

STATE OF FLORIDA

FLORIDA GEOLOGICAL SURVEY

Guy H. Means, *Director and State Geologist*



REPORT OF INVESTIGATION NO. 122

**GROUND-PENETRATING RADAR SURVEY OF ICHETUCKNEE SPRINGS
STATE PARK SOUTH ENTRANCE PARKING LOT AND PICNIC AREA**

By

Casey Albritton, P.G. #3061

and

Tyler Barnett, G.I.T.

Prepared for

Ichetucknee Springs State Park

TABLE OF CONTENTS

List of figures	iii
Project Overview	1
Geology	1
GPR Background	1
Data Collection	2
Data Processing	2
Results	2
Interpretation	3
Recommendations	3
References	12
Appendix	13
Ground-Penetrating Radar Processing Filters	13
Lithologic Boring Report from W-10780	13
Ground-Penetrating Radar Data	13
Supplemental Information	14

LIST OF FIGURES

Figure 1. Ichetucknee Springs State Park (ISSP) in northern Florida	4
Figure 2. Locations of sinkholes in picnic area and parking lot	5
Figure 3. Topographic map of Ichetucknee Springs State Park and surrounding area.....	6
Figure 4. 250-MHz transect map of parking lot and GPR setup	7
Figure 5. Partial radargram proximal to new sinkhole with 50 thickness-equivalent "time slices" 8	
Figure 6. Processed radargram (above) and interpretation (below).....	9
Figure 7. Plan view anomaly map from modeled depth of 6 to 10 m BLS.	10
Figure 8. Primary areas of interest identified for further inquiry and monitoring.....	11

PROJECT OVERVIEW

Florida Park Service (FPS) officials contacted the Florida Geological Survey (FGS) to conduct a ground-penetrating radar (GPR) survey of Ichetucknee Springs State Park's south entrance parking lot. This request was in response to a newly-formed sinkhole in the grassy area between the asphalt parking lot rows (Figures 1 and 2A). The park has had several sinkholes form in the parking lot before, all which were filled and grouted. Therefore, the FPS requested a survey of the entire parking lot to identify any other areas of possible concern below the paved surface (Figures 2B and 2C). This investigation was needed due to increased public visitation during the spring and summer months. The objectives of the survey were to create an anomaly map showing possible areas of concern, evaluate the potential extent of the newly-formed collapse feature, and identify sites at risk for possible future sinkhole formation based on the modeled GPR data.

GEOLOGY

Ichetucknee Springs State Park encapsulates the entire Ichetucknee River upstream from US Highway 27. The spring run flows southwest into the Santa Fe River, which lies within the greater Suwannee River Basin, an area known for its abundance of springs and other karst features. Karst is the name given to describe natural geological features produced by acidic waters flowing on or through limestone which cause the rock to dissolve over time. This process is called dissolution. A light detection and ranging (LiDAR)-derived hillshade model illustrates the regional karst where sinkholes and a spring run can be seen (Figure 3).

The geology at the park's south entrance is represented by well boring W-10780 (appendix), which is drilled to ~21 meters (m), or 70 feet (ft), total depth below land surface (BLS). The borehole is located next to the gift shop at the north end of the parking lot. The depths and corresponding geologic units encountered in the well begin with 0 to 4 m (0-12.5 ft) of sand and 4 to 5 m (12.5-17 ft) of sandy clay. The sand and sandy clay comprise the undifferentiated Quaternary sediments (Qu), which overlies the top of the upper Eocene Ocala Limestone (To) encountered at ~5 to 6 m (~17-20 ft) BLS. The Ocala Limestone continues to the total depth of the borehole. The top of the Ocala Limestone is an irregular surface in this region of Florida (Green et al., 2007). Understanding the on-site geology allows for increased accuracy when interpreting subsurface signal depths rendered by the GPR interface. As seen in figures 2 and 3, sinkholes like the one at the park are common to this area because of the veneer of sediments overlying karstic limestone.

GPR BACKGROUND

GPR is a non-intrusive geophysical method that is an effective tool for investigating near-surface karst features in a variety of settings. GPR operates by sending an electromagnetic pulse, or radar wave, into the ground via a transmitting antenna where the signal returns from objects and layers in the ground (Conyers, 2016). The GPR can "see" into the subsurface because different layers and objects have contrasting electromagnetic properties. Radar waves reflect off these surfaces and back to the receiving antenna and display on screen as **reflectors**. When there is

significant electromagnetic contrast in the subsurface, the area is termed an **anomaly**. Anomalies can represent various objects and changes in the subsurface geology, and one must take care when interpreting these features. Additionally, several materials may cause **interference** with, or **attenuate** and diminish the radar signal. Refer to the supplemental information section at the end of this report for more general GPR information regarding methodology, limitations of the technology, and explanations of terms with **bold font**.

DATA COLLECTION

Initially, the survey was planned to target points of interest (POIs) noted by park staff using a 500-MHz antenna, which provides greater resolution with less penetration (3 m [10 ft] or less). These POIs included the new sinkhole, two grouted sinkholes, and a depression by the education center. However, due to the limited penetration, that GPR configuration was determined to be unsuitable for the depth of observed subsurface anomalies at the site. Therefore, only the 250-MHz antenna was used for the GPR survey.

A 250-MHz MALA shielded antenna, coupled with MALA X3M™ and ProEx™ systems and a Spectra SP60 GPS, was used to collect data. This combination was selected to allow for moderate penetration, and resolution capabilities that would be adequate for large-scale mapping of the entire parking lot (Figure 4). Although signal attenuation became more prominent with depth due to the water table's proximity to land surface, overall depth penetration was acceptable for this GPR survey. A coarse grid of **transects** of roughly five to 10-m (16 to 33 ft) spacing was run over the entire 15-acre site with transects totaling approximately 10 kilometers (6.7 miles) in length (Figure 4).

