Final Report

March 2026

Appendix M: Project 1007 Surface Water Treatment Evaluation

Project 1007 Feasibility Study
Minnesota Pollution Control Agency

MINNESOTA POLLUTION
CONTROL AGENCY

Prepared for:

Minnesota Pollution Control Agency
520 Lafayette Rd
Saint Paul, MN 55155

Prepared by:

AECOM
800 LaSalle Avenue
Minneapolis, MN 55402
(612) 376-2000
aecom.com

Minnesota Pollution Control Agency
520 Lafayette Road North | Saint Paul, MN 55155-4194 |
651-296-6300 | 800-657-3864 | Or use your preferred relay service. | Info.pca@state.mn.us
This report is available in alternative formats upon request, and online at www.pca.state.mn.us.
Document number: c-pfc1-27m

Contents

Figures

Tables

Referenced Figures (Found in Feasibility Study Appendix A)

Acronyms and Abbreviations

AOC	Area of Concern
CAPEX	Capital Expenditure
cm/s	centimeters per second
cy	Cubic Yard
DG #1	Lake Elmo Downgradient #1
ENR	Engineering News Report
EPA	United States Environmental Protection Agency
FS	Feasibility Study
ft	Feet
ft/s	feet per second
ft^2	Square Feet
GAC	Granular Activated Carbon
GRA	General Response Action
HALT	Hydrothermal Alkaline Treatment
IC #3	Intermittent Creek #3
IX	Ion Exchange
IX	Ion Exchange
LTM	Long-Term Monitoring
Max	Maximum
MCL	Maximum Contaminant Level
min	Minute
MPCA	Minnesota Pollution Control Agency
NFA	No Further Action
ODS	Oakdale Disposal Site
OPEX	Operating Expenditure
PAB	Permeable Adsorptive Barrier
PFAS	Per- and Polyfluoroalkyl Substances
PFBA	Perfluorobutanoic acid
PFBS	Perfluorobutanesulfonic acid
PFHxA	Perfluorohexanoic acid
PFHxS	Perfluorohexanesulfonic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctanesulfonic acid
RI	Remedial Investigation
SCWO	Supercritical Water Oxidation
SSC	Site-Specific Water Quality Criteria
WCL	Washington County Landfill

M1 Introduction

The Project 1007 Corridor is in the Twin Cities East Metro Area of St. Paul, Minnesota and is a large flood control project constructed by the Valley Branch Watershed District (VBWD) in 1987 to mitigate flooding in the landlocked sub-watershed of the Tri-Lakes area of the City of Lake Elmo. The conveyance system, consisting of open channels, pipes, dams, storm sewers, and existing surface water bodies, directs water from the Tri-Lakes area to the St. Croix River. As a result of the proximity of two historical PFAS disposal sites to Project 1007, this stormwater conveyance system may have facilitated the further migration of PFAS from the PFAS source areas of the Washington County Landfill (WCL) and Oakdale Disposal Site (ODS). In summary, the headwaters of Raleigh Creek, which flows into the Project 1007 conveyance system, are located immediately upstream of ODS. High PFAS concentrations have been observed in Raleigh Creek immediately downstream of ODS which continue to flow through the Project 1007 conveyance system into Eagle Point Lake. Although the Project 1007 conveyance system bypasses Lake Elmo, impacts from WCL have likely migrated through groundwater to discharge into Lake Elmo, which is predominantly groundwater fed. Impacts from the two source areas mix downgradient of Lake Elmo, resulting in the combined PFAS impacts flowing through West Lakeland and ultimately discharging into the Lower St. Croix River and St. Croix National Scenic Riverway managed by the National Park Service. The St. Croix River is classified as a Class 1B surface water body, determined by Minnesota Rule 7050.0470, which requires that the water quality be suitable to allow for the existence of aquatic biota and their habitats, be suitable for all types of aquatic recreation, and also protects surface waters as a drinking water source. The surface water pathway is shown in Table M.1. Along this pathway, infiltration of surface water to groundwater has likely facilitated a direct pathway from surface water to groundwater, resulting in widespread groundwater impacts including impacts to aquifers currently used for drinking water in the East Metro.

This Feasibility Study (FS) develops alternatives to address the PFAS impacts in the East Metro with a focus on the protection of drinking water aquifers. While surface water impacts can also pose risks to recreational users and ecological receptors, those receptors are not directly addressed with this FS. The Conceptual Site Model (Section 5 of the FS) and Appendix C (Project 1007 Remedial Investigation Report) discuss PFAS impacts across the Site and the dominant PFAS migration pathways including how surface water contributes to the impacts observed in the drinking water aquifers. The purpose of this appendix is to further evaluate potential treatment technologies for use in surface water at the Site that were screened in Section 9 of the FS, provide a conceptual design for the recommended technology with a high-level cost estimate, and recommend the next steps required for implementation.

The surface water impacts were divided into six areas of concern (AOCs) within the Site boundaries based on the surface water bodies and PFAS migration pathways. These, along with the groundwater and sediment AOCs, are described in detail in Section 7 of the FS. The surface water AOC numbers and descriptions are given in Table M.1. Locations and size of surface water AOCs are shown in Figure 159 (see Appendix A).

AOC 3 (ODS – Surface Water) was included in this FS because of its contributions to downgradient surface water PFAS impacts. However, remedial alternatives for ODS are not discussed in this FS as development of remedial alternatives for that source area will be considered as part of the superfund process at ODS, as ODS is currently managed under the MPCA Superfund Program. Site investigation and development of remedial alternatives at ODS was not within the scope of this FS. This FS assumes that Raleigh Creek will be routed around ODS and that PFAS impacted surface water will no longer be released from ODS. For this reason, AOC 3 is not discussed further in this appendix.

Table M.1: Project 1007 Surface Water Areas of Concern.

AOC	AOC Description
1	WCL – Surface Water and Shallow Groundwater
3	ODS – Surface Water
5	Raleigh Creek – Surface Water
6	Eagle Point Lake – Surface Water
8	Lake Elmo – Surface Water
9	Horseshoe Lake and West Lakeland – Surface Water

M1.1 Surface Water Site-Specific Water Quality Criteria

The MPCA has developed Site-Specific Surface Water Quality Criteria (SSC) for select PFAS to be protective of drinking water resources that are connected to surface water bodies (MPCA, 2023; MPCA, 2020). All of the surface water bodies within the Project 1007 conveyance system are considered Class 1 (beneficial use of domestic consumption) because of the infiltration of precipitation to aquifers used for domestic consumption (drinking water). SSC have been developed for perfluorobutanoic acid (PFBA), perfluorobutanesulfonic acid (PFBS), perfluorohexanoic acid (PFHxA), perfluorohexanesulfonic acid (PFHxS), perfluorooctanoic acid (PFOA), and perfluorooctanesulfonic acid (PFOS) (MPCA, 2023). Applicable SSC, as well as summarized PFAS data from Site surface water bodies are summarized in Table M.2. PFAS detections in surface water are described in detail in Section 5 of the FS and Appendix C.

Table M.2: MPCA Site-Specific Water Quality Criteria Applicable to Site Surface Water.

PFAS Species		PFOS (1)	PFOA (1)	PFHxS (1)	PFHxA (1)	PFBS	PFBA (1)
MPCA SSC (ng/L)		0.05	25	20	220	140	5700
AOC 1: Sunfish Lake	Mean	6.28	112	3.49	57.5	4.61	4700
	Max	18.0	189	1.93	92.4	7.56	7910
AOC 5: Raleigh Creek	Mean	1810	604	55.4	70.4	21.8	376
	Max	8810	2500	242	272	81.4	1290
AOC 6: Eagle Point Lake	Mean	544	121	12.8	16.2	6.30	148
	Max	5340	627	41.3	58.9	19.8	895
AOC 8: Lake Elmo	Mean	135	71.3	7.21	21.5	3.45	676
	Max	482	105	13.0	14.9	5.60	1170
AOC 9: Horseshoe Lake	Mean	150	78.8	8.57	15.2	4.15	575
	Max	74.8	253	17.3	28.9	9.51	1210
AOC 9: West Lakeland Ponds	Mean	163	73.5	9.27	13.5	4.30	403
	Max	736	193	14.5	22.7	7.16	961

(1) Bolded text indicates samples or averages exceeding the relevant SSC.

