Validation and Update of the Sinkhole Index (BDV24 TWO 977-41)

PRESENTED BY:
Ryan Shamet, Ph.D., P.E. (Co-PI) – UNF
Jiannan Chen, Ph.D. (PI) – UCF

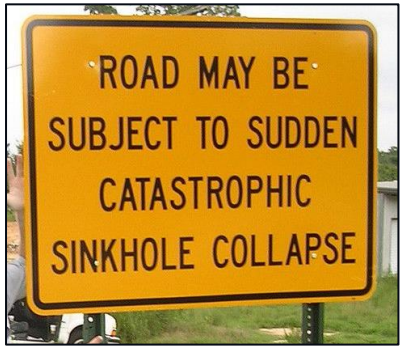
Graduate Students:
Timothy R. Copeland, Ph.D., P.E. (Ph.D. student) - UCF
Sylvia Pesha (M.S.) - UNF

August 17th, 2023

UCF

Outline

- Technical Refresher
- Brief Project Overview
  - Benefits
  - Objectives
  - Scope
- New and Improved Data!
- Validation of Analysis Tools
- What's **Next**

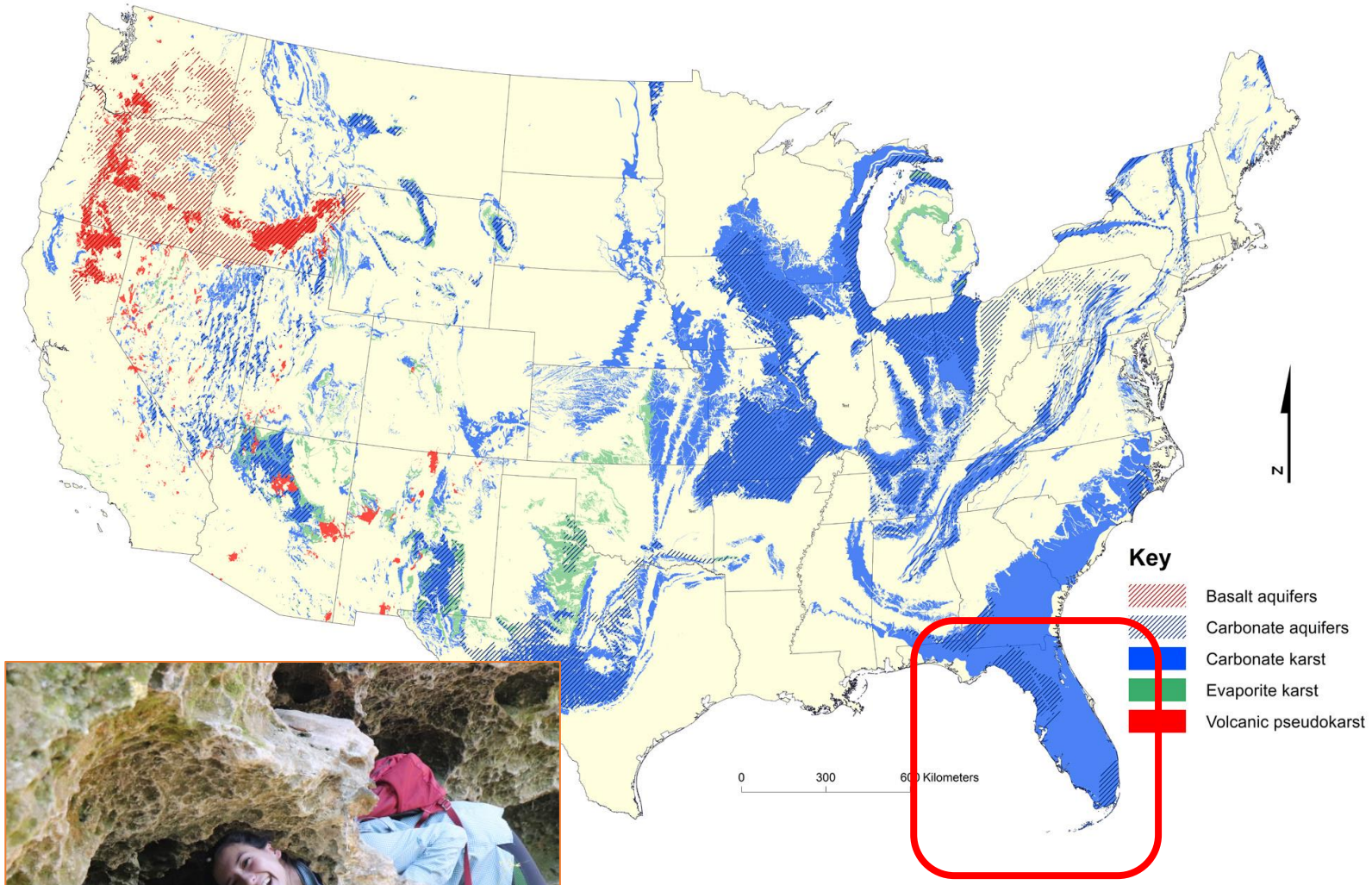


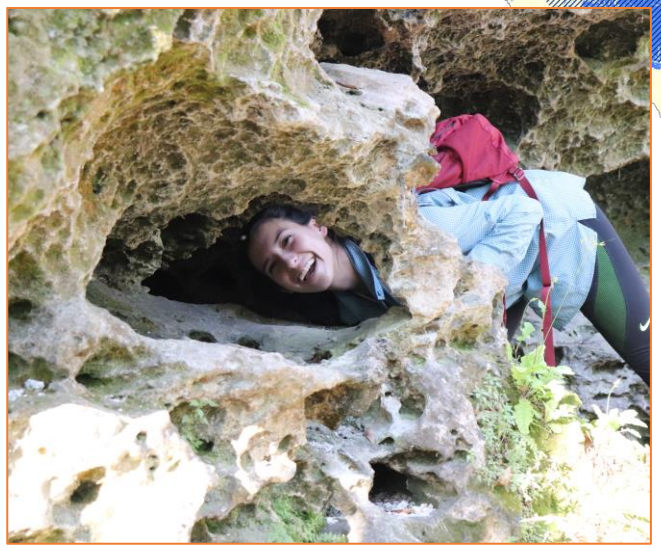
Karst:

Landscape developed by the dissolution of sediment and rocks.

“Eogenetic” karst:

- *youngest* karst (55mya)
- Extensive primary porosity
- “undisturbed” overburden





✓ Provides clean drinking water to the state.

✗ Creates a landscape vulnerable to sinkholes.

Karst Water’s Institute: After Weary and Doctor (2014)

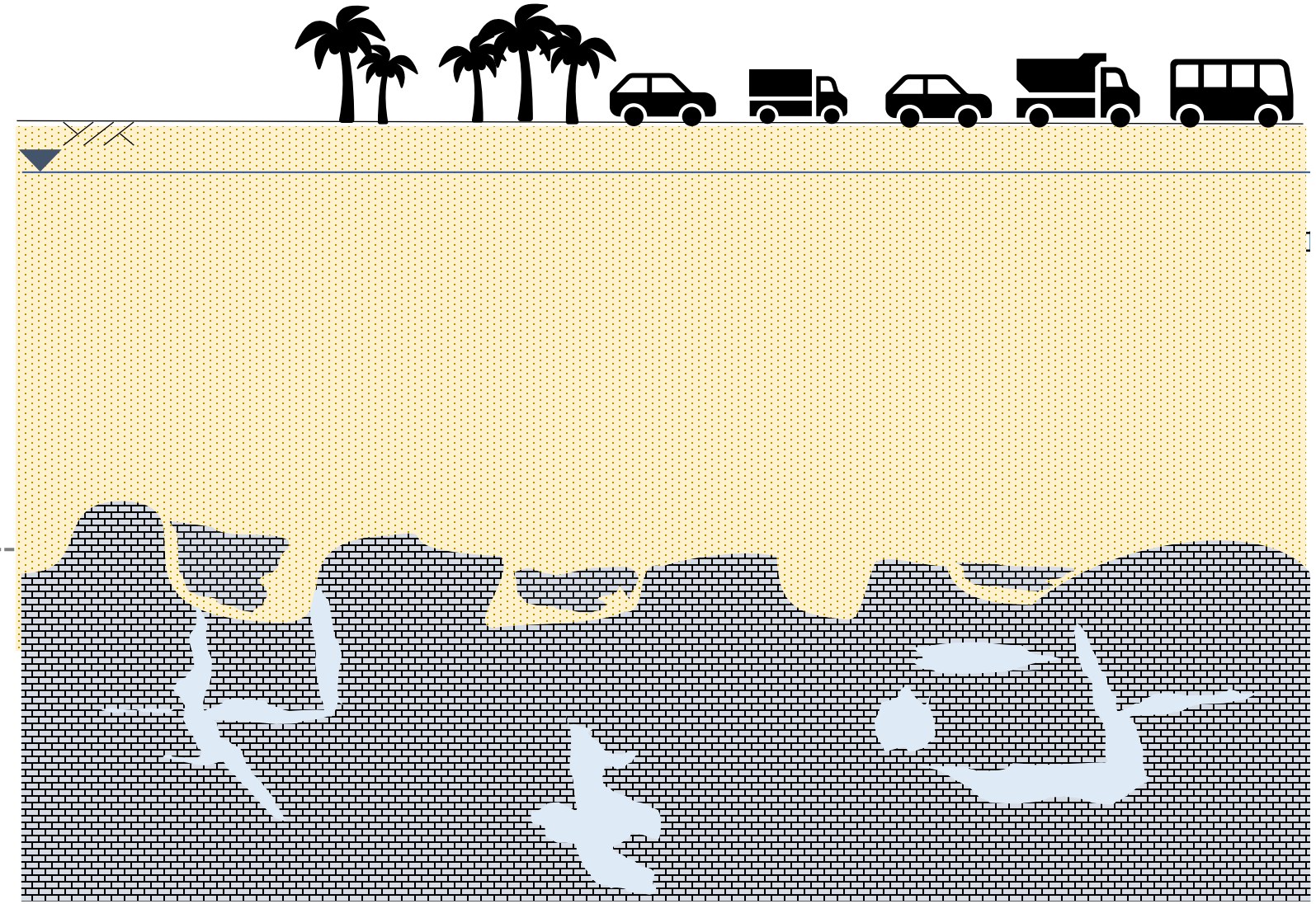
Upchurch et al. 2019: *Karst Systems of Florida*

Generalized* Florida Sinkhole Mechanism

(*VERY!)

Mixed Sands
SILTS
CLAYS
(overburden)

Cemented Silts and Sands, Limestone & Dolostone
(Floridan aquifer)



No Scale

Modified from Braunstein et al. 1988 & Florida Geological Survey, 1962

Generalized* Florida Sinkhole Mechanism

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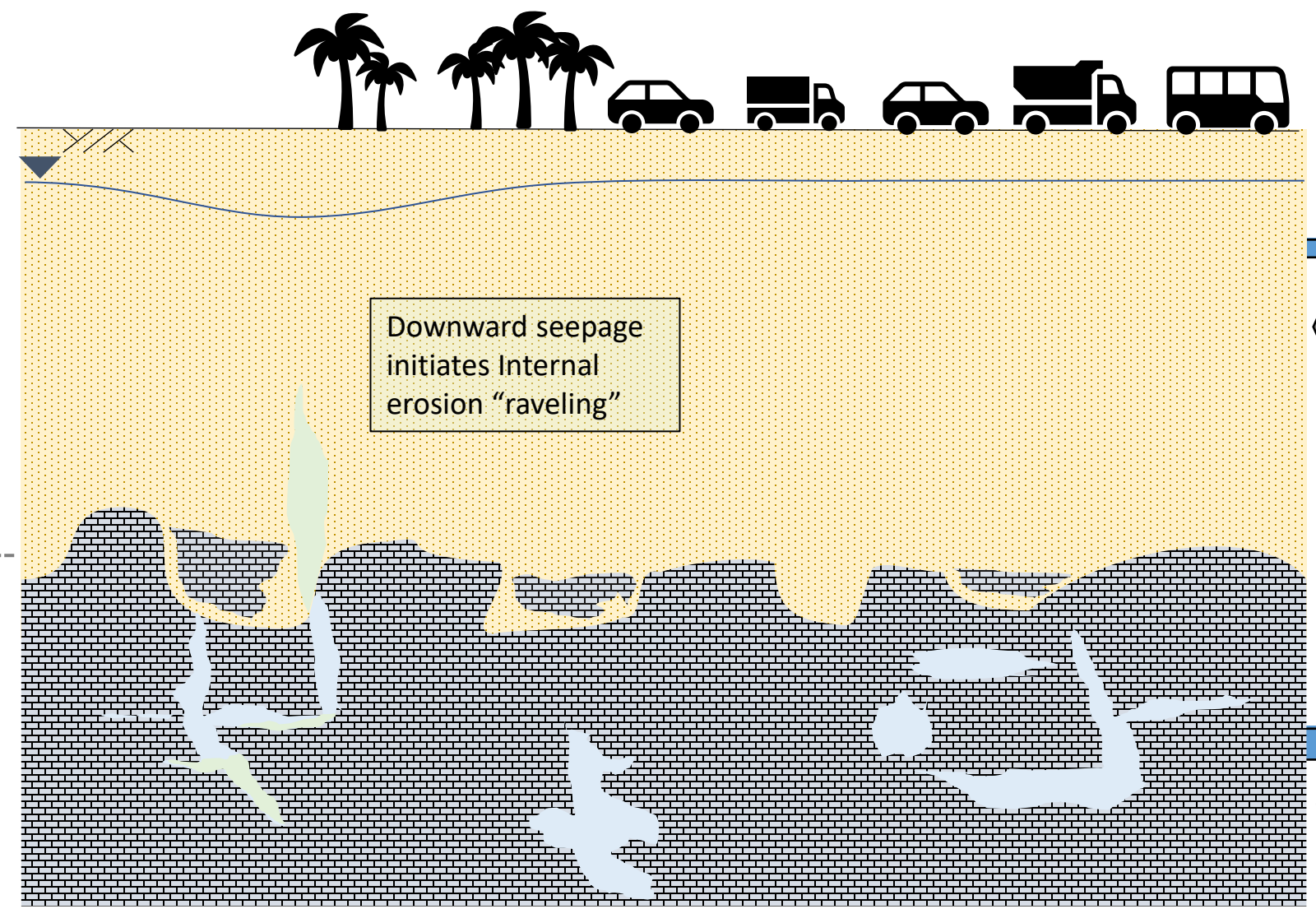

Head different between aquifers
Orlando ~ 30ft
(Wilson and Beck 1992)

Hydro-geological

SAS

FAS

SAS: surficial aquifer system
FAS: Floridan aquifer system

No Scale

Modified from Braunstein et al. 1988 & Florida Geological Survey, 1962

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Generalized* Florida Sinkhole Mechanism

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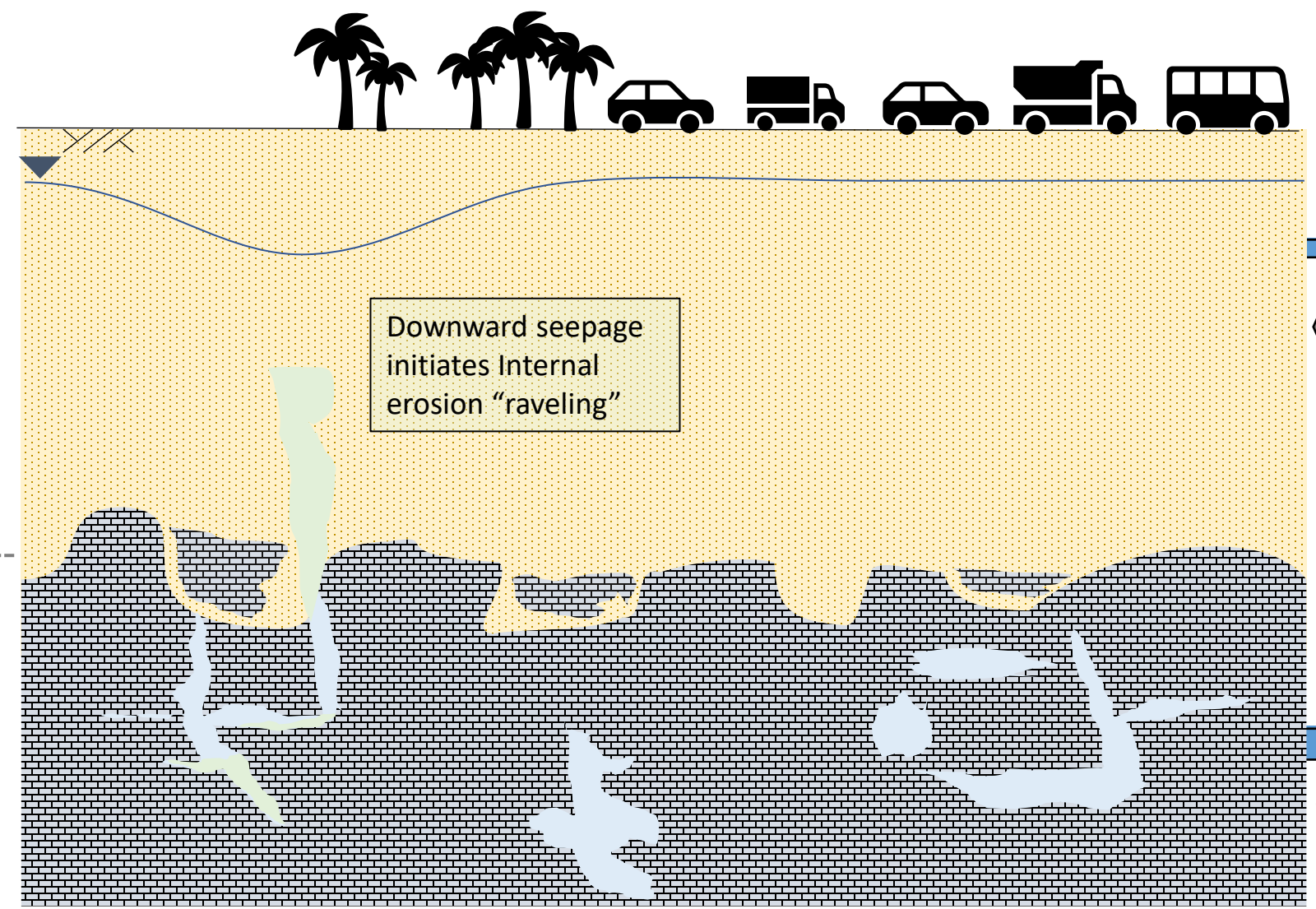

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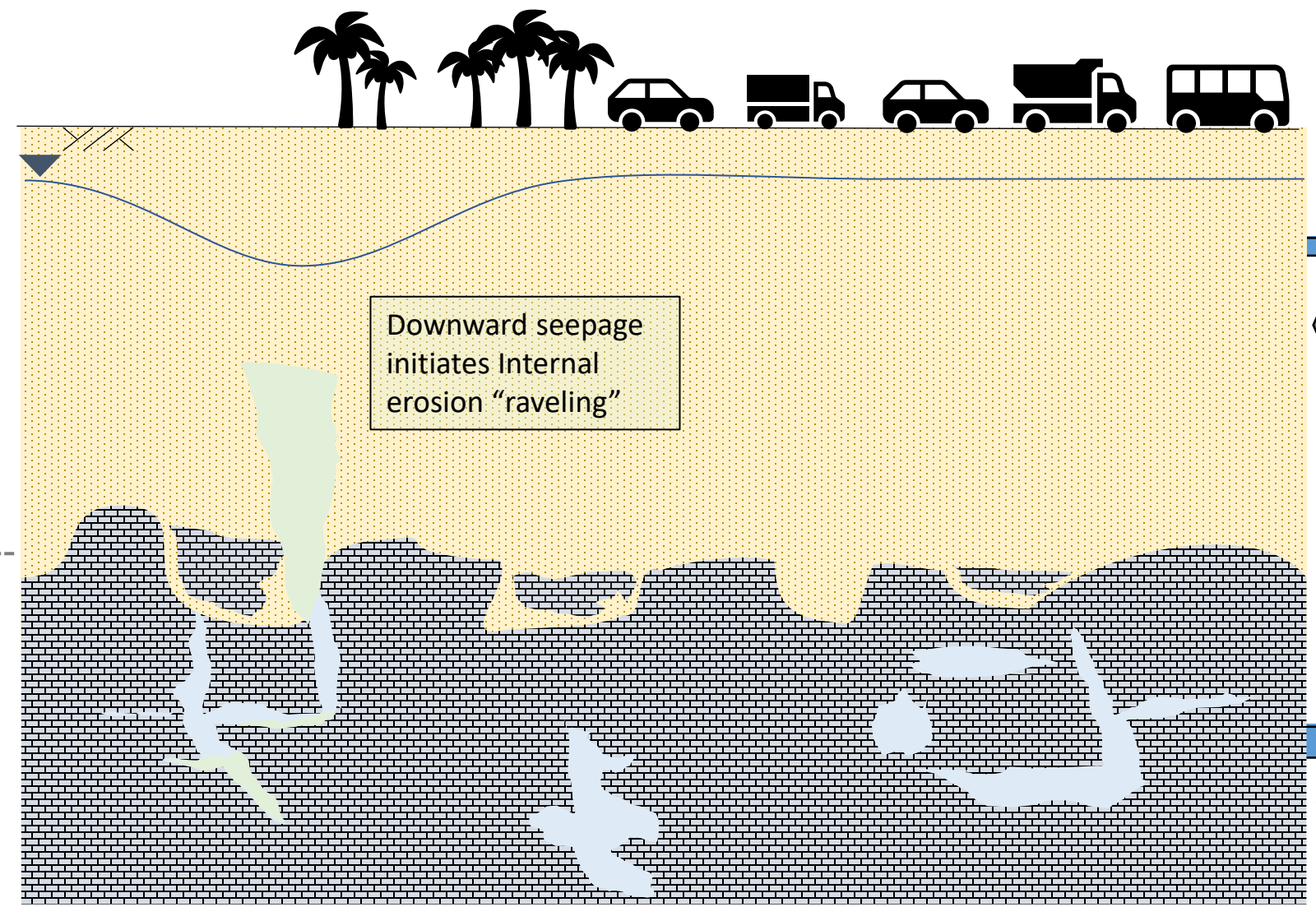

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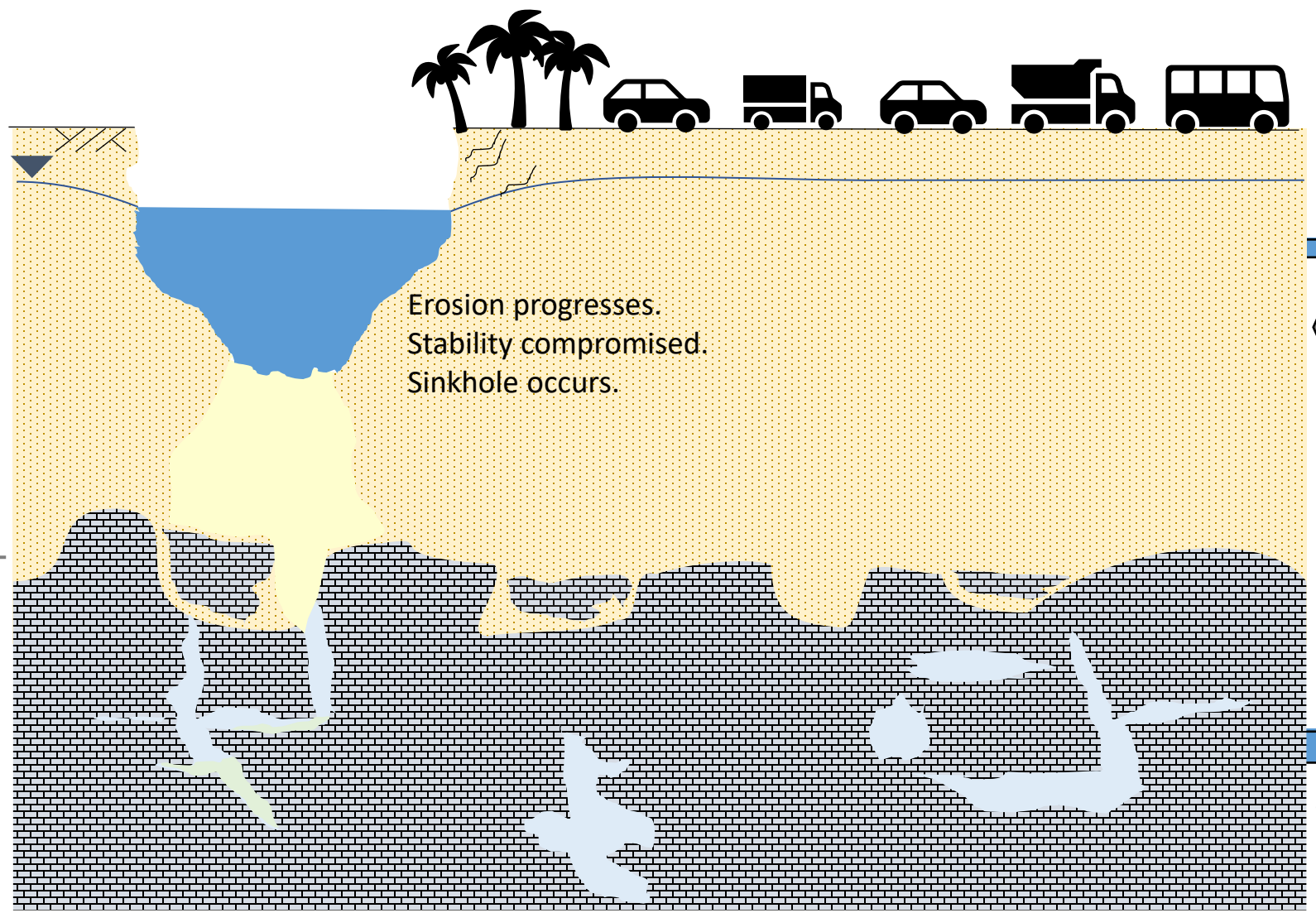

