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Prepared in cooperation with the Town of Woodbury, Connecticut

Mapping Bedrock Surface Contours Using the Horizontal-to-Vertical Spectral Ratio (HVSR) Method Near the Middle Quarter Area, Woodbury, Connecticut

The bedrock surface contours in Woodbury, Connecticut, were determined downgradient of a commercial zone known as the Middle Quarter area (MQA; fig. 1) using the novel, noninvasive horizontal-to-vertical (H/V) spectral ratio (HVSR) passive seismic geophysical method. Boreholes and monitoring wells had been drilled in this area to characterize the shallow subsurface to within 20 feet (ft) of the land surface, but little was known about the deep subsurface, including sediment thicknesses and depths to bedrock (Starn and Brown, 2007; Brown and others, 2009). Improved information on the altitude of the bedrock surface and its spatial variation was needed for assessment and remediation of chlorinated solvents that have contaminated the overlying glacial aquifer that supplies water to wells in the area.

Depth to bedrock near the MQA was first determined using the HVSR method, which uses three-component seismometers to record the ambient seismic noise, such as that induced by distant weather or ocean waves impacting the shore. In areas that have a strong acoustic impedance contrast between the bedrock and overlying sediments, such as near the MQA, the seismic noise induces resonance at frequencies in the range of about 0.1 to 100 hertz. The ratio of the average horizontal- and vertical-component amplitude spectrums produces a spectral ratio curve with peaks at fundamental and higher order resonance frequencies. Resonance frequencies are a function of both sediment layer thickness and average layer shear-wave velocity.

Measurements were made along several transects downgradient of the MQA (fig. 1) using the field methods described in Lane and others (2008). Additional measurements were collected at several surrounding bedrock wells where the altitude of the bedrock surface is known. These were used to calculate a local regression line based on the relationship between the sediment thickness (z) and the resonance frequency (f_r; in hertz) of the main peak in H/V spectra:

$$z = a\, f_r^{-b}. \tag{1}$$

where

a and *b* are empirically derived coefficients (Ibs-von Seht and Wohlenberg, 1999).

Once calculated, the local regression line was used to determine sediment thickness from observed frequencies within the same geologic framework. The values for *a* (209.17) and *b* (0.798) were determined from the observed resonance frequencies and corresponding depths to bedrock (table 1; fig. 2) at six well locations around the MQA. Using these values for a and b, the depth of the bedrock (y; in feet) is calculated to be:

$$y = 209.17 f_r^{-0.798}\,. \tag{2}$$

Once the depths to bedrock were calculated using the local regression, bedrock altitude was determined by subtracting the depths determined from a 2-ft contour light detection and ranging (LiDAR) digital elevation model (State of Connecticut, 2011) or from land-surface altitudes previously surveyed at monitoring wells; these bedrock altitudes and regional-scale studies of the bedrock surface (Starn and Brown, 2007; Burton, 2011) constrained by bedrock outcrops and drilling logs from domestic wells were used to draw bedrock altitude contours (fig. 3).

The bedrock-surface contour map shows a high area to the southwest of the MQA within a larger bedrock valley. The bedrock surface could affect the movement of dense nonaqueous phase liquids (DNAPLs) in the glacial aquifer. The modeled bedrock surface provides a tool to help target drilling locations for characterization of DNAPL contaminants in the source area.

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U.S. Department of the Interior
U.S. Geological Survey

Open-File Report 2013–1028
Version 1.1, March 2013

Base map from Google Earth, 2012
Projection: Connecticut State Plane Feet

Figure 1. Aerial photograph of study area showing locations of seismometer readings, the study transects, and the monitoring wells in Woodbury, Connecticut.

