2	**4.3**
	SVT7 – Rednal – UV treatment	[✂]	-0.004	1750	0.084	3.3	**3.4**
	SVT8 – Edgmond Bridge – UV treatment	[✂]	-0.116	1750	0.086	2.2	**2.3**
	SVT9 – Cresswell – UV treatment	[✂]	-0.078	1750	0.140	13.4	**13.5**
Groundwater Nitrate	SVT10 – Beckbury (Nedge Hill DSR) – Ion Exchange treatment	[✂]	-0.153	354	0.176	21.8	**22.0**
	SVT11 – Nurton DSR blend (Cosford) – Ion Exchange treatment	[✂]	-0.185	456	0.348	17.8	**18.1**
Algae	SVT12 – Whitacre WTW – Dissolved Air Floatation (DAF) treatment	[✂]	-0.342	87,528	0.314	67.0 (3.5 Base)	**67.3**
Lead	SVT13 – Homesford WTW – Ceramic membrane treatment	[✂]	-0.002	20,382	0.001	74.9 (15.8 Base)	**74.9**
PFAS and future emerging contaminants	SVT-2023-00002* – Thornton to Cropston – treatment and removal verification	[✂]	-0.175	TBC	1.030	17.9	**18.9**
	SVT3 – Witches Oak WTW (River Trent) – catchment management, treatment and removal verification	[✂]	-0.977	TBC	3.650	31.3	**34.9**
	SVT3 - Laboratory capability and future monitoring		N/A	TBC	0.000	2.4	**2.4**
Catchment management	Beckbury, Bratch, Grindleforge, Puleston Bridge, Tack Lane – AMP7 continued schemes.	[✂]	N/A	0	0.756	0.4	**1.1**
Total		338.40	-2.277	117,902	6.903	309.9	**316.7**

**Regulation 28 Notice applied – outside PR24 submission process – refer to Section 2.2.5.*

Table 30 describes how we have weighted views across customers, stakeholders and regulators in the development of this investment proposal.

Table 30: Summary of stakeholder feedback regarding proposed schemes

Raw water deterioration		
	Relative weighting	Summary of view
Majority customer preference	Medium/High	Over many years our customer research has shown that delivering safe drinking water is our customers' highest priority. More recent PR24 research has shown our customers want us to maintain a consistent, high quality and reliable source of water now and in the future, and tackling raw water deterioration is a fundamental part of delivering that. Customers also expect us to deliver our statutory obligations.
Specific customer segments	n/a	No specific differences for customer segments.
Stakeholder/ expert view	Medium	We have sought stakeholder views through two forums – expert climate input to review and improve our analysis of the relationship between climate change and raw water deterioration and through independent view of our technical solutions. In both cases stakeholders were of the view that the information and analysis was comprehensive and fit for purpose.
Regulatory requirement	High	This case relates to statutory obligations to address any deterioration in raw water quality. We are required to set out risk assessments to evidence that we will remain fully complaint with Water Quality (Water Supply) Regulations. There is also a policy ambition that wherever possible catchment (nature-based) solutions are considered.
How this has shaped our plan	There is consensus across all views that this is a very important driver and that the necessary investment must be made to ensure emerging risks are mitigated. There is no choice on pace (all improvements are needed by 2030) and we have taken on board stakeholder and regulatory views through the optioneering and solution selection process. Alongside catchment management, our plan is to install additional treatment processes at 12 water treatment works to tackle a range of water quality issues (including pathogens, PFAS, nitrate, lead and algal blooms).	

5. Robust & efficient costs

5.1 Cost robustness

Given that the scope of this proposal has been produced as a result of statutory drivers and is supported by the DWI, demonstrating that our costs are robust and efficient is critical to make sure our customers get the best possible deal.

Our estimates are based on a large and relevant bank of data comprised of our own completed projects over the last five years and projects completed by the sector since 2020/21. These have been used and combined with market testing, where historic data is not available, to challenge ourselves to be the most efficient deliverer of DWI-supported drinking water quality schemes and statutory obligations. This section sets out the key evidence to demonstrate this. Full details of our costing methodology and overall efficiency can be found in Annex 4a 'Costs, efficiency and stretch'.

5.1.1 Cost derivation

We have a well-established cost estimating approach from completed DWI statutory and supported programmes over the last 20 years. Our main capital projects/programmes of work have all been costed using the same estimating approach (explained in full in Annex 4a), but the source data has varied depending on the availability of suitable data.

Table 31 provides an overview of the of the cost data we have used. Due to new, specific site and technical requirements for each of the 12 sources in this case, the majority of costs (80%) have had to be built bottom up without the benefit of the large historical project data set we have (STUCA). However, many of these are based on robust estimates from our supply chain partners who are delivering similar project/programmes in AMP7. And we have carried out market testing and benchmarking for all schemes to ensure our costs are robust and efficient (see section 5.2).

Table 31: Cost derivation for AMP8 DWI supported/statutory schemes

Scheme/programme	Severn Trent unit cost database – STUCA (outturn past projects) – % of value derived	Non-standard bottom-up build* - % of value derived	AMP8 totex (£m)
Groundwater cryptosporidium/bacteria	35	65	77.1
Groundwater nitrate	45	55	40.1
Algae – Whitacre WTW	10	90	67.3
Lead – Homesford WTW	10	90	74.9
PFAS – Witches Oak WTW	0	100	34.6
PFAS – Thornton to Cropston	22	78	18.9
Other	0	100	3.8
Total	20	80	316.7

**100% of non-standard capital projects have been tested by bottom-up benchmarking/market testing*

For each programme/project listed above we now provide a cost breakdown and describe the key basis for cost derivation.

Groundwater – Cryptosporidium/bacteria

We started major installations of UV treatment in AMP5 at 10 sites, and UV has played a substantial part of the DWI water quality programme since AMP6, through which we have installed 36 UV plants. Our STUCA cost curves are therefore based on a significant number of previous, recently completed projects. We also have substantial experience in the delivery of these types of projects – this has enabled us to build a library of previous non-standard item costs to draw upon and gain a very good understanding of the typical level of cost estimating risk on projects of this nature.

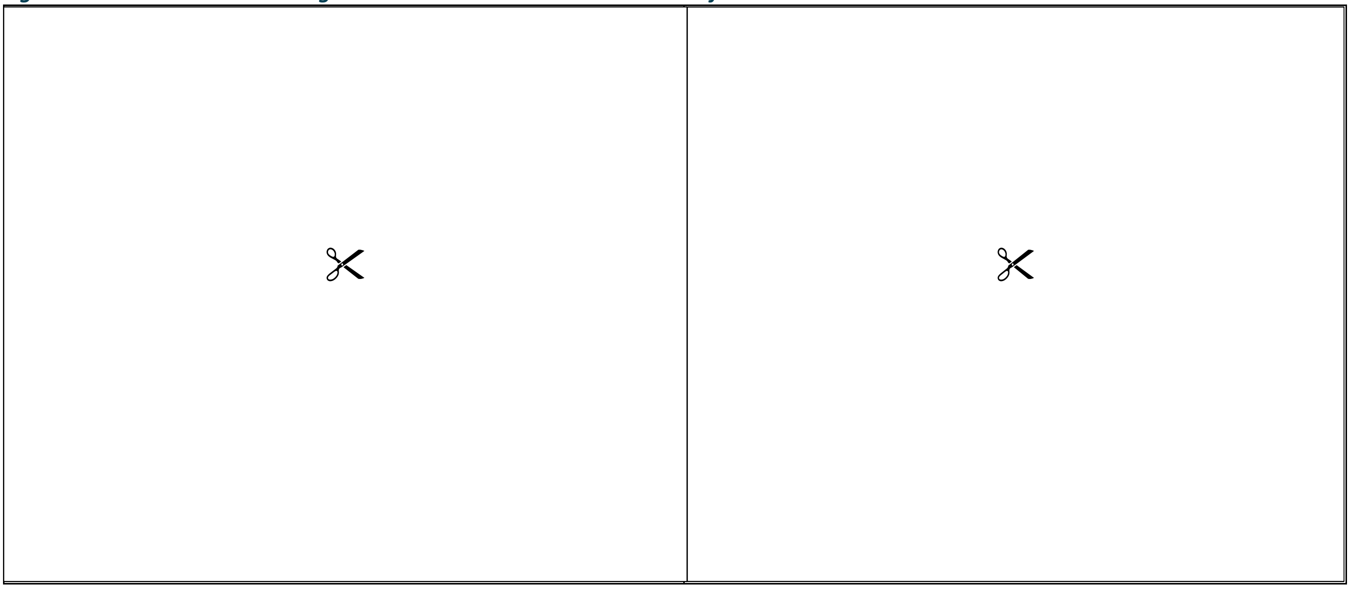
Table 32: Breakdown of scheme cost components for Groundwater Cryptosporidium/Bacteriological programme (£000)

Cost Component	Cresswell	Dunhampton	Edgmond Bridge	Rednal	Far Baulker/ Rufford	Wildmoor
Standard	5,775.5	668.3	891.9	8,452.9	133.7	-
Non-standard	2,178.7	378.5	434.5	22,183.1	1,804.4	2,474.1
On cost	2,138.9	281.5	356.7	8,238.0	521.1	665.3
Subtotal	10,093.0	1,328.2	1,683.2	38,874.0	2,459.2	3,139.4
Optimism bias	2,523.3	332.1	420.8	9,718.5	614.8	784.8
Burden	788.5	103.8	131.5	3,037.0	192.1	245.3
Total	13,404.8	1,764.1	2,235.4	51,629.5	3,266.1	4,169.5

Standard cost items:

For three of the schemes, our chosen solution is to use our standard 40mJ/m^2 UV dose – this follows our standard design manual which specifies dose rates required for the types of pathogens present at each specific raw water source. For this dose rate, we have an asset level cost curve to derive estimates. Figure 16 below illustrates the historic data used generate this cost curve.