DATA PROCESSING

Data were **post-processed** using GPR-Slice© software, which is designed for creation of 2D and 3D subsurface images. After the raw data were imported, a series of filters (see Appendix for further discussion on filters) were applied which included bandpass, background removal, migration, and regain. **Data quality** was satisfactory overall despite some signal attenuation due to the presence of the local water table within 5 meters of the surface. A velocity model was created for the dataset using the hyperbola search function during post-processing. The velocity model that is eventually applied to the **radargrams** is created by measuring features at varying depths throughout the entire range of depths. Once complete, the velocity model allows for data to be converted from time to depth (Conyers, 2016). Processed 2D **radargrams** are then used to construct a 3D model. To accomplish this, individual radargrams are split into 50 thickness equivalent depth slices (Figure 5). These depth slices are then interpolated to generate a 3D volume of the modeled GPR data which can be used for interpretation.

RESULTS

Data collected using the 250-MHz antenna provided coverage and ample depth penetration for a near-continuous model to be created of the entire parking lot area. Several anomalies were detected in the subsurface, particularly in the depth ranges from 6 to 10 m (20 to 33 ft; Figures 6

and 7). Based on these observations, a map of anomalous zones in the subsurface was created by combining vertically contiguous anomalies in the targeted range of 6 to 10 m (20 to 33 ft) BLS. This map was compared to “karst-related anomalies” identified during post-processing of the data (Figure 7) to create a correlation map representing the areas deemed to be most vulnerable to future sinkhole development (Figure 8). These areas were chosen based on anomalies that were detected within multiple radargrams and the vertical and horizontal extents of each anomaly in the subsurface.

INTERPRETATION

There are numerous subsurface anomalies in the study area that are likely associated with karst processes across geologic time. Anomalies were identified in the GPR data based on recognized signatures that are characteristic of the site’s known karst features, as seen in Figure 5, and as seen in data from other areas of Florida with similar geology. Some anomalies potentially represent voids, while others may be indicative of raveling zones, which refer to a downward sediment migration due to gravity.

Areas exhibiting similar characteristics in the subsurface were identified by examining radargrams individually and in conjunction with a modeled anomaly map. These areas are noted as “prioritized areas of interest” since these possible subsurface karst features may express themselves at land surface in the future (Figure 8). Several of these prioritized areas of interest are within proximity to known subsurface karst features and may be connected to, or an extension of, previously known features. The depths of the anomalies range 6 to 10 m (20 to 33 ft) BLS, within the karstic Ocala Limestone. This report provides a good starting point for park officials to consider further exploration and potential mitigation of the suspected karst anomalies underlying the parking lot.

RECOMMENDATIONS

The Florida Geological Survey recommends that investigative geotechnical drilling be conducted at the sinkhole site to verify subsurface geological conditions and formulate a remediation plan. Additionally, it is recommended that park staff visually monitor the areas in Figure 8 designated as “prioritized areas of interest.”

It is impossible to predict the activation timing of potential karst features. However, these findings provide potential clues regarding where possible future sinkholes may occur. Park staff should monitor for visual signs of subsidence that may represent sinkhole formation. The signs may include concentric ring cracks or depressions forming on the asphalt or ground, water pooling where it did not previously, focused draining, or vegetation showing signs of stress or death in these locations. Should any of these observations occur, the location should be blocked off and further investigated by conducting a follow-up geophysical survey or directly inquiring with a geotechnical consulting firm to assess and possibly remediate the feature in question.

