Project Report

Geophysical investigations to map possible saltwater intrusion, Seaside, California

September 2025

Client:
Seaside Basin Watermaster
Monterey, CA
Att. Mr. Robert S. Jaques

GEOPHYSICAL
IMAGING
PARTNERS

Project #	25004
Project Name	Geophysical investigations to map possible saltwater intrusion, Seaside, California
Date	29 September 2025
Client	Seaside Basin Watermaster
Prepared by	Ahmad-Ali Behroozmand, Max Halkjaer and Jesse Crews
Project description	Ground-based sTEM geophysical surveys to investigate potential saltwater intrusion near Sentinel Well #4.
Cover Photo	The sTEM system being prepared at a station near the shoreline.

Geophysical Imaging Partners, Inc.

Pleasant Hill, California

Email: ahmad@geophysicalimaging.com, max@geophysicalimaging.com

Phone: +1 415-430-7173

September 29, 2025

Mr. Robert S. Jaques
Seaside Basin Watermaster
P.O. Box 50512
Pacific Grove, CA 93950

GEOPHYSICAL IMAGING PARTNERS

Geophysical Imaging Partners, Inc.
261 Gladys Dr.
Pleasant Hill, CA 94523

Geophysical investigations to map saltwater intrusion, Seaside, California

Dear Bob,

We are pleased to submit this project report summarizing the results of the geophysical investigations conducted near Sentinel Well #4, west of Seaside, California.

The main objective of this survey was to better understand variations in the geological sediments and to investigate possible saltwater intrusion.

A one-day sTEM geophysical survey was conducted at thirteen locations across the study area. This report presents the surveys and results of the project.

We would like to thank Mr. Jaques for his support during the project planning and fieldwork. It has been a pleasure to work with you on this project. We remain available to discuss this report or to answer any questions you may have.

Yours Sincerely,

Ahmad-Ali Behroozmand, PgP, PhD
Senior Geophysicist
ahmad@geophysicalimaging.com

Max Halkjaer, M.Sc.
Principal Geophysicist/Hydrogeologist
max@geophysicalimaging.com

Executive Summary

This report presents the findings of a geophysical investigation conducted by Geophysical Imaging Partners, Inc. for the Seaside Basin Watermaster to assess potential saltwater intrusion near Sentinel Well #4 (SW4), west of Seaside, California. The study was prompted by induction logs at SW4 showing a consistent increase in electrical conductivity within the 180–200 ft depth interval, suggesting possible seawater influence.

A one-day stationary Time-domain Electromagnetic (sTEM) survey was performed on July 11, 2025, at thirteen locations across the study area. The sTEM method measures subsurface electrical resistivity without direct ground contact, enabling detailed imaging of geological variations. Data were processed and inverted to generate resistivity models, which were interpreted alongside borehole data.

Data quality was generally high, though some soundings were affected by noise from powerlines and infrastructure, reducing depth of investigation locally.

Resistivity models indicate a stratigraphic sequence from unsaturated dune sands to freshwater-saturated sands, transitioning to zones of saltwater-saturated sands, and deeper Paso Robles and Purisima formations. The zone of interest (180–200 ft) exhibits localized low resistivity values at some locations near SW4. Inland soundings toward east show higher resistivity values, suggesting seawater intrusion has not significantly progressed beyond SW4.

The results support the interpretation that seawater intrusion is occurring near SW4 but remains spatially irregular, likely controlled by lithologic variability and preferential flow paths. Continued monitoring and integration with hydrogeologic data are recommended to refine intrusion mapping.

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Abbreviations

1D	One Dimensional
2D	Two Dimensional
BGS	Below Ground Surface
DOI	Depth of Investigation
EM	Electromagnetics
Ft	Foot
GERDA	Geophysical Relationship Database
GPS	Global Positioning System
HM	High Moment
KG	Kilogram
LM	Low Moment
M	Meter
PDF	Portable Document Format
QC	Quality Control
SNR	Signal-to-noise ratio
sTEM	Stationary Time-domain Electromagnetics
TEM	Transient Electromagnetics
ATV	All-Terrain Vehicle

Introduction

This project was conducted through an agreement between the Seaside Basin Watermaster (the Client) and Geophysical Imaging Partners, Inc. (GIP) to provide geophysical services to improve understanding of the hydrogeological setting and investigate possible saltwater intrusion within the study area near Sentinel Well #4 (SW4), west of the City of Seaside, California.

As shown in Figure 1, at SW4, induction logs collected in recent years indicate a consistent increase in electrical conductivity within the ~180-200 ft (55-61 m) depth interval, raising the question of whether this trend may be related to possible saltwater intrusion in this zone.

To investigate further, one day of ground-based, stationary Time-domain Electromagnetic (sTEM) data was collected at the site.

Following data processing, the sTEM data were interpreted as smooth (multi-layer) electrical resistivity models through geophysical inversions. The results provide a detailed representation of electrical resistivity variations along the survey lines and are presented as vertical resistivity sections. The sTEM depth of investigation (DOI) extends to less than 100 m (328 ft) below ground surface (bgs) near the coastline and increases to greater than 100 m farther inland.

Airborne electromagnetic (AEM) data from two previous surveys conducted near the site were also revisited and used where found helpful. These surveys include the Department of Water Resources (DWR) statewide AEM survey (DWR survey report dated October 15, 2023) and the Marina Coast Water District (MCWD) 2019 survey. The location of the surveyed AEM data is shown in Figure 2.

This report provides a summary of the field operations and a description of the results. In addition, the following appendices provide supplementary information:

Appendix 1 covers a general introduction to the TEM method,
Appendix 2 provides information about the field operation, a list of sounding numbers and coordinates and an overview map,
Appendix 3 describes the sTEM system specifications, including the complete configuration of the system and information about data processing and inversion settings,
Appendix 4 provides quality control (QC) plots, and
Appendix 5 describes data file formats for the deliverables.

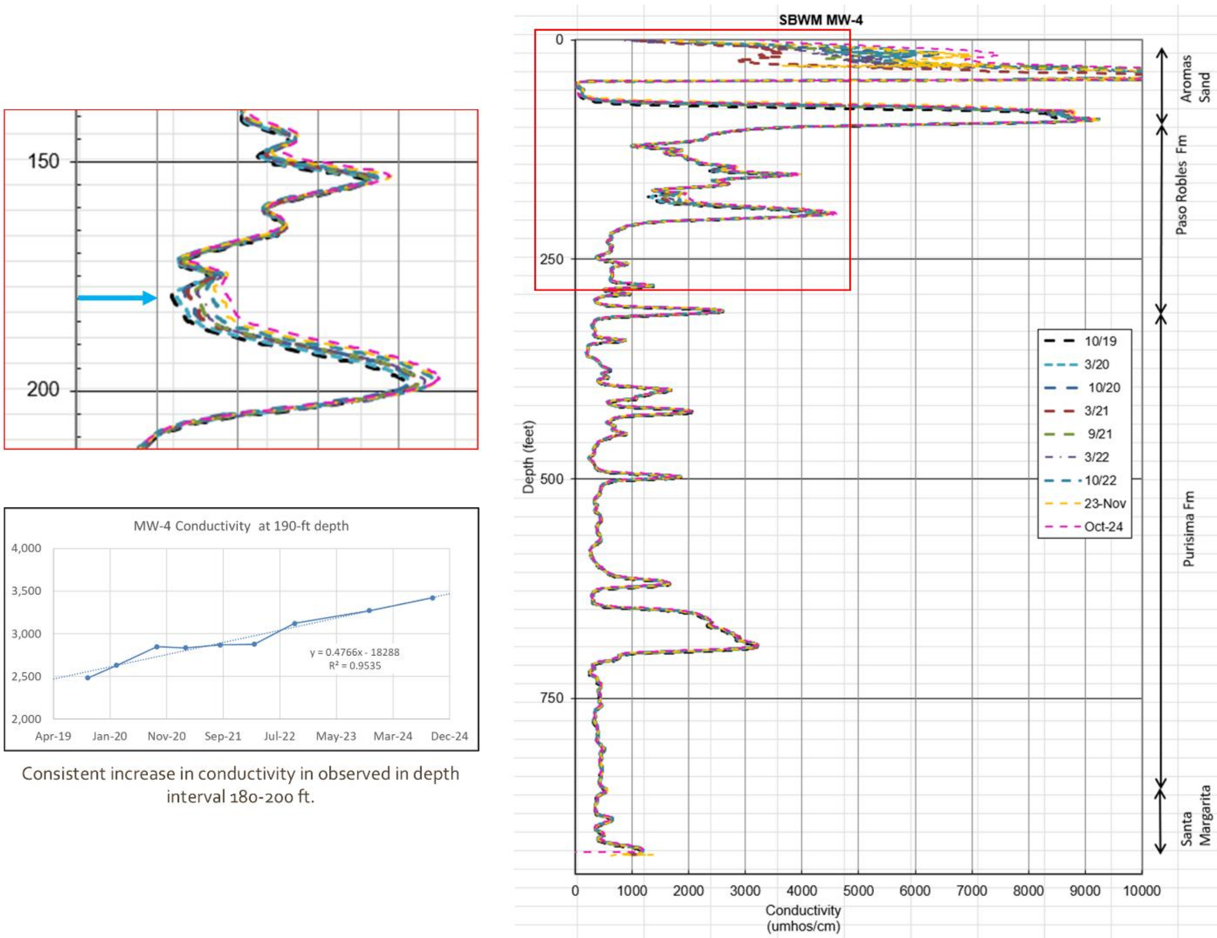


Figure 1 (Right) Induction logs from SW4 recorded over multiple recent years. (Top left) Close-up view of the 180-200 ft depth interval. (Bottom left) Time series of conductivity at 190-ft depth, showing a consistent increase over time.

