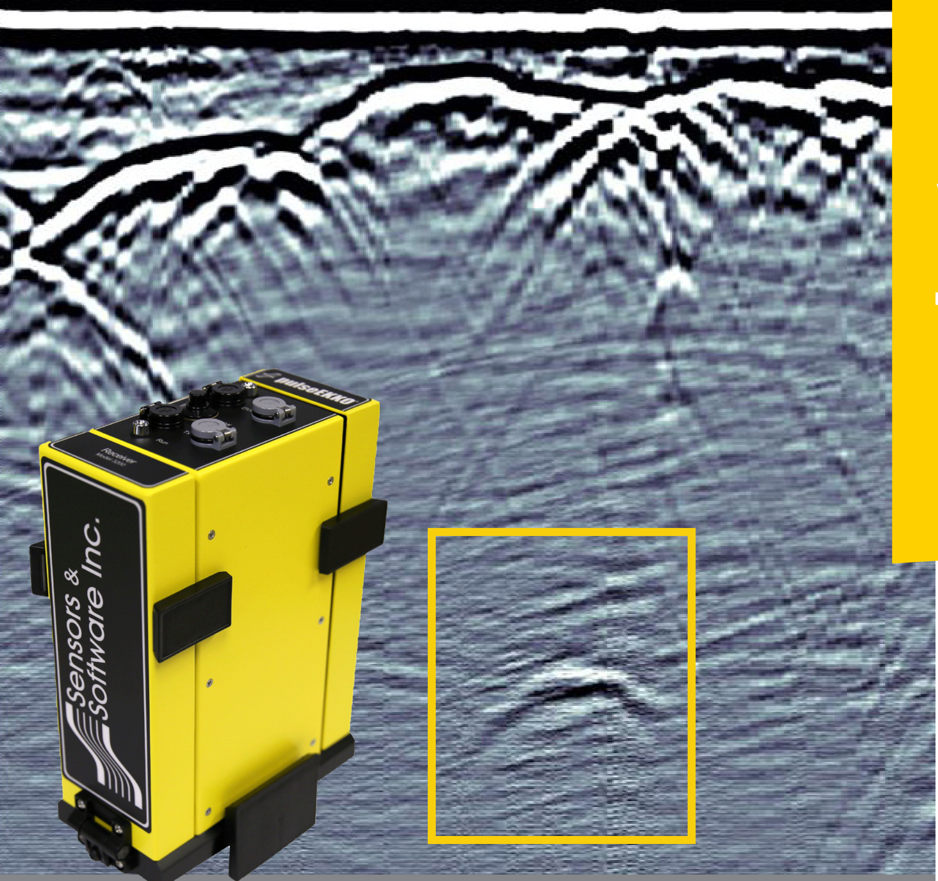

SUBSURFACE VIEWS

CELEBRATING OUR NEWSLETTER ANNIVERSARY

25th Anniversary

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In this issue

Ultra Receiver – Revolutionizing Low Frequency GPR Data

Within a few months of its release, the pulseEKKO® Ultra Receiver is already changing the way low frequency GPR data is collected and interpreted. Its ability to collect data 1000 times faster than before allows GPR signals to be stacked tens of thousands of times with no reduction in data acquisition speed. This technology makes it possible to see subtler and deeper GPR features than ever before.

"Stacking" is the term applied when GPR traces are collected multiple times at one location and averaged. Stacking GPR traces many times reduces the random noise floor to 1/√stacks (Table 1); for example, 65,536 stacks, the highest number of stacks available on the Ultra Receiver, reduces the noise floor to less than 0.5% compared to 1 stack. This means that weak GPR signals, up to about 200 times smaller, are now detectable in GPR data.

The following highlights a few examples of data collected with the pulseEKKO® Ultra Receiver to showcase its abilities, including how it increases the depth of penetration by stacking tens of thousands of times.

