Physical Characterization of the PFAS-Contaminated Fractured Rock Aquifer Beneath the Rutland - Southern Vermont Regional Airport

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Abstract

Statewide testing for per- (and poly-) fluoroalkyl substance (PFAS) contamination of groundwater has been taking place since the 2016 discovery of PFAS contamination in the Town of Bennington. In 2018, numerous wells and springs near the Rutland-Southern Vermont Regional Airport (RSVRA) were found to be contaminated with PFAS. The primary PFAS sources are assumed to be from the use of Aqueous Fire-Fighting Foam (AFFF) during equipment tests and at 2 crash sites. This study utilizes geologic mapping and geophysical logging approaches to characterize PFAS-contaminated aquifers; the former consists of surficial and bedrock mapping (including UAV surveys), spatial analysis of well reports, and geophysical logging and the latter is comprised by analysis of groundwater for PFAS species, major and trace elements, stable isotopes, and recharge-ages. This report focuses on the physical approach.

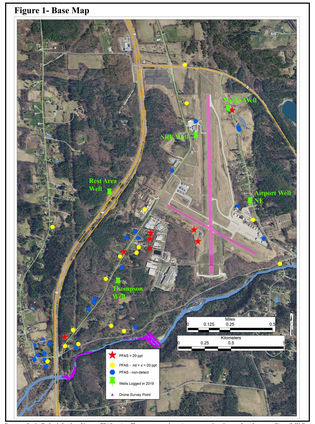
To supplement bedrock mapping of the contamination area, detailed structural analysis along river gorges and state highways are underway. Along the lower and upper Clarendon gorges, UAV surveys have acquired multi-altitude imagery to assemble mosaics using photogrammetry software. Preliminary analysis of the imagery and field data shows well-defined, steeply-dipping, N-S, E-W, and NE-SW -striking fracture zones, which may influence groundwater flow.

By correlating accurate well locations with well driller reports, preliminary maps were made in GIS of bedrock surface elevation, thickness of overlying unconsolidated sediment, and the potentiometric surface. The integration of structural data with these maps indicates that fracture zones control surface water drainage and thickness of overburden.

Five bedrock wells in the RSVRA area, ranging in depth from 220-800', were logged with natural gamma, temperature, resistivity, conductivity, gamma, caliper, acoustic televiewer (AT), and heat-pulse flowmeter (HPF) tools. HPF measurements show upward flow from the bottom of all wells under ambient conditions. The attitudes of all planes intersecting the wells are being calculated from AT data.

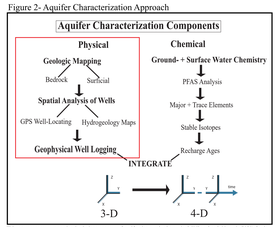
The physical hydrogeological characterization forms a 3-dimensional framework to evaluate the chemical data sets, leading to an enhanced understanding of the fate and transport of PFAS.

Figure 1- Base Map



Base map for the Rutland- Southern Vermont PFAS project. The runways are shown in magenta and can be seen for reference on Figure 3. Wells tested that exceed the 20 parts/billion (ppt) limit for PFAS (sum of PFOA, PFOS, PFHxS, PFHpA, and PFNA) are shown with red stars, those wells with PFAS levels above the detection limit, but < or = to 20 ppt are shown as yellow circles; and those wells that have PFAS levels below the analytical detection limit (~2 ppt) are show as blue circles. The location of wells logged using geophysical equipment are shown as green pins. The locations of drone video surveys in the Clarendon Gorge are shown with purple triangles (see Figure 4 for drone photomosaics).

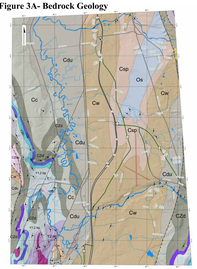
Figure 2- Aquifer Characterization Approach



This poster concentrates on the physical components of aquifer characterization at the RSVRA. See Cobb et al. (2020) for the chemical components.

Geologic Maps and Spatial Analysis of Wells

Figure 3A- Bedrock Geology



Bedrock geologic map of the field area (modified from Ratcliffe et al., 2011). Airport runways shown in magenta. Lithologies in airport vicinity: Ow- Shelburne Fm. (marble and limestone); Csp- Clarendon Springs Fm. (dolostone); Cw- Winooski Fm. (dolostone and dolomitic quartzite; Cdu- Dunham Fm. (dolostone).

