# USING TIME-DOMAIN ELECTROMAGNETICS AND LiDAR DATA TO CHARACTERIZE WATER FLOW PATHS AND VOID SPACES IN THE WATER SINKS AREA, HIGHLAND COUNTY, VA, USA

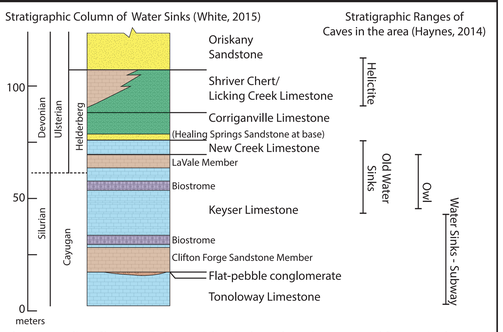

**Shamsuddin Ahmed**[1], Alondra del Mar Valle-Hernández[2], Zoe Williams[3], R Shane McGary[4]

[1]Department of Geological and Environmental Sciences, Appalachian State University, Boone, NC 28608; [2]Department of Geology, University of Puerto Rico – Mayagüez Campus, Mayagüez, PR 00682
[3]Geological Sciences Department, Ohio University, Athens, OH 45701; [4]Department of Geology and Environmental Science, James Madison University, Harrisonburg, VA 22807

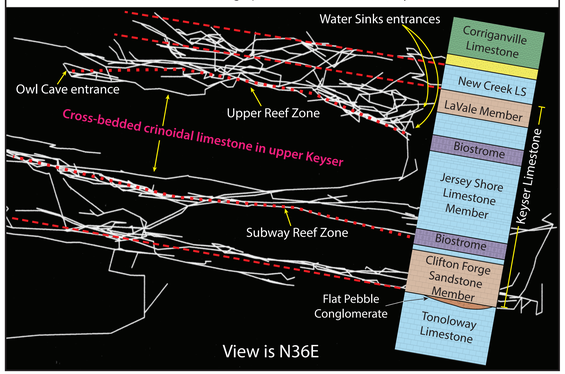

## ABSTRACT


The Water Sinks area has a karst topography replete with sinkholes, a steep depression, and at least three known cave systems– Helictite, Owl, and Water Sinks. All three of these cave systems are located along the axis of the Chestnut Ridge anticline and occur in successively older strata. The water table in and around the Water Sinks depression has shifted over the past few decades, and the reasons for its migration and specific pathways have not previously been studied. In this study, we used time-domain or transient electromagnetics (TDEM or TEM) resistivity tomography data and a water flow model derived from airborne LiDAR (Light Detection and Ranging) using ArcGIS, in an attempt to characterize the water flow paths, groundwater movement, and void spaces in the study area. We collected nine TEM datasets using the Geonics G-TEM system at various stations throughout the area, many of which were in close proximity (if not coincident) to the locations where DC resistivity data for a concurrent study by Valle-Hernández et al. were collected. We generated inverse models for the TEM data using Interpex IXG-TEM software. Combining the TEM results with the resistivity data and streamflow analysis, we are able to locate the groundwater flow paths both past and present. By evaluating these data within the context of the geology near the anticline, we are able to show that the evolution of the cave systems were primarily driven by the presence of impermeable biostromes.


## 2. GEOLOGY




- The northeast trending Chestnut Ridge anticline is the only major structural feature in the Water Sinks area, and all three major cave systems developed along its fold axis (White, 2015).
- Local strata primarily consist of various limestone units and some sandstone units (White, 2015).
- Most caves formed in the Devonian-Silurian Keyser (of the Helderberg Group) and Tonoloway Limestones.
  - The 7-9 m thick, massively bedded crinoidal Jersey Shore Limestone Member, which has shallow-angle crossbeds and biostromes of corals and stromatoporoids, seems to be resistant to cave development (Haynes).
- The figure below shows a cross-sectional diagram (facing N36E) of cave passages (shown as white lines) correlated with the stratigraphic column of the area (Haynes, 2014).




