

Technical Note

Project name **Angus Fire Permit Variation**
Project no. **1620016373**
Client **Angus Fire Limited**
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1 Introduction

This Technical Note has been prepared in support of the Permit Variation Application (EPR Ref.: EPR/XP3832NV/V004) and to address the Environment Agency's (EA's) Comment 22, as provided in their Schedule 5 Letter of 7 August 2025. The objective of this Note is to assess the different treatment technologies for the removal of Per- and polyfluoroalkyl substance (PFAS) that were available to Angus Fire Limited and identify the Best Available Techniques (BAT) defined as the most effective and feasible treatment technology that could be installed to meet the proposed post-treatment discharge requirements for their facility at High Bentham ('the Site').

To address the comment provided in the EA's Schedule 5 Letter, the Technical Note is structured as follows:

1. Characterise Site influent PFAS concentration and flow rate that is required to be treated.
2. Provide a description of the treatment technologies that were available for consideration.
3. Assessment of the positives and negatives of the treatment options that were available for consideration.
4. Demonstrate that the Best Available Technique (BAT) based on the assessment of the different treatment technologies was identified.

It is unlikely that one treatment technology will be sufficient to meet the post-treatment discharge requirements as there is no one proven technology for removing PFAS with 100% effectiveness. Therefore, the options appraisal considered the use of multiple treatment technologies ('treatment train') to ensure that an appropriate level of treatment is achieved for the concentrations of known PFAS that has been identified on-site.

Whilst there are technologies in pilot scale or development for the removal of PFAS from surface water, due to the time sensitive nature for the

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implementation of the proposed treatment plant, these are not considered viable and therefore not assessed.

2 Characterisation of Site Influent

2.1 Influent Source

Angus Fire propose to undertake treatment of contained stormwater from areas at the installation where there is potential for PFAS compounds (including perfluorooctane sulphonic acid (PFOS)) to be present. Stormwater is collected from areas of the Site that have been associated with historic manufacturing and testing activities that have the potential to contain PFAS compounds. Stormwater in these areas of the Site is collected and drains towards a sump. The contained stormwater is pumped to the pre-treatment storage tanks located in the external tank farm and will then be directed to the proposed treatment train.

A more detailed description of the contained stormwater collection process is provided in Section 4 of the Permit Variation Application Report.

2.2 Contaminant Concentration

Stormwater collection across the affected part of the Site has been assessed to determine the potential for PFAS and PFOS presence within the flow, and monitoring has been undertaken to confirm this.

The stormwater collected during the sampling program only identified the following 13 PFAS Compounds - PFOS, 6:2FTAB, 6:2FTS, PFHxA, 8:2FTS, PFPeA, PFHpA, PFBA, PFOA, PFHxS, FHxSA, PFNA and PFDA.

Angus Fire propose to store contained stormwater in influent storage tanks prior to treatment. This allows for blending of flows, creating a relatively stable influent with significant storage capacity (165 m³ in total) that provide buffering prior to treatment. Any peaks in concentration would be blended away in the holding tanks.

Notwithstanding this, monitoring has been undertaken from different areas of the Site that are likely to have been impacted, in addition to the influent storage tanks that are located on-site. This has allowed the concentration of PFOS and multiple PFAS chemicals to be established for a range of locations across the Site, with concentrations of up to 8 µg/l PFOS identified (see Figure 2-1).

