Phase II Environmental Site Assessment First Nations, Thunder Bay, Ontario

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Abstract

The text discusses an environmental assessment of a property owned by Avenors Inc. Pulp and Paper Mill in Thunder Bay, Ontario, Canada. The assessment was carried out in 1996 by Bosgoed Project Consultants as part of a requirement by the Fort William First Nation to investigate the effects of waste disposal on their land. Avenor Inc. Pulp and Paper Mill operated a bark and ash disposal site adjacent to the community from 1973 to 1980. The landfill was closed in 1980 due to a revoked Certificate of Approval issued by the Ministry of Environment of Ontario. The assessment reported an existing leachate percolation through the landfill and a lack of maintenance of the system constructed to treat the leachate, which was ineffective prior to 1996. Abibow Canada Inc., also known as KGS Group Consulting Engineers, has been providing periodic reports on the site since 1994. The First Nation community reported a rise in cases of leukaemia, which was hypothesized to be contributed from the contamination of the bark dump. The aim of the report is to investigate the current migration of the leachate through the landfill to understand the extent of the contamination in the area.

KEYWORDS: leachate plume, contamination, Thunder Bay, First Nation's community

TABLE OF CONTENT

FIGURE LIST

TABLE LIST

1. INTRODUCTION

In 1996 the company Bosgoed Project Consultants reported a Phase II Environmental Issue Inventory as part of a requirement by the Fort William First Nation in order to investigate a property owned by Avenors Inc. Pulp and Paper Mill (1996) located northeast of the community, in the city of Thunder Bay, Ontario, Canada. The consultant company provides air quality, water quality, soil and waste sampling reports in addition to historical background of the owned property. The reason for the investigation was to analyze the effects of waste disposal bordering the First Nation's lands. The company Avenor Inc. Pulp and Paper Mill (1996) operated a bark and ash disposal site adjacent to the community from 1973 to 1980, with a total disposal amount of 130,000 m2/year (Bosgoed Project Consultant Ltd., 1996).

The bark dump site is located at the base of Mt. McKay, along the northern boundary of the First Nation's community. It was used as a shale quarry, which removed more than 380,000 m2 of material over the years of operation (Bosgoed Project Consultant Ltd., 1996). The landfill was closed in 1980 due to a revoked Certificate of Approval No A590111, May 13, 1980, issued by the Ministry of Environment of Ontario (Ministry of Environment of Ontario, 1980). According to Bosgoed Project Consultants (1996) the company built a leachate collection system on the land to mitigate the leachate flow's effects in a long-term operation. The Phase II reported an existing leachate percolation through the landfill based on analysis of the monitoring wells and water quality measured in site (Bosgoed Project Consultant Ltd., 1996). They also reported a lack of maintenance of the system constructed to treat the leachate, which was ineffective prior to 1996 (Bosgoed Project Consultant Ltd., 1996).

Another company involved with the bark dump, Abibow Canada Inc. also known as KGS Group Consulting Engineers, has been providing reports since 1994 on the bark dump site (Abibow Canada Inc., 2010). Since 2010, this group has been providing periodic reports named, Mt. McKay Waste Disposal Site which include information on air, water and groundwater quality, leachate collection system inspections, methane monitoring, background well evaluation, remediation strategy, topographic maps, monitoring of soil sampling, stratigraphy, and boreholes logs, to evaluate the impacts of the dumping site on the First Nation's community (Abibow Canada Inc., 2010).

The First Nation community reported to the city of Thunder Bay a rising in cases of leukaemia, hypothesized to be contributed from the contamination of the bark dump. The aim of the report below is to investigate the current migration of the leachate through the landfill in order to understand the extent of the contamination in the area (Jacome 2023).

2. STUDY AREA, METHODOLOGY AND APPROACH

2.1. Study Area

2.1.1. Configuration of the Bark Dump

The bark dump is an area of 14.18 hectares located in Thunder Bay, Ontario, northeast of the First Nation's community, across Highway 61B (base of Mt. McKay), and it was used as waste disposal for 7 years. According to Bosgoed Project Consultant (1996), the bark dump is composed of 5200 m3 (4%) of wastewater treatment sludge, 6500 m3 (5%) of coil (boiler) ash, 11700 (9%) of lime mud, 11700 (9%) miscellaneous yard debris and construction rubble, 42900 (33%) of reactor ash and 52000 (40%) of bark and wood waste and covered in 1980s. Figure 1 shows the designated area for waste disposal. The landfill has a configuration with the highest elevation measured at the top of 229.113 metres and the lowest elevation measured 189.100 metres as shown in Figure 2.

Figure 1. General Overview Thunder Bay, Ontario, Canada, image taken from Google Earth, 2023 and modified in Surfer Golden Software to show the designated area for waste disposal.

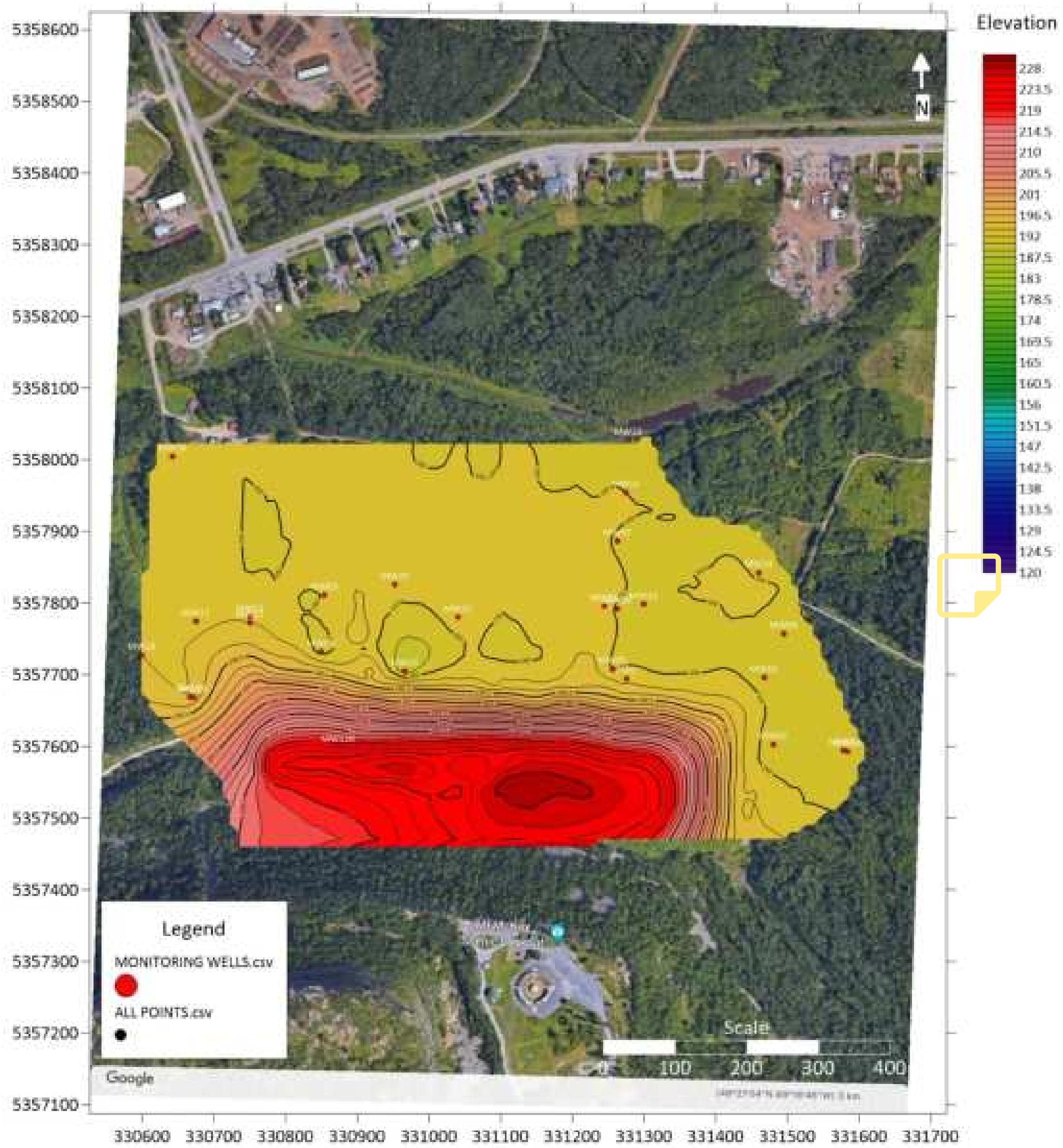

Figure 2. Contour map, elevation of the surface, bark dump, Google Earth 2023 and modified in Surfer Golden Software.

According to Trevisan & Oshki-Aki LP, (2021), the bark dump is monitored using the existing monitoring wells, as the location shown in Figure 3, MW01, MW02, MW03, MW04, MW05, MW06, MW07, MW08, MW09, MW10, MW11R, MW13, MW14, MW15, MW16, MW17, MW18, MW19, MW20, MW21, MW22, MW23, MW24, MW25, MW26, MW27, PW1. The red points on Figure 3 represent the existing monitoring wells and the black points represent the topographic points collected in site (elevation and coordinates). The depth of each monitoring well can be found in section 2.4 of this report.

Figure 3. Overview of the monitoring wells bark dump, Google Earth, 2023 and modified in Surfer Golden Software.

2.2. Methodology and Approach

To understand the existence and extent of contamination, the direction, and the migration of the plume several methodologies were used. One methodology was the application of Electrical Resistivity Tomography (ETR). The ETR provides, upon multiple and repeated measurements, a numerical result of the electrical resistivity and chargeability of the soil in the region of interest. The results correlate with the ability of each substance present in the soil to deliver electrical stimulation (Cheng et al., 2019). According to (Cheng et al., 2019), the ETR can detect; horizontal or gently dipping soil-rock interfaces correctly, soils stored in localized fissures, and can detect if the bedrock is weakly resistive. Bedrocks can be weakly resistive due to potentially intense weathering and a combination of high water and clay content (Cheng et al., 2019). Figure 4 shows the four lines defined by Jacome (2023) to assess the site.

A second methodology used was the Ground Penetrating Radar (GPR). GPR has been previously used successfully at sites to characterize subsurface geology, locate inorganic contaminant plumes, and find buried barrels, pipes and storage tanks (Redman, 2009). In this current investigation (Jacome et al., 2021) used the GPR to assess and find pockets of volatile organic compounds (VOCs) in the soil. VOCs are known to get trapped in the high clay content layers (Jacome et al., 2022) Due to the above reason, the GPR was also passed through the field, following the grid lines previously determined, in order to collect the image of the possible voids in the clay layers.

The third methodology involved the integration of the contour and isopach maps in order to model a stratigraphy of the soil. The isopach maps show the thickness of each type of soil and allows one to identify the probable location and percolation of the leachate plume since soils with high clay content have low permeability. One of the properties of clay is the ability to trap gasses originating from the biodegradation of the contamination due to its high-density properties.

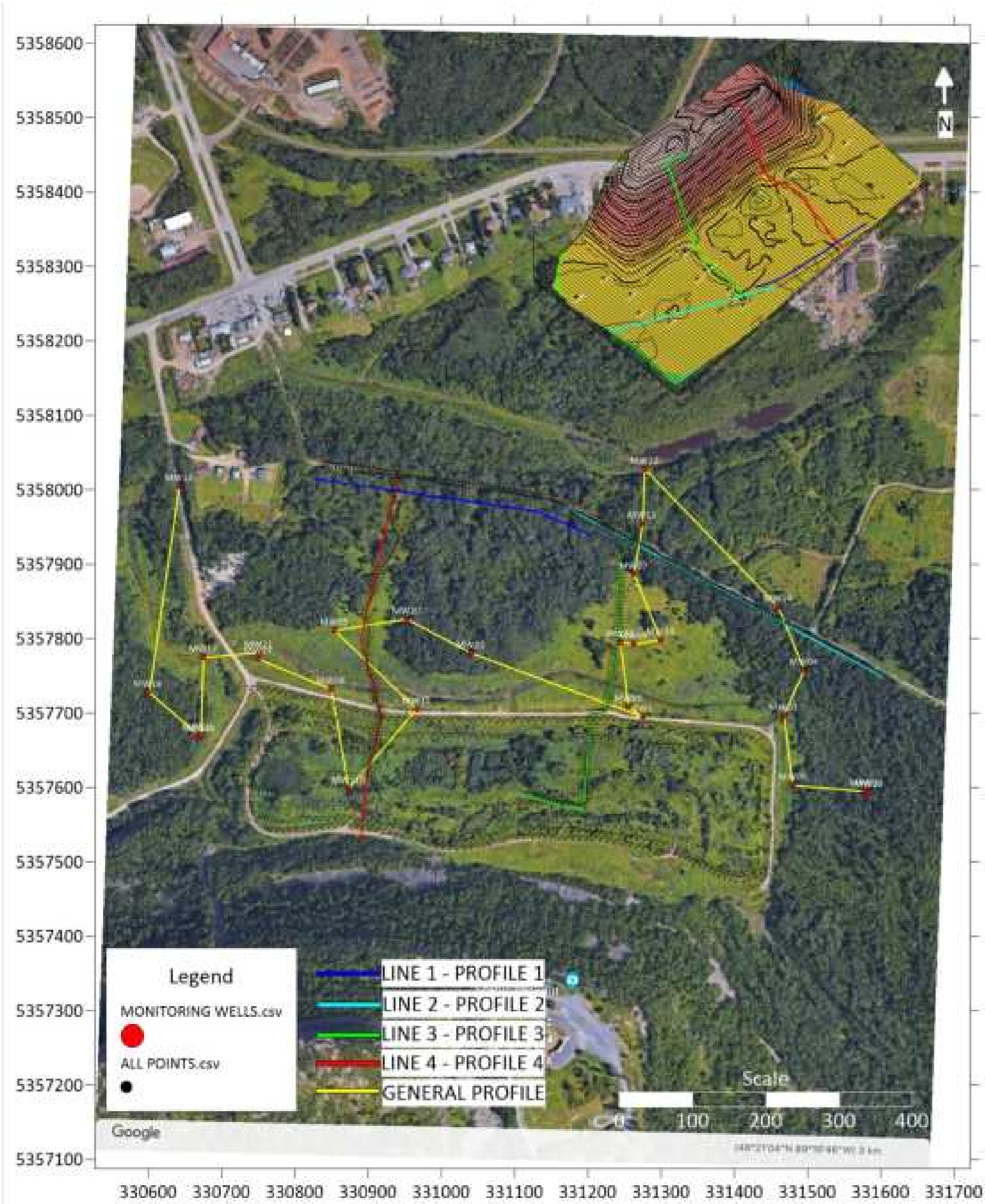

Figure 4. Overview lines of collecting data and profiles Google Earth, 2023 and modified in Surfer Golden Software.

The last methodology used was to measure the concentrations of carbon dioxide and methane on site during the assessment and to check the values of the water quality report provided by KGS Group from 2010 to 2021 (Trevisan & Oshki-Aki LP, 2019).

2.2.1. Defining Area of Concern

This report creates areas of concern (AC) to describe an issue, problem, or abnormal data collected that needs to be addressed, investigated, or discussed. Those areas were applied mainly in the ETR and in the GPR.

3. ELECTRICAL RESISTIVITY TOMOGRAPHY (ETR)

3.1. Procedures, Electrical Resistivity Tomography (ETR)

The electrodes were placed 5 metres away from one another along the surveyed lines. In Figure 4, the lines are labelled as: Line 1 through 4. During the installation, it was important to build a bed for the electrodes before humming it into the soil since the organic material can interfere with the data collected. Crocodile connectors link the electrodes to the cable that delivers the electricity from the tomography to the connectors. The tomography is fed by 12V batteries and were installed in the middle point of the cable. Salty water was poured into the bed for the electrodes to create a positive electrical interface between the electrode and the soil.

The tomography checked for the functioning of the electrodes and provided a warning if one of the electrodes is malfunctioning. In the case that an electrode was not functioning, a check was conducted to identify the problem. Finally, the tomography read the resistivity and chargeability of all electrodes during approximately 3 hours and 40 minutes.

Table 1. Materials used during the ETR procedures.

• Tomography • Electrodes • Cable	• Crocodile Connectors • Battery 12V • 5L of distilled water	• Salt • Hummer • Hand Shovel

3.1.1. Software for Analysis

The software used to process the ETR data collected was Surfer. The program allowed to map the areas of high and low resistivity and chargeability from the tomography.

Software: Surfer Golden Software V25 2023

Developer: Golden Software

3.1.2. Parameters of Analysis of Resistivity and IP Chargeability

Most of the geological materials found in soil are generally poor conductors, except for sulphide ore and graphite. Poor conductivity helps the contaminants sleuth, which is detected by the vast tools used to collect data. Geological materials vary in their resistivity due to the differences in their physical and chemical properties. Different minerals and rocks have different electrical properties, which can affect their resistivity.

In summary, resistivity measures the capacity of the soil to deliver electrical stimulation; some materials, such as quartz, are highly resistive, while others, such as graphite, are highly conductive. Additionally, the porosity of a material affects its resistivity, according to (Loke, 2004), a high (saturated) porosity and clay content will significantly increase the conductivity of a soil. According to (Waxman & Smits, 1968), clays have the capability to absorb large amounts of ions, and even a small clay presence can lower the electrical resistivity of a soil significantly. Additionally, local resistivity changes may also reflect fracture zones filled with pore water, ore bodies or other structures (Robert et al., 2010).

Chargeability measures the residual electrical potential of the electrical stimulation during the application of the ETR. The induced polarization effect is a material's ability to temporarily retain a residual charge from an induced current, essentially forming a capacitor (Butler, 2005). In fact, the relationship between the resistivity and conductivity is inversely related, however the conductivity is directly proportional to the chargeability since both measure the capacity of the material to deliver the current in different ways (Butler, 2005). The table below represents the different analysis completed by different authors about the reading of resistivity and chargeability in past years of investigations.

Table 2. Interpretation of resistivity and chargeability, (Abdulrahman et al., 2016).

IP in landfills after Abdulrahman et al. 2016

Subsurface section	*Resistivity (Ωm)*	*IP (msec)*
Uncontaminated saturated soil	Intermediate (30-150) (Guerin et al., 2004; Dahlin et al., 2010)	Low (<20) (Dahlin et al, 2010)
Uncontaminated saturated clay	Low (<10) (Guerin et al., 2004)	High (>70ms) (Slater et al. 2006, Breede and Kemna 2012, Gazoty et al., 2012)
Unsaturated soil	High (> 1000) (Leroux et al., 2007)	Low (<20) (Leroux et al., 2007)
Unsaturated waste	High(>1000)(Leroux et al., 2007; Dahlin et al., 2010)	High (>70) (Dahlin et al., 2010)
Saturated waste without leachate	Intermediate (30-150) (Dahlin et al, 2010)	High (>70) (Dahlin et al, 2010)
Mixture of Leachate and Waste	Low (<10) (Dahlin et al, 2010)	High (>70ms) (Dahlin et al, 2010)
Leachate plume	Low (<10) (Guerin et al., 2004; Kaya et al., 2007)	Low (<20) (Gallas et al., 2011)

The IP might help in differentiate between clays and leachate, both with comparable low resistivities

3.1.3. Stratigraphic Profile East-West (EW) Line 1

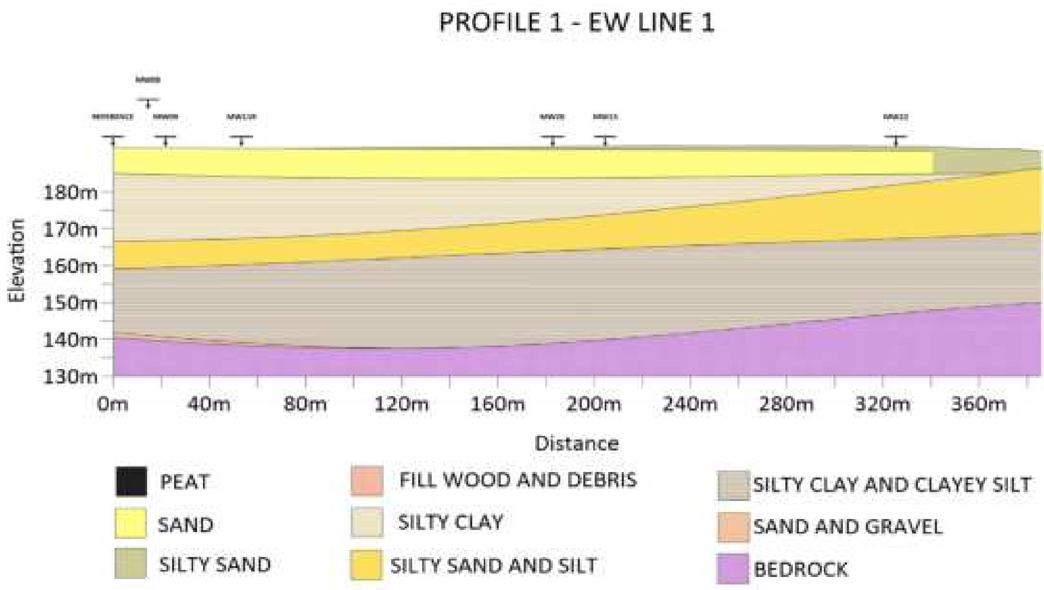

Figure 5. Profile 1 - EW LINE 1, describes the stratigraphy of the soil.

