Development of Sinkhole Risk Evaluation Program
(BDV24 TWO 977-17)

Presented by:

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University of Central Florida

Presented to:

FDOT GRIP Meeting

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Presentation Outline

- Introduction
- Task 1 –Subsurface characterization by CPT
- Task 2 – In-situ groundwater sensing
- Task 3 – Development of groundwater model for high-resolution recharge map
- Future plan

Introduction

- Research objective:
  - to develop a procedure to evaluate the level of sinkhole vulnerability based on in-situ CPT
  - to develop a high-resolution recharge map
  - to explore in-situ groundwater sensing/monitoring
- Research methodology
  - In-situ tests (SPT, CPT, etc.)
  - Piezometer sensor installation
  - Numerical analysis (finite difference, finite element)

UCF Sinkhole Research Team

Dr. Boo Hyun Nam
Geotechnical Eng.

- Sinkhole stability analysis for risk evaluation

-Subsurface characterization of geotechnical system

- Laboratory evaluation of geomaterials

Dr. Dingbao Wang
Water Resource Eng.

-Surface water and groundwater interaction

- Water resources systems analysis

- GIS and remote sensing applications in water resources

Dr. Andrew H. Yun
Structural Eng.

- Sinkhole sensing and prediction algorithm

- Signal processing & data mining; Civil infrastructure monitoring

- Multi-physics modeling

**Dr. Manoj Chopra**
Geotechnical Eng.

- Physical groundwater model test

-Soil erosion and sedimentation

- Nonlinear soil consolidation & stress analysis

Task 1. Subsurface characterization by CPT (at Wekiva pwky site)

Wekiva Parkway Project – Site Description

- Lake County

- About 40 minutes North of Downtown Orlando.

- Focus Section: North end of SR 46 to Mt. Plymouth Rd connector toll road.

- Located north of wekiva springs and south of Seminole springs. Numerous relic sinkholes.

- Interchange consists of 3 bridges, 4 earth-embankment ramps

Wekiva Parkway

Bridge over an active sinkhole zone
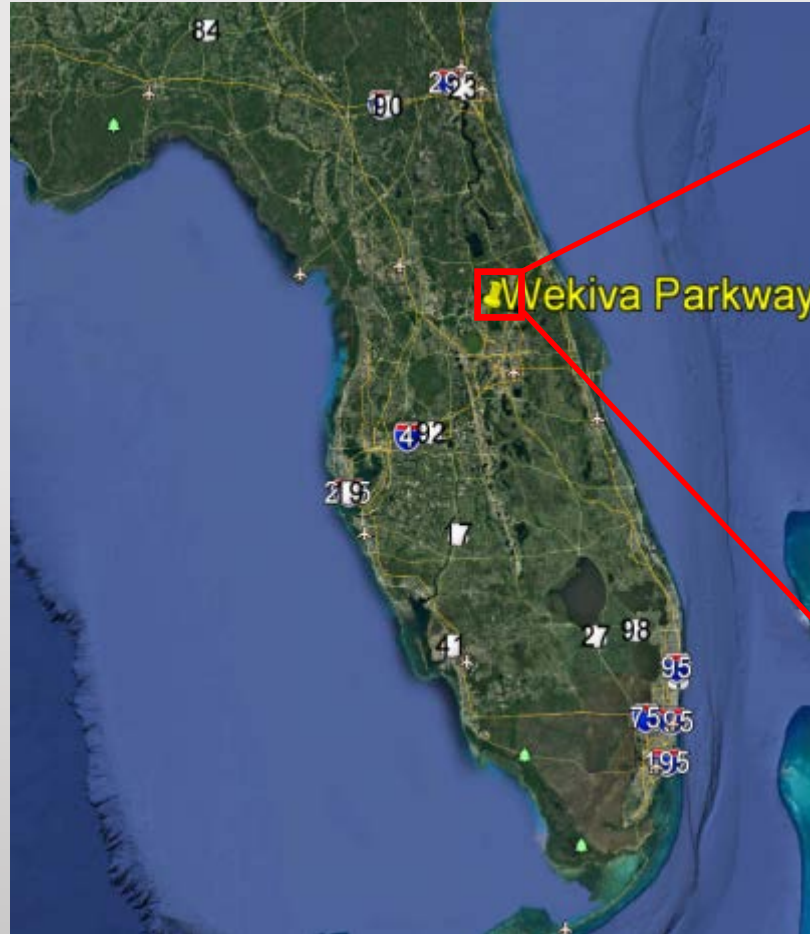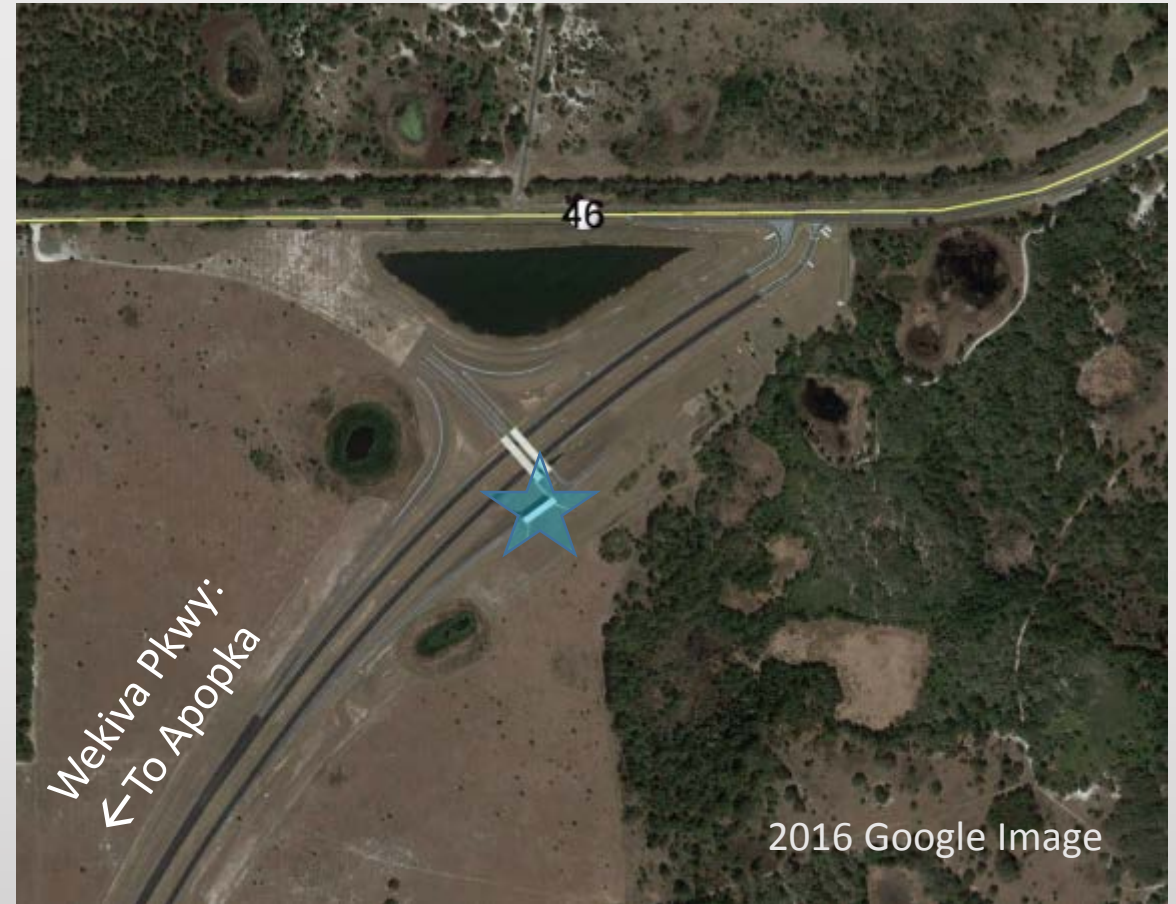
Field investigation performed by FDOT and Professional Services Inc.

- **74 CPT soundings** performed till refusal
- **14 SPT borings** through performed till

⭐ Focus thus far on constructed bridge over sinkhole anomaly.

- 3 Total Grids of 15 or more CPTs performed on/near sinkhole anomaly areas.

- Bridge grid (shown right) consists of 17 CPT and 4 SPT performed within roughly an acre.

- Depth to Limestone varies from 60 to 130 feet.

- Borings show very loose soil (WH/WR & Tip resistance < 10 TSF) directly above the limestone bedrock.

