SENSORS & SOFTWARE
from RADIODETECTION

SPX

Field Guide for Archaeologists Using GPR

Table of Contents

1. Introduction

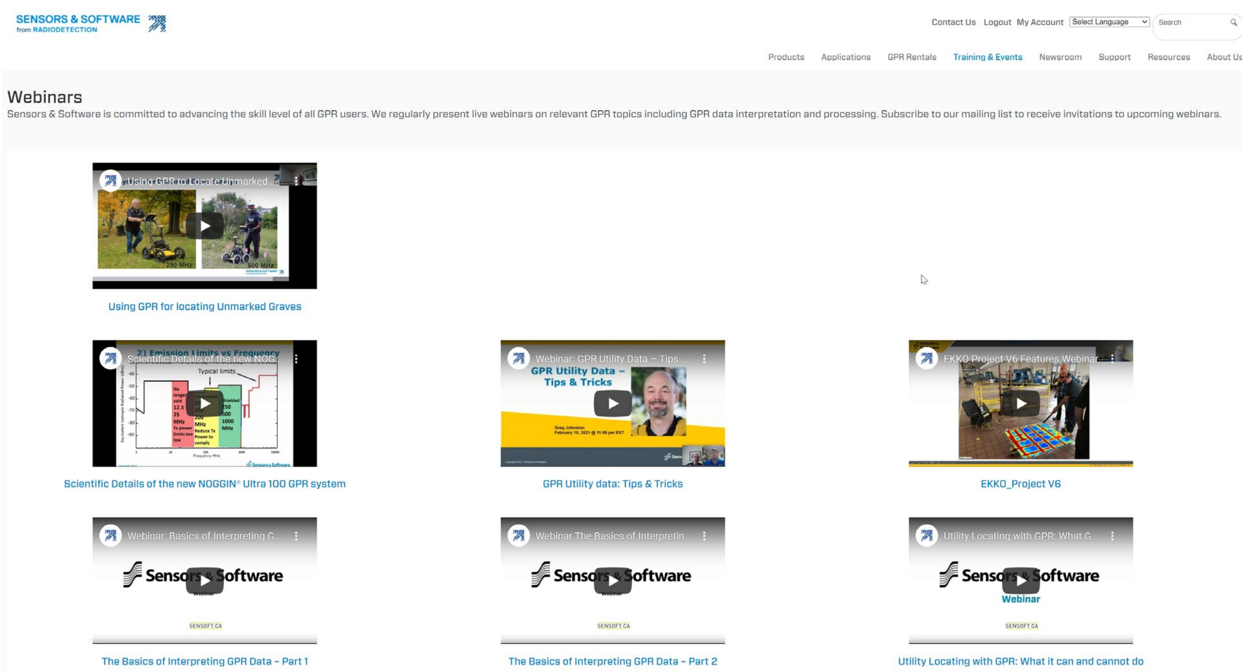
GPR is an amazing tool for exploring the subsurface. However, it's important to understand the limitations of GPR so as to maximize your survey results.

This guide is written to assist archaeologists using GPR, or to serve as a short refresher if you haven't used the equipment in a while. It assumes you've used the GPR before and are familiar with its basic functionality.

If you are new to GPR, read the GPR system user's guide; it contains valuable information about settings, system configuration, data acquisition, file management and exporting data.

There are also some useful resources on our website, www.sensoft.ca. These include:

- Product Training Videos
- Software Webinars
- Application Case studies



For additional information, please contact us:

Sensors & Software Inc.

1040 Stacey Court

Mississauga, Ontario

Canada L4W 2X8

Tel:(905) 624-8909

E-mail: sensoft_training@spx.com

2. Considerations for using GPR

GPR detects changes in material composition, based on their dielectric properties. GPR will not give a “photograph” of the subsurface, but it can create an image that can show the structure of the subsurface, including soil layers, rocks, tree roots and man-made objects such as utilities, buried artifacts and foundation walls.

By observing the soil layering, it is possible to detect where the soil structure has been “disturbed”, possibly by someone digging a hole and filling it back in, often of interest to archaeologists.

Collecting and observing enough GPR data from the survey area allows you detect “patterns” and consequently “anomalies”; locations where the subsurface structure or patterns “change” or something looks “different” compared to other areas. These are usually the areas of interest for archaeologists.

It is very important to understand that GPR does not determine the composition of the soil or objects it detects in the subsurface.

The following are factors to consider before conducting a GPR survey.

2.1. Factors Affecting GPR Success

2.1.1. Electrical Conductivity of the soil

Soils with higher electrical conductivity will limit GPR penetration. As an example, clay soil will limit penetration to 1.0 – 1.5 meters deep, whereas sandy soil may permit penetration 5m or deeper.

2.1.2. Target material

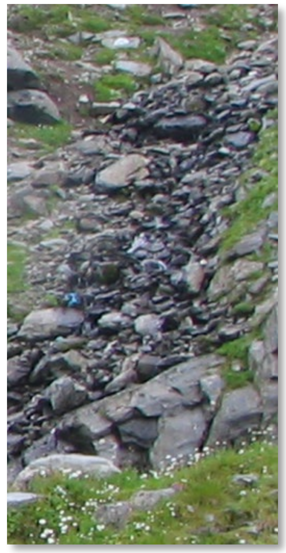
While metal objects are the easiest to detect, one of the strengths of GPR is its ability to detect non-metallic objects. The greater the dielectric contrast between the object and the surrounding material, the more GPR energy that reflects and therefore the easier the object is to detect. Objects that have similar dielectric properties to the soil are more difficult to detect.

2.1.3. Target Depth to Size Ratio

The bigger an object or disturbance, the easier it is detected by GPR. The deeper the object is in the ground, the larger it should be for the GPR to detect it. A good “Rule of Thumb” is that, providing it can penetrate to the object (see Conductivity of the Soil above), GPR can usually detect an object with a depth to size ratio of 24:1 to smaller.

2.2. Surface terrain

Smooth, relatively flat, areas are best suited to GPR surveys. This allows the GPR antenna to be in contact with the ground, maximizing penetration depth. As well, flat ground allows the wheels (and therefore, the odometer) to turn freely, which trigger the GPR to pulse and keep track of the distance travelled. Be wary of collecting data in situations similar to the ones shown below because data quality will be affected:



2.3. GPR Antenna Center Frequency

Higher frequency systems have better resolution, but less depth penetration. Lower frequency systems have diminished resolution, but better depth penetration.

The antenna frequency typically used for archaeology is 500 MHz because it provides high resolution and typically 1 to 2 meters of penetration, which is often the zone of interest.

For deeper surveys, in the 3-to-5-meter range, consider using a 250 MHz antenna or, in cases where maximum penetration is desired, perhaps up to 10 meters, try 100 MHz antennas.

No matter what antenna frequency you use, understand that the depth of penetration cannot be guaranteed for any particular site because it ultimately is based on the electrical conductivity of the soil. Even using 100 MHz antennas in a clay soil with high electrical conductivity will not increase the depth of penetration much beyond 1 meter.