3.1.4. EW - Line 1 - Results Resistivity (oms.m)

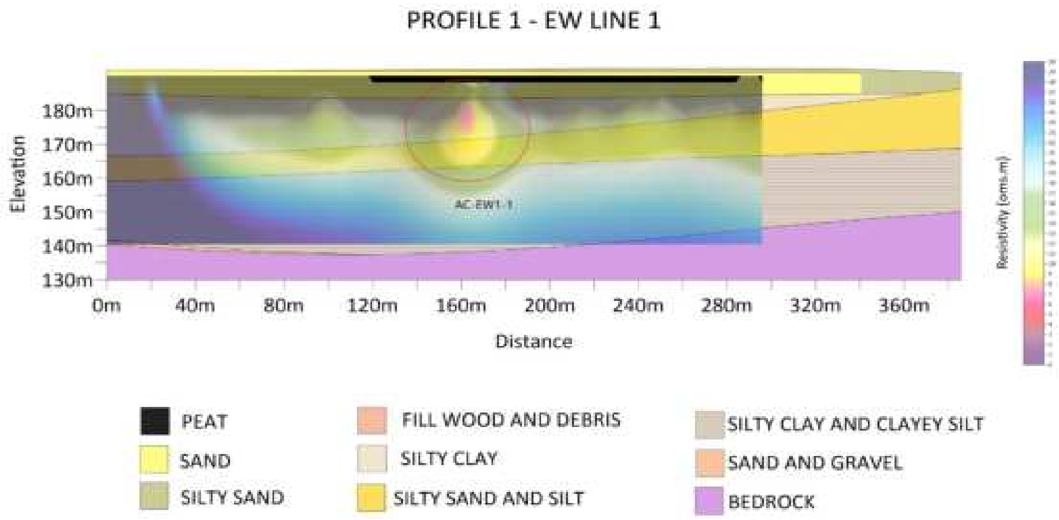

Figure 6. Profile 1 - EW LINE 1, describes the resistivity of the soil.

3.1.5. EW Line 1 - Chargeability

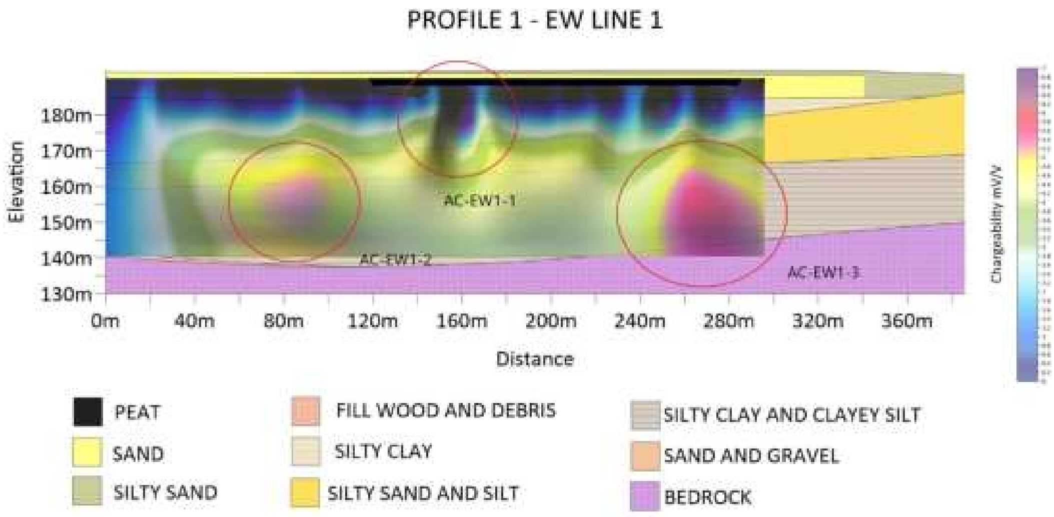

Figure 7. Profile 1 - EW LINE 1, describes the chargeability of the soil.

3.1.6. Analysis ETR EW Line 1

The Profile 1 - EW LINE 1 starts from East (0m) to West (385.80m) and intersects the NS LINE 4 at 109 metres from the beginning. The total elevation of the profile is 192.43 metres.

Area of Concern (AC):

- AC-EW1-1 - The area of concern EW1-1 presents with a high value of resistivity and low value of chargeability. The centre of the area is 160 metres along line 1 and has an average elevation of 180 metres from the surface. The area has, approximately, a length of 20 metres and a depth of 21 metres. The composition of the soil in this area is silty clay and silty sand and silt.
- AC-EW1-2 - The area of concern EW1-2 presents with a slight rise in the value of chargeability and had a high value of resistivity. The centre of the area is 80 metres along Line 1 and has an average elevation of 155 metres from the surface. The area has, approximately, a length of 41 metres and a depth of 19

metres. The composition of the soil in this area is silty clay and clayey silt and silty sand and silt.

- AC-EW1-3 - The area of concern EW1-3 presents with a considerable rise in chargeability and a low value of resistivity. The centre of the area is 270 metres along Line 1 and has an average elevation of 150 metres. The area has, approximately, a length of 46 metres and a depth of 26 metres. The composition of the soil in this area is silty clay and clayey silt and bedrock.

3.1.7. <u>Stratigraphic Profile East-West Line 2</u>

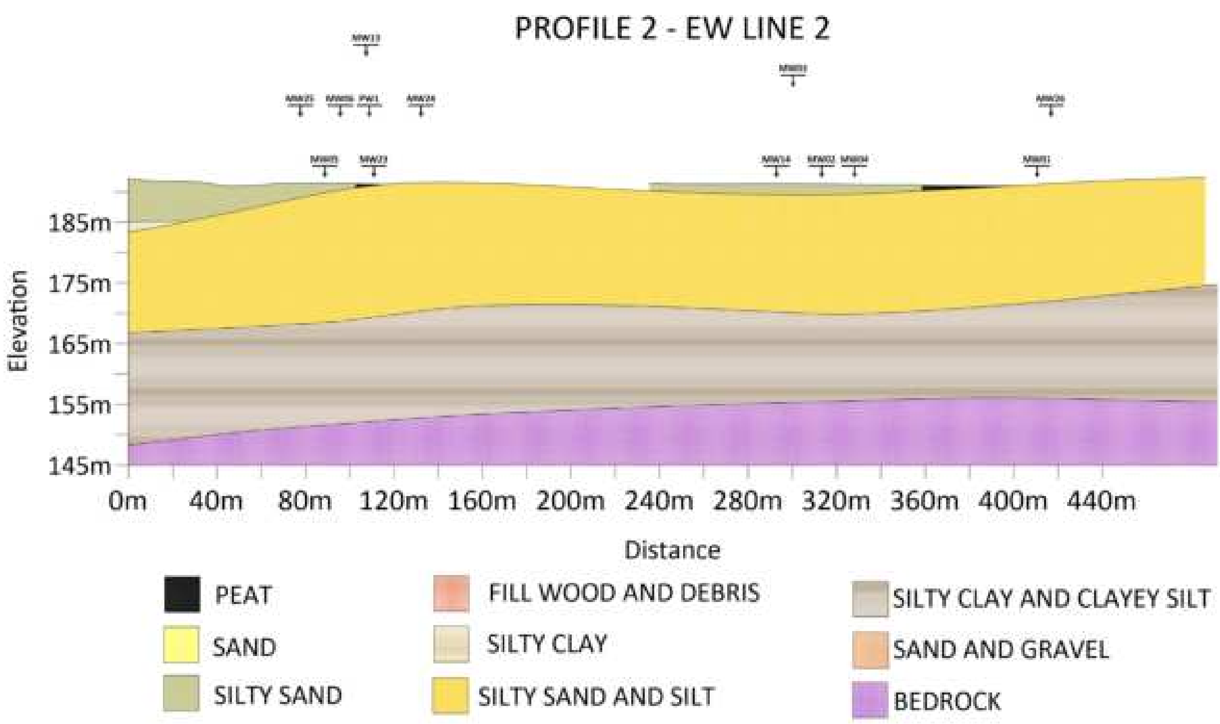

Figure 8. Stratigraphy of the soil, profile 2.

3.1.8. EW Line 2 - Resistivity

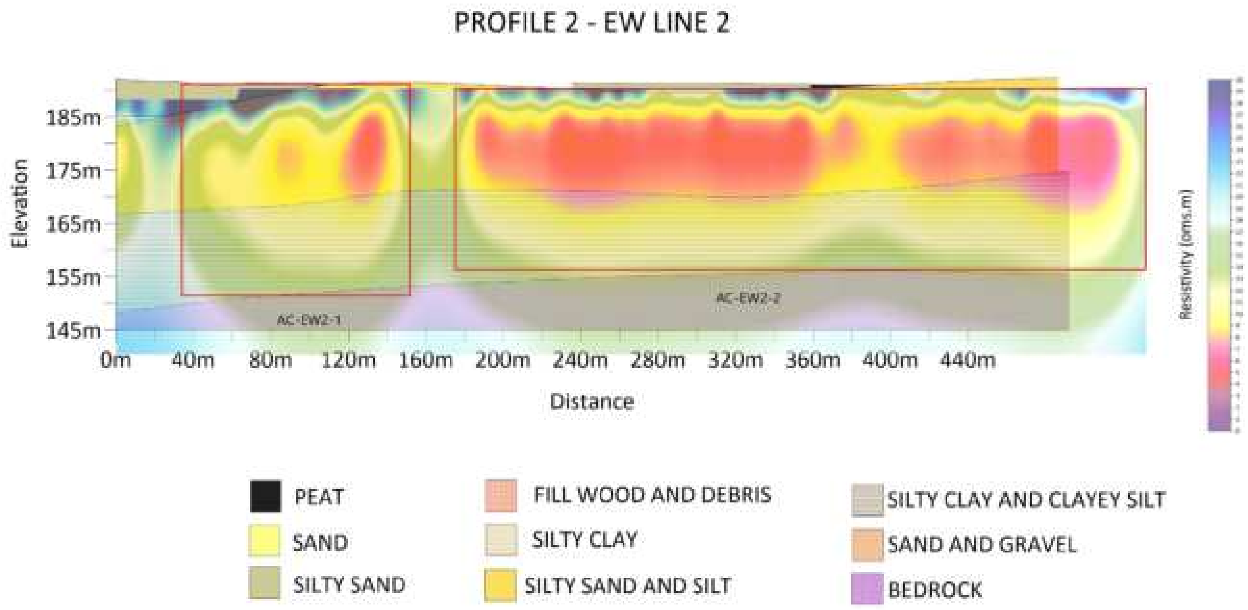

Figure 9. Resistivity Line 2 and areas of concern.

3.1.9. EW Line 2 - Chargeability

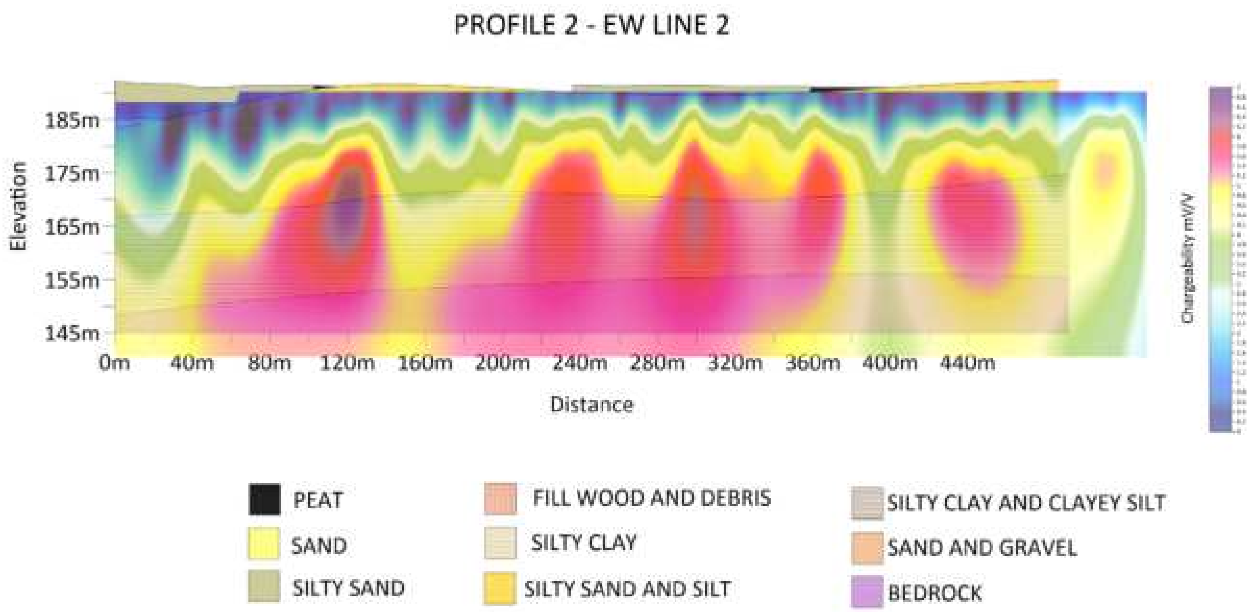

Figure 10. Chargeability Line 2.

3.1.10. Analysis ETR East-West (EW) Line 2

The Profile 2 - EW LINE 2 starts from East EW LINE 1 (375.80m (0m)) to West (867.95m (492.15m)) and intersects the NS LINE 3 at 100 metres from the beginning. The total elevation of the profile is 192.33 metres.

Areas of Concern

- AC-EW2-1: The area of concern EW2-1 presents with high values for resistivity and chargeability. The centre of the area is located 120 metres from the beginning and has an average elevation of 170 metres. The area has, approximately, a length of 129 metres and a depth of 35 metres. The composition of the soil in this area is silty clay, silty sand and silt.
- AC-EW2-2: The area of concern EW2-2 presents with the same characteristics as EW2-1 for resistivity and chargeability. The centre of the second area of concern is located 360 metres from the beginning, with an average elevation of 170 metres from the surface. The area has, approximately, a length of 353 metres and a depth of 31 metres. Along the areas of concern, the layers are composed of silty clay and clayey silt and silty sand and silt.

3.1.11. Stratigraphic Profile North-South (NS) Line 3

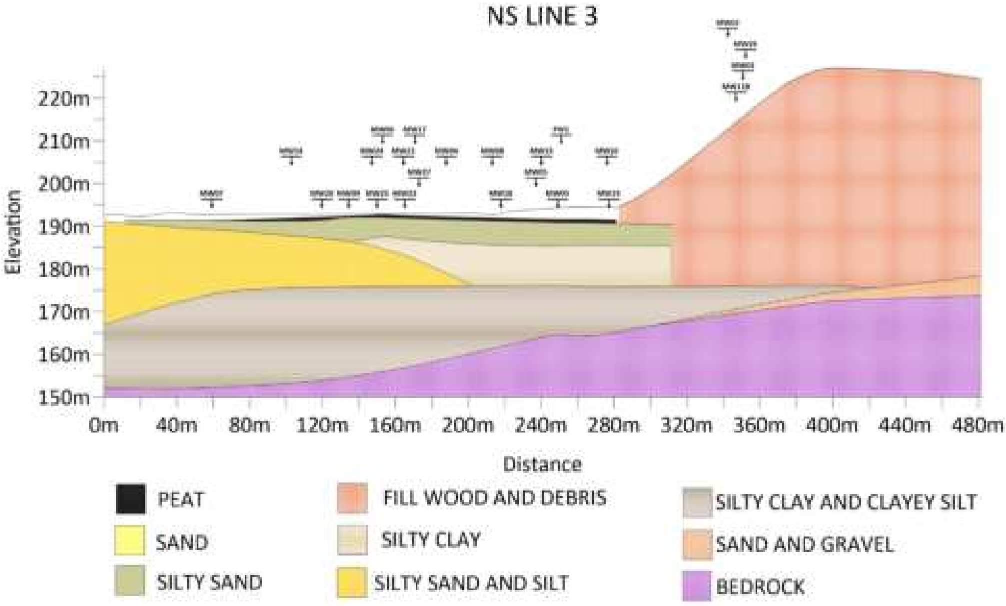

Figure 11. Stratigraphy of soil Line 3.

3.1.12. NS Line 3 - Resistivity

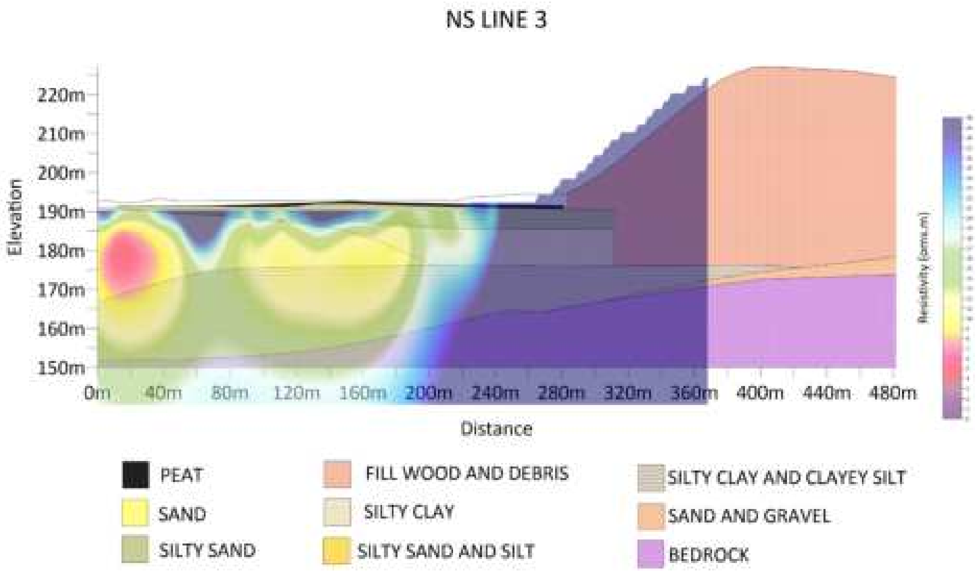

Figure 12. Resistivity of Line 3.

3.1.13. NS Line 3 - Chargeability

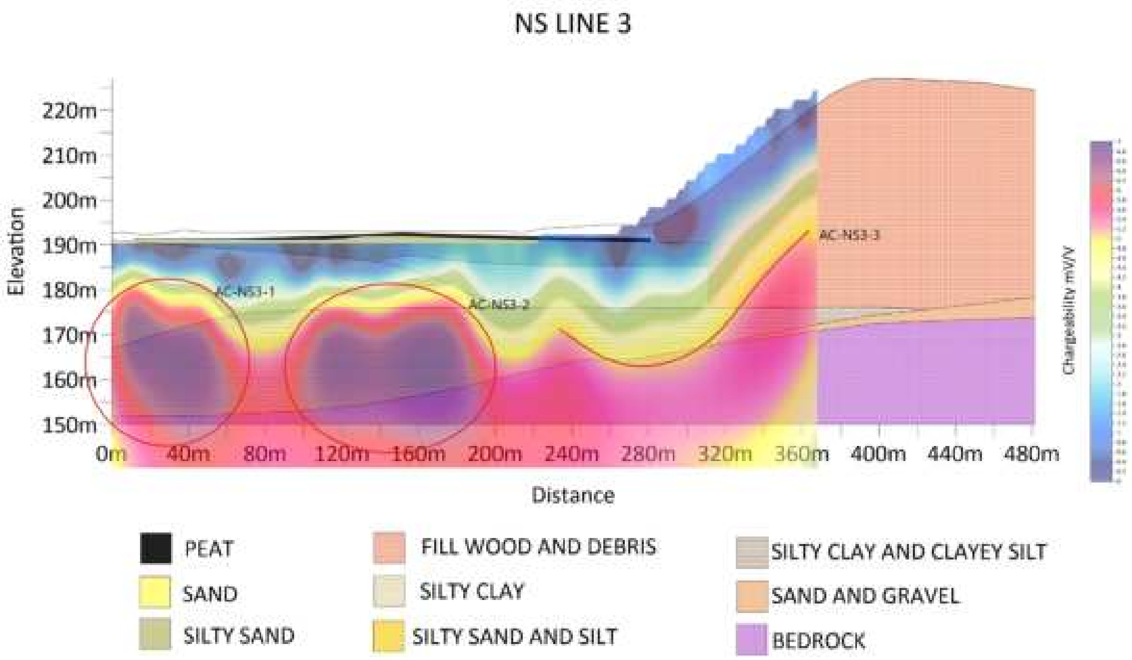

Figure 13. Chargeability of Line 3 and areas of concern.

3.1.14. Analysis ETR North-South Line 3

The profile NS LINE 3 starts from North (0m) to South (481.60m) and intersects EW LINE 2 at 15 metres from the beginning. The total elevation of the profile is 227.04 metres.

Areas of Concern

- AC-NS3-1: The area of concern NS3-1 presents with a slightly high value for resistivity and a high value in chargeability. The centre of the area is located 35 metres from the beginning and has an average elevation of 165 metres. The area has, approximately, a length of 61 metres and a depth of 30 metres. The composition of the soil in this area is silty clay, silty clay and clayey silt, sand and gravel, silty sand and silt and bedrock.
- AC-NS3-2: The area of concern NS3-2 presents with the same characteristics as NS3-1. The centre of the area is located 140 metres from the beginning and has

an average elevation of 165 metres. The area has, approximately, a length of 129 metres and a depth of 35 metres. The composition of the soil in this area is silty clay, silty clay and clayey silt, sand and gravel and clayey silt and silty sand and silt.

- AC-NS3-3: The area of concern NS3-3 presents with a high value of chargeability connecting the bark dump to NS3-1 and NS3-2. The centre of the area is located from an elevation of 180 metres to 155 metres. The area has, approximately, a length of 175 metres and a depth of 25 metres. The composition of the soil in this area is fill wood debris, silty clay and clayey silt, sand and gravel, and bedrock.