Figure 16: Historic data used to generate the civil and M&E cost curves for UV



Non-standard cost items:

The remaining three schemes are based on 'non-standard' solutions and are as follows.

Table 33: Schemes with non-standard solutions

Solution	Description
Higher dose UV treatment (95mJ/m^2)	Required for Rednal and Wildmoor, based on our due diligence check on the type of pathogens that are at risk of being present. To generate estimates for these schemes we have engaged with our existing AMP7 framework suppliers (Lintott) to obtain quotations for the specific sizes of treatment plant required. Lintott has been our framework supplier since the beginning of AMP6 for the 36 UVs we have installed during that period. Our framework suppliers are selected through a rigorous tendering process that allows us to compare the most technically proficient and economic suppliers against each other and we therefore have confidence in the quotations provided being robust. Their estimates include data from Trojan, their preferred supplier for the UV plant, and BGEN which provides control panels – both of which have a well-established delivery model with Lintott.

Ultrafiltration (UF) Membrane treatment	Required at Far Baulker because of high risk of bromate formation, which is a toxic byproduct, regulated by DWI, that can be formed during UV treatment when bromide is present. The estimate for this scheme is based on a supplier quotation from Nanostone. We have been exploring wider pilot plant opportunities with them because of their innovative, next generation of ceramic membranes – which are more efficient than other ceramic membranes due to their patented design. They are also the only supplier of ceramic membranes that can provide the Ultrafiltration (as opposed to Microfiltration) that is required for DWI-approved cryptosporidium removal. We are trialling this technology for our Homesford WTW scheme which has also been benchmarked for cost estimates above.

Groundwater – Nitrate removal

Nitrate removal by Ion Exchange played a substantial part of the DWI statutory programme in AMPs 4 and 5 and we require two plants into AMP8. Given the age of the data from previous installations, we have not used cost curves for our cost estimates but have instead obtained supplier quotations. Other components of the cost estimates are a combination of standard and non-standard items and are summarised below in the following table.

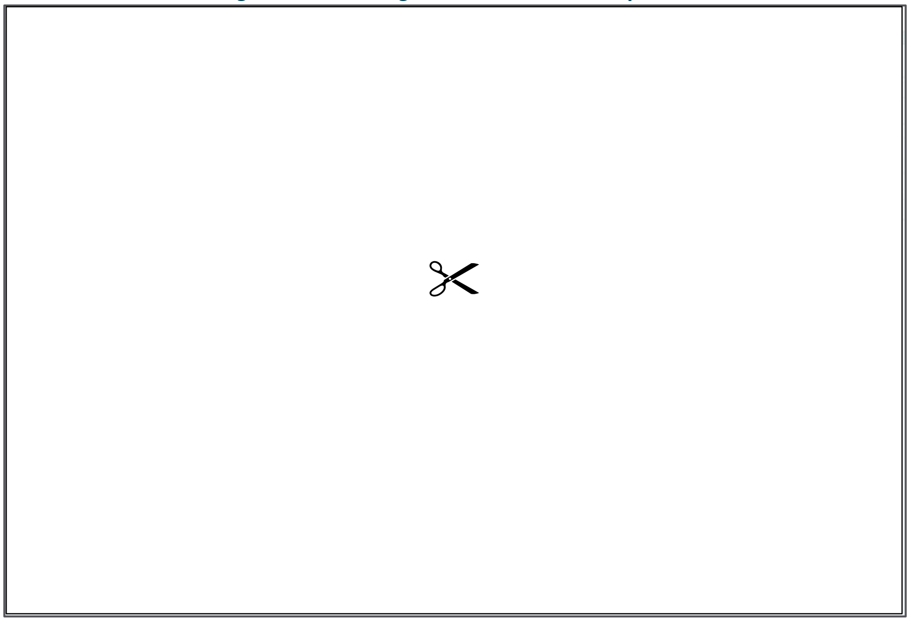
Table 34: Breakdown of cost components for Groundwater Nitrate projects (£000)

Cost component	Nurton	Nedge Hill
Standard	3,509.0	7,195.8
Non-standard	7,023.7	5,761.0
On cost	2,832.2	3,484.0
Subtotal	13,364.9	16,440.8
Optimism bias	3,341.2	4,110.2
Burden	1,044.1	1,284.4
Total	17,750.3	21,835.5

<u>Standard cost items:</u>

A significant proportion of the cost for these schemes is for sewerage pipe work to deal with waste streams and transportation to appropriately robust wastewater treatment works. The lengths required are 15.6km (Nedge Hill scheme) and 5.6km (Nurton scheme). For sewerage assets, we have an asset level cost curve to derive estimates – Figure 17 below illustrates the historic data use generate this cost curve.

Figure 17: Sewerage cost curve and data points



Non-standard cost items

Ion Exchange treatment	We have established cost estimates based on supplier quotations from Ovivo and had these sense-checked against USEPA guidance for Ion Exchange capex costs to improve our confidence in the quotations provided. These were also benchmarked as outlined above.

Algae – Whitacre WTW

Dissolved Air Flotation treatment is a process which we currently operate at nine of our major WTWs. The last time we installed a DAF plant was in AMP5 (at Bamford WTW), and prior to this in AMP1 at three sites. We therefore have limited historical cost data to draw upon for cost estimating, so our DAF cost estimate is based on direct supplier quotations, while other scheme components are a combination of standard and non-standard estimates.

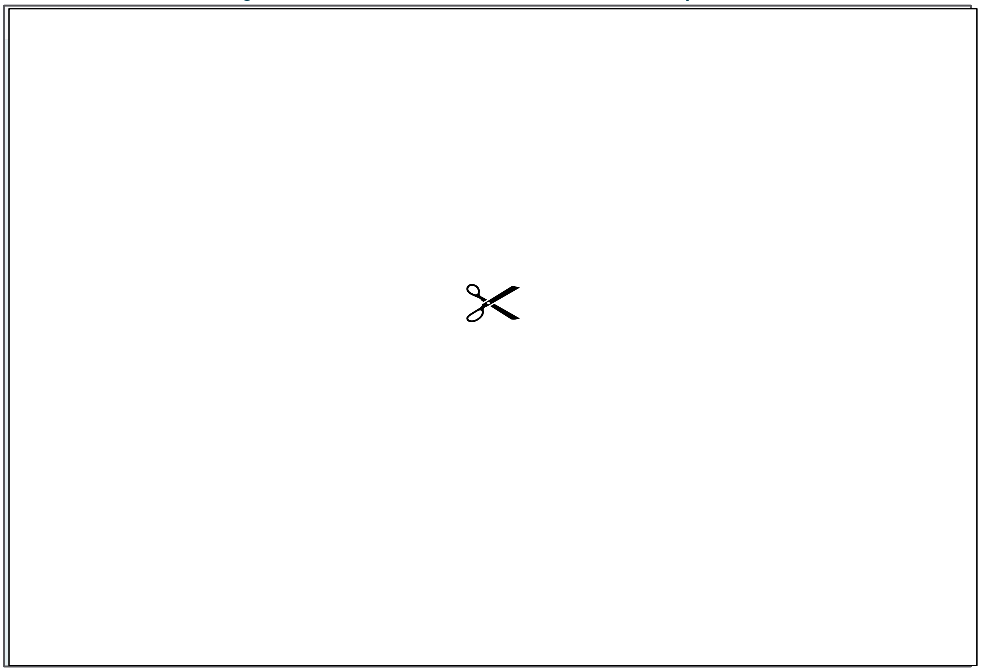
Table 35: Breakdown of cost components of Whitacre DAF scheme

Cost component	£000
Standard	4,052.5
Non-standard	35,627.3
On cost	10,669.1
Subtotal	50,348.9
Optimism bias	12,587.2
Burden	3,933.5
Total	66,869.6

Standard items:

The highest proportion of standard cost estimates for this scheme comes from pressure mains, due to the new pipework configuration needed to manage water quality. The lengths of pipe work vary from 150m to 800m. Costs are based on a standard cost curve for pressure mains which has a total of 541 data points from previously delivered schemes: see Figure 18 below.

Figure 18: Pressure mains cost curve and data points



Non-standard cost items:

Table 36: Non-standard Items

Item	Description
DAF treatment plant	Cost estimates based on supplier quotations from Doosan, which has innovative DAF technology that we referred to in Section 2.2.3 above. We have also benchmarked these estimates as outlined above.
Washwater and sludge treatment	Based on a live AMP7 project at Trimpley WTW which is in contract and due for commissioning in AMP7.
DAF sludge treatment	Due to the high levels of algae that will be present in the DAF sludge, we cannot use conventional sludge treatment plants and so standard costs have not been used. We are reviewing innovative wastewater technology types and our current estimate is based on a using a hydrocyclone, incorporating estimates for a pumping station and pipework.
Caustic Dosing	Required for pH control for disinfection – our estimate is based on a recently delivered AMP7 project at Trimpley WTW.

Lead – Homesford WTW

We are in the process of installing our first ceramic membrane at Witches Oak WTW as part of our AMP7 Green Recovery project for which we have a cost comparison for the estimate at Homesford. We are also in the process of trialling ceramic membranes with Nanonstone, on-site at Homesford.