M1.2 AOC Evaluation

Section 11 of the FS details potential treatment options for each AOC based on the General Response Actions (GRAs) that were screened in Section 9 of the FS. Considerations of PFAS migration pathways were used to determine if treatment should occur in each AOC. As treatment in upstream AOCs will directly impact those downstream, active treatment in some AOCs was not further recommended. Long term monitoring of the following AOCs is recommended:

- AOC 1 includes both surface water and shallow groundwater at WCL and proposed actions focus on shallow groundwater rather than Sunfish Lake, as this will be more effective source zone control to reduce migration of impacts to the drinking water aquifers. Potential actions and a treatment train evaluation are discussed in Appendix J (Technology Analysis for Project 1007 Non-Drinking Water Treatment Alternatives). Treatment in AOC 1 is not discussed further in this appendix.
- AOC 6 (Eagle Point Lake) is fed by Raleigh Creek. Treatment within Raleigh Creek would limit the PFAS input into Raleigh Creek and likely result in a reduction in Eagle Point Lake PFAS concentrations.
- AOC 8 (Lake Elmo) has PFAS impacts resulting from groundwater discharge and intermittent flow from Eagle Point Lake. Addressing PFAS impacts in the groundwater will help limit this migration. Additionally, Lake Elmo is large and would require extensive treatment beyond what is technically or financially feasible for a decrease in PFAS to be observed.

Based on this screening of the AOCs, only AOC 5 (Raleigh Creek – Surface Water) and AOC 9 (Horseshoe Lake and West Lakeland – Surface Water) were further considered for surface water treatment. To be protective of AOC 9, treatment of the combined flow from Lake Elmo and Eagle Point Lake Dam could occur prior to discharge in Horseshoe Lake, or the two lake discharges could be treated separately. Based on Site visits, this appendix will assume that treatment of the combined flow downgradient of the discharge pipes from Lake Elmo and Eagle Point Lake Dam. Treatment on Raleigh Creek would likely occur downstream of the Anna's Grove Wetland Complex. This would allow for the treatment of PFAS that desorbs from the sediment impacts observed within the wetland areas closer to the discharge from ODS. Treatment closer to ODS is not recommended as the reroute of Raleigh Creek is assumed to occur. However, leaching from sediment is still expected to result in PFAS within Raleigh Creek when it flows into Project 1007 at Tablyn Park.

M1.3 Retained General Response Actions and Treatment Technologies

Section 9 of the FS and Appendix D (Remedial Technology and Action Screening: Detailed Descriptions and Analysis) screen General Response Actions (GRAs) as well as potential remedial technologies and their applicability to surface water, groundwater, and sediment AOCs. Retained surface water GRAs and technologies were:

- No Further Action (NFA)
- Long-Term Monitoring (LTM)
- Surface Water Hydrology Modifications – Flow Reduction at Eagle Point Lake Dam
- In-Situ Treatment – Permeable Adsorptive Barriers (PABs)
- Ex-Situ Treatment – Single-use Granular Activated Carbon (GAC)
- Ex-Situ Treatment – Reactivated GAC

- Ex-Situ Treatment – Regenerated GAC
- Ex-Situ Treatment – Foam Fractionation
- Ex-Situ Treatment – Single-use Ion Exchange (IX)
- Ex-Situ Treatment – Regenerable IX
- Ex-Situ Treatment – Destructive/Disposal Technologies
    - Landfilling, Incineration, Super-Critical Water Oxidation (SCWO), Hydrothermal Alkaline Treatment (HALT), electrochemical oxidation, plasma, photolysis & photochemical destruction

NFA and LTM are evaluated as part of the eight remedial alternatives discussed in Section 9 of the FS. NFA is included to compare taking no remedial actions to monitoring and active remediation. As NFA is included as one of the Site-wide alternatives (Alternative 1), it is not discussed further in this appendix. Similarly, LTM is a component of the majority of the Site-wide alternatives as treatment upgradient would impact downgradient PFAS impacts. This is discussed further in the development of alternatives in Section 9 of the FS and is not discussed further in this appendix.

Destructive and disposal technologies are applicable to the spent adsorptive media, concentrated PFAS streams, or waste stream(s) generated by in-situ or ex-situ treatment technologies. Ultimate disposal of a concentrated PFAS waste-stream is an important consideration for each of the in-situ and ex-situ treatment technologies and considerations may be different between surface water and groundwater derived waste streams. General considerations are discussed in Section 9 of the FS and Appendix D. Additionally, destructive technologies including results from bench-scale testing are evaluated further in Appendix G (Leachability Study for PFAS-Impacted Sediments for Project 1007 Bench-Scale Report). Thus, destructive and disposal technologies are not evaluated further in this appendix.

M1.4 Technology Evaluation

To evaluate technologies and their application to the Site, technologies were scored using a qualitative evaluation of their expected performance. Technologies were scored as 1 (low or poor), 2 (medium), or 3 (high or good), with higher scores indicating favorable performance in a category. For example, a technology that is scored a 3 for cost would be a lower cost alternative while a technology that is scored a 1 would be a higher cost alternative. Criteria and descriptions are listed below, along with a description of the 1 through 3 rankings as they relate to a criterion. A multiplication factor of 1 through 5 was then used to weight individual categories. At this stage of evaluation, technologies are scored independent of AOC; technologies with the highest scores are next evaluated by AOC for potential implementation.

- PFAS Mass Reduction: This criterion estimates the total mass of PFAS removed by a treatment technology. A score of 1 would indicate little to no PFAS is removed, while a score of 3 would indicate a large mass removal of PFAS is expected.
- PFAS Removal Efficiency: This criterion evaluated how efficiently PFAS is removed by an adsorptive media or the overall expected removal efficiency. This criterion differs from PFAS Mass Reduction by qualitatively evaluating the expected percent removal of a treatment technology as opposed to the total mass of PFAS removed. For this evaluation, only PFAS species with an MPCA SSC (PFBA, PFOA, PFBS, PFHxA, PFHxS, PFOS) are considered. A score of 1 would indicate low percent removal or low efficiency of removal, while a score of 3 would indicate a high percent removal or high efficiency of removal.
- Technological Readiness: This criterion considers how widely used a technology is currently, relative amount of time a technology has been used for full-scale PFAS treatment, ease of access to spare parts or replacement media, and technical feasibility of construction and operation. A

score of 1 would indicate low industry adoption and few, if any, full-scale installations, while a score of 3 would indicate a mature, widely used technology that has many full-scale installations.

- Implementability: This criterion evaluates potential challenges to implementation and considers how easily a technology could implemented at full-scale. A score of 1 indicates low implementability while a score of 3 represents high implementability.
- Space Requirements: Total amount of space needed to implement a treatment technology is considered by this criterion. A score of 1 indicates a large or significant amount of space is required, while a score of 3 indicates little to no space is required to implement a technology.
- Pretreatment Requirements: This criterion evaluates the expected pretreatment requirements for a treatment technology. As an AOC specific evaluation is not performed at this stage of evaluation, pretreatment for surface water in general is considered. A score of 1 indicates high levels of pretreatment expected for a technology while a score of 3 indicates low levels of treatment expected for a technology.
- Cost – CAPEX: This criterion evaluates the relative capital expenditure (CAPEX) required to install a treatment technology. A score of 1 would indicate the highest expected CAPEX cost while a score of 3 would indicate the lowest expected CAPEX cost.
- Cost – OPEX: This criterion evaluates the relative operating expenditure (OPEX) required to install a treatment technology. Relative energy use is considered as part of this criterion, as energy use relates directly to higher OPEX costs. A score of 1 would indicate the highest expected OPEX cost while a score of 3 would indicate the lowest expected OPEX cost.
- Maintenance Requirements: This criterion evaluates the expected relative frequency and difficulty of maintenance, the relative ease/difficulty of operating a treatment technology, and, where appropriate, considers the relative number of operators/technical staff required to operate and maintain a treatment technology installation. A score of 1 would indicate frequent and/or difficult maintenance, while a score of 3 would indicate very infrequent or easy maintenance.

Results from the scoring evaluation are summarized below in Table M.3. Details on relative scoring are provided in Table M.8. Of all options evaluated, in-situ PAB and foam fractionation scored the highest largely due to lower maintenance requirements, lower space requirements, lower cost, and higher implementability.

Table M.3: Qualitative Scoring of Surface Water Response Options.

		Treatment Technology							
Parameter	Weight	FR	PAB	SU GAC	React GAC	Reg GAC	FF	SU IX	Reg IX
PFAS Reduction	5	1	2	3	3	3	3	3	3
PFAS Removal Efficiency	5	1	2	2	2	2	2	3	3
Space Requirements	5	3	3	1	1	1	2	1	1
Technological Readiness	3	3	2	3	3	1	2	3	2
Implementability	5	1	3	1	1	1	2	1	1
Pretreatment	2	3	2	2	2	1	2	1	1
Cost - CAPEX	2	3	2	1	1	1	1	1	1
Cost - OPEX	2	3	2	1	2	1	2	1	1
Maintenance Requirements	2	2	2	1	1	1	2	1	1
Score (1)		61	72	54	56	46	65	57	54

Legend: FF = foam fractionation; FR = flow reduction (only implementable in AOC 6); React GAC = reactivated GAC; Reg GAC = regenerative GAC; Reg IX = regenerative IX; SU GAC = single-use GAC; SU IX = single-use IX.