3.1.15. <u>Stratigraphy NS Line 4</u>

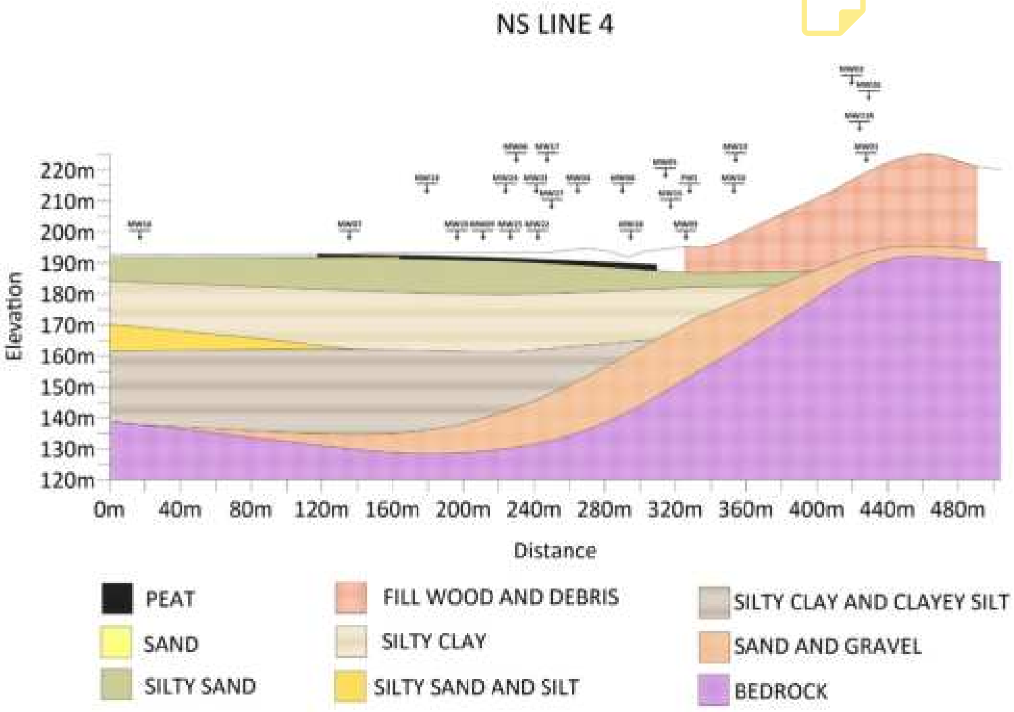

Figure 14. Stratigraphy of the soil Line 4.

3.1.16. NS Line 4 - Resistivity

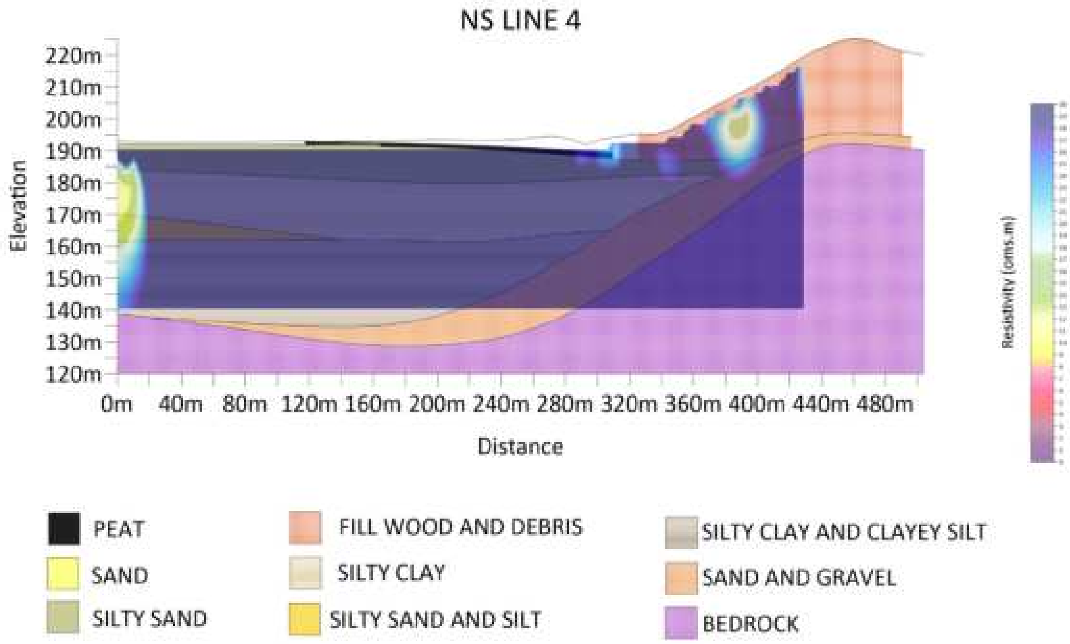

Figure 15. Resistivity of Line 4.

3.1.17. NS Line 4 - Chargeability

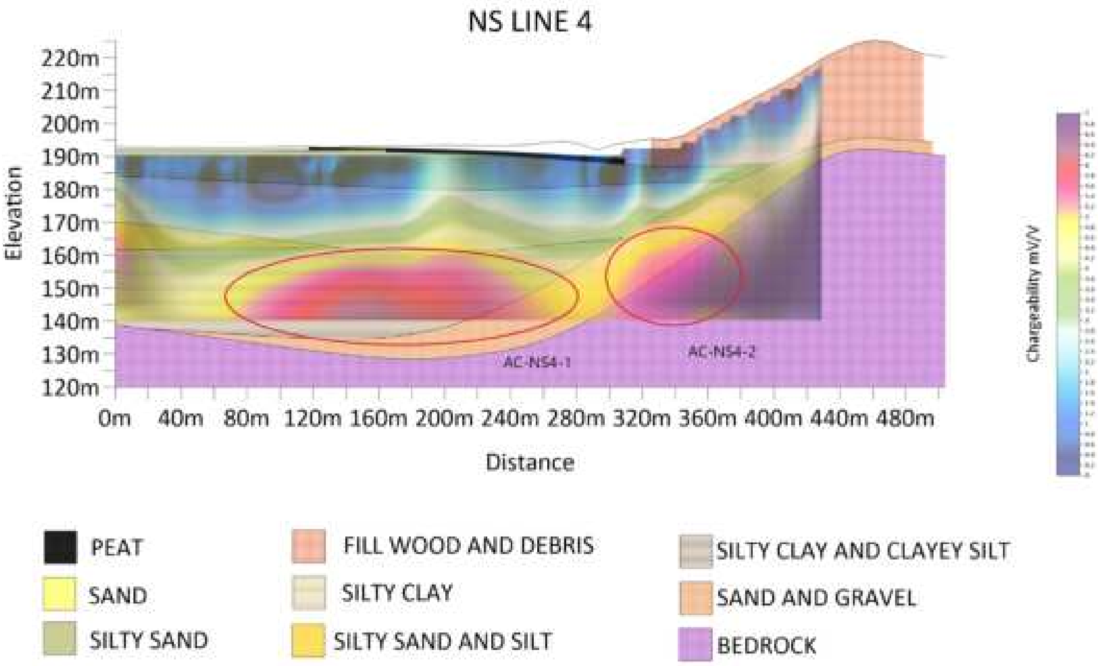

Figure 16. Chargeability of Line 4 and areas of concern.

3.1.18. Analysis ETR North-South Line 4

The profile NS LINE 4 stars from North (0m) to South (504.09m) and intersects the EW LINE 1 at 24 metres. The total elevation of the profile is 225.28 metres.

- AC-NS4-1: The area of concern NS4-1 presents with a low value in resistivity and a high value in chargeability. The centre of the area is located at 180 metres from the beginning and has, approximately, an average elevation of 140 metres. The area has, approximately, a length of 200 metres and a depth of 21 metres. The composition of the soil in this area is silty clay and clayey silt, sand and gravel, silty sand and silt and bedrock.
- AC-NS4-2: The area of concern NS4-2 presents with the same characteristics as NS4-1. The centre of the area is located 340 metres from the beginning and has an average elevation of 150 metres. The area has, approximately, a length of 30 metres and a depth of 26 metres. The composition of the soil in this area is sand and gravel, and bedrock.

4. GROUND PENETRATING RADAR (GPR)

4.1. Procedures, Ground Penetrating Radar (GPR)

The GPR equipment must be installed according to the manufacturer's instructions. It involves having to connect the control unit, antenna, data storage device and the GPS. The frequency must be adjusted in accordance with the depth of the area being surveyed. In this site, the area surveyed was 100Mhz. The collection of the data consists in moving the antenna across the required area and monitoring the data collected by the GPR system. The GPR then detects any objects that may be buried beneath the surface. The GPR was used in Line 1 and Line 2 during the installation of the ETR on October 23rd, 2022. The GPR passed through Line 3 on October 25th, 2023 and in Line 4 on October 26th, 2022.

4.1.1. Software for Analysis

Software: Ekko Project V5 R3.

Developer: Sensor and Software from Radiodetection.

4.1.2. Configuration and processing of the images

Bandpass was the methodology used to process the images. According to Sensor and Software, 2023, Bandpass processes whereby a range of frequencies are retained in GPR data and all other frequencies are suppressed. GPR are ultra-wideband recording devices and can contain noise signals that are not created by the GPR transmitter. Judicious selection of the frequencies to retain and suppress can enhance the interpretability of GPR images. Bandpass filtering is most commonly achieved by Fourier Analysis and spectrum weighting, but it can also be achieved by temporal convolution of the GPR signal with the suitable temporal filter impulse response. The range of frequencies used in the Bandpass filter corresponds to Fc1 = 40, Fp1 = 80, Fp2 = 120 and Fc2 = 160 Jacome (2023).

- Colour Palette Settle up: Seismic.cmp;
- Velocity: 0.080 m/ns;
- Gain: Minimum gain settled up 5 and maximum 7.

4.1.3. Interpretations GPR Image - EW LINE 1

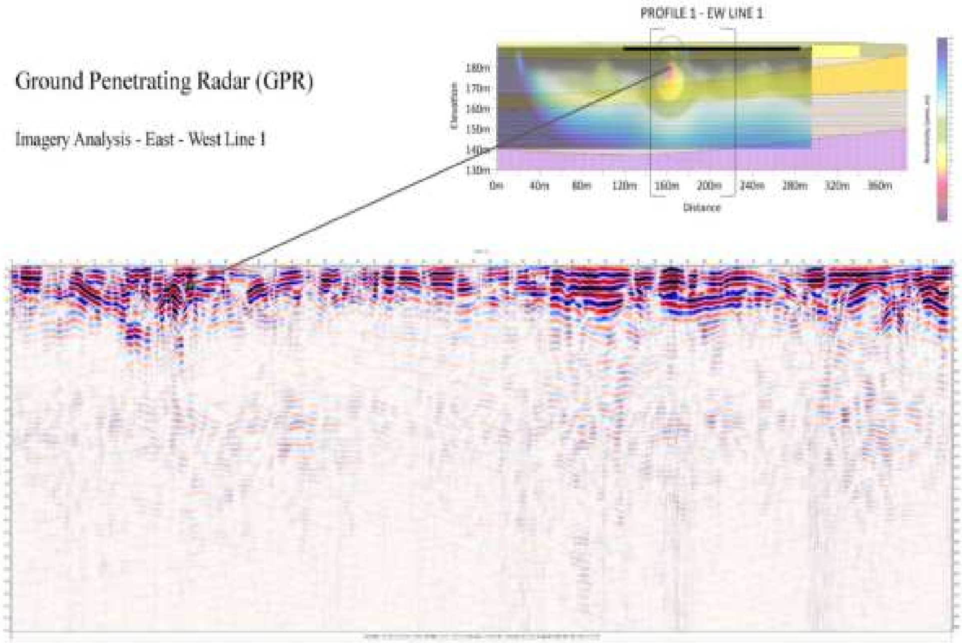

Figure 17. Local interpretation of resistivity of the area of concern AC-EW1-1.

Figure 17 shows the area of concern AC-EW1-1. The GPR shows a consistent area of deflection that according to Jacome et al., (2021) is related to a deposit of clay.

4.1.4. Raw Data Collected EW-LINE 1

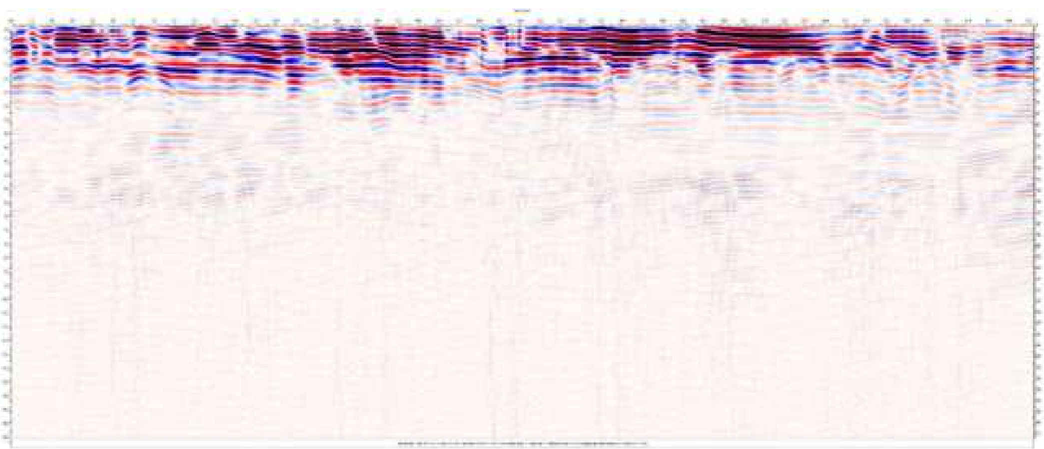

Figure 18. GPR - LINE 1 0 to 50 metres.

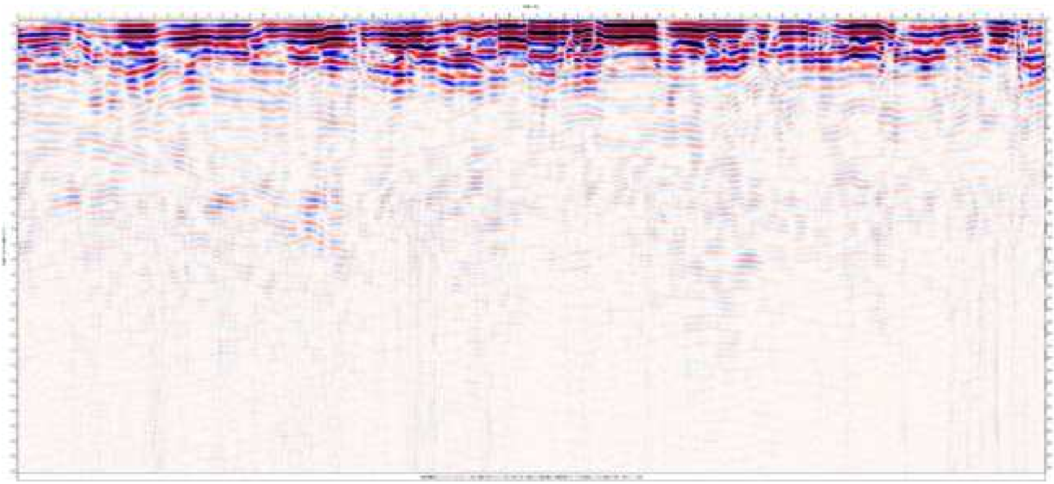

Figure 19. GPR - LINE 1 50 to 125 metres.

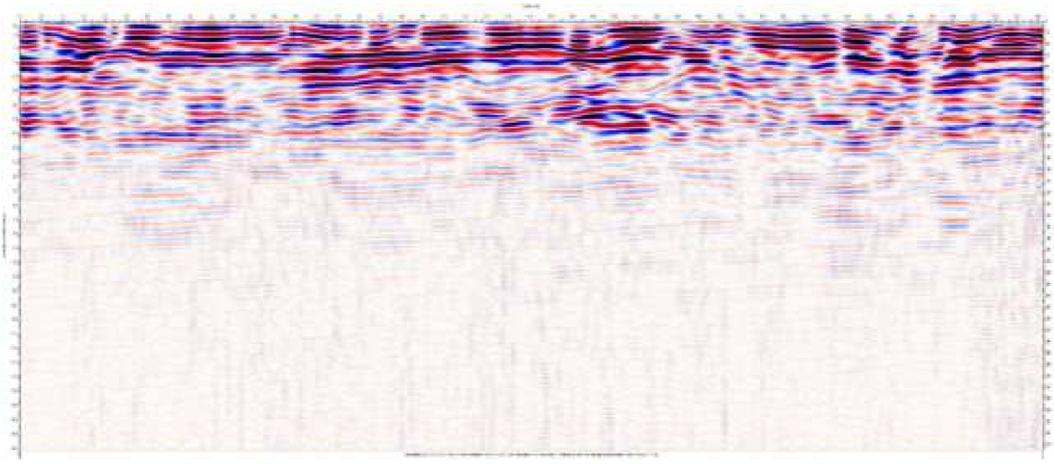

Figure 20. GPR - LINE 1 125 to 149 metres.

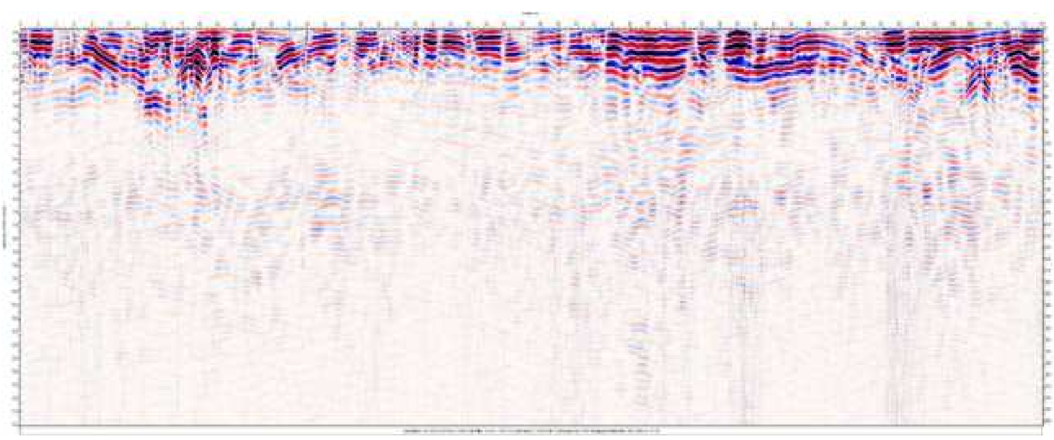

Figure 21. GPR - LINE 1 149 to 228 metres.

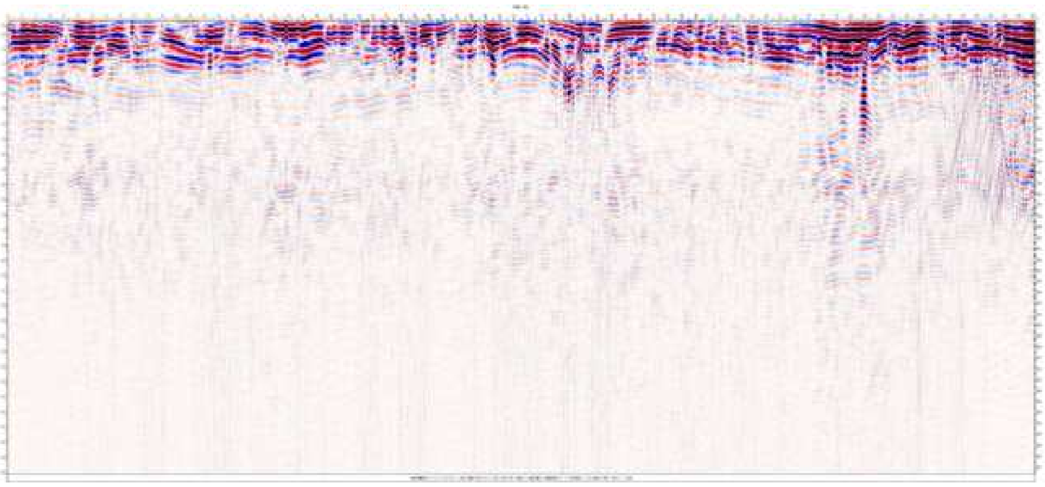

Figure 22. GPR - LINE 1 228 to 374 metres.

4.1.5. Interpretation GPR Image - EW LINE 2

Figures 23, 24 and 25 show all points of possible pockets of VOC along Line 2. The GPR shows a non-consistent area of deflection that according to Jacome et al., (2021) is related to voids into the soil.

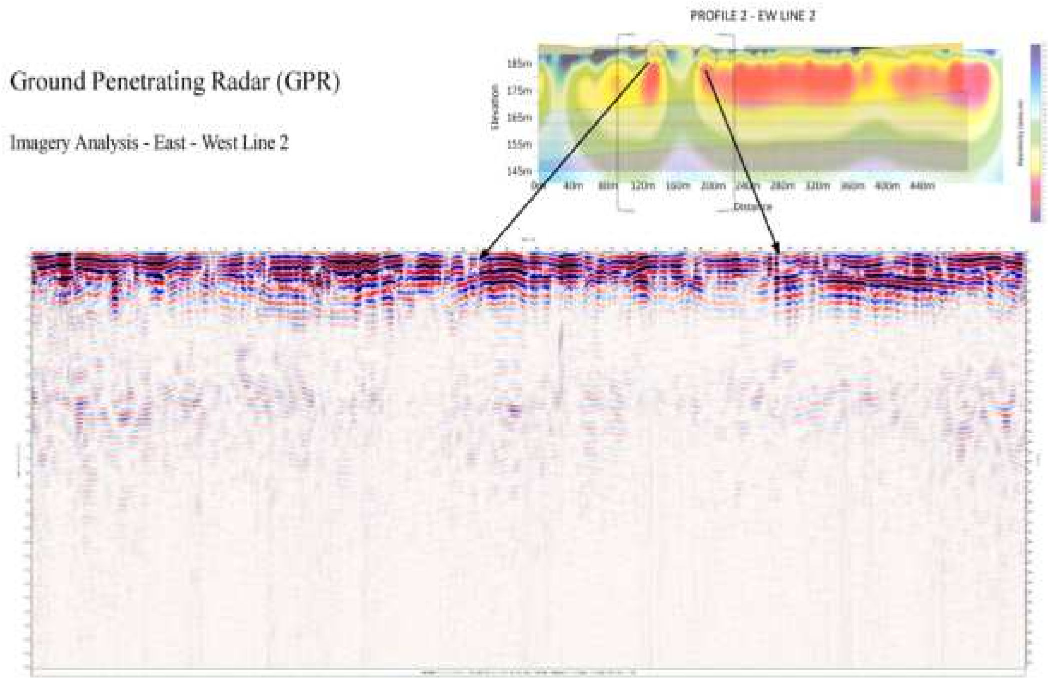

Figure 23. Local interpretation of resistivity of the area of concern AC-EW2-1.