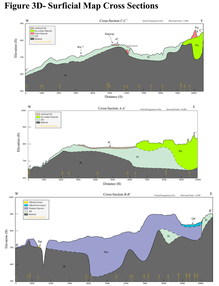
Figure 3B- Surficial Geology

Surficial geologic map of the field area (modified from DeSimone, 2019). Airport runways shown in magenta. Surficial materials in airport vicinity: Pt- till; Pm- moraine; Pw- ice contact deposits; Ha- alluvium; Haf- alluvial fan deposits; Hat- alluvial terrace deposits; Hbw- wetland deposits; af- artificial fill.

Figure 3C- Isopach Map

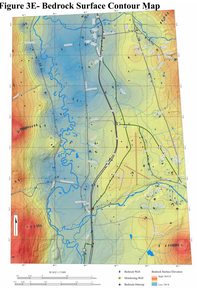
This map was made in GIS by contouring the thickness of overburden (surficial materials) from the Vermont database of well driller reports. The contour interval is 20' and brown shading denotes areas where overburden is > or equal to 40'.

Figure 3D- Surficial Map Cross Sections



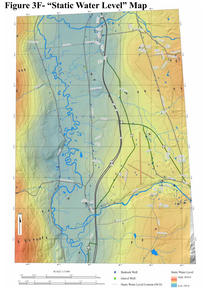
Cross sections from the surficial geologic map of DeSimone (2019). See Figure 3B for locations.

Figure 3E- Bedrock Surface Contour Map



This map was made in GIS by assigning elevations to the top of bedrock in each well and then contouring the bedrock elevation in the field area.

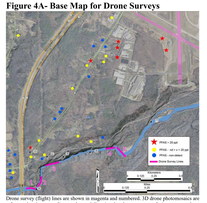
Figure 3F- "Static Water Level" Map



This map was made in GIS by assigning elevations to the "static water level" (potentiometric surface) in each well and then contouring this surface for the bedrock aquifer in the field area.

Drone Surveys and Structural Analysis

Figure 4A- Base Map for Drone Surveys

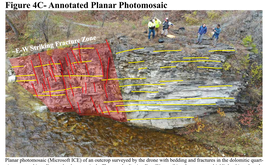


Drone survey (flight) lines are shown in magenta and numbered. 3D drone photomosaics are shown in grey-scale; line numbers are shown in the direction of the camera during the survey mission. Structural symbols (foliation) were modified from Ratcliffe (1999). PFAS levels for tested wells are shown. Airport runways are highlighted in pale magenta.

Figure 4B- Drone Survey in Action

Members of the VTRANS UAS (Unmanned Aerial Services) Team acquiring drone imagery in the Clarendon Gorge during the fall of 2019. Evan Robinson (left), Brian Pinsonnault (center), and Chris Beitzel (right).

Figure 4C- Annotated Planar Photomosaic



Planar photomosaic (Mercmott ICE) of an outcrop surveyed by the drone with bedding and fractures in the dolomitic quartzite annotated in yellow and red, respectively. The steeply dipping East-West striking fracture zone highlighted in pale red.

Figure 4D- 3-D Photo Mosaic of Line 1-Northward View

Agisoft Metashape Pro mosaic of photos 48-76. See location on Figure 4A.

Asymmetric folds that are visible in the center part of the 3-D mosaic of Figure 4D.

Figure 4E- 3-D Photo Mosaic of Line 1- Southward View

Agisoft Metashape Pro mosaic of photos 19-44. See location on Figure 4A.

Figure 4F- 3-D Photo Mosaic of Line 2- Westward View

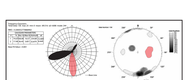
Agisoft Metashape Pro mosaic of photos 77 - 113 (left) and 119 - 149 (eastward view). See location on Figure 4A. The photo mosaic on the left is composed of the same group of photos as Figure C.

Close-up of steeply-dipping, east-west striking fracture zone at the southernmost end (left) of Figure 4F. Fractures are parallel to hammer handle.

Figure 4G- 3-D Photo Mosaic of Line 2- Eastward View

Figure 4H- 3-D Photo Mosaic of Line 3- Southward View

Agisoft Metashape Pro mosaic of photos 203 - 219. See location on Figure 4A. Rose diagram and contoured equal area show structural data from this outcrop.



