*International Conference on Hydropower and Dam Development for Water and Energy Security – Under Changing Climate, 7-9 April, 2022, Rishikesh, India*

# IMAGING OF DEEP KARST USING THE MULTI-ELECTRODE RESISTIVITY IMPLANT TECHNIQUE (MERIT) CASE STUDY OF A DAM IN FLORIDA

**DAVID HARRO AND HENOK KIFLU**
*The G3 Group, 2509 Success Drive, Suite 1, Odessa, FL 33556*

**SANJAY RANA**
*PARSAN Overseas Pvt. Limited*

## ABSTRACT

*Based on the current state of technology for detection of internal erosion in earthen dams the need exists for a technique that can provide reliable and accurate information of all potential dam failure modes. The current geophysical methodology for detection of internal erosion struggles to provide accurate information on location and size of internal erosion, deep karst and foundational seepage. Many dams enter a critical state before internal erosion and potential remedial actions are evaluated and taken. This approach is extremely costly and is typically due to the lack of early detection capability and the inability to perform preventative measures early in the internal erosion process.*

*This paper focuses on a unique approach with application of geophysical implant technology in mine tailing dam used of cooling pond. The case study site lies within karst geology of central Florida.*

*A water budget analysis performed by the consultant of three piezometers in the colling pond dams indicated the current amount of unaccounted for loss that may be flow into developing karst features was at least 4548 to 7944 MLPY. The threat of a sinkhole to the cooling pond is the potential loss of pond water by destabilizing one or more of the exterior dikes and/or by draining it into the underlying aquifers.*

*The Multi-Electrode Resistivity Implant Technique (MERIT), a geophysical technique that utilizes of small implant devices that are places inside the dam itself near the foundation, was selected based-on experience of the consultant with these techniques deep image capabilities. Three arrays of fifth six (56) implants and arranged in an array along a 335m length of the dam at 6m spacing and depth of 11.6m. The geophysical implants were combined with fifth six (56) surface electrodes for any array of 112 electrodes total.*

*MERIT achieved an optimal imaging that resulting in three 2D geophysical profiles (Figures 6,7,8):*

- *Full image extent of all three profiles of subsurface coverage area of 25,460m for each 335m long array*
- *Three stratums were clearly identified at depths along with the material type and subsurface position as confirmed by three Standard Penetration Test boring completed to 150 to 180 feet at each of the piezometer locations under investigation (Figure 3).*
- *Details depositional contact of stratum 3, the limestone formation, was clearly mapped in the MERIT images at depths of 30m*
- *Paleo karst/sinkhole throats of located at depths of 30m and 30m across were clearly identified in MERIT images of P-12 and P-13 (Figures 6,7)*

- *A complex paleo karst/sinkhole was clearly identified in P-05 location at depth of 30m (Figure 8)*
- *In all three MERIT images paleo karst/sinkhole features can be clearly see extending to the depth of the geophysical survey of 76m.*
- *While the level of effort and cost to install implants is higher than surface geophysical methods the greater ability of results of MERIT resulted in more complete understanding of deep karst features size and depth that can be more precisely located and measured.*
- *Since implants are permanently installed the consultant future plans include 3D imaging long term monitoring using the MERIT system.*

## INTRODUCTION

The application of geophysical surveys to investigate seepage in dams has typically been performed as a onetime event. While this methodology has lower cost the full benefit of monitoring is not utilized to understand changes over time.

Implant technology is well suited to perform long term monitoring and has a significant cost benefit. This can be of advantage where monitoring seepage conditions occur over time before the decision to remediate is made. If significant changes occur as shown by the implant technology this may trigger the need for a more immediate response by increased investigation or emergency remedial actions.

Multi-Electrode Resistivity Implant Technique (MERIT) is a technique utilizes a tomographic configuration (Figure 1) that combines measurements with surface and deep electrodes that significantly improve geophysical surveys using electrical resistivity (Harro and Kruse 2013).

The impact of large number of instrumentations installed into dams would only be minimally invasive. A full array with small implants that are only 1.9cm in size are permanently installed using direct push technology (DPT) using tooling that is only 3.8cm. This approach would not result in a decrease in the performance of a core due to limited size of the implants due to the very low radius of influence on the soil. When compared to drilling methods such DTH hammer drilling technology and hydraulic top hammer drills that both techniques (0.5m along the borehole axis). Top hammer drillings in combination with a casing drilling system (Symmetrix)indicate an increased average zone of influence of 0.7m around the boreholes Riechers J (2012). In more demanding drilling environments geophysical sensors can be installed with sonic drill rigs with 11.4cm casing maybe be utilized.

