

FACT SHEET

Fiber-Optic Distributed Temperature Sensing (FO-DTS) Technology for Groundwater-to-Surface Water Interface Investigations



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Introduction

Identifying the location where contaminant-impacted groundwater enters surface water is crucial for protecting aquatic ecosystems and human health. Groundwater plumes discharging as “seeps” into streams, wetlands, or coastal waters can transport pollutants; however, these discharge points are often preferentially distributed and can be overlooked by traditional site investigation methods. Traditional methods (e.g., point sampling with seepage meters or Trident probes) only measure specific locations and may not capture the full extent of the groundwater-surface water interface (Iery et al. 2025). Therefore, improved tools have been developed to locate and delineate groundwater seeps. This fact sheet discusses one advanced tool, fiber-optic distributed temperature sensing (FO-DTS), which is a direct-contact technology that shows promise in improving site investigations.

How Does It Work?

FO-DTS uses a fiber-optic cable as a continuous thermal sensor (**Figure 1a**) to pinpoint active discharge zones along the cable by detecting subtle temperature differences between groundwater and surface water. As groundwater typically maintains a relatively constant temperature, temperature anomalies are created when groundwater discharges to nearby surface water during winter and summer, causing significant temperature changes at the cable location. For example, cooler groundwater enters warmer surface water in the summer, and warmer groundwater enters cooler surface water in the winter. These anomalies are detected over distance and time (**Figure 1b**), using laser interrogator pulses through a fiber-optic cable and temperature-dependent Raman backscatter (Rey et al. 2025). Temperature is typically calculated every 0.25 to 1 meter (m) to a precision of approximately 0.1°C along fiber-optic cables that can extend several kilometers (km) (Domanski et al. 2020; Selker et al. 2006; United States Geological Survey [USGS] 2023). When FO-DTS cables are placed along sediment at the groundwater-to-surface water interface, investigators can map seep locations over hundreds to thousands of meters in a single deployment (**Figure 1c**), rather than one point at a time. FO-DTS has emerged as a powerful component of temperature sensing approaches, complementing thermal infrared (TIR) imaging and manual measurements to improve seep detection coverage and reduce the likelihood that seeps are missed (Henderson et al. 2009; Rey et al. 2025).

How Can It Help?

- **Efficient survey technique.** A single FO-DTS cable can screen hundreds of meters of shoreline or streambed in one pass (Iery et al. 2025; Rey et al., 2025; Rosenberry et al. 2016).
- **High-resolution mapping.** Submeter temperature data can delineate narrow groundwater pathways and plume edges that point sensors miss or that may be obscured from imaging by vegetation (Rey et al. 2025).
- **Targeted contaminant sampling.** Thermal anomalies highlight exact locations where groundwater enters surface water, allowing teams to direct chemical sampling to those hotspots and avoid blind or grid-based sampling approaches (Iery et al. 2025; Rey et al., 2025).
- **Continuous temporal monitoring.** Paired with vertical temperature profilers (VTPs) and modeling, FO-DTS time series can reveal seepage fluctuations under tidal pumping at a coastal landfill (Briggs et al. 2025).
- **Cost and time savings.** Studies have shown that an FO-DTS survey with limited confirmatory samples can reduce field effort and analytical costs by providing continuous coverage that reduces the need for dense well networks and repeated mobilizations (Iery et al. 2025).
- **Minimal disturbance and broad applicability.** FO-DTS can be operated year-round whereas TIR tools are less effective in warmer months and only capture the water surface ‘skin’ temperature. In addition, the millimeter-thick cables are installed by hand with little habitat impact and have proven effective when deployed in rivers, streams, wetlands, estuaries, and armored coastlines (Briggs et al. 2013; Iery et al. 2025).

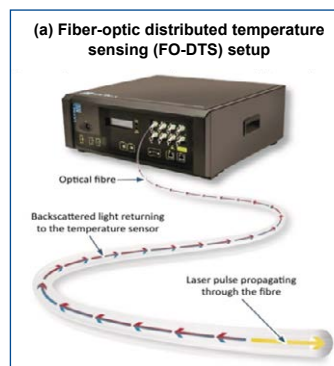


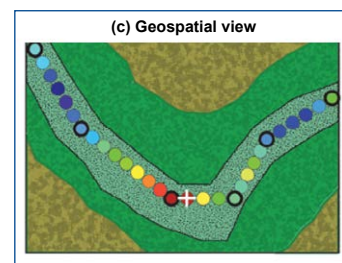
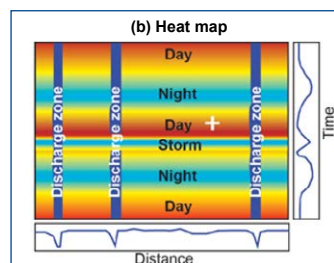
Figure 1.