SPT Boring performed by PSI

CPT Boring performed by FDOT
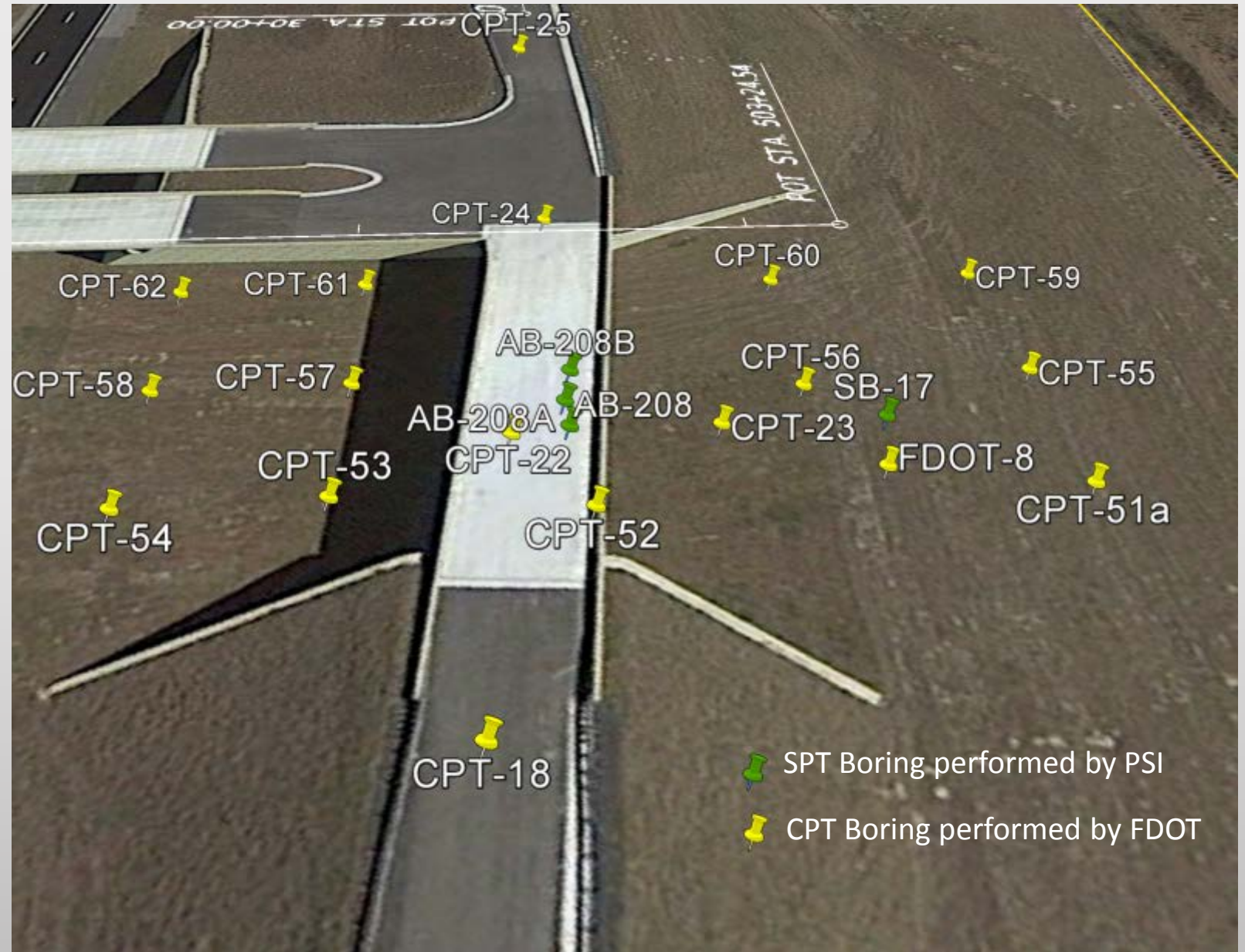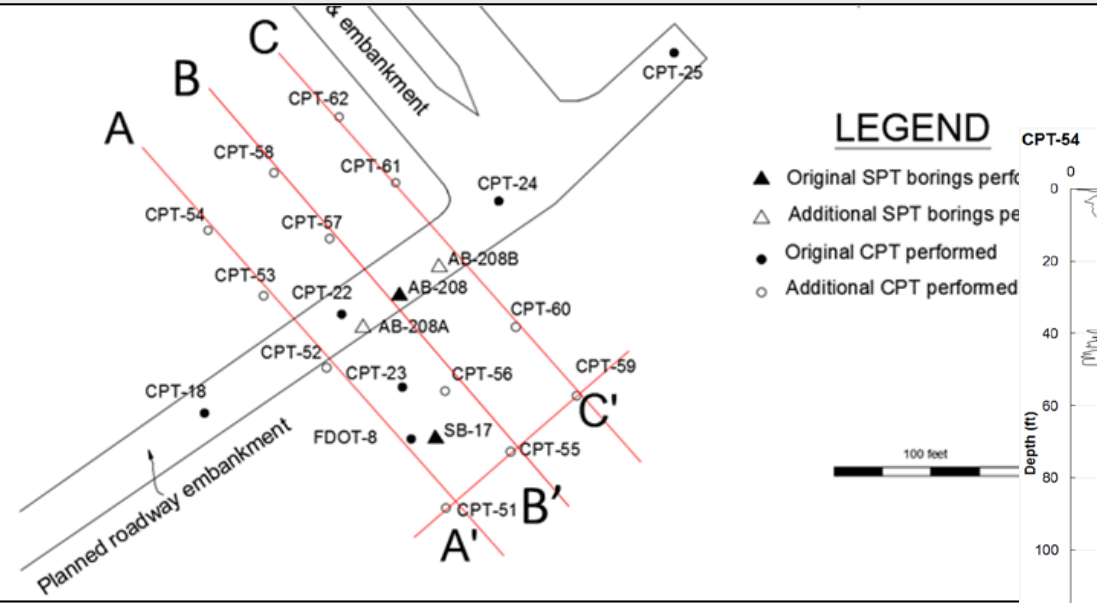
- CPT data are plotted along the lines to visualize soil strata stiffness profile and possible sinkhole anomaly along each profile line shown in the figure above.
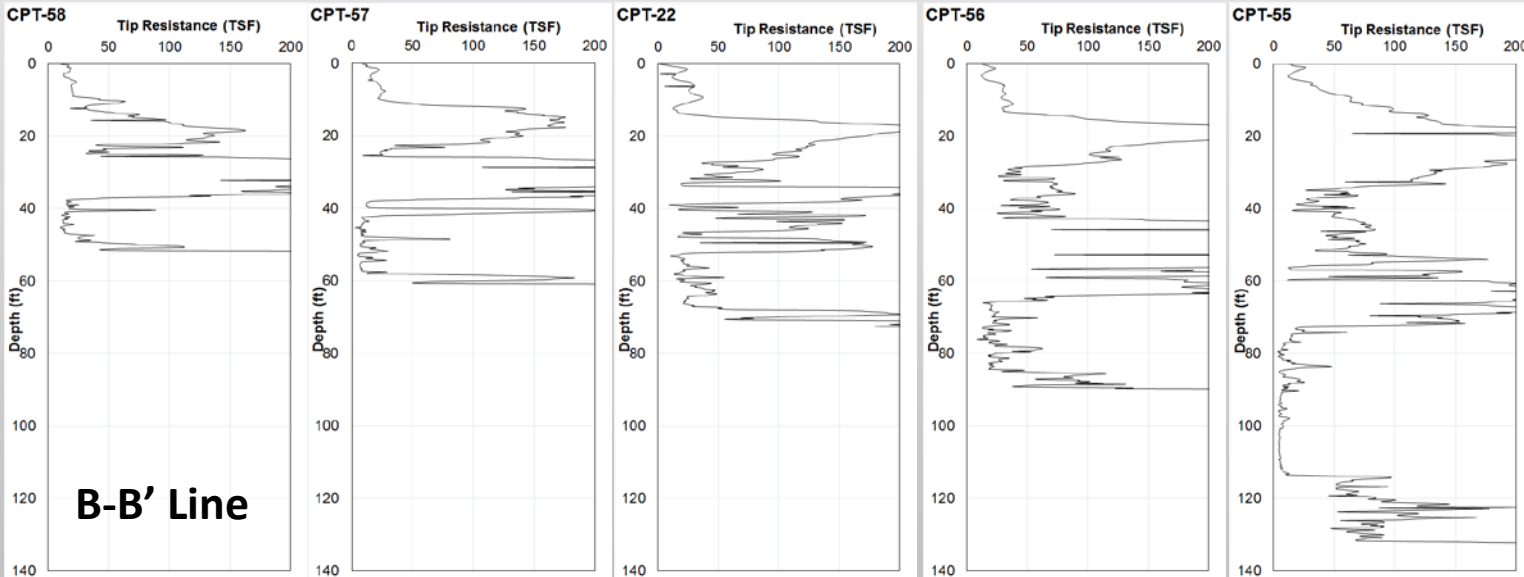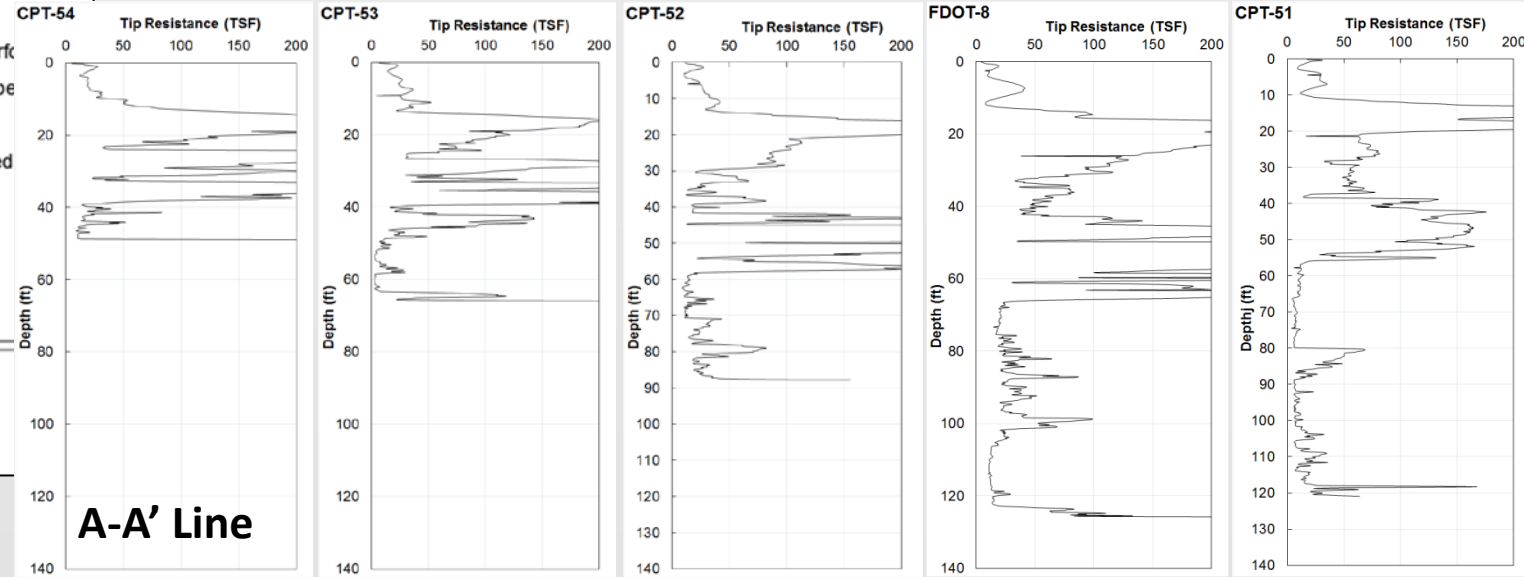
2D CPT Imaging (tip resistance data)

- 2D CPT imaging was created in MATLAB to visualize soil strata stiffness profile and possible sinkhole anomaly along each profile line.
- 3D Surface plot with interpolated shading. Color scale from 0 to 200 TSF.
- Very low tip resistance within the "bowl" or "valley" of limestone surface suggest that subterranean erosion of overburden soils has occurred (Raveling).

