ANNEX A3(i)

Basis of Design Report

This document has been written in line with the requirements of the RAPID gate two guidance and to comply with the regulatory process pursuant to Severn Trent Water's and Affinity Water's statutory duties. The information presented relates to material or data which is still in the course of completion. Should the solution presented in this document be taken forward, Severn Trent Water and Affinity Water will be subject to the statutory duties pursuant to the necessary consenting process, including environmental assessment and consultation as required. This document should be read with those duties in mind.

Minworth SRO

Severn Trent Water & Affinity Water

Process Basis of Design

Document no: A7W13155-WT-REP-221009
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Severn Trent
A7W13155

Minworth SRO
3 November 2022

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Process Basis of Design

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Executive summary

Minworth Strategic Resource Option (SRO) is included as an SRO in the Price Review 19 Final Determination as a source option for the Severn to Thames Transfer (STT) SRO and Grand Union Canal (GUC) SRO. The project is now advancing through the Regulators' Alliance for Progressing Infrastructure Development (RAPID) gated process and is proceeding to Gate 2.

There are currently multiple flow rates that are being considered for the Minworth SRO: 57 Mld, 115 Mld, 172 Mld, and 230 Mld. It is yet unknown if the Minworth SRO will serve the River Avon, the GUC, or both. 115 Mld has been identified as the preferred flow rate and was used for the majority of the analysis in this document and discharge to both River Avon and GUC was analysed.

The Minworth SRO is currently envisioned to treat Minworth WwTW effluent and discharge to either the River Avon, the GUC, or both. The treated water would then be used as a flow augmentation scheme to support downstream abstractions. It is important that the Minworth SRO complies with anticipated discharge permit requirements to the receiving water(s) and that the Minworth SRO does not cause deterioration of the receiving water(s).

A thorough screening analysis was conducted to identify the anticipated determinands that will need to be removed to comply with a future discharge permit. The "Surface Water Pollution Risk Assessment for Your Environmental Permit (2016)" document was strictly followed to identify the determinands that would be flagged for additional modelling. For the purpose of this document, it is assumed that any determinand that is flagged for additional modelling needs to be treated to a level at which it would no longer be flagged. This document details the determinands that are flagged in this screening test and identifies the percent removal needed prior to discharge to the receiving water(s). Figure ES-1-1 shows the flagged determinands and the needed removal.

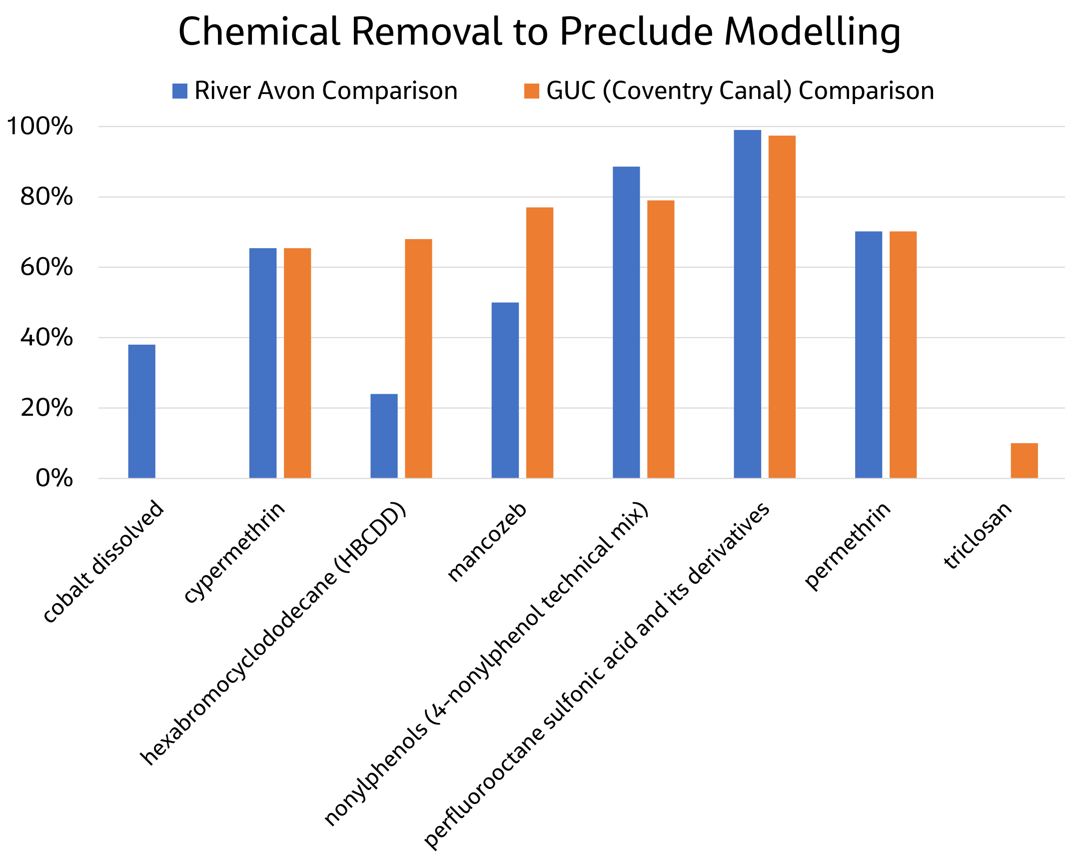

Figure ES-1-1: A comparison of the removal requirements for the River Avon and the GUC (Coventry Canal)

After identifying the determinands that need to be removed and the removal requirements, this document identifies a recommended advanced treatment train that will likely achieve the removal for most of these contaminants noting the current published Environmental Quality Standard for PFOS of 0.00065 ug/l is technically unachievable. Removal percentages will need to be verified via bench and pilot tests. A treatment train consisting of coagulation-flocculation-sedimentation, ozone oxidation, biologically activated carbon filtration, granular activated carbon (GAC) adsorption, and ultraviolet disinfection is introduced and recommended for the Minworth SRO. Figure ES-1-2 provides a draft process flow diagram of the recommended treatment train.

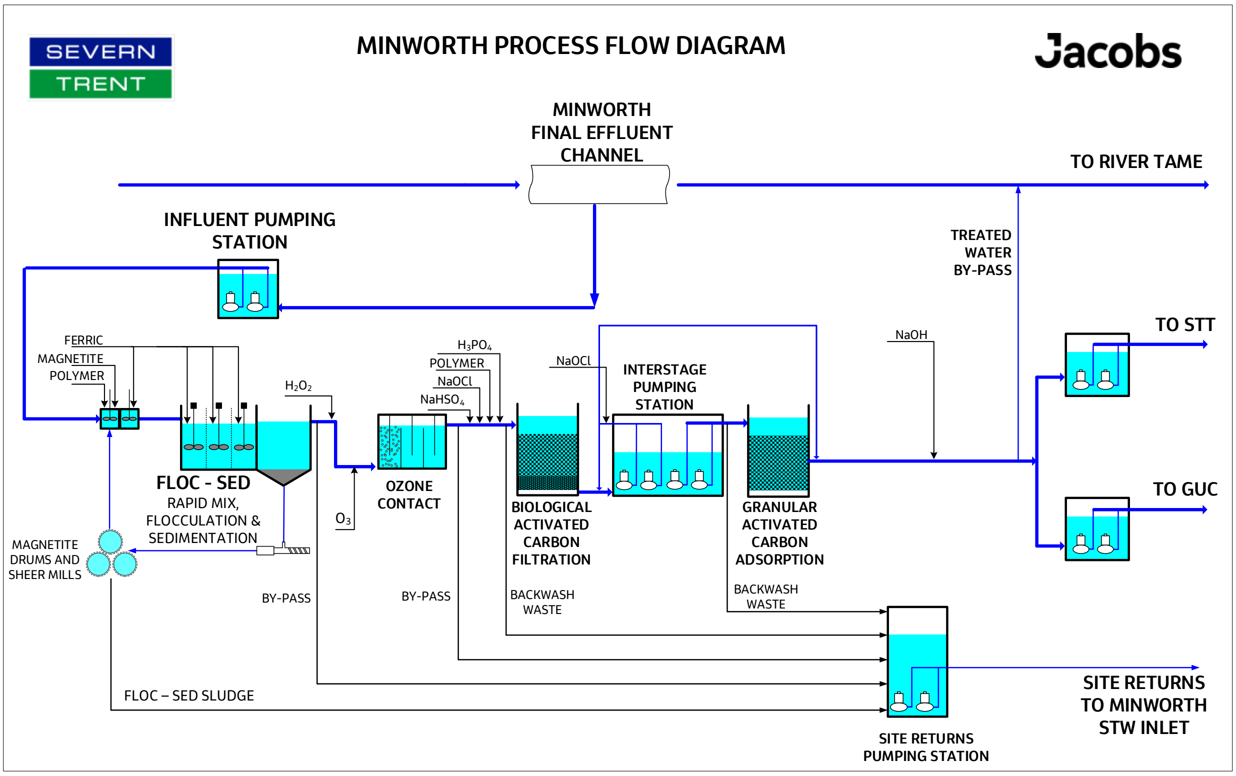

Figure ES-1-2: Minworth Advanced Water Treatment Works Process Flow Diagram

A reverse osmosis-based treatment scheme would also achieve the treatment requirements but would add significant cost, energy consumption, greenhouse gas emissions, and permitting challenges, primarily due to management of the waste brine stream. Reverse osmosis treatment schemes are typically utilized in coastal locations where ocean disposal can be used for the brine. In the absence of ocean disposal, deep well injection, mechanical evaporation, or evaporation ponds are typically utilised. These were not deemed practical for this project and thus reverse osmosis was eliminated as a treatment option for the Minworth SRO.

The recommended treatment train has been well-studied and has proven effective at treating WwTW effluent. It provides multiple treatment barriers for determinands and organics and will likely achieve good removal of most of the determinands identified in Figure ES-1-1. Bench and pilot testing on the Minworth WwTW is recommended to confirm determinand removal performance and the required GAC replacement frequency to meet water quality goals. It is noted that this treatment scheme achieves excellent (>90% removal) of perfluorooctane sulfonic acid (PFOS) for only a short period while the GAC media is new. As the GAC ages, the treatment train will not be able to achieve the required PFOS removal (nearly 100% shown in Figure ES-1-1.) However, GAC provides the Best Available Technology (BAT) given that reverse osmosis is not feasible for this project.

The formation of ozonation transformation products/disinfection by-products is a key parameter in Bench and Pilot trials. Trace organics are generally not completely mineralised during ozonation but are transformed into both polar ozonation products and bioavailable organic matter. Therefore, it is imperative the efficacy of the biological treatment step (BAC) and downstream GAC is assessed during trials. Critical to this assessment is deriving an optimised ozone dose (Ozone:DOC ratio) which helps to mitigate the risks.

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Acronyms and abbreviations

AA	Annual Average
AWTP	Advanced Water Treatment Plant
BC	Background Concentration
DWF	Dry Weather Flow
EA	Environment Agency
EFOM	Effluent Organic Matter
EFR	Effluent Flow Rate
EQS	Environmental Quality Standard
Mg/l	Milligrams per litre
Mld	Mega-litres per day
OSM	Operator Self-Monitoring
PC	Process Contribution
PEC	Predicted Environmental Concentration
RC	Release Concentration
RFR	River Flow Rate
SRO	Strategic Resource Option
UT	Upper Tier
UWWTD	Urban Wastewater Treatment Directive
GUC	Grand Union Canal
STT	Severn Thames Transfer
WwTW	Wastewater Treatment Works

1. Background Information

Minworth Strategic Resource Option (SRO) was included as an SRO in the PR-19 Final Determination as a source option for the Severn to Thames Transfer (STT) SRO via the River Avon and Grand Union Canal (GUC) SRO. Minworth Wastewater Treatment Works (WwTW) is envisioned as a flow augmentation scheme for both or either the STT or the GUC as it offers a robust and reliable source of water that is resilient to drought.

Flow partitioning to both the River Avon and the GUC is yet to be finalised. However, at this stage, four total flow options which cover all possible outcomes are being evaluated. The design flows required to be transferred are listed in the Table 1-1. In order to achieve those treated water flow rates, it is assumed the treatment processes will have design capacities 5% higher to account for water needed within the treatment process (e.g., backwash water). Backwash water is returned to Minworth WwTW ensuring no net loss of water to the River Tame aside from the conveyance flows.

Table 1-1: Flow options for Minworth

Option	Transferred Flow (Mld)
TREAT57	57
TREAT115	115
TREAT172	172
TREAT230	230

This report provides the basis of design for the Minworth Advanced Water Treatment Plant (AWTP) to supply the two SROs. This includes a technical review of the determinands that need to be removed to discharge to either the River Avon or the GUC including an Alternative scheme (denoted as ALT) - refer to section 3.4 for further details. The report provides an overview of the recommended treatment processes for both alternatives.

The Minworth AWTP will treat effluent from the Minworth WwTW to Best Available Technology (BAT) treatment levels so that it can be discharged into either the River Avon or the GUC. The following sections provide background and context on Minworth WwTW and each of the potential discharge locations.

1.1. Minworth Wastewater Treatment Works

Minworth WwTW serves an estimated 2.1 million population equivalent (PE). Between 10 – 20% of the treated load is derived from trade effluent or industrial processes. Figure 1-1 gives a birds-eye-view of the site detailing the location of the permitted final effluent point and one of two existing discharges to the River Tame. Minworth WwTW consists of the following treatment processes:

- An inlet works with 3 Dry Weather Flow (DWF), 6 mm aperture screens with downstream grit removal.
- Primary Settlement. 7 activated sludge plants (ASPs) operating in parallel that are fully nitrifying and meet the phosphorus removal permit by running a University of Capetown (UCT) Biological Phosphorus removal process.
- Thermal Hydrolysis Process (THP) with the return ammonia liquors being treated in an Anammox plant prior to being channelled back to the primary tanks.
- One permitted final effluent point and two discharge locations to the River Tame.