(1) Bolded scores are retained for further evaluation.

Adsorptive treatment technologies (variation of GAC and IX treatment) scored lower overall despite high PFAS reduction and high PFAS removal efficiency scores. While these technologies would remove the most mass of PFAS from surface water, construction of a surface water treatment plant would be hampered by high cost, significant pretreatment needs, and low implementability. Additionally, Raleigh Creek and the outflow from Lake Elmo and Eagle Point Lake flow through residential areas. There are not large parcels of land easily available for construction of a surface water treatment plant. Intermittent flow would increase operational difficulty and space required for treatment; building a system to meet the maximum flow would result in a system overdesigned for all but the highest rainfall events. Alternatively, building a smaller system with storage capacity would require a large area to collect surface water during high flow events. While partial treatment of flow could be pursued, the main appeal of GAC and IX variation is their ability to remove a large mass of PFAS; partial treatment of flow could make justifying the cost of the treatment system more difficult. Due to these concerns, GAC and IX are not considered further.

Flow reduction at Eagle Point Lake Dam scored similarly to adsorptive media, largely due to increased ease of implementation and lack of cost associated with reducing flow at the Dam. However, while reducing flow at the Dam would decrease PFAS loading to the downgradient wetlands, no PFAS would be removed from the environment. PFAS would remain upstream of the Dam and would either infiltrate into the ground or remain in Eagle Point Lake. Upstream flooding is also a concern; floodwater could potentially spread PFAS contamination to other areas if not properly managed. If this were to be pursued, modeling would need to be performed to ensure flooding risk is minimized. As modeling is outside the scope of this appendix and this action is only relevant to one AOC, it is not discussed further as the potential reduction in PFAS loading is unlikely to be worth the increased flood risk.

Based on the scoring in Table M.3, foam fraction was retained for further evaluation for surface water treatment. However, foam fractionation treatment of surface water was evaluated during a pilot test using a Surface Active Foam Fractionation, or SAFF® treatment unit as part of the treatability testing performed for this project. As a result of treatability testing, foam fractionation was not recommended for surface water treatment across the Site; while effective at removing PFAS, implementation of foam fractionation is not expected to be achievable due to space constraints and ability to capture surface water, particularly during high flow events. For more information on the foam fractionation pilot study completed as part of this FS, see Appendix E (Surface Active Foam Fractionation (SAFF®) Pilot Study Report). Foam fractionation is not discussed further in this appendix.

M2 Permeable Adsorptive Barrier Preliminary Design

As the results from the technology screening in the previous section indicate, use of a PAB to reduce mass flux of PFAS through surface water AOCs could be a cost-effective method to decrease PFAS migration. This section provides a high-level design, cost estimate, and next steps for implementation of PABs.

M2.1 Location Selection

Based on the discussion in the AOC section above, two PAB locations were considered in this evaluation. PAB A would be installed in Raleigh Creek upstream of Tablyn Park to reduce PFAS mass loading to Eagle Point Lake (AOC 6) from ODS (AOC 3) via Raleigh Creek (AOC 5). PAB B would be installed at the outlet of the Eagle Point Lake diversion pipe on the southeast side of Lake Elmo. PAB B would treat PFAS-impacted water from Eagle Point Lake (AOC 6) and Lake Elmo (AOC 8), reducing mass loading of PFAS to surface water in Horseshoe Lake and West Lakeland (AOC 9). It is important to note reduction of PFAS migration through surface water AOCs will decrease PFAS mass loading to downgradient groundwater AOCs as well. Evaluated PAB locations are shown in Figure M.1.

Within each area, the PAB would be placed sufficiently downstream of culvert discharge points to prevent direct interception of high velocity flow which could displace media. High velocity flow conditions are expected to be more problematic during and immediately after snow melt and precipitation events. Additionally, the PABs would be placed across the widest point (locally) in a stream. Selecting a wider location would help prevent water from circumventing the PAB and help to manage overall flow velocity. Flow velocity would also be managed by installation of a weir and overflow channel to reduce flow velocity through the media during periods of high flow and prevent upstream flooding. While this would reduce the percentage of flow treated during high flow, it would reduce the risk of damage to the PAB during high flow events and improve treatment efficiency of the portion of water being treated during high flow events.

M2.2 Materials Selection

PABs can utilize different types of adsorptive media, with site-specific conditions dictating the preferred media. Preliminary design assumed use of AquaGate (AquaBlok) + Fluoro-Sorb® (Cetco) as this material is designed to have a higher hydraulic conductivity than other adsorptive media. These materials have also been used by AECOM previously in the full-scale design and installation of a PAB for PFAS treatment at another client site. Other media should be evaluated during the design phase with final selection dependent on ability of a media to adsorb PFAS, available porosity/flow characteristics, and resistance to fouling. However, for the purposes of cost estimating with this appendix, AquaGate + Fluoro-Sorb® is considered as pricing was readily available for the materials.

AquaGate + Fluoro-Sorb® is a composite-aggregate technology comprised of AquaGate, an aggregate material at the core that can facilitate high flow through the material, and Fluoro-Sorb®, and adsorbent designed to remove PFAS. The standard aggregate used in AquaGate is #8 aggregate, as graded by the American Association of State Highway and Transportation Officials (AASHTO #8) (AquaBlok, 2022). This aggregate is then coated at 15% to 30% by weight with Fluoro-Sorb®, a surface modified clay designed specifically to remove PFAS from water. Fluoro-Sorb® has been used previously to treat all PFAS with an SSC, with the best removal observed with the long-chain PFAS (Cetco, 2021; Cetco, 2024). The overall permeability of AquaGate + Fluoro-Sorb® particles is 0.01 to 1 centimeters per second (cm/s), or 0.0003 to 0.03 feet per second (ft/s). The dry bulk density is 75-85 pounds per cubic foot (AquaBlok, 2022).

M2.3 Flow Data Collection

Surface water data was collected as part of Site investigation, including near the two locations for proposed PAB installation. Beginning in October 2020 flow was measured intermittently using a staff gauge installed at Raleigh Creek (termed Intermittent Creek #3 or IC#3) and a staff gauge installed downgradient of Lake Elmo (termed Downgradient #1 or DG #1). Results are summarized in Table M.4. Flow rates were calculated using the staff gauge data; minimum, geometric mean, and maximum (max) results are given in Table M.4. Photos of the two locations are given in Figure M.2 (IC #3) and Figure M.3 (DG #1).

Table M.4: Staff Gauging Results and Corresponding Flow Rate.

Parameter		Raleigh Creek	Lake Elmo Downgradient
Abbreviation		IC #3	DG #1
PAB Name		PAB A	PAB B
Flow Type		Intermittent	Continuous
Flow Data Collection Date Range		October 2020 to August 2022	August 2020 to May 2021
Total Number of Gauging Events		12	6
Number of Excluded Events (Outliers or Measurement Errors)		5	0
Width (feet)	Minimum	5.5	18
	Geometric Mean	8.1	23
	Maximum	9.0	29
Water Depth (feet)	Minimum	0.10	0.6
	Geometric Mean	0.80	1.2
	Maximum	1.7	2.3
Total Discharge (cubic feet per second)	Minimum	1.5	0.40
	Geometric Mean	4.9	4.6
	Maximum	12	12

M2.4 Conceptual Design

This conceptual design utilizes a gravity-fed system for the PABs. This would eliminate the need for pumps and associated piping and electrical, simplifying the design and decreasing the cost of installation. The use of a gravity-fed system has been demonstrated by existing AECOM projects with one such project shared publicly at the Battelle Chlorinated Solvents Conference in 2022 (Cuthbertson, 2022). This approach was also shared in a design presented at the Battelle Chlorinated Solvents Conference in 2024 (Shores, 2024).

Two of the most critical design parameters are contact time and flow rate. Contact time between the media and surface water will affect the amount of PFAS removed, with contact times of 5 to 30 minutes preferred (AquaBlok, 2024). Flow rate must also be considered, because if the flow rate exceeds the permeability of a material, upstream ponding or bypass of the media is likely to occur. Permeability of the AquaGate with Fluoro-Sorb® is 0.0003 to 0.03 ft/s. For the purposes of this initial design, a permeability of 0.03 ft/s was assumed and used as the velocity through the media. This was determined to be acceptable after discussions with the vendor as higher permeabilities have been observed (AquaBlok, 2024). Further evaluation is needed to verify this design assumption.

