Multi-Scale Thermal and Electromagnetic Technologies Toolbox for Improved Mapping and Monitoring of Contaminated Groundwater Discharges to Surface Water

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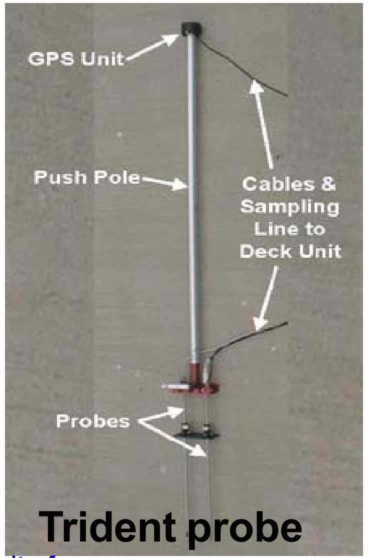
Problem Statement

Background

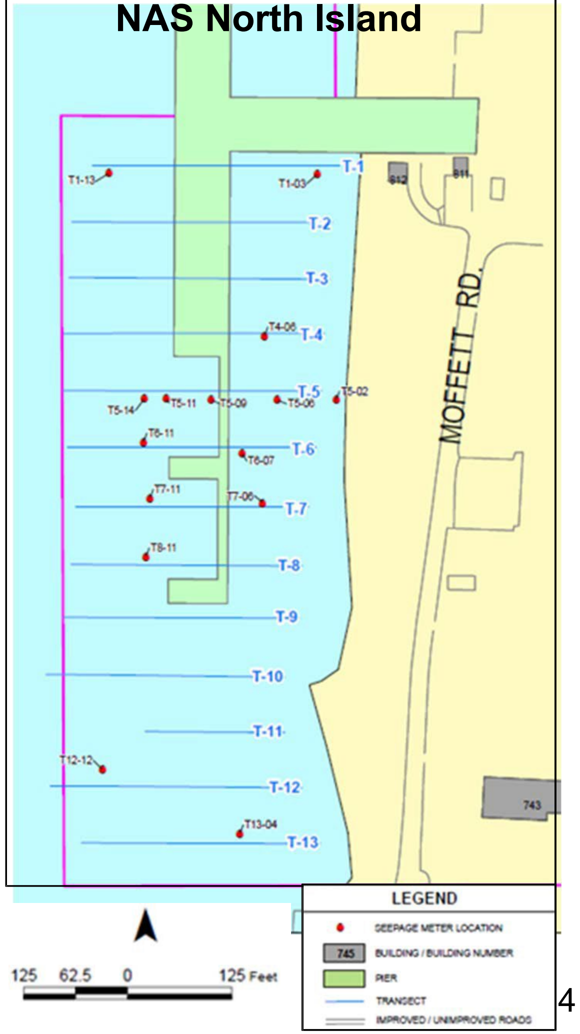
- GW to SW seepage occurs at 75% of RCRA and CRCLA sites within 0.8 miles of a surface water body (*EPA 2000*)
- 43% of the 67 Naval Installations on the NPL are in coastal areas (NRC 2003)
- 78% of Navy sites evaluated during optimization review had GW to SW seepage (Navy 2015)

Current Solution

- Trident Probe, UltraSeep
- Provide single snap-shot at selected point – can easily miss seeps



Seepage meter locations at NAS North Island



http://clu-in.org/programs/21m2/navytools/gsw/default.cfm

Technical Objectives

To develop and validate a multi-scale thermal and electromagnetic technologies toolbox for mapping and monitoring the interactions between contaminated groundwater and surface water

Toolkit Test Design

Task 1 – Site Selection
1 Freshwater and 1 Saline DOD Site

Task 2 - Spatial Coverage (~6.2 miles/day, resolution 16.4 ft)
- Infrared Unmanned Aerial Survey
Electromagnetic

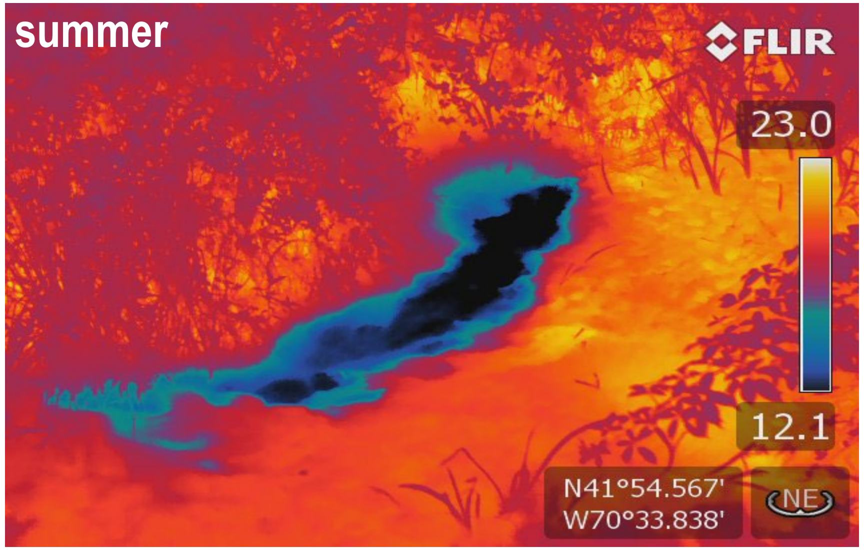
Task 3 – High Resolution Monitoring
- Fiber-optic Distributed Temperature Sensing
- Vertical Temperature Profiling

Task 4 - Method validation (compare to traditional methods)
- UltraSeep
- Seepage Meter

Task 5 - Contaminant Flux Determination
- Porewater Concentrations

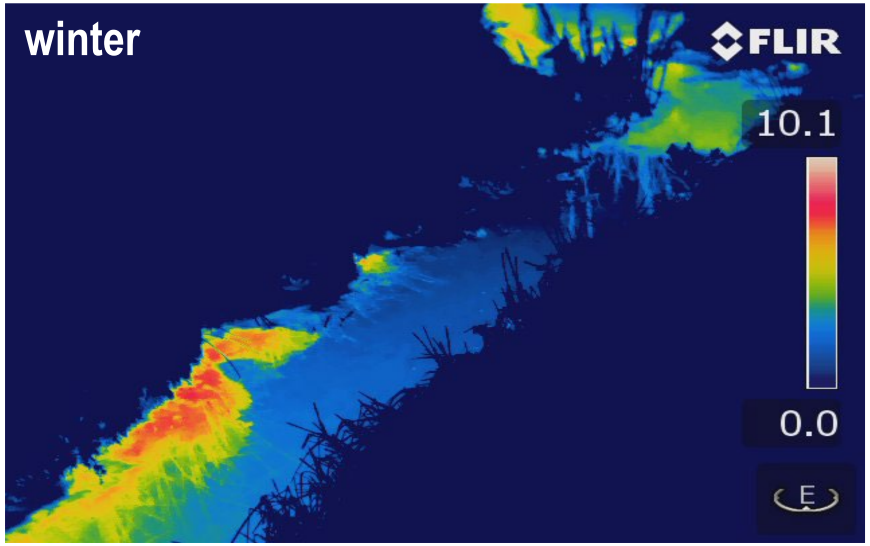
Task 6 - Decision Matrix

Technologies: Thermal Infrared Mapping of Discharge Locations

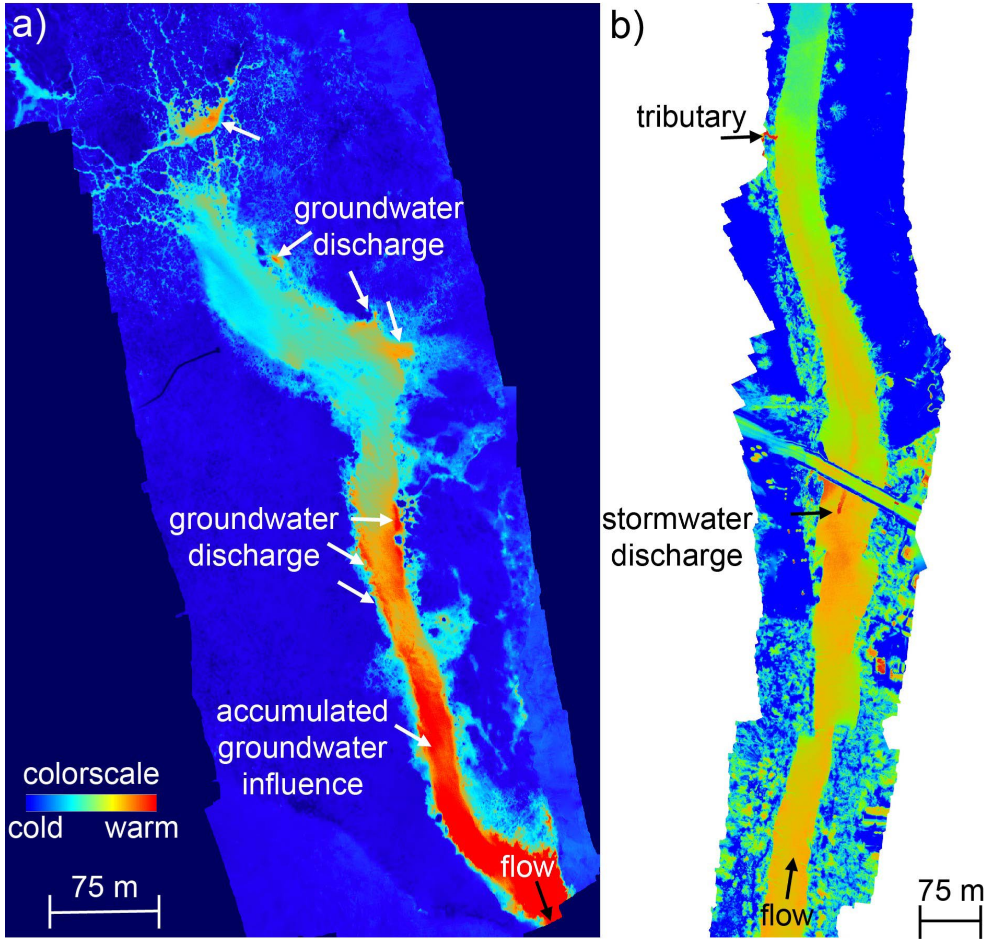


Groundwater temperature is relatively constant throughout the year, and therefore acts as a natural tracer which may be relatively cold and dense in summer…

