Modeling Karst-Sensitive Areas in Southwest Florida

ESRI Paper # 1608

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Abstract

Sinkholes are a common occurrence in karst-sensitive areas throughout Southwest Florida. As development pressures continue, more comprehensive regulations need to be developed to protect the aquifer in karst-sensitive areas from untreated storm water. A raster model was developed to help identify these areas where sinkholes are likely to occur. Conditions surrounding existing sinkholes were analyzed to find trends where sinkholes exist. Factors such as soil type and depth to aquifer were evaluated. Once trends were determined, a raster model was created using the established criteria. Each contributing element was given a weighted rank, based on the advice of the project geologist, and combined to create a karst-sensitive area model. The model will help drive regulation that will protect the aquifer in vulnerable areas.

1.0 INTRODUCTION

1.1 BACKGROUND

As population pressures continue at a relentless pace throughout Florida, development guidelines are needed to help ensure the safety and quality of our ground water drinking supply. The Southwest Florida Water Management District (SWFWMD) oversees this responsibility for most of the West and Southwest counties of the state. This area is known for its propensity toward sinkholes due to its karst topography. This subsurface characteristic (karst) is formed from solution pins or holes in the limestone below the soil, often described as a “swiss cheese” formation. Sinkholes can open up a direct connection to the Floridan Aquifer, Florida’s major water supply. Along with potential aquifer contamination, sinkholes cause a number of problems for Floridians including property and infrastructure damage. Jones Edmunds was challenged with helping SWFWMD to determine SKAs throughout their District. From this information, development guidelines can be created that will help reduce the occurrence of sinkholes.

To determine areas where future sinkholes are likely to occur, Geographic Information Systems (GIS) was used to analyze conditions around existing sinkholes. Subsurface Environmental Investigations (SEI) provided the locations of 2830 sinkholes in a spreadsheet format with spatial coordinates. These locations were projected to point locations in a GIS dataset to be used in the analysis. These sinkholes are believed to be the most comprehensive listing of locations in Florida. It is understood that this is not a complete list of all sinkholes in Florida but it is the best available data to date.

2.0 APPROACH AND METHODS

2.1 APPROACH

Sensitive Karst Areas are often characterized by the formation of sinkholes. By studying where sinkholes occur and the conditions surrounding them, correlations can be drawn as to what conditions favor sinkhole occurrences, and thus SKA.

Factors that could have an influence on sinkhole occurrence were considered for this study. Examples of these factors included soil type, and depth to Floridan Aquifer. Each individual factor used in this study will be further discussed in the following paragraphs.

The criterion was examined individually with respect to its influence on sinkholes. The sinkhole locations were intersected with each criterion to determine a rate of occurrence for the attributes making up that criterion. For example, with regards to soil type, soils were intersected with each of the 2830 sinkholes. Then the percentage of each soil type was calculated for the whole study area. From that information, a rate of occurrence was calculated. In the case of Hydric Group C soils, 234 sinkholes occurred on this type of soil type, where Hydric Group C makes up 13.5% of the study area resulting in a .0066 sinkholes per 100,000 acres rate of occurrence for Hydric Group C soils. This rate of occurrence was calculated for each soil type in the study area.

From the data obtained by each criterion we could draw correlations between each individual criterion and sinkhole occurrence. In the case of soils we had a strong correlation between sinkhole occurrence and Hydric Group A soils. From this data we could begin to put together a model, using raster modeling, where grid surfaces are used to weight the significance of criteria associated with sinkhole occurrence.

2.2 METHODS

Raster modeling was used for the analysis that supported this study. The following is a background on this type of GIS modeling:

GIS layers are created for the various site selection evaluation criteria. GIS layers are equivalent to variables in a mathematical statement. A rectangular mesh, or grid, is imposed on the GIS layers, thereby dividing the layers into grid cells. Each grid cell represents a location and a value for each variable. Grid layers are ranked and weighted by importance and combined to create a composite map depicting site suitability based upon all variables.

3.0 SINKHOLE EVALUATION

3.1 INTRODUCTION

Sinkhole occurrence suitability criteria were developed and evaluated by Jones Edmunds staff specializing in geology, environmental science and GIS with input from representatives of SWFWMD. The following geophysical and environmental factors were determined by Jones Edmunds to possibly have and influence on the rate of sinkhole occurrence.

- Top of the Intermediate Aquifer
- Top of the Floridan Aquifer
- Thickness of the Surficial Aquifer
- Thickness of Overburden of Floridan Aquifer
- Thickness of Hawthorn Group
- Hydric Soil Group
- Recharge and Discharge Conditions
- Closed Topographic Depression Density

- Marine Terraces
- Urban and Built-Up Land Use

3.2 EVALUATION CRITERION

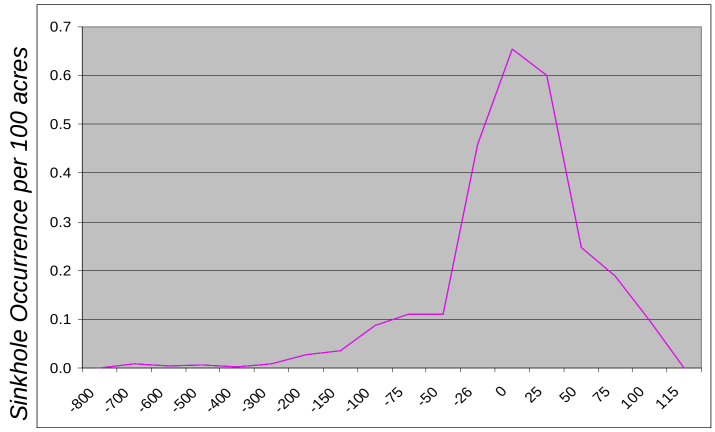
The following paragraphs explain each criteria listed above. The results of each criteria is demonstrated through a map showing the spatial locations of sinkholes and the attributes of that criterion. A map or chart of is also provided that demonstrates the rate of occurrence.

3.3.1 Proximity to Various Aquifer Depths and Subsurface Layer Thickness

Florida Geological Survey (FGS) created several GIS layers modeling different subsurface factors within the SWFWMD district. These data were created in a grid format with a 400x400 meter cell size. For this study the following subsurface factors were evaluated:

- Top of the Floridan Aquifer
- Top of the Intermediate Aquifer
- Thickness of the Surficial Aquifer
- Thickness of Overburden of Top of Floridan Aquifer (Ground Surface Elevation minus Top of Floridan Aquifer Elevation).
- Thickness of the Hawthorn Layer

3.3.2 Elevation of the Top of the Intermediate Aquifer



Elevation of the Top of the Floridan Aquifer
(feet above mean sea level/NGVD)

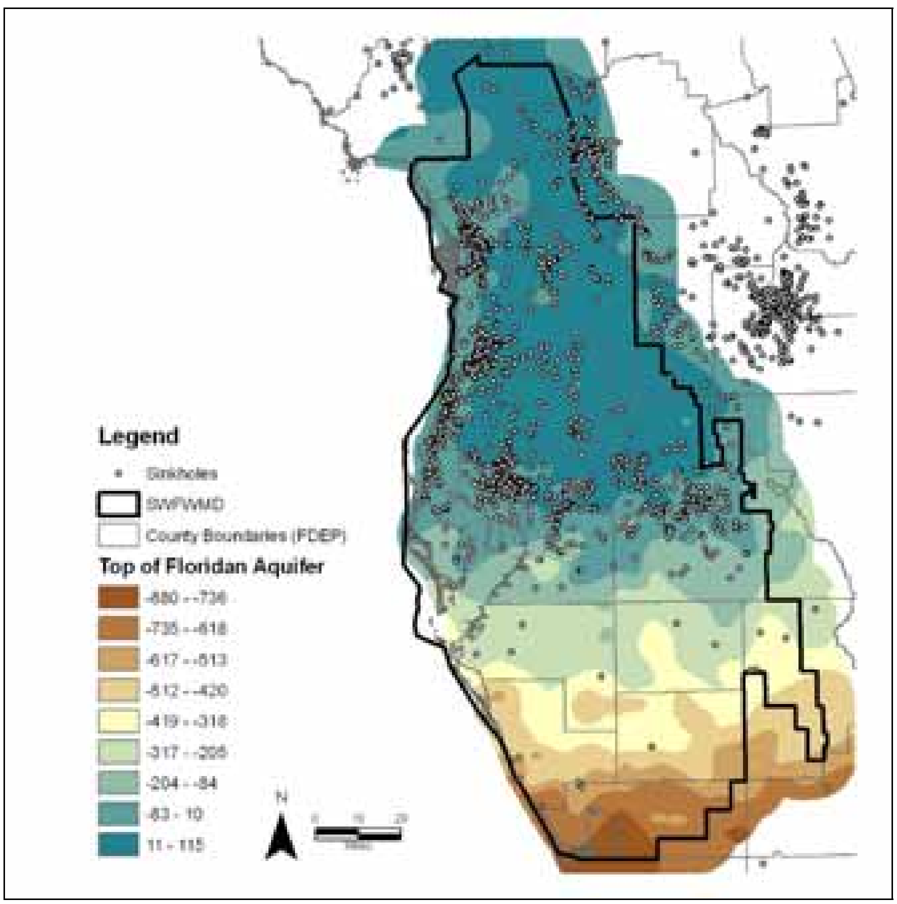
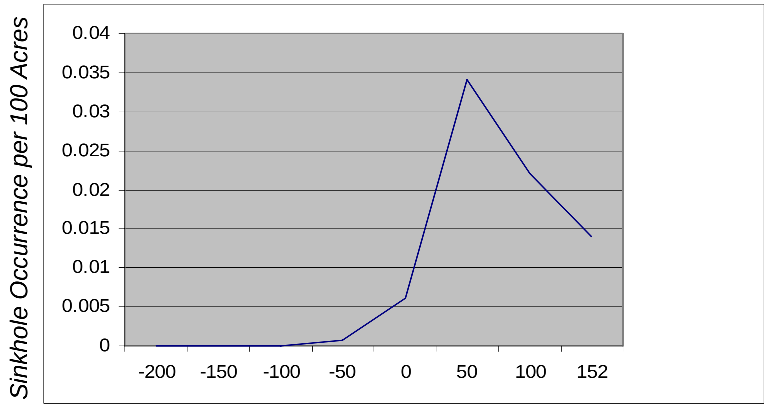