Stacks	Noise	Noise %
1	1/1	100
4	1/2	50
16	1/4	25
256	1/16	6
1024	1/32	3
4096	1/64	1.6
16,384	1/128	0.8
65,536	1/256	0.4

One order of magnitude (10x smaller)

Two orders of magnitude (100x smaller)

Table 1: The relationship between random background noise levels and the number of stacks

Data Example 1 – Petawawa, Ontario, Canada

The first data example was collected with a pair of 100 MHz pulseEKKO® antennas in a SmartCart® configuration. The area has a high sand content that allows good GPR penetration down to 12+ meters with 64 stacks (Figure 1, left). The random noise is visible starting at 10 or 11 meters depth. By 14 meters depth, the noise dominates the GPR line, making it difficult to see real, coherent GPR reflectors.

The same line was then collected with 8192 stacks, using the Ultra Receiver (Figure 1, right). It is important to note that the speed of collection of this line with the Ultra Receiver is the same as collection time for 64 stacks on the standard pulseEKKO receiver. This line looks clearer with no random noise and coherent GPR reflections down to 22+ meters.

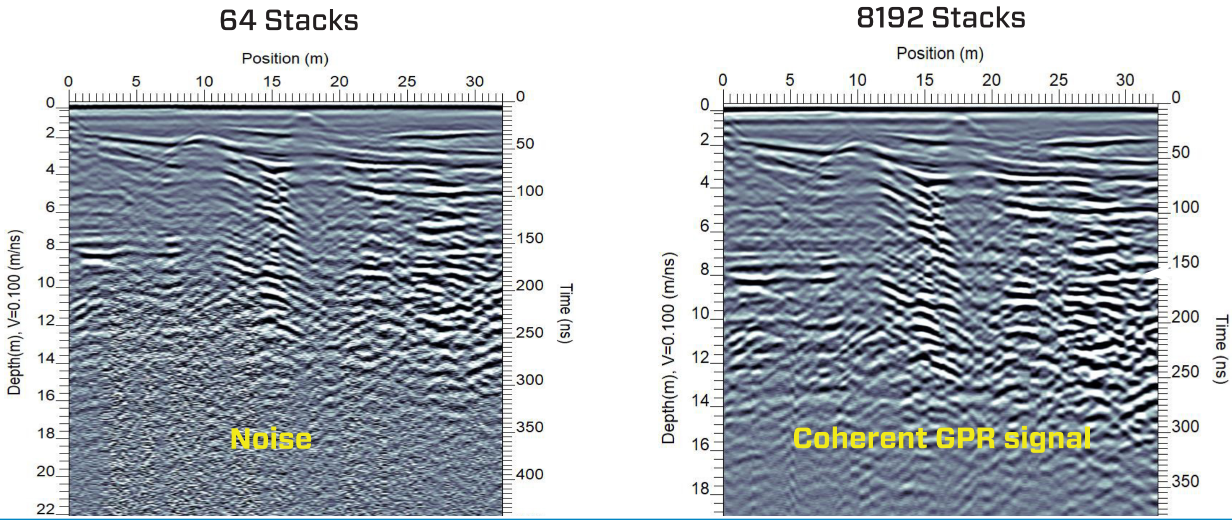

Figure 1: Data collected with 64 stacks (left) is dominated by random noise below 14 meters depth while the same line collected with 8192 stacks (right) shows coherent reflectors to more than 22 meters in depth.

Based on Table 1, the theory says that increasing the number of stacks from 64 to 8192 should drop the noise floor by:

(1/√64) / (1/√8192) = 0.125/0.011 = 11.3 times

While the GPR line collected with the higher number of stacks looks better, let's analyze these lines quantitatively to see how the GPR signals were improved by stacking. The best way to see the improvement in the signal is by using the Average Trace Amplitude or ATA plot, a type of plot that was discussed in the July 2018 newsletter. Briefly, an ATA plot shows the average signal level for an entire GPR line, from before the GPR transmitter fires to the end of the time window, after all the GPR signals attenuate back down to the noise floor. The noise floor is visible as the background signal level before the transmitter fires (vertical red and green lines in Figure 2).

The ATA plots provide information about the random noise floor and the depth of GPR penetration.

Figure 2 shows the noise floor for 64 stacks (vertical red line) is about 0.04 millivolts while the noise floor for 8192 stacks (vertical green line) is 0.004 mV; this is 10 times smaller – very close to the theoretical value calculated above of 11.3.

