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480 BARNSTABLE ROAD
HYANNIS, MASSACHUSETTS
RELEASE TRACKING NUMBER 4-26347

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1.0 INTRODUCTION

The Horsley Witten Group, Inc. (HW) has been retained by the Cape Cod Gateway Airport (the "Airport") to prepare this revised Phase II Comprehensive Site Assessment (Phase II) for its property located at 480 Barnstable Road, Hyannis, Massachusetts (Figure 1). The Phase II focuses on the release of Per- and Poly-Fluoroalkyl Substances (PFAS) in soil and groundwater and 1,4-dioxane in groundwater. For the purpose of this report, the term PFAS is defined as the laboraoty's analyte list as of the date of this Phase II. In general, the laboratories are reporting between 21 and 34 diffferent PFAS analtes. The Massachusetts Department of Environemtnal Protection (MassDEP) curently regulates six of these PFAS analytes.

On November 9, 2021, HW submitted a Notice of Delay in Compliance with Response Action Deadlines relating to the Phase III Remedial Action Plan for PFAS and 1,4-dioxane in soil and/or groundwater. The original deadline to submit this report was November 10, 2021. The delay was related to the following reasons as outlined below:

- On August 24, 2021, the Airport received a Notice of Audit Findings and Notice of Non-Compliance (Enforcement Document Number 00011495) that identified additional information that MassDEP required as part of the comprehensive audit of the Final Phase II Comprehensive Site Assessment submitted on March 12, 2021 (the "2021 Phase II").
- During subsequent discussions with MassDEP including two remote meetings held on August 30, 2021, and October 1, 2021, the Airport indicated that the Phase III Remedial Action Plan (Phase III Report) could not be completed until there was agreement regarding the source of the 1,4-dioxane groundwater plume and the extent of the Airports PFAS plumes documented in the 2021 Phase II. The Airport indicated that a comprehensive response to Notice of Audit Findings and Notice of Non-Compliance (the "Notice of Audit Findings Response") would be submitted to the MassDEP on November 10, 2021. The response provided additional documentation that the source of the 1,4-dioxane plume is related to unknown off-site source and that the Airports PFAS plume has not yet impacted the Maher Well Field. The response also included a new timeline for submittal of a revised Phase II and Phase III Report as follows:
    - Submission of the response to the Notice of Audit Findings: **November 10, 2021**
    - Receipt of comments/question from MassDEP: **December 10, 2021**
    - Submission of a revised Phase II Report: **January 28, 2022**
    - Submission of the Phase III Report: **April 1, 2022**

HW did not receive any questions or comments from MassDEP regarding the Notice of Audit Findings Response as of the date of this Phase II (January 28, 2022). A copy of the Notice of Audit Findings Response is included in Appendix A. It should also be noted that the supplemental information requested by MassDEP has not changed the findings of the 2021 Phase II.

2.0 EXECUTIVE SUMMARY

For the purpose of this report, the term "Airport" specifically refers to the Cape Cod Gateway Airport property located at 480 Barnstable Road, as set forth above, and the term "Disposal Site" refers to the area impacted by the release of oil and/or hazardous material (OHM) subject to Release Tracking Number (RTN) 4-26347. A Site Locus Map and the Disposal Site Map are provided as Figures 1 and 2

HW has prepared this Phase II in accordance with the Massachusetts Contingency Plan 310 CMR 40.0000 (MCP). The Phase II has also been prepared consistent with the Final Public Involvement Plan (the "Final PIP") for the Airport dated September 16, 2019. Consistent with the Final PIP, all persons identified on Table 1, Community Notification List, have been notified on the availability of this Phase II. The Airport previously provided a 21-day review period to allow for comments from the public. Public comments were only received by Mr. Tom Cambareri on behalf of the Town of Barnstable Department of Public Works. Where appropriate, Mr. Cambareri's comments were incorporated into this 2021 Phase II and have also been incorporated into this Phase II. A copy of Mr. Cambareri's comments are included in Appendix B.

The Phase II is based on the collection and laboratory analysis of the following samples collected between 2015 and 2021:

- 125 soil samples for laboratory analysis of PFAS;
- Three surface water samples for laboratory analysis of PFAS;
- 158 groundwater samples for laboratory analysis of PFAS;
- 45 groundwater samples for laboratory analysis of 1,4-dioxane;
- Eight fire truck spray water samples;
- Six soil and two building material samples for synthetic precipitation leaching procedure (SPLP) analysis;
- 13 groundwater and one surface water samples for Stable Isotope Analysis; and,
- 1 aqueous film-forming foam ("AFFF") sample.

As documented in "*Interim Guidance on Sampling and Analysis for PFAS at Disposal Sites Regulated Under the Massachusetts Contingency Plan", a fact sheet* prepared by the MassDEP and dated October 21, 2020, the following six PFAS analytes are currently regulated in Massachusetts:

- Perfluorodecanoic Acid (PFDA);
- Perfluoroheptanoic Acid (PFHpA);
- Perfluorohexanesulfonic Acid (PFHxS);
- Perfluorooctanoic Acid (PFOA);
- Perfluorooctanesulfonic Acid (PFOS); and,
- Perfluorononanoic Acid (PFNA)

Although MassDEP is currently regulating the six PFAS analytes described above, it does recommend that the 14 analytes included in EPA Method 537.1.1 be evaluated to determine if other PFAS analytes may be present in a release. MassDEP has not provided toxicity information sufficient for the purposes of conducting a MCP risk assessment beyond the six PFAS analytes documented above (refer to the Technical Support Document titled "*Per-and Polyfluoroalkyl Substances (PFAS): An Updated Subgroup Approach to Groundwater and Drinking Water Values*" prepared by the MassDEP and dated December 26, 2019).

The Airport has gone beyond the recommended list of 14 PFAS analytes included in EPA 537.1.1 and instead is currently evaluating the PFAS release using approximately 21 to 34 PFAS-analytes that are reported by the laboratory. The sum of all 21 to 34 compounds is used to determine "Total PFAS" present in soil, groundwater, and surface water. The term "Total PFAS" does not include the over 4,000 other PFAS analytes that are not reported in the current analytical testing method. This term is also different from the "Sum of Six" which is the sum of the MassDEP six regulated PFAS analytes (PFDA, PFHpA, PFHxS, PFOA, PFOS, and PFNA).

Based on interviews with Airport staff (Mr. Art Jenner and Bob Holzman) who have worked at the Airport since the 1980s, AFFF was only intentionally sprayed at the Airport during tri-annual drills (1991, 1994, 1997, 2000, 2003, 2006, 2009, and 2012), during an Airport Emergency (1981 and 2016 aircraft crash), and once per year between 2004 and 2015 as part of the Federal Aviation Administration ("FAA") annual foam testing requirement (14 CRF 139). With the exception of the 1991 tri-annual drill, all drills have been conducted at the unpaved Deployment Area (Figure 2) located adjacent to the East Ramp at the Airport. With the exception of the events detailed above, the two Airport staff indicated that foam testing was not completed prior to 1991 due to cost, limited availability, and lack of an FAA requirement mandating foam usage.

Historical Airport purchase records indicate that a fluorotelomer-based AFFF (Chem-Guard 3% mil spec) has been purchased by the Airport since 2000, and interviews with Airport staff indicated that this type of foam was also purchased as early as the 1980s. According to the Interstate Technology Regulatory Council (ITRC), fluorotelomer-based AFFF has been available since the 1970's. As indicated above, fluorotelomer-based AFFF contains multiple PFAS analytes including the MassDEP Sum of Six and substantially higher levels of 6:2 FTS when compared to other PFAS analytes.

In addition to the tests and training usage with AFFF, daily (approximately 5 gallons) and monthly (100 gallons) testing of the fire apparatus is conducted with just water. The test is conducted to verify that the fire apparatus pumps are operational. No foam is intentionally sprayed during these tests. The spray water from the fire trucks were tested for PFAS in 2019 to verify that the valve mechanism that segregates the AFFF tank from the water tank was working properly. The analytical results indicated that AFFF was being mixed with the water unintentionally (no visible foam generation) from the internal AFFF holding tanks, and the resulting spray water had a concentration of PFAS above the MassDEP Sum of Six Method 1 GW-1 standard (Table 2).

It was determined that the valve that segregates the AFFF was faulty and was the cause of the unintentional mixing. The faulty valve was replaced, and a maintenance schedule has been initiated to prevent the unintentional mixing. Subsequent testing of the spray water indicates that PFAS levels are less than the current Method 1 GW-1 standard, although PFAS is still detected (Table 2). The combination of tri-annual drills, the annual AFFF testing, and, to a lesser extent, the daily and monthly spraying of water have contributed to the AFFF related PFAS impacts in the Deployment Area. The Airport stopped using AFFF in the tri-annual training drills in 2015 and purchased an ecological cart in 2016 to stop spraying AFFF as part of the annual FAA testing requirement.

The extent of the PFAS plume in the vicinity of the Deployment Area is indicated on Figure 2. The plume location is based on analytical data, environmental forensics (to distinguish PFAS sources in co-mingled plumes), and PFAS related fate and transport mechanisms of the MassDEP Sum of Six and 6:2 FTS. based on analytical data and forensics, the Airport AFFF PFAS plume in the Deployment Area does not appear to have impacted the Maher Wells with the MassDEP Sum of Six PFAS analytes at this time. However, due to the direction of groundwater flow which is moving south/southeasterly, it is understood that the Airport's PFAS Plume is migrating downgradient toward the Maher Wells and will likely impact them in the near future.

The current Airport Rescue and Firefighting/Snow Removal Equipment (ARFF/SRE) Building was constructed in 1996, and PFAS is assumed to have been released in this area through what is presumed to be incidental spillage, drips from fire hoses that are hung to dry, and cleaning of equipment in the event of accidentally engaging the foam pump button. Interior floor drains within the ARFF/SRE building historically discharged to the adjacent grass area that was capped in the fall of 2020 to reduce infiltration of stormwater. The interior floor drains were closed in the 2000's and connected to a permitted discharge to the Barnstable Wastewater Treatment Plant.

The extent of the PFAS plume in the vicinity of the ARFF/SRE Area is indicated on Figure 2. Again, this projected plume location is based on analytical data, environmental forensics (to distinguish PFAS sources in co-mingled plumes), and PFAS related fate and transport mechanisms of the MassDEP Sum of 6 (See Section 5.0 for more information). The Airport's AFFF PFAS plume in the vicinity of the ARFF/SRE Building does not appear to have impacted the Maher Wells with the MassDEP Sum of Six PFAS analytes. However, due to the direction of groundwater flow which is moving south/southeasterly, it is understood that the Airport's PFAS Plume is migrating downgradient toward the Maher Wells and will likely impact them in the near future.

Prior to 1996, the Airport fire truck was housed in the former ARFF/SRE Building located adjacent to the former terminal along the North Ramp as indicated on Figure 2. This building was demolished in 2011. Based on interviews with two firefighting staff who have worked at the Airport since the 1980s, AFFF containers were also stored in this building. The building did have two floor drains that were closed prior to 1997 (discharge location unknown) and a third-floor drain that was traced to a catch basin that discharged to Upper Gate Pond. The former building was surrounded in its entirety by asphalt and, according to stormwater plans from 1999, storm drains in proximity to the building discharge to Upper Gate Pond. Investigation conducted in the vicinity of the former ARFFF/SRE Building did not identify any of the six regulated PFAS analytes in soil above the laboratory reporting limit (Table 3). Groundwater testing in the area did identify concentrations of the Sum of Six PFAS above the applicable Method 1 GW-1 Standard, however the impacts are not consistent with the Airports AFFF release (Table 4). The detections appear to be related to the off-Airport PFAS source(s) that are migrating onto the Airport. Additionally, testing of surface water from Upper Gate Pond did not identify any of the Sum of Six PFAS analytes above the laboratory reporting limit (Table 5).

During the assessment to delineate the nature and extent of PFAS relating to the Airport's use of fluorotelomer-based AFFF, PFAS in groundwater above the MassDEP Sum of Six Method 1 GW-1 Standard was identified entering the Airport from several upgradient locations. Forensic techniques, including data normalization and the preparation of Radar Plots for the purpose of distinguishing PFAS sources, was necessary to differentiate the Airport's PFAS source from other nearby, off-site sources. Radar plots were generated for each of the groundwater monitoring wells tested both on and off Airport property, from the fire truck spray water, and from AFFF concentrate. The data normalization used all laboratory reported PFAS and their contribution to the "Total PFAS" concentration detected in groundwater. The Radar Plots are considered a PFAS fingerprint. The PFAS fingerprint was used to determine plume migration relating to the Airport PFAS release as well as contributions from other off-site non-Airport related sources.

As indicated on Figure 2, PFAS impacted groundwater is migrating onto the Airport from hydraulically upgradient sources that are not consistent with the AFFF PFAS plume associated with Airport. Additionally, as indicated on Figure 2, the PFAS plume associated with the Airport does not appear to have reached the Maher Wells at the time of monitoring. Additional testing of soil and/or groundwater is planned as part of ongoing IRA activates to further support the Conceptual Site Model, aid with any proposed remedial design, and refine the forensic approach for source delineation.

The Airport has also contained a majority of its sources of PFAS in soil and groundwater relating to the historic deployment of AFFF via the installation of two impermeable caps (as indicated on Figure 3). The cap installations were completed in the Fall of 2020, and additional details are included in the report titled "*Immediate Response Action Plan Status Report 8*" dated October 2020 which is available for direct download from the MassDEP Searchable Sites Database using RTN 4-26347.

Additionally, 1,4-dioxane is noted as a contaminate of concern at the Airport. It has been detected in one deep monitoring well (HW-L [d]) on the Airport property and within several monitoring wells located off-Airport property, both hydraulically upgradient, cross-gradient and down-gradient. A potential source of 1,4-dioxane at the Airport is a historic release of 1,1,1-trichloroethane (1,1,1-TCA, RTN 4-00823) from an oil/water separator associated with a floor drain in the former Provincetown Boston Airlines hangar (currently leased to Cape Air) and from the use of aircraft deicing fluids. However, multiple groundwater samples collected from the former 1,1,1-TCA release area in the North Ramp did not detect 1,4-dioxane above the laboratory reporting limit (Figure 4).

A second potential source of 1,4-dioxane is from Aircraft deicing fluids. These fluids are not discharged to the unpaved surface but, instead, are currently discharging directly to the municipal sewer under an approved connection. Historic deicing (pre-2015) was conducted on the paved surface and the sprayed fluid was vacuumed up and directly discharged to the municipal sewer system under an approved discharge. Two of the deicing locations are located upgradient of HW-L(d), and groundwater testing downgradient of these locations did not identify 1,4-dioxane above the laboratory reporting limit. The third deicing location was historically located approximately 1,500 feet cross-gradient to HW-L and groundwater testing in the vicinity of this de-icing pad also did not identify 1,4-dioxane above the laboratory reporting limit. Considering the depth at which the 1,4-dioxane has been detected at the Airport and Maher Wells (70 to 123 feet below grade), the 1,4-dioxane appears to be from an off-Airport source located more than 6,000 feet hydraulically upgradient. The location of the current and former deicing areas is shown on Figure 3. The estimated extent of the 1,4-dioxane plume is depicted on Figure 2 and a cross-sectional representation of analytical data from monitoring wells is presented on Figures 5 and 6.

3.0 DISPOSAL SITE INFORMATION

Pursuant to 310 CMR 40.0835(4)(a), (b) and (c), a Phase II Comprehensive Site Assessment shall include the following Disposal Site information.

