

Racing Surfaces Testing Laboratory

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Ground Penetrating Radar Standard Operating Procedure

June 16th, 2023



Racing Surfaces
Testing Laboratory



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GPR Overview

Ground Penetrating Radar (GPR) is a method that uses radar pulses to image a subsurface's layers and determine their approximate depths.

How does it work?

- The radar uses an antenna to broadcast a microwave band in the radio spectrum and then detects the reflected signal off subsurface boundary layers.
 - This works similar to how your car radio works- radio tower broadcasts today's top hits and your car radio is tuned into to a specific radio frequency in a given spectrum.
 - It is also similar to the principles of sonar for detecting fish or the bottom of the body of water when boating.
 - The FBI uses GPR to find grave sites.
 - It is also used to find subsurface pipes, rebar in concrete, and many other cases.
- When used on the racing surface, we are primarily looking for the relative depths across the racing lanes (0-20' off the rail) of the:
 - Cushion Layer
 - Pad Layer
 - Base Layer
- Additionally, we can detect pipes such as those used for drainage in synthetic and turf surfaces.

Radar Antenna – broadcasts and detects reflections

Survey Wheel– every partial revolution tells the radar antenna to send a radar pulse and record for signal reflections

When performing GPR, there are multiple factors that need to be considered:

- All measurements are relative- they are not exact as the result of:
 - Moisture content- If a surface has varying moisture content, the radar will interpret a layer as becoming more shallow or deeper. This is because it will change what is known as the dielectric constant of the surface. This is an electrical property that is related to how quickly the radar pulse may travel through a medium (surface layer) and is measured prior to GPR testing. (Lower value = faster travel and deeper penetration)
 - Surface composition – this is generally a non issue but large variations may change boundary reflections and the dielectric constant reducing the data quality.
 - Surface compaction – GPR is preferably taken on floated or sealed surfaces as it helps increase data quality by making boundary layers more defined. It also changes the dielectric constant by reducing air pockets and increasing volumetric moisture at a given point. However, when compacted this may decrease reported depth values (cushion layer may be 3.5" when loose but reported at 3" since it is compacted at the time of testing.).
 - Data processing- when processing, depth can only be picked in the middle of a boundary layer, such as the cushion depth, potentially making measures be relatively off by a ¼". An example will be shown. This is considered okay.

Material	Dielectric Constant
Snow/Ice	3.0
Dry Sand	4.0
Pavement	6.0
Rock	8.0
Dry Soil	9.0
Ave. Soil	14.0
Wet Soil	20.0
Wet Sand	25.0
Water	81
Custom	1-81

The dielectric constant is measured prior to testing to increase data quality and accuracy. Note how it changes with moisture and composition.

Other things to consider:

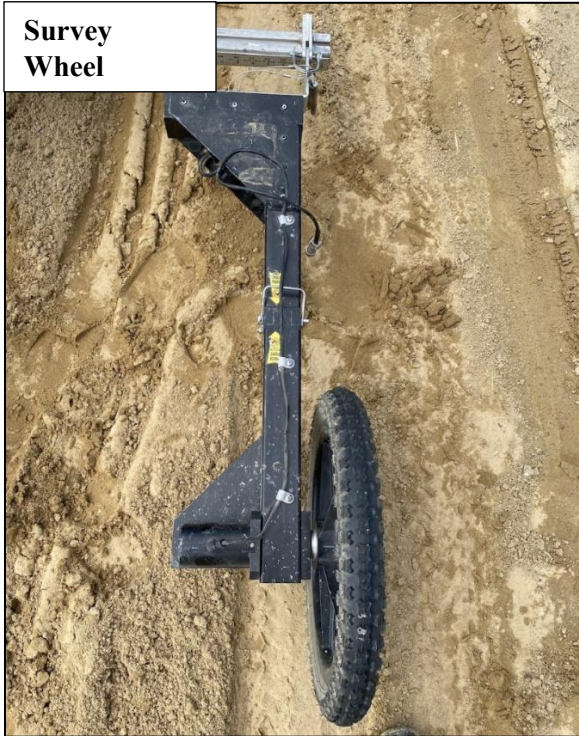
- Bulk Density between Layers
- Equipment used on the Surface
- Salinity



GPR 2D Equipment Setup

- 1) Collect required equipment
 - Sled Adaptor (Antenna Cable)
 - Sled
 - GSSI 1600 MHz Antenna
 - Computer (SIR 4000)
 - Survey Wheel
 - SIR 4000 Battery with Yellow Cap Cover
 - GPS (Geode)
 - RS232 Cable
 - GSSI USB
 - GSSI Cable
 - Survey Wheel Adaptor

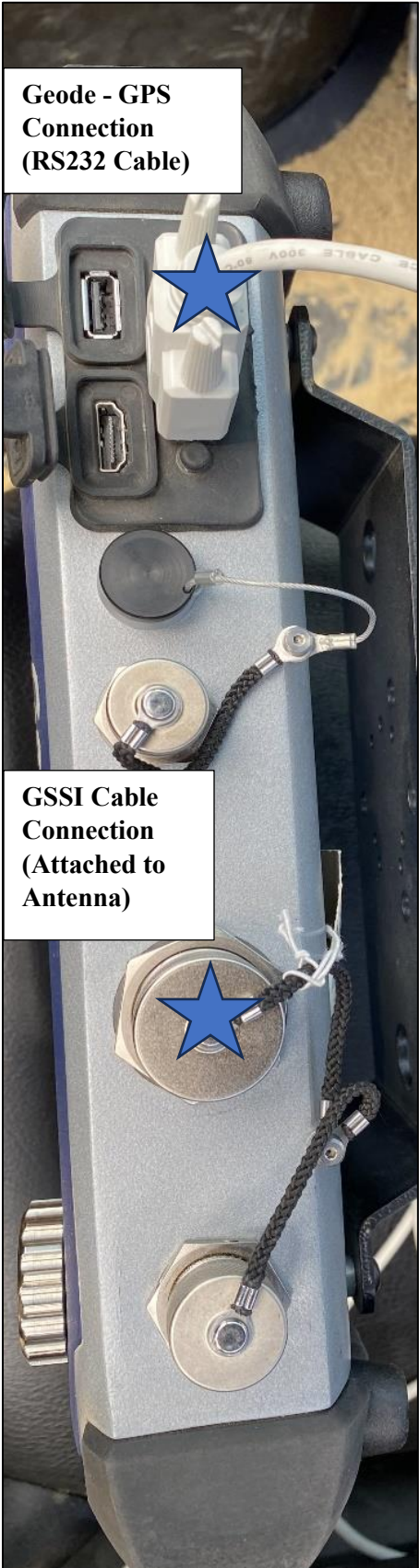












**Geode - GPS
Connection
(RS232 Cable)**

**GSSI Cable
Connection
(Attached to
Antenna)**





2) Pin in the Sled and the Survey Wheel

- Survey Wheel Check list:
 - Make sure when pinning in the Survey Wheel that the plate attached to the wheel is facing down
 - Make sure the Survey Wheel isn't loose
 - Make sure the Survey Wheel tire is not flat
 - Use the same SIR 4000 with the same Survey Wheel (or you will have to calibrate the Survey Wheel)
- Sled Check list:
 - If the onsite test is taking place on an open track instead of sealed, place something that is of decent weight on the sled (weigh it down)



3) Take the Sled Adaptor Cable (Antenna Cable) and connect it with the Survey Wheel Adaptor Cable

- Make sure no debris is inside the cable
- Twist and lock the cable in place- **DO NOT** force the cable ends together
- Plug in the female part of the adaptor with the male adaptor from the 1600 MHz Antenna
 - The pins inside the male adaptor side are sensitive- **DO NOT** force the cable ends together

4) Take the GSSI cable and plug it into the port on the GSSI 1600 MHz Antenna



- 5) Organize cables for testing
 - Make sure the cable is supported and can reach the front of the UTV
 - Make sure the cable is clear of the exhaust pipe
 - Support the cable over the OBST





- 6) Collect the SIR 4000, SIR 4000 Battery, Geode GPS, GSSI Cable (already connected to the antenna), and the RS232 Cable
- 7) Plug in the GSSI Cable into the SIR 4000
 - o The other end of the cable is already attached to the antenna



8) Attach the RS232 cable with the Geode device and the SIR 4000 (screw in connection)





- 9) Power on the Geode device (press the power button)
 - Green light = Power
 - Flashing red light = Needs to be charged (**Must use** the designated Geode micro-USB to charge or you can damage the Geode device)
- 10) Check Satellite connection with the Geode device
 - Solid Orange = Satellite Connection
- 11) Place the Geode device where it can reach the SIR 4000
 - Image example shown above
- 12) Place the SIR 4000 Battery into the Computer (port on the left side of the SIR 4000)
 - Store the batteries yellow cap
 - Twist and lock the panel to keep the battery in place
 - **DO NOT place the battery into the SIR 4000 until all cables are connected!**



13) Power on the SIR 4000

- Press the upper left side button

14) Make sure the computer settings are ready for data collection

- Make sure the battery gauge is at a satisfactory percentage
- Make sure the memory has enough space for collection
 - 2% means there is 98% empty space for data collection
 - Anything above 50% should be modified (delete old data- not recent data)
 - Play Back => Choose Path => Delete Path => Hold Stop; this is all done using the knob at the top right corner of the SIR 4000



15) Turn on the GPS State and check its settings

- Grey to red (means no Satellite connection)
 - This can be due to interferences such as: Powerlines, Grand Stands, Bodies of Water (electromagnetic fields)
 - Best to Setup GPS on the outside rail of the track
- Grey to green (means there is Satellite connection)
- Baud Rate: **FIXED** rate of 19200
- Format: D. DDDD°
- After all the settings are fixed, select “Start”
- Make sure collection looks correct
 - Run a test by spinning the Survey Wheel lightly while it is held up in the air by an object with decent height and sturdiness
 - Watch on the SIR 4000 for data to be collected correctly or incorrectly



- Then you can select “Stop” => “Apply”

16) Start a New Project

1. For New track data collection select “New Project”
2. Name file
 - TrackNameYearYearMonthMonthDayDay
 - i.e. RSTL230602
3. Apply
4. Make sure GPS Satellite is still green
 - GPS Configuration can also be done in the New Project Folder if the connection wasn't set up prior

