12/30/08

Docket # 52-029 & 52-030
Levy LCOA

TO: Nuclear Regulatory Commission,

Please accept these documents as an attachment to the information sent on December 23, 2008 by me, for the Levy County Environmental Scooping Meeting. Due to many distractions during this time period (various and numerous holidays within a multicultural family) this information did not get into the packet.

Thank you for your understanding and willingness to work with the general public.

Sincerely
Emily Casey

10/14/08
73 FR 60726
(4)

SUNSI Review Complete
Template = ADM-013

E-RIDS = ADM-03
Add = B Anderson

12/23/08

Docket # 52-020 & 52-030
Levy LCOA

TO: Nuclear Regulatory Commission

Problems With Nuclear Plants Addressed:

Tidewater Monitoring Well:

Progress Energy's environmental report documents all wells in the area that have been used in the past for monitoring quantity and quality , except for ONE – *Tidewater*.

USGS website: wdr.water.usgs.gov
Tidewater #1 – Floridan Aquifer System

The very one that is active, monitored and recording everyday. It is north and a little east of the proposed plant location and thus gives a good picture of the water flowing within the Floridan Aquifer at any moment. This well for the past several years has been reading in the critical low water stages. This shows there is already stress on the system – what will 1 **million gallons per day** or more, pumped out do to this system?? It is stated by PE that the water movement is west – southwest in the proposed area, which is just in line with the water supply for Inglis and Yankeetown.

From an important recharge zone in this area the water flows downward in all directions. Some available water flows toward the Rainbow Springs Watershed, some flows toward the Waccassassa River Basin and still some flows toward the Withlacoochee River Basin. It is hard to predict in the extremly karst area, just where the water will flow. It all depends on the amount of water in the system at any time. This area is just south of the hydrological divide, where the water that goes into the aquifer is only supplied by the amount of rainfall the area receives. The amount of rainfall in this area over time has declined thus leaving the springs in this area and their waters vulnerable to a decline in water quantity and thus water quality.

MACCS2 Modeling Program

Thus another problem – It is stated in the text for Table 2.3.18 that almost no surface water is used within a 50 mile radius of the LNP site. The logic used to rationalize why the surface water contamination would be small is appalling. Even if air contamination were small it does not mean that aquifer water contamination would be small!! The problem here is the fact that there is very little difference in surface water and groundwater. The surface water becomes part of the Floridan aquifer rapidly in this area –hence the reason it is vulnerable!

The biggest problem with this statement is when PE has explained what the MACCS2

Computer air pollution model analyzes and then states - this **program does not model groundwater pathways (for example, aquifers)**. Then, how can an assumption be made that any effects would be small?? Both water quantity and water quality for all living things in the environment are in peril if these plants are allowed to be built.

Where Does Ten Mile Stop?

On Progress Energy Maps the small creek named Tem Mile stops north of the site at Highway 19 - see Progress Energy Map in the December 23 packet. I have enclosed the Levy County Soils Map published in 1996 which shows Ten Mile starts in the area just east of the proposed plants and actually flows north to merge with Cow Creek, that flows into the Waccasassa River and thus contributes to the water quantity of that river, which has been designated by the Minimum Flow and Levels. The area where Ten Mile starts is within a large cypress swamp and the entire area could be restored back to the original hammock land that it once was. The ONLY degradation in this area is that the trees have been cut down, but over time and with care it can restored!

NO NUKES IN A GREENFIELD SITE

Important and Vulnerable Recharge Zone

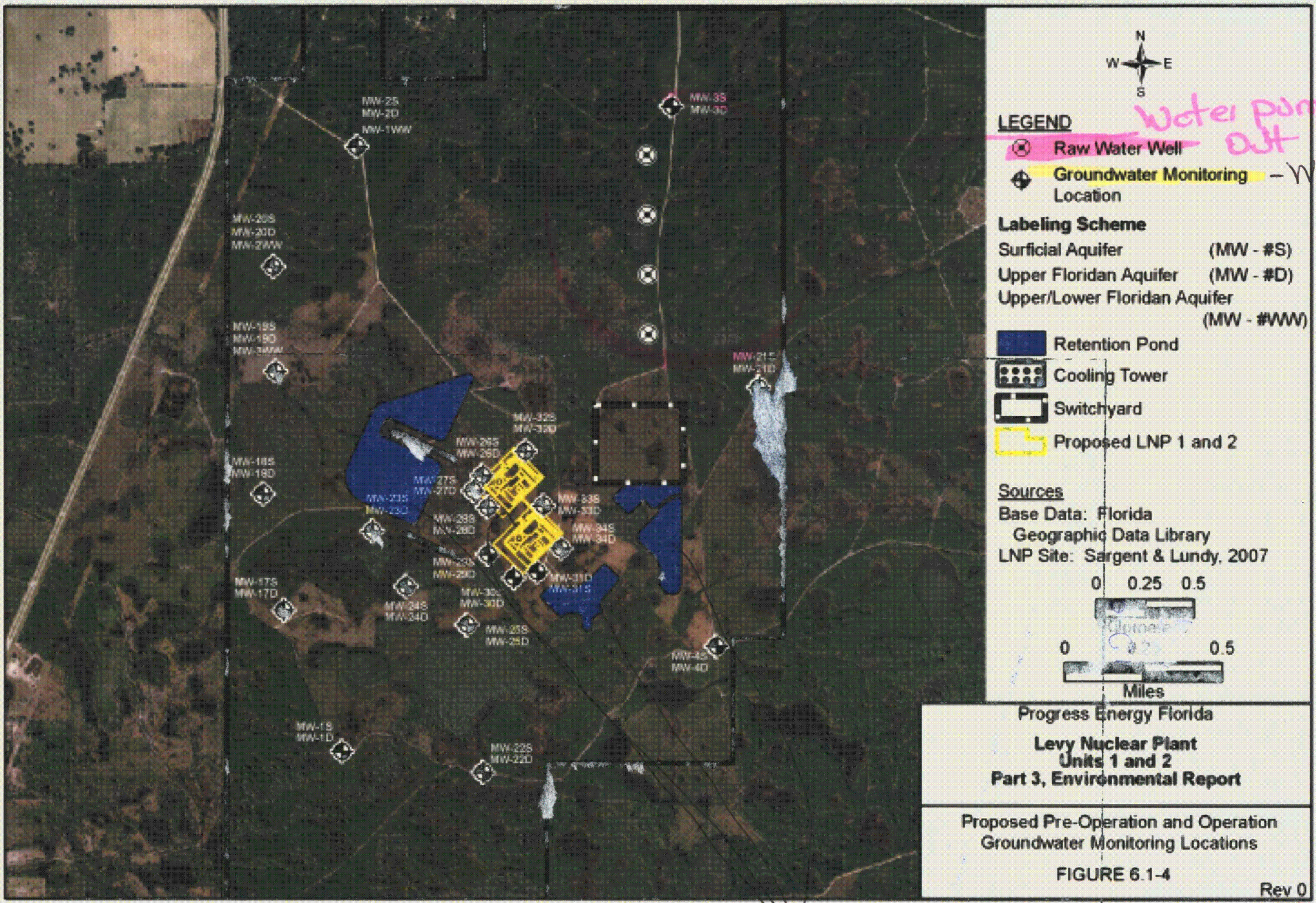
The site area provides a very important watershed function for the entire region. Since it is in the vicinity of the potentrimetric high for that area the increase in the quantity of water pulled from the shallow aquifers will affect every waterbody, spring and community water supply within that region.

This holds true for the water quality also. Power produce by the reaction of splitting atoms to heat water, which makes steam to turn turbines routinely releases radioactive material into the air and water. This put people's Drinking water in peril, by both contamination from radioactive particles and by salt water intrusion. People and our environment can not live without pure, clean and fresh water.

This document addresses mostly the environmental concerns of the Levy County site and does not attempt to address the MANY issues surrounding the use of Nuclear Power. the economics, the thermal pollution, the radioactive contamination, the entire concept of obtaining useable uranium, the cost, the many options of using renewable energies and many other concerns which have been addressed by many well informed and concerned citizens.

Sincerely
Emily Casey
Environmental Alliance of North Florida (EANof)
and Nature Coast Sierra Club

Emily Casey
Southern Director
Environmental Alliance of North Florida (EANoF)
Also on behalf of the Nature Coast Serria Club



Proposed Pre-Operation and Operation Groundwater Monitoring Locations

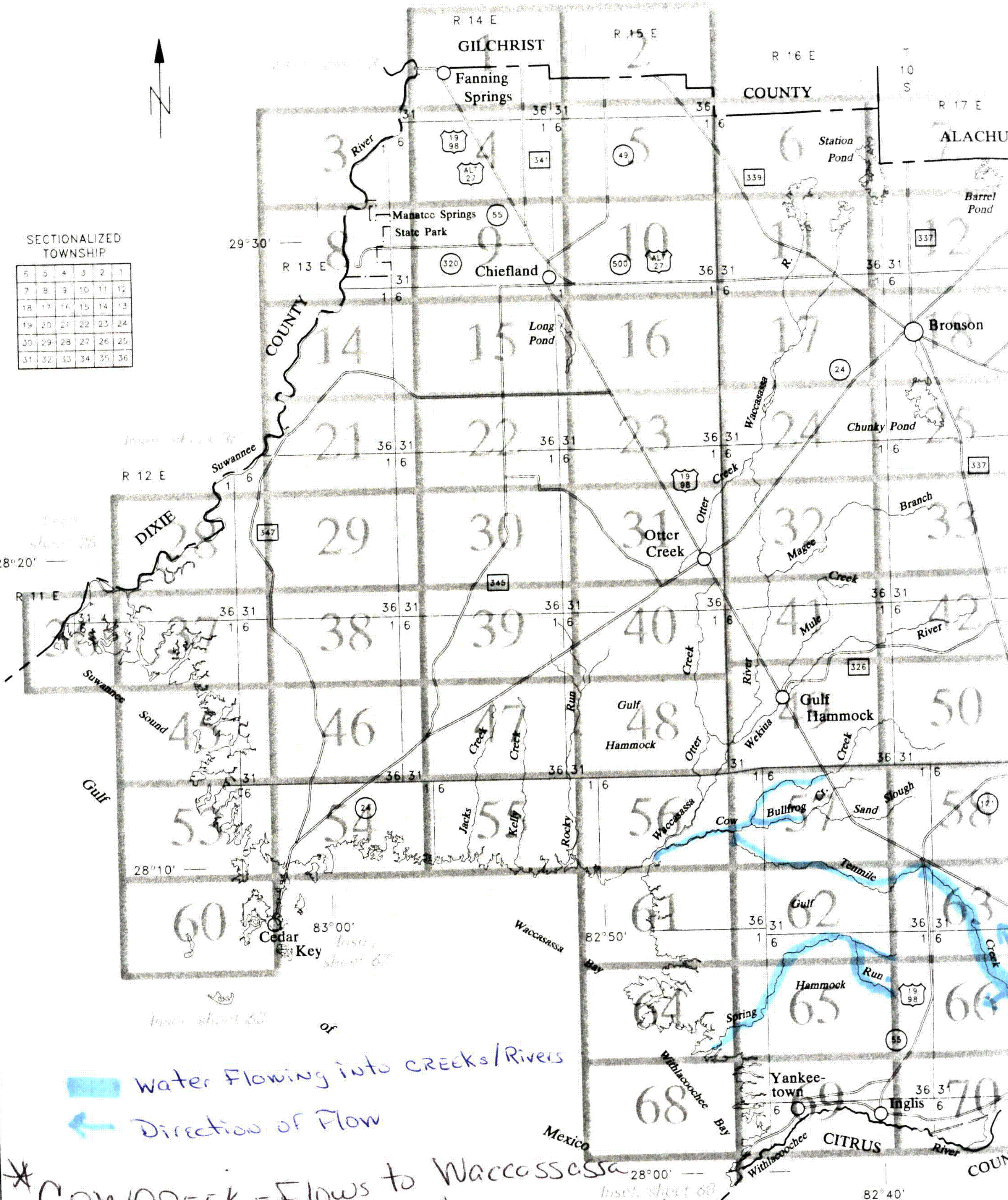
FIGURE 6.1-4

Rev 0

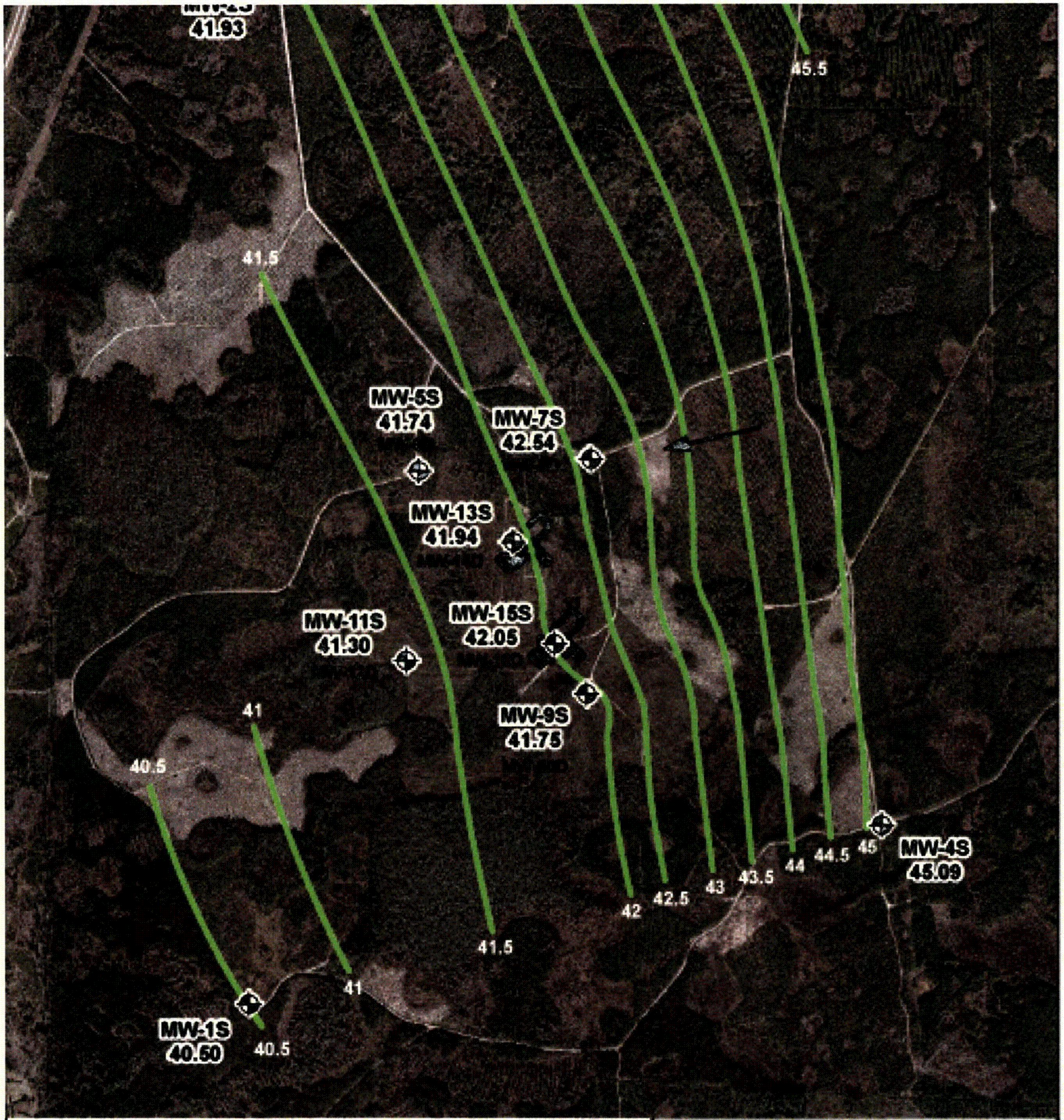
Water pumped Out

– WHAT ?

All Resut in water Flow pattern change!



*COWCREEK - Flows to Waccassassa and Ten mile Flows into Cow CREEK
Tenmile is just to the East of the LNP 1:2
It is missing From many maps - and this Flows North



LEGEND

- Monitoring Well
- Groundwater Flow Direction

N W E S

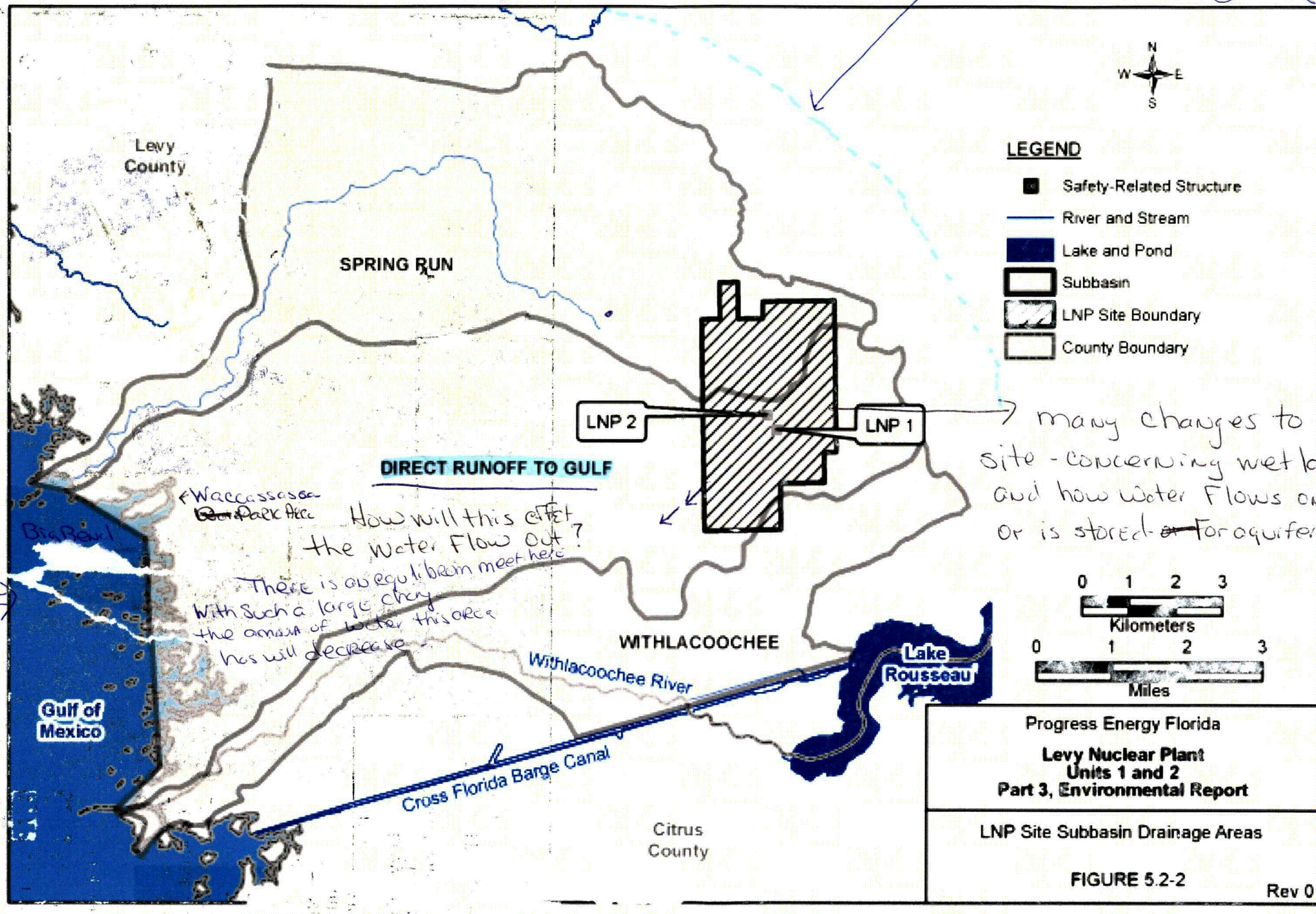
0 250 500

Progress Energy Florida

Levy Nuclear Plant
Units 1 and 2
Part 3, Environmental Report

Inglis? Yankeetown

approximate location of Ten Mile - which Feeds Cow Creek - so this flows North - Cow Creek Feeds into the Waccassassa River - There is Already a Problem with Salt Water Intrusion and the MFL has been set. What happens when this water is not available anymore?