The ATA plots in Figure 2 also show the point where the GPR signals attenuate down to the noise floor – this intersection point is the average time (and consequently depth) of GPR signal penetration for the GPR line. In this case, the 64-stack data provides about 280 ns of penetration (about 14 meters depth based on a material velocity of 0.10 m/ns), while the 8192-stack data has GPR signals down to 420 ns (about 21 meters depth). Therefore, the penetration increased about 50% by increasing the number of stacks to 8192.

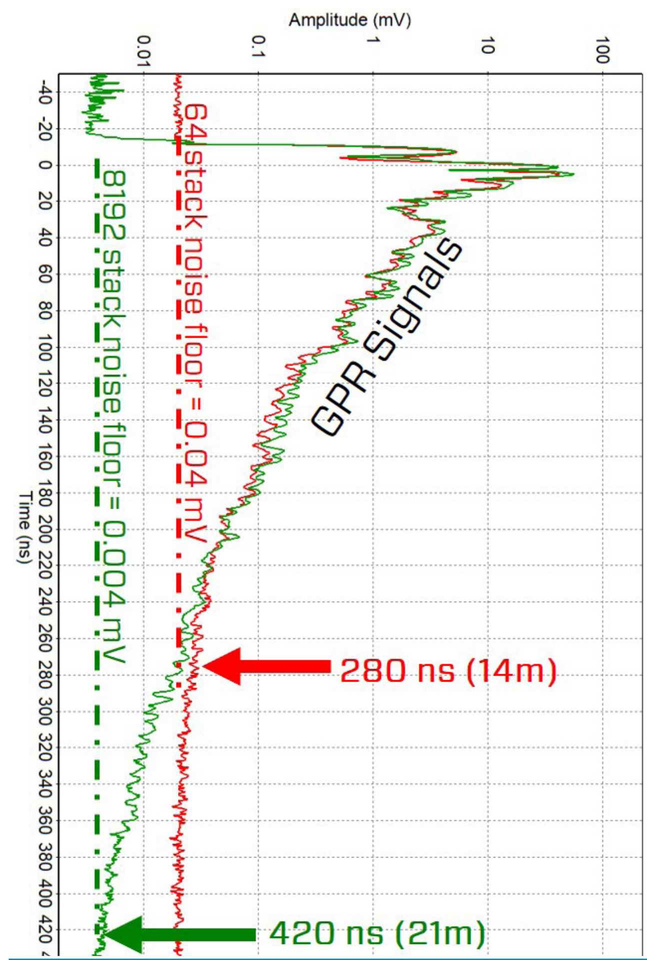

Figure 2: Increasing the number of stacks from 64 to 8192 decreases the random noise floor from the red line to the green line. The lower noise floor allows weaker GPR reflections to be detected. In this example, the depth of penetration has increased from 280 to 420 ns, about 14 to 21 meters, a 50% increase.

Data Example 2 – Tampa Bay Florida, USA

Using 100 MHz pulseEKKO® antennas, a GPR line was collected in the SmartCart® configuration, as shown in Figure 3. The data was first stacked 64 times (Figure 4, left); the random noise is visible starting at a depth of 5 meters. By 7 meters depth, the noise dominates the GPR line, making it difficult to see real, coherent GPR reflectors – this is the average depth of penetration for this GPR line.

The same line collected with 8192 stacks, using the Ultra Receiver, is shown in Figure 4, right. The highly stacked line shows a hyperbolic, coherent reflector at a depth of 9.5 meters.

Figure 3: pulseEKKO® PRO 100 SmartCart® setup in Tampa Bay.