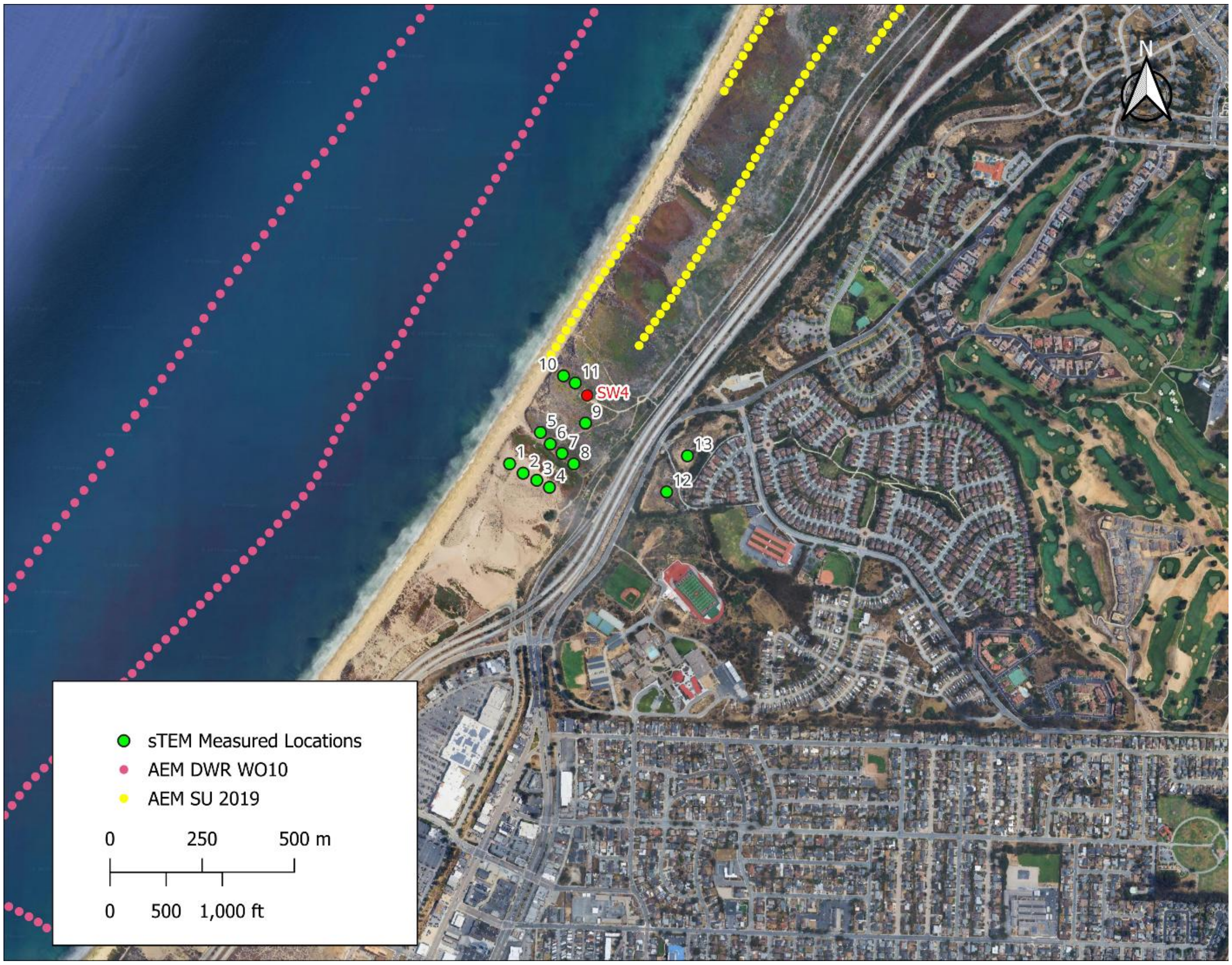


Figure 2 An overview map of the survey area. Green dots show the sTEM measured locations. Pink and yellow dots show the DWR statewide AEM (report dated 10/15/2023) and MCWD 2019 survey flight lines, respectively. Location of SW4 is shown with a red dot.

Stationary Time-domain Electromagnetics (sTEM)

The time-domain electromagnetic (TEM) method measures electrical resistivity of the subsurface materials. The physical principle of the TEM method is based on the electromagnetic induction phenomenon, meaning no direct contact to the ground is required. The ground is first energized by a primary magnetic field generated by a direct current injected in a transmitter loop. When the current stabilizes, the transmitter is turned off abruptly and a receiver coil measures electromagnetic response of the ground (Figure 3). Electrically resistive ground generates weak TEM signal while electrically conductive ground generates strong TEM signal.

The sTEM is a hand-carried system that involves laying out a 40 x 40 m (130x130 ft) square-shaped transmitter loop, along with a 3 x 3 m (10x10 ft) receiver loop placed at the center of the transmitter loop for each measurement (see Figure 4). The instrument is lightweight and can be hand carried in the field by a crew of two people, which enables surveying lands with different terrains and without causing any damage to plants and soil.

The TEM response, referred to as TEM “sounding”, is measured and interpreted as a function of time. Early time data contain information about the resistivity of the shallow layers, while late time data contains information about the resistivity of the deeper layers. Measuring a TEM sounding will therefore provide information about resistivity as a function of depth.

The resolution and depth of investigation (DOI) of TEM data depend on the strength of the energizing field, geological conditions, water quality (salinity), and the signal-to-noise ratio. Typically, sTEM provides subsurface information to depths of approximately 200-300 meters beneath the transmitter loop. However, in very conductive environments, for example in the presence of massive clay layers or seawater, the EM signal cannot penetrate as deeply, which reduces the DOI. This happens because in highly conductive media the primary magnetic field is strongly attenuated and cannot penetrate to greater depths.

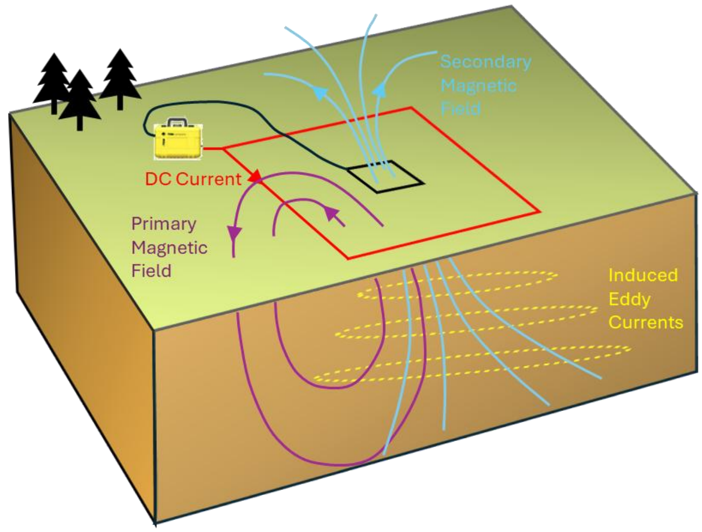


Figure 3 Basic principles of a TEM measurement.

More information about the sTEM method can be found in Appendix 1.

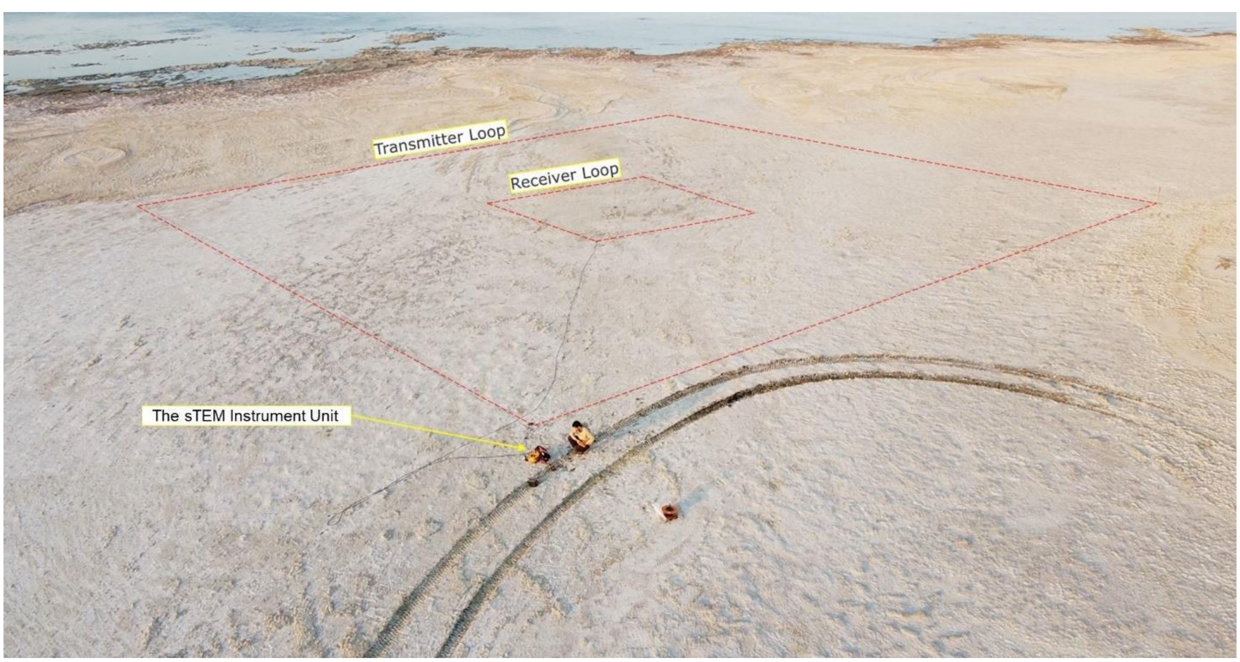


Figure 4 Configuration of the sTEM system.

Field Operation

Data Collection

The sTEM survey was conducted by Ahmad-Ali Behroozmand (GIP) and Jesse Crews on July 11, 2025. The system was hand carried in the field. Special care was taken to avoid harming environmentally sensitive vegetation at the site.

The survey was conducted using a sTEM10 system manufactured by TEMCompany. Prior to the survey, the sTEM system underwent a detailed testing and documentation process at a test site with a known geologic model. In addition, GIS layers containing geographic locations of the study area and sounding locations were uploaded into cellphones to enable accurate tracking of the measuring points during the survey.

Data acquisition involved laying out the transmitter and receiver loops in a central loop configuration and connecting them to the instrument. During fieldwork, the team was careful to avoid stepping on or running cables through environmentally sensitive vegetation.

During start-up, the system was carefully inspected to ensure that all parts were intact and secure. Each planned measuring location was first assessed for nearby noise sources, and when needed, the measuring location was moved to the nearest suitable location. Throughout each measurement, the data were quality controlled. Special care was taken by checking all measuring parameters, sounding curves and signal levels. At the end of the day, acquired data files were checked, and preliminary processing and inversion of the data was performed.

No instrumentation issues were encountered during the survey.

Weather conditions were favorable for surveying. It was cloudy in the morning and sunny later during the day, with a high temperature of 67F.

In total, thirteen (13) single-site sounding data were acquired, of which two soundings east of Highway 1 were deemed to be influenced by noise from nearby installations and hence should be interpreted with care.

“Noise” in sTEM data refers to any unwanted interference that disturb the true subsurface signal. It can come from nearby metal objects, buried cables and utilities, electrical powerlines, natural atmospheric effects, or even the instrument itself. These noise sources can bias the measurements and reduce the depth of investigation, and if not properly identified and removed, lead to inaccurate geological or hydrological interpretations.

The soundings were numbered 1 to 13. The location of soundings are shown in Figure 2. All coordinates are listed in a table in Appendix2.

Figure 5 The field crew setting up sTEM loops for measurement.

Figure 6 Photos from the field. (left) The sTEM system in operation. (right) data acquisition controlled in real time from a cellphone.

Figure 7 (Left) The sTEM system in operation at a station near the shoreline. (Right) Photo of the transmitter loop (red wire) laid out on the ground.

Figure 8 Examples of noise sources at the site. (Top left) powerline at SW4; (Top right) metal fences in an area just east of SW4; (Bottom) powerline and large metal drainage pipes running underground at the two basins east of Highway 1.

Data Processing and Inversion

sTEM Data Processing and Inversion

The processing and inversion of the sTEM data were completed with the software package Aarhus Workbench (https://www.aarhusgeosoftware.dk/aarhus-workbench). The Workbench is a well-documented and technically sound software package used for processing and inversion of ground-based and airborne electromagnetic and geoelectrical data. We utilized an application that is specifically designed for processing and inversion of sTEM data.

Detailed information about the processing and inversion settings can be found in Appendix 3.

Results

As described in the previous sections, the sTEM data are modeled to represent electrical resistivities at different depths, which can then be interpreted as lithology (i.e. the types of underground geological materials) to better understand the site geology. The inversion of sTEM data results in one-dimensional (1D) resistivity models at each sounding location. These results are presented as vertical resistivity cross-sections.

Color scale

To obtain the subsurface lithologic information, the measured electrical resistivities must be transformed into lithologies. Transforming resistivity to lithology is based on general correlations between resistivity and sediment type. Figure 9 shows a general correlation, where low permeability clay has a low resistivity value, sandy clay typically has a medium-range resistivity value, and sand to coarse sand has a relatively large resistivity value. This correlation is a general assumption and the range of resistivity for each lithologic unit may vary depending on local conditions.

