FLORIDA GEOLOGICAL SURVEY
FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION

PLATE 1

Relative Vulnerability Map of the Surficial Aquifer System

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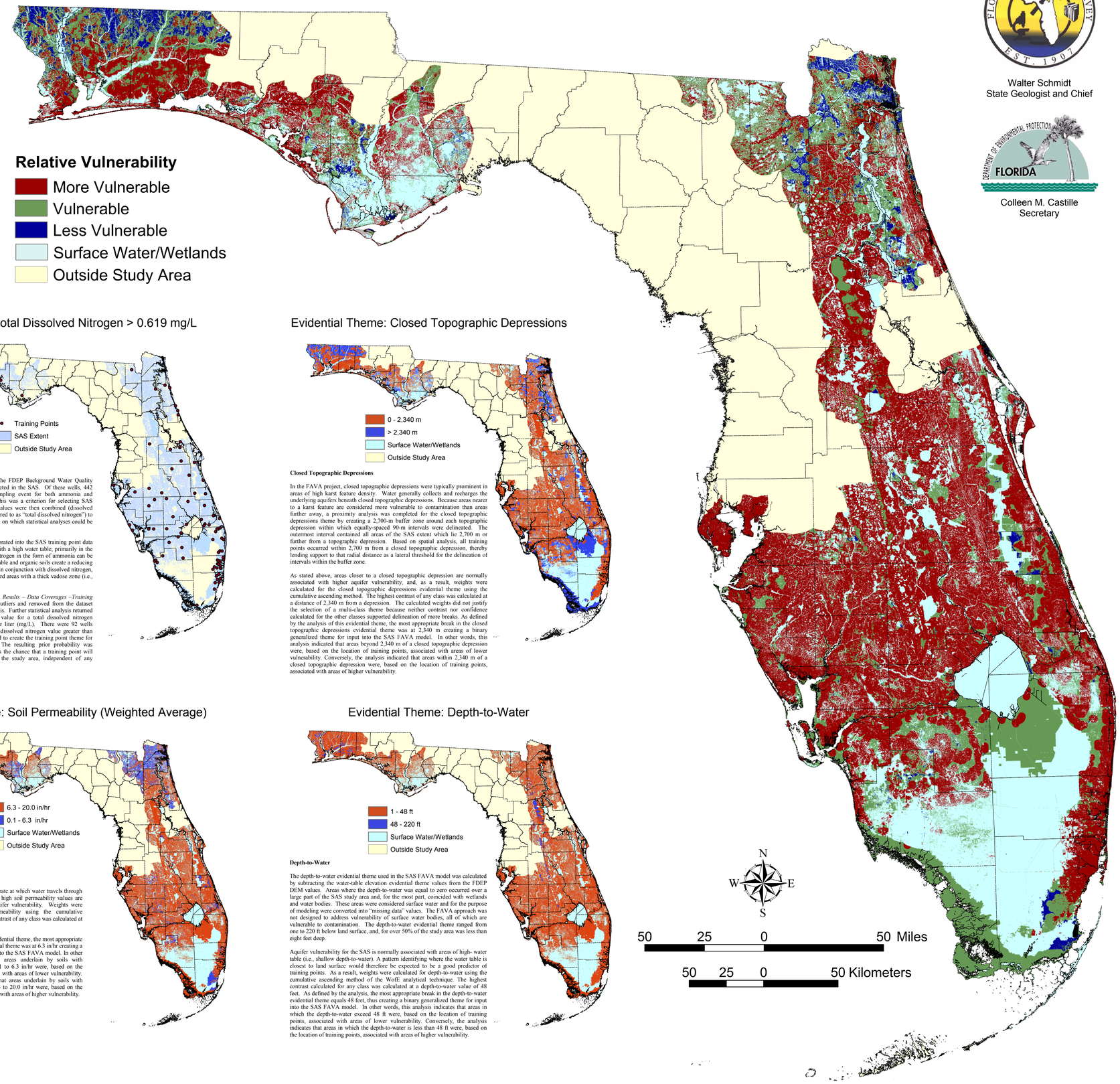


Study Area and Extent

The Surficial Aquifer System (SAS) is the permeable hydrostratigraphic unit in Florida contiguous with land surface that comprises principally unconsolidated siliciclastic deposits, and to a lesser extent, carbonate rocks. The lower limit of the SAS coincides with less permeable sediments of the top of the Intermediate Aquifer System (Southeastern Geological Society, 1986). The SAS occurs throughout much of the State and is used extensively in the western panhandle (Sand and Gravel Aquifer) and the southeastern peninsula (Biscayne Aquifer) as a principal source of drinking water.