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No Scale

Modified from Braunstein et al. 1988 & Florida Geological Survey, 1962

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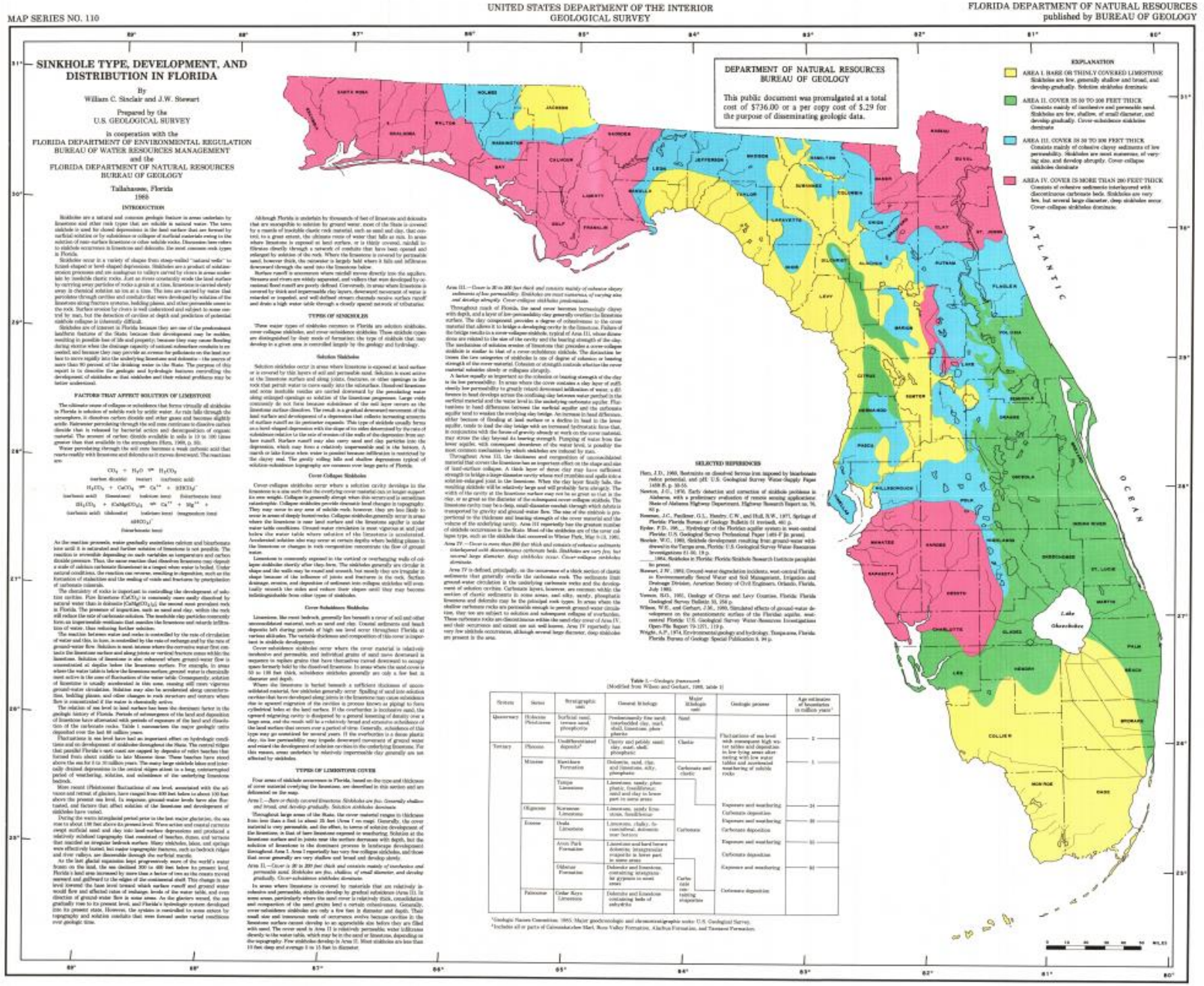
AREA I:

- Bare or Thin Overburden
- Quick forming Collapse
- “solution” type

AREA II:

- 30-200 ft Overburden
- Sandy
- Less developed macro porosity
- “Subsidence” type



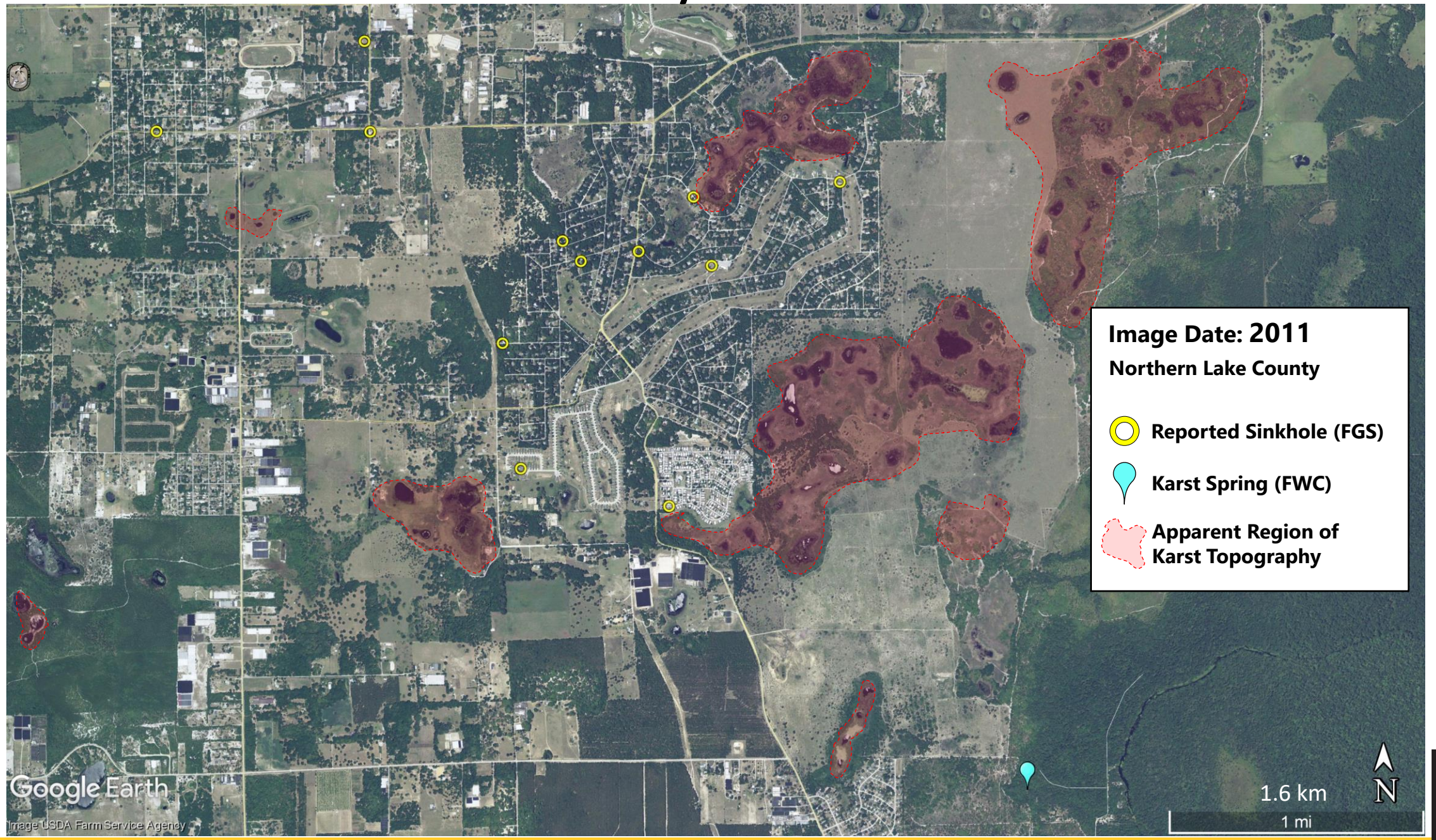
AREA III:

- 30 – 200 ft Overburden
- Mixed (cohesive)
- Highly developed macro porosity
- “Cover Collapse”

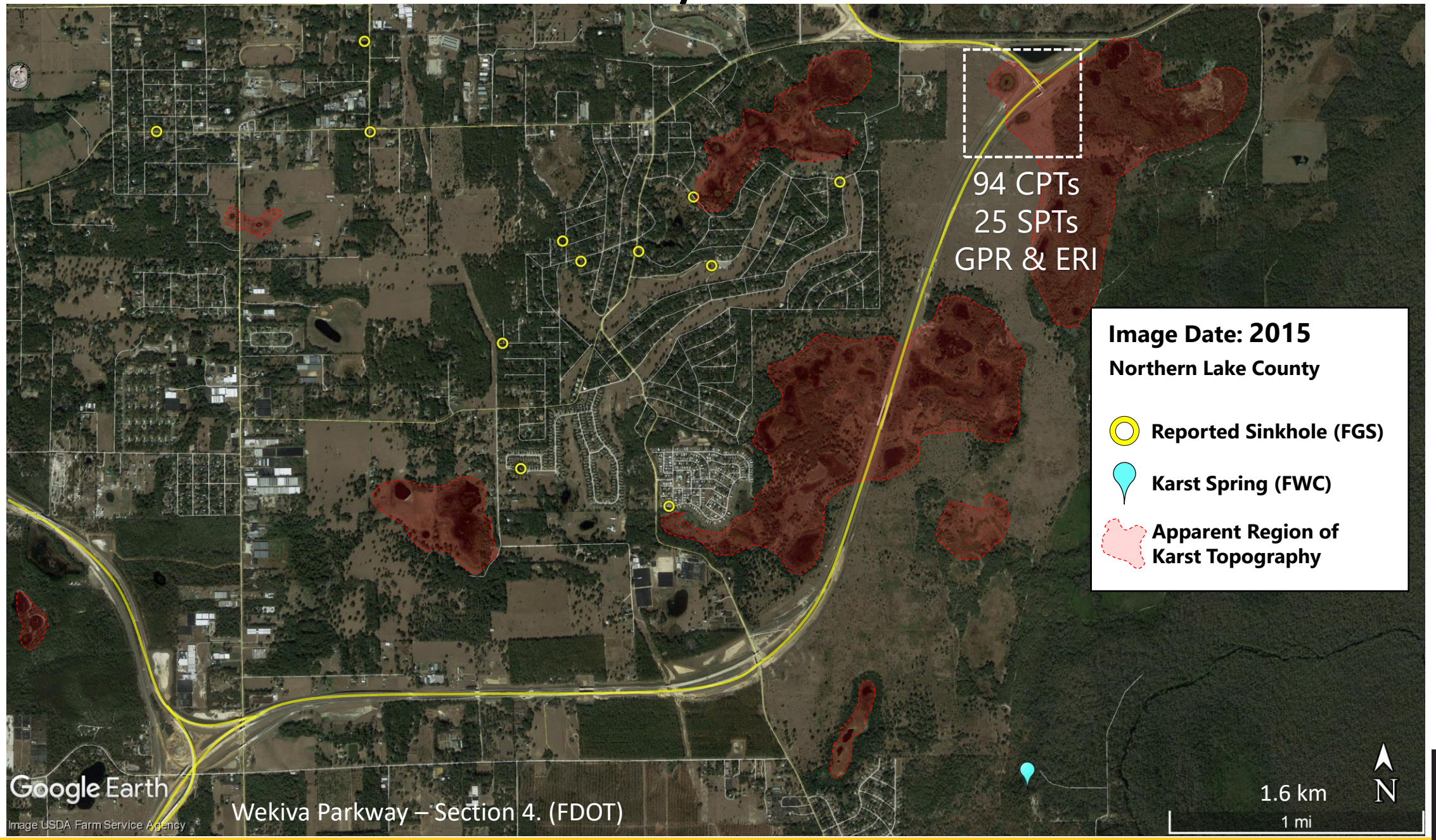
AREA IV:

- <u>DEEP</u> MIXED Overburden
- Mixed (cohesive & Rock)
- “Relic Sinks”

Karst Terrain – Area 3 – Wekiva Parkway



Karst Terrain – Area 3 – Wekiva Parkway



“Assessment” Components

Sinkhole contributing factors: (Upchurch 2019)

- Cover Material
- Internal erosion (raveling) development
- Aquifer Potentials
- Rainfall
- Human Activities

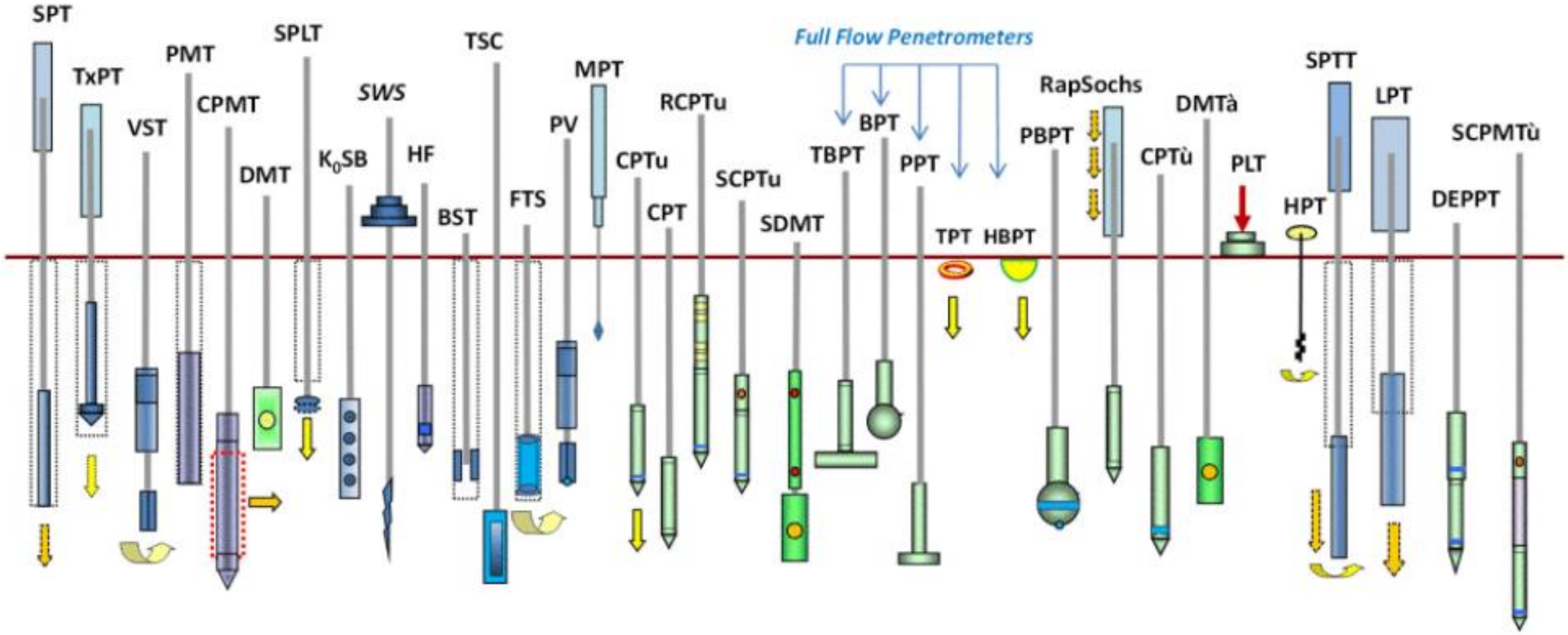
During typical subsurface investigation in karst:

- Identify raveled (effected) soils
- Characterize the raveling severity
- Quantify the vulnerability to sinkhole

Objective:

Develop Subsurface characterization tools for better decision making in Florida’s karst

Subsurface Investigation Geotechnical Techniques



Courtesy of Dr. Paul Mayne

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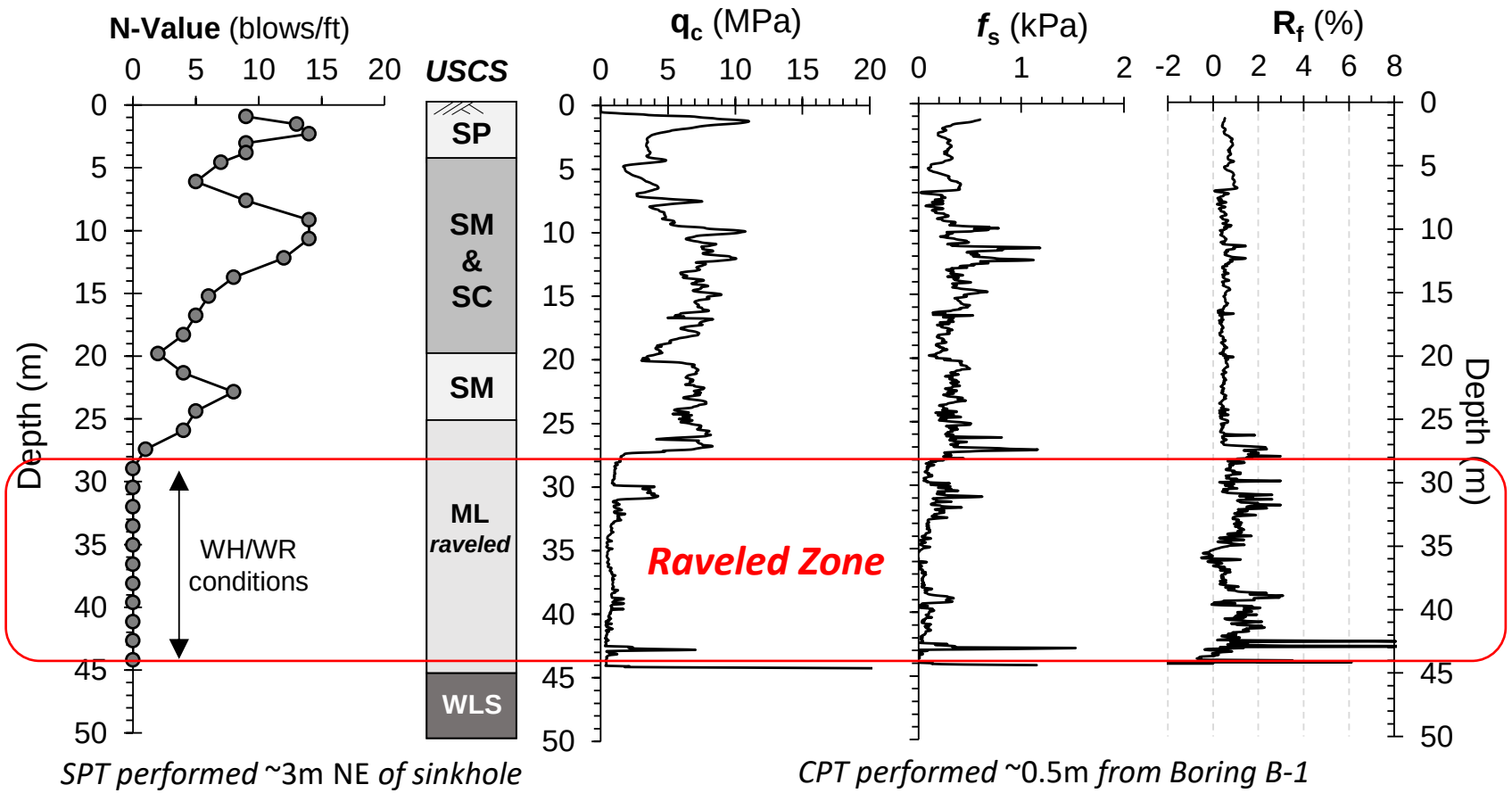
CPT and SPT

CPT

SPT



Cone penetration test (**CPT**): **0.16 ft** [60ft ~ > **1 hr**]

Standard penetration test (**SPT**): **2.5 ft** [60ft ~ **half day**]

Important for ground verification

2018 : BDV24-977-17

Final Report

FDOT Contract NO.: BDV24-977-17

DEVELOPMENT OF A SINKHOLE RISK EVALUATION PROGRAM

Prepared by:

Boo Hyun Nam, Ph.D. (Principal Investigator)
Ryan Shamet, M.S., E.I.
Moataz Soliman, M.S.
Dingbao Wang, Ph.D.
Hae-Bum Yun, Ph.D.

Department of Civil, Environmental, and Construction Engineering
University of Central Florida
12800 Pegasus Drive, 442B, Engineering II
Orlando, FL 32816

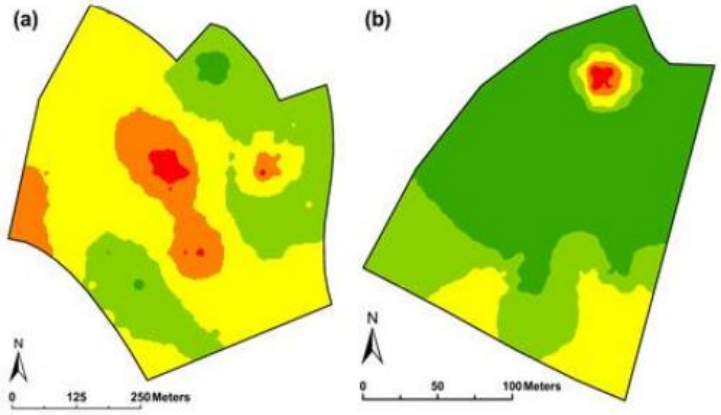
Developed for the

FDOT Florida Department of TRANSPORTATION

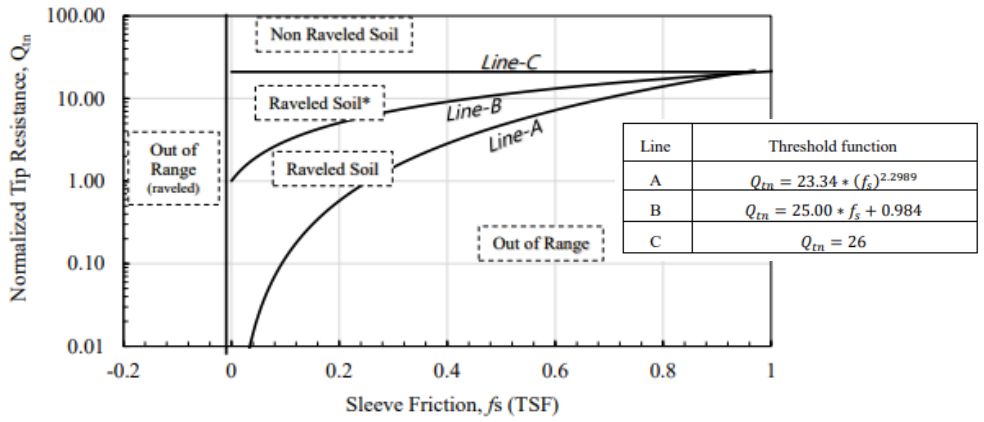
Project Manager: David Horhota, P.E., Ph.D.

