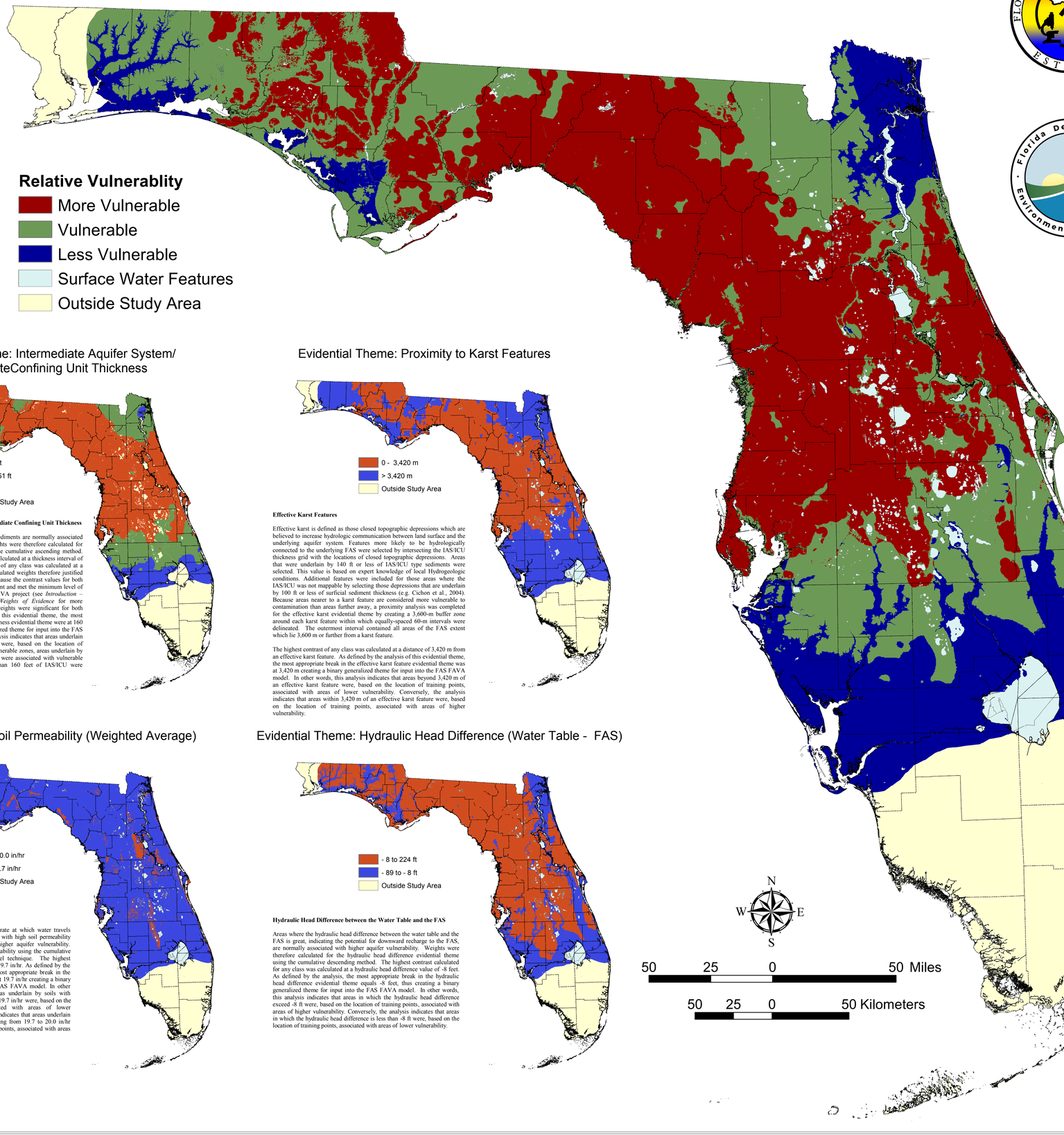
DEPARTMENT OF ENVIRONMENTAL PROTECTION
FLORIDA GEOLOGICAL SURVEY

Relative Vulnerability Map of the Floridan Aquifer System



Study Area and Extent

The Floridan Aquifer System (FAS) comprises a thick sequence of carbonate rocks that function regionally as a major aquifer system. It ranges from a fully-confined aquifer system where overlain by the Intermediate Aquifer System/Intermediate Confining Unit (IAS/ICU) to an unconfined aquifer system in areas where it is at or near land surface. The FAS extends throughout the entire State of Florida, however, in the southern peninsula and western panhandle, it is not used as a source of public water supply due to high salinity of ground water (Southeastern Geological Society, 1986).

The extent of the FAS used for input into the FAVA model was based on the distribution of FDEP public water supply wells. FDEP wells were plotted in a GIS with a 20-km buffer to develop a study area extent for the FAS, and this extent adequately represented areas where this aquifer system is used as a principal aquifer system.

Large water bodies (those covering greater than approximately 50 acres) were omitted from FAS FAVA model because a well would never be drilled in these areas – therefore, they would never contain a training point. If the lakes were left in the model, the surface area was increased with no chance of increasing the number of training points. This would unnecessarily bias the model. Further, large water bodies typically have no soils or other input data associated with them, thus the model output omits these areas due to lack of data or potential bias in the calculated probabilities.

Weights of Evidence Model

Use of the Weights of Evidence (WofE) modeling technique involves the combination of diverse spatial data that are used to describe and analyze interactions and generate predictive models (for a detailed discussed of this statistical modeling technique see Bonham- Carter, 1994; Raines et al., 2000). WofE is a data- driven