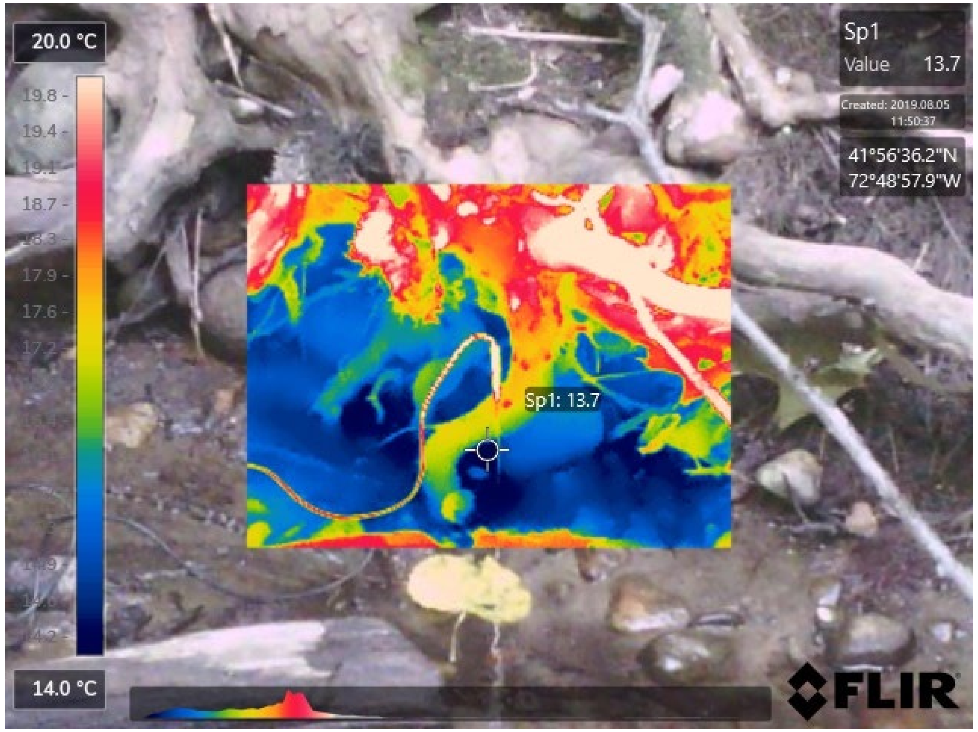
…and relatively warm and buoyant in the winter, compared to surface water. Groundwater inflows can be identified quickly throughout aquatic systems if there is a ***surface*** temperature expression.



Technologies: Thermal Infrared Mapping of Discharge Locations



UAS-based thermal IR can efficiently map large areas under favorable conditions



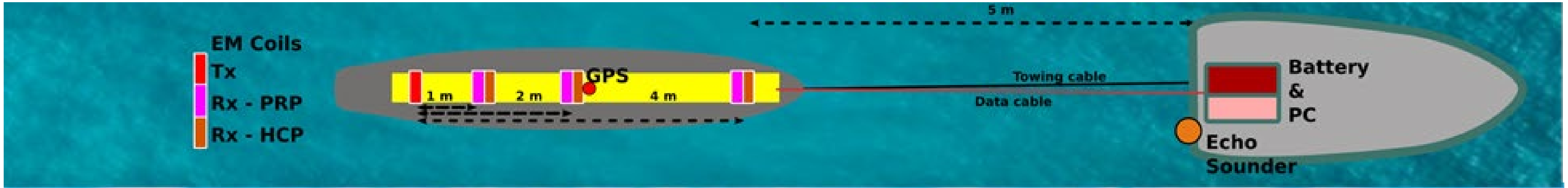
Handheld thermal IR offers higher resolution and the ability to 'see' below riparian vegetation

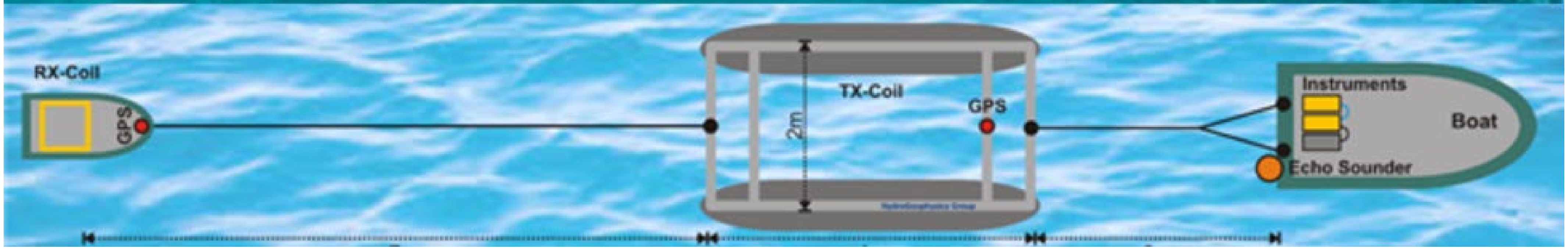
Briggs et al., 2022

Technologies: Electromagnetic

Boat Towed EM – Conductivity expression of seeps (6.2 miles of line per day)

Dualem (shallow water)