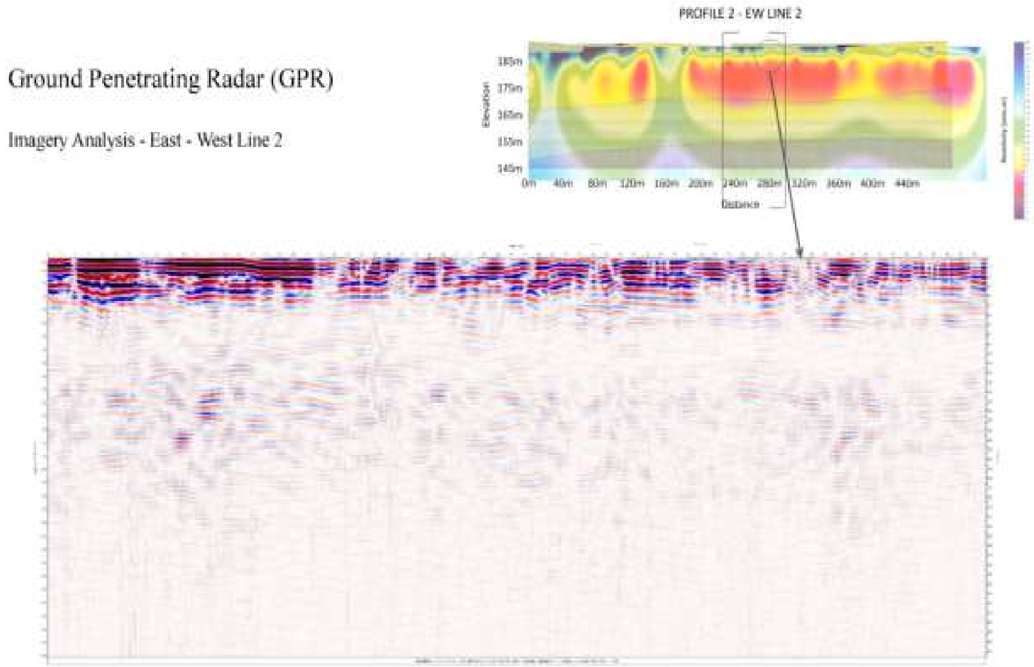

Figure 24. Local interpretation of resistivity of the area of concern AC-EW2-2.

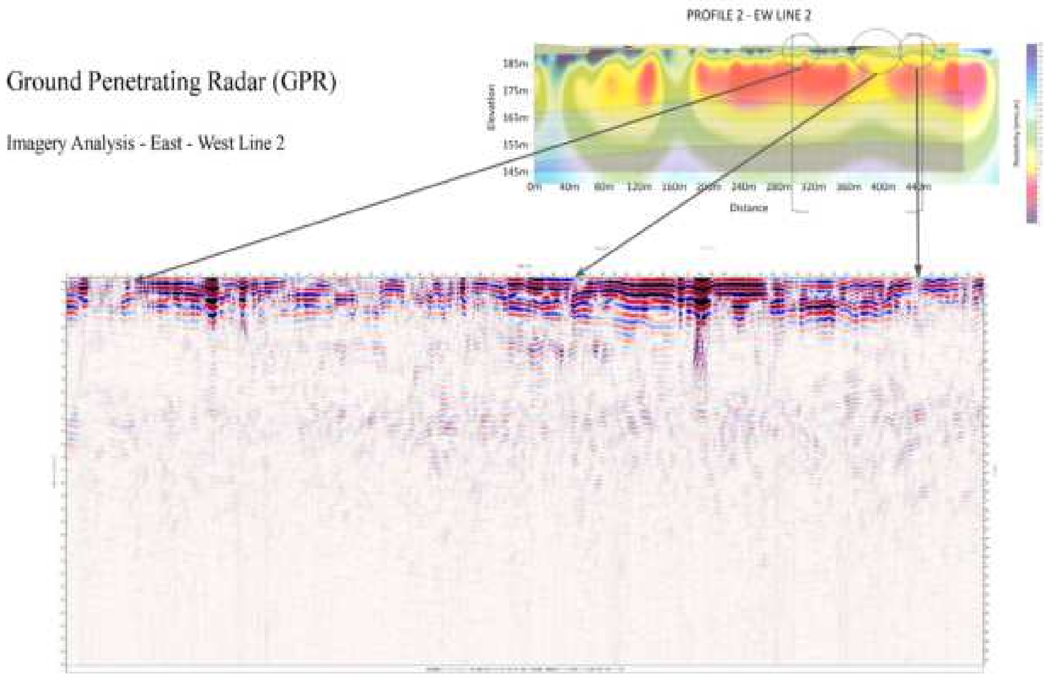

Figure 25. Local interpretation of resistivity of the area of concern AC-EW2-2.

4.1.6. Raw Data Collected EW-LINE 2

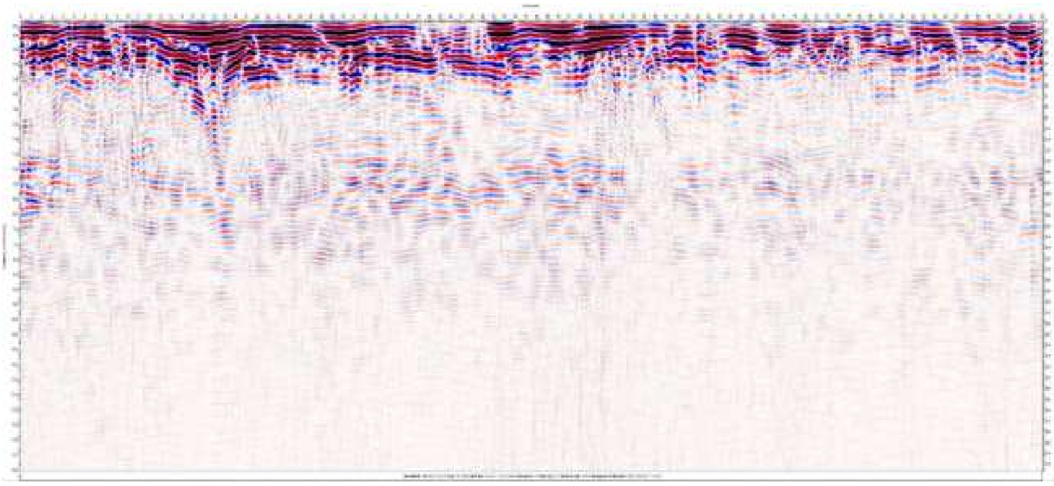

Figure 26. GPR - LINE 2 374 to 469 metres.

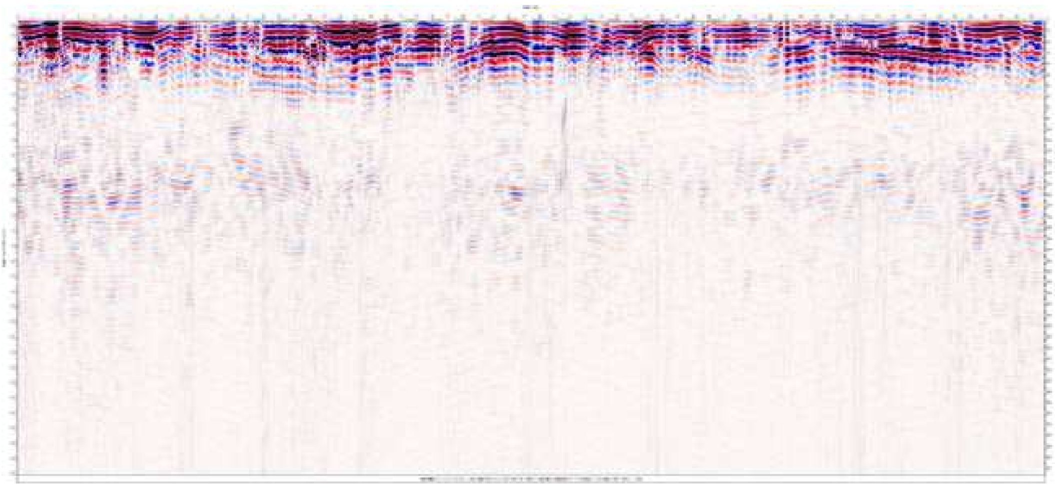

Figure 27. GPR - LINE 2 469 to 602 metres.

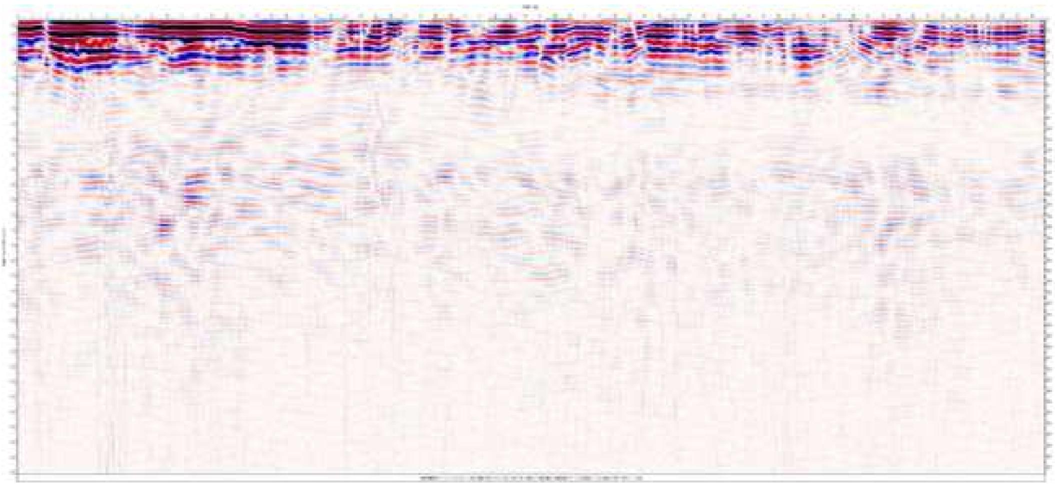

Figure 28. GPR - LINE 2 602 to 670 metres.

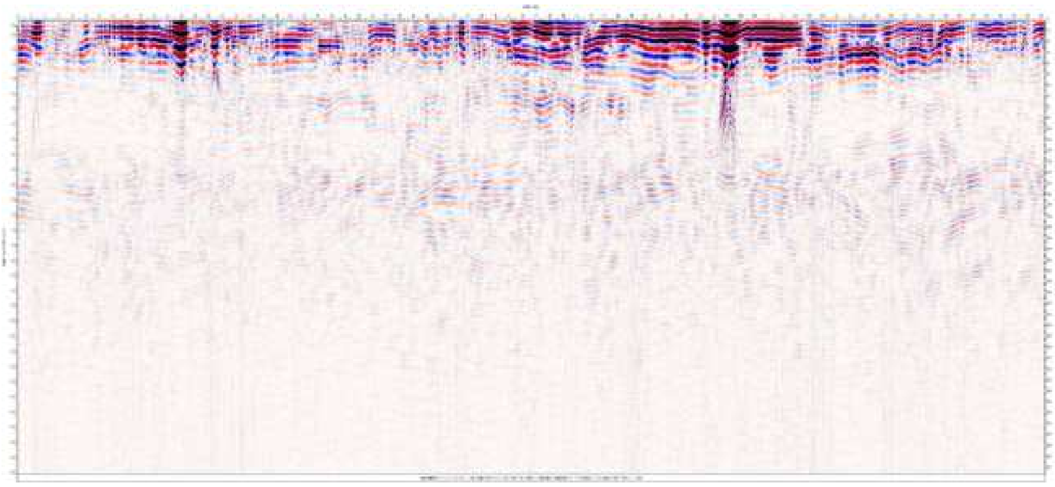

Figure 29. GPR - LINE 2 670 to 820 metres.

4.1.7. Interpretation GPR Image - NS LINE 3

Figures 30, 31 and 32 below show the GPR of all the points of possible pockets of VOC along the Line 3. The GPR image shows a consistent area of deflection, but there is a lost in signal at the point GPR - LINE 3 195.2 to 214.2 metres. According to Jacome et al., (2021) the lost in signal is related to voids into the soil.

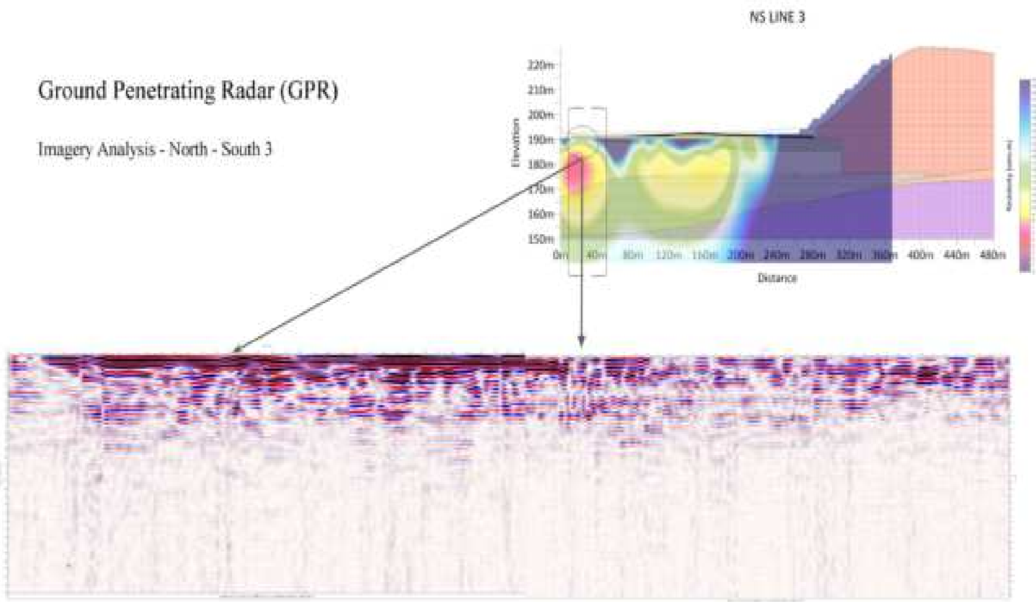

Figure 30. Local interpretation of resistivity and area of concern.

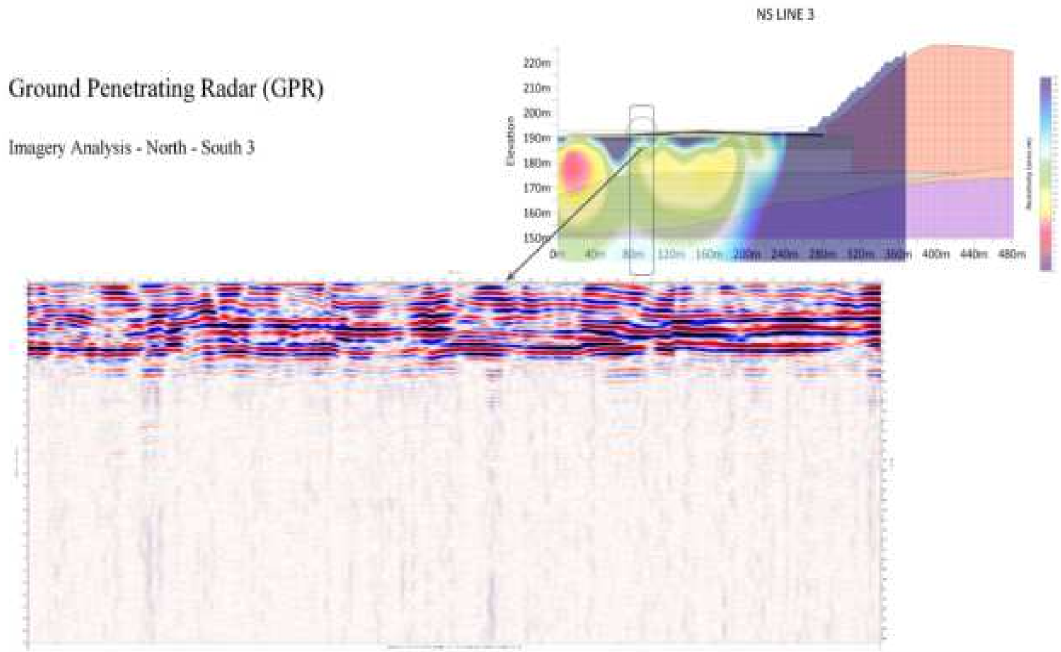

Figure 31. Local interpretation of resistivity and area of concern.

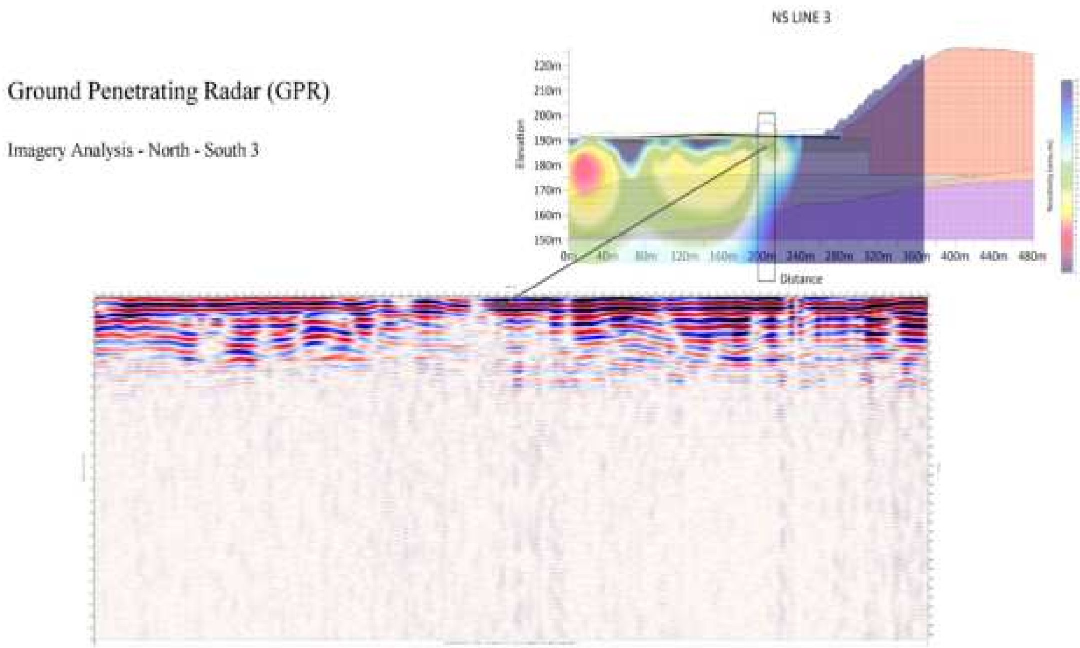

Figure 32. Local interpretation of resistivity and area of concern.

4.1.8. Raw Data Collected NS LINE 3.

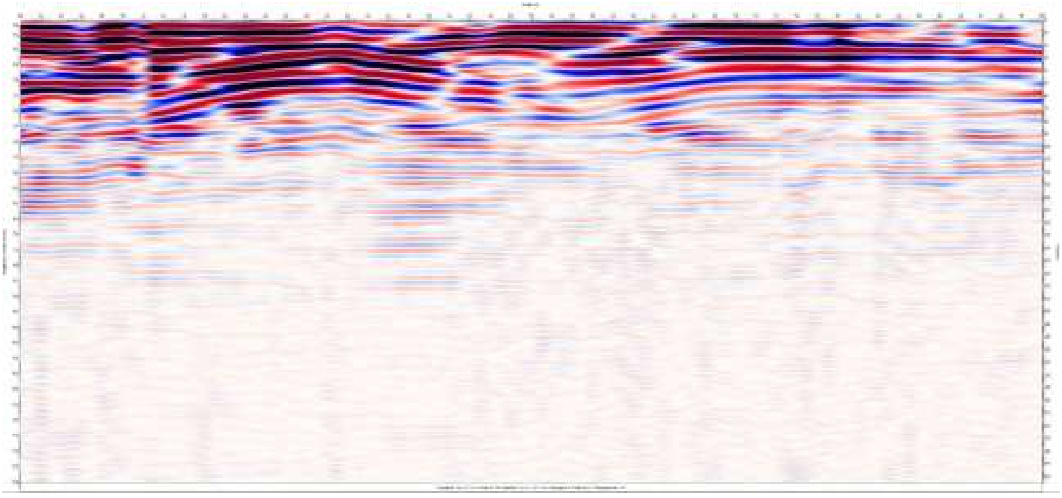

Figure 33. GPR - LINE 3 0 to10 metres.