Sinkhole Anomaly Profile – Tip Resistance (TSF)

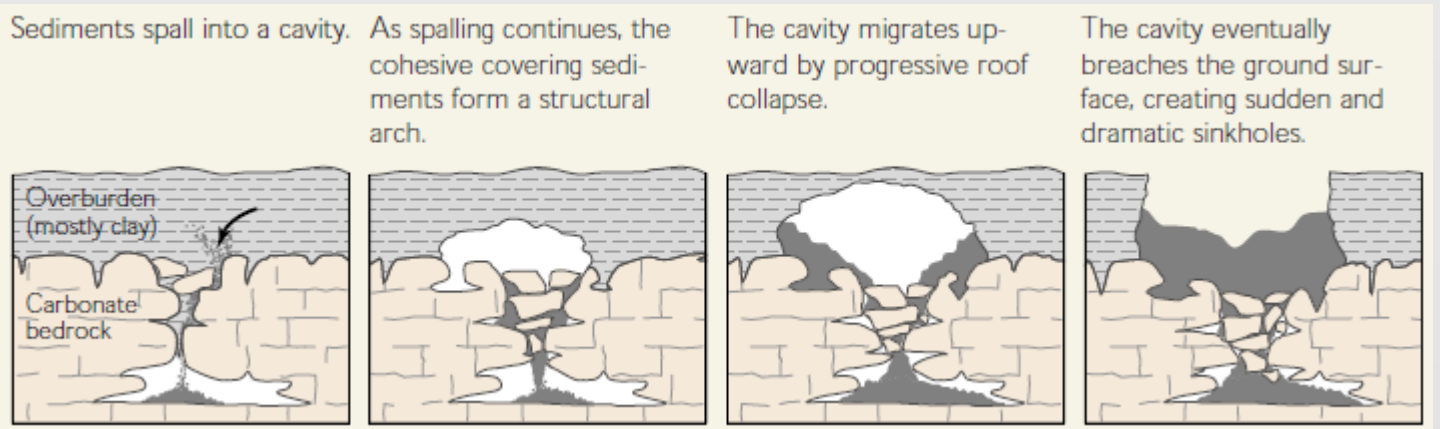(a) A-A'

(d) A'-C'

(b) B-B'

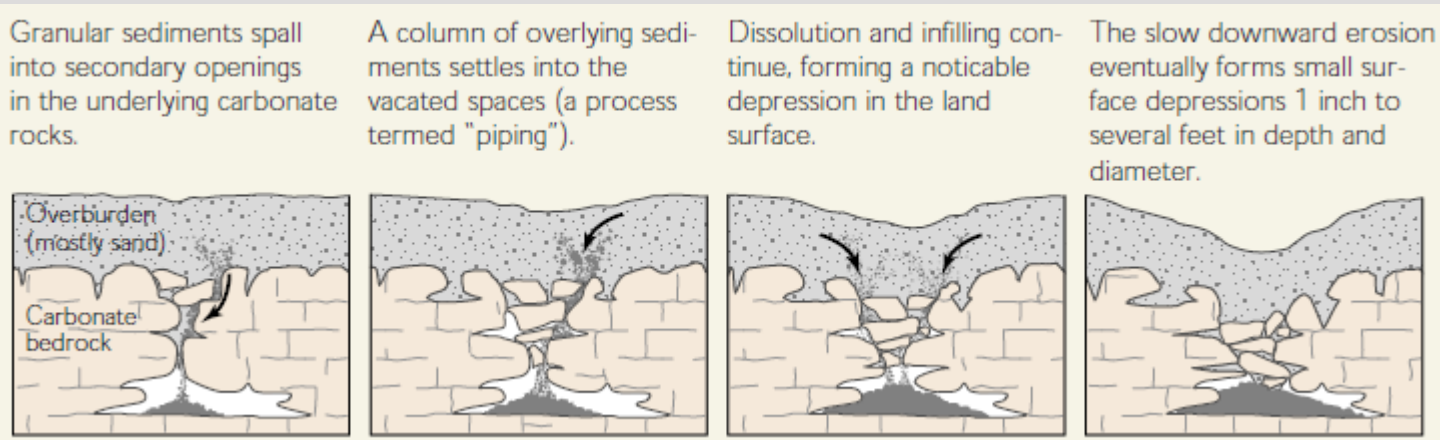(c) C-C'
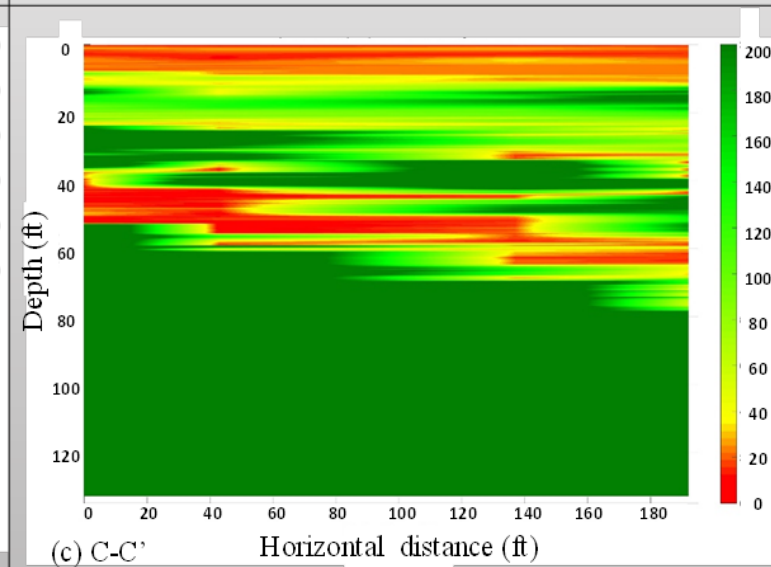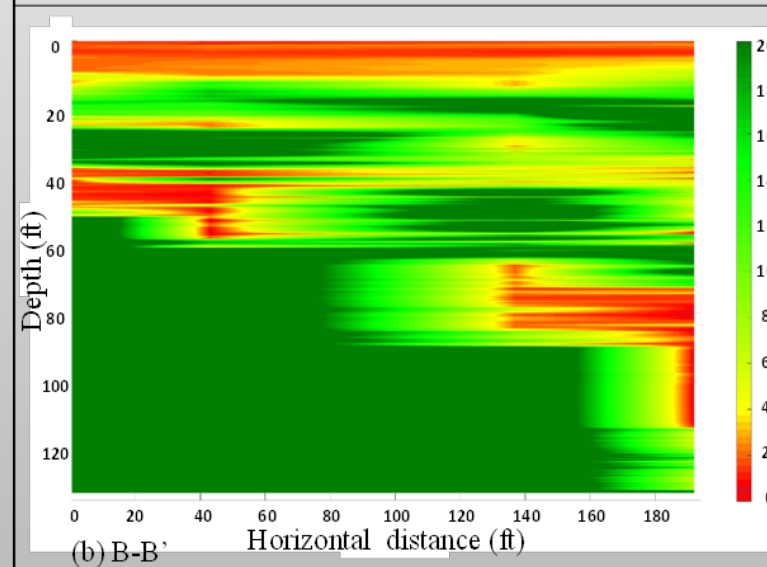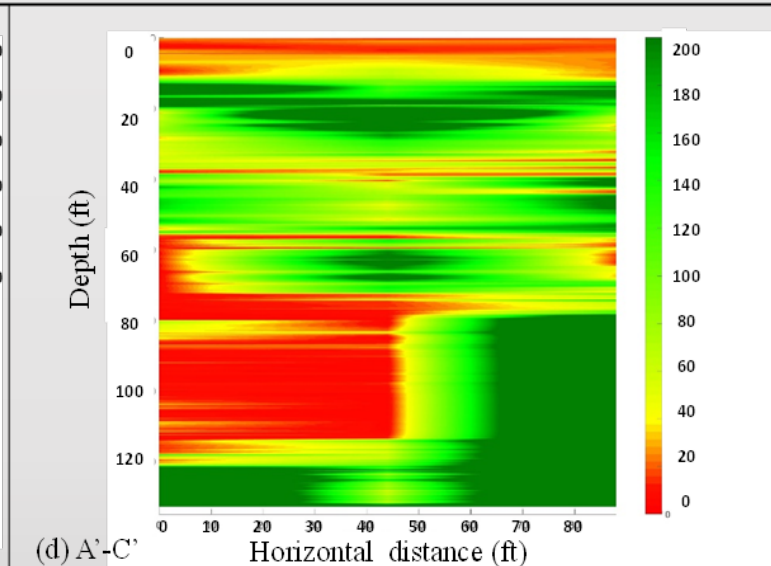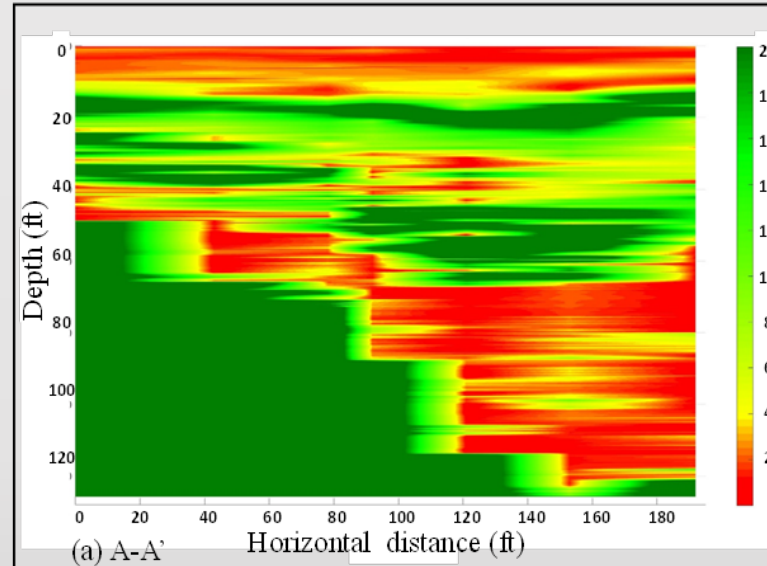
Soil Raveling in sinkhole prone area

- Soil raveling

The groundwater from unconfined aquifer to confined aquifer weathers the carbonate limestone and erodes the overburden soils causing sinkholes. The overburden soils can be raveled before any noticeable subsidence or sinkhole-like identifiers are shown on the ground surface. Best time to perform mitigation measures

Cover-subsidence sinkhole

Sediments spall into a cavity. As spalling continues, the cohesive covering sediments form a structural arch. The cavity migrates upward by progressive roof collapse. The cavity eventually breaches the ground surface, creating sudden and dramatic sinkholes.

Overburden (mostly clay)

Carbonate bedrock

Cover-collapse sinkhole

Granular sediments spall into secondary openings in the underlying carbonate rocks. A column of overlying sediments settles into the vacated spaces (a process termed "piping"). Dissolution and infilling continue, forming a noticable depression in the land surface. The slow downward erosion eventually forms small surface depressions 1 inch to several feet in depth and diameter.