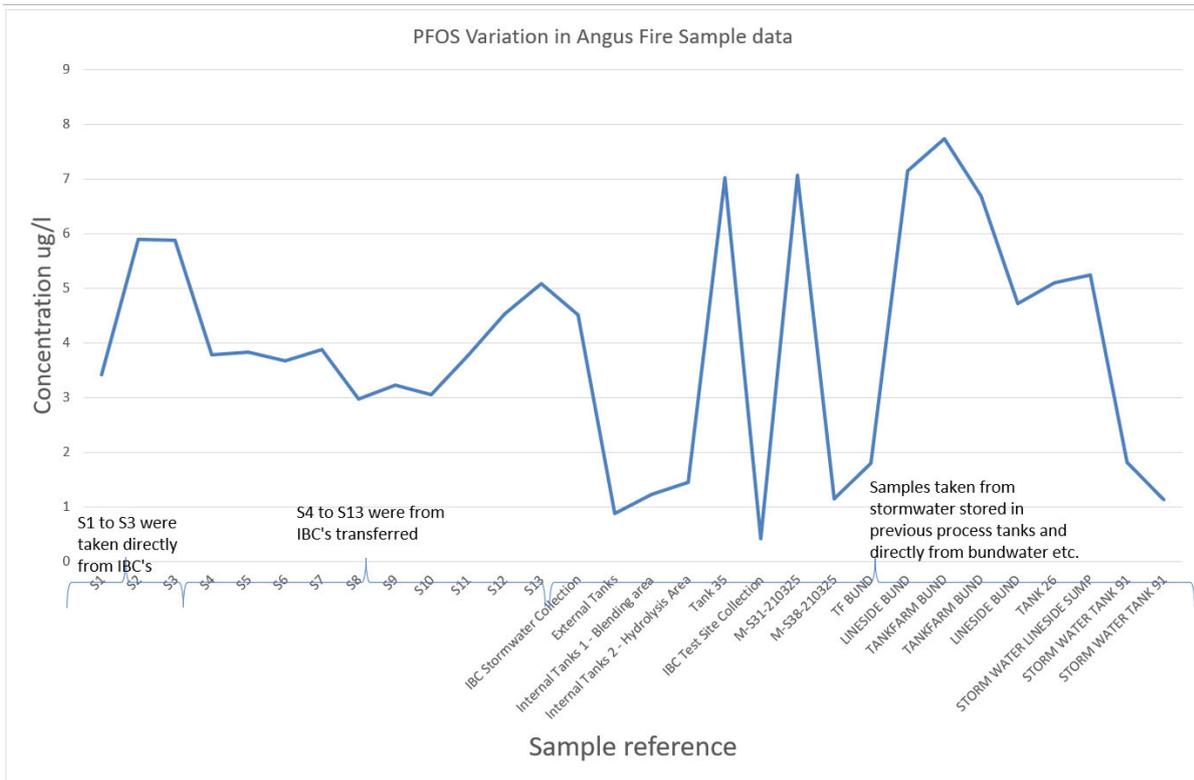


Figure 2-1: Concentrations of PFOS from Storage and Drainage at the Angus Site

There are currently no emission limits applied to the release of PFAS compounds from the installation, and only a single freshwater Environmental Quality Standard (EQS) for PFOS. For the purposes of determining a baseline for discharge requirements, an emission limit value for PFOS of 10 ng/L has been assumed, in line with similar regulated PFAS discharge operations in England. However, Angus Fire’s broader approach to the treatment of contained stormwater will focus on minimising and preventing the discharge of the known PFAS compounds identified at the site.

2.3 Treatment System Capacity

Angus Fire propose to treat up to 48 m³/day of contained stormwater with the contaminant concentrations described in Section 2.2.

3 Treatment and Disposal Technologies

A high-level review of different treatment and disposal technologies that were considered is provided below. In view of the criticality to implement a treatment system, only technologies that are currently commercially available in the region have been considered as part of this options appraisal.

3.1 Sorption

3.1.1 Activated Carbon

Activated carbon (AC) is a manufactured carbonaceous material with a large surface area and strong adsorption capabilities. AC is a mass transfer process, substances that are present in the influent are adsorbed onto the AC and removed from the influent.

Two common types of AC are Granular Activated Carbon (GAC) and Powdered Activated Carbon (PAC). The adsorption of PFAS using AC is a well-established technology with many commercial applications and has proven effective for removing long-chain PFAS such as PFOS¹. For both AC media, once the AC in the treatment vessel reaches the maximum loading of the PFAS compound(s) that it can adsorb then it is required to be replaced with new or regenerated material. This can be determined through the monitoring for the PFAS compound(s) in the effluent.

When the 'spent' AC is removed from the treatment vessels it is typically incinerated or disposed of at a landfill. AC is used for the treatment of a range of compounds, that is, it will adsorb compounds other than PFAS. High concentrations of other compounds in the influent can lead to a reduced amount of PFAS that can be adsorbed prior to breakthrough and a higher generation of 'spent' material that is to be disposed of through incineration or disposal to landfill. Further, higher levels of turbidity can also lead to pressure loss during filtration and require frequent filter rinsing for fixed-bed treatment systems.