Table 37: Breakdown of cost components of Homesford WTW Lead removal treatment scheme

Cost component	£000
Standard	4,494.5
Non-standard	39,946.2
On cost	11,950.1
Subtotal	56,390.7
Optimism bias	14,097.7
Burden	4,405.5
Total	74,893.9

Figure 19: Directional drilling cost curve and data points

Standard items:

The highest proportion of the standard cost estimate comes from the directional drilling required for a new waste main (2km). Our standard cost curve for this has 181 data points from previously delivered schemes – see Figure 19 above.

Non-standard cost items:

Table 38: Non-standard Items

Item	Description
Ultrafiltration membrane treatment	The estimate for this scheme is based on a supplier quotation from Nanostone, with input from their delivery partner Ross-Shire Engineering (RSE),and based on their experiences of installations at Scottish Water. They are the only supplier of ceramic membranes that can provide the Ultrafiltration (as opposed to Microfiltration) that is required for DWI-approved cryptosporidium removal. We have also benchmarked these estimates as outlined above.
Building Costs	A higher than standard cost per square metre has been applied for this scheme as Homesford is located within the Derwent Valley Mills world heritage site and is therefore subject to more stringent planning requirements for new buildings – we have seen this from projects at our nearby Matlock sewage treatment works. Another specific non-standard is that the building needs to be higher than average, to allow equipment to be raised above the flood plain.
Site specific security requirements	As the new plant will need to be outside the boundary of our existing WTWs because of site constraints, specialist non-standard cost estimates used for security-rated fences and CCTV based on supplier quotations in line with current security guidance.
Site Specific flood storage compensation requirements	Non-standard cost estimated based on best practise and rates provided by our in-house cost estimating team.

PFAS - Witches Oak WTW – ActiFlo Carb treatment

At present there is only one supplier (Veolia) which provides this treatment process in conjunction with the required flocculation, clarification and re-use of carbon. We have an ongoing AMP7 Green Recovery project at Witches Oak with a dedicated design and delivery team who have been working on the AMP8 requirements for this PFAS treatment stage, and who are installing and running Veolia's pilot plant to establish PFAS removal efficacy.

Table 39: Breakdown of cost components of Witches Oak PFAS treatment scheme

Cost component	£000
Standard	-
Non-standard	20,200.5
On cost	3,131.7
Subtotal	23,332.2
Optimism bias	5,833.1
Burden	1,822.8
Total	30,988.1

Non-standard items:

Because this is such a new statutory requirement, using a treatment technology that we have no previous cost information for, our project estimate can only be based on non-standard items. These have been built up by the design and delivery team currently working on our AMP7 project at Witches Oak who are very familiar with the WTWs and its capacity, constraints and location.

Table 40: Non-standard Items – PFAS Witches Oak WTW

Item	Description
Activated Carbon Lamella: 'Actiflo-Carb'	Based on supplier quotations from Veolia, currently the only supplier able to provide this technology, which we will be testing soon with a pilot plant.
Sludge plant	Will be nearly identical to the one being installed to deal with wastewater from other processes being constructed in AMP7 at Witches Oak – based on the current AMP7 project target price for that component in the existing contract.
Interstage pumping station	Estimate based on the contracted AMP7 project target price for similar pumping (GAC backwash pumps) currently being delivered by the team on site at Witches Oak.
Associated civils (i.e. PAC contact tank) and electrical works	Based on estimates from current similar sized installations going on on-site as part of the AMP7 project at Witches Oak.

PFAS - Cropston WTW – PAC dosing

We have produced a preliminary design based on PAC dosing and downstream risk mitigation, based on similar plants we have installed.

Table 41: Breakdown of cost components of Thornton to Cropston PFAS treatment scheme

Cost component	£000
Standard	2,532.8
Non-standard	8,930.3
On cost	3,845.0
Subtotal	15,308.1
Optimism bias	1,530.8
Burden	1,052.4
Total	17,891.3

<u>Standard items:</u>

These cover pipelines and pumping stations. The highest proportion of the standard cost estimate (60%) comes from the directional drilling required for a new waste main (2km). Our standard cost curve for this has 181 data points from previously delivered schemes – see Figure 18 discussed previously.

<u>Non-Standard items:</u>

Table 42: Non-standard Items – PFAS Cropston WTW

Item	Description
PAC Dosing System	Budget quote from Transvac which has previously provided PAC dosing systems to Severn Trent for Frankley. Their quotation is based on sizing for the 15Ml/d capacity of this source.
Boll Filter and Amazon Filter	This is based on a recent installation costs of amazon & boll filters completed in 2022/23 at Wallgrange ([✂]Ml/d) and prorated for [✂]Ml/d.

Other cost estimates:

The remaining 1% of totex is made up of: i) Catchment Management – our cost estimating methodology reflects learnings from our 13+ years of experience running catchment management schemes whereby for every £1 we invest, we save between £2 and £20 in future water treatment costs and create £4 of wider environmental benefits (more details, including benchmarking, are provided in our WINEP business case, which is where the majority of catchment management costs sit); and ii) competitive costs for additional laboratory equipment and monitoring based on recent purchase costs.

5.1.2 Assurance and independent challenge

We have sought challenge and reviewed the costs at several stages throughout the development of the solutions along with more formal assurance. The key inputs include:

- STUCA (unit cost database) – since it was built in 2006, process and data assurance has been carried out by PwC (PR09), Atkins (PR14), and our Group Compliance and Assurance team (PR24). Benchmarking of outputs has been carried out by EC Harris/Arcadis (AMP5 and AMP6), Mott MacDonald (PR19), Aqua Consultants (AMP7), and Jacobs for PR24;
- Arup review of costs and methodology in 2021;
- Turner and Townsend review of approach against published best practice;
- Mott Macdonald top-down benchmarking review of 100% of the programme, and bottom up benchmarking review of 20%;
- Aqua Consultants' bottom-up benchmarking of 100% of the capital projects;
- Jacobs, as part of our formal three lines of assurance; and
- Internal review and challenge – senior management and director level review of the business case, the Cost Reliability and Maturity (CRAM) process, technical governance through our Water Service Area Board and Water Quality Strategy Group, and 14 site visits involving 43 personnel from across our operational and engineering functions to give a broader view.

Internal challenge and review

As described in Annex 4a 'Costs, efficiency and stretch', as part of our commitment to continuous improvement we commissioned cost consultants, Turner and Townsend, to assess our approach against best practice[3]. We mapped our approach to the eight steps described through the Cabinet Office best practice and found it aligned well in most places. The key improvement we have made is to formalise the cost estimating reporting and to track the change in the estimate and corresponding improvement in the estimate maturity as we developed both the costs and the solution over time (using a Cost Reliability and Maturity (CRAM) tool).

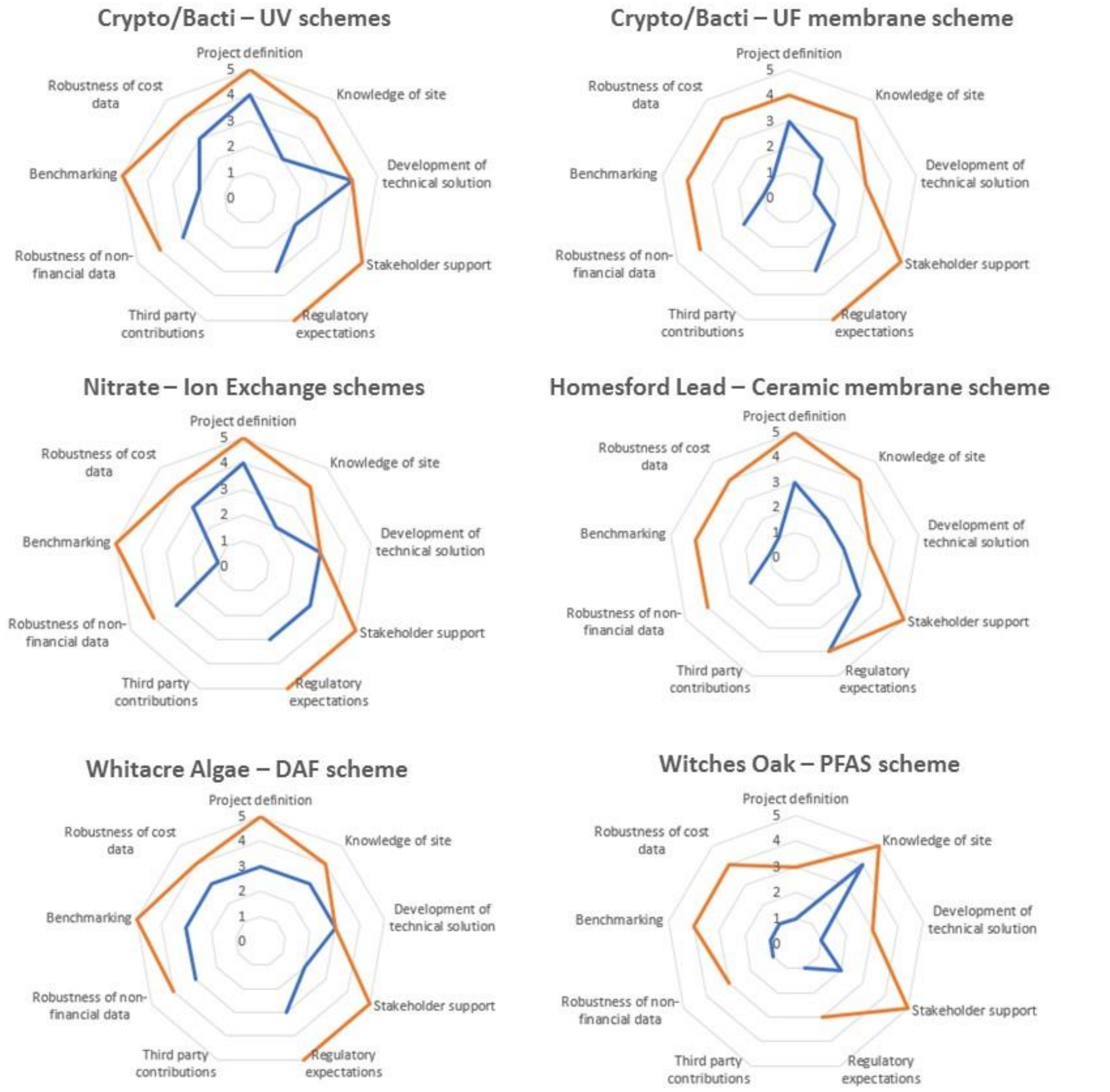
Figure 20 shows how our cost reliability maturity increased as we developed the solution and estimates. Some of the key changes during our iterative process that came about by internal reviews and challenges included:

- Scope certainty
  - 14 site visits involving 43 personnel from across our operational and engineering to:
    - Validate scheme and asset sizing and future operating parameters;
    - Review of base investment needs per site versus enhancements;
    - Look at raw water source flow scenarios and hydraulic reviews;
    - Participate in Solution Options matrix workshop with site asset operators; and
    - Meet suppliers for innovation trials and full works' consideration.
  - Process Options Reports (PORs) were finalised by our process engineering design teams following more technical data gathering;
  - Cryptosporidium/bacteria – more information and dialogue with supplier of UF membranes, more site information and survey data compiled from recently delivered capital projects on same sites;

[3] Cabinet Office & HM Treasury Cost Estimating Guidance https://www.gov.uk/government/publications/cost-estimating-guidance

  - Nitrate – we firmed up the requirement and route for waste mains and suitability of wastewater treatment works;
  - Further certainty on finalising future operating flows aligned with WRMP24 requirements and our core pathway – at one stage of our planning process we did have WRMP24 solution options costs included for increased output at Homesford and Whitacre WTW;
  - Further certainty on groundwater sources and alignment with WINEP – checking that future groundwater licence reductions are factored in;
  - Whitacre WTW – further planning with Wastewater and Bioresources business functions allowed a "sludge to sewer" route, which reduced project scope costs for on-site sludge treatment; and
  - Establishing synergy of catchment management plans with WINEP – removing potential double counting between business cases.
- Cost certainty
  - Reviews were carried out by our expert in-house cost estimating team who have generated non-standard costs for common key ancillary items such as buildings and Motor Control Centres (MCCs) etc based on: i) use of best practice methods; and ii) regular contact with the supply chain about estimates, iii) use of a standardised rates book; and
  - Detailed scope item-based bottom-up benchmarking as outlined in Section 5.2.3 below.

Figure 20: Improvement in Cost Reliability and Maturity (CRAM) assessments – from Iteration 4, November 2022 (Blue Line) through to Business Plan submission (Brown Line) *NB.Third party contributions not relevant for this business case*



This demonstrates the significant improvement in cost maturity as we developed our understanding of the requirements and completed all of the activities described above. This level of maturity is well in excess of what would typically be expected at strategic planning phase.

5.1.3 Data table mapping

The costs for this case are located in table CW3.97-102, as shown in Table 43 below.

Table 43: PR24 Data table lines and costs related to this business case

PR24 Data table line description	Type of cost	Line number	Cost (£)
Addressing raw water quality deterioration (grey solutions)	Capex	CW3.97	279,016,709
Addressing raw water quality deterioration (grey solutions)	Opex	CW3.98	6,147,218
Addressing raw water quality deterioration (green solutions)	Capex	CW3.100	639,260.00
Addressing raw water quality deterioration (green solutions)	Opex	CW3.101	755,660.00
Sub Total - AMP8			286,558,847
Transition into AMP7	Totex	CW12.94	30,200,000
Raw water deterioration Business Case Total	**Totex**		**316,758,847**

5.2 Demonstrably efficient costs

Ensuring efficiency is a really important part of keeping costs down for customers. To do this we have considered efficiency through three lenses:

- **Continuous improvement** – demonstrating efficiency improvements over time (dynamic efficiency);
- **Top-down benchmarking** – evidence to show we are delivering this statutorily driven programme efficiently. This method of benchmarking is good because it captures two key forms of efficiency, i.e we are choosing the right solutions (productive efficiency) and then delivering them efficiently (allocative efficiency); and
- **Bottom-up benchmarking** – we have challenged ourselves to ensure the individual components are being delivered efficiently. This is particularly useful if it is not possible to do top down benchmarking.

The following sections provide the evidence to support our view that our costs represent demonstrably efficient costs through each of these lenses.

5.2.1 Continuous improvement

In Annex 4a, we describe all the components of our approach to ensuring continuous improvement.

We have also sought to extract all possible learning from the AMP7 and additional Green Recovery schemes to ensure efficiencies are built into our forecasts. Section 2 sets out the areas of innovation we have been developing to both improve the efficacy of the technology and drivers of efficiency.

5.2.2 Top-down benchmarking

Our understanding is that, during PR19, Ofwat was unable to identify a suitable cost driver associated with reported Raw Water Deterioration data, preventing the creation of an econometric or unit cost model to establish an appropriate allowance. Allowances were determined based on a combination of deep and shallow dives before a 5% efficiency challenge was factored in.

We understand that, for PR24, it may be possible to establish econometric models for both water treatment assets and nature-based solution costs, based on Ml/d information and number of sites – the subject of recent Ofwat data requests as part of PR24.

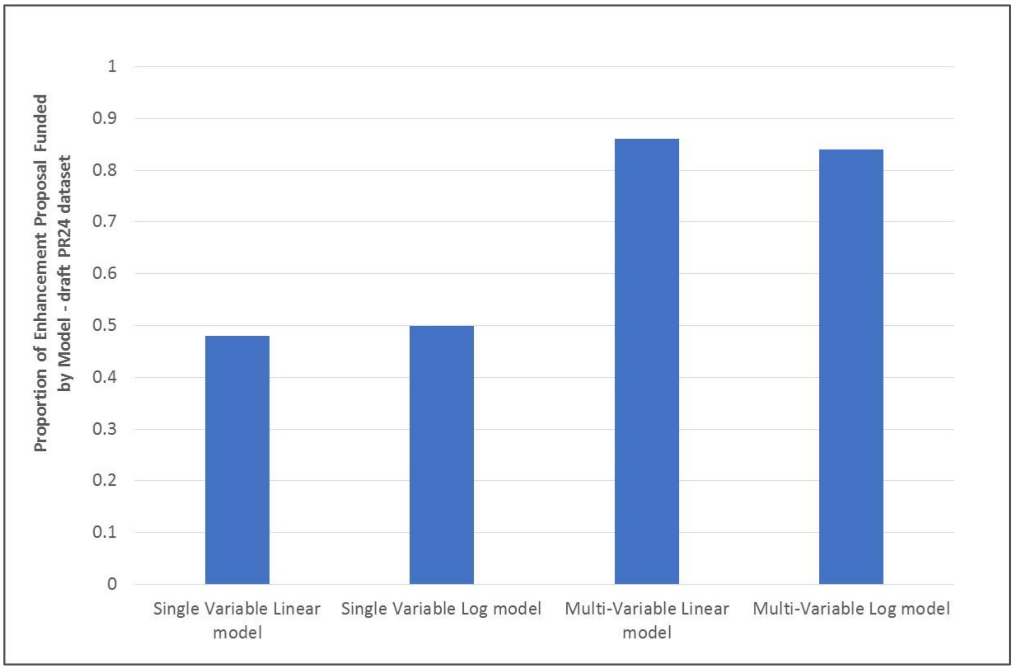
To understand if this top-down modelling approach could be used to reveal insights about our comparative efficiency we asked Mott MacDonald to undertake a review of possible modelling assessments given the industry data sources that are available from PR19, AMP7 and PR24 draft positions in their anonymised cost database. They were able to create the models listed in Table 40. The multi-variable log model, which includes Ml/d and number of sites, had the highest statistical significance, as indicated by R squared values. The available industry PR24 data showed the strongest correlation albeit with only four observations at this time. The number of observations is one of the limiting factors that could prevent any type of modelling/ unit cost comparisons on this enhancement driver.

Table 44: Mott MacDonald cost modelling assessments – R squared values by model type and data set

Model	PR19 Submission	PR19 Determination	PR24	PR19 Sub. & PR24	PR19 Det. & PR24
Single variable – Linear	0.187	0.221	0.435	0.537	0.538
Single variable – Log	0.456	0.477	0.786	0.552	0.524
Multi-variable – Linear	0.925	0.909	0.999	0.539	0.541
Multi-variable – Log	0.976	0.972	0.999	0.774	0.759
Ml/d Unit Cost (£m)	0.352	0.286	0.517	0.453	0.427
No. Observations	6	6	4	10	10

Having established potential models, we asked Mott MacDonald to provide a view of our relative efficiency for our proposed raw water deterioration enhancement investment at the time. Results are presented in Figure 21 below for all models using draft PR24 industry data which was very limited in terms of number of observations.

Figure 21: Proportion of Raw Water Deterioration enhancement proposal (as at November 2022) funded by model based on PR24 draft industry data



At best, our values at the time showed we were 14% higher than predicted by the model. If we believe this model, with so few observations, is revealing information about efficiency then this would suggest our costs looked inefficient at this point in our planning process. To understand the reasons for this we carried out detailed bottom-up costings to better understand this potential efficiency gap and to provide further confidence in the costs we put forward – this work is summarised below.

