ANNEX A3(ii)

Process Options 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 Options Report

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Minworth SRO
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Process Options Report

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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. The treated water would then be used as a flow augmentation scheme for downstream drinking water users.

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, and other contaminants. The anticipated discharge permit requirements are detailed in the Basis of Design Report and include a suite of trace chemicals that met the criteria for further environmental modelling based on screening guidance from the Environment Agency.

The treatment train selected is a carbon-based treatment process: coagulation, flocculation, and sedimentation (floc/sed) followed by ozone oxidation, biologically active carbon (BAC) filtration, granular activated carbon and (GAC) adsorption (as shown in Figure 1-1). This process provides multiple barriers of treatment for solids, organics, and pathogens and is a robust, well-studied advanced treatment scheme. An alternate treatment scheme using reverse osmosis was considered but was eliminated due to its larger capital and operating cost, higher energy consumption, and the expected challenges with managing the brine concentrate flow.

Floc/sed includes the addition of a chemical coagulant and a coagulant or flocculant aid polymer to remove solids and organics. Chemical flocculants are formed and settled out, preparing the water for effective filtration. The floc/sed process and subsequent filtration steps also remove phosphorous. During ozone oxidation, ozone is added to oxidize high molecular weight organics for downstream removal in biofiltration as well as for direct oxidation of trace organics. This step also achieves disinfection of pathogens. BAC filtration consists of deep-bed granular media filters that provide excellent particle and pathogen removal, in addition to biological removal of organic matter. The GAC adsorption provides removal of trace organics through both biological and adsorption mechanisms as the contaminants are adsorbed onto the GAC media.

Although the unit treatment processes are standard and proven, there are many variables that require a greater understanding to inform on the operational requirements of this scheme. Therefore, it is imperative bench and pilot tests are conducted to inform the final iteration of this plant design. Notably, this will help estimate the GAC regeneration frequency and the ozone consumption which together represent a significant amount of the total estimated operational cost.

Following discussions with the project team an alternative option that addresses phosphorus removal down to 0.2mg/l alone has been developed. Similar to the above stated treatment train, all the flow passes through the Floc-Sed process but then flows directly to the conveyance pumping station for the respective SROs, GUC and STT. Design specifications are the same for the Floc-Sed process above however this section has been separated out in the report to give clarity. As such Table 3-2 below gives the technical specifications for the Floc-Sed process.

With this alternative treatment train, compared to the Floc-Sed, Ozone, BAC and GAC, a smaller site backwash pumping station is required. The interstage pumping station is not required and the chemical requirements reduce down to Ferric and Polymer and Sodium Hydroxide. Additionally, the site footprint also reduces significantly.

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 help to mitigate risks.

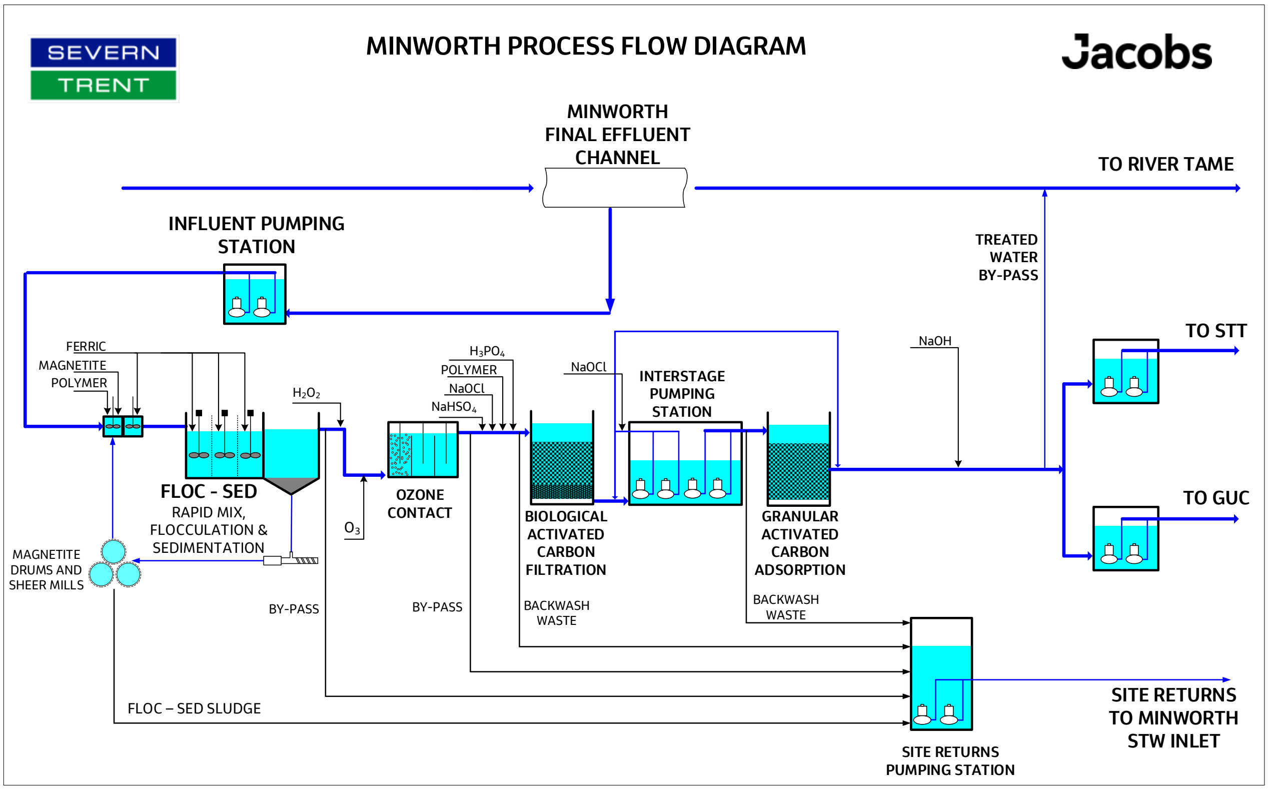

Figure 1-1 Minworth Advanced Water Treatment Works Process Flow Diagram

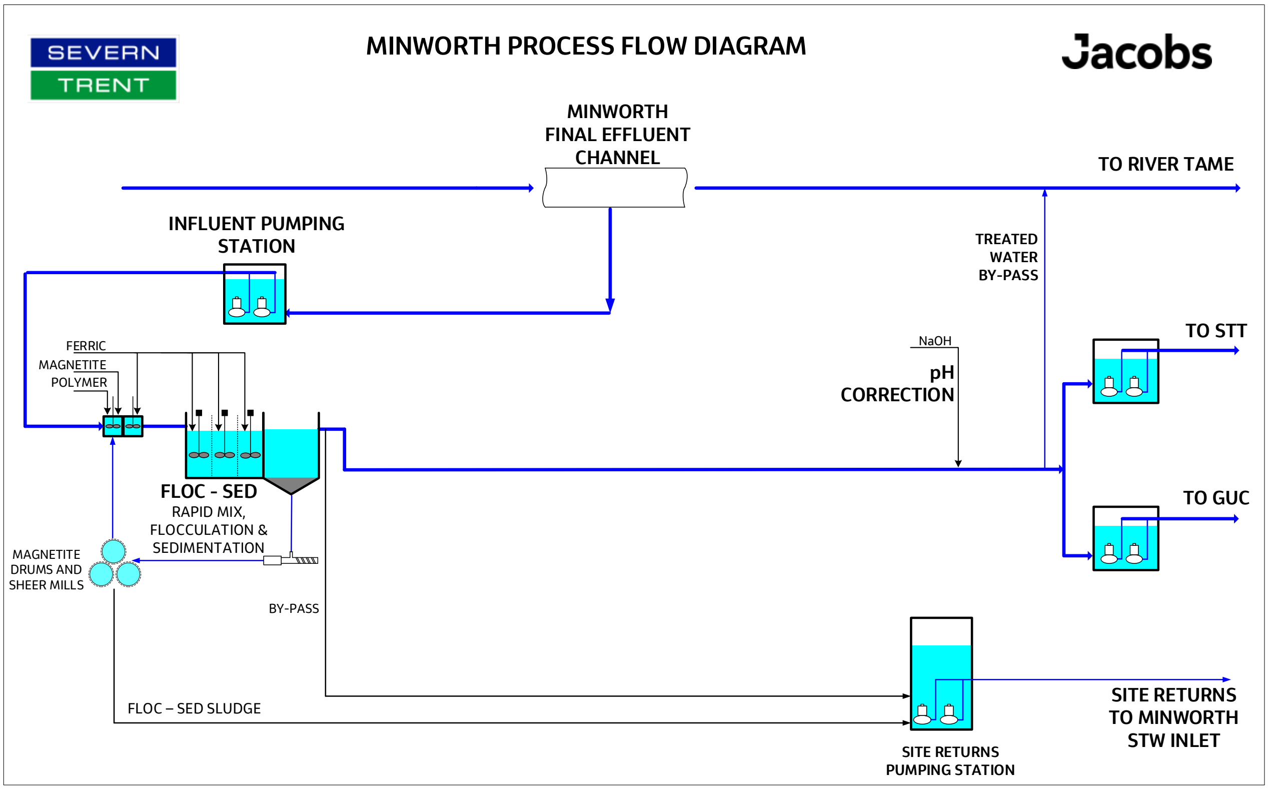

Figure 1-2: Alternative Treatment Option (Floc - Sed)

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Acronyms and abbreviations

AWTP	Advanced Water Treatment Plant
BAC	Biological Activated Carbon
BAT	Best Available Technology
CAPEX	Capital Expenditure
CAPEX	Capital Expenditure
EBCT	Empty Bed Contact Time
Floc-Sed	Flocculation and Sedimentation
GAC	Granular Activated Carbon
GIS	Geographic Information System
GUC	Grand Union Canal
MODA	Multi-Objective Decision Analysis
OPEX	Operation Expenditure
OPEX	Operational expenditure
SRO	Strategic Resource Option
STT	Severn to Thames Transfer
TOC	Total Organic Carbon
TOTEX	Total Expenditure
WwTW	Wastewater Treatment Works

1. Introduction

1.1 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 Work (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 treated water flow options which cover all possible outcomes have been evaluated and are as listed in the table below.

Table 1-1: Flow options for Minworth

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

1.2 Report Objectives

This report follows on from the Basis of Design Report, A7W13155-WT-REP-221009, which details how the two alternative treatment schemes were selected based on the anticipated discharge permit requirements to the River Avon or GUC. This report solely discusses the process design aspects for the Minworth Advanced Water Treatment Plant (AWTP). Please refer to Annex A3(i) Basis of Design for the Minworth site description, effluent analysis, and likely treatment limits.