Waccassassa Park Area

Big Bend

How will this effect the water Flow out?

There is an equilibrium meet here. With such a large change the amount of water this area has will decrease.

Many changes to site - concerning wetlands and how water Flows on land or is stored for aquifer use

Estuary For Many Species such as Manattee! Turtles, lots of Fish.

2.3 loca... tion

Many sport [fishermen] now From the South Say they must travel up to this area to Follow the Fish, because the waters are warmer than the waters in the South so the Fish are moving North - That is totally setting the Southern Ecosystems off balance - What will happen with even MORE WARM WATER -

12/23/08

Docket 52-029 & 52-030
Levy LCOA

TO: Nuclear Regulatory Commission

GOT WATER?

THE NEED TO SOLVE BOTH THE ENERGY AND THE WATER CRISIS NOW

Our economy is in crisis – Just not enough money for everyone to sustain their previous lifestyle and now several thing are occurring

1. Everyone is cutting back on their usage of money and making wise decisions on their purchases
2. Globally governments are bailing out financial institutions and big business, who did not manage or use their money wisely in the past/
3. Everyone is learning that we can not continue with business as usually, all over the world people are having to make difficult choices about their finances that will effect the future of many generations to come
4. This country is in an important period where change needs to occur quickly and smartly, the world IS watching

Just like with the economy the world is beginning to realize that we are now experiencing the starting point of global water crises!!

1. People are slowly cutting back on unnecessary water usage and are starting to making wise choices on when and where to consume water
2. Globally people are suffering from the lack of clean, fresh water and there is no government that can bail us all out of this crisis
3. Everyone is learning that we can not continue with business as usually, all over the world people are having to make difficult choices concerning how much water they can obtain for food, cleanliness, health and industry uses, the choices made today will affect the future of not only many generations of humans to come but the health of all ecological systems on this planet!
4. This county is in an important period where change needs to occur quickly and smartly, the world IS watching

The above represents a quick snapshot of how the economy and water are expercing a similar crisis, the only way our environment is ever going to be able to recover from the water deficit is to allow the earth's ecological banking system to work!!!

Where can this banking system be found and what types of resources are needed to make this accounting system function properly?? The recharge areas, which allow water from rainfall to percolate into the Floridan Aquifer quickly and the wetlands, which hold (save) water after the rainfall event, must be protected NOW!!

The location of the proposed Levy 1 and 2 nuclear power plants would be in the area of the single most important recharge zone for southern Levy County and thus for the Waccaassa Bay, the Big Bend Seagrass Beds, the Withlacoochee River and its associated watershed area, the Goethe State Forrest, the Gulf Hammock Wildlife Preserve the Rainbow Springs Watershed area and aquaculture farms in Cedar Key and of utmost importance for the area would be that it provides fresh drinking water to the inhabitants of most of the southern part of Levy and Marion County and to the northern part of Citrus County. This small red zone shown on the Levy County, Floridan Aquifer Vulnerability Assessment map (ex.1) shows an area where our groundwater's quantity and quality are extremely vulnerable. It is a very karst area, meaning that the thin limestone covering of the Floridan Aquifer has lots of hole in it (sinkholes in fact) (ex 2), and water can and will flow in many different directions, it just depends on the amount of water in the system!

Surrounding the vulnerability recharge area (money spent quickly) is the most important assets Florida has, the wetlands (savings account). From Cedar Key through an area north of Bronson and over to Daytona Beach it is now known that the aquifer only receives water from rainfall. The monitoring well set up north of the proposed power plant area (Tidewater station) * by USGS shows that the system is at a critical stage for water quantity a lot of the year. The less rainfall, the less water there is to go into the system. The less water in a system along with extremely high increases in consumption can and will be catastrophic to this area.

. We tend to think of countries that have lots of oil under their feet as being rich. We should understand that an area with fresh, clean water has a treasure under their feet and it must not be wasted anymore. Placing the proposed plants in this area would contribute to the degradation of the ecological banking system that has worked for this earth in the past and would work better in the future if the area was restored. We can use the wetlands and the trees that will grow there as part of the carbon sequestration banking system in a truly safe, clean and secure world using many combinations of RENEWABLE resources

It has been estimated that to provide water needs for all uses through 2030, the world will need to invest as much as $1 trillion a year on technologies toward that end. By not placing even more demands on the Floridan Aquifer, but to restore habitat and allowing nature to work as it was intended to, there does exist a low cost system to provide the most precious commodity we all need; clean and fresh water.

Thank You,

The Question for Progress Energy: Why Nuclear!!!

Some of The Concerns are listed below then Alternative Recommendations are given

Mailed to the Nuclear Regulatory Commission on December 23, 2008.
Docket # 52-029 and 52-030
Levy County Nuclear Plants 1and 2

1. The cost is extremely high and rising - the ultimate cost of building the plants is not known yet. Whatever the cost and risk, it is being financed by the rate payer. This is wrong, due to the economy many people are forced to make choices between medical care (medicine) or food and now they will have to make another choice – to use electricity or not (to cook, to bath or to stay warm). What were our legislatures thinking!!??

2. We the residents of Florida have been told our rates will increase by 25% in January 2009 for subsidizing the cost of constructing a still unapproved plant design and will be made in Japan – maybe?.

3. Progress Energy is adjusting the fuel rate cost upward 14+ dollars which is included in the rate increase. Uranium is also a non- renewable resource – As this resource is used more - the cost in the future will rise as the amount available decreases. We see this happening to another non- renewable resource – COAL. The transportation industry (CSX) is proposing to raise the rail shipment cost by 200 -400% next year! This of course will be passed on to the consumer!

4. Got Water? The amount of water a plant uses is extremely large. Depending on the type of cooling system and cooling towers used a plant can require tens of thousands of gallons per minute to operate.

This does not even include the 1 million gallons (plus) of water per day being pumped out of the aquifer for general plant purposes.
How will this affect the barge canal or the Withlacoochee River and its watershed? A large straw put into the canal will draw the salty water up into the area quickly.

5. If brackish water is used then the parts of the plant associated with the reactor needs to be constructed with high grade metals such as molybdenum, to insure that corrosion will not occur to quickly. This will increase cost and increase the carbon footprint.

6. The whole process of mining uranium/ processing uranium/transporting to enrichment facilities/ enrichment process of the pellets/transporting pellets to plants would occur routinely and these actions ARE NOT CARBON FREE!!

7. Many health concerns exist with the people and environment where the above actions occur

8. Radioactive spent fuel is stored onsite because an off site storage area does not exist. Transporting the spent fuel rods are another problem to deal with if the time should occur when a storage area is completed. Storage of the spent fuel in caskets in this extreme karst topography is an unnecessary risk to take with peoples drinking water.

9. We are told that the liquid radwaste at a nuclear plant is sampled to ascertain its radioactive contents and if the radioactive contents are below federal limits on liquid releases, the water is pumped into the discharge flow which dilutes the radioactivity concentration and gets diluted more when it mixes

with the gulf water. Therefore by design when water is discharged from a nuclear power plant it contains radioactive elements and as they go through the decay process the concentration of radioactive nucleotides increases!

The same contamination process occurs in our air, then falls to the ground, gets absorbed by plants and the animals that eat those plants, then humans either eat the plants or the animals and thus a cycle is started and bioaccumulation within the system begins. There are many studies that show this has a detrimental effect on human's health over time.

10. Change in water volume in the surrounding water bodies and the Floridan Aquifer - from loss of sheet flow, loss of water available for the small creeks, loss of wetlands =loss of water percolating into the aquifer

    Change in water temperature and volume of water introduced from increase in thermal plume area into the an area of critical concern!

    These components will result in even more change to the sensitive ecosystems (the seagrass beds and the surrounding estuaries)

11. The need for the plants has not been established. Florida is not growing as has been projected – schools are closing and teachers are not being hired at the previous rate. Even Progress Energy earnings for the first quarter are down due to slowed growth and they have laid off workers.

12. Greenhouse gases will continue to rise if we wait until 2016-2917 for new nuclear plants to come on line in order to "reduce greenhouse gases" and do not start using renewable resources NOW

13. Why in 2018 is the use of Coal reduced only by 4%, Oil use reduced only 2%, Natural gas use is reduced by 20%, but Renewable energy use does not change, it is still the same token 3% if the plants are built!!

14. It was stated at an informational meeting on August 7, 2008 by a Progress Energy project engineer that the plants would meet the PSC 20% reserves requirement only until 2023! When he was asked then what? The reply was maybe we will go solar or just build MORE NUCLEAR PLANTS!! This process will never end according to him, in the mean time the energy crisis nor the water crisis will be solved and the rate payers will never finish paying for them!!

ALTERNATIVE RECOMENDATIONS

1. At first glance transportation may not seem to be a part of this discussion, however it makes up the largest percentage of carbon emissions. If Florida is truly wanting to reduce the amount of carbon emitted then the transportation system in Florida needs to be overhauled.

2. Homes/ Business/ Industries – need to make a conscientious effort to
   * Conserve energy
   * Use more energy efficient products
   * Design/ build more energy efficient buildings
   * Use renewable energy sources

3. Progress Energy should increase use of renewable energy sources. A large base load plant would not be necessary if solar/ wind/geothermal, etc. were used

4. The above concept leads to the use of distrubutive co – generation of power – if the Villages need more power

then locate a solar collector energy farm in that area

5. Large buildings such as schools, hospitals should have solar or wind power generating stations on top of the usually large flat roof area. Or panels can be installed in the large parking lots and cars can be parked in shady areas.

6. By 2010 a company will be mass producing a thin film solar voltaic cells which could be rolled out onto a roof. It is predicted to cost around 10 - 15 cents a square foot.

7. It is not that we lack the technologies to actually create a state or nation which uses sustainable energy for its electrical power production, it is the economic system which is keeping everyone hostage to unsustainable, non-renewable resources to generate electricity. The act of subsidizing nuclear power and not renewable energies need to stop!

We are at the fork in the road. We now have the ability to decide which road our state will travel upon. Will we choose to continue down the same road that we are traveling with oil supplies or will we actual be progressive and take the road which leads us into a sustainable 21st century?

Emily Casey
Southern Chairperson
Environmental Alliance of North Florida (EANoF)
(352) 476-4425

12/30/08

Docket 52-029 & 52-030
Levy LCOA

TO: Nuclear Regulatory Commission,

The black and white copies are the explanations to the colored maps of Levy County Florida Aquifer Vulnerability Assessment Phase II (FAVA) report.

The FAVA report was completed for the Department of Environmental Protection of Florida in 2007. The maps show the siting area of the proposed nuclear power plants is located within an area of high aquifer vulnerability.

Please read the highlighted explanations in this document, they explain each colored map sent with the packet mailed on December 23, 2008.

Thank You,
Emily Casey

Florida Aquifer Vulnerability Assessment Phase II
Levy County, Floridan Aquifer System

Michael Sole, Secretary

INTRODUCTION

The Floridan aquifer system is the most important and prolific source of fresh water in Levy County. Groundwater use from the Floridan aquifer system in Levy County is an estimated 57 million gallons of water per day for public supply, agriculture and other uses. In addition to this amount, there are over 6,257 self-supply wells in the county tapping the Floridan aquifer system providing fresh water to homeowners (SWFWMD, 2006, 2003 (Revised), and 2004). Levy County's 34,450 residents (U.S. Census Bureau, 2000) rely almost exclusively on the Floridan aquifer system for their fresh water needs.

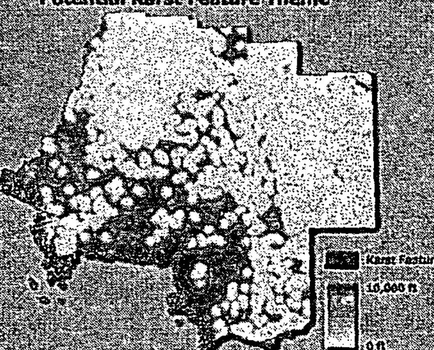
Identifying areas of Levy County where the Floridan aquifer system is more vulnerable to contamination from activities at land surface is a critical component of a comprehensive groundwater management program. Protection of the Floridan aquifer system is an important measure to take in helping ensure viable, fresh water is available from the Floridan aquifer system for continued future use in the Levy County study area. Aquifer vulnerability modeling allows for a pro-active approach to protection of aquifer systems, which can save significant time and increase the value of protection efforts. Maps of three types of data were used to determine aquifer vulnerability in Levy County; soil pedality, karst features and recharge potential. Maps explaining these data are displayed below.

Soil Pedality Theme

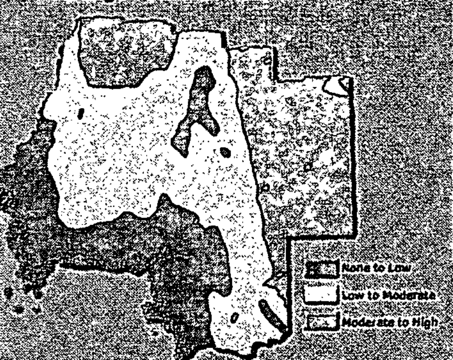
Soil pedality is a relatively new concept used to estimate how water moves through soil (Lin et al. 1999). The rate that water moves through soil is a critical component of any aquifer vulnerability analysis, as soil is an aquifer system's first line of defense against potential contamination. Soil pedality values, which are calculated based on soil type, soil grade, and soil structure, are unitless, and higher values correspond to higher flow rates and therefore higher aquifer vulnerability. In 2006, Levy County soils data were redesigned for the study area by the Natural Resources Conservation Service. As a result, more detailed information is available for soils analysis for the LCAVA project than during previous projects.

Karst features, or sinkholes and depressions, can provide preferential pathways for movement of surface water into the underlying Floridan aquifer system and increase an area's aquifer vulnerability where present. The closer an area is to a karst feature, the more vulnerable it may be considered. Karst features tend to be generally circular in nature (in contrast to non-karstic depressional features which may not be circular) and can be identified and extracted from a digital elevation model based on this characteristic. These resulting potential karst features can be buffered into zones as shown here to allow for a relative distance analysis.

Potential Karst Feature Theme



Recharge Potential Theme



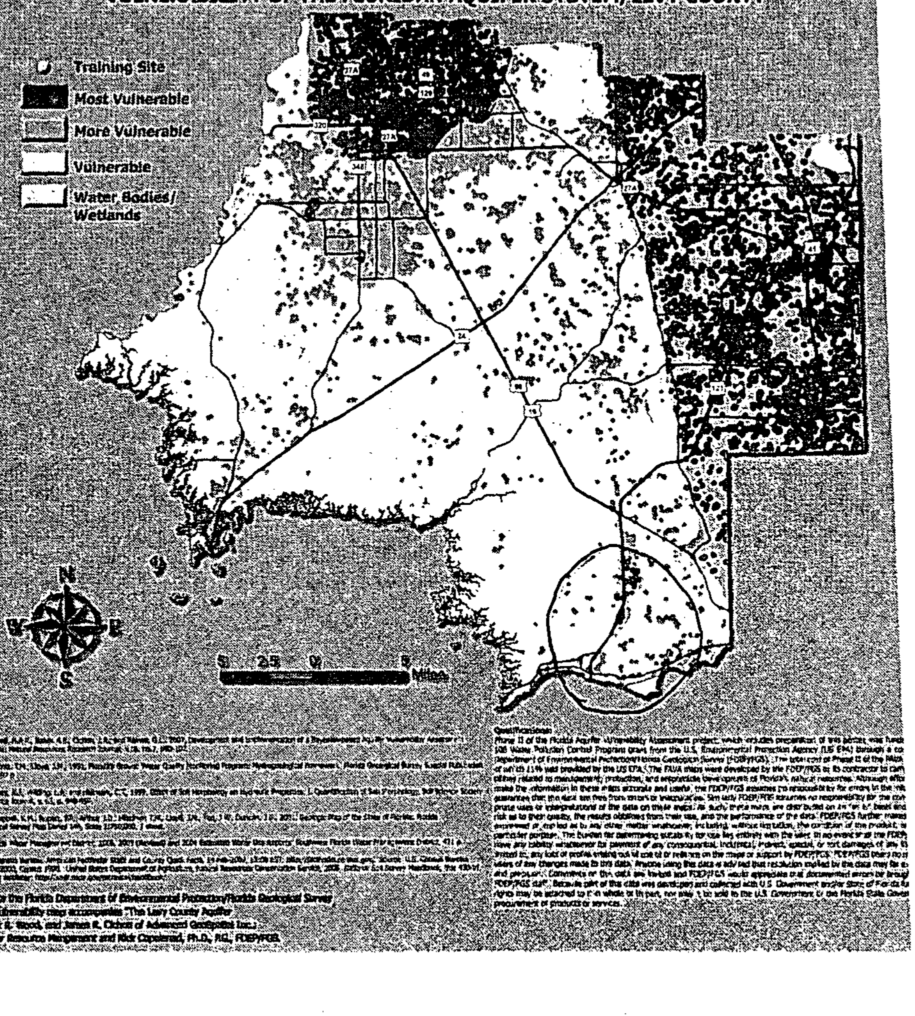
In Copeland et al. (1991), the area of the Brooksville Ridge in central Florida is defined as having higher recharge potential than adjacent areas. The Brooksville Ridge is chiefly composed of undifferentiated Hawthorn Group sediments which are poorly to moderately consolidated clayey sands and silty clays (Scott et al., 2001). In the study area, these sediments are estimated to exceed 100 feet in thickness. In other areas of Florida, Hawthorn Group sediments forming the Intermediate Confining Unit normally provide an effective confining or semi-confining unit for the underlying FAS. In Levy County, however, these sediments are generally highly weathered, leaky, thin and intensely breached by karst features. These factors combine to increase the recharge potential to the FAS in the study area where these sediments are present. Where recharge potential is high, aquifer vulnerability is increased.