process that utilizes known occurrences as model training sites to create maps from weighted continuous input data layers. These input data layers, known as evidential themes, are then combined to yield an output data layer (or result of the model), known as a response theme (Raines, 1999). WofE was adapted to mineral potential mapping in a GIS and is based on the application of Bayes' Rule of Probability, with an assumption of conditional independence (Raines et al., 2000). Although Bayesian theory has been applied to ground- water related issues in recent years (e.g., Soulsby et al., 2003; Meyer et al., 2003; and Feyen et al., 2004), the specific application of WofE to ground-water issues is very limited to date (Cheng, 2004).

Training Points Theme and Prior Probability

Training points are locations of known occurrences. In mining applications for example, ore deposits are known occurrences. In an aquifer vulnerability assessment, wells with water quality indicative of high recharge are potential known occurrences. Training points are used in WofE to calculate the following parameters: *prior probability* (or, density of training points), weights for each *evidential theme*, and posterior probability of the *response theme*.

Evidential Themes

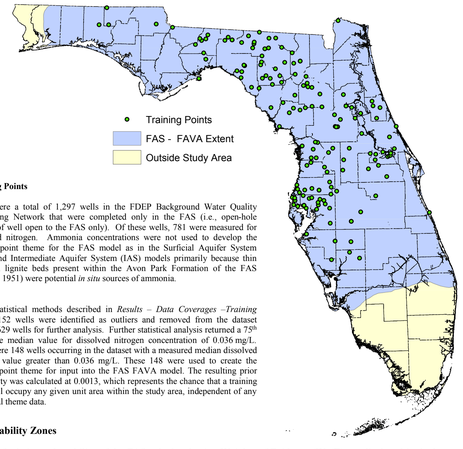
An evidential theme is defined as a set of continuous spatial data that is associated with the location and distribution of known occurrences, i.e., training points. In GIS terms, an evidential theme is analogous to a data layer or coverage. Evidential themes in the mining example might include an area's proximity to faults. In the FAVA project, soil permeability and thickness of confinement are examples of evidential themes. Weights calculated in WofE establish spatial associations between training points and evidential themes. The four evidential themes used for the FAS FAVA model are displayed to the right and include Intermediate Aquifer System thickness, effective karst features, soil permeability, and hydraulic head difference.