This minimally invasive small implants can reduce the potential impact while significantly increasing the instrumentation range to span the entire length of a dam with high density of sensors.  The implanted sensors can have the ability to obtain profile of electrical resistivity, self-potential geophysical data as well as capability of additional instrumentation.

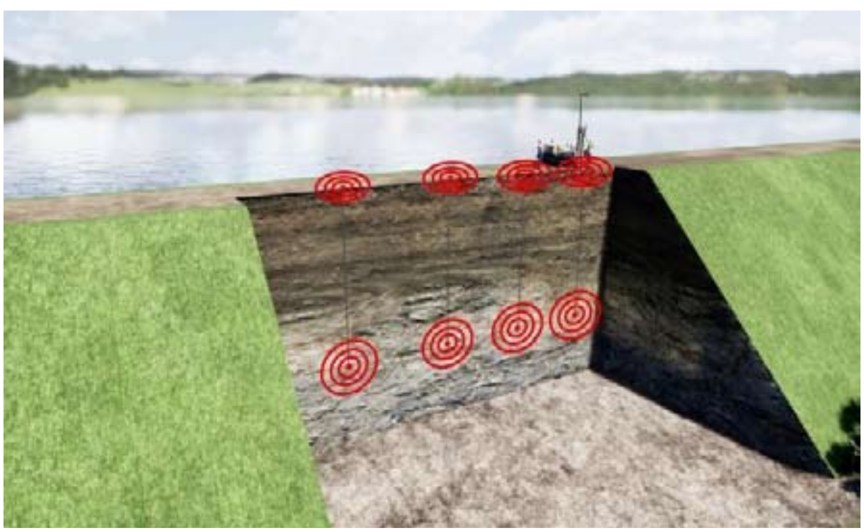

**Fig. 1** : Deployment of implants for MERIT in a dam, note tomographic configuration of identical spaced surface and lower arrays.

The implant technique can also be enhanced with capabilities that include the following:

- Electrical Resistivity
- Spontaneous Potential
- Thermal
- Piezometers

Thermal and Piezometers instrumentation can be applied to each implant in the array or selected implants.

When installed by DPT to the desired depth the tooling is retracted with only a wire(s) coming to the surface. Bentonite fluid can be introduced into the tooling string to seal the small diameter borehole.

No casing or large diameter boreholes are required to install the implants if DPT installation is possible. DPT drilling production is reasonably high which reduces drilling cost of installing implants over traditional drilling methods.

The benefits of full array configuration of implants can clearly be understood by the following:

- Implants in an array format provide greater detail than discreet points
- After the installation of the implants repeat measurement can be taken for temporal analysis of conditions subsurface

Electrical Resistivity (ER) geophysical surveys have been used to investigate; seepage, internal erosional in dams Butler, D. K. (1984), Koester, J. P., Butler, D. K, Cooper, S. S., and Llopis, J. L. (1984), Panthulu, T. V., Krishnaiah, C., and Shirke, J. M. (2001) (Lum and Sheffer 2005). Surface ER geophysical surveys methods have distinct limitations. These limitations for applications on dams are:

- Low resolution at depth affecting the ability to resolve detail of the core or foundation
- Very limited lateral resolution at abutments
- Limited depth of penetration of electrical current in saturated clay rich soils
- Non-uniqueness problem

The Multi-Electrode Resistivity Implant Technique (MERIT), with its novel configuration of surface electrodes and implanted or buried electrodes has been shown to provide greatly improved results over 2D surface electrical resistivity (Harro and Kruse 2013), (H. Kiflu, 2016). With optimization the MERIT technique was enhanced with greater depth of investigation and increased lateral resolution (M H Loke 2015). MERIT 3D is also shown to provide improved results over surface 3D electrical resistivity (In Publication H. Kiflu, M.H. Loke, P. Wilkinson, D. Harro, S. Kruse)