(a) FO-DTS control unit with fiber-optic cable.

(b) FO-DTS data displayed in a heat map as temperature versus distance and time.

(c) Temperature along the cable, with locations interpolated linearly between points.

Note: FO-DTS photo courtesy of Silixa LLC. Images adapted from Domanski et al. (2020).



CASE STUDY 1:

Joint Base Cape Cod



Project Objectives

FO-DTS was deployed in June 2022 to identify and characterize preferential groundwater discharge points (PDPs) in the Quashnet River wetland system downgradient of Joint Base Cape Cod (JBCC) in Massachusetts (Rey et al. 2025). This FO-DTS deployment complemented earlier TIR surveys conducted in March 2022 using an unmanned aerial vehicle (UAV) and a handheld TIR camera. The main objective of the case study was to locate discharge zones where per- and polyfluoroalkyl substances (PFAS)-impacted groundwater emerges into the river and to quantify the spatial and temporal variability in PFAS mass loading at those discharge zones. The field demonstration was conducted under the Department of Defense (DoD) Environmental Security Technology Certification Program (ESTCP) Project [ER21-5237](#).

Site Background

The Quashnet River and its associated wetlands are located downgradient of JBCC's historical firefighting training areas, where aqueous film-forming foam (AFFF) was used during past operations. The river drains a variety of terrain from sandy valley sections to open bog areas, all of which are substantially influenced by groundwater seepage. Nearby flow-through kettle ponds and lakes are also known to have an effect on groundwater flowpaths (**Figure 2**). In addition, drainage ditches from previous cranberry farming operations complicate aquifer to surface water connectivity. The main channel of the Quashnet River averages approximately 4 meters (m) in width with flow ranging from 0.20 to 0.45 cubic meters per second (m^3/s). Groundwater temperatures are relatively stable at about 9.5 to 11.5 °C year-round, whereas surface water temperatures vary widely from 5 to 25 °C by season.

Results

FO-DTS was deployed to capture fine scale information on active seeps and temporal dynamics (**Figure 3**). In total, 57 high-flow PDPs were confirmed across the two site investigation campaigns (March 2022 and June 2022). Seepage meters were then placed at nine representative PDPs to estimate discharge. Specific discharges ranged from 0.2 to 3.2 m/day with a mean of 1.1 m/day.

High-flux PDPs were sampled for dissolved oxygen, stable water isotopes ($\delta^2\text{H}$, $\delta^{18}\text{O}$), and forty PFAS compounds. The data collected also allowed for the calculation of discharge-weighted estimates of PFAS mass loading. FO-DTS guided sampling recorded total PFAS concentrations ranging from non-detect to 4,677 nanograms per liter (ng/L). The highest PFAS concentrations were located within 100 m of the downgradient shoreline of a kettle pond (Johns Pond) and also corresponded to the PDP with the highest discharge rate at 3.2 m/day. Chemical fingerprints in the seepage water differed sharply; some seeps were rich in perfluorooctane sulfonate (PFOS), and other seeps contained predominantly short-chain acids or precursors. The isotopic analysis of the seepage water also differed by location with some waters showing a signature for meteoric water recharge (e.g., water derived from precipitation) and others showing evaporatively enriched pond or lake water. By pairing seep-scale fluxes with laboratory PFAS concentrations, the FO-DTS data connected each thermal anomaly to a PFAS signature and flow-path history.

The study determined that PFAS loading showed a similar spatial pattern across seasons when corrected for contributions from direct surface water outflow from Johns Pond. These results confirm FO-DTS can provide both a comprehensive seepage inventory and a quantitative foundation for evaluating contaminant mass loading and seasonal variability at the groundwater-surface water interface.

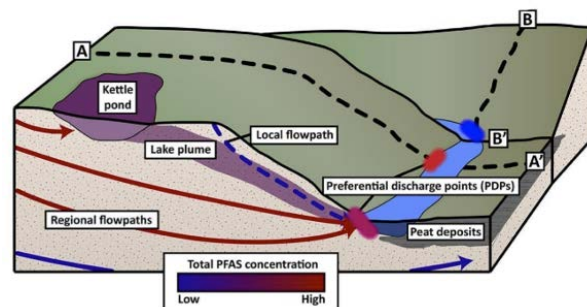


Figure 2. Conceptual site model showing PFAS sources and groundwater flowpath characteristics (Adapted from Rey et al. 2025).