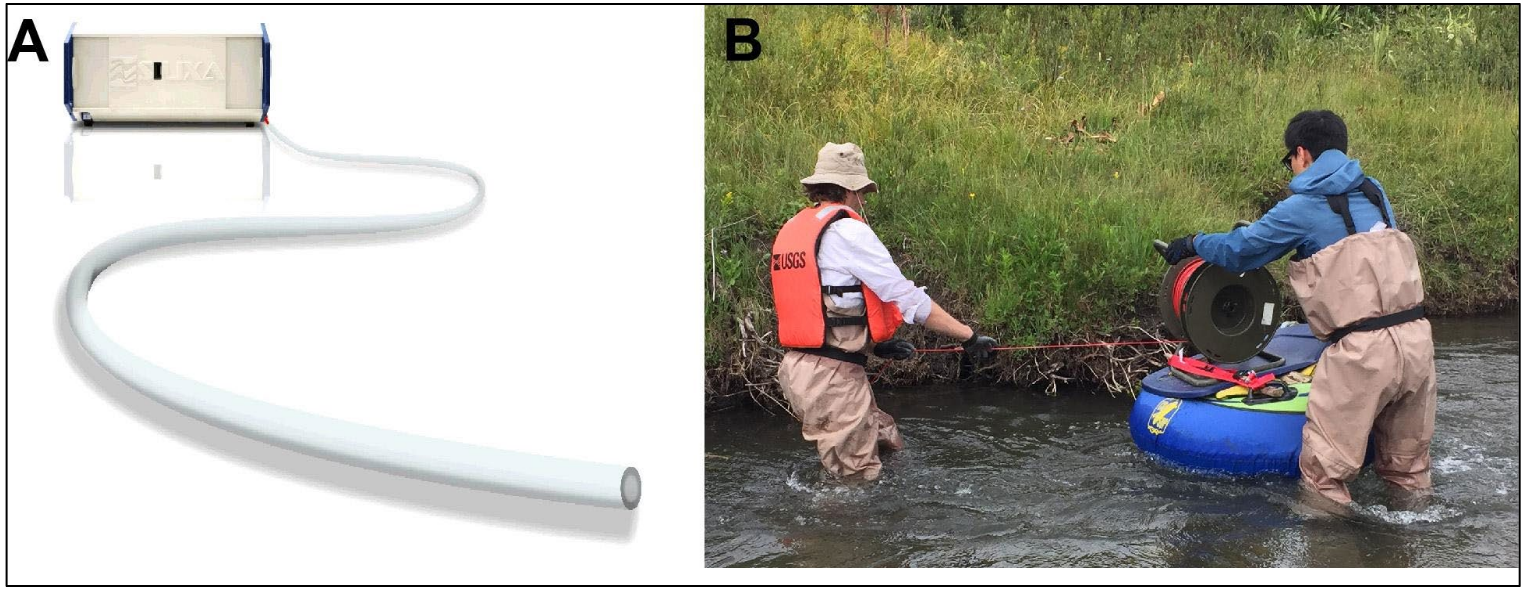


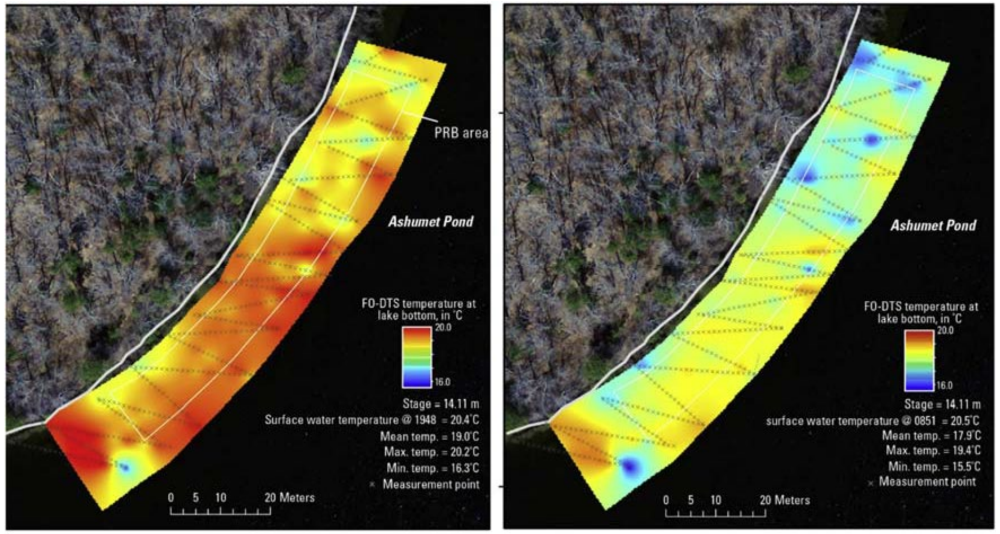
FloaTEM (deep water)

Receiver coil(s) (RX), transmitter coil (TX), GPS, boat, and echo sounder for bathymetry

Technologies: FO-DTS Installation

Fiber optic distributed temperature sensing – will obtain high resolution monitoring data along the cable several km in length





A: Conceptual fiber-optic cable attached to a FO-DTS control unit (courtesy Salixa)
B: Installation of an armored cable along a riverbank that is accomplished by floating the cable reel on a small raft.

FO-DTS (cable track indicated by black dots) during day-time (left) and night-time (right), revealing GW seeps through a permeable reactive barrier (delineated by white line) in Ashumet Pond, MA. (from McCobb et al., 2018).

Video

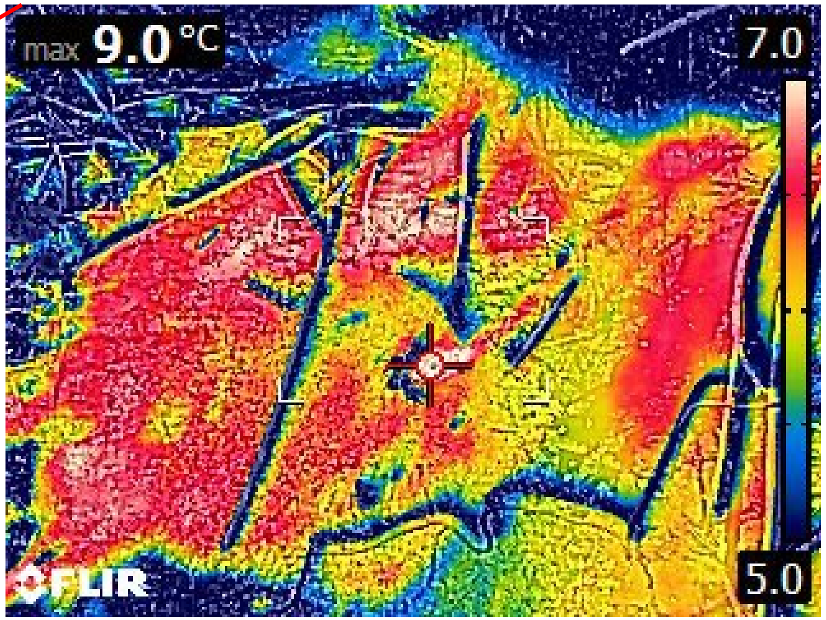
9

Results: Handheld Thermal IR

- Candidate seeps for PFAS sampling were flagged at their ‘warmest’ points so that piezometers could be inserted directly into the (presumed) highest flux locations when collecting groundwater for analysis the following days.
- In June, a similar approach will be used to guide seepage meter and VTP deployments (at the coldest observed points).

10

Results: Handheld Thermal IR



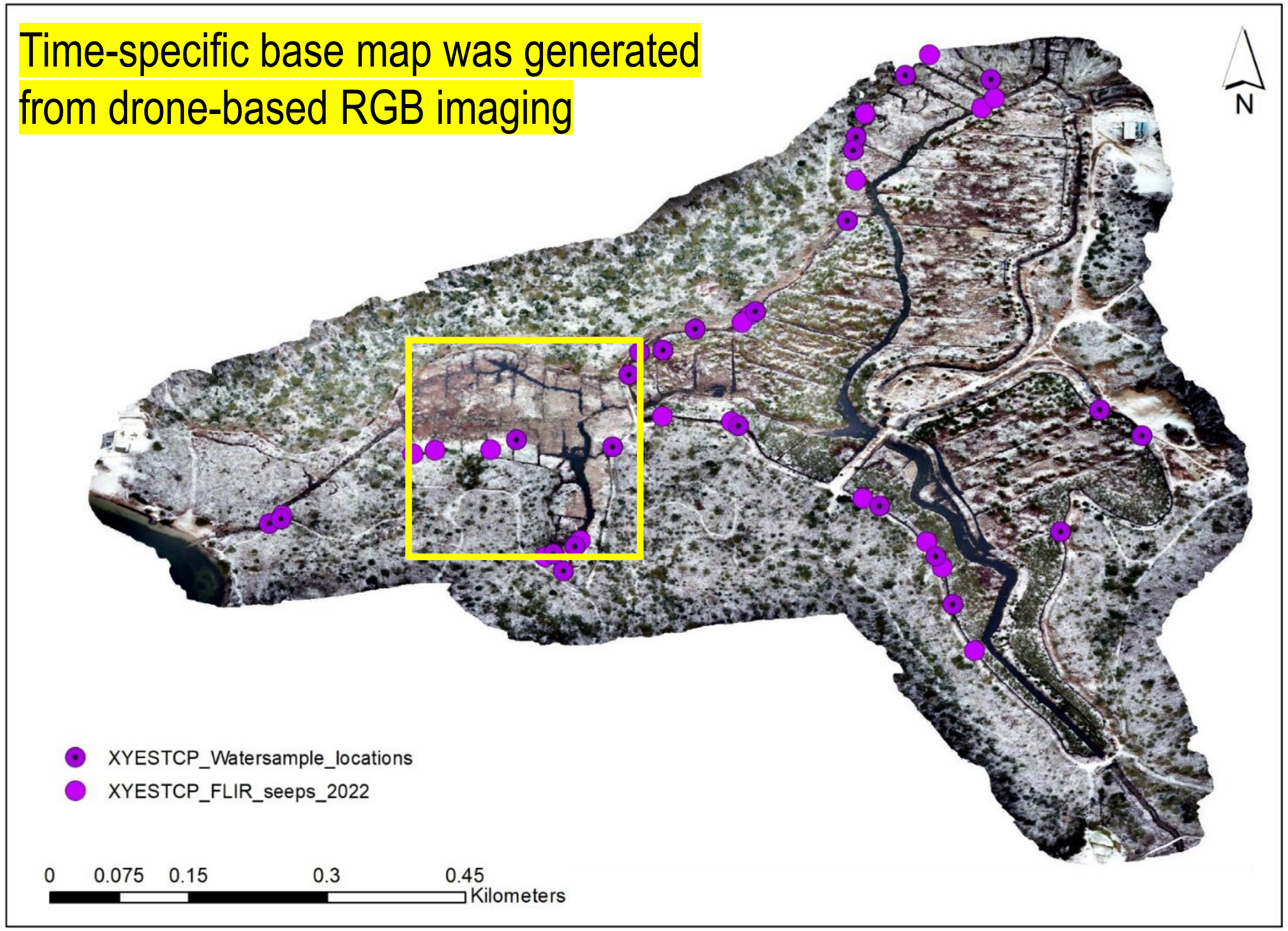
- Preferential groundwater discharge zones were located across the site using thermal IR along streambanks and in shallow water.
- Surface conditions were cold and emergent groundwater was relatively warm (appx 9-11 ºC) and buoyant, an ideal combination for IR mapping of seeps.
- Direct temperature measurements and ‘secondary’ indicators also important (watercress vegetation, Fe deposition, sand boils) in confirming active seeps.