3.1 Disposal Site Name and Location

Pursuant to 310 CMR 40.0835(4) (a) the Disposal Site name and location are set forth below.

Cape Cod Gateway Airport
480 Barnstable Road
Hyannis, Massachusetts 02601

3.2 Disposal Site Map

Pursuant to 310 CMR 40.0835(4)(b), Figure 2 provides a detailed Disposal Site Map depicting all investigatory sampling points relevant to the Phase II and the boundaries of the Disposal Site.

3.3 Disposal Site History

Pursuant to 310 CMR 40.0835(4)(c), the Disposal Site History is set forth below.

3.3.1 General Airport Description

The Airport is located in Hyannis, Massachusetts, and provides scheduled airline service, general aviation services, and other aviation related activities. The Airport is owned by the Town of Barnstable and is managed through the Barnstable Municipal Airport Commission ("BMAC"). The Airport began as a private airport consisting of a single grass runway before being given to the Town of Barnstable in the 1930's. With the outbreak of World War II, the Airport was taken over by the federal government for wartime training and defense purposes. During the 1940's, the United States Navy used the Airport and expanded the airfield to include three runways. In 1946, the Airport was returned to a two-runway municipal airport (each runway has a designation at each end, being 15-33 and 6-24). In 1948, the Airport was conveyed by the United States government (pursuant to the Surplus Property Act of 1944) to the Town of Barnstable, acting by and through its Airport Commission.

Currently, the Airport is comprised of approximately 645 acres of land, with approximately 140 acres that are impervious (e.g., paved areas such as parking lots, runways, taxiways, aircraft parking aprons, concrete walkways, and building rooftops). The Airport's structures include the main terminal and the Air Traffic Control Tower ("ATCT"), which are located south of the runways and taxiways, as well as several hangars used for general aviation and operations services. In addition, the current ARFF/SRE Building is located in the southeast corner of the property. The Airport is situated in an area of Hyannis zoned for Business and Industrial uses. A topographic map with the Airport property boundary outlined is attached as Figure 1, and the area impacted by the release of PFAS and 1,4-Dioxane is indicated on Figure 2.

3.3.2 General Regulatory History

The evaluation for 1,4-dioxane at the Airport began in July 2015 when the MassDEP requested samples be collected from existing monitoring wells to evaluate the presence or absence of this analyte on Airport property. The request was related to the detection of 1,4-dioxane at the Maher Well field, located south of the Airport property, and the potential for the detection to be attributed to historic releases from a floor drain at the former Provincetown Boston Airlines hangar (currently leased to Cape Air) located on the North Ramp (RTN 4-823, closed). The historic release had been known to contain 1,1,1-TCA, which is a product known to potentially contain 1,4-dioxane.

In August 2016, the Airport conducted an initial round of groundwater sampling to evaluate the presence of PFAS compounds, also at the request of MassDEP. Subsequently, a Notice of Responsibility (NOR), dated November 10, 2016, was issued to the Airport by the MassDEP. The NOR requested that the Airport conduct additional field investigations to evaluate:

- The source(s) of PFAS including PFOS and PFOA detected in groundwater at the Airport;

- The source(s) of 1,4-dioxane detected in a monitoring well downgradient of the Airport on the Maher Well field property; and
- To identify potential impacts to public water supply wells operated by the Hyannis Water District at the Mary Dunn and Maher Well fields.

A proposed Immediate Response Action (IRA) plan was submitted to the MassDEP for approval in response to the NOR. Subsequently, a meeting was held by MassDEP at the Airport that included other stakeholders including the Barnstable Department of Public Works, the Hyannis Water District, and Barnstable County representatives (representing the Fire Training Academy). At the meeting, IRA plans were coordinated between the Airport and Fire Training Academy including sampling locations, type of analysis, groundwater modeling, goals, and next steps. The IRA plan served as the guide for the soil and groundwater testing conducted since November 2016 to follow up on the results of the previous analyses.

In June 2019, the MassDEP issued a Request for Modified Immediate Response Action Plan/Interim Deadline dated June 18, 2019 (the "Modified IRA Request") to the Airport. The Modified IRA Request asked that the Airport propose response actions to *"reduce infiltration of precipitation through PFAS-impacted soil, such as temporarily capping the source areas; excavating and properly disposing of the PFAS-impacted soil; or some equivalent approach".* The Airport's response is documented in the report titled "*Final Immediate Response Action Plan Modification",* prepared by HW and dated December 2019 (the "IRA Modification"). The IRA Modification included details for the installation of an impermeable cap in two select areas to reduce precipitation infiltration. The two areas are identified as the Deployment Area and the ARFF/SRE Area. The two capped areas total approximately 94,100-square feet and represent a majority of the known PFAS source areas at the time of the report relating to the historic use of AFFF. The caps were completed in September 2020 and are documented in the report titled "*Immediate Response Action Plan Status Report 8".* The surficial extent of the two capped areas is indicated on Figure 4.

3.3.3 Sources of PFAS at the Airport

The source of PFAS related to Airport operations is from the use of AFFF for training and emergencies. Personnel working at the Airport since the 1980's were consulted to determine when AFFF use occurred for training purposes or during an actual aircraft accident. Details concerning AFFF usage is set forth below.

AFFF Usage for Testing and Training

- Historical Airport purchase records indicate that a fluorotelomer-based AFFF (Chem-Guard 3% mil spec) has been purchased by the Airport over the last twenty years, and interviews with staff indicated that this type of foam was also purchased as early as the 1980s. With the exception of the events detailed below, AFFF was not intentionally sprayed due to cost and limited supply of AFFF.

  - Further information regarding foam use was provided through interviews with Art Jenner and Bob Holzman who have worked at the Airport since the 1980's. Both are firefighters and first responders and stated that fluorotelomer based foam was purchased by the Airport since the 1980s. Additionally, according to the ITRC document titled *"Aqueous Film-Forming Foam (AFFF)"* dated August 2020 (refer to Attachment A), fluorotelomer-based AFFF has been available since the 1970s and other AFFF formulations have been available since the late 1960s.

- FAA regulations require a Tri-Annual Drill which is a full-scale live exercise that simulates a major airport disaster to test the emergency coordination and response skills of the Airport and other first responders. AFFF was used at the Deployment Area between 1994 and 2004 for triannual drills and between 2004 and 2015 for annual AFFF mixture testing. Two firefighting personnel, employed by the Airport since the 1980's, indicated that foam was not used prior to 1991 due to cost, limited availability, and lack of an FAA requirement mandating foam usage. With the exception of the drill in 1991, as shown on the Figure 3, all drills occurred at the unpaved Deployment Area, indicated on Figure 3. The tri-annual drills occurred as follows:
  - July 17, 1991
  - Nov. 16, 1994
  - Nov. 17, 1997
  - Nov. 2, 2000
  - Oct. 18, 2003
  - Oct. 25, 2006
  - Oct. 22, 2009
  - Oct. 11, 2012
  - Oct. 28, 2015 (No AFFF used during this drill – just water)
  - Sept 5, 2018 (No AFFF used during this drill – just water)
- There was one triannual drill in 1991 that occurred in an area on the north ramp of the Airport where HW investigated and collected soil data from six sampling locations (Figure 3). With the exception of a detection of PFHxS at location 1991B 0-1', none of the soil samples exceeded the applicable Method 1 Standard for any of the MassDEP six regulated PFAS compounds (Table 3). The detection of PFHxS at this location is not consistent with the Airport's use of AFFF and is consistent with the 20 background samples (Table 6) collected and discussed in addital detail below. Furthermore, soil samples consistent with the Airports AFFF contain elevated levels of 6:2 FTS, PFNA, and PFHpA. None of these compounds were detected in sample 1991B 0-1'.
- Beginning in 2004, annual testing of the AFFF mixture became an FAA requirement. The test was conducted to ensure that the foam used by the Airport consists of the appropriate AFFF to water mixture (3%). Historically, the test consisted of shooting the

mixture of AFFF from the fire rescue vehicle at a small square target. Adjustments were then made, if needed, to allow for proper spray coverage consistent with the FAA regulations. According to Airport personnel, testing of the foam consistency prior to 2004 was not completed due to the cost, supply of AFFF and lack of an FAA mandate.

  - Approximately 80 gallons of 3-percent AFFF concentrate was historically used annually beginning in 2004 to conduct the test (see table below).
  - All testing has been conducted in the same unpaved location on the Airport since 2004 (Deployment Area).
  - The Airport purchased an Ecological Cart in 2016 so that the AFFF mixture could be verified without using or spraying foam. The Airport has not used AFFF for testing purposes since 2016. The Ecological Cart was the first unit purchased by a Massachusetts airport and well before FAA approval for universal airport usage.

- FAA regulations require a supply of AFFF concentrate on hand to resupply two trucks. The concentrate is stored in the ARFF/SRE Building located in the ARFF/SRE Area as indicated on Figure 2. As of January 2022, the Airport has 907 gallons of AFFF concentrate on hand. This includes 500 gallons within containers and 407 gallons within the fire trucks.
- Expired AFFF that is no longer useable is removed by Global Remediation, a licensed waste disposal company. As indicated on the manifests included in Appendix C, Global Remediation removed 100-gallons of AFFF concentrate on June 13, 2019 and 50-gallons on March 4, 2020.

The current ARFF/SRE Building was constructed in 1996, and PFAS is assumed to have been released in this area through what is presumed to be incidental spillage, dripping from fire hoses s hung to dry, and cleaning of equipment in the event of accidentally engaging the foam pump button. Prior to 1996, the Airport fire truck was housed in the former ARFF/SRE Building located adjacent to the former terminal along the North Ramp (see attached Figure 2). This building was demolished in 2011. Based on interviews with two firefighting staff who have worked at the Airport since the 1980s, AFFF containers were also stored in this building. The building did have two floor drains that were closed prior to 1997 (discharge location unknown) and a third-floor drain that was traced to a catch basin that discharged to Upper Gate Pond. The former building was surrounded in its entirety by asphalt and, according to stormwater plans from 1999, storm drains in proximity to the building also discharge to Upper Gate Pond.

Investigation conducted in the vicinity of the former ARFFF/SRE Building did not identify any of the regulated Six PFAS analytes in soil above the laboratory reporting limit (HW-X(m) [7-9] , Table 4) . Groundwater testing in the area did identify concentrations of the Sum of Six PFAS (HW-X[s] and HW-X[m], Table 2) above the applicable Method 1 GW-1 Standard, however the impacts are not consistent with the Airports AFFF release. The detections appear to be related to the off-Airport PFAS source(s) that are migrating onto the Airport. Additionally, testing of surface water from Upper Gate Pond did not identify any of the Sum of Six PFAS analytes above the laboratory reporting limit.

Interior floor drains within the current ARFF/SRE building historically discharged to the adjacent grass area that was capped in the fall of 2020 to reduce infiltration of stormwater. In the event the foam pump was accidentally engaged, equipment was rinsed by pumping water through it and then discharging the water to the adjacent grass area that has since been capped. Stormwater, in the vicinity of the recently capped area, also historically infiltrated into this area and included both the building's roof and surrounding paved surface areas. The interior floor drains historically discharged to this area but were closed and connected to a permitted discharge to the Barnstable Wastewater Treatment Plant in the early 2000's. As part of the cap installed in 2020, stormwater was redirected away from this area and instead infiltrates beyond the PFAS impacted area. The oil/water separator is inspected quarterly by Airport staff and then pumped, cleaned, and serviced by Global Remediation, as needed. As indicated on the manifest in Appendix C, 1,290-gallons of the oil/water separator liquid was pumped on October 29, 2017. The oil/water separator is located within the extent of the PFAS plume at the location indicated on Figure 2.

Within MassDEP's Notice of Audit Findings, there was mention of additional available records of past foam usage for fire training exercises at the Airport. HW reviewed these additional records which included a picture from a YouTube video provided in an email to MassDEP from an outside party during the audit process. HW viewed this video, which documents a fire training exercise at the Airport in 1956. However, AFFF with PFAS was manufactured in the United States beginning in the late 1960s, according to the ITRC document titled *"AFFF"* dated August 2020 (see Attachment A), about 10 years after the exercise shown in the video. This event included in the photo took place before AFFF was manufactured with PFAS compounds, and therefore, it does not constitute a release of PFAS at the Airport.

Additionally, it is important to note that the Barnstable Fire Training Academy (BFTA), the neighboring parcel, came into existence in 1956, per the BFTA website. This facility was built to provide a location for local fire departments to conduct local and regional training exercises and, as such, the need to use the Airport as a training venue was reduced.

AFFF Usage for Emergencies

- Personnel working at the Airport since the 1980's were consulted to determine when AFFF use occurred during an actual aircraft accident and only two instances were identified. Please note that AFFF is NOT used during an incident unless there is a spark of fire. The majority of accidents do not result in the use of AFFF. Airport personnel identified the following aircraft emergencies where AFFF was used: The 1981 crash of a Beech 18 aircraft east of runway 24 between Yarmouth Road and the Airport (off-Airport property). The 2016 crash of a Cirrus aircraft in the parking lot of the rental car facility west of the terminal building. Approximately 10 gallons of the 3-percent AFFF concentrate was used during the crash response, and 100% of this AFFF liquid was contained within a solid bottom catch basin and removed via a vacuum truck by Global Remediation during response actions. There was no known release to groundwater. A copy of the waste disposal manifests is included in Appendix C.

AFFF Purchase Quantity and Usage

Historical Airport purchase records indicate that a fluorotelomer-based AFFF (Chem-Guard 3% mil spec) has been purchased by the Airport over the last twenty years, and interviews with staff indicated that this type of foam was also purchased as early as the 1980s. According to Airport available purchase, the following quantities of AFFF concentrate have been purchased and used by the Airport since 2000:

Year	AFFF Type	AFFF 3% Concentrate Purchased	Approximate AFFF 3% Concentrate Used for Training	Approximate AFFF 3% Concentrate Used for Tri-Annual Drill	Approximate AFFF 3% Concentrate Used for Annual Testing	Approximate Total AFFF Concentrate Used Annually	Approximate Total AFFF Concentrate and Water Mix	Approximate AFFF Stockpiled Based on Use*
		(Gal.)	(Gal.)	(Gal.)	(Gal.)	(Gal.)	(Gal.)	(Gal.)
2000	Chem-Guard 3% mil-spec foam	200	0	40	0	40	1333	485
2001	None purchased	0	0	0	0	0	0	485
2002	Chem-Guard 3% mil-spec foam	30	0	0	0	0	0	515
2003	Chem-Guard 3% mil-spec foam	40	0	40	0	80	2667	475
2004	Chem-Guard 3% mil-spec foam	40	0	0	80	80	2667	435
2005	None purchased	0	0	0	80	80	2667	355
2006	Chem-Guard 3% mil-spec foam	220	0	40	80	120	4000	455
2007	Chem-Guard 3% mil-spec foam	25	0	0	80	80	2667	400

Year	AFFF Type	AFFF 3% Concentrate Purchased	Approximate AFFF 3% Concentrate Used for Training	Approximate AFFF 3% Concentrate Used for Tri-Annual Drill	Approximate AFFF 3% Concentrate Used for Annual Testing	Approximate Total AFFF Concentrate Used Annually	Approximate Total AFFF Concentrate and Water Mix	Approximate AFFF Stockpiled Based on Use*
		(Gal.)	(Gal.)	(Gal.)	(Gal.)	(Gal.)	(Gal.)	(Gal.)
2008	Chem-Guard 3% mil-spec foam	90	0	0	80	80	2667	410
2009	Chem-Guard 3% mil-spec foam	90	0	40	80	120	4000	380
2010	Chem-Guard 3% mil-spec foam	100	0	0	80	80	2667	400
2011	Chem-Guard 3% mil-spec foam	180	0	0	80	80	2667	500
2012	None purchased	0	0	40	80	120	4000	380
2013	None purchased	0	0	0	80	80	2667	300
2014	Chem-Guard 3% mil-spec foam	180	0	0	80	80	2667	400
2015	Chem-Guard 3% mil-spec foam	265	80	0	80	160	5333	505
2016**	Chem-Guard 3% mil-spec foam	250	0	0	0	0	0	755
2017	None purchased	0	0	0	0	0	0	755
2018	None purchased	0	0	0	0	0	0	755

Year	AFFF Type	AFFF 3% Concentrate Purchased	Approximate AFFF 3% Concentrate Used for Training	Approximate AFFF 3% Concentrate Used for Tri-Annual Drill	Approximate AFFF 3% Concentrate Used for Annual Testing	Approximate Total AFFF Concentrate Used Annually	Approximate Total AFFF Concentrate and Water Mix	Approximate AFFF Stockpiled Based on Use*
		(Gal.)	(Gal.)	(Gal.)	(Gal.)	(Gal.)	(Gal.)	(Gal.)
2019	Chem-Guard 3% mil-spec foam	105	0	0	0	0	0	860
2020	None purchased	0	0	0	0	0	0	860***
Total Quantity Between 2000-2020		1,815	80	200	960	1,280	42,667	Not Applicable

Notes:

* The Airport is required by FAA regulations to have enough stockpiled AFFF on hand to resupply two (2) trucks. Therefore at least 407 gallons of the 3% AFFF concentrate is regularly stored at ARFF building. This excludes the 407 gallons that are stored in the two ARFF trucks.

