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B. Dietiker

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SUMMARY

To support selection of prospective sediment drilling sites in Orleans (Ottawa), geophysical investigations allowed a rapid estimation of depth to firm ground for several candidate locations within Champlain Sea deposits. In the Bilberry and Voyageur Creek areas, 12 ambient seismic noise measurements were recorded. Processed data from all sites fulfilled criteria for a reliable Horizontal-To-Vertical Spectral Ratio (HVSR) curve and a clear resonance peak at the fundamental resonant frequency for soft soil. Despite the low-frequency noise from windy weather and sub-optimal instrument-ground coupling, 11 sites had peak amplitudes between 6.3 and 9.8. One site had a broad peak and a low amplitude of 3.5, suspected to correlate with a dipping firm ground surface. Fundamental resonance frequencies range from 0.81 to 1.31 Hz, which translate to firm ground depths of 80 to 43 m below surface. The deepest site is located near Voyageur Creek. Within the Bilberry Creek watershed, the deepest sites are located within upstream reaches towards the southeast.

RÉSUMÉ

Afin de mieux identifier des sites de forage de sédiments à Orléans (Ottawa), des études géophysiques ont permis une estimation rapide de la profondeur du fond rocheux pour plusieurs emplacements potentiels dans les dépôts meubles de la mer de Champlain. Dans les environs des ruisseaux Bilberry et Voyageur, 12 mesures de bruit sismique ambiant ont été enregistrées. Les données de tous les sites remplissaient les critères d'une courbe fiable et d'un niveau maximum de résonance claire à la fréquence fondamentale. Malgré le bruit à basse fréquence causé par le temps venteux et le couplage sous-optimal entre l’instrument et le sol, 11 sites avaient des amplitudes de pointe entre 6,3 et 9,8. Un site avait un niveau maximum d’amplitude faible de 3,5 soupçonné d'être en corrélation avec une surface inclinée d’un contraste d’impédance fort. Les fréquences fondamentales variaient de 0,81 à 1,31 Hz, ce qui se traduit par des profondeurs de terrain meuble de 80 à 43 m. Le site le plus profond est situé près du ruisseau Voyageur. Dans le bassin versant du ruisseau Bilberry, les sites les plus profonds sont situés dans les tronçons en amont vers le sud-est.

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1. INTRODUCTION

The Rideau Valley Conservation Authority (RVCA), together with the City of Ottawa, initiated a hazard mapping project, identifying potential flood risk and slope stability hazards in the fine-grained Champlain Sea sediments (muds) along Bilberry Creek in Orleans, Ottawa (Figure 1). The Geological Survey of Canada (GSC) has a long history of conducting surface and downhole geophysical investigations for geohazard-related studies in Champlain Sea sediments (e.g., Gadd, 1986; Evans and Brooks, 1994) and experience in geophysical downhole logging (e.g. Crow et al., 2011). To support fundamental research into the deposition of the sediments, and processes governing pore fluid movement and the development of sediment sensitivity to mechanical remolding, the GSC is collaborating with the RVCA in this investigation.

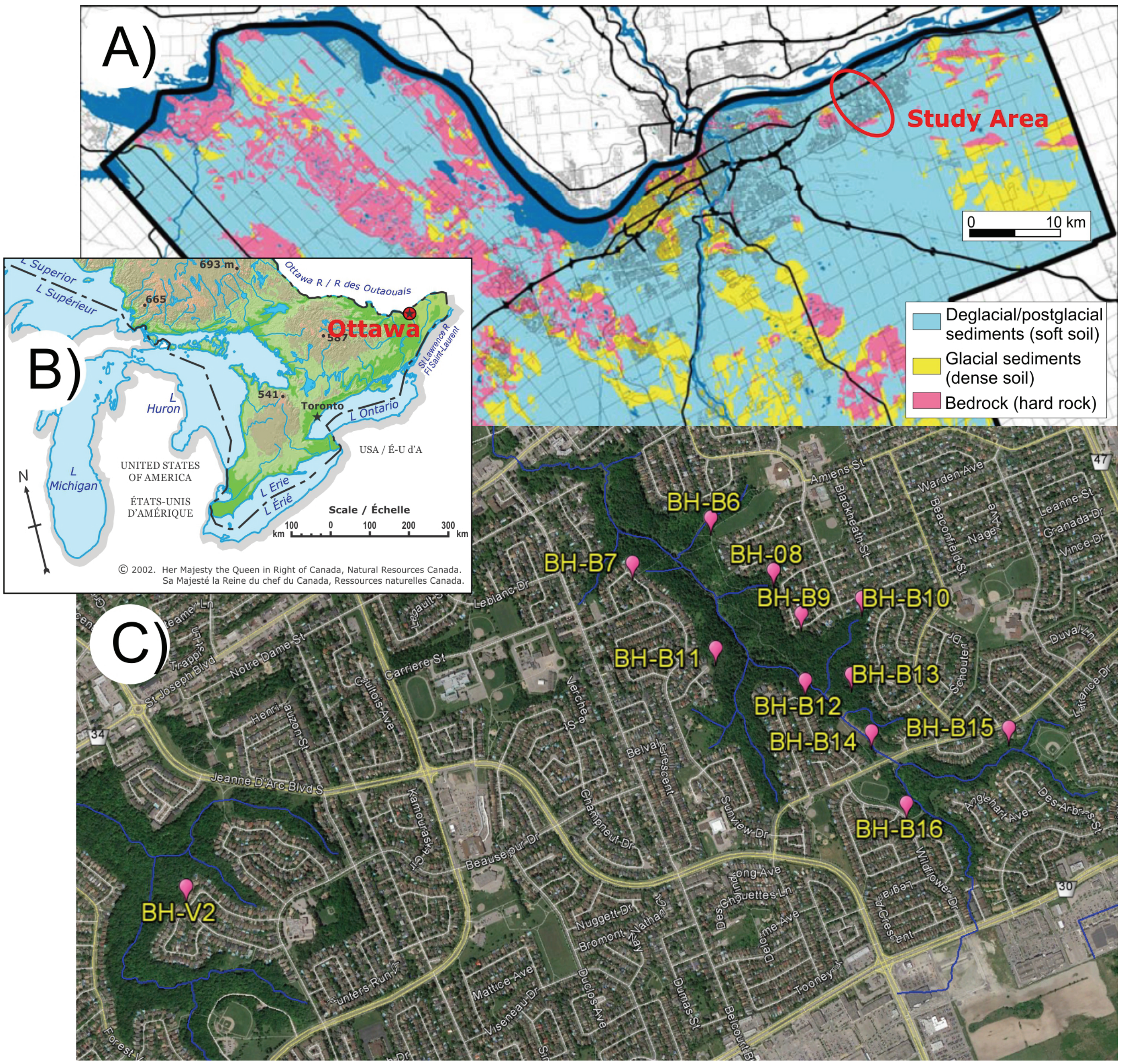

Figure 1. A) Simplified surficial geology (Hunter et al., 2010a) of Ottawa with outline of study area. B) General location, and C) Location of 12 HVSR measurement sites near Bilberry (East) and Voyageur Creeks (West; © Google Earth, 2020).

This GSC Open File is the second report of a series for this research activity to document pertinent methods and results from Champlain Sea deposits in Ottawa and its vicinity. The first provides details of on-site core preservation techniques (Alpay et al., 2020).

The purpose of this reconnaissance study is to provide estimates of the depth to firm ground from Horizontal-to-Vertical Spectral Ratio (HVSR) measurements to locate the thickest Champlain Sea sequence for detailed GSC and partner studies. The Horizontal-to-Vertical Spectral Ratio (HVSR) method is used routinely for seismic site characterizations (e.g. Konno and Ohmachi, 1998; Site Effects Assessment Using Ambient Excitations (SESAME), 2004) and for groundwater studies to obtain bedrock or firm ground depth estimates (e.g. Chandler and Lively, 2016; Ibs-von Seht and Wohlenberg, 1999). Prior HVSR measurements in Ottawa and Orleans were made by Hunter et al. (2010a) and Mallozzi (2017) (Figure 2), but in this survey, more local depth estimates were necessary to plan for the RVCA and City of Ottawa drilling campaign. Specifically, the GSC was seeking two deep sites for drilling nearly continuous core for a parallel study to complement the investigations of the RVCA and the City of Ottawa.

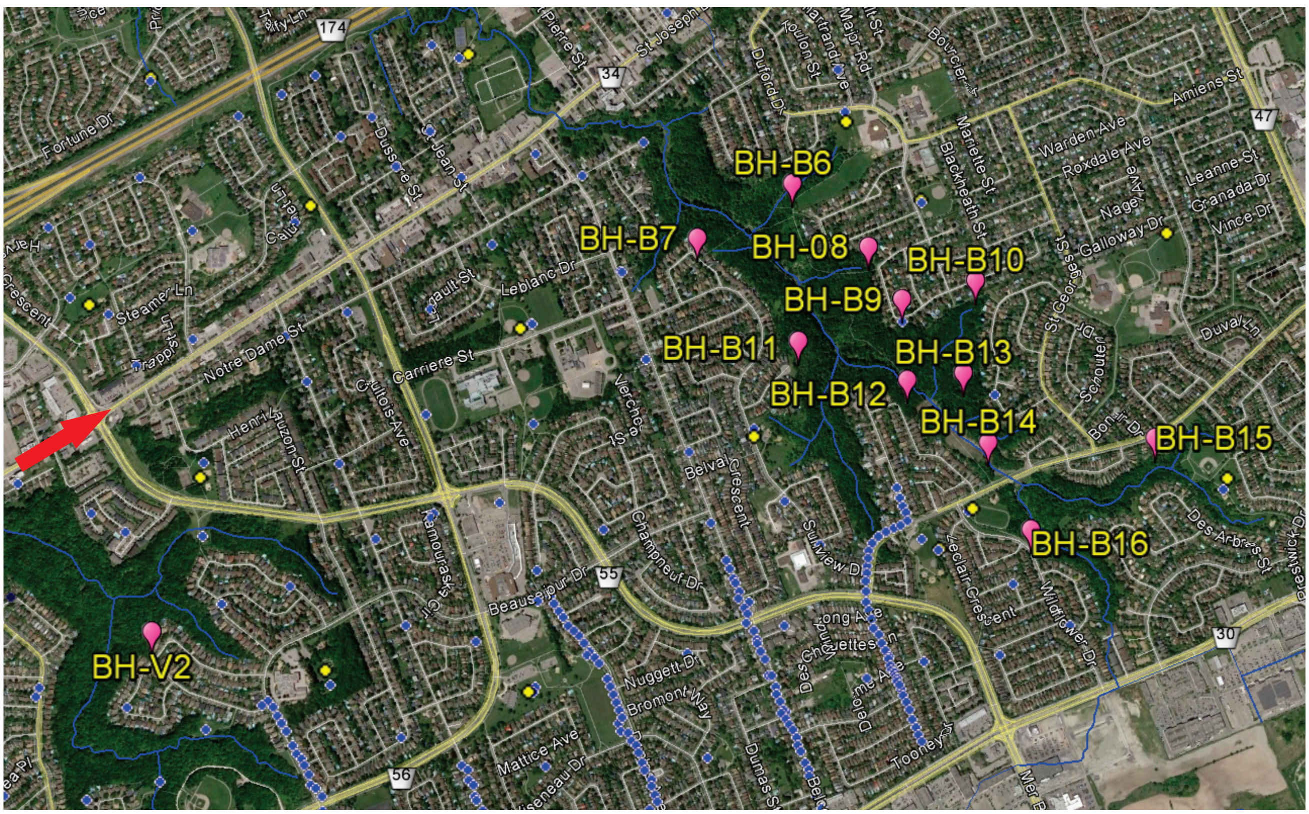

Figure 2. Location of HVSR measurements near Bilberry and Voyageur Creeks (© Google Earth, 2020) from Hunter et al. (2010a; yellow) and Mallozzi (2017; blue). Boulevard St. Joseph is marked with a red arrow.

Ambient seismic noise or microtremors are minuscule ground movements, created by various sources, like root movements from plants/trees moving in the wind, road traffic, distant (teleseismic) earthquakes, and waves hitting shorelines (fresh water or seawater). Depending on the subsurface (sediment type and structure) at the measurement site, the frequency spectra of these recorded ground motions can be highly variable. In particular, horizontal and vertical components of these movements fluctuate to such an extent, that they lead to variable ratios between horizontal and vertical frequency-amplitude spectra (Nogoshi and Igarashi, 1971; Nakamura, 1989). Konno and Ohmachi (1998) showed that the H/V ratio of these weak motions displays amplification (resonance) at the fundamental frequency of a site similar to the amplification caused by weak motion earthquakes (as long as soil response remains linear). Therefore, the fundamental frequency of a site is important for geotechnical assessments.

Although the exact nature of the motions (surface waves, Rayleigh, Love, Airy waves) contributing to microtemors is as yet being debated (Lachet and Bard, 1994; Nakamura, 2000; Fäh et al., 2001; Bonnefoy-Claudet et al., 2006), under the assumption of fundamental mode Rayleigh wave propagation, the thickness of the surface layer H overlying firm ground can be determined as (Kramer, 1996):

$$H = Vs / (4F_0) \qquad (1)$$

where Vs is the shear-wave velocity of the surface layer (e.g. soft soil) and F_0 is the fundamental resonant frequency where the H/V amplification is at its maximum. It is important to highlight that Eq. 1 is valid only for a single sediment layer overlying a rigid half-space, and having a constant shear wave velocity.