Figure 1 - Top of the Floridan Aquifer Elevation

3.3.3 Top of the Intermediate Aquifer



Elevation of the Top of the Intermediated Aquifer
(feet above mean sea level/NGVD)

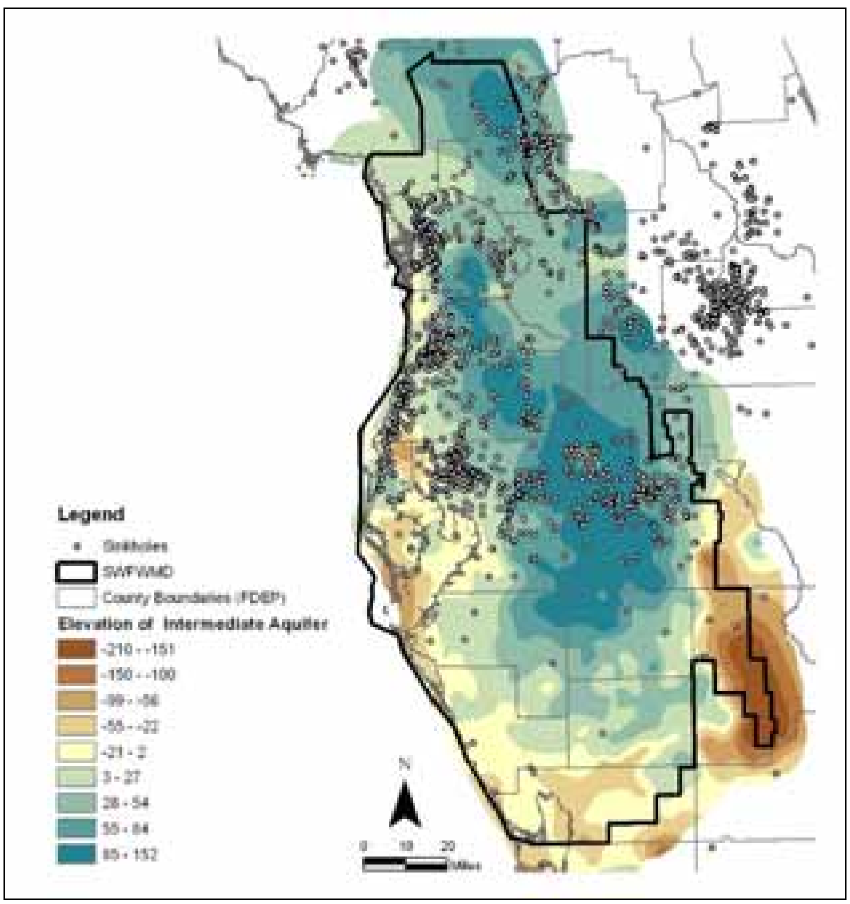
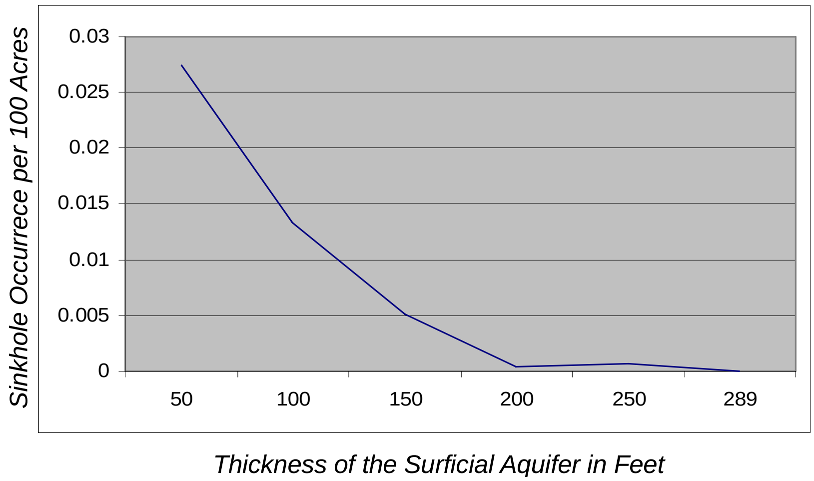


Figure 2 – Top of Intermediate Aquifer

3.3.4 Thickness of Surfical Aquifer



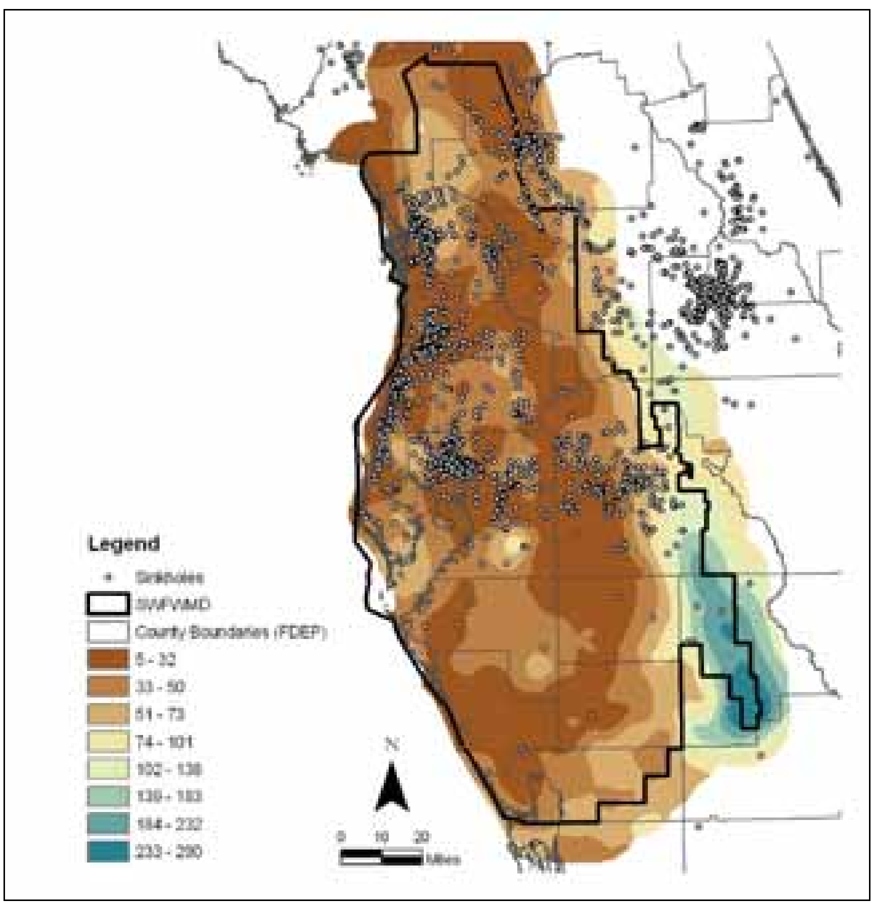
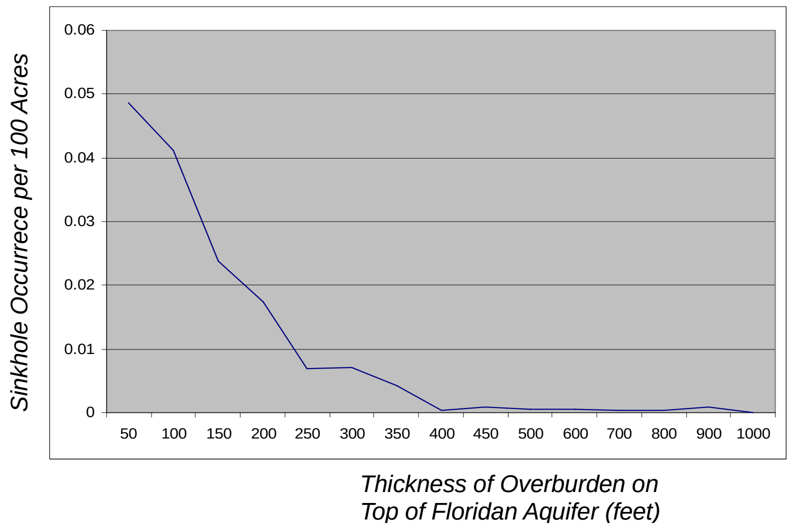


Figure 3 – Thickness of the Surficial Aquifer

3.3.5 Thickness of Overburden over the Floridan Aquifer



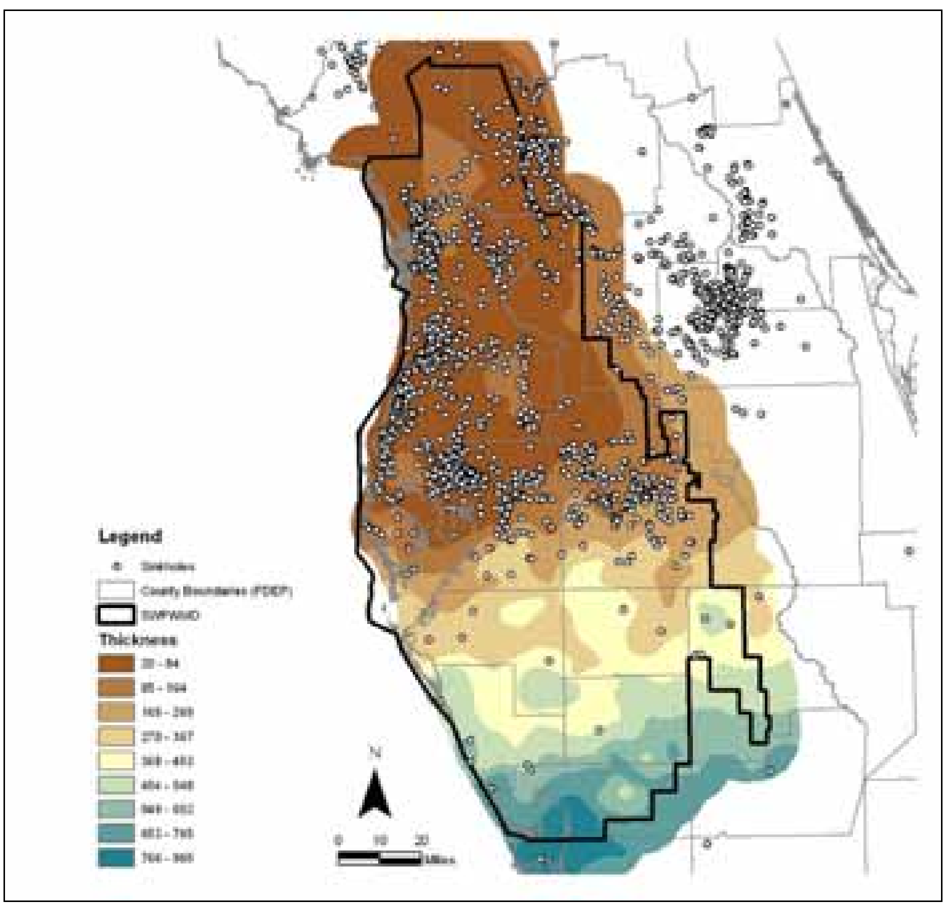
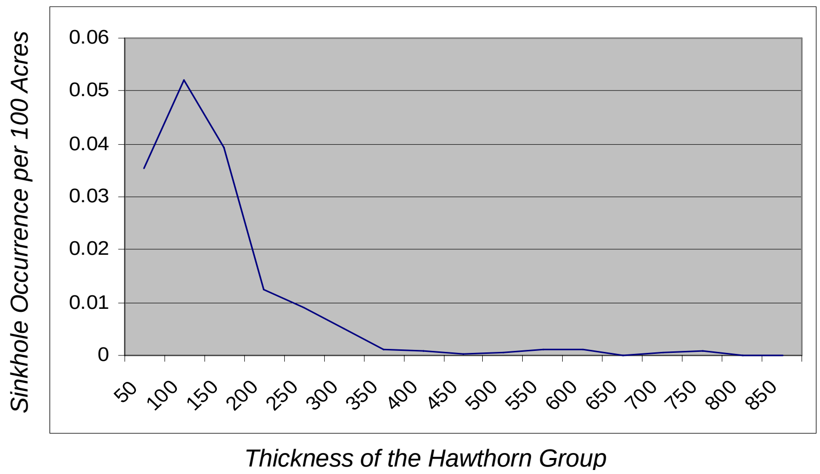