June 2018

Groundwater Monitoring & Sinkhole Risk Model (MODFLOW)



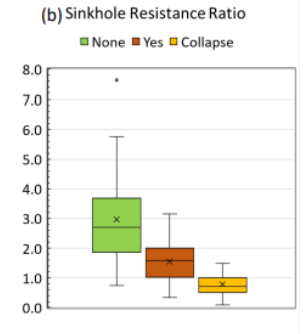
CPT - Based Raveling Chart



Line	Threshold function
A	$Q_{tn} = 23.34 * (f_s)^{2.2989}$
B	$Q_{tn} = 25.00 * f_s + 0.984$
C	$Q_{tn} = 26$

CPT point based vulnerability INDEX

$$SRR = \left(\frac{q_{over} + q_{ravel}}{100 * \sigma'_{vo}}\right)\left(\frac{t_{over}}{t_{ravel}}\right)$$



3 Sinkhole Sites (Central Florida)

Sinkhole Index

Sinkhole Resistance Ratio (SRR)

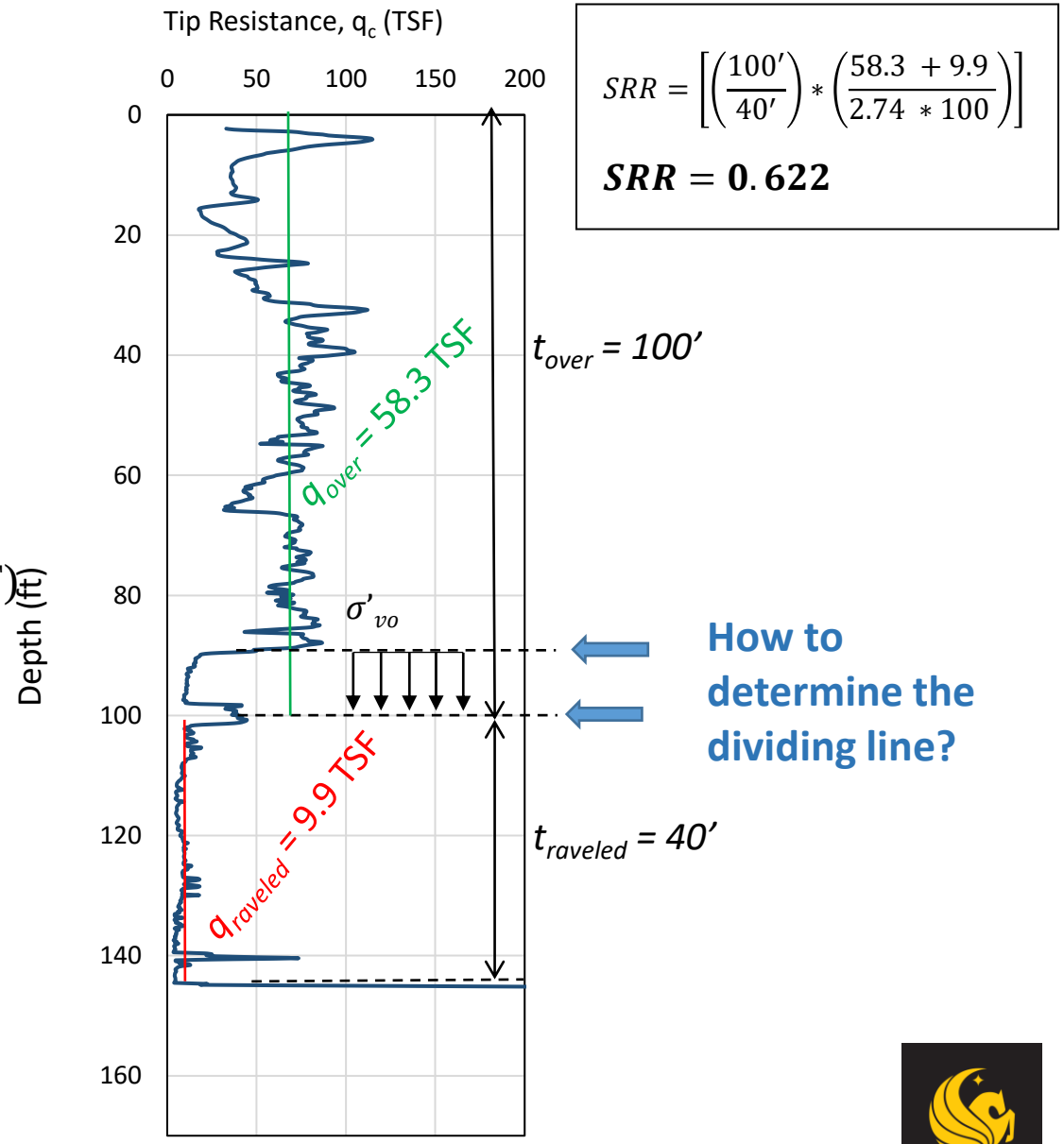
$$\text{SRR} = \left(\frac{q_{over} + q_{ravel}}{100 * \sigma'_{vo}}\right)\left(\frac{t_{over}}{t_{ravel}}\right)$$

Where:

q_{over} = average q_t measured in overburden soils (TSF)
q_{ravel} = average q_t measured in Raveled soils (TSF)
σ'_{vo} = effective vertical stress at depth raveled soils start (TSF)
t_{over} = thickness of overburden (ft)
t_{ravel} = thickness of raveled zone (ft)
q_t = Corrected cone tip resistance (corrected for p.w.p)

Effective stress calculated using estimated unit weight: (Robertson and Cabal 2010):

$$\gamma_{sat} = \gamma_w[0.27[\log(R_f)] + 0.36\left[\log\left(\frac{q_c}{P_a}\right)\right] + 1.236] * \frac{G_s}{2.65}$$

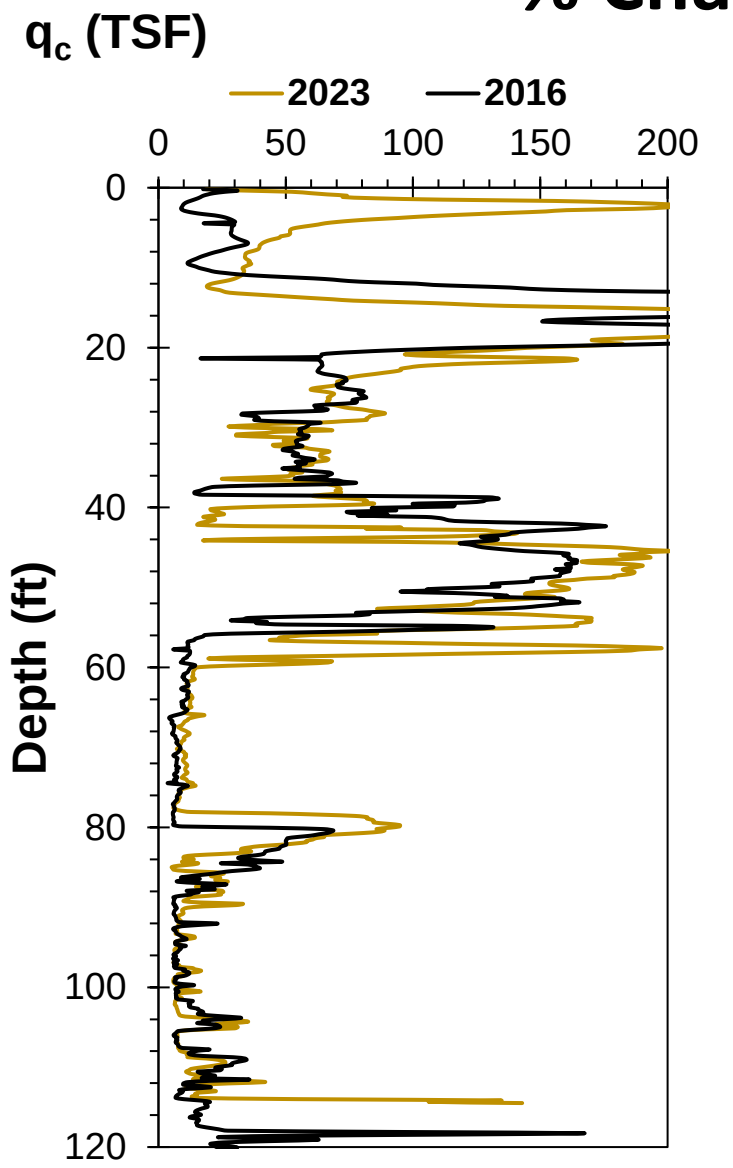


$$SRR = \left[\left(\frac{100'}{40'}\right) * \left(\frac{58.3 + 9.9}{2.74 * 100}\right)\right]$$

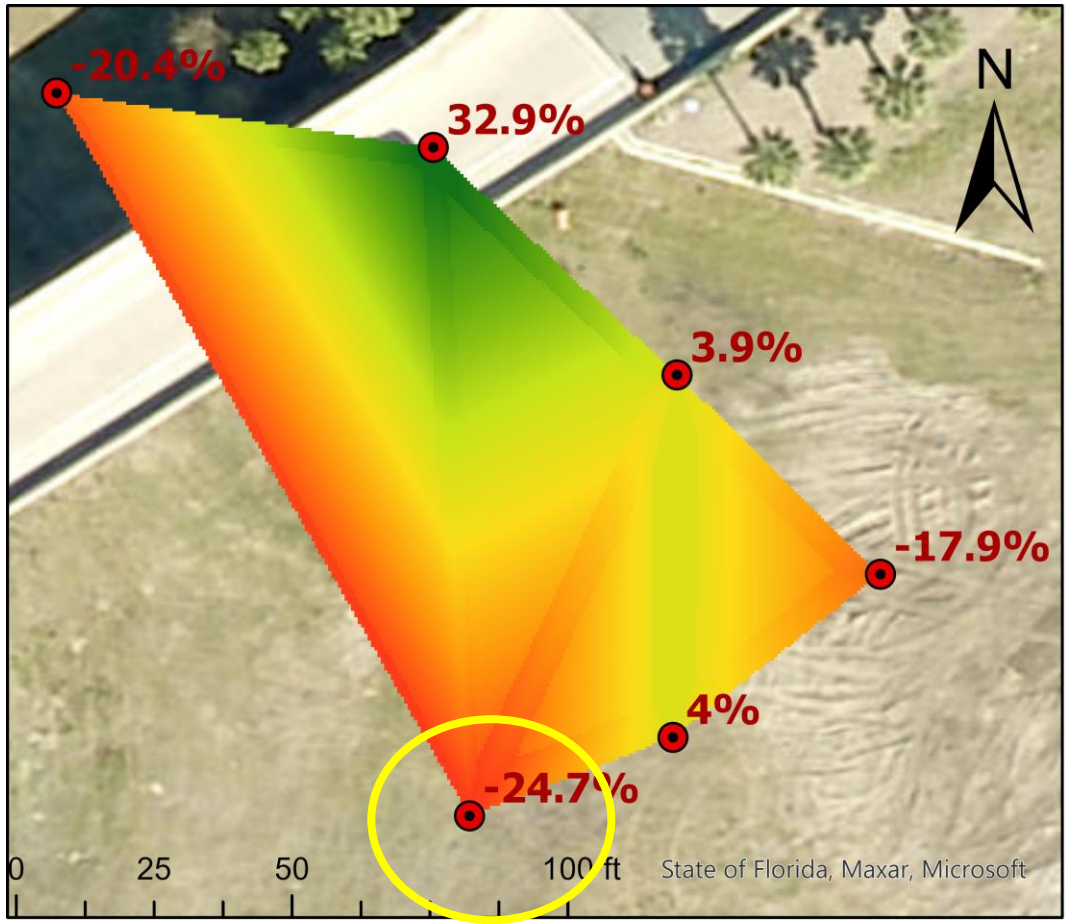
$$\boldsymbol{SRR = 0.622}$$

Sinkhole Index

% Change over time



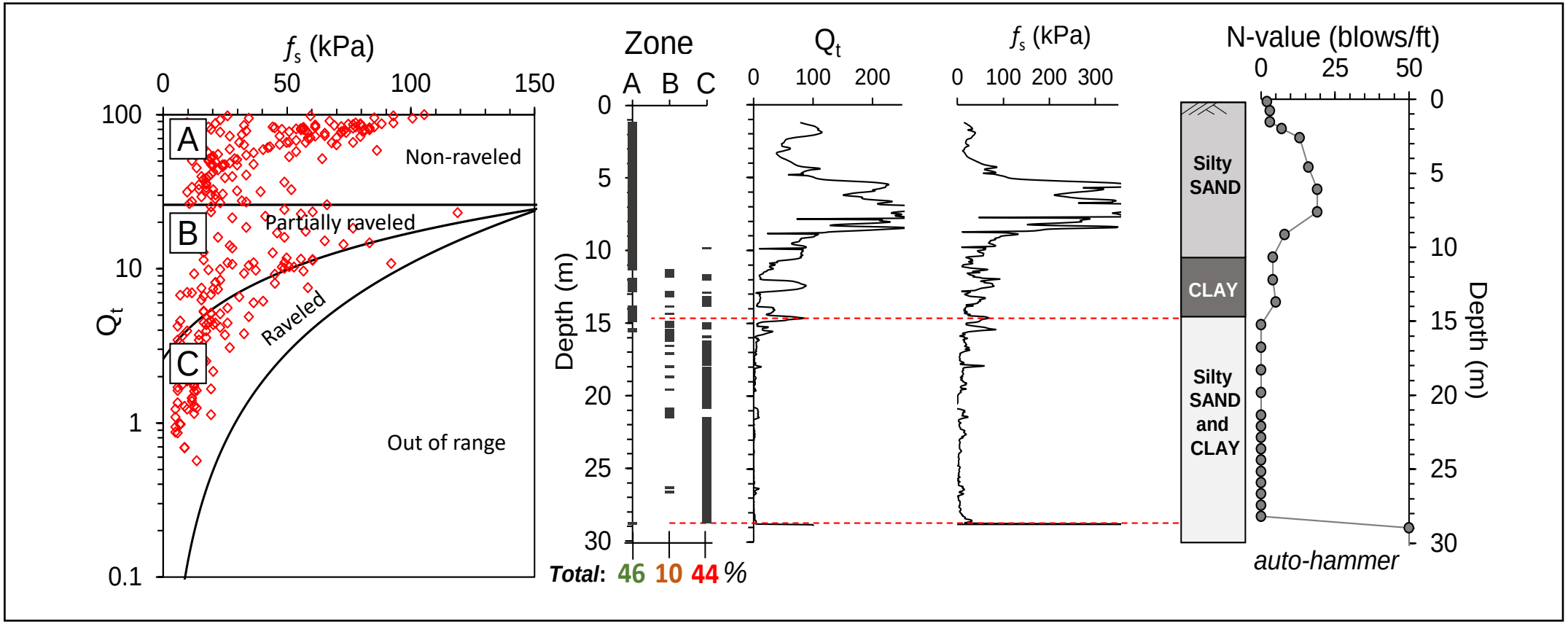
More severe SRR due to decrease in $q_{c,over}$



CPT-based Raveling Chart

Application

- Identify sinkhole raveling and severity (?)
- Identify the depth of raveled zone



Project Background

- The **current index and chart** were developed based on the limited number of datasets involving THREE sinkhole sites with only Cypresshead geological formation (West-NW Orland).
- Both index and chart need to be **validated** with sufficient number of datasets collected throughout the state of Florida, particularly with different geological formations (e.g., Ocala LS/Hawthorn formation) and geotechnical conditions.
- In addition, the criterion to determine the dividing line of raveled and overburden zone is unclear and subjective.

Project Objectives

1) **Validate** the sinkhole index and chart through updated dataset & both large-scale sinkhole testing to simulate various geologic conditions.
2) **Develop** a set of **criteria** and **guidance** for the sinkhole index and vulnerability assessment,
3) **Evaluate** the raveling progression and the correlation between the sinkhole index and grout-take volume.





Project Scope

Task 1 – Data Collection and Case Studies

Task 2 – Validation and update of the sinkhole index and chart

Task 3 – Set-up of the Large-Scale Soil Box (LSSB)

Task 4 – Sinkhole physical test using the LSSB

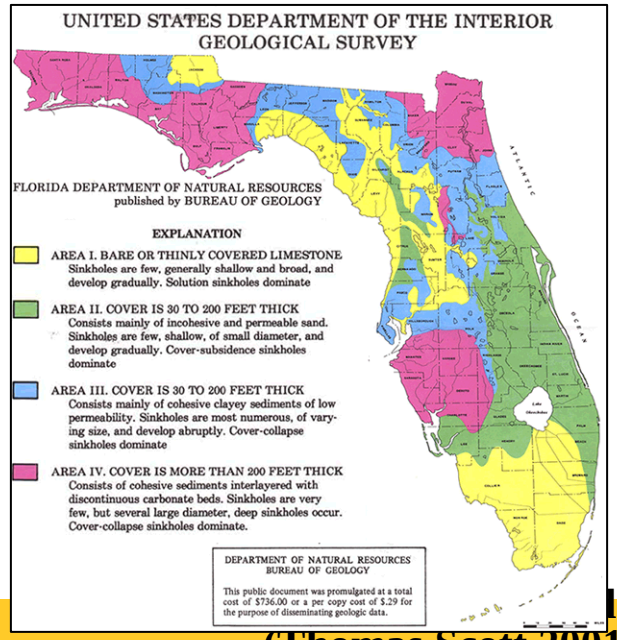
Task 5 – Establish the severity criteria of the sinkhole index and correlate the index to the grout-take volume

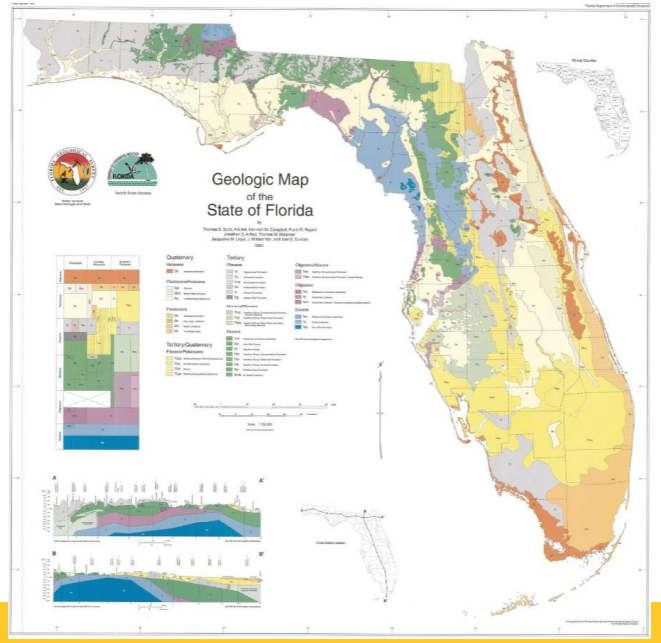
Task 6 – Draft Report and Closeout Teleconference

Task 7 – Final Report

Task 1: Data Collection Summary

- **49 sites** (47 contained the usable CPT data)
- **237** total CPTs
  - Number of CPTs per site varied from 1 to 13
- **36 sites** included detailed layout
- Surficial Geology Unit determined from USGS Geological Map



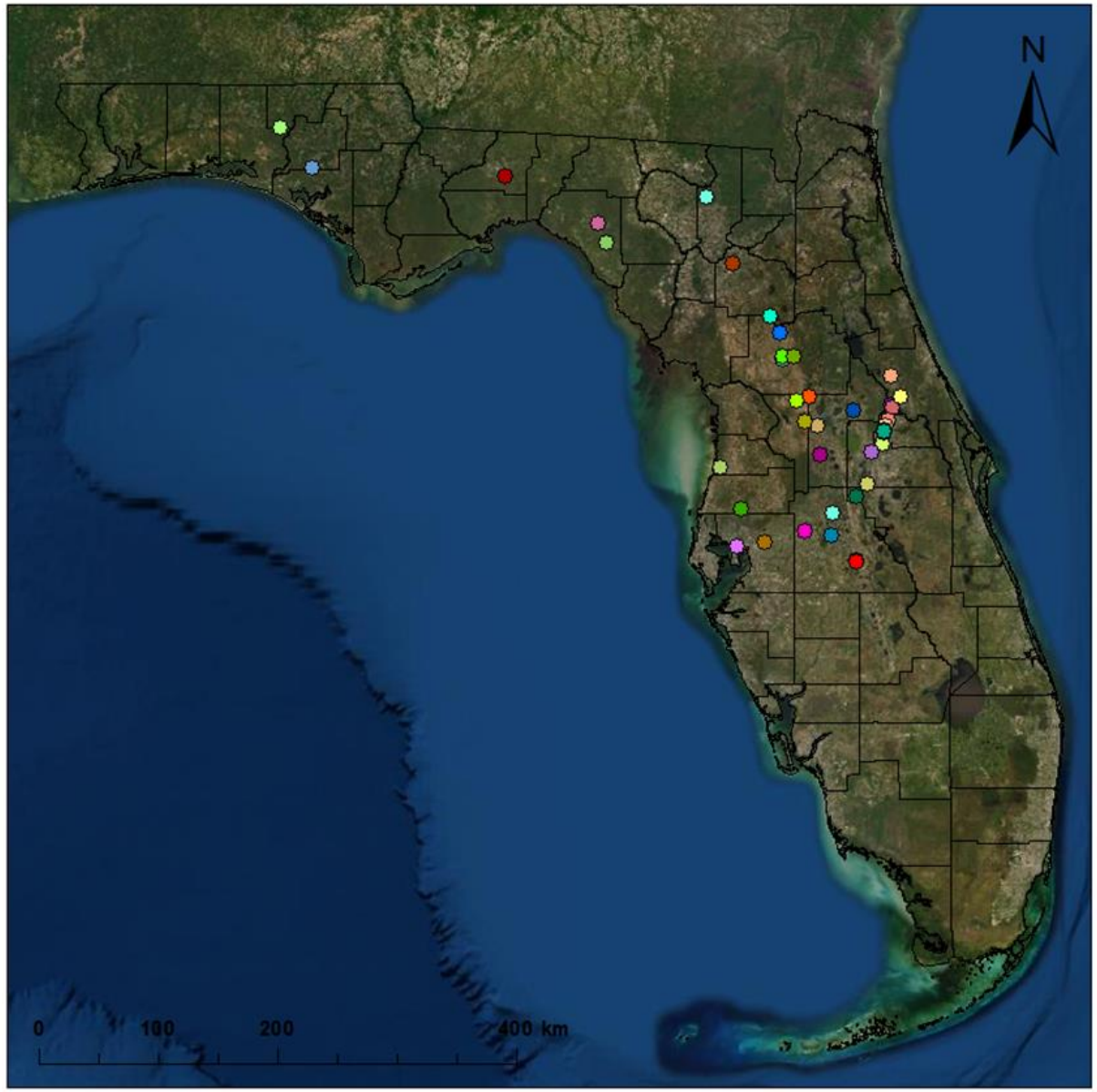


(Thomas Scott 2001)