APPROACH TO MODEL DEVELOPMENT

The primary purpose of the Levy County Aquifer Vulnerability Assessment, or LCAVA, is to provide a science-based, water-resource management tool that can be used to help minimize adverse impacts on ground-water quality, including focused protection of sensitive areas such as springsheds and ground-water recharge areas. The modeling process used for the LCAVA project is "weights of evidence," and is based in a geographic information system (GIS). The approach used in the project is a modification of the technique used in Phase I of the Florida Aquifer Vulnerability Assessment project (Arthur et al. 2007). One of the main benefits of applying this technique to the LCAVA project is that it is data-driven, rather than expert-driven, and model output is dependent upon a training site dataset, which produces a self-validated model output. For LCAVA, training sites are groundwater wells with water quality indicative of a good connection between the aquifer and land surface, or simply, aquifer vulnerability.

Model generation is accomplished by associating training sit[es] data layers representing natural conditions which control aq[uifer vulnerabil]ity. Data layers used for the LCAVA project are described o[n the] side of this poster and include karst features, soil pedality, a[nd recharge po]tential. The model helps determine which areas of each dat[a layer have] greater association with aquifer vulnerability based on the [locations of] training sites, and then combine them in a map as shown her[e. Model] results are an estimate of the natural vulnerability of the aquif[er; land] use types and human activities are not used as input. Th[e] output map indicates that the areas of highest vulnerability [are those] with dense karst-feature distribution, higher soil pedality val[ues, and] having a higher recharge potential.

VULNERABILITY OF THE FLORIDAN AQUIFER SYSTEM, LEVY COUNTY



REFERENCES

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Copeland, R., Scott, T.M., Lloyd, J.M., 1991, Florida Ground Water Quality Monitoring Program: Hydrogeological Framework: Florida Geological Survey Special Publication No. 32, 97 p.

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This poster is developed as part of Florida Aquifer Vulnerability Assessment (FAVA) Phase II for the Florida Department of Environmental Protection/Florida Geological Survey per FDEP/FGS Contract No. RM059. Version 1.5: July 10, 2008. This vulnerability map accompanies "The Levy County Aquifer Vulnerability Assessment Report" prepared by Alan E. Baker, P.G. 2324, Alex R. Wood, and James R. Cichon of Advanced GeoSpatial Inc.; FAVA Phase II project managers are Allan Stodghill, P.G. (FDEP), Division of Water Resource Management and Rick Copeland, Ph.D., P.G., FDEP/FGS.

THE LEVY COUNTY AQUIFER VULNERABILITY ASSESSMENT

Part of the Florida Department of Environmental Protection Florida Aquifer Vulnerability Assessment Phase II Project, RM059

Prepared for the Florida Department of Environmental Protection by Advanced GeoSpatial Inc.

Version 1.1: August 13, 2007

THE LEVY COUNTY AQUIFER VULNERABILITY ASSESSMENT

Prepared For:

The Florida Department of Environmental Protection as part of the Florida Aquifer Vulnerability Assessment (FAVA) Phase II Project, Contract No. RM059

Prepared by

Alan E. Baker, P.G. 2324, Alex R. Wood, and James R. Cichon of
Advanced GeoSpatial Inc., 2441 Monticello Drive, Tallahassee, FL 32303

August 2007

PROFESSIONAL GEOLOGIST CERTIFICATION

I, Alan E. Baker, P.G., no. 2324, have read and agree with the findings in this report titled THE LEVY COUNTY AQUIFER VULNERABILITY ASSESSMENT and do hereby certify that I currently hold an active professional geology license in the state of Florida. The model and report were prepared by Advanced GeoSpatial Inc., a State of Florida Licensed Geology Business (GB491), and have been reviewed by me and found to be in conformance with currently accepted geologic practices, pursuant to Chapter 492 of the Florida Statutes.

Alan E. Baker, P.G.
Florida License No. 2324

Date

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LIST OF FIGURES

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For additional information regarding this project, please refer to the associated 24" x 36" interpretive poster of the same title as this report, and/or the GIS project data and associated metadata. At the time of this report, these GIS files may be accessed using ArcMap™, version 9.x.

THE LEVY COUNTY AQUIFER VULNERABILITY ASSESSMENT

Alan E. Baker, P.G. 2324, Alex R. Wood, and James R. Cichon
Advanced GeoSpatial Inc., 2441 Monticello Drive, Tallahassee, FL 32303

INTRODUCTION

The Floridan Aquifer System is the most important and prolific source of fresh water in Levy County. According to Southwest Florida and Suwannee River water management districts, permitted ground-water use from the Floridan Aquifer System in Levy County is approximately 57 million gallons of water per day for public supply, agriculture, and other uses. In addition to this amount, there are over 6,257 self-supply wells in the county tapping the Floridan Aquifer System providing fresh water to homeowners (SRWMD Water Use Specialist, 2007; SWFWMD, 2006). Levy County's nearly 34,450 residents (U.S. Census Bureau, 2000) rely almost exclusively on the Floridan Aquifer System for their fresh water needs.

Levy County is underlain by thick and highly permeable carbonate rocks which comprise the Floridan Aquifer System. Clastic sediments overlying this aquifer system are chiefly composed of permeable silica sands with lower permeability clayey sand and silty clays present on the Brooksville Ridge and Wacassassa Flats. Most of the aquifer system is unconfined except where the lower permeability sediments provide limited aquifer confinement. Karst features are very prominent throughout the area and include sinkholes, swallets, and springs such as Manatee and Fanning Springs, both first magnitude springs. (Scott et al., 2004).

Identifying areas of Levy County where the Floridan Aquifer System is more vulnerable to contamination from activities at land surface is a critical component of a comprehensive ground-water management program. Protection of the Floridan Aquifer System is an important measure to take in helping ensure viable, fresh water is available from the Floridan Aquifer System for continued future use in Levy County. Aquifer vulnerability modeling allows for a pro-active approach to protection of aquifer systems, which can save significant time and increase the value of protection efforts. Successful implementation of an aquifer vulnerability assessment benefits:

- Environmental protection
- Wellhead protection
- Development of wastewater guidelines
- Source-water protection
- Land-use planning
- Sensitive land acquisition

Project Objective

The Florida Department of Environmental Protection (FDEP) through the Florida Geological Survey (FGS) contracted with Advanced GeoSpatial Inc. (AGI) in November of 2006 to develop Phase II of the Florida Aquifer Vulnerability Assessment (FAVA) project. As part of this project, AGI developed the Levy County Aquifer Vulnerability Assessment (LCAVA) model characterizing the natural (or intrinsic) vulnerability of the Floridan Aquifer System (FAS) in Levy County. The primary purpose of this project is to provide the FDEP and Levy County with a scientifically-defensible, water-resource management tool that can be used to help minimize adverse impacts on ground-water quality. The project intent is to allow end users of the model to make improved decisions about aquifer vulnerability with regard to model input selected, including focused protection of sensitive areas such as springsheds and ground-water recharge areas.

Derivative Products: Protection Zones

Relative vulnerability zones defined in this project may be applied to develop derivative maps, such as a protection-zone map. Ideally, data layers not included as input in the aquifer vulnerability model would be considered to help in defining such protection zones and may include ground-water flow modeling, stream-sink features, induced drawdown areas from large well fields, and distribution of drainage wells. These layers, while important to aquifer vulnerability, do not form usable input into this aquifer vulnerability assessment project.

Aquifer Vulnerability

All ground water and therefore all aquifer systems are vulnerable to contamination to some degree (National Research Council, 1993) and, as a result, different areas overlying an aquifer system require different levels of protection. An aquifer vulnerability assessment provides for the identification of areas which, based on predictive spatial analysis, are more vulnerable to contamination from land surface. AGI uses a definition of aquifer vulnerability similar to that of the FDEP in the FAVA Phase I report: the tendency or likelihood for a contaminant to reach the top of a specified aquifer system after introduction at land surface based on best available data coverages representing the natural hydrogeologic system (Arthur et al., 2005).

APPROACH

AGI is currently the single source provider of aquifer vulnerability assessment analysis using weights of evidence as defined by FDEP. The weights of evidence methodology, and the weighted logistic regression methodology, were employed in FDEP's FAVA project (for detailed information please refer to Arthur et al., 2005). Use of these methods involves combination of diverse spatial data which are used to describe and analyze interactions and generate predictive models (Raines et al., 2000). The following sections provide a brief overview of the methodologies; project-specific and more detailed information is presented in *Project Results.*

Weights of Evidence/Weighted Logistic Regression

Weights of evidence and weighted logistic regression were used in the LCAVA project to develop an aquifer vulnerability assessment model of the FAS. The data-driven weights of evidence method was used to measure the spatial association between training points and evidential themes. Resulting from conditional independence issues, weighted logistic regression was then used to combine the binary layers to predict the distribution of the training points and generate final model output (see *Discussion* for more information.

These modeling techniques are based in a geographic information system (GIS) and executed using Arc Spatial Data Modeler (Arc-SDM), an extension to ESRI's ArcGIS software package. For more information on these methods please refer to Arthur et al. (2005), Kemp et al. (2001), Raines et al. (2000), and Bonham-Carter (1994). Primary benefits of applying these techniques to the LCAVA project are that they are data-driven methods, rather than expert-driven, and model generation is dependent upon a training dataset resulting in a self-validated model output.

Data Acquisition and Development

The initial phase of an aquifer vulnerability assessment project comprises acquisition, development and attribution of various GIS data coverages representing natural hydrogeologic conditions for use as input into the model. The input data chosen during this phase determines the level of detail, accuracy, and confidence of final model output, i.e., vulnerability maps. Examples of data typically used in an aquifer vulnerability assessment include:

- Digital Elevation Data
- Aquifer Recharge
- Confinement or Overburden Thickness
- Karst Features/Topographic Depressions
- Water-Quality Data
- Soil Hydraulic Conductivity and Soil Pedality
- Recharge Potential

Vulnerability Modeling

Upon completion of the development and adaptation of necessary data coverages for the vulnerability assessment, the modeling phase using weighted logistic regression is initiated to generate aquifer vulnerability response themes, which, for the LCAVA project, are expressed as favorability maps.

Study Area and Training Points

The initial step in implementing the vulnerability modeling phase is the identification and delineation of a study area extent. Levy County political boundary served as the model study area for this project. Training points are locations of known occurrences. In an aquifer vulnerability assessment, ground-water wells with water quality indicative of high recharge are selected as known occurrences. Dissolved oxygen or dissolved nitrogen analytical concentrations were used to develop training point datasets. The occurrence of a training point does not directly correspond to a site of aquifer system contamination, but is indicative of aquifer vulnerability.

Evidential Themes (Model Input)

An evidential theme is defined as a set of continuous spatial data that is associated with the location of the training points and is analogous to the data layers listed and described above, such as soil hydraulic conductivity or thickness of confinement. Weights are calculated for each evidential theme based on the presence or absence of training points with respect to the study area and spatial associations between training points and evidential themes are established. Themes are then generalized to determine the threshold or thresholds that maximize the spatial association between the evidential theme and the training points (Bonham-Carter, 1994).

Response Theme (Vulnerability Maps)

Following generalization of evidential themes, output results (response themes) are generated and display the probability that a unit area contains a training point based on the evidential themes provided. The response theme generated in this project is a probability map displayed in classes of relative vulnerability for the FAS in Levy County.

Sensitivity Analysis and Validation of Model Results

Sensitivity analysis and validation are a significant component of any modeling project as they allow evaluation of the accuracy of results. Sensitivity analysis is applied during development of each evidential theme and validation exercises are applied to assess model strength and confidence.

LCAVA Technical Advisory Committee

An advisory committee was formed to provide technical review and support during the development of the FAVA Phase II project. From within this committee, specific members were assigned to the LCAVA project and consisted of professionals in the water resource, planning, engineering, hydrogeology and other environmental fields. Members, listed below, participated in workshop meetings, provided technical review of model progress and final results and report.

Table 1. LCAVA Technical Advisory Committee members.

Name	Organization
Allan Stodghill, P.G.	Florida Department of Environmental Protection
David Dewitt, P.G.	Southwest Florida Water Management District
Larry Gordon, P.G.	Florida Department of Health
Richard Deadman	Florida Department of Community Affairs
Carlos Herd, P.G.	Suwannee River Water Management District
Gail Mowry, P.E.	Marion County Clean Water Program
William Wise, Ph.D., P.E.	University of Florida
Gary Maidhof	Citrus County
Tom Greenhalgh, P.G.	Florida Geological Survey/FDEP

PROJECT RESULTS

Study Area

The political boundary of Levy County was used as the LCAVA model study area extent (Figure 1). Because of the sizes of some polygons representing soil data, a grid cell size of approximately 10,000 square feet (ft^2) was selected for evidential theme development. This grid cell size, while necessary to capture resolution available in some input data layers, does not reflect appropriate resolution of final model output. Appropriate scale of use of model results is discussed in *Model Implementation and Limitations*.

Water bodies were omitted from the model extent for two main reasons: first, the main goal of this project is to estimate vulnerability of the FAS and not vulnerability of surface water features, and second, data for water bodies is typically not available – i.e., wells are not drilled in water bodies, nor do soil surveys normally contain information regarding lake and stream bottoms.

Training Point Theme

In the LCAVA model, training points are ground-water wells tapping the FAS with water quality data indicative of high recharge. Dissolved oxygen analytical values served as training point data for the LCAVA model, and dissolved nitrogen concentrations were used for validation of model output. Naturally occurring oxygen and nitrogen are generally considered ubiquitous at land surface as primary components of the atmosphere; moreover, relatively low concentrations of these analytes occur in well protected – or less vulnerable – aquifer systems. Accordingly, where these analytes occur in elevated concentrations in ground-water, they are good indicators of aquifer vulnerability (Arthur et al., 2007).

Water quality data sources explored include the FDEP background water quality network, FDEP STATUS network, Florida Department of Health, and Southwest Florida Water Management District (SWFWMD). From these data sources, 51 wells measured for dissolved oxygen were identified as being potential candidates for training points. Statistical analyses revealed that there were no wells considered statistical outliers. The upper 25th percentile of this set – or all wells with median dissolved oxygen values greater than 4.45 milligrams per liter (mg/L) – served as the training point theme and consists of eleven wells. Figure 2 displays the distribution of water wells used to derive training points and the resulting training point theme across the study area.

Training points are used to calculate prior probability, weights for each evidential theme, and posterior probability of the response theme (see *Glossary*). Prior probability (training point unit area divided by total study area) is the probability that a training point will occupy a defined unit area within the study area, independent of evidential theme data. The prior probability value, a unitless parameter, is 0.0038

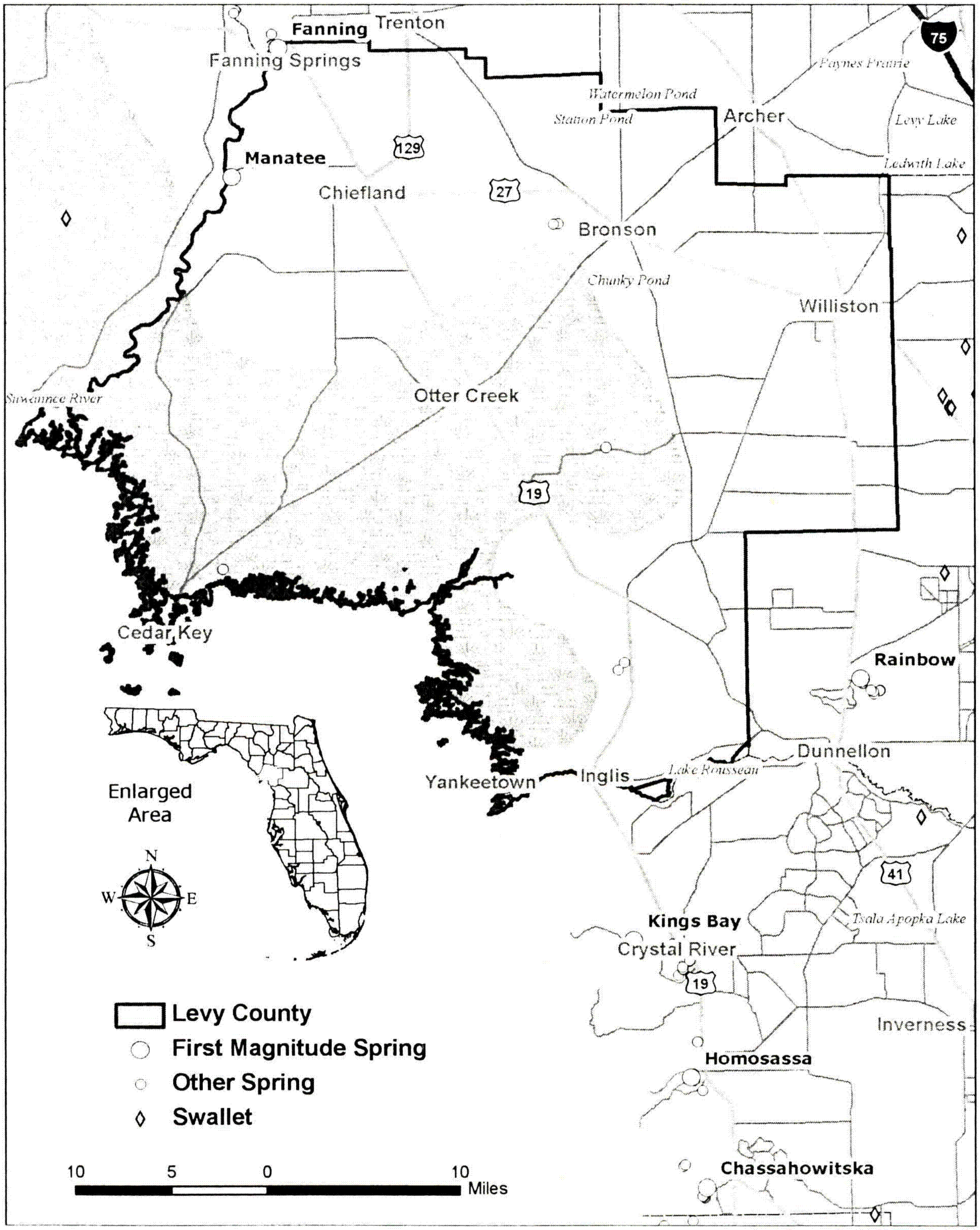


Figure 1. Levy County Aquifer Vulnerability Assessment project study area corresponds to the County's political boundary.