Rose diagrams and contoured equal area nets for bedding (pale red petal and contoured area) and fractures (black petals and black and grey contour intervals) for measured poles 203 - 219.

Geophysical Logging and Structural Analysis

Figure 5A- Airport Well- Northeast

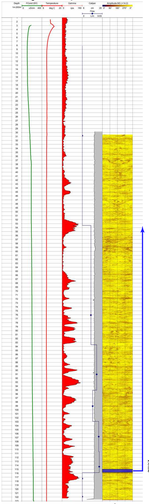


Figure 5B- Weeks Well

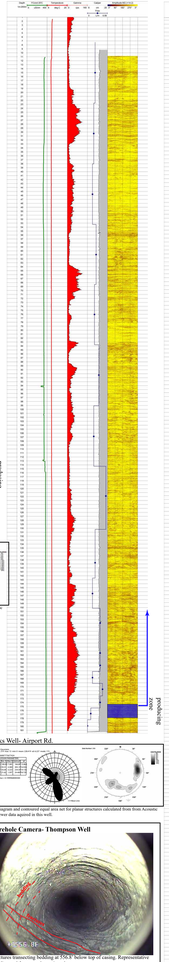


Figure 5C- Thompson Well

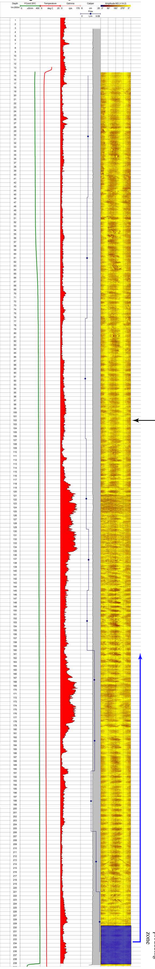
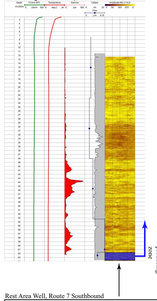


Figure 5D- Rest Area Well



Geophysical Tools

GeoVision Borehole Camera

Temperature+Conductivity Tool

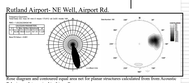
Gamma Tool

Caliper Tool

Acoustic Televiewer

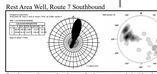
Heat Pulse Flowmeter

Rutland Airport- NE Well, Airport Rd.



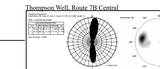
Rose diagram and contoured equal area net for planar structures calculated from Acoustic Televiewer data aquired in this well.

Rest Area Well, Route 7 Southbound



Rose diagram and contoured equal area net for planar structures calculated from Acoustic Televiewer data aquired in this well.

Thompson Well, Route 7B Central

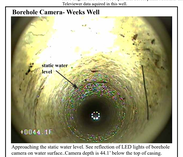


Rose diagram and contoured equal area net for planar structures calculated from Acoustic Televiewer data aquired in this well.

Logging the Weeks Well

Airport runway in the background

Borehole Camera- Weeks Well

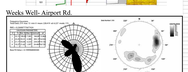


Approaching the static water level. See reflection of LED lights of borehole camera on water surface. Camera depth is 44.1' below the top of casing.

Borehole Camera- Weeks Well

Fractures intersecting the borehole at 89.3' below top of casing.

Weeks Well- Airport Rd.



Rose diagram and contoured equal area net for planar structures calculated from Acoustic Televiewer data aquired in this well.

Borehole Camera- Thompson Well

Fractures intersecting bedding at 90.6' below top of casing. Representative bedding and fractures shown in red.

Fractured Rock Aquifer Consortium

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Vermont Geological Survey

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Middlebury

The UNIVERSITY of VERMONT

References:
DeSimone, D. J., 2017, Surficial Geology of the Bennington Area, Vermont: Vermont Geological Survey Open-File Report VG2017-1, 1Plates 1 - 4), scale 1:12,000, GIS Data.
Ratcliffe, NM, Stanley, RS, Gale, MH, Thompson, PJ, and Walsh, GJ, 2011, Bedrock Geologic Map of Vermont: U.S. Geological Survey Scientific Investigations Map 3184, 3 sheets, scale 1:100,000.
Salvini, F., Billi, A., and Wise, D., 1999, Strike-Slip Fault-Propagation Cleavage in Carbonate Rocks: the Mattinata Fault Zone: Southern Appennines, Italy- Journal of Structural Geology, v. 21, p. 1731-1749.