Most of the limitations of surface electrical resistivity are fundamental due to data collection methodology. Standard data collection methods for electrical resistivity such as Wenner, Schumberger, Dipole-Dipole etc. rely maximum separation of current electrodes “a” based on sequence of progression measurements along a fixed array length. The result is inverted trapezoid of data, where the number of data points is reduced with each progressive data level deeper in the subsurface. This profiling method does not involve manipulating electrode spacing in but instead the electrode spacing is kept constant along on fixed profile MERIT overcomes many of the limitations of data collection geometry of surface electrical resistivity by having two arrays, one on the surface and one implanted array at depth. MERIT profiling method does involve manipulating electrode spacing between the surface and buried array. This tomographic arrangement changes the spacing between electrodes vertically producing overlapping fields with offset data levels that increases the depth at which the survey can reach, and resolution. The MERIT is well suited for linear structures such as dams. Implanted array of electrodes reaching deep into the core of dam greatly enhance the capability of electrical resistivity and spontaneous potential geophysical measurements of the core and foundation and underlying. This is especially event for dam in karst environments

## PROJECT DESCRIPTION

A closed loop water from a 4.8 km$^2$ cooling pond to recycle water from the plant. Water harvesting from wetland systems is pumped to the cooling pond along with blowdown that is discharged from the plant boilers. A series of low-level dams form the perimeter of the cooling pod and the wetland systems. A review of water budget suggests the potential downward migration of water at the locations of piezometers in Dam Section N and Dam Section K as shown in Figure 2.

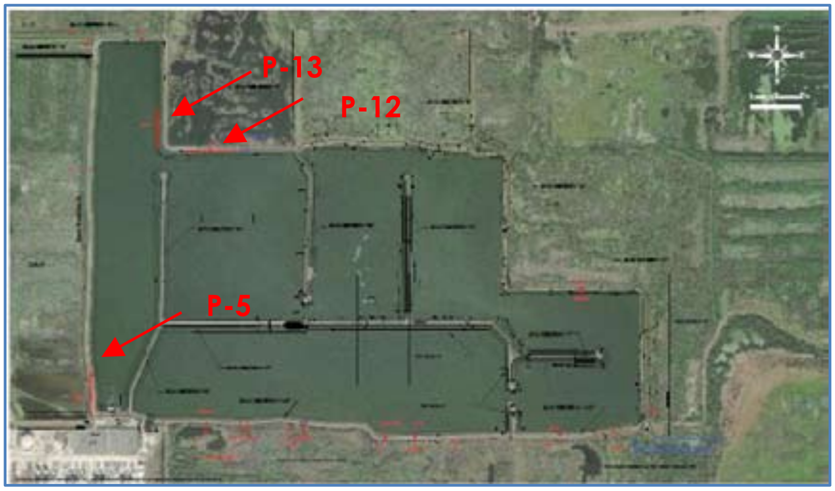


**Fig. 2** : Showing the cooling pond location of the MERIT arrays and piezometers

Based on the evaluation performed, the potential for karst or sinkhole conditions which are a concern for this project. The application of the MERIT system abilities to provide deep geophysical images was deemed beneficial to the project. The target of the three MERIT geophysical investigation location of piezometers P- 12, P-13 and P-5 in dam sections N and K.

The consultant performed a desk top review and concluded: A water budget analysis of three piezometers indicated the current amount of unaccounted for loss that may be flow into developing karst features is at least 4548 to 7944 MLPY. The threat of a sinkhole to the Cooling Pond is the potential loss of pond water by destabilizing one or more of the exterior dikes and/or by draining it into the underlying aquifers.

The consultant also concluded that due to the presence of the thick phosphatic clays on the bottom of the pond and their very low permeability compared to the cast overburden soils forming the dams, these boring logs collectively indicate that the preferred seepage path from the Cooling Pond to the underlying Intermediate Aquifer is most likely through the embankment sections and into the foundation beneath them.

## GEOMORPHOLOGY

The study area is in Polk County, located in the central portion of Florida. Polk County is one of the largest sources of mining phosphate in the state since the late 1800's known as the Bone Valley region. One byproduct of the extraction process for phosphate is clay, which is stored in settling ponds and eventually comprises 30%-40% of a mine site. Some of these ponds can measure thousands of acres. The site is in the location of former phosphate mining clay settling pond which now used for closed loop water for power generation.

Much of the western part of Polk County lies in the Polk and Lake Uplands. These uplands are characterized by moderate relief, shallow lakes, and moderate water-table depths. The Polk Upland is a broad sandy area that ranges in altitude from about 20m above NGVD 29 along parts of the Peace River to about 45m above NGVD 29. In the northern part of the county, the Polk Upland merges with the Lake Upland. The boundary between the Polk and Lake Uplands is inferred because there is not a distinct topographic break between the two uplands (White, 1970).