3. Survey Methodology

There are three basic ways of collecting GPR data:

1) Line Scan,
2) Grid Scan,
3) Pseudo Grid Scan

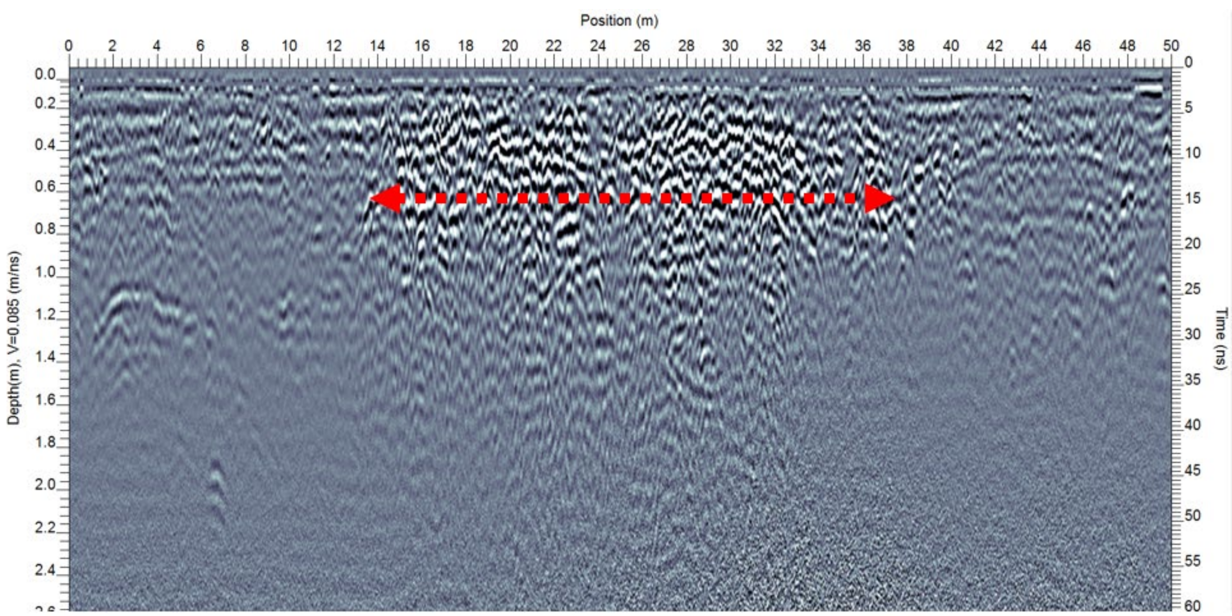
These are described in detail in the next few sections.

For archaeology, collecting a Grid Scan or Pseudo Grid Scan over the area of interest is always the preferred method because the data density grids provide means that the entire area has been scanned with no gaps.

Line Scan is considered a “reconnaissance” type of survey; typically, only used in archaeology surveys when it is not possible to collect grid data or when the survey area is so large that it is necessary to collect multiple smaller grids. In the latter situation, use Line Scan to collect long reconnaissance lines across the area and look for localized “anomalies” (see the examples below). Then collect smaller grids in these areas.

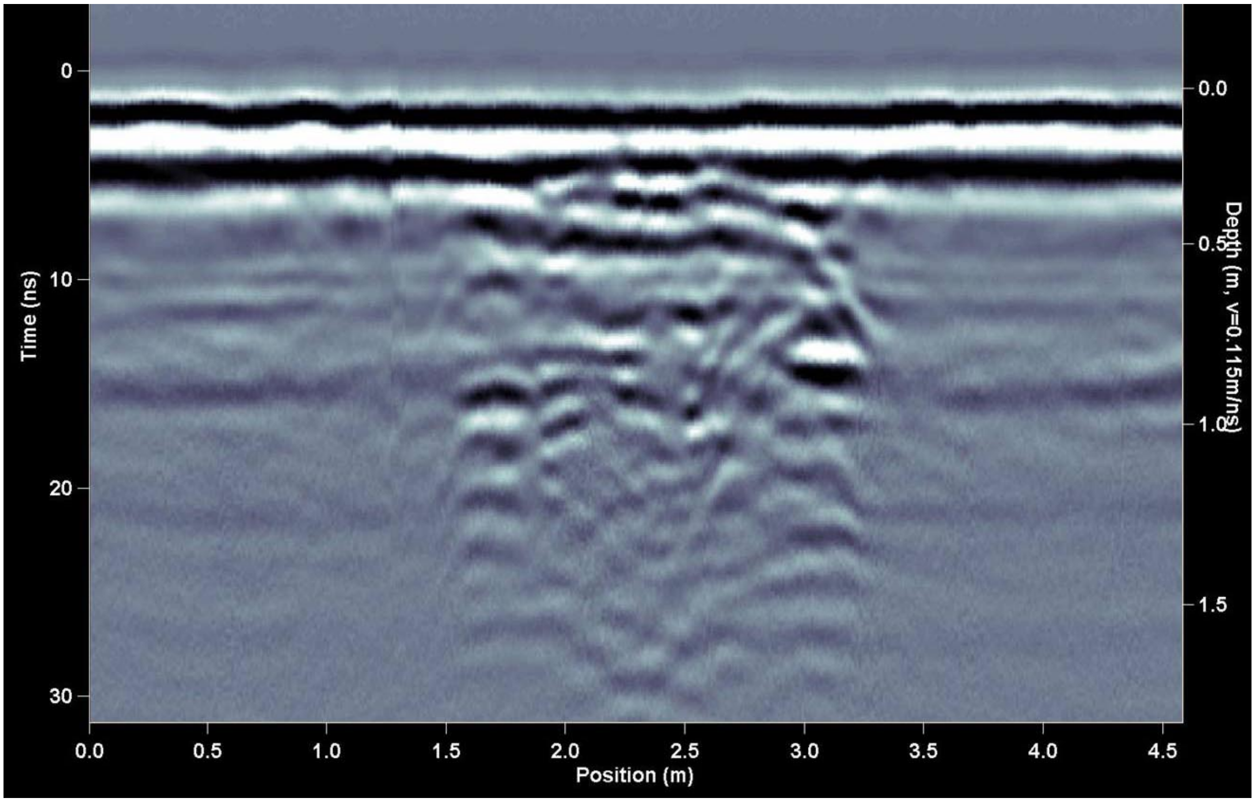
To define the area for grid collection, use the back-up indicator on the GPR system and put flags on the ground to note the center location or edges of anomalies. Grids should be large enough to extend beyond the edges of the anomalous area to put the anomalous area into context.

Example 1 below shows a Line Scan with an anomaly that lasts for about 22 meters in length. Notice how the GPR reflections in this area are different from the surrounding area. Fully understanding the nature of this anomalous area likely requires the collection of a grid over it.



Example 1: GPR Line Scan showing an anomalous area zone, where collecting a grid maybe be beneficial to understand the nature and areal extent of the reflections.

Example 2 below shows an anomaly interpreted as disturbed soil, based on how the soil structure is different from the surrounding area.



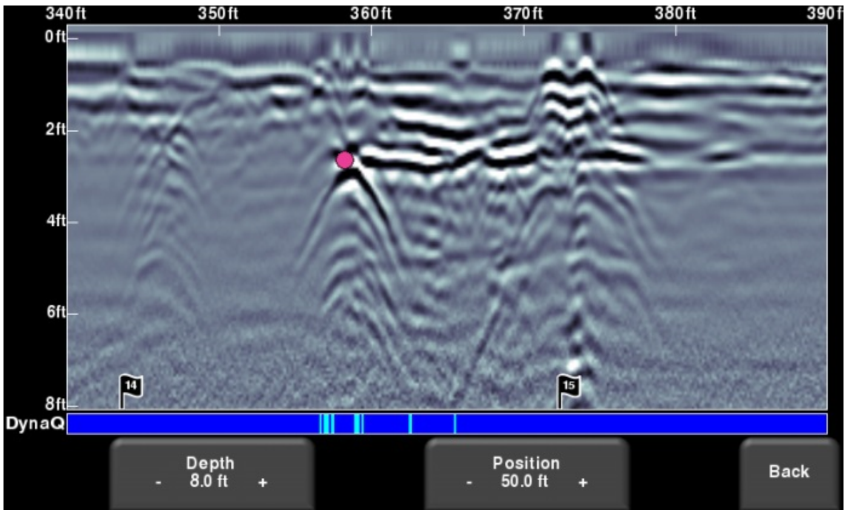
Example 2: GPR Line Scan showing disturbed soil, a location that might be of interest to archaeologists. Collecting a grid over this area will help define the areal extent of the disturbance.

4. Line Scan Settings

4.1. Depth

If you know approximately how deep your targets are, set the depth window to about 1.5 or 2 times your expected depth. For example, if you expect a burial to be about 0.9 meters deep, set your depth window to 2.0 meters.