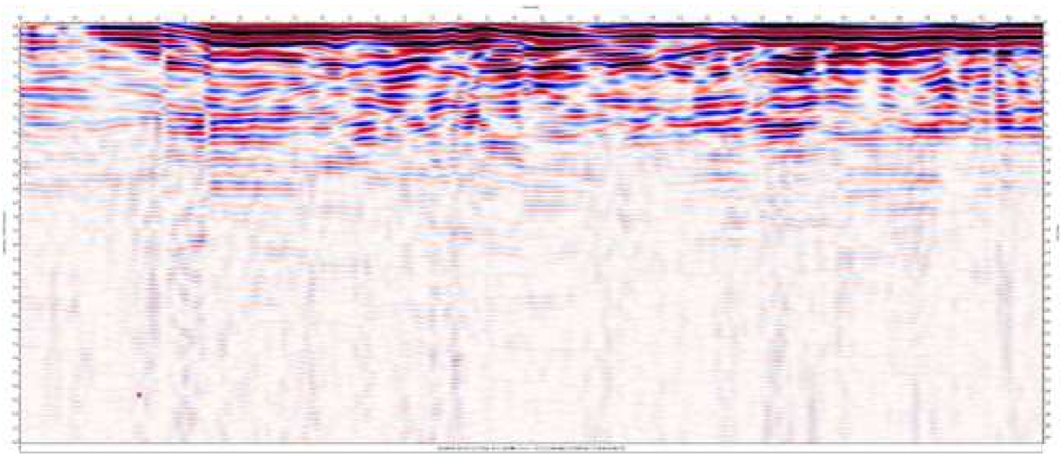

Figure 34. GPR - LINE 3 10 to 28.5 metres.

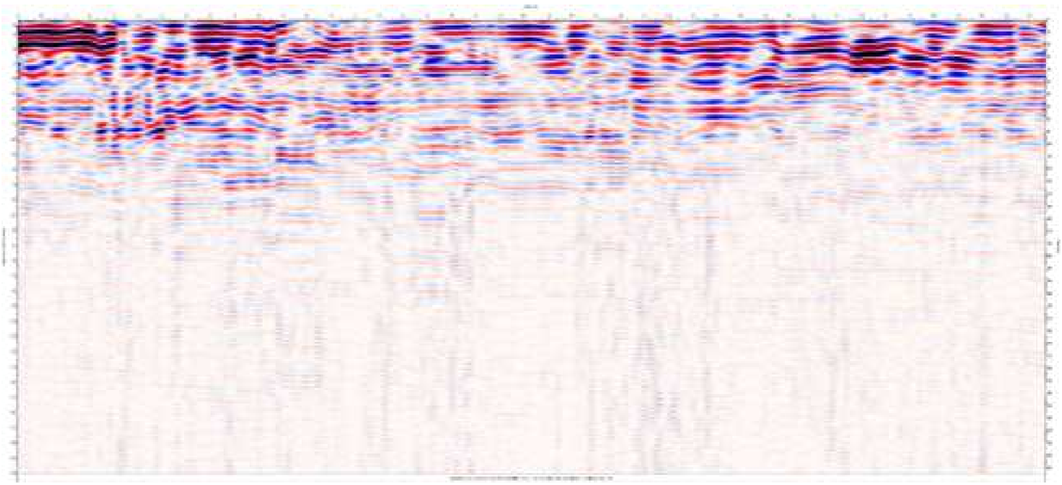

Figure 35. GPR - LINE 3 28.4 to 49.5 metres.

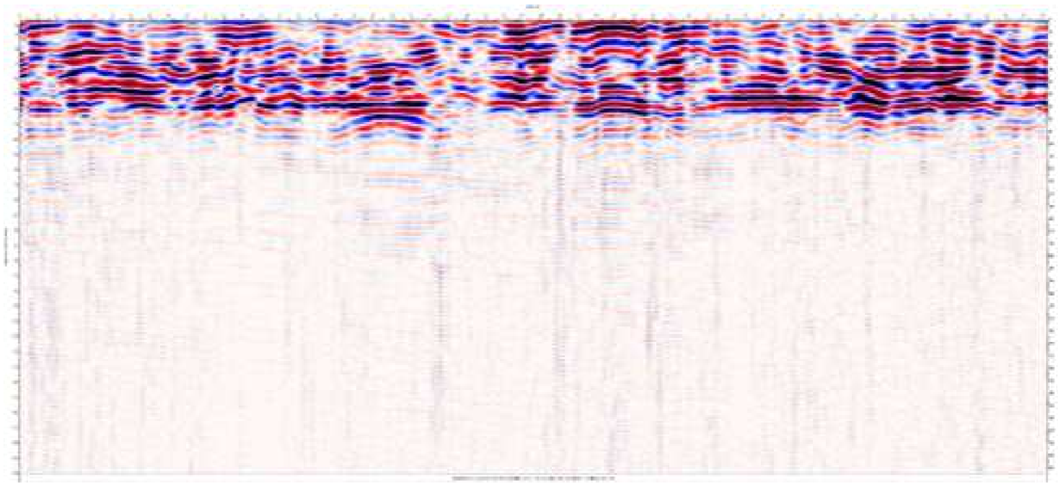

Figure 36. GPR - LINE 3 49.5 to 77 metres.

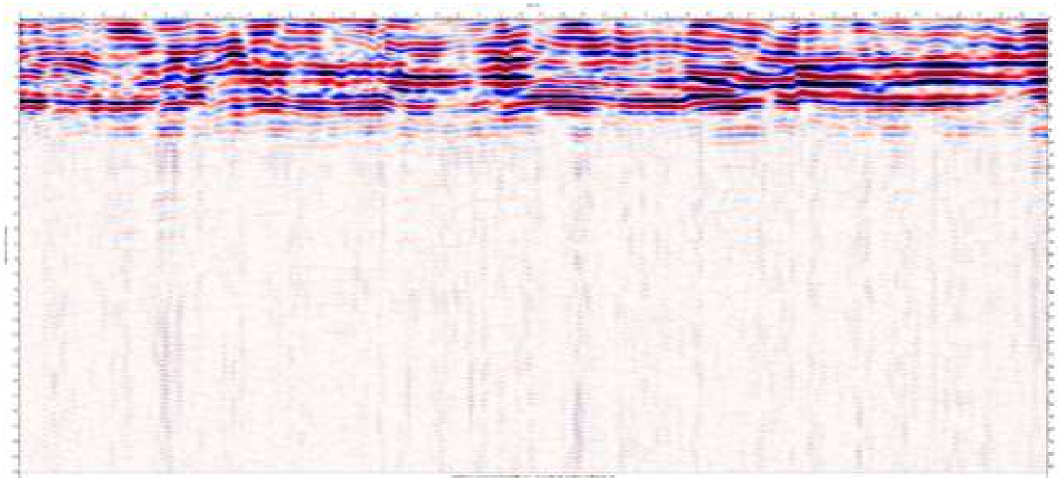

Figure 37. GPR - LINE 3 77 to 101.5 metres.

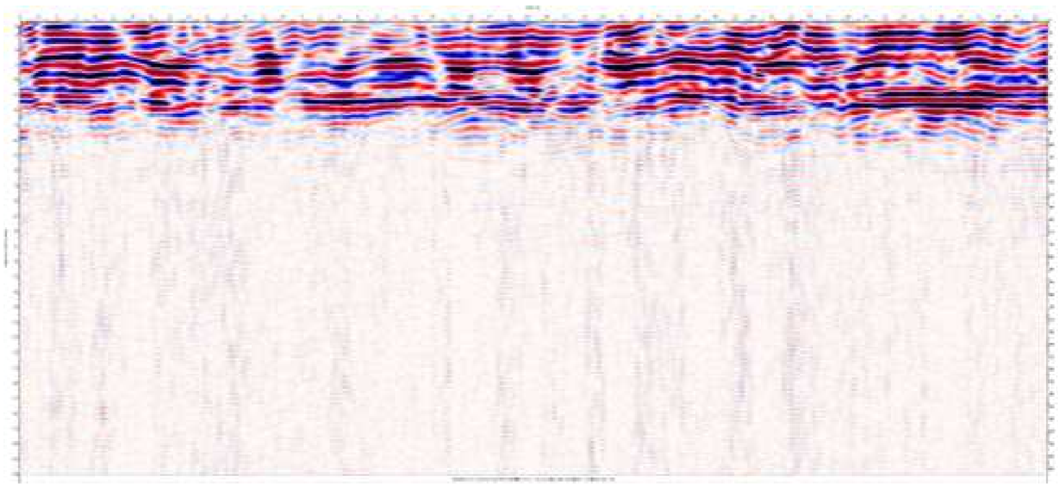

Figure 38. GPR - LINE 3 101.5 to 128.5 metres.

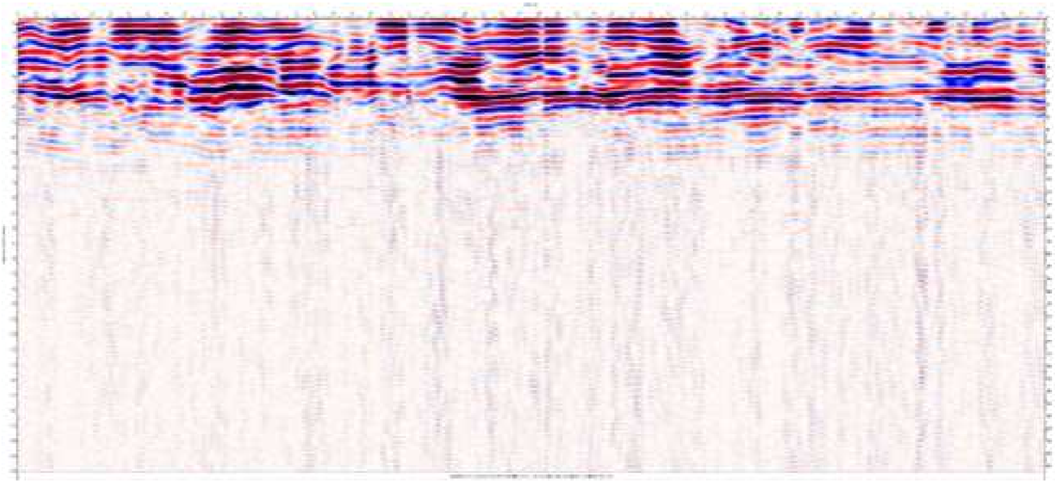

Figure 39. GPR - LINE 3 128.5 to 156 metres.

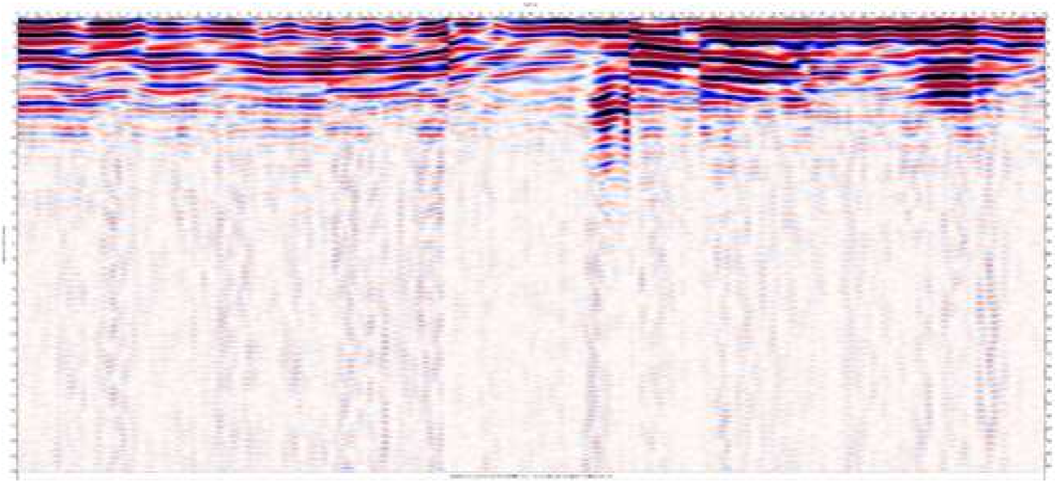

Figure 40. GPR - LINE 3 156 to 176.4 metres.

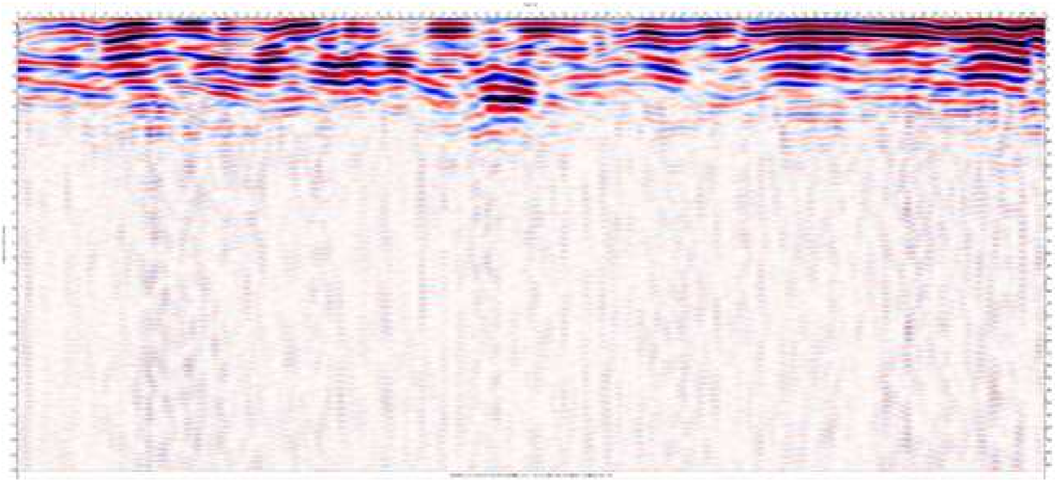

Figure 41.GPR - LINE 3 176.4 to 195.2 metres.

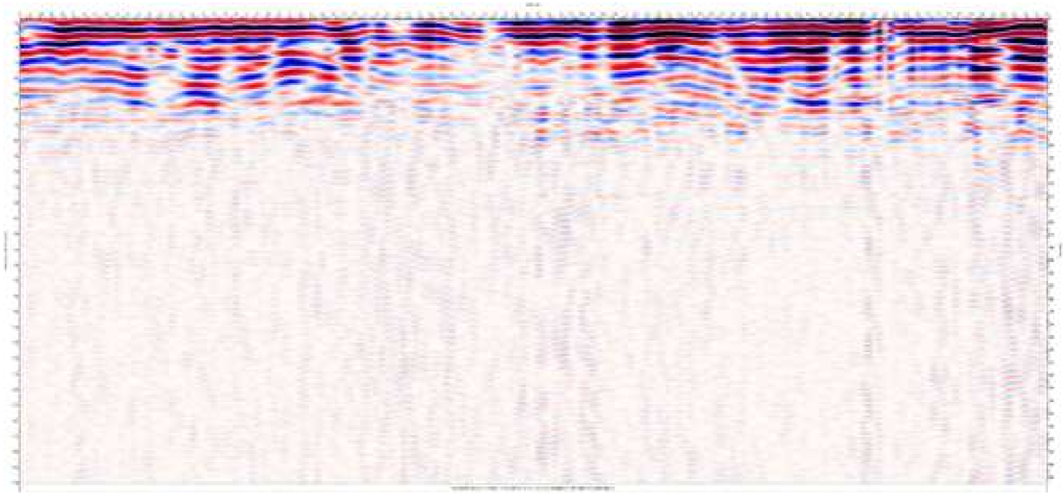

Figure 42. GPR - LINE 3 195.2 to 214.2 metres.

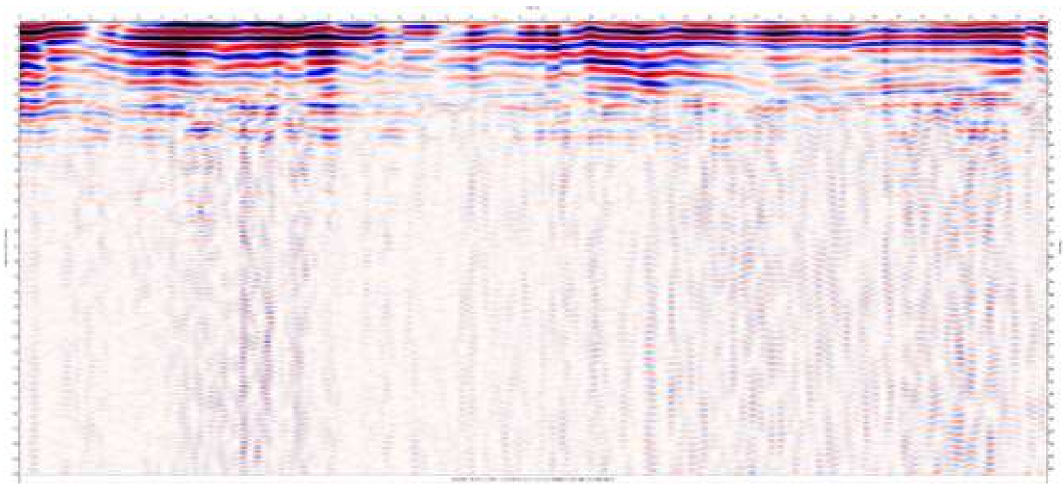

Figure 43. GPR - LINE 3 214.2 to 235.7 metres.

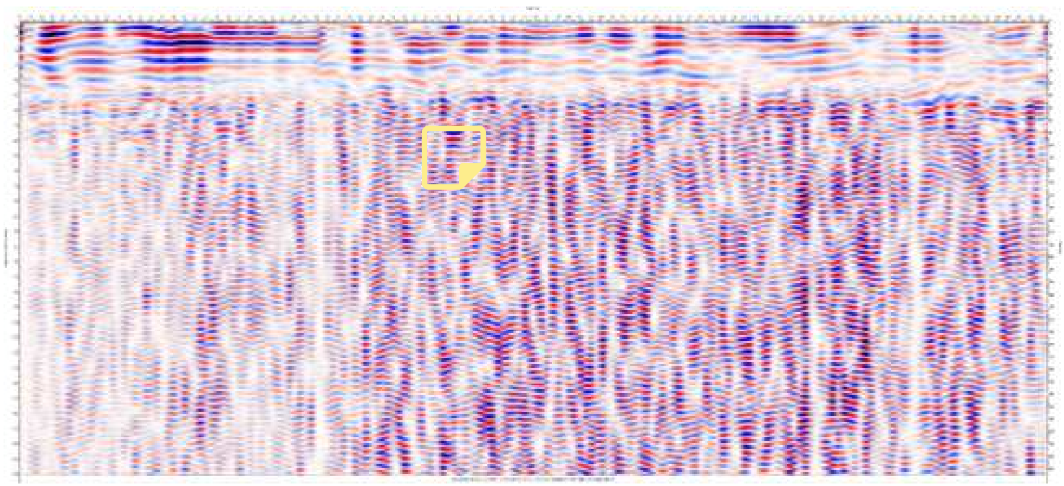

Figure 44. GPR - LINE 3 235.7 to 254.3 metres.

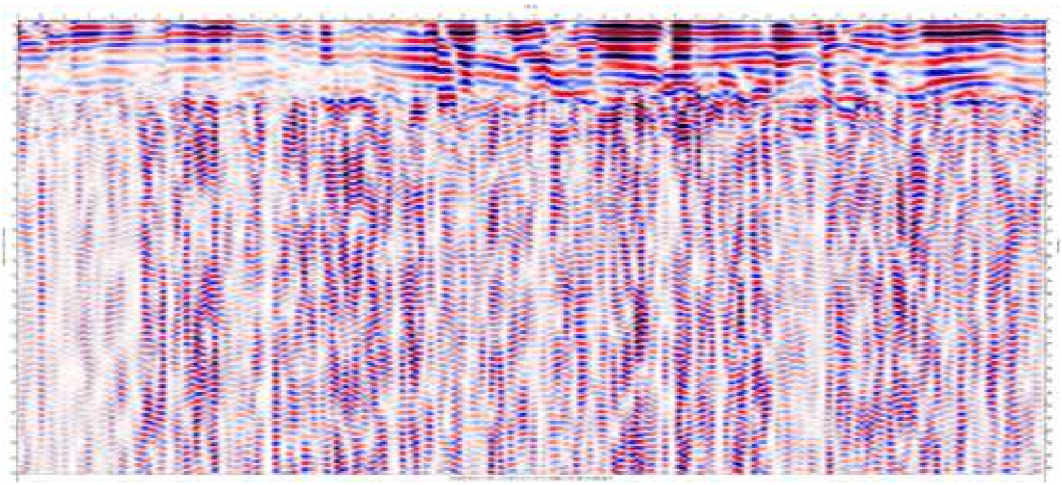

Figure 45. GPR - LINE 3 254.3 to 275.7 metres.

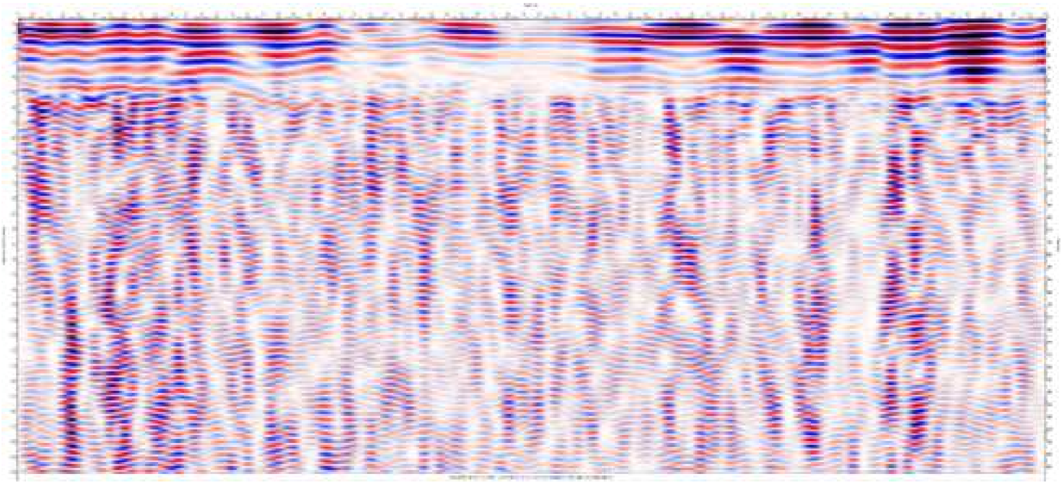

Figure 46. GPR - LINE 3 275.7 to 289.1 metres.