The objectives of this technical report are to provide:

- Fundamental process and design background for each of the main treatment process units.
- The design criteria parameters that will be used to size each treatment process, including chemical storage and feed systems.
- Flow balance summary tables.
- Conclusions and recommendations.

The information developed in this report also informs all subsequent treatment aspects of the project, including both CAPEX and OPEX and the overall site footprint as well as power requirements and chemical usage.

1.3 Commercial Suppliers

At this stage the commercial supplier selection has not been conducted. The project team used Jacobs' proprietary Replica Parametric Design tool to develop estimates of the footprint, and power consumption of each of the treatment facilities to inform the overall site footprint. Select suppliers were contacted to provide equipment estimates for the major treatment processes to benchmark the outputs of the Replica Parametric Design tool. The suppliers contacted include:

- Denora
- Evoqua
- Suez-Curio
- Xylem Wedeco Leopold

No commercial considerations have been made at this stage in the supplier selection and it is expected that competitive tendering will be required for the design and installation stage of this project.

Schematic redacted

2. Treatment Units

The major process units considered for the Minworth AWTP, and the Alternative scheme are shown in Figure 2-1 & Figure 2-2 below:

[redacted]

Figure 2-1: Minworth SRO treatment process

[redacted]

Figure 2-2: Alternative Treatment Option (Floc - Sed)

The process included within the schemes are:

- Flocculation and Sedimentation (Floc-Sed): Coagulant dosing, rapid mixing, flocculation, and clarification
- Ozone Oxidation: Generation, injection, contact and off-gas destruction
- Biological Activated Carbon (BAC) Filtration
- Granular Activated Carbon (GAC) Adsorption

The transfer pumping stations to STT and the GUC are addressed in the Concept Design reports for each respective SRO, however, throughputs and power requirements for the influent and intermediate pumping stations covered in this report.

2.1 Flocculation and Sedimentation (Floc - Sed)

Chemical coagulation, flocculation and clarification is essential to achieve the Best Available Technology (BAT) limit of 0.2 mg/l total phosphorus and to reduce the total organic carbon (TOC) by 20 - 30%. It will also be an important particle removal step to prepare the water for filtration. Table 2-1 shows average and 95th percentile total suspended solids (TSS) data from the Minworth effluent and with the design AWTP coagulant chemical dose. As shown in Table 2-1, this process will be designed to have an effluent TSS less than 3.2 mg/l average and less than11.3 mg/l 95 percentile for the all the four treatment flow cases.

Table 2-1: Floc - Sed Design Parameters

Floc - Sed Design Parameters:		
	Units	Value
Average Influent suspended solids (from treatment process)	mg/l	7.0
95%ile influent suspended solids (from treatment process)	mg/l	15.0
Average influent suspended solids including chemical dose (total)	mg/l	15.8
95%ile influent suspended solids including chemical dose (total)	mg/l	23.9
Design Average floc-sed effluent suspended solids	mg/l	<3.2
Design 95%ile floc-sed effluent suspended solids	mg/l	<11.3

There are many different viable floc-sed treatment processes that are suitable for this application, including magnetite ballasted clarification, sand ballasted clarification, and lamella plate clarification. A magnetite ballasted flocculation process has been developed further in this report due to its condensed footprint - for example Co-Mag. However, a generic assessment of the footprint requirements for a standard lamella clarification installation has been allowed for at this stage to ensure several technology options can still be considered for this treatment process at Gate 3. As such the layout of the treatment plant developed at this stage allows for the consideration of other floc-sed technologies.

2.1.1 Magnetite Ballasted Flocculation

The magnetite ballasted flocculation treatment system, shown in Figure 2-3, is an enhanced clarification system designed to efficiently reduce total suspended solids, total phosphorus, turbidity, colour, pathogens, and metals below the level achieved by conventional systems. It uses magnetite to ballast chemical flocs, thus enhancing agglomeration and settling rates.

Magnetite (Fe_3O_4) is fully inert (does not rust) iron ore particles, with a high density. In this process, it is used as a ballasting agent to physically bind to particulate flocs. It is non-abrasive and magnetically retrievable allowing for high recovery in the sludge stream. Reports from current operational installations suggest magnetite recovery levels may be lower. As seen in Figure 2-3, this treatment system comprises a reaction tank (A), clarifier (B) and a recovery system (C).

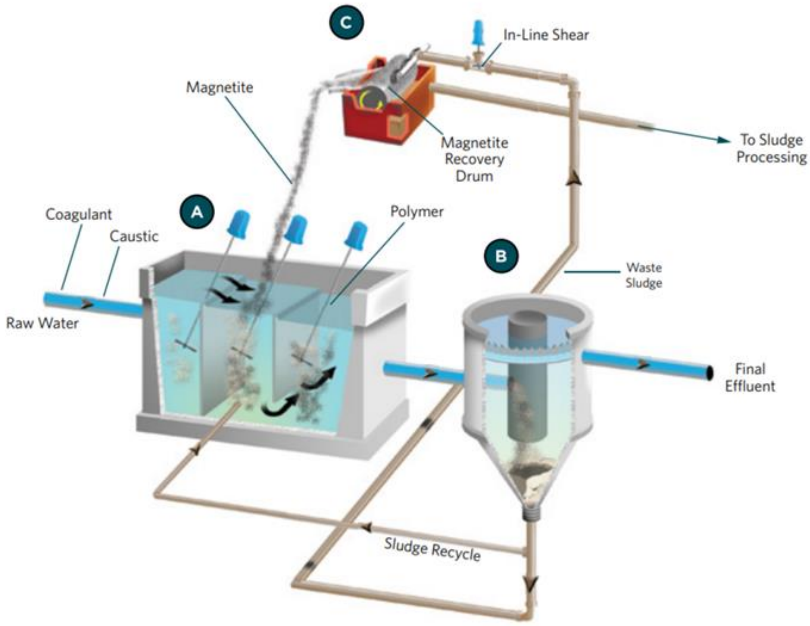


Figure 2-3: Ballasted Floc - Sed Treatment Process Schematic

2.1.1.1 Reaction tank

In the reaction tank, a choice of either alum, ferric or poly-aluminium chloride is added to the influent stream. The chemical floc is then infused with magnetite which increases the density of the solids enhancing settleability. The magnetite ballasted floc is then passed through to the clarifier.

2.1.1.2 Clarifier

The high-density magnetite ballasted flocculants enter a modified high-rate clarifier where they settle rapidly, leaving a clear effluent. The size of the clarifier required is smaller than conventional clarifiers due to the use of magnetite. This clarifier has baffle plates included to aid in directing the flow for optimal settling. A sludge rake is used to collect the sludge in a sump at the bottom.

2.1.1.3 Solids Pumping and Magnetite Recovery

A sludge recycle function is also included to help increase the performance of the system and the final effluent clarity. Approximately 80% of the clarifier underflow is recirculated back into the reaction tank. A high-speed shear mixer is positioned on the recycle loop where the magnetite is separated from the floc. The slurry is passed onto a magnetic recovery drum where more than 99% of the magnetite is returned to the system (according to Evoqua). This continual recovery of the magnetite provides a sustainable process with claimed low operating costs. The sheared sludge, without the magnetite, is sent for dewatering.

The system allows for rapid start-up and process optimisation where frequent shutdown and restarts may be required. The system is also fully automated with minimal operator attention required (Evoqua, 2022). Feedback on current operational plants suggests higher magnetite loss rates than what is claimed by Evoqua. This shall be investigated further at the next design stage.

2.2 Ozonation

Ozone (O_3) is utilised in water treatment facilities for a range of disinfection and oxidation purposes. Ozone is formed when oxygen (O_2) is exposed to a source of high energy causing the O_2 molecules to dissociate and subsequently collide with other oxygen molecules to form the unstable gas, ozone (O_3).

In this application, ozone is primarily utilized to oxidize trace and bulk organics, although the system will also benefit from its disinfection capabilities. Ozone is a very powerful oxidant that can break down a wide range of organic compounds and microorganisms (EPA, 1999). Ozone attacks the surfaces of microorganisms and destroys their cell walls. Ozone also has the capability to oxidise metallic ions to produce insoluble solid oxides which can then be separated by filtration or sedimentation.

The formation of ozonation transformation products/disinfection by-products is a key parameter in Bench and Pilot trials which are required prior to the final detailed design of the full scale plant.

Figure 2-4: Supplier proprietary ozone generator (Courtesy of Xylem Wedeco)

Ozone is a colourless gas with a distinctive odour about 1.6 times heavier than air. Ozone is a powerful oxidising agent and can react explosively with oil and grease. Since ozone is a highly reactive substance, any adverse health effects will be found essentially at the sites of initial contact: the respiratory tract (nose, throat and airways), the lungs, and at higher concentrations, the eyes. The principal health effects are produced by irritation of and damage to the small airways of the lung.

Ozonation is a standard process in the water treatment industry, but as this is an oxidative process, adherence to standard health and safety procedures in both handling and storing chemicals is required in accordance with the COSHH Regulations - specifically focussed on the prevention of exposure to the gas. In addition, special attention to the location of oxygen storage vessels and the ozone generators and destructors is imperative to reduce the intrinsic hazards posed by the gas.

2.2.1 Ozone Generation

Due to ozone's short half-life, it must be produced onsite. It can be generated from dried, compressed air or oxygen. The use of air requires additional mechanical units such as compressors, coolers, and dryers, and produces a low concentration of ozone. As such, pure oxygen is generally the preferred generation source. This can be purchased as liquid oxygen (LOX) or generated onsite by pressure swing adsorption (PSA) or vacuum swing adsorption (VSA). Onsite pure oxygen generation is generally only economical where the oxygen demand is very high, with LOX being the preferred method where possible. At the current design stage, LOX has been selected due to its general ease to both store and manage.

The most commercially viable type of ozone generation from oxygen at municipal water treatment facilities is Corona Discharge. Horizontal, medium/high frequency, large diameter tube generators are most commonly used due to their reliability, their proven usage in municipal water treatment and their efficiency. The ozone if formed via an electrical discharge that is diffused over an area using a dielectric to create the Corona Discharge. As the oxygen passes through the Corona Discharge it is converted to ozone.

The effectiveness of ozonation is dependent on susceptibility of the target organisms in the influent, the contact time selected, and the ozone dose used. The ozone process primarily oxidizes effluent organic matter and degrades some of the trace chemicals. This increases the biodegradable matter which would have passed through the activated sludge process untreated. Hence it is essential that this treatment step is followed by biological treatment.