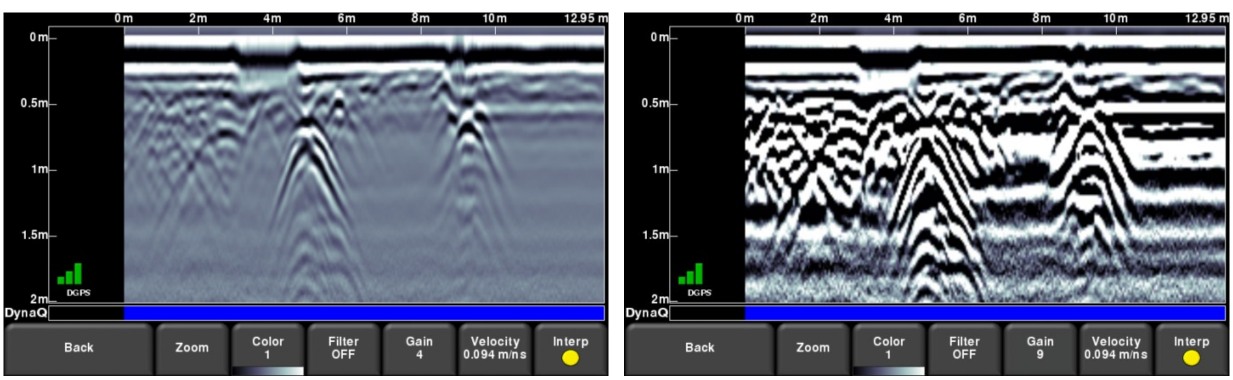
If you don't know the depth of the targets, set the depth between 2 and 3 meters (6 to 10 feet) and see if any anomalies are visible on the screen. You can then adjust the depth window such that the objects of interest should appear in the middle of the screen, not near the bottom.



4.2. Gain

The gain is used to amplify signals that get absorbed due to the ground conditions. The gain value goes from 1 to 9, with 9 being the maximum gain. The image on the left shows a good gain, whereas the one on right has too much gain applied. Too much gain makes interpretation difficult.

Note that the Gain setting used during data collection is strictly the preference of the operator; it does not affect the raw data saved for post-processing.

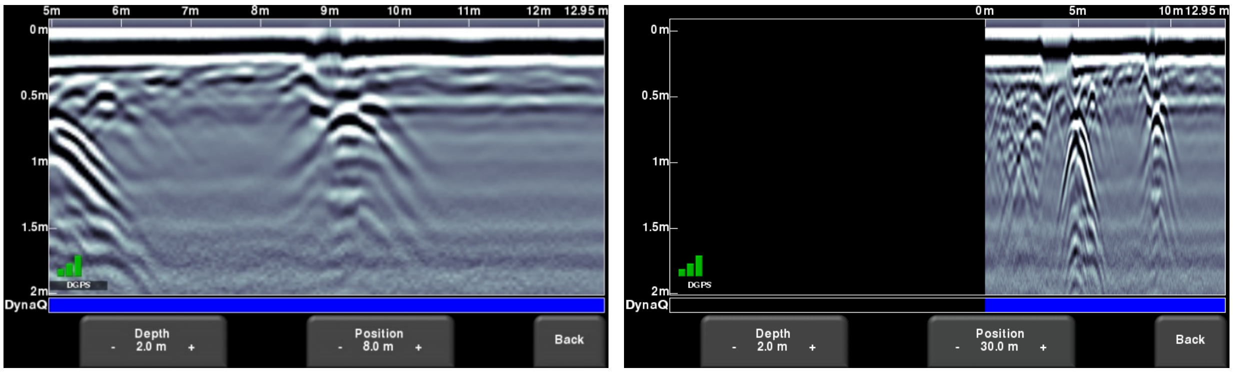


The Gain value is used to amplify the GPR signal for the real time display of the data.

4.3. Horizontal Scaling

To help with real-time interpretation in the field, you can control how much data is displayed on the screen at a time by changing the value under the **Zoom > Position** button.

The data on the left is zoomed in, showing only 8m of linear data per screen, while the one on the right is zoomed out, showing 30 meters of linear data per screen. When looking for smaller objects, it's better to keep the position setting to 10 meters or less, but if looking for larger scale features, it should be 15 meters or greater so you can compare the GPR responses with the surrounding area.

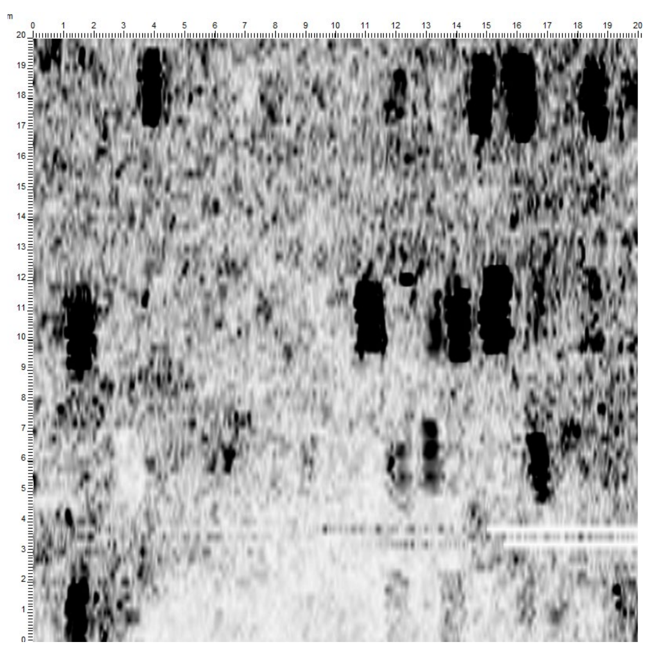


Horizontal Zoom changes how much horizontal data is displayed on the screen at once. Zoom in to show less data and Zoom Out to show more data. This changes the aspect ratio and sometimes help to see targets better.

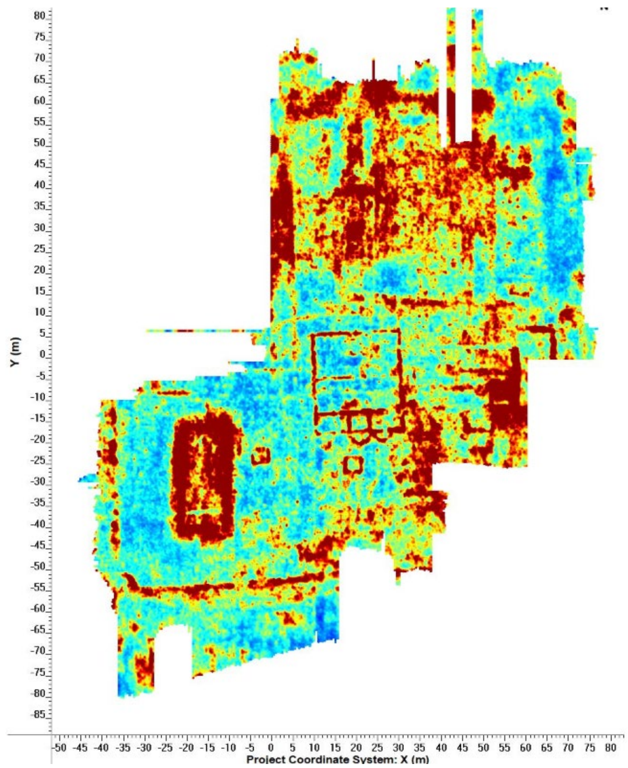
5. Grid Scan Settings

Grids are laid out as a series of parallel and perpendicular lines, referred to as X and Y lines. Data is collected along each line.

The data collected from a grid is used to generate depth slices and 3D images, which will help to visualize the buried features a lot better than cross-sectional Line Scans alone. Most archaeological data is presented as depth slices (see examples below).



Depth slice from a 20x20m grid showing burials in a cemetery.