5.2.3 Bottom-up benchmarking

Mott MacDonald

To supplement their top-down work, we asked Mott MacDonald to compare project and asset level costs. We provided them with a selection of our schemes which made up c.20% of our overall programme costs. Individual schemes were then compared to costs which were held in Mott

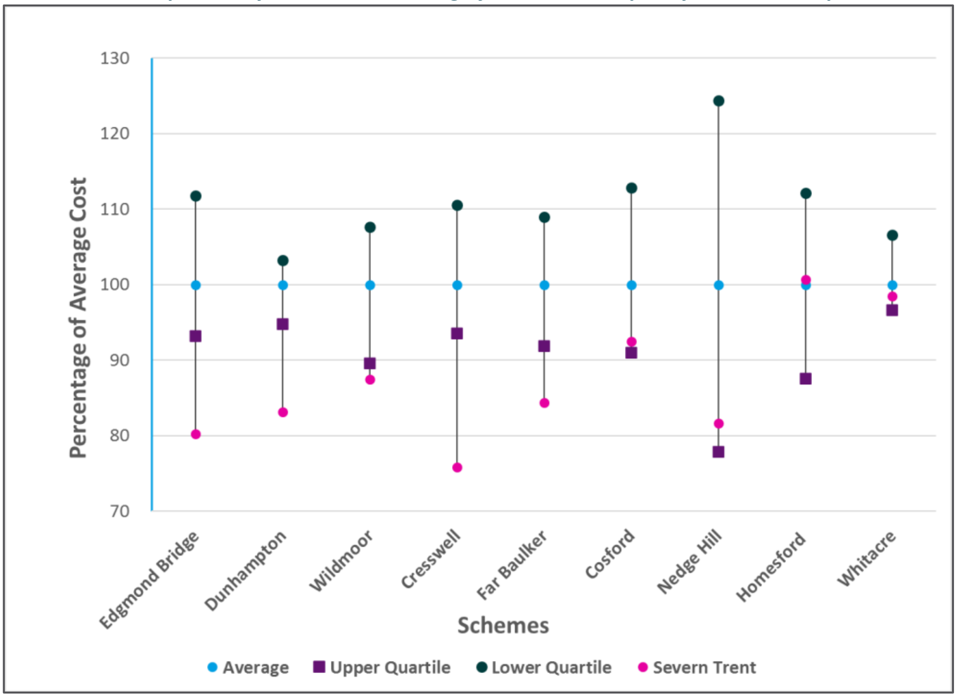
MacDonald's databases to give a comparison against average and upper quartile efficiency. At the time, our costs were shown to be 33% above the benchmark (i.e inefficient), indicating that we needed to think more about ensuring how the costs we put forward are efficient and deliverable.

Aqua Consultants

To help us identify the areas of inefficiency and improve the robustness of the non-standard cost estimates we engaged Aqua Consultants to test all our proposed scheme costs, down to scope item level. The conclusion of this analysis was that the scope items were comparable, but we had a higher risk allowance than similar projects.

Aqua reviewed the recent activities we had completed (see section 5.1.2) and the CRAM assessments, and we concluded we had completed enough scope development to reduce the optimism bias. We therefore reduced initial optimism bias (which was based on Green Book supplementary guidance[4]) from 66% down to 25%, which Aqua considered to be more reflective of both the cost maturity and the level of complexity of these projects. This led to a reduction of 20% across our groundwater scheme costs (UV) and resulted in our costs now being close to the upper quartile industry position on efficiency, while remaining confident there was sufficient budget to deliver our statutory obligations. Our final cost benchmarking position is presented below in Figure 22. It shows that, at an overall programme level, we are close to upper quartile on efficiency and in several cases operating beyond it. Aqua was not able to benchmark the Witches Oak scheme because they had no comparable cost data for PFAS technology.

Figure 22: Bottom-up industry cost benchmarking of AMP8 water quality schemes – Aqua Consultants



This combination of analysis gives us confidence that we have challenged ourselves to ensure our costs are efficient. It also raises some concerns about the degree to which a top-down benchmarking approach will reveal reliable insights about efficiency. It would be important to understand the range of technologies being deployed and the quality of the incoming water to ensure any comparisons are not just revealing differences in complexity of treatment process required to address the raw water deterioration.

[4]https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/191507/Optimism_bias.pdf

6. Customer protection – being accountable for delivery

We have been careful to protect customers from:

- Paying twice: Some of the sites and assets that require investment due to raw water deterioration are linked to a base maintenance investment driver. We have applied proportional allocation rules (Tables 21-22, Section 2.3) to ensure that we identify synergies and also to ensure there is no double-counting. This enhancement case is net of any implicit allowance;
- Paying without experiencing the intended benefits: We have proposed a Price Control Deliverable to ensure we report delivery to customers and return money if the outcome is not delivered. In addition, our customers are protected against non-delivery of our solutions in AMP8 through the legal instruments applied by the DWI; and
- Paying for an unfair share compared to future customers: All investment has been supported by the DWI in their decision letters to protect water quality and is therefore composed of 'no-regrets' investment only. This means customers are paying for only those actions we are certain are needed during AMP8. We have also demonstrated that: i) we have taken every possible step in previous years to mitigate the hazards through catchment management; and ii) we continue to look ahead at future contaminants and hazards to ensure we have the maximum possible time to put in lower cost catchment controls to enable us to minimise the overall cost to customers.

We are confident that this proposal represents the best programme for customers and that it will deliver best value overall in terms of costs, risks, affordability of customers' bills, and wider environmental and social benefits. The following sections provide more explanation on how we are protecting customers from non-delivery.

6.1 Our proposed Price Control Deliverable

We have developed a Price Control Deliverable which sets out the outcomes customers can expect as a result of this enhancement expenditure, and we have taken into account outcome delivery incentives where appropriate.

Our aim is to ensure customers are protected from under or late delivery through deliverables that are easy to measure, track and verify. We have taken account of existing regulatory reporting mechanisms and have aligned our deliverables with these mechanisms where appropriate.

We will continue to develop the detailed measurement methodology which will include third line assurance review to ensure there is sufficient specificity in the definition to meet the repeatability and reporting accuracy required as part of the APR requirements.

Table 45: Proposed Price Control Delivery (PCD) to ensure customers are protected from non-delivery

PCD	DWI statutory and supported schemes
Description	Our DWI supported raw water quality improvement programme will be delivered by 12 schemes in AMP8. We will track the delivery of these schemes according to an agreed delivery programme set out in the deliverables table below, and will complete an annual assessment of performance. This will be based on the DWI milestone reporting process already in place for those schemes that have DWI Regulation 28 (4) notices applied to them.
	Measure 'On track' schemes. **Measurement** Each year we will evidence the scheme progress against planned work and the delivery profile in the deliverables table below (scheme completion). For those schemes with Regulation 28(4) Notices, we will assign and agree annually with the DWI a status of 'on-track' or 'off-track' for completion against the date. For those DWI supported schemes without Regulation 28(4) Notices, the status of 'on-track' or 'off-track' will be based on completion by end of AMP8.
Conditions on scheme	Assessment is to be carried out in line with the DWI guidance and notices. For schemes with legal instruments, this programme is subject to agreement by the DWI and their issuing of Regulation 28 Notices confirming the scope and delivery dates – these are **due by 29 February 2024.**
Assurance	For schemes with Regulation 28 (4) Notices, assurance must be completed in line with the DWI processes for annual reporting of progress against legal instruments. The view of the DWI will be definitive. Also, for these schemes and those supported without Notices, there will be independent third-party assessment and assurance of capital scheme completed milestones and forecast likely outturn. This assurance process will be set up to ensure the same level of rigour is applied across all schemes.
Cost sharing incentive payments	Cost sharing Incentive rates have been calculated using the Ofwat PCD payments model using the following assumptions: • a cost-sharing rate of 50/50 is used for underspends and overspends • WACC = 3.23% • the time incentive rate is set at 3.5% of totex, • Totex = £317m • Deliverables = No. On track schemes (12) • PCD rate = £11.9m / scheme • Time Incentive rate = £0.9m / scheme
Impacts on performance in relation to performance commitments	None

Deliverable	Unit	2025/6	2026/7	2027/8	2028/9	2029/30
Number of schemes with "on track" delivery	No.	0	0	1	5	6

6.2 Impact on our common Performance Commitments

During AMP8 there is no overlap with the common performance commitments. The table below identifies the water quality related measures and provides an explanation about why we consider there is no overlap and therefore no adjustment is required to the performance commitment target.

Table 46: Evidence of no overlap with the AMP8 Performance Commitments (PCs)

Performance Commitment	Impact (L/M/H)	Rationale for no PC adjustment
Compliance Risk Index	Low	No adjustment has been made to this PC in relation to this business case. Impact is low as the investment will have no impact on the target. As described in section 2.2 though, our proposed schemes will reduce risk of CRI failures in future AMPs – offsetting future pressure.
Supply Interruptions	Low	Benefit of raw water deterioration schemes is reduced risk of interruptions beyond AMP8, when failures are predicted to occur.
Unplanned outage	Low	We note that the new Ofwat definition of this asset health PC for AMP8 no longer has an exclusion for the impact of raw water quality. Consequently, the schemes put forward in this case may contribute to maintaining this PC after AMP8 investment, as the WTWs will be re-engineered to operate within the new control limits needed to deal with raw water deterioration.