4.1.9. <u>Interpretation GPR Image - NS LINE 4</u>

Figures 47 and 48 show all the points of possible pockets of VOC along Line 4. The GPR shows a consistent area of deflection that according to Jacome et al., (2021) is related to a deposit of clay. However, a probable buried pipeline was found in the line GPR - LINE 4 0 to 43 metres.

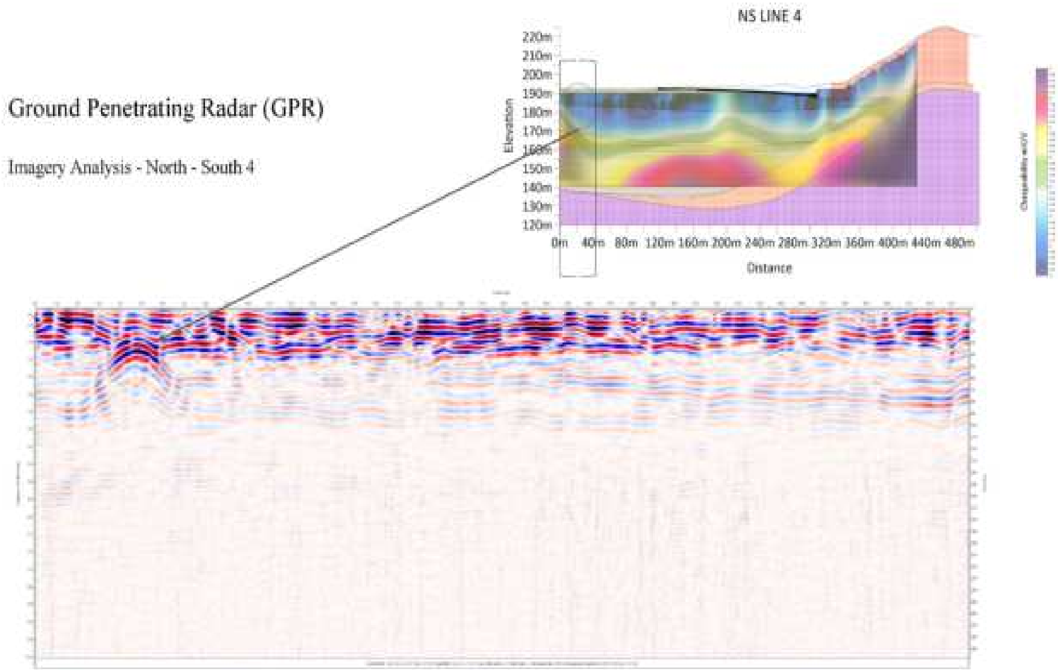

Figure 47. Local interpretation of chargeability and area of concern

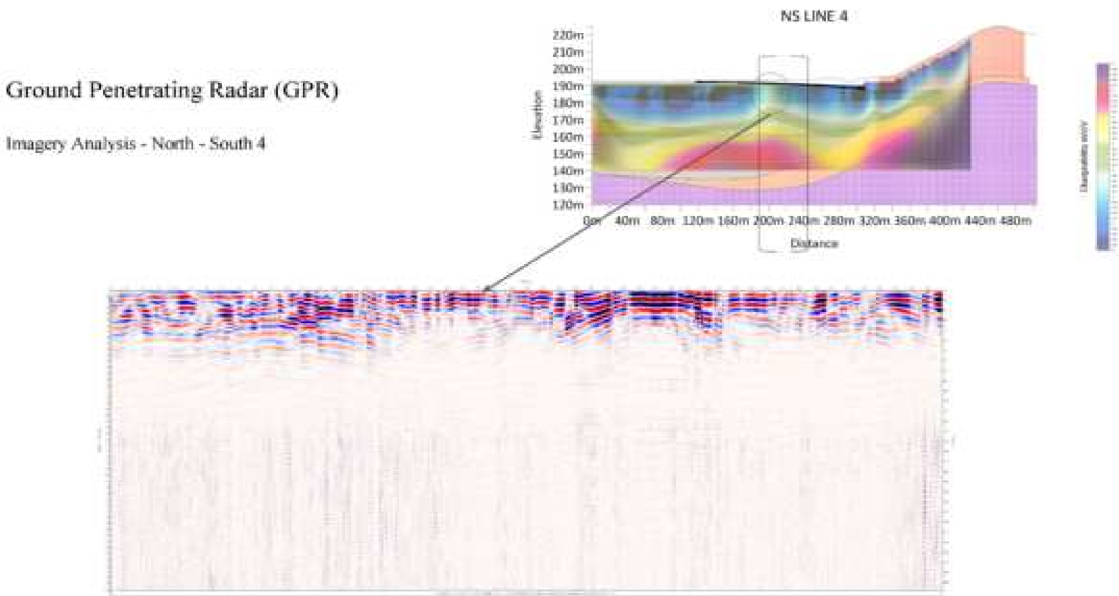

Figure 48. Local interpretation of chargeability and area of concern.

4.1.10. Raw Data Collected NS LINE 4

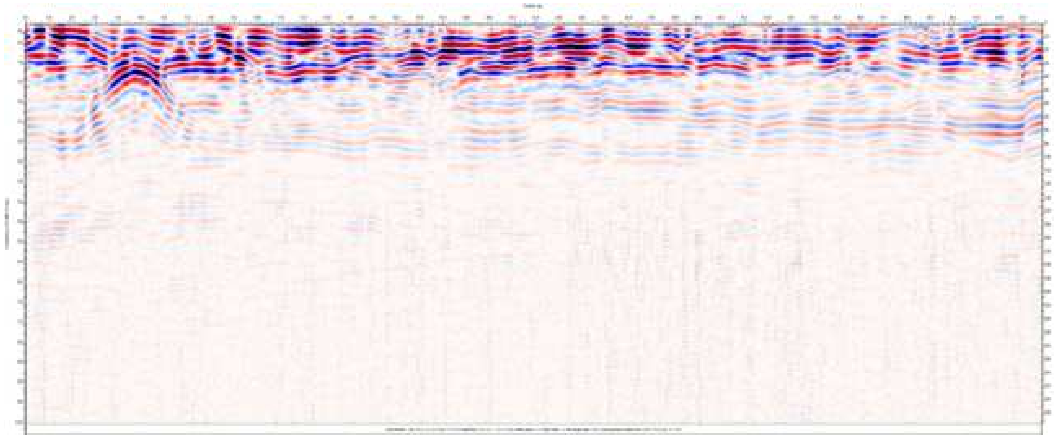

Figure 49. GPR - LINE 4 0 to 43 metres.

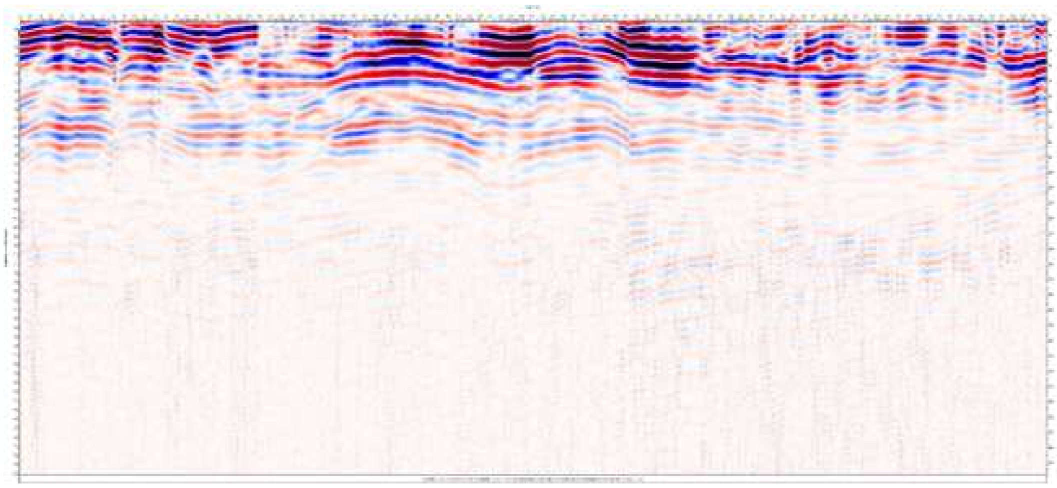

Figure 50. GPR - LINE 4 43 to 92 metres.

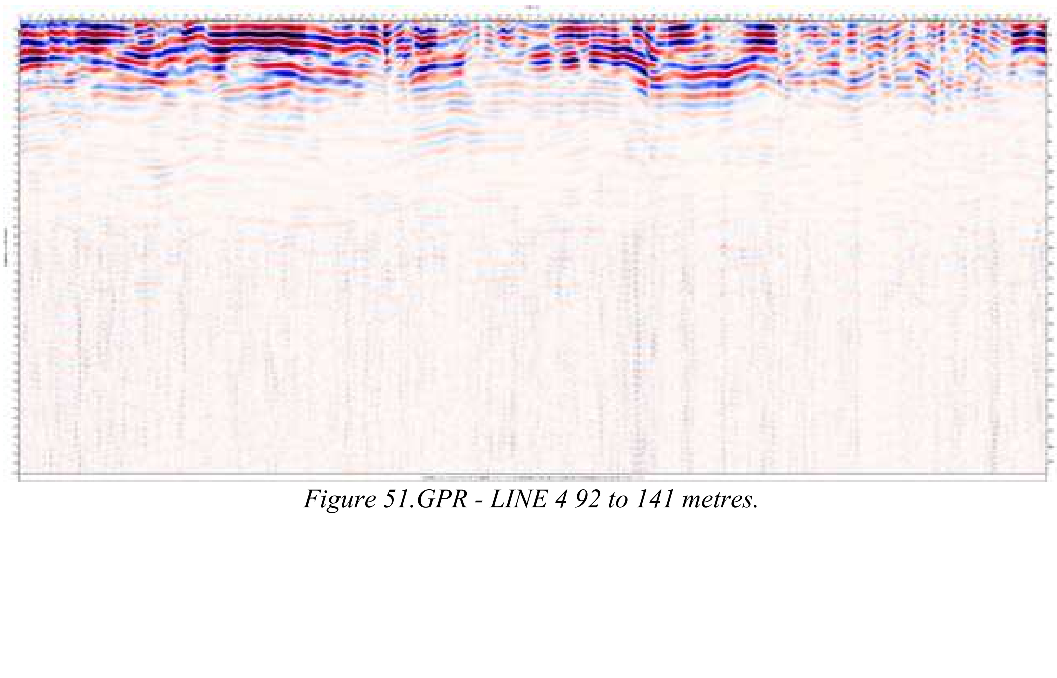

Figure 51.GPR - LINE 4 92 to 141 metres.

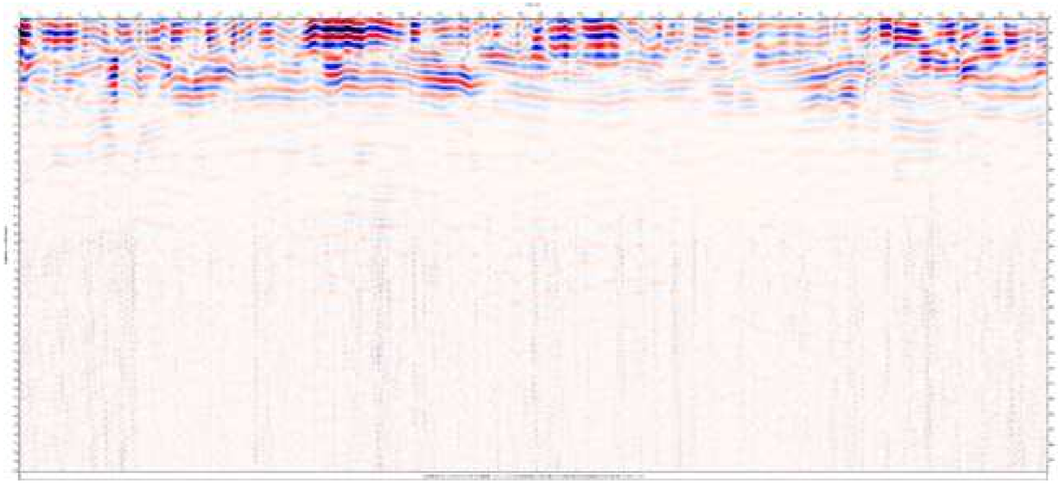

Figure 52. GPR - LINE 4 141 to 192 metres.

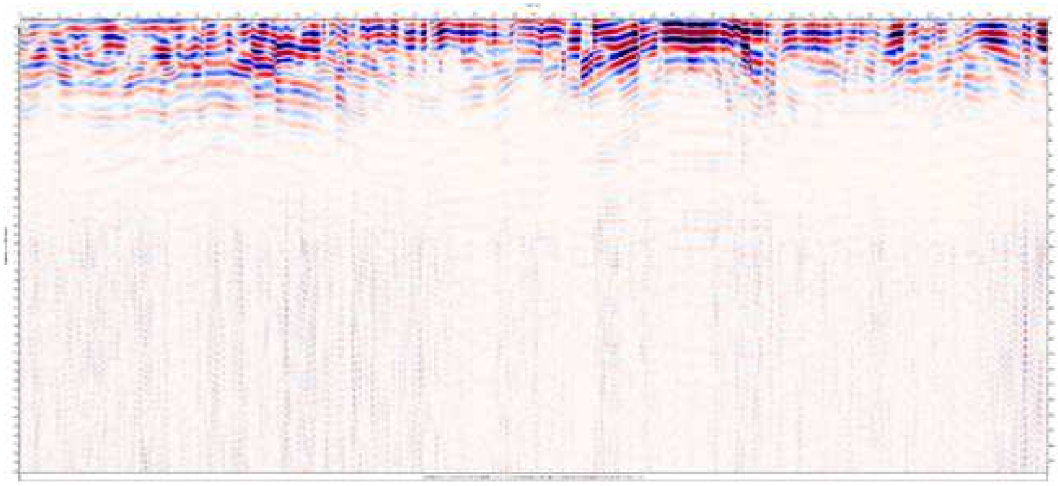

Figure 53. GPR - LINE 4 192 to 243 metres.

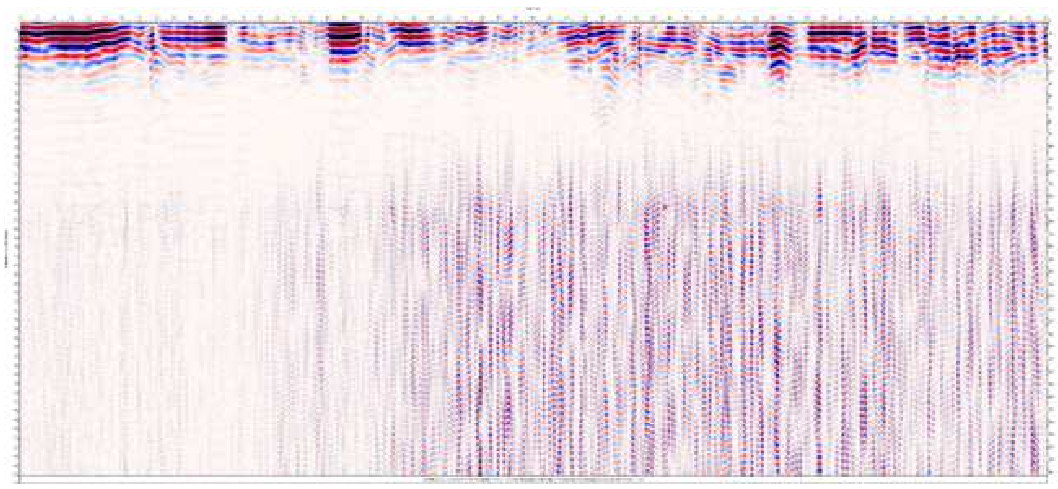

Figure 54. GPR - LINE 4 243 to 303 metres.

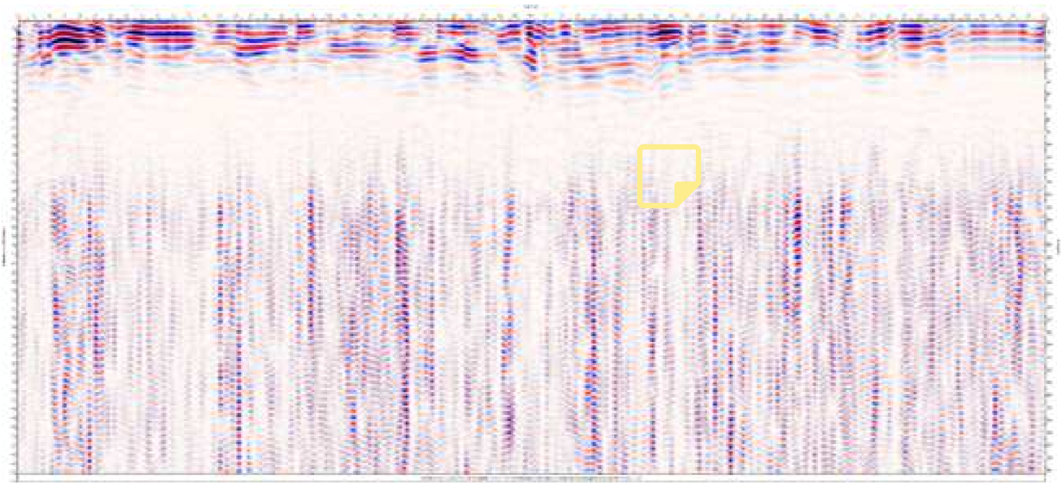

Figure 55. GPR - LINE 4 303 to 336 metres.

5. LANDFILL, CONTOUR MAPS AND ISOPACH MAPS

5.1. Landfill and Modifications

During the analysis of the summary logs, some layers found in the logs were modified in order to simplify and create a model of the soil in the software for analysis. Table 1 and the general profile below corresponds to all modifications and elevations for each layer of the model in the software. According to Trevisan & Oshki-Aki LP, (2019) summary log report, the layers present with the following characteristics:

- Peat - Dark brown to black, non-woody, fibrous, wet.
- Fill Wood Debris - Dark Brown to black, partial to extensive decomposition, soft, zones of dry to very wet.
- Interlayered Silty Sand and Silt - Grey, Silty Sand layers, fine to medium grained, loose, saturated; Silt layers, trace Clay, trace fine sand, non to very low plastic, soft to firm, moist.

- Interlayered Silty Clay and Clayey Silt - Grey; Silty Clay layers, low plasticity, soft to firm, wet to moist; Clayey Silt layers, occasional Silty Sand seams, very low plastic to firm, moist.
- Silt - Grey, some fine Sand. non-plastic, moist.
- Silty Clay - Grey, trace fine sand, low to intermediate plasticity, soft to very soft wet.
- Silty Sand - Grey, fine to medium-grained, loose, saturated.
- Sand and Gravel - Dark grey to black, trace Clay, angular coarse sand/fine Gravel.
- Bedrock.

The soil modifications applied were:

- Interlayered silty clay and silty sand: This layer turned into Silty Clay and Clayey Silt.
- Gravel and silty clay till This layer turned into sand and gravel.

Table 3. Elevation, layers of soil and Depth.

East	North	Surface	Monitoring Well	Peat	Fill - Wood Debris	Sand	Silty Sand And Silt	Silty Sand	Silt Clay	Silty Clay And Clayey Silt	Sand And Gravel	Bedrock	End Borehole	Water Table	Depth (m)
331577.4848	5357594.629	191.29	MW01	191.29			190.68		184.89				184.43	191.29	6.86
331480.1231	5357602.944	191.50	MW02	191.50			190.89			179.80		157.90	184.73	191.65	6.77
331467.3033	5357696.495	191.29	MW03	191.29			190.68		182.45	175.14		156.30	172.24		19.05
331495.0219	5357757.476	190.95	MW04	190.95			190.34			172.30		156.90	184.43	190.24	6.52
331255.6023	5357708.275	191.57	MW05	191.57				190.96	184.80	176.63		165.05	164.96		26.61
331262.5319	5357792.47	191.70	MW06	191.70			189.00	191.24		176.00		156.00	185.96	191.63	5.74
331262.5319	5357886.367	191.07	MW07	191.07			190.46		183.45	175.52		152.90	159.89		31.18
330849.5244	5357732.182	191.14	MW08	191.14				190.23	180.00		156.00	132.50	186.26	191.17	4.88
330854.0287	5357811.181	191.99	MW09	191.99				191.38	179.50	157.80	140.00	130.00	185.19	191.72	6.80
330666.235	5357669.469	193.48	MW10	193.48				191.19					182.91	193.48	10.57
330873.4317	5357598.44	220.00	MW11R		220.00						196.22	194.09	173.52		46.48
331274.3123	5357954.624	191.90	MW13				191.90		185.80	165.08		152.25	150.14	186.97	41.76
331459.6806	5357842.71	191.30	MW14				189.78	191.30	183.37	169.04		155.32	151.66	187.28	39.64
330966.2891	5357705.157	189.10	MW15	187.58	189.10			184.68	183.61	168.68	174.77	156.79	149.34		39.76
330642.3276	5358004.864	192.25	MW16			192.25	169.00	189.96	190.42		159.00	154.00	189.96	190.55	2.29
330674.897	5357774.8	192.98	MW17	192.98			167.80	191.00	188.71		138.50	129.00	186.88	192.76	6.10
330599.3638	5357727.678	193.50	MW18	193.50		193.14	174	191.82	191.47		149.50	134.00	186.79	193.34	6.71
330671.7787	5357668.43	193.96	MW19	193.96				193.05	184.82		149.76	131.00	143.67	192.67	50.29
330952.7763	5357825.733	192.38	MW20	192.38				190.86	180.19	166.47	134.47	127.15	125.32	187.85	67.06
330750.7768	5357781.036	193.27	MW21	193.27			147.55	192.66	178.33		134.00	133.49	147.55	189.74	45.72
331040.4364	5357780.344	193.00	MW22	193.00				192.62	182.00	169.80	153.00	144.90	186.30	190.66	6.70
331277.7772	5358027.386	190.79	MW23			190.79	187.13			165.10		155.90	184.08		6.71
331299.2591	5357798.361	191.97	MW24	191.97			185.87	191.67	179.78	176.73		154.66	151.71	187.61	40.26

331244.5148	5357795.589	192.70	MW25	192.70			185.08	192.09	187.67	176.00		156.00	184.47	192.77	8.23
331583.7215	5357593.243	191.46	MW26	191.46			190.55			182.32	157.02	155.50	153.67	187.59	37.79
330750.0838	5357772.374	193.54	MW27	193.54			147.82	192.93	178.30		134.41	133.49	131.05	188.07	62.49
331275.6983	5357694.416	193.48	PW1		193.48		165.59	191.35	185.86			165.44	159.34	190.42	34.14

All the measurements are in metres.

