

### Abstract

Kriging is a statistical technique that uses semi-variograms to produce a continuous surface from point data and provide an estimate for unsampled locations. Kriging will provide a means of interpolating water quality values for locations not sampled using knowledge about the underlying spatial relationships in a data set. This study aims to predict contamination of wells using two different kriging methods: universal and ordinary to determine which method is optimal in predicting contamination of wells. Each methods performance was assessed by calculating the proportion of sites that were misclassified as non-contaminated when they were actually contaminated and vice-versa. The methods were validated with a subset of wells not included in the original simulation. The study looks at Nitrate  $NO_3^-$  contamination in the Polk County Region of Florida. Comparisons of the various methods were made using ArcGIS, GS+, and GRASS. Preliminary results show that there are considerable differences in prediction of contaminate potential with different kriging methods. This study will provide a basis for future comparisons of vulnerability maps to the well contamination.

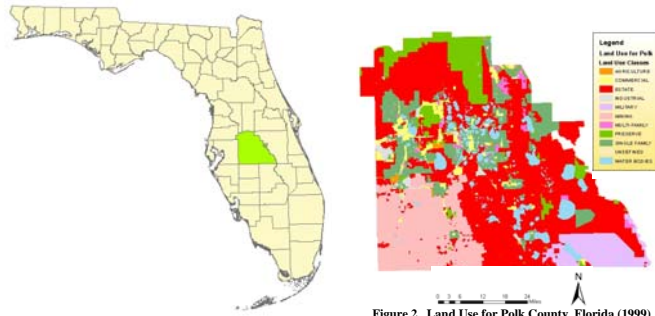


Figure 1. Study area Location.

Figure 2. Land Use for Polk County, Florida (1999). (Source: Southwest Florida Water Management District (SWFWMD))

### Introduction

Groundwater provides drinking water for more than half of the population in United States and is the only source of drinking water for many in rural areas and some cities (Solley et al. 1993). In 1990, groundwater accounted for 39 percent of water used for public supplies for cities and rural areas of which 96 percent was withdrawn by private user-owned wells for domestic use (Nolan et al. 1998). In its natural state groundwater is mostly excellent in quality and can be used without any costly filters or purification treatments, until recently it was thought that groundwater was immune to many chemicals and contaminants commonly used in industry, agriculture and even chemicals for household use (Trautman et al. 1998). Because drinking water is an important resource it merits protection from potential contamination.

In Florida the extensive groundwater resources available serve as the primary source of drinking water for 90% of the state's population. Florida is unique in water quality in that it has well drained soils which overlay porous limestone which combines with a shallow water table and high rainfall to increase the probability of a contaminant reaching the groundwater (FDOH). In dealing with threats to groundwater, communities and individuals need knowledge of groundwater such as where it flows, and what contaminates it (Trautman et al. 1998).

### Objectives

- To create kriged surfaces using the geostatistical approaches viz: universal and ordinary kriging.
- To compare the ground water vulnerability maps generated using Neural Networks (NN) to the well water quality and resultant kriging maps.
- To assess suitability of Universal and Ordinary Kriging Methods

### Study Area

Polk county is located in central Florida, equidistant between the east and west coasts (Figure 1). Polk lies on the Interstate-4 corridor, 25 miles east of Tampa and 35 miles southwest of Orlando, it is the geographical center of Florida. It is estimated that more than 7.5 million people live within a 100-mile radius of the county (Polk County). Polk county has an area of 2,010 square miles, total land area is approximately 1,849 square miles, with natural freshwater lakes covering 135 square miles (Central Florida Development Council (CFDC)). Polk County's 2003 total population estimate is 511,929. The economy in Polk County has been historically linked with three industries: phosphate, agriculture and tourism. Polk county has the largest area of farmland than any other county in state with 621,489 acres. With the main agriculture activities being citrus and livestock mainly cattle (CFDC). Polk Counties various phosphate mining operations responds to 75% of the phosphate need in the United States and 25% worldwide (Florida Phosphate). Figure 2 describes the land usage as of 1999 as described by SWFWMD. Wells located within Polk County are displayed in Figure 3 and contaminates detected in those wells are described in Figure 4 (below).