## 1. INTRODUCTION

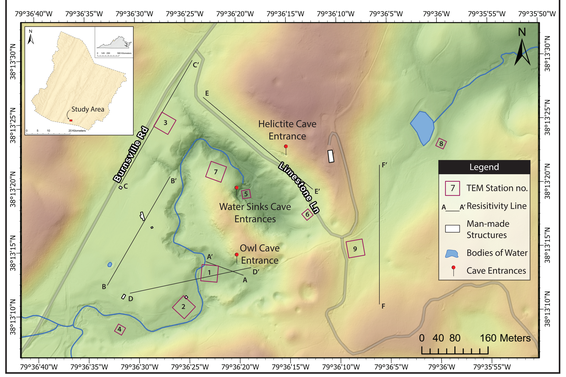
**The Study Area a.k.a. the Water Sinks Area**

- The study area lies east of Virginia State Route 609 (Burnsville Rd) in Highland County, VA. It is focused around the Water Sinks depression (See map below).
- The Chestnut Ridge anticline trends ~025° (NNE) in the area, with Helictite and Owl Cave entrances falling to the east, and Water Sinks entrances to the west of its axis.
- All data collection was done on privately owned land with the owners' permission.

Much of the area used to be covered by a lake, thus, the top-most layer below soil in much of the area likely to be lake deposits.

The water table in the area has migrated over the past few decades due to reasons not well-studied. A combination of factors are likely influencing the migration pattern and pathways. These include:

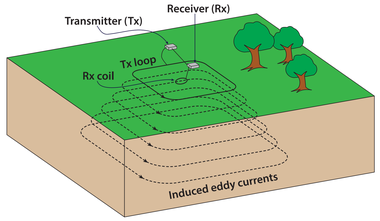
- Confining/restrictive lithologic unit(s),
- Dip angle of layers in the region, and
- A lineament of unknown nature, almost perpendicular to the anticline axis (White, 2015).




## 3. METHODS

**Time-Domain or Transient Electromagnetics (TDEM or TEM)**

- AC current is passed through a loop (Tx loop), which generates a magnetic field.
- EM waves induce eddy currents and generate secondary magnetic fields in the subsurface.
- We measure the change in the secondary magnetic fields to build a picture of the subsurface resistivity-conductivity structure.
- Nine datasets (five being from 40x40 m Tx loops, and four from 20x20 m Tx loops) collected using the Geonics G-TEM system which are still being processed using Geonics Protix64 and Interpex IXG-TEM.




**DC Electrical Resistivity Tomography**

- A concurrent study by Alondra del Mar Valle-Hernández used the AGI SuperSting to collect DC resisitivity data. Some of the resistivity sections are used here to inform our preliminary TEM results.

**LiDAR Data Processing using ArcGIS Pro**

- Airborne LiDAR data from the USGS was used to make an artificial surface waterflow model.

## 4. PRELIMINARY RESULTS AND DISCUSSION

**TEM (Preliminary) Results**

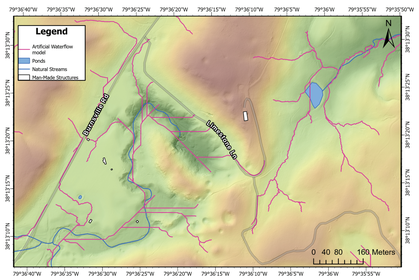
- TEM data are still being processed. Here we present preliminary results from the 40x40 m loop datasets only.
- Graphs show change in apparent resisitivity [Ohm-m] over time [ms].
- We do not know exactly how deep our instrument was able to penetrate (some hundreds of meters), thus, it is difficult to accurately interpret these results.

**Electrical Resistivity Tomography**

- These inverted resistivity sections are from the concurrent study done by Valle-Hernández et al.
- On the sections, the areas with potential water are marked with a white 'w' and the dashed black line approximates the boundary between soil and weathered/unconsolidated rock, and consolidated rock.
- The purple dotted lines on the inverted resisitivity sections represents the approximate location along which the TEM stations collected data.

**Surface Waterflow Model**

- The water flow model (shown below) reveals areas where water is most likely to accumulate and flow on the surface, which possibly contribute to groundwater recharge in the area (further analyses and studies are needed)
- There do not seem to be any surficial elements that clearly hint at possible reasons for the migratory pathways of the groundwater. Therefore, understanding the subsurface constraints became more important to understand.

