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Investigating Groundwater – Surface Water Interaction Using Distributed Temperature Sensing (DTS) Technology

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INTRODUCTION

At an approximate 350-acre railyard, a long history of diesel fuel use and subsurface releases have resulted in an approximate 30-acre area impacted with light non-aqueous phase liquid (LNAPL). Studies showed this LNAPL body was present in a shallow (perched groundwater zone) and deeper groundwater (lower aquifer). The two LNAPL-impacted aquifers are dissected by a culverted stream that flows across the site through a 1,750-foot long and 25-foot wide culvert with an open bottom resulting in sheening on the stream. The site is currently under a consent order to stop sheening on the stream.

One pathway with sheening potential into the culverted stream is via groundwater discharge. Previous investigation efforts examining the extent and quantity of groundwater discharge into the stream were limited to using conventional approaches collecting surface water elevations and hydraulic head data from piezometers within the culvert and nearby monitoring wells. As a means to gather higher resolution groundwater discharge data, a DTS survey was completed.

DTS utilizes fiber optic cables buried in the stream substrate to record temperature of sediment porewater and allow for comparison to surface water temperature. Temperature differentials can be used as an indicator of where groundwater discharge is occurring. The magnitude of the differential data is used in a heat transfer model to estimate the rate of groundwater discharge. Therefore, use of DTS overcomes limitation of installing piezometers within the culvert and provides high resolution temporal and spatial data in understanding surface water – groundwater interaction that may contribute to sheening. These data were used to locate and quantify areas of groundwater discharge to the stream and support a feasibility study for remedy selection.

Site Location & History

The Rail Yard ("Site") is located along a river and began operations in 1880s with yard construction activities continuing through 1950s. The Site construction filled a portion of naturally occurring riverbank and culverted a naturally occurring stream to build the rail yard.

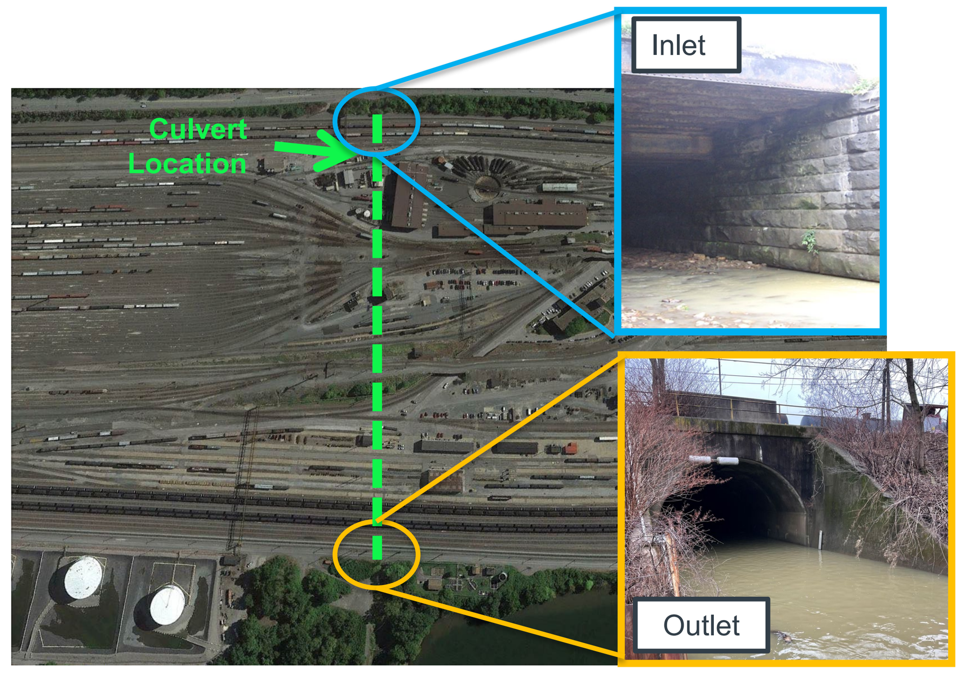

FIGURE 1: Site Layout. Approximate location of culvert is shown as green dashed line.

The culverted stream is approximately 1,750 feet long, 25 feet wide, and 18-20 feet in height with the culvert constructed using either stone blocks or concrete depending on the location within the culvert. Site layout and photo images showing the differences in construction material are shown in Figure 1.