District	Site Info/File Name	Number of CPTs	Surficial Geology Unit
1	I-4 Rest Area Polk County 2011	3	Reworked Cypress (Tquc)/(Tc)
	Recker Highway 2005	1	Cypresshead (tc)
	US 27 Polk County 2010 North	2	Cypresshead (Tc)
	US 27 Polk County 2010 South	4	Reworked Cypresshead (Tquc)
	US 92 Memorial Cracked CP 2012	3	Cypresshead (Tc)
2	I-10 Columbia County 2007	1	Hawthorne. grp (Tht)/Beach(Qbd)
	I-75 Northbound Depression Alachua 2005	4	Ocala LS/Hawthorne (Thc)
	I-75 Southbound Depression Alachua 2005	3	Ocala LS/Hawthorne (Thc)
	SR 55 Taylor County 2021	4	Undifferentiated sediments (Qu)
	US 27 Perry 2021	2	Hawthorn Group (Th)
	US 441 Micanopy Depression 2012	4	Hawthorne (Thc)
	US 441 Micanopy Depression 2015	2	Hawthorne (Thc)
3	FDOT Ponce Operations Facility 2006	11	Alum Bluff Group (Tab)
	SR 319 Leon County 2004	7	Hawthorne. grp (Tht)/Beach(Qbd)
	SR 77 Roadway Depression 2020	4	Hawthorne grp (Tht)
5	Deland 15A North 2016	6	Cypresshead (Tc)
	Deland 15A South 2016	5	Cypresshead (Tc)
	Deltona Howland 2004	10	Dunes (Tqd)
	I-4 CR 46 Depression 2002	5	Cypresshead (Tc)
	I-4 Lake Mary Blvd Depression 2002	4	Cypresshead (Tc)
	I-4 Maitland Blvd Depression 2004	12	Cypresshead (Tc)
	I-4 Rest Area Seminole County 2003	2	Cypresshead (Tc)
	I-4 Seminole County Irma 2017	2	Cypresshead (Tc)
	Rose Down Blvd Debary 2018	4	Cypresshead (Tc)
	Silver Star Road 1990	5	Cypresshead (Tc)
	SR 35 Silver Springs Marion County Irma 2017	6	Undiff. Sed.(Qu)/Hawth.(Thc)
	SR 400 Lake Mary Depression 1996	4	Cypresshead (Tc)
	SR 434 EB Depression 2012	3	Cypresshead (Tc)
	SR 44 Depression 2014	4	Cypresshead (Tc)
	SR 50 Groveland 2020	5	Cypresshead (Tc)
	SR 500 Lady Lake Irma 2017	8	Cypresshead (Tc)
	SR 535 Meadow Creek 2006	3	Cypresshead (Tc)
	US 17 Ponce Deleon Springs 2005	5	Cypresshead (Tc)
	US 17-92 Debary VFW 2005	6	Cypresshead (Tc)
	US 27 Lake County 2008	11	Ocala LS/Hawthorne (Thc)
	US 27 Ocala 2004	4	Cypresshead (Tc)
	US 27 Villages Sinkhole 2015	4	Undiff. Sed.(Qu)/Hawth.(Thc)
	US 301 Depression 1 Oxford 2015	4	Undiff. Sed.(Qu)/Hawth.(Thc)
	US 301 Depression 2 Oxford 2015	3	Undiff. Sed.(Qu)/Hawth.(Thc)
	US 301 Depression 3 Oxford 2015	2	Undiff. Sed.(Qu)/Hawth.(Thc)
	US 301 Depression 4 Oxford 2015	3	Undiff. Sed.(Qu)/Hawth.(Thc)
	US 441 North Ocala 2005	13	Ocala LS/Hawthorne (Thc)
	US 441 Reddick Marion County Irma 2017	13	Cypresshead (Tc)
7	I-275 Green St. 2020	4	Undifferentiated sediments (Qu)
	PSI Pasco County Land O' Lakes 2018	5	Undifferentiated sediments (Qu)
	SR 33 USF 2012	11	Undifferentiated sediments (Qu)
	US 19 Sealawn 2011	6	Undifferentiated sediments (Qu)
Turnpike	Mile Post 299 Pavement Settlement 2020	-	Reworked Cypresshead (Tquc)
	Western Beltway Sinkhole 2010	-	Cypresshead (Tc)

Project Site Map

- Deland 15A North 2016
- Deland 15A South 2016
- Deltona Howland 2004
- FDOT Ponce Operations Facility 2006
- I-10 Columbia County 2007
- I-275 Green St. 2020
- I-4 CR 46 Depression 2002
- I-4 Lake Mary Blvd Depression 2002
- I-4 Maitland Blvd Depression 2004
- I-4 Rest Area Polk County 2011
- I-4 Rest Area Seminole County 2003
- I-4 Seminole County Irma 2017
- I-75 Northbound Depression Alachua 2005
- I-75 Southbound Depression Alachua 2005
- Mile Post 299 Pavement Settlement 2020
- PSI Pasco County Land O' Lakes 2018
- Recker Highway 2005
- Rose Down Blvd Debary 2018
- SR 319 Leon County 2004
- SR 33 USF 2012
- SR 35 Silver Springs Marion County Irma 2017
- SR 400 Lake Mary Depression 1996
- SR 434 EB Depression 2012
- SR 44 Depression 2014
- SR 50 Groveland 2020
- SR 500 Lady Lake Irma 2017
- SR 535 Meadow Creek 2006
- SR 55 Taylor County 2021
- SR 77 Roadway Depression 2020
- Silver Star Road 1990
- US 17 Ponce Deleon Springs 2005
- US 17-92 Debary VFW 2005
- US 19 Sealawn 2011
- US 27 Lake County 2008
- US 27 Ocala 2004
- US 27 Perry 2021
- US 27 Polk County 2010 North
- US 27 Polk County 2010 South
- US 27 Villages Sinkhole 2015
- US 301 Depression 1 Oxford 2015
- US 301 Depression 2 Oxford 2015
- US 301 Depression 3 Oxford 2015
- US 301 Depression 4 Oxford 2015
- US 441 Micanopy Depression 2012
- US 441 Micanopy Depression 2015
- US 441 North Ocala 2005
- US 441 Reddick Marion County Irma 2017
- US 92 Memorial Cracked CP 2012
- Western Beltway Sinkhole 2010



Task 1: Data Collection Summary Cont.

- **29 sites** with SPT data
- **14 sites** with Grouting Information
  - 12 contain CPT data

- Grouting information will be used to determine a correlation between the determined SRR from the CPT data and the grout intake (Task 5)

District	Site Info/File Name	SPT Data	Grout Information
1	I-4 Rest Area Polk County 2011	Yes	Yes
	Recker Highway 2005	No	No
	US 27 Polk County 2010 North	Yes	Yes
	US 27 Polk County 2010 South	Yes	Yes
	US 92 Memorial Cracked CP 2012	No	No
2	I-10 Columbia County 2007	No	No
	I-75 Northbound Depression Alachua 2005	Yes	Yes
	I-75 Southbound Depression Alachua 2005	No	Yes
	SR 55 Taylor County 2021	Yes	No
	US 27 Perry 2021	Yes	No
	US 441 Micanopy Depression 2012	No	No
	US 441 Micanopy Depression 2015	No	No
3	FDOT Ponce Operations Facility 2006	No	No
	SR 319 Leon County 2004	No	No
	SR 77 Roadway Depression 2020	Yes	Yes
5	Deland 15A North 2016	No	No
	Deland 15A South 2016	No	No
	Deltona Howland 2004	No	No
	I-4 CR 46 Depression 2002	Yes	No
	I-4 Lake Mary Blvd Depression 2002	No	No
	I-4 Maitland Blvd Depression 2004	Yes	No
	I-4 Rest Area Seminole County 2003	No	No
	I-4 Seminole County Irma 2017	No	No
	Rose Down Blvd Debary 2018	No	Yes
	Silver Star Road 1990	No	No
	SR 35 Silver Springs Marion County Irma 2017	No	Yes
	SR 400 Lake Mary Depression 1996	No	No
	SR 434 EB Depression 2012	No	No
	SR 44 Depression 2014	Yes	No
	SR 50 Groveland 2020	No	Yes
	SR 500 Lady Lake Irma 2017	No	Yes
	SR 535 Meadow Creek 2006	Yes	No
	US 17 Ponce Deleon Springs 2005	No	No
	US 17-92 Debary VFW 2005	No	Yes
	US 27 Lake County 2008	No	No
	US 27 Ocala 2004	No	No
	US 27 Villages Sinkhole 2015	No	No
	US 301 Depression 1 Oxford 2015	No	No
	US 301 Depression 2 Oxford 2015	No	No
	US 301 Depression 3 Oxford 2015	No	No
	US 301 Depression 4 Oxford 2015	No	No
	US 441 North Ocala 2005	No	No
	US 441 Reddick Marion County Irma 2017	No	Yes
7	I-275 Green St. 2020	Yes	Yes
	PSI Pasco County Land O' Lakes 2018	Yes	No
	SR 33 USF 2012	No	No
	US 19 Sealawn 2011	Yes	No
Turnpike	Mile Post 299 Pavement Settlement 2020	Yes	Yes
	Western Beltway Sinkhole 2010	Yes	Yes

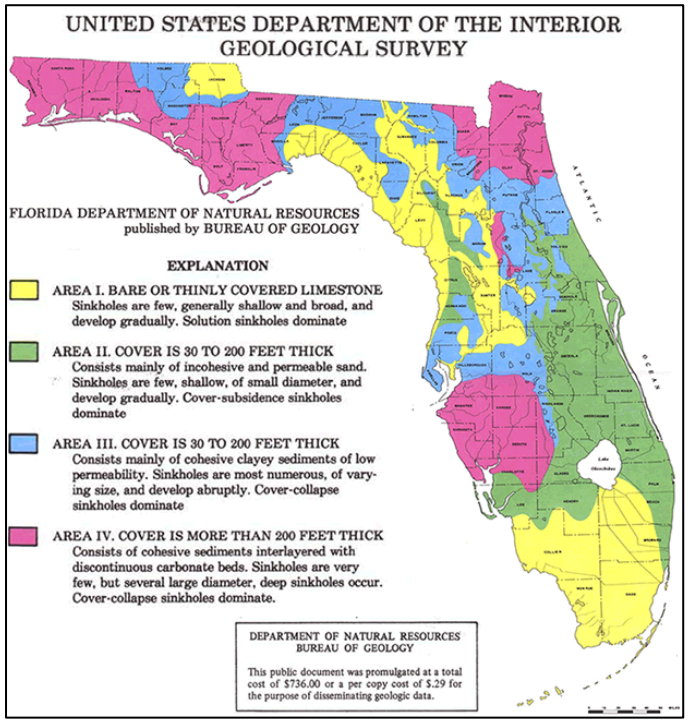
Task 1: Data Collection
Summary Cont. – Sinkhole Area Type

- Using the reports and other miscellaneous information additional sinkhole characteristics were identified including size, type, and surficial geological unit.

- The type of sinkhole was determined for each site based on the Florida Geological Survey (FGS) sinkhole map:
  - AREA **1** → **11** **[45 CPTs]**
  - AREA **2** → **6** **[5 CPTs]**
  - AREA **3** → **31** **[153 CPTs]**
  - AREA **4** → **1** [zero]

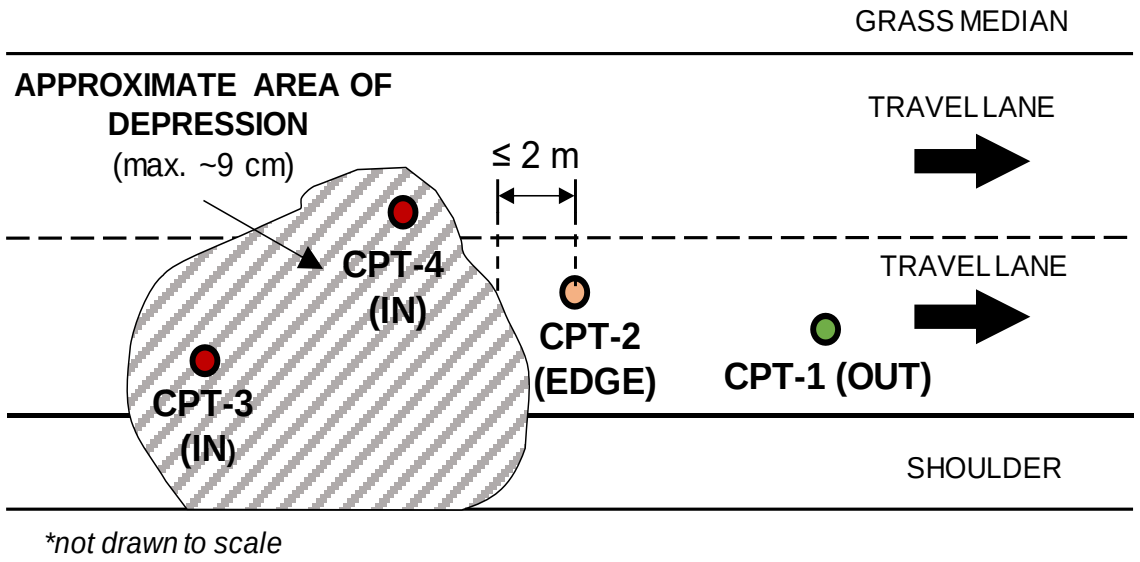
- Each site reviewed to verify sinkhole mechanism – designation adjusted if needed

- Note: Data density correlated with frequency of sinkhole occurrence (FGS report)



Sinkhole type map (DNR 1985)

Task 1: Data Collection Summary Cont. – Spatial categorization



36 Project Sites		
Total # of CPTs	"IN"	23
	"EDGE"	82
	"OUT"	55

"INSIDE" = Most Vulnerable conditions
"EDGE" = Vulnerable conditions
"OUT" = Least vulnerable conditions

Assuming:

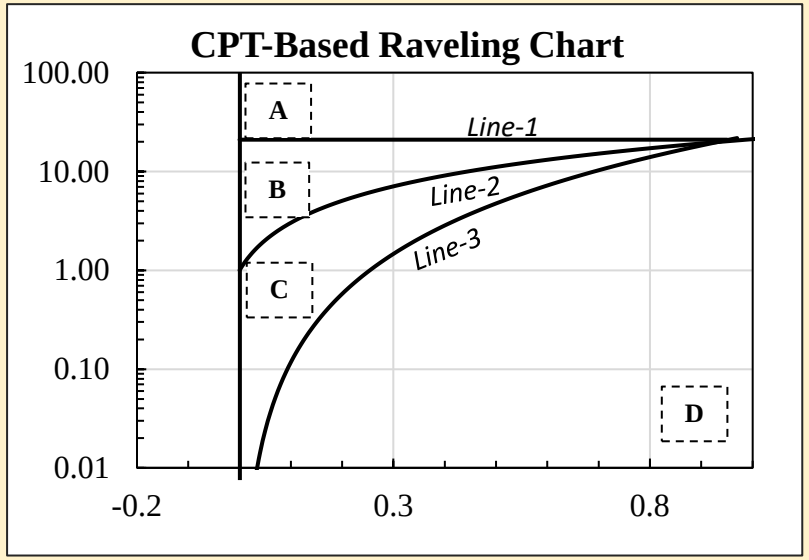
- Distance ∝ Disturbance
- Closer to center of sinkhole is more representative of **severe** conditions.
- Subsurface conditions < 2 m from observed sinkhole still effected by internal erosion.
- > 2m: less disturbed

Task 2: Validation and update of the sinkhole index and chart

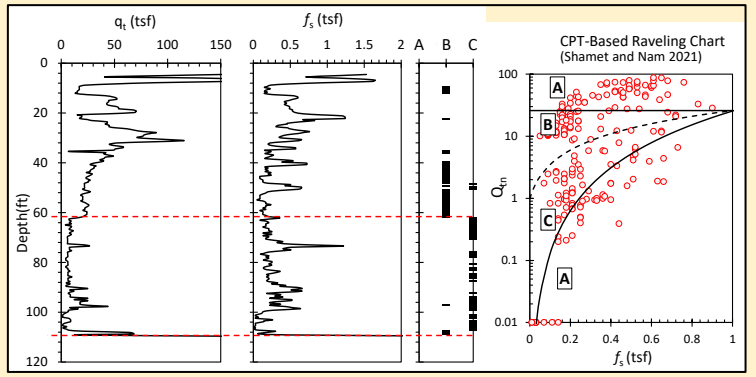
- Test the raveling chart's accuracy with newly updated datasets (n = 118). The chart is used not only (a) to help determine the dividing line from the raveled (t_{ravel}) to the non-raveled zone (t_{over}) but also to provide the raveling severity characteristics along depth.
- Develop the criteria and a standard procedure to determine the dividing line between raveled (t_{ravel}) and non-raveled overburden (t_{over}) zone.
- To validate and evaluate the performance of the SRR through the new datasets. If needed, the PIs will modify the index (e.g., adjustment factor).

Task 2: Methodology

Robust Database



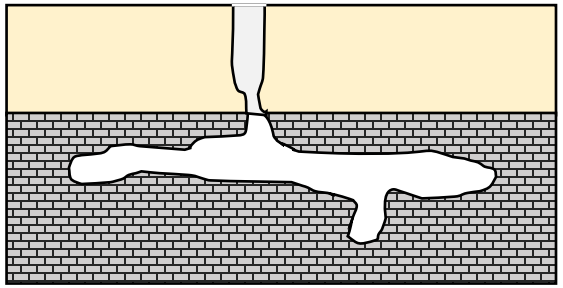
- Subset of data from high quality sites (n = 118)
- Identified apparent raveling depths from q_c profile
- Tested result of points along depth located within correct zone of chart.
- Identified statistics of True Positive, False Positive, Negative & False Negative for all Area Types

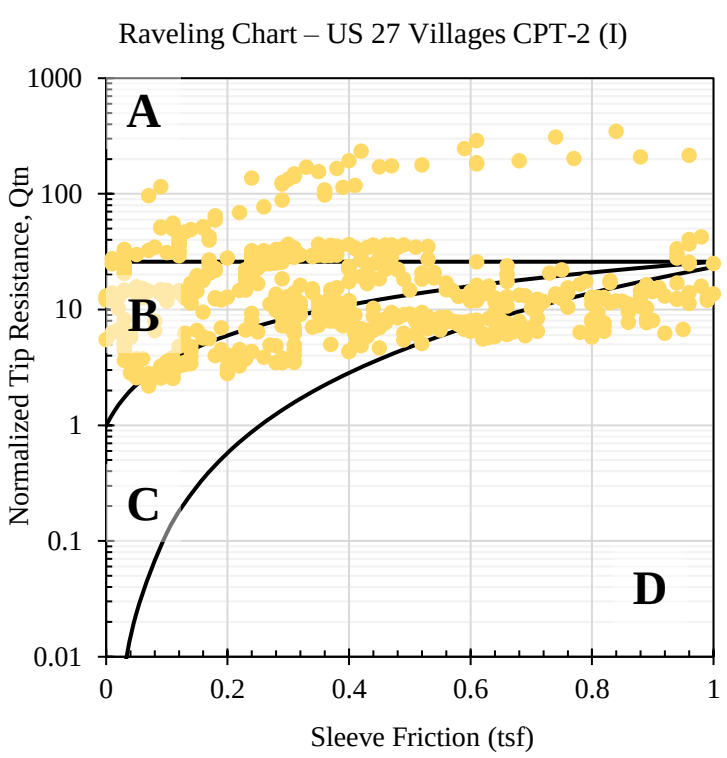


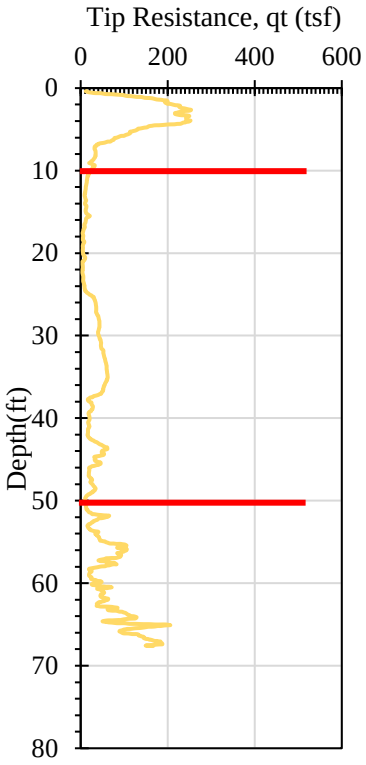
$$\text{SRR} = \left(\frac{q_{over} + q_{ravel}}{100 * \sigma'_{vo}}\right)\left(\frac{t_{over}}{t_{ravel}}\right)$$

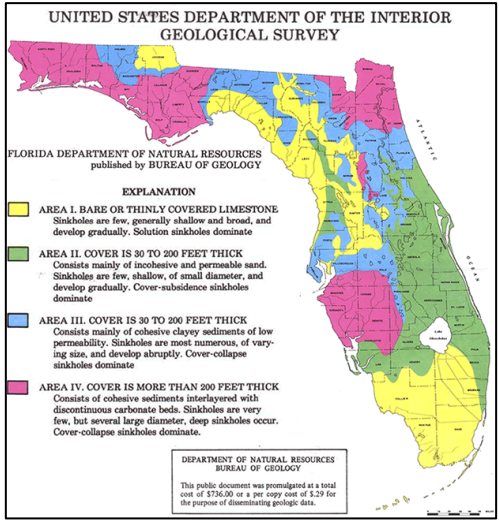
- Calculated for each area type based on spatial category (I/E/O)
- Identified ranges to determine % of unique values
- Tested Correlation of terms against vulnerability
- Decision making:
  - Break point values
  - Historical Probabilistic of occurrence

Type 1 – US 27 Villages Sinkhole CPT-2



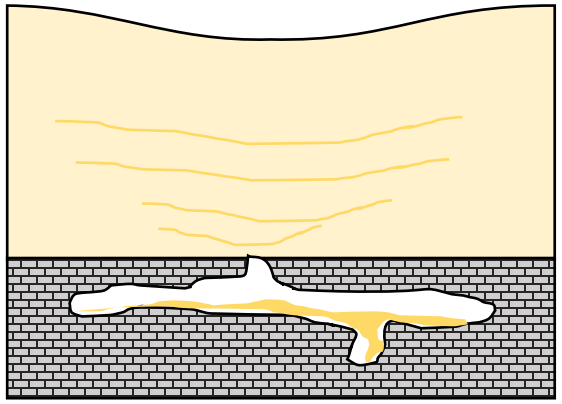


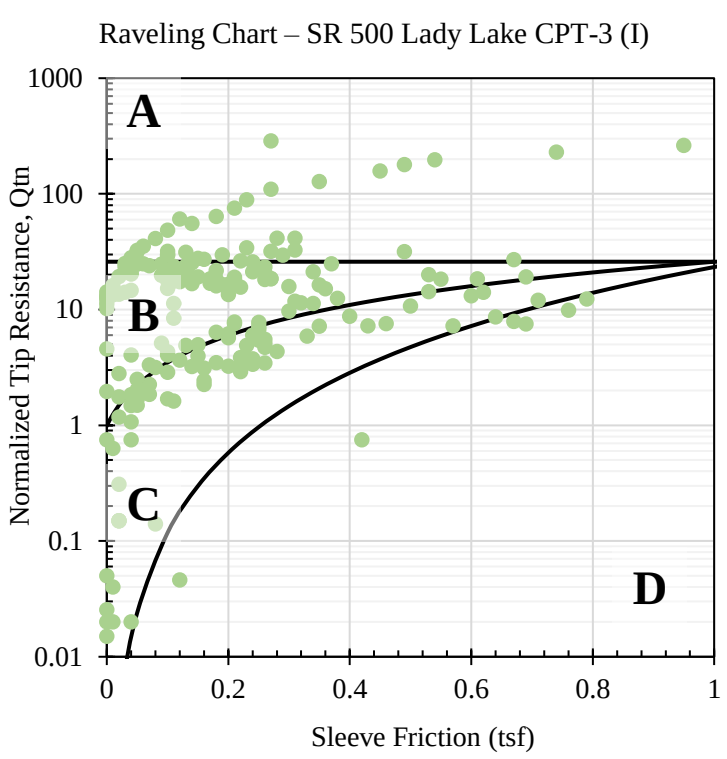


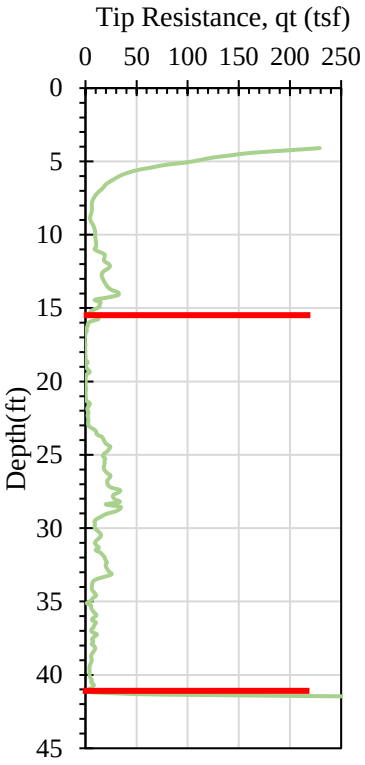


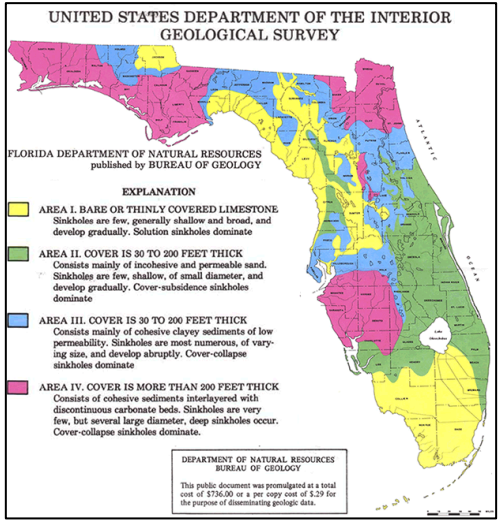
Name (CPT Location)	Ravel Start (ft)	Ravel End (ft)	Positive	False Positive	Negative	False Negative
US 27 Villages CPT-2 (I)	10	50	67.00%	33.00%	85.30%	14.70%

