GEOSTATISTICAL ANALYSIS OF WATER-LEVEL AND WATER-QUALITY DATA FOR THE ICHETUCKNEE SPRINGSHED

Prepared for the

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Sam B. Upchurch, Ph.D., P.G.	Kyle M. Champion, P.G.
Vice President and Principal Geologist	Senior Hydrologist
Florida License No. 4	Florida License No. 2044

Introduction

This report presents the methodology and results of a monitoring design using geostatistical analysis of Floridan aquifer nitrate (or nitrate + nitrite) and water-level data for the Ichetucknee springshed, which is located in Columbia and Suwannee Counties, Florida.

The goals of the proposed study were to determine if there are sufficient monitoring sites (monitoring wells, domestic wells, etc.) within and immediately adjacent to the spring basin to allow for characterization of the extent of the ground-water basin and determination of its hydraulic and hydrochemical properties. If the number of monitoring points is insufficient, then additional monitoring locations will be proposed.

Geostatistical Analysis

Geostatistical analysis consists of two steps. First, a structural analysis is performed to determine the pattern of variance with distance between sample pairs. The results of this analysis assist in determining how far apart the samples can be before they are no longer correlated and beyond which contour lines can no longer be drawn. In addition, the structural analysis allows one to establish rules for estimating the uncertainty, in terms of standard deviations, of interpolations between correlated data points.

Once the structural analysis is completed and the "rules" of uncertainty estimation are completed, the second step, kriging, is initiated. Two maps are prepared as part of the kriging phase. The first is the traditional contour map showing the distribution of the property being contoured. The second map is an uncertainty map, which illustrates the areas where one cannot interpolate or extrapolate because the data points are too far apart and the magnitudes of uncertainty, in standard deviations, between correlated points are too high. This map is used to select additional monitoring locations, if needed, and to evaluate the errors associated with the contour map.

Kriging of the spring basins is especially important because of the need to contour the potentiometric-surface data at close intervals (*i.e.*, 1 or 5 feet). The kriging will allow for estimation of the uncertainty associated with the contour maps and assist the District in defending spring-basin boundaries.

Background

In 2000, Environmental Resources Management (ERM) prepared a District-wide *Ground Water Monitoring Plan*[1] based on geostatistical analysis of Floridan aquifer water levels and nitrate concentrations. Reference is made to this report for additional details and references dealing with geostatistical analysis. With respect to Floridan aquifer potentials, ERM analyzed water levels measured District-wide in 1980, 1985,

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[1] Environmental Resources Management, 2001. Ground Water Monitoring Plan. Contract report prepared by Sam B. Upchurch and Brian W. Goodwin for the Suwannee River Water Management District, Live Oak, Florida, December 6, 2000.

1990, 1995, and 1999. From this analysis the Ground Water Level (GWL) monitoring network was devised. The GWL Network became part of the District's WARN (Water Assessment and Reporting Network) network. The well spacing was selected to preserve correlation between monitoring points in order to produce a defensible contour map based on 10-foot contour intervals of the District. The design was not intended to be utilized for delineation of springsheds, which require a high resolution monitoring network.

The Trend Network is a purposefully designed network to be utilized for time (trend) monitoring in areas where nitrate contamination is present or where the outcomes of District resource management are to be evaluated. The Trend Network was not designed for randomness or spatial coverage.

The Status Network utilizes a random design in order to assess the status of ground-water quality District-wide. Wells are randomly sampled and there is no effort to provide a spatial analysis as part of the monitoring design. However, ERM did perform a geostatistical analysis of nitrate in ground water as part of the investigation.

Springs within the District have been experiencing increases in nitrate concentrations[2], and a grant has been obtained from the Florida Department of Environmental Protection's Springs Initiative to characterize five, first-magnitude springs, including the Ichetucknee Springs system. As part of this effort it is essential that the spring basins be accurately delineated and that potentiometry and water-quality mapping within each basin be accurate and defensible. The sample point spacing and uncertainties associated with the present, District-wide GWL Network are such that contouring the potentiometric surface at a one- or five-foot intervals is difficult. A denser well network should assist in this effort.