Generalization of evidential themes follows calculation of weights in the WofE modeling process. Themes are generalized in an effort to establish which areas of the evidence share a greater association with locations of training points. During calculation of weights for each evidential theme, a contrast value is calculated, which is a combination of the positive and negative weights (positive weight – negative weight) as described in *Introduction – Approach – Models Considered – Weights of Evidence.* 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).

Response Theme

Following the generalization of evidential themes, WofE output results are generated and are known as response themes. A response theme is an output data layer showing the probability (posterior probability) that a unit area contains a training point based on the evidence (evidential theme) provided. Areas of higher posterior probability indicate that an area is more likely to contain a training point, whereas areas of lower posterior probability indicate that an area is less likely to contain a training point. For the FAVA project, a response theme can be a probability map that is displayed in classes of relative vulnerability based on selected water-quality analytes in training point wells.

Training Points: Dissolved Nitrogen > 0.036 mg/L



Training Points

There were a total of 1,297 wells in the FDEP Background Water Quality Monitoring Network that were completed only in the FAS (i.e., open-hole portion of well open to the FAS only). Of these wells, 781 were measured for dissolved nitrogen. Ammonia concentrations were not used to develop the training point theme for the FAS model as in the Surficial Aquifer System (SAS) and Intermediate Aquifer System (IAS) models primarily because thin peat and lignite beds present within the Avon Park Formation of the FAS (Vernon, 1951) were potential *in situ* sources of ammonia.

Using statistical methods described in *Results – Data Coverages –Training Points*, 152 wells were identified as outliers and removed from the dataset leaving 629 wells for further analysis. Further statistical analysis returned a 75th percentile median value for dissolved nitrogen concentration of 0.036 mg/L. There were 148 wells occurring in the dataset with a measured median dissolved nitrogen value greater than 0.036 mg/L. These 148 were used to create the training point theme for input into the FAS FAVA model. The resulting prior probability was calculated at 0.0013, which represents the chance that a training point will occupy any given unit area within the study area, independent of any evidential theme data.

Vulnerability Zones

Zones of relative vulnerability of the FAS calculated using Weights of Evidence (WofE) are displayed in the large map to the far right. As noted in the report, all ground water is vulnerable to contamination. As a result, this generalized FAS FAVA map reflects three levels of vulnerability. Each zone represents a range of probability values that an area is vulnerable to contamination from land surface. Evidential themes (data coverages) used for input into this model include: soil permeability, an area's proximity to karst features, thickness of the Intermediate Aquifer System, and the difference in head between the water table and FAS.

More Vulnerable
Areas of the vulnerability map designated in red represent the *more vulnerable* zone based on output probabilities calculated using WofE. The *more vulnerable* zone encompasses approximately 52,100 km^2, which is approximately 45% of the total study area.

Vulnerable
Areas of the vulnerability map designated in green represent the *vulnerable* zone based on output probabilities calculated using WofE. The *vulnerable* zone encompasses approximately 39,100 km^2, which is approximately 34% of the total study area.

Less Vulnerable
Areas of the vulnerability map designated in blue represent the *less vulnerable* zone based on output probabilities calculated using WofE. The *less vulnerable* zone encompasses approximately 24,100 km^2, which is approximately 21% of the total study area.

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Evidential Theme: Intermediate Aquifer System/ IntermediateConfining Unit Thickness