## INTERMEDIATE CONFINING UNIT AND INTERMEDIATE AQUIFER SYSTEM

The surficial aquifer system underlies the intermediate confining unit or intermediate aquifer system of late Oligocene to Pliocene age. These deposits have varying degrees of permeability, consisting of permeable sands or carbonates, or relatively impermeable layers of clay, sandy clay, or clayey carbonates. The intermediate confining unit is present throughout much of northern and eastern Polk County. The intermediate confining unit serves as a confining layer (except where breached by sinkholes) that restricts the vertical movement of water between the surficial aquifer system and the underlying Upper Floridan aquifer. The unit consists mostly of interbedded clay, silt, phosphate, and sand, but includes some limestone and dolostone of the Hawthorn Group. In many areas, the intermediate confining unit also can include low-permeability clay and silt layers of early Pliocene age.

Thickness of the intermediate confining unit generally ranges from less than 11m in the northern part of the county to more than 61.m in the southeastern part of the county. The unit is locally thin or absent in the extreme northwestern part of Polk County. Thickness of the unit is variable throughout Polk County due to past erosional processes and sinkhole formation.

The intermediate aquifer system includes all water-bearing and confining units between the base of the surficial aquifer system to the top of the Floridan aquifer system. Generally, the intermediate aquifer system includes an upper confining unit of clayey sand, clay, shell, and marl, and a lower confining unit of sandy clay and clayey sand. These confining units are highly variable both spatially and vertically. Lying between these confining units in Polk County are one or two water-producing zones, which also are separated by another confining unit. The water-producing zones are composed primarily of clastic sediments interbedded with carbonate rocks. As a whole, however, the entire system, including the water-bearing units, restricts vertical movement of ground water between the overlying surficial aquifer system and underlying Upper Floridan aquifer (Spechler, R.M., and Kroening, S.E., 2007).

## KARST DEVELOPMENT

A review "Sinkhole Development and Distribution" map indicates the subject property lies in AREA III on the map. This area is where the cover material is 30 to 200 feet thick and consists of mainly of cohesive clayey sediments of low permeability. Cover-collapse sinkholes dominate Area III. Cover-collapse sinkholes occur where a solution cavity develops in the limestone to a size such that the overlying cover material can longer support its own weight. Generally circular in shape, cover collapse sinkhole have walls that are typically irregular because of the influence of joints and fractures in the underlying rock (Sinclair and others, 1985).

Subaerial exposure surfaces, indicating periods of lower sea level, are common in the limestones of Florida, as are paleokarst features associated with these surfaces. Of particular importance is the mid-Oligocene unconformity at the top of the Suwannee Limestone as it marks the end of 100 million years (Ma) of nearly continuous carbonate deposition in the Florida peninsula (Florea, Lee J. 2008).

The spatial locations of interfaces are not temporally constant; and therefore, multiple horizons of concentrated karst features can occur within the carbonate strata. The wide fluctuations in sea-level stands over the Floridan platform were accompanied by periods of intense karst development as seen in Figure 3.