2.2.2 Ozone Dose

The ozonation system shall be designed to deliver average and maximum applied ozone doses of 7 and 10 mg/l, respectively (subject to pilot testing), with a 5-minute contact time. Sampling facilities and online monitoring shall be provided including the ozone residual and off-gas post destruction.

Online monitoring of the influent nitrite levels shall be provided as nitrite exerts a large ozone demand and will make operation of the ozone system quite challenging. It is imperative that the Minworth WwTW produces consistent, low (<0.2 mg-N/L) nitrite concentrations.

2.3 Biological Activated Carbon (BAC) Filtration

This is a multi-media filter with 0.3 m sand under 1.5 m of granular activated carbon. The sand filters out particulates and the activated carbon is used to develop a biological community to biodegrade the organics that the ozone process has made assimilable. Due to the accumulation of particles and sloughing of biological matter, biofilters typically require backwashing every 24-48 hours. This requires a combination of both water and air scouring of the media, similar to conventional filters used in drinking water treatment. Backwashing of the biofilters constitutes the bulk of the site returns to the Minworth WwTW inlet.

Empty bed contact time (EBCT) is the primary design criteria for biofilters, along with the filter loading rate. EBCT is the residence time of the filtered water in the activated carbon media. The design EBCT for this project is 10 minutes at the specified design flow with all filters in service. This will provide sufficient time for biological degradation to occur while maintaining a reasonable site footprint.

At this stage, gravity-fed biofilters are preferred, however, a pressure filter arrangement can be considered if it is deemed to have advantageous life cycle costs. The activated carbon media is typically replaced every 15-20 years and consideration shall be made for working access and how media can both be fed and withdrawn from the filters.

The BAC provides several treatment benefits as part of this process. It biodegrades bulk and trace organics which the ozone process partially breaks down, reducing the TOC load that goes to the GAC and reducing many industrial chemicals. In addition, the ozonation process increases the concentration of NDMA, a disinfection by-product, which is removed well by BAC. Furthermore, the BAC process media is a combination of Granular Activated Carbon and sand which provides an important particle barrier that protects the downstream GAC from clogging. An assessment of the degradation of ozonation transformation products/disinfection by-products by the BAC process requires special attention in Bench and Pilot trials. Outcomes of which will be used to risk assess the design efficacy and feed into the final full scale design.

Figure 2-5: BAC Filtration Treatment cell (courtesy of Xylem-Leopold)

2.4 Granular Activated Carbon (GAC) Adsorption

Similar to BAC, GAC is also an activated carbon adsorption technology. However, this process relies on adsorption as the primary removal mechanism and thus requires frequent replacement or regeneration of the media (every 12-24 months, subject to pilot testing). While the GAC media will develop some biological activity, it does not have a sand layer and is not considered a particle barrier. The GAC media has a micro-crystallite structure that consists of fused hexagonal rings of carbon. This structure allows for spaces (pores) in between individual micro-crystallites where adsorption takes place. Adsorption on the micro-crystallite structures is a result of both physical (physisorption) and chemical (chemisorption) bonding.

GAC is suitable for the removal of both bulk and trace organic matter, thus allowing for a reduction in TOC together with trace chemicals. Removing TOC in the floc-sed and BAC processes upstream of GAC preserves more of the GAC adsorption sites for chemical adsorption, reducing the regeneration frequency.

Similar to BAC filters, GAC adsorbers can either be installed as pressurised or gravity fed beds, depending on life cycle cost considerations. At the flow rates being considered for the Minworth AWTP, gravity filters and adsorbers present the lowest capital and operating cost and have been selected at this stage.

EBCT is the primary design criteria for GAC adsorbers. These units have been sized to run at an EBCT time of 20 minutes at average flow with all units in service. Backwashing is also required for GAC adsorbers, but because they are downstream of the primary particle removal barrier (BAC filters), backwashing is only expected to be needed once or twice per month. Air scour is typically not used to backwash GAC adsorbers and instead a water-only backwash procedure is followed at a slightly lower backwash loading rate compared to BAC filters.

Approximately 5-6 m of headloss is expected through both the BAC filters and the GAC adsorbers. Given both are currently planned to be gravity filters, there either needs to be a 5-6 m elevation difference between the two processes or an interstage pumping station. A pump station is currently assumed so that the BAC filters and GAC adsorbers can have the same site elevation and can potentially be located in a combined building. The pump station includes the GAC feed pumps as well as the backwash pumps and is currently sized to have enough volume for three consecutive backwashes, which is helpful for operations.

Replacement or regeneration of the GAC media is one of the highest operating costs for this treatment scheme and, as such, it is important that replacement frequency is minimized. It is expected that replacement will be needed every 12-24 months, but this is dependent on many variables, including the influent TOC and trace organic concentrations and the GAC effluent water quality goals. More information, and pilot testing, is needed to better estimate life cycle costs for the GAC facility.

Figure 2-6: GAC Adsorption Treatment Cell (courtesy of Xylem-Leopold)

3. Process Design Parameters

3.1 Treatment Process Design Criteria

The process design parameters for the treatment processes described above are detailed in this section in the table below. These design criteria and outputs have been used to develop site footprints and cost estimates.

Table 3-1: Process design Criteria

Minworth SRO Design Criteria	57Mld	115Mld	172Mld	230Mld	Units
Criteria	**Value**	**Value**	**Value**	**Value**	**Units**
Fully Treated Water Flow Rate	57	115	172	230	Mld
Inline Influent Pumping Station					
Design Flow (Including Return Flows)	62	123	184	246	Mld
Flow Capacity	713	1,428	2,130	2,850	l/s
Design Total Dynamic Head	15	15	15	15	m
Pumping Power Rating	112	336	597	746	kW
Duty Pumps	2	3	4	5	
Standby Pumps	1	1	1	1	
Ballasted Floc - Sed					
Design Feed Flow	61.6	123.4	184	246.2	Mld
Number of Rapid Mix Trains	2	3	4	5	
Coagulant	Ferric Chloride	Ferric Chloride	Ferric Chloride	Ferric Chloride	
Design Average Coagulant Dose (as Fe)	5	5	5	5	mg/L as Fe
Design Rapid Mix Mixing Gradient	1000	1000	1000	1000	1/s
Flocculation Aid Polymer Type	Non-Ionic (Jar Tests Required)	Non-Ionic (Jar Tests Required)	Non-Ionic (Jar Tests Required)	Non-Ionic (Jar Tests Required)	
Flocculation Aid Polymer Dose	0.75	0.75	0.75	0.75	mg/L
Total Reaction Tank Volume	524	1056	1576	2108	m3
Number of Clarifiers	2	2	2	2	
Circular Clarifier Diameter	11.5	16	20	23	m
Sidewall Depth	4.3	4.3	4.3	4.3	m
Number Magnetite Recovery Drums	1	1	1	2	
Magnetite Initial Charge	20182	36926	55490	72728	kg
Magnetite Daily Usage (Theoretical)	75	152	227	304	kg/d
Magnetite Daily Usage (Adjusted in line with operational Feedback)	113	228	341	456	kg/d
Magnetite Bulk Density	1800	1800	1800	1800	kg/m3

Minworth SRO Design Criteria	57Mld	115Mld	172Mld	230Mld	Units
Number of Magnetite Silos	1	1	1	1	
Magnetite Storage Capacity	18000	18000	18000	18000	kg
Magnetite Storage Capacity	10	10	10	10	m3
Number of Days Storage	160.0	78.9	52.9	39.5	days storage
System Recovery (Sludge)	98.5%	98.5%	98.5%	98.5%	
Design Effluent Flow	60.68	121.56	181.34	242.63	Mld
Waste Flow	10.2	20.5	30.6	40.9	L/s
Sludge Removal Type	Intermittent	Intermittent	Intermittent	Intermittent	
Intermittent Sludge Removal On Duration	10	10	10	10	min
Intermittent Sludge Removal Off Duration	50	50	50	50	min
Instantaneous Maximum Waste Flow	61.3	122.9	183.3	245.2	L/s
Daily Sludge Flow	0.9	1.8	2.68	3.58	Mld
Ozone					
Ozone Reactor Feed Flow	60.7	121.6	181.3	242.6	Mld
Maximum Ozone Dose	10	10	10	10	mg/L
Maximum Ozone Delivery	607.7	1217.5	1816.2	2430.1	kg/d
Contact Tank Hydraulic Residence Time	5	5	5	5	min
Number of Contactors	2	3	3	4	
Minimum Contact Tank Volume	210.7	422.1	629.7	842.5	m3
Number of LOX Storage Tanks	3	3	3	3	
LOX storage volume/tank	26.3	53.5	79.8	106.9	m3
Total LOX storage (15 days storage)	78.9	160.4	239.3	320.8	m3
Annual LOX (Oxygen) usage	2,190	4,453	6,643	8,906	tons/year
Hydrogen Peroxide Maximum Dose	5	5	5	5	mg/L
Sodium Bisulfite Maximum Dose	3	3	3	3	mg/L
BAC Filtration					
BAC Filter Feed Flow	60.7	121.6	181.3	242.6	Mld
BAC Filter Empty Bed Contact Time, each	10	10	10	10	min
BAC Filter EBCT, 1 out of service	7.5	8.3	8.8	9.0	min
Number of Parallel BAC Filters	4	6	8	10	
Volume Per Filter	105	141	157	168	m3
Total Process Volume	421	844	1259	1685	m3
BAC Filter Feed Flow, each	15.2	20.3	22.7	24.3	Mld

Minworth SRO Design Criteria	57Mld	115Mld	172Mld	230Mld	Units
Number of Standby/Backwash BAC Filters	0	0	0	0	
BAC Filter GAC Media Depth	1.5	1.5	1.5	1.5	m
GAC Media Volume	351	703	1049	1404	m3
BAC Filter Sand Media Depth	0.3	0.3	0.3	0.3	m
Sand Media Volume	70	141	210	281	m3
Area per BAC Filter	70	100	105	114	m2
BAC Filter Loading Rate, all in service	9.01	8.43	8.98	8.85	m/hr
BAC Filter Loading Rate, 1 out of service	12.02	10.11	10.26	9.84	m/hr
BAC Filter Media Effective Size	1.4	1.4	1.4	1.4	mm
BAC Filter Media Uniformity Coefficient	1.4	1.4	1.4	1.4	
Sand Filter Media Effective Size	0.7	0.7	0.7	0.7	mm
Sand Filter Media Uniformity Coefficient	1.4	1.4	1.4	1.4	
Phosphoric Acid Design Dose	0.2	0.2	0.2	0.2	mg/L
Filter Aid Polymer Type	Non-Ionic	Non-Ionic	Non-Ionic	Non-Ionic	
Filter Aid Polymer Design Dose	0.1	0.1	0.1	0.1	mg/L
Backwash Frequency	1	1	1	1	days
Backwash Loading Rate (Low Water Wash)	18.3	18.3	18.3	18.3	m/h
Backwash Loading Rate (High Water Wash)	61	61	61	61	m/h
Backwash Duration (Low Water Wash)	10	10	10	10	min
Backwash Duration High Water Wash)	7	5	5	5	min
Filter To Waste Duration	20	20	20	20	min
Average Daily Filter to Waste Volume	831	1677	2508	3354	m3/d/filter
Backwash Flow Rate (High)	1186	1694	1779	1932	L/s
Average Daily Backwash Volume	2847	4880	6832	9272	m3/d
Duty Air Scour Blowers	2	2	2	2	
Standby Air Scour Blowers	1	1	1	1	
Max Air Loading Rate	1.22	1.22	1.22	1.22	m/min
Min Air Loading Rate	0.61	0.61	0.61	0.61	m/min
Max Blower Capacity	85.3	121.9	128.0	139.0	m3/min
Interstage Pumping Station (Wet Well)					
Design Flow	62	123	184	246	Mld