Data Sources

The District identified almost 100 wells within the projected springshed of the spring system for monitoring. These wells consist of monitoring and domestic wells. All wells were located with a GPS system and their elevations surveyed in by a District consultant. The wells were then sampled for water levels and water quality. Water levels were measured in May 2002 and September 2002. The wells were completed at similar depths and samples were taken over a short time frame to ensure a synoptic sampling. These data were supplied to SDII Global Corporation (SDII) in electronic format.

Five springs in the Ichetucknee System (Ichetucknee Head Spring, Cedar Head Spring, Blue Hole Spring, Mission Spring, Devils Eye Spring, and Mill Pond Spring were also sampled for water quality parameters.

Scope of Work

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[2] Katz, B.G., H.D. Hornsby, J.F. Bohlke, and M.F. Mokray, 1999. Sources and Chronology of Nitrate Contamination in Spring Waters, Suwannee River Basin, Florida. U.S. Geological Survey, Water-Resources Investigations Report 99-4252.

The following nine (9) steps were completed for the data from the Ichetucknee springshed. Two analytes, Floridan aquifer potentials and nitrate (+nitrite) concentrations within and near the study areas, were studied.

- ***Step 1 - Condition data*** - Data received from the District were placed in the proper format for geostatistical analysis. Conditioning efforts included determination of statistical outliers and determination of data homogeneity.

- ***Step 2 - Structural analysis -*** Water level and nitrate + nitrite data were subjected to a structural analysis in order to identify the "rules" for uncertainty estimation. The structural analysis was performed using the U.S.E.P.A. code Geo-Eas[3].

- ***Step 3 - Preparation of kriged contour and K_{SD} maps -*** Floridan aquifer potentiometric surface and nitrate + nitrite data were kriged in order to develop the distribution and uncertainty maps. The potentiometric surface map of each study area was contoured in either 1- or 5-foot intervals, depending on the spacing of the contour lines. The uncertainty map, which is a contour map of the K_{SD} (kriged standard deviation), was appropriately contoured to display areas where additional monitoring is needed and areas where confidence is appropriate for the problem. The kriged maps were developed using the U.S.E.P.A. code Geo-Eas[3] and contouring utilized Surfer[4].

- ***Step 4 - Conversion to ArcView coverages -*** Once the kriged maps were prepared, the ArcView coverages were prepared. This written report presents the results of the investigation in "hard copy format." A CD ROM will be provided with the coverages ready for District use.

Results

The semivariograms developed as part of the structural analysis are presented in Figures 1a, 1b, and 2. The kriged parameters are presented in Table 1.

Floridan aquifer potentials were modeled with a spherical model with a range of 40,000 feet. The range is the distance over which water level data are correlated. Nitrate + nitrite (nitrate) data were also modeled by a spherical model with a range of 25,000 feet. The range is the distance over which data are correlated. When distances greater than the range separate monitoring points, the data points are not correlated and contouring between the points is theoretically incorrect.

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[3] Englund, E., and A. Sparks, 1991. Geo-Eas 1.2.1 - Geostatistical Environmental Assessment Software User's Guide. U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Office of Research and Development, Las Vegas, NV, EPA 600/4-88/033.

[4] Golden Software, Inc., 1997. Surfer (Win 32). Version 6.04.