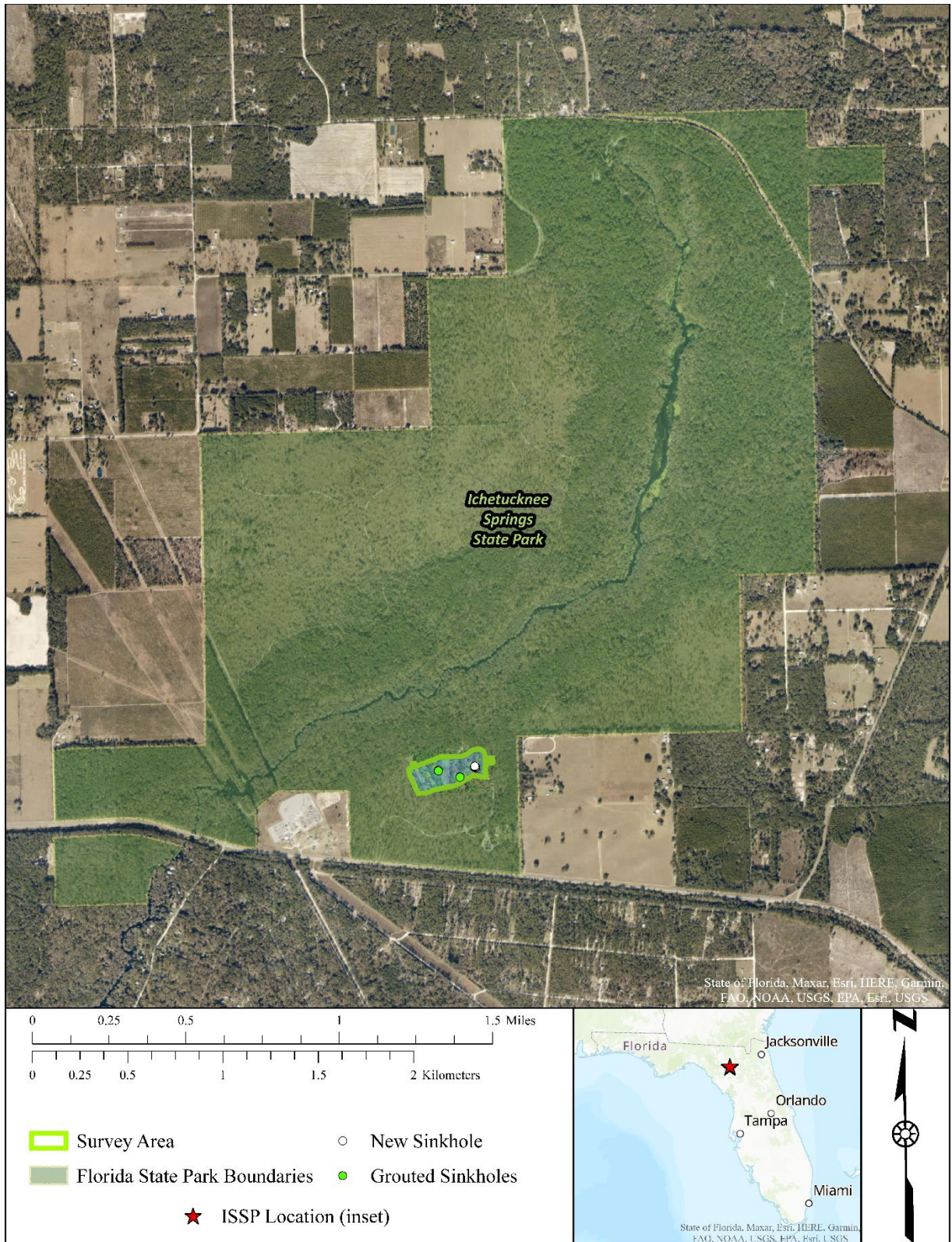


Figure 1. Ichetucknee Springs State Park (ISSP) in northern Florida (inset). The GPR survey area is highlighted by the bright green polygon at the south entrance to the park. Points denote locations of new sinkhole and grouted sinkholes.



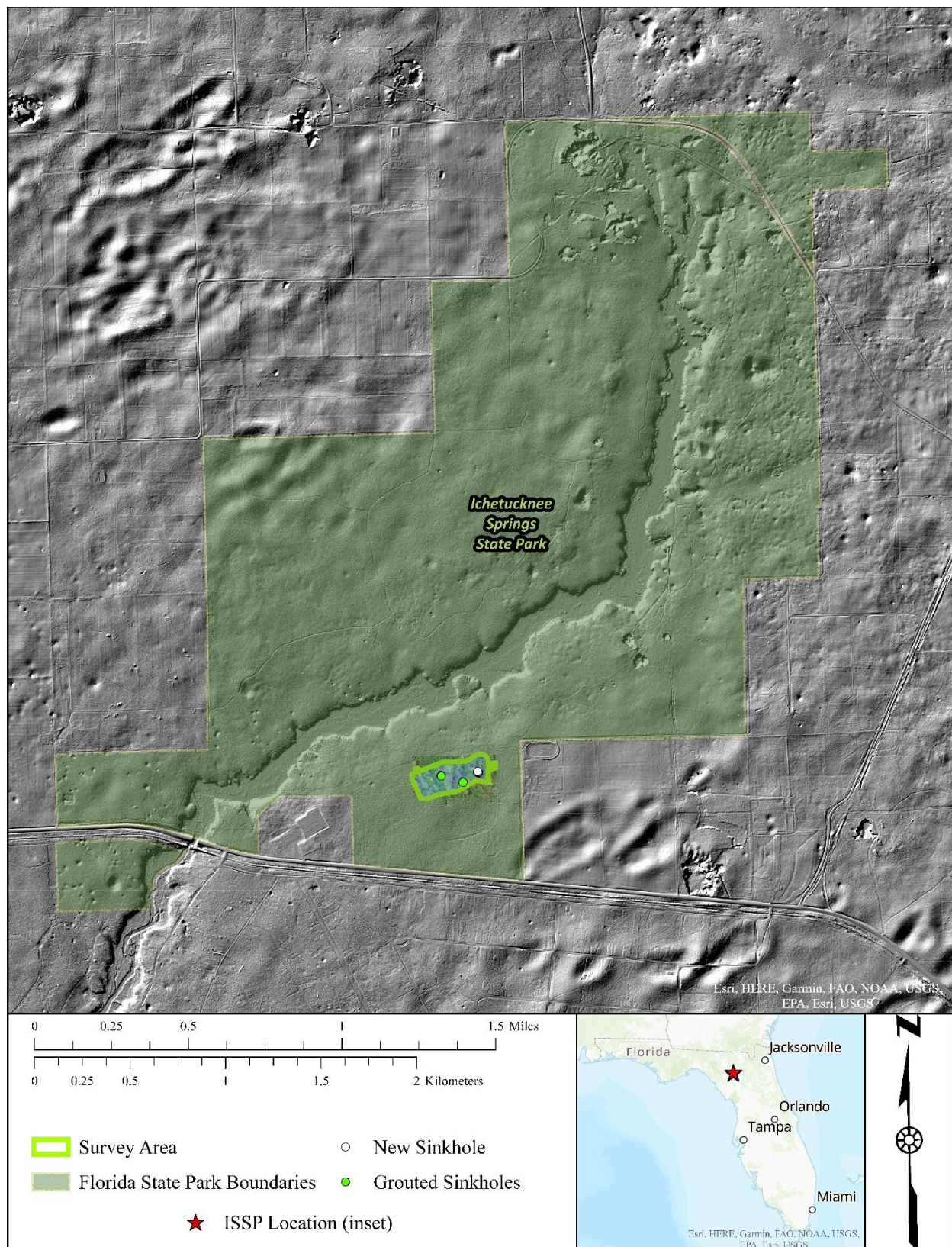


Figure 3. LiDAR-derived hillshade topographic map of Ichetucknee Springs State Park (ISSP) and surrounding area. Numerous karst depressions occur throughout the region.