6.3 Deliverability

Our plans for AMP8 are ambitious and will be challenging to deliver but we believe we are in a unique situation in terms of deliverability. We have strong, in-house capabilities with a proven track record of delivering DWI statutory and supported schemes over several AMPs. We acknowledge that concerns about the deliverability of the sector's ambitions is also, in part, a reflection of the pressures caused by the wider UK infrastructure plans. Recognising this, we have removed ourselves from the fight for resource and support the outlook for others. Specific actions include:

- Making an early start on these plans using transitional spending. In October we will be announcing an acceleration of our AMP8 plans, pulling forward planned AMP8 delivery into 2023-24 to 2024-25, including £30m of the DWI-supported programme. This is made possible by our low gearing and excellent financeability and will mean we will be investing at a run rate beyond the expected run rate throughout AMP8;
- Over the next 12 months we will be insourcing a further 1,000 roles to further reduce reliance on the market. This will cover a wide range of roles, including additional engineers, project managers, technicians and mains renewal pipe laying gangs;
- We have invested heavily in a framework management team to reduce wasted time on construction sites, including up-to-date design and construction standards, the use of prefabricated elements, and digital construction rehearsals as standard practice. Activities such as these improve efficiency and improve safety of the build phase. All of these steps mean that our draw on the supply chain will be less, which frees up more resource for others; and
- We have invested heavily in artificial intelligence to reduce rework, and, as such, reduce capital costs. We aim to share our learning with other companies to help them to increase their rate of delivery and reduce re-work.

6.3.1 Direct Procurement for Customers (DPC)

Eligibility for delivery through DPC has been assessed against the Size and Discreteness tests set by Ofwat. There are no individual schemes in this case with a whole lifecycle totex great than the eligibility threshold of £200m. We also considered the possibility of creating work packages to meet the £200m DPC eligibility threshold, for example by combining a package of UV schemes. These schemes were then put forward for the Discreteness test. Schemes or programmes passing both these tests have been proposed by us as suitable for delivery by DPC at PR24. KPMG has acted as an objective third-party in interpreting and applying Ofwat's guidance on DPC and where appropriate we have followed their recommendations.

After careful consideration, no schemes in this enhancement case were assessed as meeting Ofwat's eligibility criteria for DPC. For a detailed explanation of our interpretation of the Ofwat guidance and the process we followed to assess schemes against the DPC criteria please refer to Annex 4d 'Supporting Markets and Direct Procurement for Customers'.

6.3.2 Preparing to deliver our water quality programme

In terms of the DWI statutory obligations and supported schemes put forward in this business case, we have a great track record of delivery, and this was called out in the Chief Inspector's Report 2020, when we were moved out of their transformation (enforcement) programme – which they said was:

> *"... a highly significant occurrence since it endorses the strategic action at the highest level in a company, to invest and drive action to prioritise their consumers and public health by maintaining and improving drinking water quality as a central strategy. This is a commendable approach and serves as an example to the industry of the necessary qualities in water company leadership."*

However, we know we must not be complacent, and we have been working hard on putting in place mitigating actions to ensure successful delivery of this programme, especially given the difficult external challenges that we face as an industry – Table 47 provides some key examples of these.

Table 47: How we are preparing for successful delivery – AMP8 DWI supported programme

Additional capacity – growing our teams	Additional productivity - levers to pull on	Risk profile change and mitigation achieved
• In-house optioneering; • Partnership with suppliers to drive innovation; • Design – ensuring progression to contractor for design as early as possible; • Specific design and delivery team growth; • Skillsets: Matrix working for design; and • Additional project management, site supervision and commissioning resource required to support.	• Early engagement with suppliers; • Modular design and construction; • Innovative water treatment processes reviewed and introduced where possible; • Pilot plants; • Significant scale of project to determine batching projects versus standalone commercial approach; and • Utilise our current framework expertise as well as entry from innovative processes.	• Better clarity on scope and affordability for delivery; • Innovative processes reviewed against DWI requirements, e.g. time for new technologies to gain approval for use; • Lead time for equipment could be significant so early procurement where possible; and • Ultrafiltration ceramic membranes are a new technology – projects in AMP7 and special contractors to test and learn ahead of AMP8.

6.3.3 Tracking delivery

We set out the formal progress tracking and regulatory commitments below. But given many of these projects are multi-year schemes it is important we put tight controls and reporting in place throughout the delivery period. We have a well-established Project Management Office (PMO) and Capital Governance bodies in place to ensure outputs and outcomes are delivered to time, cost and quality. These are a key part of our Asset Management Framework that we described in our Asset Management Maturity Assessment submissions to Ofwat, in September 2021.

In preparation for AMP8, we now have Power BI software linking directly into contract schedule and risk management software (Asite). This allows us to track the milestones behind each individual DWI commitment and enables us to look ahead against milestone dates using the latest-contractor delivery information, including schedules, cost forecasts, and risk and mitigation registers populated by our internal delivery managers and external delivery partners (example of our Power BI tool below in Figure 23). Managed by our PMO, this approach allows swift, accurate and consistent communication to Project Sponsors, Project Managers and Asset Operators – the three key roles we now routinely establish for each capital project following the implementation of our Asset Management Framework at the start of AMP7. These roles are a key part of managing delivery risk too.

Figure 23: Power BI PMO tool developed in AMP7 – tracking DWI statutory and supported schemes

Appendix A – Summary of data science studies on the impact of climate change on raw water quality.

1. WRc Portfolio Project – Water Quality and Water Resources Planning CP261.

- Finding data to base investment businesses cases in PR24 on raw water quality is very challenging for the industry;
- We know this through our work with WRc, and our own literature research and data science on raw water deterioration;
- There is certainly a need for additional sampling, monitoring, sensors, and analysis to inform business cases for future investment;
- Current WRMP processes in the industry consider the impact of climate change on the quantity of water available but there is little consideration of how climate change will impact the quality of the available water;
- In July 2021 we joined a WRc Portfolio project with 5 other water companies to address this;
- Project deliverables included:
    - **Literature review** of research around future water quality risks, focusing on the impact of climate change, and identifying how this may affect future water supply;
    - **Review of the data** held by companies and regulators – input from statisticians in relation to sampling frequency as well as spatial and temporal coverage;
    - **Best practice guidance** in terms of data collection and monitoring to better understand linkages between raw water quality and outputs; and
    - **Risk management framework** to consider the long-term raw water quality risks that might impact on water resources planning, due to climate change.
- The Key conclusions we took away from the project were:
    - **Do companies have good enough data/enough good data for climate change-based investment?** No, only in the last 10 or 12 years have we started to collect the right amount of sample data, but this is too short a period to consider climate trends;
    - **What is the potential for climate change to cause quality issues in raw water sources?** The project outputs did show the impact of certain weather variables on certain water quality parameters, so can assume this would get worse with climate change;
    - **Has climate had an impact on treatability?**
        - The work suggested that most sites looked at can cope with the weather extremes experienced to date from a final water compliance perspective;
        - However, it suggests that vulnerable sites will be subject to greater cost pressures, if not compliance pressures, under a climate change scenario which predicts a higher frequency of extreme weather events (either persistent or heavy rainfall, or long periods of warm dry weather followed by heavy rain);
        - Climate change will have an impact on treatability at a few sites**;**
        - Although data sample is limited, paired exceedance analysis showed that there is an observable impact on water quality from the last 20 years of weather impacts; and

- The risk of non-compliance can be expected to increase at a few sites if these extreme events become more frequent as projected. In more cases, however, we can expect climate change (and the increased frequency of weather extremes it is likely to bring) will make it more costly to maintain water quality compliance**.**

***Key Message*: It is only really since 2008 when enough data of sufficient quantity and variety for climate change trend analysis started to be collected. The prior historical record is poor, so we need to start to collect more.**

Table A1: Number of samples, per parameter, taken by water companies over the last 20 years.

	Year																						
standard det	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total
Colour	834	871	970	960	943	1,208	1,233	1,351	3,383	3,360	2,931	2,717	3,229	3,169	3,123	2,960	2,979	2,859	2,722	3,031	1,870	1,962	48,665
Conductivity	921	875	913	843	714	1,121	1,129	1,212	3,308	3,346	2,915	2,991	3,209	3,044	3,104	3,136	3,073	2,896	2,799	3,272	2,109	2,133	49,063
Iron	275	241	310	243	285	347	378	573	1,263	1,128	1,049	492	2,874	2,900	2,990	2,884	2,887	2,692	2,667	3,246	3,308	2,049	35,081
Turbidity	1,123	1,046	1,220	1,248	874	1,326	1,470	1,662	3,417	4,154	3,889	4,061	3,511	5,150	4,876	5,857	5,294	4,802	4,522	4,650	3,765	3,086	71,003
Pesticides	0	55	51	171	108	170	186	141	561	605	655	559	626	594	643	589	561	530	824	2,182	1,426	1,461	12,698
DOC	0	0	1	0	1	50	51	60	270	351	267	296	275	257	354	405	478	1,046	1,019	1,156	1,072	897	8,306
Geosmin	0	0	0	0	0	0	0	8	311	302	288	343	358	345	405	1,032	2,627	2,238	2,314	2,832	2,765	1,956	18,124
Total	3,153	3,088	3,465	3,465	2,925	4,222	4,447	5,007	12,513	13,246	11,994	11,459	14,082	15,459	15,495	16,863	17,899	17,063	16,867	20,369	16,315	13,544	242,940

Taking the five companies as a whole, the quantity of data available on water quality determinants improves from 2008 onwards, although for individual sites and individual determinants, the data record varies.

For the important determinants of colour, conductivity and turbidity, the graphic highlights they are better populated, and so clearer trends can be expected with those across a longer time period. Contrast this with the sampling of DOC and pesticides, where the temporal record is shorter.