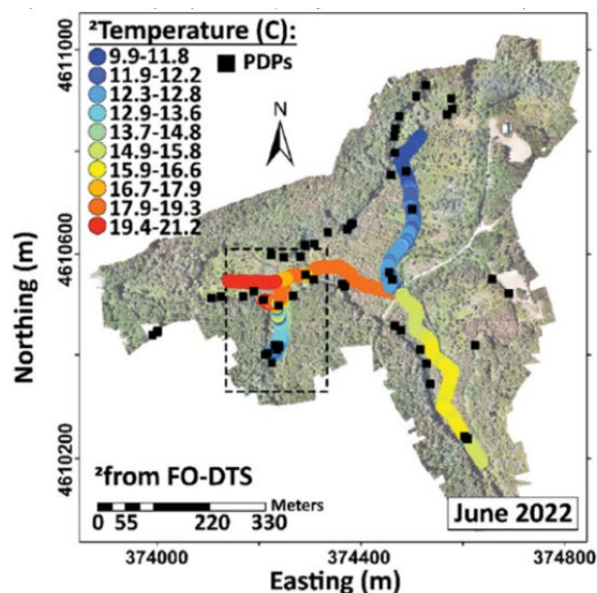


Figure 3. Identified PDP locations (black squares) and FO-DTS stream bed temperature from June 2022 survey (colored circles). The location of the TIR survey footprint is shown in a dashed box (Adapted from Rey et al. 2025).

Outcome: FO-DTS delineated dozens of discrete groundwater discharge zones along the Quashnet River, including many not detected by aerial or handheld thermal imaging, and logged submeter temperature time series for each zone. Integrating these data with seep PFAS concentrations yielded flow-weighted PFAS mass loading estimates that can inform future monitoring network design and remedial measures.

CASE STUDY 2: McAllister Point Landfill



Project Objectives

FO-DTS was deployed at the McAllister Point Landfill site at Naval Station (NAVSTA) Newport in Rhode Island. The study aimed to validate a site investigation approach that integrates multi-scale thermal and electromagnetic tools to map groundwater-to-surface water interactions and to quantify mass flux of metals to Narragansett Bay (**Figure 4**). The field demonstration was conducted under the DoD ESTCP Project [ER21-5237](#) (Iery et al. 2025). The demonstration combined FO-DTS data with information from waterborne electrical resistivity (wERI), waterborne electromagnetic induction (EMI), point-specific conductance measurements, UAV-TIR, handheld TIR camera imaging, VTPs, seepage meters, and metal concentrations. The combined data were used to evaluate whether metals-impacted groundwater was entering Narragansett Bay and to characterize the location and rate of groundwater discharge (Moore et al. in review). FO-DTS data were specifically used to identify focused shoreline discharge zones in order to guide the selective placement of VTPs and seepage meters for quantification of fluxes (Iery et al. 2025).

Site Background

McAllister Point Landfill is a 10.5-acre Installation Restoration Program site capped in 1995 on the west shore of Aquidneck Island. The impacted aquifer includes thin glacial till overlying weathered shale with groundwater levels at 3.0 to 4.6 m below grade that are influenced by semidiurnal tides. Post-cap management of the landfill includes semiannual inspections and a monitoring well network for collecting groundwater samples for copper, nickel, and other related constituents. For this FO-DTS study, the fiber-optic cable was deployed along the inland and bayward beaches, logging temperature every 40 minutes to map cooler summer groundwater discharge. Concurrent hydraulic and geochemical data was collected utilizing the tools outlined above.

Results

UAV-TIR revealed a 200 m band of cool surface water (at 16.7 to 19.1 °C) along the landfill's southern shoreline that contrasted with the Bay's surface water temperature (at 22.9 to 23.5 °C), indicating groundwater discharge along the southern shoreline (Iery et al. 2025; Moore et al. in review). These results were supported by subsequent FO-DTS measurements which yielded average and minimum temperatures along the cable that were cooler towards the southern section of the McAllister Point Landfill site (**Figure 5**). Waterborne EMI, wERI, and point-specific-conductance measurements also independently showed groundwater discharge from seeps within the southern zone.

FO-DTS time-series data then captured the temporal dynamics that drive these seeps (**Figure 6**). Temperatures at the inland beach location stayed about 1 °C below a central reference site. The temperatures also tended to rise and fall with each semidiurnal tide and dropped a further 0.4 °C after a storm, documenting the influence of precipitation-enhanced flushing. Seepage meters measured specific fluxes from -0.15 to -2.51 m/day, averaging -0.60 m/day. VTP data were also utilized to estimate a modeled maximum groundwater discharge of 1.16 m/day, which corroborated the magnitude of the seepage meter data (Moore et al. in review).