Minworth receives a cocktail of wastes both from the Trade Effluent customers and Tankered Trade Waste. As the site is permitted to receive a wide variety of wastes ranging of landfill leachates, industrial washwaters to tankered domestic waste, the available sampling data over the past 2 years captures the variability in discharges, noting samples collected as part of the SRO are analysed for an extensive 399 determinants per sample. In addition, any changes to the permitted EWC codes which designated wastes that can be accepted on site have to go through the normal EA permitting process allowing for future risks to be flagged beforehand. Therefore the proposed design accounts for the noted variability, with significant changes to the Minworth influent requiring EA permitting, this will allow for risk assessment to be performed accordingly

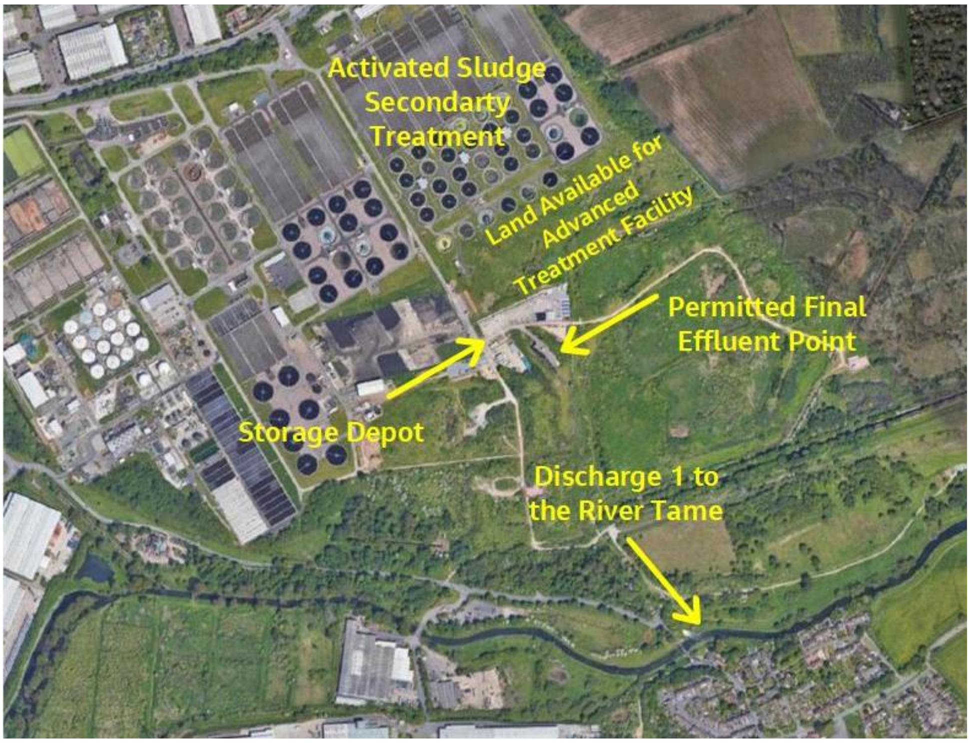


Figure 1-1: Minworth Wastewater Treatment works and the final effluent discharge points

Minworth is permitted to a DWF (20 percentile flow, Q80) of 450 Mld. The Minworth effluent measured DWF (Q80) between 2018 and 2021 was 417 Mld while the average flow during the same period was 533 Mld. Between 2018 and 2020 the River Tame **upstream of Minworth** averaged 421 Mld and a 20 percentile flow (Q80) of 180 Mld sourced from the UK National River Flow Archive.

As shown in Figure 1-2, with the River Tame 20 percentile flow (Q80) averaging 180 Mld upstream of the site and Minworth current Q80 averaging 417 Mld in the same period, the effluent from Minworth currently makes up approximately 70% of the total Q80 flow downstream of the WwTW.

With the transfer of up to 230 Mld there may be up to a near 40% reduction in the Q80 of the River Tame during transfers. The impact of this future reduction in flows to the river Tame is evaluated in the G2 Minworth EAR and WFD reports. These reports also reference the impact on the HOF at North Muskham on the River Trent and feasibility studies for storage support options to mitigate this impact are underway.

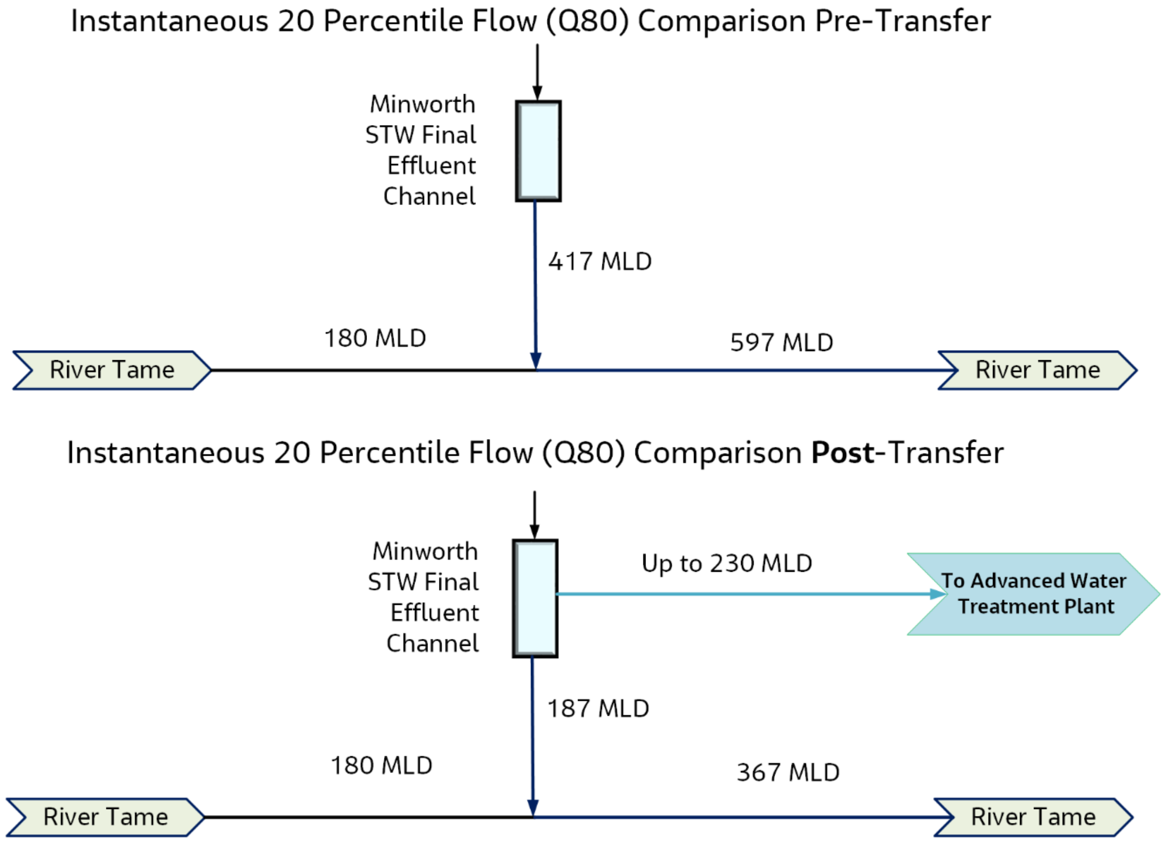


Figure 1-2: Comparison of Dry Weather Flows Pre and Post Transfer

Minworth WwTW full flow to treatment is permitted at 1,071.3 Mld. The site complies with this adequately, with a measured 99 percentile flow of 989 Mld.

1.1.1. Overnight Flows

Minworth overnight instantaneous flows as shown in Figure 1-3 are always above the conveyance target throughput. This suggests it is highly unlikely a water storage balance tank may be required upstream of a future Advanced Water Treatment Plant (AWTP).

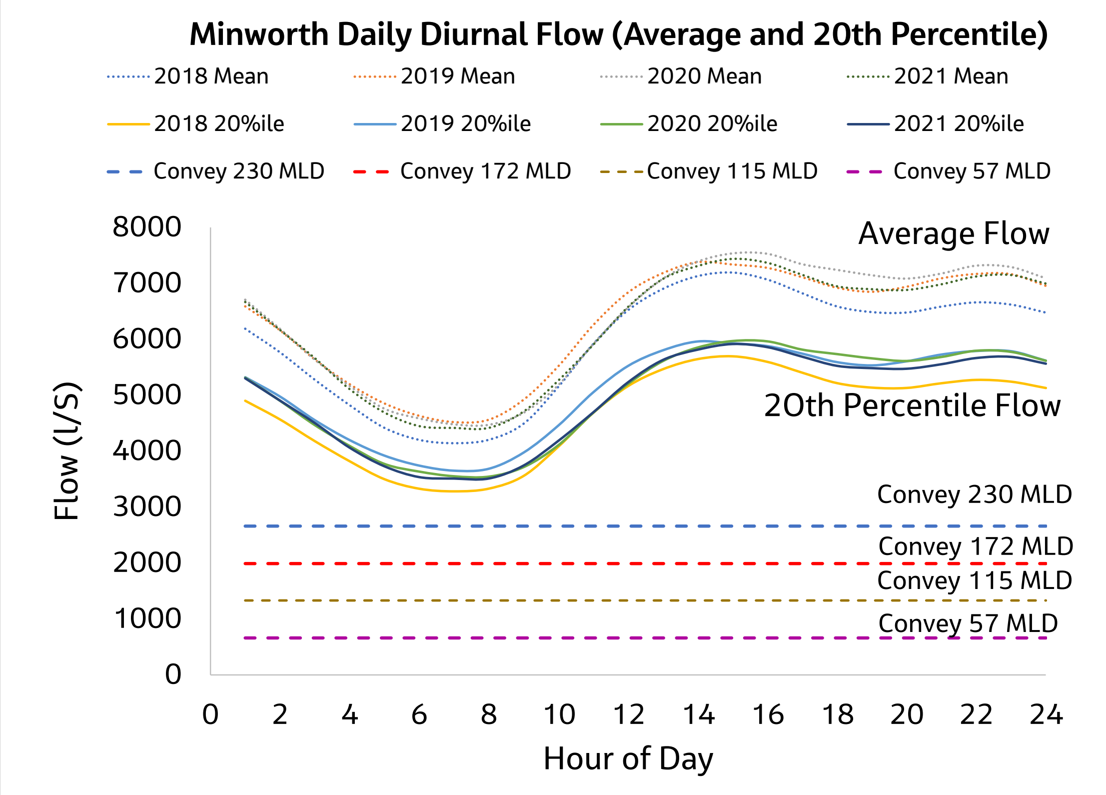


Figure 1-3: Minworth Diurnal Flow

1.1.2. Minworth WwTW Sampling Data

Sampling data was evaluated to better understand the current performance of the Minworth WwTW and to calculate the removal that will be needed to meet anticipated discharge permits for the SRO. 399 determinands were sampled over the past three years, including both permitted and non-permitted determinands. Table 1-2 provides the average and 95th percentile values for relevant determinands.

Table 1-2: Summary of Minworth Final Effluent Sampling Data

Parameter	Unit	Minworth Final Effluent Permit	No. Samples	Average	95%ile
Alkalinity as CaCO3	mg/l		14	88.4	120.5
Ammoniacal nitrogen	mg/l as N	3 (12 UT)	98	0.53	1.95
BOD (5 day)	mg/l	15 (50 UT)	97	1.93	5.00
Chemical Oxygen demand (COD)	mg/l		99	41.9	65.5
Chromium (III) dissolved	ug/l		14	1.6	2.70
Cobalt dissolved	ug/l		13	1.75	2.44
Dissolved organic carbon	mg/l		14	7.99	11.7
EDTA	ug/l		13	112.77	147.80
Fluoranthene	ug/l		14	0.0017	0.00
Hexabromocyclododecane (HBCDD)	ug/l		14	0.000973	0.00
Mancozeb	ug/l CS2		13	1.308	2.60
Nonylphenols (4-nonylphenol technical mix)	ug/l		14	0.35	0.62
Perfluorooctane sulfonic acid (PFOS) and its derivatives	ug/l		6	0.0211	0.03
Permethrin	ug/l		14	0.0034	0.01

Parameter	Unit	Minworth Final Effluent Permit	No. Samples	Average	95%ile
Soluble reactive phosphorus (Ortho-Phosphate)	mg/l P		77	0.27	1.03
Suspended solids @ 105øc	mg/l	25	99	6.87	15.0
Terbutryn	ug/l		14	0.0207	0.02
Total organic carbon	mg/l		13	9.408	12.6
Total phosphorus	mg/l	1 (AA)	98	0.478	1.13
Trichloromethane (chloroform)	ug/l		14	1.143	2.00
Triclosan	ug/l		14	0.0236	0.03
Turbidity	NTU		13	3.615	8.00
Total iron	mg/l	3.5 (8mg/l UT)	98	0.163	0.38
Antimony as Sb	µg/l	5 (UT)	13	0.94	1.18
Cadmium as Cd	µg/l	1 (UT)	14	0.024	0.04
Trichloromethane (Chloroform as chcl3)	µg/l	8 (UT)	14	1.14	2.0
Nickel (total)	µg/l	300 (UT)	14	13.7	17.7
Trichloroethylene as c2hcl3	µg/l	4 (UT)	<1	<1	<1
Dissolved nickel	µg/l	24 (AA) from Dec 2022	14	12.9	17.7
Dissolved Zn	µg/l	122 (AA) from Dec 2022	14	45.2	113.5
Calcium	mg/l		13	54.08	60.4
Chloride	mg/l		13	65.25	94.40
Magnesium	mg/l		13	8.838	10
pH			14	7.071	7.31
Sodium	mg/l		13	55.54	67.40
Sulphate	mg/l		13	71.92	96.80
Nitrate	mg/l N		13	13.2	19.8

Minworth operates well within its permit limits. There are no recorded Operator Self-Monitoring (OSM) Look-Up-Table or Urban Wastewater Treatment Directive (UWWTD) failures recorded in recent years.

BOD/COD

The Minworth final effluent has a COD:BOD ratio of approximately 22:1, with an average final effluent BOD of 1.93mg/l against a permit limit of 15mg/l. The high residual COD may be related to landfill leachate being treated on site, but this needs to be verified. Figure 1-4 shows the concentrations of both COD and BOD.