A conceptual design for the in-stream PABs is shown in Figure M.4 (section view) and Figure M.5 (plan view). This preliminary design assumes a multi-cell system with a coarse screen and removable pretreatment to extend the life of the adsorptive media. Concrete housings for the adsorbent and pretreatment cells are assumed to increase ease of media changeout. To increase the volume of media and thus the contact time, treatment cells are expected to extend below the grade of the streambed. Full treatment of flow at peak flow is not expected to be practical or technically feasible, thus an overflow channel is included in preliminary design. An overflow channel would prevent upstream flooding during periods of high flow and could be controlled using an adjustable weir. The overflow channel could also be designed such that when maintenance is required on the PAB (e.g. pretreatment media cleaning or replacement or adsorptive media replacement), the weir could be removed to divert the entire flow around the PAB, allowing for maintenance to occur without requiring no stream flow.

Minimum and mean volumetric discharges were used to evaluate velocity through adsorptive media for both PABs based on preliminary designs. Evaluation included variation of the treatment cell length, PAB/treatment cell width, and treatment cell depth were also evaluated. Flow rate through the cell was calculated by using the assumed permeability of the media (0.03 ft/s) and the surface area of the treatment cell. Note that the treatment cell length is one-half the total length of the treatment cell. Considered treatment cell lengths were 3, 4, 5, and 6 feet. Design width was also varied in this evaluation, with the width varying based on the widest measured width of the channel. For PAB A (IC #3), the maximum width measured and thus the narrowest width considered was 9 feet. For PAB B (DG #1), the maximum width was measured 23 feet, thus the narrowest width considered was 23 feet. Widths of 10 feet to 18 feet were also considered for PAB A in increments of 1 foot to increase the surface area of the PAB, though this would require removal of bank on either side of the stream. Similarly, widths up to 36 feet were considered for PAB B[1]. Required flow rates to treat all flow for a specific length and width are summarized in Table M.9 (IC #3) and Table M.10 (DG #1) along with the expected percentage of flow that would actually receive treatment (assuming a maximum velocity through the media at 0.03 ft/s).

PAB width and cell length determine the surface area through which water can flow. Results in Table M.9 and Table M.10 demonstrate that at mean volumetric stream flow, a PAB wider than the stream channel would be necessary to treat all water. No cell length and PAB width considered could treat the maximum flow, though this is expected due to the high variation between mean and maximum flow. While a longer cell length could be used to increase surface area within the existing channel footprint, uneven flow loading could be experienced at longer cell lengths. Additionally, increased cell lengths would increase the weight of each cell, increasing difficulty of installation and removal. A cell length of six feet was assumed to be the upper limit of size, though this assumption would require validation prior to full-scale design.

For PAB A (IC #3), no combination considered could treat all flow at mean flow, with a maximum of 86% of mean flow expected to be treated at a width of 18 feet width and a cell length of 6 feet. For PAB B (DG #1), 100% of mean flow would be treated at a width of 31 feet and a cell length of 5 feet. Contact time is the same for both PABs when less than 100% of the flow is treated by the PAB. Because the flow velocity through the media is identical, only the percentage of flow through the PAB varies while the contact time remains the same. Contact time only changes as the media depth changes. Contact time at a depth of 3 feet corresponds to a 3 minute and 20 second contact time, a depth of 4 feet corresponds

---

[1] For the purposes of this evaluation, treatment cells were assumed to span the entire stream, though at full-scale design, treatment cells would likely be broken into smaller sections of flow to increase ease of removing media. If desired, gate valves could be incorporate to allow operation of the PAB while maintenance activities occurred, though the increase in cost to incorporate valves may not justify the reduction in downtime, particularly if maintenance activities were performed during periods of low flow.

to a 4 minute and 27 second contact time, a depth of 5 feet corresponds to a 5 minute and 33 second contact time, and a depth of 6 feet corresponds to 6 minute and 40 second contact time. Three cells with a 6-foot depth were assumed for the purpose of this design, though the final number of cells requires more analysis. The total estimated contact time for PABs is 20 minutes at mean flow, with 86% of mean flow treated by PAB A and 100% of mean flow treated by PAB B. These dimensions were used for a high-level cost analysis and are summarized in Table M.5.

Table M.5: Assumed Design Parameters for Conceptual PABs.

Parameter	PAB A (IC #3)	PAB B (DG #1)
Width (feet)	18	31
Cell Length (feet)	6	5
Surface Acre (ft^2)	108	155
Flow Treated at Mean Flow	86%	100%
Cell Depth (feet)	6	6
Contact Time per cell (min)	6.67	6.67
Number of Cells	3	3
Total Contact Time (min)	20	20
Volume Media per Cell (cy)	48	69
Total Media (cy)	144	207

Legend: cy = cubic yards; ft^2 = square feet; min = minute.

M2.5 Cost Estimate

Preliminary CAPEX estimates were prepared for the two PABs considered in this appendix. Unit cost estimates reflect the opinion of AECOM of probable construction costs utilizing information available at the time the document was prepared. A unit cost of $1500/cy was assumed for adsorptive media, though final media selection will impact this cost.

AECOM has based the unit costs on AACE Class V estimating guidance. This opinion of probable costs is based on conceptual design and the basis of estimate summarized in this report. All costs were developed in September 2024 dollars based on the Engineering News Report (ENR) Building Cost Index for Minneapolis. All project descriptions and cost estimates in this report represent planning-level accuracy and opinions of costs (-50%, +100%).

The estimated unit cost includes the sum of materials, labor, and equipment of reasonably identified features of a project. The estimated total project cost is the sum of construction costs with additional allowances for direct and indirect costs and contingencies. The engineering costs include design and surveying.

The following additional direct and indirect costs and contingencies were included while developing costs:

- Direct:
  - Mobilization and Site Setup (5%)
  - Bonding and Insurance (3%)
- Indirect:
  - Contractor Overhead and Profit (15%)

  - Engineering and Construction Contingencies (45%)

CAPEX estimates are given in Table M.6.

Table M.6: CAPEX Estimates for Conceptual PABs.

Parameter	PAB A	PAB B
Site Survey	$10,000	$10,000
Site Clearing & Excavation	$50,000	$75,000
Concrete & Overflow/ Treatment Cell Structure	$250,000	$350,000
Pretreatment	$50,000	$75,000
Media Cost	$216,000	$310,000
Engineering Design	$250,000	$300,000
Subtotal	$826,000	$1.120,000
Mobilization & Setup (5%)	*$41,000*	*$56,000*
Bonding & Insurance (3%)	*$25,000*	*$34,000*
Contractor Overhead & Profit (15%)	*$124,000*	*$168,000*
Engineering & Construction Contingency (45%)	*$372,000*	*$504,000*
Total	$1,388,000	$1,882,000

OPEX were also estimated and are provided in Table M.7. OPEX estimates assume yearly media replacement, monthly screen cleaning (April to November), labor for the media replacement, and media disposal. Additional maintenance, more frequent media changeouts, selection of an alternate media, or alternate disposal method could impact estimated OPEX costs.

Table M.7: Estimated OPEX costs.

Parameter	PAB A	PAB B	**Assumptions**
Screening Cleaning	$16,000	$16,000	Monthly Cleanings April to November at $2000 per trip
Media Replacement	$216,000	$310,000	Yearly Replacement
Media Changeout Labor	$50,000	$75,000	Includes Crane Rental
Media Disposal	$20,000	$30,000	Assumes Landfilling at $310 per ton and a bulk density of 2700 pounds per cy
Contingency	*$50,000*	*$50,000*	
Total	$352,000	$481,000	

M2.6 Implementation Challenges

There are several challenges to implementation that must be considered prior to pursuing full-scale design. First, access to PAB locations presents feasibility challenges. There is limited area outside of the stream bed to stage or install equipment, which could result in more site preparation. It is possible this could require an environmental impact study prior to vegetation or tree removal, or for more intensive rehabilitation. Additionally, privately owned land may need to either be purchased or an easement put in place. Consultation with the VBWD and a more thorough review of available land prior to full-scale design would be essential.

The flood risk along the stream is also not well defined. In lieu of additional stream flow data, overdesign of the bypass channel may be required to protect system infrastructure. Alternatively, designing the system such that it could be submerged in event of a high flow event/flood could improve system resiliency, but the potential impact on design and cost is unknown at this time.

M3 Conclusions and Recommendations

Initial screening of treatment technologies in Section 9 of the FS indicated many possible in-situ and ex-situ treatment technologies that could be applied for treatment of surface water AOCs. However, after additional screening and evaluation, only in-situ PABs were retained as a potential treatment technology. Two locations were identified as part of the Site-wide alternatives development for surface water treatment to provide protection of downstream water bodies and to reduce migration of PFAS into drinking water aquifers. This appendix presents a high-level design and cost estimate that is intended only for capital planning purposes.