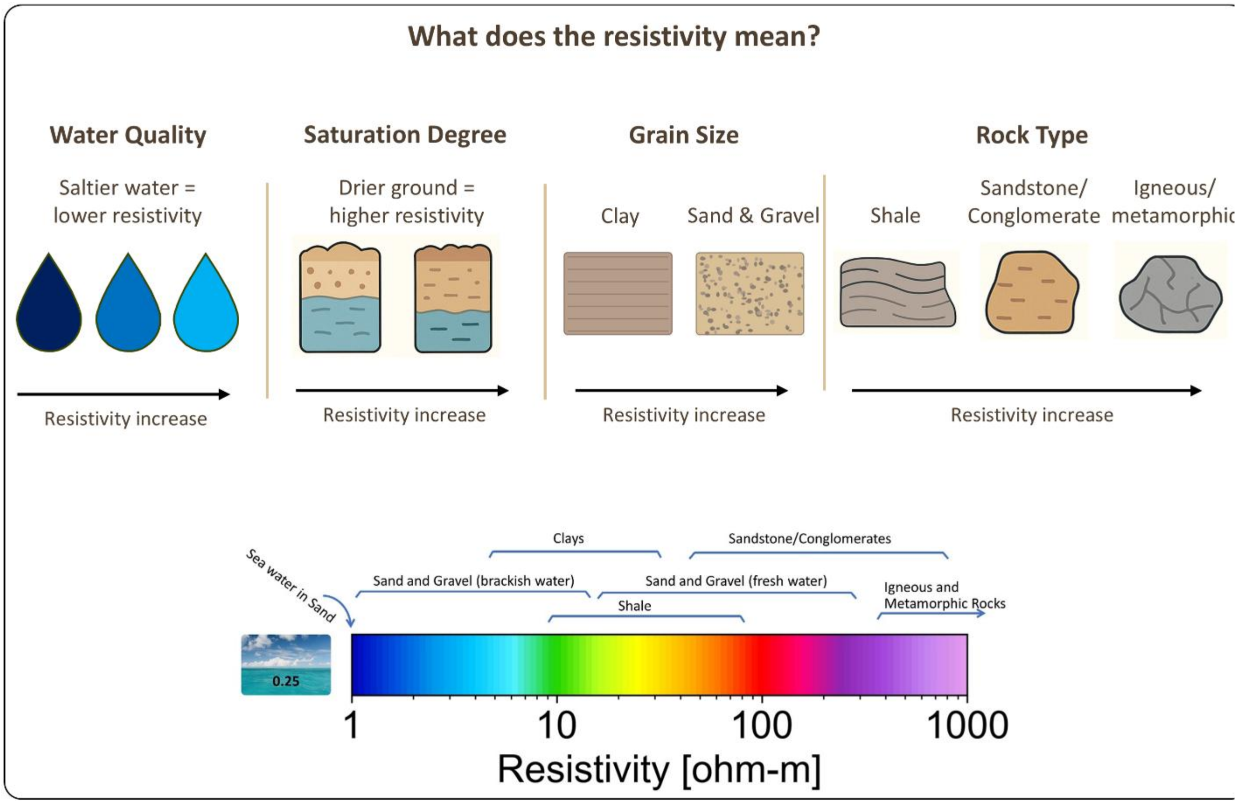


Figure 9 General correlation between resistivity, type of geologic materials, and water quality.

The water quality and saturation degree can also impact the resistivity, i.e., the more saline the water, the lower the formation resistivity and the lower the saturation degree (freshwater), the higher the formation resistivity. Therefore, correlating resistivity models with additional data sources if available (such as borehole and water quality information) and general geologic knowledge of the study area are crucial to obtain the most accurate description of the subsurface hydrogeology.

It is important to note that when evaluating resistivity models, factors influencing resistivity values should be considered.

In areas with a limited range of resistivity variation, the resistivity colormap is typically adjusted to represent geologic variations across the study area. In this project, however, due to the broad range of resistivity values (1-1,580 ohm-m), the color scale presented in Figure 9 was deemed satisfactory.

Data quality

Good quality data was obtained at most locations. The quality of the sounding data used for modelling is evaluated based on the last useable time gate (last data points remained after processing), data residual (data misfit), and the depth of investigation.

Data from soundings 12 and 13, east of Highway 1, is influenced by noise. In addition, late time data (related to deeper information) at sounding 11, next to SW4, was noisy due to the proximity of this sounding to the powerline (see Figure 10). As a result, lower DOI is achieved at this location.

The quality control plots can be found in Appendix 4.

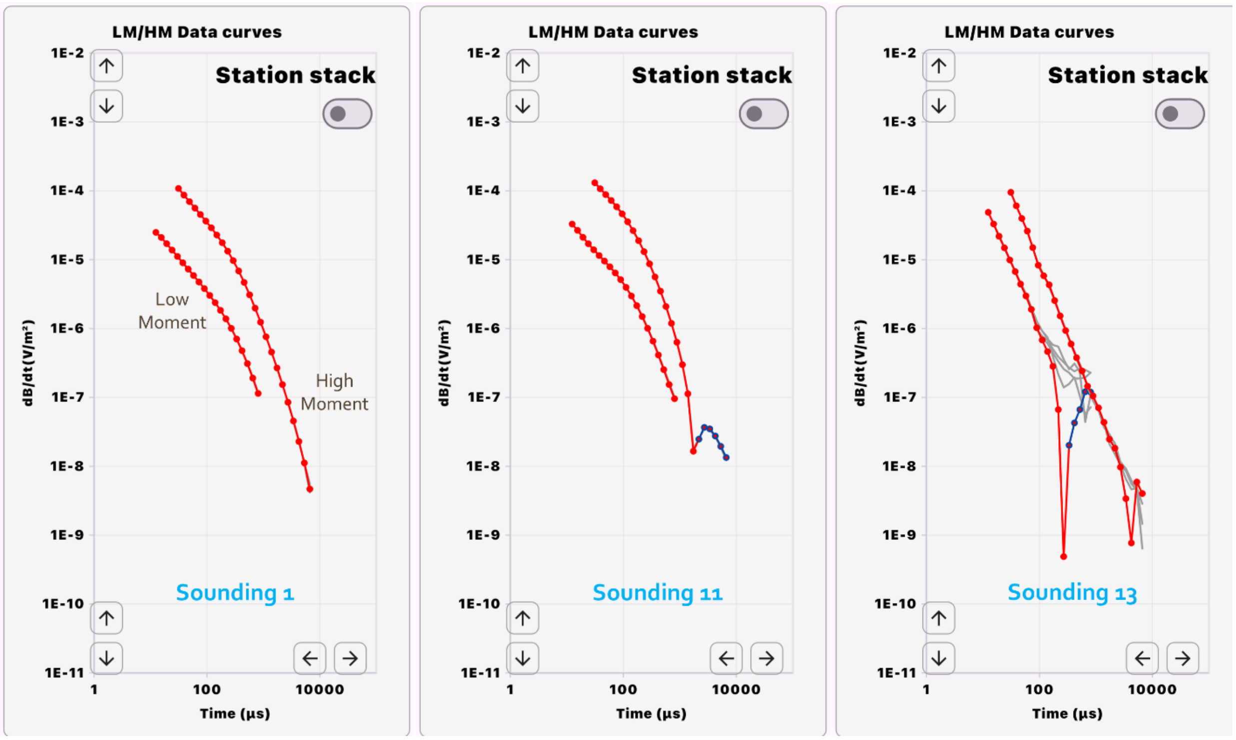


Figure 10 Examples of Sounding data. (Left) Sounding 1 data represents good data quality obtained at most locations, (Middle) Late time data at Sounding 11, next to SW4, is influenced by noise from a nearby powerline, (Right) Sounding 13 data are influenced by noise. sTEM is a so-called dual moment system utilizing both low moment (lower power) and high moment (higher power) to achieve both shallow and deep information. The recorded signal is a time derivative of the magnetic flux passing through the receiver coil (db/dt). The curves show stacked signal, i.e. an average of all transient measurements at each station.

Last gate

For most of the soundings, all the data for the entire sounding curve are used for the inversion. This is due to the very high signal level caused by the electrically conductive layers (clays or layers with saline water).

Data residual

The data residual, i.e. the misfit between the measured data (as shown in Figure 10) and the forward response of the resistivity model, describes how well the model fits the data. The parameter is used to evaluate the inversion results. In this survey, residual values were mostly below 1, which indicates a very good data fit (a residual of 1 or lower indicates data are well fitted within the data standard deviation).

Depth of Investigation

Across the survey area, the depth of investigation (DOI) was calculated for each model, which for most soundings west of Highway 1 extended to depths less than 100 m (328 ft) below the ground surface (bgs). Greater DOIs are achieved at soundings 8, 9, 12 and 13. On vertical sections, depths beyond the DOI are shown with fading colors.

Resistivity models

The sTEM results are presented as vertical cross-sections as shown in the following figures. Color-coded bars on the sections represent the inversion models at each sounding location.

Borehole data are shown on the sections as narrow vertical bars. Each bar includes the borehole ID at the top, dark brackets indicating screen intervals, and color-coded lithology, simplified as follows:

- Sand (‘S’) – yellow
- Clayey Sand (‘CS’) – yellow
- Clay (‘C’) – brown
- Sandy Clay (‘SC’) – brown
- Rock (‘R’) – gray

Blue dotted lines on the sections indicate the interpreted groundwater level, based on borehole data where available and extended using the resistivity models.

Black dotted lines on the sections indicate the interpreted bottom of a possible seawater wedge, which is based on borehole and geophysical logs, and extended using the resistivity models.

Solid black lines on top of the models show the terrain elevation, based on the USGS digital elevation model (DEM; 1m).

The x-axis on the sections show distance along the section line as shown on the GIS maps.

Section P1 is orientated from northwest to southeast (Figure 11) and runs through soundings 1-4. Borehole data from wells PCA-West (PCAW) and SNG are projected onto the section.

Section P2, orientated from northwest to southeast (Figure 12Figure 11), runs through soundings 5-8.

Section P3 is orientated from northwest to southeast (Figure 13) and runs through soundings 10 and 11. Borehole data from wells Sentinel Well#4 (SBWMMW4) and SDM MW-2 are projected onto the section.