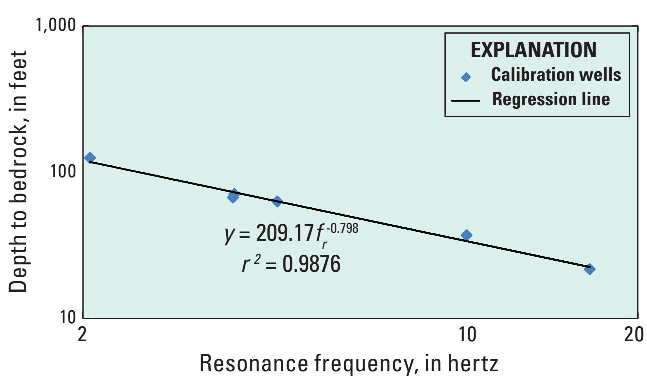

Figure 2. Regression plot and line equation for resonance frequency and depth to bedrock in Woodbury, Connecticut. (f_r, resonance frequency; r^2, coefficient of determination; y, depth to bedrock).

Table 1. Resonance frequencies and estimated bedrock depths and altitudes for seismometer reading sites and calibration wells in Woodbury, Connecticut.

[NAVD 88, North American Vertical Datum of 1988, in feet]

Seismometer reading sites	Resonance frequency, in hertz	Estimated bedrock depth, in feet	Estimated bedrock altitude, in feet (NAVD 88)
2–1	4.16	67.1	161.4
2–2	4.36	64.6	164.3
2–3	5.28	55.4	174.0
2–4	5.63	52.7	176.6
2–5	6.04	49.8	179.4
2–6	5.45	54.1	175.4
2–7	4.42	63.9	160.1
2–8	4.06	68.4	147.3
3–1	3.45	77.9	152.0
3–2	3.48	77.3	153.2
3–3	3.94	70.0	160.2
3–4	3.98	69.5	158.3
3–5	4.22	66.3	159.5
3–6	4.27	65.7	160.8
3–7	4.31	65.2	161.3
3–8	3.81	71.9	155.1
3–9	4.31	65.2	162.9
3–99	4.73	60.5	168.2
4–1	3.39	79.0	147.0
4–2	3.25	81.7	145.1
4–4	3.22	82.3	146.2
4-5	2.73	93.8	144.4
5–1	3.47	77.5	152.8
5–2	3.63	74.8	158.0
5–3	3.81	71.9	161.3
5–4	3.80	72.1	160.8
5–5	3.86	71.2	160.4
5–6	3.80	72.1	159.4
5–7	3.75	72.8	158.6
5–8	3.52	76.6	153.0
5–9	3.59	75.4	149.7
5–20	3.44	78.0	140.5
5–21	3.47	77.5	137.9
6–0	3.06	85.7	143.5
6–1	3.17	83.3	145.4
6–2	3.75	72.8	159.5
6–3	3.70	73.6	157.1
MQT-1	3.17	83.3	146.6
7–0a	3.72	73.3	159.4
7–0b	3.77	72.5	159.3
7–1	3.93	70.2	160.4
7–2	4.08	68.1	161.9
7–3	4.19	66.7	161.1
7–8	4.19	66.7	155.1
7–10	4.41	64.0	151.5
WY83	8.16	39.2	206.2
WY84	4.92	58.7	184.1
WY931	7.28	42.9	208.7
WY75	4.09	68.0	150.5
Calibration well	**Resonance frequency, in hertz**	**Bedrock depth, in feet**	**Bedrock altitude, in feet (NAVD 88)**
WY69	3.73	66.9	166.3
WY77	4.48	63.0	175.1
WY89	9.83	37.1	226.0
WY98[1]	16.39	21.7	230.6
WY106	3.75	70.9	148.9
WY11[1]	2.06	125.0	140.0

[1]Outside of the area shown in figure 1.