17) Recall Setup Settings

- Radar:
 - Make sure it is in Collected Mode
 - Samples per scan **NEEDS** to be 256
 - Scans per foot **NEEDS** to be 12
- Process: Audio Gain Mode – 3-point Gain Curve
- Output: NA
- Calibrate: Only needed for when a New Survey Wheel is attached



18) Set Depth Range and Dielectric Constant (DC)

- The default base depth is 10 inches
- Synthetic Tracks: ~12 inches, generally a DC of 8
- Sand Tracks: ~8 inches
- Rule of Thumb: Max depth plus 1 inch
- GSSI Rule of Thumb for scans per foot: 10/ Target Depth (ft)
- The usual DC we collect at is between 12-18
- ❖ Testing for base depth:
 - Tube of water – dial to its peak depth
 - Turf probe – shows where resistance is felt
- ❖ Turn the knob at the top right of the SIR 4000, till the DC reflects your proper layers
 - As the DC increases, the layers on the SIR 4000 increase (Vis Versus)
 - The target layer you are measuring should line-up with the cushion depth range that has been measured on-site previously (inches-left hand side of the SIR 4000 screen)
- ❖ Run the Survey Wheel a small distance and make sure the chosen DC is appropriate for track collection
 - You may have to change the DC after viewing what is collected
 - For a more in-depth explanation of dialing the DC, view under the header “GPR On-Site Collection & Ground Truthing”

19) Collect data

- View steps under the “GPR On-Site Collection & Ground Truthing” header

20) Save data

- Plug your USB into the SIR 4000
- Select “Play Back”
- Select “Select All”
 - Check marks will appear by all sections
- Select “Copy USB” – **DO NOT select “Move USB” (all data collected will be lost)**
- Select “Stop”
- Power down the SIR 4000 – hold down the power button
- Remove the SIR 4000 Battery and place the Yellow Cap back on the top of the battery – **YOU MUST do this step before removing any cables**
- Once the **Battery is removed**, then you can disconnect the cables
 - Place all pin caps on cables and the SIR 4000

21) Plug in the USB into your personal laptop and save the collected data from the GPR onto its appropriate project folder in Dropbox

22) If possible, before leaving the track, pick the first lap collected by the GRP

- Steps to do this is under the header “GPR Point Picking & Data Processing”



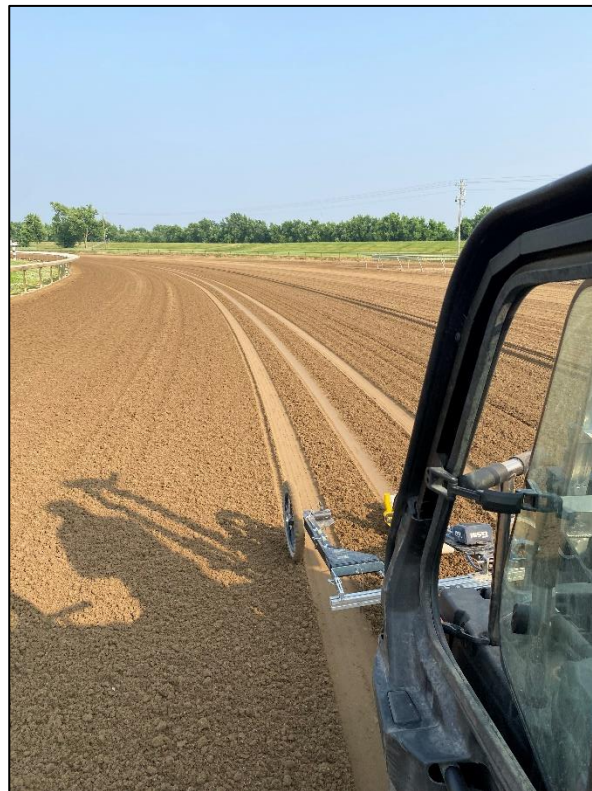
GPR On-Site Collection & Ground Truthing

1. Set up all equipment; expressed under the “GPR 2D Equipment Setup” header
2. Position the UTV on the inside rail (around 6 ft for data collection)
3. Set the collection base depth based on the type of surface being tested (how far down the RADAN file will collect)
 - a. i.e. ELP track set at 8 inches
4. Dial the dielectric constant (DC) for proper collection
 - a. Make a mental note of the layer that will be the basis of collection (proper cushion layer)
 - b. Increase the DC until the chosen layer lies within the onsite measured cushion depth
 - c. Test the DC
 - i. Drive about 180 ft and see how the DC affects the collection on the SIR 4000
 - a. Make sure to drive 5 mph; **DO NOT** exceed this speed or loss of resolution will occur
 1. Dial the DC where the layers are most visible (within a range of 12-18 DC)
 2. Increase the gain rate to view the layers better as well
 3. It may take a few tests to find the appropriate DC
 - d. Start collecting data
 - i. Press start on the SIR 4000
 - ii. Drive around the full track on the inside rail - Make sure to drive 5 mph; **DO NOT** exceed this speed
 1. Make a mental note of the pole location that is near where you started collecting data
 2. Make sure when you are traveling around the track to try and avoid tire marks and equipment (could affect the RADAN file’s visibility)





- a. If needed, press stop on the SIR 4000 and move out of the way of equipment
 - b. Press start when the equipment has passed and the UTV is back to where the RADAN file was stopped
 - c. If this is performed, you must combine csv. file laps during data processing
 - i. This process can be viewed under the “GPR Point Picking & Data Processing” header
3. Make sure to travel the same distance off the inside rail around the full track



- a. Exception: going around tire tracks
 - i. If this is done, keep track of where this was done (pole location) and for what lap



4. Keep an eye on the SIR 4000
 - a. Watch for base layer variation (rising) and artifacts
 - b. If it seems that the layer of basis is not at the proper depth, move the UTV further from the inside rail (view the SIR 4000 to see if this helped resolve the issue)
 - c. If something seems wrong with the layer depth stop the UTV; **ONLY** if you are in distance collection mode with the Survey Wheel
 - d. Step off the UTV and quickly check the cushion depth using a ruler prior to continuing the lap
 - e. If you are in time collection mode then you must completely stop collection on the SIR 4000 to halt the UTV

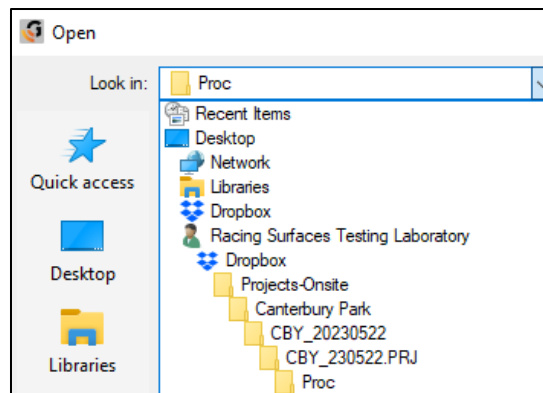


- f. Layers can also disappear on the RADAN file due to moisture levels
 - iii. Once the first lap is completed press stop on the SIR 4000
 1. Press stop once you've gone a short distance past the pole location where collection started (there should be a bit of overlap between laps)
 2. The Survey Wheel lap distance should be around the length of the track
 - a. i.e. 1 mile track \approx approximately 5280 ft on RADAN file
 - iv. Perform 3 more laps of the track following the same instruction as done for the first lap
 1. Do not change the DC; use the same one as the first lap
 2. The 4 laps all are performed at different distance off the inside rail (approximately 6 inches - 12 inches - 18 inches - 24 inches)
5. Helpful tips:
 - a. **Do not** perform the test going faster than 5 mph (as speed increases, resolution decreases)
 - b. GPR usually occurs on a sealed surface (can be done on an open surface, but not preferred)
 - c. Perform GPR on the track's interpretation of a "Race Ready" or "Training Ready" Track

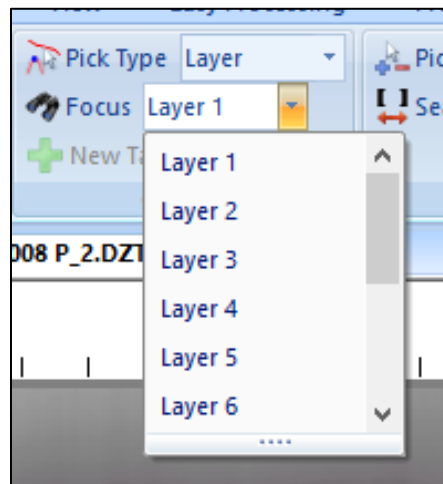


GPR Point Picking & Data Processing

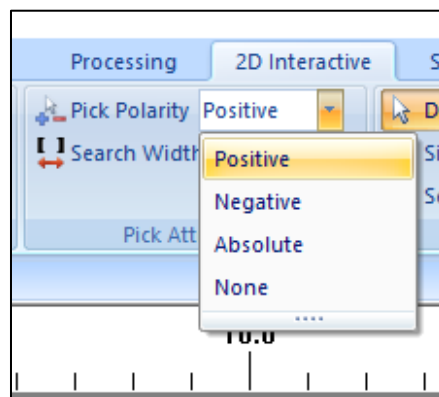
- 1) Importing files into Radan 7:
 - a. File => Open => Dropbox => Projects Onsite =>
 - b. Select appropriate track name i.e. <Laurel Park>
 - c. Select folder with corresponding date i.e. LRL_20230418 for data collected on 4/18/23 at Laurel Park. Date format is YYYYMMDD
 - d. Select folder with <. PRJ> extension i.e. LRL_230419.PRJ Date format is YYMMDD
 - i. . PRJ – radar info
 - ii. . DZT – data files to process
 - e. Select file name with DZT extension corresponding to the location on the tract to be examined i.e. LRL_230419_001.DZT to look at the first pass of data collected at Laurel Park on 4/19/23.
 - i. File 1 is on the rail