The preliminary extent of the SAS for the FAVA project was based on the extent of the Intermediate Aquifer System. Modifications of this preliminary extent were based on the distribution of Miocene- Pliocene clay- rich sediments as mapped by Scott et al. (2001). In areas where sediments of the IAS were not mapped on a regional scale, the SAS was not mapped for this project (see *Results – Data Coverages – Intermediate Aquifer System Thickness* for additional information). Further refinement of the SAS extent was accomplished by omitting areas where laterally continuous SAS sediments were calculated at less than ten feet thick and where Intermediate Aquifer System sediments were at or near land surface. In some instances, SAS sediments greater than ten feet in thickness were omitted from the extent because they represented isolated, discontinuous, local packages of sediment which do not form part of a major regional aquifer system. In some of these areas, hydraulic heads in the FAS and surficial sediments differ, justifying a local water- table aquifer in the areas; however, these local occurrences are generally discontinuous. Given the statewide scale of the FAVA project, attempting to map and model these isolated areas was beyond the scope of this project. Maps showing the SAS extent in this report reflect only areas where the SAS is present in a laterally continuous and regional extent.

For modeling purposes, the extent of the SAS was further revised to exclude all areas covered by both permanent and seasonal wetlands. These wetlands were identified using the National Wetlands Inventory (NWI) database (US Fish and Wildlife Service, 1988-1993). Wetlands were omitted from the SAS extent because they were poorly represented by training points, i.e., few wells existed in wetland areas. During sensitivity analyses, model outputs for the SAS that included wetlands yielded misleading evidential theme weights and poorly predicted vulnerability of the SAS in wetland areas.

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 three evidential themes used for the SAS FAVA model are displayed to the right and include closed topographic depressions, soil permeability, and depth-to-water.

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.

Vulnerability Zones

Zones of relative vulnerability of the Surficial Aquifer System calculated using Weights of Evidence are displayed in the large map to the far right. As noted in the report, all aquifers are vulnerable to contamination. As a result, this generalized SAS 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 closed topographic depressions, and depth-to-water.

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 42,620 km^2, which is approximately 66% of the total study area.

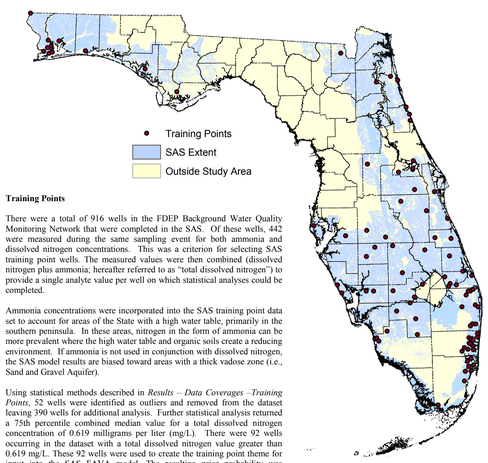
Vulnerable

Areas of the vulnerability map designated in green represent the *vulnerable* zone based on output probabilities calculated using WofE. The *vulnerable* zone encompasses approximately 19,353 km^2, which is approximately 30% 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 2,737 km^2, which is approximately 4% of the total study area.

Training Points: Total Dissolved Nitrogen > 0.619 mg/L



Training Points

There were a total of 916 wells in the FDEP Background Water Quality Monitoring Network that were completed in the SAS. Of these wells, 442 were measured during the same sampling event for both ammonia and dissolved nitrogen concentrations. This was a criterion for selecting SAS training point wells. The measured values were then combined (dissolved nitrogen plus ammonia; hereafter referred to as "total dissolved nitrogen") to provide a single analyte value per well on which statistical analyses could be completed.

Ammonia concentrations were incorporated into the SAS training point data set to account for areas of the State with a high water table, primarily in the southern peninsula. In these areas, nitrogen in the form of ammonia can be more prevalent where the high water table and organic soils create a reducing environment. If ammonia is not used in conjunction with dissolved nitrogen, the SAS model results are biased toward areas with a thick vadose zone (i.e., Sand and Gravel Aquifer).

Using statistical methods described in *Results – Data Coverages –Training Points*, 52 wells were identified as outliers and removed from the dataset leaving 390 wells for additional analysis. Further statistical analysis returned a 75th percentile combined median value for a total dissolved nitrogen concentration of 0.619 milligrams per liter (mg/L). There were 92 wells occurring in the dataset with a total dissolved nitrogen value greater than 0.619 mg/L. These 92 wells were used to create the training point theme for input into the SAS FAVA model. The resulting prior probability was calculated at 0.0014, which represents the chance that a training point will occupy any given unit area within the study area, independent of any evidential theme data.