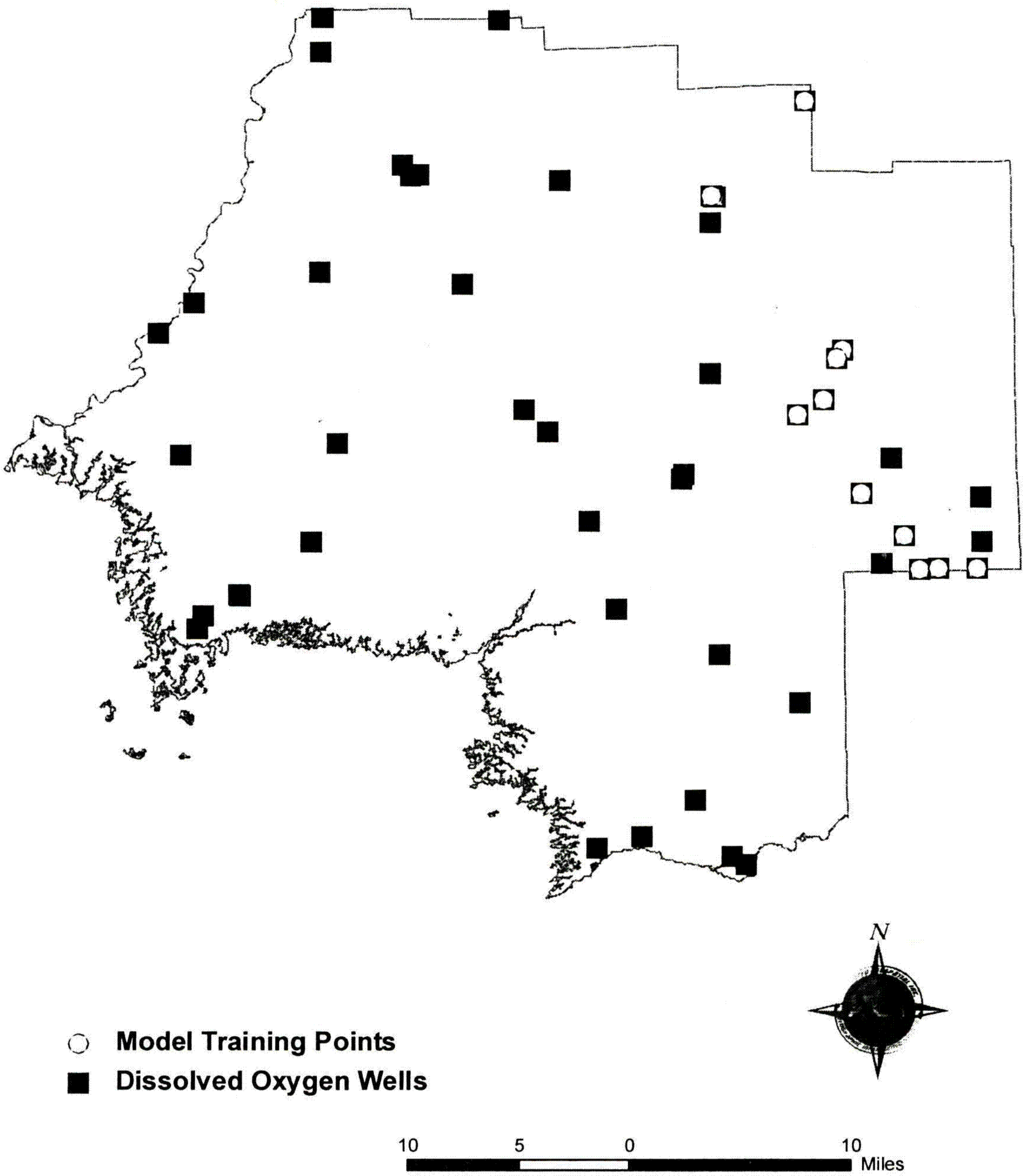


Figure 2. Location of all wells measured for dissolved oxygen, and locations of training point wells with median dissolved oxygen values higher than 4.45 mg/L.

for LCAVA. Posterior probability values generated during response theme development are interpreted relative to the value of prior probability with higher values generally indicating higher probability of containing a training point.

Evidential Themes – Model Input Layers

Input data layers, or evidential themes, representing hydrogeologic factors controlling the location of training points, and thereby vulnerability, were developed for model input. Because of the local scale nature of the LCAVA project, availability of new data, and implementation of new methodologies for estimating karst, all model inputs represent previously unavailable county-specific datasets. The factors considered for the LCAVA project include karst features, recharge potential, thickness of aquifer confinement, soil pedality, and soil hydraulic conductivity. In support of this project, FGS developed data surfaces representing the tops of the FAS and the Intermediate Confining Unit (ICU).

Soil Hydraulic Conductivity and Soil Pedality Themes

The rate that water moves through soil is a critical component of any aquifer vulnerability analysis, as soil is literally an aquifer system's first line of defense against potential contamination (Arthur et al., 2005). Two parameters of soils were evaluated for input into the LCAVA model: *soil hydraulic conductivity*, which is the "amount of water that would move vertically through a unit area of saturated soil in unit time under unit hydraulic gradient" (U.S. Department of Agriculture, 2005); and *soil pedality*, which is calculated based on soil type, soil grade, and soil pedon size, and is a unitless parameter. Soil pedality is a relatively new concept used to estimate the hydrologic parameter of soil and is generated for LCAVA using the pedality point method developed by Lin et al. (1999).

In 2006, Levy County soils data were redesigned for the study area by the Natural Resources Conservation Service. As a result, more detailed information is available for analysis for the LCAVA project than during previous projects (e.g., Arthur et al., 2005). To determine the best representation of soil hydraulic conductivity and pedality in the aquifer vulnerability assessment, numerous data coverages were generated and evaluated for model input.

Countywide datasets representing soil hydraulic conductivity and soil pedality were developed for use as input into the LCAVA model. Multiple empirical values are reported in soil surveys representing various zones in each soil column underlying a particular soil polygon. Further, multiple columns may be reported for a single soil polygon. Because the model requires a single value for each soil polygon, two steps are used. First, representative values for each horizon in a column are combined using a sum of the weighted mean. Second, because multiple columns may be reported for a soil polygon, the sum values are averaged into a single value for each polygon. This is completed for both hydraulic conductivity and soil pedality. Figures 3 and 4 display the soil hydraulic conductivity and pedality evidential themes, respectively.

Recharge Potential

In Copeland et al. (1991), the area of the Brooksville Ridge in central Florida is defined as having higher recharge potential than adjacent areas. The Brooksville Ridge is chiefly composed of Undifferentiated Hawthorn Group sediments which are poorly to moderately consolidated clayey sands and silty clays (Scott et al., 2001). In Levy County, these sediments reach a maximum calculated thickness of 167 feet and can be discontinuous, deeply weathered and highly perforated by karst features.

In other areas of Florida, Hawthorn Group sediments form the Intermediate Confining Unit and normally provide an effective confining or semi-confining unit for the underlying FAS. In Levy County, however, these sediments are generally highly weathered, leaky, thin and intensely breached

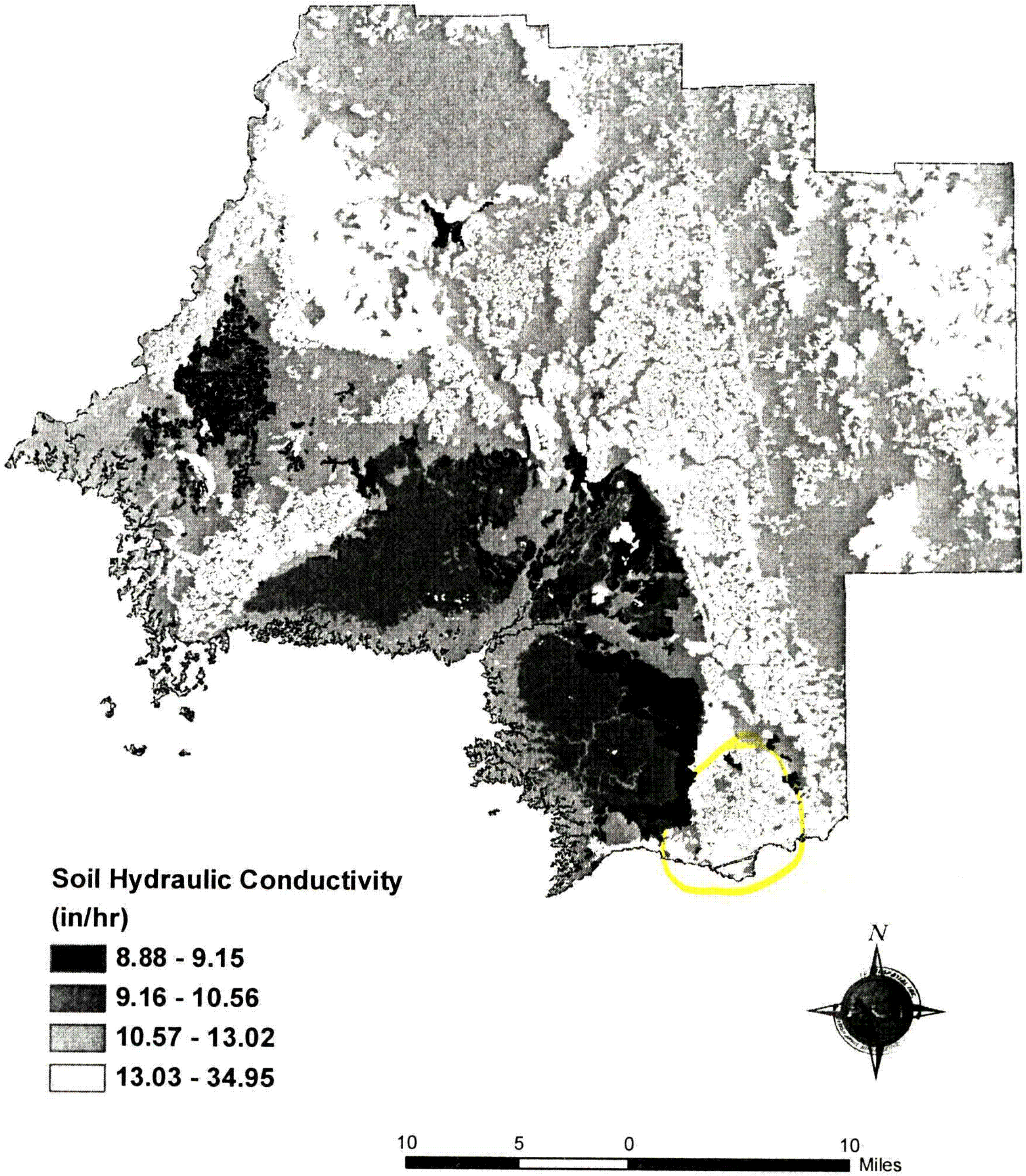


Figure 3. Distribution of soil hydraulic conductivity values across the LCAVA study area. White areas represent 'no data' areas in the soil survey data or locations of water bodies.

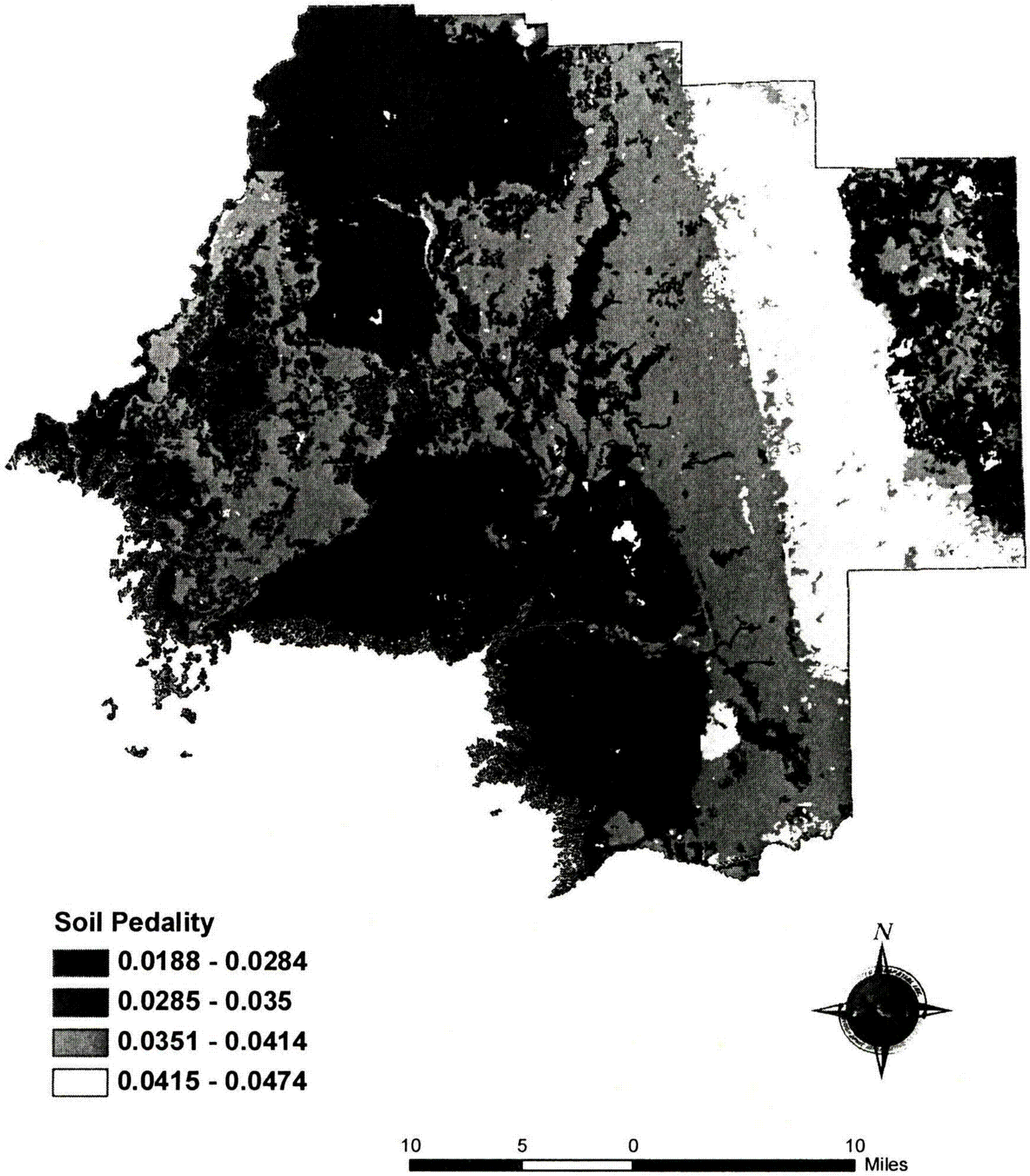


Figure 4. Distribution of soil pedality values (unitless) across the LCAVA study area. White areas represent 'no data' areas in the soil survey data or locations of water bodies.

by karst features. These factors combine to increase the recharge potential to the FAS in the study area where these sediments are present. Where recharge potential is high, aquifer vulnerability is increased.

Recharge potential values were calculated for the study area by subtracting the USGS 2000 potentiometric surface of the FAS (USGS, 2000) from land surface elevation derived from USGS 7.5" quadrangles. Resulting recharge potential values range from -18 ft to greater than 150 ft (relative to mean sea level). Negative values generally correspond to areas where the aquifer is estimated to be discharging while higher positive values are restricted to the more substantial hills located on the Brooksville Ridge.

Because the scale on which the potentiometric surface map was developed may not be appropriate for single-county scale analysis, categories of recharge potential were derived from the ranges of values calculated as described above. A preliminary weights of evidence analysis was completed on these empirical values to help guide category selection. This analysis indicated a very strong relationship between training points and recharge potential. Category breaks were then based on this preliminary weights of evidence analysis, and where the value of recharge potential is estimated at zero or less (i.e., potential discharge areas). Categories of recharge potential were ranked as displayed in Figure 5.

Use of recharge potential via this approach is restricted to areas of Florida where the FAS is not well confined (e.g., this layer may not be usable in areas which are also underlain by thicker, contiguous Intermediate Confining Unit sediments), and where there is not a laterally contiguous Surficial Aquifer System present.

Intermediate Confining Unit and Overburden Thickness Themes

Aquifer confinement – either in the form of overburden overlying the FAS, or the ICU – is another critical layer in determining aquifer vulnerability. Where aquifer confinement is thick and the FAS is deeply buried, aquifer vulnerability is generally lower, whereas in areas of thin to absent confinement, the vulnerability of the FAS is generally higher.

In support of the FAVA Phase II project, the FGS developed GIS models of the surface of the FAS and surface of the ICU. The intent of these models was to allow the calculation of aquifer confinement thickness in various study areas. Surface models were developed using a dataset of borehole records supplemented with well gamma logs that contain descriptions of subsurface materials. AGI used these surfaces to calculate thickness of the ICU (Figure 6) and thickness of overburden overlying the FAS (Figure 7) in the study area. These two layers were tested for input in the model as described in *Sensitivity Analysis*.

Effective Karst Feature Theme

Karst features, or sinkholes and depressions, can provide preferential pathways for movement of surface water into the underlying aquifer system and enhance an area's aquifer vulnerability where present. The closer an area is to a karst feature, the more vulnerable it may be considered. Closed topographic depressions extracted from U.S. Geological Survey 7.5-minute quadrangle maps served as the initial dataset from which to estimate karst features in the study area. To supplement these data, the FGS sinkhole database was included to identify karst features possibly not represented on USGS maps. These two data sources displayed in Figure 8 were combined and analyzed to develop an effective karst features evidential theme.