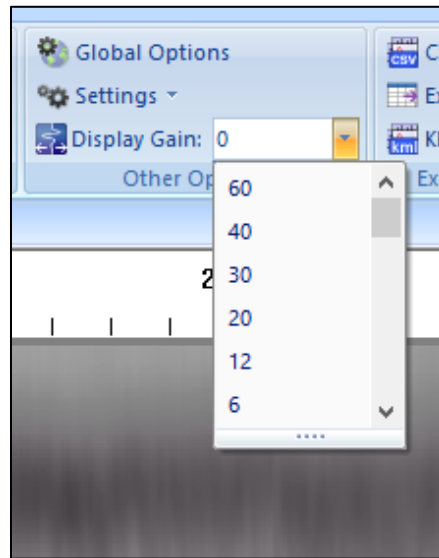
- 2) Initial Settings:
 - a. 2D Interactive tab =>
 - i. Objects =>
 1. Pick Type => Layer
 2. Focus => Layer 3 (base layer)



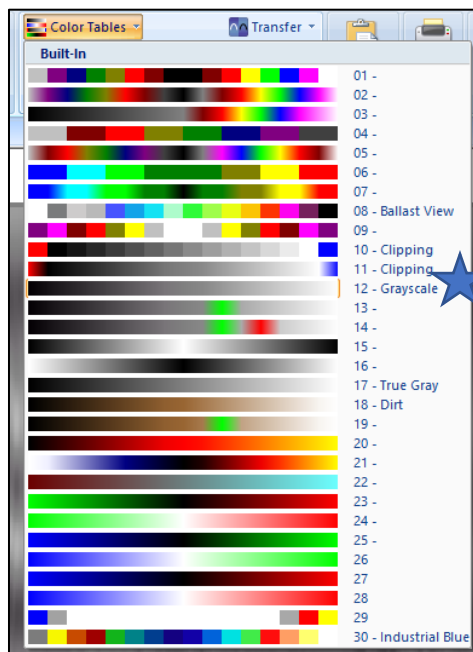
- b. Pick Attributes tab => Polarity Picking => Negative



- c. Pick Tool => EZ Tracker
- d. Other Options => Display Gain => 20
- The Display Gain can be placed on a range from 20-60. The Display Gain number you choose depends on what makes the RADAN file clearer. You want to be able to see the differentiation between the positive and negative track.
 - **However**, the higher the gain can be misleading

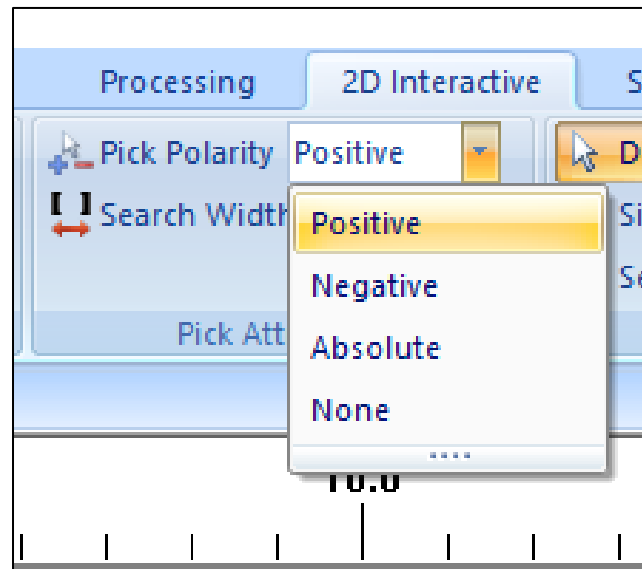
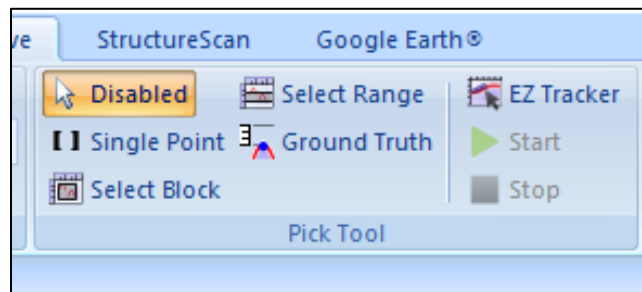


e. Color tables => Grayscale

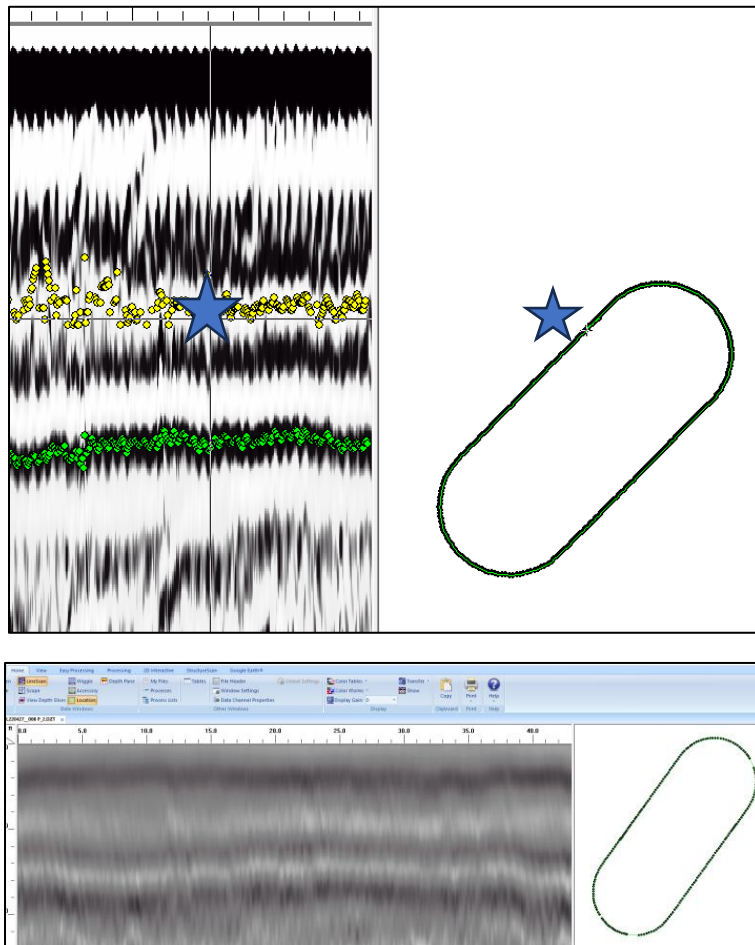


3) Selecting Positive or Negative:

- a. Generally the Negative is picked on the RADAN file
- b. The negative is the black section, while the positive is the white section
- c. The main aspect that helps you choose between positive and negative is the on-site cushion depth measurements (provided by on-site crew)
 - i. Using the “Location” function on RADAN Home tab, you can visualize what pole location the file starts at. (Make sure you are currently using the “Disabled” function to be able to use the “Location” application)



- ii. Then, you can compare the on-site measurement for the pole location and see if it falls in the positive or negative area.
- iii. Access pole locations online or collect through the on-site crew
- iv. You can also Google Earth/Maps where the grandstands (pole locations) are and compare it to the location on the RADAN file

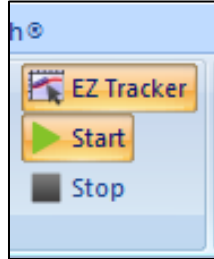


- d. Another aspect that helps choose between negative and positive is track clarity. Use the path that is easier to visualize throughout the RADAN file
 - e. If you pick POSITIVE for the first lap, ALL laps picked there after must be picked POSITIVE as well (Vis versus with negative)
- 4) Picking Individual Layers:
- a. 3 individual layers can be picked on a RADAN file
 - i. Layer 1: Cushion (Yellow points)
 - ii. Layer 2: Pad Thickness (Red points)
 - iii. Layer 3: Base (Green points)
 - b. The cushion layer is the default layer that should be picked for most tracks
 - c. Synthetic and Limestone base (Sand) Tracks typical pick the base layer



5) Selecting points:

- a. Depth (inches) is given on Y axis and position along the track (ft from start) is given on the x-axis
- b. Start the EZ Tracker feature (2D Interactive tab => Pick Tool => EZ Tracker => Start)
- c. Click with mouse in the middle of the black line of data corresponding to the depth of the layer of interest near the start of the data track.



- i. Refer to 3c to see how to use the “Location” function
- ii. Accessing the On-site Cushion Depths:
 1. Dropbox => Projects-Onsite => Select Track => Select Track with proper Collection Date=> Cushion and Base Depths (Excel file)
 - a. The Cushion Depths may also be saved under the “Reports” tab
- d. Continue to click points within that band while moving across the screen to the right.
 - i. If the file is clean enough, you can use the function “Select Range” to add points throughout the whole file
 - ii. If you do this, make sure to edit the path still due to varying lanes, on-site cushion depths, and outliers
- e. A series of points should fill in between the two mouse clicks as the EZ Tracker system automatically chooses points.
 - i. Do not pick any points in the 0-2” range. Dead zone at the top of sensor field – ignore this region.
- f. Right mouse click to UNDO last points picked
 - i. *** only 1 chance to UNDO! ***
- g. Use right & left arrow keys to progress forwards or backwards through data set one screen at a time.