** In May 2016, the Airport transitioned to the new formulation of Chemguard (a modern fluorotelomer AFFF). The prior formulation was the older fluorotelomer based version.

*** The total on-hand AFFF quantity as of January 2022 is 907 gallons. This includes 500 gallons within containers and 407 gallons within the fire trucks.

PFAS from Non-Airport Related Sources

To determine the extent of the Airport's AFFF PFAS Plumes, analytical testing of numerous groundwater wells surrounding the Airport property (Figure 7) have been completed. These wells include locations off Airport property that are hydraulically upgradient, cross-gradient and downgradient. As indicated on Table 4 and Figure 7, most these wells have detections of PFAS above the MassDEP Sum of Six standard, and based on groundwater flow, these concentrations are entering the Airport from different areas as well as impacting the Maher Wells.
The additional PFAS plumes are unrelated to the Airport's AFFF PFAS plume. These plumes appear to be originating from the Barnstable Fire Training Academy PFAS Release Site (RTN 4-26179) and other unknown locations located upgradient, cross-gradient and downgradient of the Airport. Radar plots, which are included in Appendix D, were used to help distinguish the Airport's PFAS AFFF plume from other non-Airport related PFAS sources.

It should be noted that the AFFF used by the Airport over at least the last 20 years is a fluorotelomer based foam, with 6:2-FTS (a MassDEP non-regulated PFAS analyte) comprising a significant percentage of the PFAS compounds (see below in Section 5.1.1). However, it is important to note that other PFAS compounds, including PFOA and PFOS and the regulated PFAS compounds, are also present in the soil and groundwater in the release areas at the Airport. Our documentation of PFAS concentrations in each soil (Table 3) and groundwater sample (Table 4), includes a total PFAS concentration, individual concentrations for each of the MassDEP regulated six PFAS compounds, a total sum-of-six concentration, and 6:2-FTS concentration data. These results are provided on multiple figures and data tables included in this report. Data on the MassDEP Sum of Six compounds were used to determine if groundwater concentrations exceeded the Method 1 GW-1 standard as required under the MCP and Total PFAS and 6:2-FTS concentration data was used to evaluate other unregulated PFAS analytes to help distinguish Airport related and non-Airport related PFAS sources.

Included in the following Sections, HW analyzed the environmental fate and transport of PFAS at the Airport property and surrounding parcels. HW focused primarily on the PFAS analyte 6:2-FTS for tracking the extent of the regulated PFAS compounds for two primary reasons:

1. To distinguish the Airport releases from other non-airport related sources of PFAS impacting groundwater at the Airport, as described below via the radar plots.
2. To evaluate the downgradient migration of the plumes from the Deployment Area and ARFF building, as described in Section 4.3.2.

See Section 5.1.1 for additional detail regarding 6:2-FTS.

Radar Plots

HW utilized radar plots to differentiate individual PFAS concentrations (Attachment D). A radar plot is a graphical representation of analytical data that is used to create a distinguishable fingerprint. These plots illustrate the relative concentration of each PFAS compound in a graphic representation of the Airport source composition compared to other non-airport related sources. To generate a radar plot, each PFAS groundwater sample was statistically normalized to the individual total PFAS concentration. The Total PFAS concentration is the sum of all laboratory reported PFAS analytes in a sample. Each PFAS analyte was then divided by Total PFAS to calculate the percent each analyte contributed to the Total PFAS concentration. These percentages were then plotted for each sampling location and the graphical representation of the data set was compared.

It is noted that radar plots were completed for groundwater only. No radar plots were presented for soil regardless of PFAS concentration, due to the fact that these groundwater radar plots are representative of the AFFF PFAS that has leached from the soil into the underlying groundwater. Radar plots for the soil are not necessary as it is easy to distinguish soil impacted with AFFFF relating to Airport operations from other non-AFFF sources as indicated by the high level of total PFAS including 6:2-FTS. Additionally, SPLP testing of soil sample DL8 (4) from the Deployment Area indicated that 95 percent of the total PFAS released from this sample was 6:25 FTS at a concentration of 25 ug/l and Sum of Six PFAS at 0.717 ug/l. This high level of 6:2 FTS is distinguishable in both soil and groundwater samples relating to the Airports historic use of a fluorotelomer base AFFF foam.

This forensic analysis was necessary to differentiate the various plumes identified, and radar plots are regularly used by environmental professionals to identify individual sources of contamination found at a site and evaluate the impacts to downgradient resources when comingled plumes exist. PFAS compounds were detected in every well sampled at the Airport, and there is documented evidence from wells located upgradient and off-Airport property that indicate PFAS contamination from upgradient sources is flowing through groundwater across the Airport property.

The radar plots document the Airport AFFF releases and potential other releases as these plot have distinguishable shapes from one another (See Attachment D). The plots characterize the PFAS at that specific location and then, in evaluation, that characterization was considered in light of fate and transport characteristics to provide Site specific interpretation. As seen in the radar plots included in Attachment D, the Airport AFFF releases have a unique chemical signature compared to that of the Fire Training Academy plume that migrates under the Airport or compared to other off site sources impacting groundwater below the Airport from the west. HW developed the radar plots based on the concentration of each PFAS compound measured at a monitoring well at the time the sample was taken. Nearby ponds or pumping wells do not limit the use of these plots in identifying the PFAS sources on and near the Airport. The sample radar plots provided can be used to compare the relative percent PFAS concentrations in groundwater samples from the Deployment Area source at the Airport to the Fire Training Academy source area. They show a distinct difference in the chemical composition of these two sources. The PFAS composition detected at the Maher Well field closely resembles that from the Fire Training Academy. Radar Plots for all monitoring wells sampled between 2016 and November 2020 are included in Attachment D.

As illustrated in Figure 2, the two plumes from the Airport are not near any ponds and are upgradient of the Maher Well field. The Fire Training Academy plume migrates through and below Mary Dunn Pond before it flows below the Airport. The radar plots from samples taken at wells upgradient and downgradient of Mary Dunn Pond are consistent, indicating that the pond does not influence them.

The radar plots for well HW-I(s), HW-J, HW-F, HW-H, and HW-E, located within and surrounding the Deployment Area, were used to identify and document the chemical signature of the PFAS plume associated with the Airport' PFAS release at the Deployment Area and the ARFF building. If a non-fluorotelomer-based foam was used at this location, it is still represented in the radar plot signature from these wells. The same process was used for samples taken near the ARFFF/SRE Building area.

For a comparative example, the radar plot from HW-I(s) is a good representation of the Airport's plume relating to AFFF, which is recognizable by a high percentage of 6:2-FTS and a low percentage of PFOS. Additionally, 6:2-FTS does not degrade into PFOS or PFHxS (*Fact Sheet on*

C6 Fluorinated Surfactants, Dr. Jan-Erik Jonsson), and, in fact, it migrates faster (additional details below) in groundwater than any of the regulated MassDEP PFAS analytes. Groundwater monitoring studies have shown that the predominant degradation product of fluorotelomer based AFFF is 6:2-FTS (*Fact Sheet on C6 Fluorinated Surfactants, Dr. Jan-Erik Jonsson).* Therefore, by focusing on 6:2-FTS, a distinguishable analyte, HW is able to differentiate the Airport plume, related specifically to the documented use of fluorotelomer AFFF, from potential other sources of PFAS within the vicinity of the Airport property.

As indicated above, the 6:2 FTS in only used to verify the extent of the Airport's PFAS plume. The Airport and HW acknowledge that multiple other PFAS analytes including the six regulated by MassDEP are included in the Airport's plume. Concentrations of the MassDEP six regulated PFAS compounds are located in the Airport's PFAS plume at concentrations above the applicable Method 1 GW-1 Standard. Due to the multiple PFAS detections both hydraulically upgradient, cross-gradient and downgradient of the Airport, forensic interpretation is necessary to distinguish PFAS sources.

Refer to Figure 2 for a depiction of the Airport AFFF Plume and other non-airport related PFAS plumes. Cross-sections including Radar Plots also document the extent of the Airport and other PFAS plumes. Refer to Figures 5 and 8 through 13 for select cross-sections depicting the vertical and horizontal extent of the AFFF plumes. Refer to Figure 7 for a depiction of the Sum of Six PFAS concentration detected at each monitoring well location.

3.3.4 Sources of 1,4-Dioxane

1,4-dioxane is a synthetic chemical that is completely mixable in water. It has been detected in one deep monitoring well (HW-L [d]) located at the Airport and within several off-Airport monitoring wells located hydraulically upgradient, cross-gradient and downgradient of the Airport. A potential source of 1,4-dioxane at the Airport is a historic release of 1,1,1-TCA (RTN 4-00823) from an oil/water separator associated with a floor drain in the former Provincetown Boston Airlines hangar (currently leased to Cape Air) located on the North Ramp (RTN 4-823, closed). 1,4-dioxane is also known to be an ingredient in aircraft deicing fluids. The Airport installed a centralized deicing and aircraft washing pad in 2015 which directs deicing fluids (Type I propylene glycol based) and fluids used in aircraft washing to the Barnstable Water Pollution Control Facility. Prior to 2015, deicing activates were conducted at the South Ramp, Rectrix Aerodrome, and East Ramp at the locations indicated on Figure 4. Following application of deicing fluids prior to 2015, Airport maintenance personnel recovered residual deicing fluid on the asphalt pavement utilizing a TYMCO™ Model 600 vacuum recovery unit mounted on a Freightliner™ FC 80 chassis. Prior to deicing activities, magnetic catch basin covers were placed over storm drains in proximity. Recovered deicing fluid was subsequently discharged to the Barnstable municipal sewer system under an agreement with the Town of Barnstable.

According to Airport personnel, the quantity of deicing fluid used at the Airport averages less than 100 gallons per year. Usage data, provided below for 2015-2020, show low levels of use with almost all values well below 100 gallons. Deicing fluid usage data for 2015-2020 was as follows:

- 2015 – 210 gallons
- 2016 – 63 gallons
- 2017 – 22 gallons
- 2018 – 42 gallons
- 2019 – 42 gallons
- 2020 – 64 gallons

With such a limited use, the potential for the fluid to migrate off the paved areas where it was applied was limited, and it was feasible for the Airport to vacuum it up after application. The location of the current and former deicing pads is indicated on Figure 4. An MSDS sheet (Appendix E) provided by the Airport indicate that the deicing fluid is propylene glycol based and contains less than 5 parts per billion (ppb) of 1,4-dioxane. The deicing activities are conducted consistent with an EPA Stormwater Permit and Stormwater Pollution Prevention Plan prepared by a professional engineer.

Multiple groundwater samples collected from the former 1,1,1-TCA release area (HW-1, HW-5, HW-12, HW-29, OW-6, HW-4m, HW-4d, HW-207s, HW-207d, HW-19d and HW-204) in the North Ramp did not detect 1,4-dioxane above the laboratory reporting limit (Figure 4). As indicated above, Aircraft deicing fluids are not discharged to the unpaved surface and have been discharged to the municipal sewer under an approved connection/approved discharge. Historic deicing (pre-2015) was conducted on the paved surface and was vacuumed up and directly discharged to the municipal sewer system under an approved discharge.

Groundwater testing downgradient of two of these locations (HW-L[s], HW-L[m], and HW-19d) did not identify 1,4-dioxane above the laboratory reporting limit. The third deicing location is located approximately 2,000 feet cross-gradient to HW-L (d) and does not have a hydraulic connection to this area. Groundwater testing at wells HW-E and HW-J downgradient of the third deicing pad did not identify 1,4-dioxane above the laboratory detection limit.

HW created a water table map specific to the Airport property based on data taken on April 27, 2020 from monitoring wells used during this investigation. It is attached as Figure 14. As indicated on the map, groundwater flows onto the Airport property from the west and northwest, migrates to the southeast, and exits the property at the southeast corner of the Airport. The water table maps also clearly show that HW-L(d) is hydraulically cross-gradient to the historic deicing pad located approximately 2,000 feet northeast of the well, near the Deployment Area. Groundwater flow from this historic deicing area would flow to the east-southeast.

Considering the depth at which the 1,4-dioxane has been detected at the Airport and Maher Wells (70 to 123 feet below grade) and in the particle tracking model, detailed below, the 1,4-dioxane appears to be from a source located more than 6,000 feet hydraulically upgradient and off-Airport property. 1,4-dioxane has also been detected in two wells (HW-V[m] and HW-U[d]) located hydraulically upgradient and off-Airport Property at depths consistent with the particle tracking model, detailed below, supporting the Conceptual Site Model that the detection of 1,4-dioxane in HW-L(d) and the Maher Well field is related to an off-Airport release.

All floor drains within the hangers and businesses located on the airfield have either been closed, connected to a tight tank, and/or connected to the sanitary sewer to meet the EPA and MassDEP discharge requirements. Significant groundwater monitoring has been conducted throughout the Airport in proximity to hanger buildings with historic floor drains and in proximity to de-icing areas. A figure depicting the sample locations and subsequent concentration of 1,4-dioxane is indicated on Figure 4. This information clearly indicates that the 1,4-dioxane source is not related to the Airport. Tabulated analytical data is presented on Table 7.