Minworth SRO Design Criteria	57Mld	115Mld	172Mld	230Mld	Units
Flow Capacity	713	1,428	2,130	2,850	l/s
Design Total Dynamic Head	15	15	15	15	m
Wet Well Size	3,298	4,049	5,962	7,948	m3
Duty Interstage Pumps	2	3	4	5	
Standby Interstage Pumps	1	1	1	1	
Duty Interstage Pumps Power	223	447	597	746	kW
Duty Backwash Pumps	3	4	4	5	
Standby Backwash Pumps	0	0	0	0	
Backwash Pumps Installed Power	559	597	746	746	kW
All Pumps (Interstage and Backwash)	783	1,044	1,342	1,491	kW
GAC Adsorption					
GAC Feed Flow	57	115	172	230	Mld
Number of Parallel GAC Adsorbers	4	6	8	10	
GAC Adsorber Empty Bed Contact Time, each	20	20	20	20	min
Design GAC Adsorber Media Depth	3	3	3	3	m
Total GAC Volume	792	1597	2389	3194	m3
GAC Adsorber Area	66	90	100	107	m2
GAC Adsorber Loading Rate, all in service	9.00	9.00	9.00	9.00	m/hr
GAC Adsorber Loading Rate, 1 out of service	10.80	9.82	9.53	9.39	m/hr
GAC Adsorber EBCT, 1 out of service	17	18	19	19	min
GAC Filter Media Effective Size	0.55 - 0.75	0.55 - 0.75	0.55 - 0.75	0.55 - 0.75	mm
GAC Filter Media Uniformity Coefficient	1.9	1.9	1.9	1.9	
GAC Backwash Frequency	14	14	14	14	days
GAC Backwash Loading Rate (Low)	12.2	12.2	12.2	12.2	m/hr
GAC Backwash Loading Rate (High)	36.6	36.6	36.6	36.6	m/hr
GAC Backwash Duration (Low)	5	5	5	5	min
GAC Backwash Duration (High)	10	10	10	10	min
Backwash Volume per Event	470	641	712	761	m3/filter
Average Daily Backwash Volume	134	275	407	544	m3/d
Site Returns PS					

Minworth SRO Design Criteria	57Mld	115Mld	172Mld	230Mld	Units
Site Returns Pumping Station Wet Well Size	3,572	4,532	8,594	8,701	m3
Site Returns Pumping Station Power	15	37	74.6	74.6	kW
Minworth AWTP Power					
Estimated Power Consumption	4,239	8,631	12,414	16,703	MWh/year
Total Connected Load	1502	2479	3485	4164	kW

A critical design aspect for the proposed design is the handling of the dirty backwash which is pumped back to Minworth WwTW inlet. The design specifications are given in the table above but for clarity are explained as follows for the 230Mld case:

Daily sludge from the Floc-Sed process is 3.58Mld. Minworth WwTW is permitted to and treats up to 1071.3Mld of sewage hence this return constitutes 0.33% of the maximum permitted flows to Minworth, as such is deemed insignificant. However backwash flows are balanced in a Site Return Pumping station sized at 8701m^3 for the 230Mld case.

Clean backwash is stored in the Interstage pumping station well. For the 230Mld case this is sized at 7948m^3.

By design backwashes are performed sequentially to ensure flows back to the works are adequately balanced with a total of 16.2 Mld returned to the Minworth WwTW for the 230 Mld case. This constitutes 1.5% of total permitted flow Minworth can treat hence does not affect the hydraulic efficacy of the treatment process as return flows are balanced. The return flow carries a load comparable to water treatment works returns and does not pose a risk of significant increased biological loading to the WwTW.

3.2 PC4: Alternative: Floc-Sed

Following discussions with the project team an alternative option that addresses phosphorus removal down to 0.2mg/l alone has been developed. Similar to the above stated treatment train, all the flow passes through the Floc-Sed process but then flows directly to the transfer pumping station for the respective SROs, GUC and STT.

Design specifications are the same for the Floc-Sed process above however this section has been separated out in the report to give clarity. As such Table 3-2 below gives the technical specifications for the Floc-Sed process.

With this alternative treatment train, compared to the Floc-Sed, Ozone, BAC and GAC, a smaller site returns pumping station is required. The interstage pumping station is not required and the chemical requirements reduce down to, Ferric and Polymer and Sodium Hydroxide. The site footprint also reduces.

Table 3-2: Process Design Criteria (Alternative)

Minworth SRO Design Criteria	57.ALT MLD	115.ALT Mld	
Criteria	**Value**	**Value**	**Units**
Fully Treated Water Flow Rate	57	115	Mld
Inline Influent Pumping Station			
Design Flow (Including Return Flows)	57.9	116.8	Mld
Flow Capacity	670	1,352	l/s
Design Total Dynamic Head	15	15	m
Pumping Power Rating	112	336	kW
Duty Pumps	2	3	
Standby Pumps	1	1	

Minworth SRO Design Criteria	57.ALT MLD	115.ALT Mld	
Ballasted Floc - Sed			
Design Feed Flow	57.9	116.8	Mld
Number of Rapid Mix Trains	2	3	
Coagulant	Ferric Chloride	Ferric Chloride	
Design Average Coagulant Dose (as Fe)	5	5	mg/L as Fe
Design Rapid Mix Mixing Gradient	1,000	1,000	1/s
Flocculation Aid Polymer Type	Non-Ionic (Jar Tests Required)	Non-Ionic (Jar Tests Required)	
Flocculation Aid Polymer Dose	0.75	0.75	mg/L
Total Reaction Tank Volume	524	1056	m3
Number of Clarifiers	2	2	
Circular Clarifier Diameter	11.5	16	m
Sidewall Depth	4.3	4.3	m
Number Magnetite Recovery Drums	1	1	
Magnetite Initial Charge	20,182	36,926	kg
Magnetite Daily Usage (Theoretical)	75	152	kg/d
Magnetite Daily Usage (Adjusted in line with operational Feedback)	113	228	kg/d
Magnetite Bulk Density	1,800	1,800	kg/m3
Number of Magnetite Silos	1	1	
Magnetite Storage Capacity	18,000	18,000	kg
Magnetite Storage Capacity	10	10	m3
Number of Days Storage	160.0	78.9	days storage
System Recovery (Sludge)	98.5%	98.5%	
Design Effluent Flow	57	115	Mld
Sludge Removal Type	Intermittent	Intermittent	
Intermittent Sludge Removal On Duration	10	10	min
Intermittent Sludge Removal Off Duration	50	50	min
Instantaneous Maximum Site Returns	61.3	122.9	L/s
Daily Site Returns Flow	0.9	1.8	Mld
Daily Site Returns Flow	10.2	20.5	L/s
Site Returns Pumping Station Wet Well Size	120	240	m3
Site Returns Pumping Station Power	15	37	kW
Minworth AWTP Power			
Estimated Power Consumption	1,139	2,436	MWh/year
Total Connected Load	215	464	kW

3.3 Chemical Dosing Requirements

The treatment process requires chemical storage and feed systems to function properly and efficiently.

- The floc-sed process requires a coagulant, ferric chloride, and non-ionic polymer to improve total phosphorus and total solids removal.

- Ozone oxidation is enhanced by the presence of hydrogen peroxide, which is currently included in the design. Sodium bisulfite is included to quench the ozone and hydrogen peroxide residuals prior to BAC filtration. Please note LOX storage and usage is covered the process design section above.
- BAC filtration performance is improved with the continuous addition of phosphoric acid and non-ionic polymer and intermittent addition of sodium hypochlorite to control excessive biological growth.

Bench and pilot testing shall be used to verify whether pH correction is carried forward at Gate 3.

For wastewater sites the Severn Trent Specification requires at least 30 days storage if the volume required is less than 10m^3. For larger volumes the specification is 10days storage plus 1 tanker. This plant sits between wastewater treatment and drinking water treatment and this affects the criticality of each process asset, hence a design decision to allow for 15days storage was taken. The required chemical dosages, flow rates and storage volume required for the four flows are as represented in Table 3-3, Table 3-4, Table 3-5, Table 3-6, Table 3-7 and Table 3-8 and are intended to be conservative at this design stage.

3.3.1 57Mld

Table 3-3: Treat 57 Chemical Requirements.

Service	Chemical	% Active	Specific Gravity	Dose (pure) (mg/L)	Flow Pace (Mld)	Chem Flow (L/hr)	Number of Days Storage	Storage Needed (m^3)
Floc - Sed	Ferric (as Fe)	13.8%	1.43	5	62	65.00	15	23
Floc - Sed	Non-ionic Polymer	100%	1.1	0.75	62	1.75	15	0.6
Ozone	Hydrogen Peroxide	35%	1.13	5	61	31.96	15	11.5
Ozone	Sodium Bisulfite	40%	1.3	3	61	14.59	15	5.3
BAC	Phosphoric Acid	85%	1.68	0.2	61	0.35	15	0.1
BAC	Non-ionic Polymer	100%	1.1	0.1	61	0.23	15	0.1
BAC	Sodium Hypochlorite	12.5%	1.21	0	57	0.00	15	0.0
pH correction	Sodium Hydroxide	50%	1.28	25	57	92.7	15	34

3.3.2 57Mld - Alternative

Table 3-4: Treat 57 (Alternative) Chemical Requirements.