Seepage water samples collected in 2023 contained up to 10.2 micrograms per liter (µg/L) of copper and 6.3 µg/L of nickel in the southern most section of the inland beach. Sampling efforts in 2024 showed lower concentrations of copper and higher concentrations of nickel. The maximum nickel and copper concentrations were found to be 12 µg/L and up to 2 µg/L, respectively. The concentration data from 2024 were combined with VTP modeled hydrological fluxes to determine metal contaminant mass fluxes into the bay. Copper fluxes ranged from 0.5 µg/day to 56.5 µg/day, whereas nickel fluxes ranged from 0.4 µg/day to 63.1 µg/day. Mass flux and variable geochemistry results confirmed high-flux seeps drive metals transport into Narragansett Bay (Moore et al. in review). Future remedial optimization efforts should address this spatial heterogeneity in metals mass flux and FO-DTS offers the sub-meter resolution needed to target cleanup where the highest metals loading from groundwater to surface water has been identified.

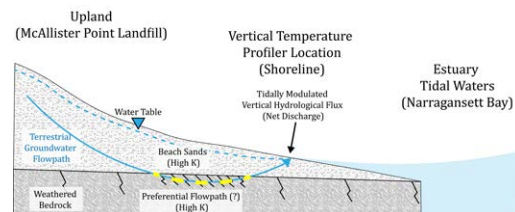


Figure 4. Conceptual site model of potential groundwater flow from McAllister Point Landfill to Narragansett Bay (Adapted from Moore et al. in review).

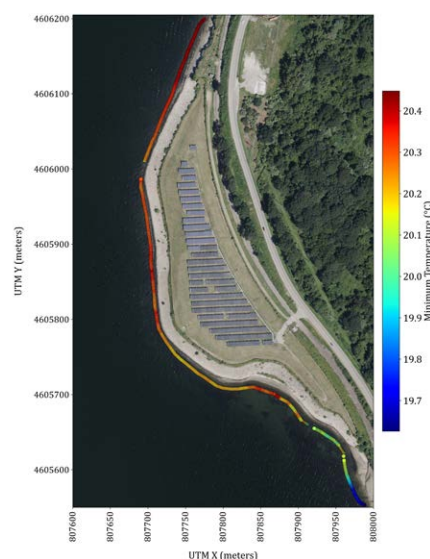


Figure 5. FO-DTS results displaying discharge of cooler water over time in the southern section of the McAllister Point Landfill (Adapted from Iery 2025).

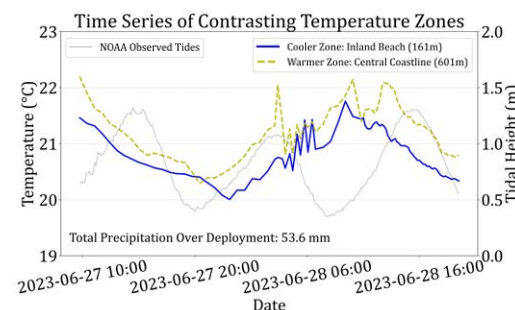


Figure 6. Select time series of temperature at two points along the FO-DTS cable, with a cooler zone on average along the inland beach and a warmer zone on average along the central coastline of McAllister Point Landfill (Adapted from Iery et al., 2025).

Outcome: FO-DTS was successfully deployed as part of a combined site investigation approach with UAV-TIR, handheld TIR, wERI, EMI, and other related tools. The DoD ESTCP study results at the McAllister Point Landfill site revealed high-flux seeps and allowed for estimation of the mass fluxes of copper and nickel that were occurring from the landfill's southern shoreline.



Conclusions



Conclusions

The field demonstrations support using FO-DTS as a valuable site investigation tool at the groundwater-surface water interface for Department of the Navy Environmental Restoration Program sites. The following are key conclusions (Rey et al. 2025; Iery et al. 2025; Moore et al., in review):

- **Provides continuous, high-resolution data coverage:** FO-DTS provides high-resolution data on the order of every 1 m over the span of kilometers.
- **Pinpoints contaminated seeps:** At a former firefighting training area (e.g., JBCC) and a coastal landfill (e.g., McAllister Point Landfill), FO-DTS identified previously unknown groundwater-surface water discharge locations, improving site characterization for future mitigation efforts and site-specific risk evaluations.
- **Captures dynamics and mass loading:** Time-series data show diurnal, tidal, and storm-driven flow shifts, yielding better mass loading estimates. FO-DTS helped guide the strategic placement of VTPs for quantification of PFAS loads at JBCC and of tide-modulated metals discharge at the McAllister Point Landfill site.
- **Guides management decisions:** FO-DTS directs sampling and well placement to confirmed discharge zones, reducing unnecessary field and lab effort.
- **Augments additional site investigation tools:** FO-DTS data can be used in conjunction with TIR imaging and geophysical conductivity surveys to identify and quantify groundwater discharges.
- **Requires specialized equipment and experience to deploy:** Field setup requires rugged gear, calibration baths, and added labor, but DoD ESTCP demonstrations show these hurdles are manageable, and shared lessons learned are easing wider adoption across Navy sites.

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