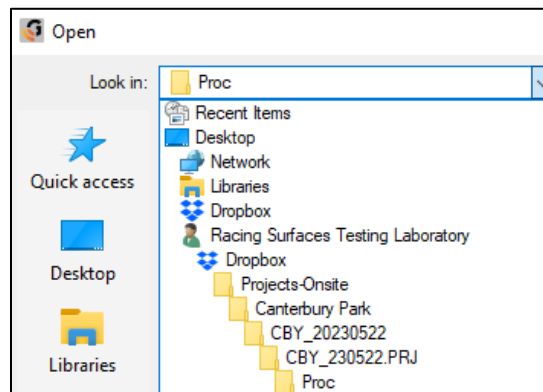
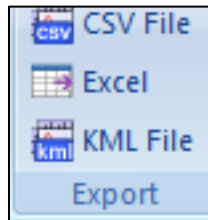
6) Removing outlier points:

- a. Choose 2D Interactive tab => Pick Tool => Select Block
- b. Use mouse to draw a box around outlier points
- c. Right click within highlighted block
- d. Choose <Delete Points> to remove outliers from data set
- e. When to clean up points:
 - i. Points should be deleted when it varies from its original layer, or when it inhabits its own space away from the main line
 1. Single Point => Right Click



- 7) When to add points back:
 - i. Points should be added where they are missing along the prominent line
 1. Select Block => Right Click => Add Points
 - a. This can also be performed when there is a disappearance of the layer you are actively picking

- 8) Save processed data:
 - a. Select “CSV file” under the “2D Interactive” tab
 - b. Save processed GPR data under the <Proc> folder.
 - c. Naming convention LRL_230419_001 P_1 <track name><date(Yymmdd)><processing run number>
 - d. If reprocessed increment the run number i.e. P_2



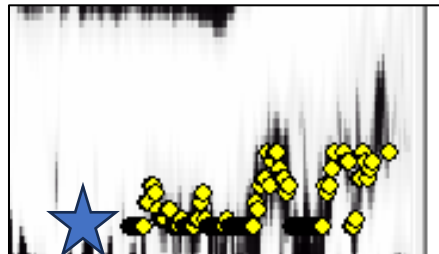


9) Items of Interest:

- a. Items of interest can be marked on Layer 5 (Artifact); **MUST** be below the base layer
 - i. 2D Interactive tab => Objects => Focus => Layer 5
- b. Example:
 - i. Drainage pipe under the surface of the track
 - ii. Harrow Bouncing
 - iii. Repaired Base
 - Problem areas on track (Under the “GPR Picking Example Artifacts”)
- c. How to save artifact on RADAN:
 - i. Change the layer picked to “Layer 5” (Must be in “Disabled” mode)
 - ii. Choose a point on the artifact using the EZ track feature
 - Can be either positive or negative
 - Must be picked below the base layer (**Can not be above base**)
 - ii. Export CSV
 - Save under the Proc folder
 - iii. Access the CSV with the layer 5 depth
 - Control + Arrow + Down
 - iii. Take a screenshot
 1. Using the Snipping Tool, take a screen shot of the artifact on the RADAN file
 - Windows logo key + Shift + S key
 - Select the whole screen (screen grab), including the track project number and lap number
 2. Save Screenshot to the project folder
 - (Name: POI_L1_0)
 - POI: Point of Interest
 - L1: The lap number
 - 0: The number of consecutive issues

10) GPR Picking User Error:

- a. If this occurs delete the bottom portion of dots that overlap:

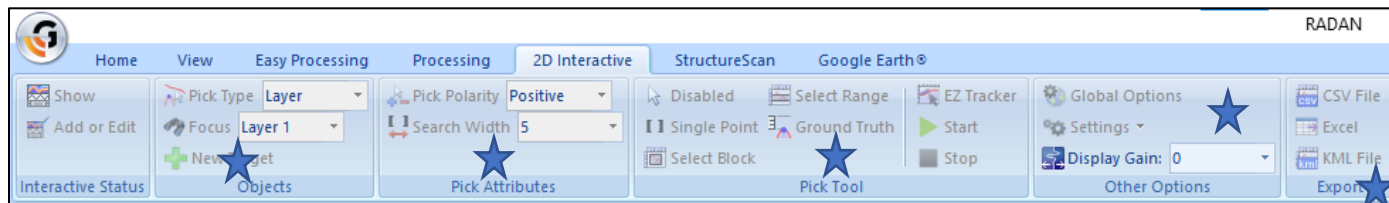
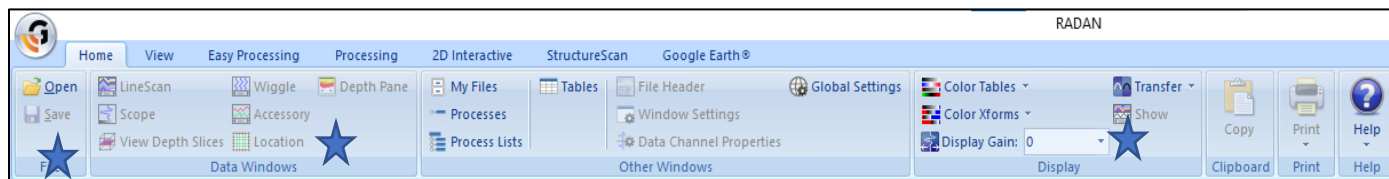




11) Combining RADAN Files:

1. Pick the laps that must be combined as you would if it were a normal RADAN file
2. Export all laps as individual CSV. into the correct project folder
3. Open all individual CSV. Files
4. View the CSV. File that immediately follows the first original lap
 - a. i.e. If you are trying to combine lap 13, 14, 15; open lap 14
5. In the file, using your mouse click on Row 2, Column A Block
6. While holding down the Shift key, press the Right Arrow key until you reach Column L
7. Then hold down Control, Shift, and the Down Arrow at the same time to select all the data from the CSV. File
8. Copy the selected data
9. Now, open up the first original laps CSV. File
10. Press the Control and Down Key at the same time
11. Press the first empty block
12. Press Control and V to paste the data that was selected from the following lap
13. Repeat these steps for the other laps that need to be combine into the first original lap
 - a. This must be in numerical order, so all laps combined are in the correct order inside the first original lap
14. Once all data is in the original first lap CSV. you must resave it
 - a. You must also delete all the old laps that were placed inside the first original lap

12) RADAN Tab Overview





GPR Python Processor

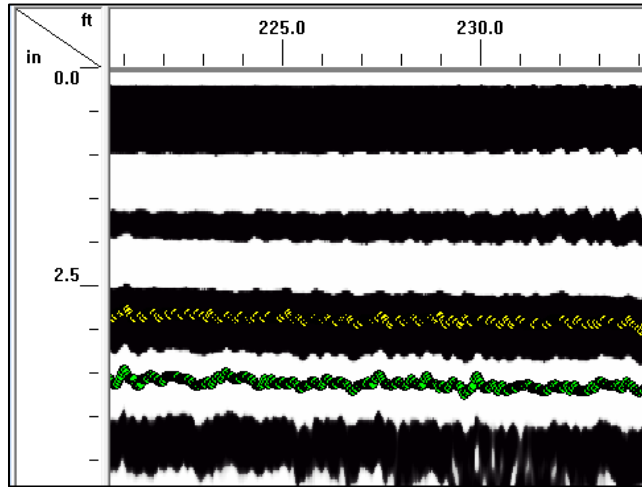
-How to check and see if your point picking is accurate:

- 1) Pick one lap => Export as CSV file
 - 2) Put the file through the python processor
 - Dropbox => Equipment and Software => GPR => Python Processor => GPRpy_V1.1=> dist. => GPRpy_V1.1
 - In the processor: Select Track Name => Date on RADAN file=> Select the layer are checking => Select the tracks Proc. Folder under the PRJ Folder=> Finish
 - 3) A graph will pop-up showing the Cushion Layer's Relative Depths throughout the track
 - You can use this to compare On-site Cushion Depth measurements taken at certain pole locations with what is seen on the graph
 - 4) A box and whisker chart are also generated when using the python processor
 - Dropbox=> Projects-Onsite => Select Track => Select Track with proper Collection Date => Select PRJ => Proc. => Processed GPR
 - From here you can select the box and whisker chart; view Average Depth and Std.
- The goal of picking these RADAN files is to have an accuracy of ± 0.25 inches from the on-site measurement

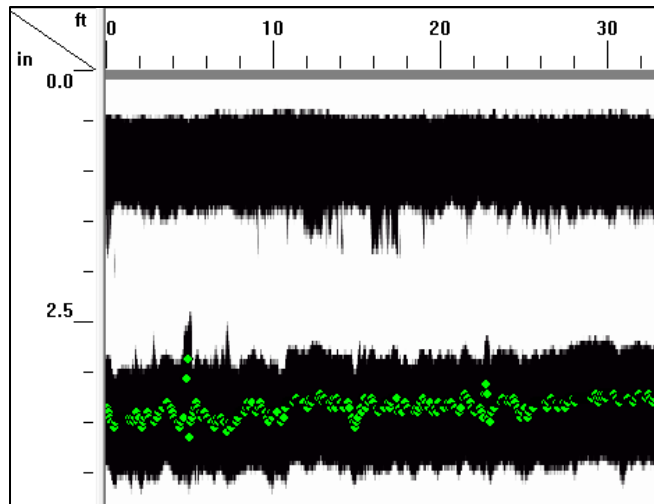


GPR Picking Image Examples for 2023

Belmont: April 10th, 2023- Example of a sand track/ limestone base (Cushion and Base layer picked)

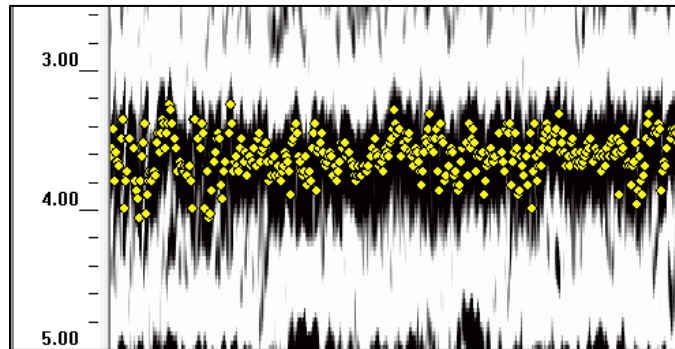


Charles Town: May 19th, 2023- Example of sand track/ limestone base (Base layer picked)