Service	Chemical	% Active	Specific Gravity	Dose (pure) (mg/L)	Flow Pace (Mld)	Chem Flow (L/hr)	Number of Days Storage	Storage Needed (m^3)
Floc - Sed	Ferric (as Fe)	13.8%	1.43	5	62	65.00	15	23
Floc - Sed	Non-ionic Polymer	100%	1.1	0.75	62	1.75	15	0.6
pH correction	Sodium Hydroxide	50%	1.28	25	57	92.7	15	34

3.3.3 115Mld

Table 3-5: Treat 115 Chemical Requirements.

Service	Chemical	% Active	Specific Gravity	Dose (pure) (mg/L)	Flow Pace (Mld)	Chem Flow (L/hr)	Number of Days Storage	Storage Needed (m^3)
Floc/Sed	Ferric	13.8%	1.43	5	123	130.22	15	47
Floc/Sed	Non-ionic Polymer	100%	1.1	0.75	123	3.50	15	1.3
Ozone	Hydrogen Peroxide	35%	1.13	5	122	64.03	15	23.1
Ozone	Sodium Bisulfite	40%	1.3	3	122	29.22	15	10.5

Service	Chemical	% Active	Specific Gravity	Dose (pure) (mg/L)	Flow Pace (Mld)	Chem Flow (L/hr)	Number of Days Storage	Storage Needed (m^3)
BAC	Phosphoric Acid	85%	1.68	0.2	122	0.71	15	0.3
BAC	Non-ionic Polymer	100%	1.1	0.1	122	0.46	15	0.2
BAC	Sodium Hypochlorite	12.5%	1.21	0	115	0.00	15	0.0
pH correction	Sodium Hydroxide	50%	1.28	25	115	187	15	68

3.3.4 115Mld - Alternative

Table 3-6: Treat 115 (Alternative) Chemical Requirements.

Service	Chemical	% Active	Specific Gravity	Dose (pure) (mg/L)	Flow Pace (Mld)	Chem Flow (L/hr)	Number of Days Storage	Storage Needed (m3)
Floc/Sed	Ferric	13.8%	1.43	5	123	130.22	15	47
Floc/Sed	Non-ionic Polymer	100%	1.1	0.75	123	3.50	15	1.3
pH correction	Sodium Hydroxide	50%	1.28	25	115	187	15	68

3.3.5 172Mld

Table 3-7: Treat 172 Chemical Requirements.

Service	Chemical	% Active	Specific Gravity	Dose (pure) (mg/L)	Flow Pace (Mld)	Chem Flow (L/hr)	Number of Days Storage	Storage Needed (m^3)
Floc/Sed	Ferric	13.8%	1.43	5	184	194.27	15	70
Floc/Sed	Non-ionic Polymer	100%	1.1	0.75	184	5.23	15	1.9
Ozone	Hydrogen Peroxide	35%	1.13	5	181	95.52	15	34.4
Ozone	Sodium Bisulfite	40%	1.3	3	181	43.59	15	15.7
BAC	Phosphoric Acid	85%	1.68	0.2	181	1.06	15	0.4
BAC	Non-ionic Polymer	100%	1.1	0.1	181	0.69	15	0.2
BAC	Sodium Hypochlorite	12.5%	1.21	0	172	0.00	15	0.0
pH correction	Sodium Hydroxide	50%	1.28	25	172	280	15	101

3.3.6 230Mld

Table 3-8: Treat 230 Chemical Requirements

Service	Chemical	% Active	Specific Gravity	Dose (pure) (mg/L)	Flow Pace (Mld)	Chem Flow (L/hr)	Number Days Storage	Storage Needed (m^3)
Floc/Sed	Ferric	13.8%	1.43	5	246.21	259.93	15	94
Floc/Sed	Non-ionic Polymer	100%	1.1	0.75	246.21	6.99	15	2.5
Ozone	Hydrogen Peroxide	35%	1.13	5	242.63	127.81	15	46.0
Ozone	Sodium Bisulfite	40%	1.3	3	242.63	58.32	15	21.0
BAC	Phosphoric Acid	85%	1.68	0.2	242.63	1.42	15	0.5
BAC	Non-ionic Polymer	100%	1.1	0.1	242.63	0.92	15	0.3
BAC	Sodium Hypochlorite	12.5%	1.21	0	230.00	0.00	15	0.0
pH correction	Sodium Hydroxide	50%	1.28	25	230.00	374	15	135

3.4 Power Requirements

The Jacobs Replica Parametric Design tool estimates the power consumption of each treatment process. The total installed load (kW) for each of the flow scenarios is shown below. Data is broken out by process unit. Both duty and standby equipment are included in these estimates but they do not include building lighting, building electricity, or other ancillary loads. It is estimated that at least 10% more site power is needed than shown.

Jacobs Replica Parametric Design was primarily used to generate these estimates but the ozone estimates were benchmarked against supplier quotes.

Table 3-9: Estimated Process Energy Requirements

Duty Power per facility (kW)	57 Mld	115 Mld	172 Mld	230 Mld
Floc-Sed	40.3	47.7	62.6	71.6
Ozone	337.1	691.3	1030.6	1394.5
Influent Pumping Station	111.9	335.6	596.6	745.7
Interstage Pumping	224	447	597	746
Backwash Pumping	559	596	745	746
Site Returns Pumping	14.9	37.3	74.6	74.6
Chemicals	13.4	13.4	13.4	13.4
TOTAL	1338	2169	3120	3791

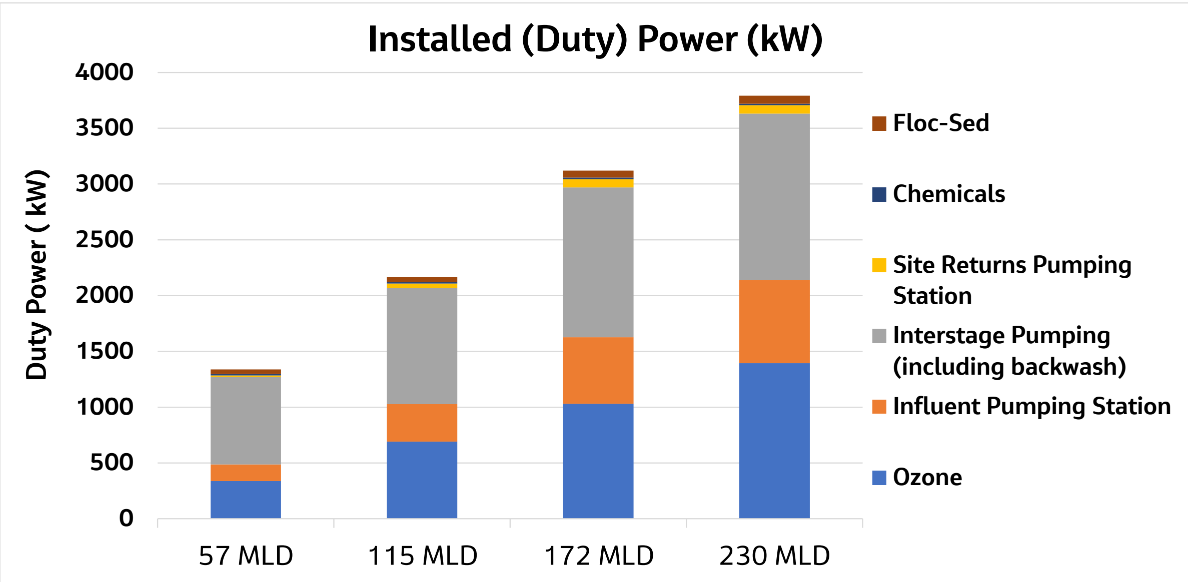


Figure 3-1: Estimated Process Energy Requirements

Table 3-10: Estimated Process Energy Requirements (Alternative Option)

Duty power per facility (kW)	57.ALT Mld	115.ALT Mld
Influent Pumping Station	149.1	335.6
Floc Sed	40.3	47.7
Site Returns Pumping Station	14.9	37.3
Chemicals	8.2	8.2
TOTAL	212	429

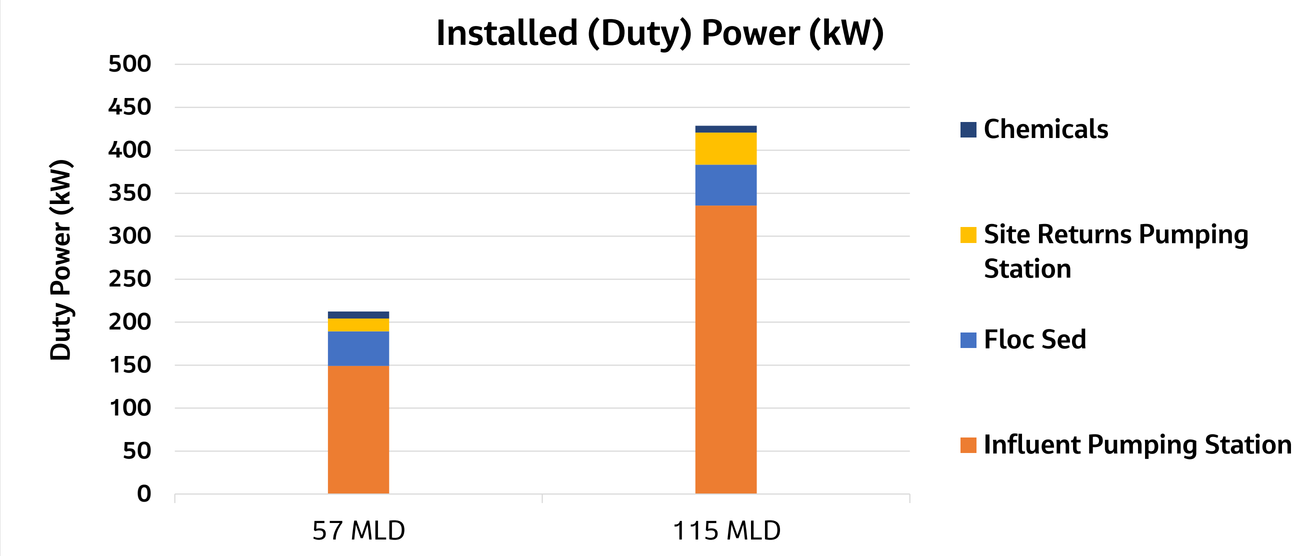


Figure 3-2: Estimated Process Energy Requirements (Alternative Option)

3.5 Generic Plant Footprint

The design criteria shown in Section 3.2 were used, in Replica Parametric Design, to develop a conservative footprint for each of the main treatment processes and pumping stations. Table 3-11 below shows the estimated footprints (m^2) for each of the four flow rates. Note that several buildings (administrative, electrical, maintenance, etc.) are not included. It is currently assumed that all chemical storage and feed systems are housed in one building but based on the site layout it may be advantageous to separate out some chemicals to be closer to their application points. The footprints below can be used to develop a full site footprint for each flow scenario but need to include space for roads, access, parking, etc.