In practice, a "Single Layer" equivalent is used as a surface layer with an average shear-wave velocity (Vsav):

$$H \approx Vsav/(4F_0) \qquad (2)$$

With a known shear-wave velocity-depth function (e.g. from borehole logging, seismic refraction or reflection surveys, multi-channel analysis of surface waves (MASW), a depth estimate to firm ground can be calculated. However, Hunter et al. (2010a) pointed out that measured shear-wave velocities vary from the "Single Layer" average velocity likely because of velocity dispersion (velocities differ for varying frequencies). Dobry et al. (1976) have shown that slight velocity gradients within the surface layer alter the fundamental site frequency substantially.

For these reasons, Ibs-von Seht and Wohlenberg (1999) suggested using a direct correlation between known surface layer thickness and fundamental frequency obtained from HVSR. Ideally, many sites within an area, with a wide range of known thicknesses, are utilized to calculate nonlinear regression fits in the form of

$$H_{est} = a\, F_0^{\,b} \qquad (3)$$

Naturally, since this method relies on information from a wider geographic region (the Ottawa area), it imposes an averaging over the local Bilberry Creek area, and despite minor local variations, this correlation provides an estimate of the local depth to firm ground.

2. SITE LOCATIONS

RVCA was investigating 15 drilling locations near Bilberry Creek and 2 near Voyageur Creek further west (also known as Bilberry Creek West; Figure 2). Since the goal of estimating depth to firm ground from HVSR measurements was to find the thickest Champlain Sea deposit sequence, measurements were constrained to the area south of the margin of a paleochannel of the Ottawa River. The former shoreline approximately coincides with Boulevard St. Joseph (Road 34, marked with a red arrow in Figure 2, Figure 5) and Notre Dame Street where sediments have not been eroded. Eleven sites were measured near Bilberry Creek and one site near Voyageur Creek, where prior work (Hunter et al., 2010a) had indicated the deepest part of the bedrock basin. UTM coordinates (NAD83 18T) of the 12 investigated sites are given in Table 1.

3. METHODS

3.1 HVSR MEASUREMENT TECHNIQUES

Data were recorded using a Tromino® engineering seismograph (www.moho.world/en/tromino/geology Castellaro et al., 2005). Each seismograph contains 3 orthogonal broad-band velocity sensors ($\pm$1.2 mm/s range) and 3 orthogonal accelerometers $\pm$ 2g). At each site, the unit was leveled and planted firmly into the soil with three metal spikes on the underside of the instrument. To ensure good coupling between the instrument and the ground, surface vegetation was cut back where necessary. Data were recorded for 30 minutes. Frequency spectra were computed for each component (vertical, N-S and E-W) over 30-second time windows, resulting in 60 separate spectra per site. Individual H/V spectral windows, showing local transient noise contamination, were removed from the data set. Thus, the "cleaned" H/V frequency data were processed with proprietary GRILLA software (MOHO, Release (2015) Rel. 7.0) following the recommended SESAME European consortium guidelines (SESAME, 2004).

3.2 DEPTH ESTIMATION PROCEDURE

Depth estimation from fundamental frequency, as described by Ibs-von Seht and Wohlenberg (1999), relies on F_0 obtained at sites with known firm ground depth. Starting in 2006, the GSC undertook a multi-year study to map the fundamental site periods ($T_0 = 1/F_0$) in the national capital region, based on borehole information, reflection/refraction surveys, high-resolution seismic reflection profiles and HVSR measurements (Hunter et al., 2010a, b; Motazedian et al., 2011; Hunter and Crow, 2012). From this work, Molnar et al. (2018) present a soft sediment case study in which the specific relationship between F_0 and the sediment thickness in the Ottawa area is given by

$$H_{est} = 64.98\ F_0^{-1.198} \pm 12.02 \text{ m } (2\sigma) \quad \text{……………………………………(4)}$$

This relation is shown in Figure 3 as the green line.

Using a subset of the database (black dots in Figure 3), which excludes the west of Ottawa where the sediments are very thick (~120 m in the Kinburn basin, Pugin et al., 2013), but includes sites in the City of Gatineau just north of the Ottawa River, a slightly adjusted relation is determined according to:

$$H_{est} = 59.21\ F_0^{-1.154} \pm 10.78 \text{ m } (2\sigma) \quad \text{…………………………………… (5)}$$

Based on eq. 4 and 5, a sediment thickness range in the Bilberry Creek area is estimated from measured F_0. These F_0 and depth values are listed in Table 1: The fundamental frequency ranges from 0.84 to 1.31 Hz with 7 unique values; 1.09 Hz was measured three times and 1.13 four times. Displayed in Figure 3 (7 red dots) are depth estimates from eq. 5 and not the exact depths to firm ground as they would have been determined in boreholes.

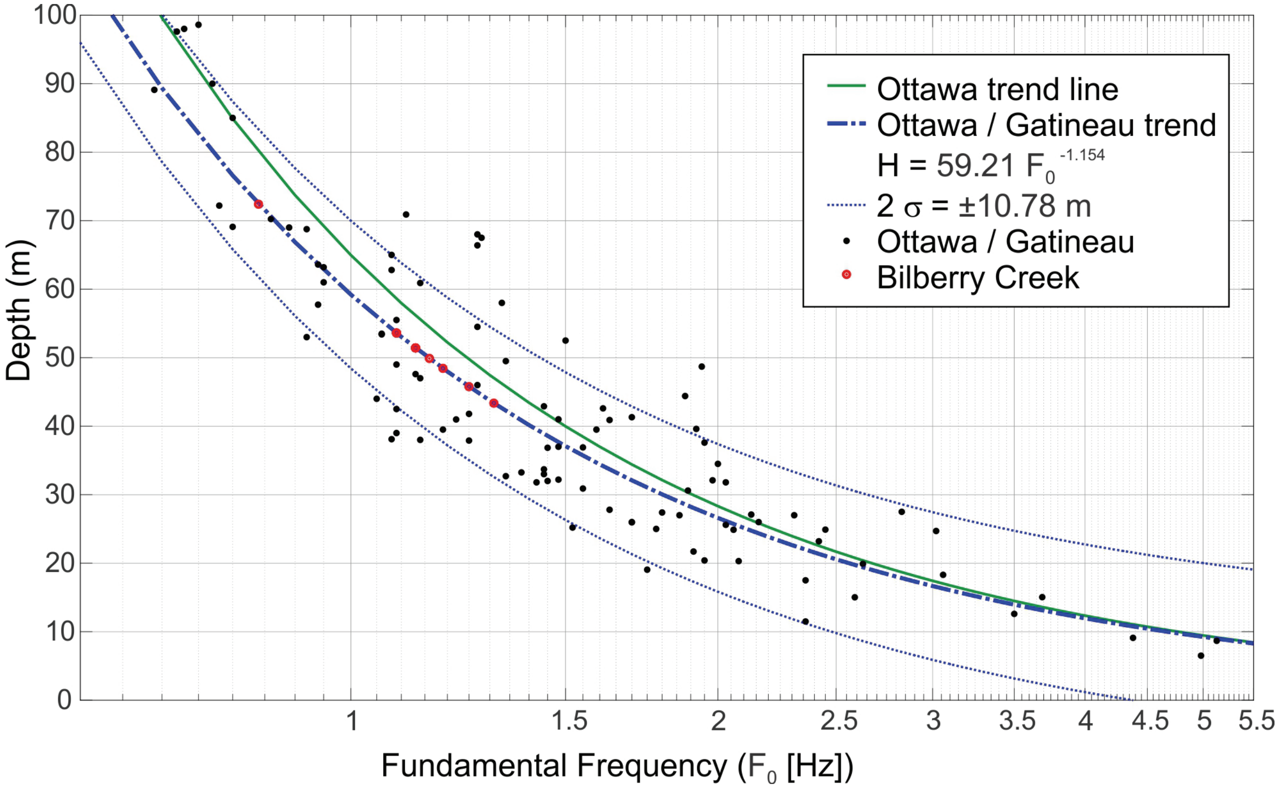

Figure 3. Fundamental frequency-firm ground depth relationship from the Ottawa area (green; eq. 4), data points from subset, including Gatineau sites (black dots), the Ottawa / Gatineau best fit (eq. 5, blue dashed line) and Bilberry Creek fundamental frequencies on the best fit line. Depths corresponding to red dots are estimates calculated with eq. 5.

4. RESULTS

A short summary of HVSR results - fundamental frequency (F_0) of raw and "cleaned" processed data and observations - are listed in Table 1. Site-specific details are given in Appendix A.

APPENDIX A: Site photograph, location, raw and processed frequency-amplitude spectrum in time windows, final HVSR amplitude and site information.

A figure summarizes each site's location and results: A photograph of the site is displayed as well as raw and processed amplitude-frequency spectra (where noisy windows were purged). The final processed HVSR amplitude versus frequency with peak frequency indicated is shown at the bottom where the statistical error (black lines) is given as 2 times the standard error (2σ), or with a 95% confidence limit. A depth estimate is given as the minimum and maximum range, where the deeper depth is calculated from eq. 4 and the shallower depth from eq. 5.

APPENDIX B: Recorded Microtremor Time Series

The raw, ambient, 3-component microseismic ground velocity from 30-minute time series are given in mm/s as .SAF ascii formats. The data have been corrected (calibrated in mm/s ground velocity) for instrument response between 0.3 Hz and 50 Hz.

Table 1: Borehole locations, interpreted HVSR resonances (F_0) and estimated depths

					raw			final			est. depth range (m)	
Borehole	**location**	**Easting***	**Northing***	**data observations**	**F_0 (Hz)**	**err (Hz)**	**amp ()**	**F_0 (Hz)**	**err (Hz)**	**amp ()**	**depth *5**	**depth *4**
BH-V2	NE Des Sapins Gardens	457958	5033935	ok, deep (low F_0)	0.81	0.18	6.00	**0.84**	0.03	6.60	**72.4**	**80.1**
BH-B11	Burningtree/Silvertree (E of Burningtree)	459908	5034791	noisy, secondary high-frequency peaks	1.16	0.02	9.20	**1.13**	0.01	8.80	**51.4**	**56.1**
BH-B7	Larkhaven Cr (next to trail)	459659	5035151	noisy, secondary high-frequency peaks	1.25	0.23	8.40	**1.25**	0.01	9.80	**45.8**	**49.7**
BH-B6	Bikepath / trail off NW corner Lacroix Ave	459902	5035270	very noisy	1.30			**1.31**	0.04	9.00	**43.4**	**47.0**
BH-08	Hoylake Cr NW corner / Bikepath	460148	5035095	very noisy	1.09	0.59	8.00	**1.09**	0.02	8.00	**53.6**	**58.6**
BH-B9	near SW corner Hoylake Cr / trail	460236	5034925	noisy				**1.13**	0.00	9.00	**51.4**	**56.1**
BH-B10	NW corner Marcoux / Bikepath	460512	5035002	**good**	1.13	0.02	8.00	**1.13**	0.02	8.00	**51.4**	**56.1**
BH-B13	near SW corner Marcoux Dr / trail	460506	5034703	noisy	1.16	0.02	> 8	**1.16**	0.02	9.80	**49.9**	**54.4**
BH-B14	Des Epinette / Bilberry Creek Trail	460488	5034507	noisy, weak resonance, secondary high-frequency peaks	1.16	0.39	3.30	**1.19**	0.05	3.50	**48.4**	**52.8**
BH-B15	south of Des Pommes Pl	461004	5034520	**good**	1.06	0.12	7.00	**1.09**	0.02	7.20	**53.6**	**58.6**
BH-B16	Wildflower / Bikepath	460654	5034244	ok	1.09	0.33	6.00	**1.09**	0.02	6.30	**53.6**	**58.6**
BH-B12	Turnberry near NE corner / trail	460252	5034642	very noisy, secondary high-frequency peaks				**1.13**	0.06	7.80	**51.4**	**56.1**
		*UTM 18T NAD83								***4 est. depth by eq. 4**		
										***5 est. depth by eq. 5**		

Conditions for HVSR measurements were not optimal as it rained heavily during two days before taking the measurements. The saturated, soft soil made the firm planting of the instrument difficult, which led to less than optimal coupling between instrument and soil at some locations. Additionally, it was very windy, leading to increased local noise from tree roots. The seismometer itself was protected against wind by an orange traffic cone (cover photograph and site pictures in Appendix A). Both effects can be seen mainly in the frequency range below ~0.6 Hz. Fortunately, the lowest peak frequency was found at 0.84 Hz, and for every measurement site there is a good separation between the spectral ratio peak and the local noise. Also, peak amplifications are between 3.5 and 9.8, much higher than those of the noise.

The thickest sediments from this survey, with an estimated depth to firm ground of 72 to 80 m, are located at BH-V2 (also known as GSC-BH-VC2) near Voyageur Creek in the west portion of the study area. This borehole has since been drilled to a depth of 65 m (Hinton and Alpay, in prep) and was terminated within Champlain Sea sediments. A shear-wave reflection seismic profile along rue Des Sapins Gardens (Figure 4), just 35 m SE of BH-V2, shows a sediment thickness of 80 m (Hunter et al., 2010a).