It is recognized that closed topographic depressions may or may not be true karst features, however, application of analytical processes to digital elevation maps and models to estimate karst has been

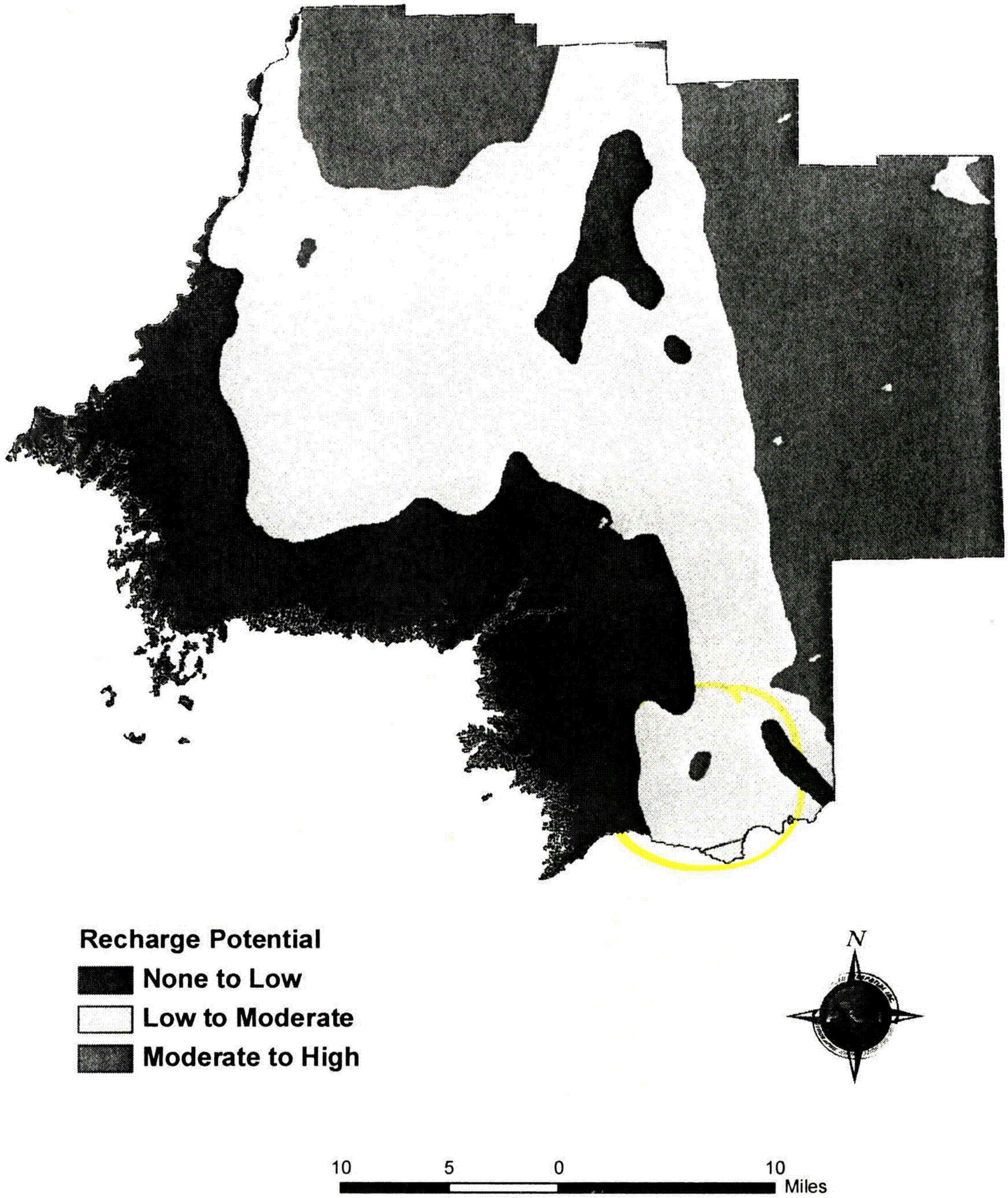
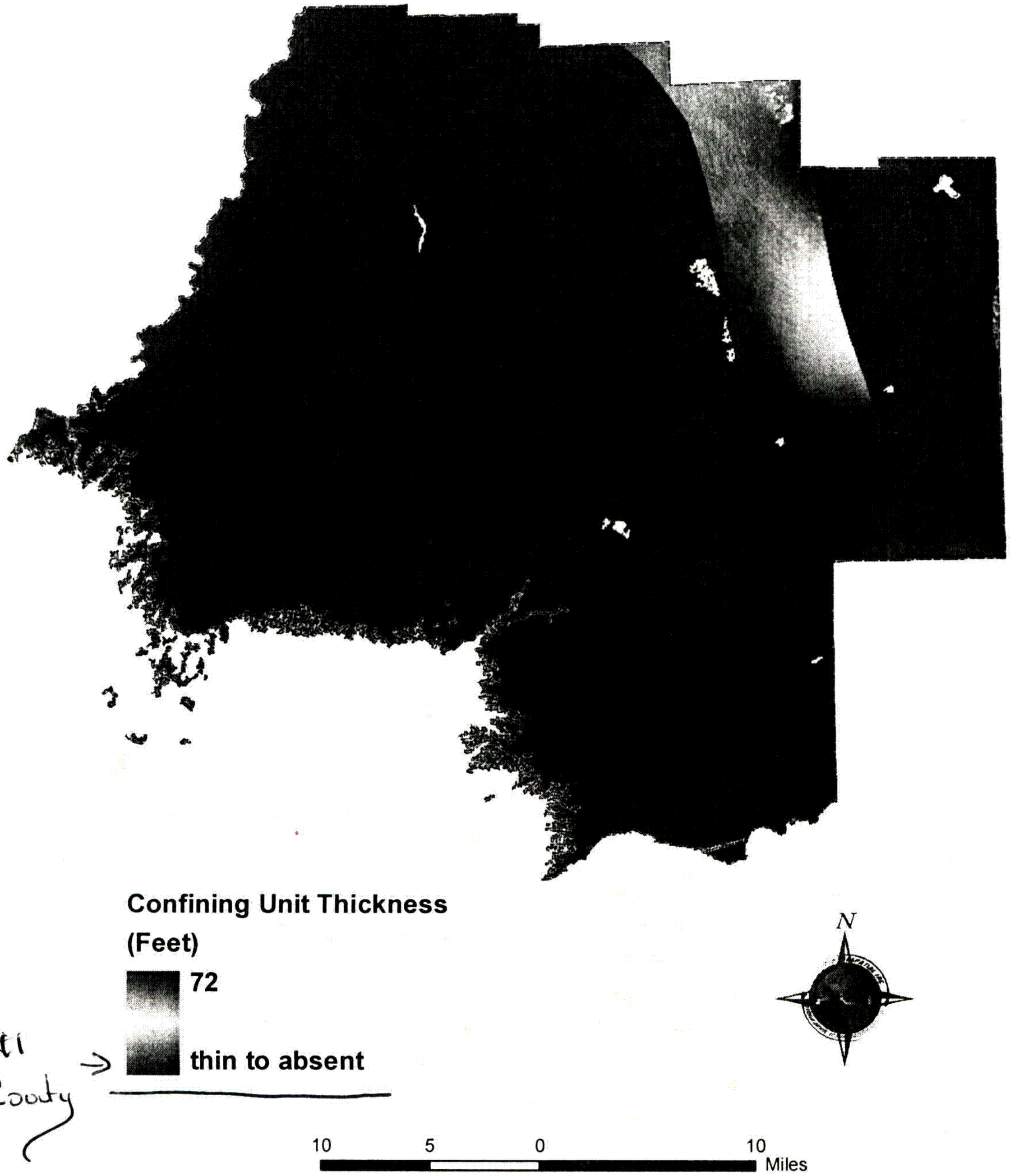


Figure 5. Recharge potential estimated from FAS potentiometric surface data, land surface elevation and estimates developed for Copeland et al., (1991). Major lakes and water bodies were omitted for input into final model.



Almost all of Levy County

Figure 6. Thickness of the ICU calculated by subtracting predicted surface of ICU from predicted surface of FAS as generated by FGS. Major lakes and water bodies were omitted for input into final model.

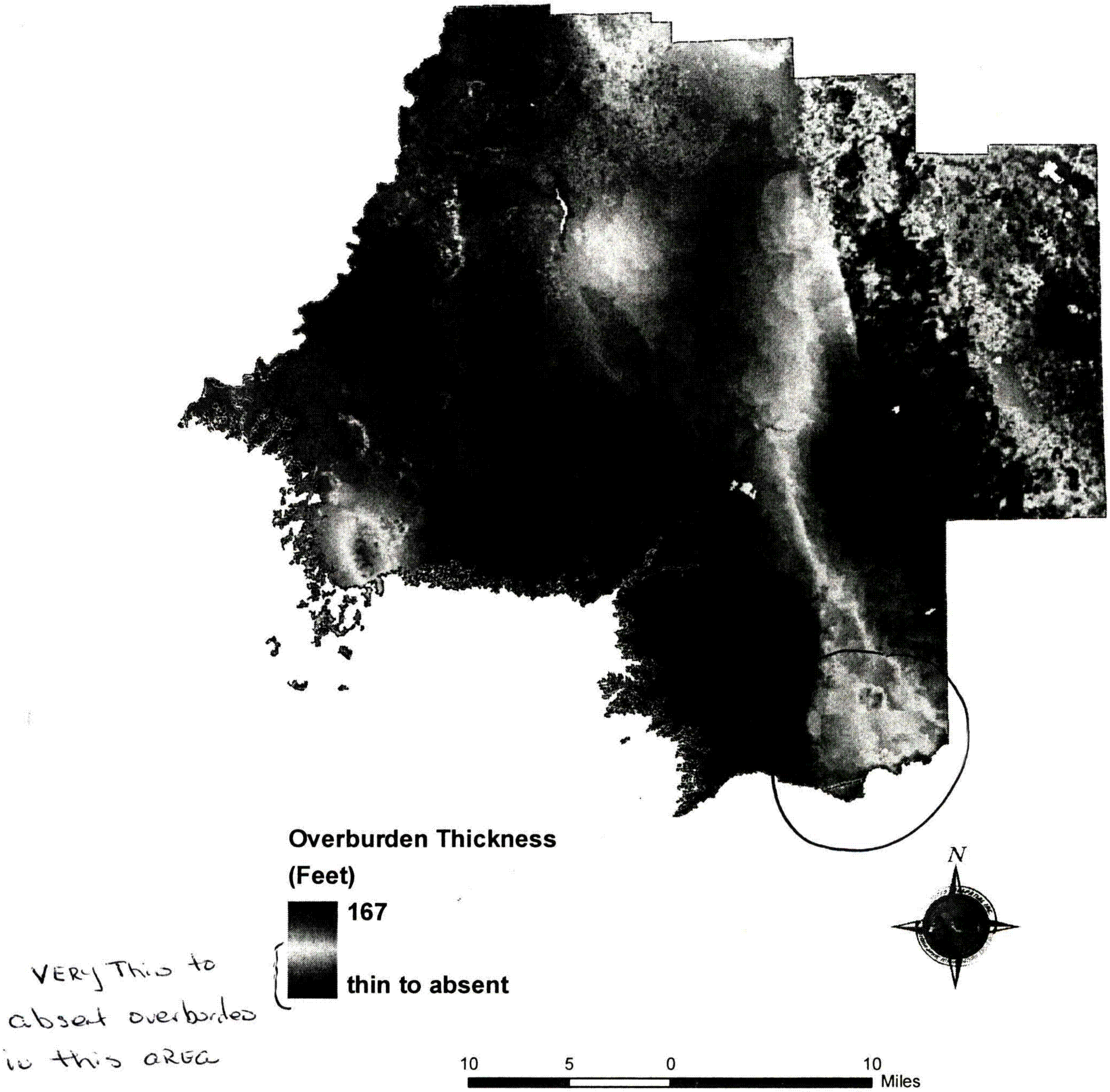


Figure 7. Thickness of sediments overlying the FAS calculated by subtracting digital elevation data from predicted surface of FAS as generated by FGS. Major lakes and water bodies were omitted for input into final model.

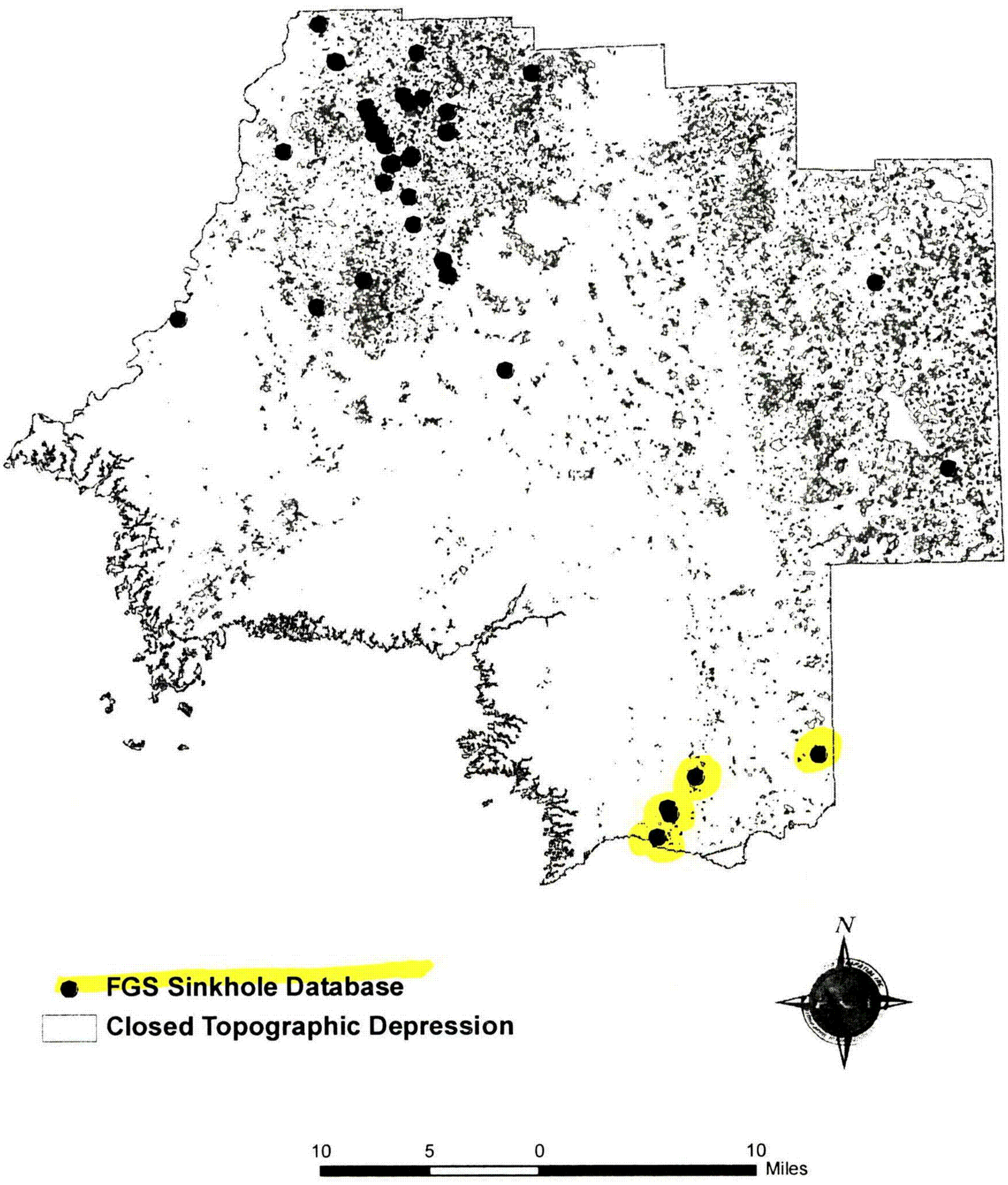


Figure 8. All closed topographic depressions extracted from U.S. Geological Survey 7.5-minute topographic contour lines and sinkholes from the FGS sinkhole database.

successfully completed in numerous projects (Baker et al., 2007; Arthur et al., 2005; Cichon et al., 2005; Baker et al., 2005; and Denizman, 2003). The most statistically significant and defensible method evaluated for this project is the circular index method described below.

Circular index method

Karst features, which form as the result of the dissolution of carbonate rocks and subsequent collapse of overlying material, are generally circular in nature. In contrast, non-karstic depressional features are common in near-shore modern terrains, relic dune terrains and other provinces, and tend to have a non-circular shape. To filter these features and other types of non-karst features in the study area, a circular index shape analysis (Denizman, 2003) was used to compare the roundness of depressional features to an ideal circle. The area of each closed depression was divided by the area of an ideal circle with the same perimeter as the depression. This resulted in a "roundness ratio" representing the degree of similarity between two such features. Several roundness ratio values were evaluated for use in the model; a value of 0.75 was found to be most suitable for this study area. Features with a roundness ratio of less than 0.75 were filtered out.

To avoid removal of nested karst features within larger, possibly karstic, but non-circular depressions, the circular index analysis was completed on five- and ten-foot topographic intervals within every topographic depression (depending on topographic map resolution). The results of this analysis were combined with the FGS sinkhole features to create an effective karst layer as displayed in Figure 9.

Sensitivity Analysis/Evidential Theme Generalization

Sensitivity analysis allows decisions to be made about proposed evidential themes by evaluating each theme's association with training points – or aquifer vulnerability – and ultimately helps determine model input. For example, themes representing both soil pedality and soil hydraulic conductivity were developed to represent the impact of soils in the model; sensitivity analysis allows, through statistical analysis, determination of which of these two layers served as the most appropriate input representing soils for the final LCAVA analysis. Results of this process indicate that effective karst features, recharge potential, and soil pedality were the best suited evidential themes for use in final modeling.

Following sensitivity analysis and selection of evidential themes to be input into the LCAVA model, themes were generalized to assess which areas of the evidence share a greater association with locations of training points. During calculation of weights for each theme, a contrast value was calculated for each class of the theme by combining the positive and negative weights. Contrast is a measure of a theme's significance in predicting the location of training points and helps to determine the threshold or thresholds that maximize the spatial association between the evidential theme map pattern and the training point theme pattern (Bonham-Carter, 1994). Contrast and weights are described in more detail below in *Discussion.*

Contrast values were used to determine where to sub-divide evidential themes into generalized categories prior to final modeling. The simplest and most accepted method used to subdivide an evidential theme is to select the maximum contrast value as a threshold value to create binary generalized evidential themes. In other models, categorization of more than two classes may be justified (Arthur et al., 2005). For the LAVA project, a binary break was typically defined by the weights of evidence analysis for each evidential theme creating two spatial categories: one with stronger association with the training point theme and one with weaker association.

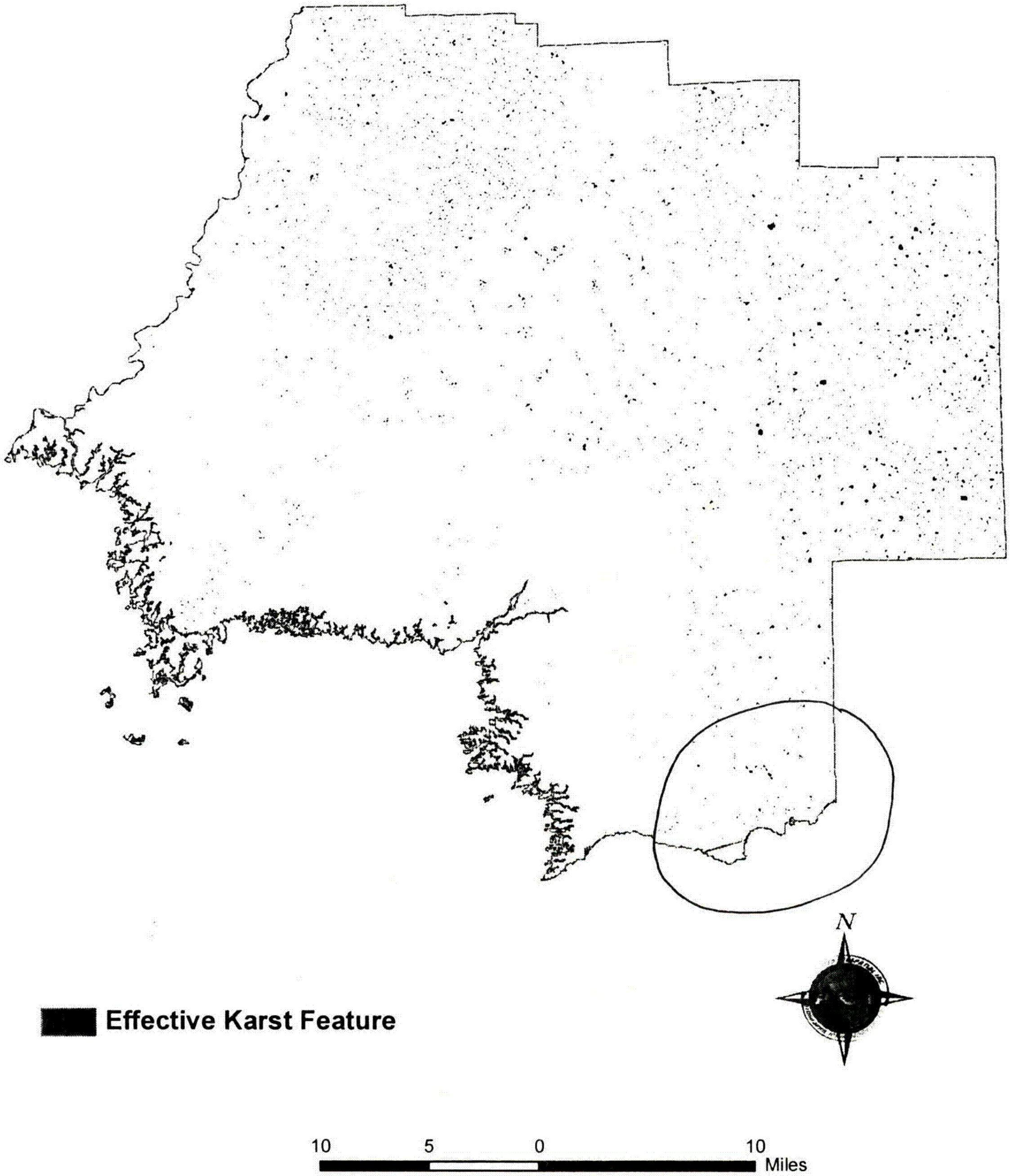


Figure 9. Effective karst features resulting from circular index method applied to U.S. Geological Survey 7.5-minute topographical contour lines combined with sinkholes from the Florida Geological Survey sinkhole database.