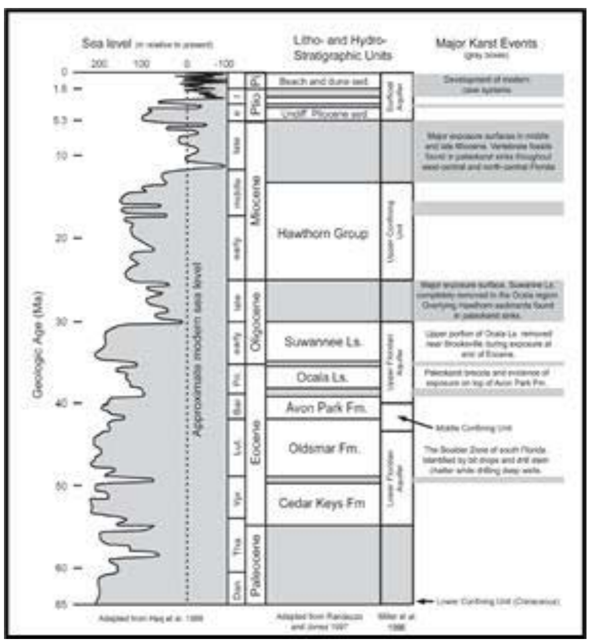


**Fig. 3** : Stratigraphic Units Polk County, and Associated Sea Level and Major Karst Events (Kuniansky, E 2001)

As sea and groundwater levels rise and fall, the karst features continue to evolve. During high sea-level stands many of the karst features become submerged. Reversing head gradients convert sinkholes into flowing springs. Many of the numerous lakes and ponds of west central Florida occupy depressions formed by overburden materials settling into cavities in the underlying limestone. Most of the documented karst features in west-central Florida are within 91m of land surface although cave divers have explored deeper passages in submerged caves. Also, exploratory well drilling has indicated the presence of enlarged fractures and cavities and associated flows at depths greater than 300 ft. (Kuniansky, E 2001)

## GEOLOGIC UNITS

A review of the Florida Geological Survey Open File Map Series 42, "Geologic Map of subject Open File Report 80 Text to Accompany the Geologic Map of Florida" indicates the subject property lies in a geologic map area defined as Hawthorn Group, Peace River Formation, Bone Valley Member - The Bone Valley Member Peace River Formation occurs in a limited area on the southern part of the Ocala Platform in Hillsborough, Polk and Hardee Counties. Throughout its extent, the Bone Valley Member is a clastic unit consisting of sand-sized and larger phosphate grains in a matrix of quartz sand, silt and clay. The lithology is highly variable, ranging from sandy, silty, phosphatic clays and relatively pure clays to clayey, phosphatic sands to sandy, clayey phosphorites. In general, consolidation is poor and colors range from white, light brown and yellowish gray to olive gray and blue green. Mollusks are found as reworked, often phosphatized casts. Vertebrate fossils occur in many of the beds within the Bone Valley Member. Shark's teeth are often abundant. Silicified corals and wood are occasionally present as well. The Bone Valley Member is an extremely important, unique phosphate deposit and has provided much of the phosphate production in the United States during the twentieth century. Mining of phosphate in the outcrop area began in 1888 and continues to the present

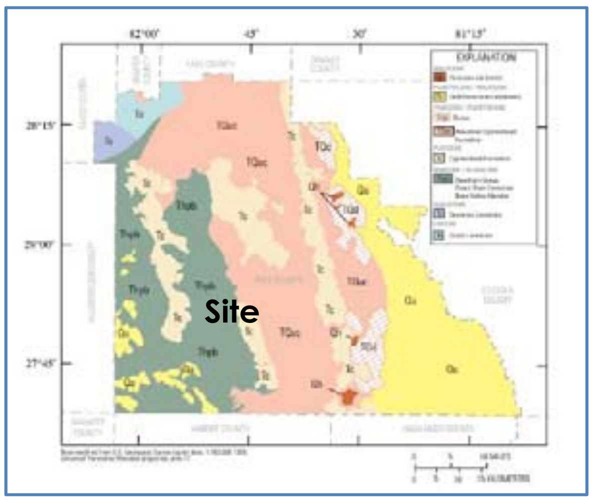


**Fig. 4** : Geologic Units of Polk County

## GEOLOGY OF THE SITE

The consultant performed 3 Standard Penetration Test (Figure 5) borings near the location of the piezometers to depths of 45m to 54m and encountered three Stratums

*Stratum 1* : Reworked mine tailing deposits of Sand and Sandy Clay, Silty Sandy Clay and Clayey Sand

*Stratum 2* : Natural material comprised of Sand Silty Clayey Sand, Clayey Sand, Clay

*Stratum 3* : Limestone, Clay

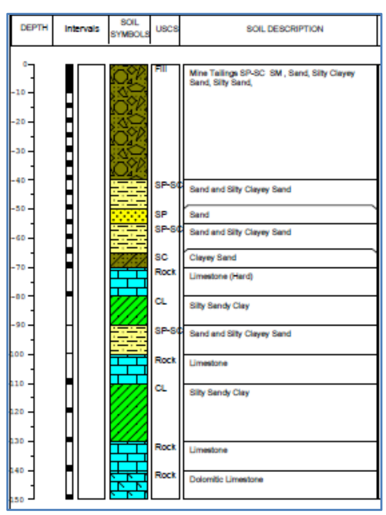


**Fig. 5** : Test boring near P-13 (in feet)

## GEOPHYSICAL DATA COLLECTION

### Drilling Installation of Implants

Drilling was selected based on the original design of 50-foot depth and results of consultant's test boring that identified the hard clay at 12m. The G3 Group encountered very hard clay at depths of 10m that continued to 15m. Based on the initial drilling results it was decided to place the implants at 12m to keep production at optimum. bls.