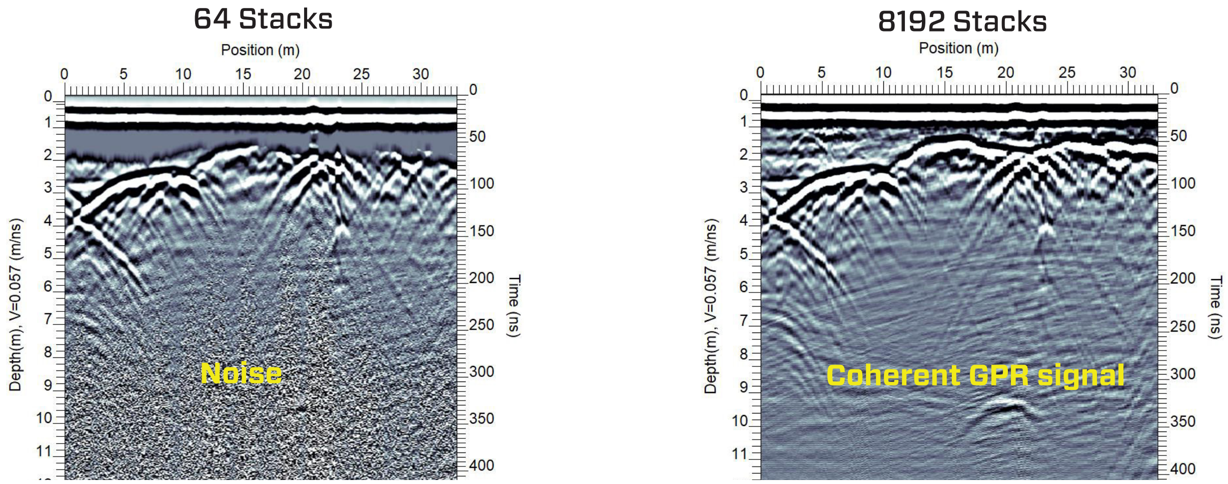

Figure 4: Data collected with 64 stacks (left) is dominated by noise below 7 meters depth while the same line collected with 8192 stacks (right) reveals a weak reflector at 9.5 meters in depth.

The increased penetration from the increased stacking revealed a deeper reflector that had never been seen in that area before. The geology in that part of Florida is well known and the researchers are interpreting that the Ultra Receiver was able to image a pinnacle in the highly dissolved limestone bedrock, underlying silty-clayey sands (Figure 5).

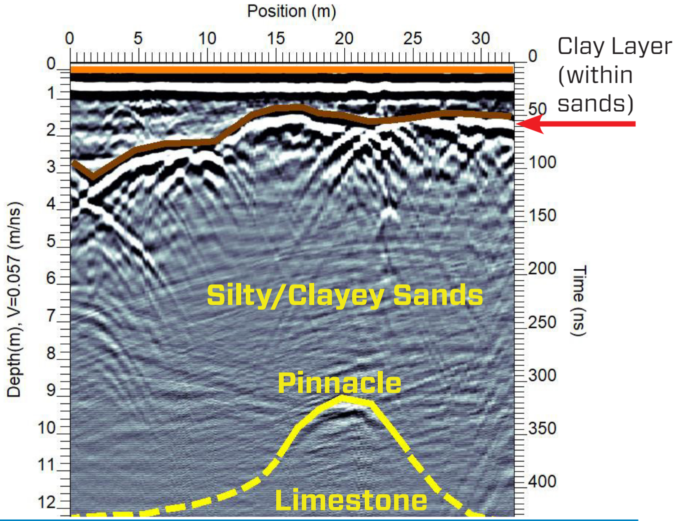

Figure 5: Interpretation of the GPR line shown in Figure 4 based on knowledge of the geology of the area. The limestone bedrock had never been imaged with GPR at this site before.

Again, there was no significant reduction in data collection speed using the Ultra Receiver at 8192 stacks versus the pulseEKKO® standard receiver at 64 stacks. Previously, high stacking compromised productivity; now, with the Ultra Receiver, the best of both worlds can be achieved.

Data Example 3 – Bandung, Java, Indonesia

The last data example was collected on the flanks of Tangkuban Perahu, an active volcano with 50 MHz pulseEKKO® antennas. A 130-meter-long line was collected with 32,768 stacks and it revealed three distinct, large diameter objects, indicated by blue dots in Figure 6.