5.1.1. General Profile

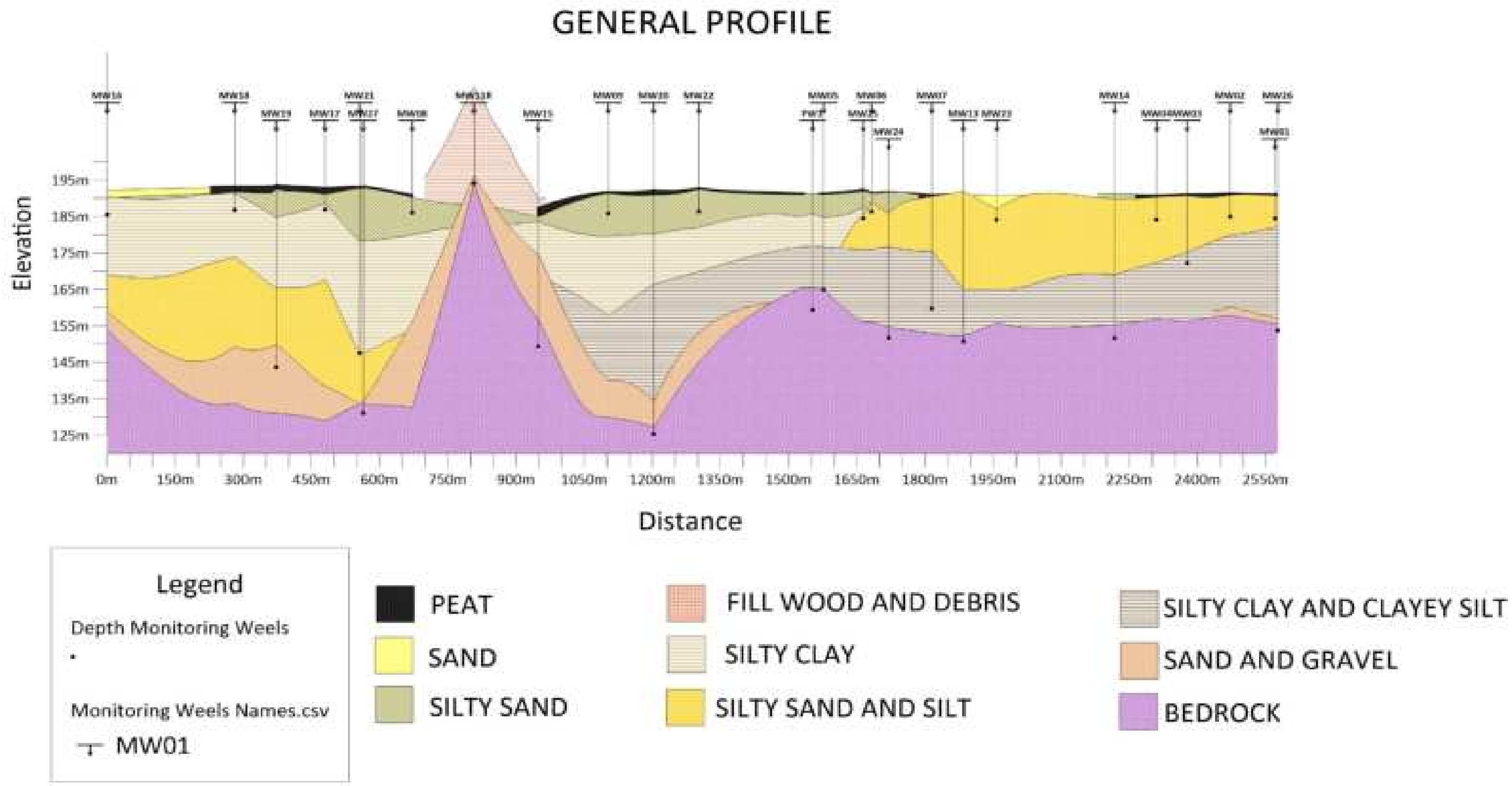

Figure 56.General profile show the stratigraphy of the site modeled in Surfer. All the boreholes matches with the summary log provided by (Trevisan & Oshki-Aki LP, 2019)

5.1.2. Contour Maps and Isopach Maps

Isopach maps illustrate the stratigraphic thickness of the upper and lower layer of soil. It is measured as the distance between the two surfaces and provides an accurate understanding of the stratigraphic thickness of the soil. The figures below shows in the left the contour maps and in the right the isopach maps Jacome (2023).

5.1.3. Software for Soil Analysis

Name: Surfer Golden Software, V25 2023

Surfer Golden software was used to calculate and to organize the layers of the soil as well as the assembly of the results given by the ETR with the current profiles taken from each line. With the software, it was possible to create a model of the site, in accordance with the summary logs provided by KGS Group Consulting Engineers in 2019, (Trevisan & Oshki-Aki LP, 2019).

5.1.4. PEAT

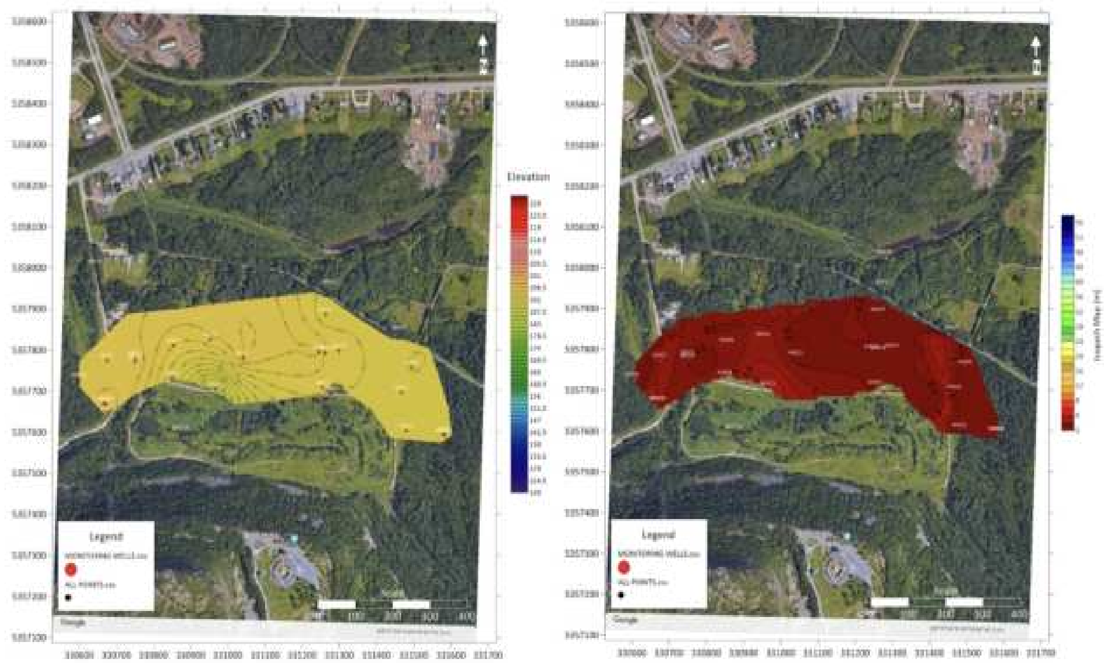

Figure 57. In the left, the contour map and in the right isopach map of the layer peat.

5.1.5. SAND

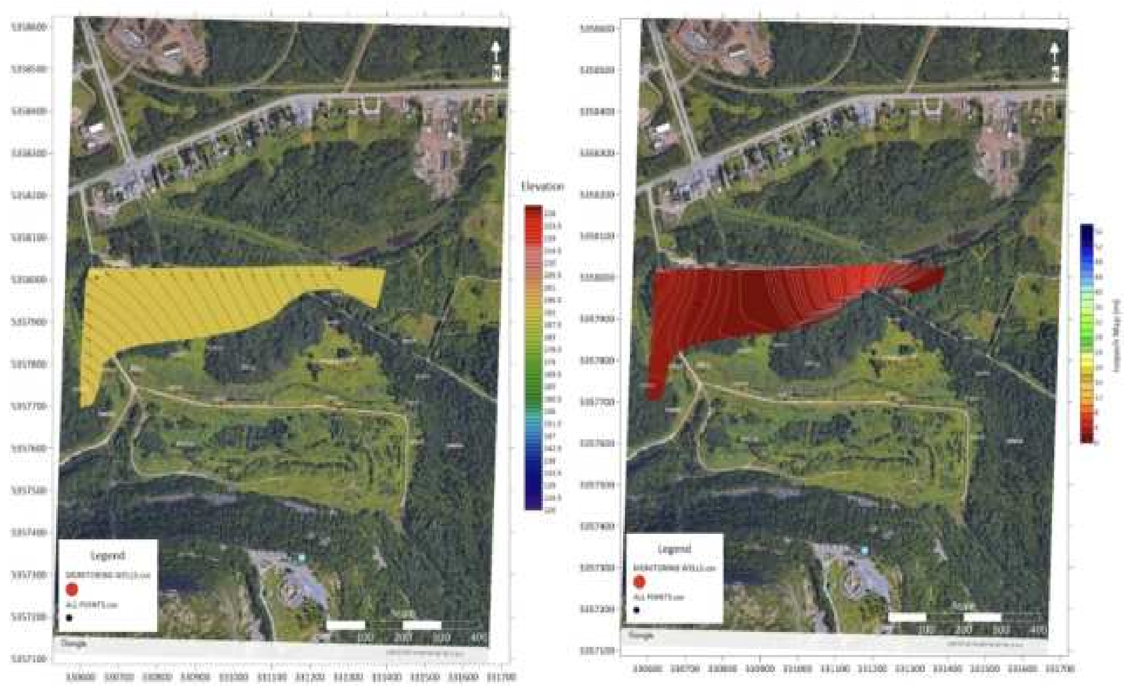

Figure 58. In the left, the contour map and in the right isopach map of the layer sand.

5.1.6. SILTY SAND

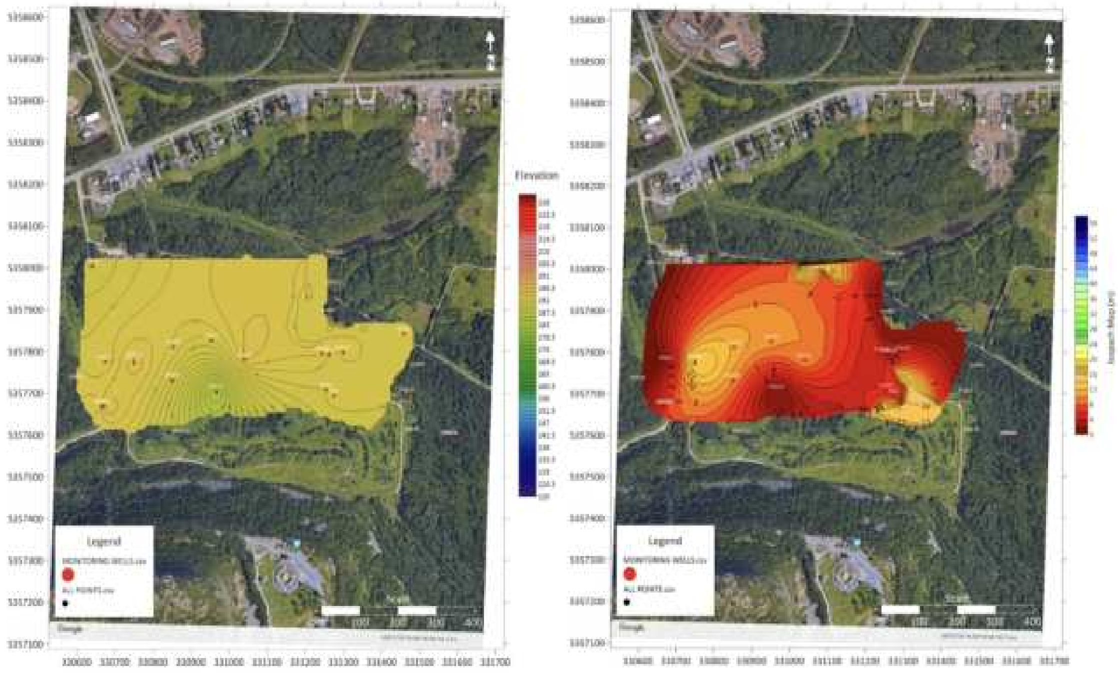

Figure 59. In the left, the contour map and in the right isopach map of the layer silty sand.

5.1.7. SILTY CLAY

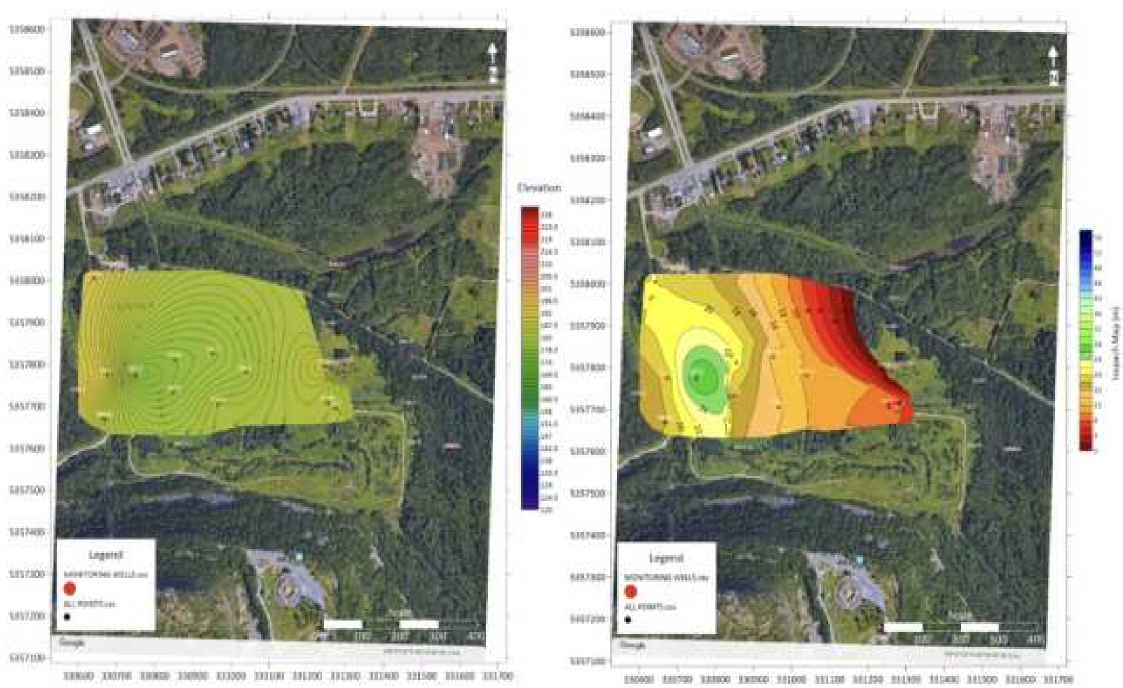

Figure 60. In the left, the contour map and in the right isopach map of the layer silty clay.

5.1.8. SILTY SAND AND SILT

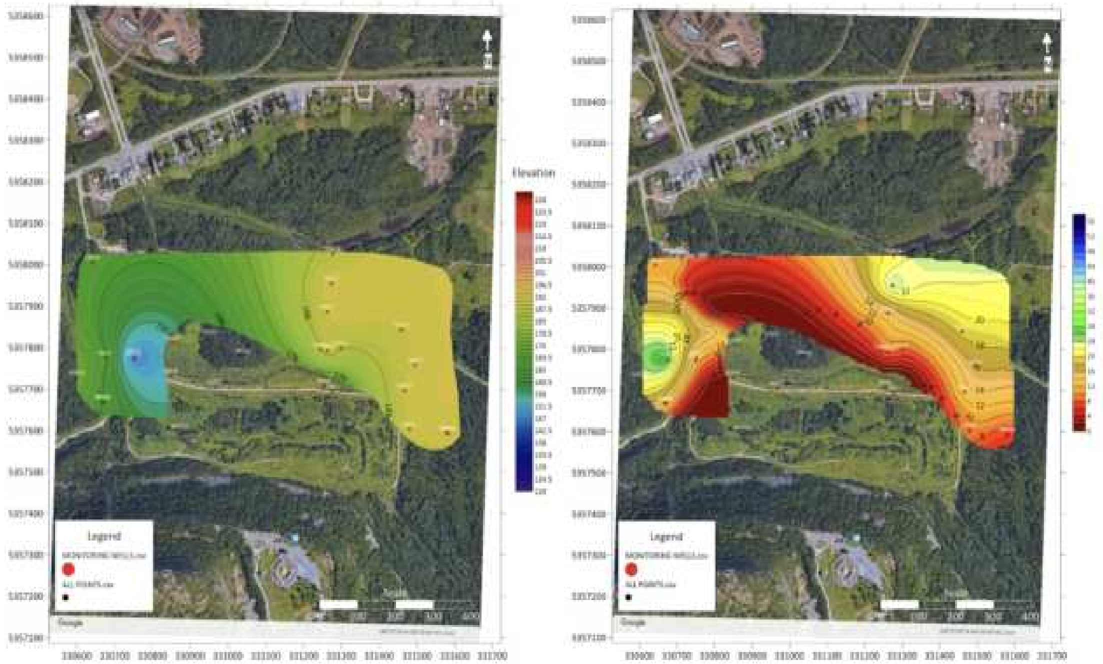

Figure 61. In the left, the contour map and in the right isopach map of the layer silty sand and silt.

5.1.9. SILTY CLAY AND CLAYEY SILT

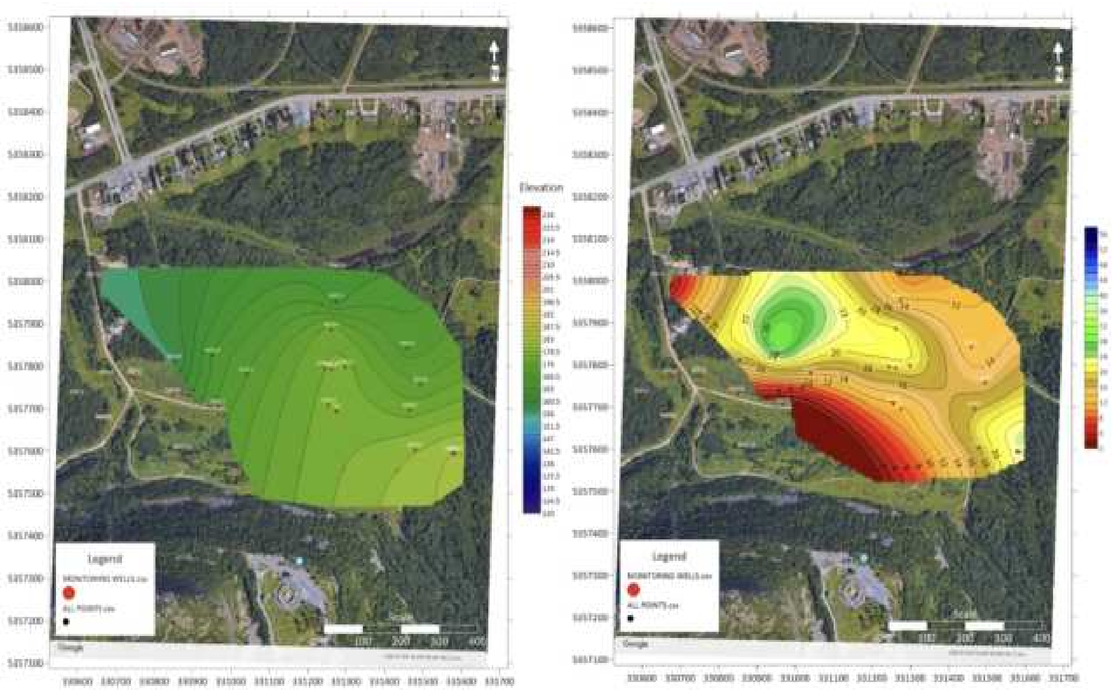

Figure 62. In the left, the contour map and in the right isopach map of the layer silty clay and clayey silt.