See p. 15 - For description of circular index method

Soil Pedality/Soil Hydraulic Conductivity

Weights calculated during sensitivity analysis for soil pedality were much stronger (i.e., had higher absolute value) than weights calculated for soil hydraulic conductivity. As a result, soil pedality was chosen as the better predictor of aquifer vulnerability because it shared the best association with training points.

Soil pedality, a unitless parameter, ranges from 0.0188 to 0.0474 across the study area. The analysis indicated that areas underlain by 0.0454 to 0.0474 were more associated with the training points, and therefore associated with higher aquifer vulnerability. Conversely, areas underlain by 0.0188 to 0.0453 were less associated with the training points, and therefore lower aquifer vulnerability. Based on this analysis, the evidential theme was generalized into two classes as displayed in Figure 10.

Intermediate Confining Unit / Overburden Thickness Themes

Weights calculated during sensitivity analysis for the overburden thickness and ICU thickness indicated no association with training points. In fact, weights values were negative and revealed an inverse association between training points and aquifer confinement. Based on this lack of association, these layers were excluded from modeling.

Recharge Potential

Recharge potential ranged from "none to low" to "moderate to high" across the study area. The analysis indicated that areas within the "moderate to high" potential recharge zone were more associated with the training points, and therefore with higher aquifer vulnerability. Conversely, areas in "none to low" and "low to moderate" recharge potential zones were less associated with the training points, and therefore lower aquifer vulnerability. Based on this analysis, the evidential theme was generalized into two classes as displayed in Figure 11. p. 19

Effective Karst Features

As mentioned above, areas closer to an effective karst feature are normally associated with higher aquifer vulnerability. Based on this, features were buffered into 100-ft zones to allow for a proximity analysis (Figure 12). The analysis indicated that areas within 787 feet of a karst feature were more associated with the training points, and therefore with higher aquifer vulnerability. Conversely, areas greater than 787 feet from a karst feature were less associated with the training points, and therefore lower aquifer vulnerability. Based on this analysis, the evidential theme was generalized into two classes as displayed in Figure 13. p. 21

Response Theme

Using evidential themes representing effective karst, recharge potential, and soil pedality, weighted logistic regression was applied to generate a response theme, which is a GIS raster consisting of *posterior probability* values ranging from 0.00018 to 0.03156 across the study area. These probability values describe the relative favorability that a unit area of the model will contain a training point – i.e., a point of aquifer vulnerability as defined above in *Training Points* – with respect to the prior probability value of 0.0038. Prior probability is the probability that a training point will occupy a defined unit area within the study area, independent of evidential theme data. Probability values at the locations of 10 of the 11 training points are above the prior probability, indicating that this model is a strong predictor of training point locations. The final response theme is displayed in Figure 14.

P. 22

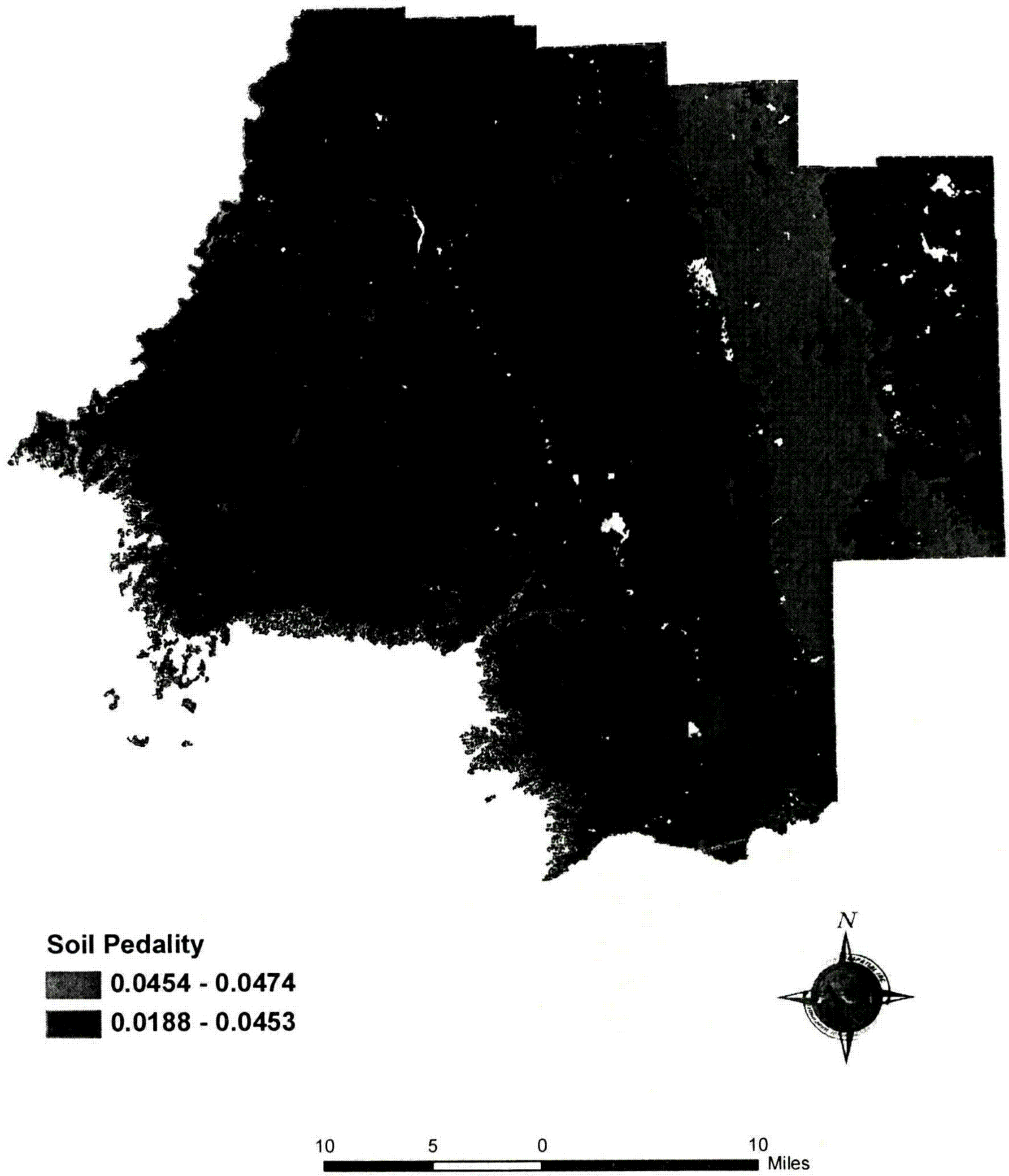


Figure 10. Generalized soil pedality evidential theme; based on calculated weights analysis blue areas share a weaker association with training points and thereby aquifer vulnerability, whereas red areas share a stronger association with training points.

Figure 11. Generalized recharge potential evidential theme; based on calculated weights analysis blue areas share a weaker association with training points and thereby aquifer vulnerability, whereas red areas share a stronger association with training points.

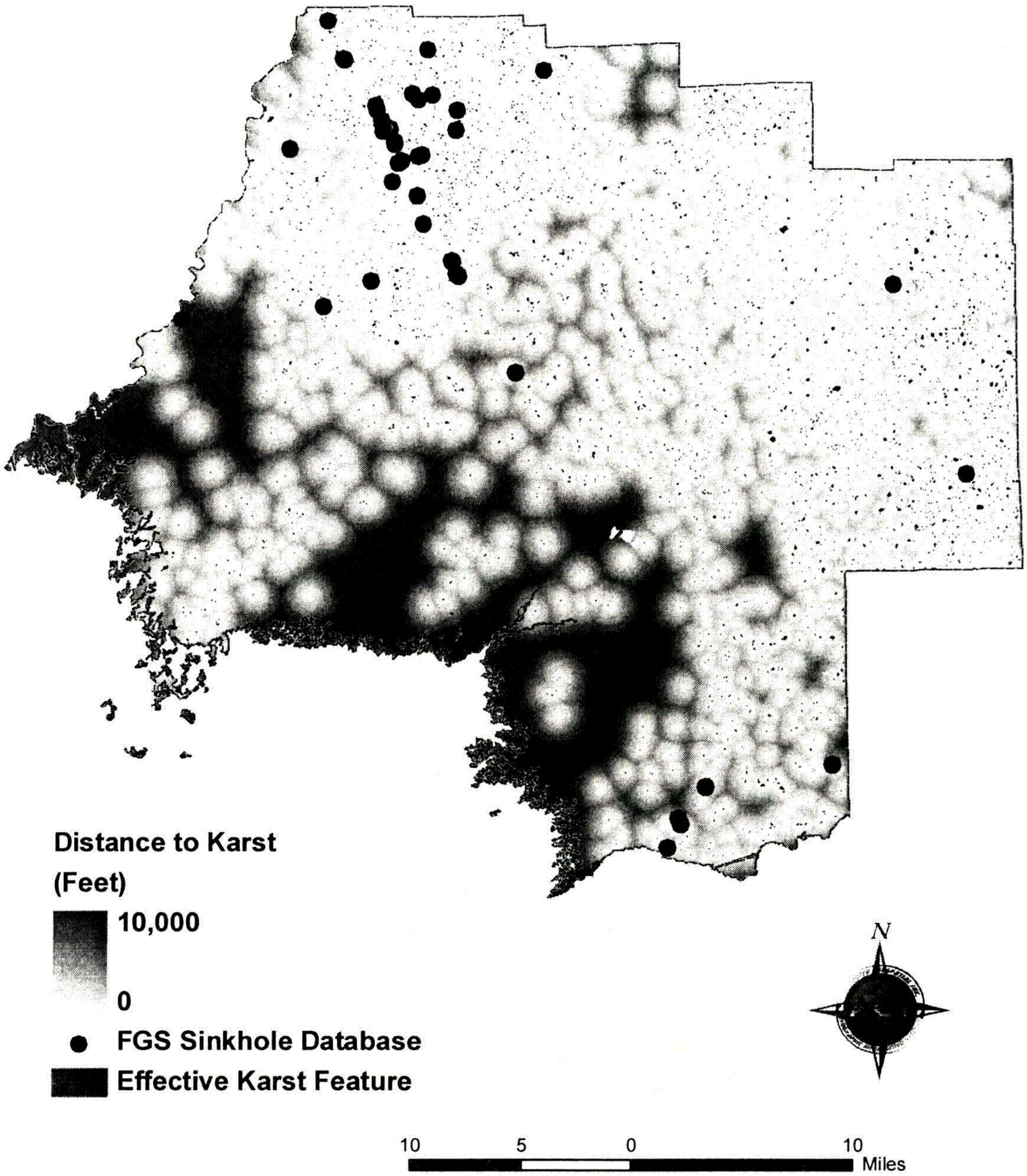


Figure 12. Effective karst features evidential theme buffered into 100-ft zones for proximity analysis in the weights of evidence analysis.

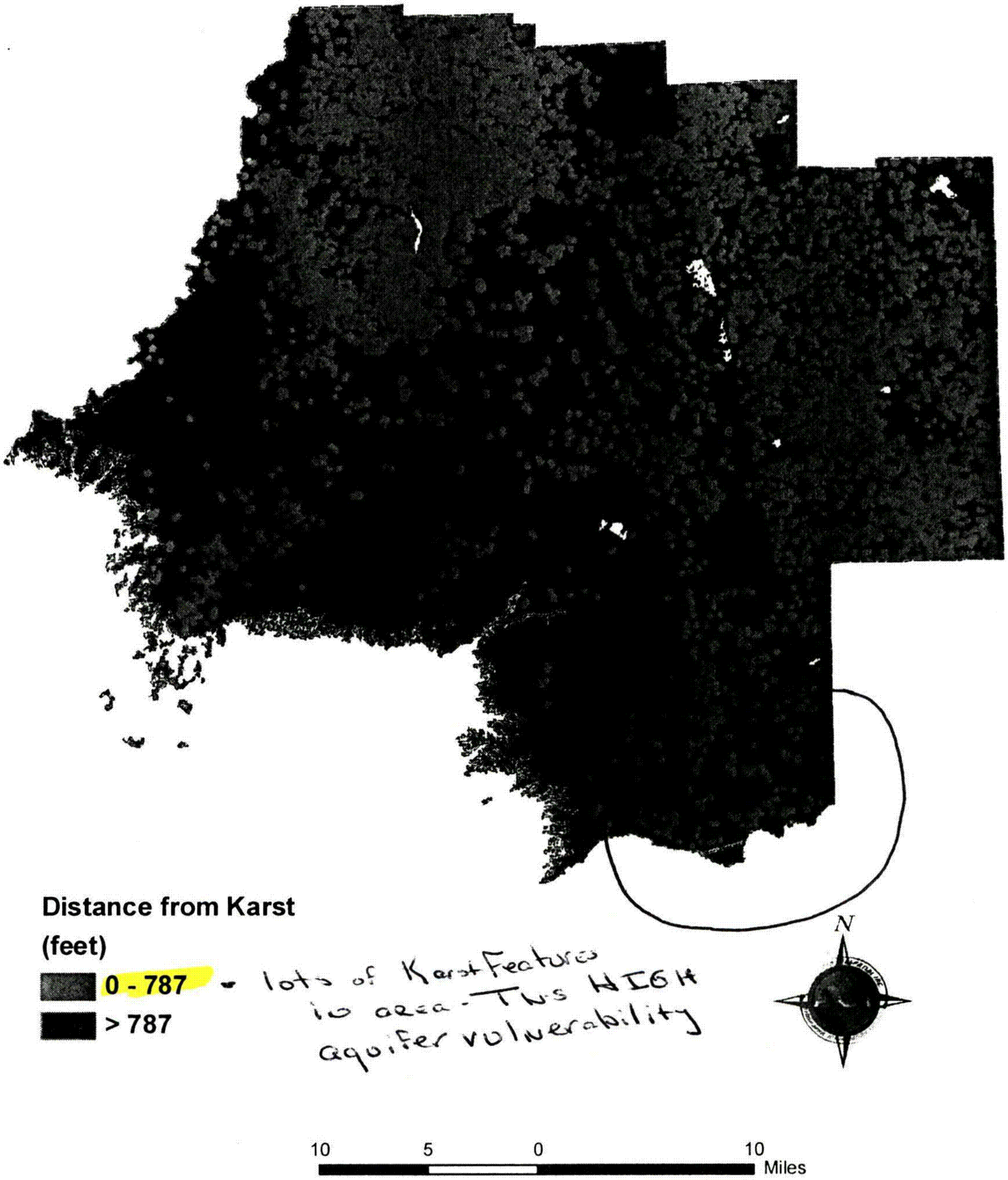
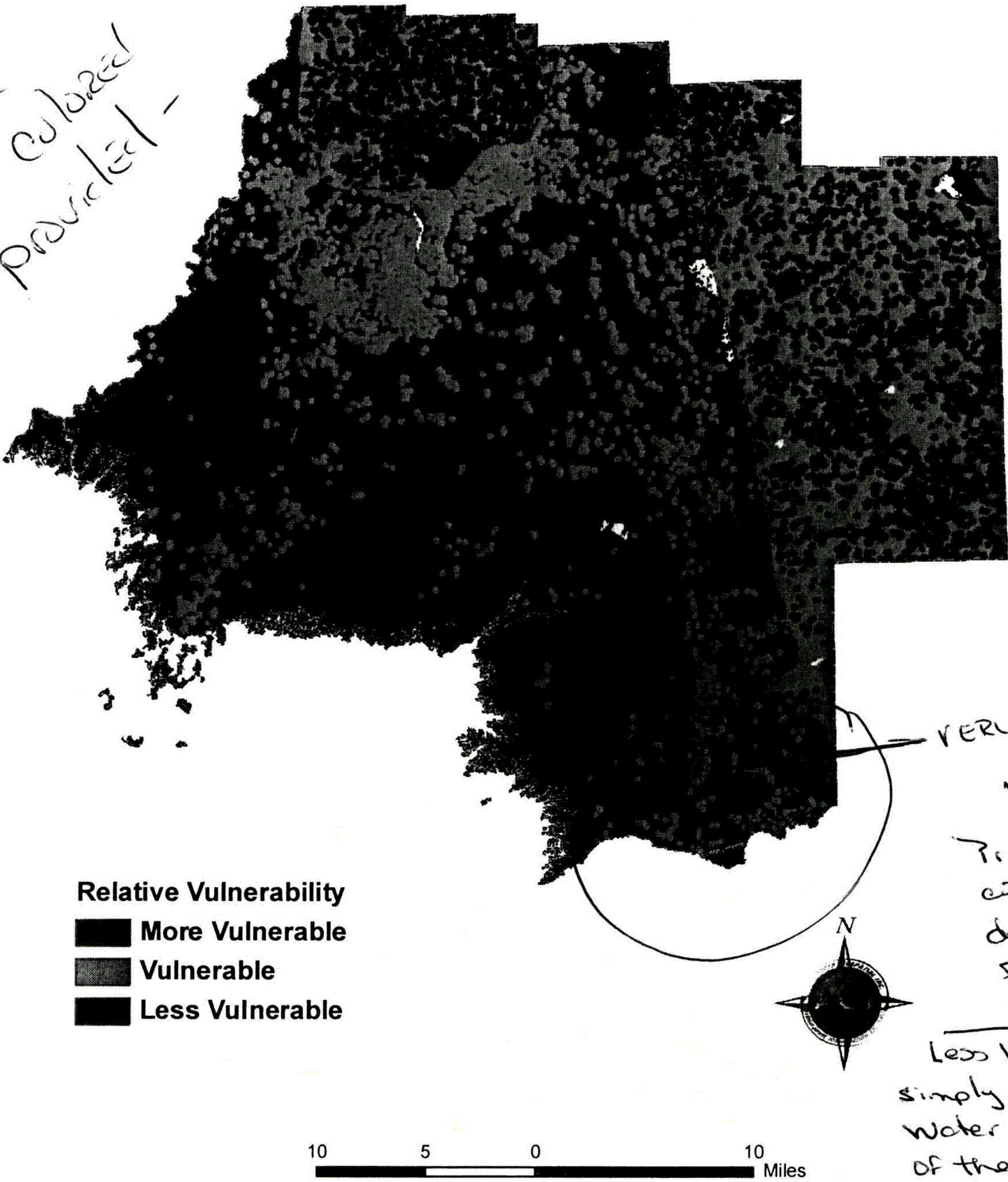


Figure 13. Generalized effective karst feature evidential theme; based on calculated weights analysis blue areas share a weaker association with training points and thereby aquifer vulnerability, whereas red areas share a stronger association with training points.