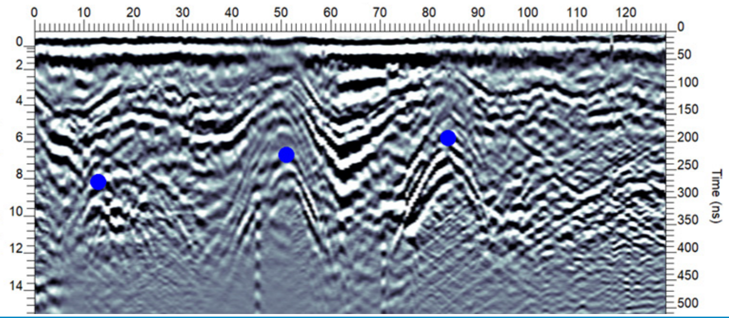

Figure 6 : GPR line collected with 32,768 stacks clearly images 3 large features (blue dots), interpreted as lava tubes or large, buried volcanic bombs; rocks ejected from the volcano during an eruption.

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Greatly reducing the random noise makes the GPR reflections image sharper; this means little time is spent processing the GPR data into an interpretable section. In this example, the data was so clear, the volcanologists started their data interpretation out in the field, arguing about the nature of the imaged objects, whether they were a result of lava tubes or buried volcanic bombs.

We are seeing the start of the Ultra Receiver revolution in low frequency GPR data collection. The Ultra Receiver is an advancement that fundamentally changes what geoscientists can achieve with ground penetrating radar. To learn how you can incorporate the Ultra Receiver into your GPR projects, contact us.

GPR Uncovers a Lost Chapter of History

Morrissey was a small mining town in the Elk Valley of southeastern British Columbia before the march of history breached its isolation. It became an internment camp during World War I (WWI) when xenophobic patriotism stirred into existence and culminated with the arrest and detention of Austro-Hungarian, mostly Ukrainian, and German foreigners living in Canada. The internment camp was in operation between 1915-1918 and was one of 24 internment camps that housed 8,579 prisoners of war (PoW) on Canadian soil.

Rumours of Morrissey's infamous escape tunnel have intrigued Sarah Beaulieu, a PhD Candidate at Simon Fraser University, since she first stepped foot in Morrissey and she was determined to locate the tunnel as part of her doctoral research.

Archaeological excavations at the Morrissey WWI Internment camp are the first extensive excavations to take place at any WWI internment site in Canada. An early newspaper report described a tunnel dug by the PoWs in an attempt to escape their barbed wire confines. The article re-counted the prisoners' tunneling out the front of the PoW building, running parallel with the roadway and toward the guard's quarters. It was assumed that the tunnel would eventually divert toward the left of a wood thicket where a reasonably secluded escape could be made. However, the plan had been thwarted the night before the escape was to take place and riots broke out upon its discovery. Had the prisoners been successful, it is likely that the entire camp would have been free to escape across the border into the state of Montana.

There is very little physical and archival evidence pertaining to the Canadian WWI internment operations. The internment buildings were dismantled upon the camp's closure and the majority of the documentary records were destroyed in 1954. Ground Penetrating Radar (GPR) was an ideal solution for locating the tunnel since it is fast, non-invasive and limits the amount of destructive shovel tests that would otherwise be required. An LMX200™ GPR, purchased with a research grant from the Canadian First World War Internment Recognition Fund, was used to survey the internment site and successfully locate the escape tunnel (Figure 1).

Figure 1: Sarah Beaulieu surveying with the LMX200™ GPR

The real-time GPR cross-section images, shown in Figure 2 (top), clearly indicated a linear anomaly at a depth of 0.5m. A 10 x 10 m grid with 0.25m line spacing was set up over this area to further map the suspected tunnel. During grid collection, by looking at the real-time results on the LMX200™ it was decided to only collect a partial grid (3 x 6 m) as most of the targets were observed in this area. The collected grid made it much easier to identify a linear target, in this case the possible tunnel, that spanned the full length (6m) of the survey area (Figure 2, bottom). After the survey data was interpreted and the potential location of the tunnel identified, three cross-sections were excavated to ground-truth the GPR results (Figure 3).