3.1.1.1 Granular Activated Carbon

The most common application for AC is for GAC to be placed in packed-bed flow through vessels that are operated in series. As the influent passes through the packed-beds, PFAS compounds adsorb to the GAC and are removed.

The effluent from the GAC beds is monitored to determine when breakthrough occurs, following breakthrough the GAC is removed and replaced. Packed-bed treatment allows for the continuous treatment of influent.

For the implementation of a GAC treatment system consideration needs to be given to the type of influent that is to be treated and whether the media will be prone to fouling, as this reduces flow and also affects the amount of PFAS that can be adsorbed prior to breakthrough. Higher loading of influent will also require a higher volume of 'spent' media to be treated or disposed and for a larger footprint of the treatment system to achieve the desired treatment level.

3.1.1.2 Concentration levels for PFOS and PFOA of 0.07 µg/l¹ as well as concentrations of 0.1 µg/L for other individual PFAS components and 0.5 µg/L for total PFAS are achievable by activated carbon treatment but may require several beds located in series. Powdered Activated Carbon
A more recent configuration for AC is for Powdered Activated Carbon (PAC) to be added to a stirred batch reactor containing the contained stormwater. This approach is preferential for batch treatment

¹ "Review of water treatment systems for PFAS removal, Concawe Report no.14/20, August 2020, Accessed at [Microsoft Word - Rpt_20-14](#)

processes, as it allows for accurate and specific dosing of an identified volume of PAC to achieve the required removal rate, minimising wastage.

As it is not applied in a fixed-bed configuration, PAC treatment systems do not require filter rinsing or continuous monitoring. However, a secondary downstream process is required to separate the sorbent from the effluent for offsite disposal.

PAC treatment systems can be implemented quickly to allow for bench scale testing of the treatment system to Site specific influent and optimisation of the treatment system. Taking this approach allows for optimal dosing of PAC on a single batch basis, which minimises the risk of fouling and reduces waste generated. It also removes the risk of breakthrough of PFAS through single-use application.

3.2 Ion Exchange Resin

Ion exchange (IX) resins remove contaminants through adsorption and electrostatic attractions. The positively charged exchange sites of the anion exchange resins attract the negatively charged head of anionic PFAS. IX resins have been used in commercial applications and have demonstrated the capacity to remove PFOS.

IX resins are used in fixed-bed treatment systems (similar to GAC) for the removal of PFAS. IX resins can be utilised as 'single-use' resins or regenerative resins, typically, 'single-use' resins have a higher removal capacity than regenerative resins. Similar to AC, once the exchange sites with the IX resins are used up then the resin is considered 'spent'. Spent single-use resins are required to be disposed of through landfilling or incineration while regenerative resins can be reused after the desorption of PFAS from the spent resin using an organic solvent. The process for regenerating resins is usually completed on-site and produces a concentrated waste product that requires further treatment or disposal.

The effluent from the resin beds is monitored to determine when breakthrough occurs; following breakthrough the resin is removed or regenerated and replaced. Packed-bed treatment allows for the continuous treatment of influent.

Similar to AC, the presence of other compounds in the influent such as dissolved organic carbon (DOC) sulphate, nitrate, and other ions may reduce the adsorption capacity of IX resins as the other compounds compete for binding sites with PFAS. In addition, there is the potential for preferential sorption to occur between individual PFAS compounds on sorption sites in the resin which may lead to unforeseeable breakthrough. When compared with single-batch dosing of PAC, this increases the potential for exceedances to occur in the final discharge.

Some IX resins have been identified to have a higher sorption capacity towards PFAS than AC and typically have a longer lifetime than GAC for long-chain PFAS (e.g. PFOS) and shorter contact time. The shorter contact time for IX resins can result in smaller treatment vessels compared to GAC treatment. The US and EU drinking water threshold values for PFOS and PFOA (0.07 to 0.1 µg/L) are achievable using ion exchange resins².

At the time of writing of this review, there are concerns regarding the commercial availability of suitable IX resins in the UK.