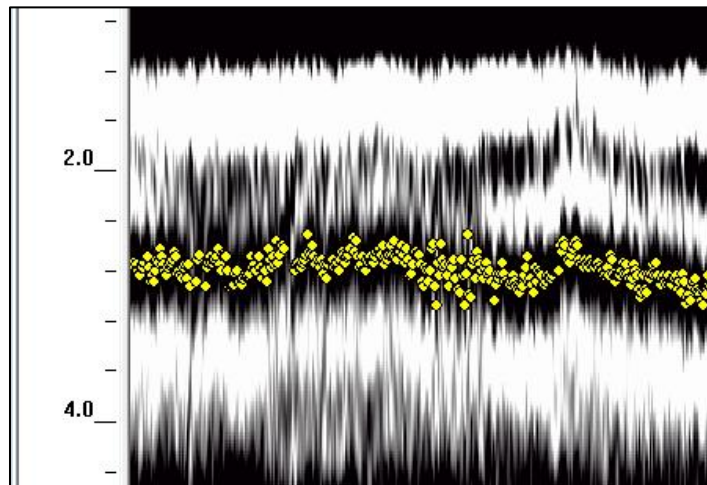




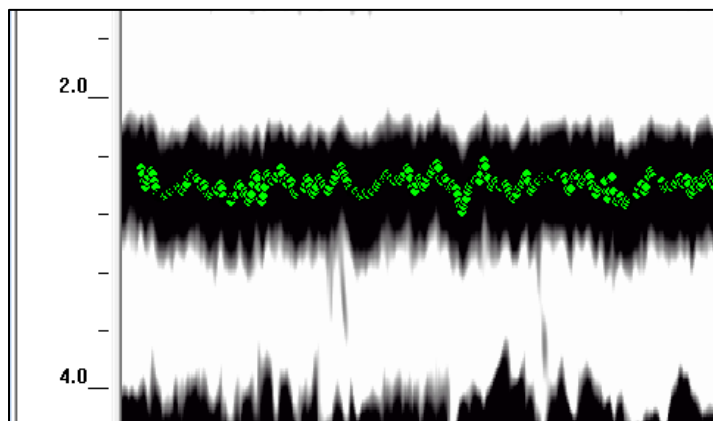
Churchill Downs: May 24th, 2023- Track with developed base that has a shallow sand or sand-and-clay track material laid over a base that is not disturbed regularly (Cushion layer picked)



Emerald Downs: April 28th, 2023- Example of a Sand-Fiber track (Cushion layer picked)

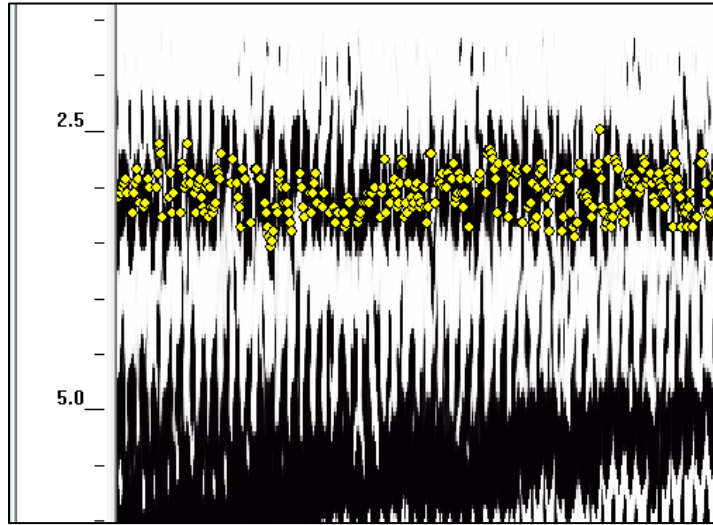


Fair Grounds: February 22nd, 2023- (Base layer picked)

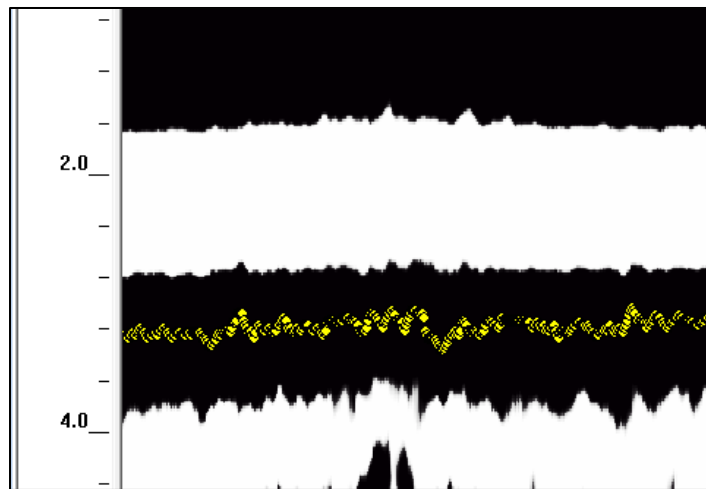




Fairmount Park: May 24th, 2023- (Cushion layer picked)



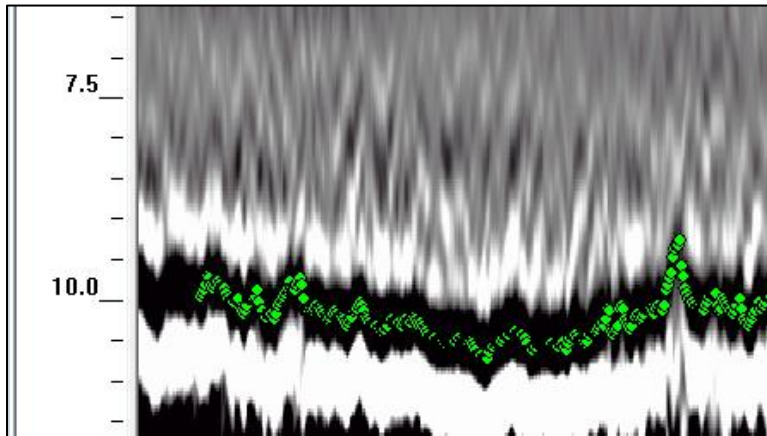
Finger Lakes: April 26th, 2023: (Cushion layer picked)



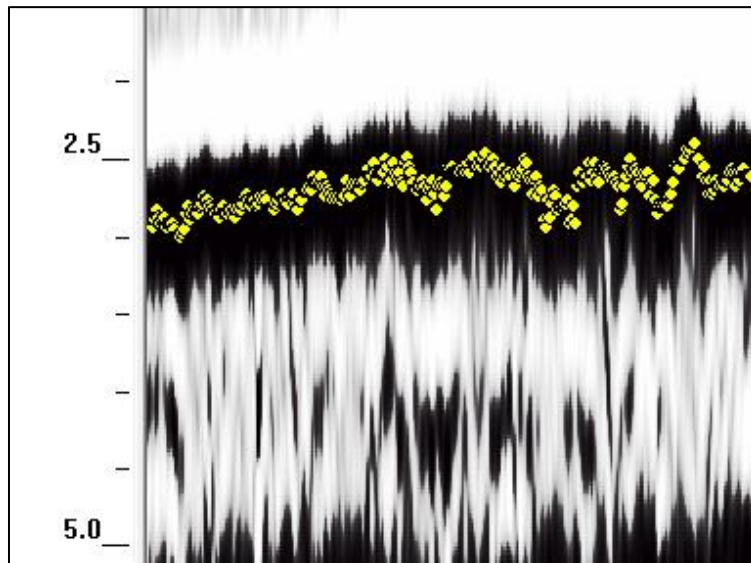


Golden Gate Fields: April 20th, 2023- Example of Synthetic track (Base layer picked)

- Synthetic tracks shouldn't have lines above the base layer (there can be faint lines)

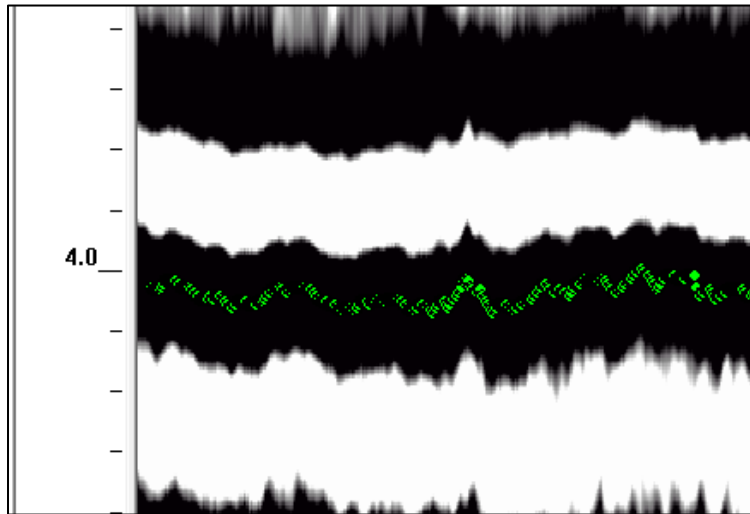


Keeneland: May 12th, 2023- Track with developed base that has a shallow sand or sand-and-clay track material laid over a base that is not disturbed regularly/ deep limestone base (Cushion layer picked)

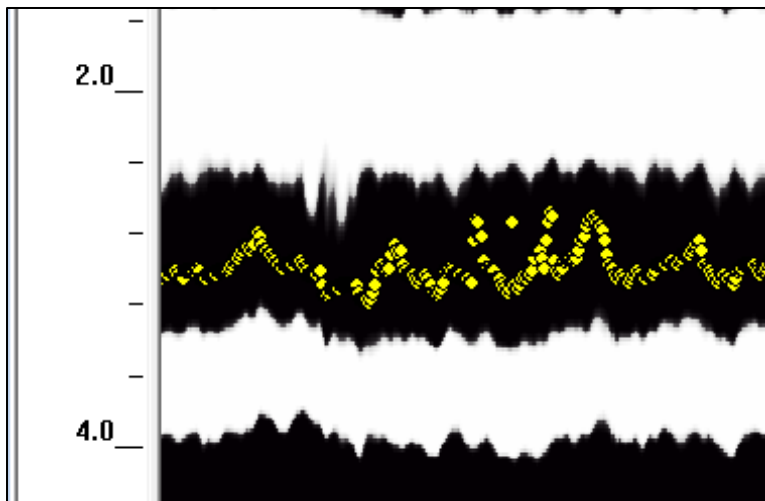




Laurel Park: April 19th, 2023- (Base layer picked)

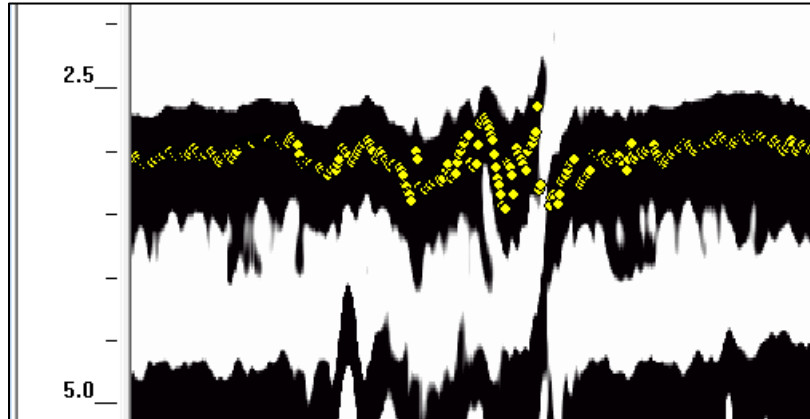


Oklahoma Training Track: April 28th, 2023- (Cushion layer picked)