Overburden (mostly sand)
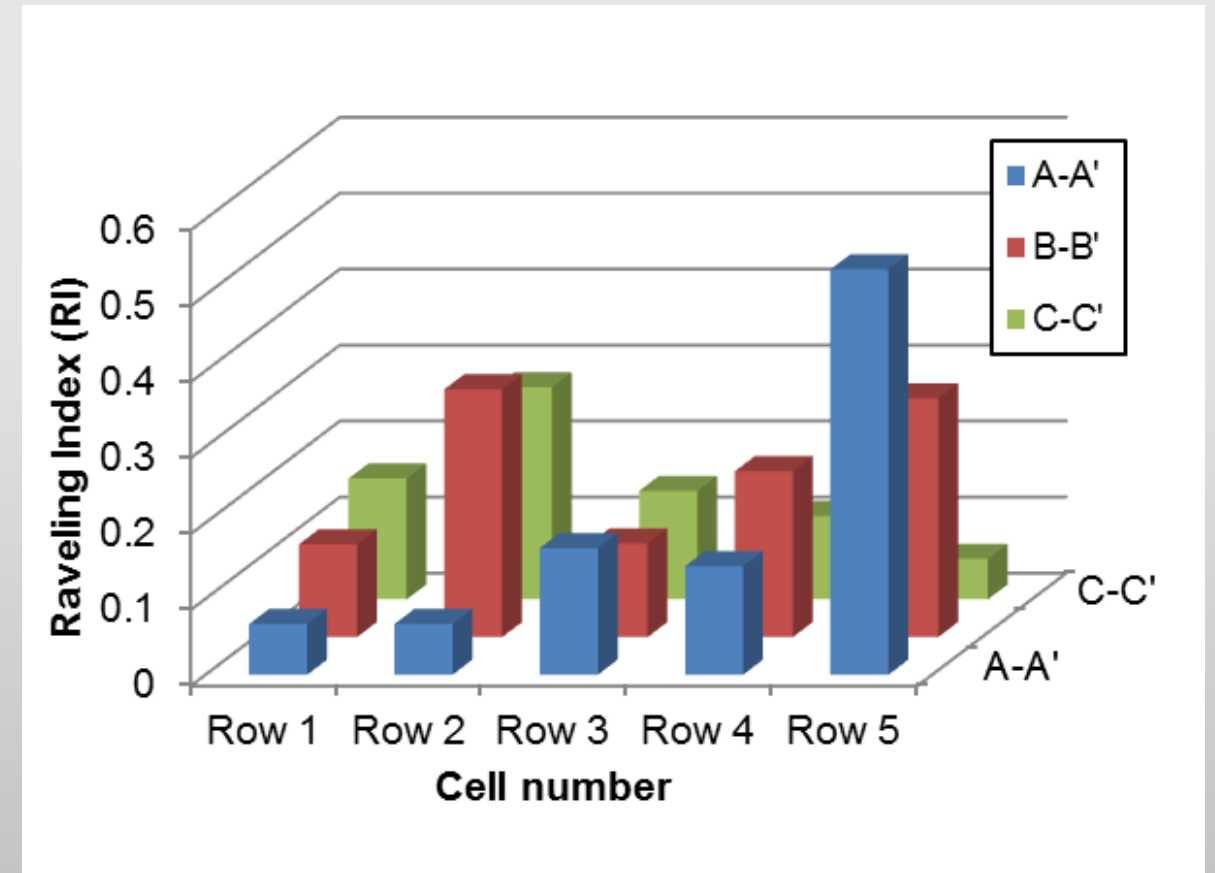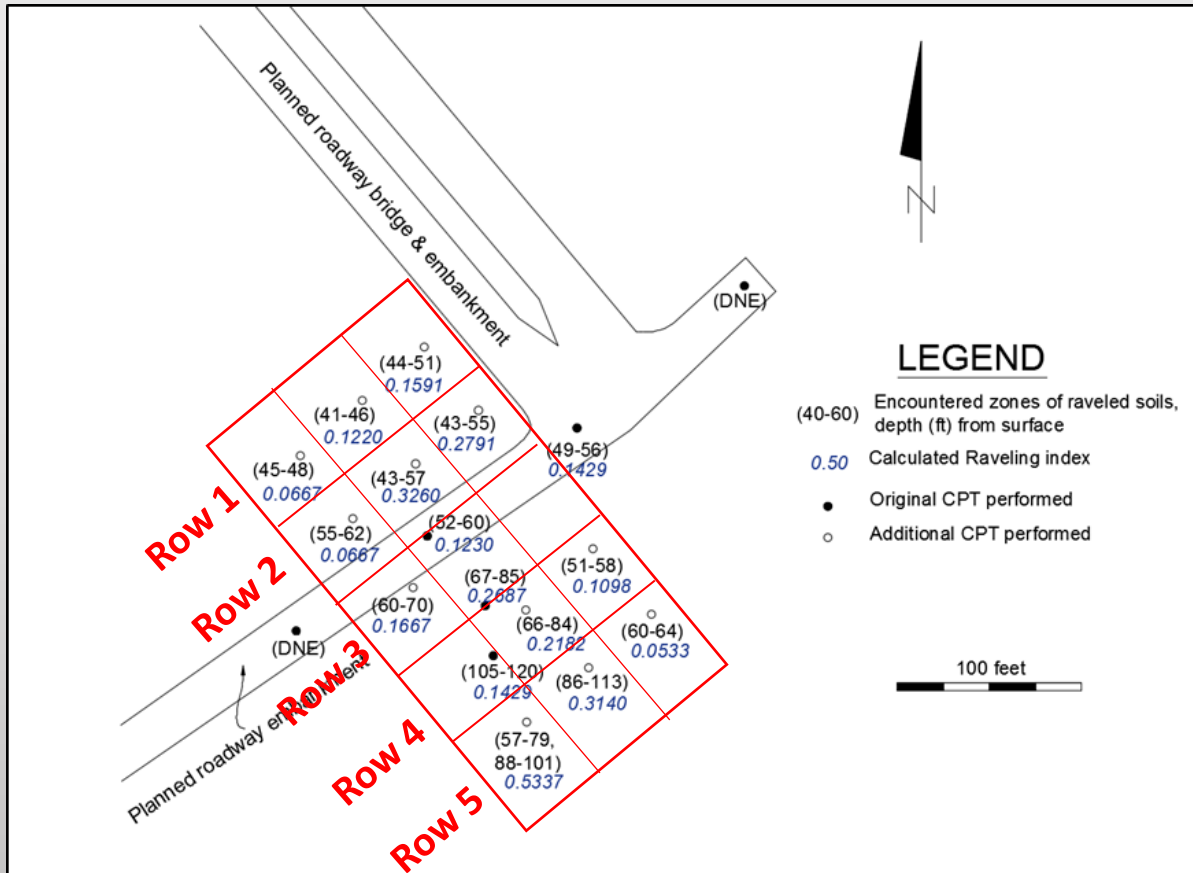
Carbonate bedrock

From Tihansky 1999

Raveling Index (RI)

- Proposed by Gray and Bixler, the raveling index is the ratio of thicknesses of raveled soil to harder "undisturbed" overburden soil. Best when calculated using CPT data because of high resolution of data.

$$RI = \frac{Thickness\ of\ raveled\ zone}{Depth\ to\ top\ of\ raveled\ zone}$$
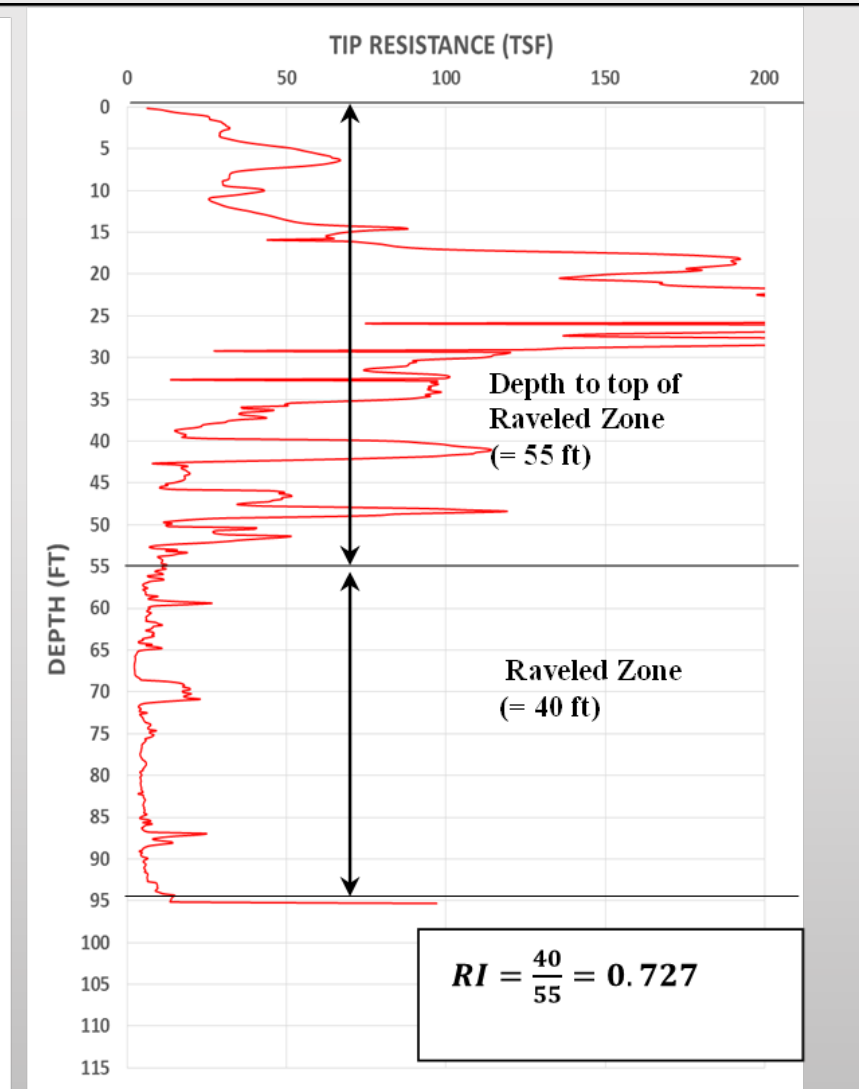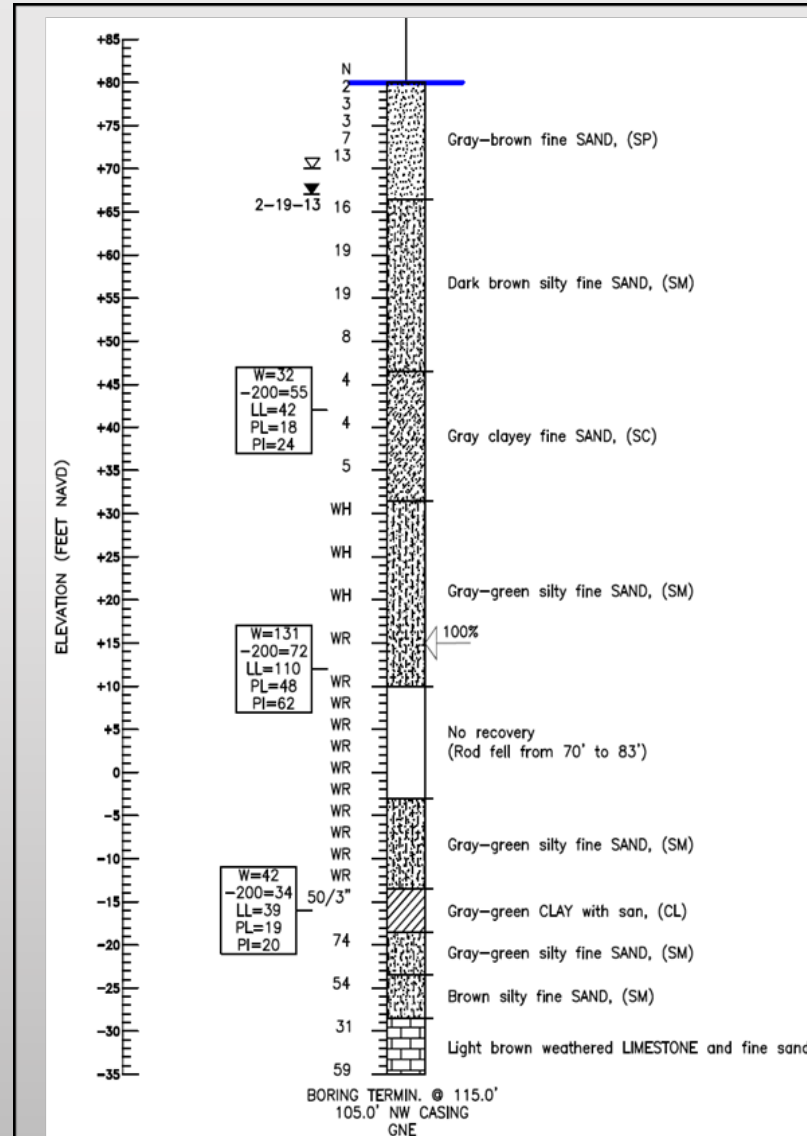
Raveling Index plot of the Wekiva Pwky site