Conceptual Site Model (CSM)

- Light non-aqueous phase liquid (LNAPL) observed in both the perched groundwater zone and lower aquifer.
- Pathways for sheening potential
  - Through sidewalls in upstream half of culvert from perched groundwater.
  - Groundwater discharge from lower aquifer throughout length of culvert.
- Use of multiple nested piezometers inside the culvert identified two areas of intermittent gaining conditions driving sheening, Station 03 and 09, with a combined discharge rate of 49.8 gpm (Figure 2).

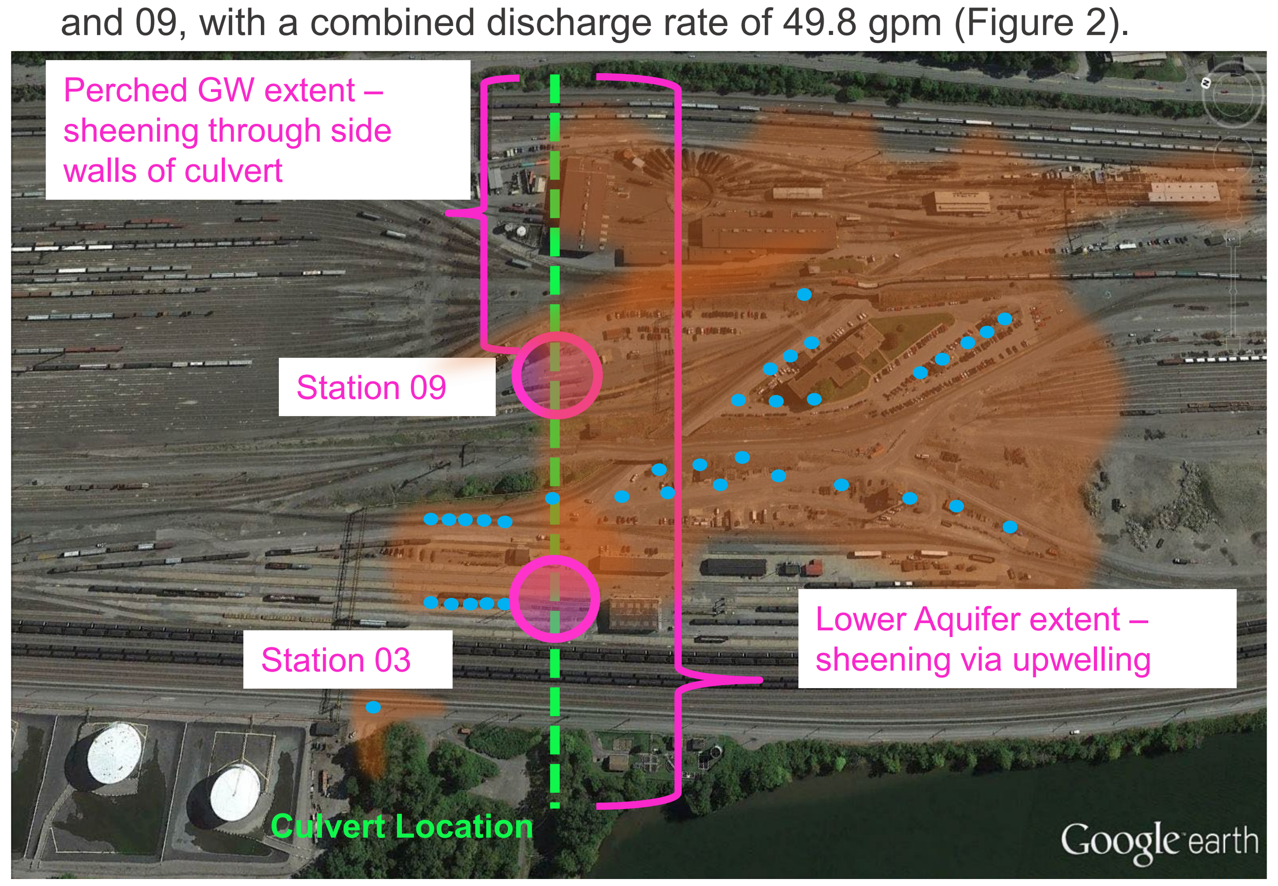

FIGURE 2: Extent of LNAPL body and sheening CSM prior to DTS survey. Approximate location of culvert, LNAPL extent, and LNAPL recovery wells are shown in green, orange, and blue, respectively. Station 03 is 300 feet from culvert outlet and Station 09 is 900 feet upgradient of culvert outlet.