Type 2 – SR 500 Lady Lake Irma 2017 CPT-3



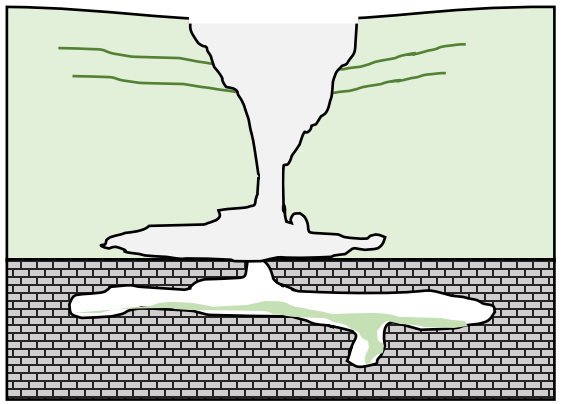


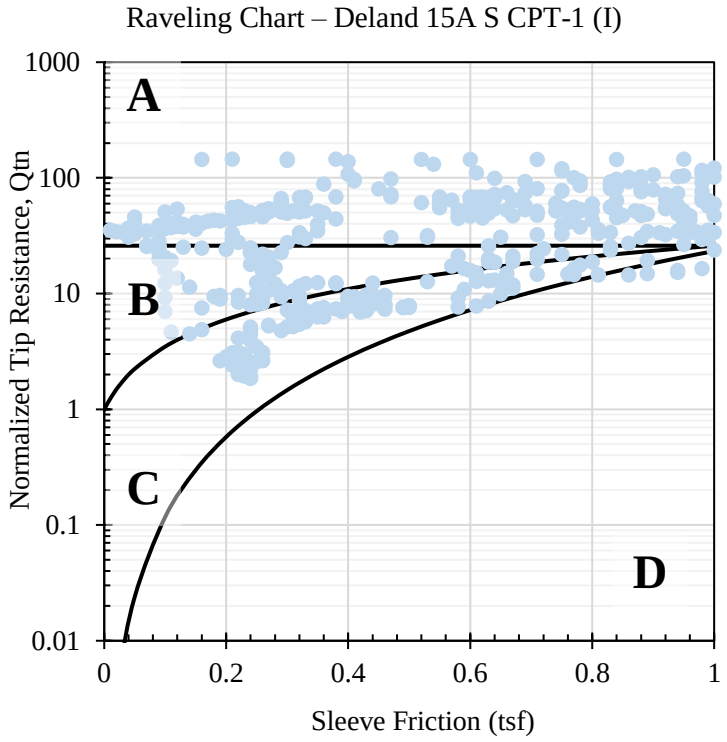


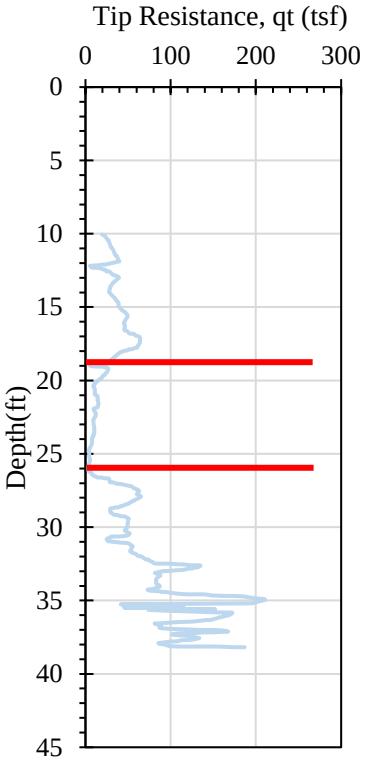


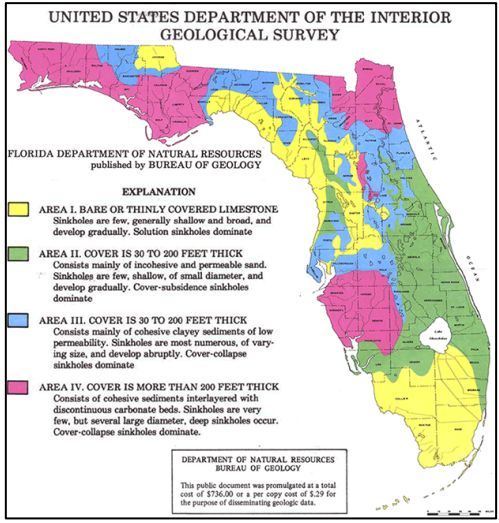
Name (CPT Location)	Ravel Start (ft)	Ravel End (ft)	Positive	False Positive	Negative	False Negative
SR 500 Lady Lake Irma 2017 CPT-3 (I)	15.3	41.2	81.10%	18.90%	42.10%	57.90%

Type 3 – Deland 15A South 2016 CPT-1





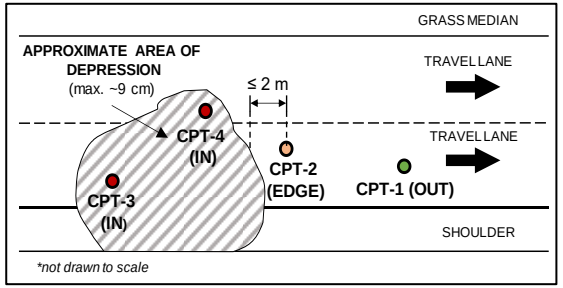




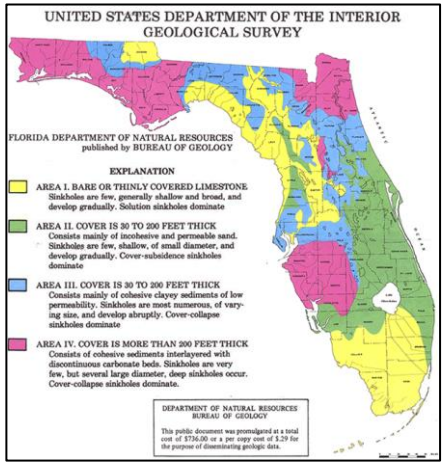
Name (CPT Location)	Ravel Start (ft)	Ravel End (ft)	Positive	False Positive	Negative	False Negative
Deland 15A South 2016 CPT-1 (I)	19	26	97.50%	2.50%	88.40%	11.60%

Evaluation of Raveling Chart

- Positive – CPT point located <u>in</u> raveled zones of the chart and the raveled zone of the CPT profile
- False Positive – CPT point located <u>in</u> raveled zones of the chart but **not** the raveled zone of the CPT profile.
- Negative – CPT point located <u>outside</u> raveled zones of the chart and the raveled zone of the CPT profile
- False Negative – CPT point located <u>outside</u> raveled zones of the chart and <u>but in</u> the raveled zone of the CPT profile



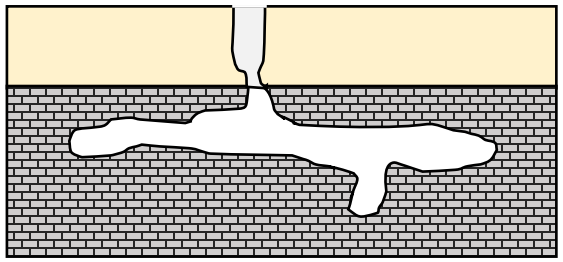
Analysis Result	Location			Sinkhole Type (FGS)			Overall
	Inside	Edge	Outside	1	2	3	
Positive	61%	61%	64%	35%	84%	67%	63%
False P.	39%	39%	36%	65%	16%	33%	37%
Negative	73%	86%	83%	87%	83%	80%	82%
False N.	27%	14%	17%	13%	17%	20%	18%



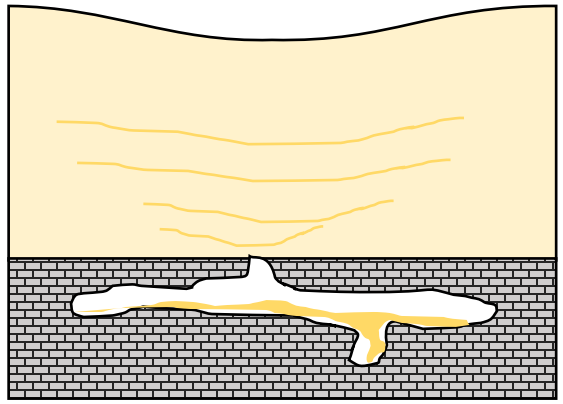
Task #2 Raveling Chart General Recommendations

- The existing raveling chart was found to accurately identify raveled soil **63%** of the time, and identify non-raveled soil **82%** of the time, within the updated database.
- Existing raveling chart is still a moderately accurate way to identify depths of raveling behavior within Area 2 and 3 anticipated Sinkhole Types.
- Caution using raveling chart in areas known for "solution" style sinkholes

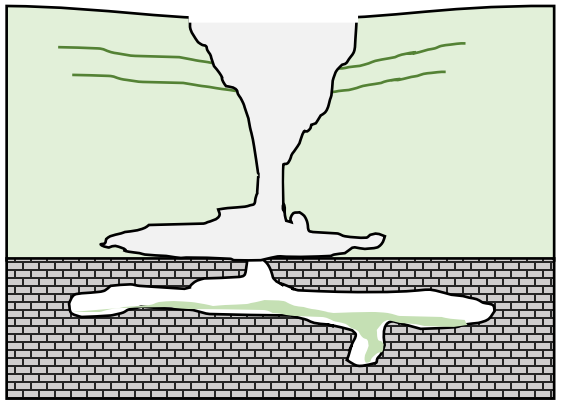
Type 1 "Solution"



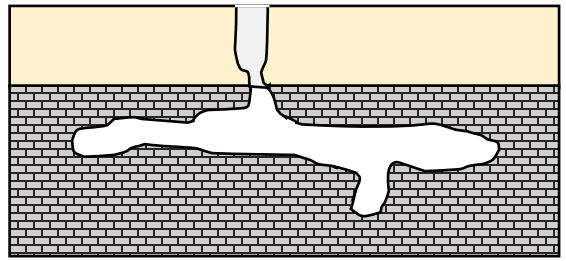
Type 2 "Subsidence"



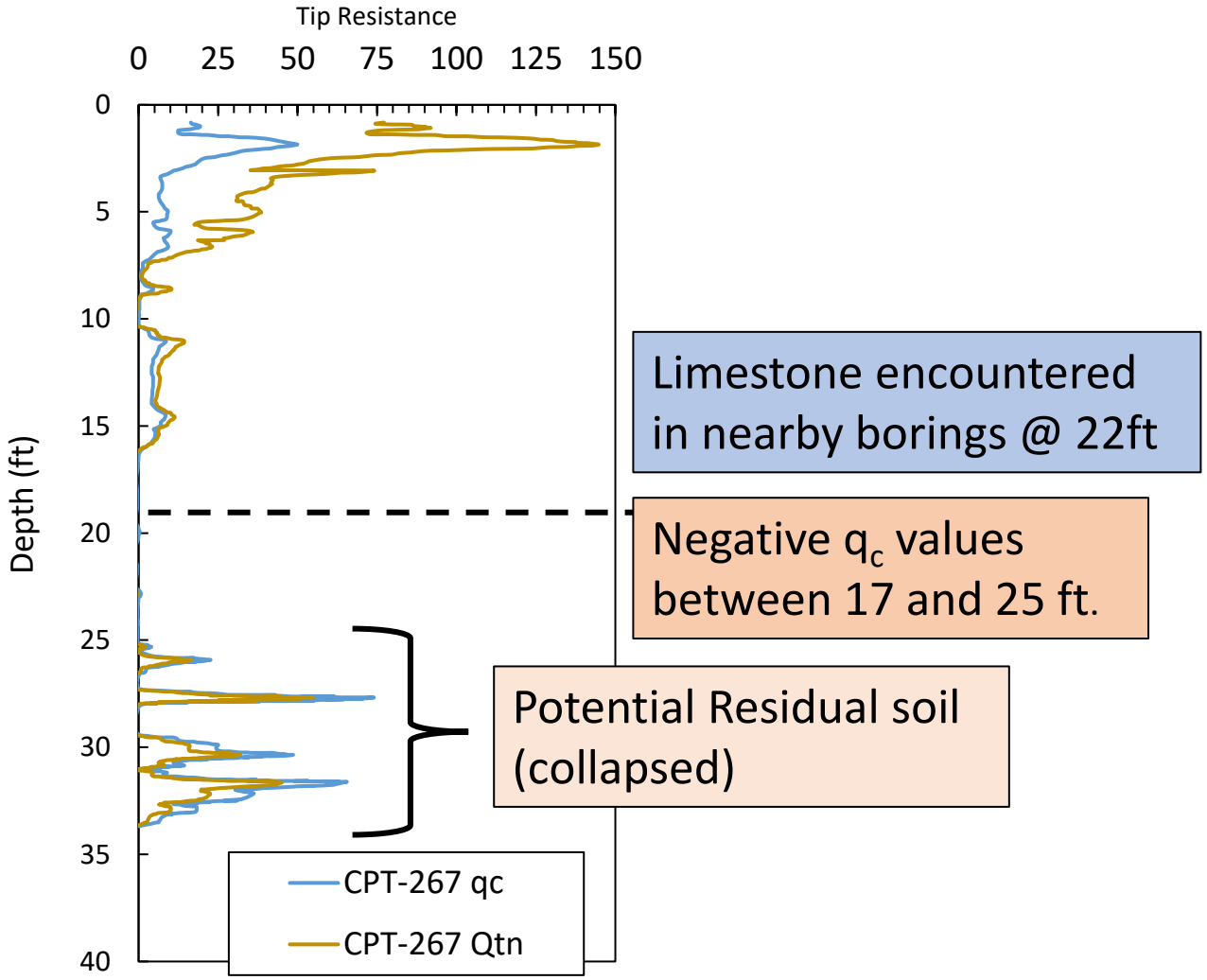
Type 3 "Cover collapse"



Task #2 Raveling Chart General Recommendations in Area 1



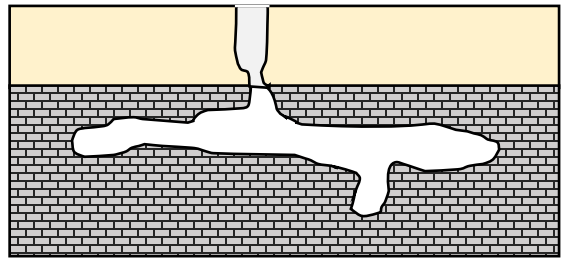
North Ocala



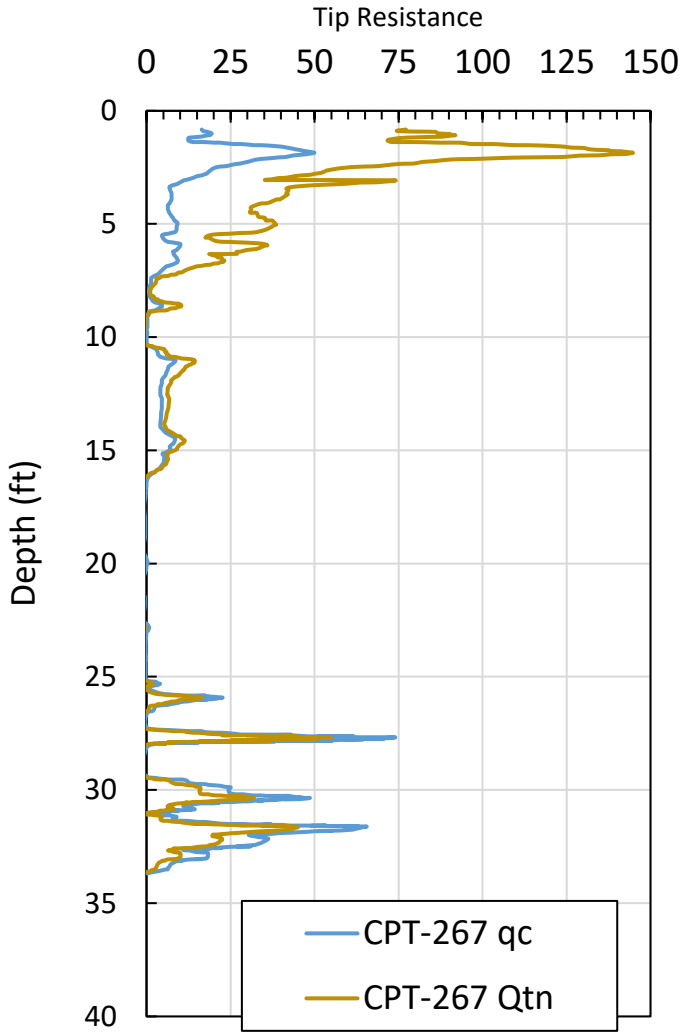
- **Area 1**
  → concentrated "siloed" raveling
- CPT data = Post Collapse
- Data from void (q_c = negative) or Residual Soil
- Shallow depths and stiffer overburden (Q_{tn} increases)

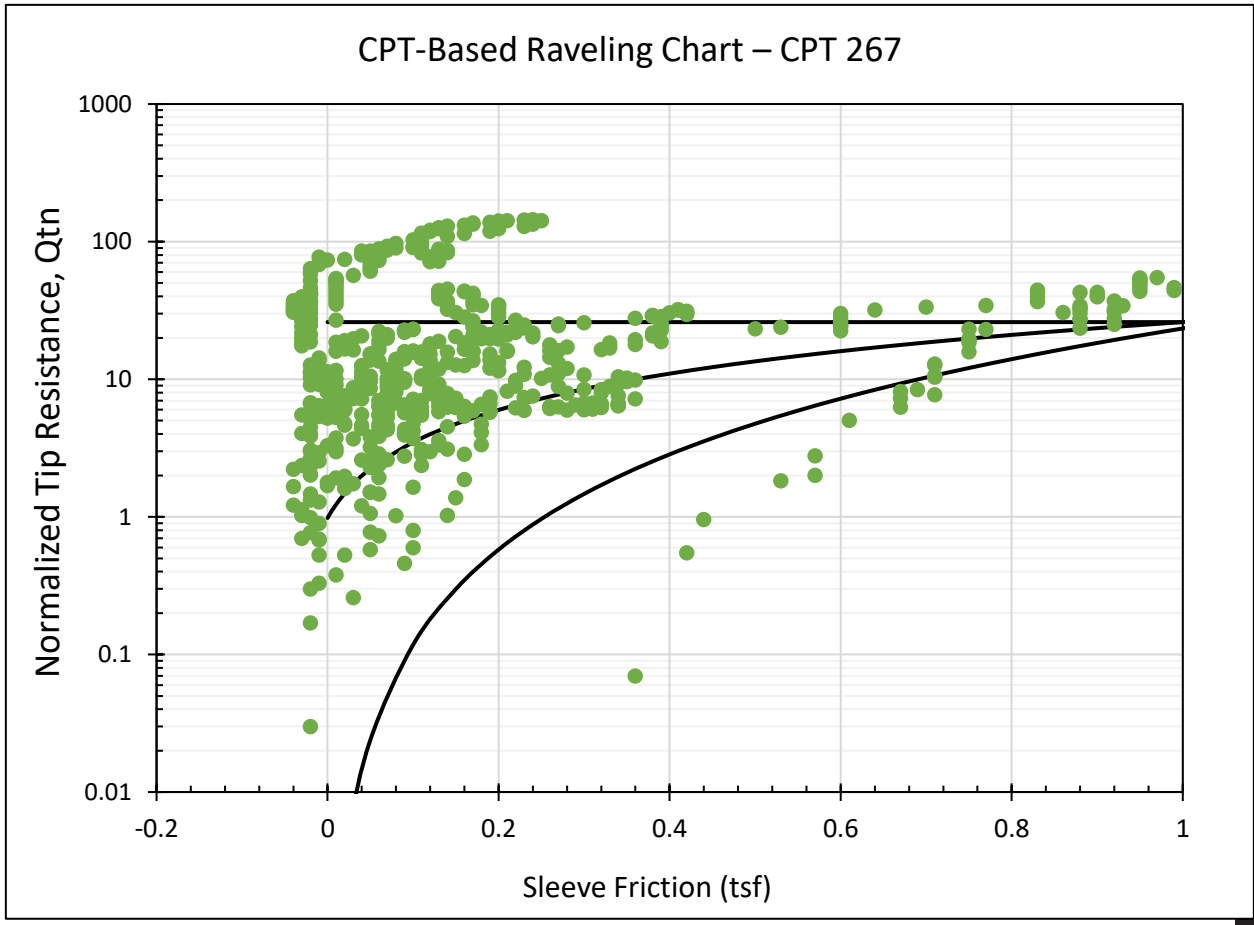
$$Q_{tn} = \left(\frac{q_t - \sigma}{p_a}\right)\left(\frac{p_a}{\sigma'}\right)^n$$

Task #2 Raveling Chart General Recommendations in Area 1



North Ocala





Task #2 SRR Validation

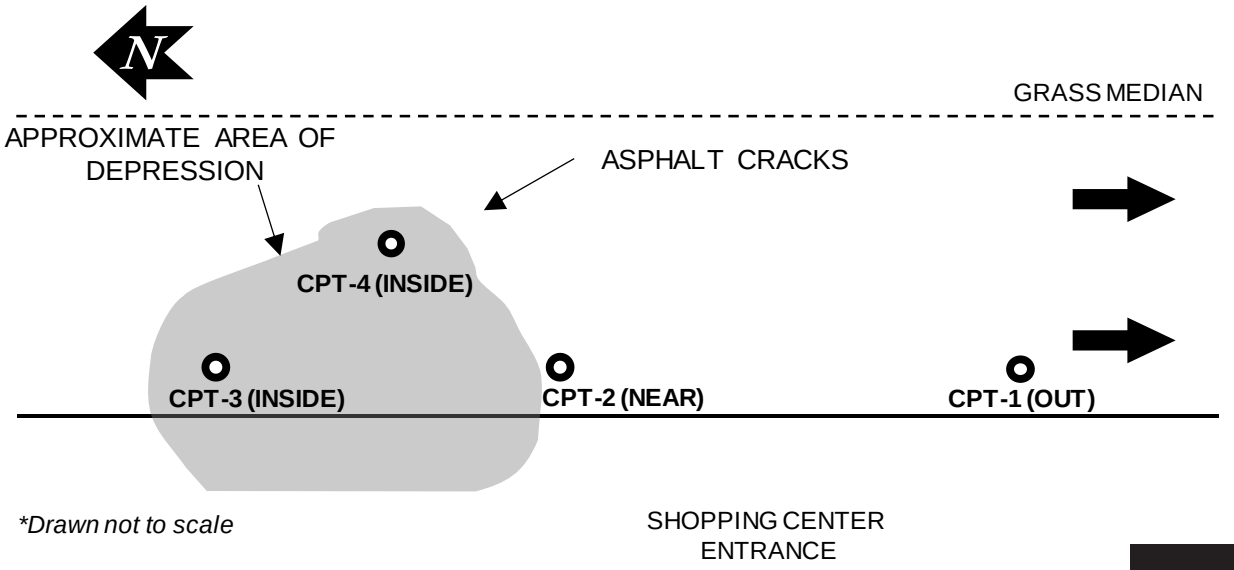
- Testing of SRR on wider Dataset.
- Is it worth the extra analysis over the Raveling Index (RI)?
  - Specific to each area group (Area 1 vs. Area 3).
- Criteria of SRR? → Quantitative for decision making