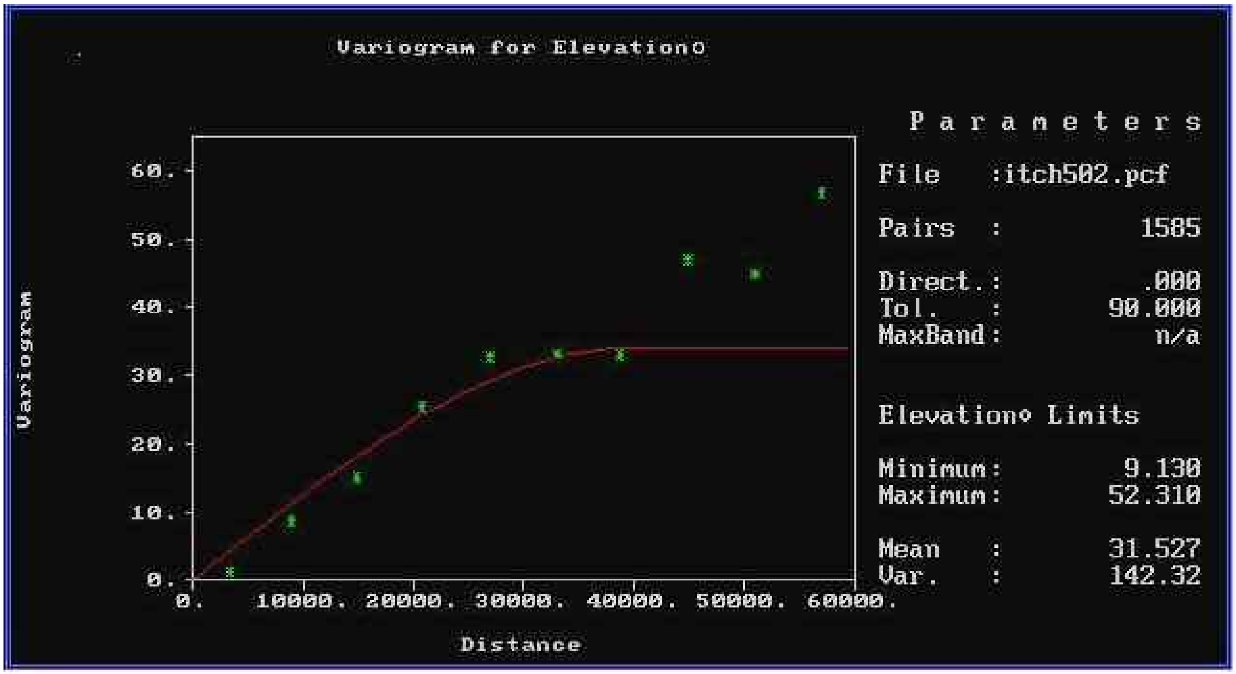

Figure 1a. Variogram for May 2002 potentiometric surface near Ichetucknee Springs.
Model Description: Lag= 6,000 ft.; Type= Spherical; Range= 40,000 ft; Nugget= 0 ln elev.^{2}; Sill= 34 ln elev.^{2} ; Ksd max= 7.78 ft.