DTS

- Utilizes a buried fiber optic cable to send and receive laser pulses and record the frequencies of backscattered light (Figure 3).
- A known relationship between temperature and the frequency of backscattered light is used to calculate temperature adjacent to the cable.
- Precise timing of the returned light identifies locations of the measured temperature in sediment porewater.
  - The absolute temperature accuracy is ~ 0.05 °C to 0.1 °C, and precision (comparing adjacent locations on the same cable, which is key to identifying seeps) is ~ 0.03 °C to 0.06 °C.
- Temperature in the sediment porewater is compared to surface water temperature as an indicator of where groundwater discharge is occurring.

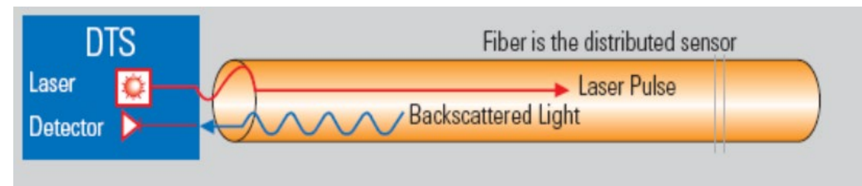

FIGURE 3: Schematic diagram of a DTS system.

- Two cables forming four transects, were buried 8 inches below the stream bed surface (Figure 4).
- Surface water level data were reviewed to select a range of stream stage elevation periods representative of transient, stable and baseflow conditions.
- For selected periods, rate and location of groundwater discharge were estimated using a heat transfer model.

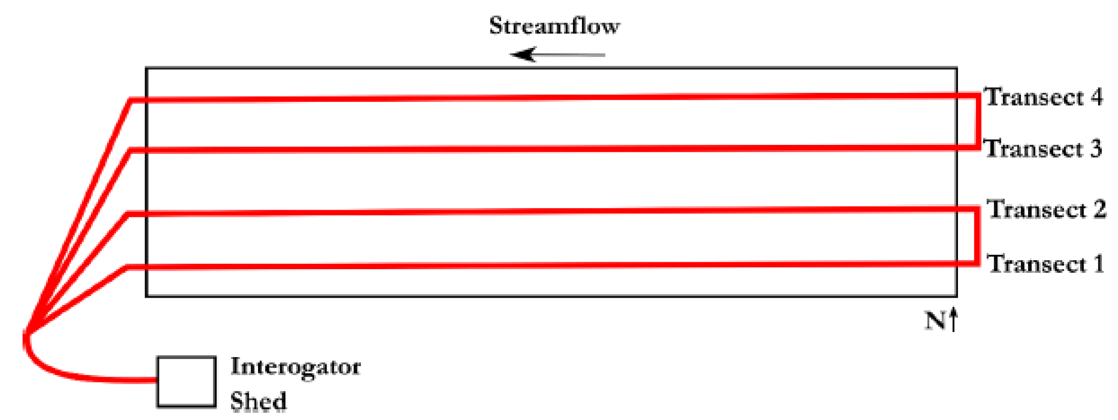

FIGURE 4: Schematic diagram showing fiber optic cable installation in stream bed. Two independent fiber optic cables were installed to create four transects running the full length of the culvert and spaced across culvert width.

DTS Installation

- Agency permitting – Received state agency and US Army Corps of Engineers joint permit waiver on the basis of DTS cable being temporary scientific monitoring device and having no ecological impact
- Restrictive work conditions
  - Restricted access, minimal ventilation, poor lighting
  - Flood risk, no work during precipitation events
- Installed silt fence and absorbent booms to control sediment and sheen migration
- Used ditch witch with exhaust pipe above breathing space to bury cables