Gray (1994):

$$\mathrm{RI} = \frac{t_{\mathrm{ravel}}}{t_{\mathrm{over}}}$$

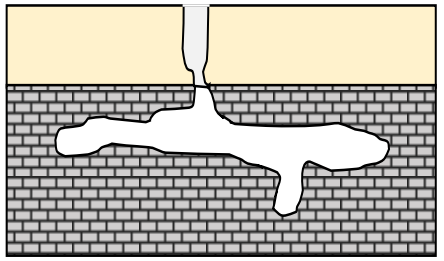
Nam et. al (2018):

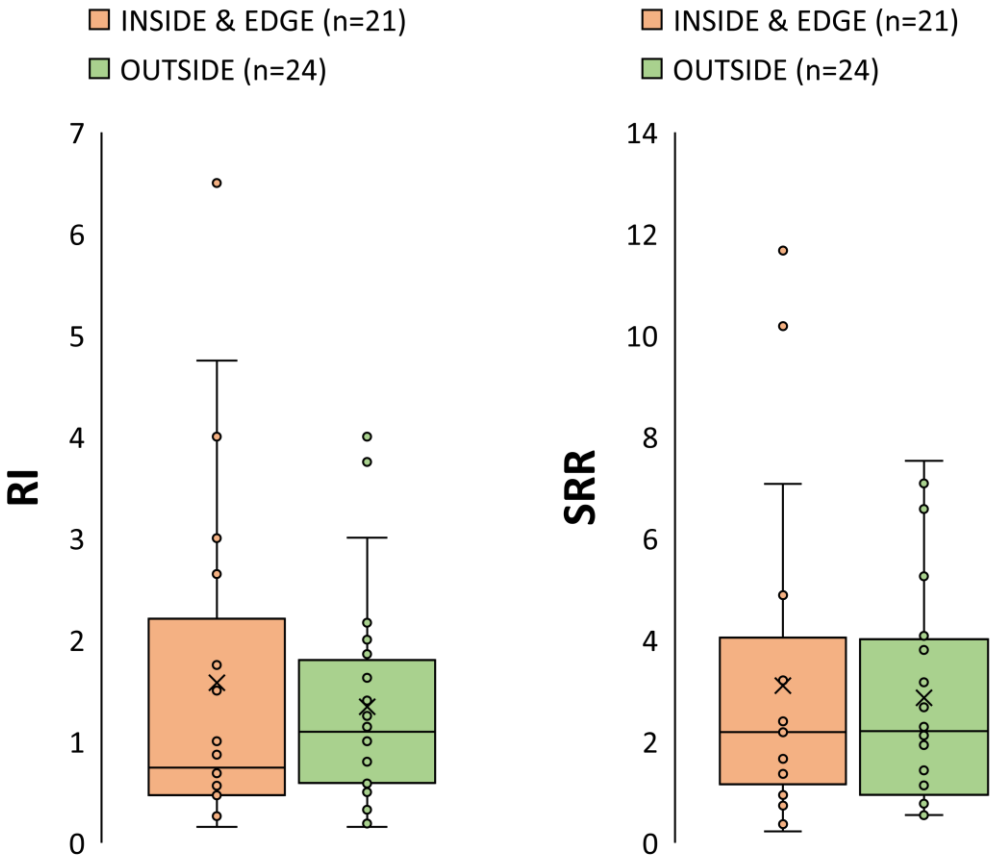
$$\mathrm{SRR} = \left(\frac{\mathrm{t_{over}}}{\mathrm{t_{ravel}}}\right) * \left(\frac{\bar{q}_{\mathrm{over}} + \bar{q}_{\mathrm{ravel}}}{100 * \sigma'_{\mathrm{vo}}}\right)$$



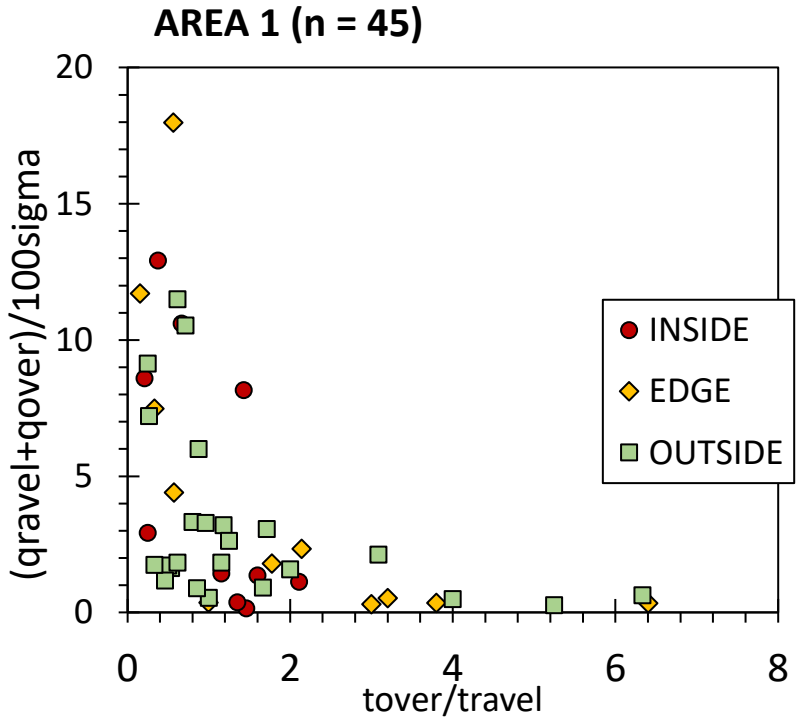
Comparison of Type 1 and Type 3

Type 1 – Solution Sink



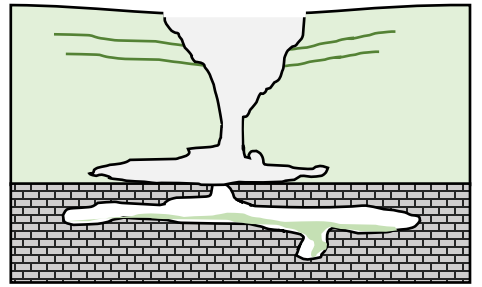


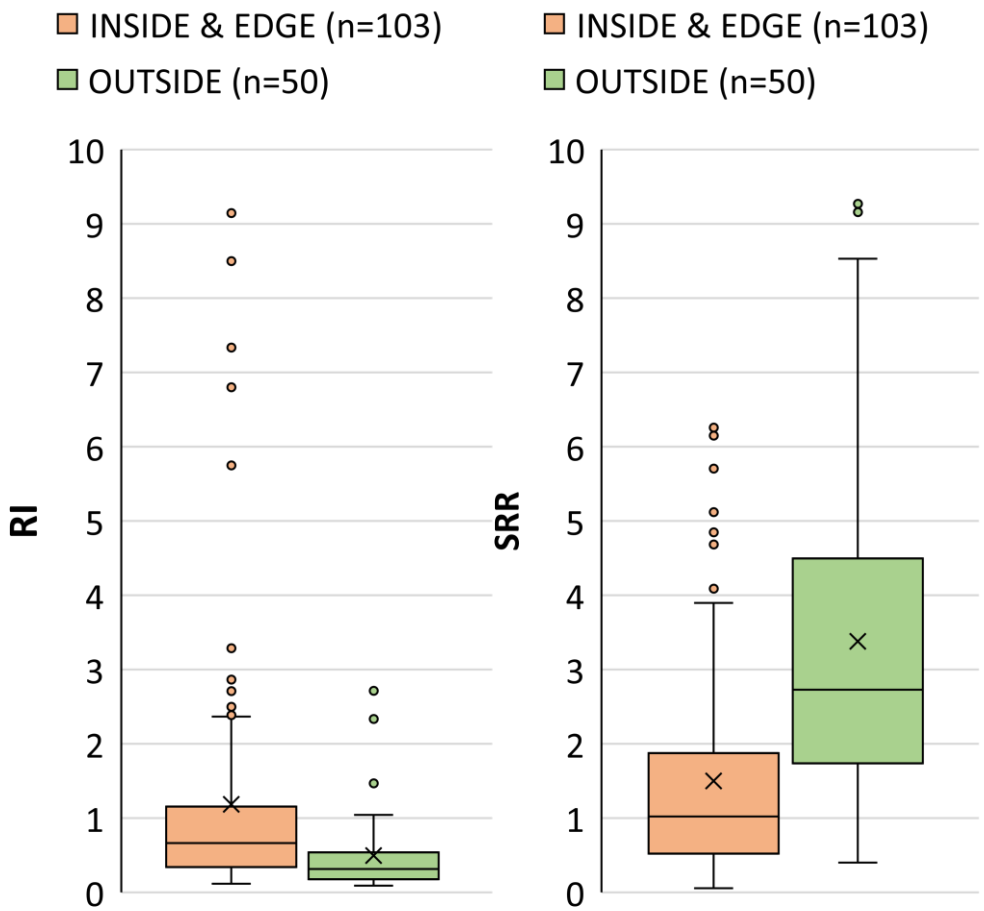
- **SRR** similar distinction as RI
- No Trend of Data in Area 1
- **NOT RECOMMENDED**



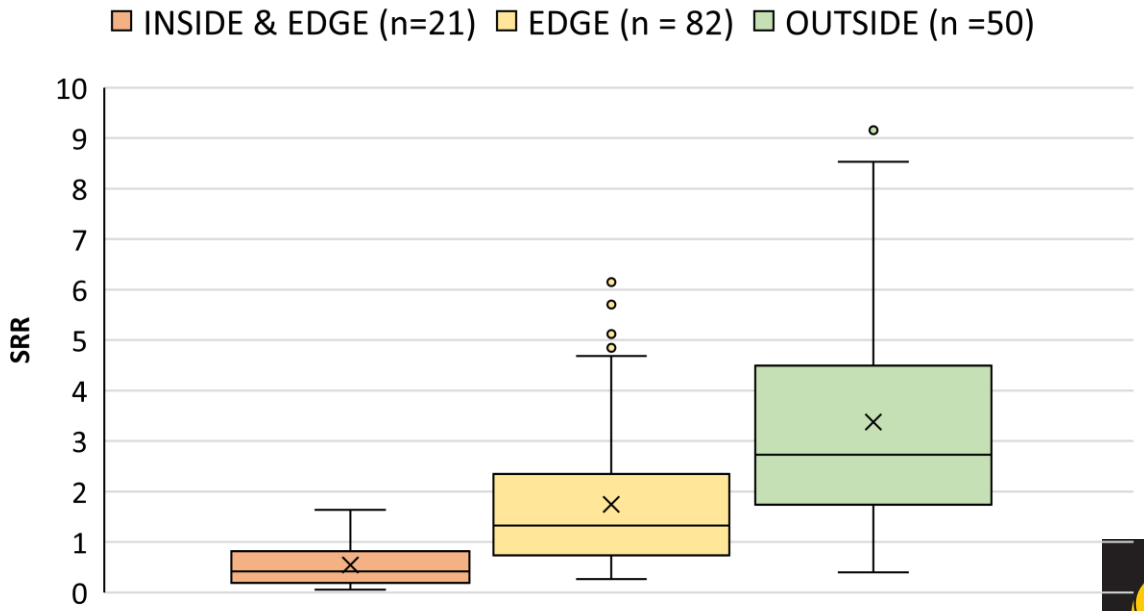
Comparison of Type 1 and Type 3

Type 3 – Cover Collapse





- **SRR** shows a better distinction in data groups than RI.
- **SRR value of 2.0** break point of data set.

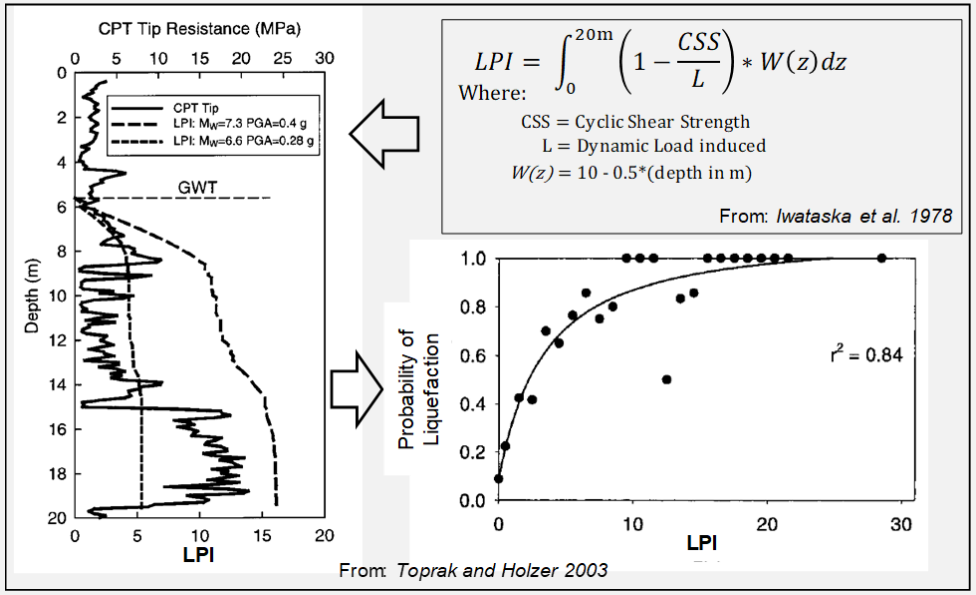


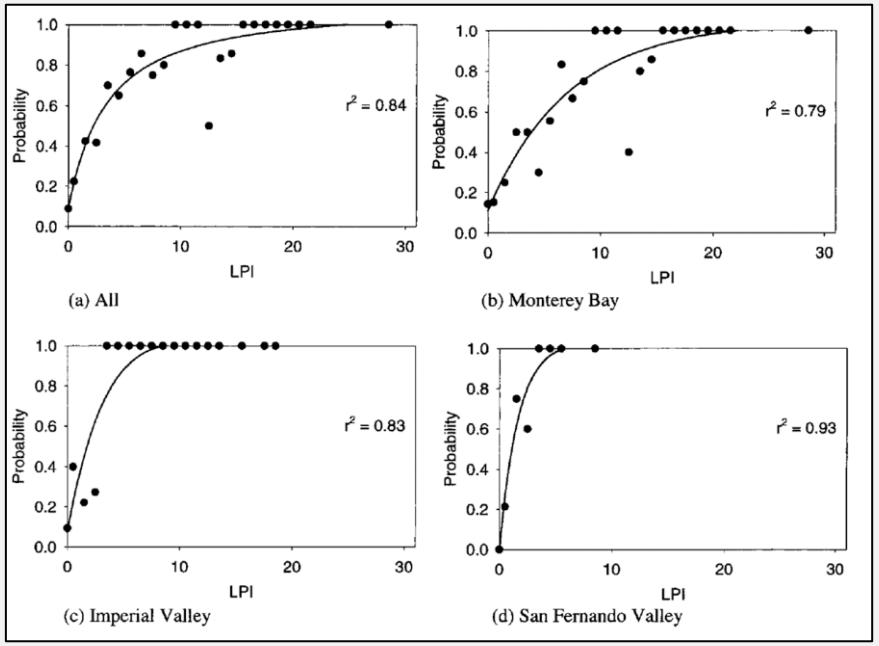
UCF

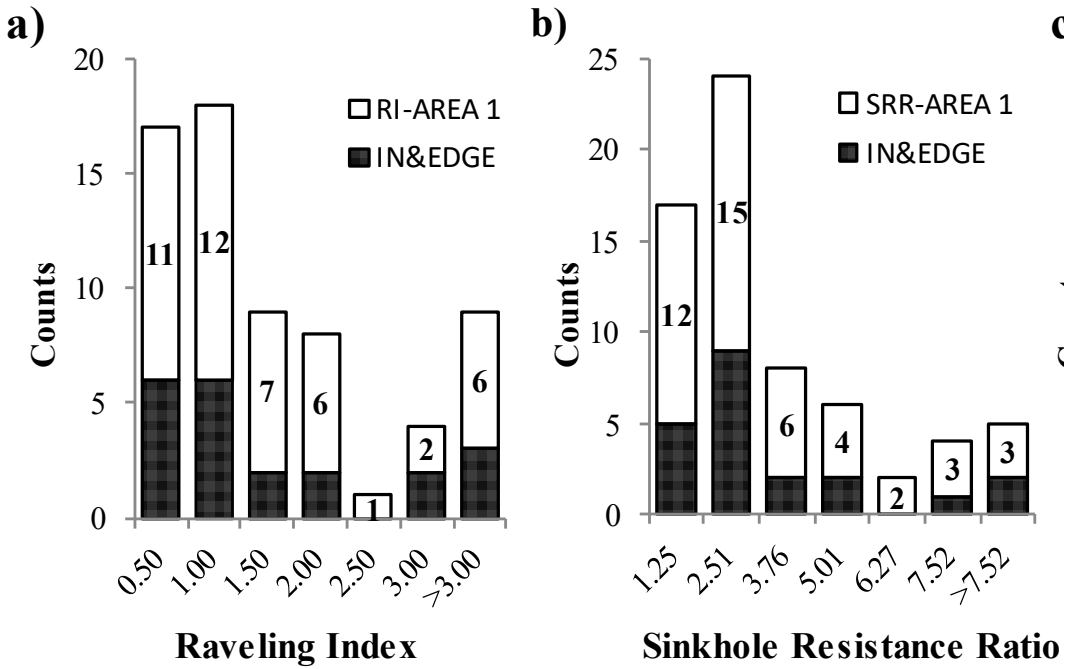
Probabilistic Analysis for Sinkhole Index

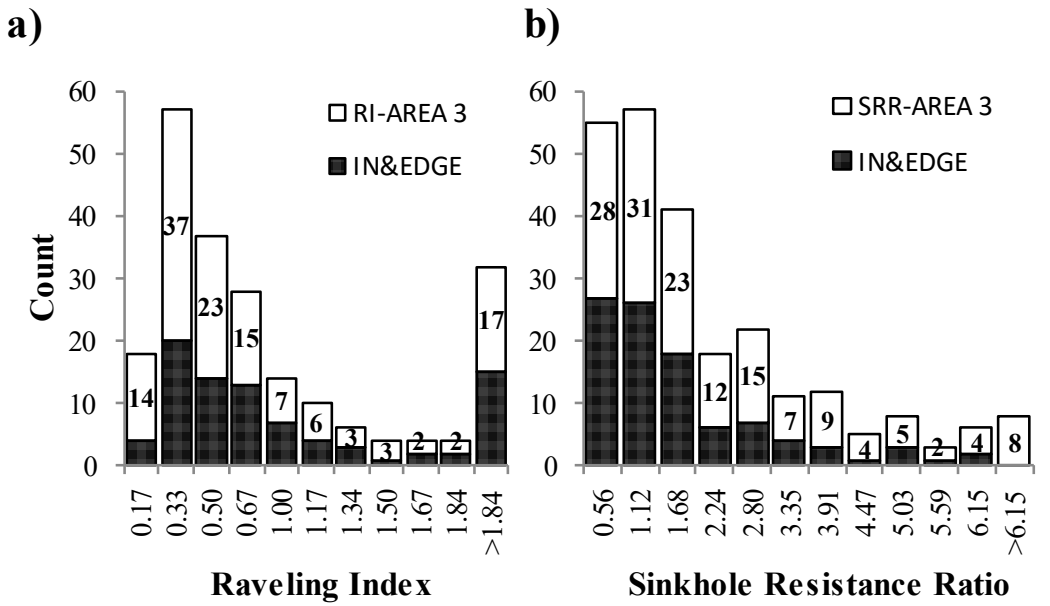
- CPTs categorized based on proximity to sinkhole [IN/EDGE vs **OUTSIDE**]
  - Raveling Chart used to identify parameters
    - Indices Calculated (SRR & RI)
      - Histograms & Frequency analysis of indices
        - → Probability = *f* (sinkhole occurrence)

Similar to Liquefaction Potential Index (LPI): ***[Toprak and Holzer 2003]***

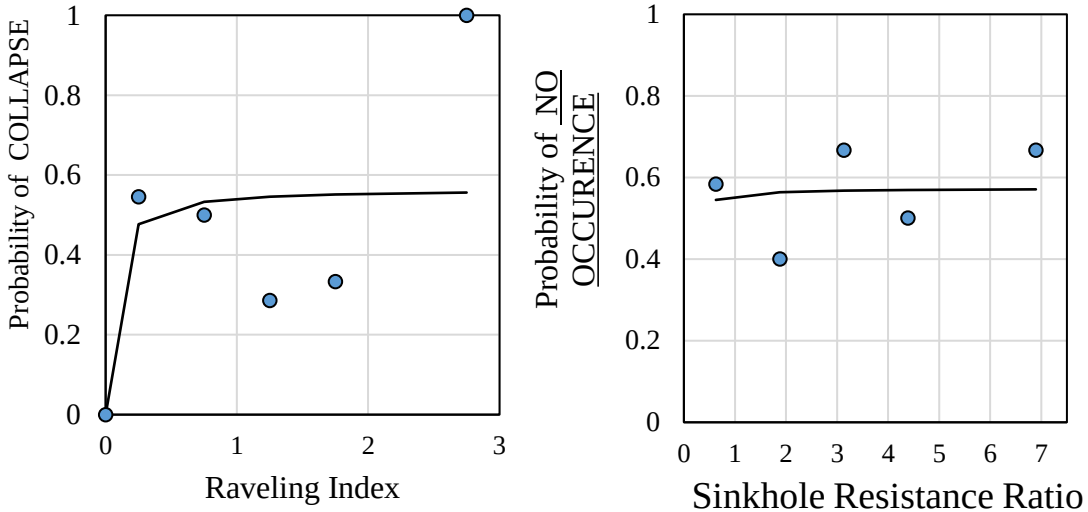




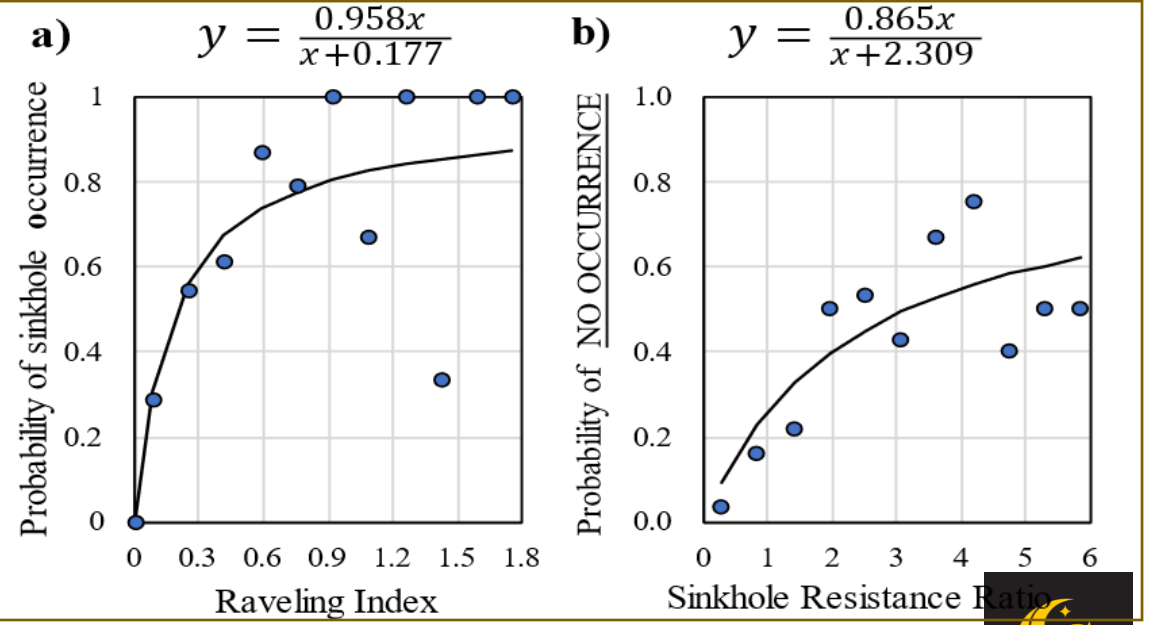




AREA 1: (Solution)