11

Preliminary data

Results: Handheld Thermal IR mapping of major seeps

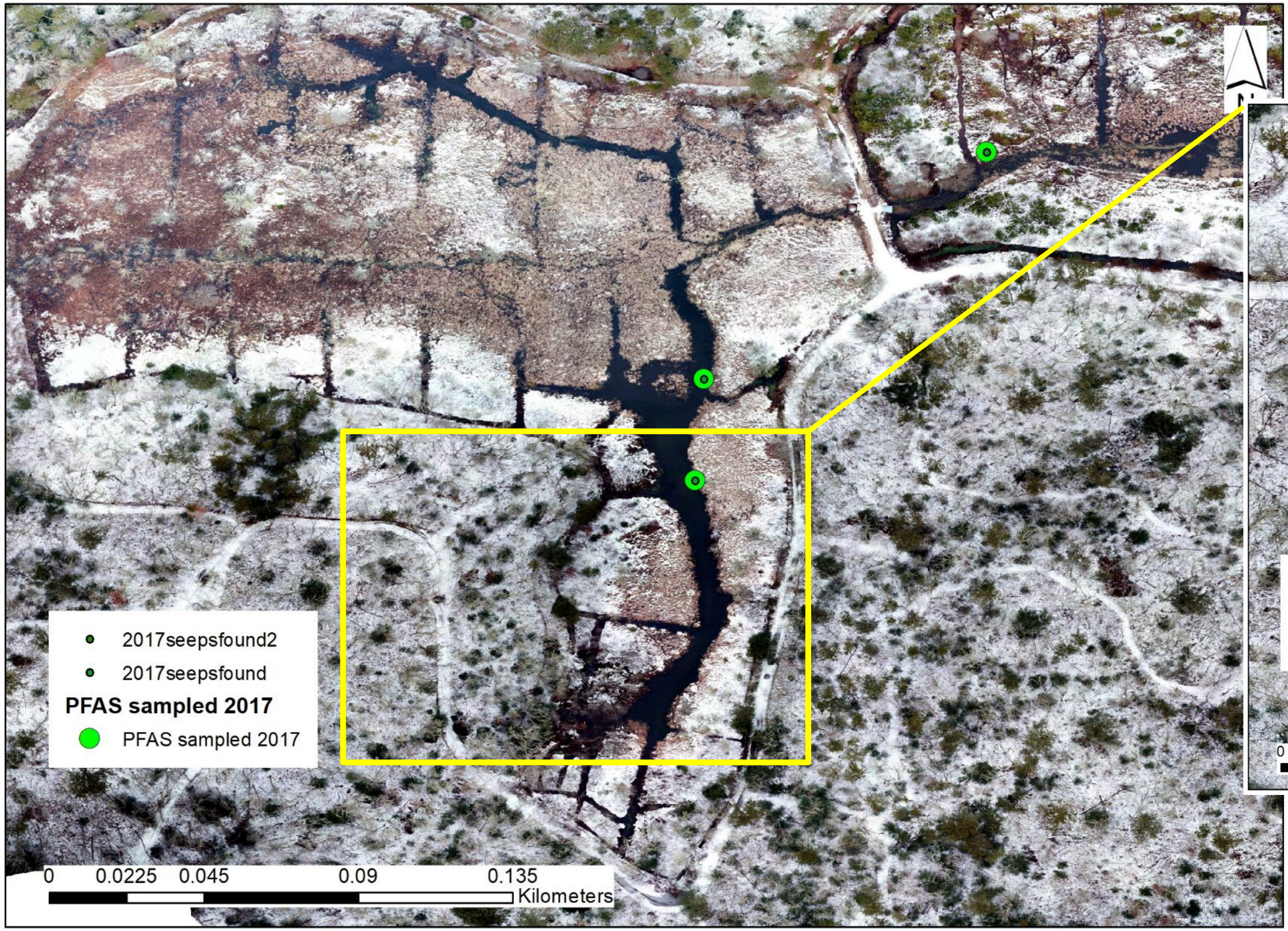
- 44 distinct seeps were mapped across the site with IR
- The north and western margins of the wetland, which show the strongest groundwater hydraulic gradients to surface waters according the regional USGS groundwater flow model.
- Apprx 25 seeps were directly sampled for PFAS compounds and other analytes related to contaminant transport.
- **Bulk PFAS concentrations at these seeps ranged from 0 to ~3500 ng/L, with highest concentrations found along the northern margin of the wetland, down gradient from Joint Base Cape Cod and other possible municipal sources**

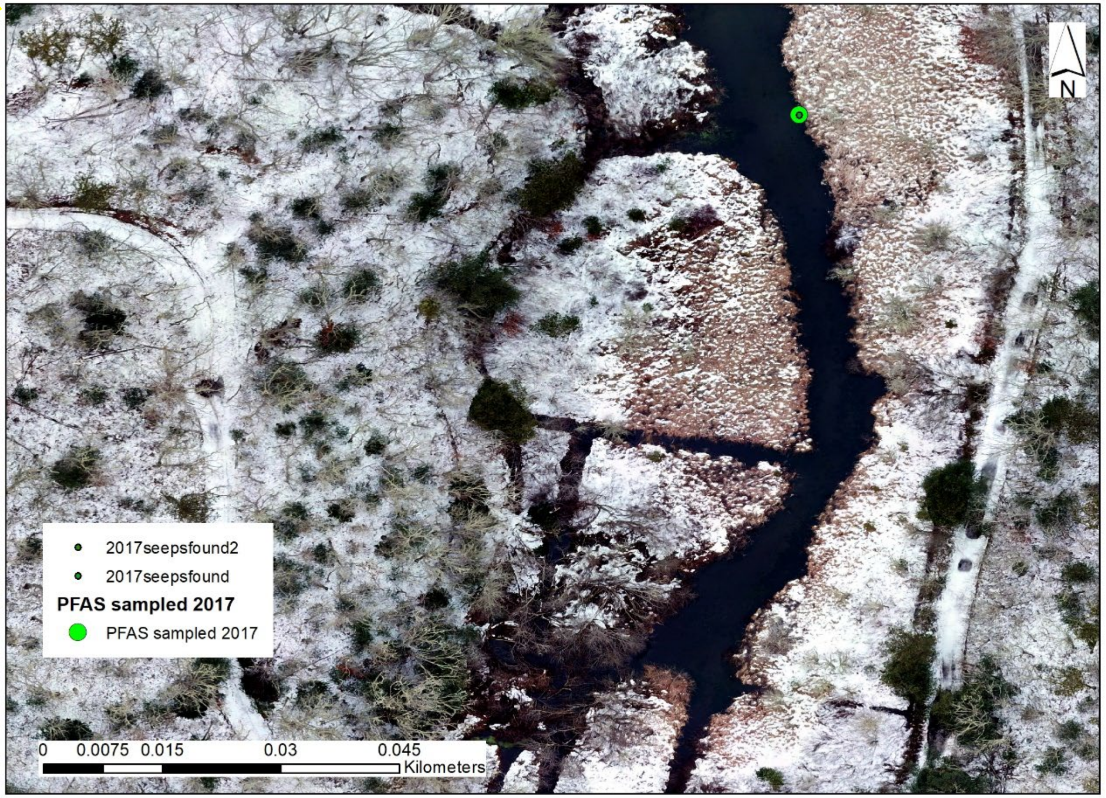


12

Preliminary data

Results: Drone-based orthomosaics



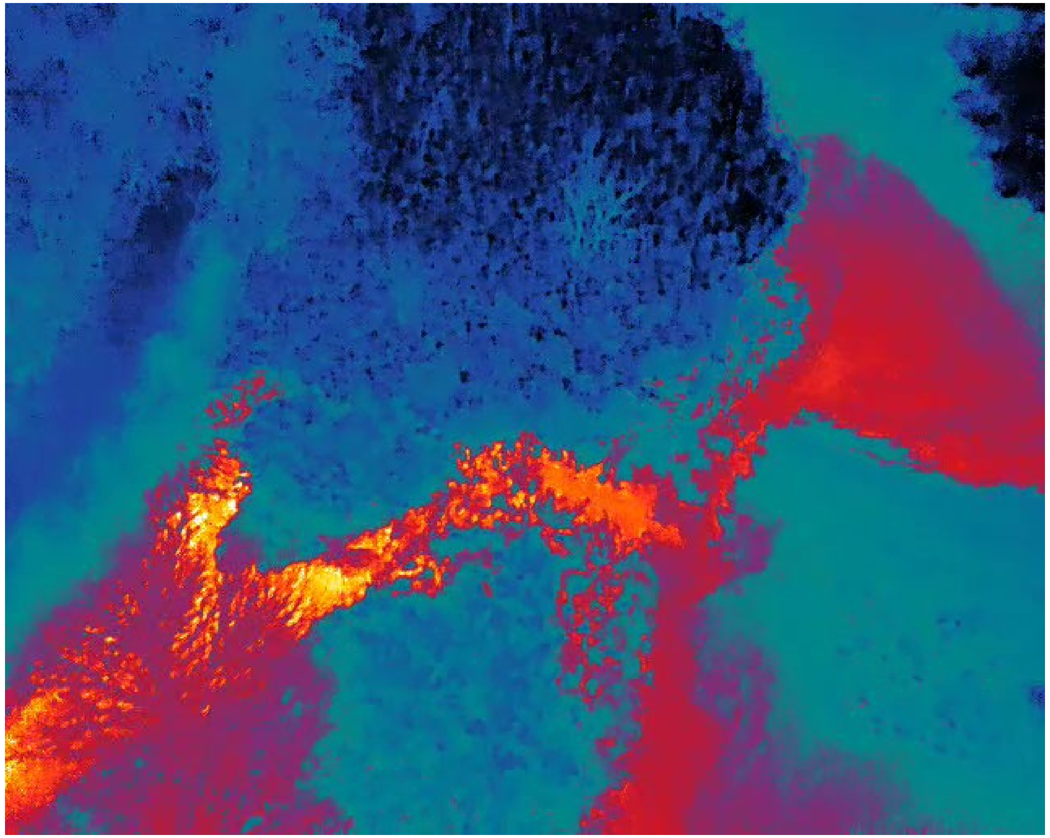


A digital surface elevation model is also derived using structure from motion methods.