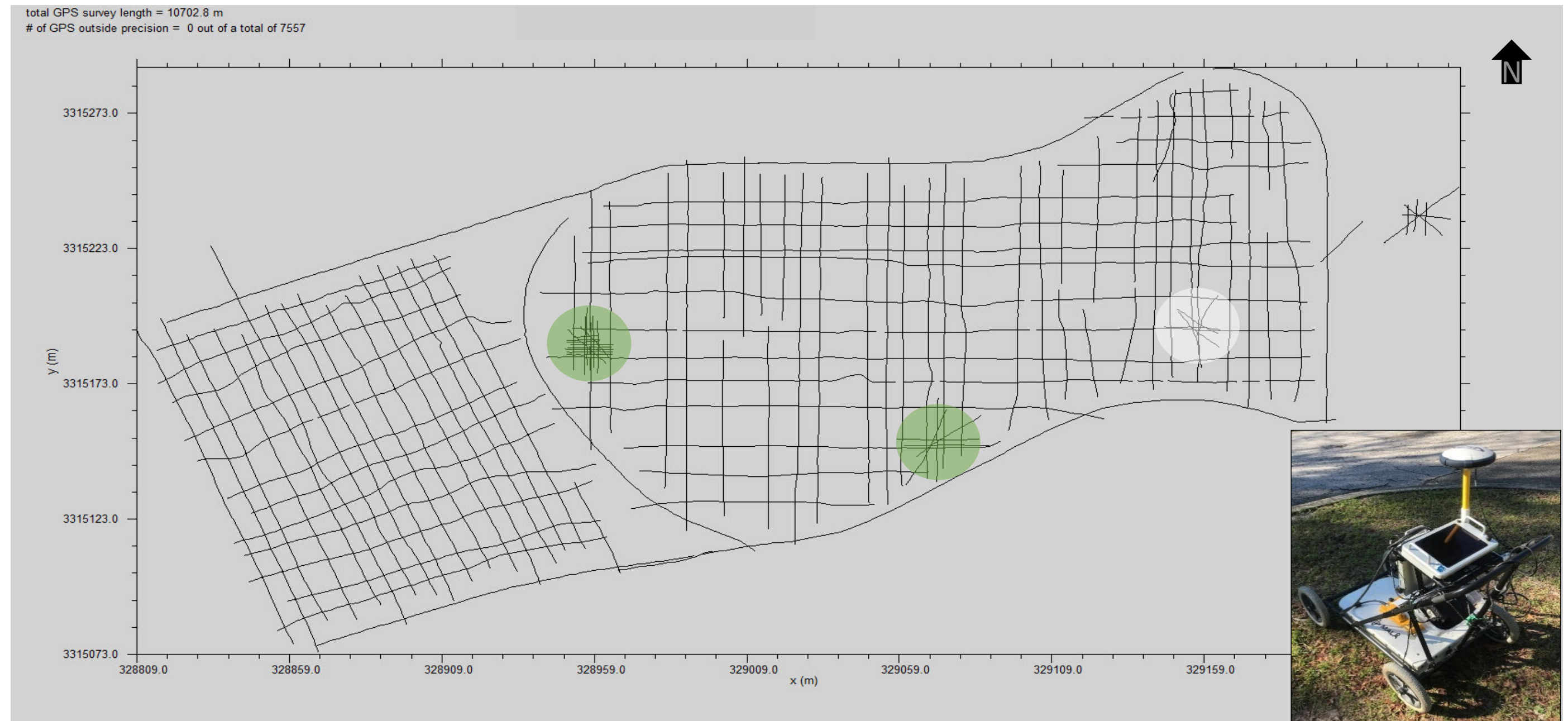


Figure 4. Transect map of parking lot showing large grid and focus areas denoted by densely spaced crossing lines. The white and green circles are the locations of the new and grouted sinkholes, respectively. Ten-meter spacing on axes with 50 m labels expressed in UTM coordinates (map). GPR setup showing 250-MHz antenna with MALA X3M™ system and GPS receiver (inset).