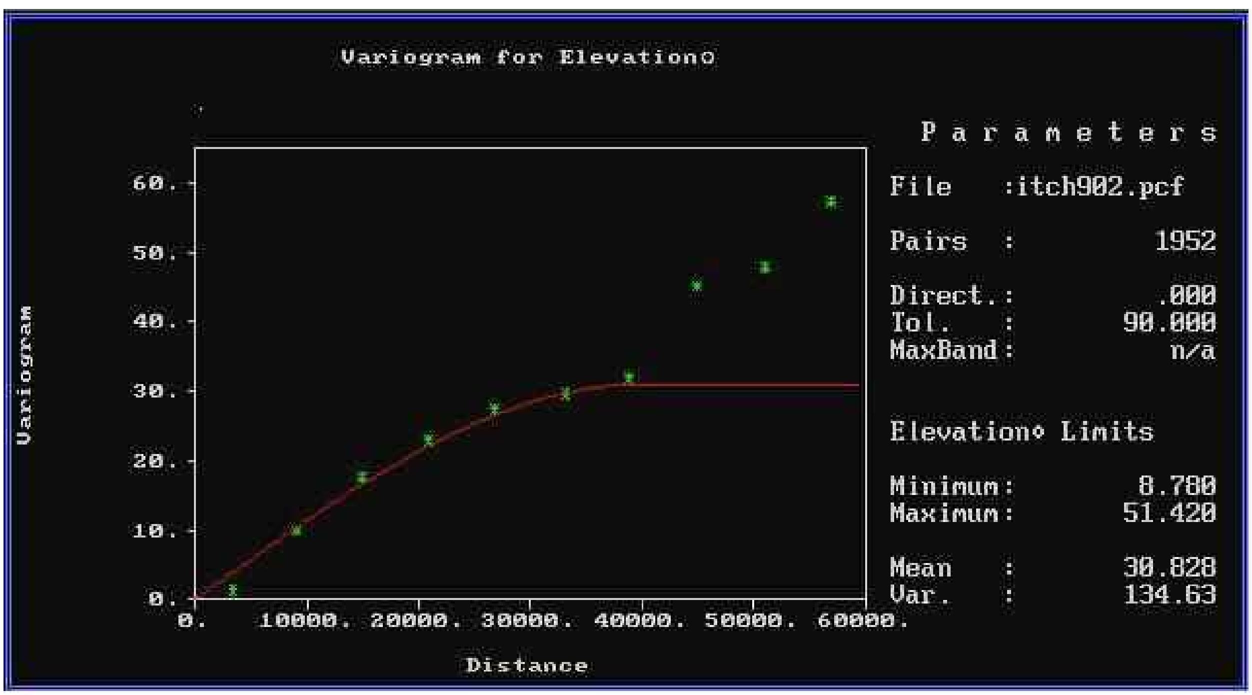

Figure 1b. Variogram for September 2002 potentiometric surface near Ichetucknee Springs.
Model Description: Lag= 6,000 ft.; Type= Spherical; Range= 40,000 ft; Nugget= 0 ln elev.^{2}; Sill= 31 ln elev.^{2} ; Ksd max= 7.44 ft.

