

A Dual Membrane Passive Diffusion Bag Sampler for PFAS in Groundwater

White Paper

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1. Introduction

Per- and Polyfluoroalkyl Substances (PFAS) are the man-made, “forever” compounds that have emerged as contaminants of concern in groundwater. There are thousands of these substances that are used to enhance the performance of products from food wrappers to sunscreen, to temperature resistant coatings and non-stick cookware. PFAS are found everywhere on the planet, in all living things, and health science is showing that cumulative exposure causes pervasive harm.

Sampling groundwater for PFAS is rapidly expanding from a limited selection of sites to mainstream and widespread monitoring, and federal and state environmental regulatory agencies are responding with increased regulation that includes setting the maximum concentration level (MCL) in drinking water in the low parts-per-trillion. Current state MCLs range from 6 ng/L to 70 ng/L (ppt) and may target specific PFAS.

Because PFAS is ubiquitous and the maximum concentrations are exceedingly low, the use of specialized and validated tools and procedures is essential to identifying pollution sources and monitoring compliance (USEPA, 2021). Additional attention to selection of personal protection equipment, sampling protocols, sample handling procedures and quality control criteria must be exercised to meet project data quality objectives (ITRC; 2020), adding an extra burden of time and cost to groundwater sampling. Further, many sampling devices and methods were designed before PFAS emerged as a contaminant of concern, and therefore may include components and accessories that are not appropriate for PFAS sampling and/or may not have been tested for effectiveness when sampling PFAS.

Although active groundwater sampling methods--volume purge and low-flow pumping--have been in use since the early days of environmental groundwater monitoring, they present some challenges that make adhering to the specialized PFAS procedures particularly expensive and time consuming. They produce volumes of contaminated wastewater that must be managed, require more equipment, which can make it difficult to access remote sites, and require longer time at each well, impacting access and safety at high-traffic areas. While passive diffusion sampling has proven to be an equally effective, significantly faster, and less expensive solution to active sampling for many constituents (Parsons ES, 2005; ITRC, 2004), most of the commercially available passive diffusion samplers existing prior to 2016 were not designed or tested for PFAS sampling.

As a response to the need for validated tools that relieve burdens of time and cost, a passive groundwater sampling device, called the Dual Membrane Passive Diffusion Bag (DMPDB™), was created, allowing for the inexpensive and effective technology of passive diffusion to be used for PFAS sampling. Bench testing and field testing have shown that the DMPDB™ is accurate and reliable for sampling PFAS in groundwater, even at concentrations as low as single-digit parts per trillion and greater. The DMPDB™ addresses the shortcomings of active sampling methods and provides advantages in cost reduction, elimination of purge waste, low turbidity, material compatibility specific to PFAS sampling, small lightweight samplers, rapid sampling, and ease of use.

Purpose & Scope of this Document

This document provides insight into a cost-effective solution for sampling PFAS in groundwater monitoring wells, using an adaptation of a passive diffusion bag sampler developed and tested over twenty years ago and widely used since then for sampling Volatile Organic Compounds (VOCs).

The technique of passive diffusion sampling using the original passive diffusion bag sampler (PDB) will be described and the benefits of passive sampling discussed. A description is then presented of the changes and enhancements made to the original PDB design to enable sampling for a wider range of analytes, beyond VOCs, to include metals, ions, SVOCs, inorganics, and contaminants of emerging concern, 1,4 Dioxane and PFAS. The design and function of the Dual Membrane Passive Diffusion Bag (DMPDB™) sampler is presented along with examples of its performance for sampling general groundwater parameters. Then, data is provided from controlled bench tests and from five independent, side-by-side field tests on the performance of the DMPDB™ for PFAS sampling.

The data from these studies will show the functionality and industry-acceptability of these samplers, for PFAS and for myriad other constituents. Overall, this document serves to inform the industry of the capability of the DMPDB™ to provide accurate and representative samples of groundwater for a wide range of contaminants and specifically for PFAS, at a lower cost, with reduced contaminated wastewater, and increased ease of use compared to pumping and purge techniques.

2. Passive Diffusion Groundwater Sampling

In 1997 the United States Geological Survey (USGS) developed and tested a method for obtaining representative groundwater samples for volatile organic compounds (VOCs) without purging or pumping the well. The method, called passive diffusion sampling, relies on natural groundwater flow through the saturated well screen to continually refresh the water below the casing or aerated portion of the saturated screen, with aquifer quality water (see Figure 1a and 1b).

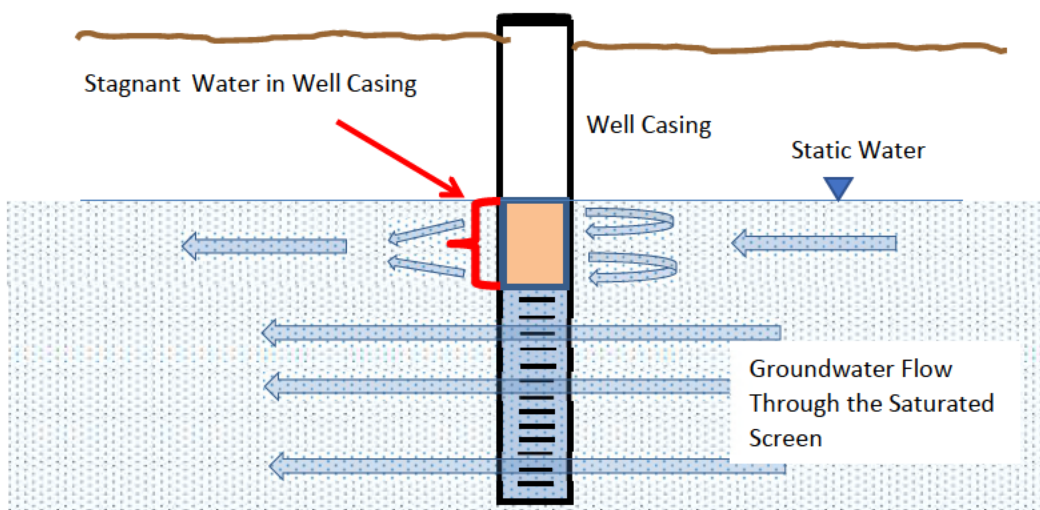


Figure 1a: Groundwater flow through a fully saturated screen. Groundwater flows through the screen and around the solid casing. The water in the casing becomes stagnant. (Section 2.0)

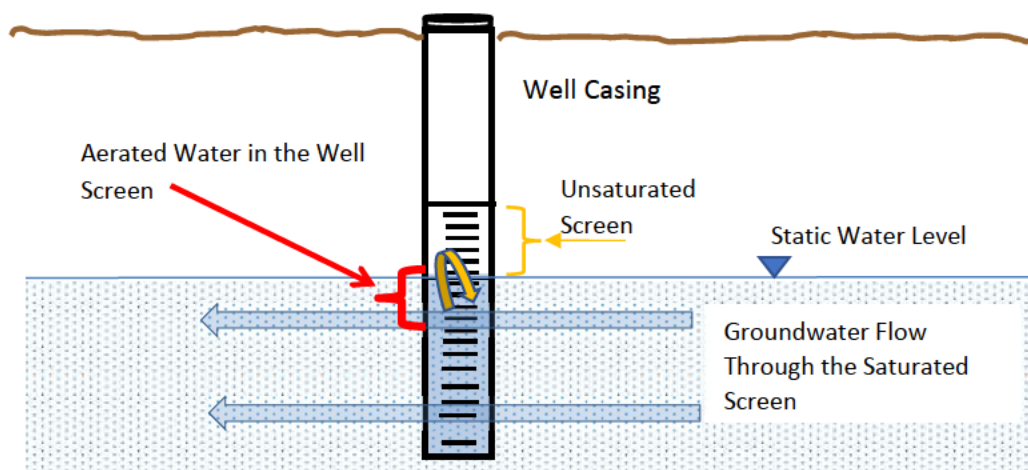


Figure 1b: Groundwater flow through a partially saturated screen. Aeration at the top of the water column may change water chemistry in the upper water column. (Section 2.0)

A Passive Diffusion Bag (PDB) sampler is constructed from a semi-permeable polyethylene membrane, filled with deionized water, and lowered into the flow portion of the saturated screen where it resides for a minimum of 14 days. The semi-permeable, hydrophobic membrane has pores that allow the movement of VOC molecules between the well water outside the sampler and the deionized water inside the sampler. If there are VOC molecules in the well water, a concentration gradient will exist between the VOCs in the well water around the sampler and the VOCs inside the sampler. The concentration gradient drives molecules to diffuse through the membrane pores until the molecules in the sampler are at the same concentration as those outside the sampler (Figure 2). If the concentration becomes lower outside the sampler than inside, the gradient is reversed, and the contaminant molecules diffuse out of the sampler until equilibrium is reestablished (Vroblesky, 2001a; 2001b).

To eliminate additional site mobilizations, passive samplers can be left in place after installation, until the next sampling event and then recovered for sampling and replaced with another PDB for a future event. Since the sample represents a time-integrated average, it will always represent the last several days of residence time. Samples are discharged by piercing the membrane with a polypropylene “juice-box” straw and draining the contents into lab bottles. Analyte concentrations are measured by the lab directly from the aqueous samples, just as with samples produced by pumping or bailing.

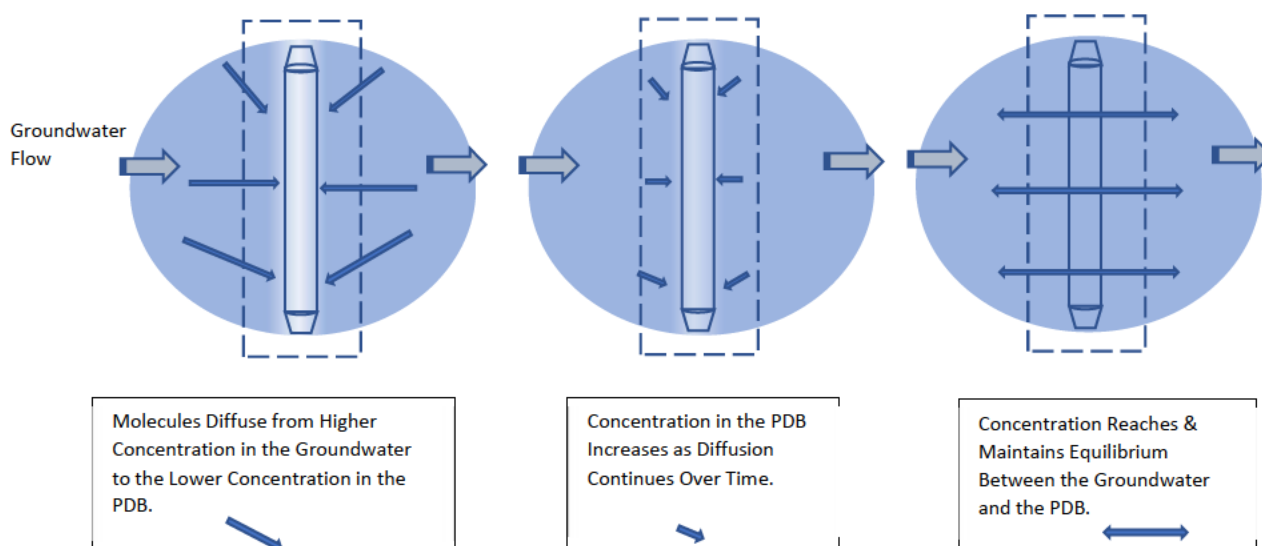


Figure 2: Molecular Diffusion into a PDB Driven by Concentration Gradient to Equilibration (Section 2.0)

2.1 Benefits of Passive Diffusion Sampling Compared to Active Sampling

The introduction of passive diffusion sampling provided a method that could mitigate some of the challenges and costs of existing, more active sampling methods, such as volume purge and low-flow. Volume purge using a bailer or pump and low-flow pumping are active groundwater sampling methods that have been in use since the early days of environmental groundwater monitoring. While these methods have been in use for years, they are known to be time consuming and require ancillary equipment, and to produce excess investigation derived waste (IDW) that may have to be containerized and disposed of according to regulations. Sampling protocols for volume purge include quantities of

water that must be removed from the well before collecting a sample, to minimize the chance of collecting a sample that includes stagnant or aerated water from the casing or in the screen at the air/water interface (Barcelona, Gibb, Helfrich, & Garske, 1985; Puls & Barcelona, 1996). In low-flow pumping, a lesser volume of water is removed prior to collecting a sample, but IDW is still produced through the discharge until stabilization parameters are reached.¹

Studies of PDBs and other passive samplers conclude that passive sampling can significantly reduce field sampling costs by 50% to 80%, inclusive of labor, equipment, and the collection, containment and transfer cost for IDW (Parsons ES, 2005). The use of passive samplers eliminates IDW and the associated logistics and costs for its disposal and/or treatment. The amount of bulky and expensive pumps, compressors, batteries, tubing, water quality instruments and measurements can be reduced because they are not required for the sampling process (ITRC, 2004). The small samplers, lightweight material, and significantly reduced support gear facilitate easy access to remote areas, shortening the time required to sample in heavily trafficked areas and resulting in safer, more sustainable operations.

Because it is often important to know the source or interval of entry for the water being sampled, passive sampling may offer additional advantages over pumping. Volume purge and pumping methods draw water into the well to acquire a flow-weighted average sample that is blend of flow across the screen, weighted toward the vertical intervals with highest hydraulic conductivity. As saturated screens become longer it is more likely there are variations in the hydraulic conductivity along the screen that will affect what the sample represents. Passive samplers do not induce flow, and therefore represent the concentrations at the placement interval. Since each passive sampler represents a specific interval in the well, passive sampling enables vertical profiling of contaminants and concentrations in wells with longer saturated screens by placing samplers at multiple intervals in the screen. It may be easier and more reliable to pinpoint higher or lower concentrations of PFAS by monitoring specific intervals than through a sample that is a blend of differing contaminants or concentrations. This is particularly helpful when used to delineate groundwater flow into surface waters (Parsons ES, 1999).