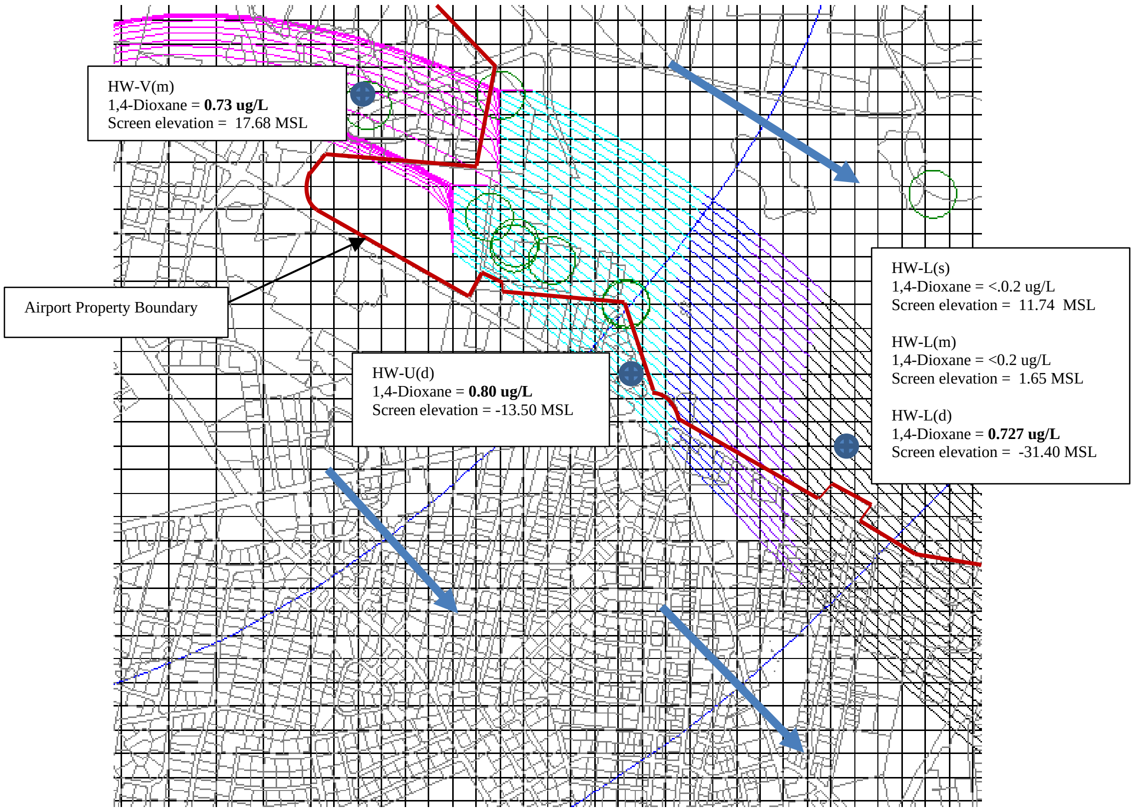
According to the EPA document titled *"Technical Fact Sheet – 1,4-dioxane"* dated November 2017, additional sources of 1,4-dioxane, unrelated to deicing, include:

- **Solvent Stabilizer** – historically, 90% of 1,4-dioxane use was to stabilize chlorinated solvents such as 1,1,1-TCA. Use of 1,4-dioxane as a solvent stabilizer was phased out under the 1995 Montreal Protocol.
- **Consumer Products** - 1,4-dioxane has been found as a by-product in paint strippers, dyes, greases, anti-freeze, and aircraft deicing fluids, and in some consumer products such as deodorants, shampoos, and cosmetics.
- **Pharmaceuticals and Plastic Manufacture** - 1,4-dioxane is used in the manufacture of pharmaceuticals as a purifying agent and is a by-product in the manufacture of polyethylene terephthalate plastic.
- **Food** - 1,4-dioxane may be present in some food supplements, food containing residues from packaging adhesives or on food crops treated with pesticides that contain 1,4-dioxane.

Some examples of how these materials can be released to the environment include:

- Releases to the ground surface, groundwater and/or surface water from industrial/commercial facilities where spills of materials containing 1,4-dioxane have occurred;
- Releases to groundwater and/or surface water from wastewater treatment plants where wastewater treatment methods were not designed to remove 1,4-dioxane compounds from the waste stream;
- Releases to groundwater and surface water from residential septic systems where 1,4-dioxane compounds were used in the household;
- Releases to the ground surface, groundwater and/or surface water from industrial facilities where polyethylene terephthalate plastic was manufactured; and
- Releases to groundwater and/or surface water from landfills were 1,4-dioxane wastes were disposed of.

Considering the depth of the 1,4-dioxane impacts, it is likely that the detection is related to an off-site source. To verify that the source of 1,4-dioxane detected in HW-L(d) and the Maher Well field was related to an off-site source, HW advanced monitoring wells HW-U(d) and HW-V(m) at locations off-Airport property and hydraulically upgradient of the Airport (see Figure 4). The well screen depths for these locations were chosen based on groundwater model particle tracks that simulate how groundwater migrates in the aquifer below the Airport. The particle tracks indicated that the depth of the 1,4-dioxane detected at the Airport and the Maher Well field was likely related to a release site located more than 6,000 feet upgradient of the Airport. The particle tracking model uses annualized average pumping rates for 2004-2008 from the Maher Wells, Mary Dun Wells, and the Airport Well. The particle tracking is shown below, and arrows depict the groundwater flow path:



The model above shows how a particle of 1,4-dioxane migrated onto the Airport property from off-site upgradient locations HW-V(m) and HW-U(d) and how the 1,4-dioxane plume migrates to the Maher Well field. The particle tracking figure is a plan view version showing the contributing area to the Maher Well field, and the particle flow path colors correspond to the falling depth of the particle. The variation in colors documents how the water flows downward into the aquifer as it migrates from upgradient areas across the Airport. The model was created by working backwards from HW-L(d) to depict the 1,4-dioxane flow path and particle depth during migration. The model was then used to pick the location and screen depth for monitoring wells HW-V(m) and HW-U(d). The model predicted that if 1,4-dioxane was detected at a depth between -27 and -32 feet below mean sea level (MSL) in HW-L(d) and not detected at the depths associated with

HW-L(s) or HW-L(m), the potential source of the release was located more than 6,000 feet away (off-Airport property). The model suggested that 1,4-dioxane would be located within the cyan colored hatching (HW-U[d] location) at a depth of -8 to -13 feet below MSL and within the magenta-colored hatching at a screen depth of 12 to 17 feet above MSL. HW subsequently installed monitoring well locations HW-V(m) and HW-U(d) to the corresponding depth predicted by the model. 1,4-dioxane was detected in both new monitoring well locations (HW-V[m] at 0.8 ug/l and HW-U[d] at 0.73 ug/l) at concentrations consistent with that detected downgradient and on Airport Property (HW-L[d] at 0.75 ug/L).

While the Maher wells are pumped regularly, the pumping will have little to no effect on the vertical plume migration as it travels from HW-V(m) to HW-U(d) to HWL(d) as these areas are upgradient of, and outside the area where the pumping of the wells would adjust the rate of travel or the depth of the plume.

Additionally, the plume is located cross gradient of the nearby ponds on the Airport and would not interact with them. This is especially true as the plume is located 30-40 feet below the water table as it passes south of the ponds. The ponds themselves are quite shallow and do not interact with groundwater found that far below the water table. There are no surface water outflows from the ponds that would cause groundwater to migrate upward to discharge to the ponds or an outlet stream. The ponds will only interact with shallow groundwater.

Overall, based on the mapping of groundwater flow, water quality data from across the Airport that tracks the plume, new shallow groundwater data showing no 1,4-dioxane in the vicinity of the deicing area on the East Ramp and North Ramp, and particle tracking data from the U.S Geological Survey groundwater model for this area of Hyannis, the 1,4-dioxane plume does not originate at the Airport but is from an upgradient source to the west-northwest of the Airport.

Based on the results of the modeling and laboratory data, it appears that the detection of 1,4-dioxane at the Airport and the Maher Wells is likely related to an unknown off-site source located more than 6,000 feet upgradient of the Airport. A graphical representation of the 1,4-dioxane plume is indicated on Cross Section-1 in Figure 6 and the location of HW-V(m), HW-U9(d), and HW-L(d) in relation to the Airport property boundary is included on Figure 4. The Cross Section-6 shows how the plume moves down into the aquifer as it travels across the Airport. A plan view of the location of wells used to create the cross-section is included as Figure 5.

The plume moves downward at a consistent rate, based on the amount of recharge to the aquifer from rainfall that infiltrates into the ground. The cross-section documents wells screened in the aquifer above the mapped plume in which no 1,4-dioxane was detected. It also documents that the concentration of 1,4-dioxane in the plume is relatively stable as it moves across the Airport property, ranging from 0.8 ug/L upgradient of the Airport in well HW-V(m) to 0.732 ug/L downgradient of the Airport in Well OW-9(dd) (See figure 4). The direction of groundwater flow and relatively stable detection levels of 1,4-dioxane suggest that there is a long-term, consistent source of 1,4-dioxane upgradient of the Airport impacting groundwater quality.

4.0 DISPOSAL SITE HYDROGEOLOGICAL CHARACTERISTICS

Pursuant to 310 CMR 40.0835(4)(d), the Site hydrogeological characteristics including details of subsurface investigation and hydrogeologic conditions are set forth below.

4.1 Subsurface Investigations and Assessments Conducted

Pursuant to 310 CMR 40.0835(4)(d)1, a description of all relevant geologic, hydrologic, geophysical, and other subsurface investigations conducted at the Disposal Site are set forth below. All laboratory reports have previously been submitted to the MassDEP and are therefore not included in this submission.

- An initial round of three soil samples were collected on December 9, 2016. One sample was taken from each location where it was determined that AFFF had been used at the Airport. The areas included the MCI Drill Area, the Deployment Area, and the 1991 Drill Location. Refer to Figure 3 for soil sample locations and to Table 3 for tabulated PFAS in soil results.
- To evaluate potential off-site sources of PFAS and 1,4-dioxane, groundwater monitoring wells were installed at six locations in April 2017. Well locations include in the vicinity of potential sources of PFAS at the current ARFF/SRE Area, at the Deployment Area, and at upgradient locations outside of the Airport. Refer to Figure 4 and 7 for monitoring well locations and Tables 4 and 7 for tabulated groundwater results.
- Groundwater from the new wells was initially sampled for PFAS and 1,4-dioxane in April 2017. Additional groundwater samples and one surface water sample were collected for analysis of PFAS on June 20, 2017. Refer to Figure 4 and 7 for sampling locations and Tables 4, 5 and 7 for tabulated results.
- A second round of soil samples were collected on June 20, 2017 adjacent to the ARFF/SRE Building and within the Deployment Area to begin to determine the extent of PFAS within the surface soils. Based on the results of these analyses, a third round of samples from these two locations were collected on September 26, 2017. The third round of sampling was designed to further delineate the extent of PFAS in soils both horizontally and vertically, with samples taken at the ground surface and at two and four feet below ground surface (BGS). Soil samples were submitted for analysis of PFAS. Refer to Table 3 for tabulated soil results and Figure 3 for sampling locations.
- One sample of AFFF concentrate was analyzed for PFAS compounds to evaluate the foam. The analysis was inconclusive (only 225.5 ug/l of total PFAS was detected) and it is assumed that the sample was not homogeneous (i.e., had separated in the foam bucket) and that the addition of water to the concentrate may affect how precursor PFAS analytes transform into various other detectable PFAS compounds. Refer to Table 8 for tabulated AFFF results.

- Six PFAS soil samples were also analyzed for leaching potential using a synthetic precipitation leaching procedure (SPLP) test between September and October 2017. The chosen samples included four samples from within the boundaries of the PFAS sites at the Airport and two samples from runway reconstruction soils stockpiled at the Airport. Refer to Table 9 for tabulated SPLP results.
- In October 2017, 20 surficial soil samples were collected both on and off Airport property to determine the background concentration of PFAS in the area not related to the application of AFFF at the locations indicated on Figure 15. Refer to Table 6 for soil results.
- In October 2017, three composite soil samples were taken from piles of soil associated with the redevelopment of Runway 15/33. These piles were located on Airport property at the site of the former Mildred's Restaurant and were analyzed for PFAS compounds to evaluate if soil removed from the Airport as part of this redevelopment contained PFAS. Refer to Table 6 for tabulated soil results.
- On August 14, 2018, 24 PFAS surface soil samples were collected in proximity to the ARFF/SRE Building Area and the Deployment Area. PFAS compounds were previously detected in these areas and additional samples were collected to determine the vertical extent of PFAS impacts in soil and to refine the soil disposal site boundary at the Airport. Refer to Table 3 for soil results and Figure 3 for sampling locations.
- In October 2018, three soil borings (DL11, DL14, and HW-F) were advanced in the Deployment Area. One soil boring (ARFF3) was advanced, and one surface soil sample (HW-3) was collected near the ARFF/SRE Building to further delineate the extent of PFAS in soils both horizontally and vertically. All soil borings were advanced using direct push methods. Refer to Table 3 for soil results and Figure 3 for sampling locations.
- In October 2018, six monitoring wells were installed at the Airport. A cluster of three wells (HW-G(s), HW-G(m), and HW-G(d)) was installed at an upgradient location to evaluate potential off-site sources of PFAS. Three additional wells (HW-H, HW-I, and HW-J) were installed southeast of the Deployment Area adjacent to the East Ramp. Refer to Table 4 for groundwater results and Figure 7 for sampling locations.
- In November 2018, six groundwater samples were collected to evaluate PFAS concentrations in the Deployment Area. Four groundwater samples and one surface water sample from Mary Dunn Pond were also collected for analysis of oxygen and hydrogen isotopes to determine the contribution of pond water from Mary Dunn Pond to the four downgradient monitoring wells. The analysis was inconclusive in tracing the contribution of pond water in the downgradient monitoring wells. Refer to Tables 4, 5, and 10 for groundwater and surface water results and Figure 7 for sampling locations.
- In December 2018, two soil samples were collected from the 1991 Drill Location to determine if PFAS detected in the area are related to background conditions. Refer to Table 3 for soil results and Figure 3 for sampling locations.
- In December 2018, 12 groundwater samples were collected for analysis of PFAS, and 13 groundwater samples were collected for analysis of oxygen and hydrogen isotopes to

determine the contribution of pond water from Mary Dunn Pond to the 13 downgradient wells. Groundwater samples were also collected from four monitoring wells in the Maher wellfield for analysis of 1,4-dioxane. Refer to Tables 4, 5, and 10 for groundwater and surface water results and Figure 7 for locations.