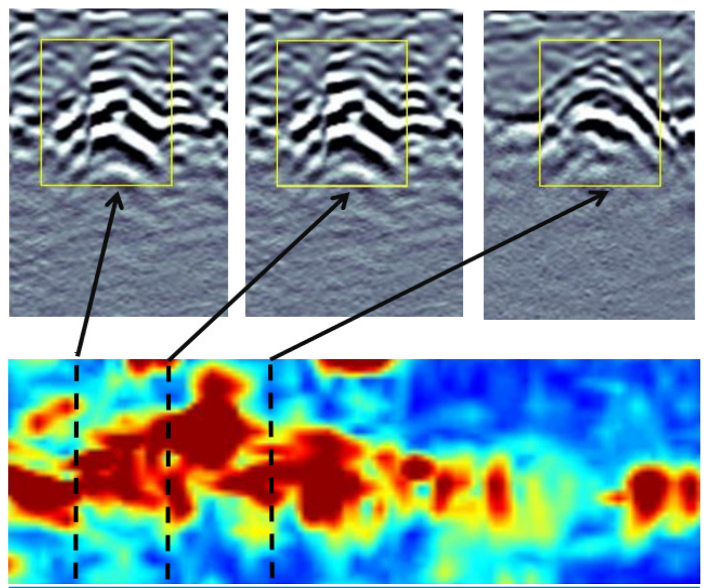

Figure 2: (Top) LMX200™ data showing the 3 LineView cross-section images of the possible escape tunnel highlighted by hyperbolic responses that were collected as part of a 3 x 6 m grid. A corresponding depth slice image (bottom) was then generated and the depth of interest was between 0.9 and 1.0 m as it outlined the presence of a linear feature indicative of a potential tunnel.

continued on page 5

Figure 3: Excavation was done at the locations indicated in the GPR cross-sections confirming the presence of the tunnel and other artefacts.

The tunnel has since collapsed; however, a fine layer of shoring remains visible. Numerous artifacts were excavated including alcohol bottles, food storage jars, paint cans, inkwells, tobacco and luxury food tins including sugar, syrup, cocoa and chocolate (Figure 4).

Figure 4: Escape tunnel artifacts uncovered using the LMX200™ GPR

The GPR survey determined that the newspaper report had deliberately misled the readership. It portrayed the prisoners' lack of intelligence, since they were intentionally tunneling toward their captors instead of away from them. The true tunnel was dug under the washhouse adjacent to the PoW building, toward the back of the prisoner yard where wilderness and freedom lay beyond. A barbed wire cross and a hand-made shovel, used by prisoners to dig the tunnel, are now on exhibit in the Canadian Museum of History.

The use of GPR to non-destructively image the subsurface in real-time provided valuable insights and guided the subsequent excavation, allowing the archeologists to discover a historical inaccuracy and shed light onto this dark part of our Canadian history.

Story courtesy of Sarah Beaulieu, Simon Fraser University

GPR Sounding in Water

Sensors & Software Inc. EKKO UPDATE

To celebrate 25 years of technical advances and helpful hints via our quarterly newsletter, we want to showcase how past articles are still relevant. This article was published in our EKKO UPDATE newsletter in October of 1994 and is still applicable today!

Ground penetrating radar is often used to map water depth and sub-bottom stratigraphy. Such applications defy the myth that GPR does not work in water.

Fresh water is an ideal environment for ground penetrating radar. The propagation velocity is very slow so that high resolutions can be achieved. Typically the propagation velocity is about 1/9 the speed of light. For example the wavelength in air at 100 MHz is 3m whereas in water it is about 33 cm.

Refractive focusing at the air-water interface generates a very narrow beam of energy into the subsurface. Figure 1 illustrates the ± 7° beam width in water.