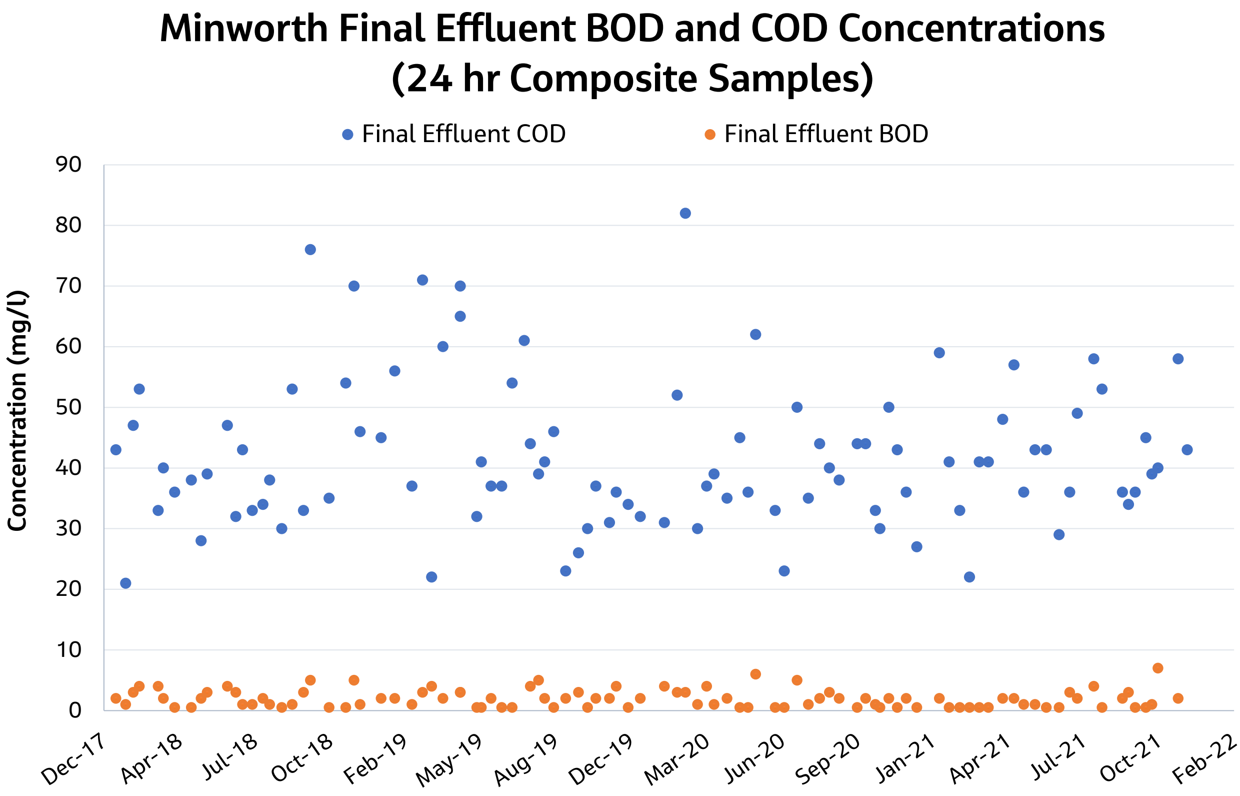


Figure 1-4: BOD and COD concentration plot

Ammonia

Effluent ammonia averages 0.53mg/l suggesting the upstream activated sludge plant is fully nitrifying. Coupled with a 95th percentile of 1.95mg/l, the activated sludge process operates well even during peak or storm loading periods.

An assessment of the sludge age is recommended during the next feasibility stage to assess both the operational practices and the headroom for future growth. A 24-hour evaluation of ammonia, nitrate, and nitrite is also recommended during the next feasibility stage to determine hour-by-hour fluctuations in each. The recommended AWTP is sensitive to nitrogen fluctuations, so it is important to fully understand Minworth WwTW's performance.

Phosphorus

Total phosphorus averages 0.48mg/l with the soluble orthophosphate fraction averaging 0.27mg/l, against an UWWTD permit limit of 1mg/l. This suggests the installation of downstream tertiary suspended solids removal and determinand dosing are both likely to contribute to a reduction in the total phosphorus concentration.

Carbon Fractionation

Total organic carbon averages 9.4 mg/l with 8 mg/l as the dissolved fraction. Figure 1-5 shows the concentrations of both total organic carbon and dissolved organic carbon. Additional TOC, DOC, BOD, and COD sampling is recommended to better characterize the discharge concentrations and its variability.

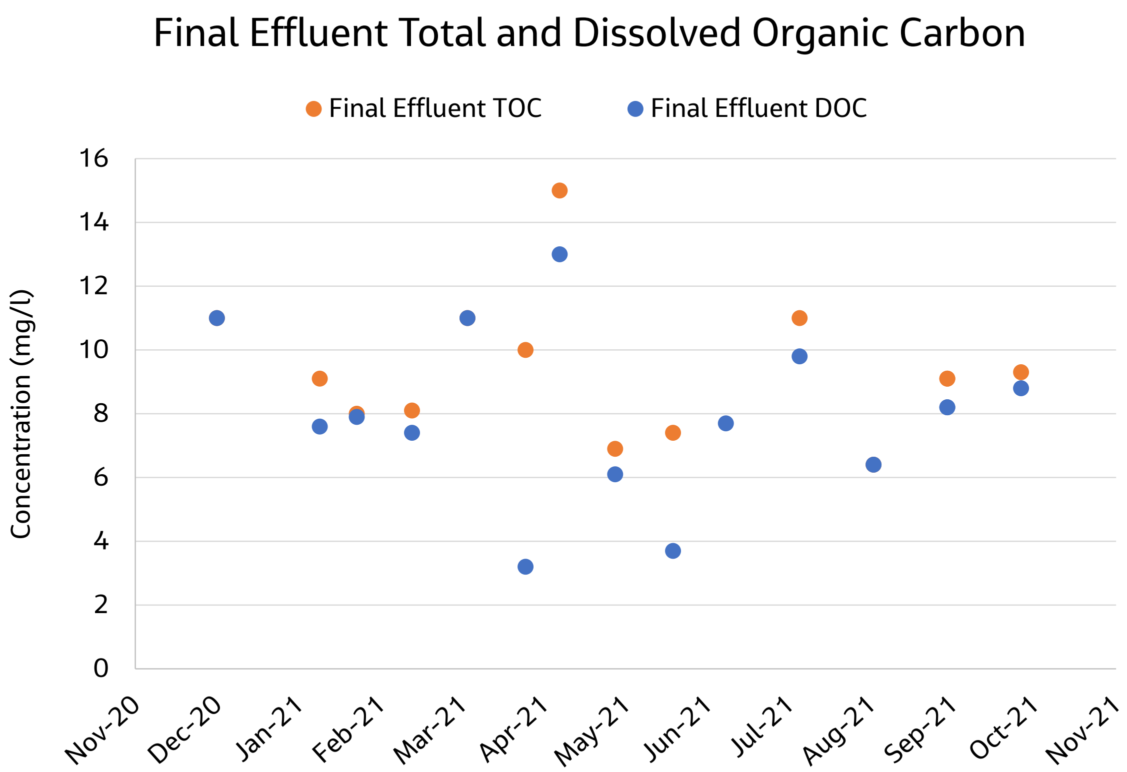


Figure 1-5: DOC and TOC concentrations plots

1.2. River Avon Flow

The Minworth SRO will discharge to either or both of the River Avon and the GUC. Flow data for the River Avon has been obtained from the National River Flow Archive. Average flow from 2016 to 2020, as measured from station 54114 in Warwick, was 691 Mld with 5th percentile (Q95) of 203 Mld as shown in Figure 1-6.

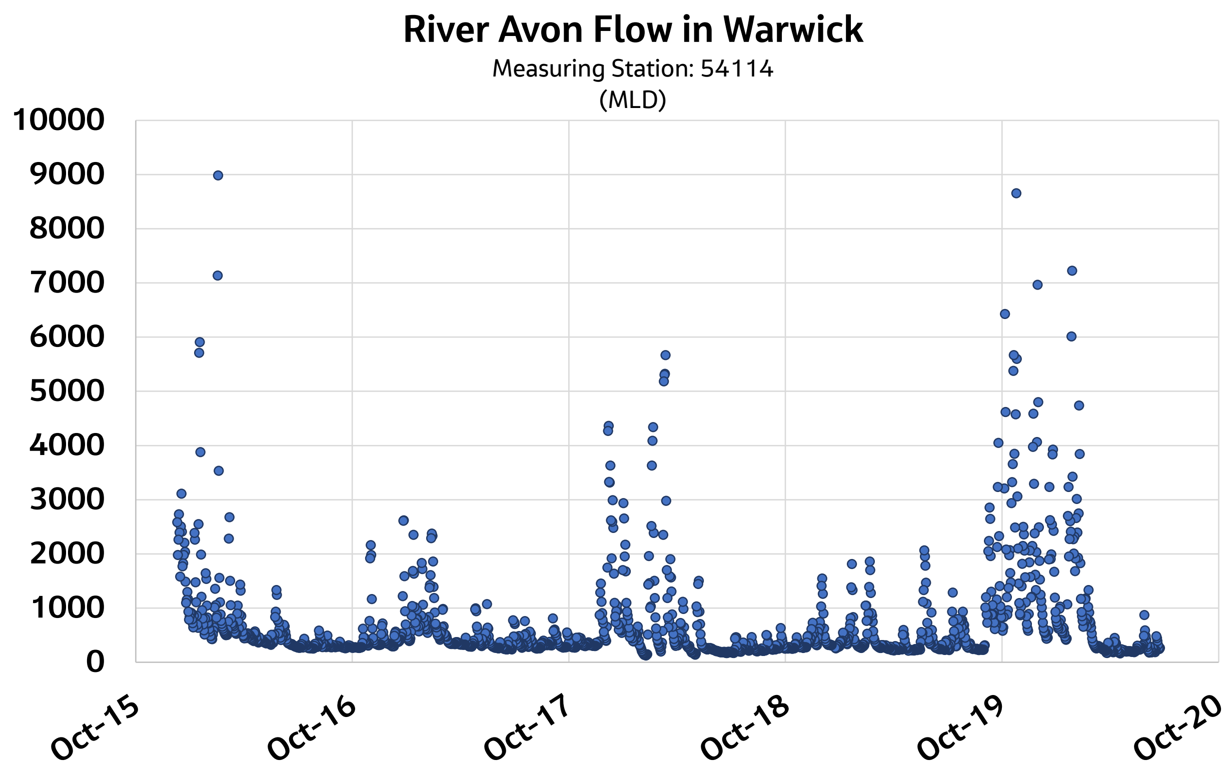


Figure 1-6: River Avon Daily Flow (Mld)

1.3. Grand Union Canal Flow

Flows at the Coventry Canal location, which is the likely discharge point for the GUC, are derived from the hydrological models and average 9.5 Mld with the 5th percentile flow (Q95) of 2.16 Mld. In comparison with the River Avon the GUC provides minimal dilution to the treated Minworth effluent. Further information on flows can be reviewed in GUC Gate 2 Submission.

2. Determinand Risk Assessment

Identifying determinands which require treatment is an important first step before the treatment process can be identified. As the Minworth SRO will include the discharge of Minworth WwTW effluent into either the River Avon, the GUC, or both, identifying the needed determinand removal is dependent on the anticipated permit requirements of the receiving water(s). This section of the report identifies the anticipated permitting framework and the specific determinands that would not meet the likely permit requirements.

Once determinands are identified that would not meet the anticipated permit requirements, it is assumed each determinand will be further assessed by running time-series Monte Carlo water quality simulations. Normal sanitary parameters such as the Biodeterminand Oxygen Demand (BOD), ammoniacal nitrogen, and total Phosphorus are normally modelled separately using stochastic models such as SIMCAT. These are not assessed in this initial screening exercise, however, following the Gate 1 solution, the Best Available Technology Limit for Phosphorus shall be used in this design.

2.1. Screening Methodology

The EA has outlined initial screening tests that must be carried out on a new discharge to a surface water body to prevent pollution from hazardous priority determinands and elements. These screening tests are published under the title, "Surface Water Pollution Risk Assessment for Your Environmental Permit (2016)". The same guidance is also found in a separate EA document titled, "LIT 13134 - Permitting of hazardous pollutants in discharges to surface waters."

This initial assessment involves subjecting determinands or elements present in the wastewater to a 5-stage screening process to understand the probable impact on the environment. If the test determines that there is a risk, the EA may require a detailed assessment to be carried out. This is within the remit of the Environmental Consultant and, at the time of this writing, finalised modelling results were pending.

It is assumed that this guidance will be followed to determine the permit requirements for the Minworth SRO. As shown in the subsequent sections, this step-by-step process identifies determinands in the Minworth WwTW effluent that would need to be removed, requiring significant advanced treatment.

The EA maintains a list of 138 determinands with published Environmental Quality Standards (EQS) in Freshwaters specific pollutants and operational environmental quality standards (EQS) and Freshwaters priority hazardous substances, priority substances and other pollutants environmental quality standards (EQS). Of the 399 determinands that were sampled in the Minworth WwTW effluent, 124 of the 138 EQS determinands have data.

The screening steps included in the EA guidance require the following information:

1. The 5 percentile flow (Q95) from the receiving river/watercourse (both River Avon and GUC)
2. The maximum, minimum and average concentrations of the pollutant in the discharge.
3. The flow from Minworth.
4. The river/canal water characterisation upstream of the discharge.
5. A Minimum of 12 samples (ideally 36). Please note values below the limit of detection (<) need to be rounded up to the nearest whole number (for example <10 is assumed to be 10).
6. The Minimum Reporting Value (limit of detection) for the determinands or elements.
7. The Environmental Quality Standards (EQS) for the specific determinand or element.

A step-by-step assessment for the River Avon discharge is detailed in the following section. Following the same methodology the outcomes for the GUC are also presented.

2.2. Screening Analysis for River Avon

The following sub-sections detail each step of the screening analysis performed for the River Avon and the determinand removal required.

2.2.1. Test 1

If a determinand has a concentration less than 10% of the EQS, it is not deemed a risk to the environment. This test identifies any determinand with a mean concentration within 10% of the EQS. The 124 determinands that have both EQS values and Minworth WwTW sampling data were reviewed and of these determinands, 103 had mean concentrations less than 10% of the EQS and were thus screened out of further tests. 21 determinands were measured over the 10% threshold value and were thus subjected to further tests. The 21 determinands are as detailed in Table 2-1.