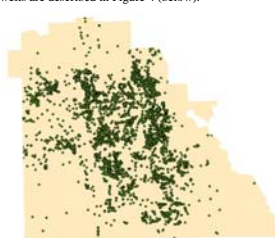


Figure 3. Location of Wells.

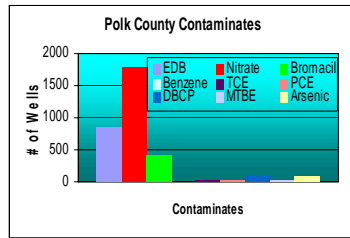


Figure 4. Polk County Contaminates.

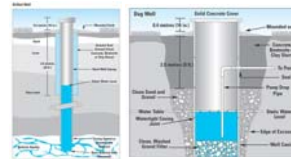


Figure 5 & 6. Typical Private Wells - Drilled and Dug. (Source: Ontario Department of Agriculture)

### Nitrate ( $NO_3^-$ )

Nitrate  $NO_3^-$  Contamination is a human health problem as well as an environmental concern, and is a direct reflection of land use in the area of study (Environment New Zealand). High nitrate levels in water have been linked to "blue baby disease" a blood-disorder in infants who drank formula mixed with the contaminated water. The level deemed to be hazardous to humans was assessed by Environmental Protection Agency (EPA) as being 10 mg/L (EPA). Natural concentrations are around 2 mg/L (Muller 1995). Concentrations above 10 mg/L are an indication of contamination from major nitrogen sources such as animal waste. Thus nitrate contamination is a major problem around hog farms and other livestock areas with large amounts of liquid animal waste (Katz et al. 1999). Nitrate is soluble in water and is able to pass through the soil to the groundwater table and can persist for decades and accumulate to high levels as more nitrogen is applied to the area every year (Nolan et al. 1998). Nitrate contamination in wells is most likely to occur in wells that are shallow and are poorly located (Nowatzki 1998). According to Trautman et al. (1998) typical sources of high nitrate concentrations are from septic systems that are spaced too close together, fertilizers that leach from lawns or agricultural areas, and liquids that percolate into the ground in areas where animal manures are concentrated. Major contamination sources in the study area of Polk County are fertilizers used in the citrus industry (USDA).

MCL	10 m/gL
% above MCL	22%
Source	fertilizer, septic tanks, sewage.
# of Wells Contaminated	1788
% of total wells	24%

Figure 7. MCL Levels and Wells Contaminated with Nitrate.

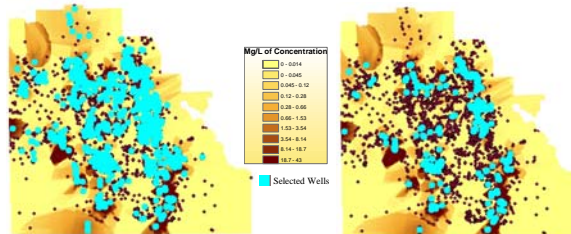


Figure 8. Well Contaminated with Nitrate.

Figure 9. Wells above MCL for Nitrate.

Nitrate accumulates in the soil during its formation process, through rainfall deposits, plant and microbe fixing of atmospheric nitrogen. According to Horby (1990) there are 4 important factors which affect the behavior of nitrate in the environment and lead to its potential to contaminate groundwater: 1. Amount and form of nitrate entering the soil. 2. Soils that overlay aquifers. 3. absorption of nitrogen by plants, microbes and other soil elements. 4. local climate conditions and irrigation practices. Nitrogen can be lost from the soil through various pathways which can reduce the potential for contamination of groundwater. They include change of state into a gas to the atmosphere, plant uptake, microbial metabolism, and leaching.

Nitrate is major concern in groundwater contamination due to its solubility and its mobile state when soluble (Horby 1990). Some non-nitrate forms of fertilizers are readily transformed into nitrate and become subject to leaching to groundwater. Excessive rainfall or irrigation will lead to leaching of nitrate below the root zone and ultimately to groundwater.