As discussed in the preliminary design of the PABs, neither PAB proposed in this appendix could treat full flow at maximum recorded flow rates, and only PAB B would treat all flow at the expected mean observed flow rate. It is likely that some amount of flow would bypass PABs after most precipitation events. Ideally, all surface water would be treated; however, as discussed earlier in this appendix, this is not technologically practical without much greater CAPEX and OPEX costs. This option can also be easily decommissioned when surface water monitoring shows that source zone treatment has effectively reduced PFAS concentrations and surface water treatment is no longer required for the protection of drinking water aquifers. Prioritization of source zone control is essential to reduce mass flux to surface water in the first place. Compared to other treatment alternatives, PABs are lower cost, and it is expected that PABs could be deployed much more quickly than a full-scale treatment system, allowing for PFAS removal from the environment to begin much sooner. Use of PABs as an interim control measure would provide a valuable tool in decreasing PFAS mass flux through surface water AOCs while additional remedial measures are installed at source zones.

Recommended next steps to work towards a full-scale design include:

- Completion of a Site survey to establish area elevations, including height of the stream bank.
- Additional flow measurements and a more detailed hydraulic analysis including seasonal flow modeling.
- Initial permitting discussions with the VBWD and other pertinent regulators to discuss potential designs. This is particularly important as modifications to the stream channels will be required to install a PAB, and limits to what regulators would allow could heavily influence final design.
- Pretreatment methods and requirements should also be further analyzed to maximize lifetime of the media and decrease labor required to maintain pretreatment.
- Evaluation of permeability of the media with Site-specific water to better understand the permeability of the media that can be expected after installation. If permeability is determined to be too low, evaluation of methods of increasing permeability would also be recommended.

These recommended next steps are likely to reduce uncertainties during full-scale design and improve outcomes of full-scale implementation.

M4 References

AquaBlok, 2024. Email communication of material unit costs.

AquaBlok, 2023. AquaGate + Fluoro-Sorb® Spec Sheet. Available: https://static1.squarespace.com/static/5c5503db4d546e22f6d2feb2/t/664b7c223c3a4f25ecb00542/1716223011054/AG%2BFluoro-Sorb+Spec+Sheet+-+May+2023.pdf.

Cetco, 2021. Adsorption of per-and polyfluoroalkyl substances (PFAS) on Fluoro-Sorb®: Adsorption capacity at high PFAS concentrations. Technical Reference FS-104 [Online]; New York, 2021. Available: fs-104-fluoro-sorb-200-adsorption-capacity-high-pfas-9-1-21.pdf (mineralstech.com).

Cetco, 2024. Stability of PFAS in spent Fluoro-Sorb® 200 adsorbent: Leaching of PFAS using three EPA protocols. July, 2024. Available: https://www.mineralstech.com/docs/default-source/performance-materials-documents/cetco/water-and-remediation/technical-references/fs-109-stability-of-pfas-in-spent-fluoro-sorb-adsorbent.pdf?sfvrsn=4d8cb7ba_6.

Cuthbertson, C., 2022. Passive Treatment of PFAS-Impacted Stormwater [Conference Presentation], AECOM, 2022 (May 22-26). Twelfth International Conference on Remediation of Chlorinated and Recalcitrant Compounds.

Minnesota Pollution Control Agency (MPCA), January 2023. Water Quality Standards: Human Health Protective Water Quality Criteria for Per- and Polyfluoroalkyl Substances (PFAS). Available: https://www.pca.state.mn.us/sites/default/files/wq-s6-63.pdf.

Minnesota Pollution Control Agency (MPCA), December 2020. Water Quality Standards Technical Support Document: Human Health Protective Water Quality Criteria for Perfluorooctane Sulfonate (PFOS). Available: https://www.pca.state.mn.us/sites/default/files/wq-s6-61a.pdf.

Powell, R.M.; Powell, P.D.; Puls, R.W.; Burden, D.S., 2002. Economic Analysis of the Implementation of Permeable Reactive Barriers for Remediation of Contaminated Ground Water. (EPA/600/R-02/034). Environmental Protection Agency. Available: https://nepis.epa.gov/Exe/ZyNET.exe/30002J70.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2000+Thru+2005&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C00thru05%5CTxt%5C00000006%5C30002J70.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL.

Shores, C., 2024. Time-Critical Gravity-Powered PFAS Remediation of Groundwater Seeps [Conference Presentation], Geosyntec Consultants, 2024, (June 2-6). Thirteenth International Conference on Remediation of Chlorinated and Recalcitrant Compounds.

M5 Figures

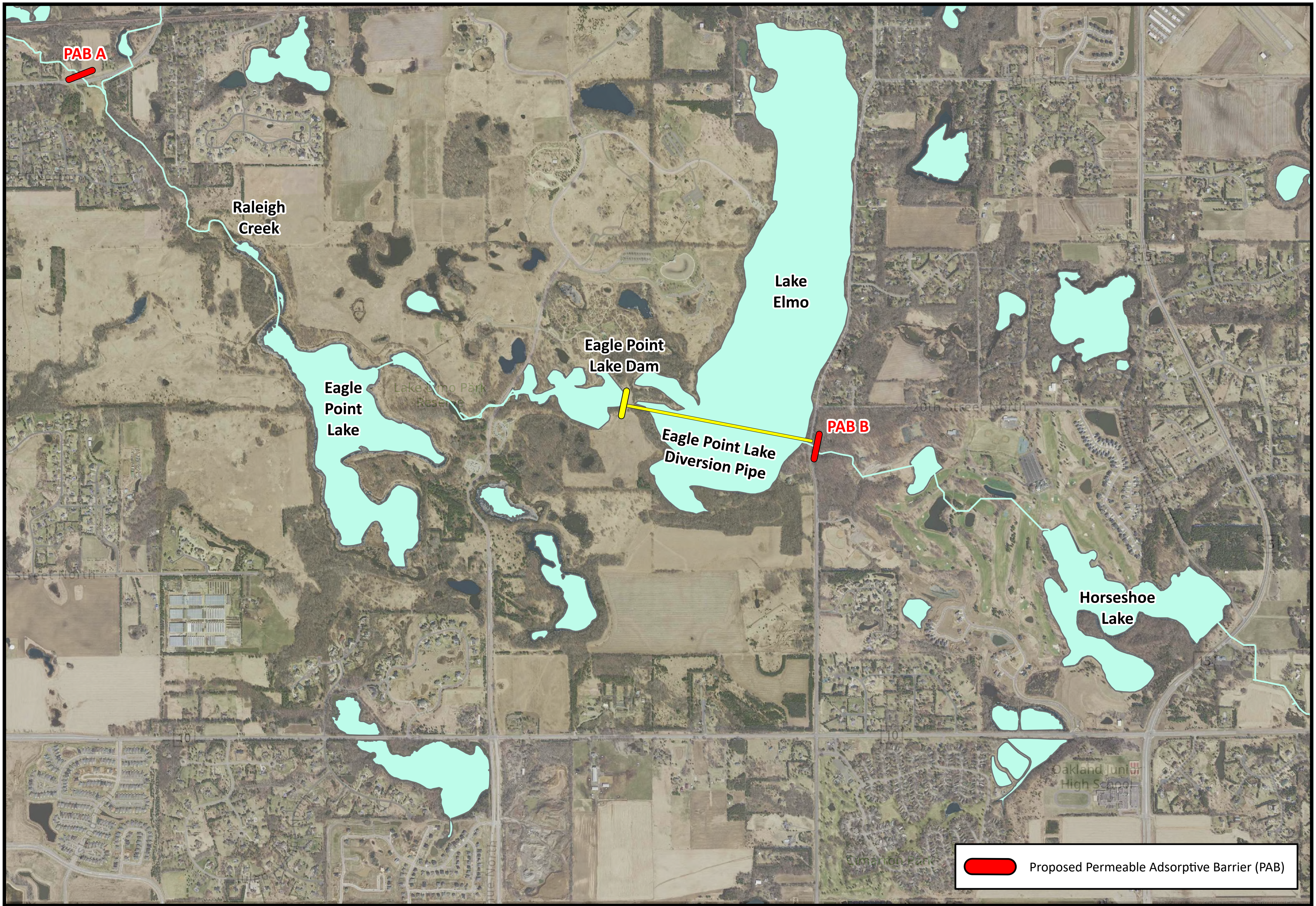

Figure M.1: Proposed Permeable Adsorptive Barrier Locations
Project 1007 Feasibility Study

MINNESOTA POLLUTION CONTROL AGENCY

AECOM

Figure M.2: IC #3 (Raleigh Creek) field observations and potential PAB footprint (outlined in red).

Figure M.3: DG#1 (Lake Elmo discharge) field observations and potential PAB footprint (outlined in red).