Depth slice showing foundation walls of buried structures and other archaeological features.

There are three settings to consider prior to grid collection:

5.1. Grid Size

Define your grid size, remembering that it is best to collect at least 10% or 20% of your data beyond the "anomalous" area or area of interest for context.

Standard grid sizes are square, 5, 10 and 15-meter square grids are typical, but some GPR systems have a "Custom" setting that allows rectangular grids to be defined.

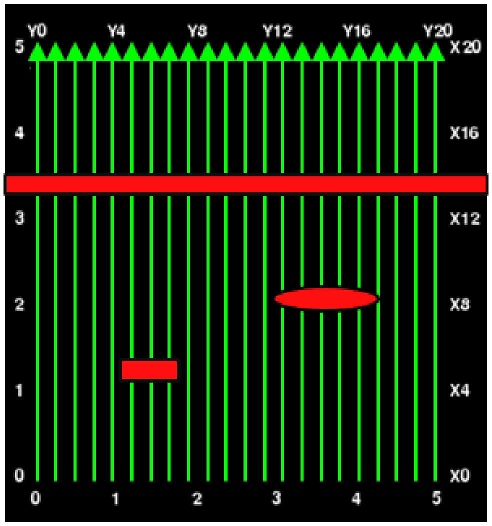
While the some of our GPR systems can work around obstructions, if there are too many obstructions, you may consider breaking the grid up into smaller ones.

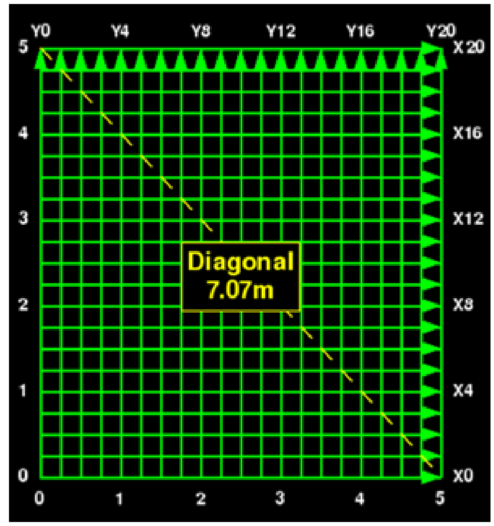
In addition, it's generally not recommended to collect a single grid larger than 50 x 50 meters. If a larger area is required, break it up into smaller grids and combine the data in the EKKO_Project software.

5.2. Collect Grid Lines in One Direction or Both?

If the orientation of the targets is known, it may be possible to save time and effort by only collecting grid lines in one direction, perpendicular to the long axis of the targets (left image below).

If the target orientation is not known, it is best to collect lines in both the X and Y directions (right image below) so the worst-case scenario is the GPR crossing the object at a 45 degree angle.

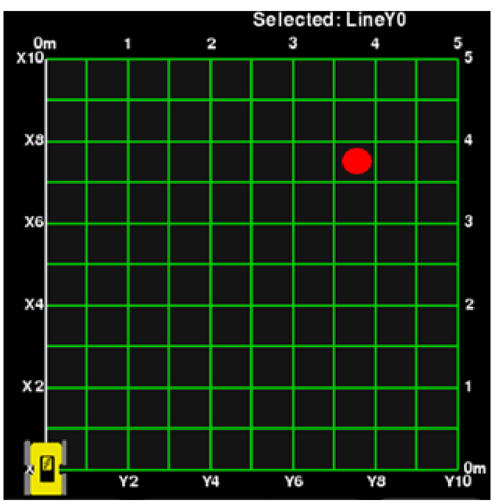


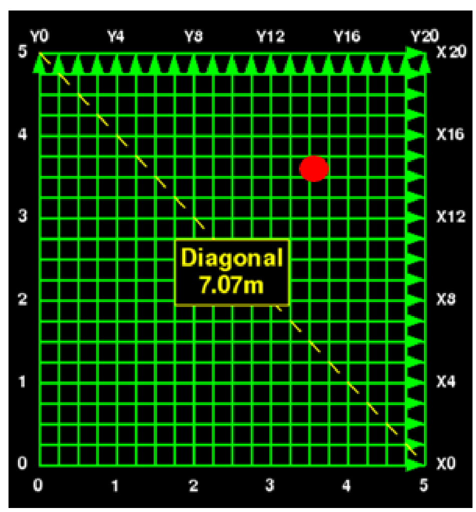


5.3. Grid Line Spacing

The grid line spacing determines how long the data collection will take. To decide on a line spacing, consider the smallest target size you are looking for. This dimension helps define the coarsest grid line spacing. For archaeology, smaller localized targets (pottery, tools, weapons) are harder to find with GPR than larger ones (building walls, wells, burials). Grid lines should be collected close enough together so as to cross the smallest target-sized object at least twice.

For example, if a buried well is 1.3-meter diameter, you need to have the lines 0.5 meters apart or tighter.



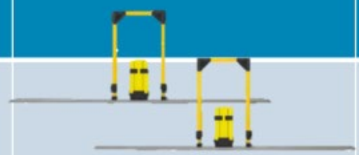
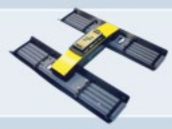


Antenna Frequency: 250 MHz
Line Spacing: 0.5 m
Antenna Length: 0.3 m
Data Gap: 0.2 m
Total Line Length: 110 m

- Antenna Frequency: 250 MHz
- Line Spacing: 0.25 m
- Antenna Length: 0.3 m
- Data Overlap: 0.05 m
- Total Line Length: 210 m

However, the more closely spaced grid lines are, the better you are spatially sampling the ground and the better the resulting depth slice images.

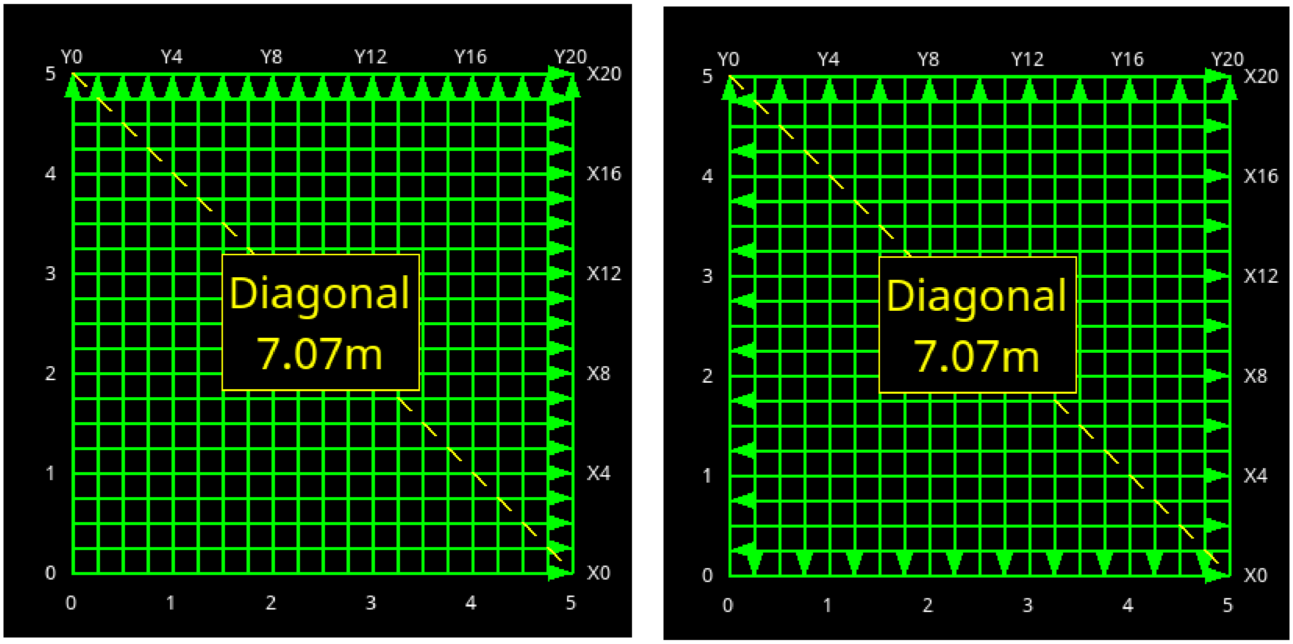
For the best depth slices and 3D images, the grid line spacing should the same or smaller than the length of the GPR antenna:

Antenna Frequency (MHz)	GPR System	Antenna Length (m)	Ideal Grid Line Spacing (m)
50		2	2
100		1	1
250		0.3	0.25
500		0.15	0.1
1000		0.075	0.05

People often say that a 0.1-meter line spacing for 500 MHz systems is very time consuming. If so, 0.15 or even 0.2 meters is often acceptable.