2.2 Widespread Acceptance and Use of Passive Diffusion Sampling

PDBs were successfully commercialized in 1998 by EON Products, Inc. (“EON”), and have grown rapidly in widespread use for VOC sampling, with over one million PDB samples collected to date as of 2022. They are used in all 50 U.S. states, on projects managed by the USEPA, U.S Airforce, US Army Corp of Engineers, USGS, USDOE, State managed sites and hundreds of privately managed sites complying with state and federal regulations. Passive Diffusion Samplers are also used in a dozen other countries.

2.3 Limits of Previous Generation Passive Diffusion Samplers

For all its benefits, the PDB cannot be used for sampling PFAS because it is limited by the polyethylene membrane to sampling VOCs, and is not effective for sampling polar compounds, metals, inorganic compounds, SVOCs, 1,4 Dioxane, or PFAS. These molecules do not pass through the membrane pores.

¹ For more information about active sampling methods such as volume purge and low-flow pumping, and how they contribute to the discussed problems, please see Appendix A.

As a result, several passive diffusion samplers have been constructed and tested using different membranes to facilitate diffusion of a wider range of contaminants than VOCs.

Results from comparative field studies of the Rigid Porous Polyethylene (RPP) sampler, Regenerated Cellulose PDB (RC-PDB) sampler, and the Nylon Screen (NS) demonstrated: 1) that diffusion samplers can be designed that facilitate sampling for an increasing number of compounds in groundwater, 2) that passive sampling can produce results that are representative of aquifer conditions across a wide range of contaminants, and 3) that the benefits of passive groundwater sampling, including cost reduction and elimination of IDW can be achieved using different types of passive sampling devices (ITRC, 2006; Parsons ES, 2005).

While these diffusion samplers tested as highly effective for sampling a wide range of compounds in groundwater, only the RPP is commercially available. The RC-PDB, and the NS are not commercially available, and none of the commercial samplers have data available for their effectiveness in sampling for PFAS. Further, all three samplers have one or more drawbacks for PFAS sampling including high cost, sampler size, sample volume, manufacturing complexity, and/or field durability issues. EON recognized that a diffusion sampling option for non-VOC constituents would provide technical, logistical, and cost-saving benefits for many groundwater sampling projects.

3. Dual Membrane Passive Diffusion Sampler

In 2010, EON began a research and development program to create an equilibrium-based passive diffusion sampler that offers the many benefits of the PDB with the additional capability of sampling the entire range of regulated compounds in groundwater. The resulting Dual Membrane Passive Diffusion (DMPDB™) sampler effectively combines the diffusion characteristics of two membrane samplers studied by the Interstate Technology Regulatory Council (ITRC), into one sampler that incorporates the capabilities and eliminates the drawbacks associated with either membrane by itself (Figure 3).



Figure 3: Dual Membrane Passive Diffusion Bag (DMDPB™) sampler. Provided by EON Products, Inc. under copyright. (Section 3.0)

3.1 Design & Function of the DMPDB™

The two semi-permeable membranes used in the DMPDB™ are aligned in series around a perforated tube to form a single sample chamber. The lower membrane is hydrophobic, with smaller pores to allow diffusion of non-polar VOCs from the surrounding groundwater into the sampler without allowing water molecules to pass, in the same way as the single-membrane PDB. For general sampling of non-PFAS contaminants, the bottom membrane of a DMPDB™ is made from LDPE. For PFAS sampling, a bottom membrane made from High Density Polyethylene (HDPE) is used. HDPE is recognized as an acceptable material for use in equipment employed for PFAS sampling (ITRC, 2020). The upper membrane is hydrophilic with large pores to facilitate diffusion of large and polar molecules, including water molecules, into the sampler from the surrounding groundwater. The upper membrane is also made from material acceptable for PFAS sampling. The results of rinsate tests performed on the DMPDB™ were negative for the presence of PFAS (see Appendix B).

Since there is only one internal chamber formed by both membranes, molecules that enter the sampler through either membrane diffuse throughout the water inside the sampler until dynamic equilibrium is reached (Figure 4) within the sampler and with the surrounding groundwater. Concentration values of samples acquired by the DMPBD™ are directly measurable by the lab from the aqueous samples, in the same way as samples acquired by pumps and bailers.

In simple terms, molecules in the surrounding groundwater diffuse horizontally through one or both membranes into the sample chamber where the molecules continue to diffuse vertically throughout the sample chamber. Through this process, equilibrium is maintained between the sample water and the surrounding groundwater.

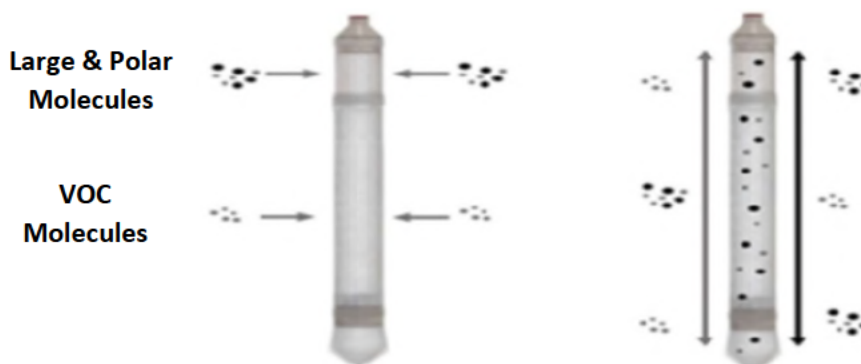


Figure 4: Diffusion of molecules into the DMPDB through the upper and lower membranes, driven by a concentration gradient. Once inside the sampler, molecules diffuse vertically throughout the sampler until the molecular concentrations equilibrate with the surrounding groundwater. (Section 3.1)

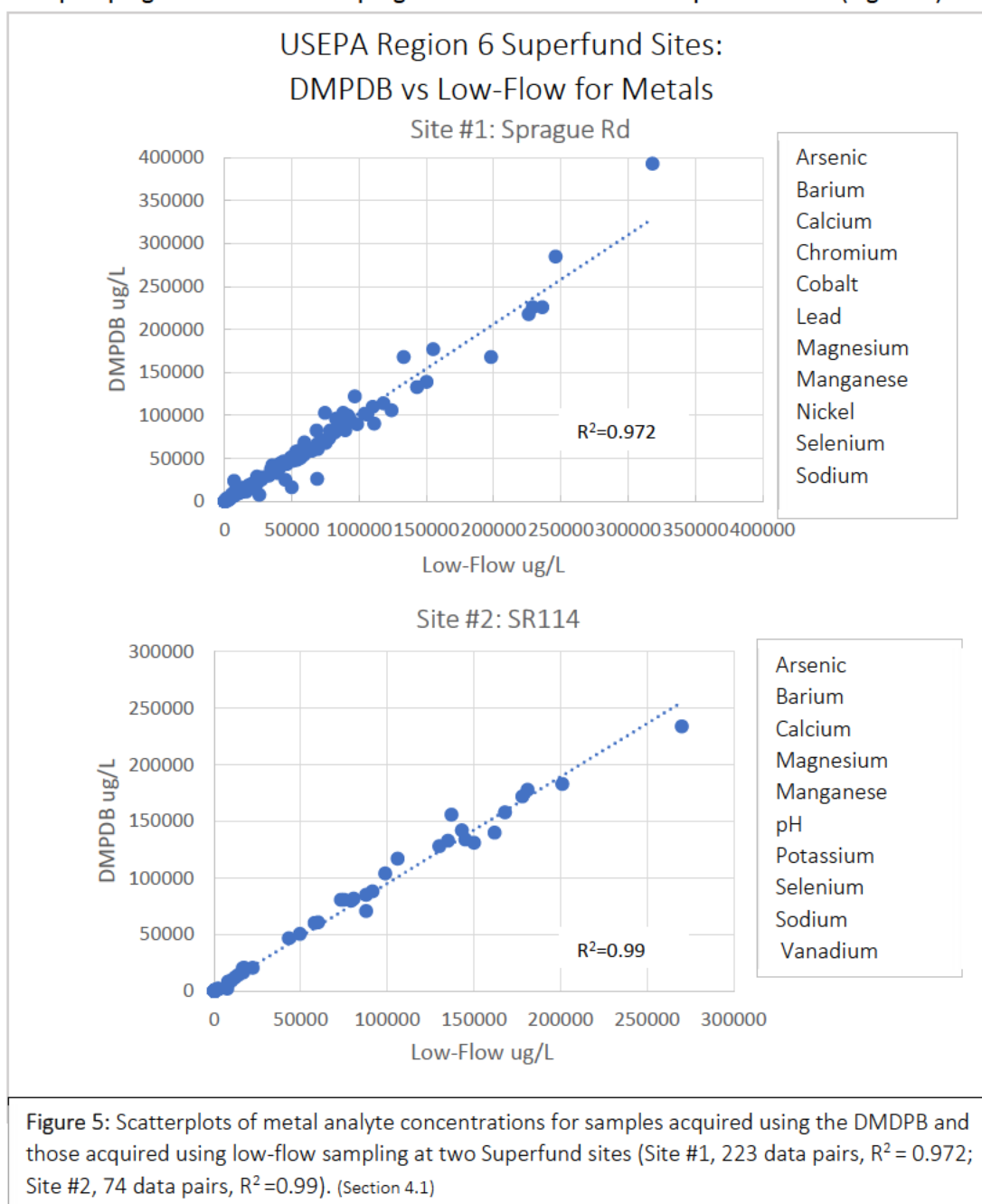
4. Using the DMPDB™ for General Analytes (non-PFAS)

In 2014 the USEPA Region VI in Texas was looking for more efficient ways to monitor and remediate their sites as costs increased and budgets were shrinking. The agency and their environmental consultant had already dramatically reduced their costs for VOC sampling by switching from low-flow pumping to the polyethylene Equilibrator™ PDB. They reached out to EON for a passive diffusion sampler effective for metals, including hexavalent chromium, and inorganics. EON offered the DMPDB™,

which resulted in the EPA conducting a series of side-by-side tests showing that the DMPDB™ is an effective method for sampling constituents beyond VOCs.

4.1 Study 1: Side-by-Side of Low-Flow and DMPDB™ at Two USEPA Superfund Sites

The USEPA and their consultant, EA Engineering, Science & Technology (EA EST, Inc), conducted a field study in 2014 comparing the results from sampling with the Dual Membrane Passive Diffusion Bag sampler to low-flow pumping for two rounds of sampling at each of two Texas Superfund sites: Sprague Road and State Road 114. Concentrations of 10 metals from DMPDB™ samples and low-flow samples were compared. Scatterplots of 297 data pairs show a positive correlation between the DMPDB™ and low-flow pumping for metals at the Sprague Road and SR114 EPA Superfund sites (Figure 5). Similarly,



samples from the DMPDB™ and from low-flow were compared and show a positive correlation for sulfate and sulfide. (Figure 6).

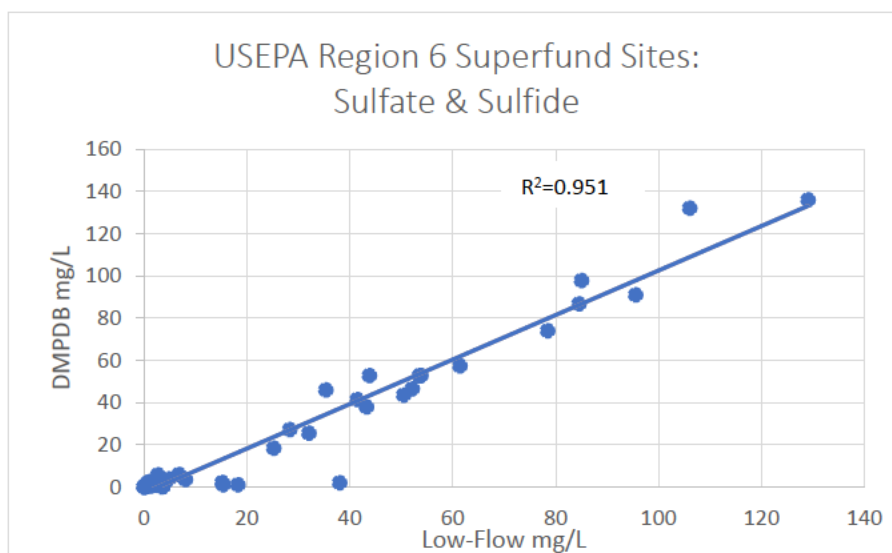


Figure 6: Scatterplot showing correspondence between sulfate and sulfite concentrations for samples acquired using the DMPDB and those acquired using low-flow sampling (52 data pairs, $y = 1.0534x - 2.7403$, $R^2=0.951$) at the Sprague Road and SR114 Superfund sites (Sites #1 & #2) in Texas. (Section 4.1)

4.2 Study 2: Side-by-Side of Low-Flow, Standard PDBs, and the DMPDB™ at Kirtland AFB

In 2016, following the success at the Texas Superfund sites, EA Engineering, Science and Technology, Inc. proposed the use of DMPDB™s at Kirtland AFB to replace dedicated low-flow pumps that were corroding and were expensive to maintain and operate. The site was being sampled for metals and inorganics and alkalinity, using dedicated pumps, and for Ethylene dibromide (EDB), using standard PDBs. Several rounds of quarterly side-by-side sampling events were conducted with the DMPDB™s and then compared to the results from low-flow pumps for metals, anions, and inorganics, and to PDBs for EDB. The concentrations of metals, inorganics, and alkalinity showed a close positive correlation between the DMPDB™ samples and the pumped samples. On the following page, Figure 7A shows the scatterplot of the DMPDB™ and pumped samples for metals at this site, further demonstrating a positive correlation, as was seen in the superfund study. Results from the DMPDB™s (Figure 7B) also closely corresponded to results from the PDBs for EDB concentrations.