Please look at colored map provided -



VERY important area = MORE vulnerable aquifer - Progress Energy computer model does not evaluate for aquifer contamination

Less Vulnerable - simply means the water stays on top of the ground for a longer period of time - It stays there to either slowly percolate into the ground and become part of Floridan Aquifer or to flow into various creeks and finds it's way to the Gulf across the land surface

Figure 14. Relative vulnerability map for the Levy County Aquifer Vulnerability Assessment project. Classes of vulnerability are based on calculated favorability of a unit area containing a training point, or a monitor well with water quality sample results indicative of vulnerability.

Less vulnerable does not mean Less Important - it just means that the water does not immediatly go into our aquifer and thus our drinking water.

The response theme was broken into classes of relative vulnerability based on the prior probability value and on inflections in a chart in which cumulative study area was plotted against posterior probability (Figure 15). Higher posterior probability values correspond with more vulnerable areas, as they essentially have a higher chance of containing vulnerability based on the definition of a training point. Conversely, lower posterior probability values correspond to less vulnerable areas as they essentially have a lower chance of containing vulnerability based on the definition of a training point.

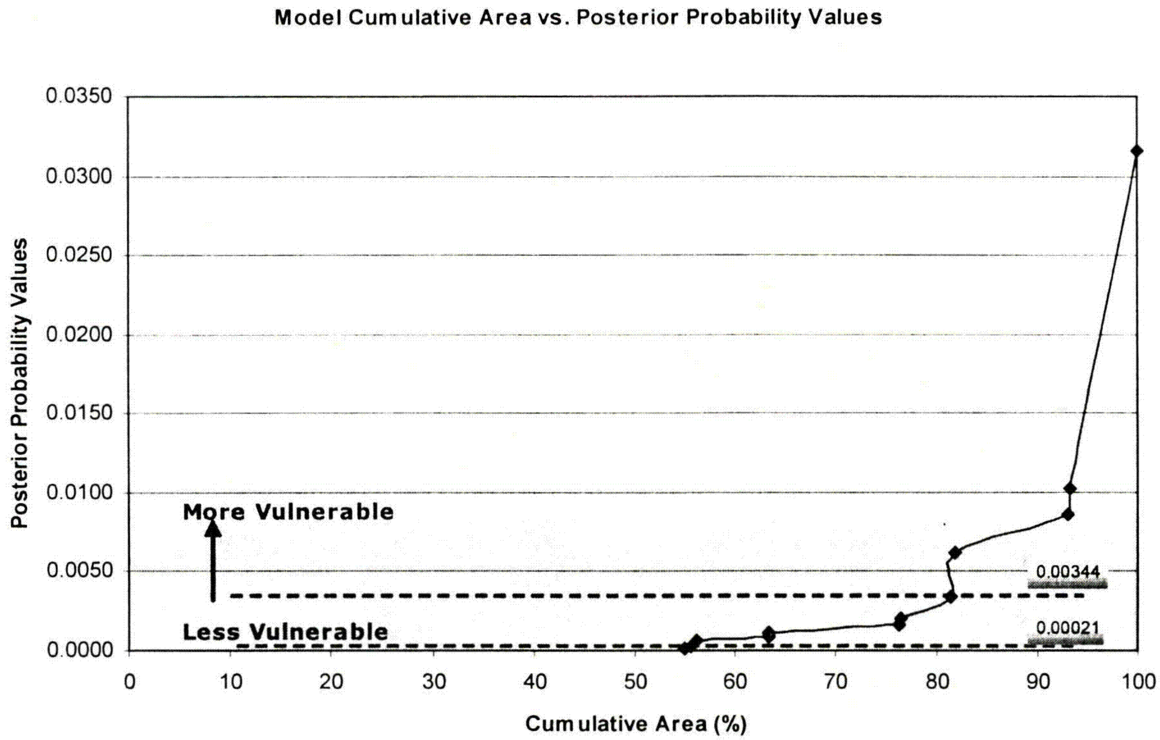


Figure 15. Vulnerability class breaks are defined by selecting where a significant increase in probability and area are observed.

As described in *Introduction*, the LCAVA model was based on the modeling technique used in the FAVA project. The FAVA project identified relative vulnerability of Florida's principal aquifer systems broken into three classes: more vulnerable, vulnerable and less vulnerable zones. This naming technique was applied to the LCAVA results to define the relative vulnerability classes.

As expected, the LCAVA model response theme indicates that the areas of highest vulnerability are associated with areas of dense effective karst-features, moderate-to-high recharge potential and higher soil pedality. Conversely, areas of lowest vulnerability are determined by sparse karst-feature distribution, lower recharge potential and lower soil pedality values.

Interpretation of Results in Context of FAVA

Results of the LCAVA project have allowed delineation of new and unique zones of relative vulnerability for the FAS in Levy County, based on the county-specific model boundary used, inclusion of a layer estimating recharge potential, incorporation of most recent soils data, a new training point set, and application of recently-developed approaches for karst estimation in a GIS. These new results, though refined and highly detailed, do not replace results of previous studies. In other words, the FDEP's regional FAVA results (Figure 16; Arthur et al., 2005) for the FAS see colored map for detail

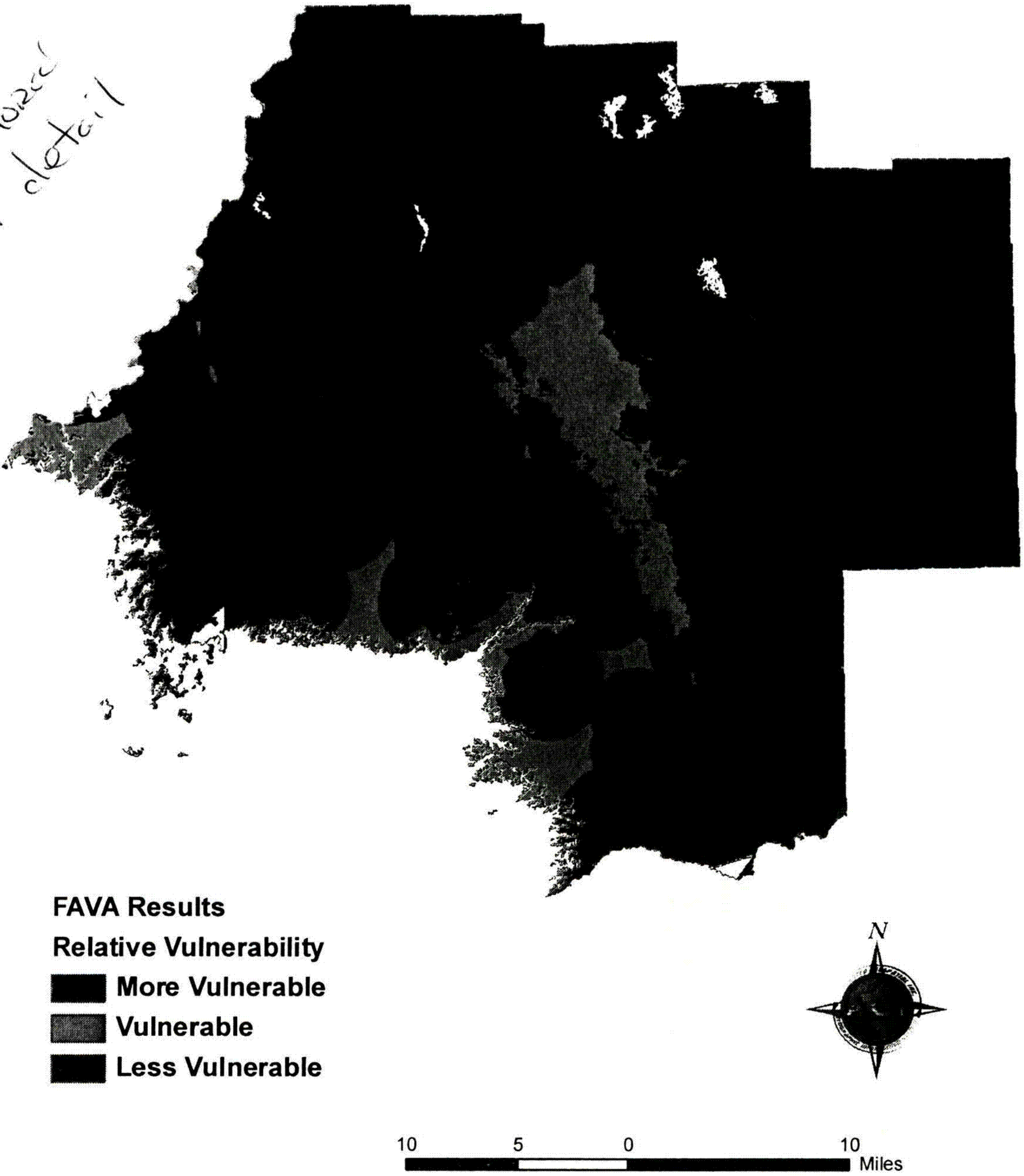


Figure 16. Results of the Florida Aquifer Vulnerability Assessment project (Arthur et al., 2005) for the FAS in Levy County. The LCAVA model relative vulnerability zones, while based on more refined data than the FAVA project, occur within the context of this regional model.

indicate that the Levy County study area occurs in primarily a "more vulnerable" zone relative to other areas in Florida; as a result the new LCAVA model output should be interpreted in the context of this major regional project. The new zones delineated in the LCAVA project are unique to the LCAVA study area, and reveal more detailed information regarding aquifer vulnerability within the regional "more vulnerable", and "vulnerable" zones identified in the FAVA project.

DISCUSSION

Prior to discussion of weights calculations during model execution, two components of a weights of evidence analysis are described to assist in interpretation of LCAVA model results: *Conditional Independence* and *Model Confidence*.

Conditional Independence

Conditional independence is a measure of the degree that evidential themes are affecting each other due to similarities between themes. Evidential themes are considered independent of each other if the conditional independence value is around 1.00, and conditional independence values within the range of 1.00 ± 0.15 generally indicate limited to no dependence among evidential themes (Bonham-Carter, 1994). Values significantly outside this range can inflate posterior probabilities resulting in unreliable response themes.

Conditional independence was calculated at 0.32 for the LCAVA project indicating that evidential themes had a high degree of conditional dependence. Because of the interrelated origin of some natural features controlling aquifer vulnerability (e.g., thin aquifer confinement/density of karst), some interdependence between evidential themes is expected. This has occurred in the past in similar projects; for example, conditional independence calculated for the FAS model in the FAVA Phase I project also indicated evidential themes had a high degree of interdependence (Arthur et al., 2005).

Weighted Logistic Regression

The weighted logistic regression method was employed to resolve a conditional independence issue in the FAVA Phase I project. The benefit of this method is it avoids the bias caused by combining datasets that are conditionally dependent and can be used to account for the inflated probabilities associated with conditional independence problems (Agterberg et al., 1993, and Bonham-Carter, 1994).

Weights of evidence models that rely on logistic regression to generate final model output do not differ greatly from standard weights of evidence model results. The primary difference is that posterior probability values can be inflated when conditional independence values fall significantly outside the acceptable range discussed above. Overall, the patterns of the response themes are extremely similar (Mihalasky and Moyer, 2004).

Model Confidence

During model execution confidence values are calculated both for each generalized evidential theme and for the final response theme. Confidence values approximately correspond to the statistical levels of significance listed in Table 2.

Table 2. Test values calculated in weights of evidence and their respective studentized T values expressed as level of significance in percentages.

Studentized T Value	Test Value
99.5%	2.576
99%	2.326
97.5%	1.960
95%	1.645
90%	1.282
80%	0.842
75%	0.674
70%	0.542
60%	0.253

Confidence of the evidential theme equals the contrast divided by the standard deviation (a student T-test) for a given evidential theme and provides a useful measure of significance of the contrast due to the uncertainties of the weights and areas of possible missing data (Raines, 1999). A confidence value of 2.9432 corresponds to a greater than 99.5% test value – or level of significance – and was the minimum calculated confidence level for LCAVA project evidential themes (see Table 3 below for evidential theme confidence values).

Confidence is also calculated for a response theme by dividing the theme's posterior probability by its total uncertainty (standard deviation). A confidence map can be generated based on these calculations. The confidence map for the LCAVA response theme is displayed in Figure 17. Areas with high posterior probability values typically correspond to higher confidence values and as a result have a higher level of certainty with respect to predicting aquifer vulnerability.

Weights Calculations

Table 3 displays evidential themes used in the LCAVA model, weights calculated for each theme, along with contrast and confidence values. Positive weights indicate areas where training points were likely to occur, while negative weights indicate areas where training points were not likely to occur. The contrast column is a combination of the highest and lowest weights (positive weight – negative weight) and is a measure of how well the generalized evidential themes predict training points. A positive contrast that is significant, based on its confidence, suggests that a generalized evidential theme is a useful predictor.

Table 3. Weights of evidence final output table listing weights calculated for each evidential theme and their associated contrast and confidence values of the evidential themes.

Evidential Theme	W1	W2	Contrast	Confidence
Recharge Potential	1.1000	-2.0375	3.1375	2.9893
Effective Karst Features	1.0665	-2.0226	3.0892	2.9432
Soil Pedality	1.6199	-0.8770	2.4969	3.9678

Because negative weights (W2) values for recharge potential and effective karst themes are stronger (have greater absolute values) than the positive weights (W1), these two evidential themes are better predictors of where training points were *less* likely to occur. In contrast, soil pedality is a better predictor of where training points are *more* likely to occur, as W1 is stronger than W2.

Table 4 also displays evidential themes used in the LCAVA model and a coefficient for each evidential theme, which, like the weights of evidence table, indicates relative importance of each evidential theme in determining the posterior probability of the response theme (Mihalasky and Moyer, 2004). The higher the absolute value of the coefficient, the better predictor the associated evidential theme is of training points, or aquifer vulnerability.

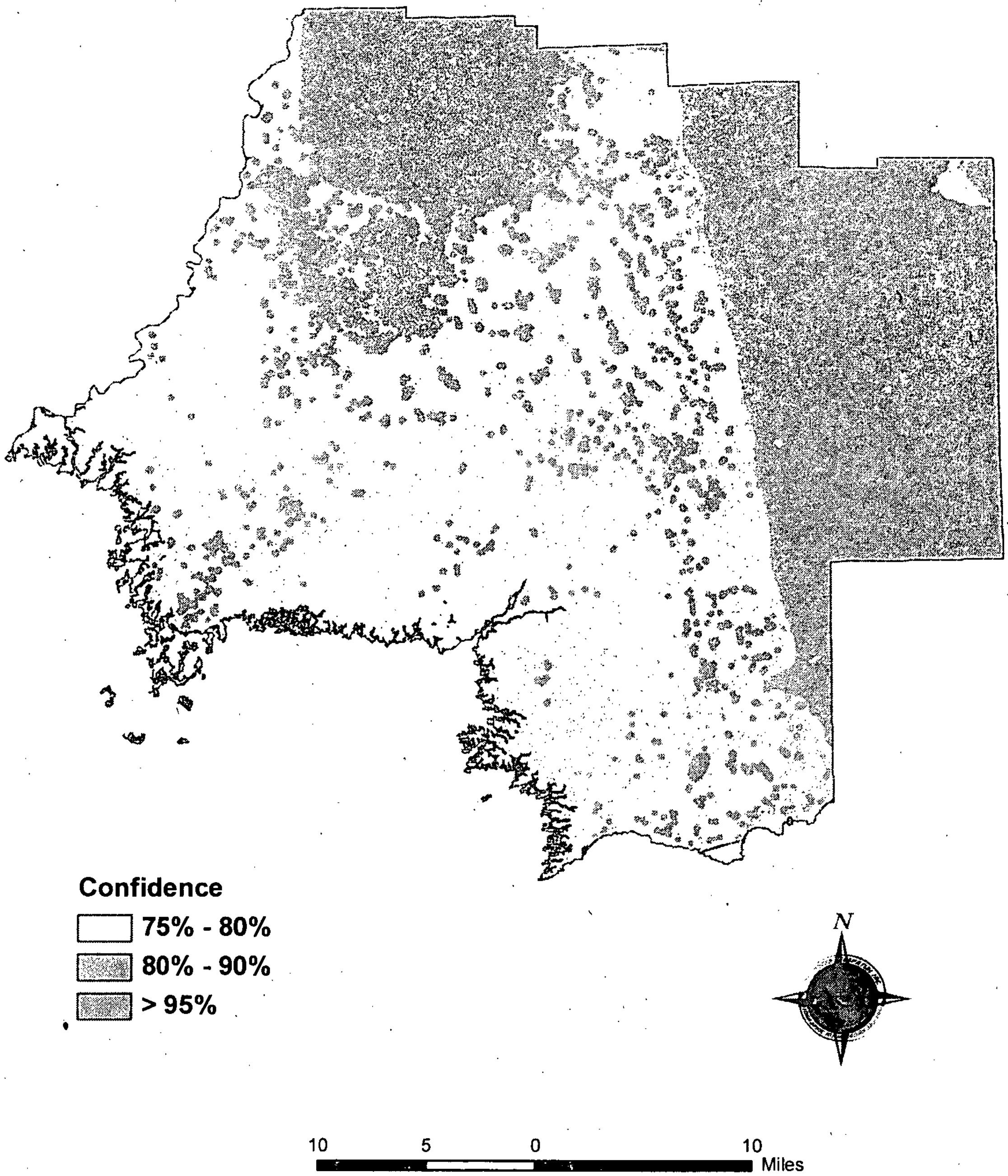


Figure 17. Confidence map for the LCAVA model calculated by dividing the posterior probability values by the total uncertainty for each class to give an estimate of how well specific areas of the model are predicted.

Table 4. Weighted logistic regression final output table listing coefficients calculated for each evidential theme.

Evidential Theme	Coefficient
Effective Karst Features	-2.245824
Recharge Potential	-1.654336
Soil Pedality	-1.317255

Based on coefficient values, the effective karst features theme has the strongest coefficient (highest absolute value) and is the primary determinant in predicting areas of vulnerability in the LCAVA model.

Validation

The weights of evidence approach, because it relies on a set of training points, which by definition are known sites of vulnerability, is essentially self-validated. Moreover, the location of 10 of 11 training points in "more vulnerable" zones indicates that the LCAVA model is a strong predictor of aquifer vulnerability based on the definition of a training point. Further strengthening the results were the evaluation of a minimum confidence threshold for evidential themes, and generation of a confidence map of the response theme. In addition to these exercises, and in the style of previous aquifer vulnerability assessments (Cichon et al., 2005; Baker et al., 2005; Arthur et al., 2005), additional validation techniques were applied to the LCAVA model to further strengthen its defensibility, and, ultimately, its utility: (1) comparison of dissolved nitrogen values with vulnerable zones of the response theme; (2) generation of a test response theme based on a subset of training points and comparison of points not used in subset to model results; and (3) comparison of dissolved oxygen values to posterior probability and evaluation of an associated trend.