13

Preliminary data

Results: Drone Thermal IR

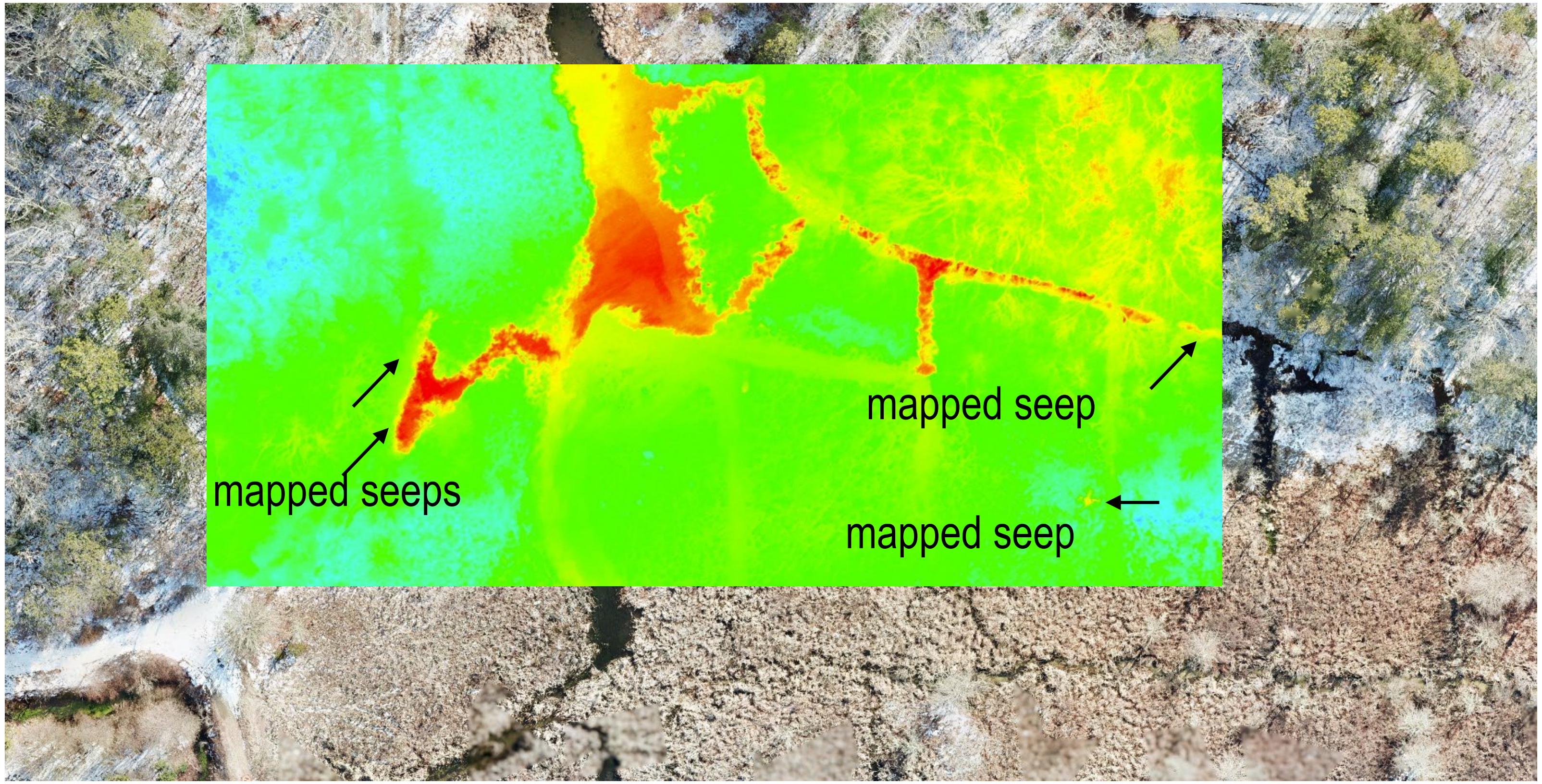


- A drone equipped with RGB and thermal IR cameras was deployed over a wetland area that was generally too wet and deep for effective ground-based investigation.
- The overhead (nadir) viewpoint reduced water surface IR reflection and located major streambank and streambed discharge zones.

14

Preliminary data

Results: Drone Thermal IR

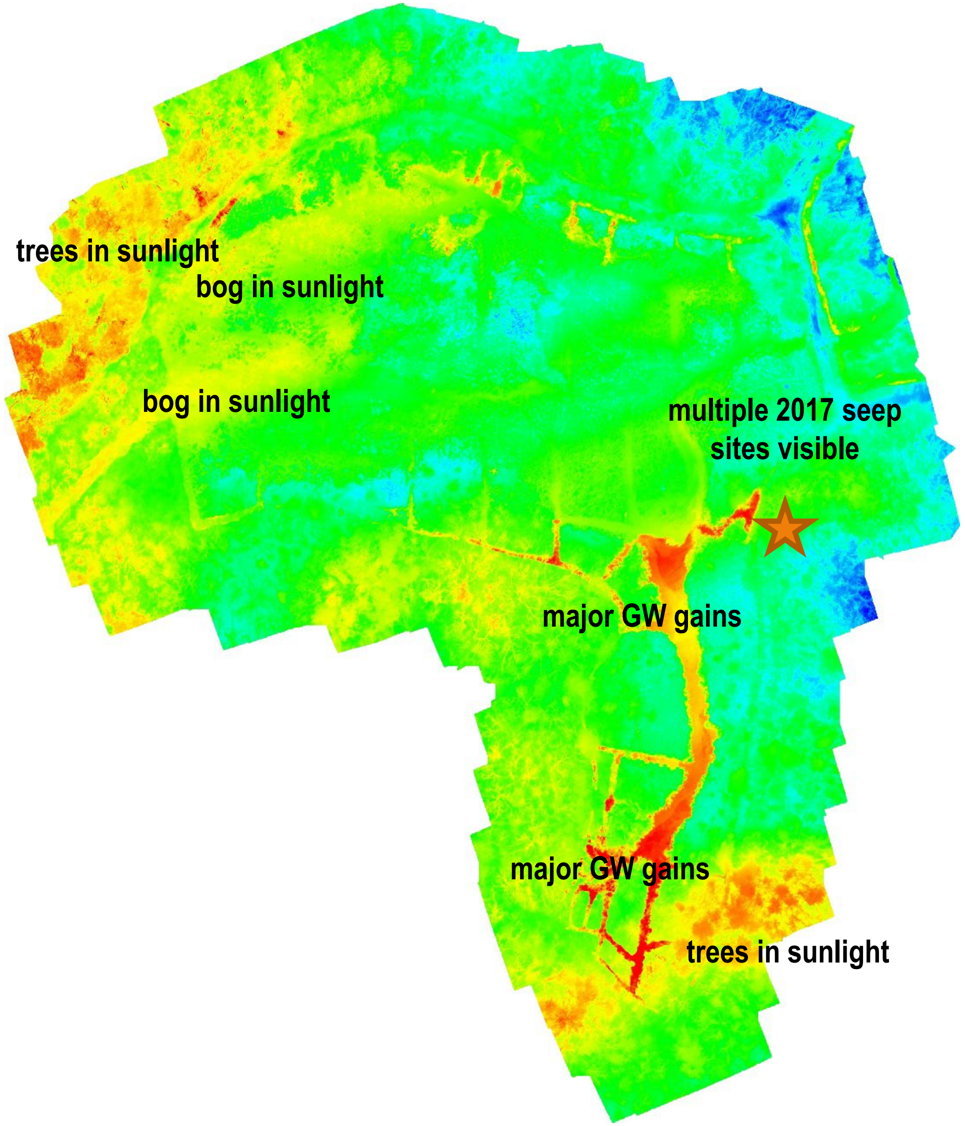


Thermal IR data overlaid on the RGB base map shows how several seeps that were located by handheld thermal IR were also evident in the drone-based data, and major discharge accumulation zones along the larger channel features were also noted.