² Lines of evidence to assess the effectiveness of PFAS remediation technologies, prepared for the Environment Agency by Geosyntec Consultants Ltd, Version 3, 28 February 2024

3.3 Reverse Osmosis

Reverse Osmosis (RO) is a physical separation process used to remove organic and inorganic compounds from water. RO membranes are a semi-permeable membrane that allow water and gases to pass through but not larger particles like PFAS. This process typically requires pre-treatment to adapt the water quality and temperature, as well as routine maintenance to maintain its efficiency. The efficiency of this process is also dependant on the concentration, pressure and water flux rate of the influent.

Due to the small pores of the RO membrane, a high pressure is required to be applied to treat the influent, therefore, the treatment technology is energy intensive.

RO treatment systems allow for continuous treatment of influent to produce a treated effluent and a concentrate (waste product). Approximately 20% of the influent volume will end up as concentrate and be required to be disposed of to landfill or treatment through high-temperature incineration.

Applications for RO in removal of PFOA and PFOS in drinking water following pre-treatment and with an influent concentration of <100 ng/L showed that a removal efficiency of >99% can be achieved².

3.4 Membrane Filtration

Membrane filtration is similar to RO in that it involves the separation of the compounds with a membrane, utilising size exclusion to remove the desired compound from the influent. Membrane filtration (microfiltration (MF), ultrafiltration (UF) and nanofiltration (NF) membranes have larger pore sizes and operate at lower pressure than RO.

The most common membrane for PFAS removal is NF; like the RO process, two products are produced from the NF treatment process, the treated effluent and concentrate (waste product). The concentrate is required to be disposed of to landfill or treated (typically using high temperature incineration).

Similarly to RO treatment, NF membranes are prone to fouling and typically require pre-treatment of influent to adapt the water quality and temperature, as well as routine maintenance to maintain its efficiency. Removal rates for PFOS using NF treatment in wastewater have been observed to range from 90% to 99%, however, due to the membranes having a more porous structure the removal rates for shorter chain PFAS are lower².

3.5 Foam Fractionation

Foam fractionation (FF) utilises the surfactant properties of PFAS that causes them to accumulate at surface interfaces, in this instance the air-water interface. During the FF process, gas is bubbled through the influent causing the PFAS to accumulate at the interface created by the bubbles. This then causes a foam of PFAS to accumulate on the top of the liquid which then process through a further 'concentration' and 'separation' phase that further reduces the PFAS containing waste product that needs to be disposed of to landfill or treated using high-temperature incineration. Approximately 0.5-2% of the influent volume will end up as concentrate for disposal.

FF treatment systems are relatively simple and require low maintenance. FF has been proven to be effective in the treatment of influent that has a PFAS concentration of greater than 0.5 µg/L and for longer chain PFAS², however in influent with concentrations lower than 0.5 µg/l or short PFAS chains, an additional method may be required to reach removal targets.

As an example, Surface Activated Foam Fractionation (SAFF) is a specific FF treatment technology that has been demonstrated in field studies to achieve >98.8% PFOs removal in influent with a PFOS concentration of 192 ng/l, with other long-chain PFAS removed at similar rates¹.

3.6 Incineration

The incineration process involves heating the water in rotary kilns, where high temperatures (typically 1100-1200°C) break down the PFAS into fluoride and carbon dioxide. This process creates flue gas which will need to be treated before release to eliminate dust and other pollutants such as hydrofluoric acid which can be created during the incineration process; this is typically achieved using wet scrubbing and activated carbon.

The incineration process and subsequent flue gas purification have a high energy use and cost, particularly in relation to the contained stormwater generated at Angus Fire. This consists almost entirely of water and has no calorific value. As a consequence, direct disposal of the contained stormwater requires significant blending with high-calorific wastes to achieve a minimum calorific threshold for incineration¹.

3.7 Disposal to Sewer

This process would involve simply disposing the contaminated water into the municipal sewage network without pre-treatment, putting the PFAS removal burden on the local sewage treatment plant. Municipal wastewater treatment plants do not currently apply treatment technologies that can remove PFAS effectively.