- In February 2019, three additional surface soil samples were collected to further delineate the soil Disposal Site boundary around the ARFF/SRE building. Refer to Table 3 for soil results and Figure 3 for sampling locations
- In May and June 2019, HW installed nine groundwater monitoring wells to delineate the vertical and horizontal extent of PFAS and 1,4-dioxane at the Airport and on adjacent hydraulically upgradient properties. Refer to Tables 4 and 7 for groundwater results and Figures 4 and 7 for sampling locations.
- In June 2019, eight groundwater samples were collected from newly installed groundwater monitoring wells HW-L, HW-K, HW-I (m), HW-I (d), HW-M, HW-D(d), HW-D (dd), and HW-N for PFAS. Refer to Table 4 for groundwater results and Figure 7 for sampling locations.
- In July 2019, one groundwater sample was collected from the newly installed groundwater monitoring wells HW-O for PFAS. One groundwater sample was collected from HW-L for 1,4-dioxane. Refer to Tables 2 and 5 for groundwater results and Figures 3 and 13 for sampling locations.
- In July 2019, two surface water samples were collected from Upper Gate and Lewis Ponds for PFAS analysis. Refer to Table 8 for surface water results and Figure 2 for sampling locations.
- In August 2019, four groundwater samples were collected from monitoring wells HW-N, HW-A(d), HW-O, and HW-1 to evaluate potential sources of 1,4-dioxane entering the Airport from unknown upgradient sources(s). One groundwater sample was also collected from groundwater monitoring well HW-E for PFAS. Refer to Tables 4 and 7 for groundwater results and Figure 4 and 7 for sampling locations.
- In August 2019, soil sample DL 11 (0-1) was collected from the Deployment Area. Refer to Table 3 For soil results and Figure 3 for the sampling location.
- In August 2019, six spray water samples were collected from discharge locations on a fire truck at the Airport. The samples were collected to verify that the valve mechanism that controls the mixing of AFFF with water was working appropriately. PFAS should not be detected in the spray water. PFAS was detected in each of the six samples collected above the GW-1 standard. Refer to Tables 2 for spray water results.
- On September 27, 2019, HW collected groundwater samples from six monitoring wells located on the Airport for 1,4-dioxane analysis. Refer to Table 7 for groundwater results and Figure 4 for sampling locations.
- In November 2019, the Airport replaced the valve mechanism in the fire truck to ensure that AFFF was no longer mixing with the water despite the mechanism not being engaged.

In December 2019, HW resampled the six discharge locations from the fire truck at the Airport. PFAS was detected at various concentrations at each location, but all were below the GW-1 standard. Refer to Tables 2 for spray water results.

- Between May 5 and May 21, 2020, HW collected 16 groundwater samples for PFAS analysis. Refer to Table 4 for groundwater results and Figure 7 for sampling locations.
- Between May 5 and May 13, 2020, HW collected groundwater samples from four monitoring wells for 1,4-dioxane analysis. Refer to Table 7 for groundwater results and Figure 4 for sampling locations.
- Between September 14 and September 24, HW and Desmond Well Drilling installed 13 monitoring wells at the locations indicated on Figure 7.
- On September 17, 2020, HW collected groundwater samples from the three Maher Wells (ME-1 through ME-3) for PFAS analysis. Refer to Table 4 for groundwater results and Figure 7 for sampling locations.
- Between September 14 and September 30, 2020, HW collected 21 soil samples for PFAS analysis. Refer to Table 3 for soil results and Figure 3 for soi sampling results.
- Between October 1 and October 7, 2020, HW collected groundwater samples from 16 monitoring wells for PFAS. Refer to Table 4 for groundwater results and Figure 7 for sampling locations.
- On October 2 and 7, 2020, HW collected groundwater samples from four monitoring wells for 1,4-dioxane analysis. Refer to Table 7 for groundwater results and Figure 4 for sampling locations.
- On November 5 and 6, 2020, HW collected five groundwater samples for PFAS analysis. Refer to Table 4 for groundwater results and Figure 7 for sampling locations.
- On November 17, 2020 HW collected two roof samples (rubber membrane and asphalt shingle) from the ARFF/SRE building for SPLP PFAS. The testing was completed to determine if roofing materials were a potential source of PFAS in groundwater through stormwater infiltration. PFAS was detected in each of the samples collected. Although the leachate is not considered drinking water, the concentration of the MassDEP Sum of 6 were below the Method 1 GW-1 and GW-3 standards. Refer to Table 9 for SPLP PFAS results.
- On February 18 and 19, 2021, HW conducted hydraulic conductivity testing at three monitoring locations. Refer to Section 4.3.1 for additional details.
- Between March 17th and March 19, 2021 HW collected 21 groundwater samples for PFAS analysis. Refer to Table 4 for groundwater results and Figure 7 for sampling locations.
- Between April 5th and April 7th, 2021, HW and Desmond Well Drilling installed monitoring wells HW-U(s), HW-U(m), HW-W(m), HW-W(d) and HW-W (dd) at the locations indicated on Figure 7.

- Between April 6th and 19th, 2021, HW collected 17 soil samples for TOC analysis from the three locations indicated on Figure 16. The TOC samples were collected from various depths between ground surface and 65 feet below grade. Refer to Table 11 for tabulated analytical results.
- On April 19, 2021, HW sampled the recently installed monitoring wells HW-U(s), HW-U(m) HW-W(m), HW-W(d) and HW-W (dd) for further analysis of PFAS compounds in groundwater. Refer to Table 4 for groundwater results and Figure 7 for sampling locations.
- In September 2021, HW installed two groundwater monitoring wells adjacent to, and downgradient of, the former Operations Building (HW-X[s] and HW-X[m]). A soil sample was collected from the unsaturated zone in the boring for well HW-X(s). Refer to Table 3 for PFAS soil results and Tables 4 and 7 for groundwater results. The sampling locations are indicated on Figure 7.
- Between September 1 and 11, 2021 HW collected 26 groundwater samples for PFAS analysis. Refer to Table 4 for groundwater results and Figure 7 for sampling locations.

4.2 Soil Boring and Monitoring Well Construction Logs

Pursuant to 310 CMR 40.0835(4)(d)2, copies of soil boring and monitoring well logs completed by HW and others are included in Appendix F. It should be noted that some of the boring logs are not available due to the age of installation (pre-2000's). Additionally, soil boring logs were not created for shallow surface samples due to the consistency of the soil through the Airport.

4.3 Geologic and Hydrogeologic Conditions

Pursuant to 310 CMR 40.0835(4)(d)3, a characterization of all geologic and hydrogeologic conditions at the Disposal Site is set forth below.

4.3.1 Groundwater Characteristics

Pursuant to 310 CMR 40.0835(4)(d)3a, a discussion of groundwater potentiometric surface, gradient, flow rate, and flow direction is set forth below.

Groundwater Flow

HW developed numerous water table maps for past projects at the Airport and has a clear understanding of the groundwater flow directions across the site. Figures 2, 3, 4, and 7 document groundwater contours which were developed by the U.S. Geological Survey as part of their regional groundwater model for the Sagamore lens aquifer that includes the area of Hyannis in which the Airport is located. The groundwater contours were used as they provide broader information regarding the migration of groundwater at the Airport, and in upgradient and downgradient areas, allowing us to evaluate how groundwater flows across the Airport and downgradient towards the Maher Well field.

HW created an additional water table map specific to the Airport property, based on data taken on April 27, 2020, from monitoring wells used by HW during this investigation. It is attached as Figure 14, and these water table maps illustrate how groundwater flows onto the Airport property from the west and northwest, migrates to the southeast, and then exits the property to the southeast corner of the Airport.

Groundwater elevations, measured by HW throughout the project, are also included on Table 4. Based upon the groundwater elevations, the estimated hydraulic gradient is set forth below.

Start (Well ID)	End (Well ID)	Distance (Feet)	Change in Groundwater Elevation (feet)	Hydraulic Gradient (Feet per foot)	Well Start Location	Well End Location
HW-1	HW-23	1,477	2.7	0.0018	North Ramp	North Ramp
HW-1	HW-4M	325	0.66	0.0020	North Ramp	North Ramp
HW-23	HW-L(d)	3,175	9.42	0.0029	North Ramp	ARFF/SRE Area
HW-302	OW-9(s)	1,201	6.57	0.0054	Steamship Parking Lot	Maher Well Field
HW-E	HW-I(s)	507	1.57	0.0030	Deployment Area	Deployment Area
Average Hydraulic Gradient				0.00302		

Hydraulic Conductivity

To determine the hydraulic conductivity, HW completed a series of drawdown pump tests using a submersible pump and a transducer capable of logging the fluctuation of the water level in hundredths of a foot in 0.5-second intervals. In general, the tests were completed over a 30-minute period at a pumping rate of 0.25 to 0.33-cubic feet per minute. Details from the pump test are indicated below.

Well ID	Well Location	Depth to Water	Total Well Depth	Screen Length	Maximum Drawdown	Pump Rate (cubic feet per minute)	Calculated Hydraulic Conductivity
HW-I(s)	Deployment Area	18.410	25.09	10	18.732	0.33	117 feet per day
HW-F	Deployment Area	20.242	26.82	10	20.483	0.25	114 feet per day

Well ID	Well Location	Depth to Water	Total Well Depth	Screen Length	Maximum Drawdown	Pump Rate (cubic feet per minute)	Calculated Hydraulic Conductivity
OW-19(m)	Maher Well Field	26.942	76.14	10	27.417	0.33	78 feet per day
Average Hydraulic Conductivity							103 feet per day

Appendix G provides the worksheets that include the data and formulas used to calculate hydraulic conductivity.

Groundwater velocity at the Airport is estimated by the following equation:

$$\text{Velocity (ft/d)} = \frac{\text{Hydraulic Conductivity (ft/d)} \times \text{Hydraulic Gradient (ft/ft)}}{\text{Effective Porosity}}$$

ft/d = feet per day
ft/ft = feet per foot

Based on experience in the area, effective porosity is assumed to be 33 percent (25-50 percent, Freeze and Cherry, 1979). Therefore, based on the slope of the water table in this area, the porosity of the aquifer, and the hydraulic conductivity of the aquifer based on tests from wells HW-1(s), HW-F, and OW-19(m), the average groundwater velocity is estimated to be 0.94 feet per day or 344 feet per year.

4.3.2 Migration of PFAS Compounds in Unsaturated Soil Above the Aquifer

Research conducted at the Joint Base Cape Cod (Weber, et al, 2017) documented that it took between 7-30 years for PFAS from AFFF sprayed at their fire training area to migrate to groundwater. The depth to water below the Deployment Area is approximately 25 feet, similar to that seen at Joint Base Cape Cod. The subsurface glacial soils in that area are similar to what exists at the Airport site indicating that PFAS compounds will adhere to the soils and only migrate slowly down to groundwater. The concentrations of PFAS measured in soils at the Deployment Area (1,524 ug/kg of Total PFAS at sample location MCI Drill (0-1)) are significantly higher than in groundwater directly below this site (15.5 ug/l of Total PFAS at sample location HW-I[s]) supporting this hypothesis. Based on HW mapping of the groundwater plume, it took approximately 21 years for PFAS compounds to enter the aquifer from the Deployment Area (1,524 ug/kg of Total PFAS at sample location MCI Drill (0-1)). This is based on the following assumptions:

- The groundwater plume in the Deployment Area is currently mapped with analytical data to be a maximum of 1,700 feet in length.

- The plume is moving in groundwater at approximately 285 feet per year (see details below) indicating that the PFAS analytes first entered groundwater in approximately 2015.
- The first application of PFAS in the Deployment Area occurred in 1994.

In addition, the limited use of AFFF at the Airport and the migration of PFAS from the ground surface to the aquifer plays a significant role in determining how long it took for PFAS compounds in the AFFF to enter the aquifer and begin to move with groundwater. AFFF was only used once per year at the Deployment Area beginning in 2004 until 2015 to confirm that the firefighting equipment used by the Airport was operating properly. Every three years, a mass casualty drill was also conducted at this location during which AFFF was also used, between the years of 1994 and 2012. These events were all required by FAA. Based on purchase records from the Airport, 1,280 gallons of AFFF were used from 2000-2015, at which time the use of AFFF for training purposes was suspended. The organic carbon in the surface soil and subsurface soils readily bound up the PFAS compounds from the foam spraying and slowed their migration downward.

Migration of PFAS Compounds in Groundwater

HW calculated the rate of PFAS transport in groundwater, separate from the migration through the surficial soils. An explanation of the calculation is provided below followed by an assessment of the transport time in groundwater for one PFAS compound: 6:2-FTS. This compound is associated with the type of AFFF used by the Airport. Although it is not currently one of the MassDEP six regulated PFAS compounds, it has a lower retardation rate compared to the other six PFAS analytes currently regulated in Massachusetts and therefore moves more quickly through groundwater as indicated on Figure 17. The use of 6:2-FTS is therefore a good representation of the maximum distance that the six regulated PFAS analytes has migrated from the Deployment Area and the ARFF/SRE Area.

Retardation Factor Calculation

The migration of PFAS in groundwater is slower than the velocity at which groundwater moves through the aquifer. This is because the PFAS compounds interact with the organic carbon present in the saturated soils, thereby slowing, or retarding the rate at which they move in the aquifer. The rate at which they move through the aquifer can be determined by calculating the retardation factor for a particular compound using the following formula:

Rf = 1 + d*Kd/n

Rf = retardation factor

d = aquifer bulk density = 1.5
n = porosity = 33 percent = 0.33

kd = (soil) distribution coefficient = foc * Koc

foc = fraction organic carbon

Koc = organic carbon/water partition coefficient

The retardation factor is then used to calculate the slower flow rate for the plume in the aquifer based on the known rate of groundwater flow.

Select soil samples were collected for TOC at the locations indicated on Figure 16. The TOC ranged from less than the laboratory reporting limit to 28,900 mg/kg as indicated on Table 11. HW calculated the retardation factor using the various statistical inputs calculated from the TOC data that are included on Table 12.

Surficial TOC samples were obtained adjacent to the documented PFAS contaminated areas in soil. Surficial or saturated soil samples from below the two source areas could not be collected because both areas have been capped to prevent further release of PFAS compounds to groundwater. Drilling a soil boring to collect soil for TOC analysis from these areas could impact the integrity of these caps. Therefore, surficial TOC samples were collected from locations both within and adjacent to the Deployment Area plume and from the multiple depths within the aquifer adjacent to the downgradient edge of the plume. Data from these areas are appropriate to use for evaluation of soil migration in both surficial soils and in areas deep in the aquifer.

The various TOC ranges documented above were used to calculate multiple retardation rates for PFAS transport, providing the rate at which each of the six regulated PFAS compounds and 6:2-FTS is traveling through groundwater while considering the substantial amount of time the PFAS compounds are bound by high TOC in the surficial soil. The TOC concentrations in the aquifer soils are significantly lower than what is detected in the soils above the water table. A TOC range was used to demonstrate that only evaluating soils in the aquifer will severely overestimate plume migration from the point of release. Once the plume reaches groundwater, it will move at a rate of285 feet or so per year. Only evaluating the deep aquifer soils will not account for the significant amount of time it takes for the PFAS analytes to move through the unsaturated zone.

The octanol/water portioning coefficient (Koc)values used by HW were obtained from the Environmental Protection Agency CompTox Chemical Dashboard to calculate the retardation rate for PFAS compounds in groundwater (https://comptox.epa.gov/dashboard). The Koc value for each of these PFOS compounds was then multiplied by the applicable TOC value (Table 12) to develop a range of portioning coefficient (Kd) values. The Kd value was then used to calculate the retardation rate for each of these PFAS compounds. This rate is multiplied by the documented groundwater flow velocity to calculate the rate at which each compound moves in groundwater. Refer to Table 12 for additional details on the calculations. As indicate above, applying a range of TOC values helps to account for the time taken for PFAS to migrate through soil (high TOC Values with slow migration) and groundwater (low TOC values with fast migration). Only taking into account groundwater migration will overestimate the plume migration from the initial date at which AFFF was applied at the Deployment Area or released near the ARFF building.

Again, 6:2-FTS was chosen specifically to evaluate the downgradient migration of the plumes from the Deployment Area and ARFF building. The purpose of this investigation was, in part, to determine a reasonable physical extent of the plumes from these areas. The Koc for 6.2-fluorotelemer is lower than the Koc for each of the six PFAS compounds regulated by MassDEP. Therefore, it does not bind to the organic carbon present in the aquifer soils at the same rate as the other PFAS compounds. Its retardation rate is somewhat lower, and it travels faster in groundwater compared to the regulated compounds. Refer to Figure 17 for a depiction of the general AFRR particle track in soil and groundwater.