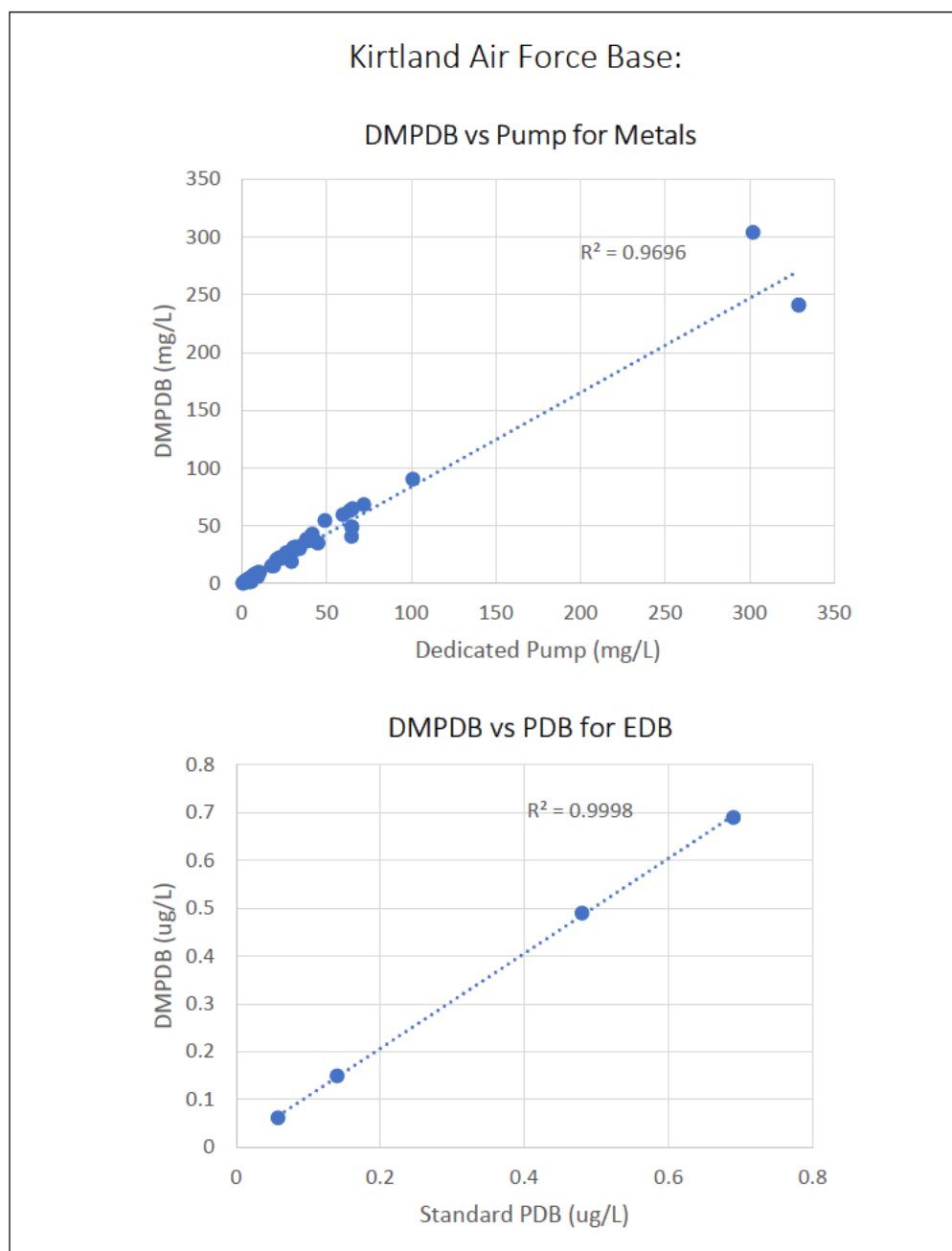


Figure 7A (upper): Scatterplot showing the correspondence between total metals concentrations for DMPDB samples compared to dedicated pump samples ($R^2 = 0.9696$).
Figure 7B (lower): Scatterplot showing the correspondence of ethylene dibromide (EDB) sample concentrations from the DMPDB compared to standard PDBs ($R^2 = 0.9998$).
From *EA Engineering*, 2016 (Section 4.2)

4.3 Conclusions: DMPDB™s for non-PFAS Analytes

For all three sites where the DMPDB™s were originally tested—the two USEPA Superfund sites and Kirtland Airforce Base, their sampling results all closely corresponded with the results from the low-flow samples collected side-by-side. At the Kirtland AFB site EDB results collected by the DMPDB™ also correlated closely with the results from PDBs. These outcomes, combined with the time and cost savings, resulted in both the EPA and EA EST, Inc. adopting DMPDB™s for continued sampling at Sprague Road, SR114, and Kirtland Airforce Base, in place of low-flow pumping and/or PDBs. Sampling with DMPDB™s is ongoing at all sites. As of 2022, DMPDB™s have been in continuing use in over 200 wells at Kirtland since 2016.

Since the USEPA and Kirtland AFB studies were completed, the DMPDB™ has become widely used for general groundwater sampling, on sites managed by the DoD, EPA, USGS and commercial/industrial sites including landfills, pharmaceutical, coal ash, and others managed by private consultants. Other projects and test results have demonstrated that the DMPDB™ is effective for sampling 1,4 Dioxane and it is listed as a suitable sampling device for 1,4 Dioxane in the ITRC Fact Sheet (ITRC, 2021). The DMPDB™ is included in the New Jersey Department of Environmental Protection's revised *Field Sampling Procedures Manual (pending, 2023)*, and the USGS's *Passive Sampling of Groundwater Wells for Determination of Water Chemistry (2020)*.

5. A Passive Diffusion Sampler for PFAS

With the emergence of PFAS as contaminants of concern in groundwater, environmental professionals began to ask for a passive sampling solution to address the increased cost of sampling, driven by specialized protocols and equipment. In particular, the disposal and/or treatment IDW and the preparation and decontamination of sampling equipment are of special regulatory concern when sampling for PFAS and can add significant additional time and cost. Also, when sampling PFAS at parts per trillion concentrations, slight variations in source water could affect concentrations enough to impact decisions, so it is important to be able to determine the specific interval represented by the sample. As noted, passive sampling provides advantages compared to active sampling methods, when sampling for general analytes, including elimination of IDW, reduced equipment requirements, elimination of cleaning equipment that is moved from well to well, ease of use, typically no sample filtration, reduced sampling time on low-yield wells, vertical concentration profiling, and rapid sampling in high traffic areas (Imbrigiotta & Harte, 2020). These benefits can provide cost reduction and time savings for the otherwise expensive and tedious process of PFAS sampling. The DMPDB™, having shown success in acquiring representative samples across a range of analytes, appeared to be a likely solution.

5.1 Considerations When Evaluating PFAS Sampling Methods

Both bench testing and field testing can be used to evaluate the effectiveness of a method for sampling for a given analyte. Bench-scale testing in a controlled environment provides insight about the effectiveness of the sampler to acquire samples of specific compounds without the effects from field variables. In a bench test, the researcher can directly control the concentrations of analytes in the chamber, which represents a groundwater monitoring well. This allows the researcher to compare concentrations in the samples with the actual concentrations of constituents in the water surrounding the sampling device. If bench results are closely correlated to controls, it is understood that the device is

technically capable of acquiring a representative sample of the analyte. However, controlled conditions may not fully translate to the use of a product under field conditions, so bench testing alone may not provide the full scope of a method's effectiveness under all circumstances.

On the other hand, field studies, such as side-by-side comparisons, provide data that is more representative of the range and variety of results that could be produced by everyday use. Further, field comparisons are the most prevalent source of data about sampling methods. Site specific side-by-side field comparisons of sampling methods may be requested under several circumstances, such as when a site is considering changing its sampling methodology, changing the contaminants of concern, or a site is adopting a technology with which the consultant, owner, or regulator is unfamiliar. When samples from differing methods are acquired from the same interval of the same well at the same time, comparisons of results from those methods can be performed by pairing one result from each sampling method, for a specific PFAS. If pairs are similar across a range of samples and constituents, the correlation is evidence that the samplers are similarly effective and are likely representative of the concentrations in the groundwater. However, making comparisons between sets of field data acquired by different sampling methods can be difficult and sometimes misleading. Limited ability to control for field variables, including geologic stratification, variable hydraulic conductivity, saturated screen length, sampler positioning, timing of sample collection, turbidity, user-induced variability, and others, may affect the results (ITRC, 2004).²

With the tradeoffs of these approaches in mind, results from both bench testing and side-by-side field testing are included in the following evaluation of the use of the DMPDB™ for PFAS sampling. The magnitude of the differences, the trend of the data within and across studies, and whether both results consistently lead to the same action decisions for a constituent should all be considered when evaluating the comparisons in these studies.

5.2 Chamber Bench Test for PFAS

EON conducted a bench-scale study in 2017 to document the effectiveness of the DMPDB™ for sampling low concentrations of PFAS in water.³

An 8-inch diameter by 8-foot-tall test chamber was filled with water and spiked to about 30ng/L (ppt) with a range of eight long-chain, medium-chain, and short-chain PFAS and nine DMPDB™ samplers were installed. The DMPDB™s were installed on the standard EON polypropylene suspension tether, with stainless-steel connection rings, and stainless-steel weight, at intervals throughout the 8-foot column.

After a 21-day residence, a control volume was taken from the water in the chamber surrounding the DMPDB™s. Three DMPDB™ samplers were removed, and their contents discharged to laboratory bottles. A second control was taken of the water in the chamber after the samplers were removed as a check on concentration variability caused by the test environment, sample handling and shipping, and

² For an in-depth comparison and evaluation of passive sampling versus active sampling methods and data, refer to the USGS publication in our reference list (Imbrigiotta & Harte, 2020).

³ See Appendix C for Bench Test data, including table of PFAS concentrations from all controls and samples and further figures.

the lab, not related to the samplers. After 41-day residence, the process was repeated: a control was taken, the remaining six DMPDB™s were removed and discharged, and a second control was taken.

The test was repeated at chamber concentrations in the single-digit ng/L range. Nine additional DMPDB™s were installed for a residence time of 21 days. Water was collected directly from the chamber as a control, all nine DMDPBS were removed and discharged into lab bottles, and a second control was taken.

Samples were sent to Eurofins TestAmerica for PFAS analysis using Method 537 (modified).

Together, the three tests resulted in 150 PFAS sample concentrations collected by the DMPDB™s. Each sample concentration was compared to the average of the two controls for its given PFAS. A scatterplot of these 150 sample-control data pairs (Figure 8) indicates a close positive correlation across the range of concentrations from 0 ng/L (ND) to 36 ng/L. The consistency of results between 21 and 41 days residence reaffirm that the samplers stay in equilibrium with the surrounding water after the initial equilibration period. Comparisons of the average concentrations between controls and DMPDB™s by PFAS also show the agreement between the sample concentrations and control concentration (Figure 9).

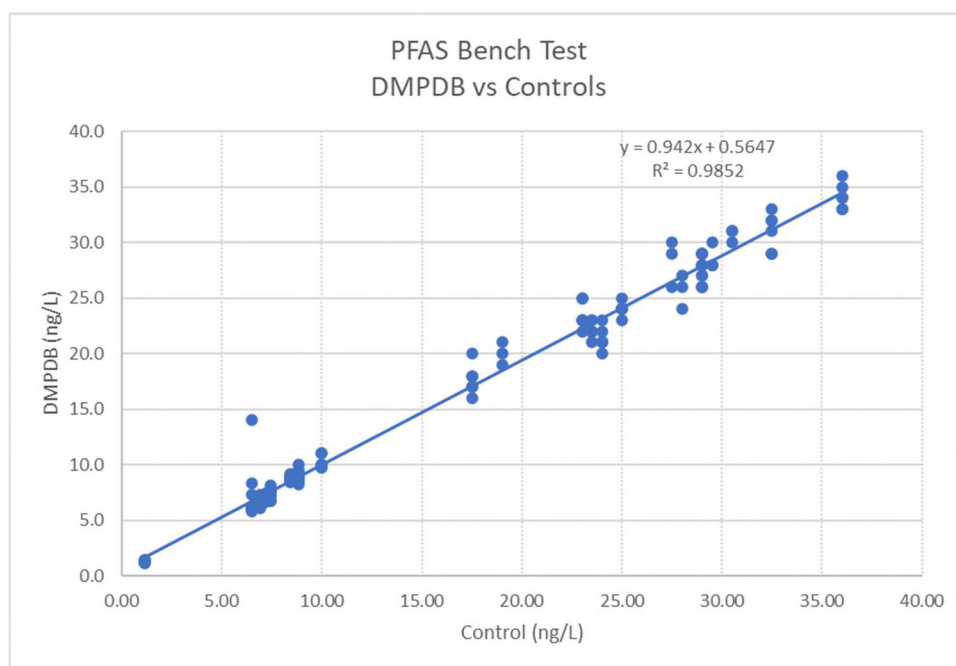
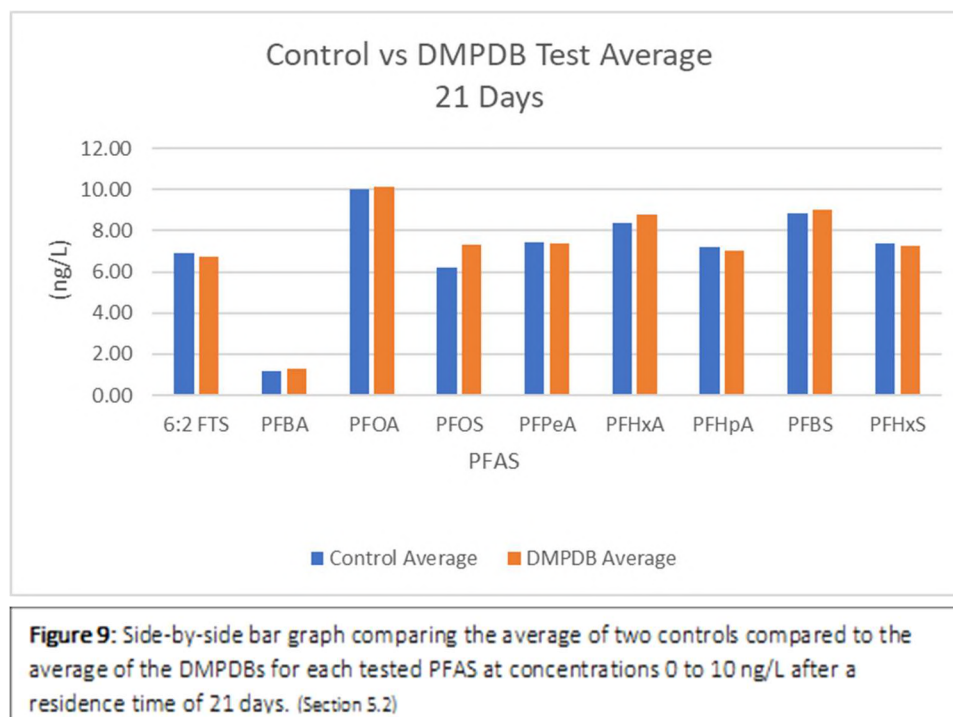


Figure 8: This scatter plot shows a summary of all the bench test data (150 data pairs) representing the concentration of 9 PFAS in water samples collect by the DMPDB, plotted against the average of two Control samples taken from the water surrounding the samplers, during each test. (Section 5.2)



For the test conducted at concentrations from 0 to 10 ng/L, the variance between the average concentration from the DMPDB™ samples and the average of the controls for most results was less than the variance between the two controls, with the average for all samples less than 0.5 ng/L. This includes one elevated result for PFOS that appears to be an outlier. The tests at the higher concentrations from 18 ng/L to 36 ng/L produced an average variance between the DMPDB™ and the controls across all samples, of 1.5 ng/L. (Tables 1-2).