15

Preliminary data

Results: Drone Thermal IR

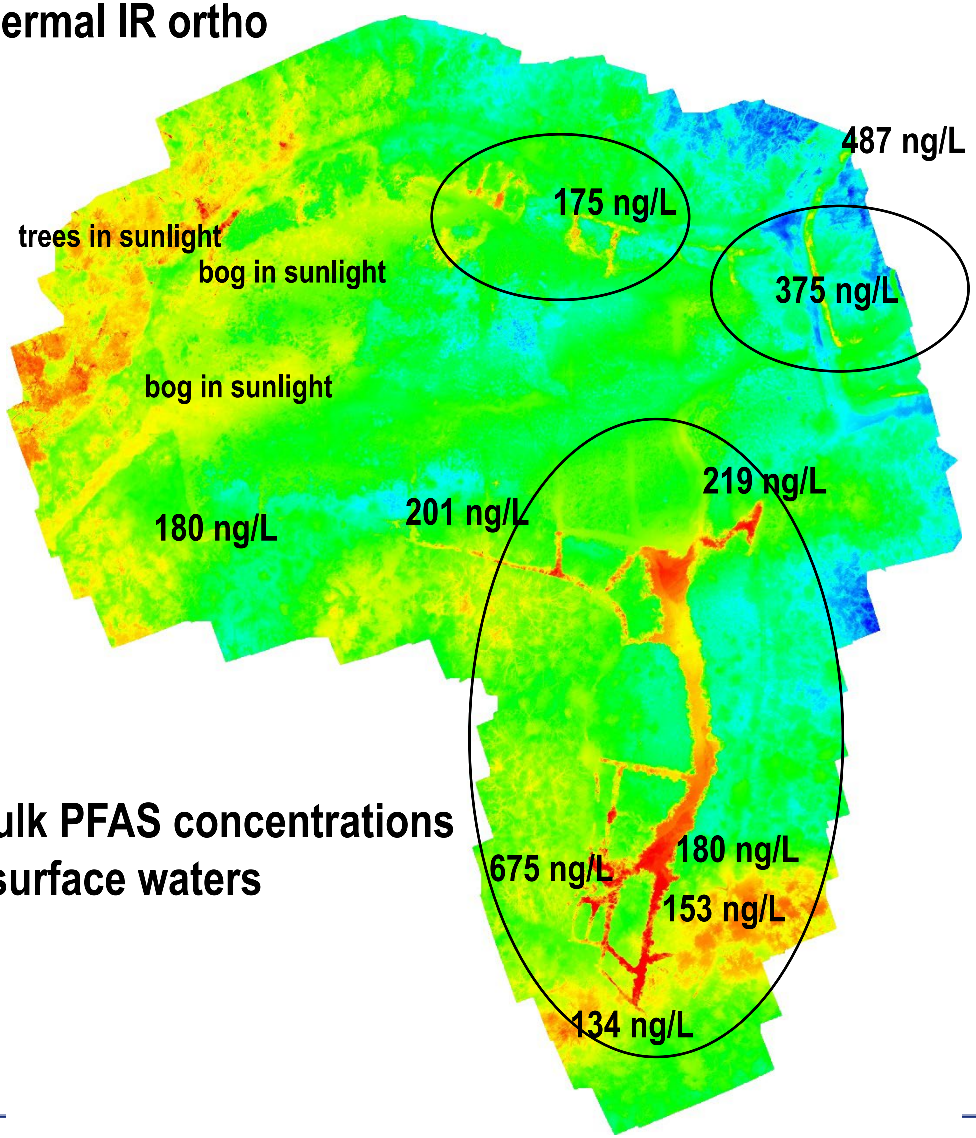


Several hundred thermal IR image stills collected at multiple angles with overlap were processed to create a georeferenced thermal orthomosiac of the site. Identification of groundwater discharge features was complicated by rapid warming of vegetation as the sun rose above the horizon. We were constrained by Air Force Base permissions in flying after sunrise, but overnight would have been ideal. This is not a consideration for summer drone IR imaging as cold seep targets are unique on the landscape.

16
Preliminary data

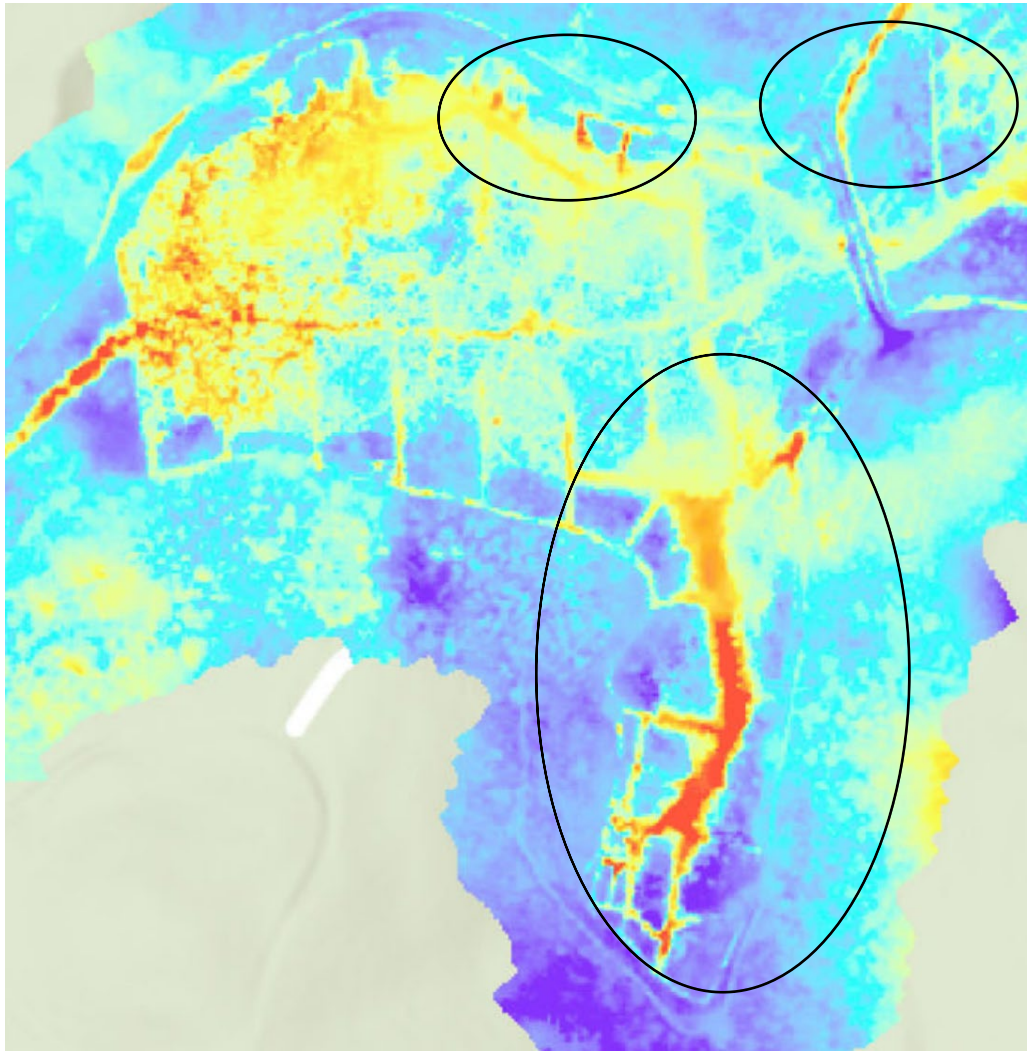
Results: Drone Thermal IR

Winter 2022 drone thermal IR ortho



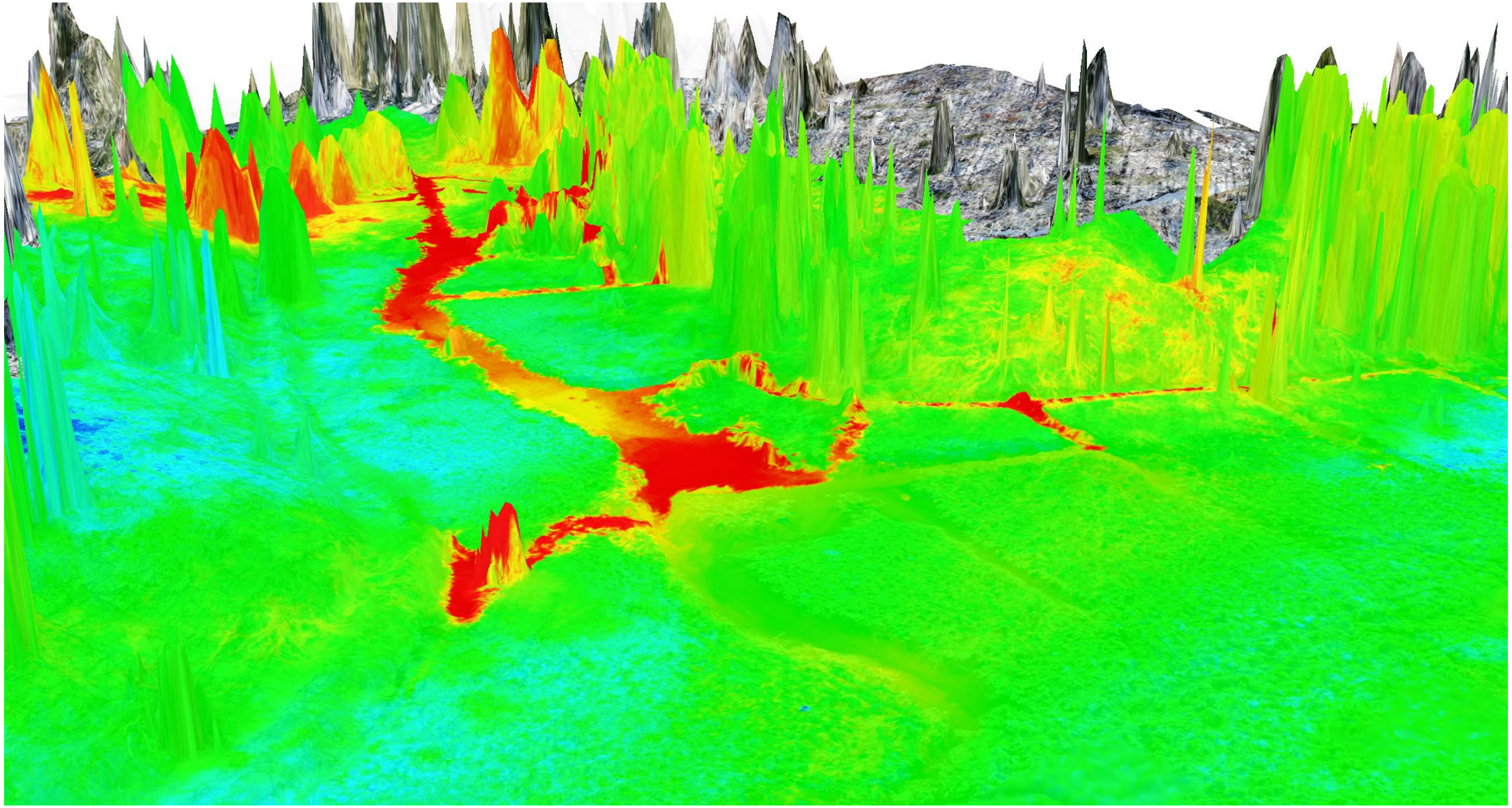
March 2022 measured bulk PFAS concentrations at seeps and surface waters

