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Preservation of Geophysical Well Logs and Borehole Video for Bedrock Water Wells in Vermont: A Hydrogeologic Resource for Groundwater Quantity and Quality Planning

Author:
Jonathan Kim Ph.D.
Vermont Geological Survey
1 National Life Drive
Montpelier, VT, 05620-3520
Phone: 802-522-5401
Email: jon.kim@vermont.gov

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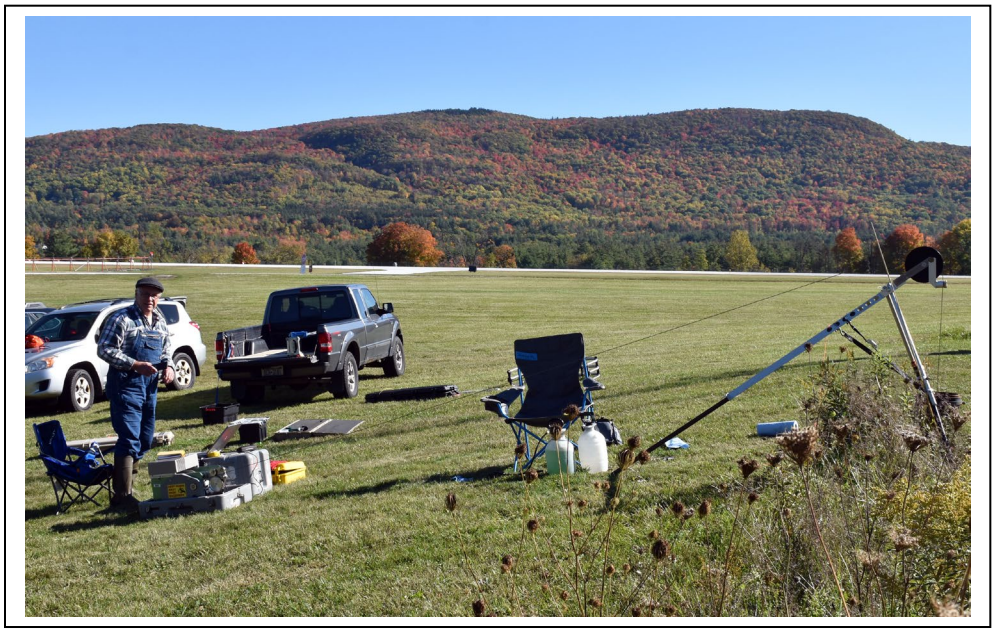

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SUNY Plattsburgh

Abstract
Bedrock wells drilled for drinking water purposes are like a 6" diameter straw that extends deep into a bedrock aquifer. Using modern geophysical logging tools, an enormous amount of information can be learned about the well itself and the "plumbing" of the encompassing bedrock aquifer, which is of great value to local, state, federal, and private sector scientists for making water quantity and quality planning decisions. From 2012 – 2023, the Vermont Geological Survey (VGS) and an academic partner at the State University of New York at Plattsburgh (SUNY at Plattsburgh) conducted geophysical logging surveys on 51 bedrock wells in Vermont, as part of collaborative hydrogeology projects. Each well was surveyed sequentially using the following tools: 1) Groundwater Temperature, 2) Groundwater Conductivity (dissolved solid content), 3) Gamma Radioactivity (rock type), 4) Caliper (well diameter), 5) Acoustic Borehole Imager (ABI)(3-dimensional well image using radar waves), 6) Heat Pulse Flowmeter (depth(s), direction(s), and velocities of groundwater in the well, 7) Borehole Camera- records a video of the inside of the well.

The goal of this study was to integrate the geophysical well data for each of the 51 wells with a Geographic information Systems (GIS) web map on the Vermont Geological Survey website that is readily available to scientists and other interested parties.

Final Report

A) Comparison of Actual Accomplishments to the Goals Established for the Period

1. The goal of this study was to integrate the geophysical well data for each of the 48 wells with a Geographic information Systems (GIS) web map on the Vermont Geological Survey (VGS) website that is readily available to scientists and other interested parties. We used the U.S. Geological Survey (USGS) GeoLog Locator web map as a model for our web map.