5.4. Line Collection Pattern

You usually collect grid lines in one direction (Forward only pattern), however, some GPR systems also provide the option to collect every other line in the reverse direction (Alternating pattern).



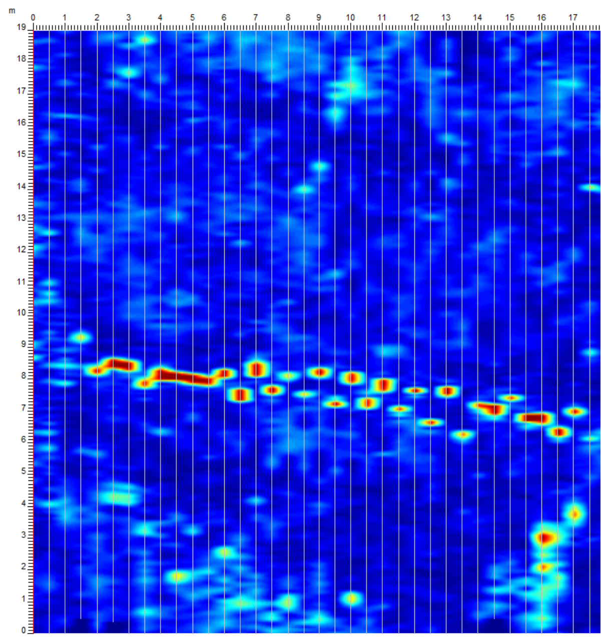
Line collection options: Forward-only lines (left) and Alternating lines (right). Notice the direction of the arrows.

Note: We recommend collecting a Forward only grid, unless the grid size is very large.

The reason is that with a Forward only grid, you only have two baselines (one for start of X lines and one for the start of Y lines), but with the alternating grid, there are four baselines in total (two for the start of X lines on each side of the grid and two for the start of Y lines on each side of the grid).

It is very important that baselines be laid our accurately, so setting up four accurate baselines takes more time and effort. If the baselines are not accurate, the resulting depth slices will be skewed and distorted, making interpretation of the data more difficult.

Further, even if your baselines are accurate, if you collect data in the Alternating pattern and the odometer wheel calibration is not accurate, the position of objects in the GPR data will change depending on the line direction. Again, resulting in distorted images that make data interpretation more difficult or impossible.



Example of the imaging distortions seen on a linear object caused by collecting data in an Alternating line pattern with an inaccurate odometer calibration.

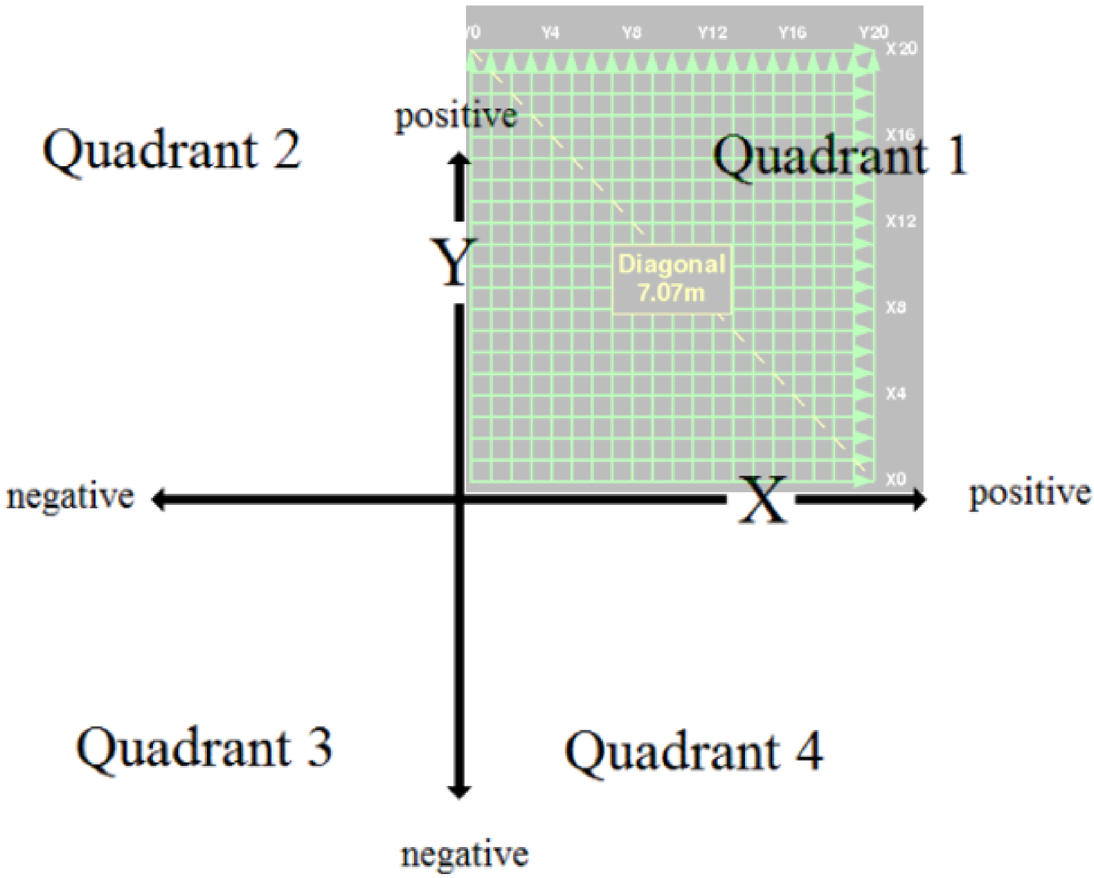
While these errors can be fixed in software in post-processing, it is often faster to spend the extra time in the field collecting lines in the same direction than editing the data later.

6. Setting Up a Grid in the Field

Once you have determined the grid parameters above, follow the steps below:

6.1. Orienting the Grid

For depth slices and 3D displays of grid data to plot in the correct orientation, either on the DVL screen or after post-processing, the grid must be collected in the first quadrant, as shown below.

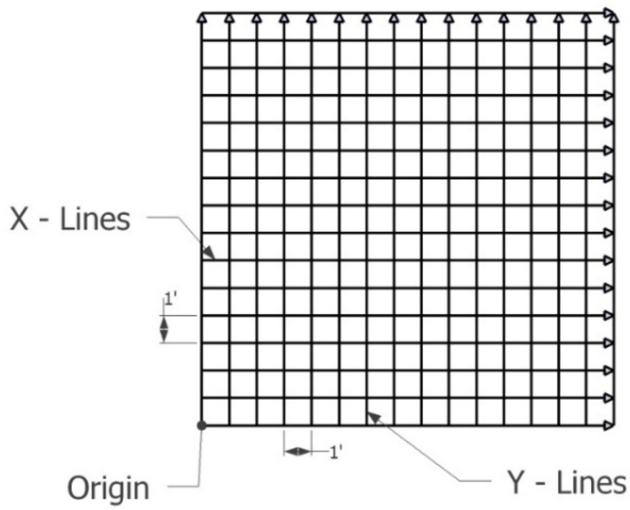


Pick the origin (X=0, Y=0) corner in the bottom left corner of the grid such that it is the furthest corner away from any obstacles. This way, all the lines start on the baselines, but they can be ended early if there is an obstruction.