Figure 4 – Thickness of Overburden Over the Floridan Aquifer

3.3.6 Thickness of the Hawthorn Group



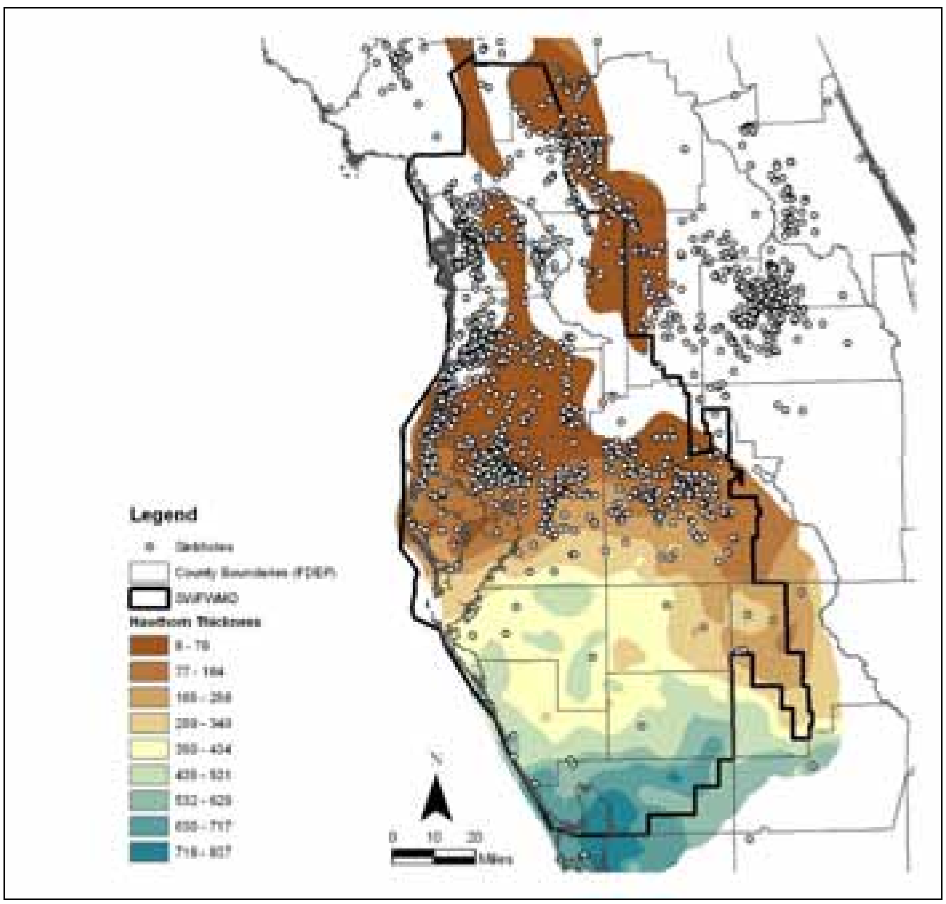


Figure 5 – Thickness of the Hawthorn Layer

3.3.7 Sinkholes in relation to Hydric Soil Groups

Soils data from SSURGO was intersected with sinkholes. This data was evaluated at the statewide level since data was available for sinkholes and soils at this level. A rate of sinkhole occurrence was calculated for each soil type.

Totals by Sinkhole		
A	854	58.33%
A/D	1	0.07%
B	8	0.55%
B/D	284	19.40%
C	234	15.98%
C/D	1	0.07%
D	82	5.60%

Totals over all by Soils		
A	7232553024	27.67%
B/D	10867533948	41.58%
B	78196967	0.30%
C	3521682055	13.48%
C/D	22214387	0.09%
D	4411881594	16.88%

A		11.81
A/D	NA	
B		10.23
B/D		2.61
C		6.64
C/D		4.50
D		1.86

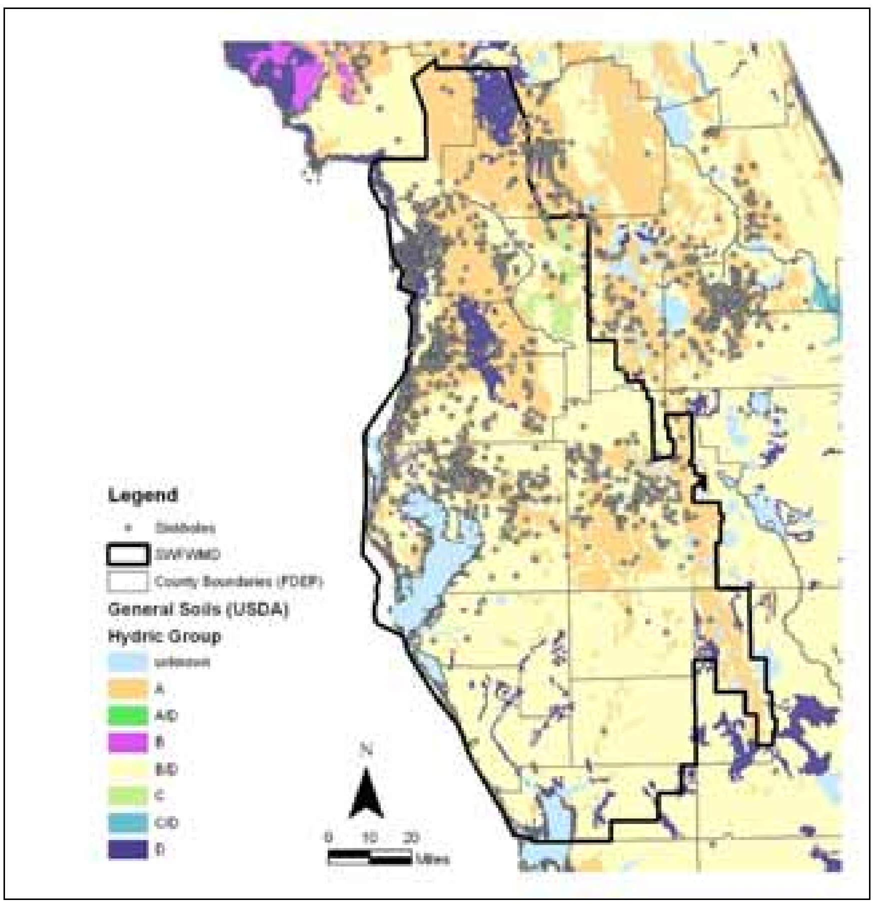


Figure 6 - Soils by Hydric Group

3.3.8 Sinkholes in relation to Recharge and Discharge Conditions

A model showing recharge and discharge of the Floridan Aquifer was created by the SWFWMD. This data as intersected with sinkholes to evaluated the areas where most sinkholes were occurring.

Totals by Sinkhole		
Discharge 0 to 9.99 inches/year	223	8.50%
Discharge 10 to 19.99 inches/year	3	0.11%
Recharge > 25 inches/year	21	0.80%
Recharge 0.01 to 3 inches/year	236	8.99%
Recharge 10.01 to 25 inches/year	1373	52.30%
Recharge 3.01 to 10.01 inches/year	769	29.30%
(blank)		
Grand Total	2625	

Totals for Whole Area		
Discharge => 20.00 inches/year	70	0.11%
Discharge 0 to 9.99 inches/year	36274	57.58%
Discharge 10 to 19.99 inches/year	122	0.19%
Recharge > 25 inches/year	162	0.26%
Recharge 0.01 to 3 inches/year	10582	16.80%
Recharge 10.01 to 25 inches/year	8171	12.97%
Recharge 3.01 to 10.01 inches/year	7619	12.09%
Grand Total	63000	

OCCURANCE		
Discharge => 20.00 inches/year	0	0.000
Discharge 0 to 9.99 inches/year	0.0061	0.615
Discharge 10 to 19.99 inches/year	0.0246	2.459
Recharge > 25 inches/year	0.1296	12.963
Recharge 0.01 to 3 inches/year	0.0223	2.230
Recharge 10.01 to 25 inches/year	0.168	16.803
Recharge 3.01 to 10.01 inches/year	0.1009	10.093