Migration of 6:2-FTS in Groundwater

Based on the site-specific TOC data, our calculations show that 6:2-FTS in the PFAS plume will travel in groundwater at a maximum of 285 feet per year. This is based on a total organic carbon concentration of 48 mg/kg. The concentrations of TOC from test locations below the water table were below the laboratory reporting limit for the analytical method used in the analysis. The detection limit ranged from 93.5 to 96.9, so 48 mg/kg represents one half the average of the reporting limit and is a reasonable estimate for the TOC concentration in the aquifer soils. Tabulated TOC data is included on Table 11.

As described previously and as documented with recent groundwater sampling, HW mapped the downgradient boundary of the main Airport plume as no more than 1,700 feet downgradient of the Deployment Area. **This suggests that PFAS in Deployment Area soils reached groundwater approximately six years ago and indicates that it took approximately 21 years for the PFAS to migrate through the site soils before reaching groundwater (original application of AFFF in the deployment area was in 1994)**. This is consistent with the rate of transport discussed in the Massachusetts Military Reservation study from Weber, et al (2017), and with the groundwater testing data and forensic analysis provided in this Phase II. Additional details regarding the retardation factor calculation are set forth below.

- The retardation calculation is site specific as it relies on site specific TOC, hydraulic gradient, and hydraulic conductivity data. By applying a range of TOC values, HW considered the amount of time it took for PFAS to migrate through the unsaturated soil (high TOC) to reach groundwater. The groundwater velocity range presented accounts for migration in both unsaturated and saturated soils. The low end of the range (38 feet per year) considers migration in both unsaturated and saturated soils, and the high end of the range (285 feet per year) is migration in groundwater only. As discussed above, it can take significant time for PFAS to migrate through unsaturated soils. To form an accurate Conceptual Site Model, the amount of time for migration in the unsaturated soils must be considered.
- The hydraulic gradient was calculated as an average from multiple wells located in the Deployment Area, ARFF/SRE Area, North Ramp, Steamship Parking Lot, and the Maher Well field. The average hydraulic gradient (0.00302 feet per foot) calculated from multiple wells is consistent with the hydraulic gradient calculated in the Deployment Area

(0.0030 feet per foot). The average hydraulic conductivity was calculated from pump tests conducted at two wells located in the Deployment Area and one well located near the Maher Well field. The use of “average” values for hydraulic gradient and hydraulic conductivity provides a conservative and realistic approach for calculating plume migration and accounts for the non-homogeneity of the subsurface saturated soils located in the aquifer.

- The Weber, et al study of the Massachusetts Military Reservation provides field-based calculations of the Kd and Koc values for PFAS compounds present in the plume they analyzed. The table below compares PFOS and 6:2-FTS Log Koc values presented in the Weber, et al study to the EPA CompTox Koc calculated for the Airport in this Phase II Report.

Value	Cape Code Study	Airport
Log Koc for PFOS	3.37+/- 0.27	3.16
Log Koc for 6:2-FTS	2.62+/- 1.01	2.97

The EPA CompTox Koc values presented in this Phase II Report for both PFOS and 6:2-FTS were within the site-specific laboratory-based values presented in Weber, et al. This indicates that the KOC values for these two analytes were similar. Refer to Table 12 for the KOC values used by the Airport.

HW initially focused on plume migration through the soils and groundwater, developing an average rate of transport through both media. The Weber, et al study, emphasized that it can take significant amount of time for PFAS analytes to migrate in the unsaturated zone before entering groundwater. The calculations provided above show that the plume may have been migrating in the groundwater for approximately six years, after taking approximately 21 years to enter the aquifer system. This assumes a very low TOC concentration in the aquifer soils based on tests conducted in proximity to the Maher Well Field.

Overall, the current location of the plume from the Deployment Area and ARFF/SRE Area is mapped based on the laboratory analysis of groundwater samples in and around the plume and supported by the forensic data described in this report and the retardation calculations discussed here. The location of the plume also fall within the migration values presented above.

4.3.3 Soil Characteristics

Pursuant to 310 CMR 40.0835(4)(d)3b, a discussion of soil type(s), stratigraphy, and permeability is set forth below.

In general, soils at the Airport in proximity to the Deployment Area and ARFF/SRE Area consisted of fine to medium sand, with some coarse sand, gravel, and cobbles down to a depth of approximately 70 feet below ground surface. Below 70 feet, a layer consisting of gray silt and clay exists. The materials encountered during the soil borings are consistent with those described by the USGS soil survey for Barnstable Outwash Plain Deposits (Oldale, 1974). Bedrock was not encountered in any of the soil borings. The location of the soil borings and monitoring wells are indicated on Figures 3, 4 and 7. Soil boring logs are included in Appendix F. It should be noted that soil boring logs were not completed for shallow soil samples and that some of the monitoring well logs from pre-2000 are not available. Analytical data suggests that soil within the two capped areas have PFAS impacts that exceed the current MassDEP S1/GW-1 standard that extend to at least 16 feet below grade as well as detectable PFAS concentrations below the MassDEP S1/GW-1 Standard at the soil/groundwater interface. The surficial extent of PFAS in soil exceeding the applicable Method 1 standards are indicated on Figure 3.

4.3.4 Bedrock Characteristics

Pursuant to 310 CMR 40.0835(4)(d)3c, a discussion of bedrock type and characteristics, depths, and contours is set forth below.

As indicated above, bedrock was not encountered in any of the soil borings and is expected to be located at a depth greater than 125 feet below grade.

4.3.5 Potential for Flooding

Pursuant to 310 CMR 40.0835(4)(d)3d, an evaluation and description of the potential for flooding is set forth below.

According to the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map, the Airport is within Zone X, an area of minimal flood hazard determined to be outside the 500-year flood (Figure 18). The Airport property is not at a high risk for flooding. A small amount of forested area near Mary Dunn Pond, within the Airport property boundary, is within an area with a 0.2% annual chance of flood hazard. Refer to Figure 18 for a depiction of FEMA flood zones at and within proximity to the Airport. HW is unaware of any flooding that has taken place at the Airport. As such, it is unlikely that flooding will impact the extent of soil impacts at the Airport.

5.0 ENVIRONMENTAL FATE AND TRANSPORT

Pursuant to 310 CMR 40.0835(4)(e), environmental fate and transport of OHM detected at the Disposal Site is set forth below.

5.1 Fate and Transport Characteristics

Pursuant to 310 CMR 40.0835(4)(e)1, an evaluation of the environmental fate and transport characterizes the OHM identified at the Disposal Site, including, without limitation, mobility, stability, volatility, persistence, and bioaccumulation potential of the OHM is set forth below. The OHM includes details on all six PFAS compounds regulated by the MassDEP, 6:2-FTS, and potential degradation products and 1,4-dioxane.

5.1.1 AFFF Usage, Release, and Degradation Potential

Based on interviews with Airport staff who have worked at the Airport since the 1980s, AFFF was only intentionally sprayed at the Airport during tri-annual drills (1991, 1994, 1997, 2000, 2003, 2006, 2009, and 2012), during an Airport Emergency (1981 and 2016 aircraft crash), and once per year between 2004 and 2015 as part of the FAA annual foam testing requirement (14 CRF 139). Airport personnel also indicated that fluorotelomer-based AFFF had been used at the Airport since at least the 1980s when foam usage was limited to 35-gallons for use in one fire rescue vehicle. AFFF was used at the Deployment Area between 1994 and 2004 for triannual drills and between 2004 and 2015 for annual AFFF mixture testing. Two firefighting personnel, employed by the Airport since the 1980's, indicated that foam testing was not conducted prior to 1991 due to cost, limited availability, and lack of an FAA requirement mandating foam usage. With the exception of the events detailed above, AFFF was not intentionally sprayed due to cost and limited supply of AFFF. With the exception of the 1991 drill, all drills and AFFF testing have been conducted at the unpaved Deployment Area.

In addition to the tests and training usage with AFFF, daily (approximately 5 gallons) and monthly (100 gallons) testing of the fire apparatus is conducted with just water. The test is conducted to verify that the fire apparatus pumps are operational. No foam is intentionally sprayed during these tests. The spray water from the fire trucks were tested for PFAS in 2019 to verify that the valve mechanism that segregated the AFFF was working properly. The analytical results indicated that AFFF was being mixed with the water unintentionally from the internal AFFF holding tanks. It was determined that the valve that segregates the AFFF was faulty and was the cause of the unintentional mixing. The faulty valve was replaced, and a maintenance schedule has been initiated. Subsequent testing of the spray water indicates that PFAS levels are less than the current GW-1 standard. The combination of tri-annual drills, the annual AFFF testing, and, to a lesser extent, the daily and monthly spraying of water have contributed to the AFFF related PFAS impacts in the Deployment Area. The Airport stopped using AFFF in the tri-annual training drills in 2015 and purchased an ecological cart in 2016 to stop spraying AFFF as part of the annual FAA testing requirement. Refer to Table 2 for tabulated analytical data from the spray testing.

The current ARFF/SRE Building was constructed in 1996, and PFAS is assumed to have been released in this area through, what is presumed to be, incidental spillage, dripping from hanging fire house apparatus to dry, and cleaning of equipment in the event of accidentally engaging the foam pump button. Interior floor drains that were closed in the early 2000's within the ARFF/SRE building historically discharged to the adjacent grass area that was capped in the fall of 2020.
Prior to 1996, the Airport fire truck was housed in the former Operations Building located adjacent to the former terminal along the North Ramp (see attached Figure 2). This building was demolished in 2011. Based on interviews with two firefighting staff who have worked at the Airport since the 1980s, AFFF containers were also stored in this building.

In the event the foam pump was accidentally engaged, equipment was rinsed by pumping water through it and then discharging the water to the adjacent grass area that has since been capped. Stormwater, in the vicinity of the recently capped area, also historically infiltrated into this area and included both the building's roof and surrounding paved surface areas. The interior floor drains historically discharged to this area but were closed in the early 2000's and connected to a permitted discharge to the Barnstable Wastewater Treatment Plant. As part of the cap installed in 2020, stormwater was redirected away from this area and instead infiltrates beyond the PFAS impacted soil areas.

Degradation Potential

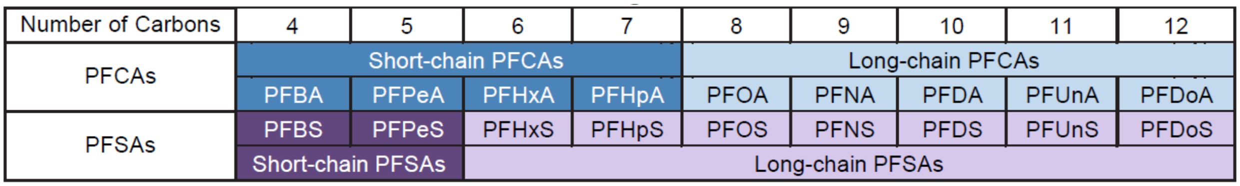
HW conducted additional research regarding PFAS to better understand the fate and transport and the degradation potential of PFAS while traveling through both soil and groundwater.

Short-Chain PFAS vs. Long-Chain PFAS

According to the document titled "*Aqueous Film-Forming Foam*" prepared by the Interstate Technology ITRC, legacy fluorotelomer-based AFFF (1970s to 2016) historically contains predominantly short-chain (C6) PFAS with formulations ranging from about 50–98% short-chains with the balance as long-chain PFAS. Additionally, the long-chain PFAS content of these foams has the potential to break down in the environment to PFOA and other PFCAs, but not to PFOS or other PFSAs (Weiner et al. 2013). This is consistent with the radar plots in the AFFF source areas which indicate 6:2 FTS constitutes over 80% of the sum of the total PFAS analytes reported by the laboratory.

According to the article titled "*Quantitative Determination of Fluorotelomer Sulfonates in Groundwater by LC MS/MS*", "groundwater monitoring studies have shown the predominant breakdown product of the short-chain C6 fluorosurfactants contained in telomer-based AFFF to be 6:2 fluorotelomer sulfonate (6:2-FTS)". This statement is consistent with the analytical results collected from the Airport source areas that indicate upwards of 83 percent of the total PFAS detected in monitoring well HW-I[s], the well with the highest concentration of Total PFAS on Airport property , was related to 6:2-FTS. This well, located within the Airport Deployment Area, was tested in November 2018 (82.4%) and then again in May 2020 (83.7%). The detection of this analyte at such a high percentage is representative of studies that indicate that fluorotelomer-based AFFF short chain PFAS transform into 6:2-FTS. Additionally, for comparison, spray water samples collected from the fire hose spray water before the valve mechanism was fixed contained 6:2-FTS at 79 percent.

According to the chart below prepared by ITRC and obtained from their document titled "*Naming Conventions for Per and Polyfluoroalkyl Substance*", short chain PFCAs include PFBA, PFPeA, PFHxA, and PFHpA. Of these included in the chart, MassDEP currently regulates the short chain PFCA compound PFHpA.



Number of Carbons	4	5	6	7	8	9	10	11	12
PFCAs	Short-chain PFCAs				Long-chain PFCAs				
	PFBA	PFPeA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA
PFSAs	PFBS	PFPeS	PFHxS	PFHpS	PFOS	PFNS	PFDS	PFUnS	PFDoS
	Short-chain PFSAs		Long-chain PFSAs						

Biotransformation

A study by Zang et al (2016) titled "*Biotransformation potential of 6:2 Fluorotelomer Sulfonate (6:2 FTSA) in aerobic and anaerobic sediment*" evaluated the biodegradation of 6:2 FTS in aerobic river sediment and concluded that it could take place fairly rapidly in this environment. This study is not relevant to the aquifer at the Airport as there is no river sediment or similar organic material at concentration that would promote the biodegradation of 6:2 FTS. Similarly, a study by Wang (2010) showed that 6:2 FTS could potentially biodegrade in aerobic conditions using wastewater sludge as the medium. Again, this type of organic material is not present in the aquifer below the Airport. Considering that 6:2-FTS has been detected in HW-S(s) which is located approximately 700 feet downgradient of HW-I(s) at very similar percentages (76 and 83.7 percent, respectively), significant biotransformation of 6:2-FTS is not occurring and the 6:2 FTS analyte appears to be stable.

It is possible, with the right conditions, for 6:2-FTS to biodegrade into one or more perflourocarboxylic acids (PFCAs). HW evaluated this issue by looking at the relative concentrations of 6:2-FTS versus the PFCA compounds using data from wells within the plume from the Deployment Area. The concentration of 6:2-FTS did decrease between well HW-I(s) in the Deployment Area and well HW-S[s] approximately 700 feet downgradient, as indicated previously. However, there was no significant increase in the PFCA concentrations in the downgradient well, and the reduction in 6:2-FTS concentration between these two wells is attributed to dilution and dispersion. The concentration of Total PFAS, 6:2-FTS, PFOA, PFOS, and the short chain PFCAs are indicated below in ug/l.