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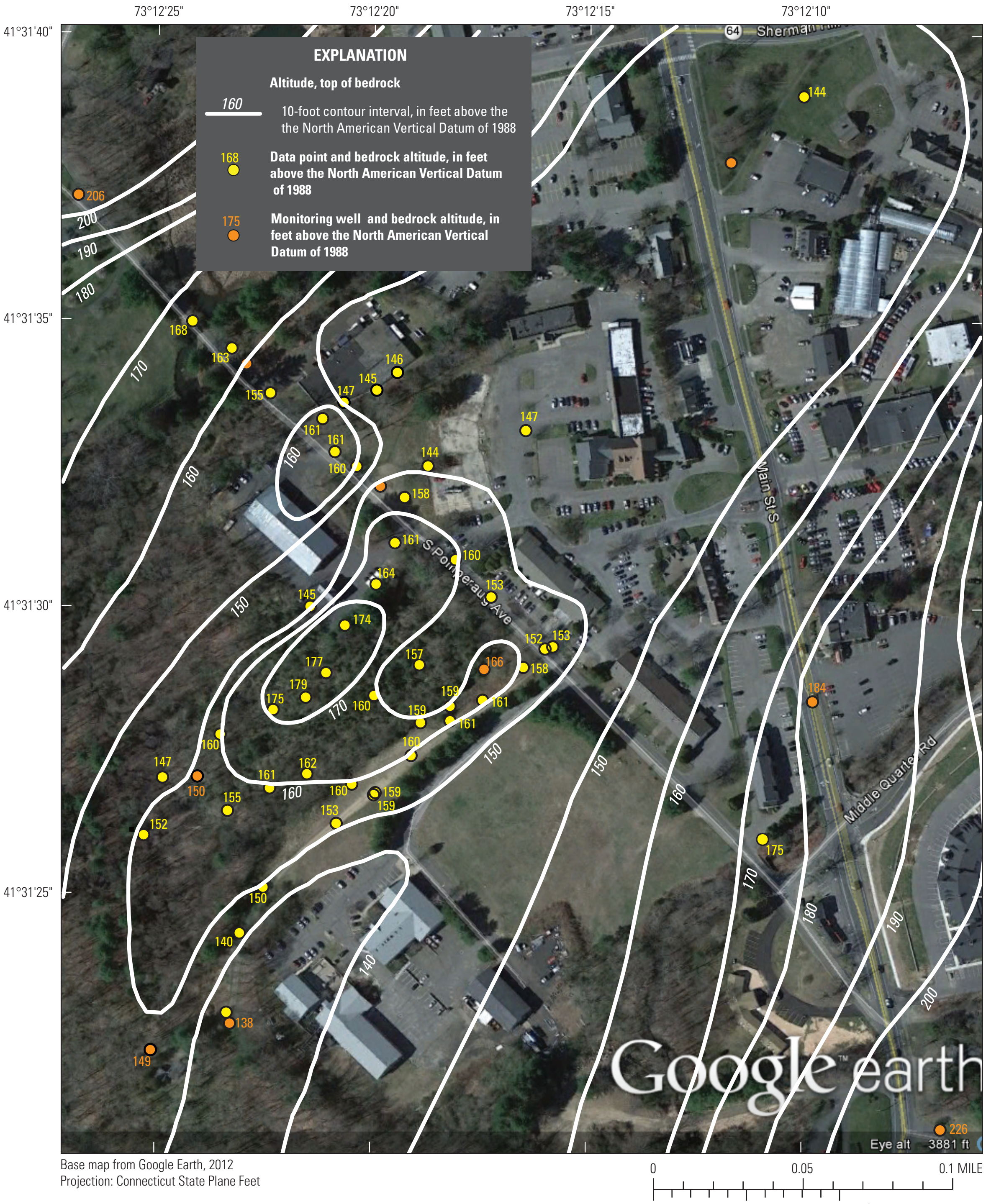

Base map from Google Earth, 2012
Projection: Connecticut State Plane Feet

Figure 3. Aerial photograph of the study area showing locations of seismometer readings, monitoring wells, and the bedrock altitudes and contours in Woodbury, Connecticut. NAVD 88, North American Vertical Datum of 1988.

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