Geophysical investigation included three MERIT survey lines 335mlong. The drilling installation of 56 implants at 6m spacing to approximate depths of 12m (below land surface). A total of 657 linear meters of drilling per survey line was accomplished to produce the buried geophysical array

### Data Collection (MERIT)

The electrodes were connected to AGI Super Sting 8 channel electrical resistivity instrument. Data collection required several hours for the primary line and the offsets each. Redundant measurements of the MERIT line were taken to insure the collection of viable data. The G3 Group utilized a propriety optimization coding to perform the up to 2500 data points collection per line.

The MERIT geophysical profiles identified seven resistivity ranges. The ranges were analyzed from on-site drill data and from values obtained from geophysical profiles. The resistivity ranges anticipated geology can be seen in Table I

**Table I** : Resistivity ranges obtained by MERIT

| Stratum | Lithology (USC) | Resistivity Range (Ohm-m) | Colors on MERIT Profile Resistivity Range (Ohm-m) |
|---|---|---|---|
| 1 | Sand (SP), Clayey Sand (SC), Silty Sand (SM), Clay (CL/CH) | 25-120 | Green 25-45 |
| | | | Yellow 45-55 |
| | | | Orange 55-65 |
| | | | Red 65-120 |
| 2 | Clay (CH/CL) | 10-45 | Blue 10-25 |
| | | | Green 25-45 |
| 3 | Weathered Limestone/Limestone | 45-130 | Yellow 45-55 |
| | | | Orange 55-65 |
| | | | Red 65-120 |
| | | | White 120-130 |

## ANALYSIS OF THE MERIT GEOPHYSICAL DATA COLLECTED

The MERIT geophysical technique collected over range of data points to complete the images. Based on the survey distance and depth of electrodes the MERIT survey penetrated to approximately 76m (below land surface). MERIT identified resistivity ranges and three distinct Stratums. Table I show the ranges of the resistivity values obtained in the MERIT survey and the associated lithology.

### Stratum 1

(Reworked Dam/Mined Material)

The material of Stratum 1 is believed to be originally Bone Valley Member that was mined and then reworked into the existing dams around the cooling pond. The majority of Stratum 1 is comprised of a matrix of inhomogeneous materials with resistivity ranges of 25 Ohm-m to 120 Ohm-m that is interpreted as conductive and resistive overburden material such as Sands (SP), Clays (CL/CH), Sandy Clays (SC) and Silty Sand (SM).

The MERIT profile identified the depth of Stratum 1 as relatively consistent at an approximate depth of 7.6m to 11m. In this profile the resistivity variations across the Stratum 1 suggest inhomogeneous and nonuniformed placement of overburden materials to construct the dam. In the geophysical image from station 0 to station 600 higher resistivity's material grades into lower conductive material from station 600 to station 900. A distinct boundary exists between Stratum 1 and Stratum 2 in the MERIT profile of Dam Section K (P-12) An undulating surface occurs at the boundary between Stratum 1 and Stratum

### Stratum 2

(Hawthorn Formation -Clay Section)

Stratum 2 is believed to be termination depth of the mining activity at the Hawthorn Formation clay section. The clay was encountered in the drilling results at depth ranged from 8m to 12m. Stratum 2 in the profile has a well-defined boundary resistivity value that range from 25 ohm-m to 45 ohm-m and discrete horizontal zones within the stratum of low resistivity values of 10 Ohm-m to 25 Ohm-m can be observed. These more conductive zones with conductive layer may indicate a significant increase in clay content or more porous zone

**Stratum 3**

(Hawthorn Formation -Limestone Section)

A distinct boundary exists between Stratum 2 and Stratum 3 exist in the profile of Dam Section K (P-12) at approximate depth of 30m. The majority of Stratum 3 has resistivity values that range from 45 Ohm-m to 120 Ohm-m (Yellow, Red, White). This is interpreted as possibly highly weathered and porous limestone at the lower resistivity values to denser less porous limestone at higher resistivity values. Stratum 3 is massive and extends across the entire profile with the exception of an anomalous deep large lower anomalous resistivity feature

The interpretation of the MERIT profile is based on understanding of combination of several considerations that include but not limited to: Review of Publications, Regional Geology and Hydrogeology, Karst, Site Specific Geology and Geotechnical Investigations, Geophysical Surveys.