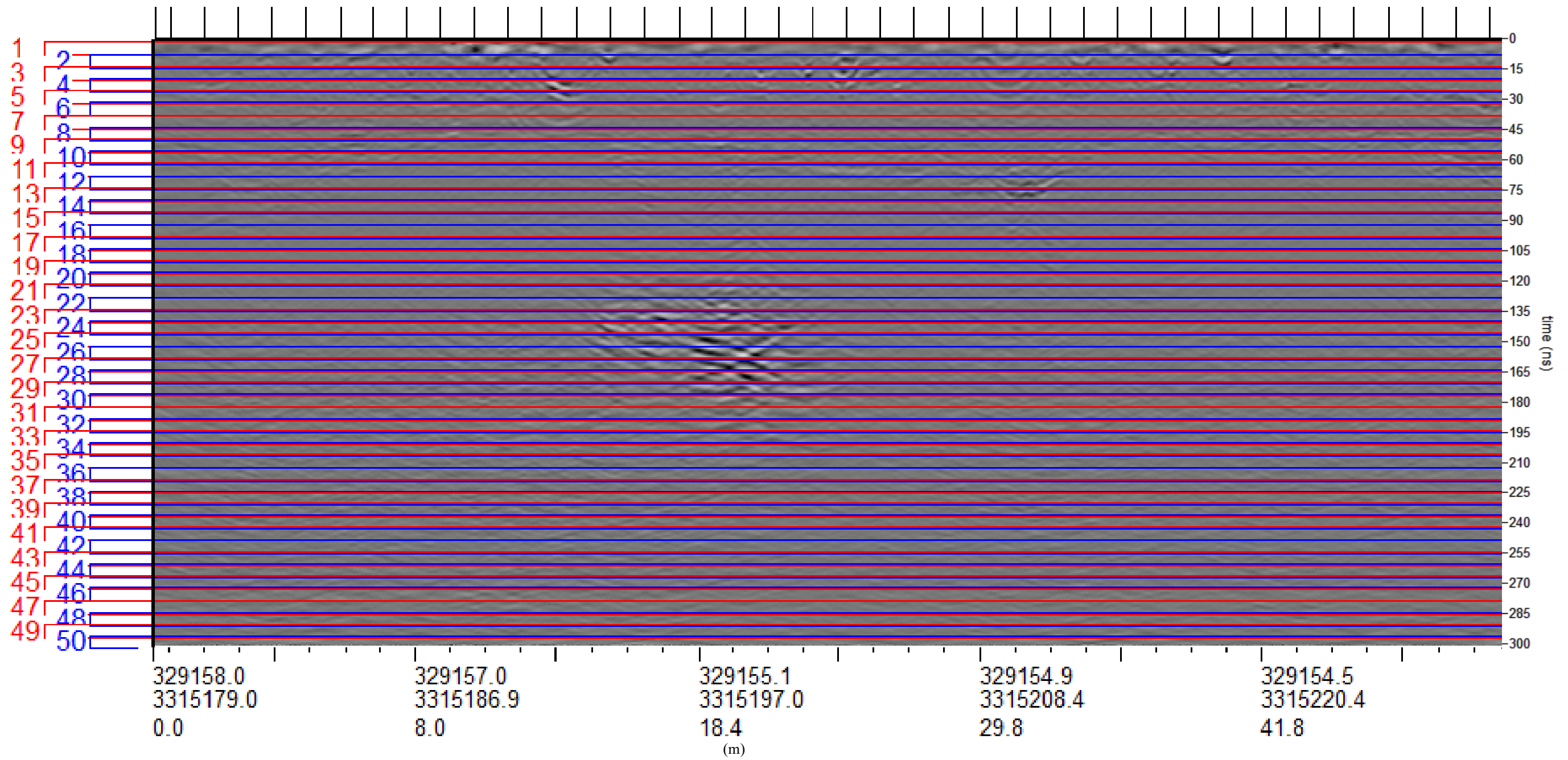


Figure 5. Partial radargram proximal to new sinkhole with 50 thickness-equivalent "time slices" with zero overlap between slices. X-axis is in meters (m) with UTM coordinates displayed above transect length. Y-axis scale, at right, is time in nanoseconds (ns).

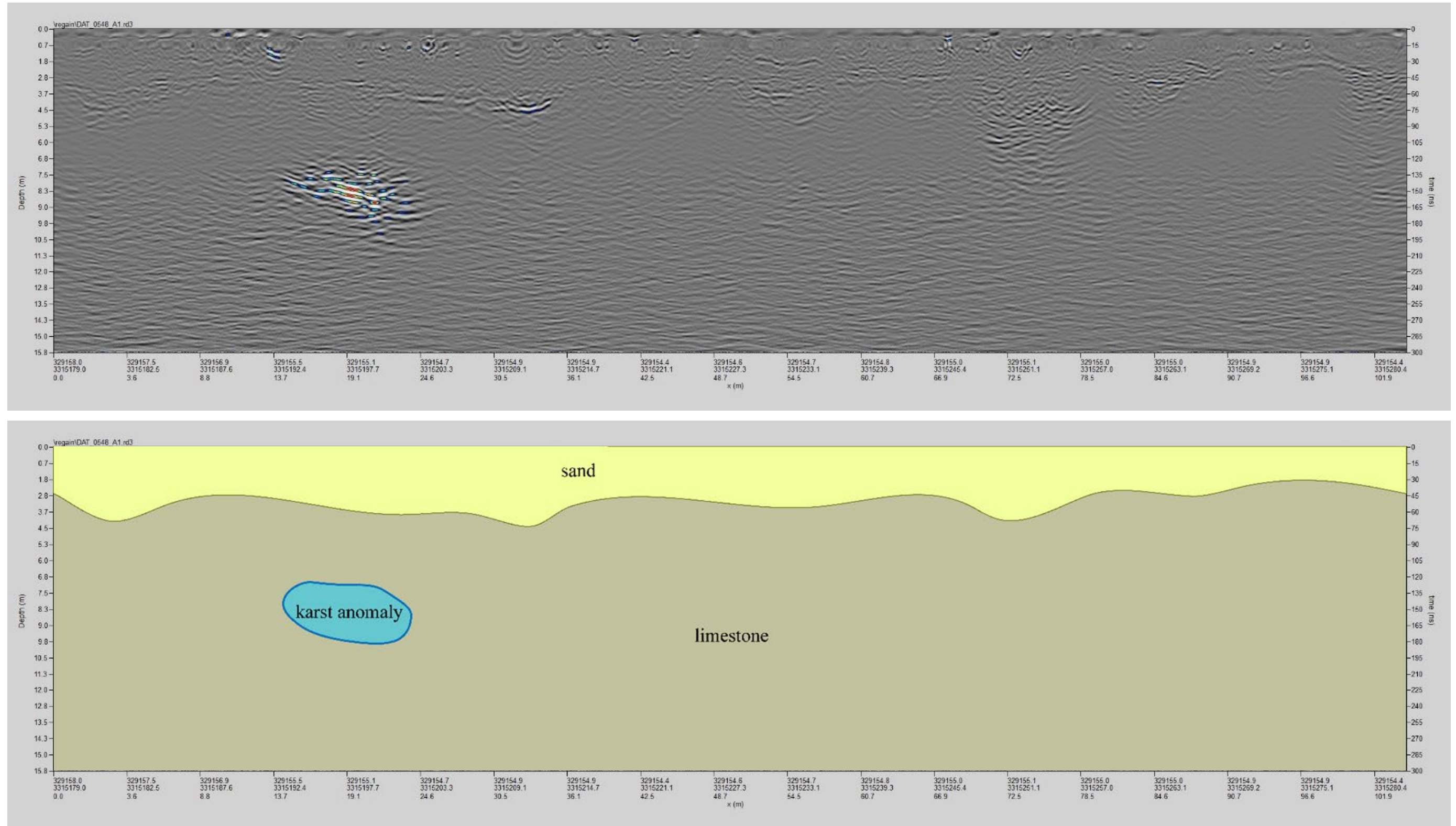


Figure 6. Processed radargram (above) and interpretation (below) showing anomalous region in the subsurface below the newly-formed sinkhole in the parking lot area. Bright colors are indicative of sharp contrast in material properties (i.e., rock vs. void). X-axis is in m with UTM coordinates. Y-axis is displayed as depth in meters (m) on the left, and time in nanoseconds (ns) on the right.