Table 3-11: Estimated Treatment Process Footprints

	Estimated Footprint Requirement (m^2)			
	57 Mld	115 Mld	172 Mld	253 Mld
Influent Pumping Station	160	374	459	544
Floc/Sed*	1128	2145	3200	4200
Ozone Contactor	336	672	924	1200
Ozone Generation	450	600	700	800
LOX	230	230	230	322
BAF	782	1443	2106	2760
GAC	782	1443	2106	2760
Interstage Pumping Station	336	512	576	640
Chemicals	680	714	748	850
Site Backwash Pumping Station	561	780	1377	1377
Total Generic Area Requirements	5445	8913	12426	15453

*Lamella plate clarification was used to develop the floc-sed footprint to be conservative

Table 3-12: Estimated Treatment Process Footprints (Alternative Option)

	Estimated Footprint Requirement (m^2)	
	57 Mld	115 Mld
Influent Pumping Station	160	374
Floc/Sed*	1128	2145
Chemicals	165	189
Site Returns Pumping Station	98	154
Total Generic Area Requirements	1551	2862

*Lamella plate clarification was used to develop the floc-sed footprint to be conservative

The following section gives the total flow balances for the AWTP. Complete load balances for the treatment plant shall be provided with the results of the bench and pilot tests at Gate 3.

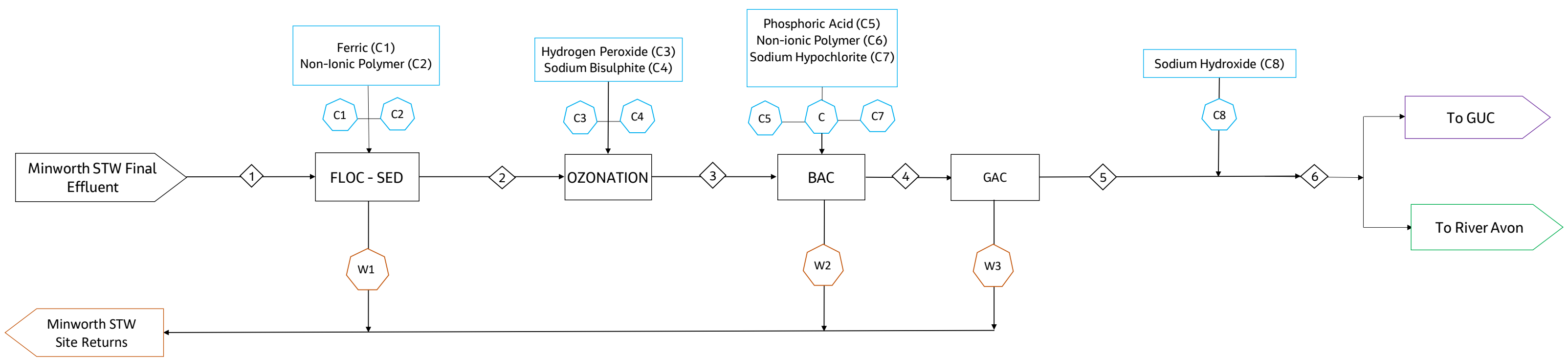
4. Mass Balances

Project Title: Minworth SRO
Client Name: Severn Trent
Project No.: B19589CF
Doc. Title: Minworth Flows and Loads
Doc. Reference: A7W13155-WT-REP-221001
Date: 21/04/2022
Rev: 0A

Jacobs

SEVERN TRENT

Process Block Diagram - 57 MLD Option



Stream Number		1	2	3	4	5	6		W1	W2	W3
Parameter	Unit	FLOC - SED	Ozonation	BAC	GAC	pH Correction	Final		FLOC - SED Waste	BAC Waste	GAC Waste
	References										
Flow	MLD	61.57	60.68	60.68	57.00	57.00	57.00		0.89	3.68	0.0001

Stream Number		C1	C2	C3	C4	C5	C6	C7	C8
Parameter	Unit	Chemical A	Chemical B	Chemical D	Chemical E	Chemical F	Chemical G	Chemical H	Chemical I
	References								
Chemical Addition		Ferric	Non-ionic Polymer	Hydrogen Peroxide	Sodium Bisulfite	Phosphoric Acid	Non-ionic Polymer	Sodium Hypochlorite	Sodium Hydroxide
% Active	%	13.80	100	35.00	40	85.00	100	12.5	50
SG		1.43	1.10	1.13	1.30	1.68	1.10	1.21	1.54
Dose	mg/l	5.00	0.75	5.00	3.00	0.20	0.10	0.00	12.00
Chemical Flow	l/h	65.00	1.75	31.96	14.59	0.35	0.23	0.00	37.01
Chemical Flow	mL/min	1083.41	29.15	532.71	243.10	5.90	3.83	0.00	616.88
Weekly Chemical Usage	L/week	10920.72	293.88	5369.74	2450.46	59.49	38.61	0.00	6218.18
Annual Chemical Usage	m^3/year	569.44	15.32	279.99	127.77	3.10	2.01	0.00	324.23
Days Storage	Days	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Chemical Storage Volume	m^3	23.40	0.63	11.51	5.25	0.13	0.08	0.00	13.32

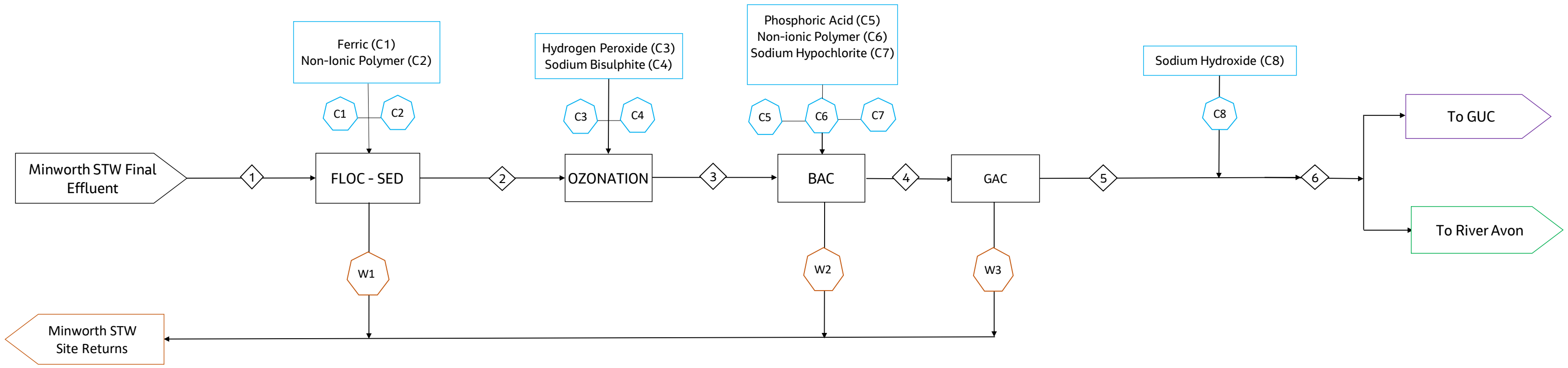
Figure 4-1: Treat 57 Process Diagram and Flow Balance

Project Title: Minworth SRO
Client Name: Severn Trent
Project No.: B19589CF
Doc. Title: Minworth Flows and Loads
Doc. Reference: A7W13155-WT-REP-221001
Date: 21/04/2022
Rev: 0A

Jacobs

SEVERN TRENT

Process Block Diagram - 115 MLD Option



Stream Number		1	2	3	4	5	6		W1	W2	W3
Parameter	Unit	Floc - Sed	Ozonation	BAC	GAC	pH Correction	Final		Floc - Sed Waste	BAC Waste	GAC Waste
	References										
Flow	MLD	123.35	121.56	121.56	115.00	115.00	115.00		1.79	6.56	0.0003

Stream Number		C1	C2	C3	C4	C5	C6	C7	C8
Parameter	Unit	Chemical A	Chemical B	Chemical D	Chemical E	Chemical F	Chemical G	Chemical H	Chemical I
	References								
Chemical Addition		Ferric	Non-ionic Polymer	Hydrogen Peroxide	Sodium Bisulfite	Phosphoric Acid	Non-ionic Polymer	Sodium Hypochlorite	Sodium Hydroxide
% Active	%	13.80	100	35.00	40.00	85.00	100.00	12.50	50.00
SG		1.43	1.10	1.13	1.30	1.68	1.10	1.21	1.54
Dose	mg/l	5.00	0.75	5.00	3.00	0.20	0.10	0.00	12.00
Chemical Flow	l/h	130.22	3.50	64.03	29.22	0.71	0.46	0.00	74.68
Chemical Flow	mL/min	2170.40	58.41	1067.19	487.01	11.82	7.67	0.00	1244.59
Weekly Chemical Usage	L/week	21877.67	588.73	10757.29	4909.05	119.17	77.35	0.00	12545.45
Annual Chemical Usage	m^3/year	1140.76	30.70	560.92	255.97	6.21	4.03	0.00	654.16
Days Storage	Days	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Chemical Storage Volume	m^3	46.88	1.26	23.05	10.52	0.26	0.17	0.00	26.88

Figure 4-2: Treat 115 Process Diagram and Flow Balance

Project Title: Minworth SRO
Client Name: Severn Trent
Project No.: B19589CF
Doc. Title: Minworth Flows and Loads
Doc. Reference: A7W13155-WT-REP-221001
Date: 21/04/2022
Rev: OA

Jacobs

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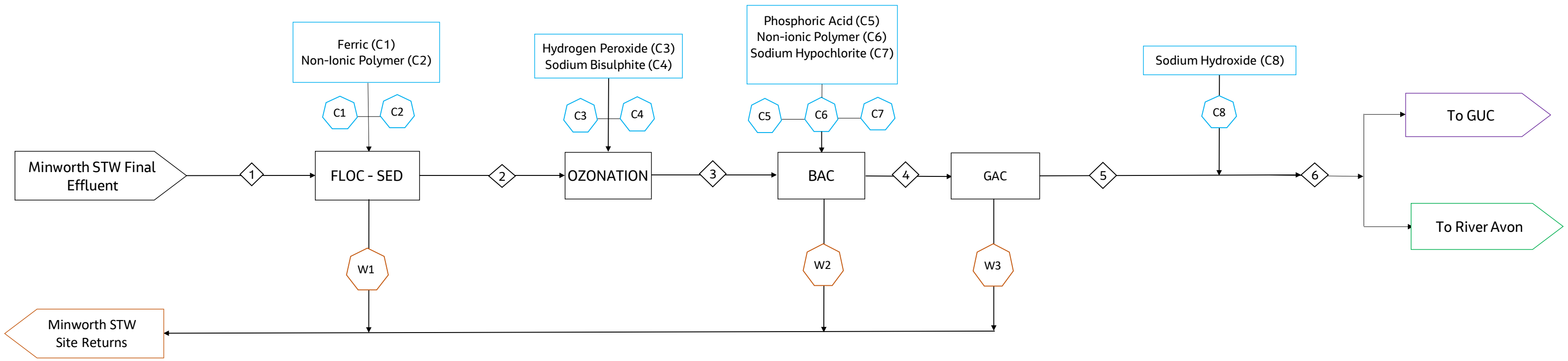
Process Block Diagram - 172 MLD Option