Table 2-1: Determinands with a mean Minworth Effluent concentration greater than 10% of the EQS

Determinand	Unit	Minworth WwTW Effluent Mean	LOD	Environmental Quality Standard (EQS) (µg/l)	Test 1 Check whether the concentration of the determinand and element in the discharge is more than 10% of the environmental quality standard (EQS) (YES/NO)
chromium (III) dissolved	µg/l	1.6	1.0	4.7	YES
cobalt dissolved	µg/l	1.75	0.16	3	YES
copper dissolved	µg/l	0.89	0.4	1	YES
cypermethrin	µg/l	0.00023	0.00008	0.00008	YES
di(2-ethylhexyl)phthalate (DEHP)	µg/l	0.19	0.15	1.3	YES
EDTA	µg/l	112.8	100	400	YES
fluoranthene	µg/l	0.0017	0.00090	0.0063	YES
hexabromocyclododecane (HBCDD)	µg/l	0.0010	0.00014	0.0016	YES
lead dissolved	µg/l	0.20	0.09	1.20	YES
mancozeb	µg/l CS2	1.31	0.10	2.0	YES
manganese dissolved	µg/l	100	0.22	123	YES
nickel dissolved	µg/l	12.9	0.5	4.0	YES
nonylphenols (4-nonylphenol technical mix)	µg/l	0.35	0.04	0.30	YES
octylphenols ((4-(1,1',3,3'-tetramethylbutyl)pheno	µg/l	0.011	0.01	0.10	YES
omethoate	µg/l	0.01	0.01	0.01	YES
perfluorooctane sulfonic acid and its derivatives	µg/l	0.021	0.00020	0.00065	YES
permethrin	µg/l	0.00335	0.001	0.0010	YES
terbutryn	µg/l	0.021	0.02	0.0650	YES
tributyltin compounds (as tributyltin cation)	µg/l	0.000038	0.00003	0.0002	YES
trichloromethane (chloroform)	µg/l	1.14	1	2.5	YES
triclosan	µg/l	0.024	0.01	0.1	YES

2.2.2. **Test 2**

This test introduces dilution from the receiving water and checks if the process contribution (PC) of a particular determinand involved is less than 4% of its EQS. PC is the concentration of a discharged determinand or element after it has been diluted by the receiving water and is calculated as follows:

$$PC=\frac{(EFR\times RC)}{(EFR+RFR)}$$

Where:

- EFR: Effluent Flowrate. An EFR of 115 Mld was considered for the Minworth SRO as this is the preferred design flow. It is noted that the selected flow rate and discharge location (River Avon, GUC, or both) will affect these calculations and will be revisited as the design progresses.
- RC: the release concentration of the specific pollutant from Minworth WwTW.
- RFR: River Flow Rate. This is the Q_{95} flow (5 percentile) of the River Avon (203 Mld)

Running this assessment on the 21 determinands and elements from step 1, all except Octylphenols ((4-(1,1',3,3'-tetramethylbutyl) pheno are above the 4% screening threshold as shown in Table 2-2.

Table 2-2: Determinands or Elements where the PC is greater than 4% of the EQS

Determinand	Minworth Mean (µg/l)	EQS (µg/l)	Process Contribution (PC) (µg/l)	Is the PC less or equal to 4% of the EQS (YES/NO)
Chromium (III) dissolved	1.6	4.7	0.579	NO
Cobalt dissolved	1.75	3	0.631	NO
Copper dissolved	0.885	1	0.32	NO
Cypermethrin	0.00023	0.00008	0.000084	NO
Di(2-ethylhexyl)phthalate (DEHP)	0.19	1.3	0.068	NO
EDTA	112.77	400	40.8	NO
Fluoranthene	0.0017	0.006	0.00062	NO
Hexabromocyclododecane (HBCDD)	0.0010	0.0016	0.00035	NO
Lead dissolved	0.20	1.2	0.073	NO
Mancozeb	1.31	2	0.473	NO
Manganese dissolved	100	123	36.16	NO
Nickel dissolved	12.88	4	4.66	NO
Nonylphenols (4-nonylphenol technical mix)	0.35	0.3	0.127	NO
Omethoate	0.01	0.01	0.004	NO
Perfluorooctane sulfonic acid and its derivatives	0.021	0.00065	0.0076	NO
Permethrin	0.00336	0.001	0.0012	NO
Terbutryn	0.021	0.0650	0.0075	NO
Tributyltin compounds (as tributyltin cation)	0.000038	0.0002	0.000014	NO
Trichloromethane (chloroform)	1.14	2.5000	0.413	NO
Triclosan	0.02357143	0.1000	0.0085	NO

2.2.3. **Test 3**

This is an assessment of whether the discharge increases the concentration of the pollutant in the river downstream by more than 10% of the determinand's EQS. The predicted environmental concentration (PEC) is a combination of the Minworth Release Concentration (RC) and Background Concentration (BC). The BC is the concentration of the determinand or element in the river upstream of the discharge.

Hence:

$$PEC = \frac{(RC \times EFR)+(BC \times RFR)}{(EFR+RFR)}$$

If the difference between the BC and the PEC is more than 10% of the EQS, the EA will need to carry out modelling. For canal and lake discharges, the modelling is carried out by the permit applicant.

The BC of dissolved copper, manganese, nickel and lead has not currently been assessed as their annual average concentrations require calculation using the BLM tool. These elements have therefore not been assessed beyond this test level, which reduces the remaining number of determinands from 20 to 16.

Performing the PEC assessment in this step further reduces the number of determinands of concern from 16 down to 7 as identified in Table 2-3. These 7 determinands need to be modelled as part of the permit application process. The 9 determinands that were screened out during this test are shown in Table 2-4

Table 2-3: Determinands with PEC minus BC greater than 10% of the EQS

Determinand	Unit	Minworth WwTW Effluent Mean	Background Concentration This is the background concentration of the receiving watercourse (BC)	Predicted Environmental Concentration (PEC)	Environmental Quality Standard (EQS) (µg/l)
cobalt dissolved	µg/l	1.75	0.26	0.8	3
cypermethrin	µg/l	0.00023	0.00011	0.00015	0.00008
hexabromocyclododecane (HBCDD)	µg/l	0.0010	0.00030	0.00054	0.0016
mancozeb	µg/l CS2	1.31	0.1	0.54	2
nonylphenols (4-nonylphenol technical mix)	µg/l	0.35	0.06	0.16	0.3
perfluorooctane sulfonic acid and its derivatives	µg/l	0.021	0.00734	0.012	0.00065
permethrin	µg/l	0.00336	0.00214	0.00258	0.0010

Table 2-4: Determinands where the difference between the BC and PEC is less than 10% of the EQS

Determinand	Unit	Minworth WwTW Effluent Mean	Background Concentration (BC)	Predicted Environmental Concentration (PEC)	Environmental Quality Standard (EQS) (µg/l)
chromium (III) dissolved	µg/l	1.6	1.279	1.395	4.700
di(2-ethylhexyl)phthalate (DEHP)	µg/l	0.19	0.15	0.164	1.300
EDTA	µg/l	112.77	101.3	105.45	400
fluoranthene	µg/l	0.0017	0.00841	0.00599	0.0063
omethoate	µg/l	0.01	0.01	0.01	0.01
terbutryn	µg/l	0.021	0.020	0.020258	0.0650
tributyltin compounds (as tributyltin cation)	µg/l	0.000038	0.000043	0.000041	0.0002
trichloromethane (chloroform)	µg/l	1.14	1.000	1.051662	2.5000
triclosan	µg/l	0.02357143	0.01	0.014908	0.1000

2.2.4. Test 4

This is a check of whether the 9 determinands that were screened out of Test 3 (the difference between the BC and PEC was less than 10% of the EQS) have PEC higher than the EQS. As shown in Table 2-4, each of these determinands have a PEC lower or equal to the EQS and are thus screened out

2.2.5. Test 5

This is a check for whether the annual discharge of the pollutants from the Minworth WwTW (Table 2-5) is below the Significant Load Limit, regardless of whether they have passed previous screening steps.

Significant Load Limits have been identified by the EA for 14 determinands and identify the maximum allowable discharge load for each over an annual basis. Each of these determinands were reviewed against the Minworth effluent data and nonylphenols (4-nonylphenol technical mix) is the only determinand that exceeds the Significant Load Limit based on mean Minworth effluent data. This determinand is already short-listed for modelling, as without treatment, the significant load limit may be breached every 25days.

It should be noted that several other determinands shown in Table 2-5 are projected to be within 20% of the Significant Load Limit and should continue to be monitored. It should also be noted that these Significant Load Limit calculations were performed using a Minworth SRO flow of 115 Mld. If the actual SRO flow is greater for an individual discharge location, the discharge load would increase accordingly; thus flow rates over 115 Mld would likely trigger additional determinands that exceed the Significant Load Limit.

Table 2-5: Determinands with Significant Load Limits

Determinand	Significant Load Limit This is the load that can be discharged in a 365day year (kg)	Annual load discharged into the watercourse where significant load limits apply (kg/year)
Anthracene	1	0.84
Cadmium	5	0.99
Endosulphan	1	0.84
Hexachlorobenzene	1	0.84
Heptachlor	1	0.04
Hexachlorobutadiene	1	0.84
Hexachloro-cyclohexane	1	0.84
Mercury and its compounds	1	0.67
Nonylphenol (4-Nonylphenol)	1	14.69
Pentachlorobenzene	1	0.29
Polycyclic aromatic Hydrocarbons (PAHs)	5	3.18
Tributyltin compounds (Tributylin-cation)	1	0.0016

2.2.6. Required Determinand Removal

The screening exercise identified 7 pollutants which are recommended for additional modelling. An additional step was performed to calculate the target Minworth effluent concentration at which the determinands would not trigger additional modelling. Table 2-6 shows this target concentration for each determinand and the calculated removal required relative to the current effluent value. In other words, if Minworth SRO was able to achieve the removal of each contaminant that is shown in Table 2-6, all determinands would be screened out of the above tests. The required determinand removals range from 24 to 99%.

Table 2-6: Removal Levels required to preclude modelling on the Target Pollutants for the River Avon Discharge

Determinand	Minworth Mean (µg/l)	Limit Of Detection (µg/l)	Environmental Quality Standard (EQS) (µg/l)	Target Minworth Effluent means concentration to preclude Modelling (µg/l)	Percent Removal (%)
cobalt dissolved	1.75	0.16	3.000	1.09	38%
cypermethrin	0.00023	0.00008	0.00008	0.00008	65.4%
hexabromocyclododecane (HBCDD)	0.0010	0.00014	0.0016	0.00074	24%
mancozeb	1.31	0.1	2	0.653	50%
nonylphenols (4-nonylphenol technical mix)	0.35	0.04	0.3	0.04	88.6%
perfluorooctane sulfonic acid and its derivatives	0.021	0.0002	0.00065	0.0002	99%
permethrin	0.0034	0.001	0.001	0.001	70.2%

2.3. Screening Analysis for GUC

A similar screening analysis was performed for Minworth SRO discharge to the GUC. The same calculations were performed as described above, but GUC flows and concentrations were used instead of River Avon values. 115 Mld was still used as the Minworth flow, as that is currently the assumed design flow, and all flow was assumed to go to the GUC. As the GUC flows are significantly less than River Avon (GUC 5th percentile is 2.16 Mld), there will be substantially less dilution in the canal and the majority of the flow will be Minworth SRO effluent.

2.3.1. Test 1

If a determinand has a concentration less than 10% of the EQS, it is not deemed a risk to the environment. This test identifies any determinand with a mean concentration within 10% of the EQS. The 124 determinands that have both EQS values and Minworth WwTW sampling data were reviewed and of these determinands, 102 had mean concentrations less than 10% of the EQS and were thus screened out of further tests. 21 determinands were measured over the 10% threshold value and were thus subjected to further tests. The 21 determinands are as detailed in Table 2-7. Dissolved Zinc has not been assessed as it requires the BLM tool to ascertain the biologically available Zinc content. This task is to be performed by the environmental consultants.

Table 2-7 Determinands with a mean Minworth Effluent concentration greater than 10% of the EQS

Determinand	Unit	Minworth WwTW Effluent Mean	LOD	Environmental Quality Standard (EQS) (μg/l)	Test 1 Check whether the concentration of the determinand and element in the discharge is more than 10% of the environmental quality standard (EQS) (YES/NO)
chromium (III) dissolved	μg/l	1.6	1.0	4.7	YES
cobalt dissolved	μg/l	1.75	0.16	3	YES
copper dissolved	μg/l	0.89	0.4	1	YES
cypermethrin	μg/l	0.00023	0.00008	0.00008	YES
di(2-ethylhexyl)phthalate (DEHP)	μg/l	0.19	0.15	1.3	YES
EDTA	μg/l	112.8	100	400	YES
fluoranthene	μg/l	0.0017	0.00090	0.0063	YES
hexabromocyclododecane (HBCDD)	μg/l	0.0010	0.00014	0.0016	YES
lead dissolved	μg/l	0.20	0.09	1.20	YES
mancozeb	μg/l CS2	1.31	0.10	2.0	YES
manganese dissolved	μg/l	100	0.22	123	YES
nickel dissolved	μg/l	12.9	0.5	4.0	YES
nonylphenols (4-nonylphenol technical mix)	μg/l	0.35	0.04	0.30	YES
octylphenols ((4-(1,1',3,3'-tetramethylbutyl)pheno	μg/l	0.011	0.01	0.10	YES
omethoate	μg/l	0.01	0.01	0.01	YES
perfluorooctane sulfonic acid and its derivatives	μg/l	0.021	0.00020	0.00065	YES
permethrin	μg/l	0.00335	0.001	0.0010	YES
terbutryn	μg/l	0.021	0.02	0.0650	YES
tributyltin compounds (as tributyltin cation)	μg/l	0.000038	0.00003	0.0002	YES
trichloromethane (chloroform)	μg/l	1.14	1	2.5	YES
triclosan	μg/l	0.024	0.01	0.1	YES

2.3.2. **Test 2**

This test introduces dilution from the receiving water and checks if the process contribution (PC) of a particular determinand involved is less than 4% of its EQS. PC is the concentration of a discharged determinand or element after it has been diluted by the receiving water and is calculated as follows:

$$PC=\frac{(EFR\times RC)}{(EFR+RFR)}$$

Where:

- EFR: Effluent Flowrate. An EFR of 115 Mld was considered for the Minworth SRO as this is the preferred design flow. It is noted that the selected flow rate and discharge location (River Avon, GUC, or both) will affect these calculations and will be revisited as the design progresses.

- RC: the release concentration of the specific pollutant from Minworth WwTW.
- RFR: River Flow Rate. This is the Q_{95} flow (5 percentile) of the Coventry Canal (2.16 Mld, supplied by JBA Consulting on 23/03/2022)

Running this assessment on the 21 determinands and elements from step 1, all are above the 4% screening threshold as shown in Table 2-8.