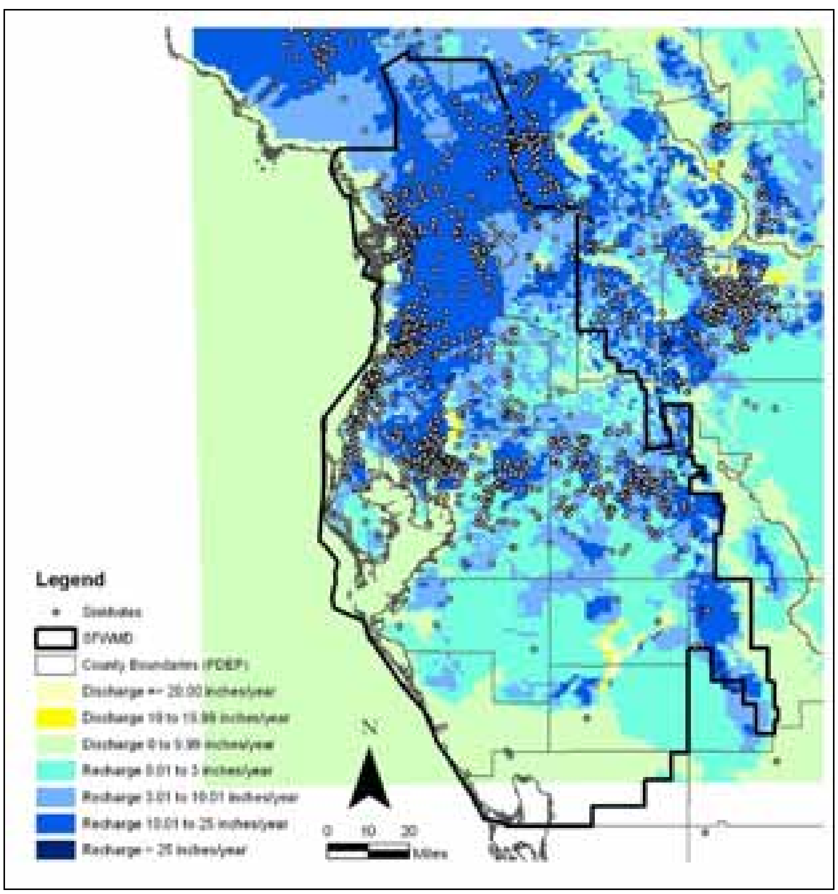


Figure 7 - Sinkholes in Relation to Recharge Areas

3.3.9 Sinkhole in relation to Closed Topographic Depression Density

Closed topographic depressions were created from USGS Quad maps. The data was digitized into a GIS dataset. From this file a point was created in the center of each closed contour. A density analysis was done and intersected with the sinkholes. It was thought that there may be a correlation between a high-density of closed topographic depressions and sinkholes, however our data did not support this.

Zone	Density	# of intersecting sinkholes	percentage of total sinkholes	total area of zone (acres)	Density within zone (sinkholes per acre)
1	0.00 - 0.01 ctd per acre	1033	61%	5,031,404	4,871
2	0.01 - 0.02 ctd per acre	528	31%	842,148	1,595
3	0.02 - 0.03 ctd per acre	126	7%	268,516	2,131
4	0.03 - 0.04 ctd per acre	10	1%	87,107	8,711
5	0.04 - 0.05 ctd per acre	1	0%	14,623	14,623
6	0.05 - 0.06 ctd per acre	0	0%	6,457	-
7	0.06 - 0.07 ctd per acre	0	0%	4,809	-
8	0.07+ ctd per acre	0	0%	337	-
	totals	**1698**	**100%**	**6,255,401**	

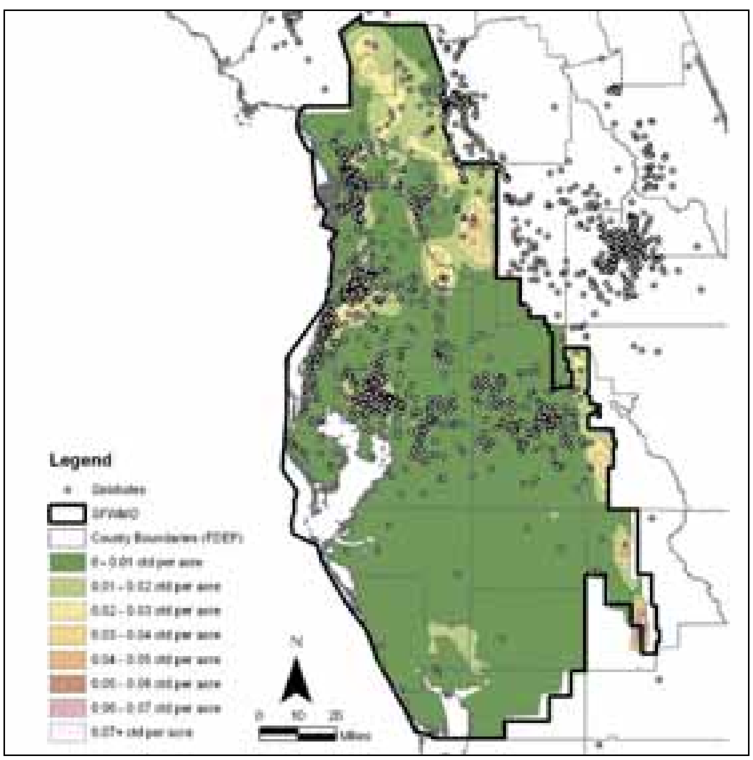


Figure 8 - Sinkholes in Relation to Closed Topographic Depressions

3.3.10 Sinkholes in Relation to Marine Terraces

				Per 10,000 Acres
Coharie Terrace	63		3.44924E-05	0.34
Includes Hazlehurst Terrace (formerly Brandywine), Coastwise Delta Plain, and part of High Pliocene Terrace	2		3.72013E-06	0.04
Includes Sunderland Terrace and Okefenokee Terrace	358		7.09475E-05	0.71
Palmlico Terrace	667		7.32305E-05	0.73
Penholoway Terrace	388		8.97091E-05	0.90
Silver Bluff Terrace	16		3.73807E-06	0.04
Talbot Terrace	401		0.000120667	1.21
Wicomico Terrace	854		0.000117328	1.17

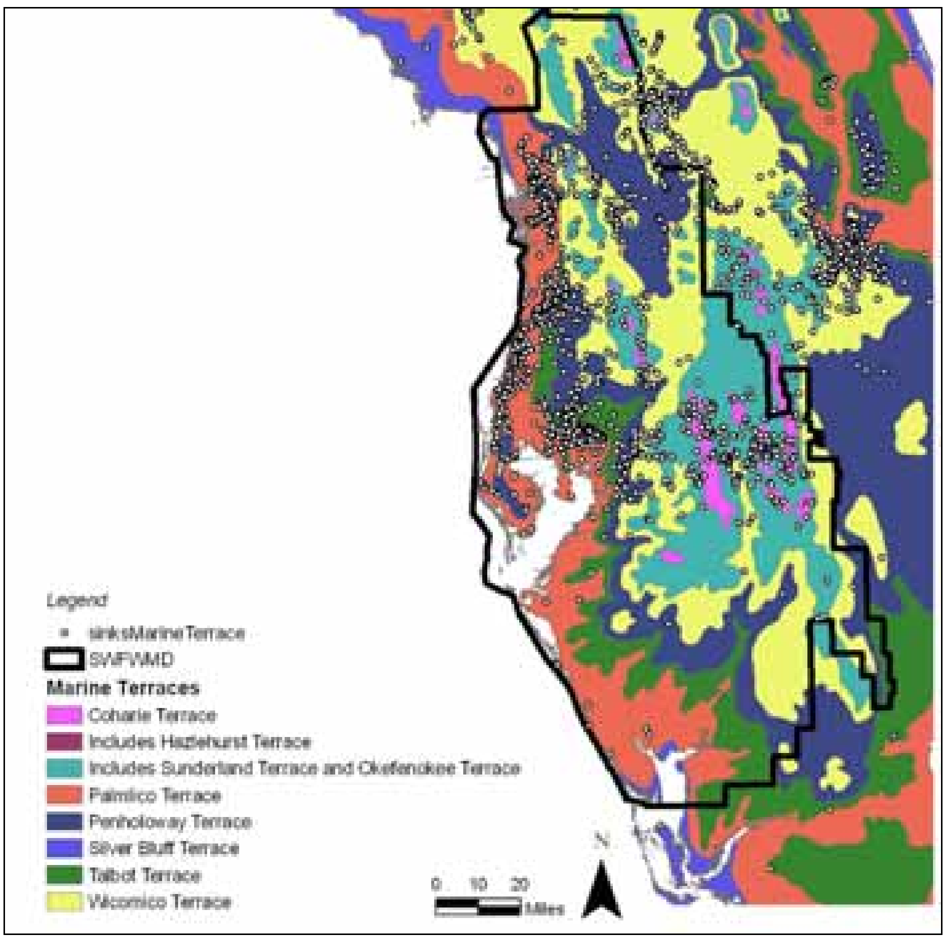


Figure 9 - Sinkholes in Relation to Marine Terraces

3.3.11 Sinkholes in relation to Urban and Built-Up Land Use.

Land Use data was provided by SWFWMD. The Urban and Built-Up areas were extracted from the data and intersected with sinkholes.