Because control volumes were collected directly from the same test chamber water during the same test, the actual concentrations in both controls should be expected to be similar or identical. Therefore, observed variance between two control volumes taken during the same test may be an indicator that some amount of variability, or “noise”, between DMPDB™ results and control results is caused during the collection, transportation, or laboratory testing processes, not related to the sampler.

These results indicate that the membrane technology and sampler design of the DMPDB™ will produce a sample of representative short-chain, medium-chain, and long-chain PFAS, with concentrations reflecting the water surrounding the DMPDB™. Because the shortest residence time in this test was 21 days, further testing could reveal that PFAS comes to equilibrium with a shorter residence time.

Table 1: Bench Test Variance between DMPDB™s and Controls for Lower PFAS Concentrations after 21 days

PFAS 0-10 ng/L	Mean of Controls 1 & 2 (ng/L)	Variance Between Controls (ng/L)	Number of Samplers	Max Variance to Mean (ng/L)	Min Variance to Mean (ng/L)	Avg Variance to Mean (ng/L)	Mode (ng/L)
6:2 FTS	6.9	0.6	9	0.8	0.2	0.4	0.2
Perfluorobutanesulfonic acid (PFBS)	8.9	0.1	9	1.2	0.0	0.4	0.0
Perfluorobutanoic acid (PFBA)	1.2	0.3	9	0.3	0.0	0.2	0.3
Perfluoroheptanoic acid (PFHpA)	7.2	0.4	9	0.6	0.0	0.2	0.2
Perfluorohexanesulfonic acid (PFHxS)	7.4	0.2	9	0.4	0.1	0.2	0.1
Perfluorohexanoic acid (PFHxA)	8.4	0.4	9	0.8	0.0	0.4	0.4
Perfluorooctanesulfonic acid (PFOS)	6.2	0.6	9	7.8	0.1	1.4	0.1
Perfluorooctanoic acid (PFOA)	10.0	0.0	9	1.0	0.0	0.3	0.2
Perfluoropentanoic acid (PFPeA)	7.5	0.1	9	0.8	0.1	0.4	0.8

Table 1 shows the variance between DMPDB sample results and the average of two controls (C1 & C2) for each PFAS at concentrations between 0 ng/L and 10 ng/L after 21 days. (Section 5.2)

Table 2: Bench Test Variance between DMPDBs and Controls for Higher PFAS Concentrations after 21 days

PFAS 18-36 ng/L	Number of Samplers	Mean of Control 1&2 (ng/L)	Control Variance (ng/L)	Max Variance to Control Mean (ng/L)	Min Variance (ng/L)	Avg Variance (ng/L)
6:2-Fts	3	29.5	1.0	1.5	0.5	1.2
Perfluorobutanoic acid (PFBA)	3	ND	0.0	ND	ND	ND
Perfluoroheptanoic acid (PFHpA)	3	27.5	1.0	2.5	1.5	1.8
Perfluorohexanesulfonic acid (PFHxS)	3	28.0	2.0	4.0	1.0	2.3
Perfluorohexanoic acid (PFHxA)	3	30.5	1.0	0.5	0.5	0.5
Perfluoro-Octanesulfonate	3	19.0	2.0	2.0	0.0	1.0
Perfluorooctanesulfonic acid (PFOS)	3	36.0	0.0	3.0	2.0	2.3
Perfluorooctanoic acid (PFOA)	3	36.0	2.0	3.0	0.0	1.3
Perfluoropentanoic acid (PFPeA)	3	30.0	0.0	1.0	0.0	1.0

Table 2 shows the variance between DMPDB sample results and the average of two controls for each PFAS at concentrations between 18 ng/L and 36 ng/L at 21 days. ND indicates that the PFAS was not detected at the lab's MDL. (Section 5.2)

5.3 Side-by-Side Field Studies of the DMPDB™ for PFAS

When it comes to PFAS, field data from private and high-profile sites are difficult to obtain because of the negative public image, and potential litigation associated with PFAS contamination. This is especially true since the movie/documentary *Dark Waters* (Haynes, 2021) highlighted a PFAS contaminated site, public health influences, and a cover-up. While a large amount of comparative field data may not be publicly available, it is worth noting that there are a growing number of sites where private, side-by-side field comparisons of the DMPDB™ with low-flow pumping, have been performed. Results from these side-by-side comparisons show overall close correlations to results from volume purge and low-flow pumping for PFAS.

Included below are data representing side-by-side field comparisons between the DMPDB™ and other sampling methods, primarily low-flow. Some of the data is provided under conditions that site and client names are redacted.

5.3.1 DMPDB™ and Low-Flow: Department of Defense Study

EA Engineering, Science, & Technology conducted a 10-well, side-by-side field study at a U.S. Department of Defense (DoD) site in 2021, comparing the DMPDB™ with low-flow sampling for 24 PFAS. The scatterplot of 124 data-pairs correlates at an R^2 value of 0.99 (.96 correlation with 2 outliers included; Figures 11a & 11b) The data were summarized and presented to stakeholders, concluding that results from DMPDB™ samplers are comparable to their current low-flow method, and that DMPDB™s provide the benefits of reduced IDW and demonstrated cost savings (Caprio, 2021). Caprio, Thieleman, and Gragert 's discussion of the pilot study was published in the August 2021 edition of "The Military Engineer" (TME) periodical.

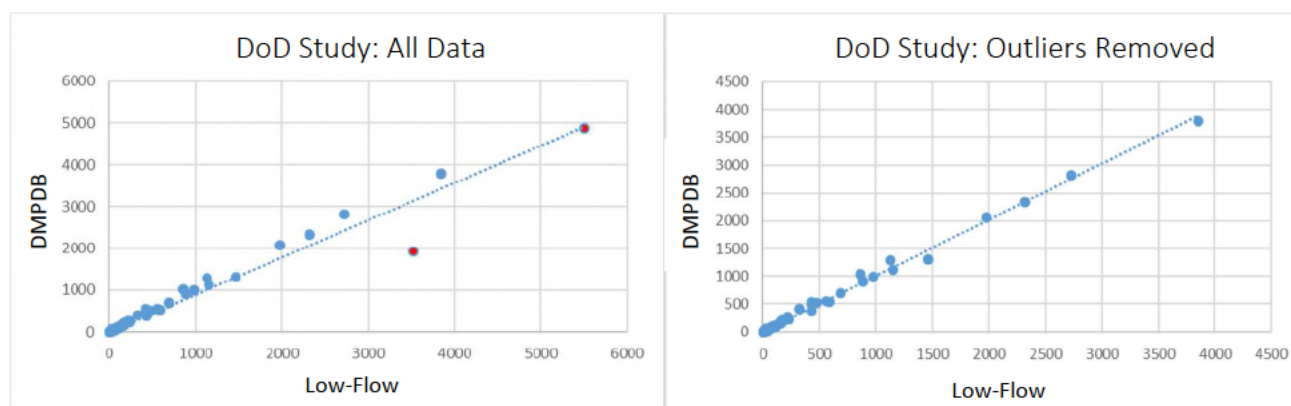


Figure 11a (Left): Scatterplot of all sample concentrations (ng/L) for DMPDBs vs low-flow pump for PFAS at DoD site, ($y = 0.895x$, $R^2 = 0.963$). Outliers designated in red. Figure 11b (Right): Scatterplot of DoD site PFAS concentrations, with two outliers removed, ($y = 1.012x$, $R^2 = 0.996$). Provided by EA Engineering Science and Technology, 2021. (Section 5.3.1)

5.3.2 DMPDB™ and Modified Low-Flow: U.S. Federal Agency Study

A U.S. federal agency conducted a field study for PFAS sampling in 2020 and 2021 that compared the PFAS concentrations from DMPDB™ samplers (installed for a minimum of 21 days) to those taken by pumping. The preliminary data were provided for EON's research and publications, under the condition that specific project references are redacted and that conclusions are not attributed to the study until the agency completes data validation and their discussion of field events and variables can be included. The study is expected to be peer-reviewed late in 2022, for public release early in 2023.⁴

Some of the 11 wells in this study were known to have short, saturated screen lengths, which limited the volume of water that could be collected. Turbidity and precipitation were also challenges in some wells and their effects have not been considered within this data set, though they could be significant in some wells. Discussion of these challenges and their effect on the data will be included in the final report along with conclusions about the merits of the sampling methods, including cost and IDW impacts.

The study targeted 28 PFAS, of which three (PFOS, PFOA, and PFNA) are on the state priority list. Preliminary, pre-validation data is comprised of 72 data-pairs from the 11 wells, where both samples have PFAS concentrations above the lab Reporting Limit.⁵ The 72 data pairs are positively correlated ($R^2 = 0.89564$; Figure 12), showing that PFAS concentrations were similar in samples from DMPDB™s and from pumping. A scatterplot of 23 data-pairs representing only the state's three higher priority PFAS, shows strong correlations ($R^2 = 0.9298$) between results from DMPDB™ and low-flow samples (Figure 13).

The 23 data pairs of priority PFAS concentrations, along with their state MCLs and Groundwater Quality Standards (GWQS), are presented in Table 4 below to compare concentrations between the pumped sample and the DMPDB™ sample. In 22 of the 23 comparisons (95%), both sample concentrations are either above or below the MCL/GWQS. That means the same practical conclusion would likely be reached using either sampling method for the priority PFAS in over 95% of the data pairs, regardless of sampling method.

In 1 of the 23 comparisons the two data points straddle the 13ng/L MCL/GWQS, with the pump results at 11.9 ng/L and the DMPDB™ results at 15.9 ng/L. The difference between the results of the two methods is 4ng/L and could be the result of well and field conditions, or variability from sample handling.

As with any field sampling results, additional information about the wells and field sampling process should be reviewed when values are close to MCLs/GWQS, when values straddle the MCL/GWQS, and when the data produces some results that vary from the general trend.

⁴ EON will update this paper and/or provide a link on our website with the results and conclusions of the published study when available.

⁵ Preliminary Data Tables for the US Federal Agency study are shown in Appendix D (EON Communications with Federal Agency, 2020- 2022).

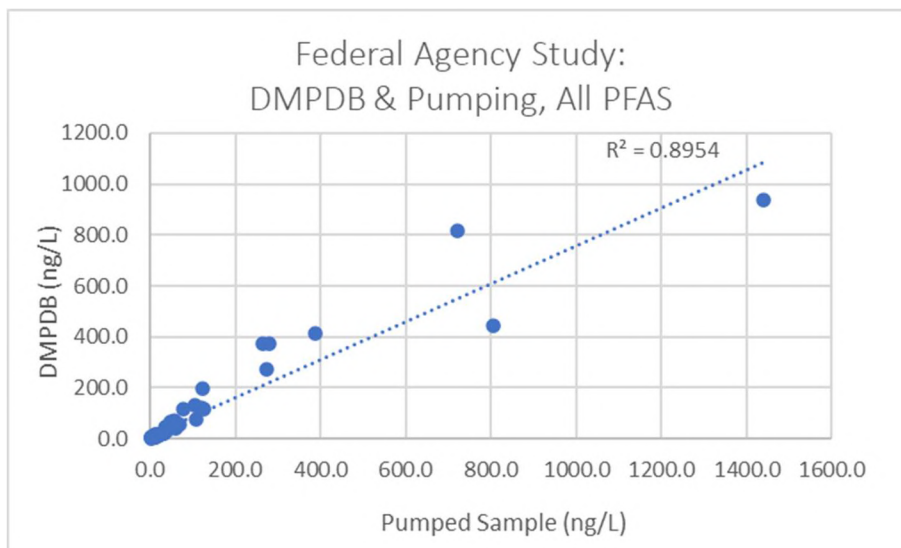


Figure 12: Scatterplot of preliminary results (72 data pairs) for PFAS concentrations from the DMPDB and from pumping. Unpublished data from an ongoing federal study of passive diffusion samplers for sampling PFAS (2021) (Section 5.3.2)

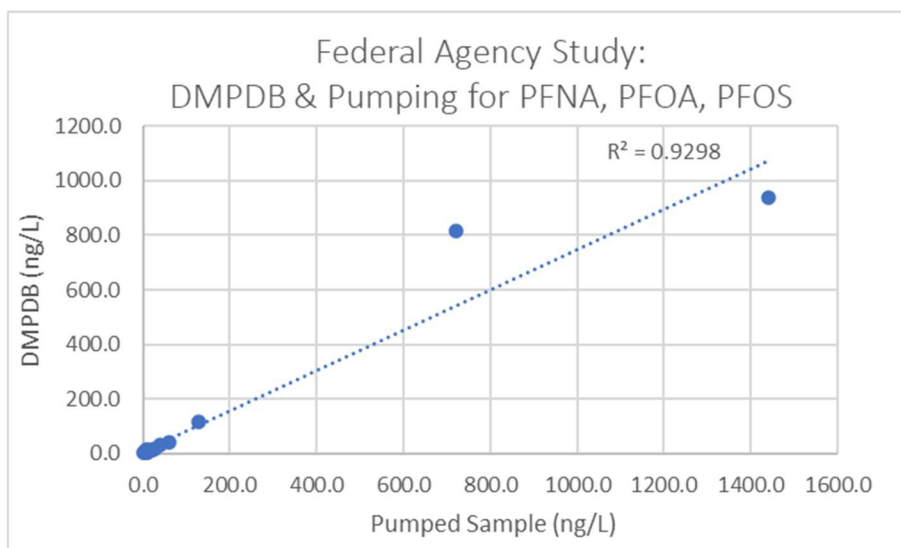


Figure 13: Scatterplot of preliminary results (23 data pairs) for concentrations of PFNA, PFOA, PFOS New Jersey priority PFAS from the DMPDB and from pumping. Unpublished data from an ongoing federal study of passive diffusion samplers for sampling PFAS (2021). (Section 5.3.2)