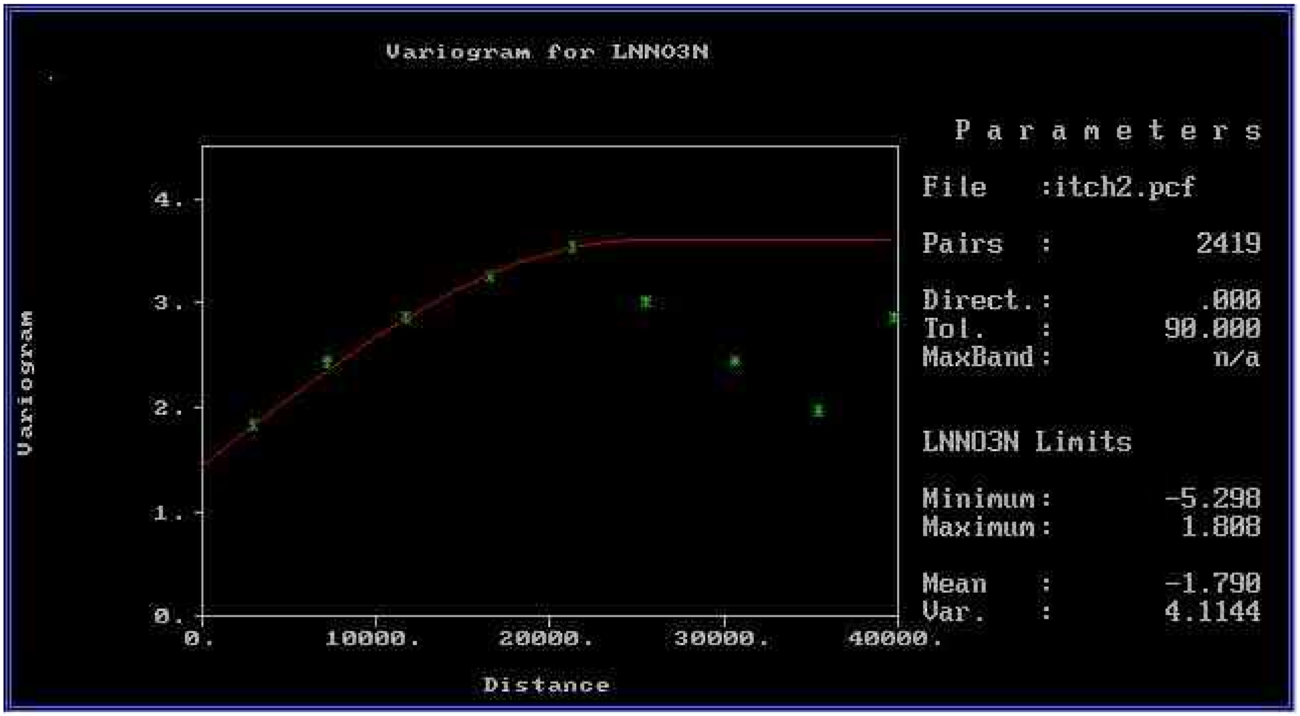

Figure 2. Variogram for natural log nitrate concentrations near Ichetucknee Springs. Model Description: Lag= 4,700 ft.; Type= Spherical; Range= 25,000 ft; Nugget= 1.45 (ln mg/l)^2; Sill= 2.15 (ln mg/l)^2 ; Ksd max= 1.37 mg/l.

Table 1
Kriged Parameters Developed as Part of the Structural Analysis
Ichetucknee Springs Springshed

Parameter	Potentiometric Surface May 2002	Potentiometric Surface September 2002	Nitrate + Nitrite
Lag spacing (feet)	6,000	6,000	4,700
Model type	Spherical	Spherical	Spherical
Nugget (units^2)	0 feet^2	0 feet^2	1.45 ln mg/L^2
C (units^2)	0 feet^2	0 feet^2	0.37 ln mg/L^2
Range (feet)	40,000	40,000	25,000
Range (miles)	7.6	7.6	4.7
Sill (Nugget + sill; units^2)	34 feet^2	31 feet^2	2.15 ln mg/L^2
Ksd at range	7.78 feet	7.44 feet	7.78 mg/L
Percent of sill represented by nugget	0	0	48

The sill is the highest local variance (semivariance) achieved within the range of the data. The sill was 34 feet^2 for water levels and 2.2 ln mg/L^2 (approximately 8.6 mg/L^2) for nitrates.

The nugget is the local variance that is present over ranges that are too short to characterize. The nugget was 0 feet^2 for water levels and 1.5 ln mg/L^2 (approximately 4.3 mg/L^2) for nitrates.

Potentiometric Surface Maps

Figures 3 and 4 illustrate the Florida aquifer potentiometric surface maps for May and September 2002, respectively. Both maps have been contoured at 1-foot intervals, and the surface water drainage basin and selected roads have been superimposed on the maps for reference. Note that the level of detail presented in each map is high and that it appears that the ground-water basin can be delineated by following natural drainage divides that appear to be depicted on each map. An "average" ground-water basin drawn by following the natural divides is also depicted on the maps. This basin generally follows the surface water basin on the western side. It extends past the surface water basin to the north and east.

Some distinctive features are visible on the potentiometric surface maps. Most importantly, the low relief area immediately north of the Ichetucknee River represents a region of well-developed karst and high hydraulic conductivity (the toe of the Cody Scarp and Coastal Lowlands). The steep isopleths to the north and east reflect the head of the Cody Scarp, where the Floridan aquifer has lower permeabilities and flow is less dynamic than in the Scarp and Coastal Lowlands.

Figures 5 and 6 depict the K_{SD} maps for the Floridan aquifer potentials for May and September. Low K_{SD} values surround monitoring points and indicate areas of high confidence in the data. The high K_{SD} values represent uncertainty as standard deviations based on the semivariance in feet. Maximum uncertainty is about 5 feet in the area east and northwest of Lake City. An uncertainty of up to about 4.5 feet lies just north of the springs. These areas would benefit from additional monitoring. The areas northwest and east of Lake City are in the Highlands and monitoring is not considered critical. At least two monitoring points should be added in the area with 4+ K_{SD} values on the May 2002 map just north of the springs.

Note in Figures 1 through 6 that many of the monitoring points lie outside of the ground-water basin as delineated herein. In time, the District may choose to delete these locations from the monitoring program, but this should wait until "wet" conditions return in order to determine if the basin boundaries shift outward. Also, as the network presently exists, the Lost River basin is well monitored and the District may choose to retain this capability.