Table 2-8 Determinands or Elements where the PC is greater than 4% of the EQS

Determinand		Minworth Mean (µg/l)	EQS (µg/l)	Process Contribution (PC) (µg/l)	Is the PC less or equal to 4% of the EQS (YES/NO)
Chromium (III) dissolved	µg/l	1.6	4.7	1.57	NO
Cobalt dissolved	µg/l	1.75	3	1.71	NO
Copper dissolved	µg/l	0.885	1	0.87	NO
Cypermethrin	µg/l	0.00023	0.00008	0.00023	NO
Di(2-ethylhexyl)phthalate (DEHP)	µg/l	0.19	1.3	0.19	NO
EDTA	µg/l	112.77	400	111	NO
Fluoranthene	µg/l	0.0017	0.006	0.0017	NO
Hexabromocyclododecane (HBCDD)	µg/l	0.0010	0.0016	0.00095	NO
Lead dissolved	µg/l	0.20	1.2	0.20	NO
Mancozeb	µg/l CS2	1.31	2	1.28	NO
Manganese dissolved	µg/l	100	123	98.16	NO
Nickel dissolved	µg/l	12.88	4	12.64	NO
Nonylphenols (4-nonylphenol technical mix)	µg/l	0.35	0.3	0.34	NO
octylphenols((4-(1,1',3,3'-tetramethylbutyl)pheno	µg/l	0.010714286	0.1	0.01	NO
Omethoate	µg/l	0.01	0.01	0.01	NO
Perfluorooctane sulfonic acid and its derivatives	µg/l	0.021	0.00065	0.02	NO
Permethrin	µg/l	0.00336	0.001	0.0033	NO
Terbutryn	µg/l	0.021	0.0650	0.02	NO
Tributyltin compounds (as tributyltin cation)	µg/l	0.000038	0.0002	0.000037	NO
Trichloromethane (chloroform)	µg/l	1.14	2.5	1.12	NO
Triclosan	µg/l	0.02357143	0.1	0.02	NO

2.3.3. Test 3

This is an assessment of whether the discharge increases the concentration of the pollutant in the river downstream by more than 10% of the determinand’s EQS. The predicted environmental concentration (PEC) is a combination of the Minworth Release Concentration (RC) and Background Concentration (BC). The BC is the concentration of the determinand or element in the river upstream of the discharge.

Hence:

$$PEC = \frac{(RC \times EFR) + (BC \times RFR)}{(EFR + RFR)}$$

If the difference between the BC and the PEC is more than 10% of the EQS, the EA will need to carry out modelling. For canal and lake discharges, the modelling is carried out by the permit applicant.

The BC of dissolved copper, manganese, nickel and lead has not currently been assessed as their annual average concentrations require calculation using the BLM tool to ascertain the biologically available fraction. The river concentrations for chromium (III) dissolved and terbutryn were not available.

Performing the PEC assessment in this step further reduces the number of determinands of concern from 21 down to 7 as identified in Table 2-9. These 7 determinands need to be modelled as part of the permit application process.

The six determinands mentioned above (dissolved copper, manganese, nickel, lead, chromium (III) dissolved and terbutryn) fall out as they have not been assessed leaving 8 determinands for further review. The 8 determinands were screened out during this test are shown in Table 2-10

Table 2-9 Determinands with PEC minus BC greater than 10% of the EQS

Determinand	Unit	Minworth WwTW Effluent Mean	Background Concentration (BC)	Predicted Environmental Concentration (PEC)	Environmental Quality Standard (EQS) (µg/l)
cypermethrin	µg/l	0.00023	0.000080	0.00023	0.000080
hexabromocyclododecane (HBCDD)	µg/l	0.00097	0.00015	0.00096	0.0016
mancozeb	µg/l	1.31	0.10	1.29	2
nonylphenols (4-nonylphenol technical mix)	µg/l	0.35	0.042	0.34	0.30
perfluorooctane sulfonic acid and its derivatives	µg/l	0.021	0.0061	0.021	0.00065
permethrin	µg/l	0.0034	0.0011	0.0033	0.001
triclosan	µg/l	0.024	0.011	0.023	0.10

Table 2-10 Determinands where subtracting the BC from the PEC is less than 10% of the EQS

Determinand	Unit	Minworth WwTW Effluent Mean	Background Concentration This is the background concentration of the receiving watercourse (BC)	Predicted Environmental Concentration (PEC)	Environmental Quality Standard (EQS) (µg/l)
cobalt dissolved	µg/l	1.75	10.8	1.91	3
di(2-ethylhexyl)phthalate (DEHP)	µg/l	0.19	0.15	0.19	1.3
EDTA	µg/l	113	100	113	400
fluoranthene	µg/l	0.0017	0.014	0.0019	0.0063
octylphenols ((4-(1,1',3,3'-tetramethylbutyl)pheno	µg/l	0.011	0.010	0.011	0.1
omethoate	µg/l	0.010	0.010	0.010	0.01
tributyltin compounds (as tributyltin cation)	µg/l	0.000038	0.000075	0.000039	0.0002
trichloromethane (chloroform)	µg/l	1.14	1.00	1.14	2.5

2.3.4. Test 4

This is a check of whether the 8 determinands that were screened out of Test 3 (the difference between the BC and PEC was less than 10% of the EQS) have PEC higher than the EQS. As shown in Table 2-4

2.3.5. Test 5

This is a check for whether the annual discharge of the pollutants from the Minworth WwTW (Table 2-11) is below the Significant Load Limit, regardless of whether they have passed previous screening steps.

Significant Load Limits have been identified by the EA for 14 determinands and identify the maximum allowable discharge load for each over an annual basis. Each of these determinands were reviewed against the Minworth effluent data and nonylphenols (4-nonylphenol technical mix) is the only determinand that exceeds the Significant Load Limit based on mean Minworth effluent data. This determinand is already short-listed for modelling, as without treatment, the significant load limit may be breached every 25 days.

It should be noted that 5 out of 12 determinands shown in Table 2-11 are projected to be within 20% of the Significant Load Limit and should continue to be monitored. It should also be noted that these Significant Load Limit calculations were performed using a Minworth SRO flow of 115 Mld operating 24 hours per day, 365 days per year. If the actual SRO flow is greater for an individual discharge location, the discharge load would increase accordingly; thus flow rates over 115 Mld would likely trigger additional determinands that exceed the Significant Load Limit.

Table 2-11 Determinands with Significant Load Limits

Determinand	Significant Load Limit This is the load that can be discharged in a 365day year (kg)	Annual load discharged into the watercourse where significant load limits apply (kg/year)
Anthracene	1	0.84
Cadmium	5	0.99
Endosulphan	1	0.84
Hexachlorobenzene	1	0.84
Heptachlor	1	0.04
Hexachlorobutadiene	1	0.84
Hexachloro-cyclohexane	1	0.84
Mercury and its compounds	1	0.67
Nonylphenol (4-Nonylphenol)	1	14.69
Pentachlorobenzene	1	0.29
Polycyclic aromatic Hydrocarbons (PAHs)	5	3.18
Tributyltin compounds (Tributylin-cation)	1	0.0016

2.3.6. Required Determinand Removal

Table 2-12 shows the result of the GUC analysis. Similar to the River Avon, there are 7 determinands that would require removal in order to pass the screening tests. Six of the determinands are the same, with triclosan being the only new determinand. The required percent removals of the identified determinands are on the same order of magnitude as the River Avon analysis.

Table 2-12: Removal Levels required to preclude modelling on the Target Pollutants for the GUC (Coventry Canal)

Determinand	Minworth Mean (µg/l)	Limit Of Detection (µg/l)	Environmental Quality Standard (EQS) (µg/l)	Target Minworth Effluent means concentration to preclude Modelling (µg/l)	Percent Removal (%)
cypermethrin	0.00023	0.00008	0.00008	0.00008	65.4%
hexabromocyclododecane (HBCDD)	0.001	0.00014	0.0016	0.000313	68%
mancozeb	1.31	0.10	2	0.3	77%
nonylphenols (4-nonylphenol technical mix)	0.35	0.04	0.3	0.0725	79%
perfluorooctane sulfonic acid and its derivatives	0.021	0.0002	0.00065	0.000548	97.4%
permethrin	0.003357	0.001	0.001	0.001	70.2%
triclosan	0.023571	0.01	0.1	0.021	10%

Further to the above, a detailed River Water Quality modelling assessment for the GUC was conducted by the GUC SRO without the screening step, suggesting 49 chemicals require treatment by the proposed BAT treatment scheme. Further detailed assessments of these outputs are to be completed at the next design stage, to demonstrate the effectiveness of the BAT to remove these additional determinands to be assessed further during bench tests to verify achievable removal levels. The output table from this river modelling exercise has been copied below - "Site 3 (Atherstone)" should be referenced in relation to Minworth SRO.

Table 2-13: Copy of Table 8-1 from GUC Annex A2.3 Output from the GUC Water Quality Impact Assessment

Determinand	WW treatment % reduction required to prevent deterioration (Mean)		
	Site 3 (Atherstone)	Site 5 (Daventry)	Site 6 (Leighton Buzzard)
4-methylphenol (p-cresol) **(Q)**	**43%**		
ammoniacal nitrogen	**58%**	16%	
antimony dissolved	58%	33%	**70%**
antimony total	57%	32%	**60%**
Bromide	**36%**		
BTEX (benzene, toluene, ethylbenzene & o,p-xylene **(Q)**	**36%**		
chemical oxygen demand (COD)	**44%**	41%	
Chloride	**31%**		
chloronitrotoluenes **(Q)**	**50%**		
chromium dissolved	73%	**80%**	61%

Determinand	WW treatment % reduction required to prevent deterioration (Mean)		
	Site 3 (Atherstone)	Site 5 (Daventry)	Site 6 (Leighton Buzzard)
chromium total	69%	**76%**	41%
conductivity @ 20øC			**10%**
cypermethrin **(Q)**	74%	**79%**	74%
di(2-ethylhexyl)phthalate (DEHP) **(Q)**	**32%**	32%	32%
dibutyl phthalate **(Q)**	**33%**		
dissolved organic carbon	48%	**54%**	38%
EDTA **(Q)**	**28%**		
fluoride	**46%**		
glyphosate **(Q)**	**87%**		
hexabromocyclododecane (HBCDD) **(Q)**	90%	**92%**	86%
iron dissolved	**53%**		
mancozeb **(Q)**	**91%**		
maneb **(Q)**	**78%**		
mecoprop **(Q)**	**72%**		
mercury dissolved		**30%**	
mercury total		**40%**	
nickel dissolved		83%	**86%**
nickel total		76%	**82%**
Nitrate (mg/l NO_3)	83%	91%	**99%**
Nitrate (mg/l N)	83%	91%	**99%**
Nitrite (mg/l NO_2)	**56%**	39%	
nitrite (mg/l N)	**56%**	39%	
nonylphenols (4-nonylphenol technical mix) **(Q)**	**93%**	93%	91%
orthophosphate as PO4	**71%**		
perfluorooctanoic acid (PFOA)	21%	21%	**70%**
Permethrin **(Q)**	**73%**		
polychloro chloromethyl sulphonamido diphenyl ethe **(Q)**	**38%**		

Determinand	**WW treatment % reduction required to prevent deterioration (Mean)**		
	Site 3 (Atherstone)	**Site 5 (Daventry)**	**Site 6 (Leighton Buzzard)**
propyzamide **(Q)**	**67%**		
salinity @ 20øC		**19%**	11%
soluble reactive phosphorus	**68%**	19%	
tetrachloroethane **(Q)**	**24%**		
total organic carbon	65%	**72%**	56%
total oxidised nitrogen	82%	**90%**	52%
total phosphorus	**40%**	22%	
triclosan **(Q)**	63%	77%	**82%**
zinc dissolved	29%	80%	**81%**
zinc total		**44%**	

2.4. Summary of Screening Analysis

The screening analysis was performed to identify the number of determinands that would increase the background concentrations in the receiving water to levels that require additional modelling. This report assumes that these determinands will not be allowed to be discharged at these high levels and would need to be removed to concentrations that would allow them to be screened out of this analysis. Thus, the identified determinands and the target removals becomes the basis of design for the Minworth SRO project.

In general, the River Avon and GUC analyses were similar and identified similar determinands and required removals. The main differences between the two receiving waters were:

- Dissolved Cobalt was triggered for the River Avon due to the river's low background levels.
- HBCDD and mancozeb require significantly more removal in the GUC due to the reduced dilution in the Canal.
- Triclosan was triggered in the GUC as it is marginally (0.011µg/l against a Limit Of Detection of 0.01µg/l) above the limit of detection in the Canal

Figure 2-1 shows the required removal of the 8 identified determinands for both analyses. As the differences in determinands identified and required removals are marginal, it appears plausible that one treatment train would be suitable to treat the water to be discharged to either to the River Avon or the GUC or both.