Intermediate Aquifer System/Intermediate Confining Unit Thickness

Areas underlain by thinner IAS/ICU sediments are normally associated with higher aquifer vulnerability. Weights were therefore calculated for the IAS/ICU evidential theme using the cumulative ascending method. The highest contrast of any class was calculated at a thickness interval of 451 feet. The second highest contrast of any class was calculated at a thickness interval of 160 feet. The calculated weights therefore justified the selection of a multi-class theme because the contrast values for both of these breaks are statistically significant and met the minimum level of confidence (75%) selected for the FAVA project (see *Introduction – Approach – Models Considered – Weights of Evidence* for more information). Further, the calculated weights were significant for both breaks. As defined by the analysis of this evidential theme, the most appropriate breaks in the IAS/ICU thickness evidential theme were at 160 ft and 451 ft creating a ternary generalized theme for input into the FAS FAVA model. In other words, this analysis indicates that areas underlain by greater than 451 feet of IAS/ICU were, based on the location of training points, associated with less vulnerable zones, areas underlain by between 160 and 451 feet of IAS/ICU were associated with vulnerable zones, and areas underlain by less than 160 feet of IAS/ICU were associated with more vulnerable zones.

Evidential Theme: Proximity to Karst Features

Effective Karst Features

Effective karst is defined as those closed topographic depressions which are believed to increase hydrologic communication between land surface and the underlying aquifer system. Features more likely to be hydrologically connected to the underlying FAS were selected by intersecting the IAS/ICU thickness grid with the locations of closed topographic depressions. Areas that were underlain by 140 ft or less of IAS/ICU type sediments were selected. This value is based on expert knowledge of local Hydrogeologic conditions. Additional features were included for those areas where the IAS/ICU was not mappable by selecting those depressions that are underlain by 100 ft or less of surficial sediment thickness (e.g. Cichon et al., 2004). Because areas nearer to a karst feature are considered more vulnerable to contamination than areas further away, a proximity analysis was completed for the effective karst evidential theme by creating a 3,600-m buffer zone around each karst feature within which equally-spaced 60-m intervals were delineated. The outermost interval contained all areas of the FAS extent which lie 3,600 m or further from a karst feature.

The highest contrast of any class was calculated at a distance of 3,420 m from an effective karst feature. As defined by the analysis of this evidential theme, the most appropriate break in the effective karst feature evidential theme was at 3,420 m creating a binary generalized theme for input into the FAS FAVA model. In other words, this analysis indicates that areas beyond 3,420 m of an effective karst feature were, based on the location of training points, associated with areas of lower vulnerability. Conversely, the analysis indicates that areas within 3,420 m of an effective karst feature were, based on the location of training points, associated with areas of higher vulnerability.

Evidential Theme: Soil Permeability (Weighted Average)

Soil Permeability

Soil permeability is a measure of the rate at which water travels through the upper vadose zone. Areas with high soil permeability values are normally associated with higher aquifer vulnerability. Weights were calculated for soil permeability using the cumulative descending method of the WofE model technique. The highest contrast of any class was calculated at 19.7 in/hr. As defined by the analysis of this evidential theme, the most appropriate break in the soil permeability evidential theme was at 19.7 in/hr creating a binary generalized theme for input into the FAS FAVA model. In other words, this analysis indicates that areas underlain by soils with permeability values ranging from 0.1 to 19.7 in/hr were, based on the location of training points, associated with areas of lower vulnerability. Conversely, the analysis indicates that areas underlain by soils with permeability values ranging from 19.7 to 20.0 in/hr were, based on the location of training points, associated with areas of higher vulnerability.

Evidential Theme: Hydraulic Head Difference (Water Table - FAS)

Hydraulic Head Difference between the Water Table and the FAS

Areas where the hydraulic head difference between the water table and the FAS is great, indicating the potential for downward recharge to the FAS, are normally associated with higher aquifer vulnerability. Weights were therefore calculated for the hydraulic head difference evidential theme using the cumulative descending method. The highest contrast calculated for any class was calculated at a hydraulic head difference value of -8 feet. As defined by the analysis, the most appropriate break in the hydraulic head difference evidential theme equals -8 feet, thus creating a binary generalized theme for input into the FAS FAVA model. In other words, this analysis indicates that areas in which the hydraulic head difference exceed -8 ft were, based on the location of training points, associated with areas of higher vulnerability. Conversely, the analysis indicates that areas in which the hydraulic head difference is less than -8 ft were, based on the location of training points, associated with areas of lower vulnerability.