Winter 2019 drone thermal IR ortho



Preliminary data

Results: Drone Thermal IR

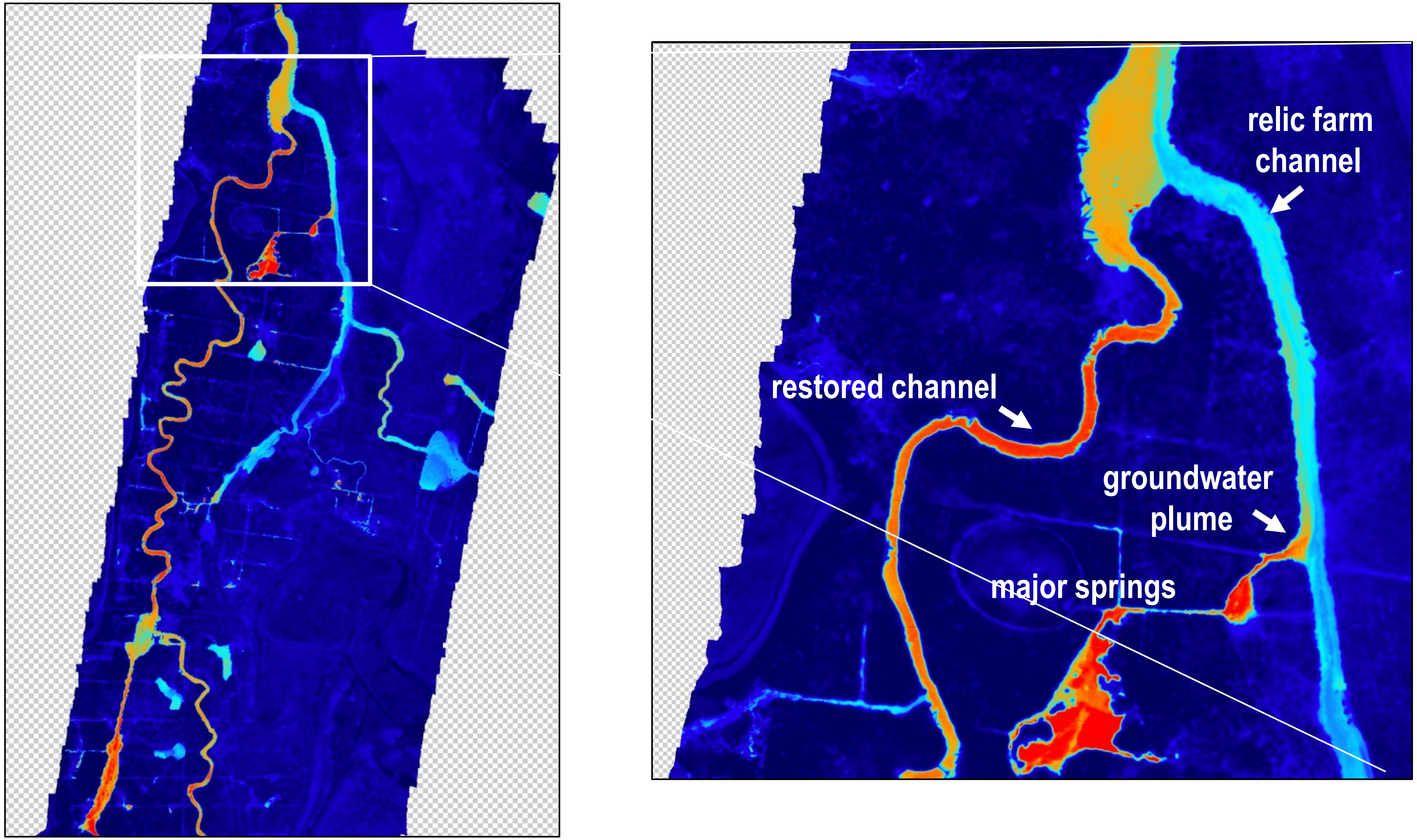


Seep hunting in the metaverse?