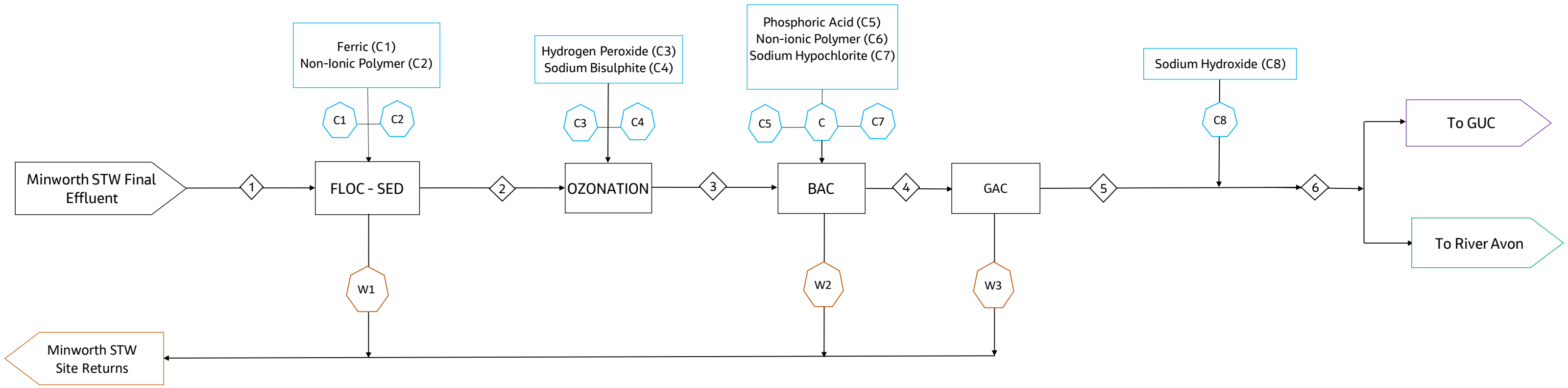
Stream Number		1	2	3	4	5	6		W1	W2	W3
Parameter	Unit	Floc - Sed	Ozonation	BAC	GAC	pH Correction	Final		Floc - Sed Waste	BAC Waste	GAC Waste
	References										
Flow	MLD	184.02	181.34	181.34	172.00	172.00	172.00		2.68	9.34	0.0004

Stream Number		C1	C2	C3	C4	C5	C6	C7	C8
Parameter	Unit	Chemical A	Chemical B	Chemical D	Chemical E	Chemical F	Chemical G	Chemical H	Chemical I
	References								
Chemical Addition		Ferric	Non-ionic Polymer	Hydrogen Peroxide	Sodium Bisulfite	Phosphoric Acid	Non-ionic Polymer	Sodium Hypochlorite	Sodium Hydroxide
% Active	%	13.80	100	35.00	40.00	85.00	100.00	12.50	50.00
SG		1.43	1.10	1.13	1.30	1.68	1.10	1.21	1.54
Dose	mg/l	5.00	0.75	5.00	3.00	0.20	0.10	0.00	12.00
Chemical Flow	l/h	194.27	5.23	95.52	43.59	1.06	0.69	0.00	111.69
Chemical Flow	mL/min	3237.83	87.13	1592.05	726.53	17.64	11.45	0.00	1861.47
Weekly Chemical Usage	L/week	32637.37	878.27	16047.85	7323.38	177.79	115.40	0.00	18763.64
Annual Chemical Usage	m^3/year	1701.81	45.80	836.78	381.86	9.27	6.02	0.00	978.39
Days Storage	Days	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Chemical Storage Volume	m^3	69.94	1.88	34.39	15.69	0.38	0.25	0.00	40.21

Figure 4-3: Treat 172 Process Diagram and Flow Balance

Project Title: Minworth SRO
Client Name: Severn Trent
Project No.: B19589CF
Doc. Title: Minworth Flows and Loads
Doc. Reference: A7W13155-WT-REP-221001
Date: 21/04/2022
Rev: 0A

Process Block Diagram - 230 MLD Option



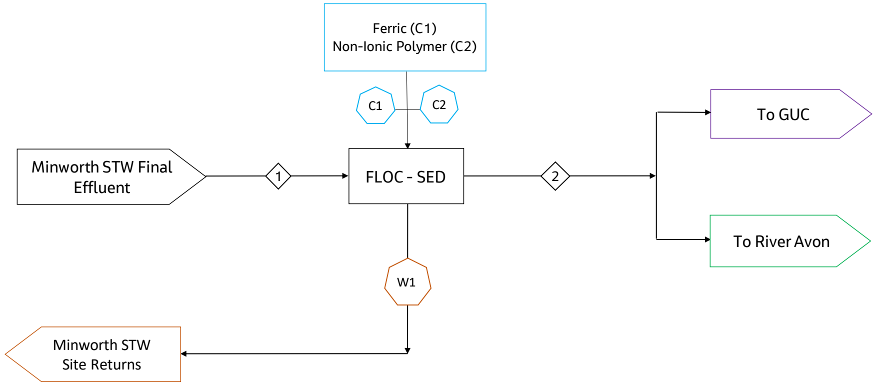
Stream Number		1	2	3	4	5	6		W1	W2	W3
Parameter	Unit	Floc - Sed	Ozonation	BAC	GAC	pH Correction	Final		Floc - Sed Waste	BAC Waste	GAC Waste
	References										
Flow	MLD	246.21	242.63	242.63	230.00	230.00	230.00		3.58	12.63	0.0005

Stream Number		C1	C2	C3	C4	C5	C6	C7	C8
Parameter	Unit	Chemical A	Chemical B	Chemical D	Chemical E	Chemical F	Chemical G	Chemical H	Chemical I
	References								
Chemical Addition		Ferric	Non-ionic Polymer	Hydrogen Peroxide	Sodium Bisulfite	Phosphoric Acid	Non-ionic Polymer	Sodium Hypochlorite	Sodium Hydroxide
% Active	%	13.80	100.00	35	40	85	100	12.5	50
SG		1.43	1.10	1.13	1.30	1.68	1.10	1.21	1.54
Dose	mg/l	5.00	0.75	5.00	3.00	0.20	0.10	0.00	12.00
Chemical Flow	l/h	259.93	6.99	127.81	58.32	1.42	0.92	0.00	149.35
Chemical Flow	mL/min	4332.09	116.58	2130.10	972.06	23.60	15.32	0.00	2489.18
Weekly Chemical Usage	L/week	43667.51	1175.09	21471.39	9798.39	237.87	154.40	0.00	25090.91
Annual Chemical Usage	m^3/year	2276.95	61.27	1119.58	510.92	12.40	8.05	0.00	1308.31
Days Storage	Days	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Chemical Storage Volume	m^3	93.57	2.52	46.01	21.00	0.51	0.33	0.00	53.77

Figure 4-4: Treat 230 Process Diagram and Flow Balance

Project Title: Minworth SRO
Client Name: Severn Trent
Project No.: B19589CF
Doc. Title: Minworth Flows and Loads
Doc. Reference: A7W13155-WT-REP-221001
Date: 28/07/2022
Rev: 0A

Process Block Diagram - 115 MLD (Alternative Option)



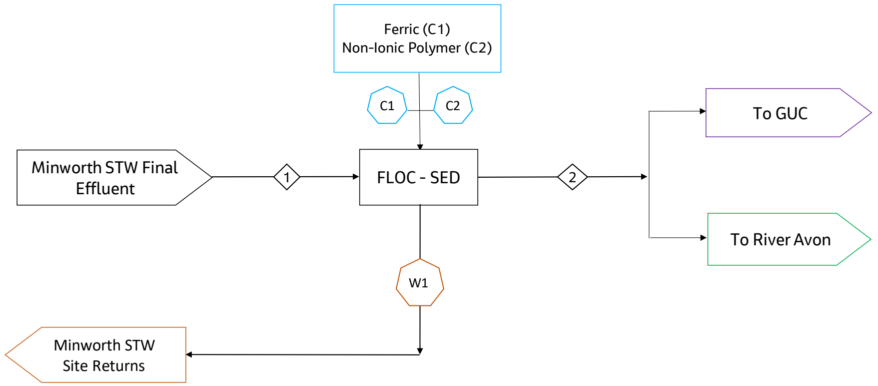
Stream Number		1	2	W1
Parameter	Unit	Floc - Sed	Treated Water	Floc - Sed Waste
Flow	MLD	116.8	115	1.8

Stream Number		C1	C2
Parameter	Unit	Chemical A	Chemical B
	References		
Chemical Addition		Ferric	Non-ionic Polymer
% Active	%	13.8	100
SG		1.43	1.1
Dose	mg/l	5.0	0.75
Chemical Flow	l/h	130.2	3.5
Chemical Flow	mL/min	2170.4	58.4
Weekly Chemical Usage	L/week	21877.7	588.7
Annual Chemical Usage	m^3/year	1140.8	30.7
Days Storage	Days	15	15
Chemical Storage Volume	m^3	47	1.3

Figure 4-5: Treat 115 Alternative

Project Title: Minworth SRO
Client Name: Severn Trent
Project No.: B19589CF
Doc. Title: Minworth Flows and Loads
Doc. Reference: A7W13155-WT-REP-221001
Date: 28/07/2022
Rev: 0A

Process Block Diagram - 57 MLD (Alternative Option)



Stream Number		1	2	W1
Parameter	Unit	FLOC - SED	Treated Water	Floc-Sed Waste
Flow	MLD	57.9	57	0.9

Stream Number		C1	C2
Parameter	Unit	Chemical A	Chemical B
Chemical Addition		Ferric	Non-ionic Polymer
% Active	%	13.8	100
SG		1.43	1.1
Dose	mg/l	5	0.75
Chemical Flow	l/h	65.0	1.75
Chemical Flow	mL/min	1083.4	29.2
Weekly Chemical Usage	L/week	10920.7	293.9
Annual Chemical Usage	m^3/year	569.4	15.3
Days Storage	Days	15	15
Chemical Storage Volume	m^3	23	0.63

Figure 4-6: Treat 57 Alternative

5. Conclusions and Recommendations

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. The anticipated discharge permit requirements were detailed in the Basis of Design Report and include a suite of trace chemicals that met the criteria for further environmental modelling based on screening guidance from the Environment Agency.