This means that if you are standing at the X=0, Y=0 corner of the grid:

a) Y lines are parallel to the Y axis, are collected in front of you and increase in line number to the right.

b) X lines are parallel to the X axis, are collected to your right and increase in line number to the right.

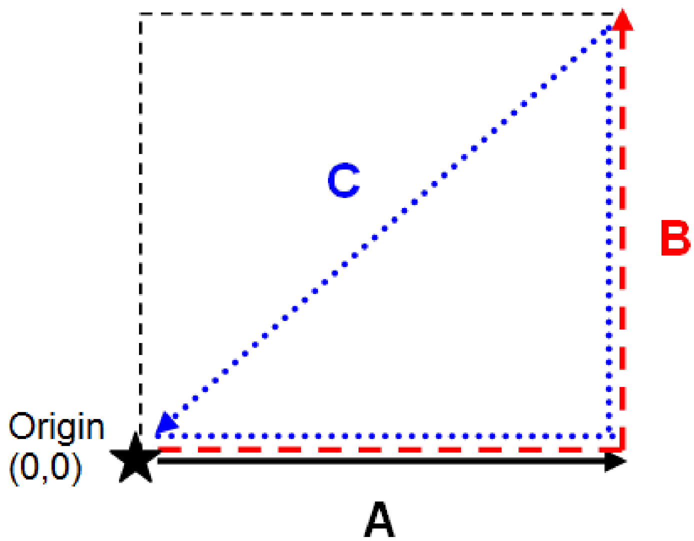


X Lines, Y Lines and the origin (X=0, Y=0) of the grid

If the grid is collected in a different quadrant, it can be corrected in software later, but if you abide by the first quadrant convention, the workflow to a final depth slice display is much faster and easier.

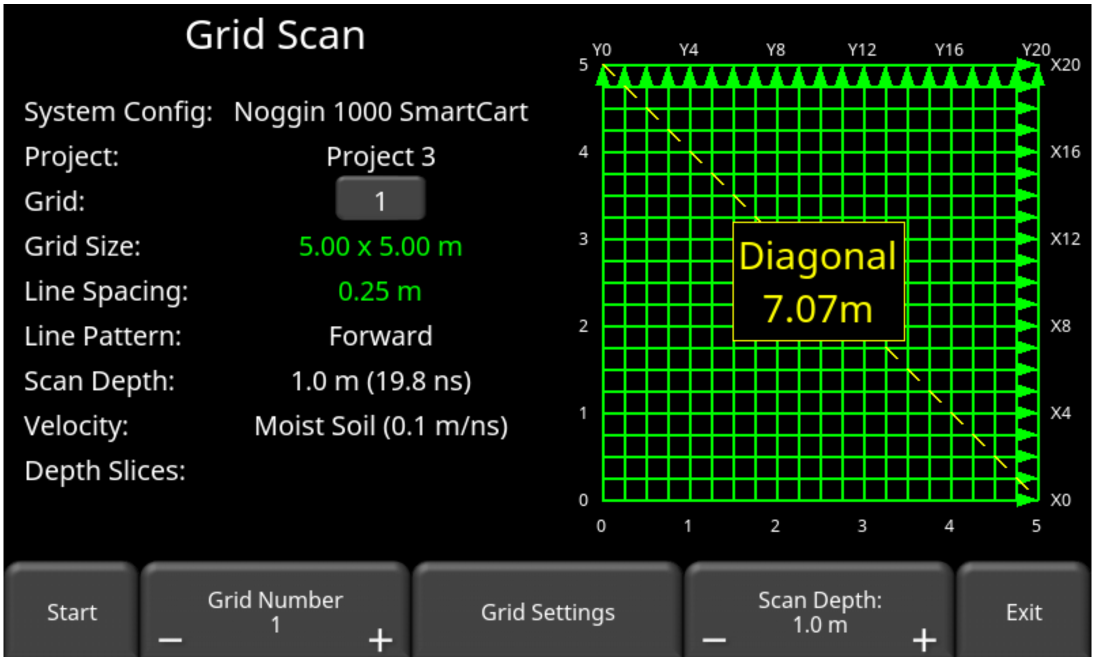
6.2. Layout the Grid

For maximum accuracy, it's very important to establish a right-angle triangle. The easiest way is to use a single tape measure and refer to the diagram below. Start at the origin, walk out the desired distance for x-axis (A) and mark that point. Then then turn 90 degrees and walk out the desired distance for the y-axis (B) and roughly mark that point. Then close in the triangle (C - hypotenuse side) back to the origin, making sure you meet the origin at the distance for C. If not, move the last point in tandem with the origin, such that the tape measure for both lengths is taut.



For example, if A distance is 10 meters and the B distance is 10 meters, the C distance (diagonal) is 14.14 meter so the 34.14 meter mark on the tape is at the origin.

On our newer GPR systems, the hypotenuse distance, called the Diagonal, is calculated on the screen in the units you are working in.

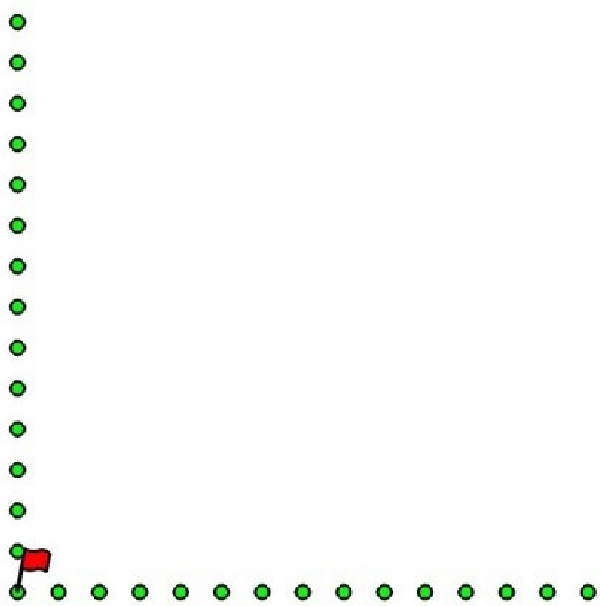


Use this table to help you determine the length of C depending on the size of your grid:

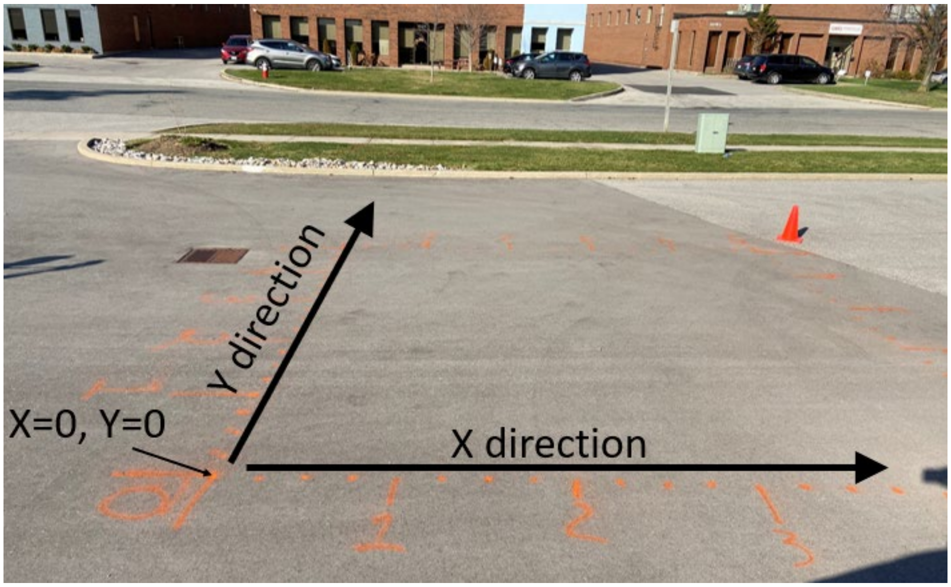
Grid Size			Setup Dimensions		
Length (m)	Width (m)	Area (m²)	Distance A (m)	Distance B (m)	Distance C (m)
5	5	25	5	10	17.07
5	6	30	5	11	18.81
5	7	35	5	12	20.60
5	8	40	5	13	22.43
5	9	45	5	14	24.30
5	10	50	5	15	26.18
10	10	100	10	20	34.14
10	12	120	10	22	37.62
10	14	140	10	24	41.20
10	16	160	10	26	44.87
10	18	180	10	28	48.59
10	20	200	10	30	52.36
15	15	225	15	30	51.21
15	20	300	15	35	60.00
20	20	400	20	40	68.28

6.3. Mark the Line Start Positions

With the tape measure still on the ground, mark the line start positions based on the line spacing. Usually flags or paint work for grass, and chalk or paint on concrete.