18

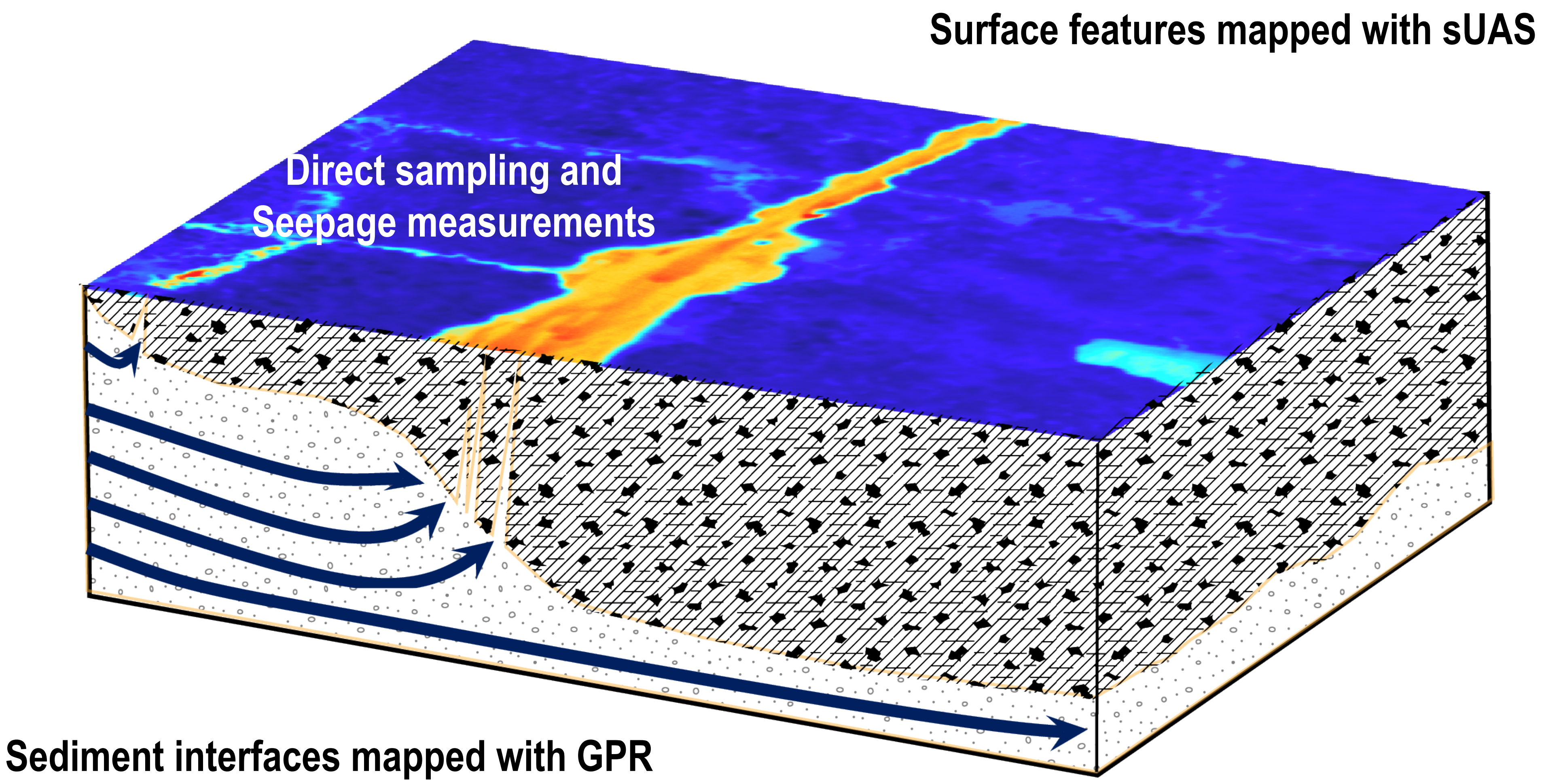
Preliminary data

Additional sUAS examples: restoration evaluation



Harvey et al., 2019

Additional sUAS examples: understanding processes



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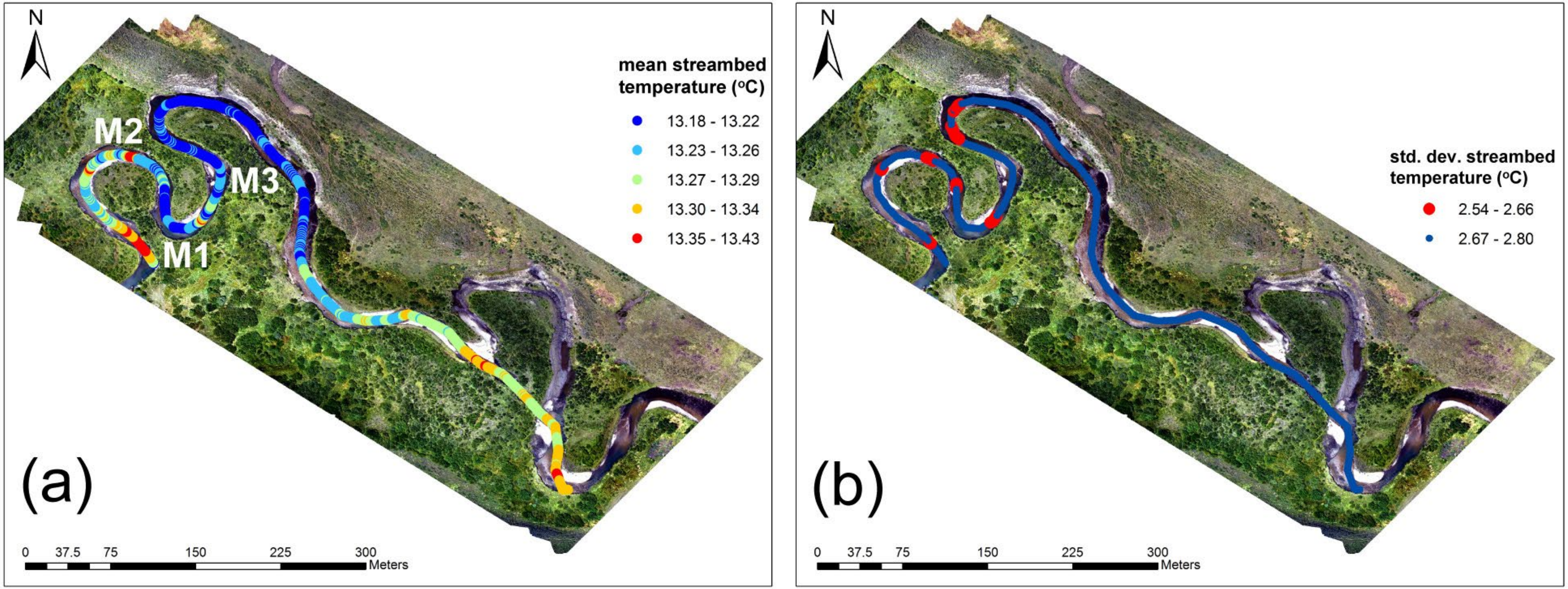
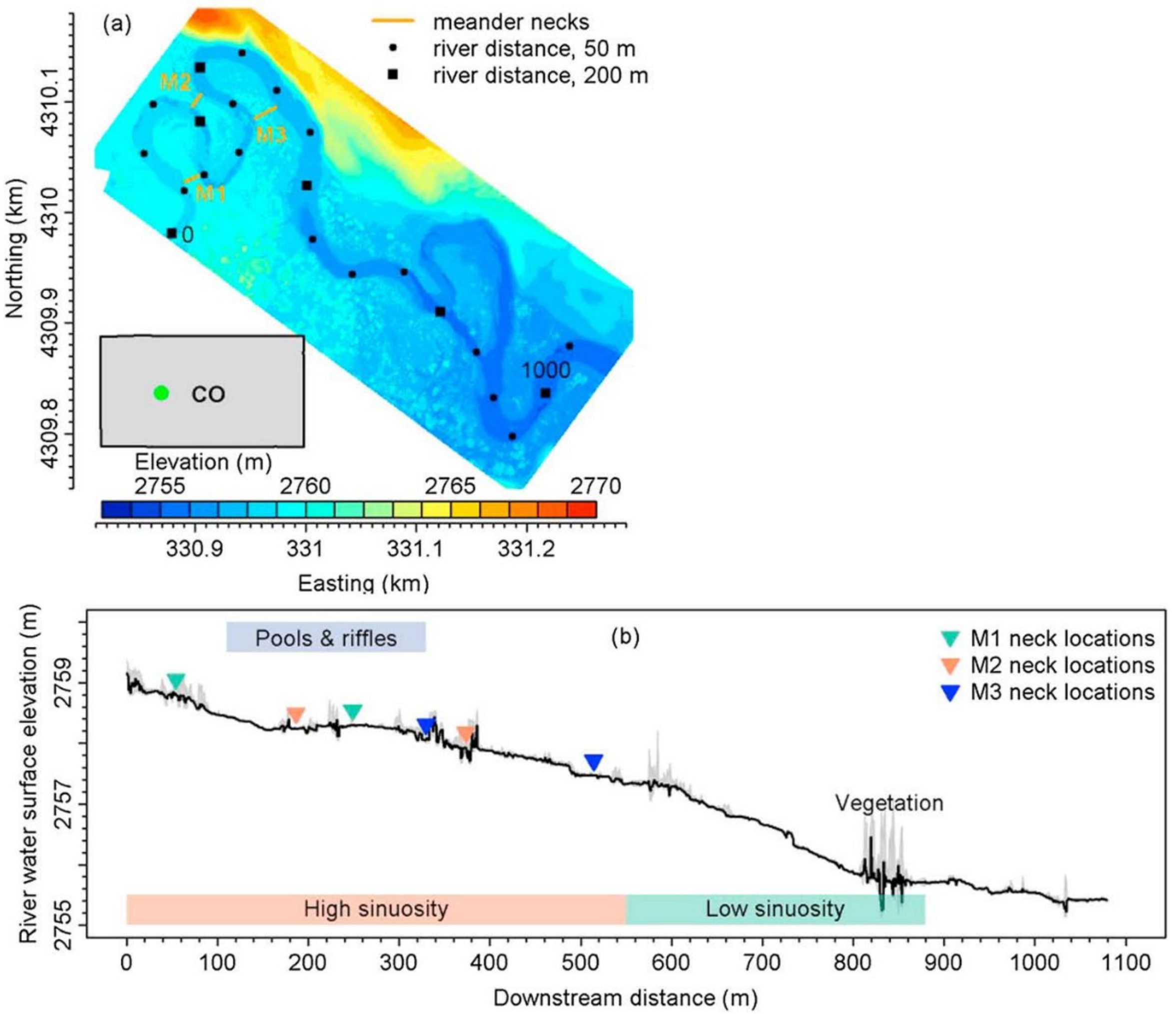
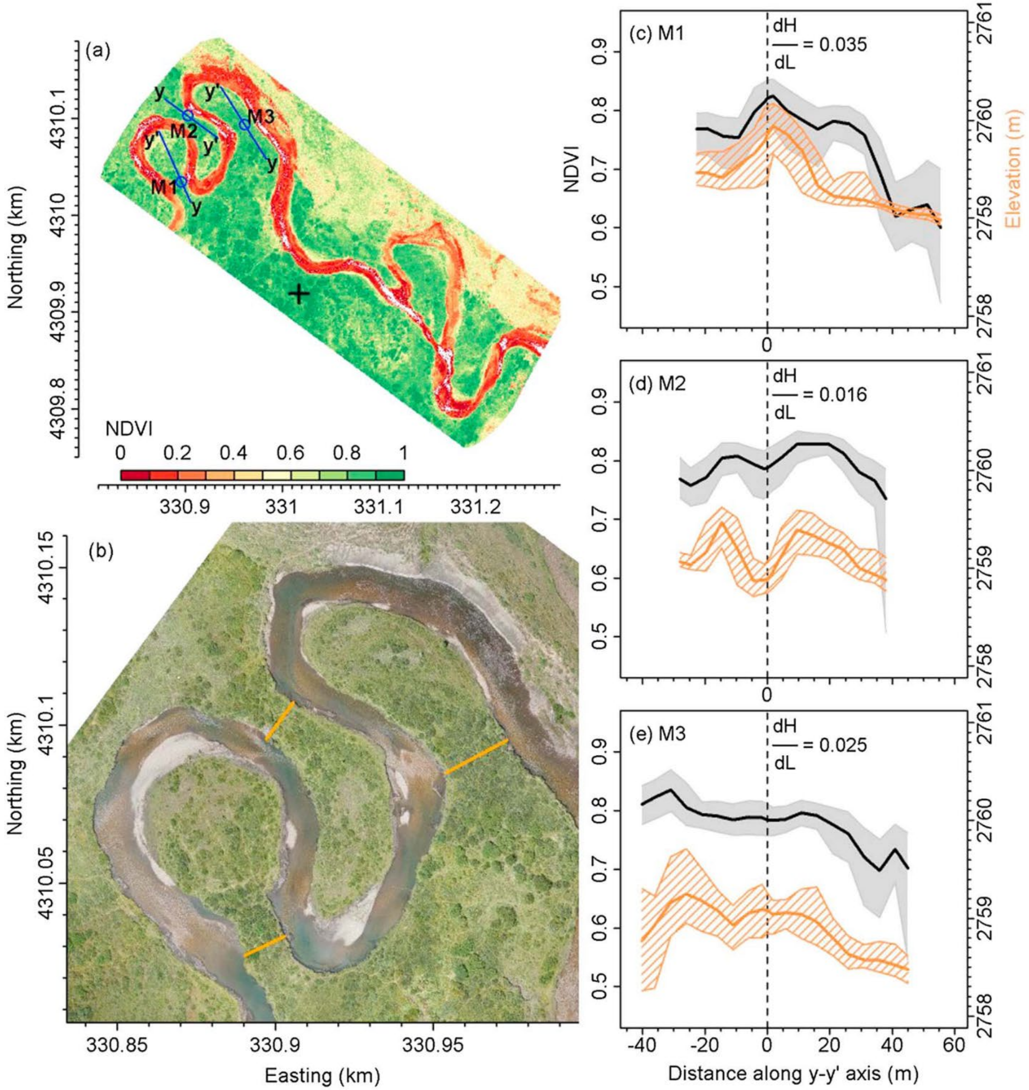


Pai et al., 2017

Additional sUAS examples: understanding processes





Pai et al., 2017

Questions and Answers