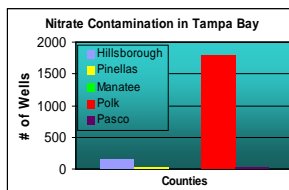


Figure 10. Nitrate Contamination in Tampa Bay Area.

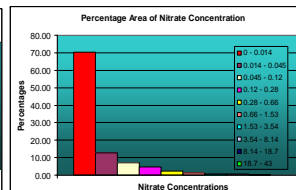


Figure 11. % of Area of Nitrate Concentrations

### Methodologies

**Data:** Data for this study was taken from the Florida Department of Environmental Protection (FDEP) in conjunction with the Florida Department of Health (FDOH) Water Supply Restoration Program (WSRP) well monitoring program which voluntarily monitors various types of wells throughout the state for 7 different contaminants (FDOH). Sampling was undertaken at various times and dates from 1998 to 2003.

**Analysis for Study Area**  
Data was first exported into excel for analysis. Data was analyzed for number of total wells. Polk was selected as the final study area for its large number of wells (7336) compared to the other counties.

### Kriging Methods

The geostatistical method of kriging was used to interpolate the nitrate values for vulnerability prediction. The methods compared in the study were ordinary kriging and universal kriging.

### Ordinary Kriging

Ordinary kriging is one of the most common kriging methods, it is used to estimate a point of a region for which the variogram is known, and there is no prior knowledge of the mean (Guyagler).

$$Z(x) = Y(x) + \beta^t f(s) \quad \text{Eq. 1}$$

Where  $Z(s)$  is denotes the  $rh$  relation at location  $s$ , and  $ni$  is the number of measurements at location  $si$ . Assume that  $\mu(s) = \mu$  is the unknown deterministic mean value and  $Y(s)$  is a smooth second order stationary process. is a second order stationary process whose variogram range is close to 0. is a white noise process composed of measurement errors (Krivoruchko 2001).

### Universal Kriging

Universal kriging is basically regression with spatial coordinates as the explanatory variables. Universal kriging is used when there is a known trend in your data. Universal kriging takes irregular spaced data points and estimates at the nodes of a regular grid for surface values (ArcGIS).

$$Z_r(s) = \mu(s) + Y(s) + \eta(s) + \epsilon_r(s) \quad \text{Eq. 2}$$

Where  $Z(x)$  is a random field, and  $x$  is the location of observations in the random field.  $Y(x)$  is a second order stationary random field and is a deterministic trend with a known function (van den Boogart and Brennen 2001).

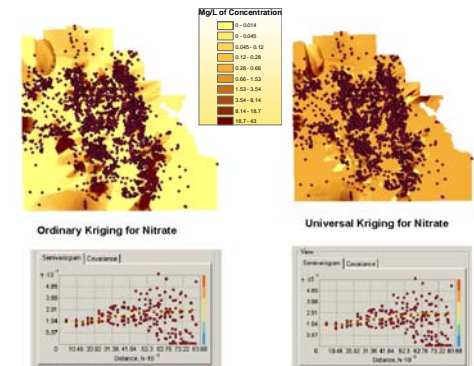


Figure 13 & 14. Results of Ordinary & Universal Kriging for Nitrate.

Coincidence analysis was performed between the kriged surfaces (spatial data) and the contaminated wells (point data). This would show the number of contaminated wells in each category of the kriged map. Result of this coincidence analysis is shown in figure 15.

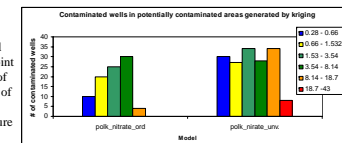


Figure 15: Coincidence analysis

### Comparison of Kriging with other Neural Network based methods

The maps created by the kriging process were compared with maps created using other methods. In this study, Neural Network (NN) based models were used for comparison.