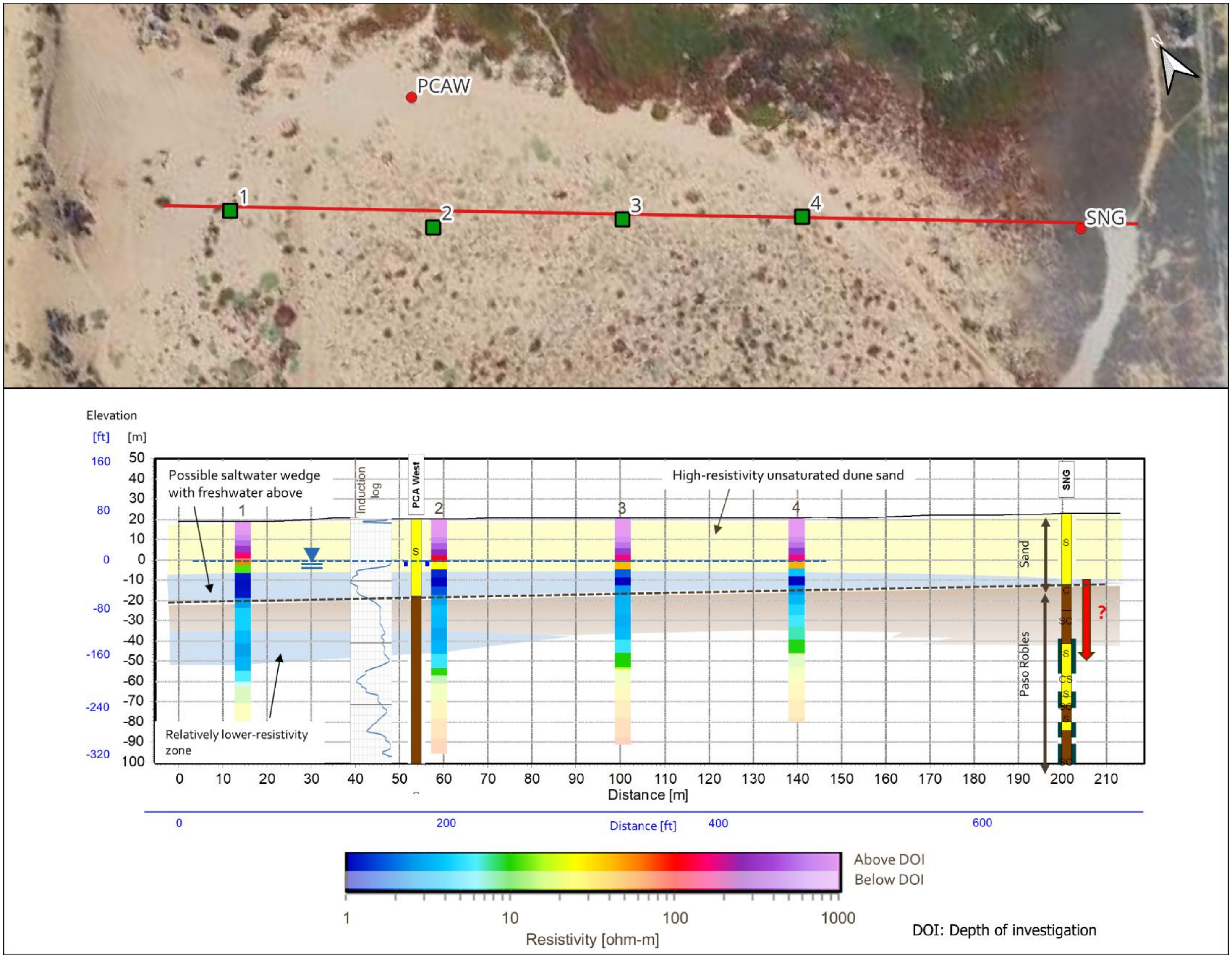


Figure 11 sTEM vertical cross section P1. The section location is shown on the upper map with a red line.

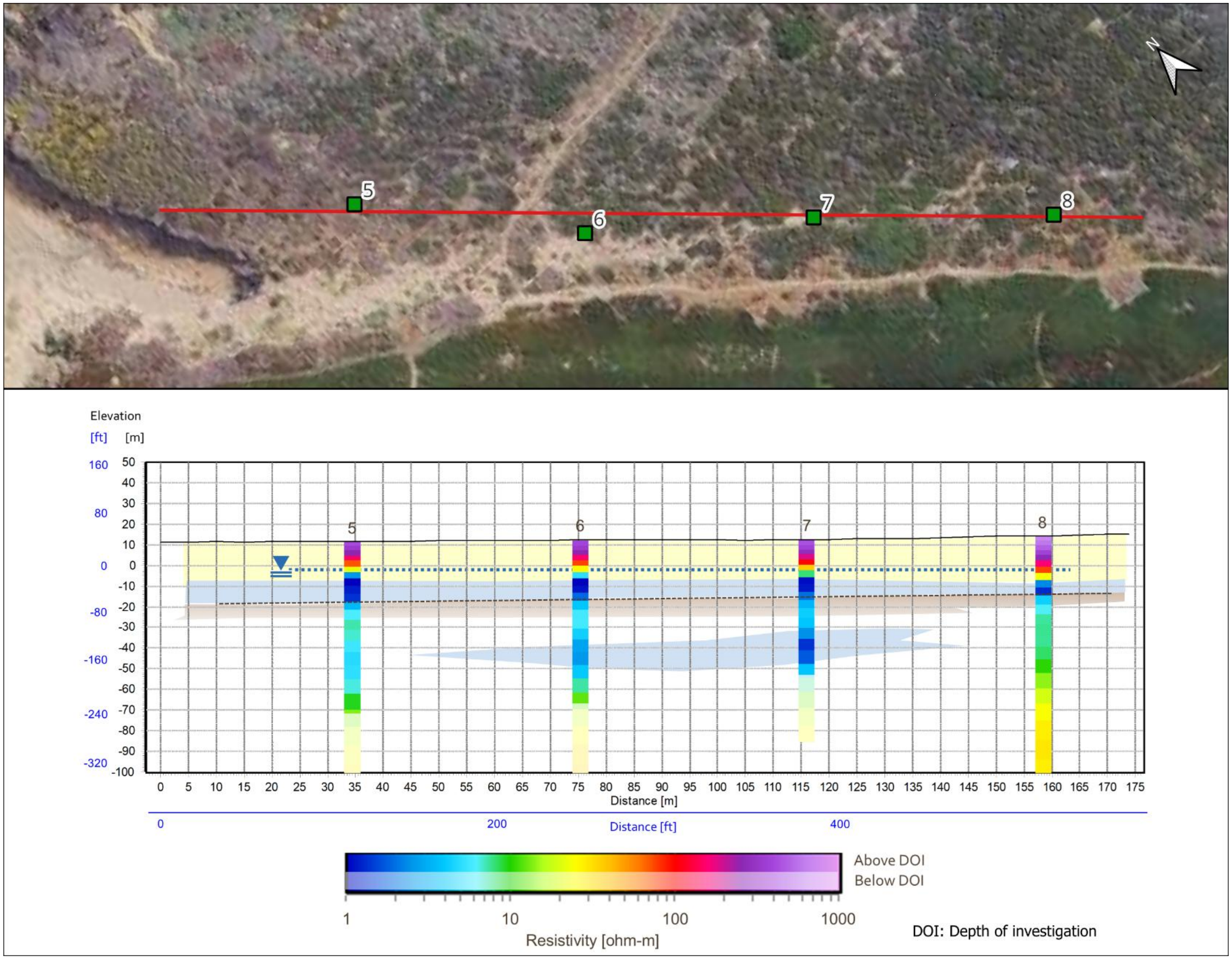


Figure 12 sTEM vertical cross section P2. The section location is shown on the upper map with a red line.

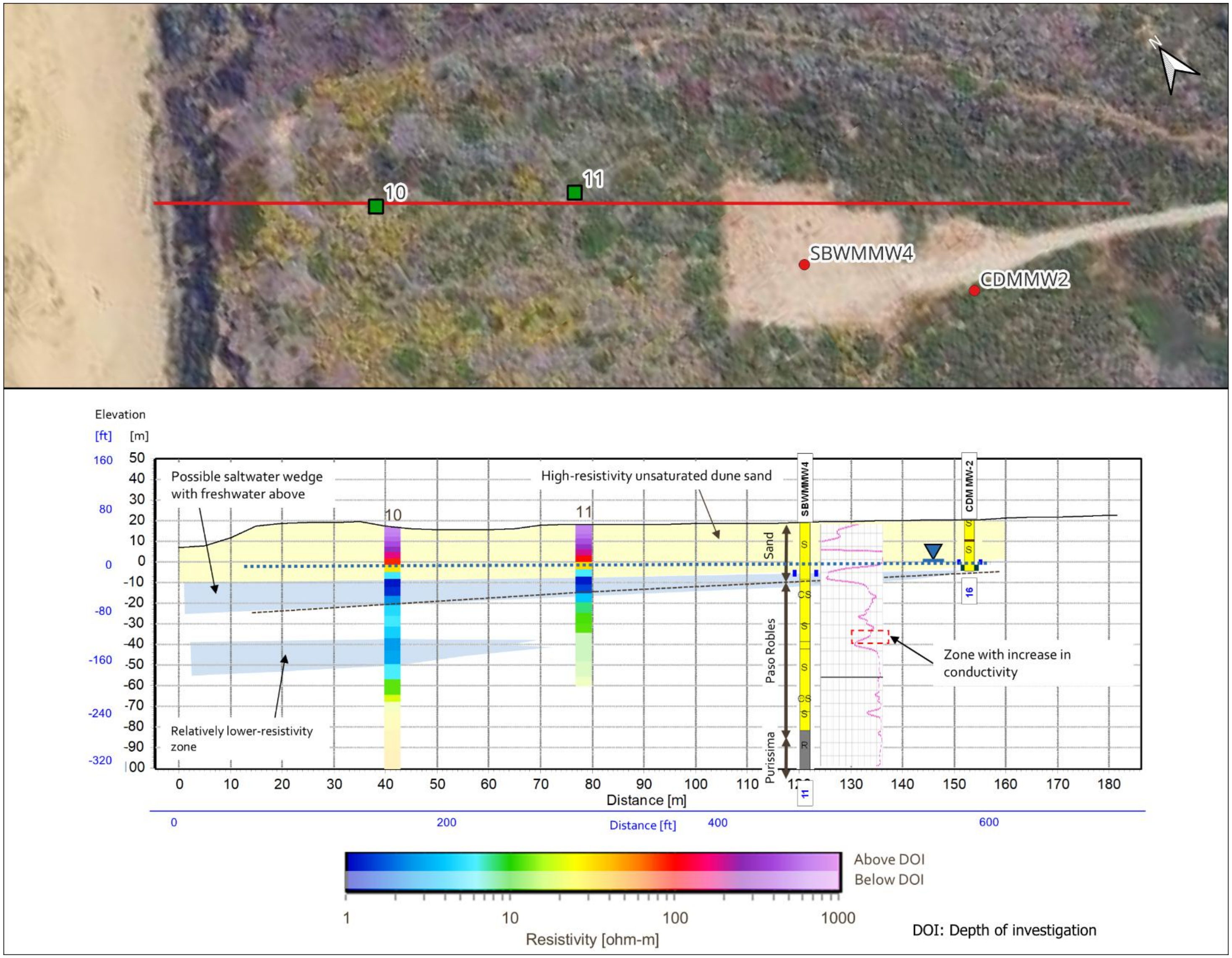


Figure 13 sTEM vertical cross section P3. The section location is shown on the upper map with a red line.

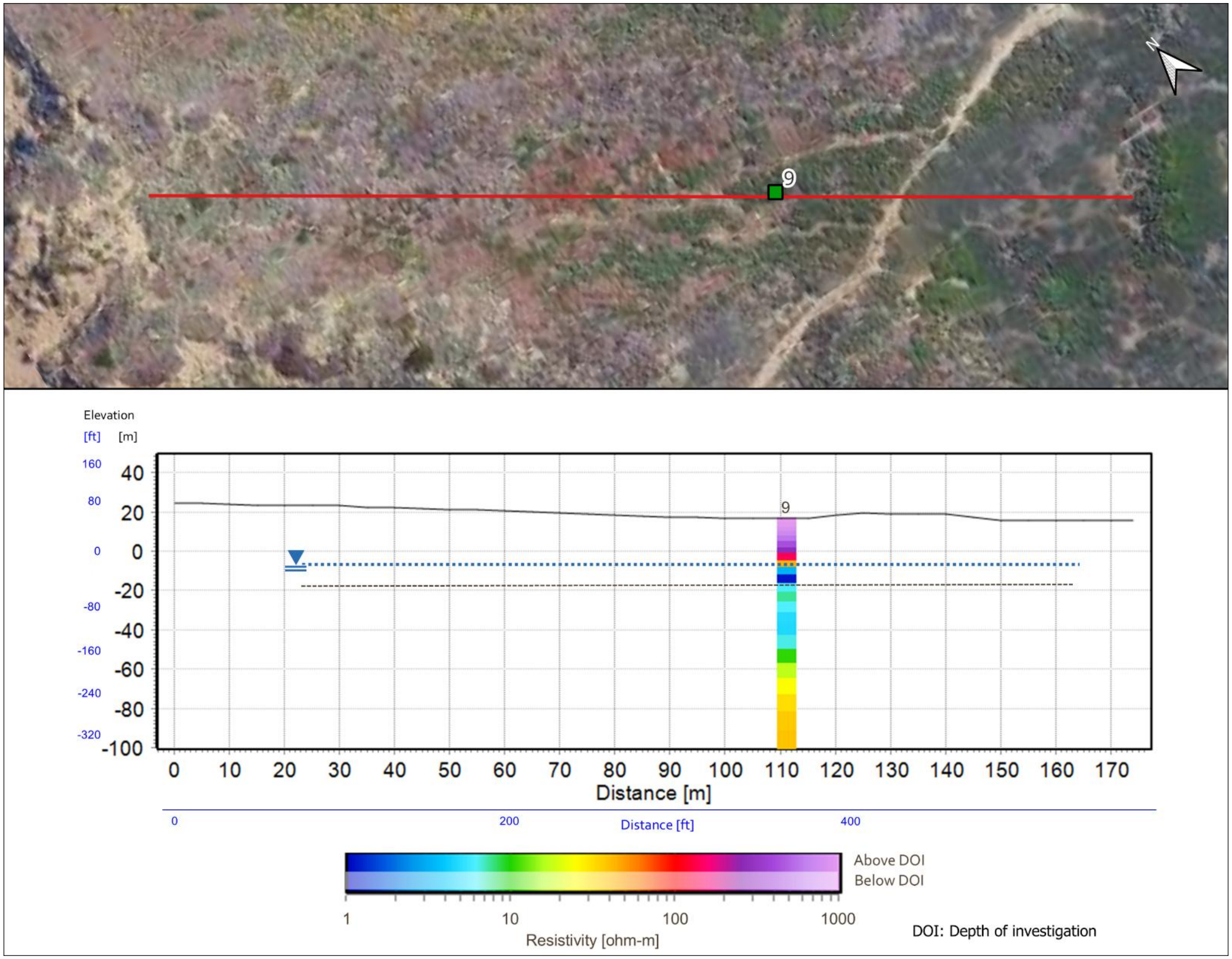


Figure 14 sTEM vertical cross section P4. The section location is shown on the upper map with a red line.