Nitrate + Nitrite Maps

Figure 7 depicts the isoconcentration map for nitrate + nitrite in mg/L. Note that there is a concentration high that extends from just south of Lake City south

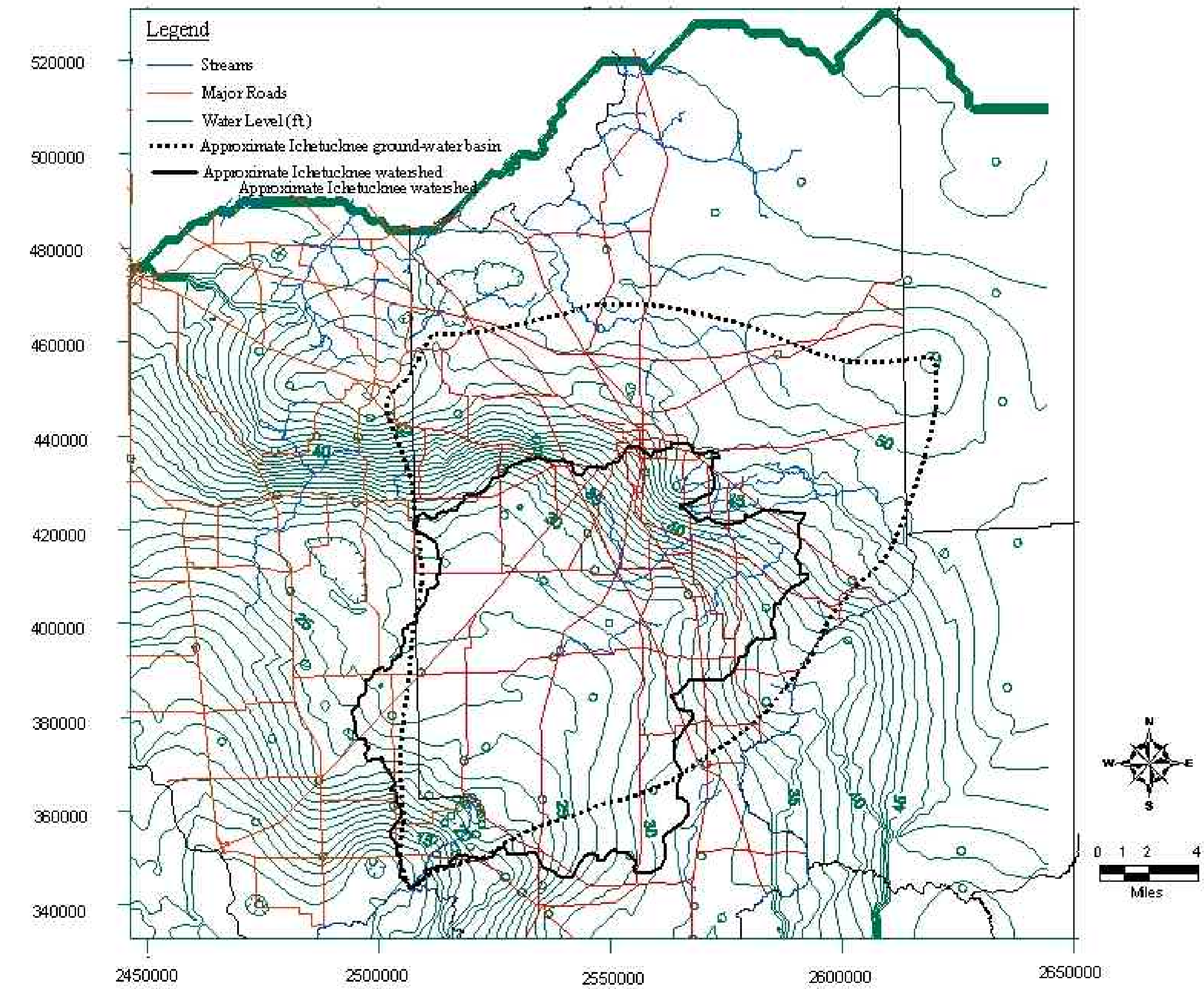

Figure 3. May 2002 potentiometric surface map of the Upper Floridan aquifer in the Ichetucknee springshed. Contour interval=1 foot.