(https://webapps.usgs.gov/GeoLogLocator/#!/search).

Because of the ongoing geophysical logging of bedrock wells during the duration of this grant, we were able to include the geophysical data from 51 wells on the web map, rather than only 48. The link to the web map on the VGS website is found at:

https://dec.vermont.gov/geological-survey/groundwater/digitized-vermont-well-logs

2. Three specific activities, each with multiple components, were outlined in the original proposal, which were Data Collation, Production of Well Log Graphics, and Putting Materials Online. The following section goes through these activities in detail.

a. Data Collation

i. The original ASCII/text format geophysical logging data for the geophysical tools used for each well (fluid temperature, specific conductivity, gamma, caliper and vertical flow) were assembled into a separate metadata spreadsheet (***Sheet 1= Point Data***) in Excel using the ***NGGDPP Borehole Template*** (Bore_hole ID, Depth, Depth Units, Value, PtUnit and Description). The Sheet 1/ Point Data Excel file for each of the 51 wells with a corresponding .XML file, which was

exported from this spreadsheet, are available on the web map under "Additional Files". See blank NGGDPP Borehole Template Sheet 1 for format details.

https://dec.vermont.gov/geological-survey/groundwater/digitized-vermont-well-logs

ii. Similarly, separate ***NGGDPP Borehole Template*** metadata spreadsheets ***(Sheet 2 = Location Data)*** were created in Excel format for each of the 51 wells and exported as a corresponding .XML file. "ToFromData", which is the third tab on this template, was not applicable to this project. The Excel and .XML files are available on the web map under "Additional Files". See blank NGGDPP Borehole Template Sheet 2 for format details.

https://dec.vermont.gov/geological-survey/groundwater/digitized-vermont-well-logs

iii. All Spreadsheet 1 geophysical data sets for each of the 51 wells, including ABI data, were plotted on a single log using WellCad™ software. The WellCad™ logs for each well were exported in .PDF and .JPG formats. The .PDF log file was merged with a well information header and is located under "PDF Links" on the web map, whereas the .JPG image file is located under "WellCad Image Links". The WellCAD log was also exported into .LAS format and is found under .LAS File Links on the web map.

https://dec.vermont.gov/geological-survey/groundwater/digitized-vermont-well-logs

iv. Borehole camera videos for the 17 wells (the original proposal said 16) were converted into .MP4 format for those that were not already in this format. The videos that are available are shown on the web map and must be accessed separately by request because of the large associated file sizes.

https://dec.vermont.gov/geological-survey/groundwater/digitized-vermont-well-logs

b. Production of Well Log Graphics

A GIS base map was constructed that shows the locations of all 51 wells logged in the context of major geographic and geologic features and is shown in the following web map link:

https://dec.vermont.gov/geological-survey/groundwater/digitized-vermont-well-logs

Using the collated data files from Procedure A, high-quality graphics files were produced for the logs for each well using WellCad™ software, the first as a PDF and the second as a JPG. As explained in section 2), a.iii., the WellCad™ logs for each well were exported in .PDF and .JPG formats. The .PDF log file was merged with a well information header and is located under "PDF Links" on the web map, whereas the .JPG image file is located under "WellCad Image Links".

c. Putting Materials Online

Data files from geophysical logging sites were uploaded to the State of Vermont, Department of Environment Conservation webserver, and are available on the Vermont Geological Survey website at the follow address:

https://dec.vermont.gov/geological-survey/groundwater/digitized-vermont-well-logs.

Downloadable data file types include PDF documents, LAS files, WellCad .jpg images, and an "Additional Files" .zip folder that contains Excel spreadsheets, .xml, .xsd, and .wcl files. The collection of geophysical well logs were also input into ESRI ArcGIS Pro as a single and updatable feature class with corresponding well log information listed as unique attributes. The feature class was then published as an ArcGIS Online Web Map and embedded on the Vermont Geological Survey – Digitized Vermont Well Logs website. Users can zoom, pan, and toggle data layers via the Online Web Map. Furthermore, each well log has been configured with a corresponding data table that allows users to select a well location from the map and view and/or download available data. Borehole video files were too large to be hosted on the Vermont web platform but are available upon request via a File Transfer Protocol "Drop-off Portal" service and stored on State of Vermont network drives. Geophysical logging data (excepting MP4 data) are being stored on local State of Vermont network drives, in addition to the State of Vermont - Department of Environmental Conservation webserver.