The objective of the NN approach was to predict ground water (GW) contamination potential using plausible input parameters that are critical in transporting contaminants in and through the soil profile including depth to ground water (D), soil structure (pedality points) of the A horizon, soil hydrologic group and landuse to name a few. Different combinations of these input variables were used to build models that predicted GW vulnerability to contamination. The models that were constructed are shown in Table 1. A general flowchart of the entire process is shown in figure 16.

The NN models were developed in PREDICT (Neuralworks Predict Version 2.4) using the Standard Back Propagation (SBP) algorithm. The general architecture of the NN is shown in figure 17. The outcomes (predictions) from these models were integrated into a Geographical Information System (GIS) for generating maps.

#### Input Variables

- D= Depth to ground water
- R= Recharge
- A= Aquifer media
- S= Soil media
- T= Topography
- I= Impact of vadose zone
- C= Hydraulic Conductivity
- Dr = Drainage
- H= Hydrologic Group
- PED = Pedality
- LULC = Landuse/Landcover
- PH = pH Level
- BD = Bulk Density
- OM = Organic Matter

Table 1: Composite models created using input variables shown above

D, R, S, I	D, R, A, S, T, I, C, Dr, H
D, R, S, I, Dr, H	D, R, A, S, T, I, C, Dr, H, ped
D, R, S, I, Dr, H, Ped	D, R, A, S, T, I, C, Dr, H, ped, LULC
D, R, S, I, LULC	Ped, Dr, H, BD
Dr, H, ped, LULC	Ped, Dr, H, BD, LULC
pH, OM, BD	

Figure 16: Schematic of NN based modeling

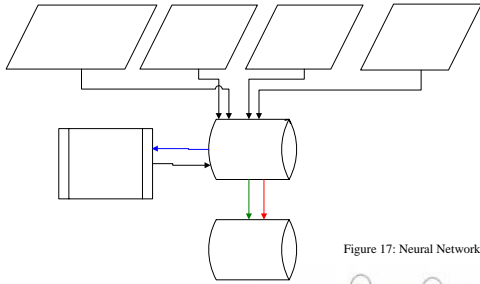
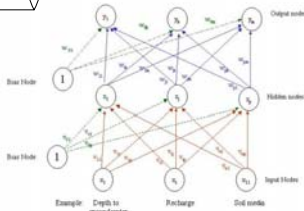


Figure 17: Neural Network Architecture



Fausett, 1994 gave a detailed explanation of NN architecture and principles. The basic architecture of the NN with input, hidden and output units is shown in figure 17.

A total of 11 vulnerability maps were created using the NN and were compared to the kriging maps for further analysis.

### Vulnerability maps created using Neural Networks

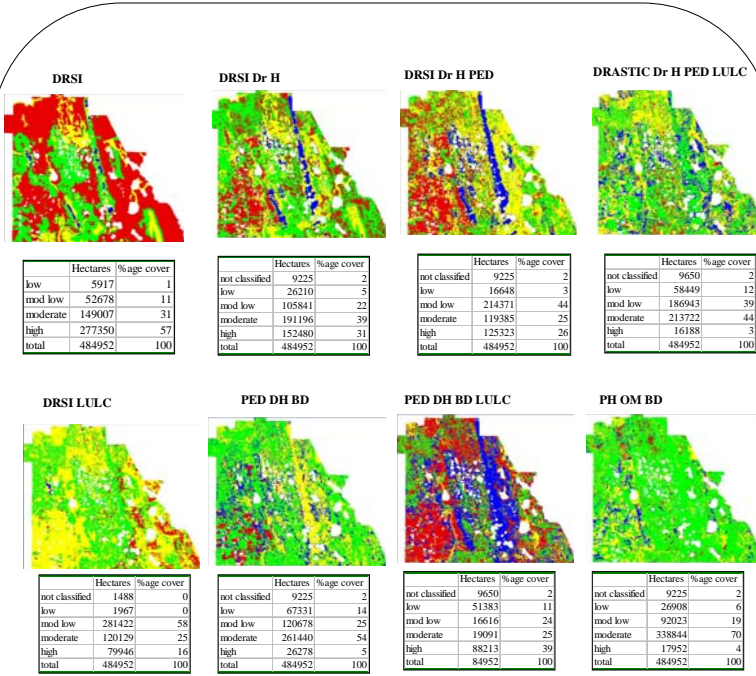
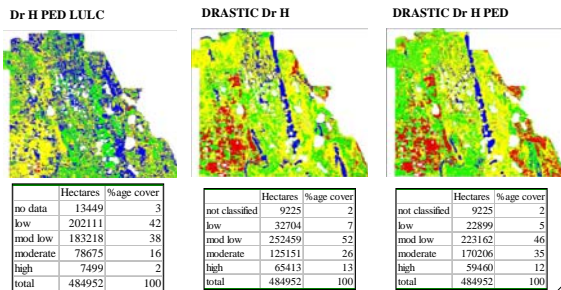