Analyte	**HW-I(s) 5/8/2020**	**HW-S(s) 10/1/2020**	**HW-19(m) 10/1/2020**
Total PFAS	15.5358	4.8958	0.37335
6:2-FTS	13.0	3.7	0.00095
PFBA	0.021	0.086	0.033
PFPeA	0.81	0.42	0.13
PFHxA	0.51	0.25	0.027
PFHpA	0.54	0.11	0.03
PFOA	0.29	0.062	0.011
PFOS	0.04	0.1	0.047

Based on the table above, the 6:2-FTS appears to be relatively stable and is a helpful analyte to monitor the AFFF plume movement. Additionally, as discussed in later sections of this report and

Section 4.3.2, 6:2-FTS moves faster in groundwater than the MassDEP Sum of Six regulated analytes (Figure 17). As such, 6:2-FTS is helpful in tracking the extent of the Airport AFFF plume. The extent of the AFFF plume in the vicinity of the Deployment Area is based on forensics, analytical results, and PFAS fate and transport mechanisms. As a conservative measure, the Deployment Area Plume has been depicted on Figure 2 as being slightly upgradient of OW-19 which does not appear to have PFAS impacts consistent with the Airport AFFF plume. A distance of approximately 1,100 feet exists between HW-S(s) and OW-19.

Considering that the source in the ARFF/SRE Area is related to incidental spillage and/or a single release event, it is not a chronic source like the Deployment Area. This is evident when reviewing the concentration (in ug/L) of 6:2-FTS, PFOA, PFOS, and the short chain PFCAs throughout the ARFF/SRE plume as indicated below.

Analyte	**HW-P(s) 10/1/2020**	**HW-302 12/3/2018**	**HW-3 5/5/2020**	**RB-1(s) 5/8/2020**	**RB-1(m) 5/8/2020**
Total PFAS	0.2458	0.3427	0.96981	0.08008	0.2015
6:2-FTS	0.011	0.13	0.13	ND	0.038
PFBA	0.041	0.014	0.0056	0.0033	0.01
PFPeA	0.1	0.042	0.33	0.0078	0.041
PFHxA	0.045	0.027	0.21	0.0058	0.021
PFHpA	0.026	0.015	0.1	0.0042	0.011
PFOA	0.0084	0.030	0.054	0.007	0.013
PFOS	0.00097	0.031	0.1	0.038	0.049

Considering the stability of 6:2-FTS and the fact that it migrates faster than any of the MassDEP regulated PFAS analytes, it appears that AFFF related compounds were released at some point in time after 1996 (ARFF/SRE Building was constructed in 1996) in the vicinity of monitoring well HW-P(s) and HW-P(m). Based on forensics, analytical results, and PFAS fate and transport mechanisms, the AFFF plume in the vicinity of ARFF/SRE Building has migrated approximately 900 to 1,000 feet. The Maher Wells are located an additional 1,000 feet downgradient of the Airport's AFFF plume. The extent of the Airport's AFFF plume is indicated on Figure 2.

As indicated on Figure 2, PFAS impacted groundwater is migrating onto the Airport from off-Airport upgradient sources that are not consistent with the AFFF specific PFAS plume associated with Airport. Additionally, as indicated on Figure 2, the PFAS plume associated with the Airport does not appear to have migrated to the Maher Wells as of when the last samples were collected. However, it is also understood that the Airport's PFAS Plume is migrating toward the Maher Wells. Additional groundwater testing is planned as part of ongoing IRA activates to further support the Conceptual Site Model and to help prepare the Phase III report.

The Airport has controlled a majority of the sources of PFAS in soil relating to the historic deployment of AFFF via two non-permeable caps installed within the vicinity of this release. The cap installations were completed in September 2020 and additional details are included in the report titled "*Immediate Response Action Plan Status Report 8*" dated October 2020 which is available for direct download from the MassDEP Searchable Sites Database using RTN 4-26347. Considering that PFAS have been detected in soil in both areas down to groundwater, the cap will prevent the further vertical migration of PFAS in soil.

Ultimately, the radar plots developed by HW clearly document which groundwater samples are related to the Airport sources and which are associated with offsite sources. The Airport groundwater plume contains all but one of the sum-of-six compounds regulated by MassDEP (PFDA) and unregulated PFAS compounds including a high concentration of 6:2-FTS. The relative concentrations of each PFAS compound (both regulated and unregulated) were used to confirm if a groundwater sample was related to the Airport releases.

HW concludes that the aquifer conditions in the vicinity of the Airport do not contribute to the biodegradation of 6:2-FTS. This is supported by the measured concentrations of 6:2-FTS and PFCAs in the Deployment Area plume. As discussed above, while these concentrations decreased in downgradient locations, the concentrations of the potential degradation compounds did not increase in a proportional manner.

5.1.2 Vapor Pressure

To continue to understand the fate and transport of PFAS and PFAS related compounds in soil and groundwater, additional chemical characteristics need to be considered. For instance, vapor pressure is a measurement of the tendency of a material to change into the gaseous or vapor state. The higher the vapor pressure, the more volatile a substance is. According to the EPA Comp Tox, the following vapor pressures are applicable to the six PFAS compounds regulated by MassDEP, 6:2-FTS and 1,4-dioxane:

Analyte	**Vapor Pressure (millimeters of mercury)**
Perfluorodecanoic Acid (PFDA)	1.53×10^{-3}
Perfluoroheptanoic Acid (PFHpA)	0.229
Perfluorohexanesulfonic Acid (PFHxS)	8.10×10^{-9}
Perfluorooctanoic Acid (PFOA)	0.952
Perfluorooctanesulfonic Acid (PFOS)	2.48×10^{-6}
Perfluorononanoic Acid (PFNA)	8.72×10^{-3}
6:2 fluorotelomer sulfonate (6:2-FTS)	8.24×10^{-7}
1,4-dioxane	38.1

5.1.3 Henry's Law Constant

The Henry's Law Constant describes the air-water partitioning of a gas dissolved in a liquid. Compounds with high Henry's Law Constants prefer to exist in the vapor phase rather than the dissolved phase. According to the EPA CompTox, the following Henry's Law Constants are applicable to the six PFAS compounds regulated by MassDEP, 6:2-FTS and 1,4-dioxane:

Analyte	Henry's Law Constant (atm-m^3/mole)
PFDA	1.50×10^{-10}
PFHpA	2.09×10^{-10}
PFHxS	1.94×10^{-10}
PFOA	1.92×10^{-10}
PFOS	1.80×10^{-11}
PFNA	1.18×10^{-9}
6:2-FTS	1.83×10^{-10}
1,4-dioxane	4.80×10^{-6}

5.1.4 Solubility

The solubility of a substance is the degree to which the substance (the solute) will dissolve into a solvent (i.e., water). The higher the solubility, the more solute will dissolve into the solvent. According to the EPA CompTox, the following solubility are applicable to the six PFAS compounds regulated by MassDEP, 6:2-FTS and 1,4-dioxane:

Analyte	Solubility (moles per liter)
PFDA	5.25×10^{-3}
PFHpA	0.324
PFHxS	6.08×10^{-4}
PFOA	1.37×10^{-2}
PFOS	1.13×10^{-3}
PFNA	2.80×10^{-3}
6:2-FTS	0.669
1,4-dioxane	11.42

5.1.5 Persistence

The persistence of a chemical is the length of time that a chemical can exist in the environment before being destroyed or transformed by natural processes. According to the EPA, a chemical is characterized as persistent if it has a half-life greater than two days. According to the EPA

CompTox, the following biodegradation half-life is applicable to the six PFAS compounds regulated by MassDEP, 6.2-FTS and 1,4-dioxane:

Analyte	Biodegradation Half Life (days)
PFDA	4.94
PFHpA	4.47
PFHxS	4.45
PFOA	4.94
PFOS	4.92
PFNA	4.94
6:2-FTS	4.95
1,4-dioxane	9.36

5.1.6 Bioaccumulation Potential

The bioaccumulation factor ("BCF") is an indication of the potential for a compound to bioaccumulate in the environment. The higher the BCF, the more likely it is to bioaccumulate. According to the EPA, a chemical is characterized as bioaccumulative if it has a BCF factor greater than 1,000. A chemical with a BCF greater than 5,000 is considered very bioaccumulative.

Analyte	Bioaccumulation Factor (unitless)
PFDA	49.3
PFHpA	92.2
PFHxS	175
PFOA	7,670
PFOS	1,900
PFNA	165
6:2-FTS	188
1,4-dioxane	0.925

5.2 Migration Pathways

Pursuant to 310 CMR 40.0835(4)(e)2, identification and characterization of existing and potential migration pathways of the OHM at and from the Disposal Site, including, as appropriate, air, soil, groundwater, soil gas, preferential migration pathways such as subsurface utility lines and other subsurface void spaces, surface water, sediment, and food chain pathways are set forth below.

5.2.1 Soil Migration

Based on the PFAS composition from soil samples collected both on and off the Airport, samples taken from the Deployment Area show that the AFFF used by the Airport contains all six of the PFAS compounds regulated by MassDEP (except PFDA in groundwater) along with other PFAS compounds. The data from areas outside the Deployment Area and the ARFF building locations do not indicate the same composition of PFAS compounds associated with the AFFF used by the Airport.

Based on the concentration of PFAS detected in soil (Table 3), none of the six regulated PFAS compounds exceed the proposed Upper Concentration Limit in soil of 4,000 ug/kg. Additionally, the Airport stopped all AFFF foam testing in 2015. AFFF use will only occur at the Airport in the event of an emergency. Also, as indicated on Figure 4, two impermeable caps were installed in September 2020 over a majority of the known PFAS in soil source area to reduce the potential for infiltration and migration. As indicated above, 1,4-Dioxane does not appear to be attributed to the Airport based on groundwater analytical data and particle tracking.

5.2.2 Groundwater Migration

Based on the concentration of PFAS detected in groundwater (Table 4), none of the six regulated PFAS compounds exceed the Upper Concentration Limit in groundwater of 5,000 to 100,000 ug/L. Additionally, as indicated above, two impermeable caps were installed in Fall 2020 over a majority of the known PFAS in soil source area to reduce the potential for infiltration and migration of PFAS in groundwater. Stormwater management systems were also constructed in these areas to allow for stormwater to infiltrate outside of the known PFAS in soil source areas. Moreover, the Airport stopped all AFFF foam testing in 2015

The extent of the PFAS plume related to the use of AFFF at the Airport is indicated on Figure 2 along with the estimated extent of other non-Airport related PFAS and 1,4-dioxane plumes. The vertical and horizontal extent of the PFAS and 1,4-dioxane plumes are also indicated on Figures 5 through 13. These figures also document that the 1,4-dioxane plume is migrating onto the Airport from an unknown source. 1,4-dioxane concentrations detected in groundwater are included on Table 7 and as indicated above, the Airport does not appear to be the source of 1,4-dioxane in groundwater.

Conversely, 1,4-dioxane migrates quickly from soil to ground water, so testing of groundwater in the vicinity of a potential release site is appropriate to determine if a release occurred. As explained above, groundwater testing in the vicinity of the historic deicing pads and historic solvent release area confirms that they are not the source of the 1,4-dioxane plume. Groundwater data clearly indicates that the source of the 1,4-dioxane is from an off-site location located hydraulically upgradient of HW-V(m).

The 1,4-dioxane plume is shown to enter the Airport near well HW-V(m) and flows southeast until it leaves the Airport property and flows towards the Maher Well field. HW created an updated hydrogeologic cross section (Figure 6) that shows how the plume moves down into the aquifer as it travels across the Airport. It moves downward at a consistent rate, based on the amount of recharge to the aquifer from rainfall that infiltrates into the ground. The cross-section documents wells screened in the aquifer above the mapped plume in which no 1,4-dioxane was detected. It also documents that the concentration of 1,4-dioxane in the plume is relatively stable as it moves across the Airport property, ranging from 0.8.ug/L upgradient of the Airport in well HW-V(m) to 0.732 ug/L downgradient of the Airport in Well OW-9(dd).

The direction of groundwater flow and relatively stable detection levels of 1,4-dioxane suggest that there is a long-term, consistent source of 1,4-dioxane upgradient of the Airport impacting groundwater quality.

1,4-dioxane was detected in well OW-18(d) at a depth of approximately 100 feet below the water table. Based on the hydrogeologic analysis, if a release occurred at the historic deicing area, it would move downward at a rate of approximately one feet of depth per 100 feet of horizontal transport. The well is located approximately 1,700 feet from the deicing area, so any 1,4-dioxane would be found at a depth 15-20 feet below the water table, not 100 feet below the water table. Additionally, sampling of HW-J which is downgradient of the former de-icing area and screened appropriately to detect a release in this area, did not contain 1,4-dioxane above the laboratory reporting limit.

The combination of these observations strongly supports the conclusion that no deicing fluid impacted groundwater at this location.

Ultimately, groundwater is flowing from the Deployment Area and ARFF/SRE Building towards the Maher Well field. This indicates that the PFAS plume from these source is headed in that direction and will likely reach the Maher Well field. Bi-annual monitoring is being conducted to track the plume migration and is being reported in IRA Status Reports submitted to MassDEP.

5.2.3 Preferential Migration Pathways

No subsurface utilities or other preferential pathways are located within the Disposal Site.

5.2.4 Air and Soil Vapor Migration

Considering the depth of groundwater (greater than 15 feet), the concentration of OHM in soil and groundwater and the vapor pressures of the OHM, vapor phase migration is unlikely.

5.2.5 Surface Water and Sediment Migration Pathways

As indicated on Figure 2, surface water samples were collected from Upper Gate Pond, Lewis Pond, and from a stormwater drainage basin located adjacent to the K-Mart Plaza. All results (Table 5) were below the laboratory reporting limit and/or below the Method 1 GW-1 and GW-3

Standard for the six regulated PFAS analytes. There is currently no surface water standard for PFAS. Additionally, based on the extent of the Airport's PFAS plume as indicated on Figure 2, surface water and sediments are unlikely to be impacted by the Airport AFFF release. It should be noted that PFAS, including the MassDEP six regulated compounds, have been identified at levels above the Method 1 GW-1 Standard entering the Airport in groundwater from the west from unknown upgradient source(s). However, the ponds themselves are quite shallow and do not interact with deeper groundwater found that far below the water table. There are no surface water outflows from the ponds that would cause groundwater to migrate upward to discharge to the ponds or an outlet stream. The ponds will only interact with shallow groundwater.

5.3 Potential for Groundwater to Impact Indoor Air

Pursuant to 310 CMR 40.0835(4) (e) 3, an evaluation of the potential for soil, groundwater, or NAPL to be a source of vapors of OHM to indoor air of occupied structures is set forth below.

Considering the depth of groundwater (greater than 15 feet), the concentration of OHM in soil and groundwater and the vapor pressures of the OHM, vapor phase migration into indoor air is unlikely.

6.0 NATURE AND EXTENT OF OHM IMPACT

Pursuant to 310 CMR 40.0835(4) (f), a discussion of the nature and extent of OHM impact at the disposal site is set forth below.

6.1 Characterization of Source and Nature of OHM Impact

Pursuant to 310 CMR 40.0835(4)(f), a characterization of the nature, and vertical and horizontal extent of OHM-impacts at the Disposal Site, including any and all source(s), the presence, distribution and stability of any non-aqueous phase liquid (NAPL), tabulation of analytical testing results, and, where appropriate, a characterization of background concentrations of OHM is set forth below.

As indicated above, the Disposal Site is the location of a release of PFAS compounds to soil and groundwater associated with the historic use of AFFF. The source of PFAS related to Airport operations is from the use of AFFF for training and emergencies and incidental spillage. Annual testing per FAA regulations is required to ensure that there is the appropriate AFFF to water mixture. Historically, the test consisted of essentially shooting the mixture of AFFF from the fire rescue vehicle at a small square target. The Airport has since purchased an ecological unit to test to the AFFF mixture without the need of physically mixing or spraying the foam. AFFF usage at the Airport is limited to emergencies only and most of the known sources within the Deployment Area and ARFF/SRE Building Area were capped in September 2020.