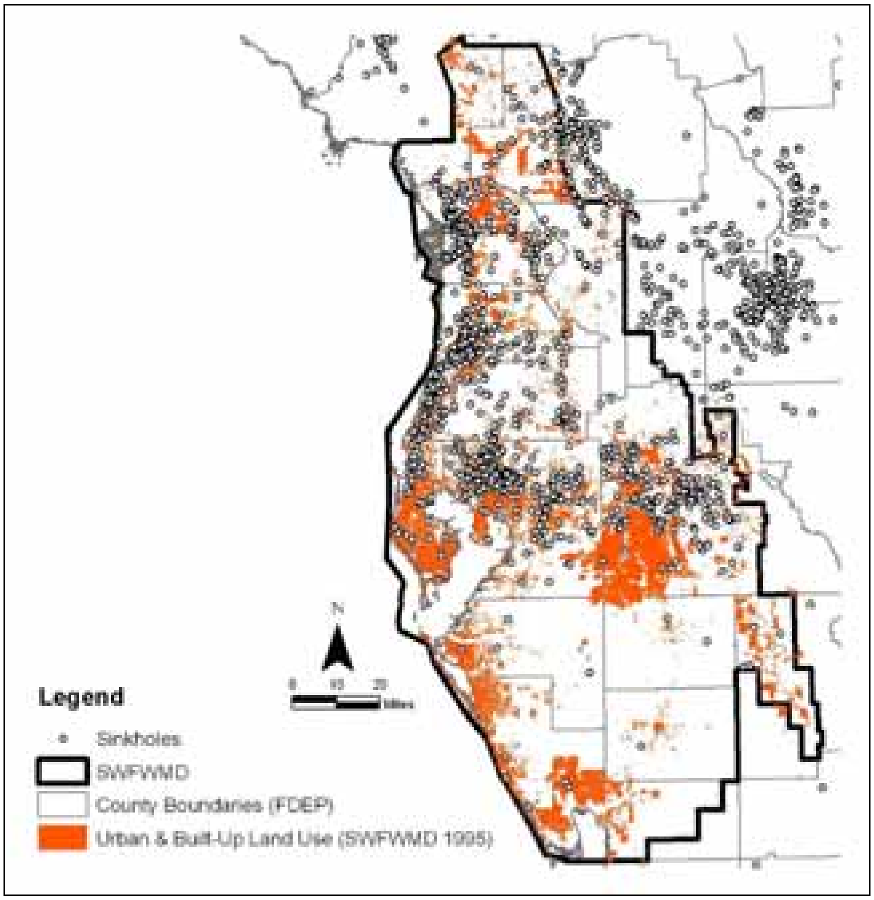


Figure 10 - Sinkholes in Relation to Urban/Built-Up Land Use

4.0 CRITERION WEIGHTING

4.1 EVALUATION

Each criterion above was evaluated for its importance to sinkhole creation based on the sinkhole rates for each attribute. Sinkhole criteria that showed a strong correlation with a particular attribute were considered to be an important characteristic of sinkhole formation. Conversely, criteria that did not show a strong correlation to a particular attribute were not considered an important element in sinkhole formation.

Each criterion determined important was then turned into a grid. Each cell of the grid represents an attribute of the criterion. Each attribute was then ranked form 0-9 based on the rate of sinkhole occurrence, 0 had no occurrence of sinkholes, and 9 had the highest occurrence of sinkholes.

The following criteria were determined to have attributes that possessed a strong correlation with sinkholes. A table is provided with the rate of occurrence for each attribute and how it was ranked. A map representing the ranking is also provided.

4.2.1 Top of Floridan Aquifer

Elevation	***Rate***	***Ranking***
-800	0.0000	1
-700	0.0081	1
-600	0.0046	1
-500	0.0059	1
-400	0.0030	1
-300	0.0091	1
-200	0.0276	1
-150	0.0350	1
-100	0.0864	2
-75	0.1105	2
-50	0.1106	2
-26	0.4593	6
0	0.6549	9
25	0.6002	8
50	0.2476	3
75	0.1889	3
100	0.0980	2
115	0.0000	1

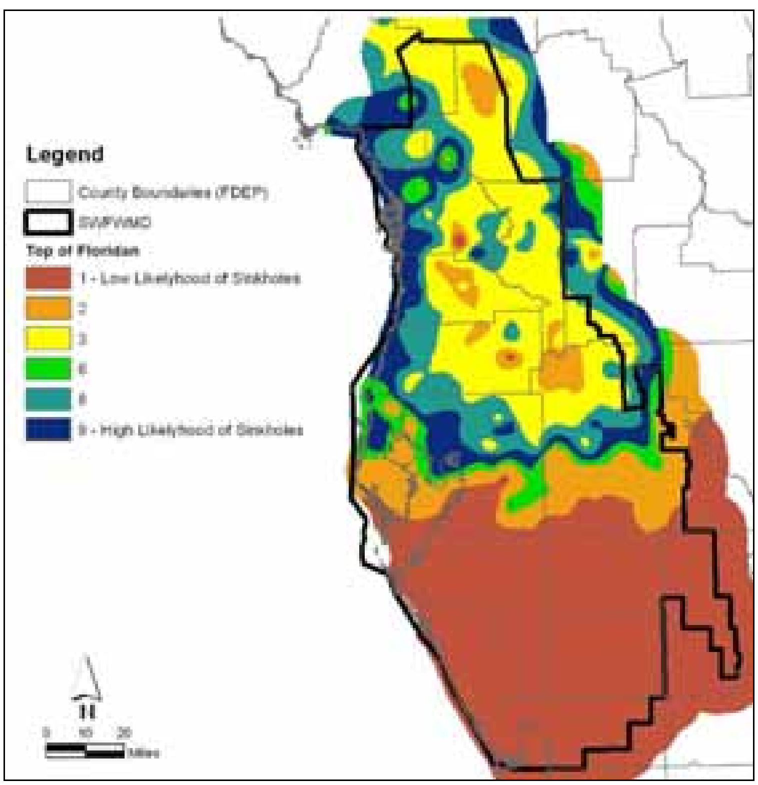


Figure 11 - Ranking of Top of Floridan Aquifer

4.2.2 Surficial Aquifer Thickness

Thickness	*Rate*	*Ranking*
1 to 50	0.027429181	9
51 to 100	0.013277151	4
101 to 150	0.00513638	2
151 to 200	0.000398668	1
201 to 250	0.000639866	1
251 to 289	0	1

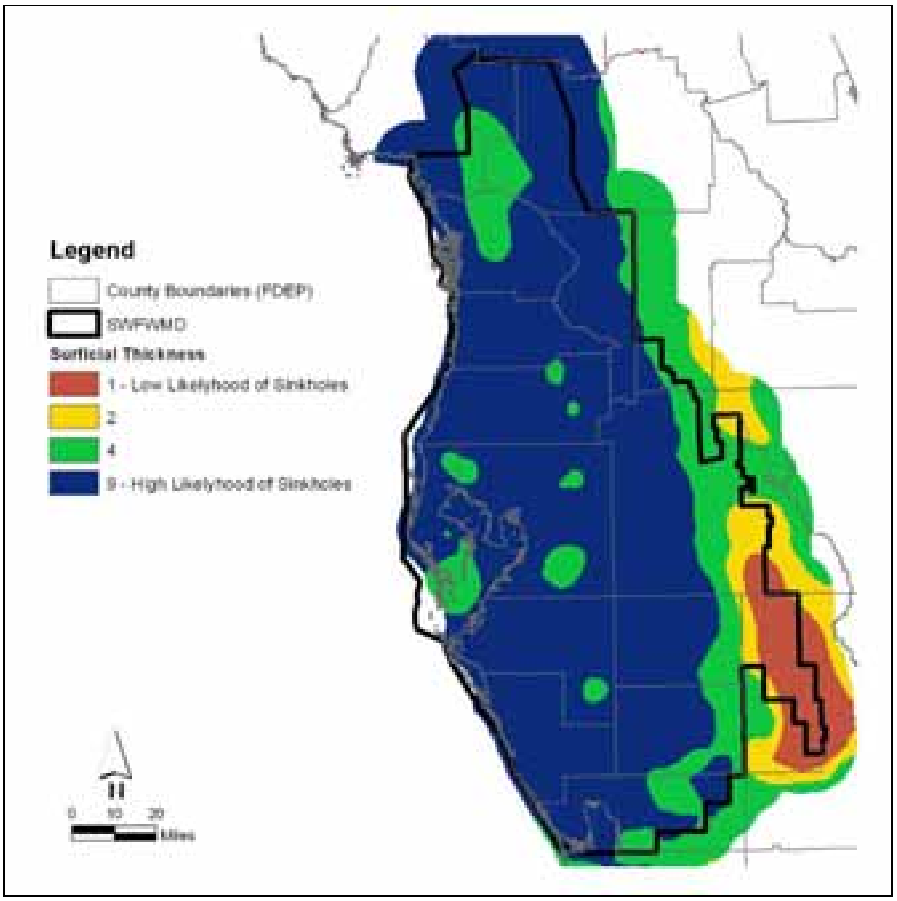


Figure 12 - Ranking of Surficial Aquifer Thickness

4.2.3 Overburden of the Floridan Aquifer

Thickness	***Rate***	***Ranking***
20-50	0.4864	9
51-100	0.4114	8
101-150	0.2373	4
151-200	0.1741	3
201-250	0.0691	2
251-300	0.0707	2
301-350	0.0430	2
351-400	0.0041	1
401-450	0.0096	1
451-500	0.0046	1
501-600	0.0060	1
601-700	0.0041	1
701-800	0.0028	1
801-900	0.0087	1
901-965	0.0000	1

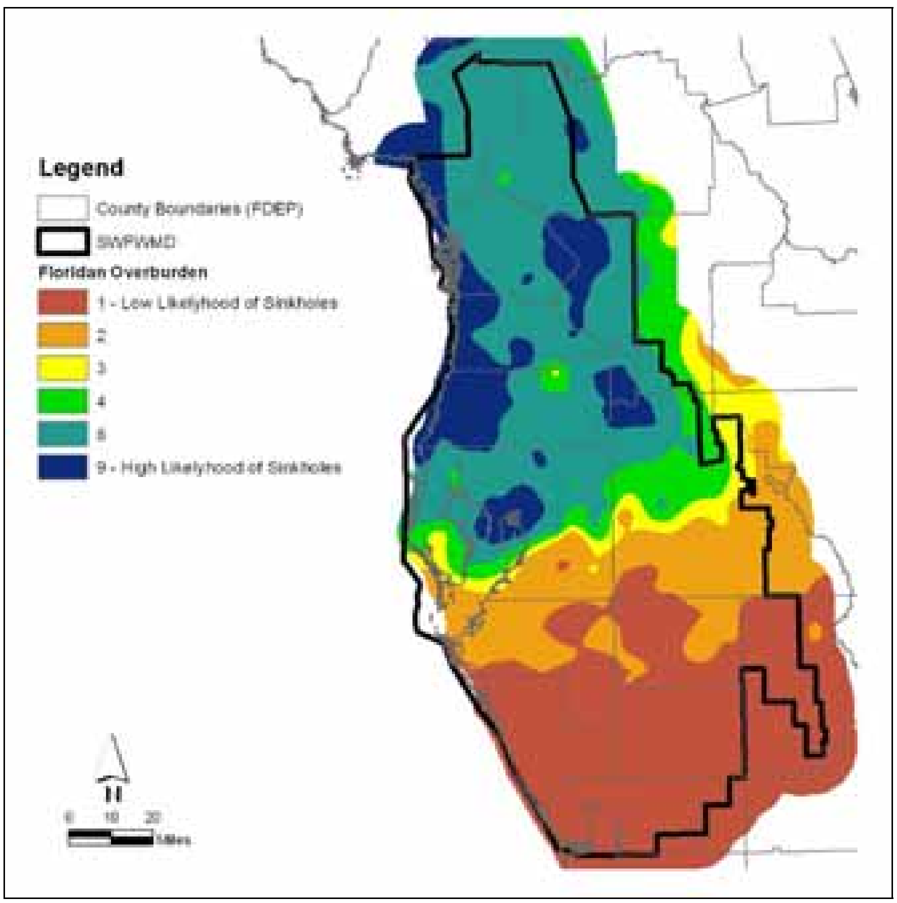


Figure 13 - Ranking of the Overburden of the Floridan Aquifer

4.2.4 Hawthorn Group Thickness

Elevation	*Rate*	*Ranking*
1 to 50	0.035300902	6
51 to 100	0.052147081	9
101 to150	0.039333489	7
150 to 200	0.012397184	2
201 to 250	0.009002483	2
251 to 300	0.005087516	2
301 to 350	0.001056949	1
351 to 400	0.000946885	1
401 to 450	0.000170539	1
451 to 500	0.000558531	1
501 to 550	0.001099457	1
551 to 600	0.001046451	1
601 to 650	0	1
651 to 700	0.000494573	1
701 to 750	0.000904417	1
751 to 800	0	1
801 to 836	0	1