# Task 2. Sensor layout & in-situ installation

Sensor layout for Wekiva pkwy

- Ground water table from MSL
  - Low: 63 feet
  - High: 70.5 feet
- Number of Zone: 4
  - No. of sensor in zone 1: 7
  - No. of sensor in zone 2: 4
  - No. of sensor in zone 3: 7
  - No. of sensor in zone 4: 2
- Type of sensor: 4500S-350kPa
- Number of Datalogger: 5
  - 4-channel datalogger: 4
  - 16-channel datalogger: 1
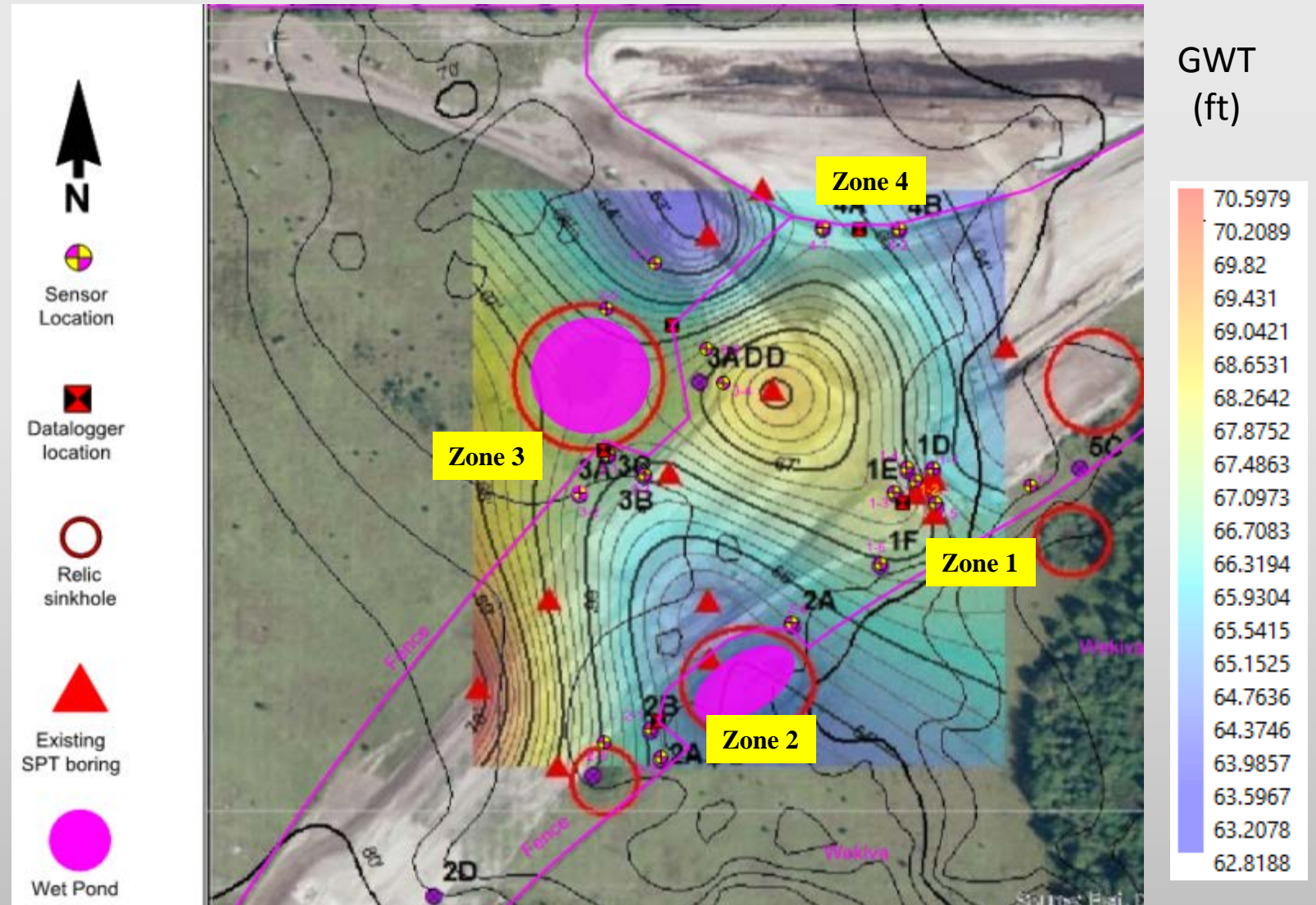
Sensor layout for fdot retention pond

o Ground water table
  - Low: 13.5 ft
  - High: 16 ft
o Number of sensor: 16
o Type of sensor: 4500S-350kPa
o Number of datalogger: 1
o Type of datalogger: 16-channel
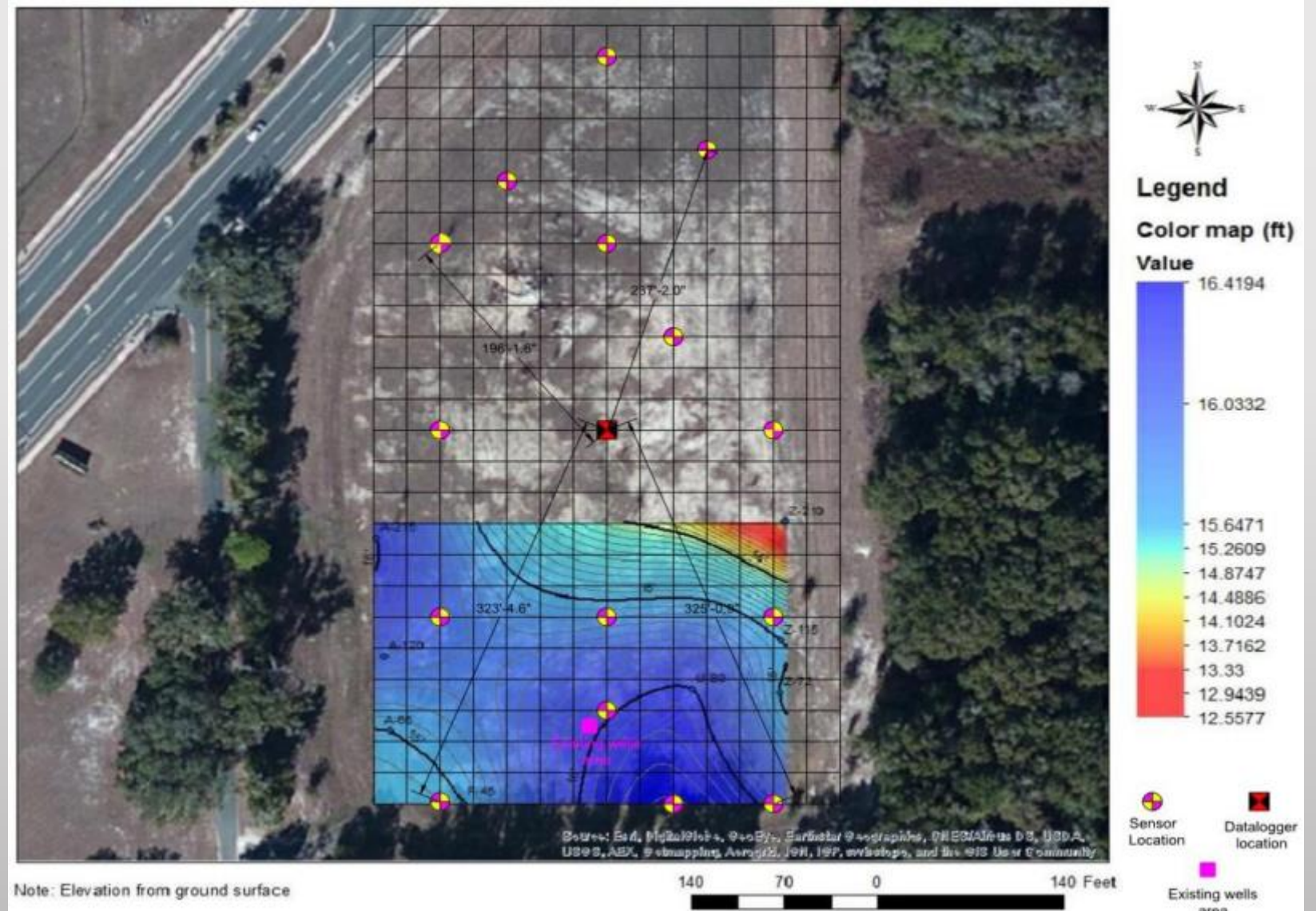
Equipment

- Piezometer sensor
- Make: Geokon
- Model: 4500S-350kPa
- Resolution: 0.025% F.S
- Accuracy:
  ±0.1% F.S.