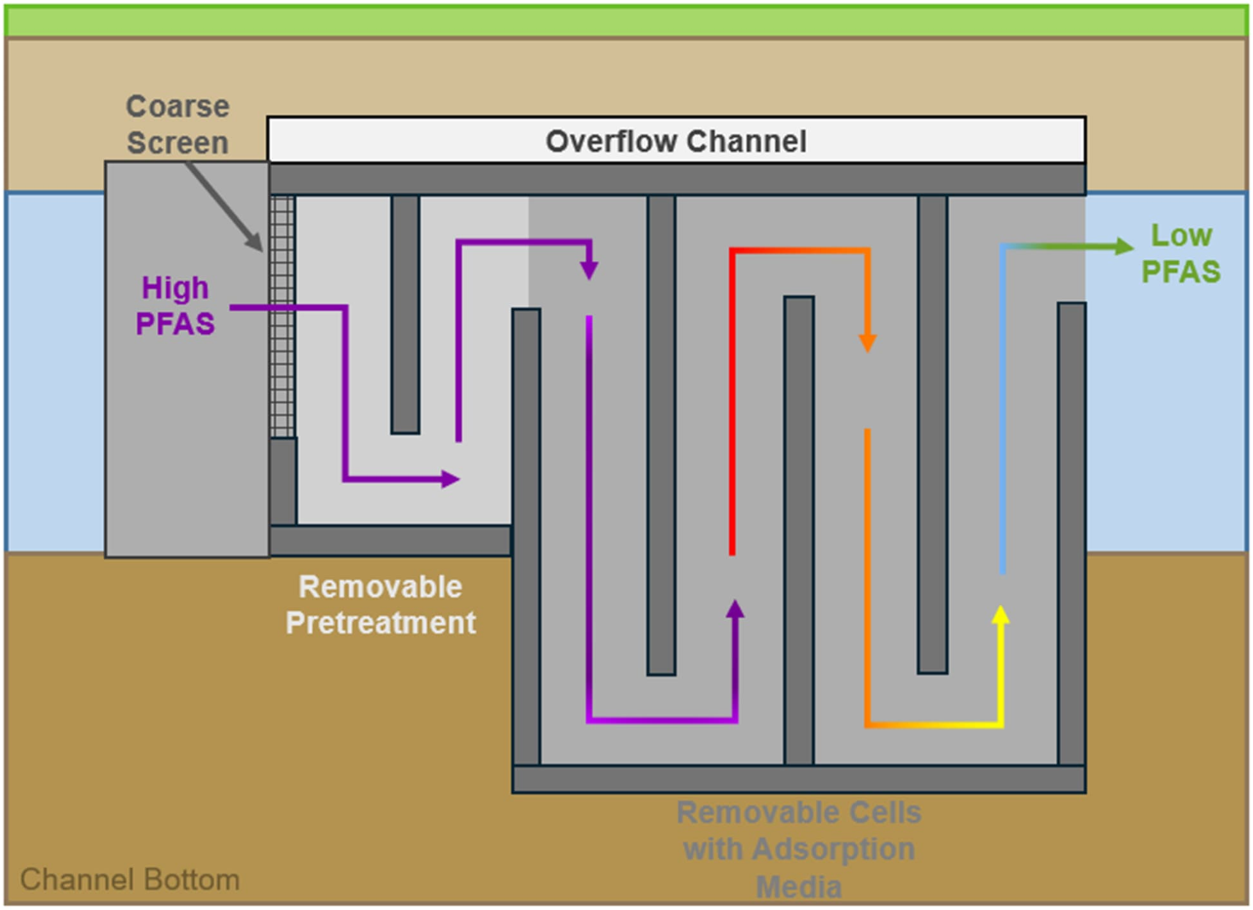

Figure M.4: Section view of conceptual in-stream PAB design. Overflow would be controlled by an adjustable weir. Additional cells could be installed as required to increase contact time or increase treatment capacity.

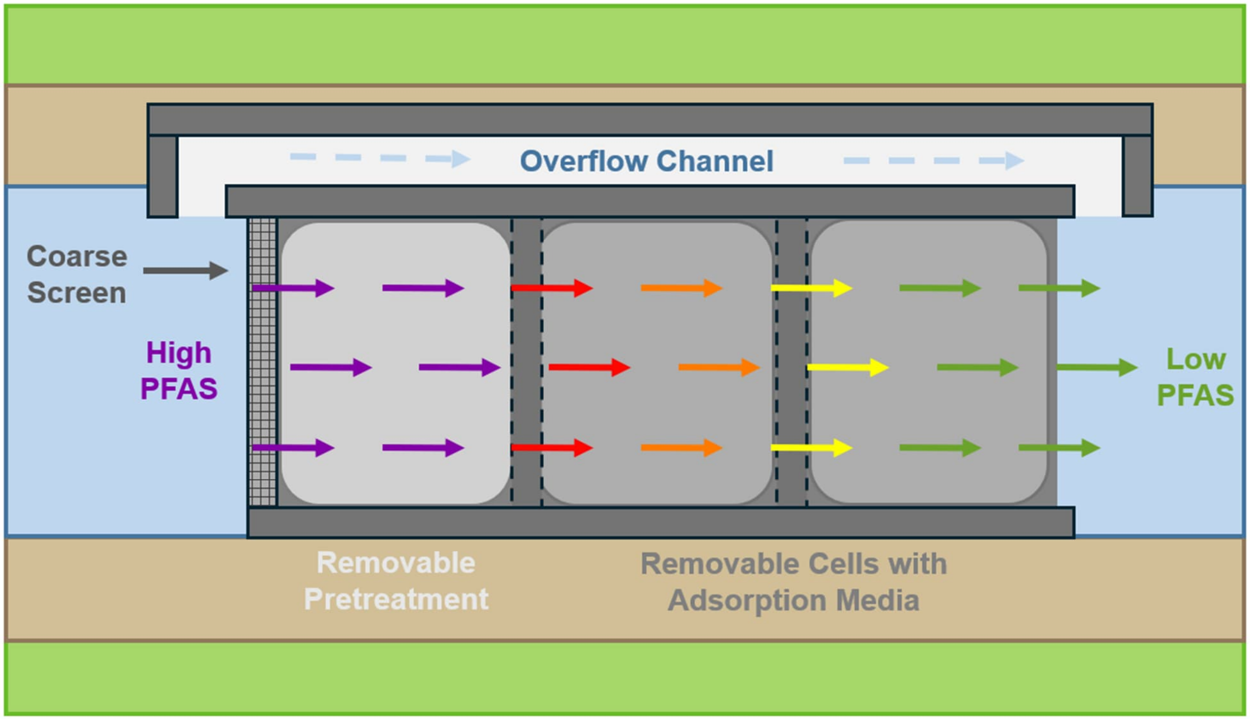

Figure M.5: Plan view of conceptual in-stream PAB design. Overflow would be controlled by an adjustable weir. Additional cells could be installed as required to increase contact time or increase treatment capacity.

M6 Additional Tables

Table M.8: Detailed Scoring of Surface Water Response Options.