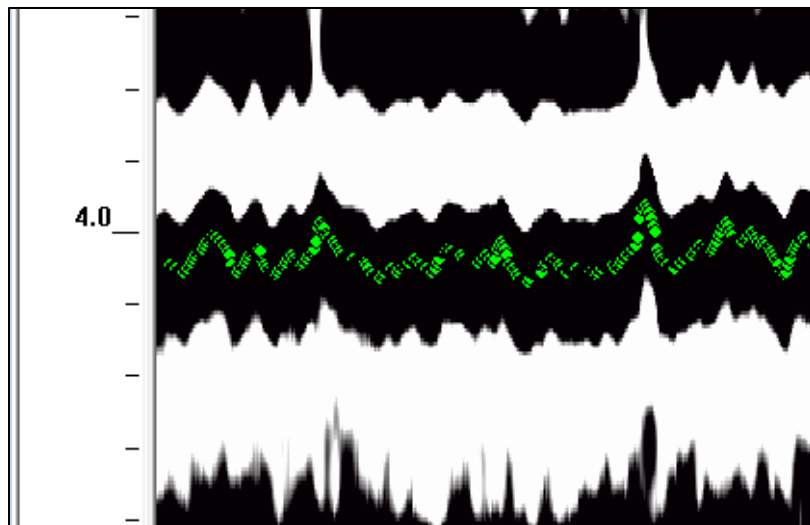




Palm Meadows Training Center: February 24th, 2023- (Cushion layer picked)

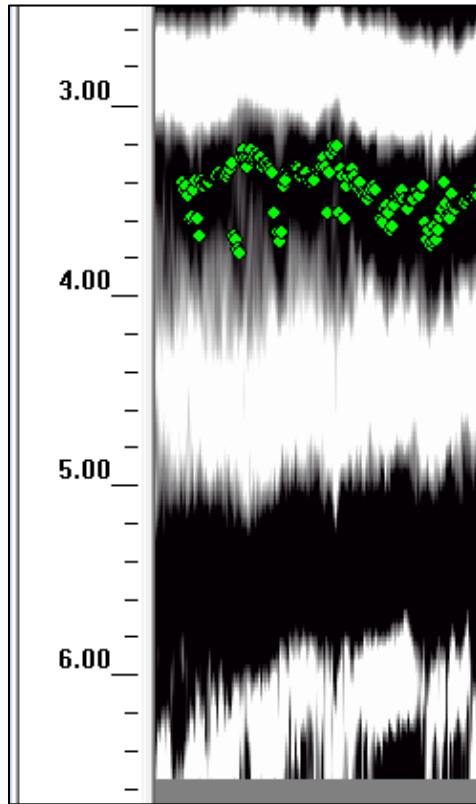


Parx: February 10th, 2023- (Base layer picked)

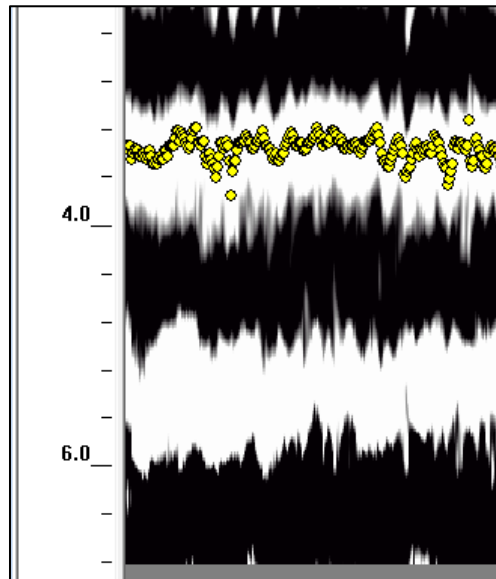




Pimlico: May 11th, 2023- Example of a limestone base (Base layer picked)

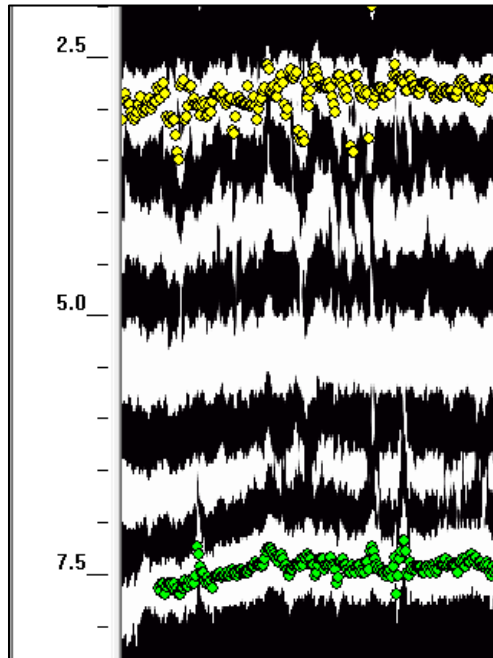


Prairie Meadows: May 4th, 2023- (Cushion layer picked)

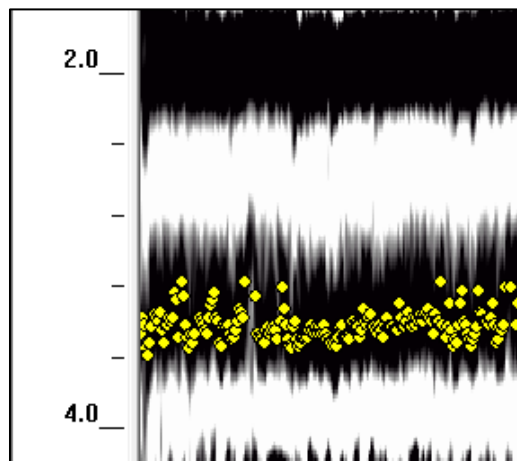




Remington Park: May 8th, 2023- (Cushion and Base layers picked)

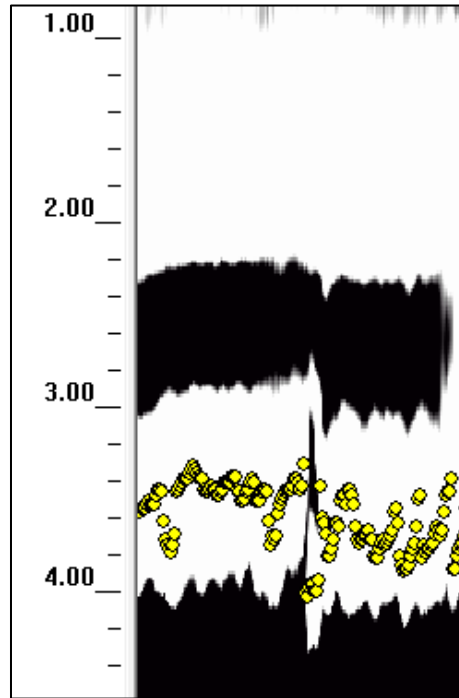


Santa Anita: April 17th, 2023- Sand and Clay track with a pad that is maintained regularly (Cushion layer picked)

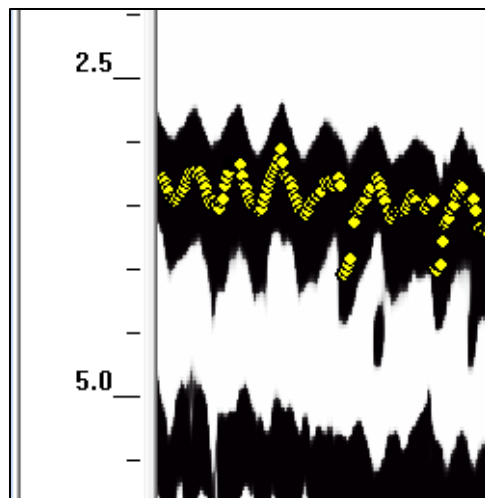




Tampa Bay Downs: March 20th, 2023- (Cushion layer picked)

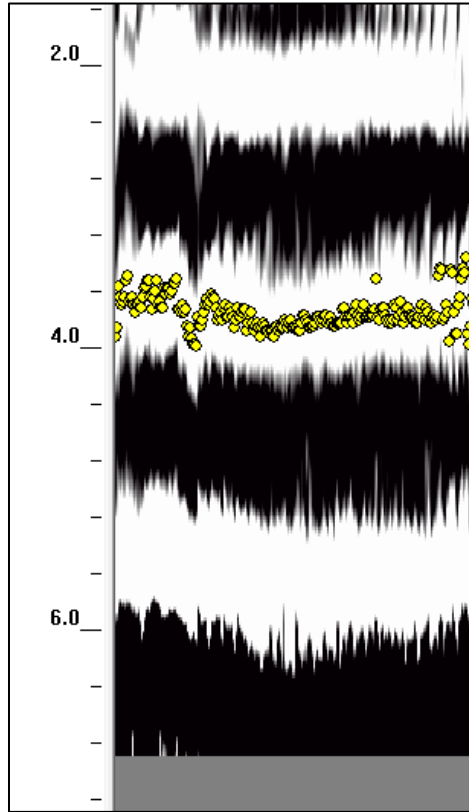


Thistledown: April 12th, 2023- (Cushion layer picked)