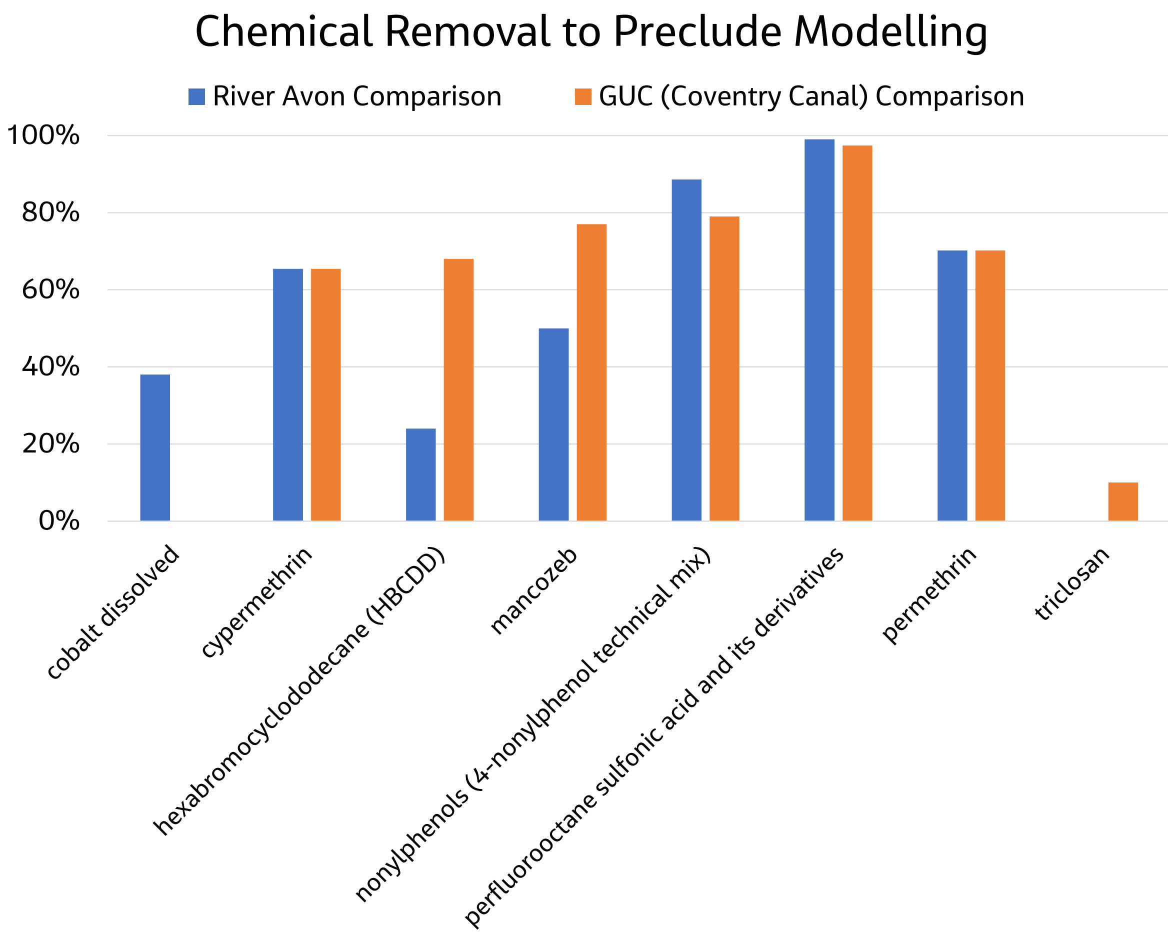


Figure 2-1: A comparison of the removal requirements for the River Avon and the GUC (Coventry Canal)

Analysis by others of water quality sampling data, which the SRO is collecting, reveals that often the Minworth treated water is of a higher quality than the receiving canal.

2.5. Total Phosphorus

As the river water quality modelling is still underway, discharge targets for Total Phosphorus into the River Avon and the GUC have not yet been identified. Thus, it is assumed that the Minworth SRO will need to be designed in line with Gate 1 estimations which required a total Phosphorus permit of 0.2mg/l to be met. The 0.2 mg/l Total Phosphorus limit will not hamper the river Avon achieving a "Good" water quality status in the future as it is also the current Best Available Technology (BAT) limit.

Targets for other common contaminants, such as BOD and ammoniacal nitrogen, will be given once the river water modelling is completed but they are not envisioned to influence the design of the Minworth SRO.

3. Process Design Basis

Minworth SRO is a flow augmentation scheme where treated water from Minworth WwTW will be discharged into the River Avon or the Grand Union Canal, and then flow downstream to a water abstraction point. The previous section identified determinands that are required to be removed to comply with anticipated discharge permits to either of the receiving waters.

An Advanced Water Treatment Plant (AWTP) at Minworth is envisioned to help meet the identified environmental discharge requirements and mitigate the deterioration of the receiving water. The AWTP will be designed to treat bulk organics, trace organics, nutrients, pathogens, and other contaminants, although only the identified determinands from section 2 are anticipated to be included in the permit.

Treatment of WwTW effluent to achieve excellent determinand removal and/or drinking water limits has been well studied and practiced within the water reuse community. There are two primary treatment trains that are typically considered for this level of treatment. Variations of these two types of schemes have been studied and successfully demonstrated at full-scale outside the UK but they typically include many of the basic treatment elements listed here:

- Carbon-based train: coagulation, flocculation, and sedimentation (floc/sed) followed by ozone oxidation, biologically active carbon (BAC) filtration, granular activated carbon (GAC) adsorption.
- Membrane-based train: microfiltration (MF) followed by reverse osmosis (RO) and ultraviolet advanced oxidation process (UVAOP).

The carbon-based train is the recommended treatment process for the Minworth SRO due to the many challenges with reverse osmosis treatment, as described in section 3.2. The carbon-based train offers a treatment scheme that is less expensive (both capital and operating), requires less energy, treats a higher percentage of the water, and is overall a more sustainable option. The following sections discuss each of the primary steps of the proposed treatment train.

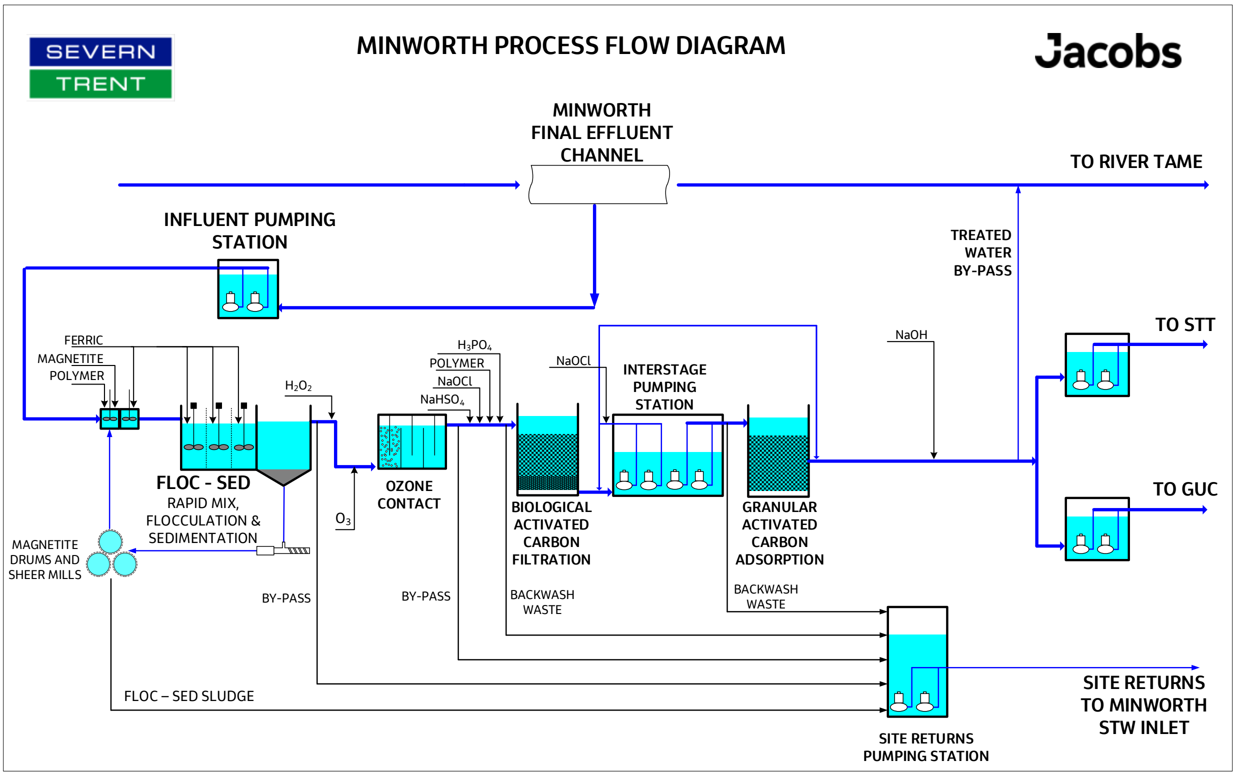


Figure 3-1: Minworth Advanced Water Treatment Works Process Flow Diagram

Figure 3-1 provides a process flow diagram for the carbon-based treatment train, including anticipated determinand addition points, pump stations, and storage tanks. This document provides the process background for the recommended treatment train. Additional design criteria, site footprint, cost estimates, and other information on the recommended treatment process will be provided in subsequent reports.

In addition to the benefits of micro-pollutant removal, an assessment of the pathogen removal efficacy requires further assessment at Gate 3 as this treatment train is optimised for micro-pollutant removal. The ozonation step provides a level of pathogen disinfection, hence log removals need to be quantified during bench and pilot tests. These tests will determine whether a UV disinfection step is required before discharge.

3.1. Recommended Carbon-Based Treatment Process

The combination of treatment processes shown in Figure 3-1 provides multiple treatment barriers for pathogens, organics, and determinands, and has been demonstrated to achieve drinking water quality effluent or better (Hogard, 2021). It is expected that this process would provide treated water that exceeds the overall quality of the receiving waters.

This treatment scheme requires WwTW effluent that is nitrifying and denitrifying and has consistent ammonia and nitrite levels throughout the day. The process does not remove total dissolved solids (TDS) and thus it is important that the receiving water is compatible with the WwTW effluent TDS. TDS was not included in the receiving water sampling data so it is currently unknown how the Minworth TDS will compare. Disinfection by-products will be created with ozone addition but are expected to be mitigated or subsequently removed later in the treatment process.

While this treatment train achieves excellent removal of most trace organics and determinands, bench then followed by pilot testing is needed to determine if determinand removal would achieve the targets identified in Figure 3-2. Based on existing research, this treatment train is not expected to consistently meet the PFOS removal requirements. Within the selected treatment train, PFOS is only measurably removed by GAC adsorption. Removal of PFOS through GAC adsorption is a function of the adsorptive capacity of the GAC and decreases with time as more water passes through it.

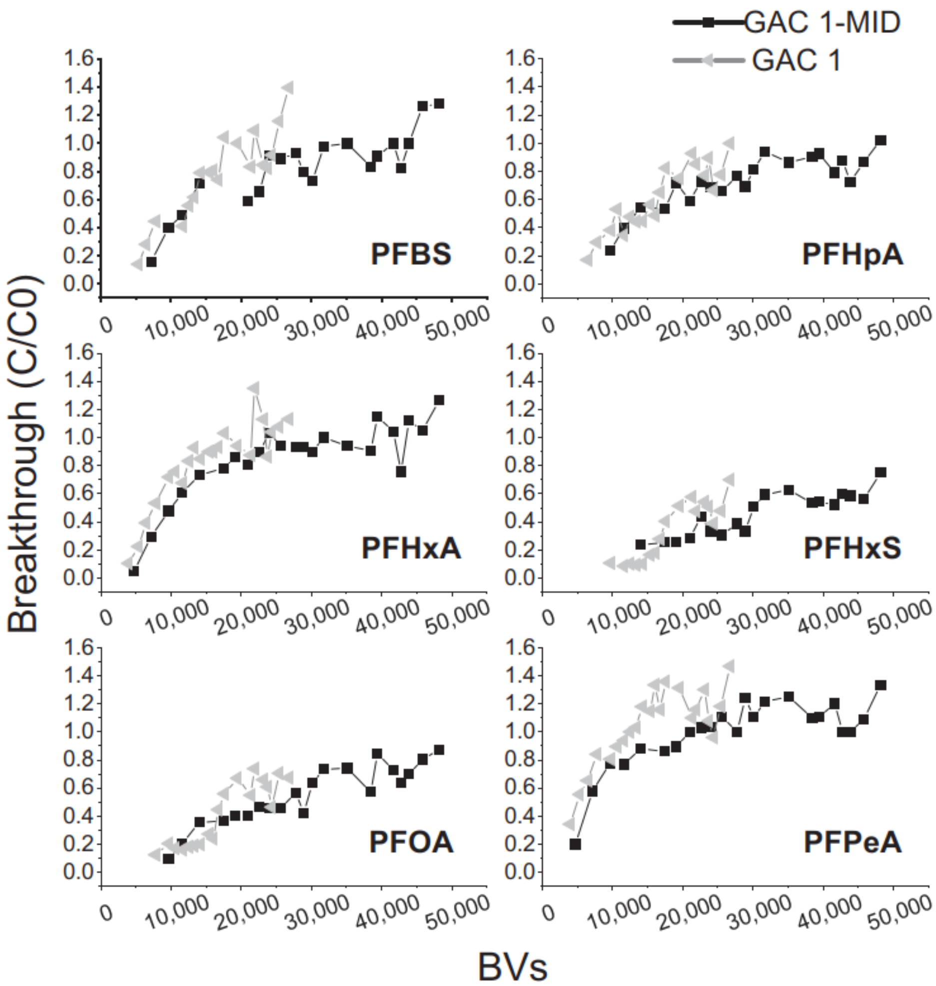


Figure 3-2: Breakthrough curves for Perfluoroalkylated substances (Gonzalez, 2021)

Figure 3-2 shows GAC breakthrough curves for different per- and polyfluoralkyl substances (PFAS) within a similar water reuse treatment train. While PFOS is not shown on this figure, its breakthrough and removal is expected to be similar to PFOA. These breakthrough curves show the percent removal as a function of bed volumes: the number of volumes of water that have passed through the GAC contactor. 99% removal of PFOS will only be achieved with a very short GAC life and would require very frequent GAC regeneration (<1 month) which would not be practical for this project. GAC is typically regenerated at >12 month frequencies, lining up with bed volumes in the range of 25,000 (based on a design empty bed contact time of 20 minutes) and corresponding to a PFAS removal of around 50%, according to Figure 3-2. This would provide an average PFOS removal of approximately 75% (assuming linear removals between 100% and 50%), which is less than the 99% required in Figure 2-1. However, given that reverse osmosis is not suitable for this project, GAC adsorption removal is the Best Available Technology (BAT) for PFOS removal and this treatment train is the BAT for the overall treatment process. More discussion is expected on the required PFOS removal and the expected performance of this treatment train.

The following sub-sections provide a brief introduction to each of the primary treatment processes in this recommended scheme.

3.1.1. CoMag Coagulation, Flocculation, and Sedimentation

Floc/sed is a conventional drinking water treatment process and includes addition of a determinand coagulant, and potentially a coagulant or flocculant aid polymer, to remove solids and organics. Determinand flocculants are formed and settled in this process which prepares the water for effective filtration. Solids removal is needed to remove the unthickened solids that have settled in the clarifier which are typically conveyed to the headworks of the WwTW in a water reuse scheme. Floc/sed units are typically operated to achieve a settled water turbidity in the range of 1 to 2 nephelometric turbidity units (ntu).

CoMag is a system that uses magnetite to ballast conventional floc/sed, which can result in improved treatment performance within a smaller footprint. Magnetite accelerates particle flocculation and settling and then is recovered from the settled solids at approximately 99% recovery rate. As shown in Figure 3-1, CoMag is currently envisioned for this project.