Table 4: Concentrations of New Jersey's State Priority PFAS for Pump and DMPDB Samples

New Jersey Priority PFAS	Well ID	MCL (ng/L)	Pump Result (ng/L)	DMPDB Result (ng/L)	Are Both Results Above/Below MCL?
Perfluorononanoic acid (PFNA)	TW12	13	5.3	4.3	Below MCL
	TW21	13	21.6	14.8	Above MCL
	TW18	13	2.6	3.8	Below MCL
	TW2	13	13.9	14.9	Above MCL
	TW32	13	11.9	15.9	Straddle MCL
Perfluorooctanesulfonic acid (PFOS)	TW8	13	9.0	5.1	Below MCL
	TW12	13	8.9	7.0	Below MCL
	TW37	13	11.9	8.1	Below MCL
	TW 25	13	7.1	7.6	Below MCL
	TW39	13	6.5	4.3	Below MCL
	TW18	13	8.3	12.8	Below MCL
	TW2	13	1440.0	936.0	Above MCL
	TW32	13	720.0	815.0	Above MCL
Perfluorooctanoic acid (PFOA)	TW8	14	29.2	19.4	Above MCL
	TW12	14	38.7	32.2	Above MCL
	TW21	14	60.9	41.0	Above MCL
	TW37	14	10.5	9.4	Below MCL
	TW 25	14	7.7	8.3	Below MCL
	TW39	14	8.5	11.1	Below MCL
	TW18	14	8.5	13.6	Below MCL
	TW35	14	6.5	7.0	Below MCL
	TW2	14	127.0	119.0	Above MCL
	TW32	14	35.8	48.5	Above MCL

Table 4 shows the concentrations of PFNA, PFOA, PFOS from samples acquired by the DMPDB and by Pumping along with the state MCL/GWQS. The far-right column indicates whether both sample results are above or below the MCL or whether the two points straddle the MCL/GWQS. Preliminary data from an ongoing federal study of passive diffusion samplers for sampling PFAS (2021). Well IDs have been renamed for confidentiality. (Section 5.3.2)

5.3.3 DMPDB™ and Low-Flow: Anonymous Consultant Study in Boston

The data scatter plot below represents the first known side-by-side field trial for PFAS sampling of a DMPDB™ sampler compared to low-flow pumping in 2016. The data represents one well with high concentrations across a range of PFAS (Anonymous Consultant, 2016). Low-flow pumping and the DMPDP resulted in samples with similar concentrations of the various PFAS in the well (Figure 14)

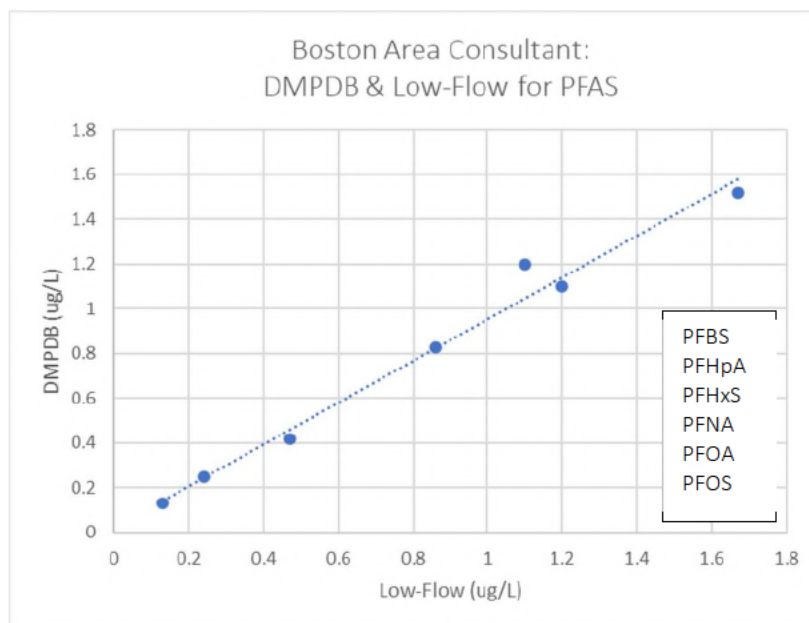


Figure 14: Scatterplot of PFAS concentrations from samples taken by the DMPDB compared to samples taken by low-flow pumping, ($y = 0.9313x + 0.0242$, $R^2 = 0.9818$). Provided by anonymous consultant in the Boston area, 2016. (Section 5.3.3)

5.3.4 DMPDB™ and Low-Flow: Geosyntec, Princeton NJ

Geosyntec (Princeton, NJ) conducted a three-well study comparing low-flow pumping to the DMPDB™ for 24 PFAS at a former manufacturing facility (Evans & Eberle, 2021). Eleven PFAS were detected at concentrations from 0 ng/L to 15 ng/L. T-tests conducted by the researchers showed that for 8 of the 11 detections (PFHpA, PFHxS, PFHxA, PFOS, PFOA, PFPeS, PFUnA, and PFNA), there were no significant differences between concentration values from DMPDB™ samples and Low-Flow samples (Table 5). For the three detections where concentration values from the DMPDB™ and low-flow differed (PFPeA, PFBA, PFBS), the researchers determined that the outlier for each compound originated from the same well and there was not enough data to know if the variations related to site conditions or sample method. Bar charts in Figure 15 show the side-by-side concentrations in DMPDB™ and Low-Flow samples for each of the three wells.

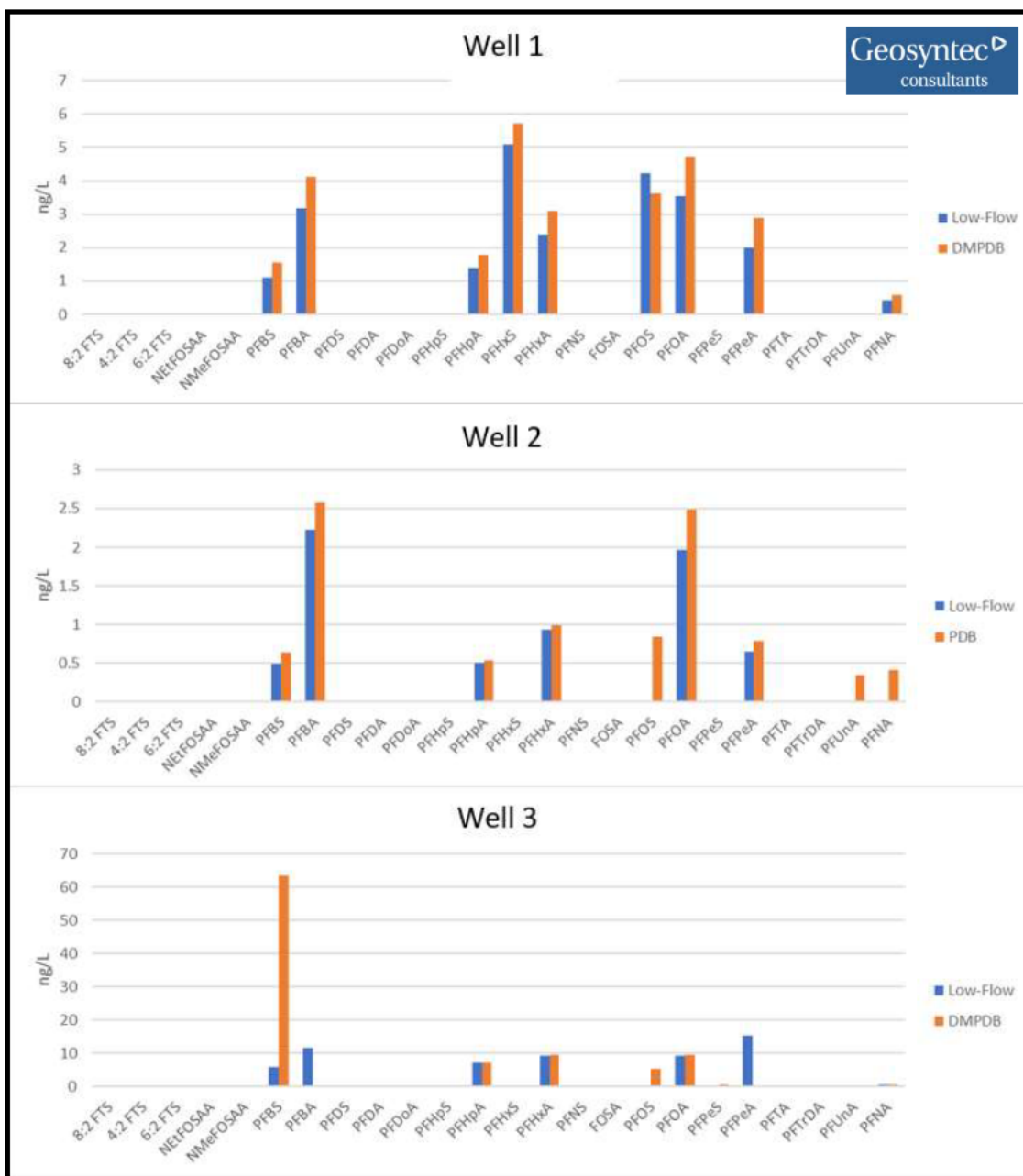


Figure 15: Bar charts show that DMPDB sample concentrations closely compare to low-flow concentrations by PFAS in 3 wells. Jessica Evans and Dylan Eberle, Geosyntec. Evans & Eberle, *Great Lakes Virtual PFAS Summit 2021*, Presentation. (Section 5.3.4)

Evans and Eberle (2021) concluded that there is overall good agreement between DMPDB™ and low-flow samples, yielding comparable results. They determined that the results are promising for regulatory acceptance and suggested that passive samplers contribute to a “weight of evidence” approach and that time-weighted averages produced by the DMPDB™ may be less susceptible to natural variations than instantaneous samples, such as those acquired by pumping or grab sampling. The advantages claimed when sampling using DMPDB™s included reduced sampling time, fewer pieces of equipment, less wastewater, and sample interval accuracy.

Table 5: T-test results for differences between DMPDB and Low-flow Samples

Compound	t<2.447 @ 95% confidence	Pass?
PFHpA	0.124	Yes
PFHxS	0.172	Yes
PFHxA	0.237	Yes
PFOS	1.649	Yes
PFOA	0.556	Yes
PFPeS	0.577	Yes
PFUnA	0.481	Yes
PFNA	0.641	Yes
PFBS	6.067	No
PFBA	2.760	No
PFPeA	3.096	No

5.3.5 DMPDB™ and Low-flow: PFAS in Groundwater & Porewater, Integral Consulting, Inc

In October 2020, Integral Consulting Inc. (Shields & Palko, 2022) conducted a field pilot study comparing PFAS concentrations in samples collected from 11 groundwater monitoring wells using the DMPDB™ and low-flow pumping. Wells sampled as part the study ranged in PFAS concentration with three wells containing concentrations greater than 1,000 ng/L, four wells containing concentrations 100 to 1,000 ng/L, and four wells containing concentrations ranging between 10 to 100 ng/L. Shields presented these results at the 2022 Battelle Conference on Chlorinated Solvents.

This study was completed in an environment where fine silts and clays are present within the aquifer, causing turbidity impacts during low-flow sampling. Elevated turbidity concentrations can elevate laboratory reporting limits to levels above the NJ MCLs/GWQS. Since the DMPDB™ is known to limit the amount of silt in the sample, it was anticipated that the use of DMPDB™s would minimize the turbidity-caused bias in lab results.

The study demonstrated, that for New Jersey's priority PFAS (PFOA, PFOS, PFNA), the results from the DMPDB™ had a very strong positive correlation with those from low-flow pumping, with R² ratios of 0.9875 to 0.9924. (Figure 16). One well, however, exhibited high turbidity at 143 NTUs and produced an outlier data point across each of the three priority PFAS. Turbidity associated with pumped samples from this well caused the lab reporting limit to be elevated to 17ng/L which is above the state MCL/GWQS of 13-14 ng/L. While the PFAS concentrations between the DMPDB™ and low-flow did not correlate closely at this well, the DMPDB™, because of the lower sample turbidity, allowed the concentrations to more accurately be measured below the state MCL/GWQS, better representing the groundwater PFAS concentrations and meeting state requirements.

As part of the same presentation, the authors also described their study comparing samples of sediment porewater in a stream environment, acquired using the DMPDB™, to samples acquired using a push-point sampler and a peristaltic pump. It was noted that the DMPDB™s provided samples with less turbidity, which reduced the analytical bias and noise. The study concluded that DMPDB™ technology

works for groundwater and porewater PFAS sampling, is a more holistic approach that provides cost savings, is suitable for long-term monitoring, and addresses site-specific considerations.