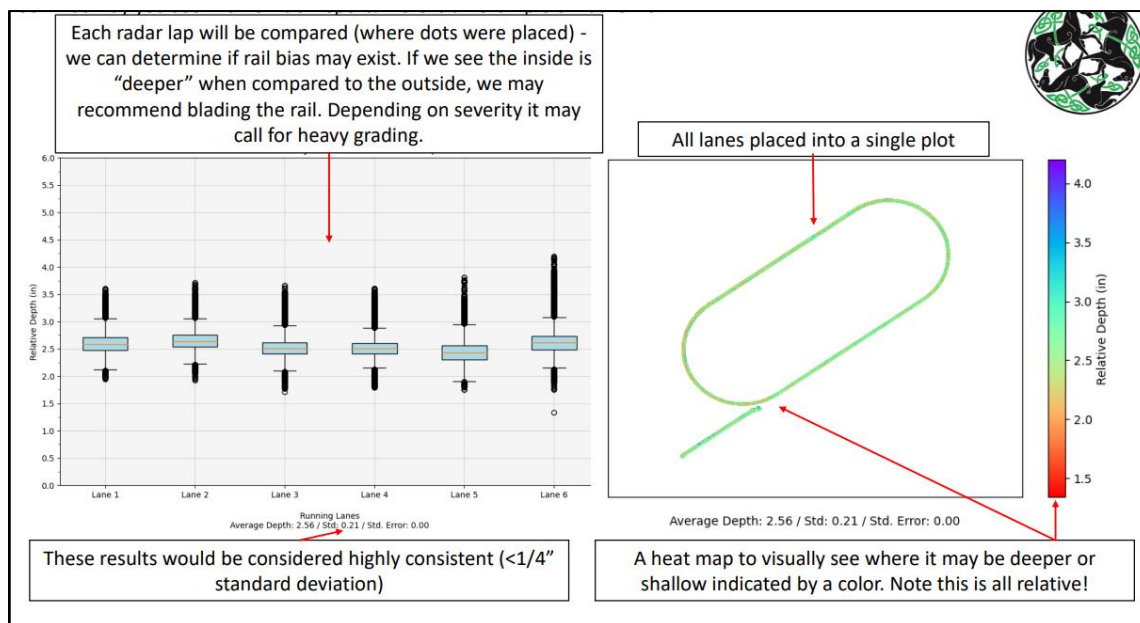
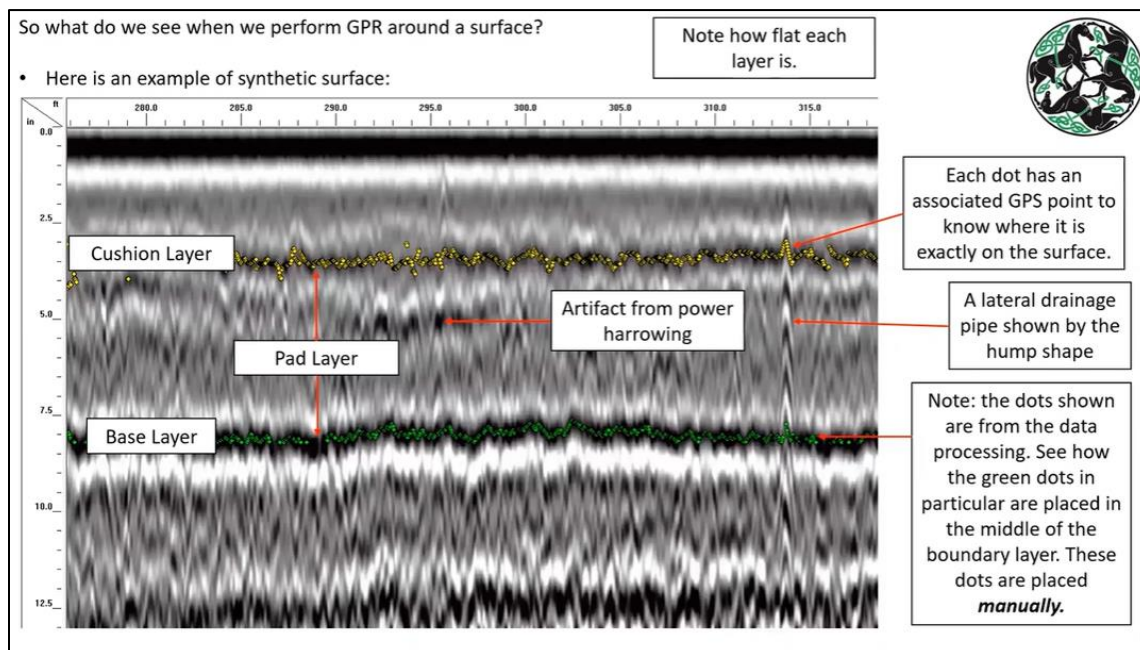


Will Rogers Downs: April 17th, 2023- (Cushion layer picked)



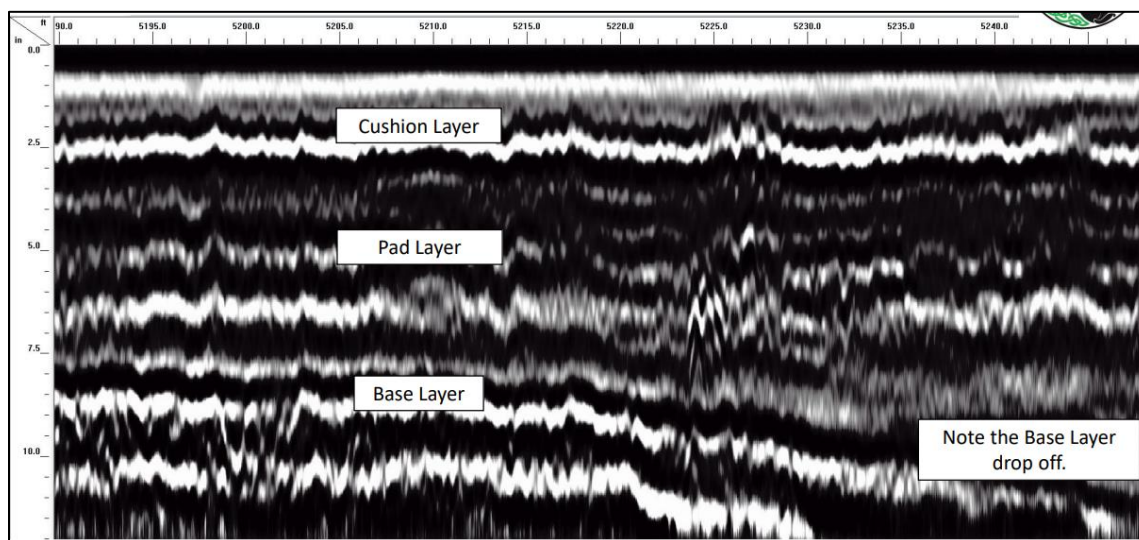
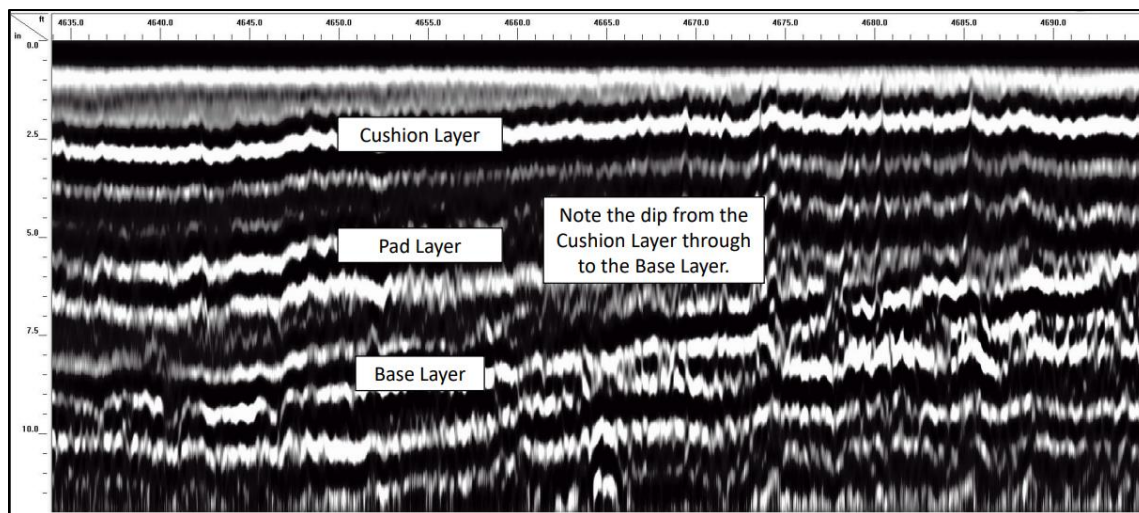


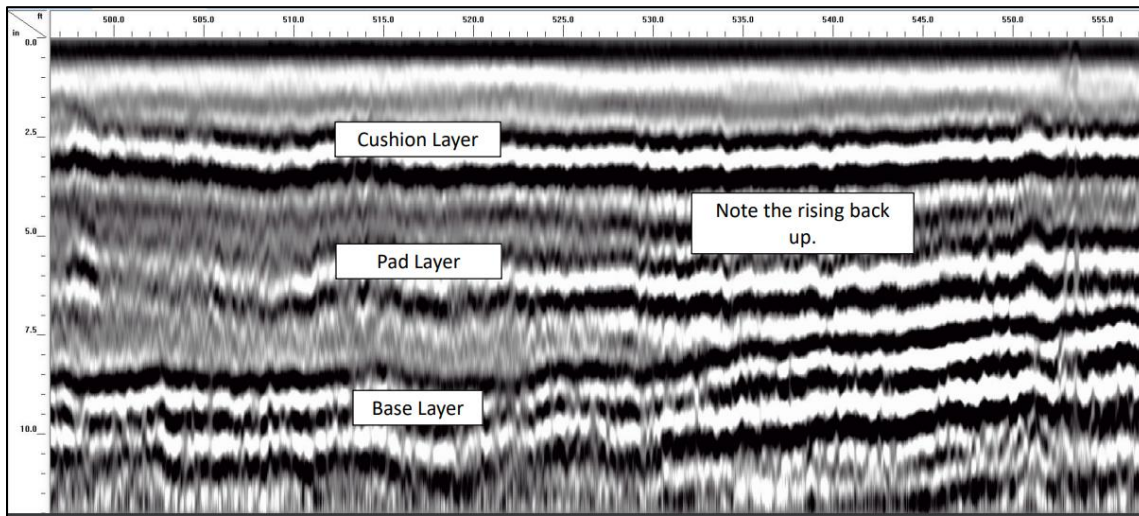
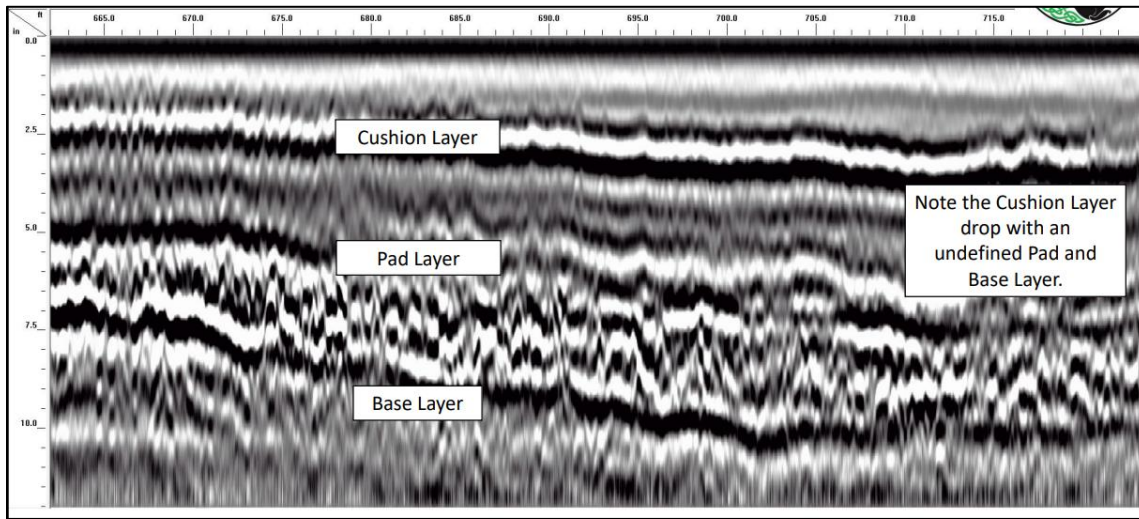
GPR Case 1