3.1.2. Ozone Oxidation

Ozone oxidation is one of the primary determinand removal steps in this treatment process. Ozone is added to oxidize high molecular weight organics for downstream removal in biofiltration and for direct oxidation of trace organics. Significant determinand removal has been demonstrated with ozone oxidation in water reuse applications (Sundaram, 2020). Disinfection of pathogens will also be achieved with ozone addition, although this is not a primary goal for this project. A quenching agent, such as sodium bisulfite, is typically added at the end of the ozone process to mitigate off-gassing of ozone to any process spaces open to the atmosphere (such as the BAC filters).

To achieve effective oxidation of organics, the ozone dose is typically based on the influent total organic carbon (TOC) concentration. Ozone to TOC ratios in the range of 0.5 to 1 mg/L of ozone per 1 mg/L of TOC are common. However, these high concentrations of ozone are known to form disinfection byproducts, most notably bromate and N-nitrosodimethylamine (NDMA). Bromate formation is a function of ozone dose and influent bromide concentration and any bromate formed during ozonation is difficult to remove in downstream processes. Therefore, mitigation strategies are applied at the ozone addition to limit bromate formation if it is found to be a problem. Bench testing or pilot testing is recommended to understand the potential for bromate formation. NDMA is also formed during ozonation but is readily removed by a well-operated BAC filter.

In addition, the formation of ozonation transformation products (OTPs)/disinfection by-products is a key parameter in both Bench and Pilot trials. Trace organics are generally not completely mineralised during ozonation but are transformed into both polar ozonation products and bioavailable organic matter. Therefore, it is imperative the efficacy of the biological treatment step (BAC) and downstream GAC is assessed during trials. Critical to this assessment is deriving an optimised ozone dose (Ozone:DOC ratio) which helps to mitigate risks. Large scale pilot trials at other facilities in the US have demonstrated optimising and control is achievable. The completion of both bench and pilot trials prior to the full scale installation is imperative.

3.1.3. Biologically Active Carbon Filtration

Biologically Active Carbon (BAC) filtration consists of deep-bed granular media filters (typically five feet of GAC over one foot of sand) that provide excellent particle and pathogen removal in addition to biological removal of organic matter. The BAC filters are operated similar to conventional drinking water filters to achieve low effluent turbidity (<0.15 ntu) and require frequent backwashing (every 24-72 hours) to remove the particles from the filter media.

Determinands are typically added upstream of the BAC filter to help with particle removal (non-ionic polymer), support the biological community (phosphoric acid) and to mitigate excessive biological activity (sodium hypochlorite). BAC filter performance in a water reuse scheme can be measured by consistent nitrification (conversion of influent ammonia to nitrate) and by removal of NDMA formed in the ozone process.

3.1.4. Granular Activated Carbon Adsorption

Granular Activated Carbon (GAC) adsorption provides removal of trace organics through both biological and adsorption mechanisms and is another primary determinand removal step of this treatment train. Contaminants adsorb to the GAC media, which achieves less and less removal as more and more water passes through the media. Once the contaminant removal is no longer meeting treatment objectives, the GAC media is removed from the contactor and replaced (either with new media or regenerated media). Contaminant removal for organics (bulk and trace) often follow breakthrough curves that describe the removal of the contaminant as a function of bed volumes (a surrogate for the amount of water that has passed through the media since it was last replaced). These breakthrough curves can help predict the required media replacement frequency, which often drives the operating cost of this treatment train. Bench or pilot testing is recommended to generate breakthrough curves specific to the Minworth WwTW effluent and the selected treatment process. GAC adsorbers require backwashing but on a much less frequent basis than BAC filters. Once per week or once per month is typical for GAC backwashing.

3.2. Inapplicability of Membrane-Based Processes: Microfiltration plus Reverse Osmosis

The membrane-based treatment process typically used for water reuse consists of MF, Reverse Osmosis, and UVAOP. RO is a physical separation process during which feed water is forced through a semi-permeable membrane using a pressure gradient. RO is extensively used for desalination of seawater and brackish groundwater. Water reuse projects also utilise this technology due to its ability to remove pathogens, dissolved determinands, TOC, trace organics and total dissolved solids (TDS) (USEPA, 2017). RO has been shown to achieve excellent removal of PFOS and other trace organics and would likely be able to achieve the contaminant removal targets shown in Figure 1-2.

The main disadvantage with RO is the highly concentrated water reject stream that is created in the process, which is typically about 15% of all treated flows (Schimmoller & Kealy, 2014). When using RO for reuse projects, this reject stream typically cannot be returned to the same treatment plant that is supplying the flow as it would increase the nutrient load and organic load (the magnitude of increase is dependent on the flow rate selected for the SRO) and would result in the cycling up of TDS and trace organics that are otherwise not removed in the WwTW process.

Ocean disposal is the most common method of brine management, as such, many RO facilities are located in coastal areas. In non-coastal areas, deep well injection of the brine flow is commonly practiced. This requires a deep well (typically >1,000 meters deep) and high pressure to inject the brine into a formation that is not connected to the water table. Where deep well injection is not allowed, evaporation ponds and/or mechanical evaporation is used to minimize the brine flow and recover salts in the brine stream. Brine management options are extremely expensive and significantly increase the overall price and energy consumption of this treatment process, as shown in Figure 3-3.

Minworth does not have the option of discharging into an estuarial water course but the site discharges to an entirely inland river. Installing an RO solution at Minworth with the brine stream being ultimately channelled into the River Tame might not result in a higher salt loading by mass to the river, as the site currently discharges into the River Tame as it stands, however this will increase the concentration of salts in the final effluent and in the River Tame. Discharge of highly concentrated salt brine to non-estuarial waters can be problematic to the ecology and environment as well as to other downstream uses of the water.

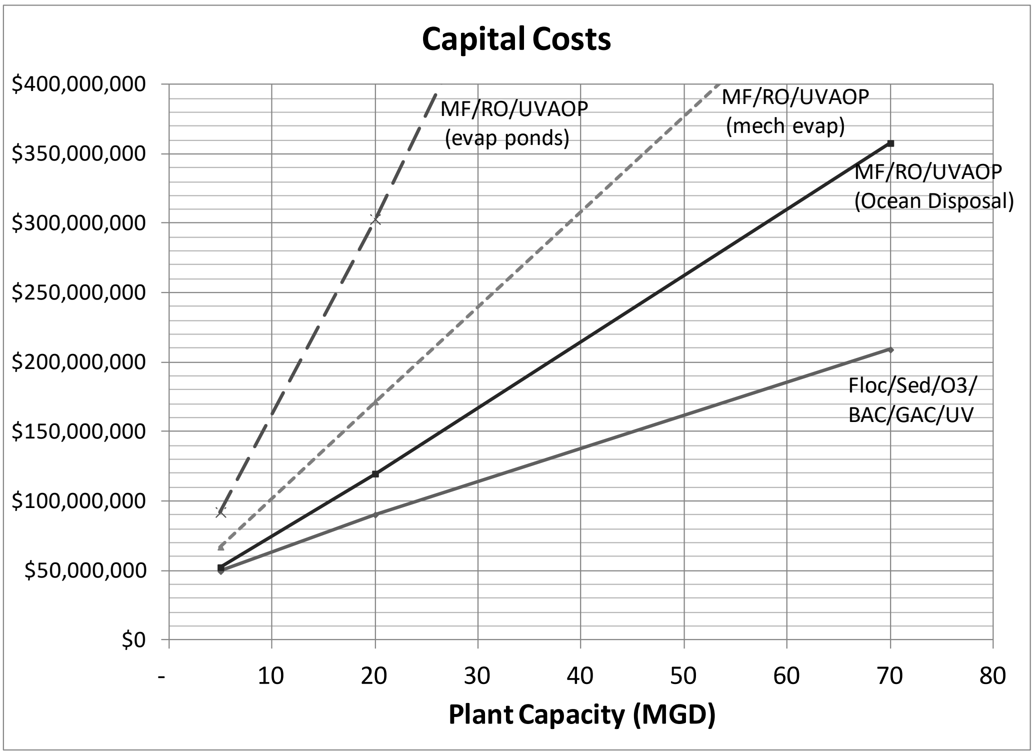
Organic chemicals, such as PFOS, will also be concentrated in the discharge to the River Tame. Although chemical toxicity can be measured on overall discharge volumes, principally, it is the concentration that mainly affects water quality. As such permits are based on the Environmental Quality Standards which are concentrations and not overall loads. Noting however the EA have significant load limits in place for 15 chemicals currently.

Compared to the Thames estuary, for example, the comparatively lower levels of dilution in the River Tame may well likely lead to a net deterioration of the river water quality. The Q80 (20 percentile flow) flow of the River Tame directly downstream of Minworth averages 597MLD while an estuarial river such as the Thames averages almost twice the flow at 1046 MLD upstream of Richmond.

Transferring 57MLD to STT and 57MLD to the GUC will likely reduce flows by nearly 20% in the River Tame. With the RO discharge being returned to the head of Minworth STW; accounting for chemicals such as PFOS which are likely not captured in the Minworth wastewater treatment process suggests a greater than 10% increase in the concentration in the River Tame may occur, subject to detailed modelling.

In comparison an estuarial river such as the Thames offers significantly higher dilution levels likely ensuring the increased concentration from the RO brine stream will not constitute a net deterioration in the river water quality, noting a deterioration is defined as a >10% increase accounting for future growth.

Deep well injection is likely the only brine management option worth considering for the Minworth SRO. If this method were to be approved and permitted (it appears that there are deep well injection projects in the UK for produced water from oil drilling operations but no deep well injection projects for RO brine are known) for this project, it would require a significant amount of energy to achieve. Assuming 85% recovery of the RO system, and thus 15% waste, a 115 Mld system would result in approximately 17 Mld of brine. Deep well injection typically requires high pressure which is dependent on the formation. However, 800 psi is a reasonable estimate based on other operating systems. 17 Mld of brine pumped to a pressure of 800 psi would require approximately 1,700 kW, a significant power draw that is over twice the expected power consumption of the full carbon-based train (750 kW). Coupled with the power draw for the rest of the MF-RO-UVAOP scheme, the total power draw would be approximately 4,500 kW. Given the uncertain regulatory framework for deep well injection, the higher capital cost for the membrane-based scheme, and the significantly higher operating cost, energy consumption, and GHG emissions, the membrane-based treatment scheme was deemed infeasible for this project.



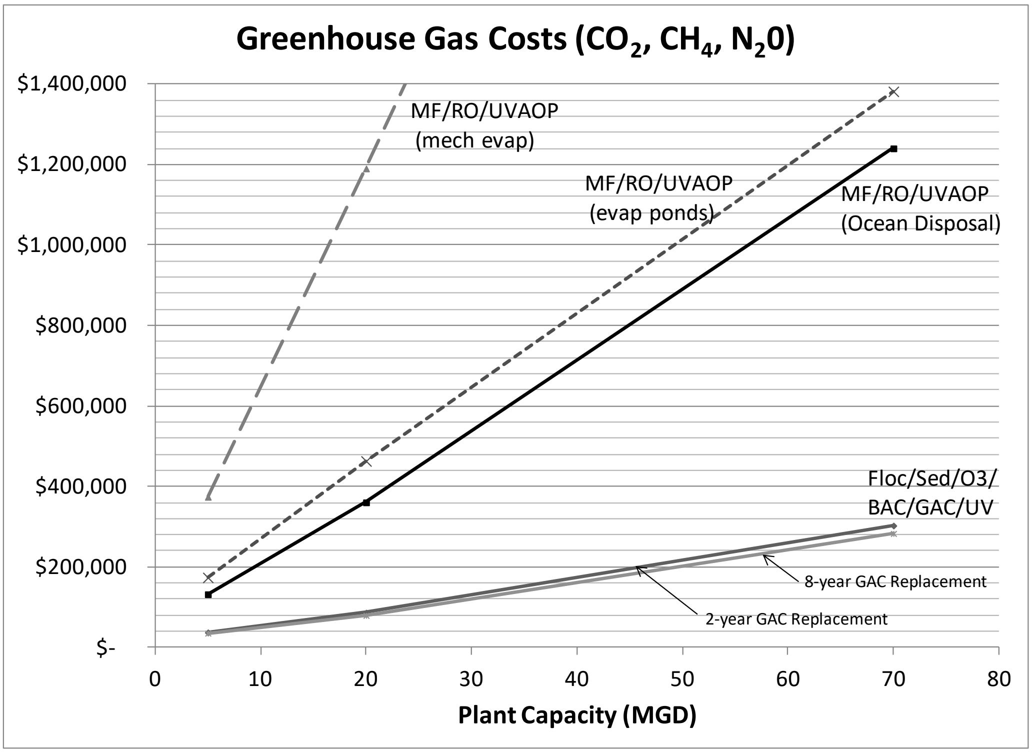


Figure 3-3: Capital cost (top) and GHG costs (bottom) comparison between GAC-based and RO-based treatment schemes (Schimmoller 2014)

3.3. Solution Development

A multibarrier approach has been taken at this stage with the following treatment stages: Floc-Sed, Ozone Oxidation, BAC Filtration and GAC Adsorption.

The determinands identified for treatment require detailed water modelling which is within the remit of the Environmental Consultants to confirm the actual removals required for either permitting to water quality deterioration considerations following Monte Carlo simulations. The indicative high level estimations in section 2.4 of this report have been used substantively.

The target determinands are shown in Table 3-1 with the treatment steps that provide primary and contributory removal, based on current literature. It is noted that pilot testing is needed to confirm actual removals. Each determinand is addressed in turn in the section below.

Table 3-1: Treatment Process and the target determinand

	Floc-Sed	Ozone	BAF	GAC
Cobalt Dissolved	Primary			Contributory
Total Phosphorus	Primary			
Nonylphenol		Primary		
Mancozeb		Primary		
PFOS	Contributory	Contributory	Contributory	Primary
Permethrin	Contributory	Contributory	Contributory	Contributory
Cypermethrin	Contributory	Contributory	Contributory	Contributory
HBCDD				Primary
Triclosan		Primary		

(dark blue)	Primary Removal Step
(light blue)	Contributory Removal Step

3.3.1. PFOS Removal

The primary removal mechanism for PFOS is via GAC however to make this process economically viable, total organic carbon levels have to be reduced using upstream floc-sed, ozonation, biological filtration to preserve the adsorption capacity of the GAC and minimise regeneration to approximately 25,000 Bed Volumes (yearly) (Gonzalez, 2021) . **The omission of upstream TOC removal processes will likely increase the regeneration frequency to a few months/weeks and markedly increase operational costs.**

The published EQS for PFOS of 0.00065 µg/ l is based on Biota back calculation (EA, 2016) . The equivalent water column limit is 0.003 µg/l (EA, 2019). The guidance from the Environment Agency under the title LIT 13134 – Permitting of hazardous pollutants in discharges to surface waters states currently Water Column standards should be used for permitting purposes with Biota based standards likely to be used in the future. Treatment wise, the difference between the 2 limits may be significant in setting the modelled treatment requirements for PFOS. As such the current Biota Based limit of 0.00065µg/l may be misaligned in the permitting context.