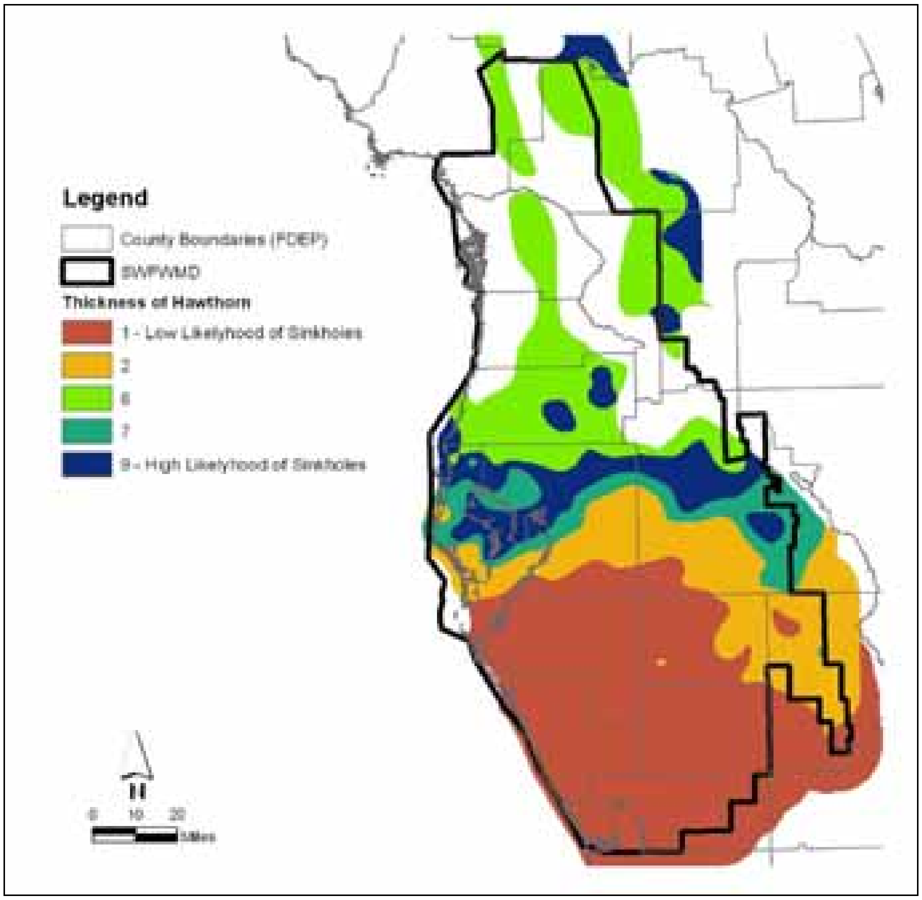


Figure 14 - Ranking of the Hawthorn Group Thickness

4.2.5 Difference between the Floridan Aquifer and Potentiometric Surface

Elevation	***Rate of Sinks***	***Ranking***
-917 to -900	0	1
-899 to -850	0	1
-849 to -800	1.13754E-05	1
-799 to -750	0	1
-749 to -700	4.14549E-06	1
-699 to -650	0	1
-649 to -600	1.01434E-05	1
-599 to -550	6.49563E-06	1
-549 to -500	1.30013E-05	1
-499 to -450	0	1
-449 to -400	1.49941E-05	1
-399 to -350	9.171E-06	1
-349 to -300	0	1
-299 to -250	3.44516E-05	2
-249 to -200	2.29625E-05	1
-199 to -150	9.48032E-05	2
-149 to -100	0.000225446	4
-99 to -50	0.000251682	4
-49 to 0	0.000519866	9
1 to 50	0.000248011	4
50 to 100	8.44324E-05	2

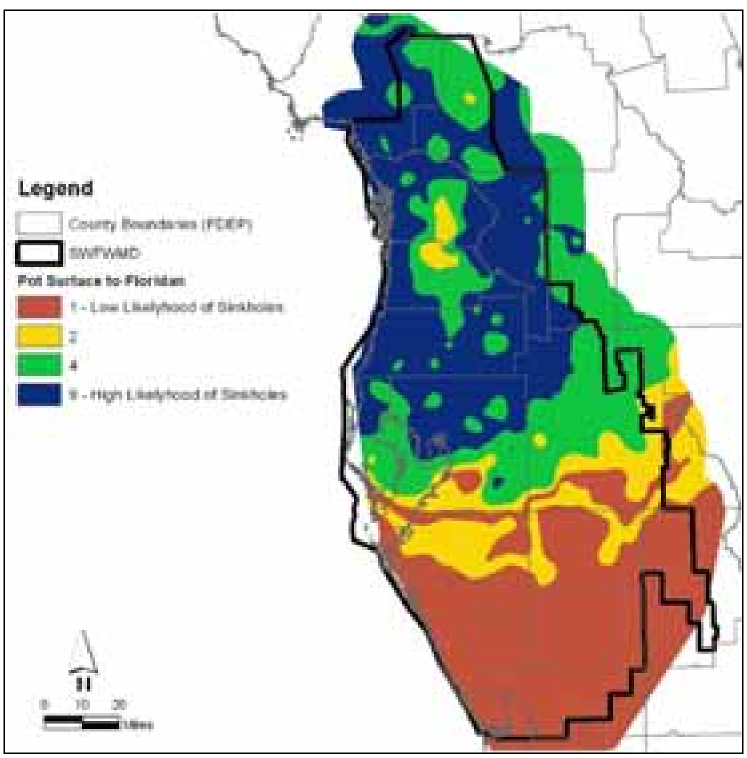


Figure 15 - Ranking of the Difference between the Floridan Aquifer and the Potentiometric Surface

4.2.6 Hydric Group Soils

Soil Type	***Rate***	***Ranking***
A	11.81	9
A/D	NA	1
B	10.23	8
B/D	2.61	2
C	6.64	5
C/D	4.50	3
D	1.86	2

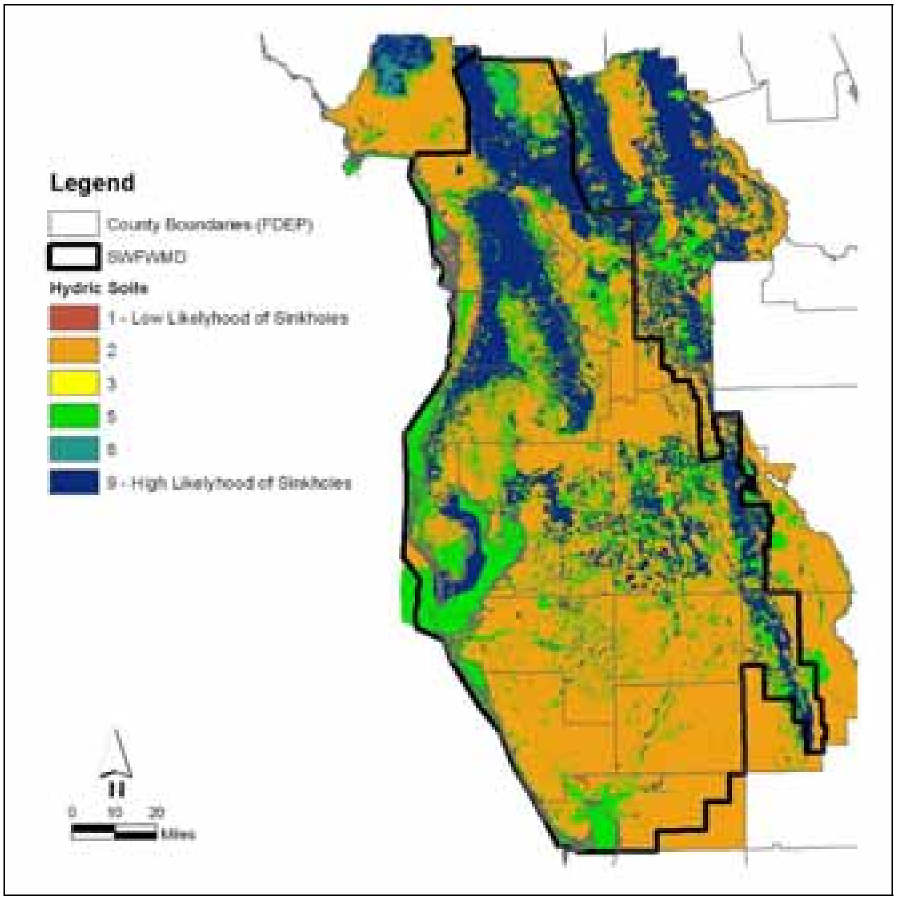


Figure 16 - Ranking of Hydric Group Soils

4.2.7 Marine Terraces

Terrace	***Per 10,000 Acres***	***Ranking***
Coharie Terrace	0.34	3
Includes Hazlehurst Terrace, Coastwise Delta Plain, and part of High Pliocene Terrace	0.04	1
Includes Sunderland Terrace and Okefenokee Terrace	0.71	5
Palmlico Terrace	0.73	5
Penholoway Terrace	0.90	7
Silver Bluff Terrace	0.04	1
Talbot Terrace	1.21	9
Wicomico Terrace	1.17	8