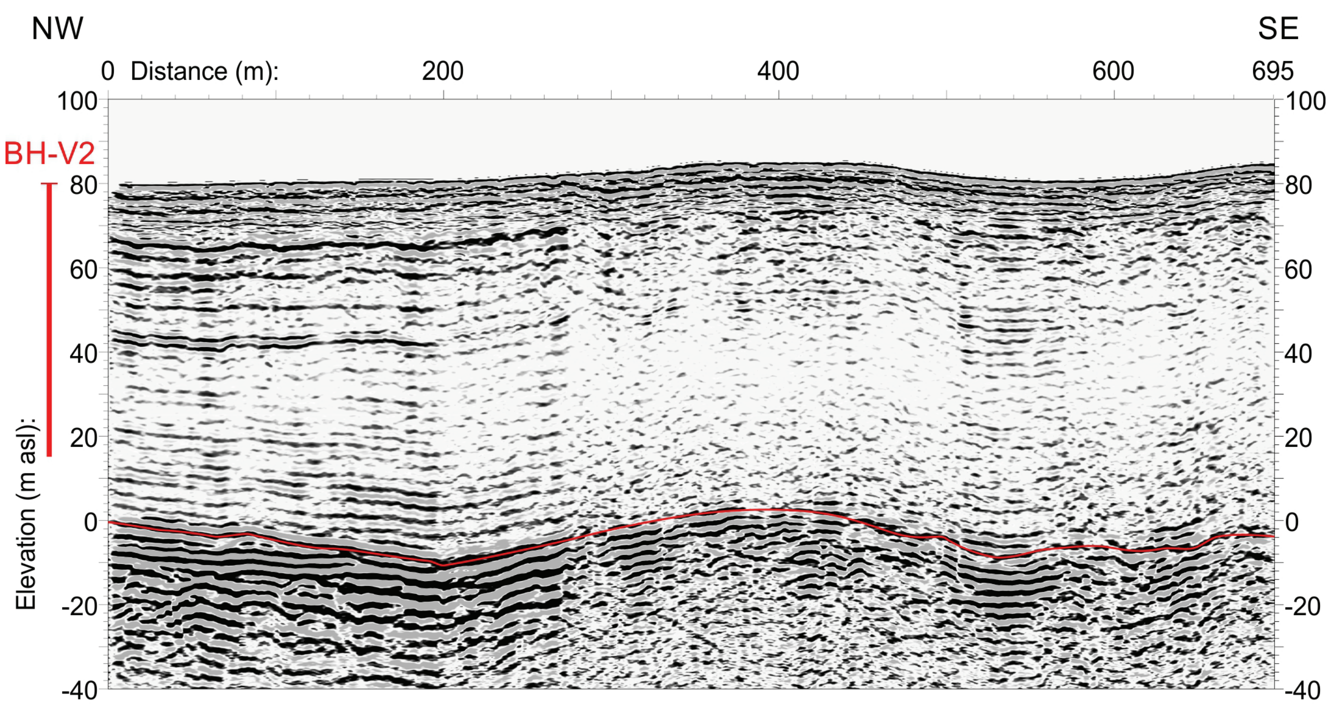

Figure 4. High-resolution shear-wave reflection seismic profile from Des Sapins Gardens (acquired 2007, Hunter et al., 2010a), showing 80 m thick sediments (the firm ground reflection is interpreted by a red line) just 35 m SE of borehole BH-V2. Profile location is shown in Figure 5.

Borehole BH-16 (also known as GSC-BH-BC16) reached the contact between Champlain Sea sediments and the underlying till at a depth of 47.5 m (Hinton and Alpay, in prep), which is considered firm ground. The borehole was terminated within the till at a depth of 48.8 m, likely close to the bedrock contact since the till is rarely very thick and typically less than 5 m (Gadd, 1986). This depth to firm ground is 6.5 m less than predicted from the HVSR results (54–59 m), but still within the 95% (2σ) confidence limit. The drilling site was approximately 20 m south of the HVSR survey location. The shallowest firm ground interface is estimated at 43 m at borehole BH-B6 (green ellipse in Figure 5).

BH-14 (circled yellow in Figure 5) has a broad, low H/V peak amplitude of only 3.5. All other sites have peak amplitudes in the range of 6.3 to 9.8. Such a signature of low amplitude and broad peak has been observed to occur over a dipping subsurface structure (Matsushima et al., 2014; Dietiker et. al., 2018; 2020; Mallozzi, 2017). In these situations, depths to firm ground can often be under-estimated.

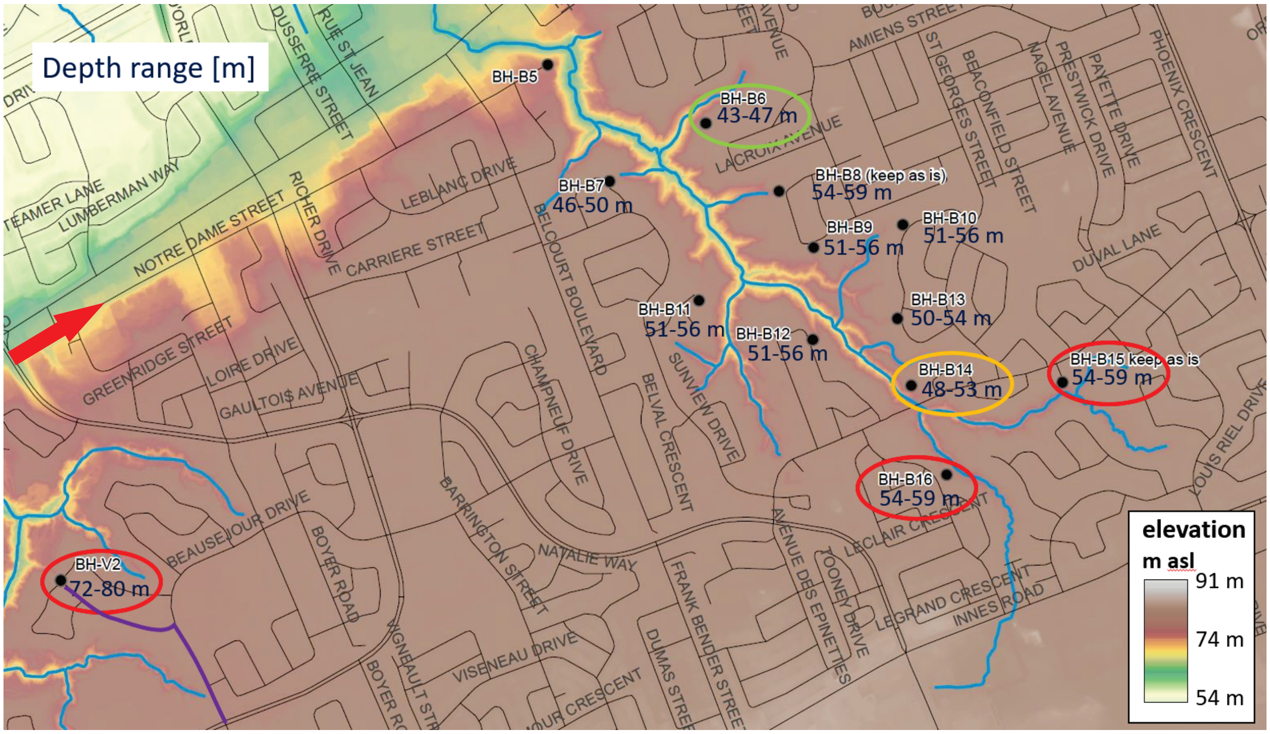

Figure 5. Digital elevation model with borehole locations and estimated depth range from eq. 4 and 5. Deepest firm ground sites are circled in red, shallowest in green. Seismic line from Figure 4 is indicated as a purple line. The red arrow points to the margin of a paleochannel of the proto-Ottawa River, incised into the Champlain Sea deposits.

5. DISCUSSION

Generally, the bedrock forms a basin with bedrock outcrops to the south (along Innes Road), north (near highway 174 and Place d'Orléans) and to the west (between highway 417 and Innes Road; blue areas in Figure 6). The basin deepens steeply northward from outcrops near Innes Road where a fault exists (Williams et al., 1984). Consequently, the deepest area of the basin occurs along the upstream reaches of Voyageur Creek. Along Bilberry Creek, the basin deepens upstream towards the southeast where bedrock is estimated at 54 m depth at boreholes BH-16 and BH-15 (red ellipses in Figure 5).

Figure 6 (Hunter et al., 2010a and Motazedian et al., 2011) shows that the new HVSR sites are located within the 40 to 50 m depth interval (orange) of Champlain Sea sediment thickness. These new control points added by this survey improve the depth estimates to firm ground for the Bilberry Creek area since most sites (except BH-B6 and BH-B7) now have indicted that firm ground is deeper than 50 m. A new 50 m contour line is suggested as shown by the red dashed line in Figure 6. However, as indicated, south of BH-16 the sediment thickness decreases, and bedrock outcrops have been observed approximately 800 m south near Innes Road (Williams et al., 1984).

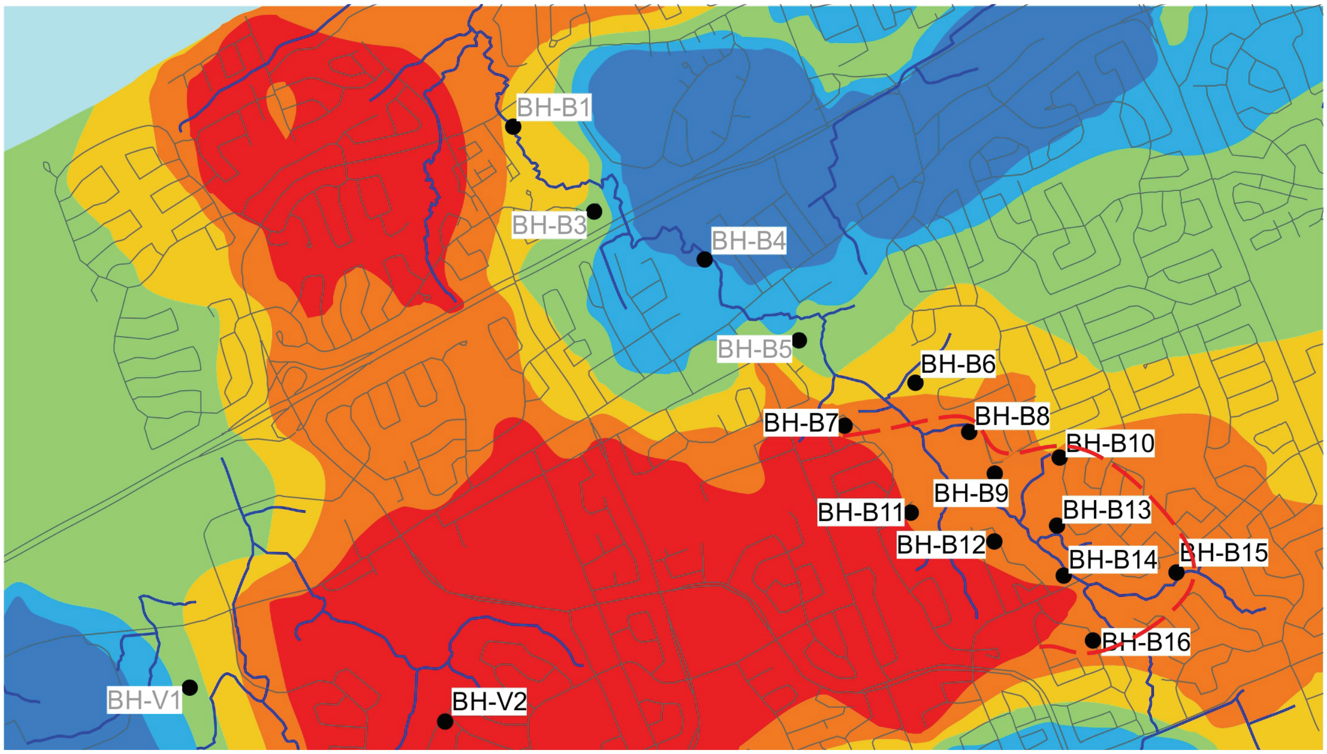

Figure 6. Champlain Sea sediment thickness in 10 m intervals (blue: 0-10 m; light blue: 10-20 m; green: 20-30 m; yellow: 30-40 m; orange: 40-50 m; red: >50 m) from Hunter et al. (2010a). HVSR sites are labelled BH-B6 to BH-B16 (black). New 50 m contour, as determined by the HVSR and drilling, is shown as a red dashed line.

H/V spectral ratios are shown side-by-side for all 11 sites along Bilberry Creek from the shallowest site BH-B6 in the NW to the deepest site BH-B16 in the SE (Figure 7). Peak frequencies are connected by a green line to visualize how the firm ground depth increases towards SE. A straight (black) line connects BH-B6 with BH-B16. BH-B8 is clearly deeper than BH-B9 to BH-B12, which all have the same F_0. The broad peak and decreased amplitude of BH-B14, mentioned above, is a clear anomaly in this illustration. Interesting also are increased H/V ratios at BH-B14 for frequencies larger than 20 Hz with a second peak at ~41 Hz. A strong (H/V > 3) second peak at ~ 32 Hz can also be observed for BH-B12. These high-frequency peaks might correlate with near-surface lithological changes, potentially to velocity inversions (Castellaro and Mulargia, 2009). Both sites are in areas where slopes along Bilberry Creek have previously been remediated.

Based on past work relating HVSR peaks to soft sediment thickness measurements in the Ottawa area, firm ground depth estimation from HVSR measurements are shown to be a fast, inexpensive tool for rapid reconnaissance in the Orleans area. It took but one day in the field and one day of processing in the office to produce these results. However, this was only possible because a substantial amount of data in this area was already available (Hunter et al., 2010a), including a frequency-depth relation.

The light, portable microseismograph allowed for field acquisition along a network of bicycle paths, removing the need for a motor vehicle. That is, a network of bike paths and trails around Bilberry Creek allowed a faster transition from one site to the next on a bicycle, rather than driving a car around the creek through the neighborhood (cover photograph).