Neither Minworth nor the River Avon or the Coventry canal currently meet the 0.00065µg/l EQS limit. It is also worth noting the drinking water requirements are less stringent than the environmental limits as shown in Table 3-2.

Table 3-2: PFOS concentrations

	PFOS	Reference
DWI Tier 3 trigger level	0.1 µg/l	(DWI, 2021)
USEPA Drinking Water Regulations	0.00002 ug/L	(USEPA, 2022)
EA EQS	0.00065 µg/l (Biota back calculation) 0.003 µg/l (Water Column)	(EA, 2016) (EA, 2019)
Minworth WwTW Effluent Average	0.021 µg/l	Sampling
River Avon Downstream of Warwick	0.0073 µg/l	Sampling
Coventry Canal (GUC)	0.0061 µg/l	Sampling
Limit of Detection	0.0002 µg/l	

3.3.2. Nonylphenol Removal

Ozonation is main removal process (Nagels, 2021).

Minworth currently does not meet the EQS standard, however with the Coventry Canal and the River Avon are currently compliant as shown in Table 3-3.

Table 3-3: Nonylphenol Concentrations

	Nonylphenols (4-nonylphenol technical mix)	Reference
WHO drinking water guidelines	-	-
EA EQS	0.3 µg/l	(EA, 2016)
Minworth WTW Effluent Average	0.35 µg/l	Sampling
River Avon Downstream of Warwick	0.06 µg/l	Sampling
Coventry Canal (GUC)	0.042 µg/l	Sampling
Limit of Detection	0.04 µg/l	

3.3.3. Permethrin Removal

Permethrin has an affinity for organic matter with its concentrations associated with both suspended and dissolved organic matter hence it is removed progressively along the Floc-Sed, Ozone, BAC & GAC train in line with overall Total Organic Carbon removal (Teerlink, 2014).

Minworth, the River Avon and marginally the Coventry Can do not meet the EQS standard, as shown in Table 3-4.

Table 3-4: Permethrin concentrations

	Permethrin	Reference
WHO drinking water guidelines	-	-
EA EQS	0.001 µg/l	(EA, 2016)
Minworth WTW Effluent Average	0.0034µg/l	Sampling
River Avon Downstream of Warwick	0.0021µg/l	Sampling
Coventry Canal (GUC)	0.0011 µg/l	Sampling
Limit of Detection	0.001 µg/l	

3.3.4. Cypermethrin Removal

Cypermethrin is related to organic matter thus reducing TOC levels is a viable method of removal in wastewater treatment (DPR, 2014). It is removed progressively along the Floc-Sed, Ozone, BAC & GAC train in line with overall Total Organic Carbon removal (Teerlink, 2014).

Minworth and the River Avon currently do not meet the EQS standard, however with the Coventry Canal is compliant as shown in Table 3-5.

Table 3-5: Cypermethrin concentrations

	Cypermethrin	Reference
EA EQS	0.00008 µg/l	(EA, 2016)
Minworth WTW Effluent Average	0.00023µg/l	Sampling
River Avon Downstream of Warwick	0.0001µg/l	Sampling
Coventry Canal (GUC)	0.00008 µg/l	Sampling
Limit of Detection	0.00008 µg/l	

3.3.5. Mancozeb Removal

Ozonation is the primary degradation step (Rodrigues, 2019)

Minworth, the Coventry Canal and the River Avon currently meet the EQS standard, however the Minworth concentration is an order of magnitude greater than the river concentrations as shown in Table 3-6.

Table 3-6: Mancozeb concentrations

	Mancozeb	Reference
WHO drinking water guidelines	-	-
EA EQS	2 µg/l	(EA, 2016)
Minworth WTW Effluent Average	1.3µg/l	Sampling
River Avon Downstream of Warwick	0.1 µg/l	Sampling
Coventry Canal (GUC)	0.1 µg/l	Sampling
Limit of Detection	0.1 µg/l	

3.3.6. HBCDD Removal

GAC adsorption is the primary removal step owing to the chemical stability (Cimbritz, 2018).

Minworth, the Coventry Canal and the River Avon currently meet the EQS standard, however the Minworth concentration is higher than the river concentrations as shown in Table 3-7.

Table 3-7: HBCDD concentrations

	Hexabromocyclododecane (HBCDD)	Reference
WHO drinking water guidelines	-	(WHO, 2017)
EA EQS	0.0016 µg/l	(EA, 2016)
Minworth WTW Effluent Average	0.00097µg/l	Sampling
River Avon Downstream of Warwick	0.00029µg/l	Sampling
Coventry Canal (GUC)	0.00015	Sampling
Limit of Detection	0.00014 µg/l	

3.3.7. Cobalt Dissolved Removal

Floc-Sed is the primary removal step (Pohl, 2020).

Minworth, the Coventry Canal and the River Avon currently meet the EQS standard, however the Minworth concentration is higher than the river concentrations as shown in Table 3-8.

Table 3-8: Cobalt Dissolved concentrations

	Cobalt dissolved	Reference
EA EQS	3 µg/l	(EA, 2016)
Minworth WTW Effluent Average	1.75 µg/l	Sampling
River Avon Downstream of Warwick	0.26µg/l	Sampling
Coventry Canal (GUC)	0.52 µg/l	Sampling
Limit of Detection	0.16 µg/l	

3.3.8. Triclosan Removal

Ozonation is main removal process (Snyder, 2007) .

Minworth, the Coventry Canal and the River Avon all currently meet the EQS standard, however the Minworth concentration is higher than the river concentrations as shown in Table 3-9.

Table 3-9: Triclosan concentrations

	Triclosan	Reference
EA EQS	0.1 µg/l	(EA, 2016)
Minworth WTW Effluent Average	0.0236µg/l	Sampling
River Avon Downstream of Warwick	0.01µg/l	Sampling
Coventry Canal (GUC)	0.011 µg/l	Sampling
Limit of Detection	0.01 µg/l	

3.4. Discussion of Alternative Permit Requirements

In addition to the initial assessment, following discussions with the project team. Four options were brought forward PC1, PC2, PC3 and PC4 as shown in Table 3-10.

Table 3-10. Additional Treatment Options

Determinand	Minworth	Canal	River Avon	EQS	PC1	PC2	PC3	PC4
PFOS	0.02	0.01	0.0073	0.003	Removal required	Removal required	Not required	Phosphorous removal only to achieve 0.2 mg/l. Aligns with existing Finham WwTW permit for River Avon discharge
Nonylphenols	0.35	0.04	0.06	0.300	Removal required	Removal required	Not required	
Permethrin	0.0034	0.0011	0.0021	0.0010	Removal required	Removal required	Not required	
Cypermethrin	0.00023	0.00008	0.001	0.00008	Removal required	Removal required	Not required	
Mancozeb	1.30	0.10	0.10	2.00	Removal required	Not required	Removal required	
HBCDD	0.00097	0.0015	0.00029	0.0016	Removal required	Not required	Removal required	
Cobalt	1.75	0.52	0.26	3.00	Removal required	Not required	Removal required	
Triclosan	0.024	0.011	0.00	0.100	Removal required	Not required	Removal required	

3.4.1. PC1

This is addressed by the currently proposed Floc-Sed, Ozonation, BAC and GAC treatment train

3.4.2. PC2

This requires the removal of PFOS, Nonylphenol, Permethrin and Cypermethrin. The removal of PFOS alone requires the upstream removal of total organic carbon by the Floc-Sed, Ozonation in combination with BAC before primary removal of PFOS by GAC adsorption. Therefore, the treatment requirements for PC2 are the same as PC1.

3.4.3. PC3

This requires the removal of Mancozeb, HBCDD, Dissolved Cobalt and Triclosan. HBCDD is removed by GAC and with Ozonation addressing Mancozeb and Triclosan, as such the same treatment train as in PC1 is required

3.4.4. PC4

This required the removal of phosphorus down to 0.2mg/l and as such requires 1 treatment step namely the Floc-Sed process. This presents a simplified treatment train which only retains the Floc-Sed process to the same specifications as in the above discussed options. PC4 has been annotated as an additional treatment option under the title "Alternative" - indicated as ALT in tables.

4. Conclusion & Recommendations

Minworth SRO is included in the Price Review 19 Final Determination as a source option for the STT SRO and GUC SRO. The project is now advancing through the Regulators' Alliance for Progressing Infrastructure Development (RAPID) gated process and is proceeding to Gate 2.

There are currently multiple flow rates that are being considered for the Minworth SRO: 57 Mld, 115 Mld, 172 Mld, and 230 Mld. It is yet unknown if the Minworth SRO will serve the River Avon, the GUC, or both. 115 Mld has been identified as the preferred flow rate and was used for the majority of the analysis in this document and discharge to both River Avon and GUC was analysed.

The Minworth SRO is currently envisioned to treat Minworth WwTW effluent and discharge to either the River Avon, the GUC, or both. The treated water would then be used as a flow augmentation scheme to support downstream abstractions. It is important that the Minworth SRO complies with anticipated discharge permit requirements to the receiving water(s) and that it does not cause deterioration of the receiving water(s).

A thorough screening analysis was conducted to identify the anticipated determinands that will need to be removed to comply with a future discharge permit. The "Surface Water Pollution Risk Assessment for Your Environmental Permit (2016)" document was strictly followed to identify the determinands that would be flagged for additional modelling. The same guidance is also found in a separate EA document, "LIT 13134 - Permitting of hazardous pollutants in discharges to surface waters." Both documents give the same high level screening guidance with the same screening steps.

Out of the 399 determinands and elements sampled, this initial screening exercise has identified 8 determinands which are recommended for modelling ahead of permitting summarised below

- perfluorooctane sulfonic acid and its derivatives
- cypermethrin
- hexabromocyclododecane (HBCDD)
- mancozeb
- nonylphenols (4-nonylphenol technical mix)
- permethrin
- triclosan
- cobalt (dissolved)

The proposed Advanced Water Treatment Plant is designed to effect measurable removal of the above determinands and also addresses, Total Phosphorus removal down to 0.2mg/l (annual average) which currently represents the Best Available Technology limit.

As Minworth is a flow augmentation scheme for the Thames catchment with the treated effluent being discharged into existing surface water bodies, both ecological and human health considerations require a multibarrier treatment approach to be taken. Hence, the following treatment process is being proposed: CoMag, Ozonation, BAC and GAC.

A RO based treatment scheme would also achieve the treatment requirements but would add significant cost, energy consumption, greenhouse gas emissions, and permitting challenges, primarily due to management of the waste brine stream. Reverse osmosis treatment schemes are typically utilized in coastal locations where ocean disposal can be used for the brine. In the absence of ocean disposal, deep well injection, mechanical evaporation, or evaporation ponds are typically utilised. These were not deemed practical for this project and thus reverse osmosis was eliminated as a treatment option for the Minworth SRO.

The recommended treatment train has been well-studied and has proven effective at treating WwTW effluent. It provides multiple treatment barriers for determinands and organics and will likely achieve good removal of most of the determinands identified above. Bench and pilot testing on the Minworth WwTW effluent is recommended to confirm determinand removal performance and the required GAC replacement frequency to meet water quality goals.

An alternative treatment option has also been considered should the environmental permit allow it to proceed which only requires the removal of phosphorus down to 0.2mg/l. This "Alternative" treatment option only requires 1 treatment step - the Floc-Sed process. This presents a simplified treatment train which only retains the Floc-Sed process to the same specifications as for the full treatment in the above discussed options.

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A. Appendix A: Water Reuse Background

This section gives a brief summary of water reuse as this underpins the design of the Minworth Advanced Water Treatment Works. Aspects discussed in this section give a context to the design decisions for this project. Although Minworth is a flow augmentation scheme, transferring water resources to the Thames catchment presents both ecological and human health considerations which this section discusses briefly.

A.1 Background

Population growth, urbanisation and climatic change are some of the factors that continue to impose stress on existing water resources (WHO 2017a). The reuse of treated wastewater provides significant environmental, social, and economic benefits and offers a sustainable source of water to alleviate water scarcity.

Water reuse involves treatment of wastewater using advanced technologies in addition to the standard wastewater treatment process. Some key definitions are provided below:

Planned Reuse: Defined as the publicly acknowledged, intentional use of reclaimed wastewater for drinking water supply (often referred to as just water reuse).

De facto reuse: A situation where reuse of treated wastewater is practiced but not officially recognised. This is the case where drinking water abstraction points are downstream of discharges from wastewater treatment works.

Direct Reuse (DPR): The introduction of reclaimed water (with or without retention in an engineered storage buffer) directly into a drinking water treatment plant. This also includes the treatment of reclaimed water at an Advanced Water Treatment Facility for direct distribution into a drinking water network (EPA, 2017).

Indirect Reuse (IPR): The deliberate augmentation of a drinking water source (lakes, rivers or groundwater aquifers) with treated reclaimed water. The lakes, rivers or aquifers provide an environmental buffer subsequent to abstraction and drinking water treatment.

A key focus of any water reuse system are the human health and environmental/ecological considerations together with an understanding of public perception. (Gawlik & Sanz, 2014).

A.2 The Multi-barrier Approach to Water Reuse

The concept of a multi-barrier approach refers to a sequence of unit processes operating in series to prevent the release of harmful microbes and determinand constituents into a water body.

A water reuse process needs to be designed to reliably treat the water to the required standard. System reliability can be achieved by including several key concepts in the design: redundancy, robustness, and resilience.

Multiple processes with the capability of removing the same contaminants means that in the event of a failure of one process unit in the treatment train, the system can still effectively perform to an acceptable standard.

Although the multiple barriers are required to achieve the intended contaminant reduction, it is generally expected that the process design will be able to accommodate a degree of redundancy, i.e. the protection of public safety is maintained after the failure of a single treatment barrier (Khan & Drewes, 2014).

The multi-barrier approach also allows for a robust process by including a series of diverse treatment technologies that address a broad range of contaminants. Resilience focuses on the ensuring plans are in place to address any failures and promptly bring the full treatment train back online (Roccaro, 2018).

The multiple-barrier approach does not prevent system failure, but instead allows a system to fail safely; with failures mitigated through well designed response plans.