5.1.10. SAND AND GRAVEL

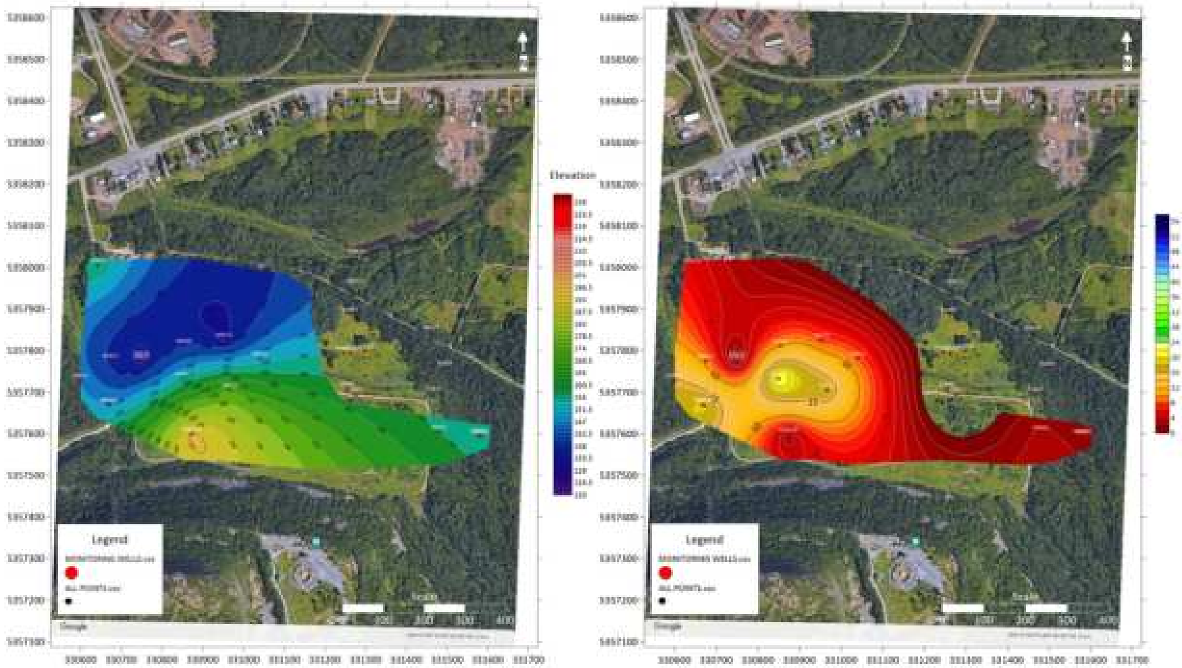

Figure 63. In the left, the contour map and in the right isopach map of the layer sand and gravel.

5.1.11. BEDROCK

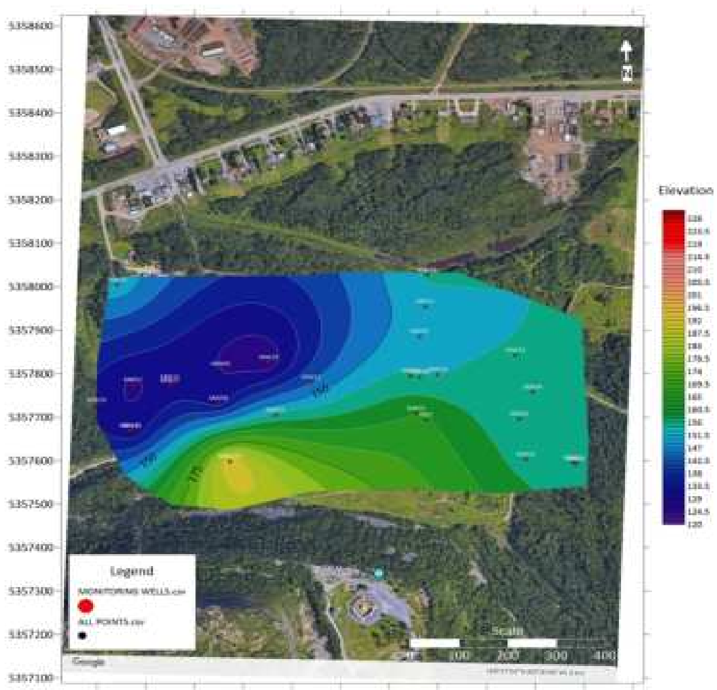

Figure 64. Contour map of the layer bedrock.

1. FILL WOOD AND DEBRIS

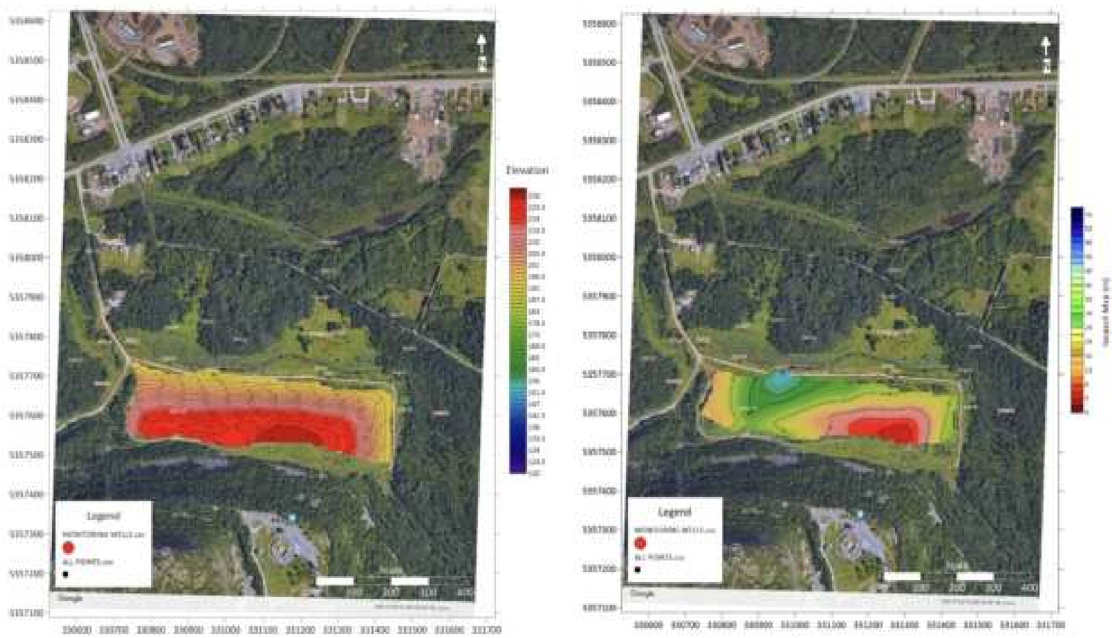

Figure 65. In the left, the contour map and in the right isopach map of the layer fill wood and debris.

6. AIR QUALITY

6.1. Air Quality Procedures

The air quality was measured using a handheld organic vapor analyzer-flame ionization detector, Photovac MicroFID, calibrated with zero air and 500 PPM of methane gas. The accuracy of the MicroFID is +- 0.5 PPM or +-10% of actual methane concentrations for a measure range of 0.5 PPM to 2000 PPM (Costanzo-Alvarez et al., 2022). The measurements were recorded above each electrode during the ETR installation. The first line to be measured was Line 1, in October 23rd, 2022, followed by Line 2 in October 24th, 2022, Line 3 in October 25th, 2022 and Line 4 in October 26th, 2022. On October 25th, 2022, a car was burned in Line 1, close to the intersection to Line 3. According to Jacome (2023), this event contributes to the increase of CO_2 measures in the area. Figures 66 and 67 below show the concentrations measured during October 25th and 27th, 2022.

6.1.1. Air Quality and General Overview - Methane (CH_4)

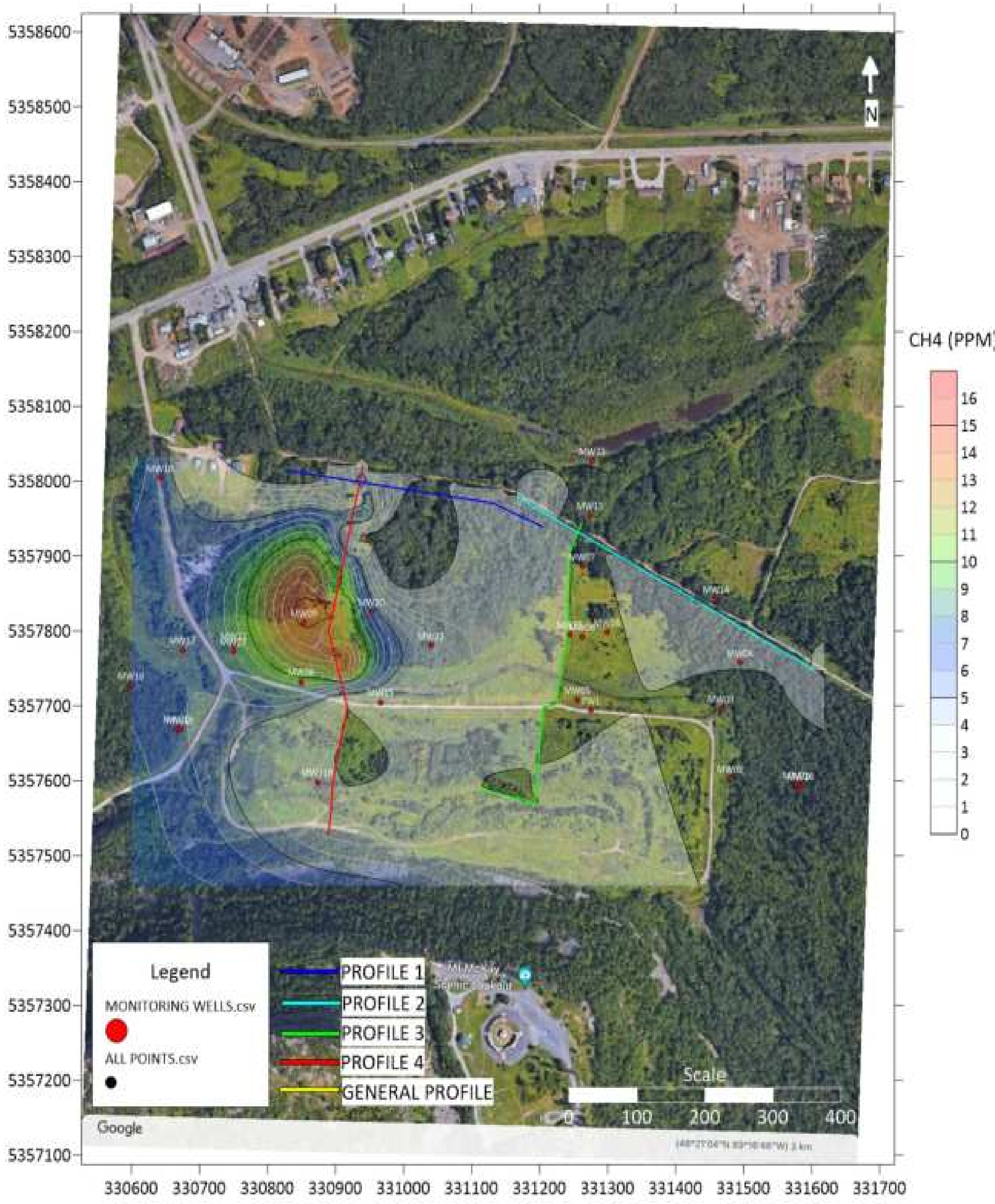

Figure 66. CH4 air quality results

6.1.2. Air Quality and General Overview - Carbon Dioxide (CO2)

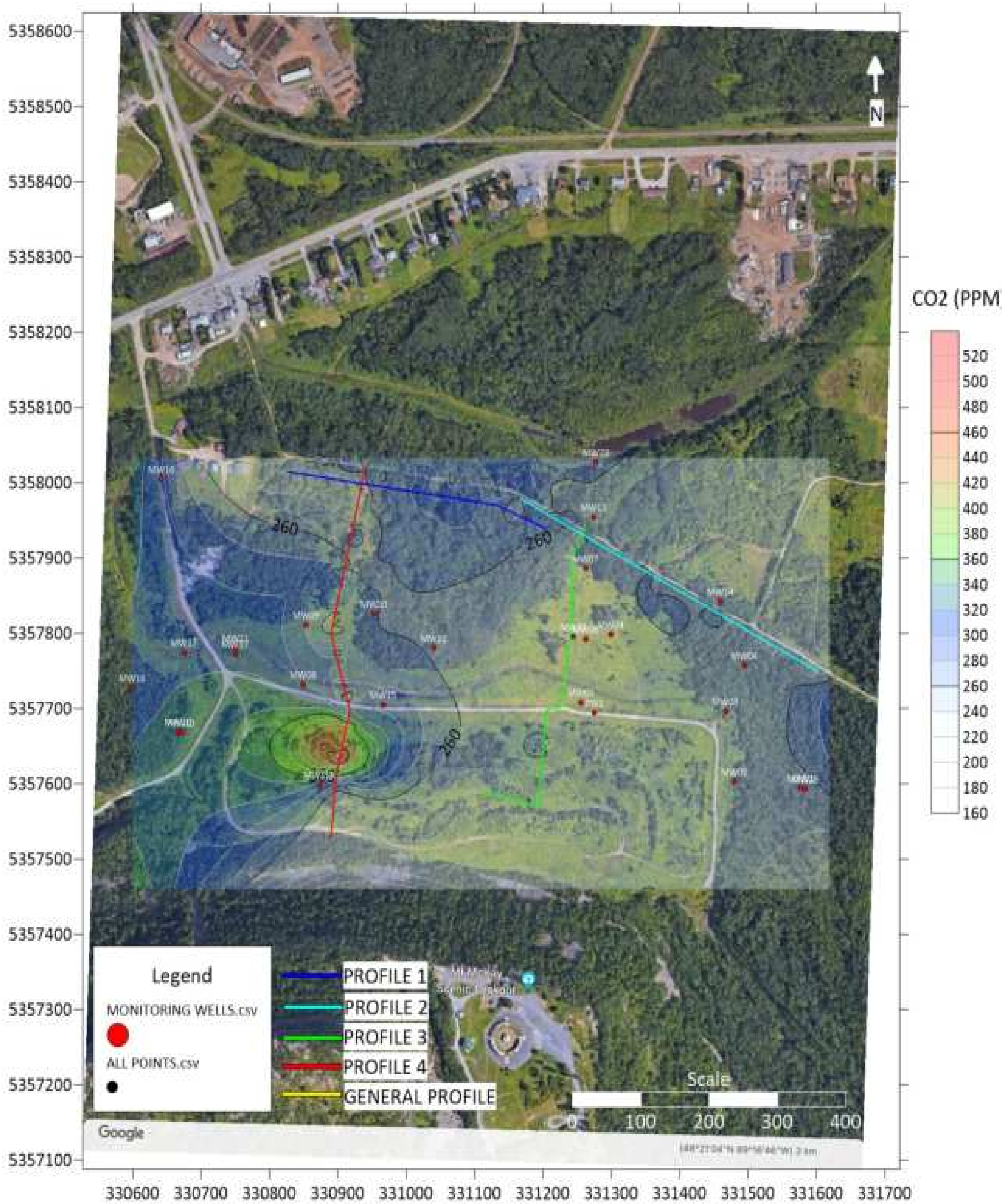

Figure 67.CO2 air quality results.

7. ANALYSIS AND CONCLUSION

7.1. Final Analysis

The analyses performed by the ETR, air quality, GPR and the stratigraphy of the soil suggest a migration of leachate plume originating at the bark dump to the East of the city of Thunder Bay, Ontario, Canada.

After the parameter of analysis was defined, in line 1, AC-EW1-1 presented with a high resistivity and low chargeability results, which indicate a deposit of clay or fresh groundwater. However, AC-EW1-2 and AC-EW1-3 exhibited different behaviours. During the analysis of the air quality, there was an increase in the concentration of methane ($CH4$) in NS LINE 4 extending to the intersection with EW LINE 1. The ETR of NS LINE 4 confirmed an area of high chargeability in the same direction of the anomaly found in the air quality ($CH4$) going to the AC-EW1-2.

In NS LINE 4, AC-NS4-1 shows low results of resistivity and a high result of chargeability. This behaviour extends to the bark dump as shown in AC-NS4-2 and exhibits the same nature found throughout NS LINE 4 and at the intersection with EW LINE1 at AC-EW1-2 and AC-EW-3.

During the analysis of the chargeability of NS LINE 3, the leachate found in AC-NS-3 runs to AC-NS3-2 and AC-NS3-1 from the fill to the north, rising from the deep layers. The behaviour of high resistivity and high chargeability changed to low resistivity and high chargeability the more northeast that the measurements were taken. The results of chargeability remained the same, but the values for resistivity increased. According to Sogade et al., (2006) the Btex compounds presented with high values of resistivity and high values of chargeability when immersed in sand and gravel. According to Vaudelet et al., (2011) the low values of resistivity and high values of chargeability in Btex compounds suggest the presence of a high number of microorganisms due to biodegradation of organic matters. According to Vaudelet et al., (2011), an alternative explanation to having high resistivity and high chargeability values is related with having highly mineralized areas close to the groundwater. While the low resistivity and high chargeability values are associated to the presence of clay (Vaudelet et al., 2011). However, the low resistivity and high chargeability values were only detected in sand and gravel, and fill wood and debris layers in this report.

According to our analysis, the leachate plume migrated northeast of the site. The analysis of the stratigraphy, isopach and contour maps elucidated a potential fracture along line 3. The leachate originated from the fill wood and debris, migrated through the sand and gravel and bedrock and maintained the same elevation in line 4 and line 1. Figure 63 shows that the layer of sand and gravel disappear at line 3, and according to Jacome (2023), that may indicate a natural fault in the deep layers of the soil. Additionally, the chargeability at NS LINE 3 showed that the contaminant migrated from the bedrock and sand and gravel, passed through the layer of silty clay and clayey silt to the layer of silty sand and silt. In line 2, the chargeability shows a higher elevation of the contaminants than in line 1, line 3 and line 4. In conclusion, the leachate appears to move towards the east due to high clay content observed in Figure 62 on the west of the site.

The analysis of the GPR and the resistivity at line 2 and line 3 suggests a potential presence of gases trapped by the silty sand and silt layer, which may indicate a biodegradation of organic matters. The analysis of the GPR at line 2, presents with many different points of discontinuous signals originating from the GPR as showed in the figure GPR - LINE 2 93.2 to 226.2 metres, GPR - LINE 2 226.2 to 294.2 metres and GPR - LINE 2 294.2 to 444.2 metres, and the analysis of line 3, presents with a point of discontinuity at GPR - LINE 3 195.2 to 214.2

metres. According to Jacome (2023) the discontinuity in signal from the GPR suggest a presence of voids or gases merging to the surface.

Figure 68 below shows the migration of the leachate. All the areas were measured and plotted in the maps in order to create a visual understanding of the migration of the contaminants.

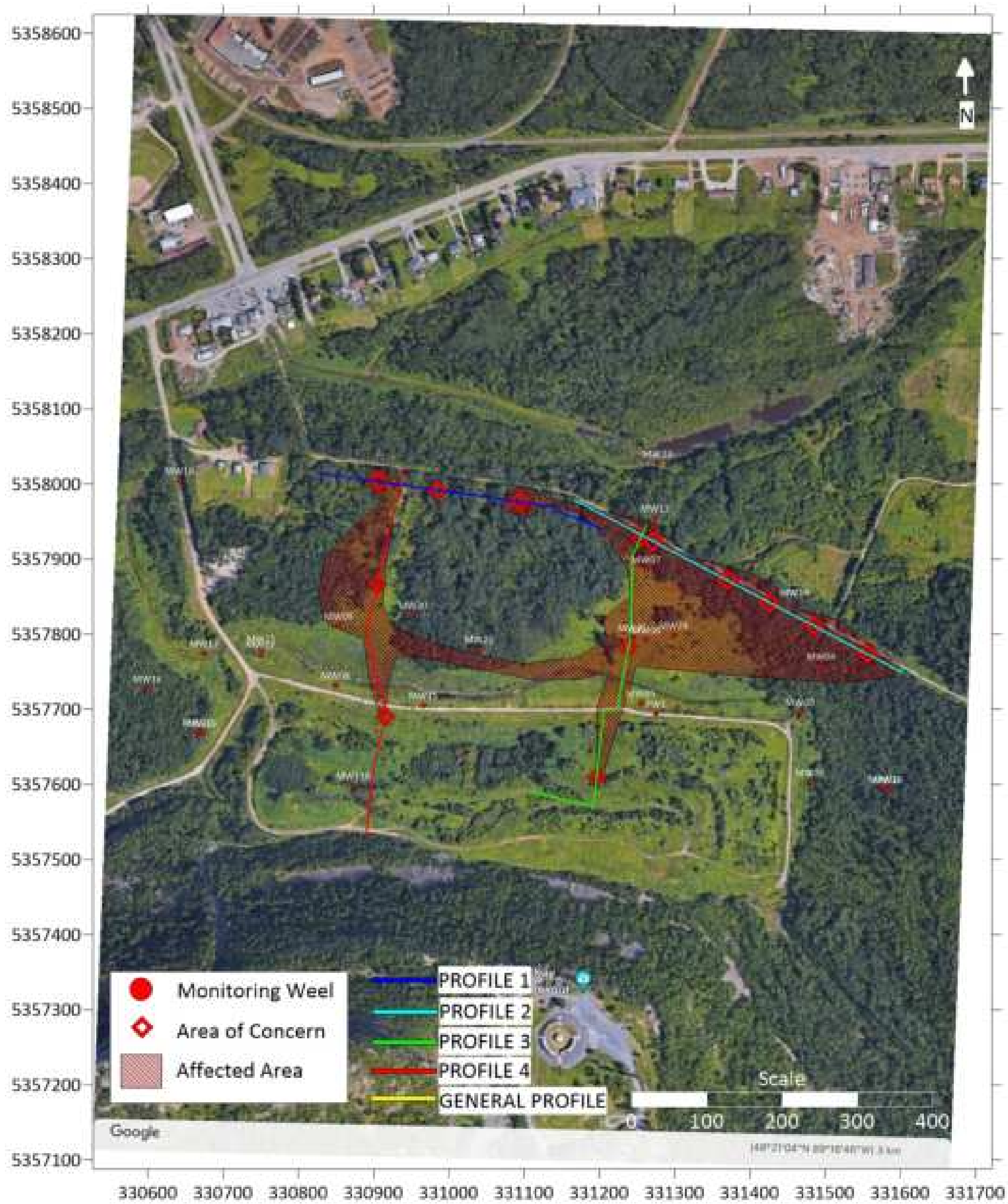

Figure 68.Contamination migration proposed by this report.

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