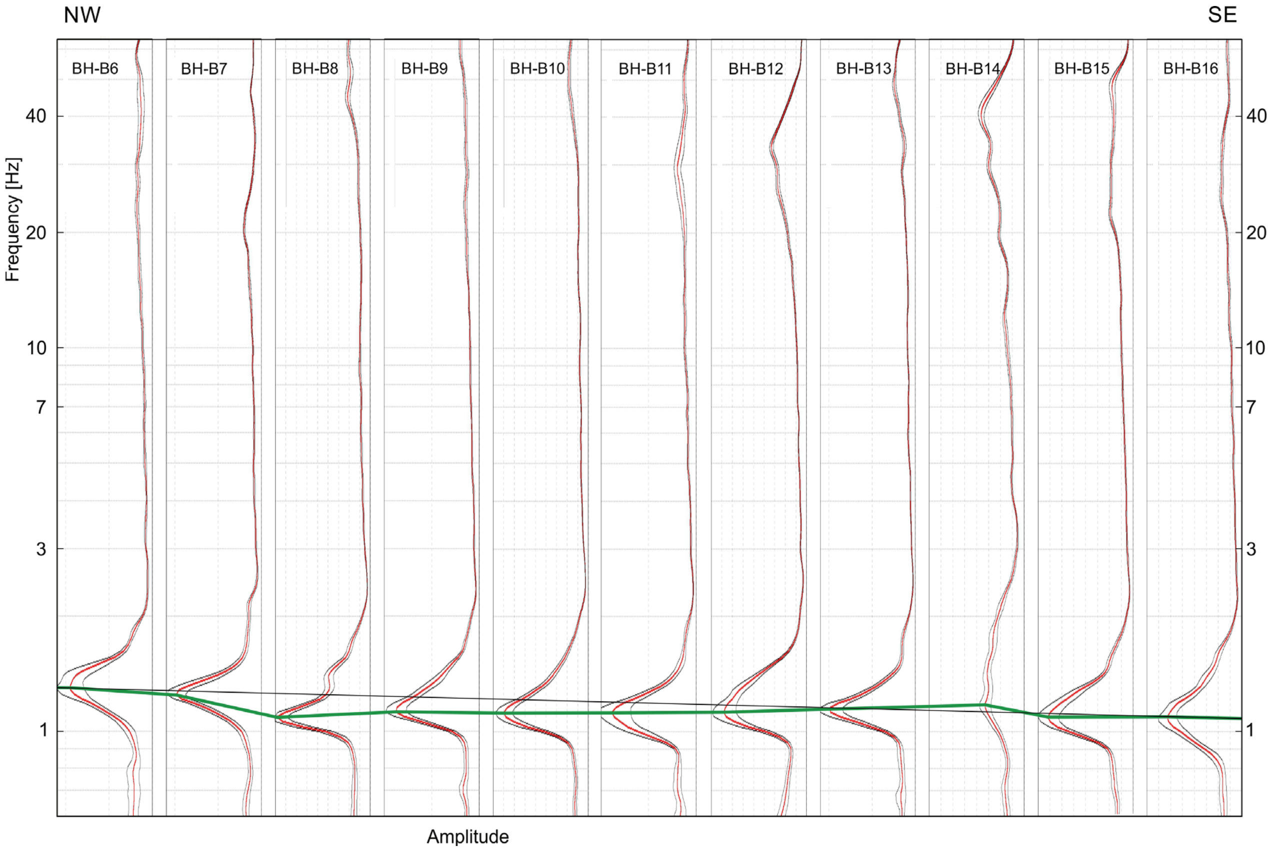

Figure 7. H/V frequency-amplitude plots of all 11 sites along Bilberry Creek from NW to SE. The green line connects all peak amplitudes at F_0 whereas the fine black line is the straight connection of the highest and lowest fundamental frequency determined in this survey (see the text for explanation).

6. ACKNOWLEDGMENTS

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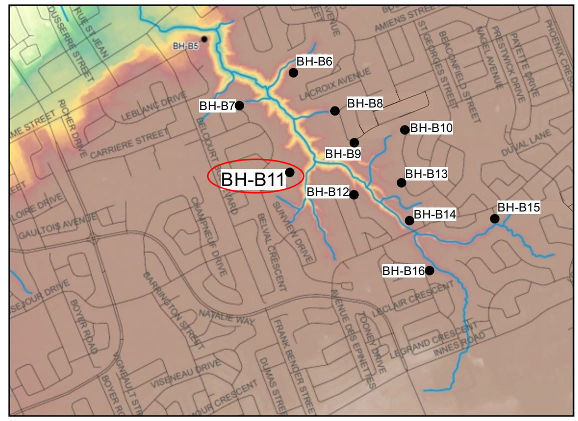
BH-B11 F_0 = 1.13 Hz Depth estimate: 51.4 - 56m

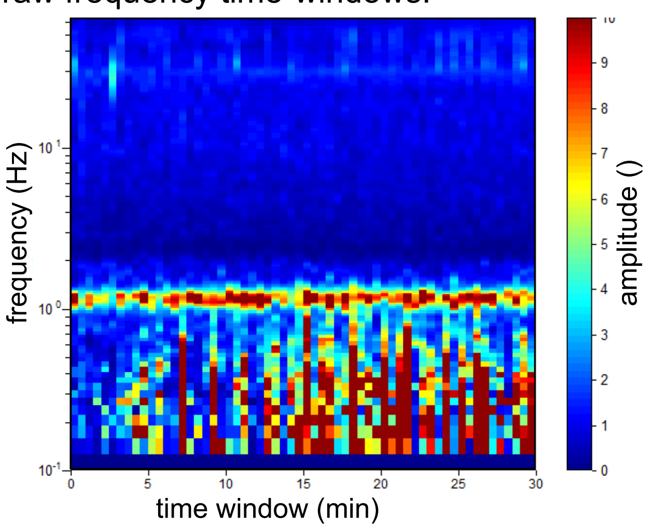
Burningtree/Silvertree - E of Burningtree (459908, 5034791 UTM NAD83)

site photograph: (by B. Dietiker. NRCan photo 2020-104)

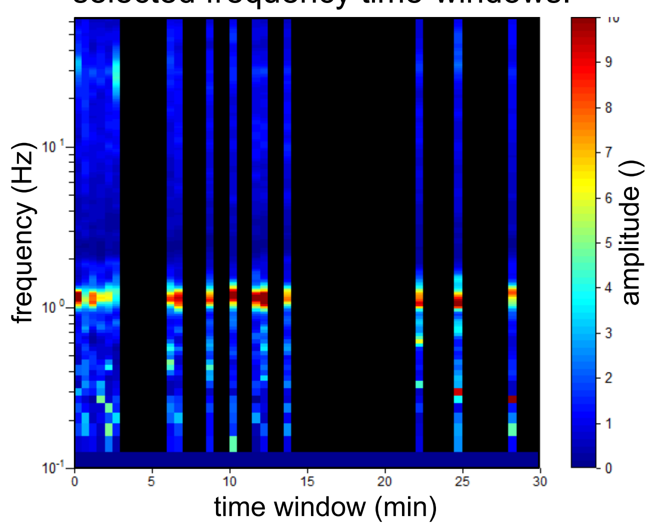
location:



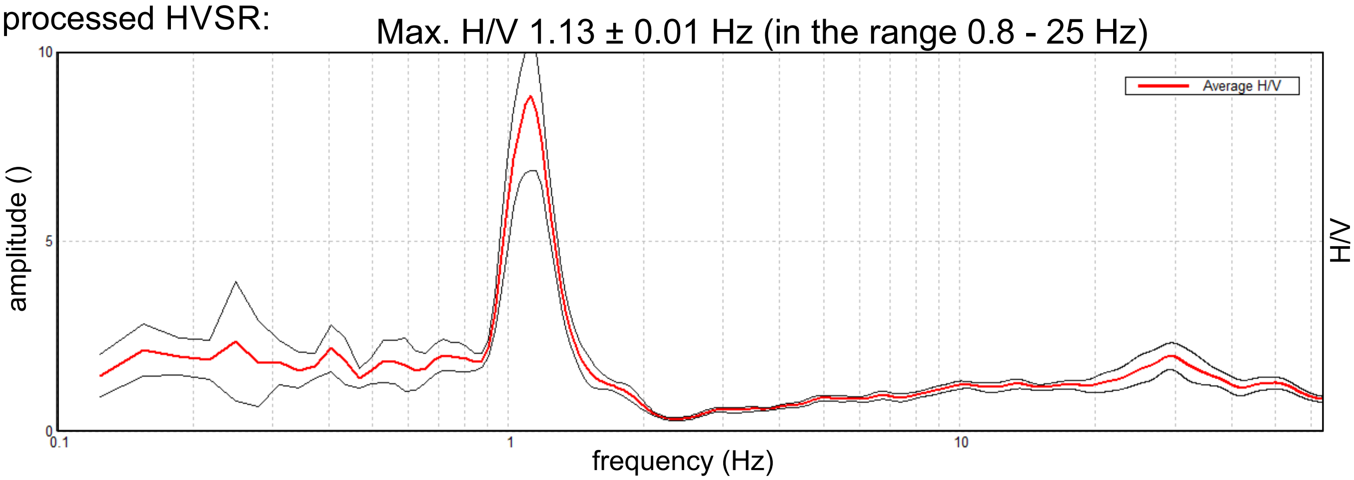
raw frequency time-windows:



selected frequency time-windows:



processed HVSR:

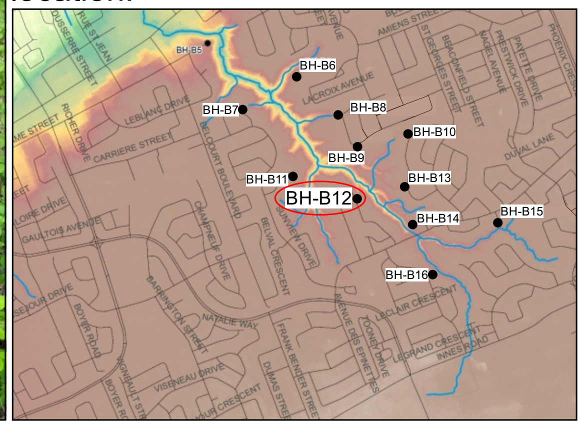


BH-B12 F_0 = 1.13 Hz Depth estimate: 51.4 - 56m

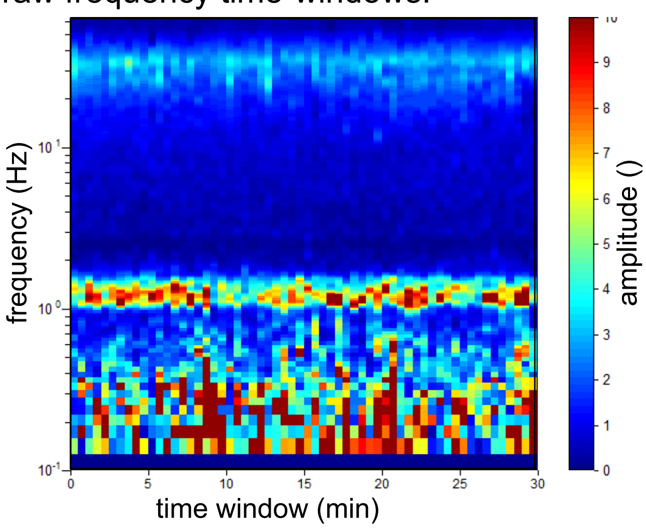
Turnberry near NE corner / trail (460252, 5034642 UTM NAD83)

site photograph: (by B. Dietiker. NRCan photo 2020-105)

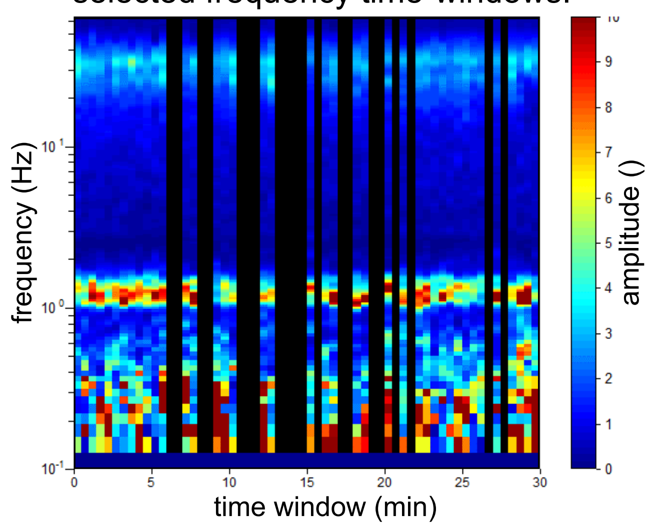
location:



raw frequency time-windows:

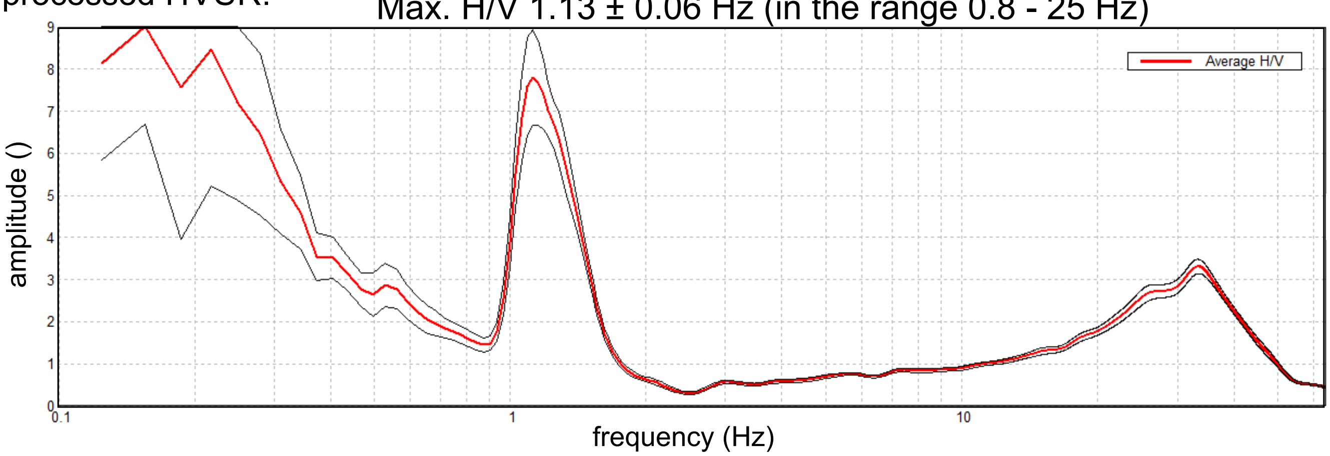


selected frequency time-windows:



processed HVSR:

Max. H/V 1.13 ± 0.06 Hz (in the range 0.8 - 25 Hz)

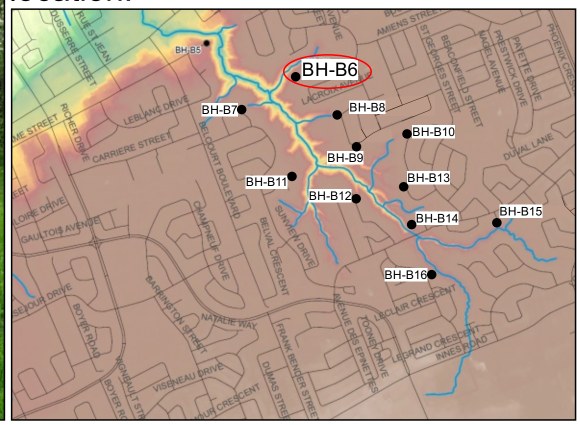


BH-B6 F_0 = 1.31 Hz Depth estimate: 43.4 - 47m

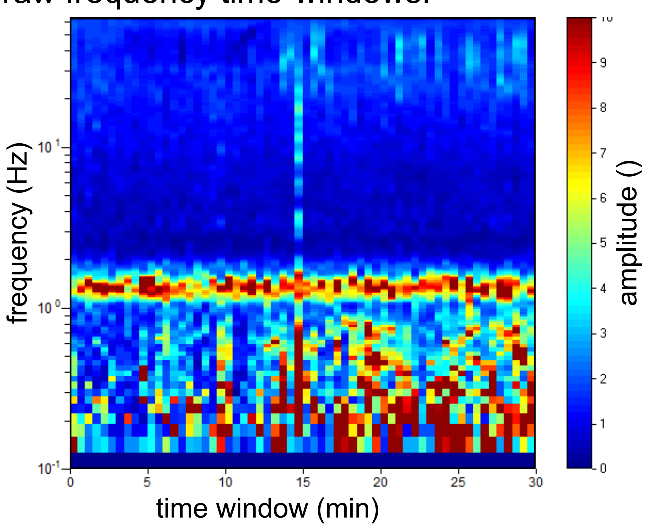
W corner Lacroix Ave / Bikepath (459902, 5035270 UTM NAD83)

site photograph: (by B. Dietiker. NRCan photo 2020-099)

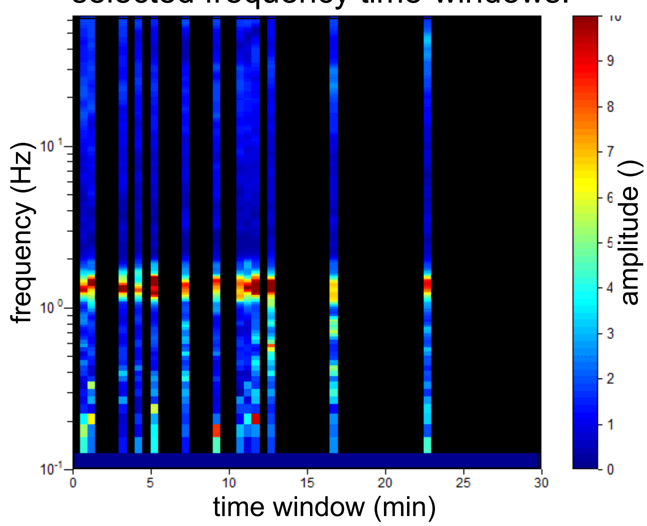
location:



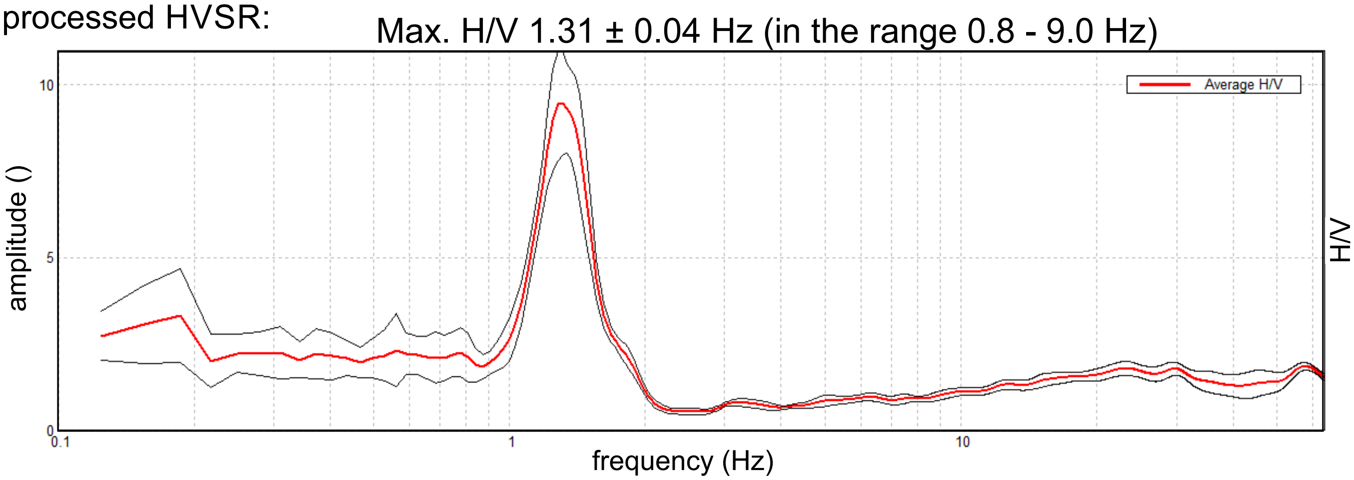
raw frequency time-windows:



selected frequency time-windows:



processed HVSR:

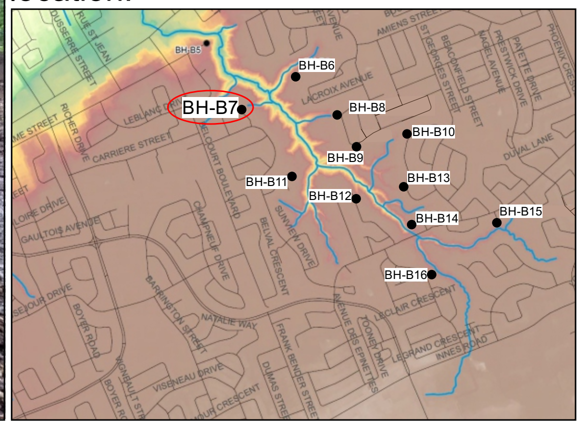


BH-B7 F_0 = 1.25 Hz   Depth estimate: 45.8 - 50m

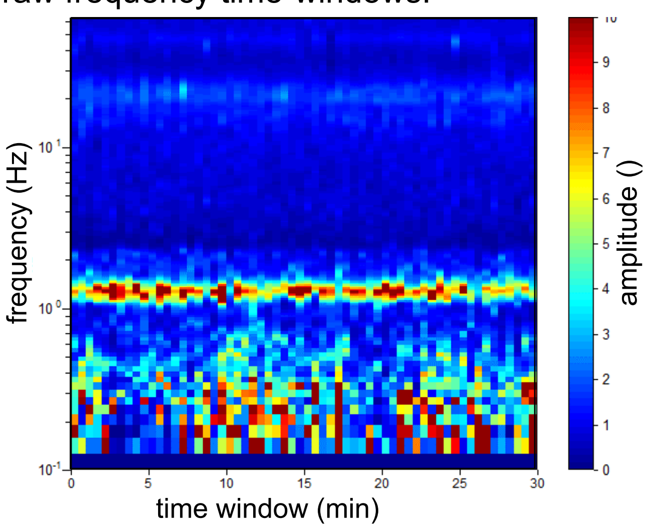
Larkhaven Cr, next to trail (459659, 5035151 UTM NAD83)

site photograph: (by B. Dietiker. NRCan photo 2020-100)

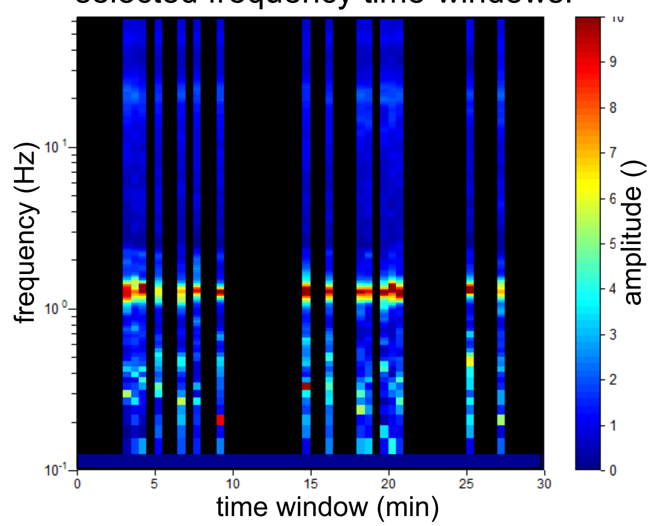
location:



raw frequency time-windows:

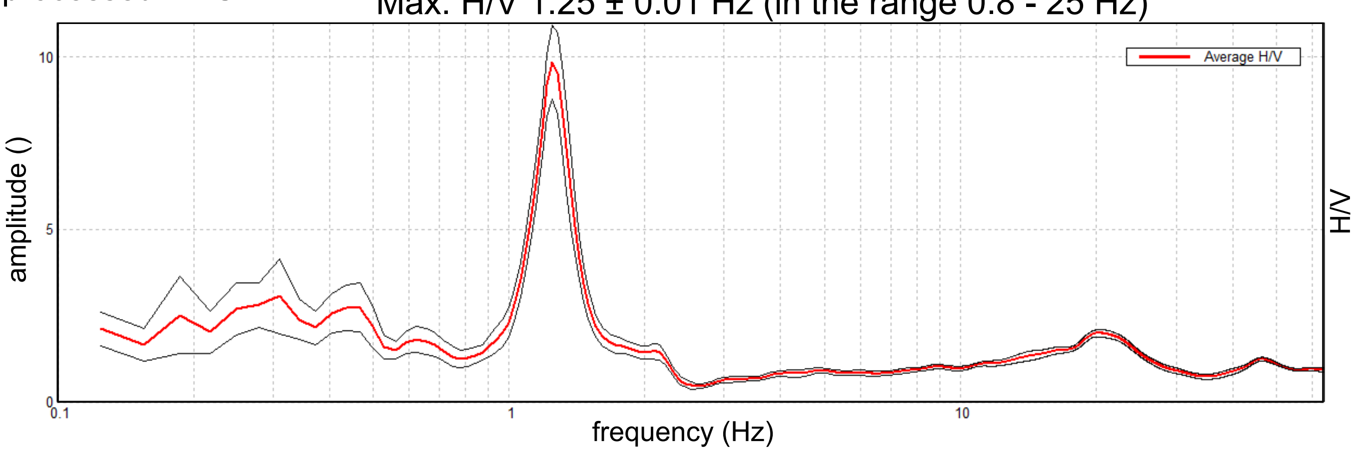


selected frequency time-windows:



processed HVSR:

Max. H/V 1.25 ± 0.01 Hz (in the range 0.8 - 25 Hz)

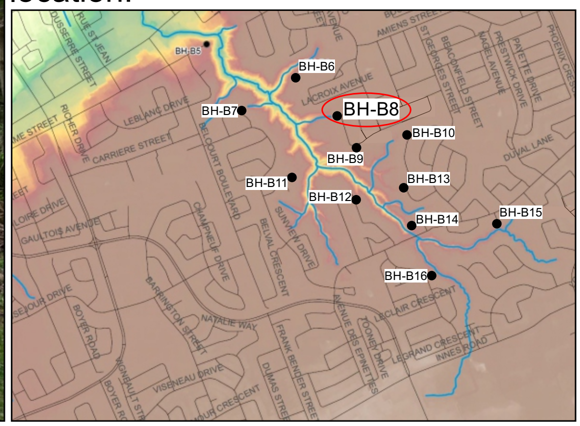


BH-B8 F_0 = 1.09 Hz Depth estimate: 53.6 - 59m

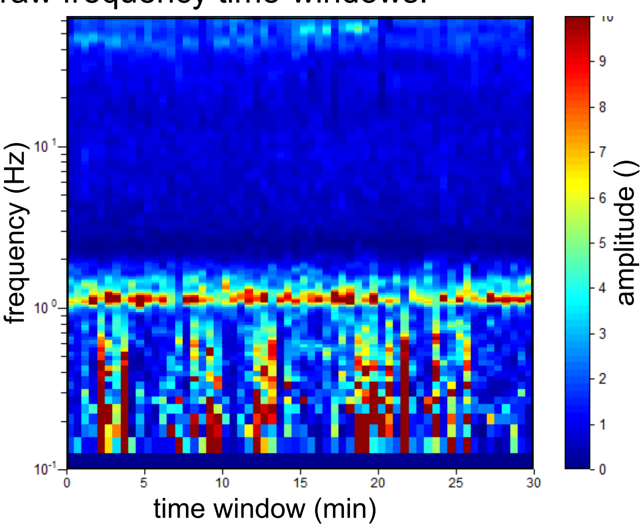
NW corner Hoylake Cr / Bikepath (460148, 5035095 UTM NAD83)

site photograph: (by B. Dietiker. NRCan photo 2020-101)