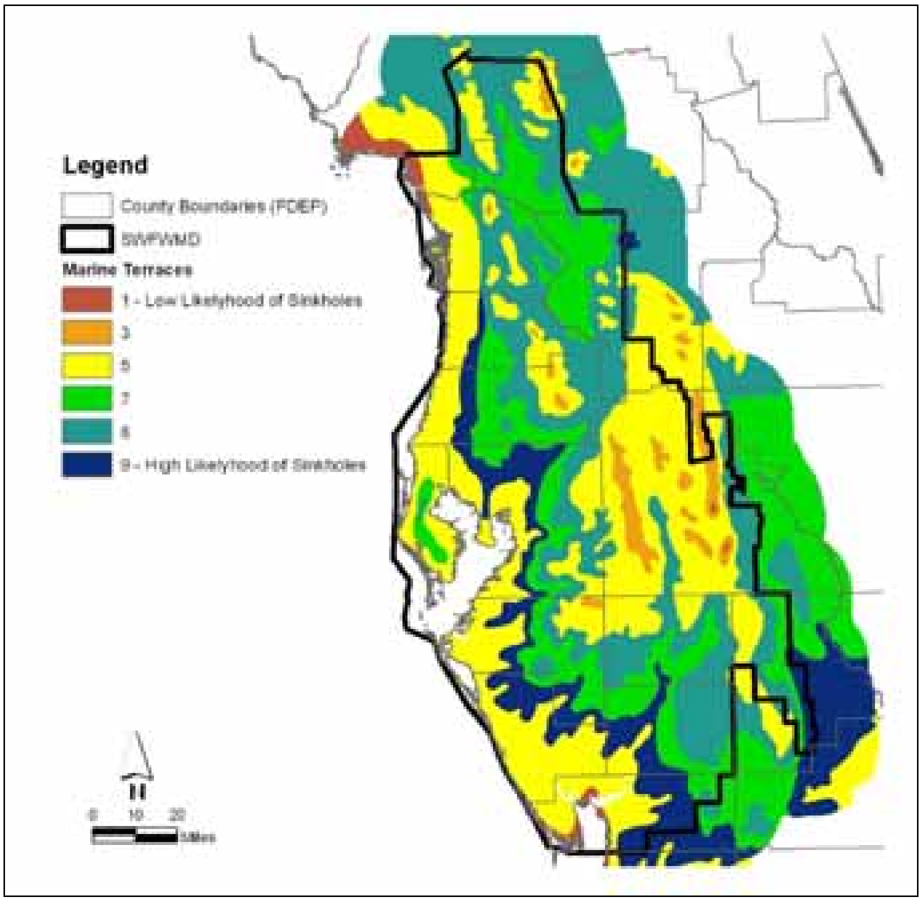


Figure 17 - Marine Terraces

4.4 DATA NOT USED

The following data was not used in a modeling portion of the study

Recharge areas – Recharge rates were not used in the study due to the coarseness of the grid the original model was created at.

Closed topographic depressions – No strong correlation was found between a high density of closed topographic depressions and sinkholes

Urban Areas – Urban areas were looked at only to show if there was a bias in where sinkholes were reported.

5.0 GIS MODELING

5.1 MODELING RESULTS

Four models were created from the above criteria. Each model was run with

For each grid cell, a ranking was assigned for each of the nine criteria (see Section 2.0 above). To come up with an overall score on a scale of 0 to 9 for each grid cell, the selected criteria were given a percent weighting according to their overall importance in the site selection. Input on criteria weighting was sought and received from Jones Edmunds personnel with expertise in Geology.

A Sensitive Karst Area score was calculated for each grid cell in the model based on the evaluation process described in Section 2.0. Grid cells that were not disqualified were scored on a normalized scale of 0-100%. A score of 90-100% meant that the grid cell's weighted average ranking was greater than or equal to the 90th percentile for all of the grid cells (i.e., the grid cell's score was greater than at least 90% of all of the grid cells). A score of 0-10% meant that the grid cell's weighted average ranking was below the 10th percentile for all of the grid cells (i.e., 90% of all of the grid cells scored better).

In terms of desirability, a score of 90-100% means that a grid cell is most likely to have sinkholes occur. Conversely, a score of 0-10% means that a grid cell is least likely to have sinkholes occur. These desirability rankings reflect only the criteria used in this study.

5.2 MODELS

5.2.1 Model #1

Marine Terraces	20%
Floridan Overburden	50%
Hydric Soils	30%

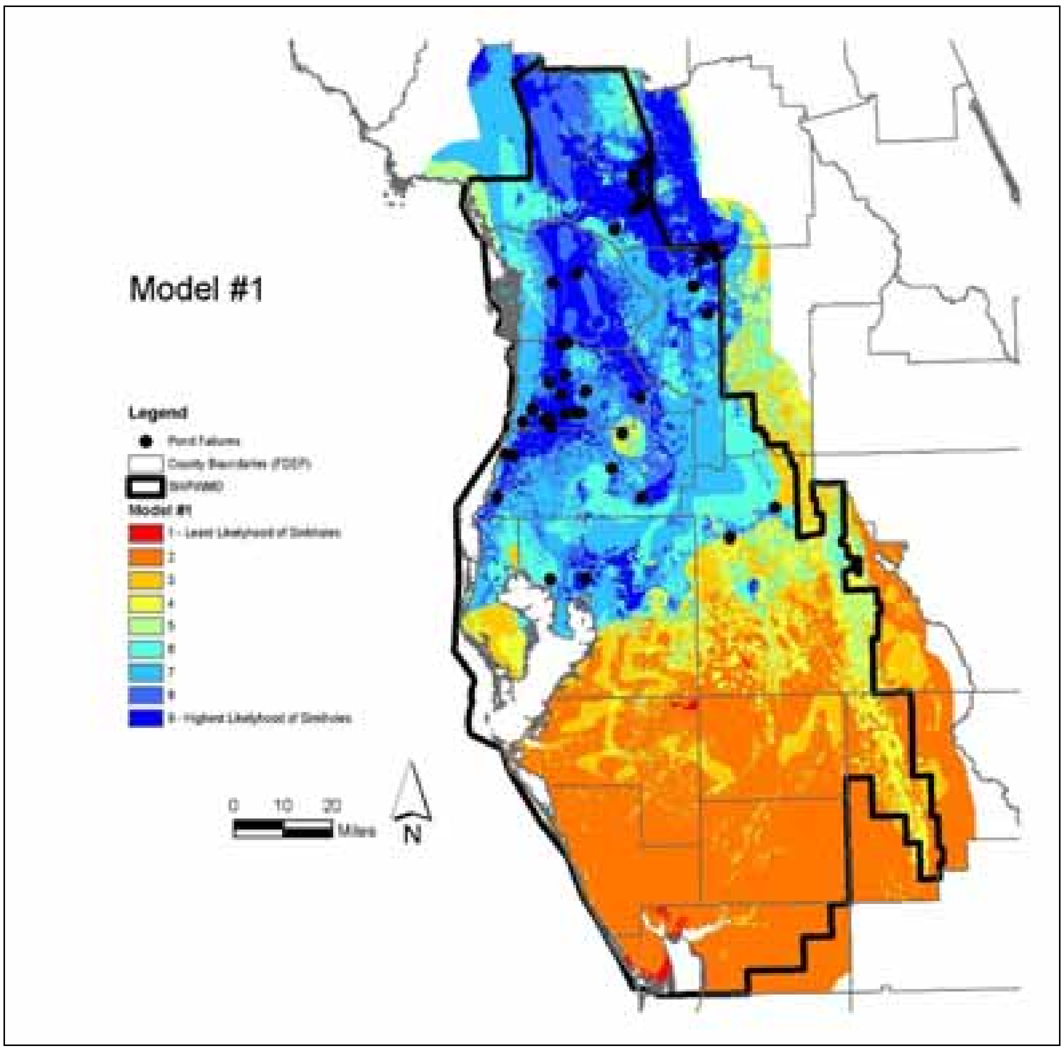


Figure 18 - Model #1

5.2.2 Model #2

Marine Terraces	20%
Florian Overburden	20%
Pot to Floridan	10%
Hydric Soils	20%
Surfical Thickness	10%
Top of Floridan	10%
Top of Intermediate	10%

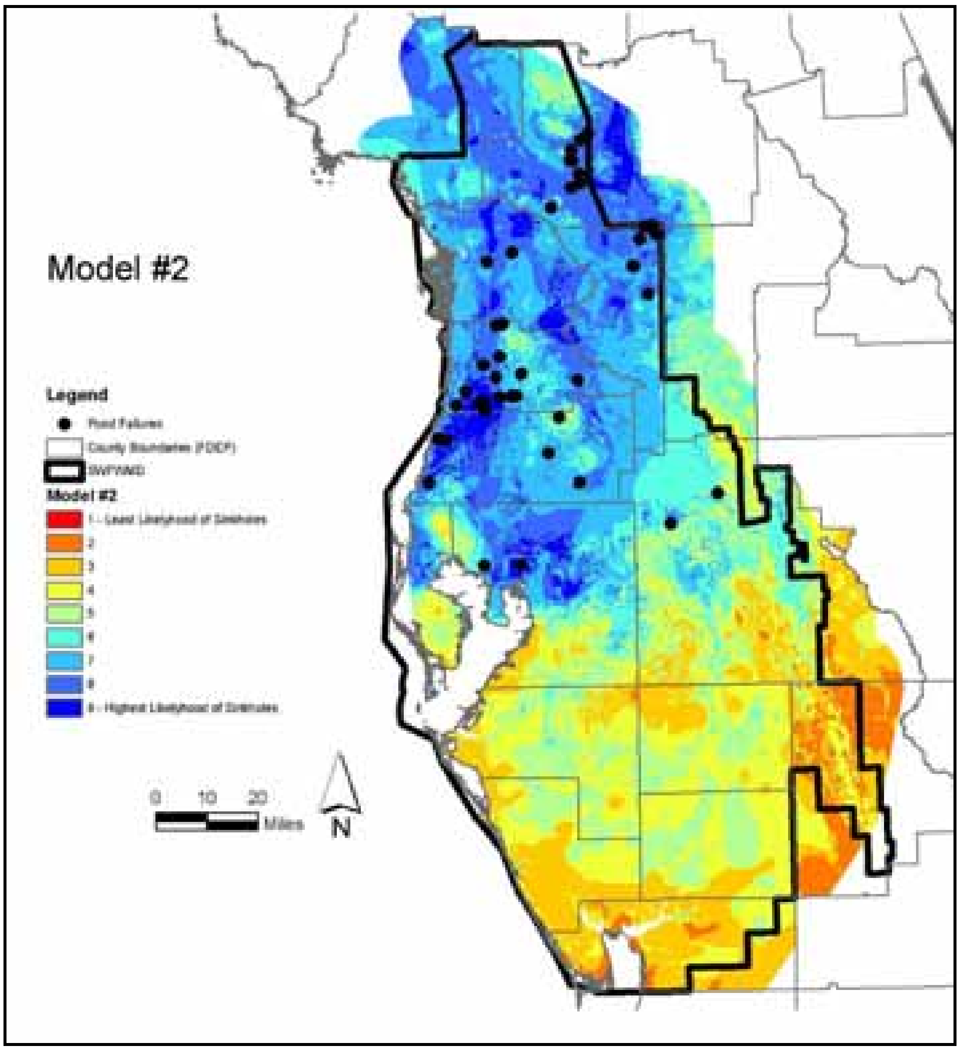


Figure 19 - Model #2

5.2.3 Model #3

Hydric Soils	30%
Surfical Thickness	30%
Top of Floridan	30%
Top of Intermediate	10%