B) lf Established Goals Were Not Met, Explanation of Circumstances and Impediments.

1) In the original proposal, it was planned to enhance the WellCad™ plots of all geophysical well logs using LogPlot™ software. To do this, a LAS file is exported from WellCad™, imported into LogPlot™ and then output as a multi-log graphics file. After several trials, we (E. Romanowicz and J. Kim) concluded that the quality and resolution of the WellCad™ plots were superior to that of LogPlot™. Therefore, this step was not performed.

C) Specific Examples of User Success Stories and/or Other Societal Benefits that Highlight Accomplishments in This Project.

Below is an annotated bibliography of Vermont Geological Survey publications that utilized the geophysical well logs from this web map.

Kim J.J., Ryan, P.C., Schroeder T., Romanowicz E., Boutt, D., Belaval, M. and Shanley, J., 2023, Four-dimensional characterization of a PFOA-contaminated fractured rock aquifer (FRA) in Bennington, Vermont, U.S.A. Frontiers in Water 5:1117780. https://doi.org/10.3389/frwa.2023.1117780.

Geophysical well logging was used to understand the complex fate and transport of Per and Poly Fluorinated Alkyl Substances (PFAS) in groundwater within the fractured rock aquifer (FRA) beneath Bennington, Vermont.

Kim, J., Klepeis, K., Ryan, P., Romanowicz, E., Boyles, J., and DeJong, B., 2022, A Conceptual Site Model for the PFAS-Contaminated Fractured Rock Aquifer Beneath the Rutland- Southern Vermont Regional Airport (RSVRA), Vermont: Vermont Geological Survey Technical Report. VGTR2022-2.

Geophysical well logging was used to understand the complex fate and transport of PFAS in groundwater in the FRA below the Rutland Southern Vermont Regional Airport, which resulted from the testing of Aqueous Film Forming Foams (AFFF) used in aircraft fires over decades.

Kim, J. J., and Dowey, C. W., 2017, Derivative maps generated from water well data logs in the Bennington area, Vermont: Vermont Geological Survey Open File Report VG2017-3, 4 Plates, scale 1:12,000. Plate 1. Plate 2. Plate 3. Plate 4.

Important new data was acquired on specific wells (n=18) by geophysical logging in the fractured rock aquifer (FRA) beneath Bennington, Vermont.

Kim, J., Klepeis, K., Ryan, P., and Romanowicz, E., 2015, Current Research in Structure, Stratigraphy, and Hydrogeology in the Champlain Valley Belt of West-Central Vermont: in Franzi, D., editor, Geology of the Northeastern Adirondack Mountains and Champlain-St. Lawrence Lowlands of New York, Vermont, and Quebec, New York State Geological Association 87th Annual Meeting, SUNY at Plattsburgh, p. 60-97. PDF.

Geophysical logging of bedrock wells in the Town of Hinesburg was integrated with bedrock geologic mapping and pumping tests to construct a conceptual site model for groundwater flow in the FRA.

Bachman, N., Kim, J.J., and Romanowicz, E., 2015, A Geothermal Investigation of 18 Bedrock Wells in Vermont, Vermont Geological Society Technical Report. VGTR2023-1.

Geophysical logging of 18 bedrock wells enabled the construction of geothermal gradient plots (temperature vs. depth) for the FRA.

Kim, J.J., Ryan, P., Klepeis, K., Gleeson, T., North, K., Davis, L., Bean, and Filoon, J., 2014, Tectonic evolution of a Paleozoic thrust fault influences the hydrogeology of a fractured rock aquifer, northeastern Appalachian foreland: Geofluids. https://doi.org/10.1111/gfl.12076.

By integrating geophysical logging with bedrock geologic mapping and groundwater geochemistry, we were able to understand the physical and chemical (radionuclides) hydrogeology of a major thrust fault in Vermont.