Dissolved Nitrogen Data

Perhaps the most rigorous validation exercise used to evaluate quality of model-generated output is to compare predicted model values with independent test values not used in the model. For the LCAVA model, this was accomplished by comparison of a separate well dataset based on dissolved nitrogen. As mentioned above in *Training Point Theme*, dissolved nitrogen is indicative of aquifer vulnerability, but is independent of dissolved oxygen. Applying the methodology described in *Training Point Theme* to dissolved nitrogen data (obtained from the same data sources as dissolved oxygen data) resulted in a dissolved nitrogen dataset of 13 wells each indicative of aquifer vulnerability.

These 13 points were evaluated against posterior probability values of the LCAVA model output. Extracting the value of posterior probability from the dissolved oxygen response theme for the location of each of the 13 dissolved nitrogen training points revealed that 11 of the 13 dissolved nitrogen training points occur in areas of the dissolved oxygen model with predicted probability values higher than the prior probability value. In other words, 85% of the dissolved nitrogen wells were located in areas predicted to have a greater than chance probability of containing a training point. Based on this test, the dissolved oxygen model is not only a good predictor of vulnerability as defined by the training point theme, it is also a good predictor of the location of an independent parameter also representing aquifer vulnerability. Figure 18 displays dissolved nitrogen data points plotted on the dissolved oxygen response theme.

Subset Response Theme

Another meaningful validation exercise similar to the exercise above is to use the existing training point dataset to develop two subsets: one to generate a test response theme, and one to validate output from this test response theme. Results from this exercise helped to further assess whether the dissolved oxygen training points are reasonable predictors of aquifer vulnerability.

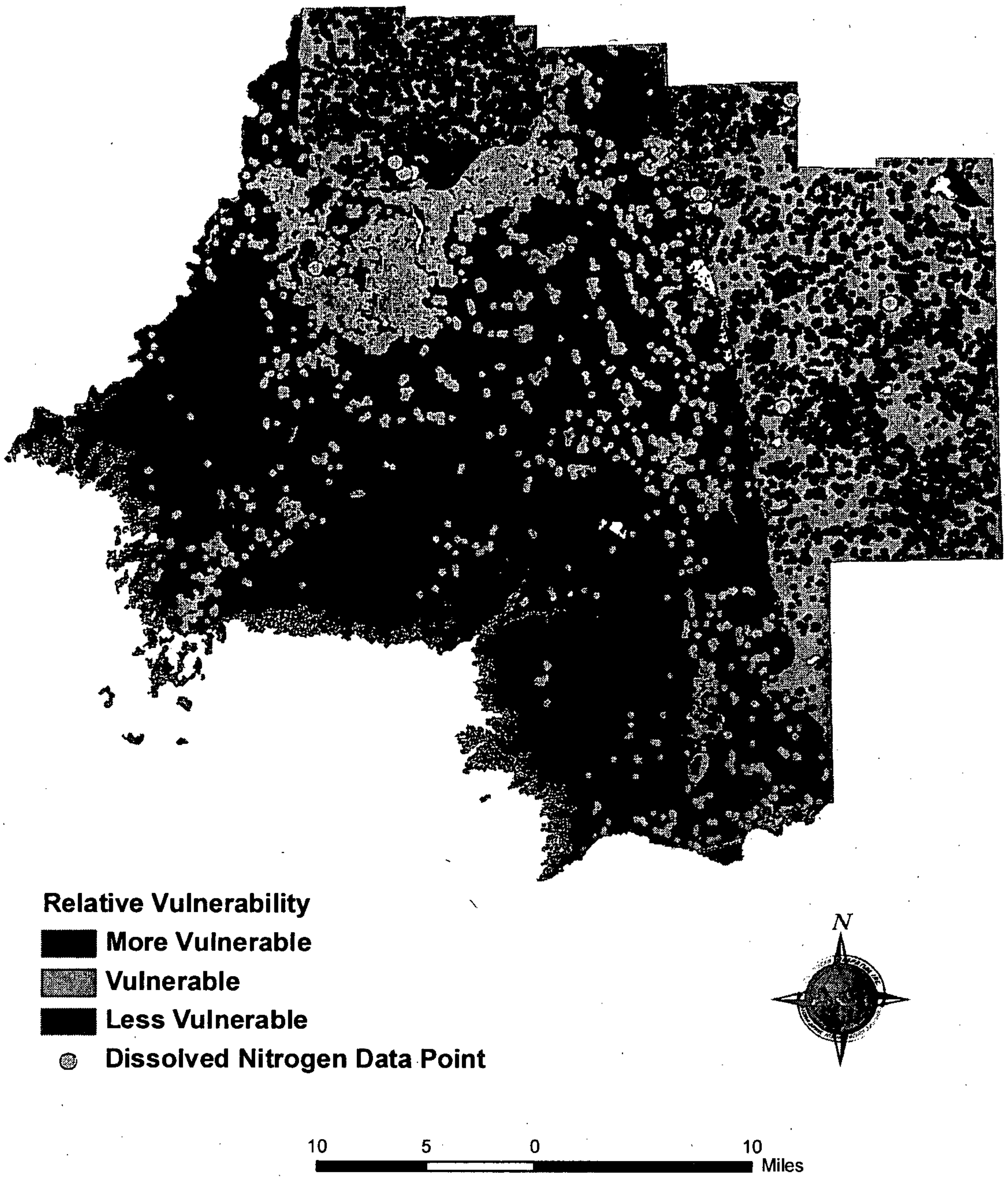


Figure 18. Dissolved nitrogen validation training points plotted in the dissolved oxygen response theme. Comparison reveals 11 of 13 wells (85%) of the independent water quality dataset are located in "more vulnerable" areas.

From the LCAVA training point theme, a subset of 75% (eight wells) were randomly selected and used to develop a test response theme; the remaining 25% (three wells) of the training points were used as the validation dataset for the test response theme. This comparison revealed that all three test wells in the validation subset, or 100%, occur in areas of the test response theme with predicted probability values higher than the prior probability value. This further supports the conclusion that the LCAVA model response theme is a reasonable estimator of vulnerability.

Dissolved Oxygen Data vs. Posterior Probability

It was expected that comparison of posterior probability values to the dissolved oxygen dataset from which the training point theme was extracted would reveal a proportional trend, in other words, as dissolved oxygen values increase, so should posterior probability values. Dissolved oxygen median concentrations were binned and averaged for each posterior probability value calculated in model output. The average values were plotted in a chart against posterior probability values (Figure 19) and a positive trend was observed.

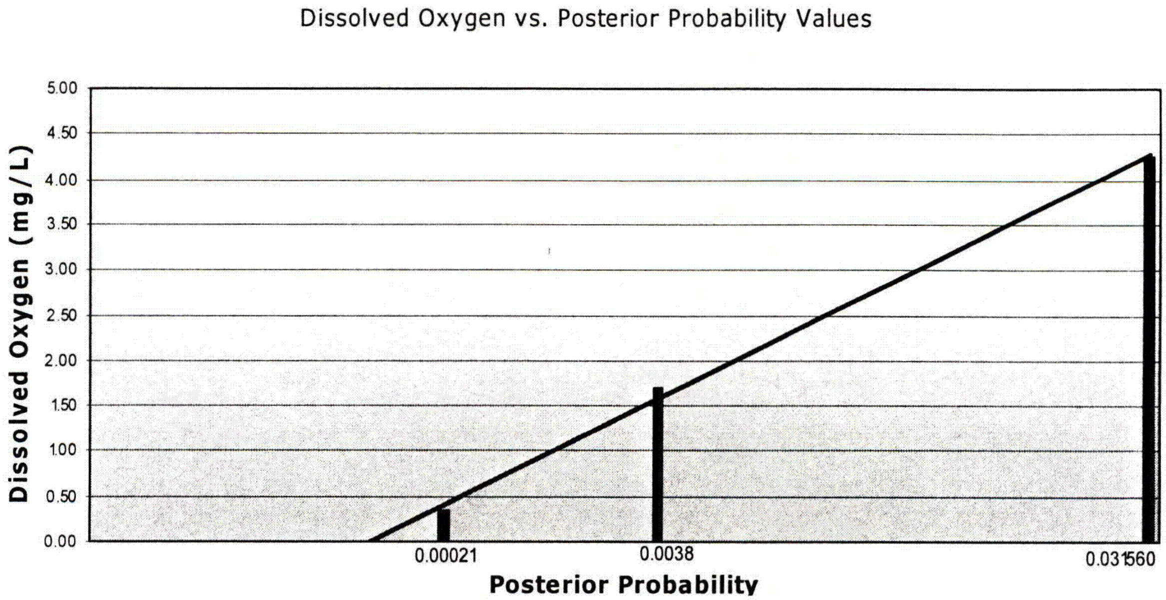


Figure 19. Dissolved oxygen values (averaged per posterior probability class) versus probability values to reveal trend between increasing dissolved oxygen concentrations and posterior probability.

An additional test involved applying a Pearson's correlation coefficient (r) test to all dissolved oxygen values versus posterior probability values. This test revealed a value of 0.64 indicating more than a 99% degree of statistical significance between the response theme values and the dissolved oxygen data.

Model Implementation and Limitations

When implementing the LCAVA project results, it is essential to remember that all aquifer systems in Florida, to some degree, are vulnerable to contamination; an invulnerable aquifer does not exist. Further, model results are based solely on features of the natural system that have significant association with the location of training points and thereby aquifer vulnerability. The LCAVA project results provide a favorability map that identifies zones of relative vulnerability in the study area based on these input data; as a result the LCAVA model output is an estimation of intrinsic or natural aquifer vulnerability. Additionally, model results do not account for human activities at land surface, take into consideration contaminant types, or estimate ground-water flow paths or fate/transport of chemical constituents.

Confidence Map

As mentioned above, a confidence map of the model's posterior probability values can be calculated by dividing the posterior probability by its standard deviation. This essentially applies an informal student T-test (as in Table 2) to the posterior probability values. The higher the confidence values, the greater the certainty is with regard to the posterior probability. This map essentially indicates the degree of confidence to which the posterior probabilities are meaningful and should be referenced when interpreting and implementing the model results. In other words, the confidence map should be used to help guide implementation of the vulnerability map as it reveals the confidence level associated with each vulnerability class (Mihasky and Moyer, 2004).

Surface Water Areas

In addition to large surface-water bodies omitted from the analysis, there are many other surface-water features which were not removed. Many of these features may represent areas of ground-water discharge; however, these discharging surface waters are not part of the aquifer, although they originate from it. Accordingly, the LCAVA model is not intended to be used to assess contamination potential of surface waters, though the discharging surface waters are highly vulnerable to contamination.

Recommendations on Scale of Use

Use of highly detailed evidential theme data as model input results in highly resolute model output as can be seen in the model response theme. These resolute features are reflections of real data used as input; however, the final maps should not be applied to very large scales such as to compare adjacent small parcels. The following recommendations are made in recognition of the need for these maps to be applied to regulation and decisions made at the parcel scale.

LCAVA model output is, in a sense, as accurate as the most detailed input layer, and as inaccurate as the least detailed layer. Wells used to define aquifer confinement thickness represent an area up to 28 square miles (mi^2), for example; on the other hand, soils polygonal data represent an area as small as 19,375 ft^2.

Reports on past projects recommended that model results be applied on a local scale of greater than or equal to approximately 1.0 mi^2 for statewide studies (Arthur et al., 2005: Florida Aquifer Vulnerability Assessment) or approximately 0.75 mi^2 for localized studies (Cichon et al., 2005: Wekiva Aquifer Vulnerability Assessment; Baker et al., 2007: Marion County Aquifer Vulnerability Assessment). Based on similarities to larger-scale projects, AGI recommends that the LCAVA model output be used for implementation on the order of greater than 0.75 mi^2, or an area of approximately 480 acres or greater. In other words, when applying model results to compare vulnerability zones, it is recommended that the user refrain from making decisions, comparing parcels, or relative vulnerability zones within a 480 acre area, or 4500-ft by 4500-ft view window. Application of model results on a less resolute scale, or simply, a more "zoomed-out" view than the 4,500-ft x 4,500-ft view window is recommended.

Every raster cell of the model output coverage has significance per the model input as discussed above. However, it is important to note that aquifer vulnerability assessments are predictive models and no assumptions are made that all input layers are accurate, precise or complete at a single-raster cell scale. Ultimately, accuracy of the maps does not allow for evaluation of aquifer vulnerability at a specific parcel or site location. It is the responsibility of the end users of the LCAVA model output to determine specific and appropriate applications of these maps. In no instance should use of aquifer vulnerability assessment results substitute for a detailed, site-specific hydrogeological analysis.

CONCLUSION

As demands for fresh ground water from the FAS underlying Levy County increase resulting from continued population growth, identification of zones of relative vulnerability becomes an increasingly important tool for implementation of a successful ground-water protection and management program. The results of the LCAVA project provide a science-based, water-resource management tool allowing for a pro-active approach to protection of the FAS, and, as a result, have the potential to increase the value of protection efforts. Model results will enable improved decisions to be made about aquifer vulnerability based on the input selected, including focused protection of sensitive areas such as springsheds and ground-water recharge areas.

The results of the LCAVA vulnerability model are useful for development and implementation of ground-water protection measures; however, the vulnerability output map included in this report should not be viewed as a static evaluation of the vulnerability of the FAS. Because the assessments are based on snapshots of best-available data, the results are static representations; however, a benefit of this methodology is the flexibility to easily update the response themes as more refined or new data becomes available. In other words, as the scientific body of knowledge grows regarding hydrogeologic systems, this methodology allows the ongoing incorporation and update of datasets to modernize vulnerability assessments thereby enabling end users to better meet their objectives of protecting these sensitive resources. The weights of evidence modeling approach to aquifer vulnerability is a highly adaptable and useful tool for implementing ongoing protection of Florida's vulnerable ground-water resources.

QUALIFICATIONS

Disclaimer and Funding Source

Maps generated as part of this project were developed by Advanced GeoSpatial Inc. (AGI) to provide the Florida Department of Environmental Protection (FDEP) with a ground-water resource management and protection tool to carry out agency responsibilities related to natural resource management and protection regarding the Floridan Aquifer System. Although efforts were made to ensure information in these maps is accurate and useful, neither FDEP nor AGI assumes responsibility for errors in the information and does not guarantee that the data are free from errors or inaccuracies. Similarly, AGI and FDEP assume no responsibility for consequences of inappropriate uses or interpretations of the data on these maps. Accordingly, these maps are distributed on an "as is" basis and the user assumes all risk as to their quality, results obtained from their use, and performance of the data. AGI and FDEP further make no warranties, either expressed or implied as to any other matter whatsoever, including, without limitation, the condition of the product, or its suitability for any particular purpose. The burden for determining suitability for use lies entirely with the end user. In no event shall AGI or FDEP, or their respective employees have any liability whatsoever for payment of any consequential, incidental, indirect, special, or tort damages of any kind, including, but not limited to, any loss of profits arising out of use of or reliance on the project results. AGI and FDEP bear no responsibility to inform users of any changes made to this data. Anyone using this data is advised that resolution implied by the data may far exceed actual accuracy and precision. Because this data was developed and collected with FDEP funding, no proprietary rights may be attached to it in whole or in part, nor may it be sold to FDEP or other government agency as part of any procurement of products or services.

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Ownership of Documents and Other Materials

This project represents significant effort and resources on both the part of FDEP and AGI to establish peer-reviewed, credible and defensible aquifer vulnerability model results. Unauthorized changes to results can have far reaching implications including confusing end users with multiple model results, and discrediting validity and defensibility of original results.

A main goal of the project is to maintain the integrity and defensibility of the final model output by preserving its data-driven characteristics. Modification or alteration of the model or its output can only be executed by trained professionals experienced with the project and with weights of evidence.

To protect both FDEP and AGI from potential misuse or unauthorized modification of the project results, all input and output results of aquifer vulnerability assessments, and the aquifer vulnerability assessment models, along with project documents, reports, drawings, estimates, programs, manuals, specifications, and all goods or products, including intellectual property and rights thereto, created under this project or developed in connection with this project will be and will jointly remain the property of FDEP and AGI.

For additional information regarding this project, please refer to the associated 24" x 36" interpretive poster of the same title as this report, and/or the GIS project data and associated metadata. At the time of this report, these GIS files may be accessed using ArcMap™, version 9.x.

WEIGHTS OF EVIDENCE GLOSSARY

Conditional Independence – Occurs when an evidential theme does not affect the probability of another evidential theme. Evidential themes are considered independent of each other if the conditional independence value calculated is within the range 1.00 ± 0.15 (Bonham-Carter, 1994). Values that significantly deviate from this range can inflate the posterior probabilities resulting in unreliable response themes.

Confidence of Evidential Theme – Contrast divided by its estimated standard deviation; provides a useful measure of significance of the contrast.

Confidence of Posterior Probability – A measure based on the ratio of posterior probability to its estimated standard deviation.

Contrast – W+ minus W- (see weights), which is an overall measure of the spatial association (correlation) of an evidential theme with the training points.

Data Driven – refers to a modeling process in which decisions made in regard to modeling input are driven by empirical data. Examples include the weights of evidence approach or logistic regression approach as in the FDEP's FAVA project (Arthur et al., 2005).

Evidential Theme – A set of continuous spatial data that is associated with the location and distribution of known occurrences (i.e., training points); these map data layers are used as predictors of vulnerability.

Expert Driven – a scientific approach which relies on the expertise and knowledge of one or more specialists to drive decisions in a modeling project. An example is the EPA's index ranking method known as "DRASTIC".

Posterior Probability – The probability that a unit cell contains a training point after consideration of the evidential themes. This measurement changes from location to location depending on the values of the evidence.

Prior Probability – The probability that a unit cell contains a training point before considering the evidential themes. It is a constant value over the study area equal to the training point density (total number of training points divided by total study area in unit cells).

Response Theme – An output map that displays the probability that a unit area would contain a training point, estimated by the combined weights of the evidential themes. The output is displayed in classes of relative aquifer vulnerability or favorability to contamination (i.e., this area is more vulnerable than that area). The response theme is the relative vulnerability map.

Spatial Data – Information about the location and shape of, and relationships among, geographic features, usually stored as coordinates and topology.

Training Points – A set of locations (points) reflecting a parameter used to calculate weights for each evidential theme, one weight per class, using the overlap relationships between points and the various classes. In an aquifer vulnerability assessment, training points are wells with one or more water quality parameters indicative of relatively higher recharge which is an estimate of relative vulnerability.

Weights – A measure of an evidential-theme class. A weight is calculated for each theme class. For binary themes, these are often labeled as W+ and W-. For multiclass themes, each class can also be described by a W+ and W- pair, assuming presence/absence of this class versus all other classes. Positive weights indicate that more points occur on the class than due to chance, and the inverse for negative weights. The weight for missing data is zero. Weights are approximately equal to the proportion of training points on a theme class divided by the proportion of the study area occupied by theme class, approaching this value for an infinitely small unit cell.

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