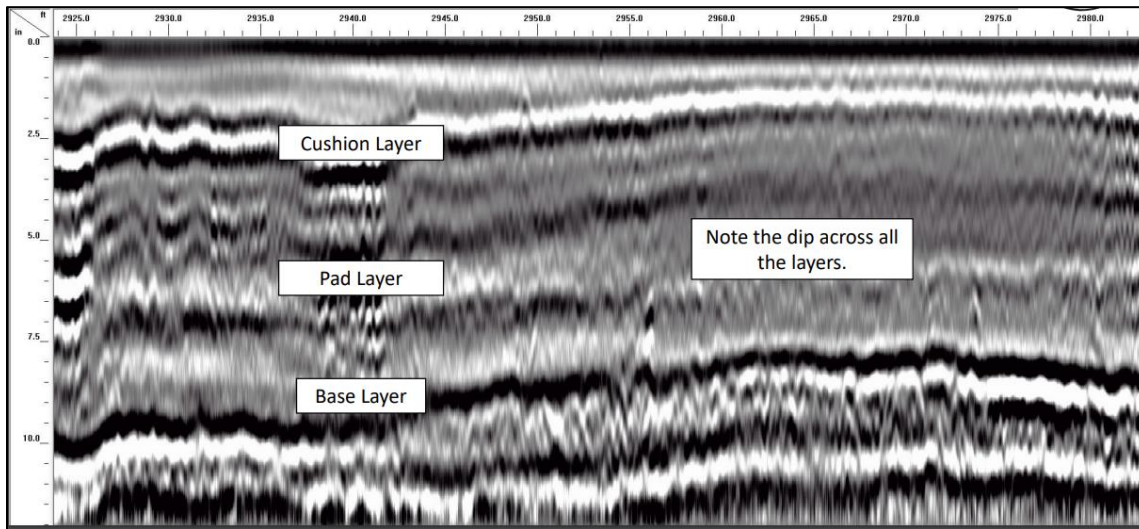
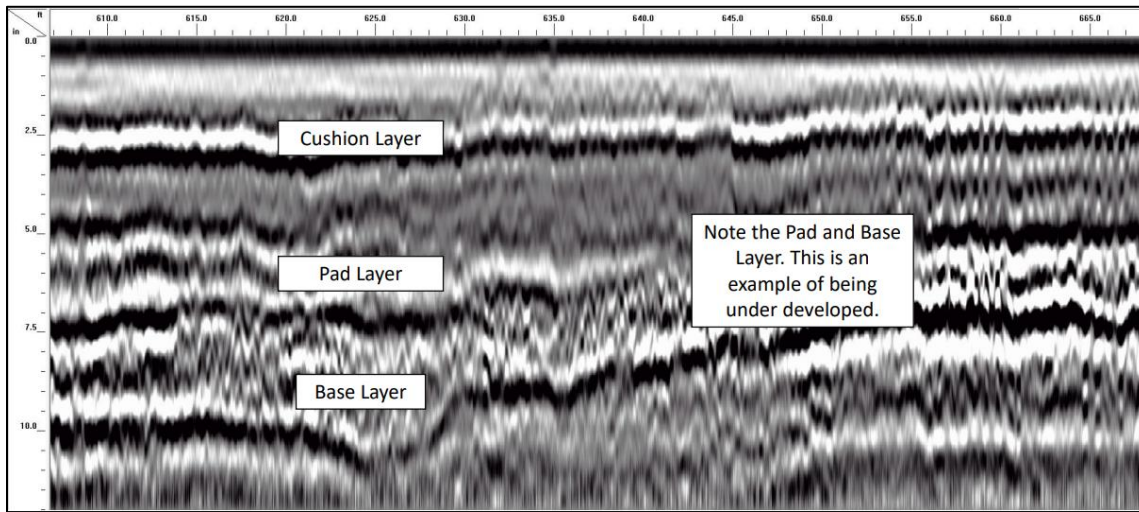


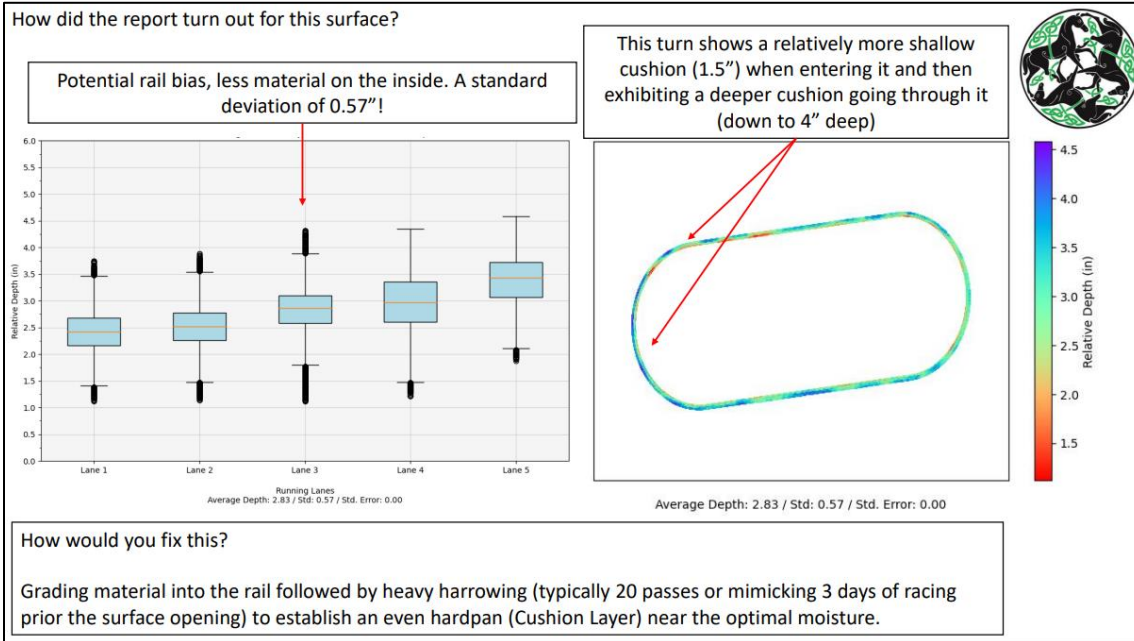


GPR Case 2





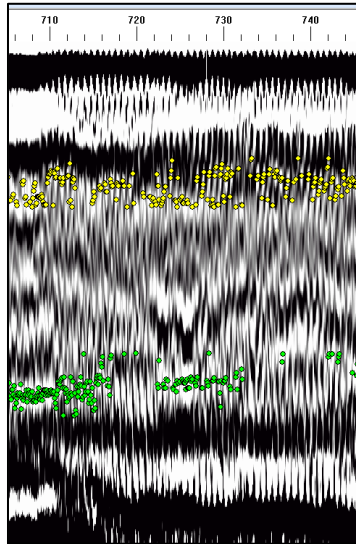




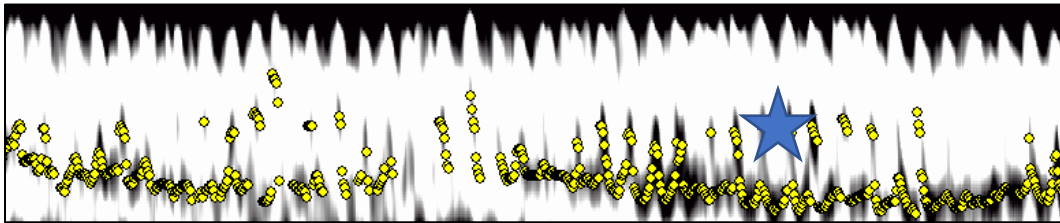


GPR Picking Example Artifacts

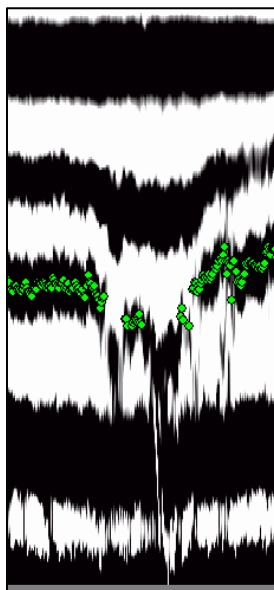
-Remington Park: May 8, 2023- Repaired Base



-Aqueduct: November 2, 2022- Tire Markings



-Pimlico: May 11, 2023- Pipe





Revisions

1) Date: June 16th, 2023

Revisor: Alexis Willis

Change: Creator of SOP