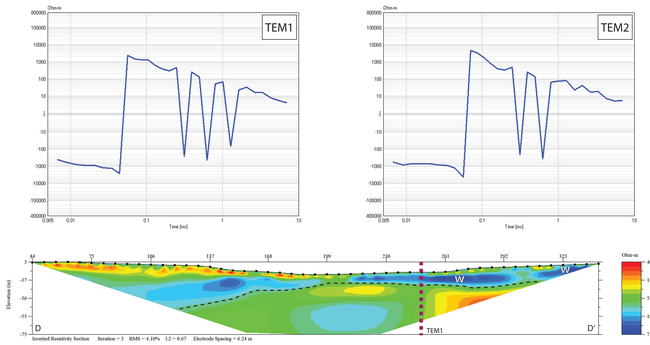



**Future Work**

- First and foremost, we will finish processing all the TEM data and create inverse models from them.
- We plan on re-collecting all the 20x20 m TEM datasets due to mistakes in setting up the stations the first time.
- More TEM data will be collected, including a station overlapping with resistivity line F-F' due to there being a huge area with very high resistivity (100,000 Ohm-m) at a depth of ~36.5 m below the surface– which could either be a long cave passage or a collection of smaller, connected void spaces (see inverted resisitivity section to the right) (Valle-Hernández et al.).

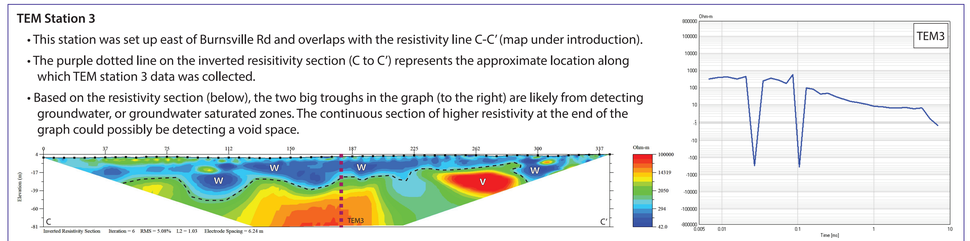
**TEM Stations 1 and 2**

- TEM Station 1 was placed just a few meters from the entrance to Owl Cave and overlaps with the resistivity line D-D'.
  Both TEM Station 1 and 2 were very close to Sinking Creek (refer to map under introduction).
- Due to their proximity to the creek, the first big spike in resistivity in both graphs (to the right) is likely a boundary between soil/sand/gravel from the creek (as well as old lake deposits) and limestone, which generally has a higher resistivity than soil/sand/gravel. Subsequent changes in apparent resistivity could be due to groundwater saturated zones or changes in lithology.
- The purple dotted line on the inverted resisitivity section, D to D' (to the right), represents the approximate location along which TEM Station 1 data was collected.




**TEM Station 3**

- This station was set up east of Burnsville Rd and overlaps with the resistivity line C-C' (map under introduction).
- The purple dotted line on the inverted resisitivity section (C to C') represents the approximate location along which TEM station 3 data was collected.
- Based on the resistivity section (below), the two big troughs in the graph (to the right) are likely from detecting groundwater, or groundwater saturated zones. The continuous section of higher resistivity at the end of the graph could possibly be detecting a void space.

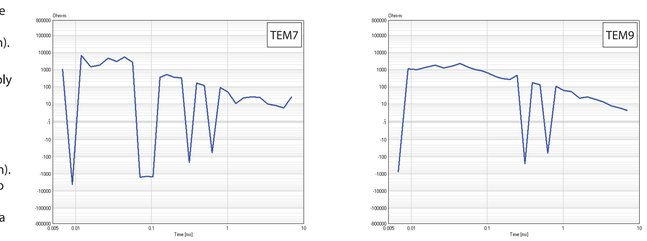


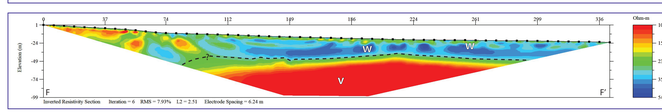

**TEM Station 7**

- This station was set up on a northern slope of the hill (Cave Hill) surrounded by Sinking Creek and the depression (refer to map under introduction).
- The troughs in this graph (to the right) likely represent groundwater, with some crests possibly being void spaces, given its proximity to both Sinking Creek and the Water Sinks cave system.

**TEM Station 9**

- This station was set up only a few meters away from resistivity line F-F' (map under introduction). It is possible that the last trough in the graph (to the right) is from detecting a void space given that the inverted resisitivity section for F-F' had a large area at the bottom of the section which detected either a large cave passage, or a set of smaller, connected void spaces.




Resistivity line F-F' (to the left). Showing a large area with very high resistivity starting at a depth of ~36.5 m below the surface. At a site where future TEM data will be collected, in order to characterize the void space(s)

## 5. ACKNOWLEDGEMENTS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