Treatment Technology	No Further Action (NFA)	Long-Term Monitoring (LTM)	Surface Water Hydrology Modifications – Flow Reduction at Eagle Point Lake (EPL) Dam	In-Situ: Permeable Adsorptive Barrier (PAB)	Ex-Situ: Single-Use GAC	Ex-Situ: Reactivated GAC	Ex-Situ: Regenerated GAC	Ex-Situ: Foam Fractionation	Ex-Situ: Single-Use IX	Ex-Situ: Regenerable IX
Relative Mass PFAS Reduction	1 - NFA will not remove any PFAS from surface beyond natural hydrologic processes.	1 - LTM will not remove any PFAS from surface beyond natural hydrologic processes.	1 - No PFAS would be removed from the environment by this alternative, thus mass of PFAS reduction is low.	2 - PABs are expected to require a bypass channel for periods of high flow (large storm, snow melt). Not all water would be treated with PABs; thus, relative mass removal would be moderate.	3 - Single-use GAC treatment of surface water would be expected to remove a large mass of target PFAS from the treated surface water.	3 - Reactivated GAC treatment of surface water would be expected to remove a large mass of PFAS from the treated surface water.	3 - Regenerated GAC treatment of surface water would be expected to remove a large mass of PFAS from the treated surface water.	3 - Foam fractionation treatment of surface water would be expected to remove a large mass of PFAS from the treated surface water.	3 - Single-use IX treatment of surface water would be expected to remove a large mass of PFAS from the treated surface water.	3 - Regenerable IX treatment of surface water would be expected to remove a large mass of PFAS from the treated surface water.
PFAS Removal Efficiency	1 - NFA will not remove any PFAS from surface beyond natural hydrologic processes, thus removal efficiency is low.	1 - LTM will not remove any PFAS from surface beyond natural hydrologic processes, thus removal efficiency is low.	1 - No PFAS would be removed from the environment by this alternative, thus removal efficiency is low.	2 - PAB removal efficiency will depend on contact time, with higher removal efficiencies at periods of lower flow. Overall removal efficiency is expected to be moderate.	2 - Single-use GAC will remove long-chain PFAS species at high removal efficiencies but will be much less efficient at removing short-chain PFAS. Targeting short-chain PFAS would require more frequent media changeouts.	2 - Reactivated GAC will remove long-chain PFAS species at high removal efficiencies but will be much less efficient at removing short-chain PFAS. Targeting short-chain PFAS would require more frequent media changeouts.	2 - Regenerated GAC will remove long-chain PFAS species at high removal efficiencies but will be much less efficient at removing short-chain PFAS. Targeting short-chain PFAS would require more frequent media changeouts.	2 - Foam Fractionation will remove long-chain PFAS species at high removal efficiencies but will be much less efficient at removing short-chain PFAS. Chain lengths of less than 6 carbons will demonstrate minimal removal.	3 - Single-use IX would remove both long- and short-chain PFAS with high removal efficiencies. Complete removal of short-chain PFAS may require more frequent media changeout.	3 - Regenerable IX would remove both long- and short-chain PFAS with high removal efficiencies.
Impact on Downgradient Communities	1 - NFA will not reduce PFAS mass loading to downgradient communities, likely increasing drinking water treatment costs in communities as they continue to be impacted by PFAS.	1 - LTM will not reduce PFAS mass loading to downgradient communities, likely increasing drinking water treatment costs in communities as they continue to be impacted by PFAS.	1 - While reducing flow could reduce PFAS loading to downgradient communities, no PFAS is removed. Migration of PFAS from EPL surface water to groundwater could still impact communities in the future.	2 - PABs are unlikely to remove all PFAS from surface water, but decreased PFAS loading to downgradient communities will have a moderate benefit to those communities.	3 - Single-use GAC would be expected to reduce PFAS concentrations in treated surface water to below Site-Specific Water Quality Criteria.	3 - Reactivated GAC would be expected to reduce PFAS concentrations in treated surface water to below Site-Specific Water Quality Criteria.	3 - Regenerated GAC would be expected to reduce PFAS concentrations in treated surface water to below Site-Specific Water Quality Criteria.	2 - Foam fractionation is expected to meet long-chain PFAS Water Quality Criteria but may not meet short-chain PFAS water quality criteria.	3 - Single-use IX would be expected to reduce PFAS concentrations in treated surface water to below Site-Specific Water Quality Criteria.	3 - Regenerable IX would be expected to reduce PFAS concentrations in treated surface water to below Site-Specific Water Quality Criteria.
Space Requirements	3 - NFA does not require any space.	3 - LTM does not require any space.	3 - Flow reduction would not require any space for additional infrastructure.	3 - PABs could be installed in-stream and would not require a significant amount of space.	1 - A single-use GAC treatment plant would require a large amount of space, including sufficient space for semi-truck access to facilitate GAC changeouts.	1 - A reactivated GAC treatment plant would require a large amount of space, including sufficient space for semi-truck access to facilitate GAC changeouts.	1 - A regenerated GAC treatment plant would require a large amount of space, including sufficient space for semi-truck access to facilitate GAC regenerations. Setbacks for solvent usage may also be required.	2 - A foam fractionation treatment site would require space for 1 or more shipping containers.	1 - A single-use IX treatment plant would require a large amount of space, including sufficient space for semi-truck access to facilitate IX changeouts.	1 - A single-use IX treatment plant would require a large amount of space, including any required setbacks for solvent handling to operate the regeneration system.

Treatment Technology	No Further Action (NFA)	Long-Term Monitoring (LTM)	Surface Water Hydrology Modifications – Flow Reduction at Eagle Point Lake (EPL) Dam	In-Situ: Permeable Adsorptive Barrier (PAB)	Ex-Situ: Single-Use GAC	Ex-Situ: Reactivated GAC	Ex-Situ: Regenerated GAC	Ex-Situ: Foam Fractionation	Ex-Situ: Single-Use IX	Ex-Situ: Regenerable IX
Technological Readiness	3 - NFA does not include a technology, thus technological readiness is high.	3 - Laboratory testing for PFAS is widely used and has been used on this project extensively; technological readiness is high.	3 - Changing the level of the EPL Dam requires no additional technology, thus readiness is high.	2 - PABs have been used historically to control contaminant plumes. In-stream application for PFAS remediation is not widely used, though several systems have been installed. Technology readiness is moderate.	3 - Single-use GAC is widely used and multiple vendors exist. Technology readiness is high.	3 - Reactivated GAC is widely used and multiple vendors exist. Technology readiness is high.	1 - On-site regeneration of GAC for PFAS remove is in development, but neither infrastructure nor vendors are in place to utilize this technology at this time.	2 - Several foam fractionation vendors have products on the market, and use is expanding. Widespread adoption has not happened though; thus, technological readiness is moderate.	3 - IX resin is widely used; technology readiness is high.	2 - Regenerable IX is not widely used, though several full-scale installations are in operation or under construction.
Implementability	3 - By definition, NFA requires no additional action, thus is readily implementable.	3 - Sampling has already been widely performed across the Site, thus LTM is easily implementable.	2 - While changing the EPL Dam level is readily implementable, modeling would be needed to evaluate the impact to EPL and the potential for upstream flooding.	3 - PABs are expected to be readily implementable and could likely be installed significantly more quickly than other treatment technologies.	1 - Single-use GAC is not expected to be implementable due to space requirements and cost.	1 - Reactivated GAC is not expected to be implementable due to space requirements and cost.	1 - Regenerated GAC is not expected to be implementable due to space requirements, safety concerns over solvent use during regeneration, and cost.	2 - Foam fractionation is expected to be implementable but may have challenges with treating full flow and space required for a foam fractionation system.	1 - Single-use IX is not expected to be implementable due to space requirements, potential for media fouling, and cost.	1 - Regenerable IX is not expected to be implementable due to concerns of space requirements, media fouling, safety concerns over solvent usage, and cost.
Pretreatment	3 - NFA requires no pretreatment.	3 - LTM requires no pretreatment.	3 - Flow reduction would require no pretreatment.	2 - Adsorptive media used in PABs is expected to require moderate levels of pretreatment to extend media life. Manual backwashes of pretreatment could be required.	2 - Single-use GAC would require pretreatment to remove large particles, but automatic backwashing of GAC could extend GAC life and decrease pre-treatment needs.	2 - Reactivated GAC would require pretreatment to remove large particles, but automatic backwashing of GAC could extend GAC life and decrease pre-treatment needs.	1 - Regenerated GAC would require more extensive pretreatment than other GAC media as media is not replaced once active sites are exhausted and regeneration may not remove NOM contamination.	2 - Foam fractionation is expected to require moderate pretreatment to remove large particles, though NOM can improve PFAS removal performance, decreasing pretreatment needs.	1 - IX resin would require extensive pretreatment to reduce the risk of media fouling from NOM.	1 - Regenerable IX resin would require extensive pretreatment to reduce the risk of media fouling from NOM.
Cost - CAPEX	3 - NFA requires no direct CAPEX spend.	3 - NFA requires no direct CAPEX spend.	3 - Flow reduction using the EPL Dam would require no CAPEX spend.	2 - PABs are expected to be moderate in CAPEX cost.	1 - A single-use GAC treatment plant is expected to have a relatively high cost.	1 - A reactivated GAC treatment plant is expected to have a relatively high cost.	1 - A regenerated GAC treatment plant is expected to have a relatively high cost.	1 - A foam fractionation treatment plant is expected to have a relatively high cost.	1 - A single-use IX treatment plant is expected to have a relatively high cost.	1 - A regenerable IX treatment plant is expected to have a relatively high cost.
Cost - OPEX	3 - NFA requires no direct OPEX spend.	3 - LTM OPEX costs would include labor to collect samples and analyze data as well as sample cost. Total OPEX would be relatively low.	3 - Flow reduction using the EPL Dam would require minimal OPEX spend. There would be some minimal cost to adjust Dam levels, but this is not expected to be significant.	2 - PABs would require adsorptive media and pre-filter cleaning at some interval. Expected OPEX cost is moderate.	1 - Single-use GAC is typically used for drinking water and has a high price point. Expected OPEX cost is high.	2 - Reactivated GAC has a lower price point than single-use GAC, thus expected OPEX is moderate.	1 - Regenerated GAC is expected to have a high operating cost due to high cost of regenerating the GAC.	2 - Foam fractionation requires minimal operational inputs, thus operating cost is expected to be moderate.	1 - Single-use IX is expected to have a high operational cost due to increased pretreatment needs and potential early media replacement due to fouling.	1 - Regenerative IX is expected to have a high operational cost due to increased pretreatment needs and potential early media replacement due to fouling.