Figure 18: Vulnerability maps generated using composite variable models in Table 1.

- Low
- Moderately Low
- Moderate
- High

Coincidence analysis between the above vulnerability maps and the contaminated wells was performed. This would show the number of contaminated wells in each vulnerability category. Figure 19 shows the output of coincidence analysis

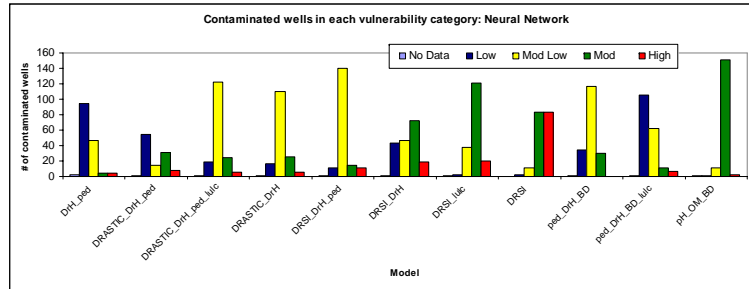


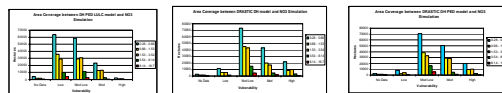
Figure 19: Coincidence analysis

### COMPARISON RESULTS OF KRIGING MAPS VS NN VULNERABILITY MAPS

THE OBJECTIVE OF THIS COMPARISON WAS TO STUDY WHAT PERCENTAGE OF AREA COVER IN THE "HIGHLY CONTAMINATED" REGION OF THE KRIGING MAP COINCIDED WITH THE "HIGHLY VULNERABLE/ HIGH CONTAMINATION POTENTIAL" REGION OF THE NN MAP.

#### Comparisons of Area Coverage using Neural Networks and Kriging Models

Figure 20: Ordinary Kriging



#### Acknowledgements

Thank you Julie Earls from the USF Geospatial Analytics Lab for help formatting this poster

### Ordinary kriging...contd.

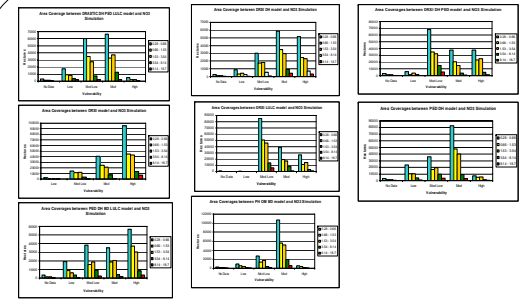
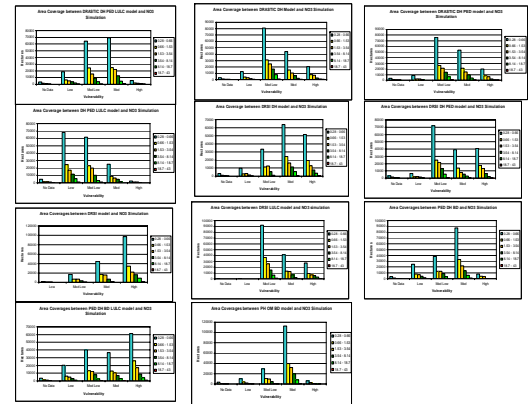