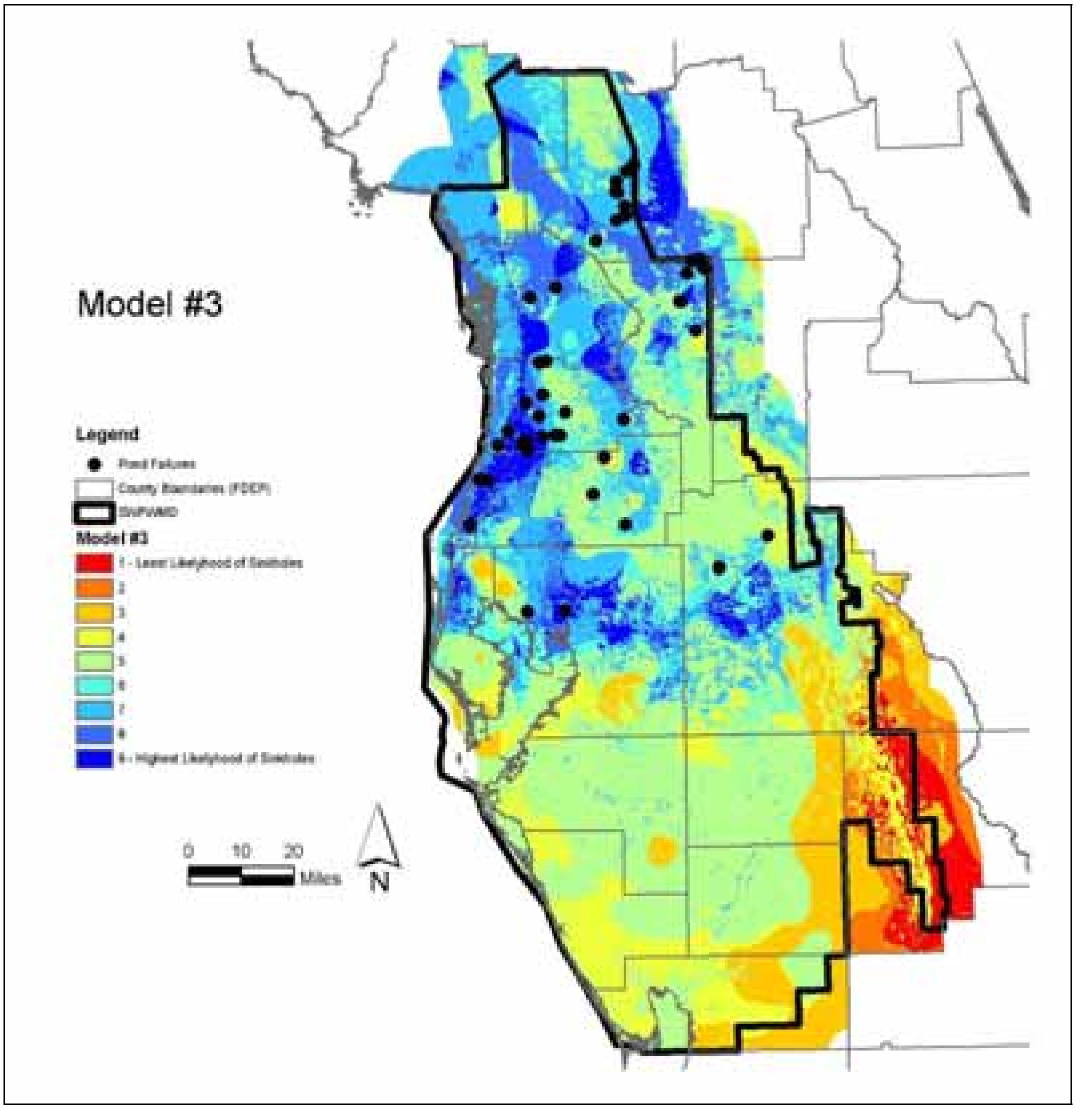


Figure 20 - Model #3

5.2.4 Model #4

Floridan Overburden	50%
Hydric Soils	50%

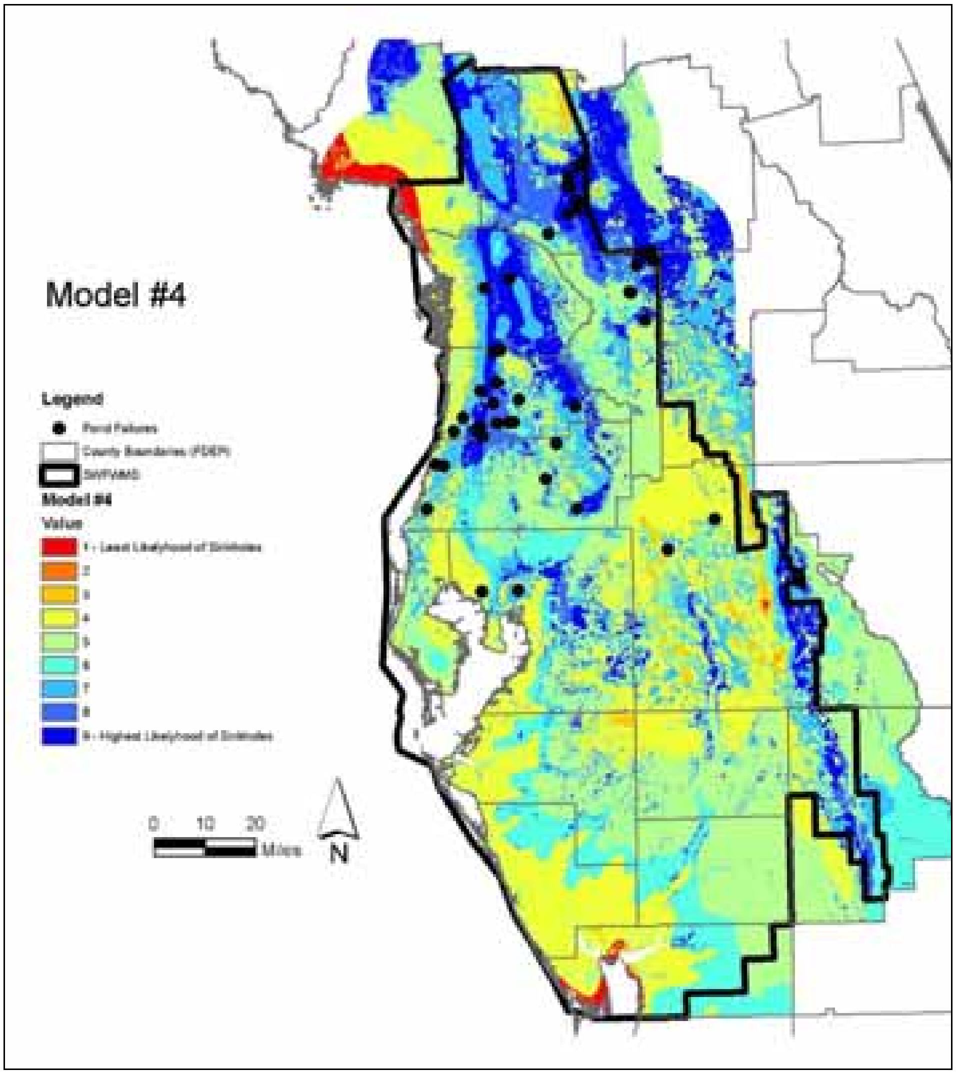


Figure 21 - Model #4

6.0 CONCLUSIONS AND DISCUSSION

6.1 CONCLUSION

The results produced by the models help give SWFWMD scientific basis for defining Sensitive Karst Areas. The results of the models were consistent with areas that were known to have a propensity toward sinkhole occurrence. The models were able to provide the District with “areas of concern” to help them regulate these areas more closely. These regulations can help set standard for development that will lessen the likelihood of sinkhole occurrence and damage, thus helping to protect our drinking water supply.

Each of the four models were run weighing in different criteria at different weights. Throughout all four models, many of the same areas showed as SKAs. These models were not intended to be a final map for the District to outline SKAs. Further review is needed by experts in the field. This project was created as a planning tool for the District.

6.2 DISCLAIMER

All data used in this study were obtained from published public domain resources and were not compiled, developed or verified for accuracy or completeness by Jones Edmunds. Jones Edmunds is not responsible for any inaccuracies or omissions in the published data. No field investigations (i.e., onsite walkthroughs, onsite photos, geotechnical and hydrogeological surveys, ground penetrating radar surveys, protected species/ ecology/critical habitat surveys, etc.) were conducted as part of this study.

6.3 DISCUSSION

The District should examine these results and discuss ways to fine tune the data into a final model. The results from this study were preliminary and not intended to be a final map for the district to base regulation on. Further input and discussion is still needed.

This study should be used a guide for the District. The models were created at 400 x 400 meter cell size scale. The results should be used as district level planning tool and should not be examined at the site specific level.

The model is flexible and as better or new relevant data is available it can be incorporated into the model to better fine tune it.

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