4 Assessment of Treatment Technologies

A high-level appraisal of the potential treatment options for untreated contained stormwater has been undertaken, as set out in Table 4-1. For the outcome column, red indicates discounted options, orange identifies possible technologies but with limitations and green identifies the for the most appropriate technologies:

Table 4-1: Options Appraisal of treatment options

Technology	Advantages	Disadvantages	Outcome
Offsite high-temperature incineration	<ul style="list-style-type: none"> • Most robust treatment approach • No permitting variation requirement • Fast to deploy • Can consistently meet regulatory requirements. • Effective across wide range of PFAS, can be scaled to different concentration levels 	<ul style="list-style-type: none"> • Requires significant blending with high-calorific wastes to achieve a suitable calorific value for incineration. • Extremely expensive and not a viable long-term option • Treatment facilities are reactive and disposal routes are not always open. • Storage container supply limitations • Suitable incinerators are far away and unsustainable long term. • Sustainability concerns over transport emissions (NO_x and CO₂) and energy usage for transportation of 48m³/day of water 	<p>Whilst this is a robust approach it is not cost-effective or environmentally sustainable in the long term.</p>
Surface Activation Foam Fractionation (SAFF)	<ul style="list-style-type: none"> • Excellent PFOS removal rates (>98.9%) – proven to be exceeded by onsite bench scale study; capable of achieving 10ng/l PFOS. • Low waste generation • Low energy demand 	<ul style="list-style-type: none"> • High cost (£1.5m-£2m CAPEX) • Longer lead time (12 weeks) • Creates a foam waste requiring further treatment or management. • Will be governed as a Waste Operation included as an activity to the installation permit. 	<p>Robust treatment approach for the removal of PFAS (including PFOS). Highly effective in removing long chain PFAS on its own and when engineered in series with other treatment technologies, it is highly effective at removing all PFAS. Proven field studies</p>

	<ul style="list-style-type: none"> • Ability to deal with variation in influent concentration. • Proven effective technology at laboratory and field scale at the site against predefined discharge criteria. • Effective across a wide range of contaminants. • Studied at bench scale and implemented at pilot and full-scale level to remove PFAS from groundwater, leachate and industrial water. • Successfully removed PFOS and PFOA to low levels (parts per trillion).³ • Co-foaming agents such as sodium dodecyl sulphate can be used to increase removal of less hydrophobic PFAS. 	<ul style="list-style-type: none"> • Ion exchange resins are generally more effective at adsorption of PFAS compared to SAFF. 	<p>show desired discharge concentration can be achieved.</p> <p>Whilst it has higher capital cost to other treatment technologies, the lower maintenance and operation costs to ensure financial sustainability.</p> <p>Less waste generated for disposal than other treatment technologies and lower energy demand.</p> <p>Extremely effective when coupled with a secondary treatment process to handle residual short-chain PFAS that have been identified on-site.</p>
PAC	<ul style="list-style-type: none"> • Quick mobilisation • Better sorption activity compared to GAC. • Proven effective technology at field scale when coupled with foam fractionation against predefined discharge criteria • Effective in reducing short chain PFAS from stormwater • Adaptable dosing process to provide an effective secondary treatment stage • Risk of breakthrough minimised through single-batch dosing 	<ul style="list-style-type: none"> • Is less effective at influent concentration rates to achieve discharge concentration as a stand-alone treatment process. • As a sorption process does not destruct PFAS and waste will require further management / likely incineration • Waste generation (removal and destruction of saturated PAC as sludge) 	<p>PAC is considered a viable secondary stage treatment post pre-treatment to add resilience into meeting the defined PFOS discharge criteria whilst also reducing concentrations of other non-regulated PFAS that have been identified on-site (i.e., short chain PFAS) as demonstrated through bench trials</p>

³ PFAS Technical and Regulatory Guidance Document and Fact Sheets, ITRC (Interstate Technology & Regulatory Council), 2023.