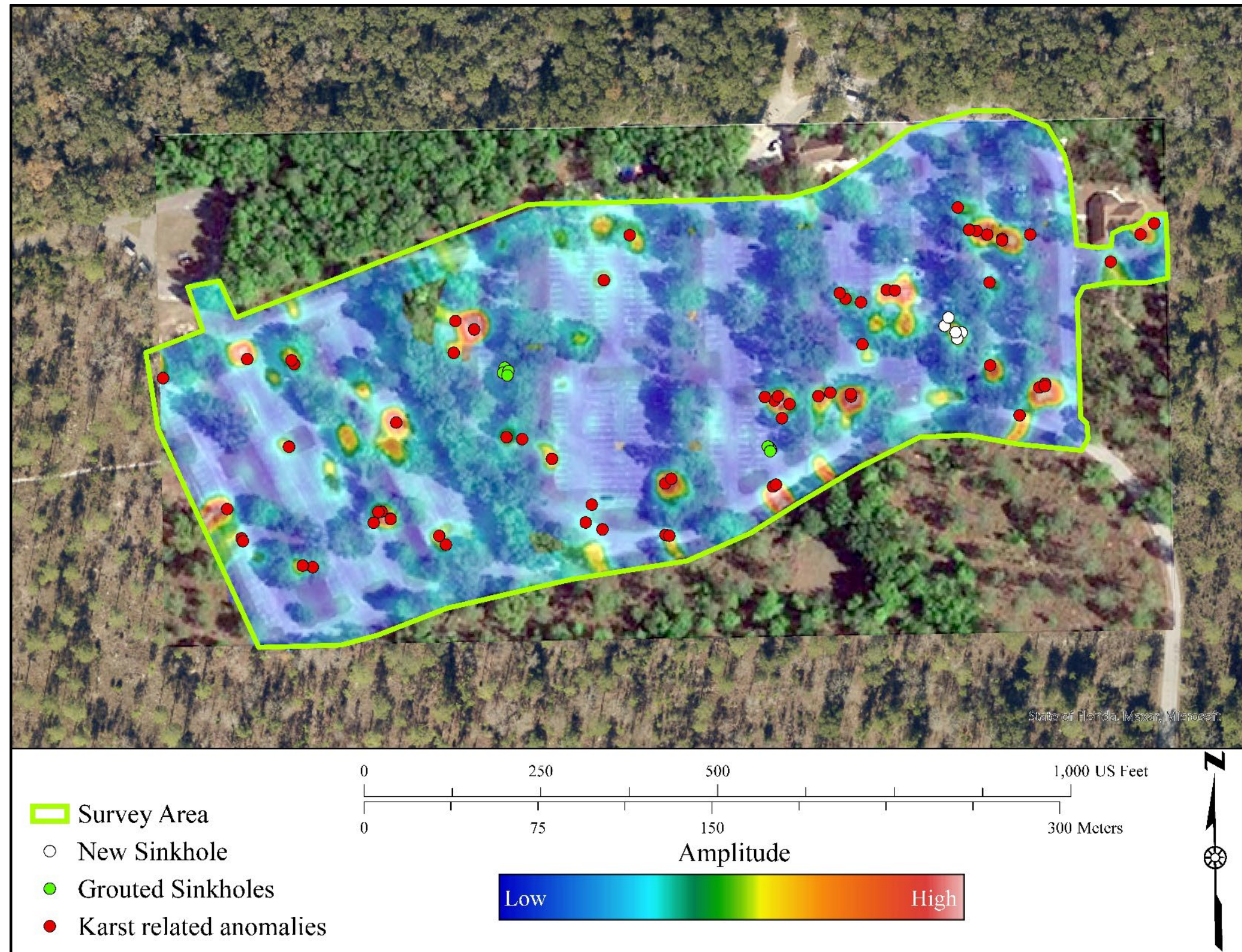


Figure 7. Plan view anomaly map from modeled depth of 6 to 10 m (20 to 30 ft) BLS. Color ramp is unitless with warmer colors representing anomalous areas. White dots represent anomalies associated with the newly-formed sinkhole.