Data Deliverables

The following files have been provided as project deliverables in a digital format.

For the TEM investigation, the following files are provided:

1. Raw data as extracted from the sTEM instrument (USF).
2. A GERDA Firebird database (GDB) containing all the acquired data, processed data, as well as the inverted model results.
3. Ascii xyz files in different formats. A detailed description of the data formats of the files from the sTEM survey is described in Appendix 8.
4. GIS layers including:
    a. Location of soundings – (SHP - ArcGIS)
    b. Location of sections – (SHP - ArcGIS)
5. The project report, delivered as a PDF file.

Conclusions

This section provides general conclusions and an overall interpretation of the results in terms of the structures observed in the geophysical data. The interpretations are made based on very limited supplementary data (i.e. limited borehole information across the study area). Two geophysical logs (Induction log) and the lithology described in the well completion report for four wells are included on the vertical sections.

The vertical distribution of sTEM resistivities measured during this field event is consistent with a sequence (from surface downward) of:

- Unsaturated sand (dune sands and Aromas Fm.)
- Freshwater-saturated sand (dune sands and Aromas Fm)
- Saltwater saturated sand (Aromas Fm)
- Relatively fine-grained Paso Robles Fm.
- Relatively coarse-grained Paso Robles Fm.
- Underlying Purissima Fm.

The spatial distribution of sTEM resistivities shows a general pattern of increasing resistivity moving inland at most depths. However, the zone of interest (180-200 ft) shows local variations from this pattern, with certain soundings showing relatively lower resistivity values, with the best examples seen in soundings (soundings 6 and 7) to the south and east of SW4. Due to the heterogeneous nature of the Paso Robles Formation, these variations could be driven by lithologic and/or pore fluid salinity changes. Given the observations at SW4, it is likely that pore fluid salinity is a contributing factor to the observed pattern, consistent with some level of variable seawater intrusion in this zone.

Within the study area, this pattern did not appear to extend inland further than approximately SW4. Because SW4 has a consistent pattern of decreasing resistivity in the zone of interest (180-200 ft) and sits at the landward edge of the observed pattern (relatively lower resistivity values) in the sTEM results, it is likely that seawater intrusion impacts are greater in the areas of notably lower sTEM resistivity values than the impacts observed at SW4. The irregular spatial distribution of this effect would be consistent with seawater intrusion occurring preferentially in higher-permeability pathways within the heterogeneous Paso Robles Formation, such as channel sands.

Soundings further inland (east of Highway 1) were likely impacted by noise from electrical infrastructure but measured notably higher resistivities within the zone of interest, which may suggest that seawater intrusion has not yet reached these areas.

Appendix 1 – TEM Theory

For decades electromagnetic (EM) methods have been used worldwide for cost effective mapping of the subsurface materials for different applications. More recently, the accuracy of the instruments and their ability to obtain information about aquifers and hydrogeological properties has improved significantly. As a result, the TEM method is now one of the most efficient geophysical technologies for groundwater investigations.

Principles of TEM

The physical principle of the TEM is based on the electromagnetic induction phenomenon. The ground is first energized by a primary magnetic field generated by a direct current injected in a transmitter (Tx) loop. When the current stabilizes, the transmitter is turned off abruptly. During this rapid decay of the current an electromotive force results in short-duration eddy currents whose strength is largest in conductive parts of the ground. The EM induction phenomenon generates what is called the secondary magnetic field, the decay of which is measured just after the end of the turn-off using an induction receiver coil located in the center of the Tx loop (central loop configuration like ground-based stationary TEM) or outside the Tx loop (off-set configuration like tTEM). The actual measurement, referred to as TEM "sounding" or dB/dt curve, is the time derivative of the magnetic flux passing through the receiver coil. An example of a measured sounding curve is shown in Figure A2- 1.

The TEM response is measured and interpreted as a function of time. Just after the current in the Tx loop is turned off, the eddy currents in the ground will be close to the surface, and the measured signal primarily reflects the resistivity of the top layers. At later times the current will run deeper in the ground, and the measured signal contains information about the resistivity of the deeper layers. This is why the method is referred to as time-domain EM or TEM. Measuring a TEM sounding will therefore provide information about the resistivity as a function of depth.

The transmitter magnetic moment (Tx loop area x current x number of wire turns) and the signal-to-noise ratio (SNR) determine the depth of investigation (DOI). A stronger magnetic moment enables deeper penetration of the magnetic fields and thus greater DOI. The SNR depends on the ground electrical resistivity and ambient noise. The higher the SNR, the greater the DOI.

More information about the principles of the TEM method can be found in Ward and Hohmann (1988).

Noise in TEM data

TEM data are comprised of different types of noise components. Noise can cause bias signals and affect the depth of investigation and if not properly identified and removed, can result in incorrect geological and hydrological interpretations. The different sources of noise include: (1) Galvanic coupling caused by the electromagnetic signal induced in a metal object, such as grounded overhead powerlines, metal pipes, metal fences etc., (2) Capacitive coupling caused by the induced EM signal in an insulated installation such as a power cable, (3) Coherent noise from electrical powerlines, (4) Atmospheric noise, and (5) Instrument internal noise.

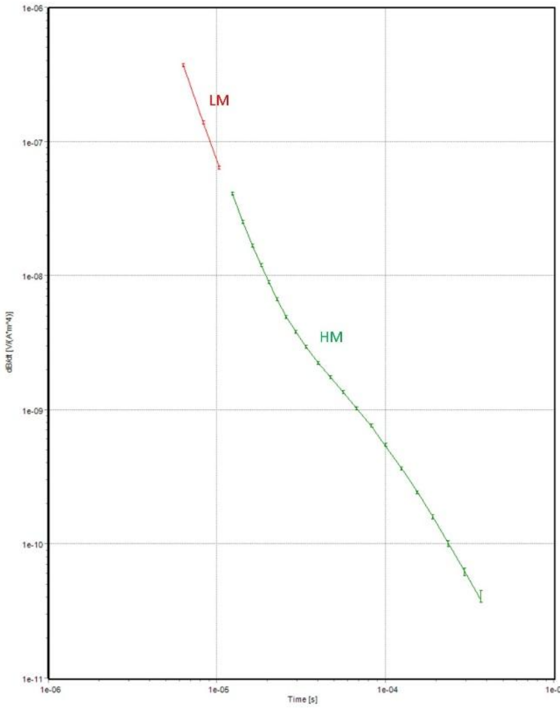


Figure A2- 1 An example of a dB/dt curve (sounding data).

References

Ward SH, Hohmann GW (1988) Electromagnetic theory for geophysical applications. In: Nabighian MN (ed) Electromagnetic methods in applied geophysics, vol 1. SEG, Tulsa, pp 131–311.

Appendix 2 – Field operation

Field Crew

The sTEM fieldwork was conducted on July 11, 2025, by Ahmad-Ali Behroozmand (Geophysicist) and Jesse Crews (Hydrogeologist). The system was hand carried in the field.

Instrument Issues

There were no instrumental issues.

Weather

The weather was favorable during the survey. The weather did not affect the quality of the TEM measurements.

Day	Temperature	Comments
7/11/2025	52-67F	Cloudy in the morning and sunny later during the day. Pleasant.

Quality Control During Survey

During each measurement, the system components were assessed to ensure that all parts were intact and secure. In addition, the TEM signal, battery voltage, current, temperature and GPS reception were constantly monitored during data acquisition. Overall, very good signal-to-noise ratios were observed.

At the end of the survey day, the acquired data were exported from the instrument and imported into the processing and inversion software. Each sounding dataset was checked for data quality and initial inversions were carried out to ensure that the data can be fit with a reasonable resistivity model.

Sounding locations

During recording, each sounding was assigned a time stamp (UTC-time from the GPS). The list below presents the time stamps together with a sounding number (integer) assigned after the field operation.

Sounding number	Date [YYYYMMDD]	Time [HHMMSS]	UTM-X [Meter]	UTM-Y [Meter]	Elevation [Meter]
1	20250711	153129	-164489.90	-152728.30	19.0
2	20250711	154923	-164453.20	-152753.70	20.4
3	20250711	160314	-164416.30	-152773.00	20.7
4	20250711	161744	-164381.90	-152792.20	20.9
5	20250711	162011	-164406.40	-152643.50	11.7
6	20250711	173530	-164379.70	-152674.90	12.0
7	20250711	180144	-164347.90	-152700.20	12.5
8	20250711	182719	-164316.20	-152728.60	14.4
9	20250711	194221	-164284.30	-152618.10	17.5
10	20250711	204252	-164343.80	-152490.30	16.9
11	20250711	210845	-164311.90	-152509.50	18.2
12	20250711	221811	-164064.60	-152804.50	10.1
13	20250711	224945	-164008.10	-152706.80	17.2

Coordinate System: EPSG: 3310 NAD83 / California Albers.

Time Stamp: UTC from the built-in GPS.

Terrain Elevation (a.m.s.l) is based on the USGS DEM, 1-m.

Appendix 3 –Instrumentation, Configuration and Processing & Inversion Settings

This appendix provides details on the sTEM instrument IDs, instrument setup, processing, and inversion settings.

The information in this appendix requires geophysical insight and is included as part of the documentation.

An overview of the general data workflow is illustrated in Figure A2- 2.