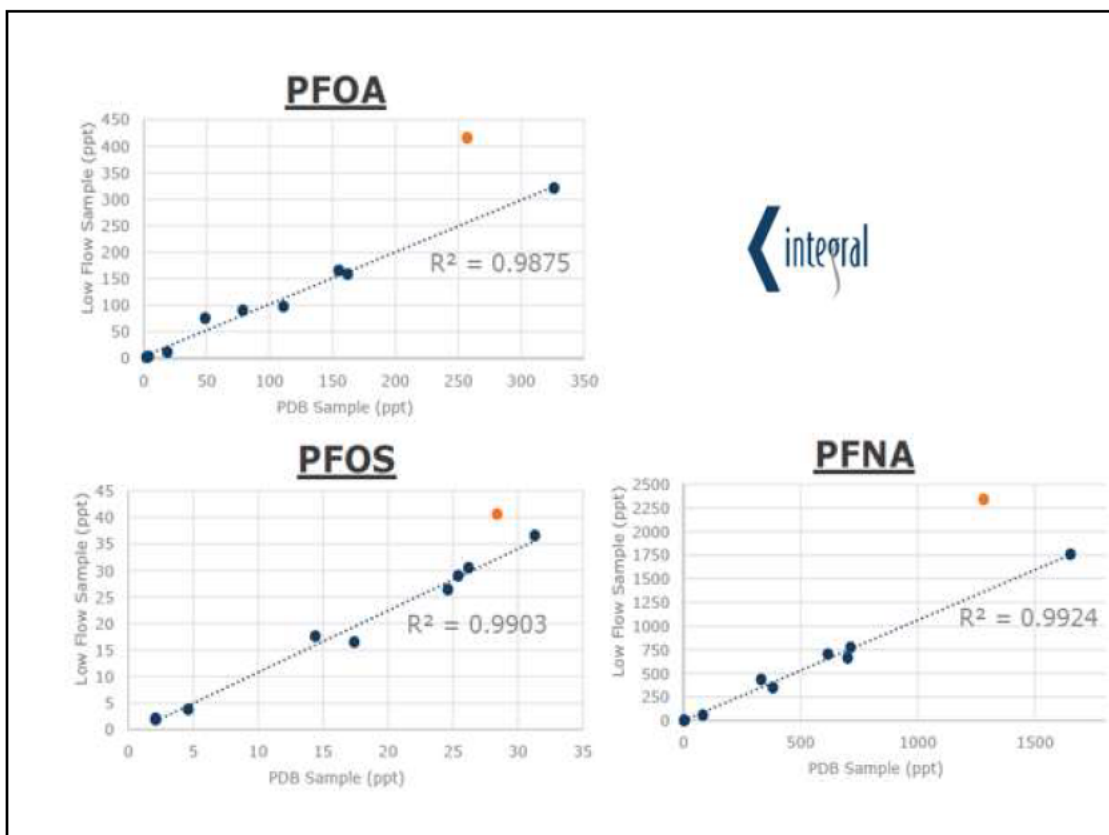


Figure 16: Scatter Plots of 3 priority PFAS concentrations acquired using the DMPDB compared to low-flow sampling. Provided by Shields & Palko, Integral Consulting, Inc. Presented at *Battelle Conference*, May 2022. (Section 5.3.5)

6.0 Conclusions: Summary and Conclusions

Passive diffusion sampling has been used worldwide since 1998 to acquire over a million samples of VOCs in groundwater. The well-documented benefits, including ease of use, portability, interval delineation, elimination of IDW, reduced turbidity, and cost savings of 50 to 80%, provide for a sustainable method that produces results comparable to active sampling methods.

The development and commercial availability in 2014 of a Dual Membrane Passive Diffusion Bag (DMPDB™) sampler has widely expanded the capabilities of passive diffusion samplers to include metals, inorganics, ions, VOCs, and SVOCs including 1,4 Dioxane. The DMPDB™ is currently in use on sites managed or sampled by the U.S. EPA, DoD, DoE, state environmental regulatory departments, and consultant-managed private sites since their introduction. At these sites, the DMPDB™s have been producing groundwater samples with results that correlate to conventional pumping and bailing techniques and have been adopted to replace active sampling methods to save reduce cost, save time, eliminate IDW and to address site-specific conditions or needs.

As PFAS has arisen as a contaminant of concern, the requirements and protocols for sampling parts-per-trillion concentrations of these ubiquitous molecules have increased above and beyond those for groundwater sampling of other contaminants. Sampling for PFAS adds cost, time, and complexity. The DMPDB™ has the design characteristics and sampling history that suggest it would be an appropriate device to reduce cost and complexity when groundwater sampling for PFAS. To validate the DMPDB™ as a tool for PFAS monitoring, it was subject to controlled bench scale testing and independently conducted field studies, thereby helping to meet the stated EPA goals outlined in their PFAS roadmap (2021) and elsewhere.

In 2017, bench-scale testing of the DMPDB™ for sampling PFAS demonstrated that the DMPDB™ acquired aqueous samples containing PFAS concentrations that compared closely to control samples ranging from 0 ng/L to 36 ng/L (ppt), and further showed that:

- Representative short-chain, medium chain, and long chain PFAS diffuse into the DMPDB™.
- PFAS that diffuse into the DMPDB™ reach equilibrium within 21 days of residence time and then maintain equilibrium with the water surrounding the DMPDB™.
- DMPDB™s accurately represent the PFAS concentrations in the water surrounding the samplers.
- The DMPDB™ is effective for very low concentrations of PFAS, making it an accurate & reliable option for even the most stringent of state and federal regulations for sampling PFAS concentrations in groundwater.

Five independent, side-by-side field studies compared concentrations of PFAS in groundwater acquired using the DMPDB™, with concentrations from samples acquired by pumping. In all five studies, the DMPDB™ sample results corresponded strongly with sample results from their comparative pumping methods. Importantly, in the majority of side-by-side comparisons where the PFAS concentration was near the MCL, the result from the DMPDB™ and the result from pumping were similar enough that both methods would likely lead to the same decisions about what actions were needed to comply with regulations. The results from field testing are promising for regulatory acceptance, and they show that:

- DMPDB™s produce field results for PFAS that are comparable to those from low-flow pumping.
 - In particular, results showed very strong positive correlations for PFOS, PFOA, PFNA, which are often listed as the most significant PFAS of concern.
- DMPDB™s show several PFAS-sampling benefits over low-flow pumping, including:
 - Eliminating purge wastewater, and therefore reducing IDW
 - Increasing the sample interval accuracy
 - Collecting samples with less turbidity, and therefore less analytical bias and noise
- DMPDB™s significantly reduce time, equipment, and costs associated with PFAS sampling.
- In addition to its effectiveness in general groundwater sampling, DMPDB™ sampling is suitable for addressing many site-specific considerations, including:

- Sediment Porewater
- Long-term monitoring
- Turbid conditions
- Wells with long saturated screens, where separate intervals should be profiled
- High traffic areas where fast and efficient methods are needed

As with all groundwater sampling projects, choice of sampling method and interpretation of results—especially of differences in side-by-side results should take site conditions, sampling environment, and data quality objectives into consideration. Under many such conditions and objectives, however, the benefits of using the DMPDB™ to sample PFAS and other groundwater contaminants are clear: it provides results that represent the surrounding groundwater, eliminates PFAS containing IDW, reduces turbidity-caused bias, allows the profiling of separate intervals in wells with long saturated screens, substantially reduces the need for equipment and instruments, allows quick sampling in high traffic areas, and reduces sampling cost by 50 to 80 percent.

References

- ⁶Anonymous Consultant. 2016. Side-by-side data comparing sampling results from a DMPDB™ with results from low-flow sampling for PFAS. Boston, MA. Unpublished Data.
- Barcelona, J., Gibb, P., Helfrich, A., and Garske, E. 1985. *Practical guide for groundwater sampling*. Illinois State Water Survey Contract, Report 374/US Environmental Protection Agency, EPA/600/2-85/104, R.S. Kerr Environmental Research Center, Ada, OK.
- ⁷Caprio, P. (2021). *DMPDB™ PFAS Study Results*. EA Engineering Science and Technology, Presentation for DoD Stakeholders.
- Caprio, P., Thieleman, E., and Gragert, S. 2021. "Collecting groundwater samples for PFAS analysis." *The Military Engineer (TME)*, Vol. 113, 76-77 p
- EA Engineering, Science, & Technology, Inc. 2014. DMPDB™ sampling results compared to results from low-flow sampling for metals and inorganics, representing USEPA Region VI Sprague Road and State Road 114 Superfund sites, 2014-2016. Unpublished data and correspondence with EON Products.
- EA Engineering, Science, and Technology, Inc., PBC. 2016. *Kirtland Air Force Base Quarterly Report, Quarters 2 & 3*. Bulk Fuels Facility, Albuquerque, NM.
- EA Engineering, Science, and Technology, Inc., PBC. 2017. *Kirtland Air Force Base Quarterly Report, Quarter 1*. Bulk Fuels Facility, Albuquerque, NM.
- EON Products, Inc. 2017. Bench Study Procedure and Results for sampling PFAS with a Dual Membrane Passive Diffusion Sampler. Unpublished Data.
- Haynes, T. 2019. *Dark Waters*. Focus Features, Produced by Mark Ruffalo and Christine Vachon.
- Evans, J. and Eberle, D. 2021. *Use of Dual-Membrane Passive Diffusion Bags to Sample PFAS*. Geosyntec, Princeton, NJ. Presented at the 2021 Great Lakes Virtual PFAS Summit.
- Imbrigiotta, T. E., & Harte, P. T. 2020. *Passive sampling of groundwater wells for determination of water chemistry* (No. 1-D8). US Geological Survey.
- ITRC (Interstate Technology and Regulatory Council). 2004. *Technical and regulatory guidance for using polyethylene diffusion bag samplers to monitor volatile organic compounds in ground water*. DSP-3. Washington, D.C.: Interstate Technology & Regulatory Council, Diffusion Sampler Team. www.ITRCweb.org
- ITRC. 2005. *Technology overview of passive sampler technologies*. DSP-4. Washington, D.C.: Interstate Technology & Regulatory Council, Diffusion Sampler Team. www.ITRCweb.org
- ITRC. 2007. *Protocol for Use of Five Passive Samplers to Sample for a Variety of Contaminants in Groundwater*. DSP-5. Washington, D.C.: Interstate Technology & Regulatory Council, Diffusion/Passive Sampler Team. www.ITRCweb.org
- ITRC. 2020. *Sampling Precautions and Laboratory Analytical Methods for Per- and Polyfluoroalkyl Substances (PFAS)*. PFAS-1. Washington, D.C.: Interstate Technology & Regulatory Council, PFAS Team. <https://pfas-1.itrcweb.org/>

⁶ Consultant & Project names redacted by request.

⁷ Client and site names redacted by request.

- ITRC. 2021. *Sampling & Analysis: 1,4 Dioxane*. 14D-1. Washington, D.C.: Interstate Technology & Regulatory Council, 1,4-Dioxane Technical Team. <https://14d-1.itrcweb.org/fact-sheets/>
- Parsons ES (Parsons Engineering Science, Inc). 1999. *Final technical report for the evaluation of groundwater diffusion samplers*. Consultant's Report to the Air Force Center for Environmental Excellence, Technology Transfer Division. Contract F11623-94-D0024.
- Parsons ES (Parsons Engineering Science, Inc). 2005. *Final results report for the demonstration of no-purge groundwater sampling devices at former McClellan Air Force Base, California*. U.S. Army Corps of Engineers; Air Force Center for Environmental Excellence; Air Force Real Property Agency. Contract F44650-99-D-0005.
- Puls, R. W. and Barcelona, M. J. 1996. *Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedures*. U.S. Environmental Protection Agency Report: Ground Water Issue. EPA/540/S-95/504, R.S. Kerr Environmental Research Center, Ada, OK.
- Shields, K. and Palko, E. 2022. *Evaluating PFAS Sample Bias in High Turbidity Environments Using Passive Sampling Methods—Pilot Studies*. Presentation at the Battelle Twelfth International Conference on Remediation of Chlorinated & Recalcitrant Compounds, 2022.
- USEPA (U.S. Environmental Protection Agency). 2021. *PFAS Strategic Roadmap: EPA's Commitments to Action 2021-2024*. https://www.epa.gov/system/files/documents/2021-10/pfas-roadmap_final-508.pdf
- ⁸U.S. Government Agency. 2021. Preliminary PFAS sampling data comparing DMPDB™ to volume purge. Agency and site names redacted by request. Correspondence with EON Products & Unpublished data.
- Vroblecky, D.A. 2001a. *Users guide for polyethylene-based passive diffusion bag samplers to obtain volatile organic compound concentrations in wells, Part 1: Deployment, recovery, data interpretation, and quality control and assurance*. U.S. Geological Survey Water-Resources Investigations Report 01-4060.
- Vroblecky, D.A. 2001b. *User's guide for polyethylene-based passive diffusion bag samplers to obtain volatile organic compound concentrations in wells. Part 2: Field Tests*. U.S. Geological Survey Water-Resources Investigations Report 01-4061.

⁸ This agency, whose name and site names were redacted on request, will publish this study in 2023, pending peer review.

Appendix A

Discussion of Active Sampling Methods

Active groundwater sampling methods use mechanical devices to artificially cause water to flow into a well at rates greater than the existing natural flow, to remove or bypass stagnant water, and withdraw a water sample for laboratory testing.

Since the early days of groundwater sampling, most samples have been acquired by one of two active methods: "Volume Purge" (Barcelona, Gibb, Helfrich, & Garske, 1985) or "Low-Flow Pumping" (Puls & Barcelona, 1996). Volume purge is performed using a bailer or pump to remove 3 to 5 volumes of water from the well before obtaining a sample. This large volume of water is removed to eliminate stagnant water that accumulates in the casing above the saturated well screen or aerated water at the top of the water column when screens are not fully saturated. The potentially contaminated purge-water is called "Investigation Derived Waste" (IDW) and may have to be containerized and disposed of at additional cost and time.

A 2-inch diameter well with 50-feet of water requires at least 90 trips up and down the well with a standard 1-liter bailer to purge the minimum of 3 volumes, which is about 25 gallons of wastewater, before the sample can be recovered. Pumps operate at a rate of up to several gallons per minute and can purge the well faster than bailing. The amount of IDW stays the same as bailing however, the reduction in labor and time that purge pumps offer may be offset by the cost and the mobility difficulties attributed to the need for an electric, gas, or compressed-air power source to run the pumps and the need to transport that equipment to each well. Pumps also have limitations in pumping depth based on size and power requirements. The life of the pump may be reduced if it is pumping turbidity or granular sediments or if corrosive conditions exist in the well.