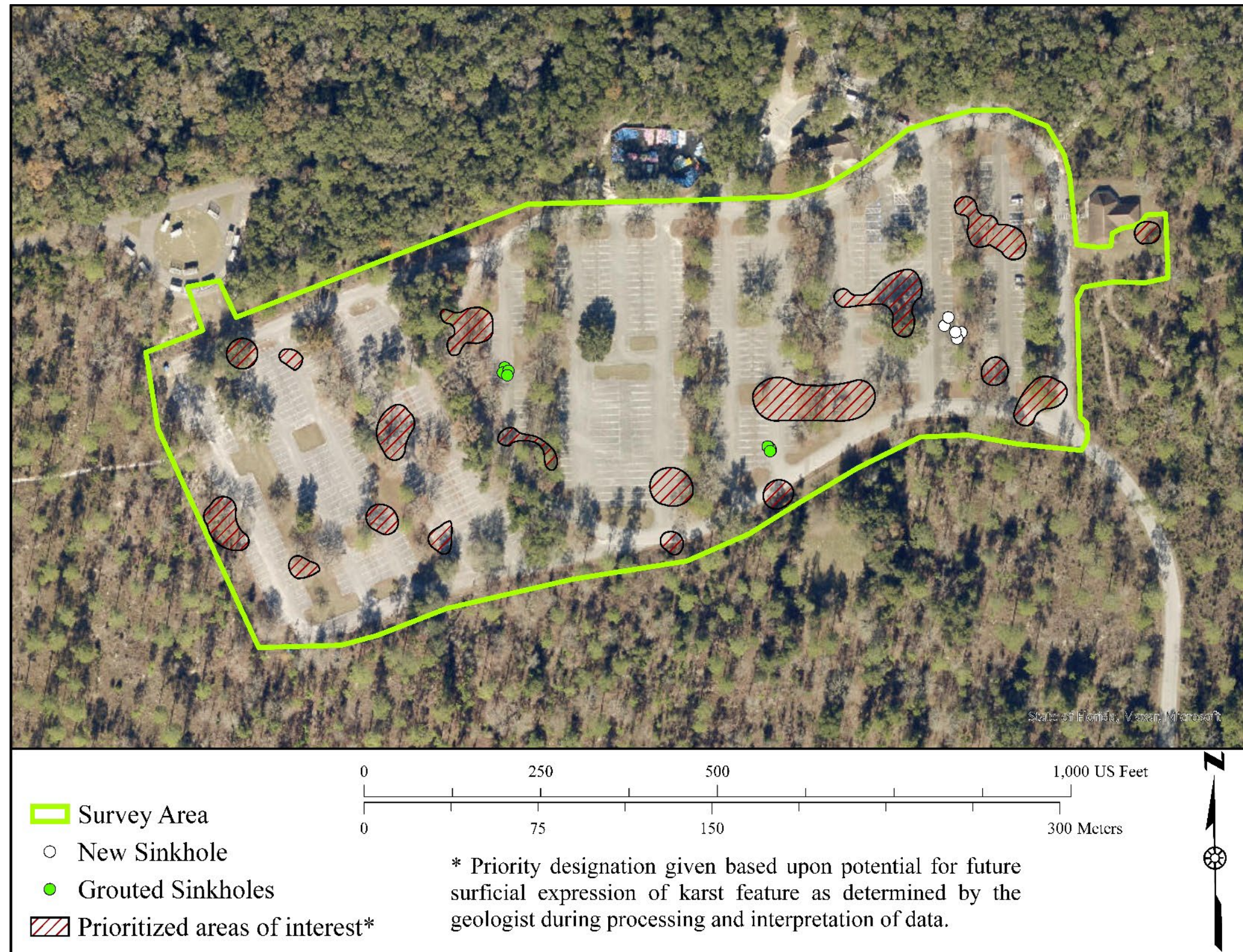


Figure 8. Prioritized areas of interest identified for further inquiry and monitoring. These polygons represent the areas that most likely possess subsurface characteristics like those of known on-site sinkholes, with potential for future karst expression at the land surface. The white dots represent anomalies associated with the newly-formed sinkhole.

REFERENCES

- Conyers, Lawrence B.; Ground Penetrating Radar for Geoarchaeology: New Analytical Methods in Earth and Environmental Science. Wiley Blackwell, 2016.
- Green, R.C., Paul, D.T., Scott, T.M., 2007, Text to accompany geologic map of the eastern portion of the U.S.G.S. Perry 30 x 60-minute quadrangle, northern Florida: Florida Geological Survey Open-File Report 91, 32 p.
- Green, R.C., Paul, D.T., Petrushak, S.B., Kromhout, C., and Scott, T.M., 2007, Geologic map of the eastern portion of U.S.G.S Perry 30 x 60-minute quadrangle, northern Florida [3 plates], scale 1:100,000, STATEMAP, Open-File Map Series 98.

APPENDIX

Ground-Penetrating Radar Processing Filters

Bandpass: Chosen frequency range passes through the spectrum and gain control set, while attenuating those outside the selected range.

Background removal: Averages the GPR trace signal and subtracts it from the radargrams.

Migration: The process of moving dipping reflectors to their true subsurface positions and collapsing diffraction hyperbola back to their origin or point source.

Regain: The process of reapplying gain control to radargrams.

Lithologic Boring Report from W-10780



Florida Department of Environmental Protection

Florida Geological Survey GEODES

Well Number: W-10780 (Ichetucknee State Park - Ft. White)

Total Depth:	Elevation: 0 feet (Unknown)	County: Suwannee
Location: Sec 0 T.S., R.E.	Drill Completion Date: 01/01/1971	Other Logs:
USGS Quad:	Lat/Long: 29° 57' 23" N; 82° 46' 15" W	Owner/Driller: Ichetucknee State Park
Described By: CASEY K. ALBRITTON	Verified By PG:	Comments: 3/5/2020. Quick description for GPR project at Ichetucknee Springs State Park. 0 - 12.5 sand; 12.5 - 17 is clayey sand; top of Ocala at ~17 feet bls.
Verification:		

Geological Formation Picks

0 - 17 ft	UDSC	Undifferentiated Sand and Clay
17 - ft	OCAL	Ocala Limestone

Ground-Penetrating Radar Data

Available upon request. Please Contact Casey Albritton at casey.albritton@floridadep.gov or call 850-617-0335 for more information.

SUPPLEMENTAL INFORMATION

Terms shown in **bold font** are referenced in main body of report and described in further detail in this section.

GPR technique description

Ground-penetrating radar (GPR) is a tool that uses pulses of electromagnetic energy in the form of radio waves to measure physical properties of the materials and structures below it. The GPR antenna detects the radar signals as they reflect off subsurface materials and structures. The collection of those reflected radar signals creates an image called a **radargram**, a 2-dimensional subsurface cross-section, which can then be used to interpret what is seen in the subsurface.

GPR can be used to interpret geology, including identification of subsurface rock, sands, clays, saltwater-freshwater interfaces, or voids. GPR can also be used to interpret areas where soil has been disturbed by excavation or back filling, measure road pavement or building foundation thickness, and detect buried structures such as plastic, metal objects (e.g. cables, barrels, or paint cans), or concrete utility pipes. When an object generates a **reflector** of unknown origin, that reflector is referred to as an **anomaly**. Identification of anomalies is a standard practice in GPR surveys.

GPR is not effective in areas where highly conductive materials or fluids exist. In these areas, the radio waves either cannot penetrate or get rapidly attenuated. Metals, clays, and saltwater are examples of materials through which radio waves cannot pass.

The depth at which GPR can detect a **reflector** is dependent upon the composition of the subsurface materials and antenna being used. For example, a higher-frequency antenna (shorter wavelength) will have shallower radio-wave penetration, allowing for smaller potential targets to be imaged. Use of a lower-frequency antenna (longer wavelength) will allow for deeper penetration of the radio waves, but any object at depth must be large enough for imaging to occur.

GPR equipment

The GPR equipment used in this survey was manufactured by MALA Geoscience, now part of Guideline Geo©. The Florida Geological Survey owns four antennas with the following frequencies: 50-MHz, 100-MHz, 250-MHz, and 500-MHz. The lower the frequency, the greater the detection depth of the antenna (e.g., 50 MHz detects deeper features and 500 MHz detects shallower features).