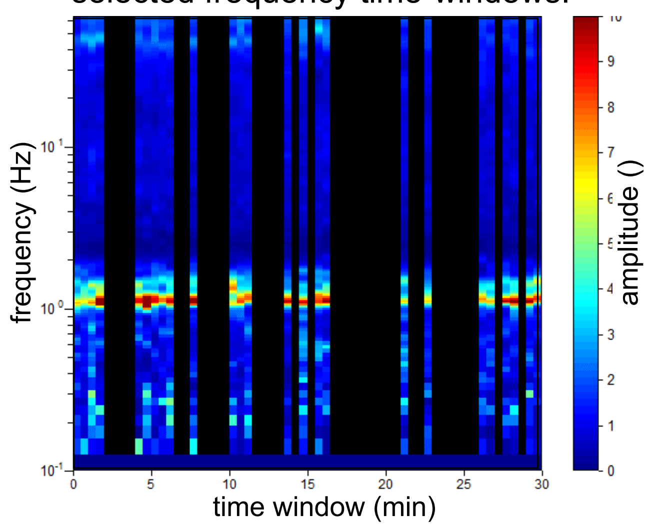
location:



raw frequency time-windows:

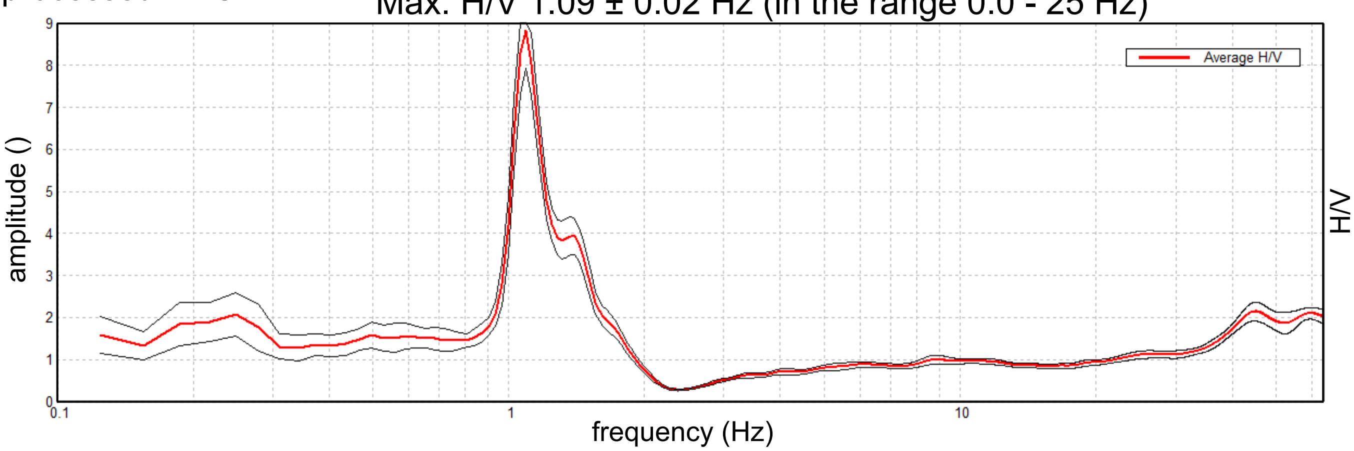


selected frequency time-windows:



processed HVSR:

Max. H/V 1.09 ± 0.02 Hz (in the range 0.0 - 25 Hz)

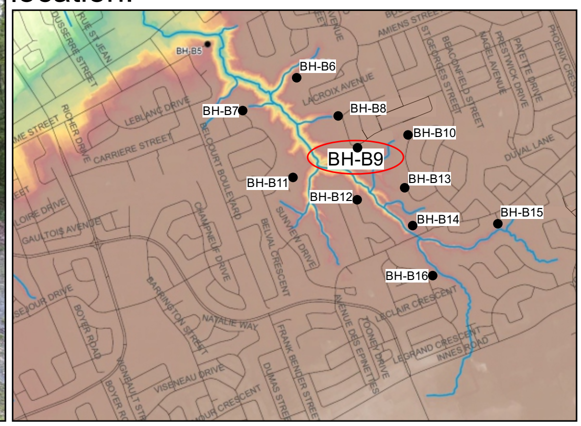


BH-B9 F_0 = 1.13 Hz Depth estimate: 51.4 - 56m

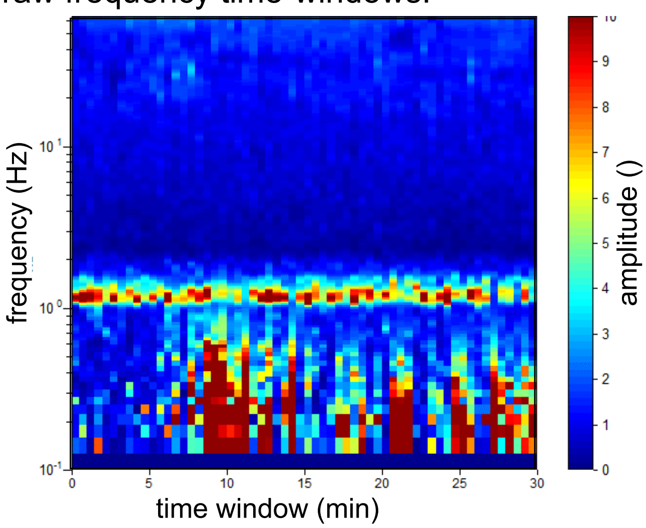
near SW corner Hoylake Cr / trail (460236, 5034925 UTM NAD83)

site photograph: (by B. Dietiker. NRCan photo 2020-102)

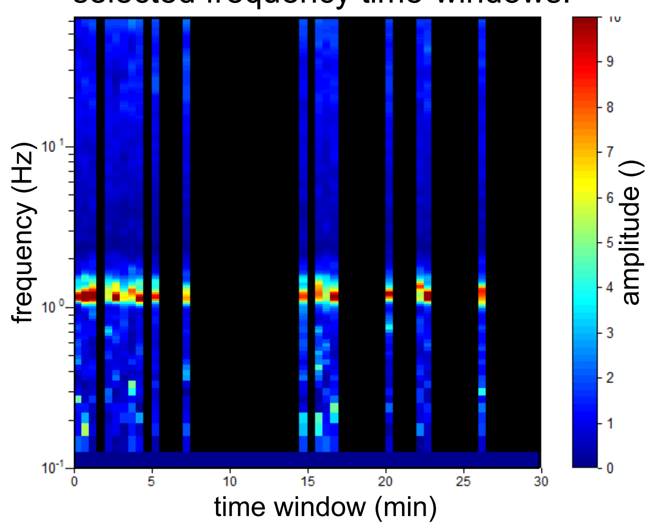
location:



raw frequency time-windows:

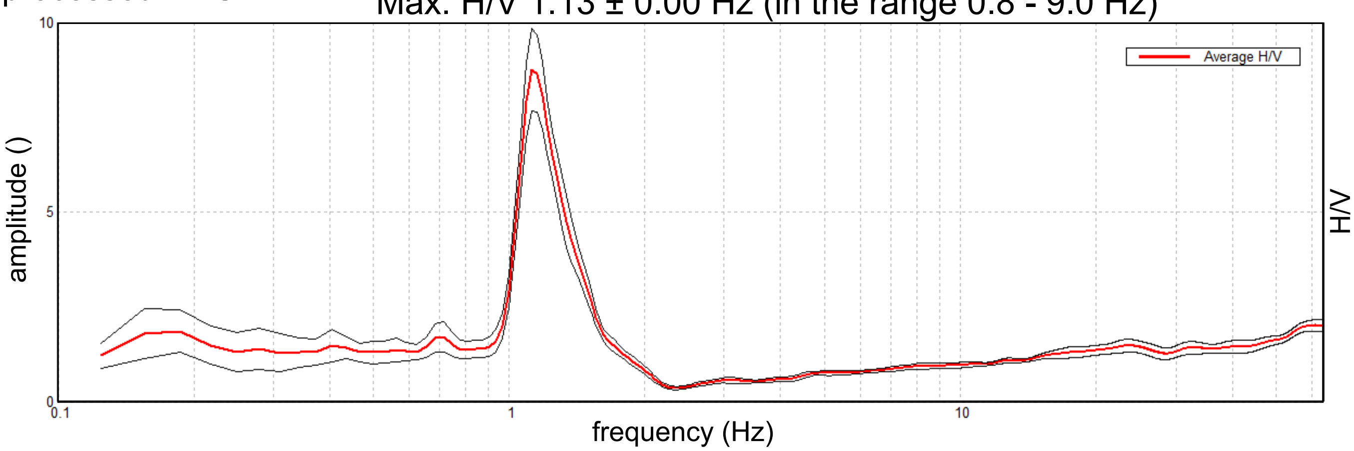


selected frequency time-windows:



processed HVSR:

Max. H/V 1.13 ± 0.00 Hz (in the range 0.8 - 9.0 Hz)

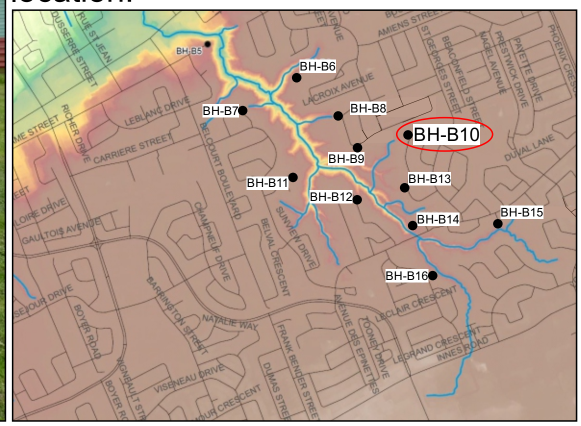


BH-B10 F_0 = 1.13 Hz Depth estimate: 51.4 - 56m

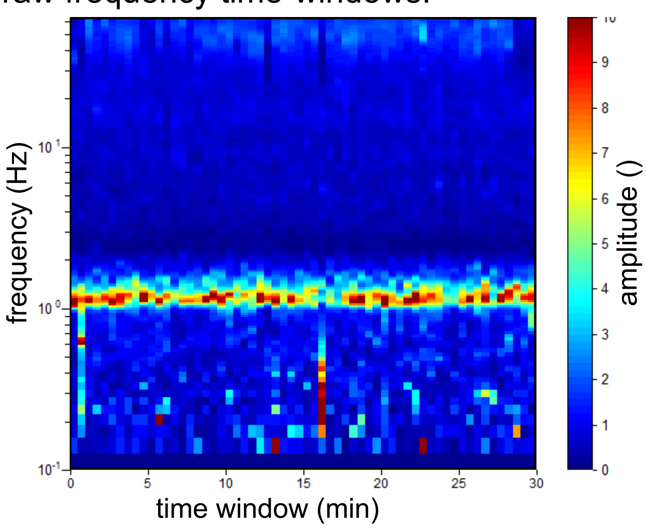
NW corner Marcoux Dr / Bikepath (460512, 5035002 UTM NAD83)

site photograph: (by B. Dietiker. NRCan photo 2020-103)

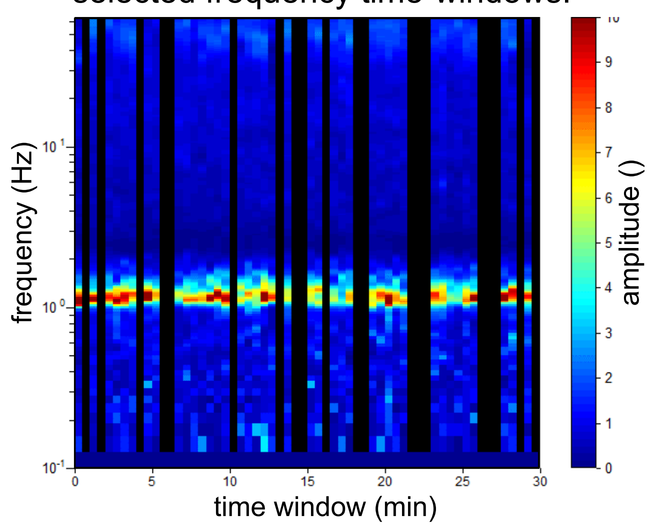
location:



raw frequency time-windows:

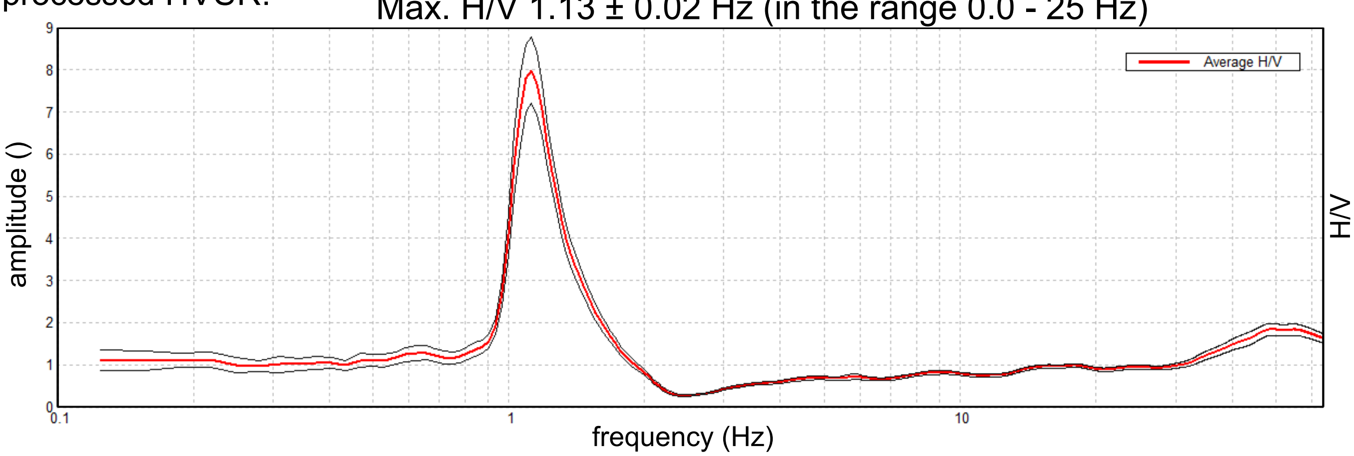


selected frequency time-windows:



processed HVSR:

Max. H/V 1.13 ± 0.02 Hz (in the range 0.0 - 25 Hz)

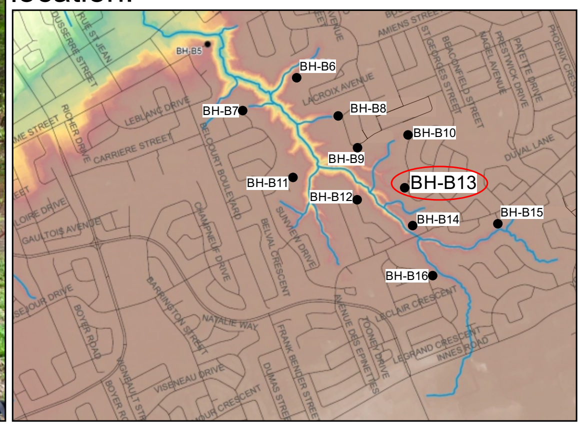


BH-B13 F_0 = 1.16 Hz Depth estimate: 49.9 - 55m

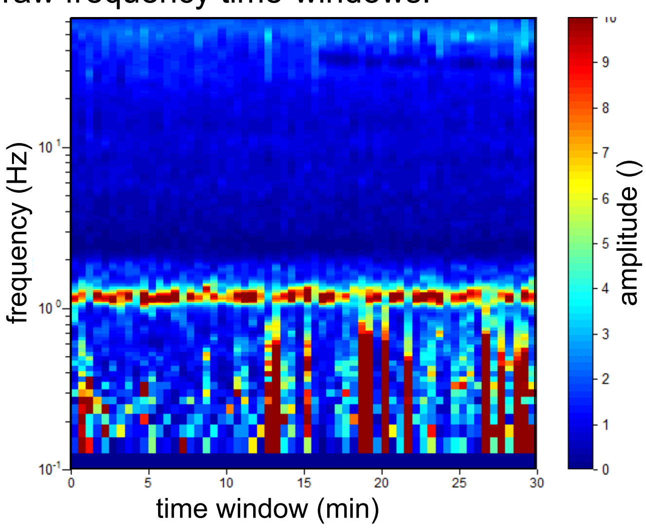
near SW corner Marcoux Dr / trail (460506, 5034703 UTM NAD83)

site photograph: (by B. Dietiker. NRCan photo 2020-106)

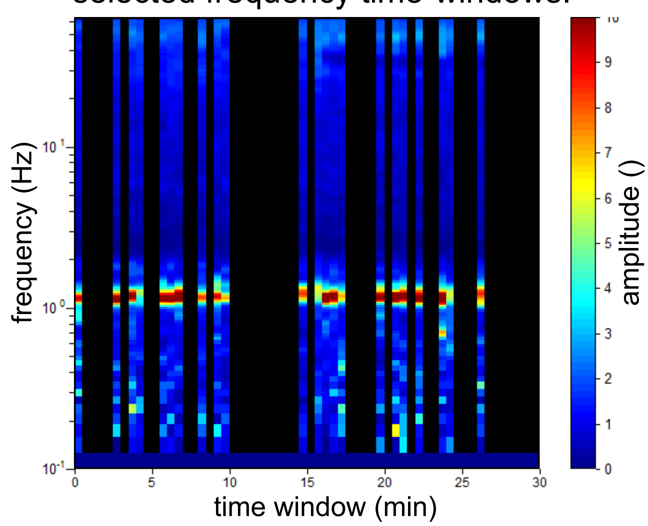
location:



raw frequency time-windows:

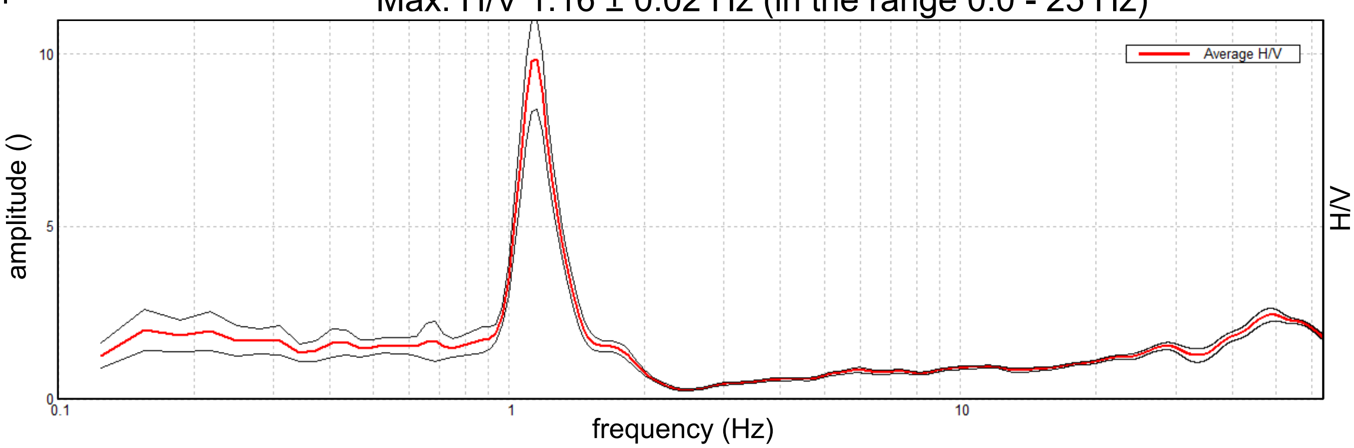


selected frequency time-windows:



processed HVSR:

Max. H/V 1.16 ± 0.02 Hz (in the range 0.0 - 25 Hz)

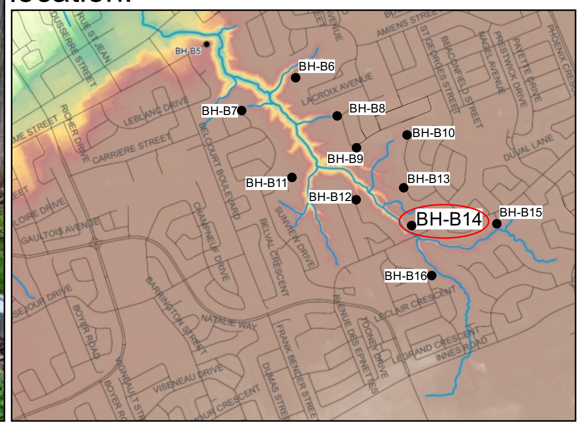


BH-B14 F_0 = 1.19 Hz Depth estimate: 48.4 - 53m

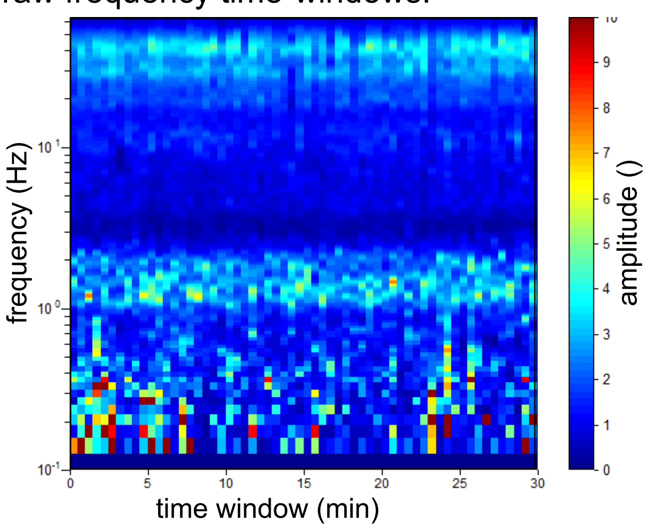
Des Epinettes Ave / Bilberry Creek Trail (460488, 5034507 UTM NAD83)

site photograph: (by B. Dietiker. NRCan photo 2020-107)

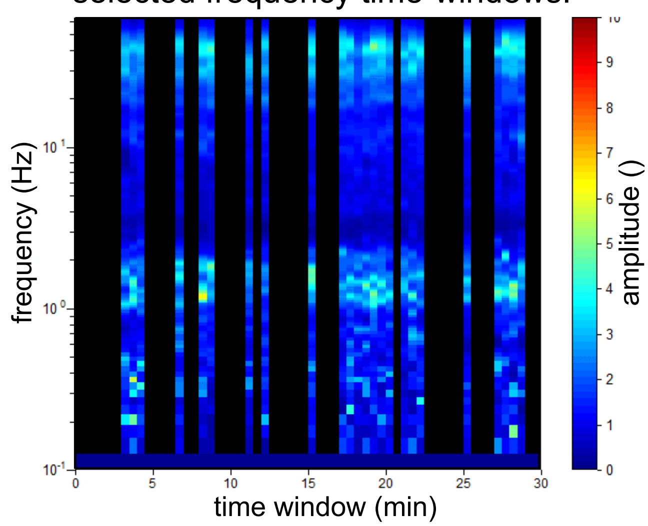
location:



raw frequency time-windows:

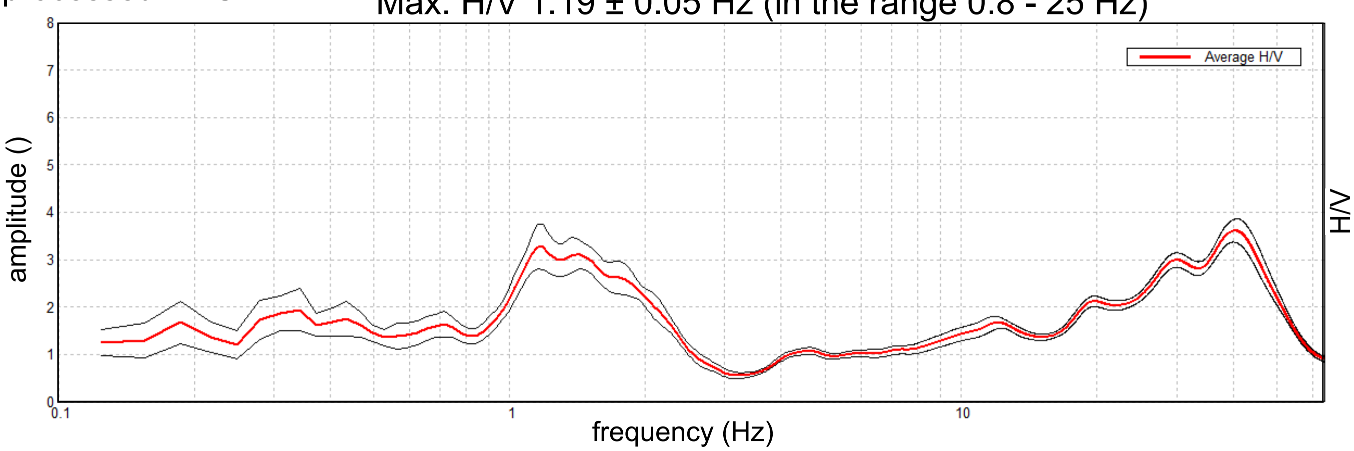


selected frequency time-windows:



processed HVSR:

Max. H/V 1.19 ± 0.05 Hz (in the range 0.8 - 25 Hz)