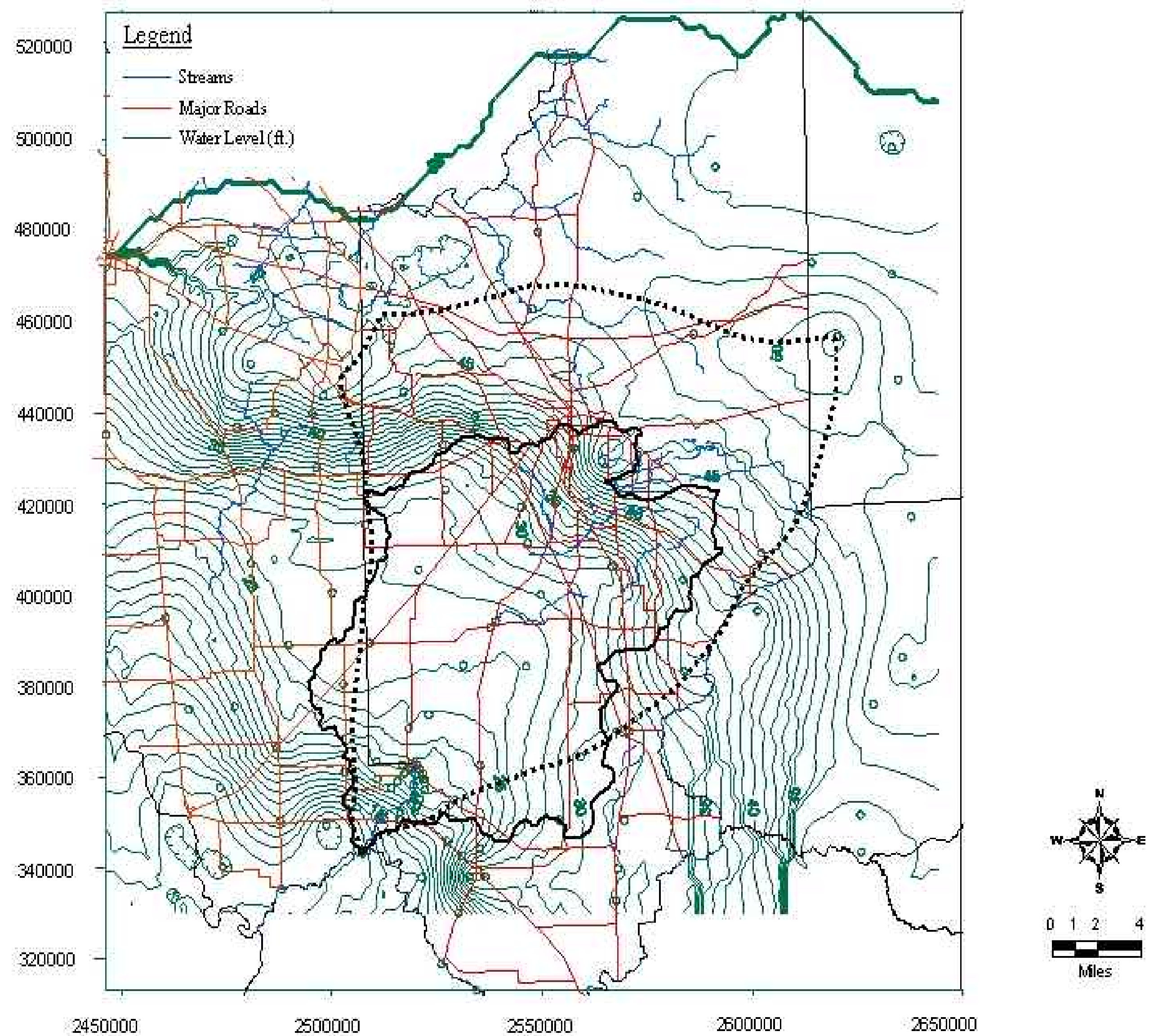

Figure 4. September 2002 potentiometric surface map of the Upper Floridan aquifer in the Ichetucknee springshed. Contour interval=1 foot.