- 4-Channel datalogger
- Make: Geokon
- Measurement Accuracy: ±0.05% F.S.
- Data Memory: 320K EEPROM
- Storage capacity: 10666 arrays

- 16-Channel datalogger
- Make: Geokon
- Measurement Accuracy: ±0.05% F.S.
- Data Memory: 320K EEPROM
- Storage capacity: 3555 arrays

Sensor preparation and installation

Step 1: Checking sensors and dataloggers in lab
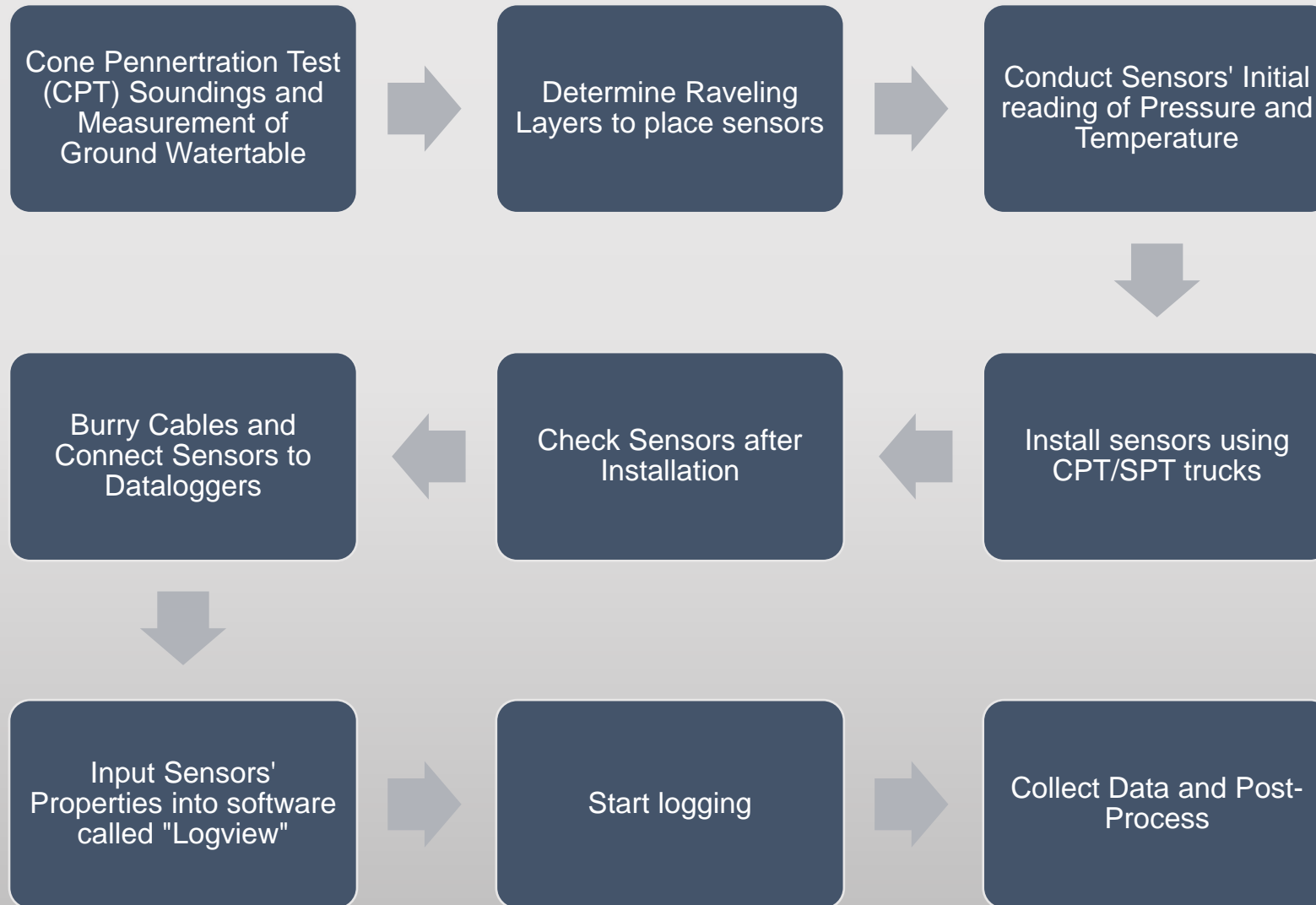

Step 2: Install sensor using CPT/SPT trucks
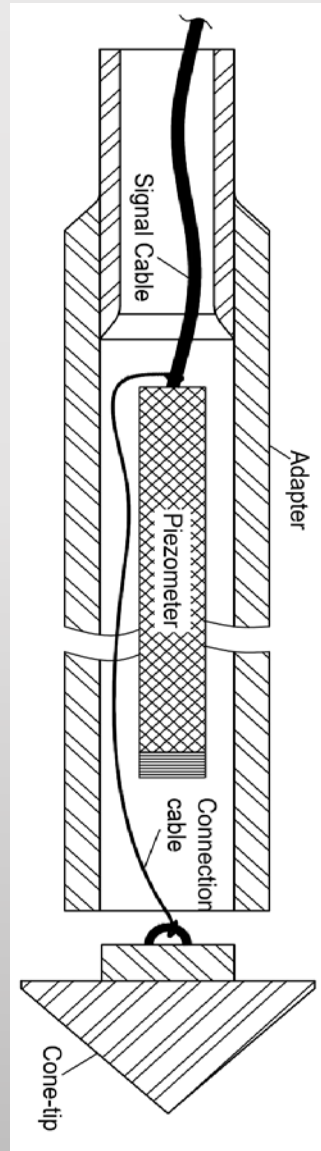

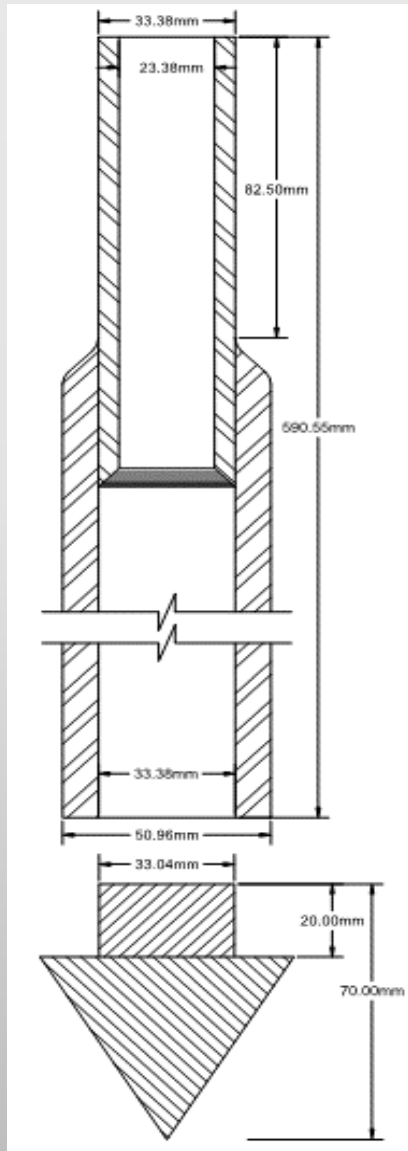Step 3: Install sensor using CPT/SPT trucks

Step 4: Connect sensors to datalogger and start logging

Process of sensor Installation

Adapter and Sacrificial cone-tip

Task 3. Development of a high-resolution groundwater recharge map

Procedures to develop the high-resolution groundwater model

1. Identify the Study Area

2. Determine the Model Domain
- Natural Boundary
- Artificial Boundary

3. Collect the Hydrogeological Data
- Land Surface Elevation
- Depth to Clay Layer
- Depth to Limestone Layer

4. Collect the Hydrological Data
- Rainfall
- Evaporation
- Transpiration
- Surface Runoff
- Depth to Water Table
- Depth to Potentiometric Level
- Lake Stage
- Stream Stage and Discharge
- Spring Discharge

5. Collect the Soil Property Data
- Hydraulic Conductivity
- Anisotropy
- Porosity
- Soil Moisture Content
- Infiltration Capacity
- Soil Compressibility
  - Specific Yield
  - Specific Storage

6. Determine the Simulation Code

7. Build Up the Conceptual Model

8. Convert the Conceptual Model to Numerical Model

9. Calibrate and Validate the Numerical Model

10. Sensitivity Analysis

11. Execute the Numerical Model and Visualize the Output

Study Area

- Mt. Plymouth, FL
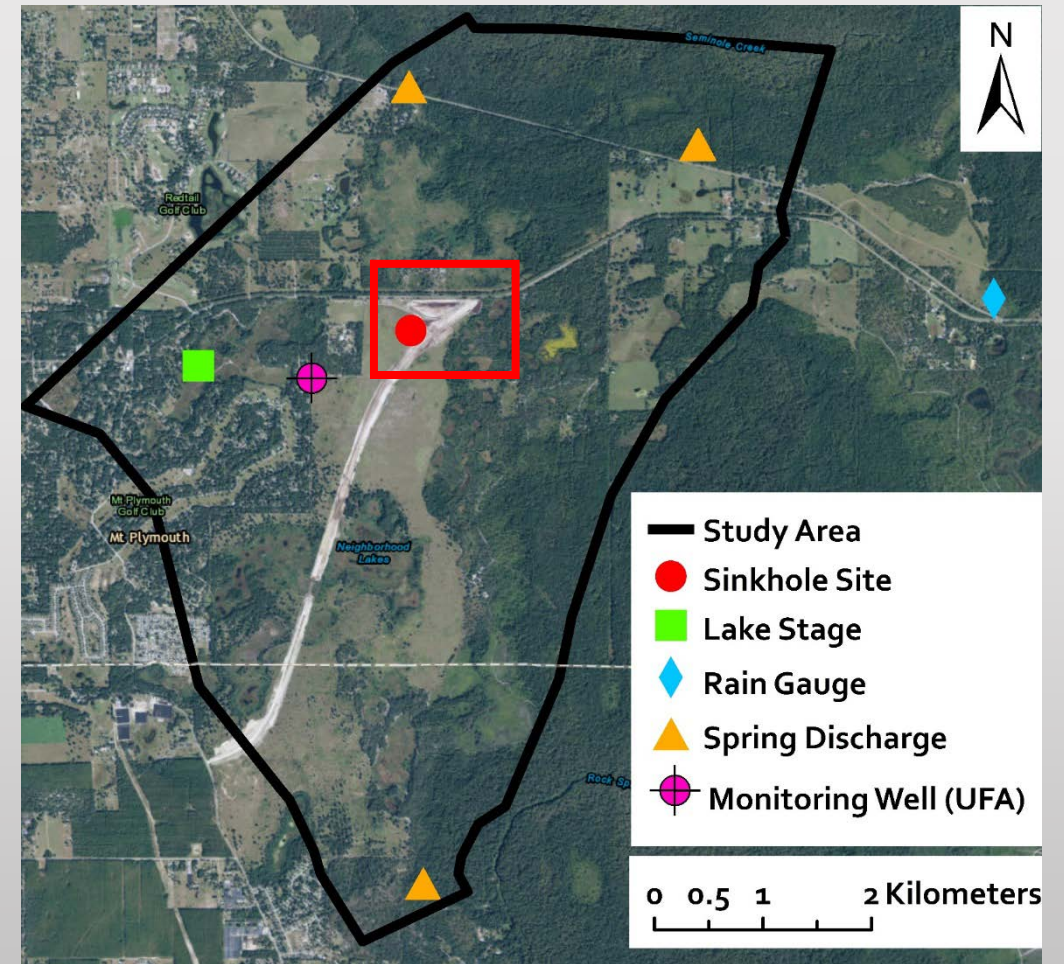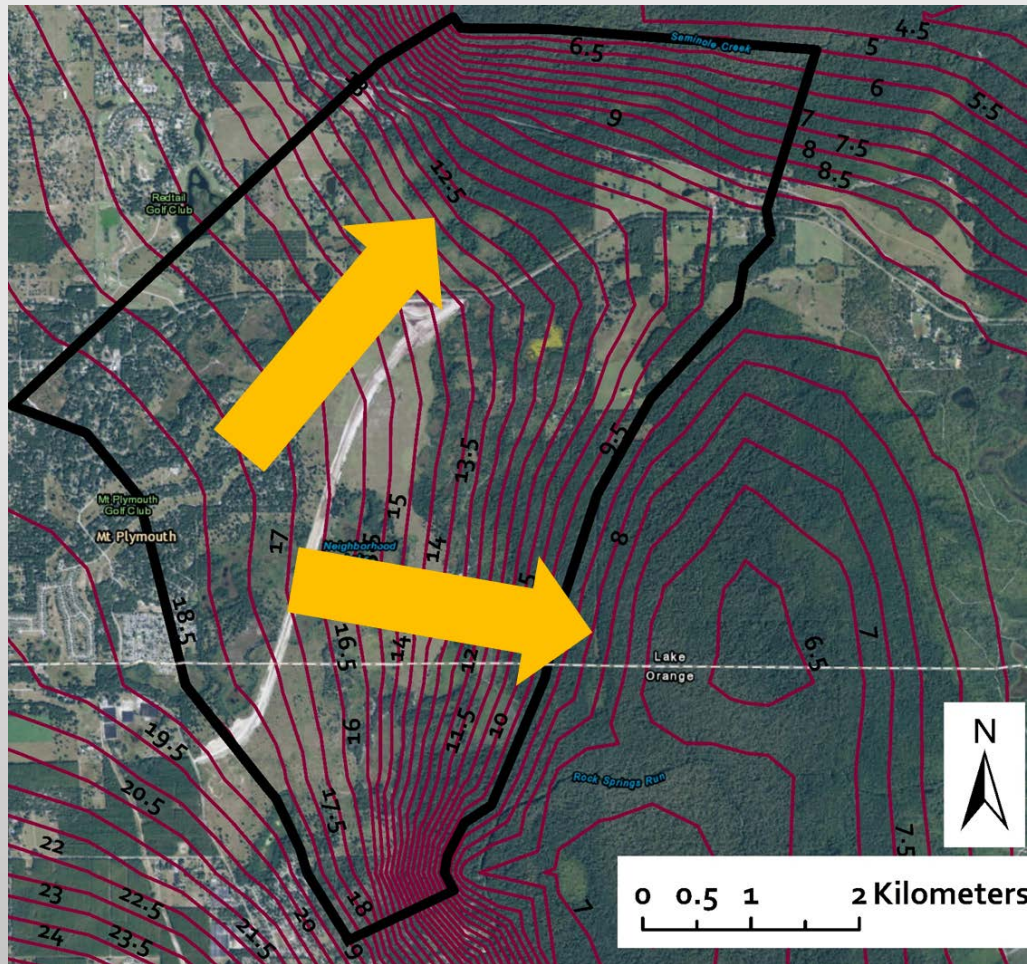 - Wekiwa Pkwy Bridge
  - Construction Site