<p>GAC</p>	<ul style="list-style-type: none"> • Virgin GAC can be effective at reducing a range of PFAS. • Continuous treatment of influent • Proven effective technology for PFAS removal. • Treatment is simpler to implement than other technologies with less operation and maintenance time and costs. 	<ul style="list-style-type: none"> • As a sorption process does not destruct PFAS and waste will require further management / likely incineration • Waste generation (removal and destruction/regeneration of saturated GAC) • Shorter chain PFAS have lower GAC loading capacities and faster breakthrough times, requiring more frequent replacement³ • Limited information is available regarding treatment of other PFAS outside of PFOS and PFOA. • Susceptible to fouling due to nature of influent if implemented as a primary treatment process 	<p>GAC is considered a viable secondary stage treatment post pre-treatment to add resilience into meeting the defined PFOS discharge criteria. However, limited information is available regarding shorter chain PFAS removal and higher possibility of unidentified breakthrough occurring, compared to PAC.</p>
<p>Ion Exchange Resin</p>	<ul style="list-style-type: none"> • Capable of reducing concentrations for a broad suite at bench and field scale to low-level detection limits. • Simple to implement and less operation and maintenance time compared to other technologies. • Similar or better sorption capacity compared to GAC 	<ul style="list-style-type: none"> • Single use PFAS resins are most well suited to treat low concentration of PFAS such as is typically encountered in potable water treatment systems, where media change out would be expected to be infrequent. • Potential that after a resin unit is in equilibrium with one PFAS compound at an initially higher influent concentration a lower concentration influent can then desorb PFAS from the resin resulting in unforeseeable breakthrough³. • High capital and operating costs. • Recent discussions with a global provider confirmed that UK 	<p>Viable treatment option, however, there are concerns on the volatile supply of resin, making it unreliable as a current method of treatment.</p>

		<p>supply of PFAS resins is likely to remain volatile for the next 12 months as manufacturer is currently manufacturing on demand on a quarterly basis only - potential operational risk in providing continuous treatment of captured stormwater.</p>	
Reverse Osmosis / Nano filtration	<ul style="list-style-type: none"> • Effective across PFAS chain lengths and chemical structures • Limited waste generation compared to other technologies. 	<ul style="list-style-type: none"> • Very expensive to acquire and operate. • Membrane requires regular maintenance. • Fouling of membrane • Multi-stage pre-treatment is commonly required. • RO requires the use of high-pressure pumps and the management of concentrate, which can be energy intensive, and would put pressure on the energy-constrained site. 	<p>RO membranes are generally effective for the removal of a wide range of PFAS. However, they are not practical for most remediation applications which are high-flow and result in high capital costs, high energy requirements and significant operation and maintenance needs.</p>
Direct discharge to sewer	<ul style="list-style-type: none"> • Low cost • Easy to implement 	<ul style="list-style-type: none"> • Receiving works not designed for PFAS removal. • Non-treated effluent likely to pose an impact on the River Wenning. 	<p>Local sewage undertaker has outlined that they will not accept effluent containing PFAS</p>

5 Proposed Treatment Technologies

As set out in Section 4, no one treatment technology is capable of removing the full range of PFAS compounds, therefore, to treat the influent to the desired PFOS discharge criterion whilst achieving a high level (>90%) removal rate across both long and short chain PFAS that are present in the contained stormwater, a 'treatment train' approach is considered to be the most suitable approach to achieve the required level of removal to meet regulatory and environmental standards.

Based on the above options appraisal, a primary treatment stage of SAFF followed by the use of PAC is considered to represent BAT as:

- SAFF delivers >99% PFOS removal, proven at the site through trials of the process;
- SAFF provides a sustainable mode of operation with a low energy input and generation of small volumes of waste;
- PAC is capable of removing short-chain PFAS which may not be fully captured through the SAFF stage;
- PAC dosing can be configured to deliver optimum removal whilst minimising waste generated;
- The combined system is capable of removing over 90% of all PFAS compounds present in the influent and a ~99.8% reduction in PFOS.
- The combination of SAFF and PAC has been demonstrated to achieve the proposed emission limit of <10ng/l PFOS.

Whilst ion exchange presents a reasonable alternative to PAC as a secondary treatment process, it has not been taken forward for the purpose of this operation as there is currently significant uncertainty over the availability of suitable ion exchange resin in the near future. As PAC achieves all the required aspects to minimise the impacts of the operation, the use of PAC is considered to be an appropriate measure for the purpose of a waste operation activity.