Based on review of deep sinkhole development in the study area and our previous forward modeling, the results of the geophysical survey perform are within detection capabilities of the MERIT technique. The anomalous features identified in the MERIT geophysical survey in this report are located within the anticipated geologic formations and have corresponding size, depth, and geometry of known karst/sinkhole development in the study area.

## CASE STUDY RESULTS

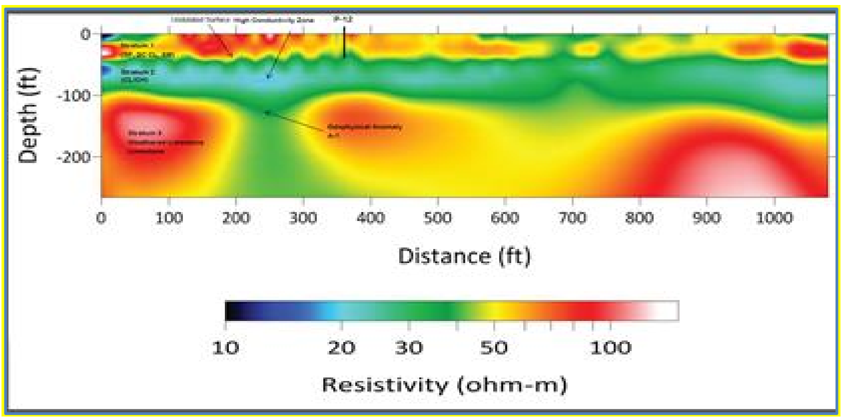


**Fig. 6** : The MERIT survey of Dam Section K (P-12)

The MERIT survey of Dam Section K (P-12) identified geophysical anomaly A-1 approximately 15m west of piezometer P-12. This feature may represent a large vertical karst feature that has penetrated Stratum 3, the inferred limestone formation, from 30m to 76m. This subsurface feature is 30m feet wide was identified in the profile starting at depth of 30m and extending 45m or greater, the feature reached the termination of the geophysical profile and therefore the total depth is unknown. Additionally in the profile Stratum 2 and Stratum 1 have aligned features that correspond to the location of the subsurface anomaly A-1.

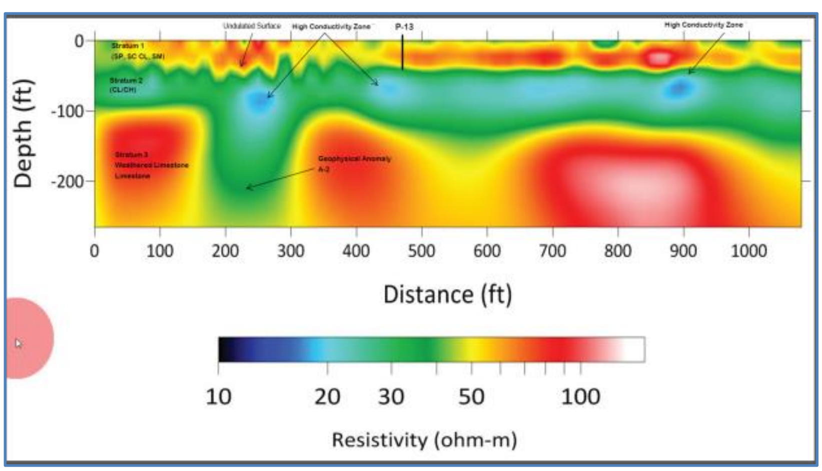


**Fig. 7** : The MERIT survey of Dam Section K (P-13)

The MERIT survey of Dam Section K (P-13) identified geophysical anomaly A-2, approximately 45m south of piezometer P-13. This feature may represent a large karst feature that has penetrated Stratum 3, the inferred limestone formation, from 30m to 76m. This subsurface feature in A-2 was identified in the profile and has dimensions of approximately 45m across and at a depth 45m reaching the termination of the geophysical profile and therefore the total depth is unknown. Additionally in the profile Stratum 2 and Stratum 1 have aligned features that correspond to the location of the subsurface feature A-2 in Stratum 3.