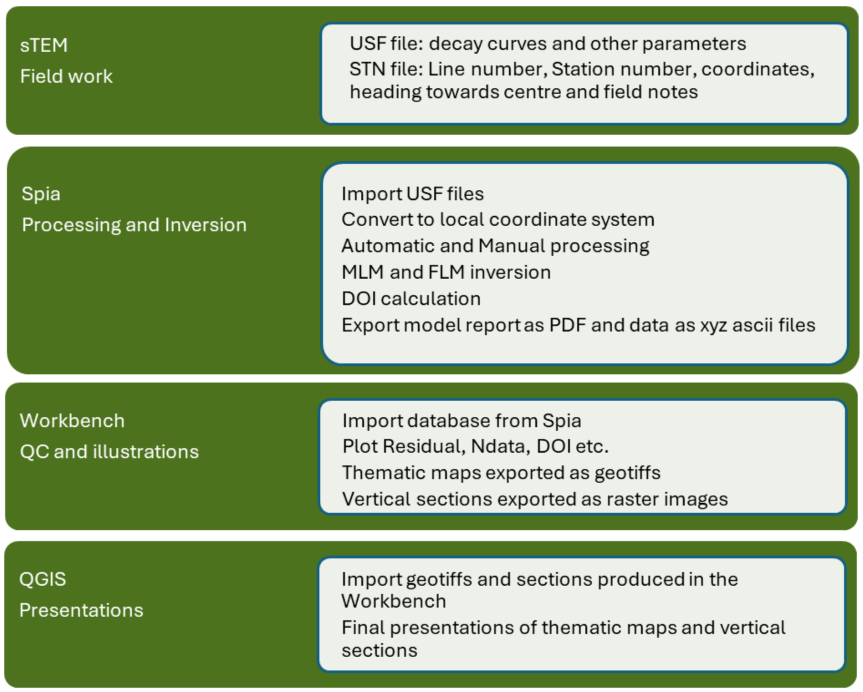


Figure A2- 2 Data Workflow.

sTEM Data Processing Steps

The collected sTEM data underwent the following processing steps:

1. Manually inspect each dataset for both low-moment (LM) and high-moment (HM) sounding curves.
2. Remove noisy data. The noise can be due to overhead powerlines, buried power cables, metal fences, and other man-made sources.
3. Assign a standard uniform 3% noise to all data.
4. Assign the transmitter loop center coordinates (acquired in the field) and Digital Elevation Model (DEM) elevation to the sounding positions.

sTEM Data Inversion Steps

The processed sTEM data were then used in the following inversion scheme:

1. Define vertical constraints on the resistivities as well as the number of model layers and layer thicknesses.
2. Invert the processed data for smooth (multi-layer) resistivity models.
3. Present the data as line models. In case the results are not satisfactory (e.g., due to high data residual), the inversion setup is revisited, and the data are re-inverted.
4. Calculate the data residual, i.e., the difference between the observed data and the mapping of the estimated model to the data space.
5. Calculate the depth of investigation (DOI), based on a sensitivity analysis of the model.

Hardware

The following hardware was used for the survey.

Unit	ID	Comments
sTEM+	V001A230007	10 A transmitter SAPI Version 1.11.0.0 Controller Version 1.0.4
sTEM RX 3x3	V004A0003	4 turns, Efficient area $36m^2$ Rx coil amplification factor 21
40x40m Transmitter loop	NA	4.0 mm^2

Figure A2- 3 Photo of the instrument and a sketch of the configuration.

Software

The following software was used for processing, inversion, and presentations.

Unit	ID	Comments
SPIA	NA	Version 3.8.0.0
Aarhus Workbench	NA	Version 6.9.0.0
QGIS	NA	Version 3.28.2-Firenze

More information about the software can be found here:

https://www.aarhusgeosoftware.dk/aarhus-spia-tem

https://www.aarhusgeosoftware.dk/aarhus-workbench

General instrument, settings, and configuration information

Parameter	Comments
Configuration	Central loop
TX loop	40 x 40 m single turn, Damping resistor 330 ohm
Rx Instrument	180 kHz 2. order lowpass filter
RX loop	Vertical Z-component 3 x 3 m, 4 turns 800 kHz 1. order lowpass filter

The sTEM instrument is operated using a smartphone application as shown in Figure A3- 4. In the application, users can monitor measurements in real time.

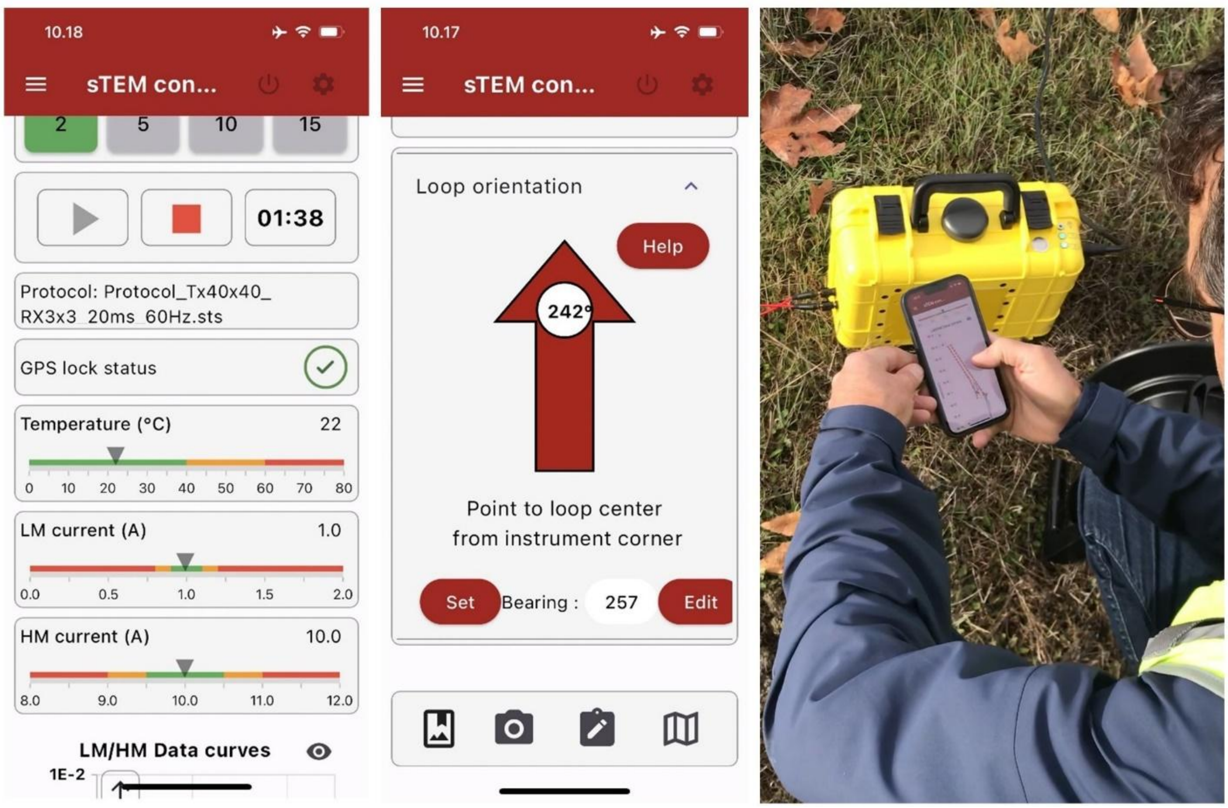


Figure A3- 4 The sTEM instrument was operated using a smartphone application installed on an iPhone. (right) the operator is checking the EM sounding curve, which is the decay of the secondary magnetic field flux in the receiver coil.

Calibration values

Prior to the survey, the sTEM instrument was calibrated at the Danish National Geophysical Test Site. Calibration involves adjusting for factors such as how the transmitted current is measured, how the turn off ramp is modelled and accounting for minor delays in the electronics. The calibration process involves applying a multiplication factor and a time shift to the data. The calibration parameters for both low and high moments are shown in the table below.

Parameter	Value	Comments
LM Time shift	0.4 usec	From the sTEM verification report by the TEMcompany dated 17-11-2023.
LM Field factor	1.045	
HM Time shift	0.0 usec	
HM Field factor	1.120	

The calibration report from the test site can be provided upon request.

Measurement cycle

Parameter	Value	Comments
Coordinate system	WGS 84 Lat-lon (epsg:4326)	The coordinates are measured using a GPS unit mounted on top of the instrument. The coordinates are then calculated for the center of the loop by measuring the bearing as shown above.
Script used in the instrument	Protocol_Tx40x40_RX3x3_20ms_60Hz.sts	Repetition frequencies are chosen to suppress signal from the 60 Hz powerline.
Uniform noise	0.03	Standard deviation
LM Ontime HM Ontime	900 usec 8333 usec	
LM Turn off time modeled HM Turn off time modeled	7 usec 13 usec	
LM Off time HM Off time	1183 usec 8334 usec	
LM Frontgate HM Frontgate	NA 17 usec	Front gate not applied on LM
Stack size per transmitter moment LM NDataSeries HM NDataSeries	LM: 154 Sweeps @stacksize= 100 HM: 154 Sweeps @stacksize= 100	Either a 2 min or a 5 min measurement period has been applied depending on the signal strength and signal-to-noise ratio for the late time gates.
Noise measurements	LM None HM none	Transmitter off. Measurements to determine the general noise level at the location at the given time.
Sign definitions	NA	The sTEM instrument will flip the sign if the inital data points are negative. This could happen if the transmitter loop and receiver loop are laid out in opposite polarities.

Figure A2- 5 The 3x3 m receiver loop installed in the center.

The transmitter waveform for the low moment (LM) is presented by piecewise linear segments, which are used during inversion.

Time [uSec]	Normalized Amplitude
-2850	0
-2755,1	-0,365
-2639,4	-0,611
-2535,5	-0,756
-2458	-0,823
-2318,6	-0,916
-2137,2	-0,97
-1950	-1
-1949,8	-0,989
-1949,4	-0,772
-1949,2	-0,712
-1948,9	-0,653
-1948,4	-0,401
-1948	-0,258

-1947,5	-0,152
-1946,9	-0,075
-1945,9	-0,028
-1944,7	-0,011
-1943	0
-900	0
-805,07	0,365
-689,39	0,611
-585,54	0,756
-507,98	0,823
-368,64	0,916
-187,23	0,97
0	1
0,207	0,989
0,621	0,772
0,821	0,712
1,093	0,653
1,579	0,401
2,021	0,258
2,464	0,152
3,121	0,075
4,093	0,028
5,264	0,011
7	0

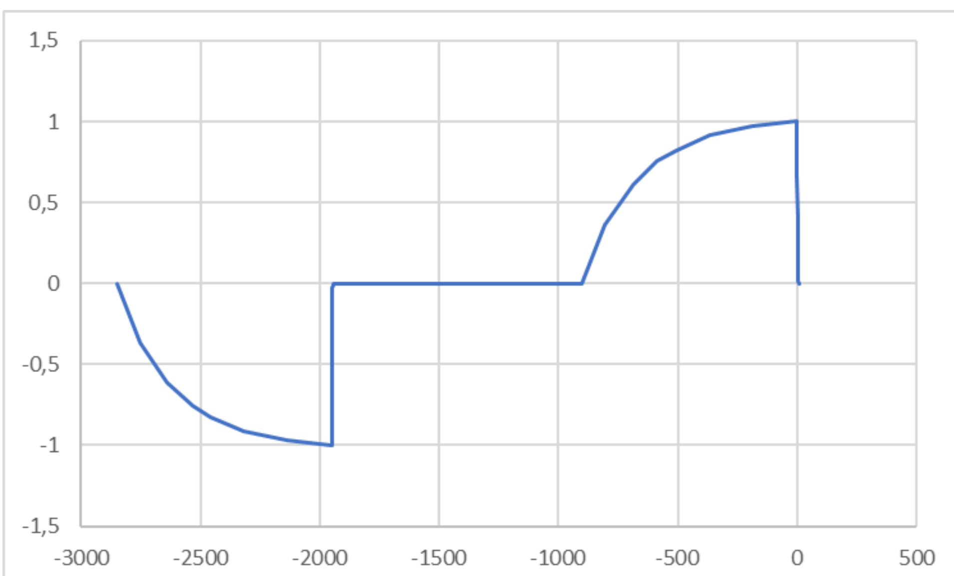


Figure A2- 6 The normalized Low Moment (LM) transmitter waveform. X-axis reprresents time in usec.