Figure 21: Universal Kriging



### Conclusions

1. Ordinary kriging and universal kriging produced different spatial distributions of contamination potential

Coincidence analysis of individual maps (spatial data) vs. contaminated wells (point data):

2. Universal kriging predicted more contaminated wells in high MCL category
3. Among the NN models, the DRSI model predicted the maximum number of contaminated wells (8 wells) in the highly vulnerable category
4. The surface obtained by ordinary kriging showed maximum (about 7096 hectares) contaminated area coinciding with the DRSI vulnerability map.
5. The surface obtained by universal kriging showed maximum (about 1660 hectares) contaminated area coinciding with the DRSI vulnerability map.
6. As compared to all other models, the DRSI model is most appropriate for this study
7. Contradictory results with the two kriging methods elicit further investigation into methods involved.

### References

"About Polk County" Polk county website visited January 26, 2005

"Best Management Practices: Water Wells" Ontario Ministry of Agriculture, Food, and Rural Affairs. Toronto, Ontario, Canada. Website visited January 16, 2005

Demographic Profile: Polk County, Florida USA on-line publication of Central Florida Development Council web site visited January 26, 2005

"Drinking Water and Human Health in Florida" USDA Cooperative State, Research, Education and Extension Service web site visited January 12, 2005.

Fausett, L. 1994. Fundamentals of Neural Networks. Prentice Hall: New Jersey. p. 460

Florida Department of Health Well Monitoring Program web site visited January 28, 2005

"Florida Phosphate Facts" Florida Phosphate Council web site visited January 26, 2005

Gyapjar, Boris "Ordinary Kriging" Stanford University Current Research website visited January 14, 2005

Harley A.G. "How Contaminates Reach Groundwater" University of Florida Institute of Food and Agricultural Sciences Extension Service, Gainesville, FL. Web site: <http://www.ifas.ufl.edu/extension/forag/forag104.htm>

Kari, B.G.; Hombly H.D.; Babbitt J.K. "Sources of Nitrate in Water from Springs and the Upper Floridan Aquifer, Swades River Basin, Florida" *Journal of the International Association of Hydrological Sciences*, Vol. 257, Pgs. 117-124 (1999).

Krivonozhko K. "Using Linear and Non-Linear Kriging Interpolations to Produce Probability Maps" From the Proceedings of the 2001 Annual Conference of the International Association for Mathematical Geostatistics, Cancun, Mexico September 6-12 2001.

Mullen D.K., Hamilton P.A., Helot J.A., Hill K.J., Rudy B.C. "Nitrates in Groundwater and Surface Water of the United States: An Analysis of Data Through 1992" US Geological Survey Water Resources Investigations Report 95-403 (1995).

"Neural Networks: Predict Version 2.4" (2001)

"Nitrate Contamination in Groundwater" Environment New Zealand Walktoe Districts Fact Sheet web site visited January 15, 2005

"Nitrates/Nitrites Contamination Fact Sheet" Environmental Protection Agency (EPA) Washington, DC. Website visited January 15, 2005

Nolan B.T.; Rudy B.C.; Hill K.J.; Helot J.A. "A National Look at Nitrate Contamination in Groundwater" *Journal of Water Conditioning and Purification* 1998 Vol. 39 Pgs. 76-79

Nowinski, J. Selig B. Sherris T. "Processing your Groundwater through farmstead assessment: Assessing the condition of your Water Well and its Location" North Dakota State University Extension Service Publication AE-1074 Dickinson, ND

Solley W.B. Pierce R.R. Pumpham H.A. 1995 "Estimated Use of Water in the United States in 1995" US Geological Survey Circular 1061 US Geological Survey Reston, VA.

Treatman N.; Porter S.; Wagner R.J. "Groundwater: What it is and how to Protect it" 1998 National Resources Council Cooperative Extension, Cornell University, Ithaca, NY.

Van den Brooght, G.; Broming, A. "Why is Universal Kriging Better than IDP-Kriging? Estimation of Variograms in the Presence of Trend" From the Proceedings of the 2001 Annual Conference of the International Association for Mathematical Geostatistics, Cancun, Mexico September 6-12 2001.