Key message: **There is no obvious trend in river turbidity over periods of several years**. Climate change is typically viewed with respect to 20- or 30-year climatological averages, so comparisons against a five-year trend component is short. Many of the warmest years on record have occurred in the last decade, so this does not mean that an association could not be found or should not be looked for. Year-to-year variation dominates long-term trends, i.e. the **annual and seasonal variations appear to be at least as, if not more, important than the multi-annual trend component.**

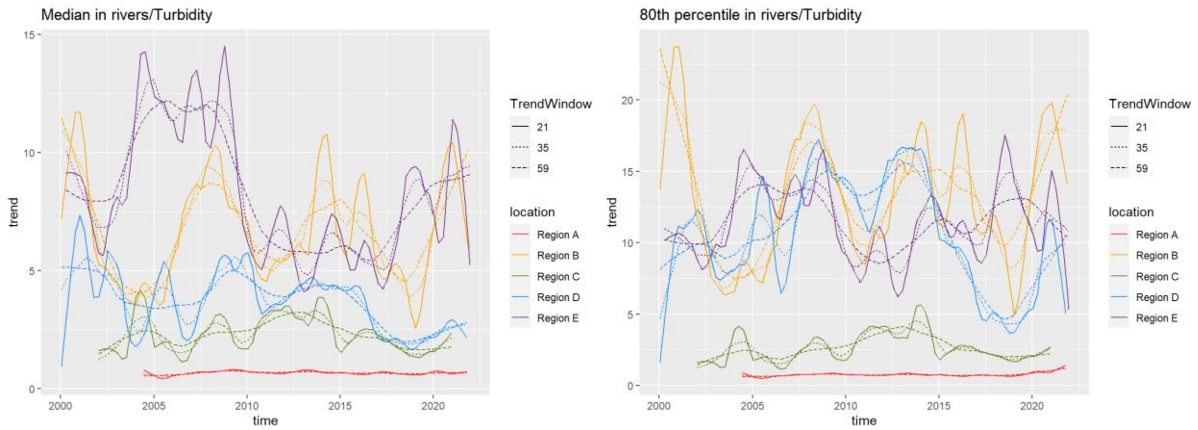


Figure A1: River turbidity data for different water company/regions over time

Key message: The trend component is more important in later years for **reservoir turbidity** for **region D**. **Other regions show a stable or declining trend – we are region E**. *This shows that a greater proportion of the changes in reservoir turbidity are down to a trend component. After a period of worsening, the trend appears to have stabilised at a new higher level in region D.*

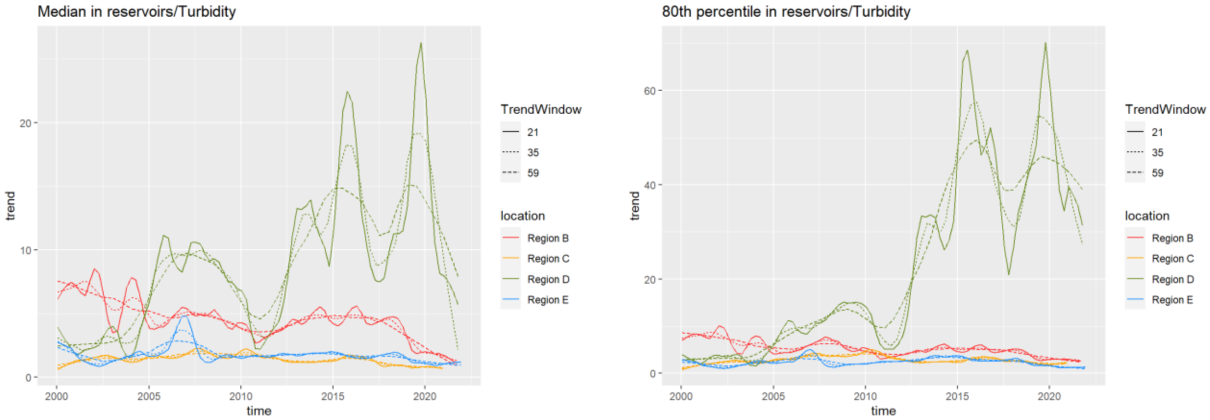


Figure A2: River turbidity data for different water company/regions over time

Key message*:* *T*he number of dry days needed, immediately followed by the quantity of rainfall needed to give an increase in river colour on a given day. Several peaks on this graph tell us that different combinations of these two factors are important for colour in rivers in the dataset. **One could expect elevated colour most often after dry periods of at least 7-10 days followed by 10-20mm of rain within a two-day period, ending on the day you observe the colour spike.**

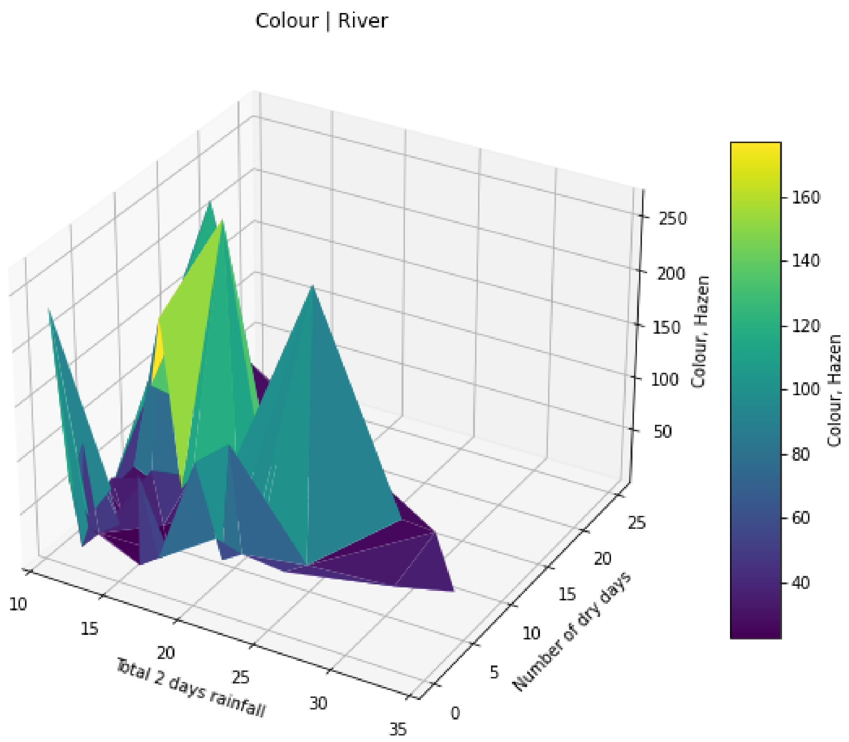


Figure A3: Relationship between rainfall, dry periods and colour measured in rivers

Key message: This *suggests* most sites can cope with the weather extremes experienced to date from a final water compliance perspective (but inevitably will increase operational costs to manage, e.g. effective coagulation and filtration would increase if the peaks in, for example, colour and turbidity were to be more frequent).

- Paired turbidity exceedances at WTW fed by river sources are positively correlated with monthly rainfall;
- If storm frequency and extreme rainfall events do increase as projected, this suggests raw water turbidity exceedances will become more frequent in the winter months which are projected to be wetter overall; and
- On a positive note, of those WTWs which fell outside their normal performance envelope (2SD) due to higher-than-average monthly rainfall, most did not exceed the 1 NTU compliance threshold.

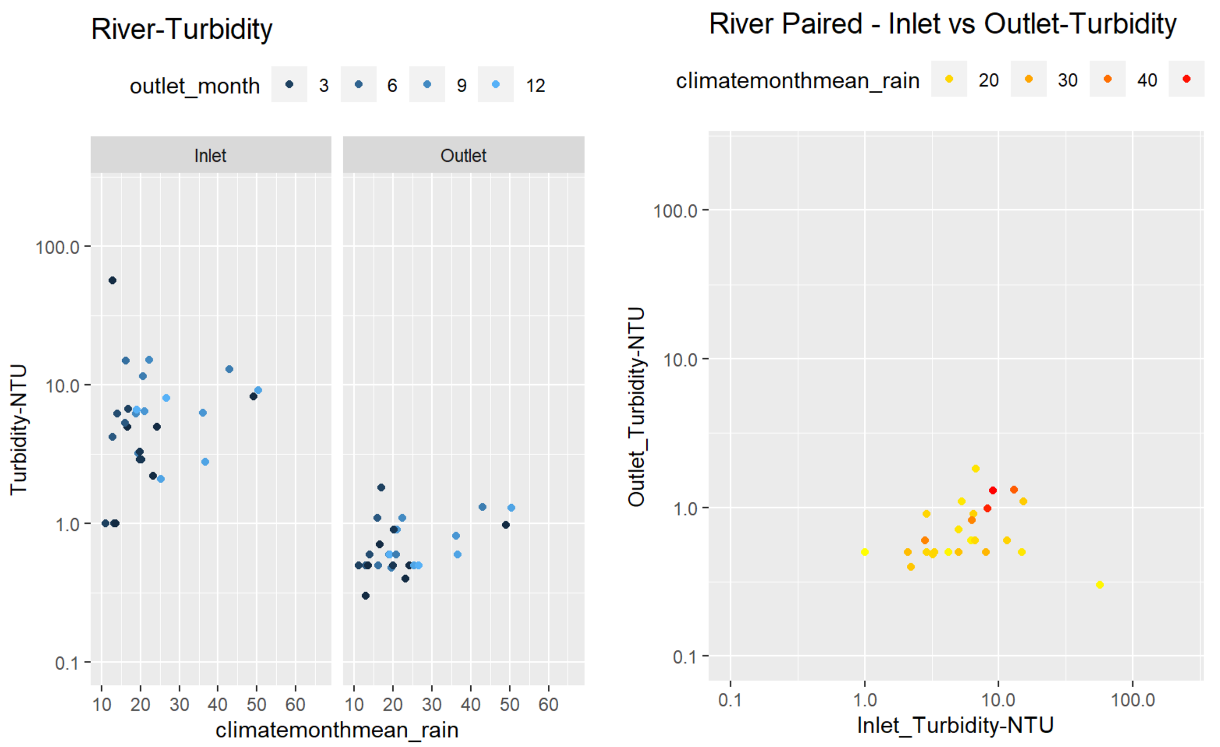


Figure A4: Correlation with rainfall and turbidity

2. IWA paper: Journal of Water and Health Vol 20 No 3, 539 doi: 10.2166/wh.2022.264 Impacts of climate change on drinking water quality in Norway.