6.2 Extent of OHM Impact

Pursuant to 310 CMR 40.0835(4)(f), a characterization of the vertical and horizontal extent of OHM impact at the Disposal Site is indicated on Figures 2 through 13 and Tables 2 through 9. Additional details are set forth below.

The estimated horizontal extent of OHM impacts at the Airport is indicated on Figures 2 through 13. Based on the spatial distribution and extent of PFAS impacted soil and groundwater, the vertical extent of PFAS impacted media is estimated to be from the ground surface to approximately 56 feet below grade. A graphical representation of the vertical and horizontal extent of PFAS is set forth on Figure 3,5 and 7 through 13. As indicated on Figure 2, the Airport is also being impacted with 1,4-dioxane and PFAS plumes from off-site sources.

6.3 Characterization of Background Conditions

Pursuant to 310 CMR 40.0835(4)(f), a characterization of background concentrations of OHM impact at the disposal site is set forth below.

Background levels of PFAS in soil have been detected at the Airport as well as throughout the Town of Barnstable. To determine background levels at the Airport and surrounding area, HW collected 20 soil samples (7 soil on-Airport and 13 off-airport) at the locations indicated on Figure 15. Total PFAS concentrations ranged from less than the laboratory reporting limit to 5.45 ug/kg.

Eight of the background samples collected off Airport property exceeded the applicable Method 1 S-1 soil standards for various PFAS analytes including PFOS. Tabulated analytical data is included on Table 6. One of the background samples collected at the Airport exceeded the applicable Method 1 S-1 standard for PFOS (BG-4 0-1’). The detection of PFOS at this location is consistent with the other background samples collected, and it is not representative of the Airports AFFF release. Further, as indicated on Table 3, soil samples consistent with the Airports AFFF contain elevated levels of various other regulated PFAS compounds including PFNA and PFHpA. With the exception of PFOS, no other regulated compound was detected above the laboratory method detection limit sample BG-4 0-1’.

It should be noted that the single exceedance from the 1991 Drill Area (1991B [0-1]), and in proximity to the Steamship Parking Lot (A10), is consistent with background and does not appear to be related to the AFFF release associated with Airport operations. Refer to Table 3 for tabulated PFAS results.

7.0 EXPOSURE ASSESSMENT

Pursuant to 310 CMR 40.0835(4) (g), an exposure assessment, including the identification and characterization of all potential human and environmental receptors that could be impacted by OHM at or migrating from the Disposal Site, and, as appropriate, the quantification of exposure of OHM-impact at the Disposal Site is set forth below.

7.1 Potential Human Receptors

Pursuant to 310 CMR 40.0835(4) (f), potential human receptors are identified and characterized below.

Human Receptors Exposed to Soil

The two PFAS release areas at the Airport (the ARFF/SRE Area and the Deployment Area) are located within restricted and secured areas where the public are not allowed access. A majority of the PFAS source areas have also been capped with either asphalt or 30-mil geomembrane. Additionally, the highest concentration of one of the six regulated PFAS compounds (100 ug/kg) detected in Airport soils is less than the Method 2 S-1 soil category (300 ug/kg) which is protective of a direct contact exposure.

As indicated above, with the exception of HW-L(d), 1,4-dioxane has not been detected in any of the groundwater wells tested at the Airport. As such, 1,4-dioxane is presumed to not be located in site soils at the Airport.

Human Receptors Exposed to Groundwater

The Airport is located within a current drinking water source area, designated as Zone II to various public drinking water supply wells. As documented in the Phase I Report, the Airport and downgradient residential properties were confirmed to have municipally supplied drinking water. No private drinking water wells at the Airport or downgradient properties were identified by HW or the Town of Barnstable Department of Public Works, Water Supply Division, and the Town of Yarmouth Health Department. Additionally, the municipal water supplier is aware that public water supply wells have been impacted with PFAS and 1,4-dioxane. The water supplier is treating the drinking water accordingly to continue to provide drinking water to the residents that meets regulatory drinking water standards. A majority of the PFAS detected in the vicinity of the public drinking water supply wells appears to be from other non-Airport related sources including the Barnstable Fire Training Academy. As indicated above, 1,4-dioxane does not appear to be associated with a release from the Airport.

7.2 Potential Environmental Receptors

Pursuant to 310 CMR 40.0835(4) (f), potential environmental receptors are identified and characterized below.

Surface water samples collected from Upper Gate and Lewis Pond were all below the laboratory reporting limits for the six regulated PFAS analytes. The laboratory reporting limit is also less than the Method 1 GW-1. There are currently no PFAS standards for surface water.

There has been no evidence of fish kills or stressed vegetation detected in surface water at the Airport. Fishing and hunting are not allowed at the Airport. Also, a majority of the PFAS source areas have been caped and access to these areas are restricted with a fence. A priority resource map is included as Figure 19.

As indicated above, the release of 1,4-dioxane does not appear to be associated with the Airport.

8.0 RISK CHARACTERIZATION

Pursuant to 310 CMR 40.0900, the characterization of risk of harm to health, safety, public welfare, and the environment is set forth below.

8.1 Soil Classification

Pursuant to 310 CMR 40.0933, the applicable soil category is selected based upon the frequency, intensity of use, and accessibility of the Disposal Site by adults and children. Pursuant to 310 CMR 40.0923, risk characterization shall consider current and reasonably foreseeable Disposal Site activities.

8.1.1 Frequency of Use

Frequency of use indicates how often a receptor makes use of, or has access to, the Disposal Site. The frequency is classified as either “High,” “Low,” or “Not Present” based on the criteria set forth in 310 CMR 40.0933(4)(a).

The Disposal Site is located within a restricted area of the Airport where access to adults is provided for work related activities. Therefore, the frequency of use for adults is considered “high”.

8.1.2 Intensity of Use

The intensity of use is based on the kind of activities and uses that occur at a Disposal Site and are classified as either “High” or “Low.” Pursuant to 310 CMR 40.0933(4)(b)(1), Site activities and uses which have potential to disturb soil and thus result in either direct contact with the soil itself or inhalation of soil-derived dust shall be characterized as high intensity use.
Based upon the current use, passive activities which do not disturb the soil, such as walking and driving, are likely to occur in the area. As such, the intensity of use would be considered “low”.

8.1.3 Accessibility

Soils are classified as “Accessible,” “Potentially Accessible” and “Isolated” based upon the depth to OHM impact and the presence of impervious material, if any. Pursuant to 310 CMR 40.0933(4)(c) impacted soils located within the first three feet of the surface in unpaved areas would be considered “Accessible.” Soils from three to 15 feet below grade in unpaved areas, or soils from less than fifteen feet below grade in paved areas, would be considered “Potentially

Accessible.” Soils greater than 15 feet below grade or beneath the footprint of a building would be considered as “Isolated”. Therefore, soils at the Disposal Site are considered “accessible”.

8.1.4 Disposal Site Specific Soil Classification

Pursuant to 310 CMR 40.0933(9), the appropriate soil classification for a Disposal Site with “high” frequency and “low” intensity of use for adults (foreseeable future uses) and where impacted soils are “Accessible” soils are classified as S-2. However, as a conservative measure, soils at the Airport will be compared to the S-1 standards.

8.2 Groundwater Classification

Pursuant to 40.0932, groundwater classification is based on several factors including the current and potential use as a drinking water source, proximity to buildings and ecological risks. Groundwater is organized into three categories: GW-1, GW-2, and GW-3.

1. The GW-1 classification applies to groundwater located within a current or potential drinking water source area. The Method 1 GW-1 Standards address potential exposure to drinking impacted groundwater.
2. The GW-2 classification applies to groundwater located within 30 feet of an existing or planned building and where the average annual depth to groundwater is 15 feet or less. The Method 1 GW-2 Standards address potential exposure to vapors collecting in buildings above or adjacent to impacted groundwater.
3. The GW-3 classification applies to all groundwater that can potentially impact surface water bodies. Pursuant to 310 CMR 40.0932(2), all groundwater is considered a potential source of discharge to a surface water body. Therefore, the GW-3 classification applies to all groundwater within the boundaries of the Commonwealth of Massachusetts.

8.2.1 Disposal Site Specific Groundwater Classification

- As set forth above, the Disposal Site is located within a drinking water source area. Therefore, the GW-1 groundwater classification is applicable to groundwater at the Disposal Site.
- As indicated on Table 4, groundwater in the vicinity of structures at the Airport are located at a depth greater than 15 feet below grade. Therefore, the GW-2 classification is not applicable to the Disposal Site.
- As set forth above, the GW-3 classification is applicable to all the groundwater located within the boundaries of the Commonwealth of Massachusetts. Therefore, the GW-3 groundwater classification is also applicable to the Disposal Site.

8.3 Method 1 Risk Characterization

Pursuant to 310 CMR 40.0973(7), a condition of *No Significant Risk* ("NSR") of harm to health, safety, public welfare, and the environment exists if no soil or groundwater Exposure Point Concentration ("EPC") is greater than the applicable MCP Method 1 Soil and Groundwater Standards. A Method 1 Risk Characterization was conducted to assess risk to human health, safety, public welfare, and the environment associated with the release of OHM at the Airport as set forth below.

8.3.1 Risk Posed by OHM Impacted Soil

As set forth in in Table 3, concentrations of PFAS were reported above applicable Method 1 S-1 Soil Standards. No compounds were detected in soil in excess of upper concentration limits ("UCLs"). Therefore, a level of NSR has not been achieved at the Disposal Site with respect to OHM-impacted soil.

8.3.2 Risk Posed by OHM Impacted Groundwater

As set forth in Tables 4 and 7, concentrations of PFAS and 1,4-dioxane were reported above the applicable Method 1 GW-1 Groundwater Standards. No compounds were detected in groundwater in excess of the GW-3 Standard or UCLs. Therefore, a level of NSR has not been achieved for the Disposal Site with respect to OHM-impacted groundwater.

9.0 CONCEPTUAL SITE MODEL

- An extensive investigation program that included the interviewing of Airport staff, the collection of 125 soil samples for PFAS analysis, three surface water samples for PFAS analysis, 158 groundwater samples for PFAS analysis, eight fire truck spray samples for PFAS analysis, 45 groundwater samples for 1,4-dioxane analysis, eight SPLP samples for PFAS analysis, 13 groundwater samples for stable isotope analysis and one AFFF sample for PFAS analysis was completed as part of this Phase II. This information has been used to delineate the nature and extent of both PFAS and 1,4-dioxane at the Airport.
- Based on interviews with Airport staff who have worked at the Airport since the 1980s, AFFF was only intentionally sprayed at the Airport during tri-annual drills (1991, 1994, 1997, 2000, 2003, 2006, 2009 and 2012), during an Airport Emergency (1981-off Airport property and 2016 aircraft crash) and once per year between 2004 and 2015 as part of the FAA annual foam testing requirement (14 CRF 139). Airport personnel also indicated that fluorotelomer-based AFFF had been used at the Airport since at least the 1980's when foam usage was limited to 35-gallons for use in one fire rescue vehicle. With the exception of the events detailed above, AFFF was not intentionally sprayed due to cost, limited supply and/or the lack of an FAA requirement (prior to 2004). With the exception of the 1991 drill, all drills and AFFF testing have been conducted at the unpaved Deployment Area. The Airport stopped using AFFF in the tri-annual training drills in 2015

and purchased an ecological cart in 2016 to stop spraying foam as part of the annual FAA testing requirement.

- HW created a water table map specific to the Airport property based on data taken on April 27, 2020 from monitoring wells used during this investigation. It is attached as Figure 14. As indicated on the map, groundwater flows onto the Airport property from the west and northwest, migrates to the southeast, and exits the property at the southeast corner of the Airport.
- The 1,4-dioxane detected at the Maher Wells is related to an unknown source that is hydraulically upgradient of both the Airport and the Maher Wells. The source has been detected in the shallow groundwater within proximity to the commercial properties located along Airport Road as indicated by detections in monitoring well HW-V(m). The release migrates both vertically and horizontally as it passes through the Airport Rotary as indicated by detections in monitoring well HW-U(d), the Airport (HW-L[d]) and then the Maher Wells. Additional details and supporting information that the Airport is not the source of 1,4-dioxane have been presented above.
- PFAS has been detected in groundwater at multiple locations both on and off Airport Property at locations both hydraulically upgradient, cross-gradient and downgradient to the Airport. As discussed above, radar plots were developed as an environmental forensic technique to determine if the groundwater impacts were consistent with the Airports AFFF release.
- The Airport has purchase records since 2000 that document the type of AFFF used is Chem-Guard 3% mil spec which is a fluorotelomer-based AFFF. This type of foam contains multiple PFAS analytes including those regulated by MassDEP. However, a very large percentage of the detectable PFAS analytes is 6:2 FTS which is a distinguishing analyte to differentiate the Airport's AFFF release from other PFAS sources. Airport personnel interviewed indicated that this type of foam has been purchased since the 1980s.
- As indicated above, the Airport's AFFF plume can be traced by the high concentration of 6:2 FTS relative to the other PFAS analytes included in the AFFF. Additionally, the 6:2 FTS analyte moves quicker in groundwater than the six PFAS analytes currently regulated MassDEP. Since the Airports AFFF has been a fluorotelomer based product for at least the last 20 years as indicated by purchase records, it is easier to distinguish the Airports PFAS contribution to the widespread PFAS problem in the area by tracing the high concentration of 6:2 FTS as it leaves the Airport.
- AFFF was introduced to the ARFF/SRE Area through what is assumed to be incidental spillage, drippings from the hanging of fire house apparatus after use and cleaning of equipment in the event of an accidental foam discharge. Prior to being closed in the early 2000's Interior floor drains within the building historically discharged to the adjacent grass area that was recently capped in 2020. In the event of accidental foam discharge, equipment was rinsed by pumping water through it and discharging that water to the adjacent grass area that has since been capped.

- ARFF was introduced to the Deployment through the drills described above, ARFFF consistency testing, and from daily (approximately 5 gallons) and monthly (100 gallons) testing of the fire apparatus. As detailed above, the spray water from the fire trucks were tested for PFAS in 2019 to verify that the valve mechanism that segregated the AFFF was working properly. The analytical results indicated that AFFF was being mixed with the water unintentionally from the internal AFFF holding tanks. It was determined that the valve that segregates the AFFF was faulty and was the cause of the unintentional mixing. The faulty valve was replaced, and a maintenance schedule has been initiated. Subsequent testing of the spray water indicates that PFAS levels are less than the current GW-1 standard.
- HW reviewed the PFAS groundwater data to verify that the 6:2 FTS was stable and not significantly degrading to short chain PFCAs. Additional details are set forth above.
- The information presented above was used to estimate the extent of the Disposal Site boundary as indicated on Figure 2. Additional leaching of PFAS to groundwater from the two Airport source areas has been minimized by the installation of two impermeable caps at the locations indicated on Figure 3.

10.0 PUBLIC INVOLVEMENT

Pursuant to 310 CMR 40.1403 and the Final PIP dated September 16, 2019, notification of the updated Phase II will be provided to all individuals on Table 1. This includes the Chief Municipal Officer and the Board of Health for both Barnstable and Yarmouth.

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FIGURES

TABLES

APPENDIX A

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