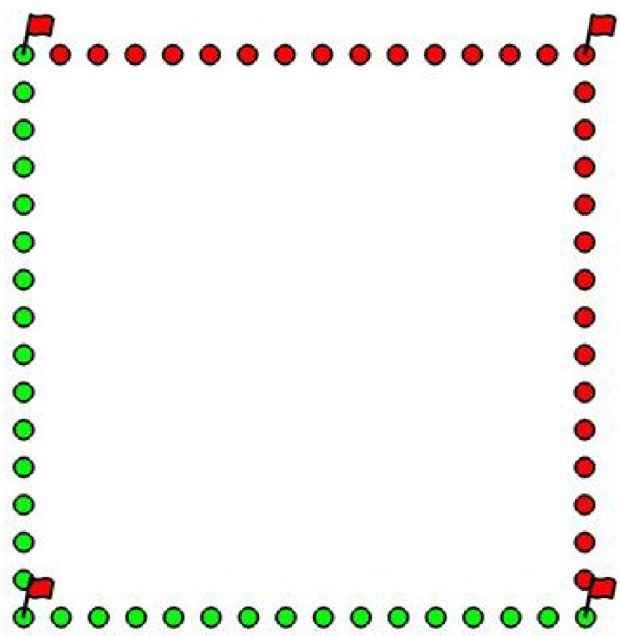


It is also recommended to paint a distance measurement every so often, in case you forget which line you're on.



6.4. Mark the End Positions

If you are doing a forward only grid, it is recommended to mark the end positions. The GPR operator needs something to aim at, at the far side of the grid, such as a flag or a cone, to make sure your grid line is collected straight. The end positions don't have to be the exact length of the line (as the GPR will stop when the set distance is reached).

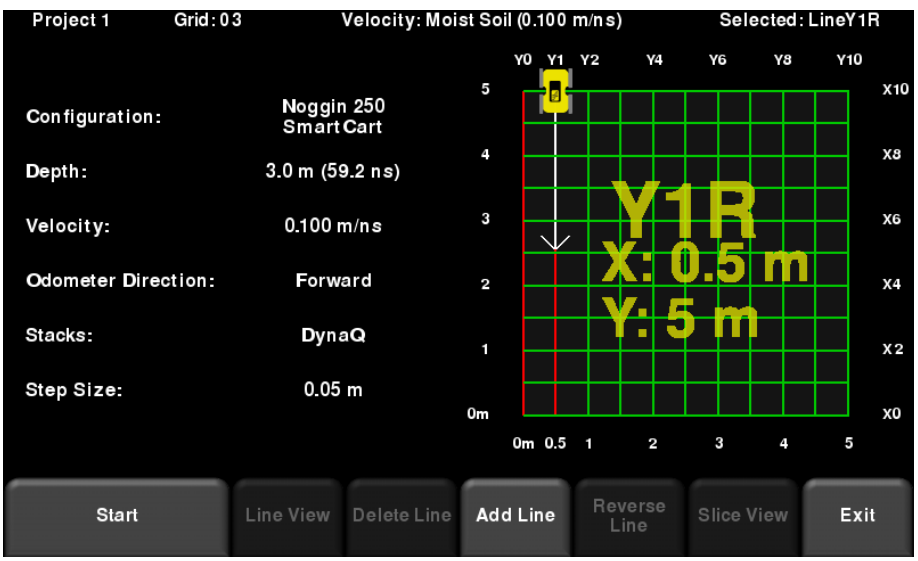


7. Collecting Grid Data

Make sure the center of the GPR system is always lined up on the base line prior to each line collection. Most systems have an arrow at the center of the system that you can line up on the base line.

Press **Start** on the screen and move the GPR system the programmed distance. Data acquisition automatically stops when that distance has been traversed. Follow the prompts on the screen and move to the next line. Pay special attention if you are doing an alternating grid pattern.

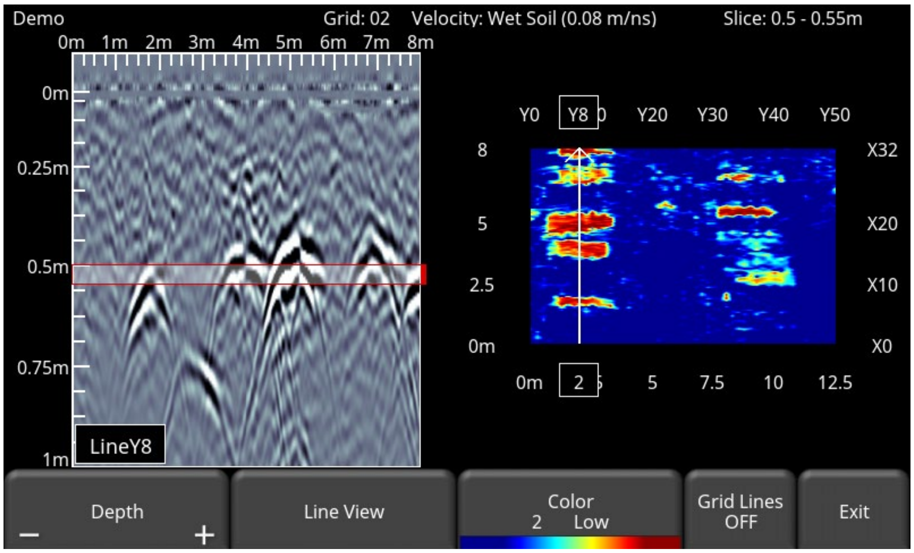
If there is an obstruction in your path, you can stop your line at the obstruction and approach it from the other side.



8. Reviewing Data

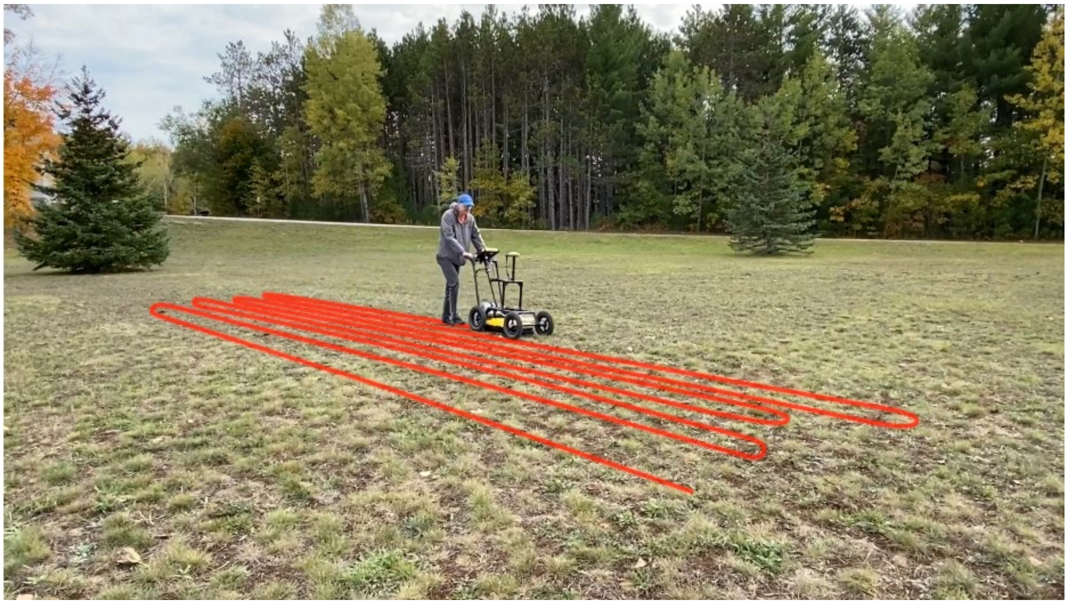
Once your grid has been completed, you can process the data by pressing **SliceView**. Make sure you calibrate your velocity first, as it will use this velocity to process the data and an inaccurate velocity affects the clarity of the depth slice images.