R. G. Skaland[a,*], B. G. Herrador[b], H. Hisdal[c], H. O. Hygen[a], S. Hyllestad[b], V. Lund[b], R. White[b], W. K. Wong[c] and K. Nygård[b]
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[b] Department for Infection Control and Environmental Health, Norwegian Institute of Public health, Postboks 222 Skøyen, 0213 Oslo, Norway
[c] Hydrology Department, Norwegian Water Resources and Energy Directorate, Postboks 5091, Majorstua, 0301 Oslo, Norway
*Corresponding author. E-mail: reidun.skaland@met.no

Our own search discovered this paper which is probably the most relevant there is for this proposal. In summary:

- Associations between weather/runoff and water at Norwegian waterworks were combined with local climate scenarios for the first time;
- With continued climate change, the raw water quality will deteriorate by the end of the century, especially due to increasing amounts of rainfall;

- Concentrations of bacteria, turbidity and colour predicted in raw water for the end of this century are, however, relatively small;
- It is therefore **likely that large waterworks will adapt to future conditions**;
- Any designs for new treatment systems will have to include projected effects from climate change, and new operational procedures may be required; and
- Estimated deterioration may cause future challenges for the treatment processes **at smaller waterworks** and for private supplies.

3. Our internal data science study on the impact of weather on river-fed water treatment works.

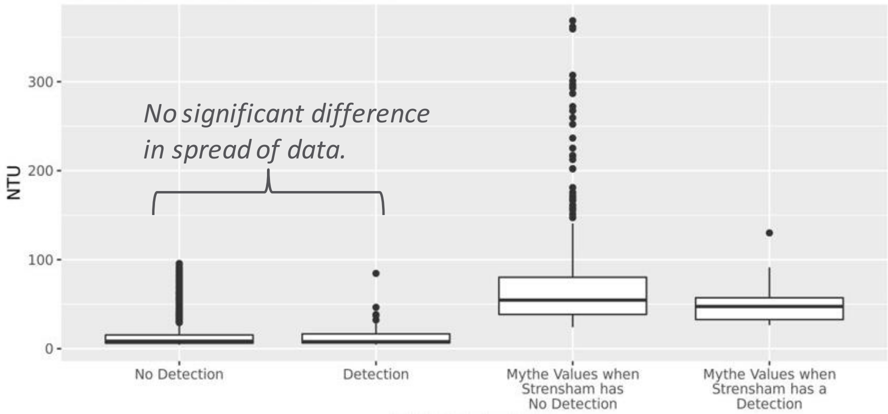
We employed our recently recruited data scientists in Asset Intelligence and Innovation to use various big data sources, internal and external, going back 20 years where possible, to look for relationships between climate change, weather patterns, and raw and treated water quality.

We concluded that:

- There was no evidence that cutting back production is getting worse for river-fed sites over time due to raw water quality/weather related changes; and
- We were limited by sensor data going back far enough to determine climate change influence, and we are working with our Asset Intelligence and Innovation colleagues to improve this as part of our Technology base plan.

Output example 1: Looking at raw water turbidity challenge and river level data versus final water coliform detections at Strensham WTWs. The relationship covers six years of data. No significant difference in raw water challenge on detection days compared with non-detection days.

a) Raw water turbidity sensor data - average - 2015 to 2021. Detection days vs. No Detection days, and Mythe comparison.



b) River level data – average – 2012 to 2021. Detection days vs. No Detection days.

c) Example: Post GAC turbidity sensor data - 2015 to 2021.

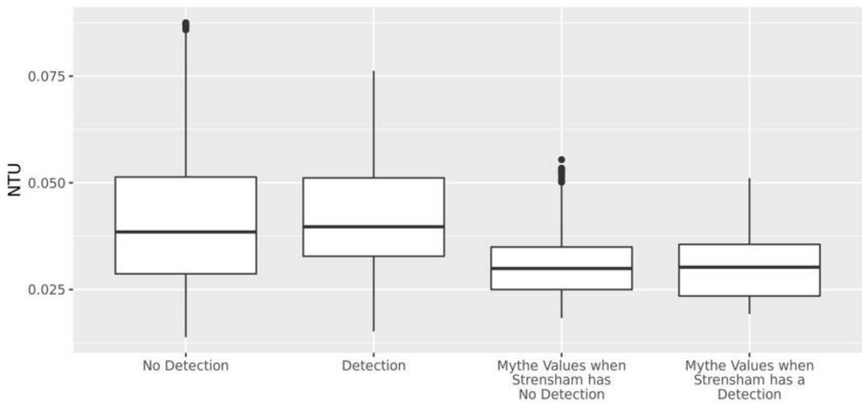


Figure A5: Strensham WTW data science outputs – raw water turbidity, river level and turbidity measurements on Coliform detection days and non-detection days

Output example 2: Surface water run-off – Extended periods of dry weather (seven days or more where daily rainfall has been below 1mm) followed by rain, has been used to model potential surface run-off events. There is no clear relationship between surface run-off and differences in raw water turbidity at Strensham WTWs inlet.

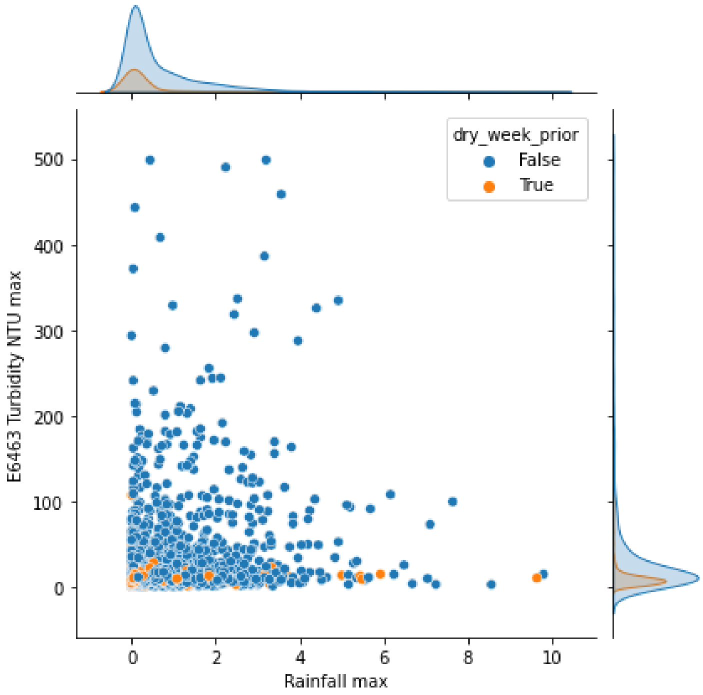


Figure A6: Strensham: Rainfall vs raw water turbidity – including prior dry week periods.

4. **Example long term Sample Data – decreasing trend in ammonia concentration over time, with upper action limits being breached less frequently.**

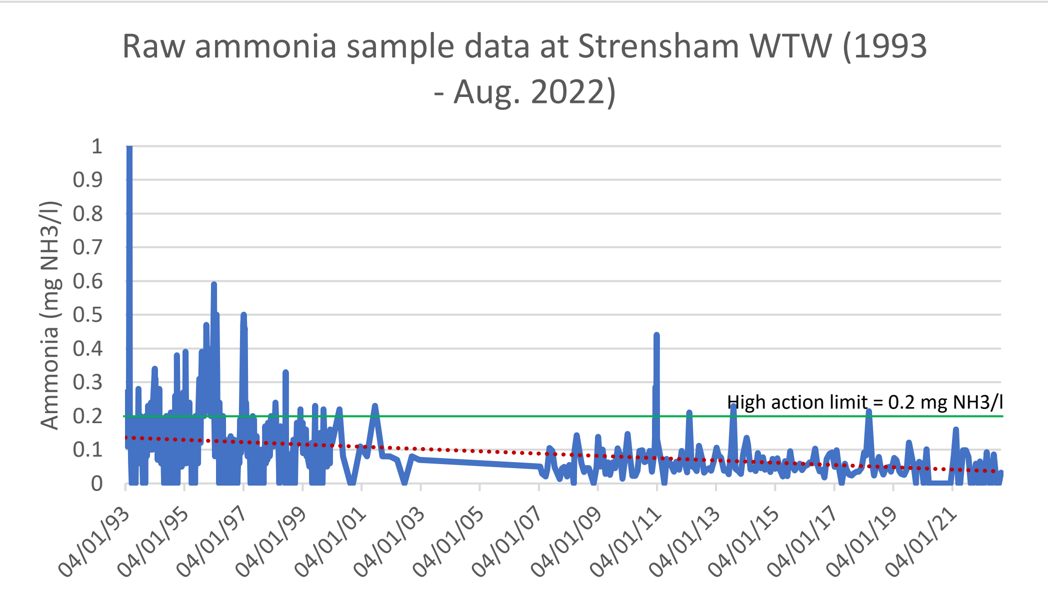


Figure A7: Raw ammonia concentrations at Strensham WTW over time