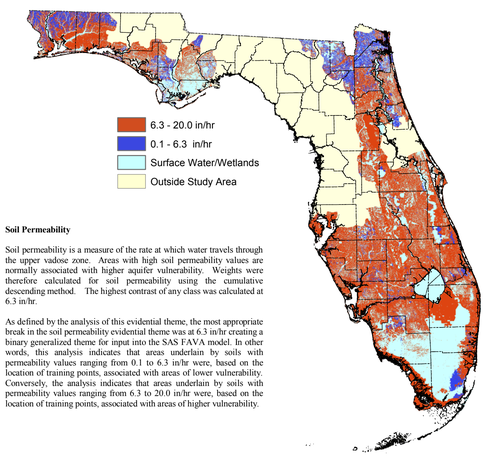
Evidential Theme: Closed Topographic Depressions

Closed Topographic Depressions

In the FAVA project, closed topographic depressions were typically prominent in areas of high karst feature density. Water generally collects and recharges the underlying aquifers beneath closed topographic depressions. Because areas nearer to a karst feature are considered more vulnerable to contamination than areas further away, a proximity analysis was completed for the closed topographic depressions theme by creating a 2,700-m buffer zone around each topographic depression within which equally-spaced 90-m intervals were delineated. The outermost interval contained all areas of the SAS extent which lie 2,700 m or further from a topographic depression. Based on spatial analysis, all training points occurred within 2,700 m from a closed topographic depression, thereby lending support to that radial distance as a lateral threshold for the delineation of intervals within the buffer zone.

As stated above, areas closer to a closed topographic depression are normally associated with higher aquifer vulnerability, and, as a result, weights were calculated for the closed topographic depressions evidential theme using the cumulative ascending method. The highest contrast of any class was calculated at a distance of 2,340 m from a depression. The calculated weights did not justify the selection of a multi-class theme because neither contrast nor confidence calculated for the other classes supported delineation of more breaks. As defined by the analysis of this evidential theme, the most appropriate break in the closed topographic depressions evidential theme was at 2,340 m creating a binary generalized theme for input into the SAS FAVA model. In other words, this analysis indicated that areas beyond 2,340 m of a closed topographic depression were, based on the location of training points, associated with areas of lower vulnerability. Conversely, the analysis indicated that areas within 2,340 m of a closed topographic depression 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 therefore calculated for soil permeability using the cumulative descending method. The highest contrast of any class was calculated at 6.3 in/hr.

As defined by the analysis of this evidential theme, the most appropriate break in the soil permeability evidential theme was at 6.3 in/hr creating a binary generalized theme for input into the SAS FAVA model. In other words, this analysis indicates that areas underlain by soils with permeability values ranging from 0.1 to 6.3 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 6.3 to 20.0 in/hr were, based on the location of training points, associated with areas of higher vulnerability.

Evidential Theme: Depth-to-Water

Depth-to-Water

The depth-to-water evidential theme used in the SAS FAVA model was calculated by subtracting the water-table elevation evidential theme values from the FDEP DEM values. Areas where the depth-to-water was equal to zero occurred over a large part of the SAS study area and, for the most part, coincided with wetlands and water bodies. These areas were considered surface water and for the purpose of modeling were converted into "missing data" values. The FAVA approach was not designed to address vulnerability of surface water bodies, all of which are vulnerable to contamination. The depth-to-water evidential theme ranged from one to 220 ft below land surface, and, for over 50% of the study area was less than eight feet deep.

Aquifer vulnerability for the SAS is normally associated with areas of high- water table (i.e., shallow depth-to-water). A pattern identifying where the water table is closest to land surface would therefore be expected to be a good predictor of training points. As a result, weights were calculated for depth-to-water using the cumulative ascending method of the WofE analytical technique. The highest contrast calculated for any class was calculated at a depth-to-water value of 48 feet. As defined by the analysis, the most appropriate break in the depth-to-water evidential theme equals 48 feet, thus creating a binary generalized theme for input into the SAS FAVA model. In other words, this analysis indicates that areas in which the depth-to-water exceed 48 ft were, based on the location of training points, associated with areas of lower vulnerability. Conversely, the analysis indicates that areas in which the depth-to-water is less than 48 ft were, based on the location of training points, associated with areas of higher vulnerability.