The treatment train selected is a carbon-based treatment process: coagulation, flocculation, and sedimentation (floc/sed) followed by ozone oxidation, biologically active carbon (BAC) filtration and granular activated carbon (GAC) adsorption. This process provides multiple barriers of treatment for solids, organics, and pathogens and is a robust, well-studied advanced treatment scheme. An alternate treatment scheme using reverse osmosis was briefly considered but was eliminated due to its larger capital and operating cost, higher energy consumption, and the expected challenges with managing the brine concentrate flow.

Floc/sed includes the addition of a chemical coagulant and a coagulant or flocculant aid polymer to remove solids and organics. Chemical flocculants are formed and settled out, preparing the water for effective filtration. During ozone oxidation, ozone is added to oxidize high molecular weight organics for downstream removal in biofiltration as well as for direct oxidation of trace organics. This step also achieves disinfection of pathogens. BAC filtration consists of deep-bed granular media filters that provide excellent particle and pathogen removal, in addition to biological removal or organic matter. The GAC adsorption provides removal of trace organics through both biological and adsorption mechanisms as the contaminants are adsorbed onto the GAC media.

Although the unit treatment processes are standard and proven, there are many variables that require a greater understanding to inform on the operational requirements of this scheme. Therefore, it is imperative bench and pilot tests are conducted to inform the final iteration of this plant design. Notably, this will help estimate the GAC regeneration frequency and the ozone consumption which together represent a significant amount of the total estimated operational cost.

Following discussions with the project team an alternative option that addresses Phosphorus removal down to 0.2mg/l alone has been developed. Similar to the above stated treatment train, all the flow passes through the Floc-Sed process but then flows directly to the conveyance pumping station for the respective SROs, GUC and STT. Design specifications are the same for the Floc-Sed process for the original scheme.

With this alternative treatment train, compared to the Floc-Sed, Ozone, BAC and GAC, a smaller site backwash pumping station is required. The interstage pumping station is not required and the chemical requirements reduce down to Ferric and Polymer and Sodium Hydroxide. Additionally, the site footprint also reduces significantly.

6. Bibliography

British Geological Survey , 2011. *Emerging contaminants in Groundwater,* s.l.: s.n.
Concawe, 2020. *Review of water treatment systems for PFAS removal* , s.l.: s.n.
DEFRA, 2008. *Survey of the prevalence of perfluorooctane sulphonate (PFOS), perfluorooctanoic acid (PFOA) and related compounds in drinking water and their sources,* s.l.: s.n.
DPR, 2014. *Pyrethroids in Wastewater: Review of Potential Sources, Occurrence, and Fate,* s.l.: Department of Pesticide Reulation Environmental Monitoring Branch Surface Water Protection Program.
DWI, 2012. *Publication of further research on Nitrosamines in water,* s.l.: DWI.
DWI, 2012. *Publication of further research on nitrosamines in water treatment coagulants and drinking water,* s.l.: DWI.
DWI, 2021. *Guidance on the Water Supply (Water Quality) Regulations 2016 specific to PFOS (perfluorooctane sulphonate) and PFOA (perfluorooctanoic acid) concentrations in drinking water,* s.l.: s.n.
DWI, 2021. *Likelihood of three endocrine disrupting substances reaching drinking water DWI 70/2/328 (25853),* s.l.: s.n.
EA, 2016. *Surface water pollution risk assessment for environmental permit* , s.l.: s.n.
EA, 2019. *Perfluorooctane sulfonate (PFOS) and related substances: sources, pathways and environmental data,* s.l.: s.n.
Environment Agency, 2019. *Cypermethrin: Sources, pathways and environmental data,* s.l.: s.n.
EPA, 1999. *Wastewater Technology Fact Sheet - Ozone Disinfection,* Washington D.C.: Office of Water EPA.
EPA, 2017. *Potable Reuse Compendium,* s.l.: United States Environmental Protection Agency.
Evoqua, 2022. *CoMag System.* [Online]
Available at: https://www.evoqua.com/en/evoqua/products--services/clarifiers--separators/ballasted-clarifiers/comag-system/#item-documentation
Gawlik, B. & Sanz, L., 2014. *Water Reuse in Europe - Relevant guidelines, needs for and,* s.l.: European Comission.
Glover, V. T. D., 2019. N-nitrosomorpholine in potable reuse. *Water Research,* pp. 306-313.
Gonzalez, 2021. Granual Activated Carbon- Based Treatment and Mobility of per - and polyflouroalkyl substances in potable reuse for aquifer recharge. *AWWA Water Science,* p. aws2.1247.
Government Chemist, 2016. *EU Persistent Organic Pollutants Regulation Updated,* s.l.: gov.uk.
Gunjate, 2014. A simulation study of the removal efficiency of modified granular activated carbon on cobalt. *International Journal of Chemical and Physical Sciences,* 3(2).
Gunjate, 2017. Adsorption of Cobalt onto Coal based Granular Activated Carbon: Kinetics and Equilibrium Studies. *International Journal of Applied Environmental Sciences* , Volume 12, pp. 1045 -1058.
Harris, 2021. Exploring variations of hexabromocyclododecane concentrations in riverine sediments along the River Medway, UK. *Royal Socienty of Chemistry* , Volume 23, pp. 776 - 785.
Hong, 2020. Nonylphenol occurrence, distribution, toxicity and analytical methods in freshwater. *Environmental Chemistry Letters.*
HSE, 2021. *Agency technical report on the classification and labelling of Mancozeb (ISO); manganese ethylenebis(dithiocarbamate) (polymeric) complex with zinc salt,* s.l.: Health and Safety Executive.
HSE, 2021. *Decision on the GB MRLs for dimethoate and omethoate amending the GB MRL Statutory Register,* s.l.: s.n.
Islam, 2018. Opportunities and constraints of using the innovative adsorbents for the removal of cobalt(II) from wastewater: A review. *Environmental Nanotechnology, Monitoring & Management,* Volume 10, pp. 435 - 456.
Jin, P. et al., 2013. Biological Activated Carbon Treatment Process for Advanced Water and Wastewater Treatment. In: *Biomass Now - Cultivation and Utilization.* s.l.:s.n.
Khan, S. & Drewes, J., 2014. Contemporary design, operation, and monitoring of potable reuse systems. *Journal of Water Reuse and Desalination* , 5(1), pp. 1-7.
Lewis, 2022. An international database for pesticide risk assessments and management. Pesticide Properties Database (University of Hertfordshire). *Human and Ecological Risk Assessment: An International Journal,* 22(4), pp. 1050 - 1064.
Liu, 2020. Effects of aqueous ozone treatment on microbial growth, quality, and pesticide residue of fresh-cut cabbage. *Food science and nutrition,* Volume 9, pp. 52 -61.
MDH, 2016. *Chloroform and Drinking Water,* s.l.: Minnesota Department of Health, Health Risk Assessment Unit .
NHMRC, 2008. *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Augmentation of Drinking Water Supplies,* s.l.: s.n.

Planas, C., 2008. Analysis of nitrosamines in water by automated SPE and isotope dilution GC/HRMS occurrencne in the different steps of a drining water treatment plant, and in chlorinated samples from a reservoir and a sewage treatment plant effluent. *Talanta,* pp. 906-913.
Roccaro, P., 2018. Treatment processes for municipal wastewater reclamation: The challenges of emerging contaminants and direct potable reuse. *Current Opinion in Environmental Science & Health,* Volume 2, pp. 46-54.
Rodrigo, 2019. Demonstrating process robustness of potable reuse trains during challenge testing with elevated levels of acetone, formaldehyde, NDMA, and 1,4-dioxane. *Journal of Water Supply: Research and Technology,* pp. 313-324.
Roosendael, 2019. Recovery of cobalt from dilute aqueous solutions using activated carbon - alginate composite spheres impregnated with Cyanex 272. *Royal Society of Chemistry,* Volume 9, pp. 18734 - 18746.
Royce, 2015. *A Full-Scale Demonstration Study Comparing UV/Cl2 and UV/H2O2 for the Treatment of 1,4-Dioxane in Potable Reuse,* s.l.: s.n.
Santos, 2010. *Microplollutant removal and technological development of membrane bioreactors,* s.l.: Cranfield University.
Tomolo, 2020. Chromium Pollution in European Water, Sources, Health Risk, and Remediation Strategies: An Overview. *International Journal of Environmental Reasearch and Public Health.*
ToxNet, 2017. *U.S. National Library of Medicine Toxicological Data,* s.l.: https://toxnet.nlm.nih.gov/newtoxnet/hsdb.htm.
USEPA Factsheet, 2017. *Technical Fact Sheet – 1.4-Dioxane,* s.l.: s.n.
USEPA Factsheet, 2017. *Technical Fact Sheet N-Nitroso-dimethylamine (NDMA),* s.l.: s.n.
USEPA, 2002. *Removing trihalomethanes from drinking water- an overview of treatment techniques,* s.l.: s.n.
USEPA, 2004. *Ethylenediaminetetraacetic acid (EDTA) and the salts of EDTA: Science Assessment Document for Tolerance Reassessment,* s.l.: s.n.
USEPA, 2007. *Reregistration Eligibility Decision (RED) for Permethrin,* s.l.: s.n.
USEPA, 2010. *Hexabromocyclododecane (HBCD) Action Plan,* s.l.: s.n.
USEPA, 2014. *Technical Fact Sheet 1.4 Dioxane ,* s.l.: s.n.
USEPA, 2016. *Drinking Water Health Advisories for PFOA and PFOS,* s.l.: s.n.
USEPA, 2017. *Potable Reuse Compendium,* s.l.: USEPA.
USEPA, 2017. *Technical Fact Sheet - 1,4 Dioxane,* s.l.: s.n.
Vatankhah, 2019. *Evaluation of Enhanced Ozone–Biologically Active Filtration Treatment for the Removal of 1,4-Dioxane and Disinfection Byproduct Precursors from Wastewater Effluent,* s.l.: Environmental Science and Technology.
WHO, 1998. *Edetic acid (EDTA) in Drinking-water,* s.l.: s.n.
WHO, 2017. *Guidelines for Drinking Water Quality,* s.l.: s.n.