Treatment Technology	No Further Action (NFA)	Long-Term Monitoring (LTM)	Surface Water Hydrology Modifications – Flow Reduction at Eagle Point Lake (EPL) Dam	In-Situ: Permeable Adsorptive Barrier (PAB)	Ex-Situ: Single-Use GAC	Ex-Situ: Reactivated GAC	Ex-Situ: Regenerated GAC	Ex-Situ: Foam Fractionation	Ex-Situ: Single-Use IX	Ex-Situ: Regenerable IX
Maintenance Requirements	3 - NFA requires no direct maintenance.	3 - LTM requires no direct maintenance.	2 - Changing the EPL Dam level is not expected to increase maintenance, however increasing the water level in EPL could lead to upstream flooding.	2 - PABs may require manual cleaning of pretreatment screens at some interval; over maintenance is expected to be moderate.	1 - While GAC systems can operate without direct oversite, the potential for intermittent flow and higher levels increase the risk of fouling, requiring more operational oversite.	1 - While GAC systems can operate without direct oversite, the potential for intermittent flow and higher levels increase the risk of fouling, requiring more operational oversite.	1 - While GAC systems can operate without direct oversite, the potential for intermittent flow and higher levels increase the risk of fouling, requiring more operational oversite.	2 - Foam fractionation systems are expected to require some maintenance and operational oversite but are not expected to require a full-time operator.	1 - IX resin would require considerable oversite to monitor for pressure increases which can indicate media fouling as well as other operational issues. Expected maintenance is high.	1 - A regenerable IX system would require significant maintenance and oversite of the regeneration system. Expected maintenance is high.

Table M.9: IC#3 Potential Design Parameters.

Cell Length (1)	Design Width	Area	Maximum volumetric flow at 0.03 ft/s	v at min flow (2)	v at mean flow(2)	Portion Treated at Min Flow	Portion Treated at Mean Flow	Portion Treated at Max Flow
ft	ft	ft^2	ft^3/s	ft/s	ft/s	%	%	%
3	9	27	0.81	0.057	0.140	53%	21%	6%
3	10	30	0.90	0.051	0.126	58%	24%	7%
3	11	33	0.99	0.047	0.114	64%	26%	8%
3	12	36	1.08	0.043	0.105	70%	29%	9%
3	13	39	1.17	0.040	0.097	76%	31%	9%
3	14	42	1.26	0.037	0.090	82%	33%	10%
3	15	45	1.35	0.034	0.084	88%	36%	11%
3	16	48	1.44	0.032	0.079	93%	38%	12%
3	17	51	1.53	0.030	0.074	99%	41%	12%
3	18	54	1.62	0.029	0.070	100%	43%	13%
4	9	36	1.08	0.043	0.105	70%	29%	9%
4	10	40	1.20	0.039	0.094	78%	32%	10%
4	11	44	1.32	0.035	0.086	86%	35%	11%
4	12	48	1.44	0.032	0.079	93%	38%	12%
4	13	52	1.56	0.030	0.073	100%	41%	13%
4	14	56	1.68	0.028	0.067	100%	44%	13%
4	15	60	1.80	0.026	0.063	100%	48%	14%
4	16	64	1.92	0.024	0.059	100%	51%	15%
4	17	68	2.04	0.023	0.056	100%	54%	16%
4	18	72	2.16	0.021	0.052	100%	57%	17%
5	9	45	1.35	0.034	0.084	88%	36%	11%
5	10	50	1.50	0.031	0.076	97%	40%	12%
5	11	55	1.65	0.028	0.069	100%	44%	13%
5	12	60	1.80	0.026	0.063	100%	48%	14%
5	13	65	1.95	0.024	0.058	100%	52%	16%
5	14	70	2.10	0.022	0.054	100%	56%	17%
5	15	75	2.25	0.021	0.050	100%	60%	18%
5	16	80	2.40	0.019	0.047	100%	64%	19%
5	17	85	2.55	0.018	0.044	100%	68%	20%
5	18	90	2.70	0.017	0.042	100%	71%	22%
6	9	54	1.62	0.029	0.070	100%	43%	13%
6	10	60	1.80	0.026	0.063	100%	48%	14%
6	11	66	1.98	0.023	0.057	100%	52%	16%
6	12	72	2.16	0.021	0.052	100%	57%	17%
6	13	78	2.34	0.020	0.048	100%	62%	19%
6	14	84	2.52	0.018	0.045	100%	67%	20%
6	15	90	2.70	0.017	0.042	100%	71%	22%
6	16	96	2.88	0.016	0.039	100%	76%	23%
6	17	102	3.06	0.015	0.037	100%	81%	25%
6	18	108	3.24	0.014	0.035	100%	86%	26%

(1) Cell Length is for one half of a total cell, as flow would serpentine through a cell. Full cell length is 2 times the length listed in this table.

(2) Required velocity through the PAB to treat all flow. Red text indicates a velocity higher than the maximum hydraulic conductivity of the media.

Table M.10: DG#1 Potential Design Parameters.

Cell Length (1)	Design Width	Area	Maximum volumetric flow at 0.03 ft/s	v at min flow (2)	v at mean flow (2)	Portion Treated at Min Flow	Portion Treated at Mean Flow	Portion Treated at Max Flow
ft	ft	ft^2	ft^3/s	ft/s	ft/s	%	%	%
3	23	69	2.07	0.0055	0.0659	100%	45%	17%
3	24	72	2.16	0.0053	0.0632	100%	47%	18%
3	25	75	2.25	0.0051	0.0607	100%	49%	18%
3	26	78	2.34	0.0049	0.0583	100%	51%	19%
3	27	81	2.43	0.0047	0.0562	100%	53%	20%
3	28	84	2.52	0.0045	0.0542	100%	55%	20%
3	29	87	2.61	0.0044	0.0523	100%	57%	21%
3	30	90	2.70	0.0042	0.0506	100%	59%	22%
3	31	93	2.79	0.0041	0.0489	100%	61%	23%
3	32	96	2.88	0.0040	0.0474	100%	63%	23%
3	36	108	3.24	0.0035	0.0421	100%	71%	26%
4	23	92	2.76	0.0042	0.0495	100%	61%	22%
4	24	96	2.88	0.0040	0.0474	100%	63%	23%
4	25	100	3.00	0.0038	0.0455	100%	66%	24%
4	26	104	3.12	0.0037	0.0438	100%	69%	25%
4	27	108	3.24	0.0035	0.0421	100%	71%	26%
4	28	112	3.36	0.0034	0.0406	100%	74%	27%
4	29	116	3.48	0.0033	0.0392	100%	76%	28%
4	30	120	3.60	0.0032	0.0379	100%	79%	29%
4	31	124	3.72	0.0031	0.0367	100%	82%	30%
4	32	128	3.84	0.0030	0.0356	100%	84%	31%
4	36	144	4.32	0.0027	0.0316	100%	95%	35%
5	23	115	3.45	0.0033	0.0396	100%	76%	28%
5	24	120	3.60	0.0032	0.0379	100%	79%	29%
5	25	125	3.75	0.0031	0.0364	100%	82%	30%
5	26	130	3.90	0.0029	0.0350	100%	86%	32%
5	27	135	4.05	0.0028	0.0337	100%	89%	33%
5	28	140	4.20	0.0027	0.0325	100%	92%	34%
5	29	145	4.35	0.0026	0.0314	100%	96%	35%
5	30	150	4.50	0.0025	0.0303	100%	99%	37%
5	31	155	4.65	0.0025	0.0294	100%	100%	38%
5	32	160	4.80	0.0024	0.0284	100%	100%	39%
5	36	180	5.40	0.0021	0.0253	100%	100%	44%
6	23	138	4.14	0.0028	0.0330	100%	91%	34%
6	24	144	4.32	0.0027	0.0316	100%	95%	35%
6	25	150	4.50	0.0025	0.0303	100%	99%	37%
6	26	156	4.68	0.0024	0.0292	100%	100%	38%
6	27	162	4.86	0.0024	0.0281	100%	100%	39%
6	28	168	5.04	0.0023	0.0271	100%	100%	41%
6	29	174	5.22	0.0022	0.0262	100%	100%	42%
6	30	180	5.40	0.0021	0.0253	100%	100%	44%
6	31	186	5.58	0.0021	0.0245	100%	100%	45%
6	32	192	5.76	0.0020	0.0237	100%	100%	47%
6	36	216	6.48	0.0018	0.0211	100%	100%	53%

(1) Cell Length is for one half of a total cell, as flow would serpentine through a cell. Full cell length is 2 times the length listed in this table.

(2) Required velocity through the PAB to treat all flow. Red text indicates a velocity higher than the maximum hydraulic conductivity of the media.