Low flow pumping is a specialized, pumping method that requires the pump intake be placed well below the casing or the top of the water column, adjacent to the intended intake zone, and pumping at a low rate, usually less than 200ml per minute. By pumping at a low rate, the operator attempts to pull water horizontally from the adjacent aquifer and minimize the vertical drawdown of stagnant or aerated water from the casing or the aerated portion of a partially saturated screen into the pump. To reduce the likelihood of sampling stagnant water, the water flowing out of the pump is monitored for "stabilization parameters" such as Oxygen, pH, EC, ORP, and sometimes turbidity, using a water quality meter and a flow-thru cell. The concentration of these parameters may be different in some parts of the well compared to the water in the aquifer so as pumping commences the parameters may change as more or less of the stagnant water is sampled. When the parameters have stabilized for a pre-determined time, usually several minutes, it suggests that the pumped water is coming directly from the aquifer and at that point the discharge tubing can be diverted from the waste container to fill the lab containers

This process is slow and can take extensive time to acquire a sample, and it requires a pump, a power source, and water quality instruments. Although to a lesser extent than volume purge, low-flow pumping also generates IDW and may increase sample turbidity. (Parsons Engineering Science, Inc., 1999, p37).

While the intent of low-flow pumping is to draw water horizontally from the adjacent aquifer, in practice, the pumped flow into and through the well will be weighted by the variations in hydraulic

Appendix A

conductivity along the length of saturated screen. Therefore, pumping, even at a low rate, can still produce samples that are a blend of water from different intervals, resulting in a flow-weighted sample or a volume integrated sample (Imbrigiotta, & Harte, 2020). As saturated screens become longer the likelihood and effect of blending from different intervals increases. It may be acceptable that the water represents weighted contributions, however it is important to understand the source of water and how that impacts decision making with regard to regulatory requirements.

Sampling for PFAS has added additional constraints and protocols that further complicate groundwater sampling. Materials used in the equipment should not contain PFAS or other materials that could bias sample concentrations if they should come in contact. In either case of volume purge or low-flow pumping, a considerable amount of time can be spent purging, IDW has to be managed, turbidity is more likely to occur because of the induced, rapid movement of water, and equipment logistics become a factor adding to project cost, sustainability, and potentially safety when sampling high-traffic areas. While volume-purge and low-flow pumping groundwater sampling methods have been employed since the early days of sampling, and have an established history of data collection, there are considerations that may give way to using alternative sampling methods.

Appendix B

Table B1: Rinsate Test Results for PFAS

Dual Membrane Passive Diffusion Bag Sampler (HDPE)

Client Sample ID: 5M7-36 Lab Sample ID: 320-48897-3 Matrix: Water	eurofins-TestAmerica				
Method: 537 (modified) - Fluorinated Alkyl Substances					
Analyte	Result	Qualifier	RL	MDL	Unit
Perfluorobutanoic acid (PFBA)	ND		1.7	0.30	ng/L
Perfluorooctanoic acid (PFOA)	ND		1.7	0.72	ng/L
Perfluorooctane sulfonate (PFOS)	ND		1.7	0.46	ng/L
Perfluoropentanoic acid (PFPeA)	ND		1.7	0.42	ng/L
Perfluorohexanoic acid (PFHxA)	ND		1.7	0.49	ng/L
Perfluoroheptanoic acid (PFHpA)	ND		1.7	0.21	ng/L
Perfluorobutanesulfonic acid (PFBS)	ND		1.7	0.17	ng/L
Perfluorohexanesulfonic acid (PFHxS)	0.27	J B	1.7	0.14	ng/L
6:2 FTS	ND		17	1.7	ng/L
Perfluoroundecanoic acid (PFUnA)	ND		1.7	0.94	ng/L
Perfluorodecanesulfonic acid (PFDS)	ND		1.7	0.27	ng/L
Perfluorotetradecanoic acid (PFTeA)	ND		1.7	0.25	ng/L
Perfluorodecanoic acid (PFDA)	ND		1.7	0.26	ng/L
Perfluorotridecanoic acid (PFTriA)	ND		1.7	1.1	ng/L
4:2 FTS	ND		17	4.4	ng/L
Perfluorononanoic acid (PFNA)	ND		1.7	0.23	ng/L
Perfluoropentanesulfonic acid (PFPeS)	ND		1.7	0.26	ng/L
Perfluorononanesulfonic acid (PFNS)	ND		1.7	0.14	ng/L
8:2 FTS	ND		17	1.7	ng/L
N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)	ND		17	1.6	ng/L
Perfluorododecanoic acid (PFDoA)	ND		1.7	0.47	ng/L
Perfluorooctanesulfonamide (FOSA)	ND		1.7	0.30	ng/L
N-methylperfluorooctanesulfonamidoacetic acid (NMeFOSAA)	ND		17	2.6	ng/L
Perfluoroheptanesulfonic Acid	ND		1.7	0.16	ng/L

Qualifier	Qualifier Description
B	Compound was found in the blank and sample.
I	Value is EMPC (estimated maximum possible concentration).
J	Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.

QC Method Blank	Result	Qualifier	RL	MDL	Unit
Perfluorohexanesulfonic acid (PFHxS)	0.357	2	0.2	0.17	ng/L

Table B1 shows the results from rinsate testing for PFAS of the DMPDB™. PFAS-free deionized water was poured into the DMDPB™, then the DMPDB™ was emptied into an HDPE lab container and shipped to eurofins Test America for analysis. The results show that the DMPDB™ does not contain or leach PFAS into water that comes in contact with the sampler.

Appendix C

Bench Test of the Dual Membrane Passive Diffusion Sampler for Per & Polyfluoroalkyl Substances (PFAS)

Purpose:

Controlled laboratory tests were conducted to validate that samples acquired using the Dual Membrane Passive Diffusion Sampler (DMPDB) represent the concentrations of PFAS in the water surrounding the sampler after a designated residence time. Eight PFAS compounds were studied, including; short-chain, medium-chain, and long-chain, to provide a representation across the range of PFAS.

Test Method:

1. The sampling tests were conducted in a controlled environment using a PVC test chamber filled with approximately 67 Liters of water and the spiked with eight lab certified PFAS, representing long, medium and short chain PFAS.
2. The chamber water was intermittently mixed using a low volume peristaltic lab pump and allowed to stabilize for 6 days after spiking.
3. 6 days after spiking, 9 DMPDB samplers were filled with 500ml each of DI water and installed in the chamber using EON's polypropylene suspension tether assemblies. The samplers were left in place for the specified residence times to allow for the concentration gradient to cause PFAS to diffuse from the chamber fluid, through the membranes and into the samplers. The total water volume for the samplers and the chamber was approximately 71.5 Liters. The water in the samplers comprised about 6.3% of the total water volume.
4. At 21 days after sampler installation, a control sample of the chamber water was obtained through a port midway along the height of the chamber, and decanted into lab supplied HDPE bottles. 3 DMPDB samplers were then removed from the chamber and the contents decanted into lab supplied HDPE bottles. After the 3 samplers were removed and sampled, a second control sample was taken of the chamber water and decanted into lab supplied HDPE bottles. The remaining 6 samplers were left in place.
5. The samples above were sent to TestAmerica labs and analyzed for the 8 spiked PFAS using method 537M.
6. At 41 days after sampler installation, a control sample was taken from the port in the chamber and decanted into lab supplied HDPE bottles. The remaining 6 DMPDB samplers were then removed from the chamber and the contents decanted into lab supplied HDPE bottles. After the 6 samplers were removed and sampled, another control sample was taken of the chamber water and decanted into lab supplied HDPE bottles.
7. The samples were sent to TestAmerica for analysis of 8 PFAS using method 537M. These first samples were tested at a TestAmerica facility in Sacramento, Ca. and the second set was tested at the TestAmerica facility in Lancaster, PA. because of the laboratory's PFAS backlog.

Discussion & Notes:

- Since the test objective was to determine if the sampler concentrations match the concentrations of the chamber water at a point in time, pre-test concentrations of PFAS in the chamber were not collected. Changes that may have occurred in the PFAS concentrations in the chamber were deemed irrelevant as long as the sampler results were similar to the chamber concentrations at each sample event.
- An initial stabilization period was allowed after spiking the chamber water to ensure the PFAS mixing and so that any potentially significant reaction of PFAS with the chamber, would be minimized before adding the samplers.
- Two control samples were acquired at each sample event, one immediately before and one immediately after the samplers were removed from the chamber and sampled. This provided a way to gauge repeatability and set a reference for test variability outside of the samplers.

- The control samples were acquired from a port midway along the height of the chamber in such a way that the control samples did not come in contact with any materials other than the test chamber and the HDPE sample bottles.
- The laboratory results from the two control samples taken at each sampler removal can be compared to the results from the sampler contents from that test to determine if the sampler produces results equivalent to the water surrounding the samplers.
- Three of the nine samplers were removed from the chamber and contents tested after 21 days and then the remaining nine samplers were removed and tested after 41 days so that it could be determined whether concentration equilibration between the sampler contents and the chamber water could be achieved in 21 days or if a longer residence was required, and are there any negative effects from a longer residence time within these residence time parameters.
- The data suggests that 21 days residence is adequate to produce a representative PFAS sample. A lower limit has not been established. Additional time may be required in slow recharge wells to accommodate the well returning to "normal" conditions after being disturbed when the samplers are added, however that time is not related to membrane diffusion time.
- There was a slight concentration decrease between the time the first samplers were removed and the second samplers were removed from the chamber. It is significant and positive that the controls and the samplers each tracked similar decreases. The cause for the decrease is unknown but possibilities include; variances in lab processing as the first set of samples were directed to one TestAmerica facility and the second set to another, or disturbing the chamber contents during two rounds of sampling caused a decrease for unknown reasons.
- Some current publications express concern over adsorption of PFAS compounds onto sampling equipment such as bailers and tubing, causing a reduction in the PFAS concentrations in the water samples after the sample is removed from the well. It is hypothesized that the longer residence time required for diffusion sampling allows PFAS in the groundwater to equilibrate with the sampler materials before the sampler is removed from the well, negating the effect of adsorption that may otherwise occur with short contact times experienced by pumping and bailing. The high degree of correlation between sampler results and the controls suggest that adsorption is not affecting DMPDB sample results because of the extended sampler residence time required for passive diffusion sampling.
- The test concentrations in the range of about 20 ng/L to 30ng/L are about half of the EPA threshold of 70 parts per trillion (ppt) (ng/L).
- *A second round of sampling, following a similar procedure, was conducted at spiked concentrations from about 1 ng/L to 10 ng/L and showed similar correlations between the controls and the sampler contents, further demonstrating the effectiveness of the DMPDB for sampling PFAS, even at concentrations below 10ng/l.*

Dual Membrane PDB (DMPDB) PFAS Test Data

Compare the DMPDB Sample results to the Control Sample results for each PFAS

Table C1: 20-30 ng/L PFAS

Method: 537 (modified) - Fluorinated Alkyl Substances			Residence Time 21 Days				
PFAS	Laboratory (ng/L)		Control Samples (ng/L)		DMPDB Samples (ng/L)		
Sample ID>	RL	MDI	4MC-16	4MC-26	4M4-16	4M5-16	4U5-16
6:2-Fts	1.75	0.87	29	30	28	30	28
Perfluoro-Octanesulfonate	1.75	0.35	18	20	20	21	19
Perfluorobutanesulfonic Acid	0.87	0.26	36	36	34	33	34
Perfluoroheptanoic acid	0.87	0.35	27	28	29	30	26
Perfluorohexanesulfonic Acid	1.75	0.35	29	27	24	27	26
Perfluorohexanoic acid	1.75	0.35	30	31	31	31	30
Perfluorooctanoic acid	0.87	0.26	37	35	33	35	36
Perfluoropentanoic acid	5.3	1.8	30	30	30	29	29

Table C2: 20-30 ng/L PFAS

Method: 537 (modified) - Fluorinated Alkyl Substances			Residence Time 41 Days							
PFAS	Laboratory (ng/L)		Control Samples (ng/L)		DMPDB Samples (ng/L)					
Sample ID>	RL	MDI	4MC-36	4MC-46	4M5-16	4L5-26	4U4-16	4MR-16	4L4-16	4M5-26
6:2-Fts	1.75	0.87	25	23	23	21	20	22	21	21
Perfluoro-Octanesulfonate	1.75	0.35	18	17	18	20	17	18	17	16
Perfluorobutanesulfonic Acid	0.87	0.26	30	28	29	29	28	28	29	26
Perfluoroheptanoic acid	0.87	0.35	24	23	23	21	22	22	22	23
Perfluorohexanesulfonic Acid	1.75	0.35	23	23	25	23	23	22	25	23
Perfluorohexanoic acid	1.75	0.35	29	29	27	27	29	26	26	28
Perfluorooctanoic acid	0.87	0.26	32	33	32	32	29	33	29	31
Perfluoropentanoic acid	5.3	1.8	25	25	24	24	23	24	24	25

Table C3: 1-10 ng/L PFAS

Method: 537 (modified) - Fluorinated Alkyl Substances			Residence Time: 21 Days										
PFAS	Laboratory (ng/L)		Control Samples (ng/L)		DMPDB Samples (ng/L)								
Sample ID>	RL	MDL	5MC-16	5MC-26	5U4-16	5U5-16	5U5-26	5L4-16	5L5-16	5L5-26	5M4-16	5M5-16	5M5-26
Perfluorobutanoic acid (PFBA)	1.9	0.33	1.3	1.0	1.4	1.2	1.3	1.3	1.4	1.2	1.1	1.4	1.3
qualifier			J	J	J	J	J	J	J	J	J	J	J
Perfluorooctanoic acid (PFOA)	1.9	0.81	10	10	9.8	9.8	11	9.8	10	11	9.7	10	9.9
Perfluorooctanesulfonic acid (PFOS)	1.9	0.51	6.5	5.9	5.9	14	6.3	5.8	8.3	6.1	7.3	6.1	6.0
Perfluoropentanoic acid (PFPeA)	1.9	0.47	7.5	7.4	7.6	6.7	7.3	6.9	7.7	7.9	6.7	8.1	7.3
Perfluorohexanoic acid (PFHxA)	1.9	0.55	8.6	8.2	9.1	9.2	8.9	8.5	8.8	8.6	9.0	8.8	8.4
Perfluoroheptanoic acid (PFHpA)	1.9	0.24	7.4	7.0	7.0	7.0	7.0	7.0	7.2	7.0	7.4	6.6	7.1
Perfluorobutanesulfonic acid (PFBS)	1.9	0.19	8.8	8.9	8.2	10	8.9	8.5	9.1	9.3	8.9	8.8	9.5
Perfluorohexanesulfonic acid (PFHxS)	1.9	0.16	7.3	7.5	7.2	7.3	7.0	7.3	7.5	7.3	7.5	7.3	7.2
qualifier			B	B	B	B	B	B	B	B	B	B	B
6:2 FTS	19	1.9	7.2	6.6	7.3	7.1	6.4	6.7	7.1	7.1	6.7	6.1	6.3
qualifier			J	J	J	J	J	J	J	J	J	J	J

Table C4: Lab Qualifiers and Method Blank for Table 3

Qualifier	Qualifier Description				
B	Compound was found in the blank and sample.				
J	Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.				
QC Method Blank	Result	Qualifier	RL	MDL	Unit
Perfluorobutanoic acid (PFBA)	0.476	J	2.0	0.35	ng/L
Perfluorohexanesulfonic acid (PFHxS)	0.357	J	2.0	0.17	ng/L

Tables C1 to C4 present lab results from bench tests of the DMPDB. Table titles show the concentration range for each test and column headings show the residence time for each test. Control Samples are from water surrounding the DMPDBs in the test chamber. Each row displays results for a specific PFAS representing short-chain, medium-chain, and long-chain PFAS molecules. All concentrations are in ng/L (ppt).