Site 1

- Newberry, FL
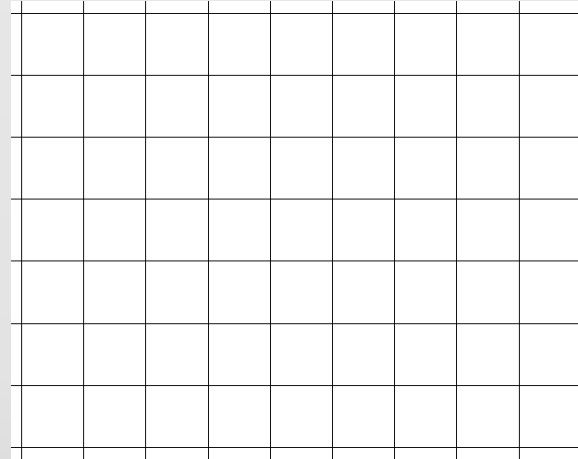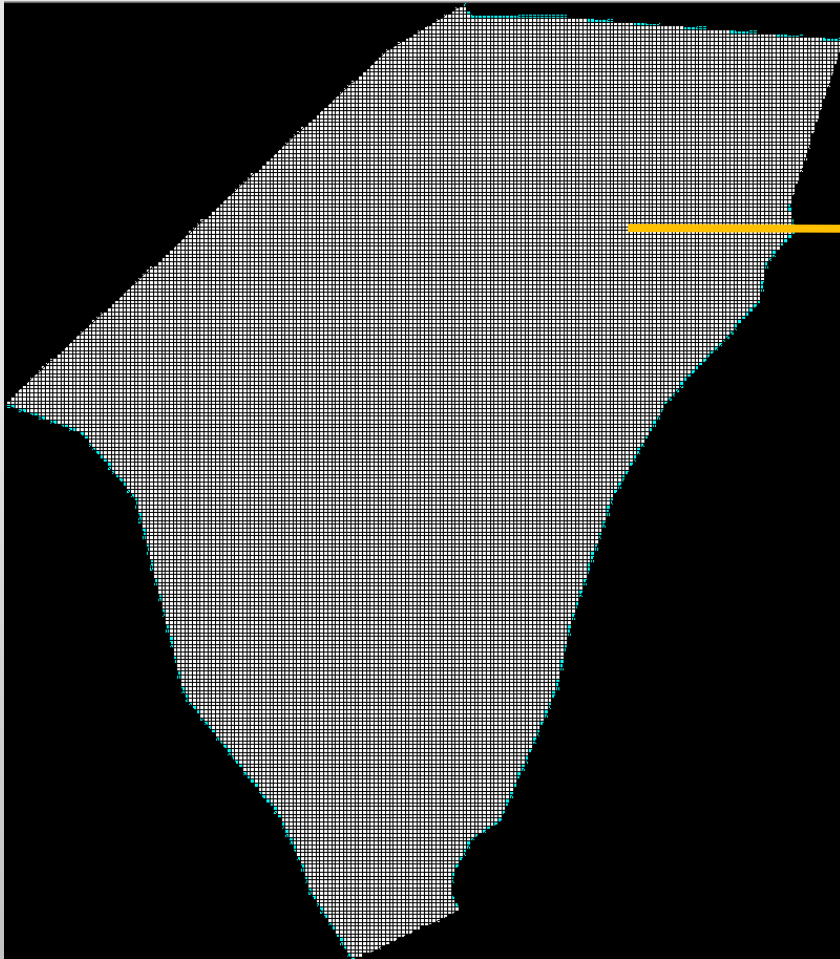 - Detention Pond

Site 2

Model Domain

Water Table Contour 2010
(SJRWMD Special Publication SJ95-SP7)

Model Horizontal Discretization

248 Rows and 218 Columns => 54,064
elements
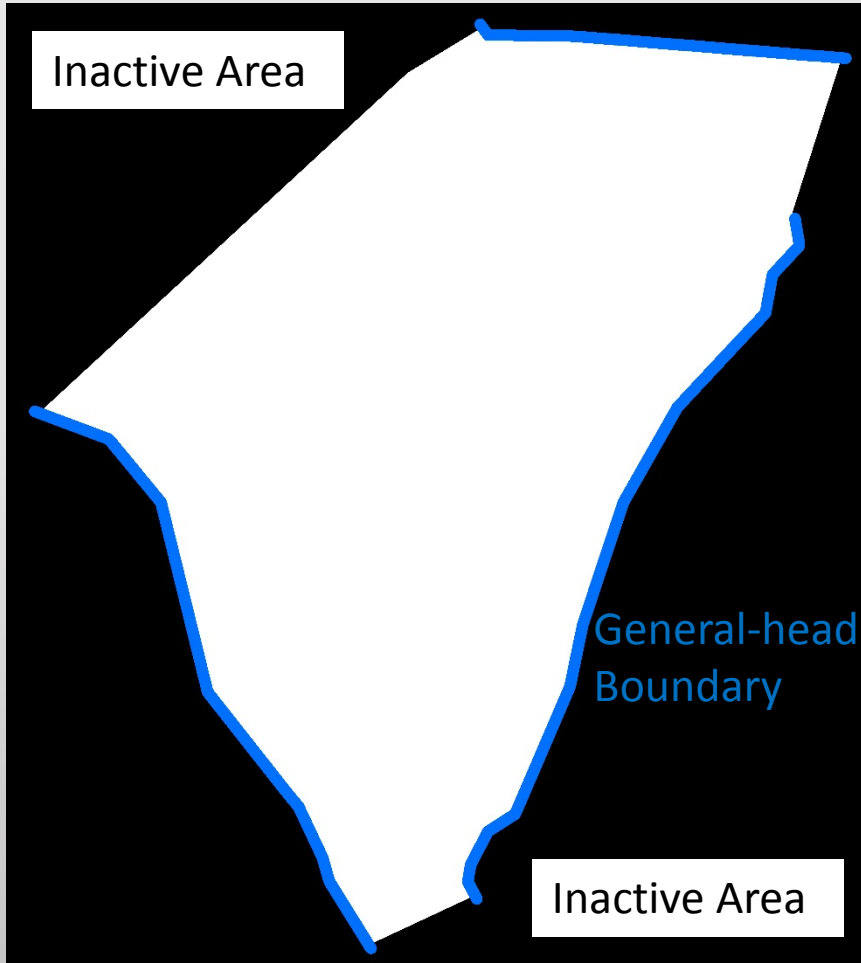
Grid Size: 30 m x 30 m

Model Vertical Discretization

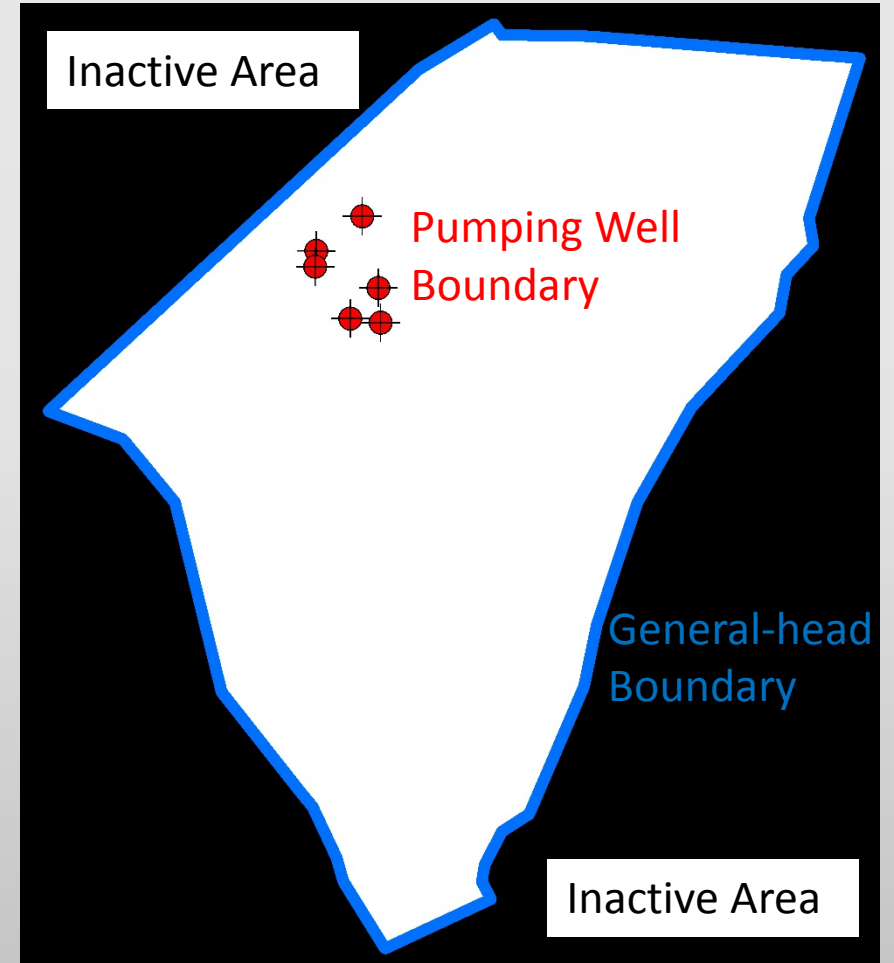Surficial Layer (Surficial Aquifer)
Primarily composed of sand