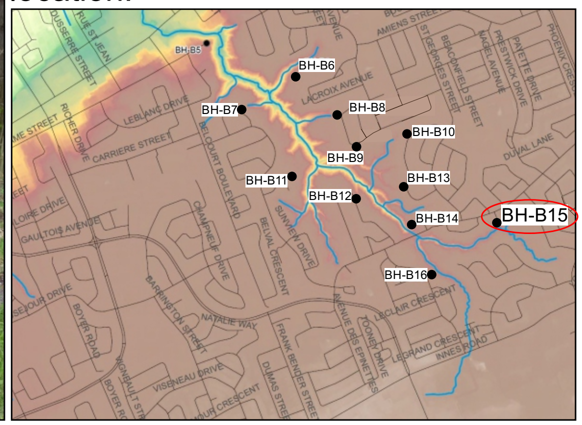


BH-B15 F_0 = 1.09 Hz Depth estimate: 53.6 - 59m

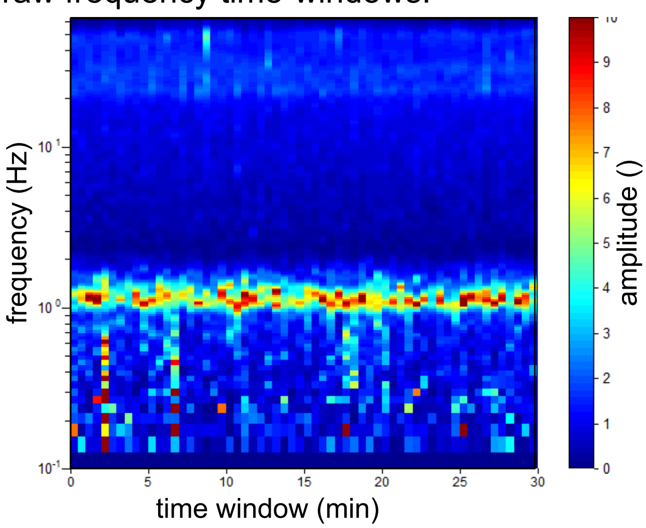
S of Des Pommes Pl (461004, 5034520 UTM NAD83)

site photograph: (by B. Dietiker. NRCan photo 2020-108)

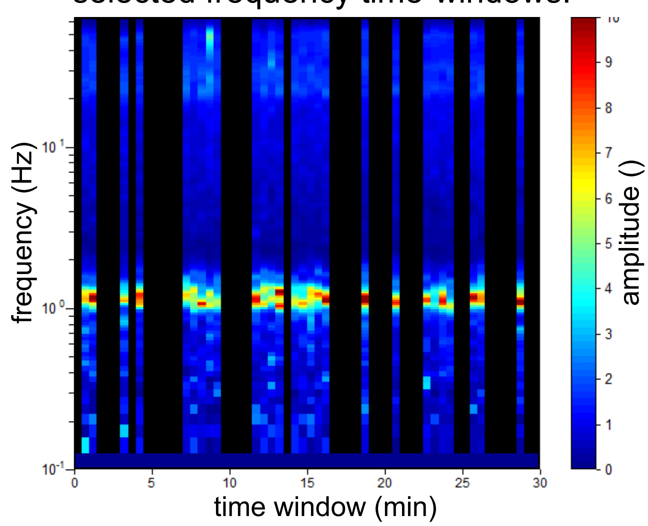
location:



raw frequency time-windows:

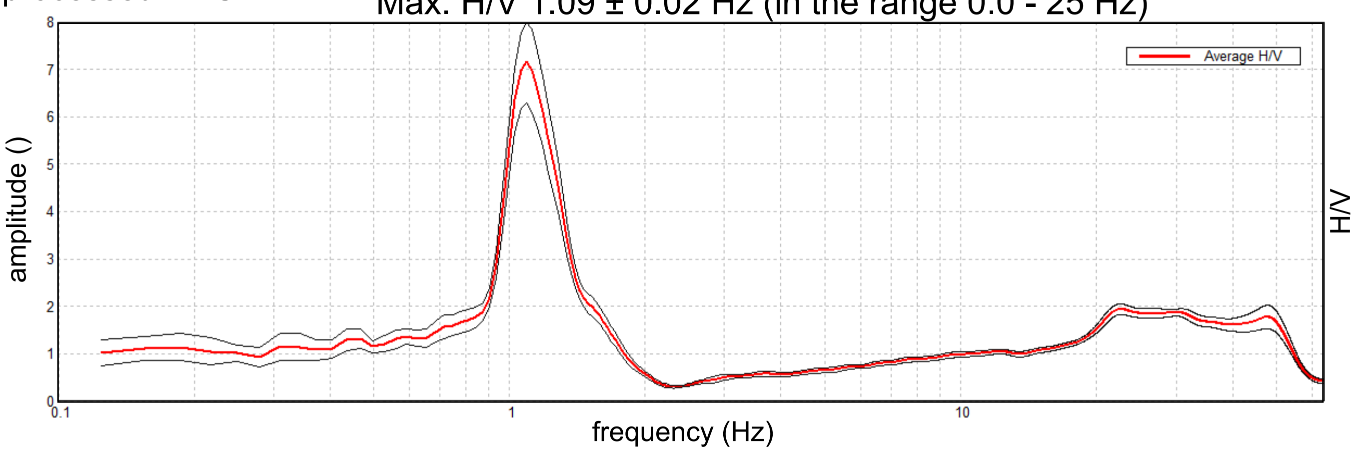


selected frequency time-windows:



processed HVSR:

Max. H/V 1.09 ± 0.02 Hz (in the range 0.0 - 25 Hz)

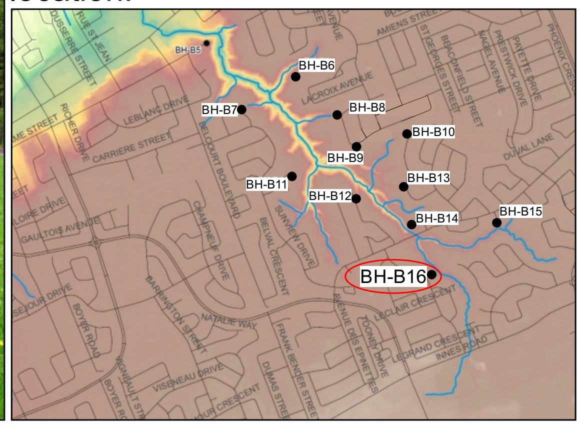


BH-B16 F_0 = 1.09 Hz Depth estimate: 53.6 - 59m

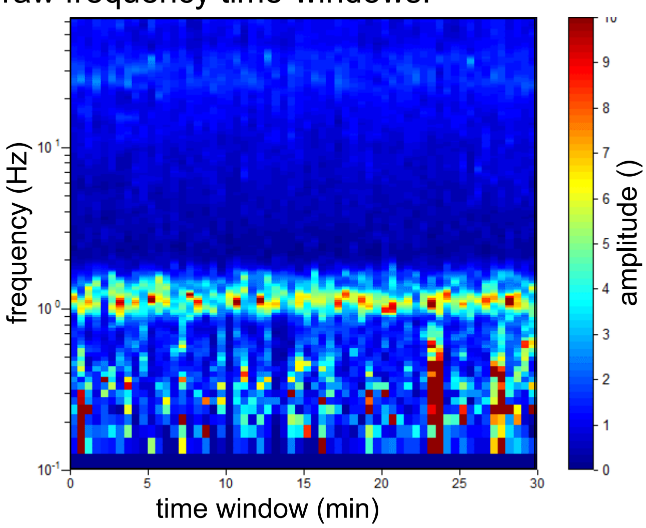
Wildflower / Bikepath (460654, 5034244 UTM NAD83)

site photograph: (by B. Dietiker. NRCan photo 2020-109)

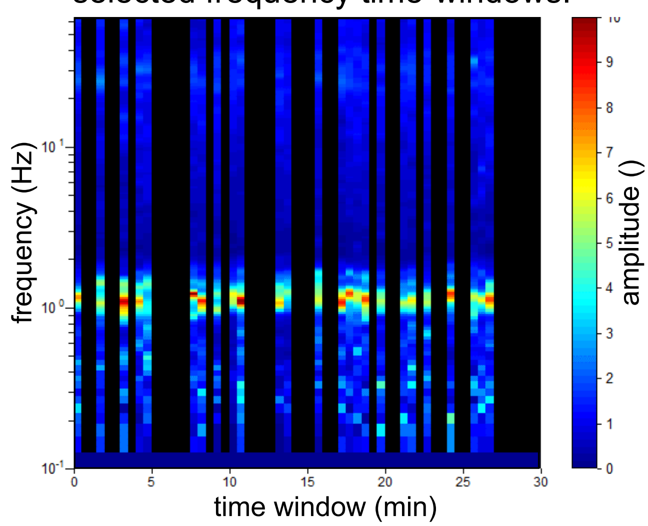
location:



raw frequency time-windows:

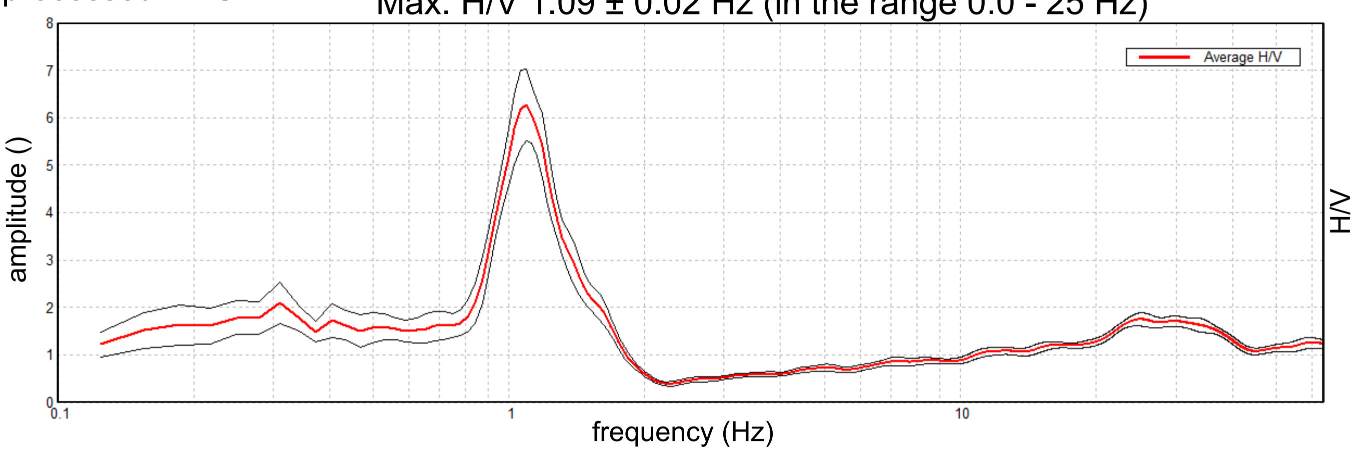


selected frequency time-windows:



processed HVSR:

Max. H/V 1.09 ± 0.02 Hz (in the range 0.0 - 25 Hz)

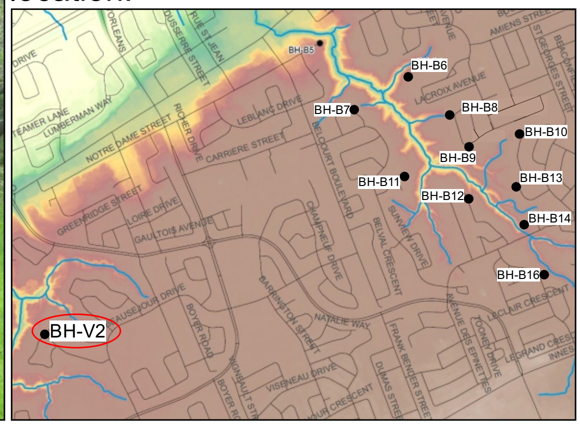


BH-V2 F_0 = 0.84 Hz Depth estimate: 72.4 - 80m

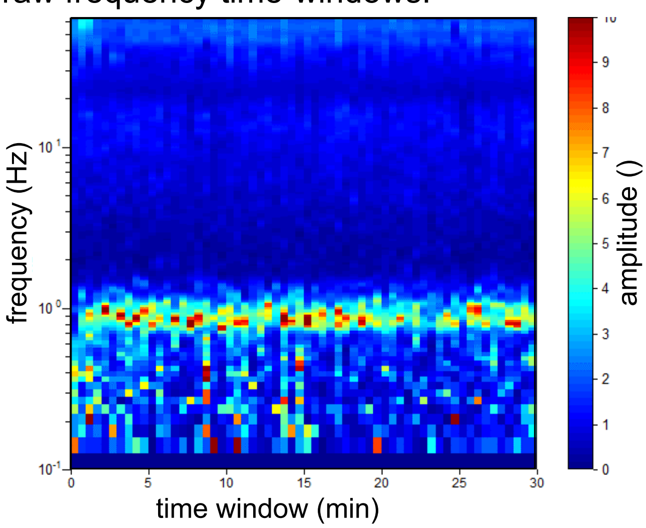
NE Des Sapins Gardens (457958, 5033935 UTM NAD83)

site photograph: (by B. Dietiker. NRCan photo 2020-110)

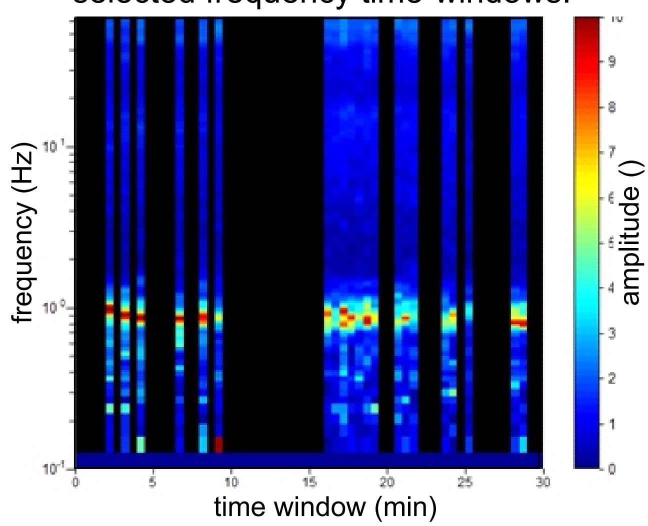
location:



raw frequency time-windows:



selected frequency time-windows:



processed HVSR:

Max. H/V 0.84 ± 0.03 Hz (in the range 0 - 25 Hz)