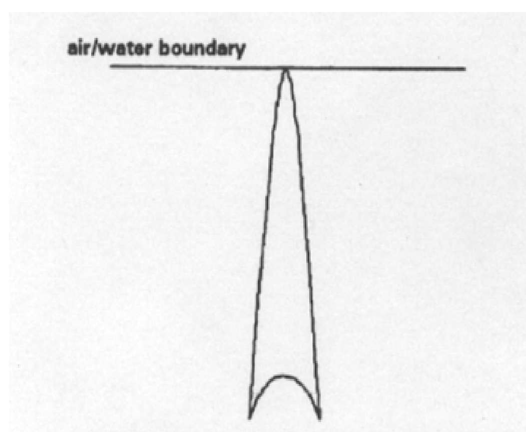

Figure 1: GPR beam pattern in water

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Sounding in water is limited by the electrical conductivity of the water. Water conductivity is controlled by the salinity or totally dissolved solids in the water.

A rough guide to GPR penetration depth in water is:

$D = 40/\alpha$ meters

Where the attenuation coefficient, α, is related to electrical conductivity, σ (in mS/m), by:

$\alpha = 0.18\ \sigma$ dB/m

The drop off in signal amplitude versus depth associated with water conductivity is illustrated in Figure 2. Fresh water shows low attenuation of signal whereas sea water eliminates the signal in a very short distance.

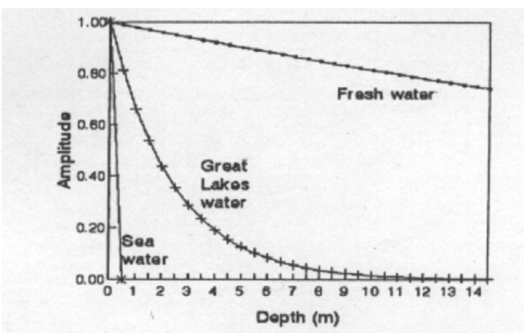

Figure 2: GPR signal attenuation vs depth in water.

Quite often one does not have water conductivity but other measures such as salinity or total dissolved solids. A rough guide to estimating conductivity of the water is to use the following relationships:

$\sigma = 0.12 \times S$ mS/m

$\sigma = 0.12 \times TDS$ mS/m

Where S is a salinity in parts per million and TDS is the total dissolved solids in the milligrams per liter. Combining the results together one gets that:

$D = 220/\sigma = 1850/S = 1850/TDS$ m

An example of GPR profiling on a lake in Arizona is shown in Figure 3. The water conductivity was 6mS/m.

The survey was carried out by simply hanging the transmitting and receiving antennas over either side of a boat. This quick survey illustrates the utility of GPR in surveying water bottom.

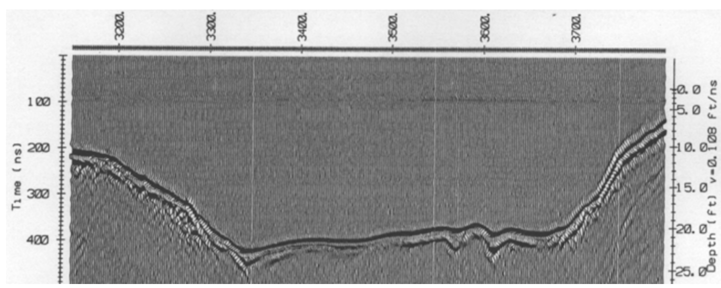

Figure 3: 50 MHz GPR profile on a lake in Arizona

Upcoming Courses

Subsurface Utility Locating with GPR course (Nulca-accredited) - November 5, 2018, Mississauga, ON, Canada

Concrete Scanning with GPR course - November 6, 2018 Mississauga, ON, Canada

Utility Locating with GPR (Nulca-accredited)- November 29, 2018, Los Angeles CA, USA

Subsurface Utility Locating with GPR course (Nulca-accredited) - January 7, 2019, Mississauga, ON, Canada

Concrete Scanning with GPR course - January 8, 2019, Mississauga, ON, Canada

Upcoming Tradeshows

Geological Society of America Convention (GSA) November 4-7, 2018, Indianapolis, IN, USA

IRF Global Road2Tunnel Conference & Expo November 4-9, 2018, Las Vegas, NV, USA

American Geophysical Union (AGU) December 10-14, 2018, Washington, DC, USA

Transportation Research Board (TRB) January 13-17, 2019, Washington, DC, USA

World of Concrete (WOC) January 22-25, 2019, Las Vegas, NV, USA

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