Similarly, the transmitter waveform for the high moment (HM):

Time [uSec]	Normalized Amplitude
-26000	0
-25903	-0,306
-25692	-0,671
-25506	-0,829
-25277	-0,925
-25007	-0,971
-24627	-0,994
-24154	-0,999
-22201	-1
-20000	-0,997
-19999	-0,88
-19998	-0,733
-19997	-0,53
-19996	-0,323
-19995	-0,15
-19994	-0,062
-19993	-0,03
-19992	-0,015
-19990	-0,006
-19987	0
-6000	0
-5902,8	0,306
-5691,5	0,671
-5505,6	0,829
-5277,5	0,925
-5007	0,971
-4626,8	0,994
-4153,5	0,999
-2201,4	1
0	0,997
0,345	0,927
0,893	0,88
1,56	0,733
2,107	0,646
2,655	0,53
3,774	0,323
4,845	0,15
5,798	0,062
6,655	0,03
7,75	0,015
9,869	0,006
13	0

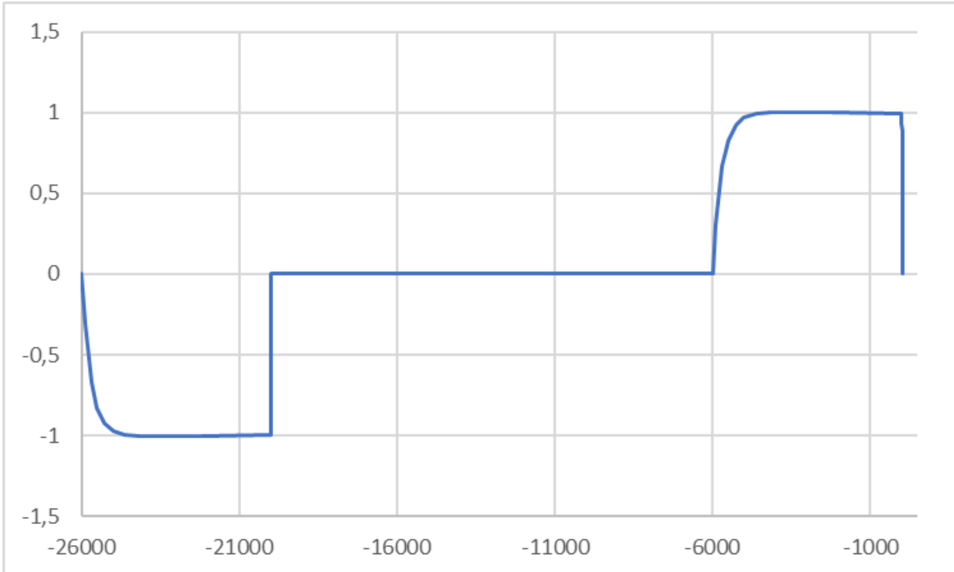


Figure A2- 7 The normalized High Moment (HM) transmitter waveform. X-axis reprresents time in usec.

The measurement time gates are presented in the following table.

Time gate number	Gate center Time [uSec]	Time gate number	Gate centerTime [uSec]
2	1.11803E-05	2	2.83141E-05
3	1.40312E-05	3	3.56371E-05
4	1.76370E-05	4	4.49444E-05
5	2.21091E-05	5	5.67395E-05
6	2.76993E-05	6	7.16371E-05
7	3.46591E-05	7	9.03922E-05
8	4.33518E-05	8	1.13982E-04
9	5.42805E-05	9	1.43666E-04
10	6.79485E-05	10	1.81036E-04
11	8.50823E-05	11	2.28217E-04
12	1.06577E-04	12	2.87696E-04
13	1.33409E-04	13	3.62687E-04
14	1.67062E-04	14	4.57300E-04
15	2.09296E-04	15	5.76621E-04
16	2.62207E-04	16	7.26995E-04
17	3.28422E-04	17	9.16583E-04
18	4.11269E-04	18	1.15573E-03
19	5.15106E-04	19	1.45720E-03
20	6.45273E-04	20	1.83728E-03
21	8.08366E-04	21	2.31643E-03
22	1.01235E-03	22	2.92050E-03
		23	3.68202E-03
		24	4.64206E-03
		25	5.85244E-03
		26	7.37798E-03

Processing and inversion settings

The processing and inversion were performed using the SPIA software. The model description and several key inversion parameters are provided in the two following tables.

Parameter	Value	Comments
Coordinate system	NAD83 California Albers (epsg:3310)	Coordinates have been converted during import (into SPIA) to EPSG 3310
Joint inversion	LM and HM are jointly inverted to reflect one inversion model	
Multi-layer model (MLM)/ Smooth model	30 layers	Fixed layer boundaries. Each layer is described in the table below.
MLM vertical constrains	Medium constrains	
Few-layer model (FLM) / Sharp model	Not applied	
Initial resistivity used in the inversion	40 ohm-m	Homogenous half-space
Minimum points per segment	2	
Depth of investigation (DOI)	standard	

Layer number	Depth to Top [Meter]	Depth to Bottom [Meter]	Layer Thickness [Meter]
1	0	2	2
2	2	4.2	2.2
3	4.2	6.5	2.3
4	6.5	9	2.5
5	9	11.7	2.7
6	11.7	14.6	2.9
7	14.6	17.7	3.1
8	17.7	21.1	3.4
9	21.1	24.7	3.6
10	24.8	28.7	3.9
11	28.7	32.9	4.2
12	32.9	37.5	4.6
13	37.5	42.4	4.9
14	42.4	47.7	5.3
15	47.7	53.4	5.7
16	53.3	59.5	6.2
17	59.6	66.2	6.6
18	66.2	73.3	7.1
19	73.3	81	7.7
20	81	89.3	8.3
21	89.4	98.3	8.9
22	98.3	107.9	9.6
24	107.9	118.3	10.4
25	118.3	129.5	11.2
26	129.5	141.6	12.1
27	141.6	154.6	13
28	154.6	168.6	14
29	168.6	183.7	15.1
30	352.3		

Appendix 4 – Overview and QC plots

Data Residual

Sounding Locations

0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5

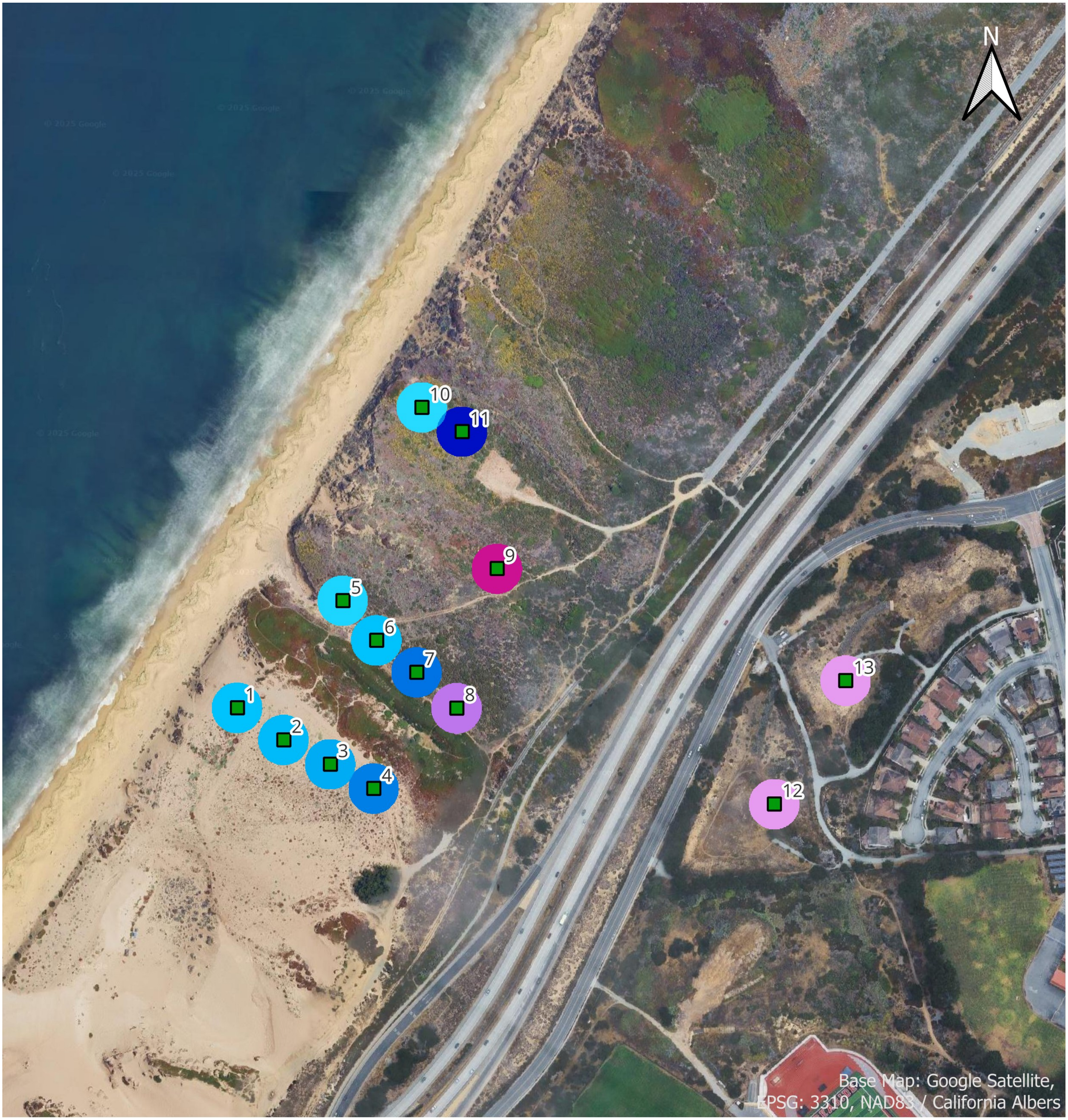
Residual
[-]

0 50 100 m

0 200 400 ft

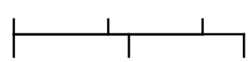
Date surveyed: 7/11/2025
Date map created : 9/29/2025
Created by: AAB
Checked by: MH