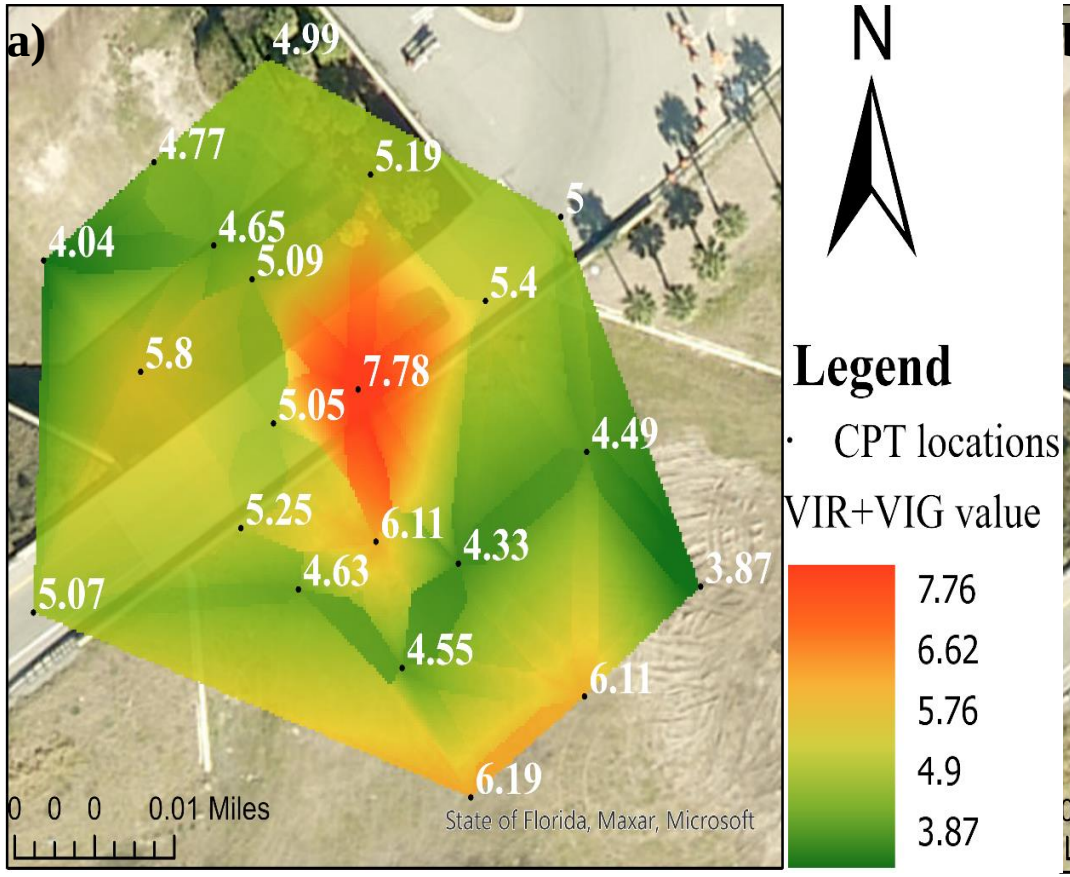


AREA 3: (Cover Collapse)

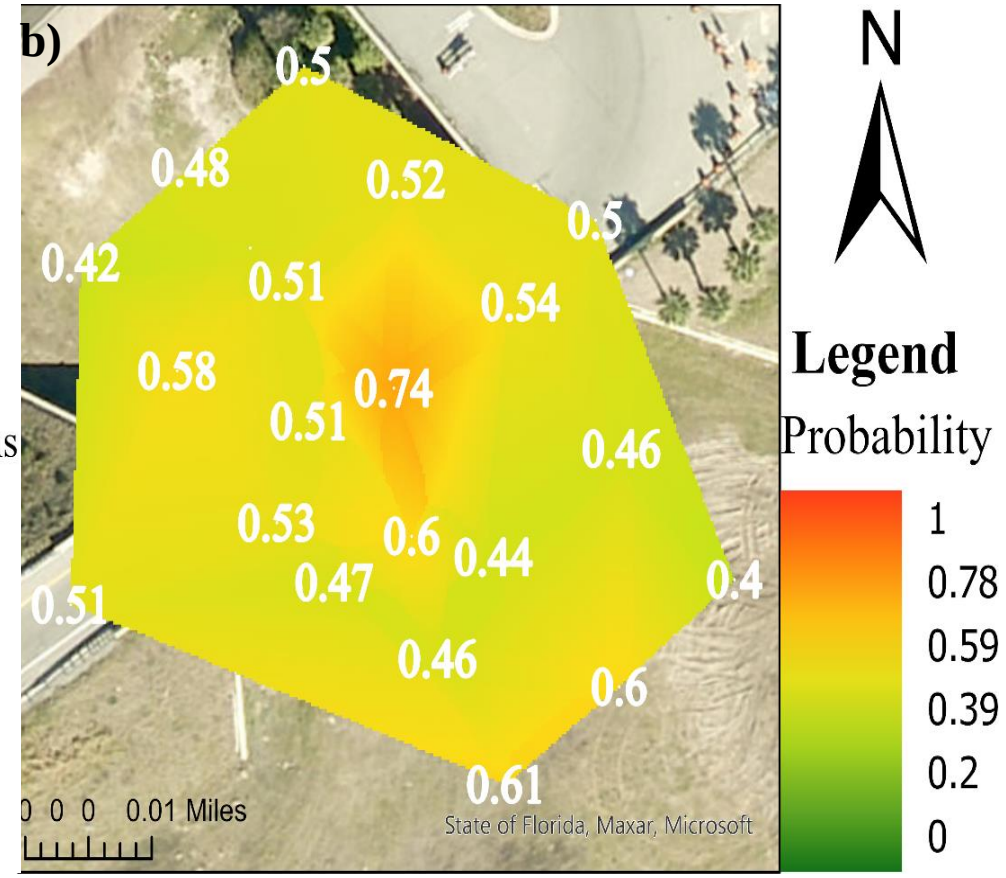


Example analysis (non-collapse site)

Index contouring



Probability contouring



Sinkhole Index Recommendations:

- Both RI and SRR show strong correlation in TYPE 3 (cover collapse) to be used as a spatial assessment of raveled soil.
- SRR showing clearer distinction in datagroups.
- Not applicable to TYPE 1 Sinkholes
  - Index only valid if directly on top of anomaly / sinkhole
  - Field testing (LSSB) & Numerical Modeling to verify Type 1 conditions
- Type 2 & 4 requires more data for validation → but is it needed?

In areas where Cover Collapse are most probable (Type 3):

- **SRR** value **< 2.0 = More Severe**
- **P*(historical occurrence)*** = $1 - 0.865\left(\frac{SRR}{SRR+2.309}\right)$

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Task 3: Setup of the Large-Scale Soil Box (LSSB)

Deconstruction (**UF**), transportation, and re-construction at campus of **UNF**

- Concrete slab, gated/locked area, tarped and covered with parking canopy
- LSSB preparation for sinkhole testing.

Deliverable **3**:

(a) Summary of the testing set up and review of site simulation

(b) Detailed description of the LSSB modification for sinkhole testing

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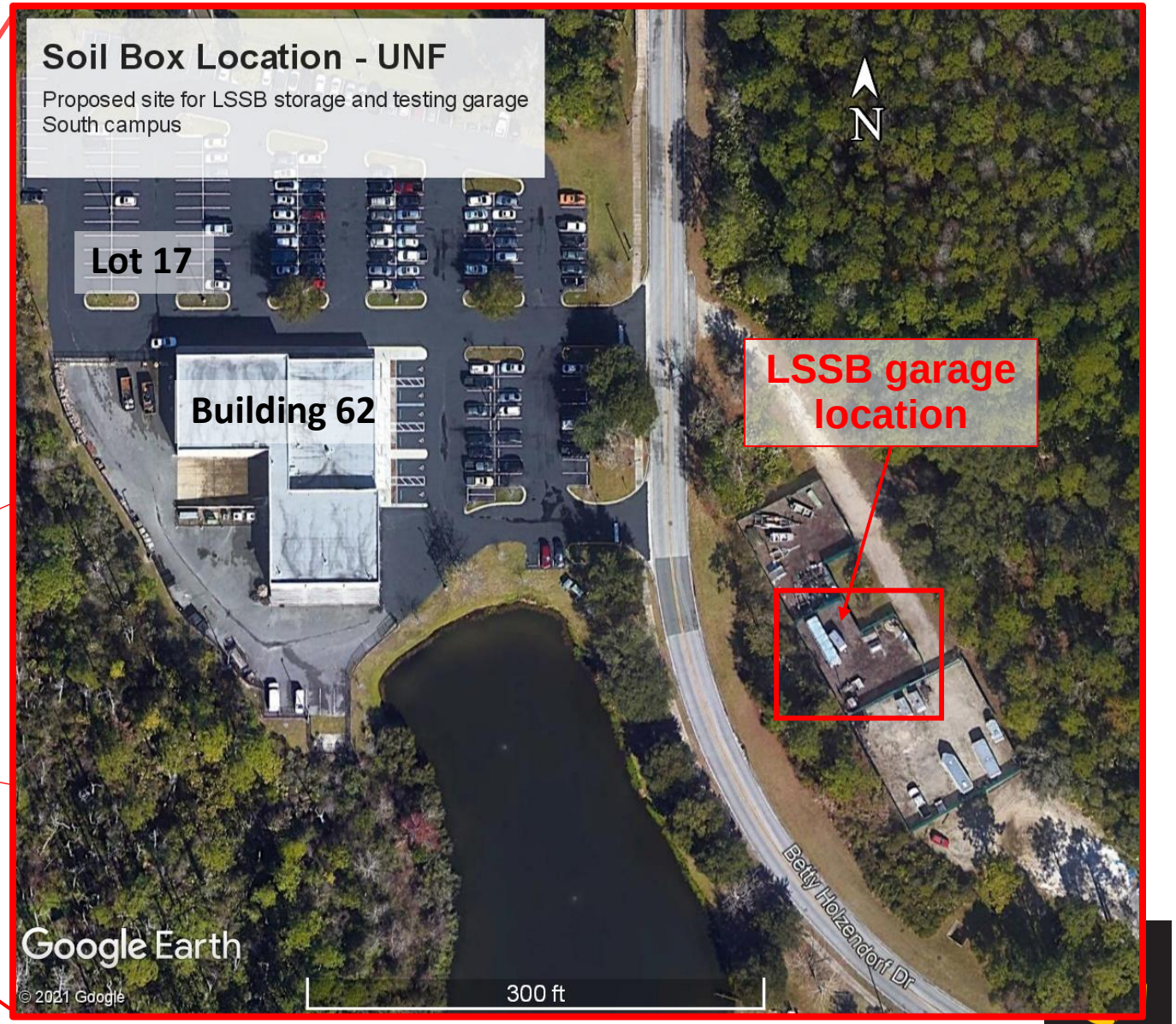


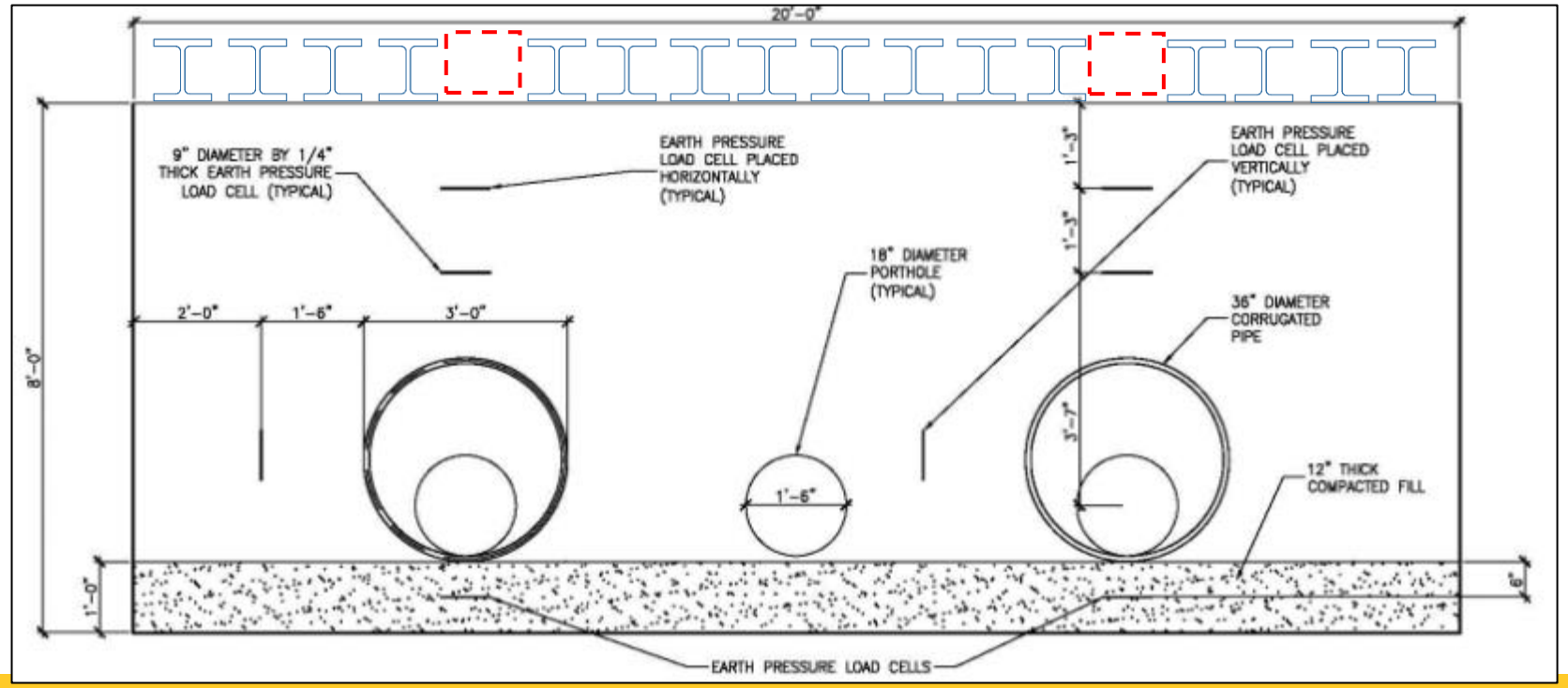
Inflated airbag to simulate overburden pressure **(ABOVE)**

Entry port for "void" installation and sediment transport **(BELOW)**

(LEFT) Installation of I-Beam roof for reaction force of airbags and overburden simulation

Planned modifications for Sinkhole Testing

- Pressure cell installation
- Piezometer installation
- Boundary conditions (plastic liner and waterproof)
- Roof plate removal/rearrange
- Catchment basin for effluent eroded slurry



(LEFT) Installation of I-Beam roof for reaction force of airbags and overburden simulation

Task 4: Sinkhole Physical Tests using the LSSB

Previous accidental sinkhole formation:
UF Thesis, Faraone 2012

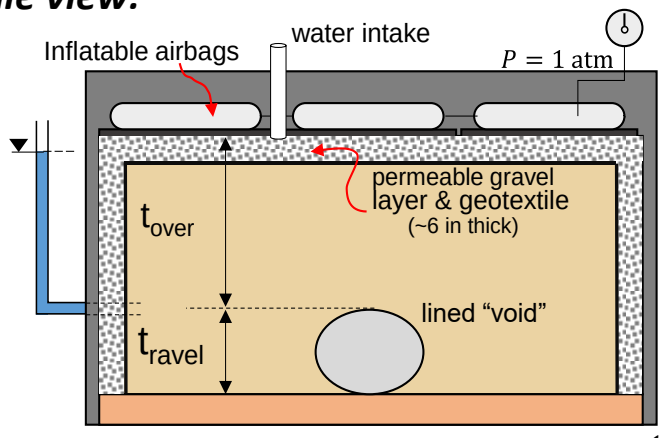
Simulate: site conditions – overburden thickness, soil type, density
Control: internal erosion – recharge via falling head
Monitor: raveling progression – collection and measurement of effluent
Identify: critical variables in relationship to sinkhole index field testing (CPT)

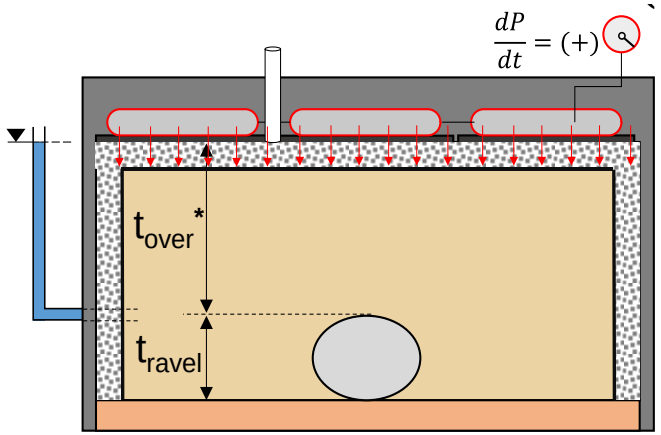
Deliverable **4**:

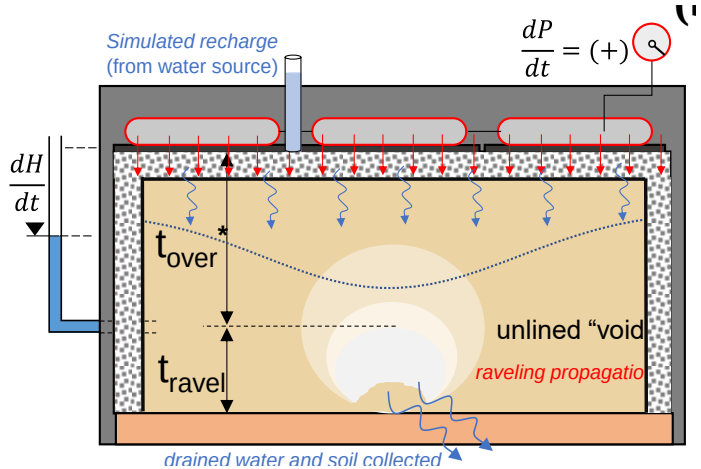
(a) Detailed testing procedure
(b) Results of physical model tests of sinkhole raveling using the LSSB

Task 4: Sinkhole Physical Tests using the LSSB

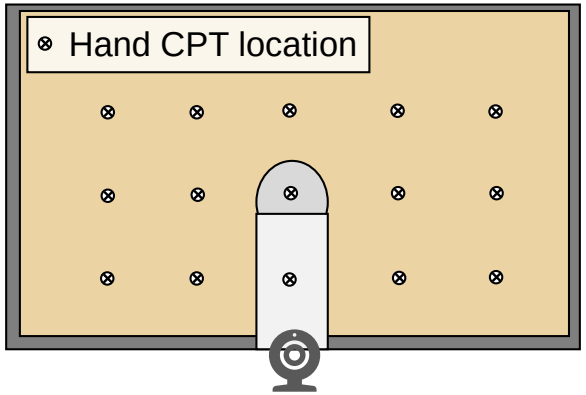
Profile view:

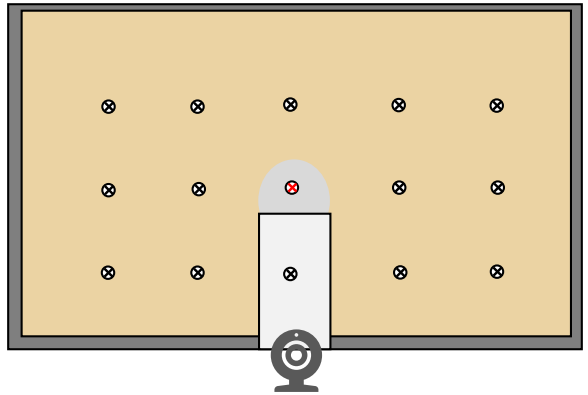


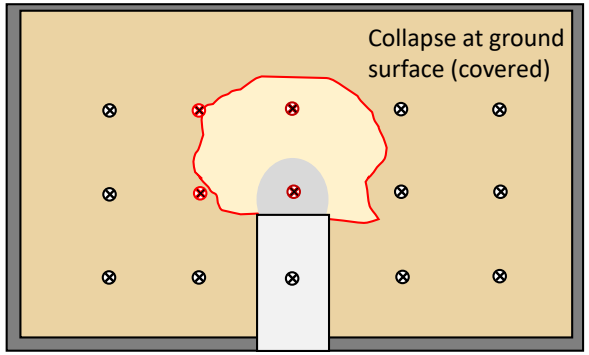




Top view:







Proposed Steps:

1. Subsurface void: installation of in situ (controllable) volume and drainage port
2. Soil fill and overburden simulation (airbag inflation)
3. reference q_c profiling (hCPT)
4. Recharge simulation, erosion monitoring, post-collapse forensics → **Sinkhole Indexing**

Task 5: Establish the severity criteria of the sinkhole index and correlate the index to the grout-take volume

- Physical meaning of the SRR values will be assigned and the corresponding severity criteria will be established.
  - Correlation between SRR and other indices (e.g., RI, probability of collapse)
  - Use of LSSB testing results to validate the SRR
- Correlation between SRR and the grout-take volume

Methodology

- Determine a method to correlate the SRR value to the amount of expected grout intake volume.
- Considerations:
  - Can a metric be developed to determine the magnitude of grouting need based on SRR value.
  - The most likely result will provide a range of expected grout volumes based on the SRR value.
  - Scale on which this research should take place; micro-scale analysis based on each individual SRR or macro-scale evaluation that considers all SRR values as a site average
- 6 sites were identified as having the necessary information; SRR values based on performed CPTs, CPT locations and grouting information to perform this analysis

Approach 1: (Macro-Scale) Site Based Analysis

Grouting Index (GI) : Compare the volume of grout used (V) and SRR, determined using the CPT profiles