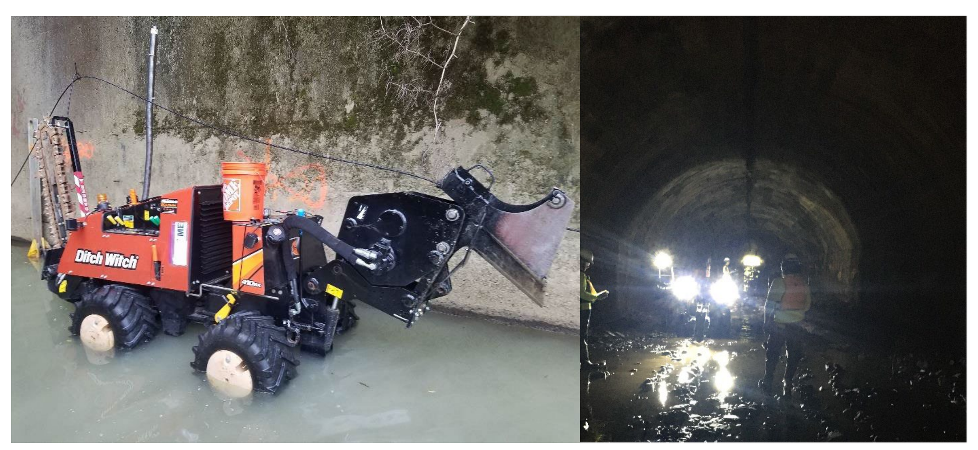

FIGURE 5: Photos of Ditch-Witch used for cable installation (left) and culvert interior during cable installation (right).

Results

Mean fiber temperature profiles from Summer 2020 and Winter 2021 are shown in Figure 6.

- More groundwater discharge locations were identified in winter than in summer (17% vs 11%), primarily located toward the inlet end of the culvert (towards the right side of Figure 6) and near the culvert walls (transects 1 and 4).
- Winter had a larger temperature contrast between groundwater and surface water (approximately 30° F in winter versus 10° F in summer), contributing to groundwater seepage zones being more pronounced than during summer monitoring.

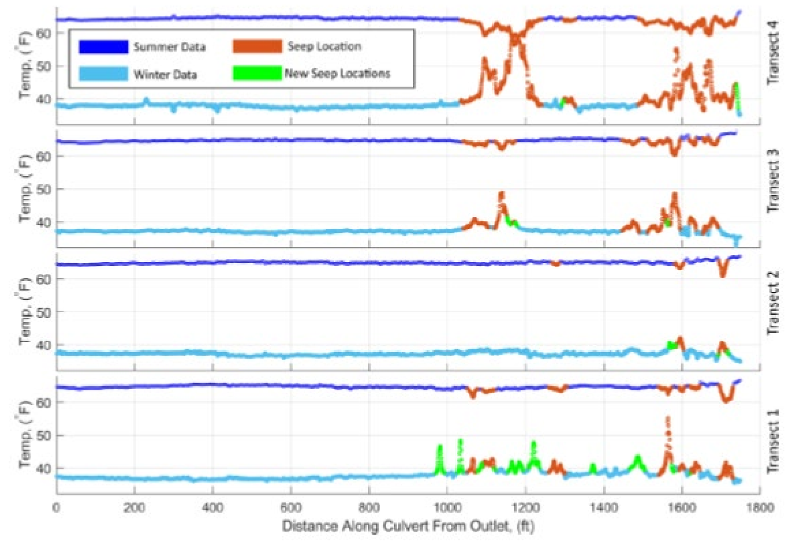

FIGURE 6: Mean cable temperature at each measurement location along the DTS fiber for each transect during the summer (upper temperature profile in each transect) and winter monitoring period (lower temperature profile in each transect). Overlaid on the temperature data, in orange, are the locations of the identified groundwater seeps from the summer analysis, and in green, the newly identified groundwater seeps from the winter dataset.

Groundwater discharge rates were estimated for specific time intervals representing stable and transient surface water level conditions. Mean groundwater discharge rates during varying conditions are summarized in Table 1.

TABLE 1: Estimated mean groundwater discharge rates at various surface water level conditions.

Culvert Flow Condition	Mean Discharge (gpm)
Winter: Transient – low and slowly falling	3.9
Winter: Stable – low and stable	4.1
Winter: Transient – near most elevated level	1.7
Winter: Transient – elevated falling level	2.6
Summer: Stable – low and stable	3.4

CONCLUSION

- Groundwater discharge was observed in approximately the same areas in both winter and summer but with a larger footprint in winter (17%) vs. summer (11%).
- Groundwater discharge was identified to occur in areas beyond those previously identified between Station 09+70 (970 feet from the outlet) to 17+45 (inlet).
- Groundwater discharge rate was highest at near base flow water level conditions. In contrast, lower discharge rates were estimated during most elevated stage levels.
- Total groundwater discharge rate was estimated to vary in the range of 1.7 to 6.8 gpm.