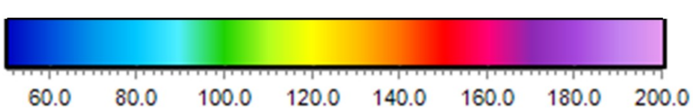
GEOPHYSICAL IMAGING PARTNERS



Depth of Investigation

Sounding Locations

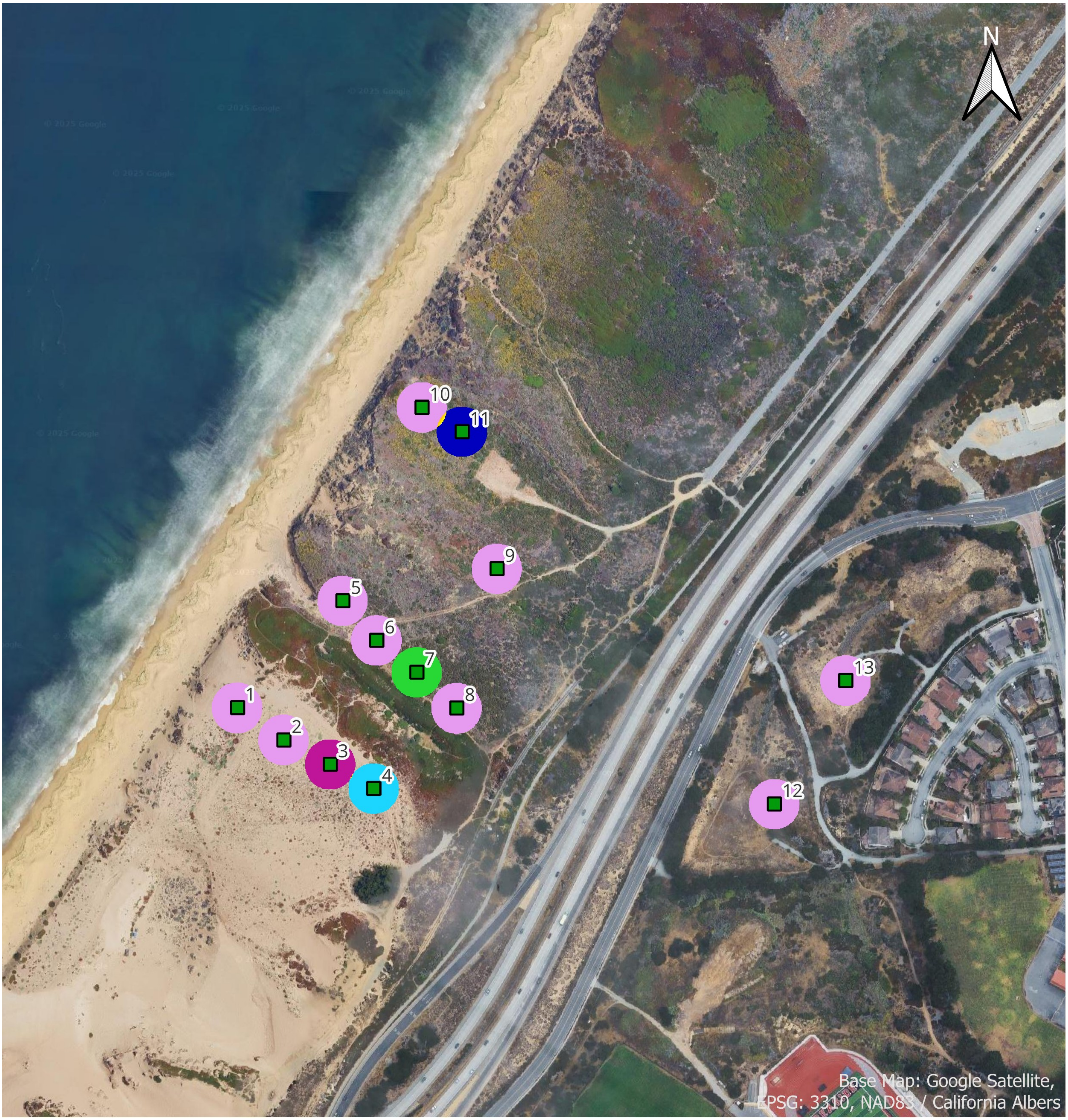




Date surveyed: 7/11/2025
Date map created : 9/29/2025
Created by: AAB
Checked by: MH

GEOPHYSICAL IMAGING PARTNERS

Project #25004

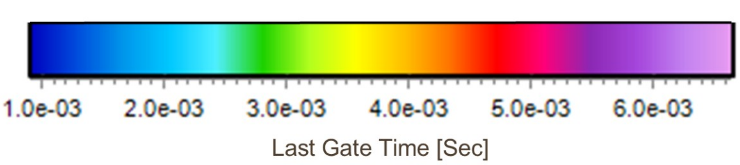


Last Gate

Sounding Locations

0 50 100 m

0 200 400 ft



Date surveyed: 7/11/2025
Date map created : 9/29/2025
Created by: AAB
Checked by: MH

GEOPHYSICAL IMAGING PARTNERS

Project #25004

Appendix 5 – Data Formats

For each model type (multi-layer model/smooth model or few-layer model/sharp model), data can be exported in different formats to facilitate import and management of data in third-party software solutions. Below are descriptions of four ASCII formats (*_byLayer.xyz, *_syn.xyz, *_inv.xyz, *_dat.xyz). The file named *Project_byLayer.xyz* might be the most generic format, suitable for visualization in software packages like Leapfrog, Rockworks, and similar. In addition to the four ASCII files, georeferenced raster files (Geotiffs) and ArcGIS shape files are typically provided as part of the data deliverables. For each sounding, the measured data are provided as an ASCII file in the USF format.

The *_byLayer.xyz file uses the following format:

Header section:

```
/INFO

/Aarhus SPIA export file. File created: 30-03-2023 13:00:34. Exported from SPIA64

/SPIA VERSION          3.7.0.0

/PROJECT NAME          Projectname.gdb

/DUMMY

/9999

/DATATYPE              Type of data

/COORDINATE SYSTEM     Coordinate System: WGS 84 UTM zone 19S (epsg:32719)

/NUMBER OF LAYERS      6 Max Number of layers

/MODEL UNIT            Base unit used for resistivities: /Resistivity (Ohm-m) / conductivity
(mS/m)

/LENGTH UNIT           Base unit used for distances: Meter
```

Main section:

```
ID                     Incrementing number

LINE_NO                Line number

LAYER_NO               Layer number

UTMX                   UTMX

UTMY                   UTMY

ELEVATION_CELL         Elevation top of Layer

RESISTIVITY            Resistivity

RESISTIVITY_STD        STD on Resistivity

CONDUCTIVITY           Conductivity

DEPTH_TOP              Depth to top of layer

DEPTH_BOTTOM           Depth to bottom of layer

THICKNESS              Thickness of layer
```

THICKNESS_STD   STD on Layer Thickness

The *_SYN.xyz file use the following format:

Header section:

```
/INFO
/Aarhus SPIA export file. File created: 30-03-2023 13:00:34. Exported from SPIA64
/SPIA VERSION          3.7.0.0
/PROJECT NAME          ProjectName.gdb
/DUMMY
/9999
/DATATYPE              Type of data
/COORDINATE SYSTEM     Coordinate System: WGS 84 UTM zone 19S (epsg:32719)
/NUMBER OF LAYERS      30 Number of layers
/MODEL UNIT            Base unit used for resistivities: /Resistivity (Ohm-m) / conductivity
(mS/m)
/LENGTH UNIT           Base unit used for distances: Meter
```

Main section:

```
LINE_NO                Line number
MODEL_NAME             Model Name
UTMX                   UTMX
UTMY                   UTMY
DATE                   Dummy value
TIME                   Dummy value
RECORD                 Record
ELEVATION              Topography
NUMDATA                Number of gates inverted
SEGMENT                Moment ID (low moment=1, high moment=2)
RESDATA                Data misfit (normalized with STD)
RESTOTAL               Total misfit
DATA_1                 Voltage (V/Am^4), for gate_1
DATA_2                 Voltage (V/Am^4), for gate_2
…
DATA_N                 Voltage (V/Am^4), for gate_N
```

The *_inv.xyz file use the following format:

Header section:

/INFO	
/Aarhus SPIA export file. File created: 30-03-2023 13:00:34. Exported from SPIA64	
/SPIA VERSION	3.7.0.0
/PROJECT NAME	ProjectName.gdb
/DUMMY	
/9999	
/DATATYPE	Type of data
/COORDINATE SYSTEM	Coordinate System: WGS 84 UTM zone 19S (epsg:32719)
/NUMBER OF LAYERS	30 Number of layers
/MODEL UNIT	Base unit used for resistivities: /Resistivity (Ohm-m) / conductivity (mS/m)
/LENGTH UNIT	Base unit used for distances: Meter

Main section:

LINE_NO	Line number (always 0)
UTMX	UTMX
UTMY	UTMY
DATE	Dummy value
TIME	Dummy value
RECORD	Record
ELEVATION	Topography
NUMDATA	Number of gates inverted
SEGMENT	Moment ID (low moment=1, high moment=2)
RESDATA	Data misfit (normalized with STD)
RESTOTAL	Total misfit
RHO_I_1	Resistivity (Ohm m) for layer_1
RHO_I_2	Resistivity (Ohm m) for layer_2
…	…
RHO_I_N	Resistivity (Ohm m) for layer_N
RHO_I_STD_1	STD on resistivity for layer_1
RHO_I_STD_2	STD on resistivity for layer_2
…	…
RHO_I_STD_N	STD on resistivity for layer_N

SIGMA_I_1	Conductivity (mS/m) for layer_1
SIGMA_I_2	Conductivity (mS/m) for layer_2
…	…
SIGMA_I_N	Conductivity (mS/m) for layer_N
IP_P1_I_1	IP parameter 1 for layer_1
IP_P1_I_2	IP parameter 1 for layer_2
…	…
IP_P1_I_N	IP parameter 1 for layer_N
IP_P1_I_STD_1	STD on IP parameter 1 for layer_1
IP_P1_I_STD_2	STD on IP parameter 1 for layer_2
…	…
IP_P1_I_STD_N	STD on IP parameter 1 for layer_N
IP_P2_I_1	IP parameter 2 for layer_1
IP_P2_I_2	IP parameter 2 for layer_2
…	…
IP_P2_I_N	IP parameter 2 for layer_N
IP_P2_I_STD_1	STD on IP parameter 2 for layer_1
IP_P2_I_STD_2	STD on IP parameter 2 for layer_2
…	…
IP_P2_I_STD_N	STD on IP parameter 2 for layer_N
...	...
IP_PM_I_1	IP parameter M for layer_1
IP_PM_I_2	IP parameter M for layer_2
…	…
IP_PM_I_N	IP parameter M for layer_N
IP_PM_I_STD_1	STD on IP parameter M for layer_1
IP_PM_I_STD_2	STD on IP parameter M for layer_2
…	…
IP_PM_I_STD_N	STD on IP parameter M for layer_N
DEP_TOP_1	Depth (m) to top of layer_1
DEP_TOP_2	Depth (m) to top of layer_2
…	…
DEP_TOP_N	Depth (m) to top of layer_N
DEP_BOT_1	Depth (m) to botttom of layer_1
DEP_BOT_2	Depth (m) to botttom of layer_2

…	…
DEP_BOT_N-1	Depth (m) to botttom of layer_N-1
DEP_BOT_N	Depth (m) to bottom of layer_N calculated as 1.5 times DEP_BOT_N-1
THK_1	Thickness (m) of layer_1
THK_2	Thickness (m) of layer_2
…	…
THK_N-1	Thickness (m) of layer_N-1
THK_STD_1	STD on thickness of layer_1
THK_STD_2	STD on thickness of layer_2
…	…
THK_STD_N-1	STD on thickness of layer_N-1
DEP_BOT_STD_1	STD on depth bottom of layer_1
DEP_BOT_STD_2	STD on depth bottom of layer_2
…	…
DEP_BOT_STD_N-1	STD on depth bottom of layer_N-1
DOI_CONSERVATIVE	DOI Conservative for resistivity/conductivity
DOI_STANDARD	DOI Standard for resistivity/conductivity

The *_dat.xyz file use the following format:

Header section:

```
/INFO
/Aarhus SPIA export file. File created: 30-03-2023 13:00:34. Exported from SPIA64
/SPIA VERSION          3.7.0.0
/PROJECT NAME          ProjectName.gdb
/DUMMY
/9999
/DATATYPE              Type of data
/COORDINATE SYSTEM     Coordinate System: WGS 84 UTM zone 19S (epsg:32719)
/NUMBER OF LAYERS      30 Number of layers
/MODEL UNIT            Base unit used for resistivities: /Resistivity (Ohm-m) / conductivity
(mS/m)
/LENGTH UNIT           Base unit used for distances: Meter
```

Main section:

```
LINE_NO                Line number (always 0)
MODEL_NAME             Model Name
UTMX                   UTMX
UTMY                   UTMY
DATE                   Dummy value
TIME                   Dummy value
RECORD                 Record
ELEVATION              Topography
NUMDATA                Number of gates inverted
SEGMENT                Moment ID (3 or 5)
RESDATA                Data misfit (normalized with STD)
RESTOTAL               Total misfit
DATA_1                 Voltage (V/Am^4), for gate_1
DATA_2                 Voltage (V/Am^4), for gate_2
…
DATA_N                 Voltage (V/Am^4), for gate_N
DATASTD_1              STD on voltage, for gate_1
DATASTD_2              STD on voltage, for gate_2
…
DATASTD_N              STD on voltage, for gate_N
```