In SliceView, make sure you view the slices at all depths. You can also correlate features on the depth slices with features in the line scan data on the left.

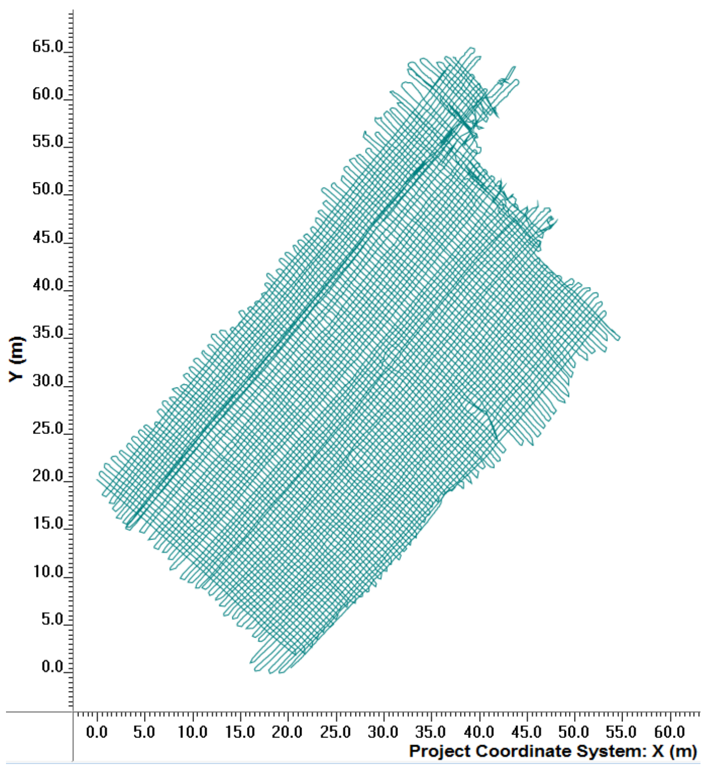


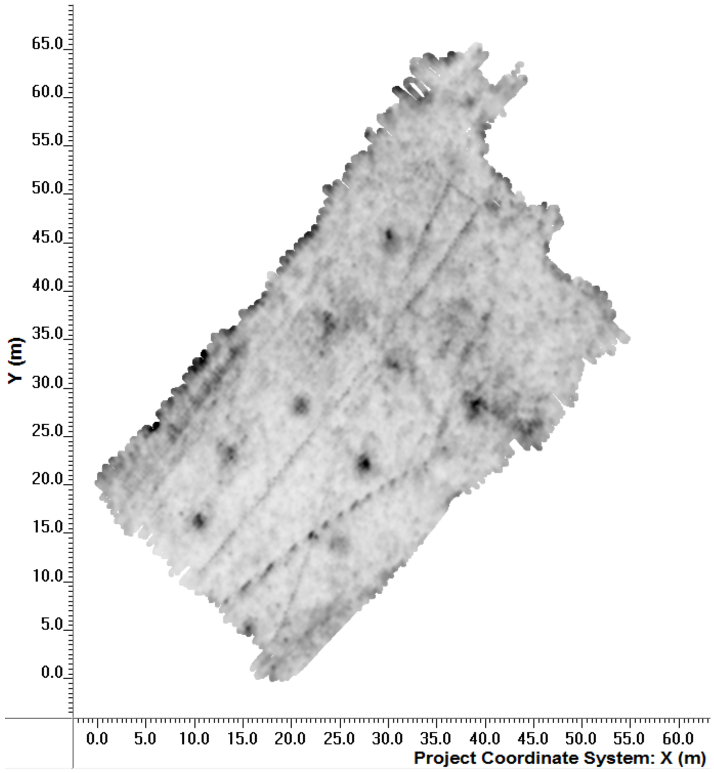
9. Collecting Pseudo-Grid Data

Sometimes setting up and collecting a formal grid is not practical, or desirable. Another way to collect data over an area is by walking going back and forth over an area, as if you were "cutting the grass". This is done in Line Scan mode, however you must have an accurate external GPS connected, as this is the only way to establish accurate positioning.



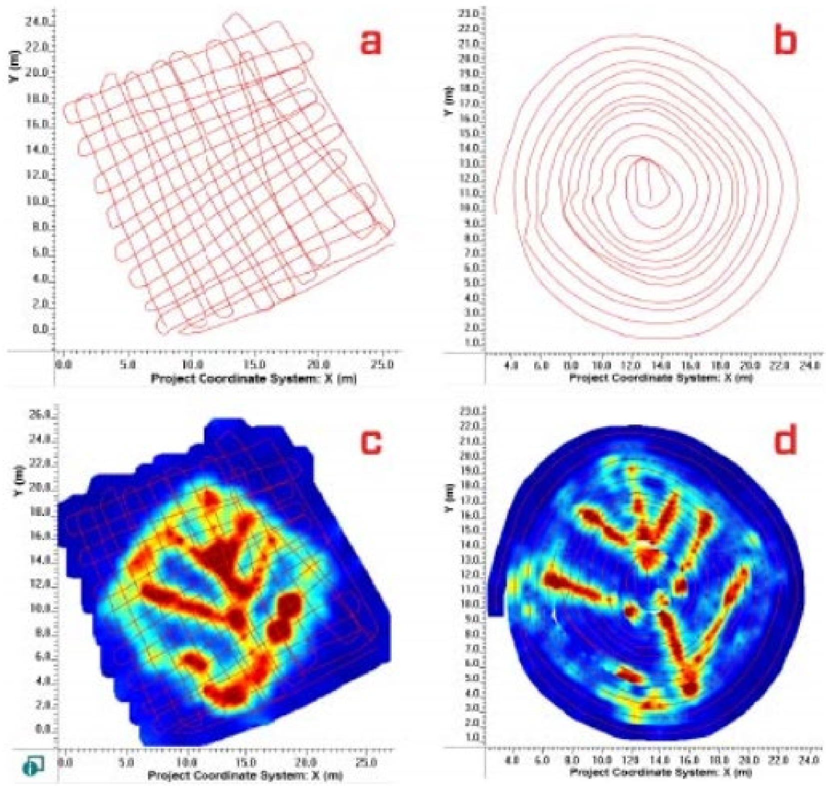
Collecting data as a "pseudo-grid" relies on the GPS for positioning the GPR data.





The collected data can only be processed in the SliceView-Lines module, part of the EKKO_Project PC software, V5 or later.

The more coverage you have, the better the resulting depth slices will be. You can choose to collect in one or both directions (diagram 'a' below), or even a spiral pattern (diagram 'b' below). If you collect more than one line of data, that is ok as well, since it can be combined in the software.



X - Y path (a) with depth slice (c). Spiral path (b) with depth slice (d)

The key to a successful survey is to cover the ground well and have a good GPS signal. The latter is a function of using a high accuracy GPS and being in an area with a clear view of the sky (away from buildings, trees etc.)