Appendix C

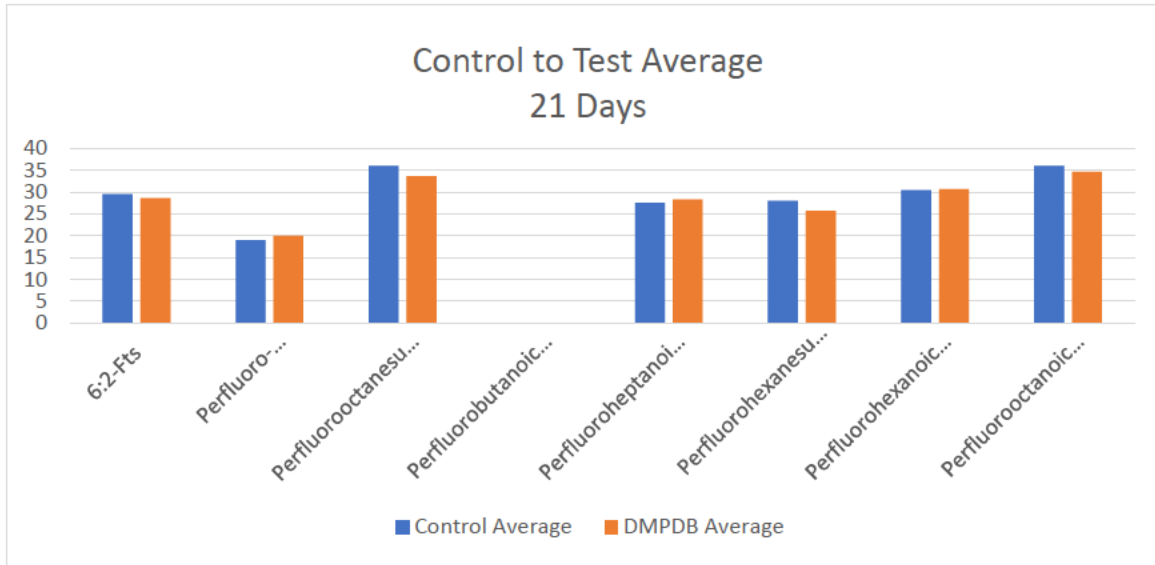


Figure C1: Side-by-Side bar graph comparing the average of two controls to the average of the DMPDB™s for each tested PFAS at concentrations 18 to 36 ng/L after a residence time of 21 days. (section 5.2)

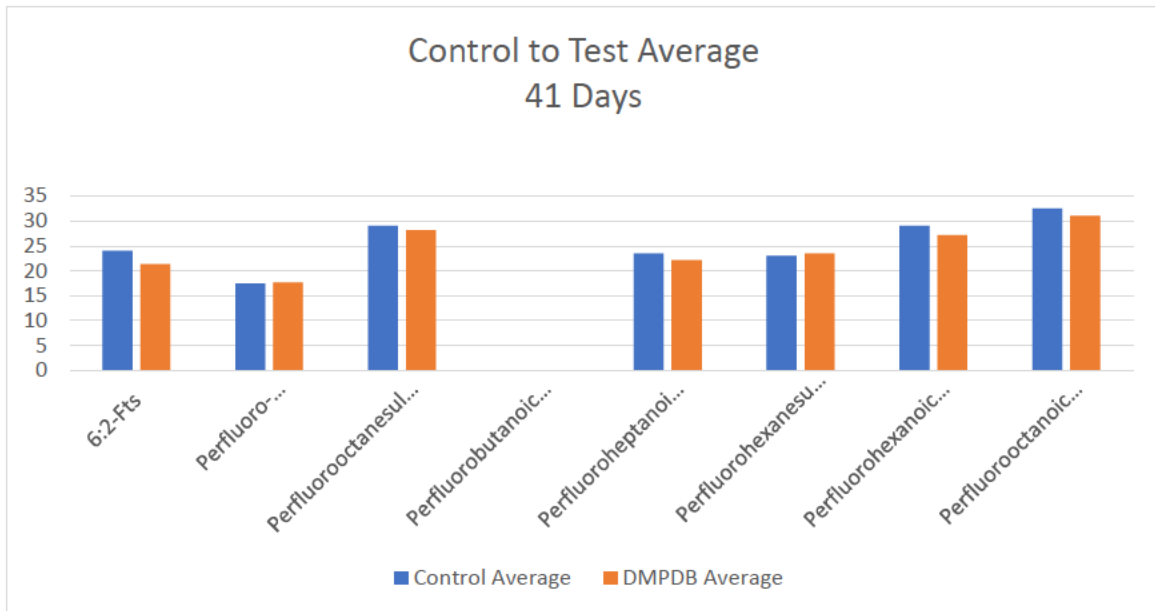


Figure C2: Side-by-Side bar graph comparing the average of two controls to the average of the DMPDB™s for each tested PFAS at concentrations 18 to 36 ng/L after a residence time of 41 days. (section 5.2)

Appendix C

Table C5: Bench Test Variance between DMPDBs and Controls for Higher PFAS Concentrations after 41 days

PFAS 17-36 ng/L (41 Days)	Number of Samplers	Control 3&4 Mean (ng/L)	Control Variance (ng/L)	Max Deviation to Control Mean (ng/L)	Min Deviation (ng/L)	Avg Deviation (ng/L)	Mode (ng/L)
6:2-Fts	6	24.0	2.0	4.0	1.0	2.7	3.0
Perfluorobutanoic acid (PFBA)	6	2.0 J	0.0	2.3 J	1.8 J	2.1 J	2.0 J
Perfluoroheptanoic acid (PFHpA)	6	23.5	1.0	2.5	0.5	1.3	1.5
Perfluorohexanesulfonic acid (PFHxS)	6	23.0	0.0	2.0	0.0	0.8	0.0
Perfluorohexanoic acid (PFHxA)	6	29.0	0.0	3.0	0.0	1.8	2.0
Perfluoro-Octanesulfonate	6	17.5	1.0	2.5	0.5	1.0	0.5
Perfluorooctanesulfonic acid (PFOS)	6	29.0	2.0	3.0	0.0	0.8	0.0
Perfluorooctanoic acid (PFOA)	6	32.5	1.0	3.5	0.5	1.7	0.5
Perfluoropentanoic acid (PFPeA)	6	25.0	0.0	2.0	0.0	1.0	1.0

Table C5 shows the variance between DMPDB sample results and the average of two controls (C3 & C4) for each PFAS at concentrations between 17 ng/L and 36 ng/L after 41 days. (Section 5.2)

APPENDIX D

Preliminary Field Data From Federal Agency Passive Sampler PFAS Test

This Data has been provided under conditions that the agency and site are not identified pending publication of peer reviewed report. Field sampling conditions and the effects on results are not included here and will be included in the agency's final report.

Table E1

Well ID	PFAS (Red are NJ Priority: PFNA, PFOA, PFOS)	Pump Result (ng/l)	DMPDB™ Result (ng/l)
TW8	Perfluorooctanoic acid (PFOA)	29.2	19.4
TW8	Perfluorooctanesulfonic acid (PFOS)	9.0	5.1
TW12	Perfluorobutanoic acid	20.3	16.3
TW12	Perfluoropentanoic acid	11.5	9.4
TW12	Perfluorohexanoic acid	13.3	11.1
TW12	Perfluoroheptanoic acid	11.4	9.6
TW12	Perfluorooctanoic acid (PFOA)	38.7	32.2
TW12	Perfluorononanoic acid (PFNA)	5.3	4.3
TW12	Perfluorobutanesulfonic acid	7.5	5.5
TW12	Perfluorooctanesulfonic acid (PFOS)	8.9	7.0
TW21	Perfluorobutanoic acid	19.0	12.6
TW21	Perfluoropentanoic acid	24.9	15.9
TW21	Perfluorohexanoic acid	32.7	21.3
TW21	Perfluoroheptanoic acid	22.3	14.4
TW21	Perfluorooctanoic acid (PFOA)	60.9	41.0
TW21	Perfluorononanoic acid (PFNA)	21.6	14.8
TW37	Perfluoropentanoic acid	5.3	5.1
TW37	Perfluorohexanoic acid	7.8	7.2
TW37	Perfluorooctanoic acid (PFOA)	10.5	9.4
TW37	Perfluorooctanesulfonic acid (PFOS)	11.9	8.1
TW 25	Perfluoropentanoic acid	6.3	6.6
TW 25	Perfluorohexanoic acid	7.1	7.4

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Table E1

Well ID	PFAS (Red are NJ Priority: PFNA, PFOA, PFOS)	Pump Result (ng/l)	DMPDB Result (ng/l)
TW 25	Perfluoroheptanoic acid	4.4	4.7
TW 25	Perfluorooctanoic acid (PFOA)	7.7	8.3
TW 25	Perfluorobutanesulfonic acid	5.7	6.5
TW 25	Perfluorohexanesulfonic acid	12.1	13.0
TW 25	Perfluorooctanesulfonic acid (PFOS)	7.1	7.6
TW39	Perfluorooctanoic acid (PFOA)	8.5	11.1
TW39	Perfluorooctanesulfonic acid (PFOS)	6.5	4.3
TW18	Perfluorobutanoic acid	8.1	9.0
TW18	Perfluoropentanoic acid	16.0	15.0
TW18	Perfluorohexanoic acid	10.5	12.4
TW18	Perfluoroheptanoic acid	4.7	6.5
TW18	Perfluorooctanoic acid (PFOA)	8.5	13.6
TW18	Perfluorononanoic acid (PFNA)	2.6	3.8
TW18	Perfluorobutanesulfonic acid	2.7	3.8
TW18	Perfluorooctanesulfonic acid (PFOS)	8.3	12.8
TW35	Perfluorobutanoic acid	5.6	6.1
TW35	Perfluoropentanoic acid	5.9	6.6
TW35	Perfluorohexanoic acid	8.2	9.4
TW35	Perfluoroheptanoic acid	3.2	3.5
TW35	Perfluorooctanoic acid (PFOA)	6.5	7.0
TW30	Perfluorobutanoic acid	9.3	6.7
TW30	Perfluoropentanoic acid	9.2	7.5

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Table E1

Well ID	PFAS (Red are NJ Priority: PFNA, PFOA, PFOS)	Pump Result (ng/l)	DMPDB Result (ng/l)
TW30	Perfluorohexanoic acid	9.2	6.1
TW2	Perfluorobutanoic acid	121.0	122.0
TW2	Perfluoropentanoic acid	388.0	416.0
TW2	Perfluorohexanoic acid	274.0	272.0
TW2	Perfluoroheptanoic acid	105.0	131.0
TW2	Perfluorooctanoic acid (PFOA)	127.0	119.0
TW2	Perfluorononanoic acid (PFNA)	13.9	14.9
TW2	Perfluorodecanoic acid	4.0	5.0
TW2	Perfluorobutanesulfonic acid	68.9	54.3
TW2	Perfluoropentanesulfonic acid	107.0	75.3
TW2	Perfluorohexanesulfonic acid	806.0	443.0
TW2	Perfluoroheptanesulfonic acid	29.1	20.6
TW2	Perfluorooctanesulfonic acid (PFOS)	1440.0	936.0
TW2	Perfluorononanesulfonic acid	12.4	7.2
TW2	6:2 Fluorotelomer sulfonate	265.0	376.0
TW2	8:2 Fluorotelomer sulfonate	13.6	16.6
TW32	Perfluorobutanoic acid	52.6	66.6
TW32	Perfluoropentanoic acid	124.0	198.0
TW32	Perfluorohexanoic acid	77.6	117.0
TW32	Perfluoroheptanoic acid	47.3	66.6
TW32	Perfluorooctanoic acid (PFOA)	35.8	48.5
TW32	Perfluorononanoic acid (PFNA)	11.9	15.9

Appendix D

Preliminary Field Data From Federal Agency Passive Sampler PFAS Test

This Data has been provided under conditions that the agency and site are not identified pending publication of peer reviewed report. Field sampling conditions and the effects on results are not included here and will be included in the agency's final report.

Table D1

Well ID	PFAS (Red are NJ Priority: PFNA, PFOA, PFOS)	Pump Result (ng/l)	DMPDB Result (ng/l)
TW32	Perfluorodecanoic acid	3.8	4.7
TW32	Perfluorobutanesulfoni acid	52.4	57.6
TW32	Perfluoropentanesulfonic acid	55.7	71.3
TW32	Perfluorohexanesulfonic acid	280.0	373.0
TW32	Perfluoroheptanesulfonic acid	12.8	16.2
TW32	Perfluorooctanesulfonic acid (PFOS)	720.0	815.0

Table D1 shows the preliminary concentration data from a side-by-side field study of the DMPDB™ compared to pumping. Results that are below the lab Reporting Limit are not included. Concentrations are in ng/L (ppt). PFAS listed in Red are the New Jersey priority PFAS. Agency and site names have been redacted and well IDs have been changed by agency request pending a full report of the study. (section 5.3.2)