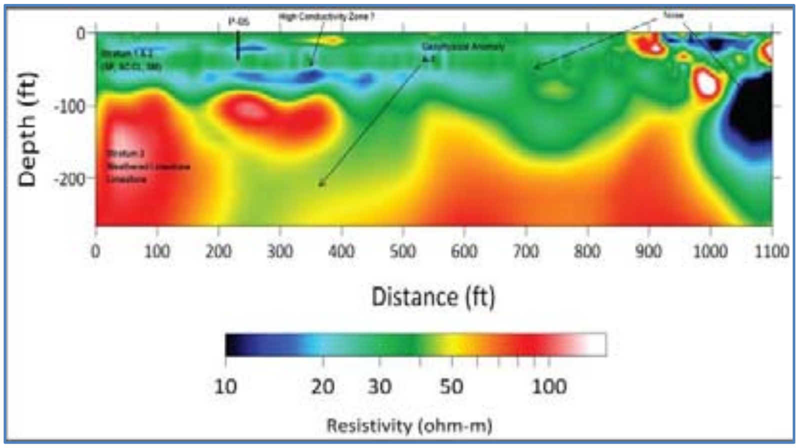


**Fig. 8** : Profile MERIT Survey Dam Section N (P-05)

Piezometer P-05 is located within the geophysical anomaly A-3 on the profile Dam Section N (P-05). Anomaly A-3 may represent a large karst feature that characterized by two coalescing angled solution channel/karst features that have penetrated the entire Stratum 3 a depth from depth of 30m to 76m the total depth is unknown. The feature A-3 in Stratum 3 is at approximately 91m in wide. The smaller solution type feature is approximately 15m south of P-05 and the larger portion of the feature is approximately 61m north of P-05.

## CONCLUSION

The case studies presented here are intended to provide a general understanding and view of the potential of implant technology for geophysical surveys of dams, especially in regions of karst. While the MERIT technique is minimally invasive and requires more investment in time and cost, the results are significantly improved over surface geophysical methods. The ability to clearly identify sinkhole geometry, geology, raveling zones and potentially the locations of the throat at depths of over 83m can lead to much greater understanding or engineering applications of risk analysis, monitoring and remediation of dams in karst.

## REFERENCES

Campbell K (1992) Geologic map of Polk County, Florida (FGS: Open file map series 46)

Florea, Lee J.. (2008). Geology and Hydrology of Karst in West-Central and North-Central Florida. Caves and

Karst of Florida,225-239.

Florida Geological Survey Open File Map Series 42, "Geologic Map of subject Open File Report 80 Text to Accompany the Geologic Map of Florida"

Fuleihan N E, Cameron J E., Henery J E (1997) The hole story: How a sinkhole in a phosphogypsum pile was explored and remediated The Engineering Geology and Hydrogeology of Karst Terranes, Beck & Stephenson (eds)

D Harro., S Kruse, (2013). Improved imaging of

covered karst with the multi-electrode resistivity implant technique. NCKRI Symposium 2. Proceedings of the 13th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst. Carlsbad, New Mexico, US.

Loke M, Kiflu H, Wilkinson P, Harro D, Kruse S (2015a) Optimized arrays for 2D resistivity surveys with combined surface and buried arrays. Near Surf Geophysics 13:505–517.

Riechers J (2012) Impact of Drilling in Embankment Dams. Master Thesis, Civil Engineering Luleå University of Technology Department of Civil, Environmental and Natural Resources Engineering

Division of Mining and Geotechnical Engineering

Kiflu, H., Kruse, S., Loke, M., Wilkinson, P., and Harro, D. (2016). Improving resistivity survey resolution at sites with limited spatial extent using buried electrode arrays. J. Appl. Geophysics. 135: 338– 355

Kuniansky, E (2001), U.S. Geological Survey Karst Interest Group Proceedings, Water-Resources Investigations Report 01-4011, p. 198-211

Sinclair, W.C., Stewart, J.W., Knutilla, R.L., Gilboy, A.E., and Miller, R.L., (1985), Types, features and occurrence of sinkholes in the karst of west central Florida: U.S. Geological Survey, Water- Resources Investigations Report 85-4126, 81 p.

Spechler, R.M., and Kroening, S.E., (2007), Hydrology of Polk County, Florida: U.S. Geological Survey Scientific Investigations Report 2006-5320, 114 p.

White, W.A., 1970, The geomorphology of the Florida Peninsula: Tallahassee, Florida Bureau of Geology Bulletin 51, 164 p.