Clay Layer (Upper Confining Unit)
Primarily composed of clay

Limestone Layer (Floridan aquifer)
Primarily composed of limestone and dolostone

Boundary conditions
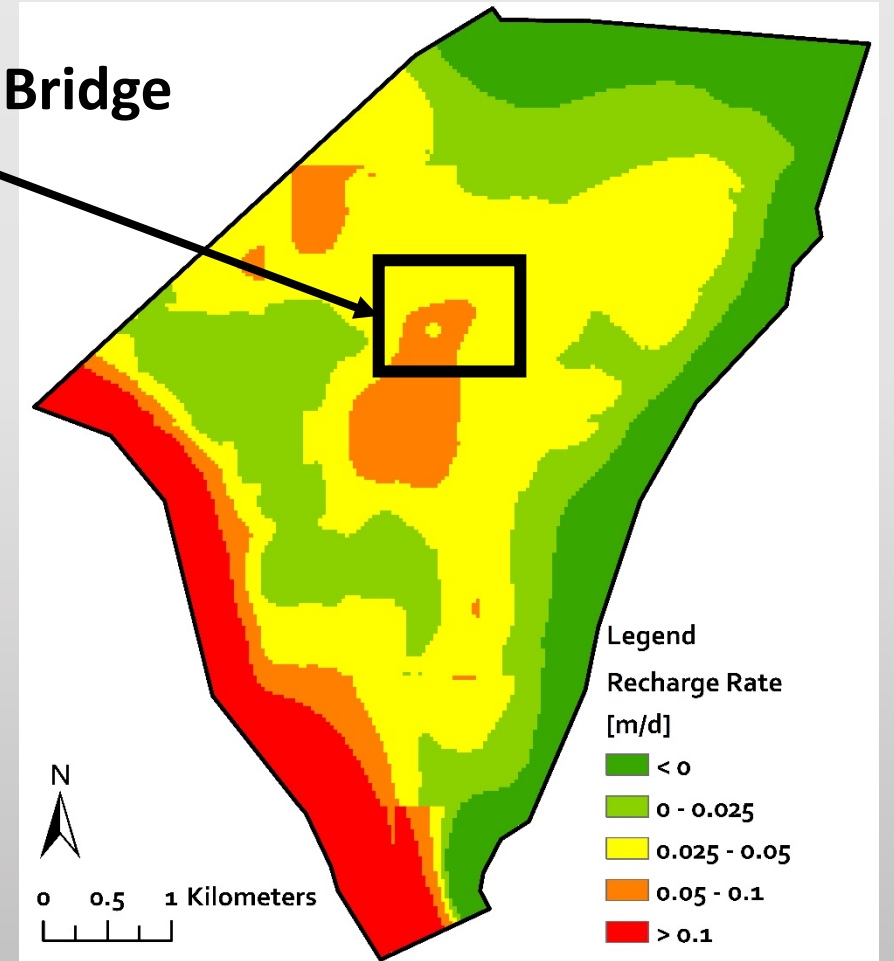

Surficial Layer

Limestone Layer

Simulation Code

- MODFLOW – 2005
  - Three-Dimensional Finite-Difference Groundwater Model
  - Most Current Release of MODFLOW
  - The Most Frequently Used Groundwater Model Tools
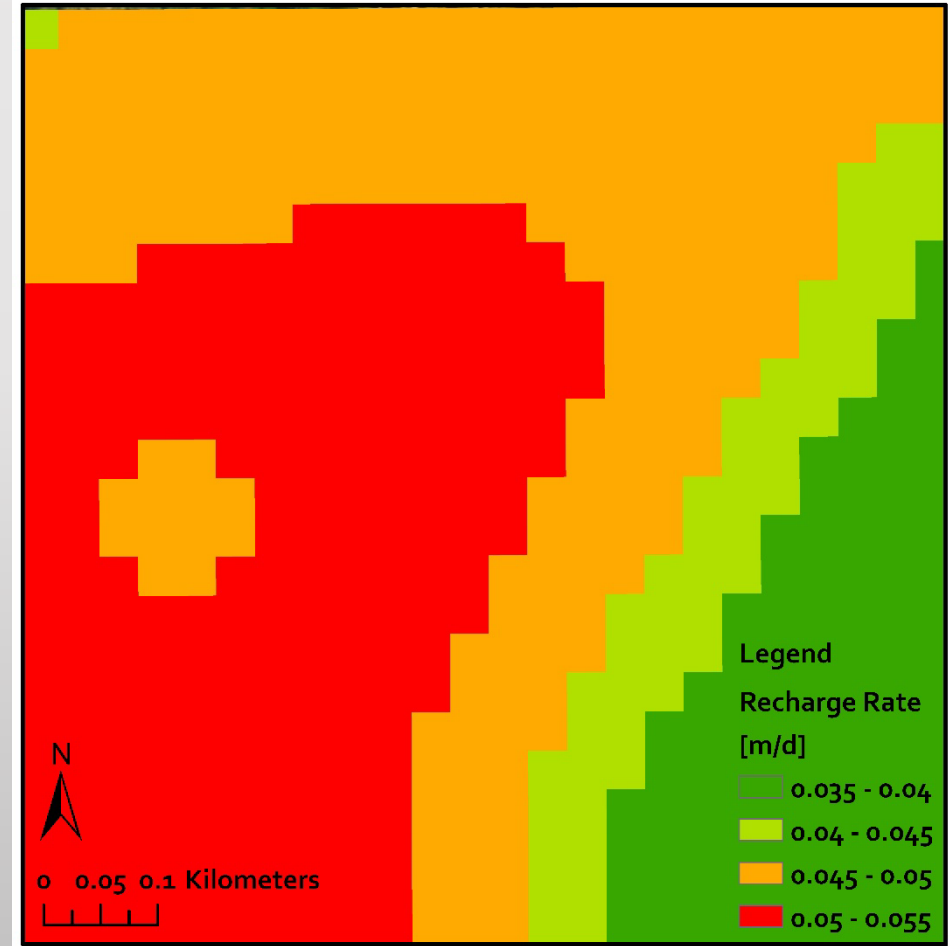 - Developed by Harbaugh (2005) From U.S. Geological Survey

Recharge

Wekiwa Pkwy Bridge

Legend

Recharge Rate [m/d]
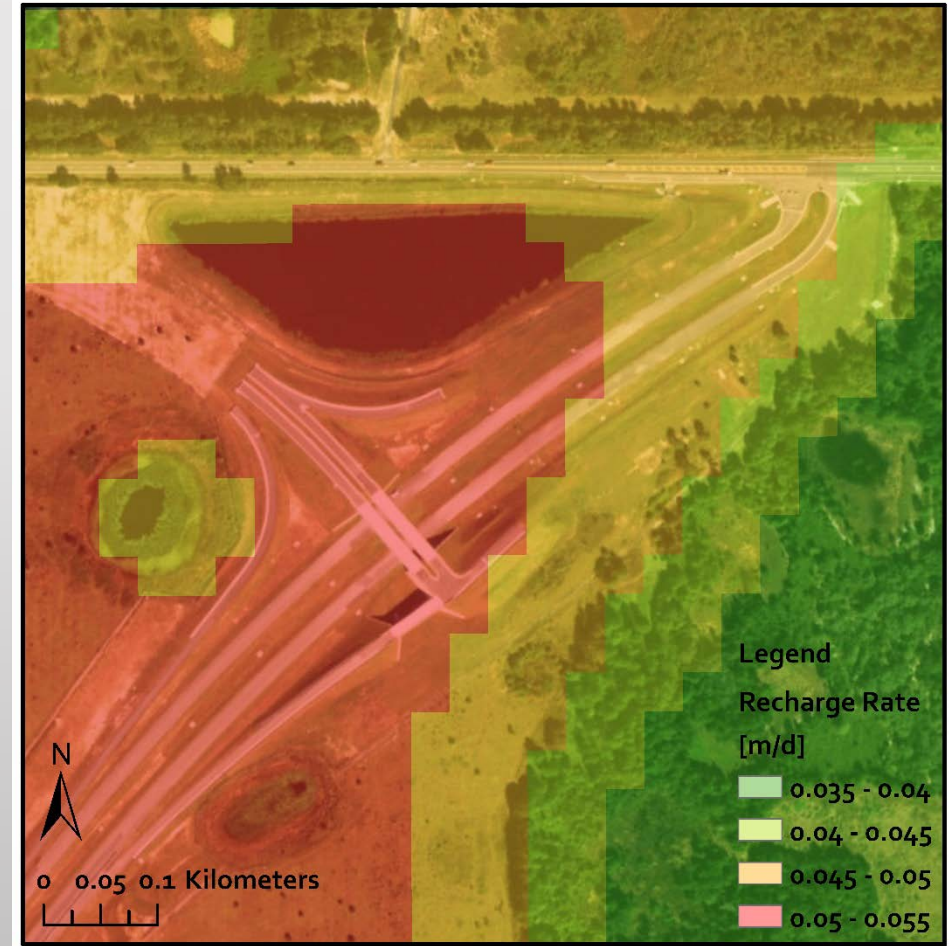
- < 0
- 0 - 0.025
- 0.025 - 0.05
- 0.05 - 0.1
- > 0.1

N

0   0.5   1 Kilometers

Recharge

Wekiwa Pkwy Bridge

Recharge

Wekiwa Pkwy Bridge

Legend
Recharge Rate [m/d]
0.035 - 0.04
0.04 - 0.045
0.045 - 0.05
0.05 - 0.055

Future work plan

- Sinkhole risk assessment
  - Reconstruct the threshold to determine soil raveling
  - Improve the Raveling Index
  - Sinkhole stability analysis (seepage-stress FE model)
- In-situ groundwater sensing
  - Continue to install the sensors in both sites
  - Monitoring the data
- Groundwater recharge work
  - Develop the groundwater model for Newberry Pond site
  - Construct the recharge map

Acknowledgement:
Special Thanks to SMO and District 5 teams for all their drilling support thus far!

Thank you!
&
Questions?