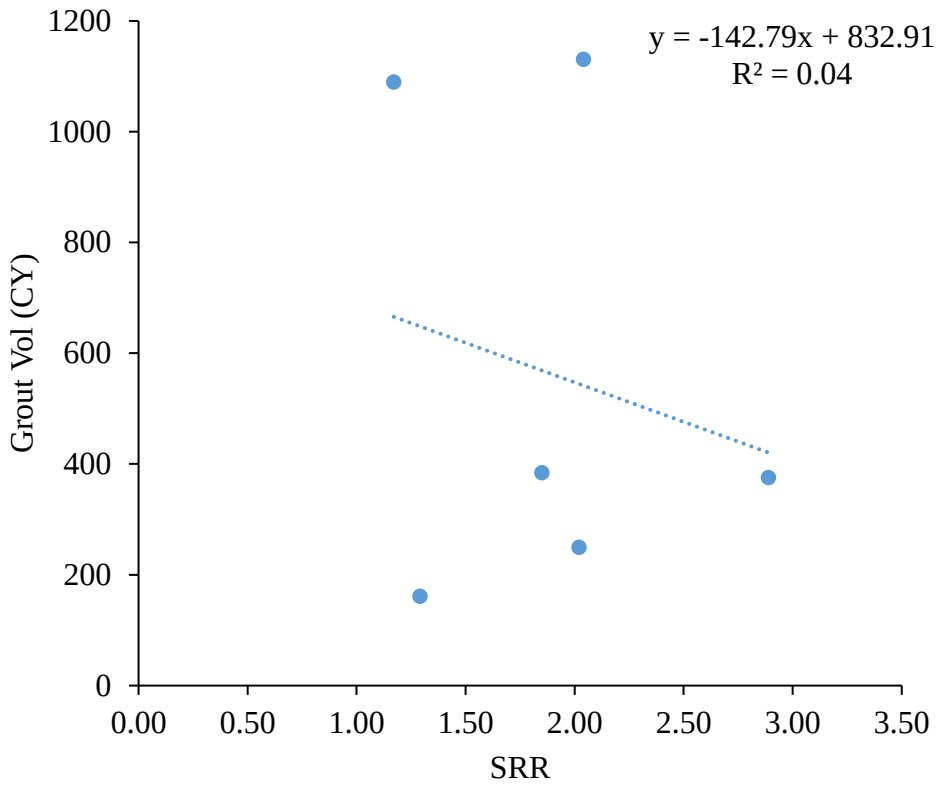
$$G_I = \frac{V}{SRR*100}$$

Use of site wide average SRR and overall grout intake

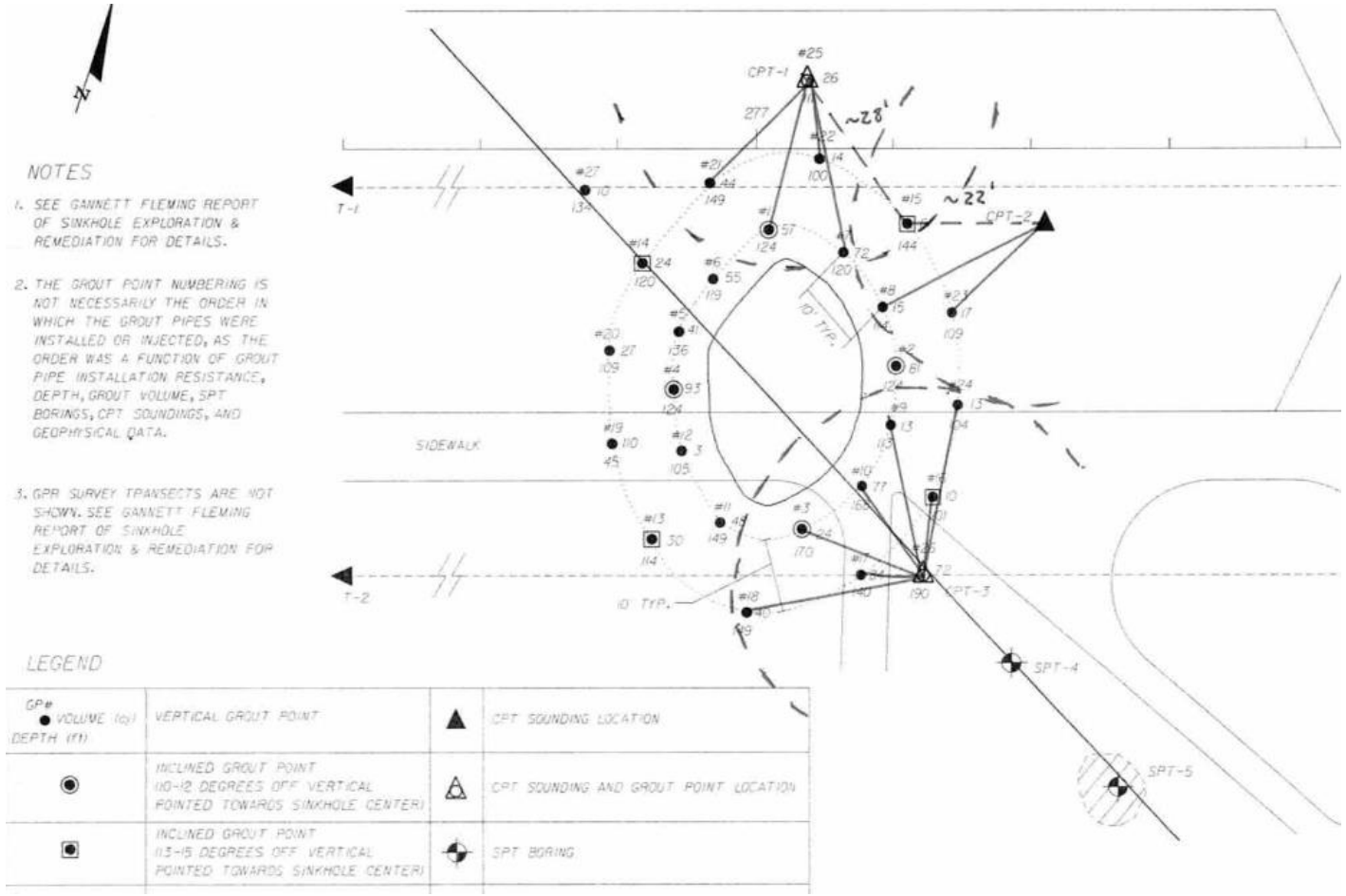
Provides a simple and quick approach to determine a relationship on a more macro scale it is dependent on the number of sinkhole site available for study.

Limitations:

- **6 sites with the available information**
- No clear indication of a correlation



Approach 2: (Micro –Scale) Individual CPT Based Analysis

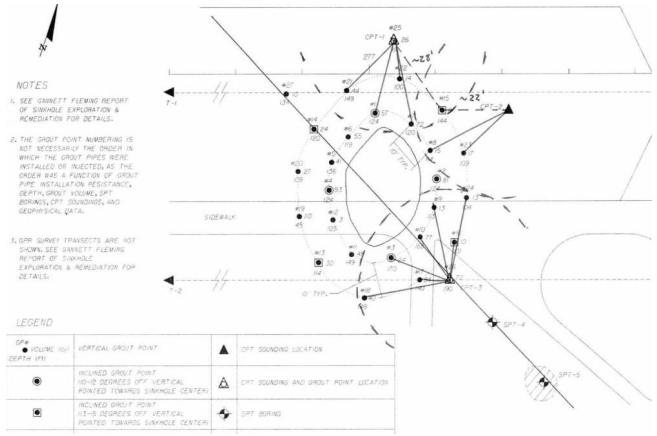


- Based on individual CPT locations compared to localized grout volumes.
- Grouting point (GP) locations must be known relative to the CPTs as well as the grout intake volume at each grouting location.
- When determining which GP to associated with which CPT, Engineering Judgement was used based on the following criteria:
  - Begin with a standard radius of influence of approximately 30 feet
  - For GPs located directly on a CPT, no other CPT will be considered as contributory
  - If another CPT is directly in the path to a GP, the original CPT is not considered as contributory
  - If a previously placed GP is directly in the path to a new GP, the new GP is not considered as contributory.

Approach 2: (Micro –Scale) Individual CPT Based Analysis

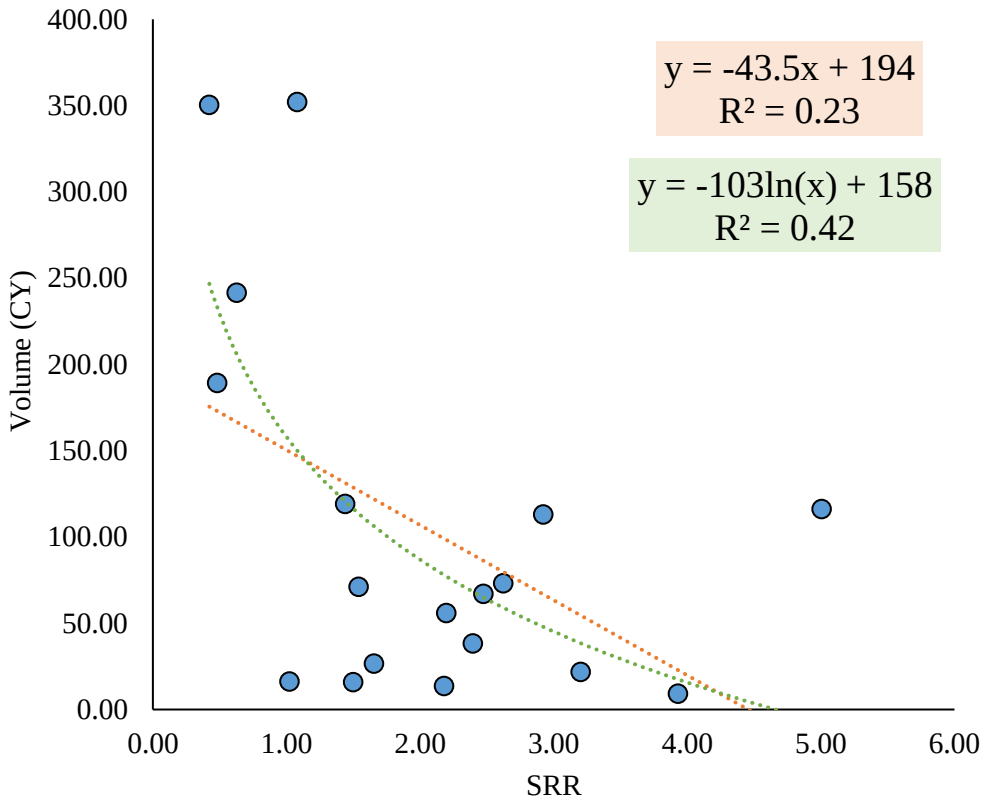
- For GP that contribute to two or more CPT locations an inverse proportionality, based on distance, is used to determine the respective grout volumes per CPT.

$$V_{CPT1\,@\,GP1} = V_{GP1}\left(\left(\frac{distance_{to\ CPT3}}{distance_{sum\ total}} * \frac{distance_{to\ CPT2}}{distance_{to\ CPT1} + distance_{to\ CPT2}}\right) + \left(\frac{distance_{to\ CPT2}}{distance_{sum\ total}} * \frac{distance_{to\ CPT3}}{distance_{to\ CPT1} + distance_{to\ CPT3}}\right)\right)$$

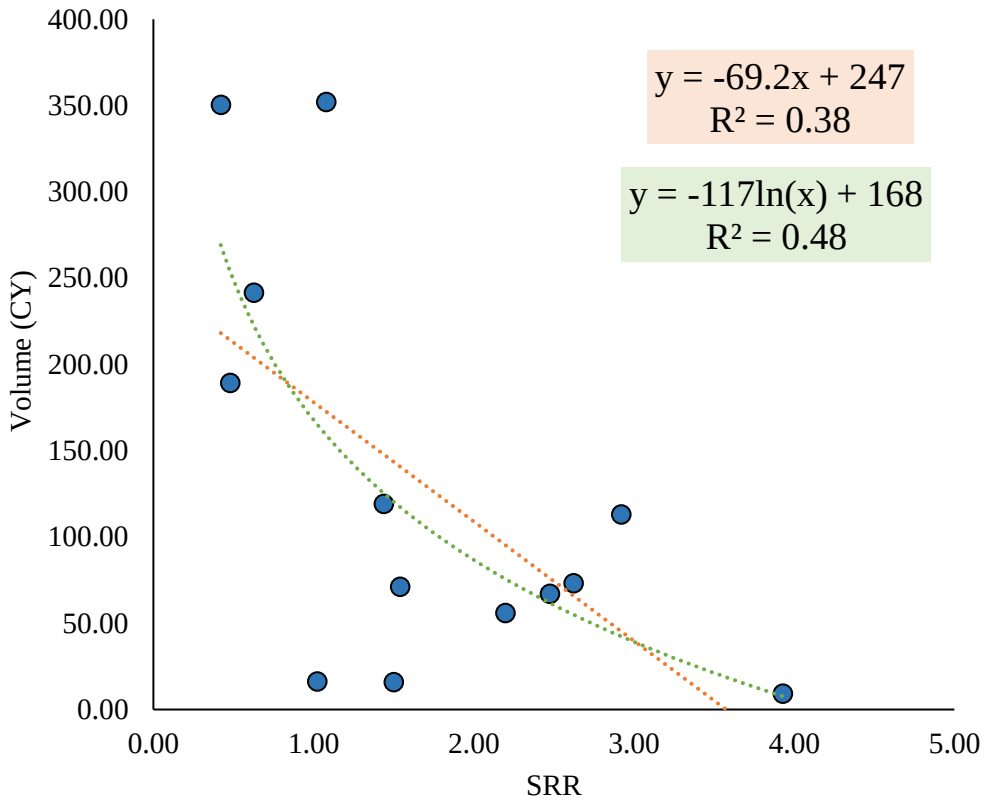


Grouting Point Number	1	7	15	21	22	25	Total Volume (CY)	SRR	GI
GP Total Volume (CY)	57.6	72.4	61.3	44	14.3	26.3			
CPT 1 GP Volume	57.6	72.4	26.972	44	14.3	26.3	241.57	0.63	3.85

Approach 2: (Micro –Scale) Individual CPT Based Analysis



All Sites



Type 3 Only

Task 5: Summary of Findings

- Based on the limited dataset a micro-scale analysis using individual CPT locations provides the best correlation between the SRR value and grout volume.
- There is a logarithmic relationship between SRR and grout volume. As the SRR value decreases, becoming more vulnerable to sinkhole development, the grout volume grows exponentially.
- The variability in grout volume need most likely increase as the SRR value decreases.
- More data will help! Field & Laboratory (LSSB?)

Project Timeline

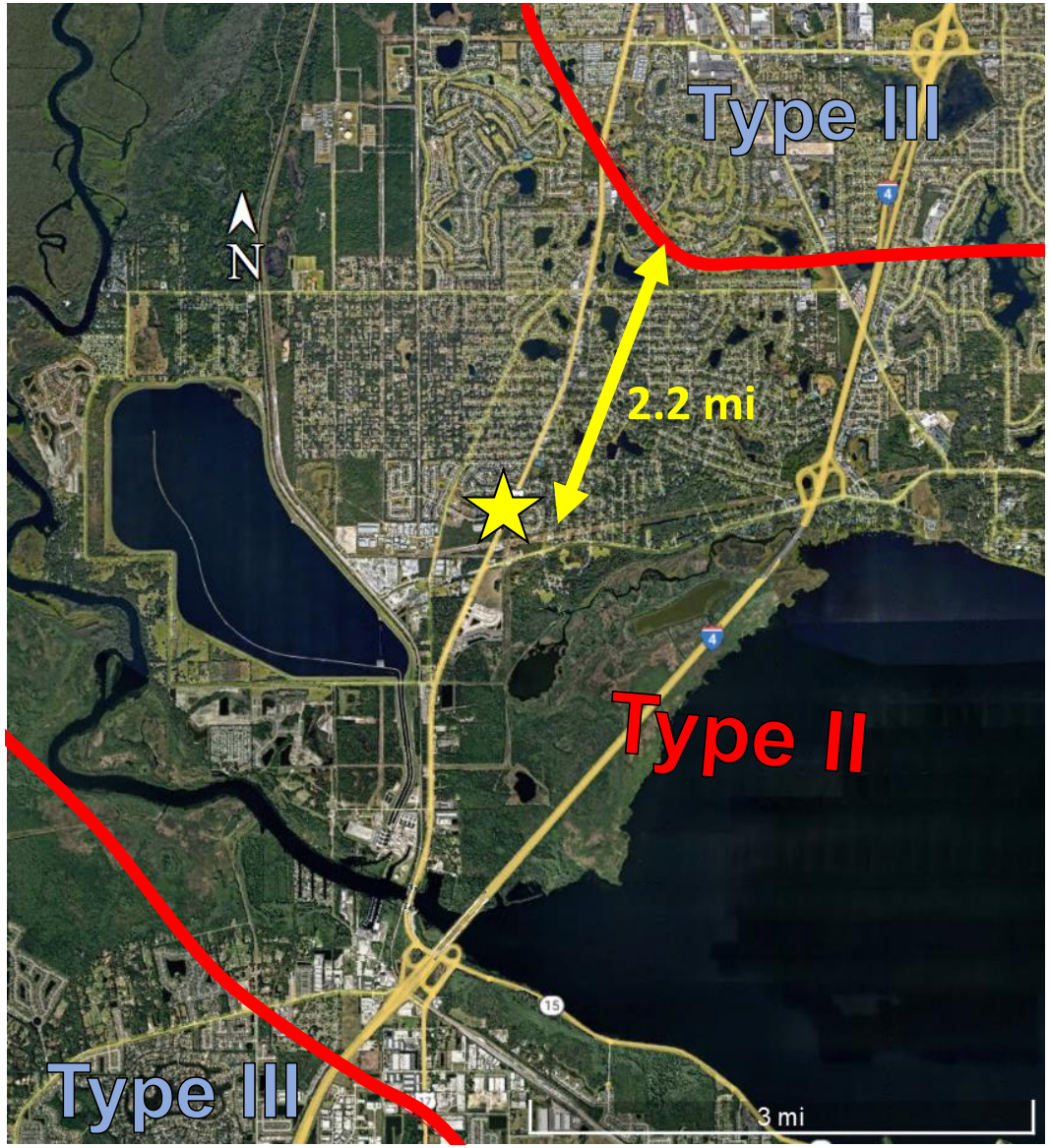
Deliverable # / Description as Provided in Scope (Associated Task)	Anticipated Date of Deliverable Submittal Month/Year	Comments
Project Kickoff Teleconference/Presentation	June 2021	Completed
Deliverable 1: A written report of the findings from Task 1, including: (a) summary of data collection and (b) summary of expert group meetings	January 2022	Completed
Deliverable 2: A written report on the findings from Task 2, including: (a) updated and enhanced sinkhole raveling chart, (b) criteria and standard procedure of the index calculation, and (c) results of the validation and modification (if necessary) of the index	August 2022	Completed
Deliverable 3: A written report on the findings from Task 3, including: (a) the summary of the LSSB setup and (b) detailed description of the LSSB.	February 2023	Completed

Project Timeline Cont.

Deliverable # / Description as Provided in Scope (Associated Task)	Anticipated Date of Deliverable Submittal Month/Year	Actual Submittal Date
Deliverable 4: A written report on the findings from Task 4, including (a) testing procedure and (b) results of physical model tests of sinkhole raveling using the LSSB	~~May 2023~~	In Process
Deliverable 5: A written report on the findings from Task 5, including: (a) severity criteria of the SRR, (b) correlation of the SRR to other indices (RI, factor of safety), and (c) evaluation of the effects of grout-take.	~~April 2023~~	In Process
Deliverable 6a: Draft Final Report	June 2023	In Process
Deliverable 6b: Closeout teleconference and PowerPoint presentation	September 2023	Pending
Deliverable 7: Final Report	September 26, 2023	Pending

Thank you!

Question?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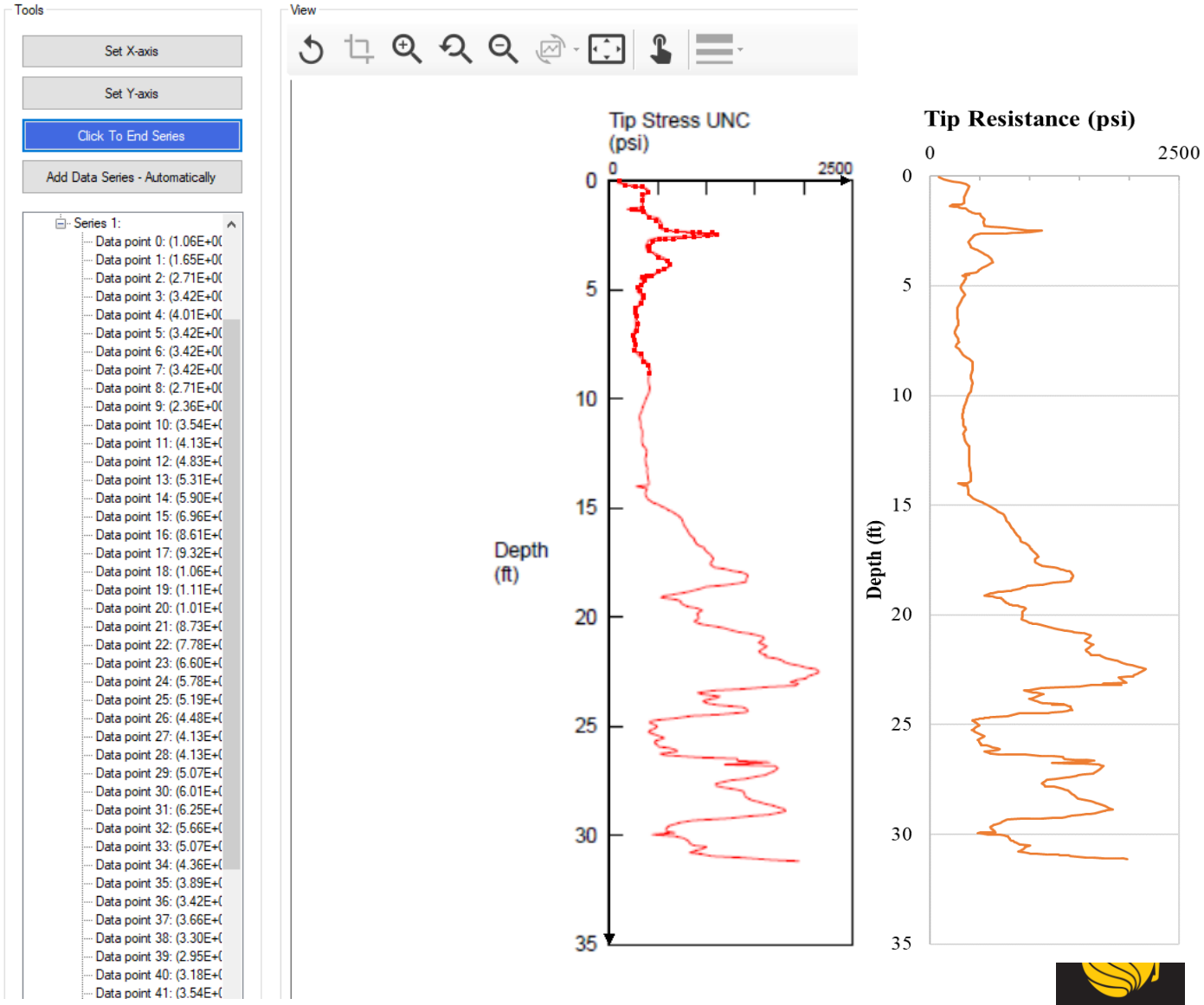
Task 1: Data Collection & Digitization

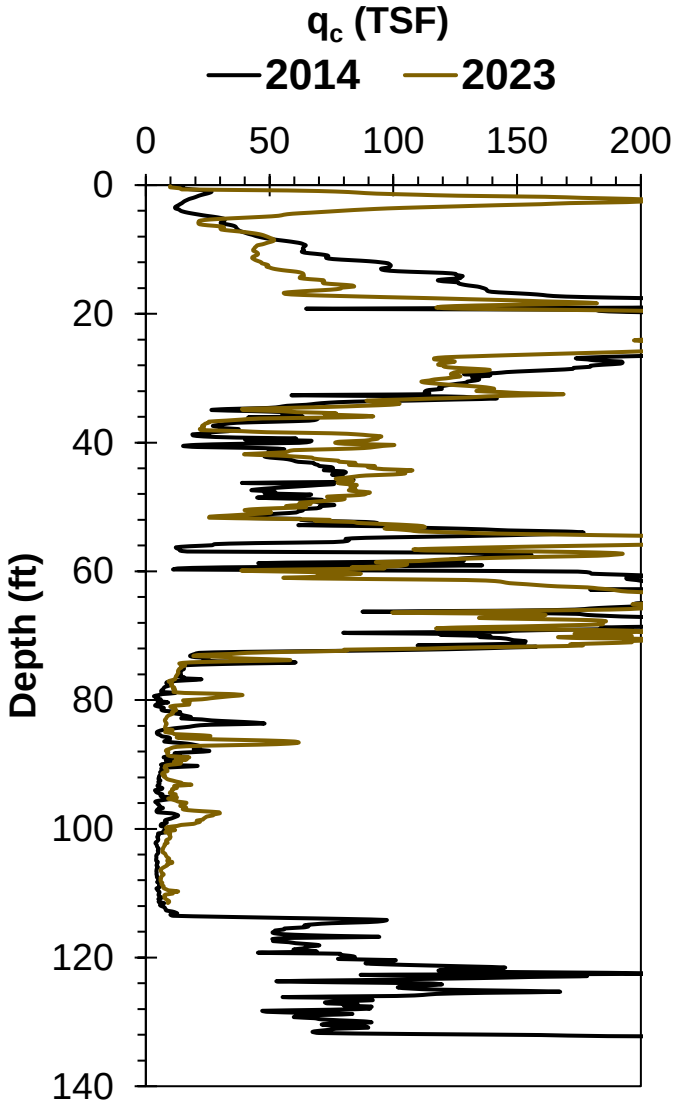
- In cases where the data was not digitized (either a picture or PDF of graphic information), the data was digitized.
- *Graph Grabber* program was used to digitize all CPT data including tip resistance (q_c), sleeve friction (f_s) and pore waster pressure when available.
  - CPT profile was imported into the software and the cursor was moved along the line and manually clicked to obtain data points.
- To aligning the tip resistance, sleeve friction and pore pressure values with depth an interpolation program was written to allow for consistent readings of each parameter per depth for each CPT data set.
- The digitized data was then compared with the PDF graphic to determine accuracy.



https://www.quintessa.org/software/downloads-and-demos/graph-grabber-2.0.2

Sinkhole Index

% Change over time



Slight % change in SRR due to CPT sensitivity