In ideal geologic conditions, each antenna is designed for surveying the following approximate depths:

- 500-MHz antenna: Shallow depths within five m (15 ft) of land surface
- 250-MHz antenna: Moderate depths to ~10 m (30 ft) of land surface
- 100-MHz antenna: Deep depths to ~30 m (100 ft) of land surface
- 50-MHz antenna: Deeper depths to ~100 m (300 ft) of land surface

Note that “shallow”, “moderate”, “deep”, and “deeper” are relative terms because the GPR signal’s penetration and detection are dependent upon the character and content of the subsurface.

The 250- and 500-MHz antennas are shielded, which decreases external electromagnetic radio-wave **interference**, therefore reducing artifacts/noise in the data. The 50- and 100-MHz antennas are unshielded antennas and can be influenced by external interference, such as electrical utilities, radio waves, and any other electromagnetic field in the vicinity. When using the 50- and 100-MHz antennas, care must be taken to avoid anything that may potentially interfere with electromagnetic radio wave transmission and reception. Unshielded antennas can penetrate slightly deeper and produce fewer signal-ringing effects than shielded antennas, which makes their usage desirable when there are few noise sources in a study area and depth penetration is favored over resolution. The GPR antennas, control unit, and GPS receiver (to record location) are either mounted to a cart (250- and 500-MHz) constructed out of poly-vinyl chloride (PVC) or a wood frame (50- and 100-MHz) for ease of deployment. Additionally, antennas can be deployed from a non-conductive single hull boat in freshwater and in water with very low salinity or total dissolved solids.

Method of data acquisition

GPR data are generally acquired by running **transects**, which are lines from which GPR data is acquired beginning at one end of the line and ending at the other. Along the length of the transect, the GPR control unit records the electromagnetic waves’ reflections and stores them in its hard drive. To correlate the transects to the surveyed location, a GPS receiver operates simultaneously with the GPR, recording the location of the unit while surveying. Coupling the data with GPS locations allows the surveyors to identify the locations of any potential anomalies and conduct an additional investigation later, if needed.

Method of data post-processing

Once collected, raw GPR data must be **post-processed**. Radargrams provide cross-sections of the subsurface reflections captured by the GPR antenna. Those radargrams are then interpreted.

The raw data are imported into GPR Slice[®]. The time window (measured in nanoseconds [ns]) and Universal Transverse Mercator (UTM) coordinates are extracted from the raw data associated with each radargram. Before post-processing filters are applied, an average velocity is set. A velocity of 0.09 m/ns was calculated using the “diffraction hyperbola search” function during post-processing. This allows conversion from reflection velocity to depth along the vertical (Y) axis of the radargram. The horizontal (X) axis is lateral distance along the transect, with waypoints shown as labeled vertical lines.

The next post-processing step is to apply a series of filters to the data, beginning with the “batch gain-wobble” function, which accounts for signal drift. Following this, a “time-zero” correction is applied to align the radargrams’ sample starting points (at ground surface). A bandpass filter is applied to all 250-MHz radargram data to suppress frequencies above ~300 MHz and below ~95 MHz, reducing noise from frequencies outside that range. This was followed by a

filter that reduced horizontal background noise in the radargrams. At this point, post-processing is complete, and interpretation can begin.

Limitations

The **data quality** and depth acquired is highly dependent upon the electromagnetic wave's ability to penetrate through the subsurface strata. Data are considered "good" if there is a high signal-to-noise ratio, while noisy data (low signal-to-noise ratio) is "bad." Noise, or interference, can come from a multitude of sources including power lines, underground utilities, generators, or any other potential electromagnetic source. These sources can produce reflections that show up in the data, obscuring the real image of the subsurface.

The more conductive a material is, the less likely an electromagnetic wave is to pass through it. Subsurface conditions can cause the GPR signal to **attenuate** or lose energy. Conductive sediments and fluids also cause signal problems, because the wave cannot penetrate through these features. Clays, brackish water and saltwater, and water with high amounts of total dissolved solids (TDS) are highly conductive and attenuate GPR waves, hindering penetration of the signal. Freshwater moderately attenuates electromagnetic waves. Low-conductivity sediments, such as dry sand and rock, allow for the GPR waves to travel deeper, providing ample data with very little noise.

At Ichetucknee Springs State Park, surficial sands provided meaningful data collection at shallow depths. The signal began to be attenuated at a depth of 3 m (10 ft) and continued due to the proximity of the water table near land surface. Signal strength is noticeably dampened in the saturated part of the Ocala Limestone.

Common general factors limiting GPR data acquisition:

- Moisture – The amount of moisture in soils can impact the effectiveness of GPR. The elevation of the water table will likely impact the maximum depth of the radar penetration.
- Depth penetration – GPR's depth range is limited by the electrical conductivity of the ground, transmitted frequency, and radiated power. With an increase in conductivity, there is a decrease in penetration depth. Good penetration is achieved in dry, sandy soils or massive dry materials such as granite, limestone, and concrete. Depth penetration is limited in moist and/or clay-rich soils and soils with high conductivity.
- Antenna frequency – Depth of penetration and resolution is dependent upon antenna frequency. Lower frequency antennas will penetrate deeper but have less resolution, while higher frequency antennas will have less depth penetration with higher resolution.
- Size of target – Detection of targets is dependent upon depth of the object below land surface and size of the target object. The deeper the target object, the larger it must be to be detected.
- Quantity of anomalies – The location of buried targets can also limit subsurface detection. For example, many closely-spaced, highly-reflective anomalies at the surface can obscure detection of subsurface objects because the transmitted radar wave is unable to penetrate deeper due to most of the signal being reflected. This can lead to misinterpretation due to a lack of quality data.

- Target composition – The ability to locate a target is dependent upon the electromagnetic conductivity of the target relative to the surrounding material. For example, a highly reflective metal pipe is much easier to locate than empty PVC pipes that have very low conductivity.