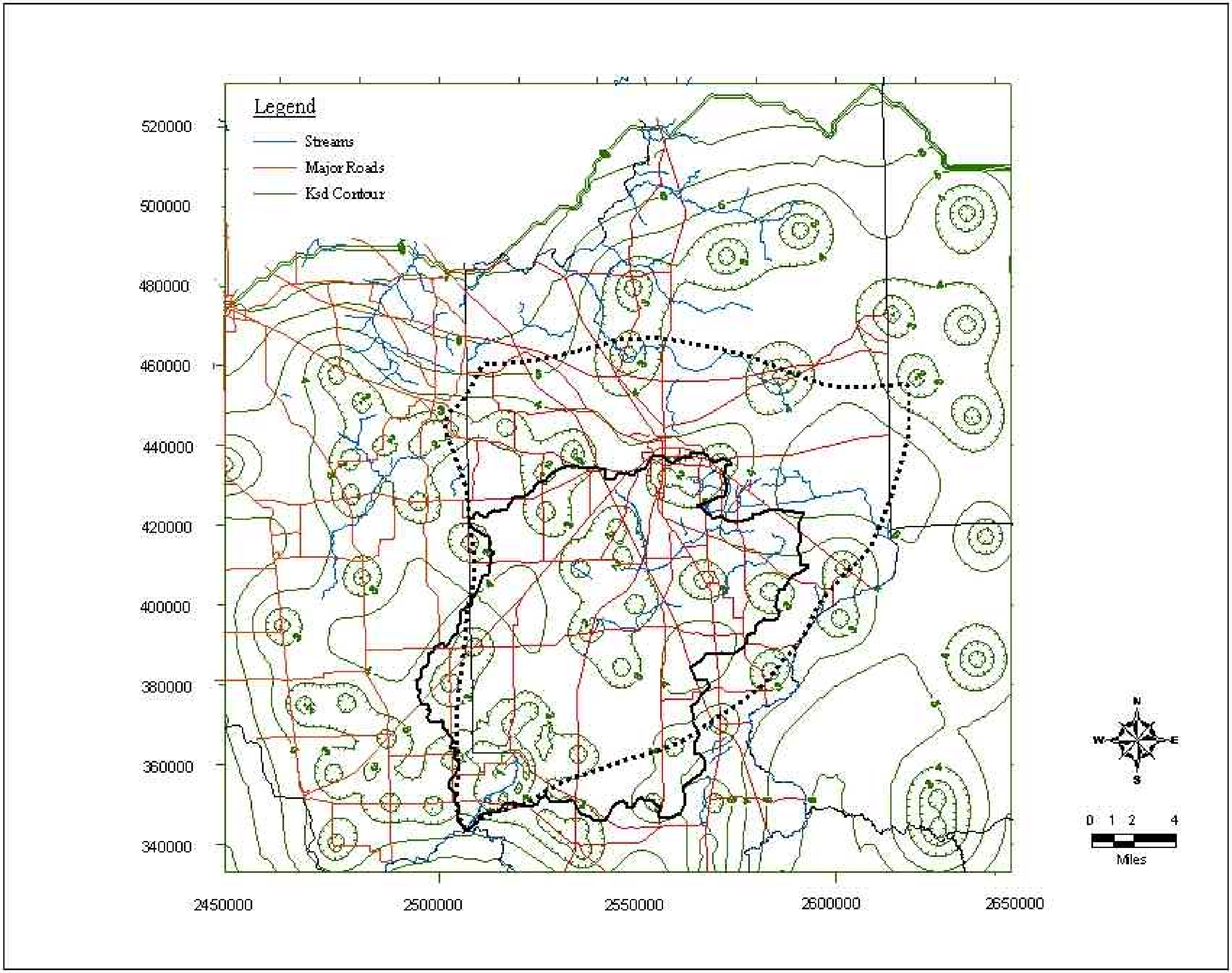

Figure 5. May 2002 potentiometric Ksd map for the Ichetucknee springshed.

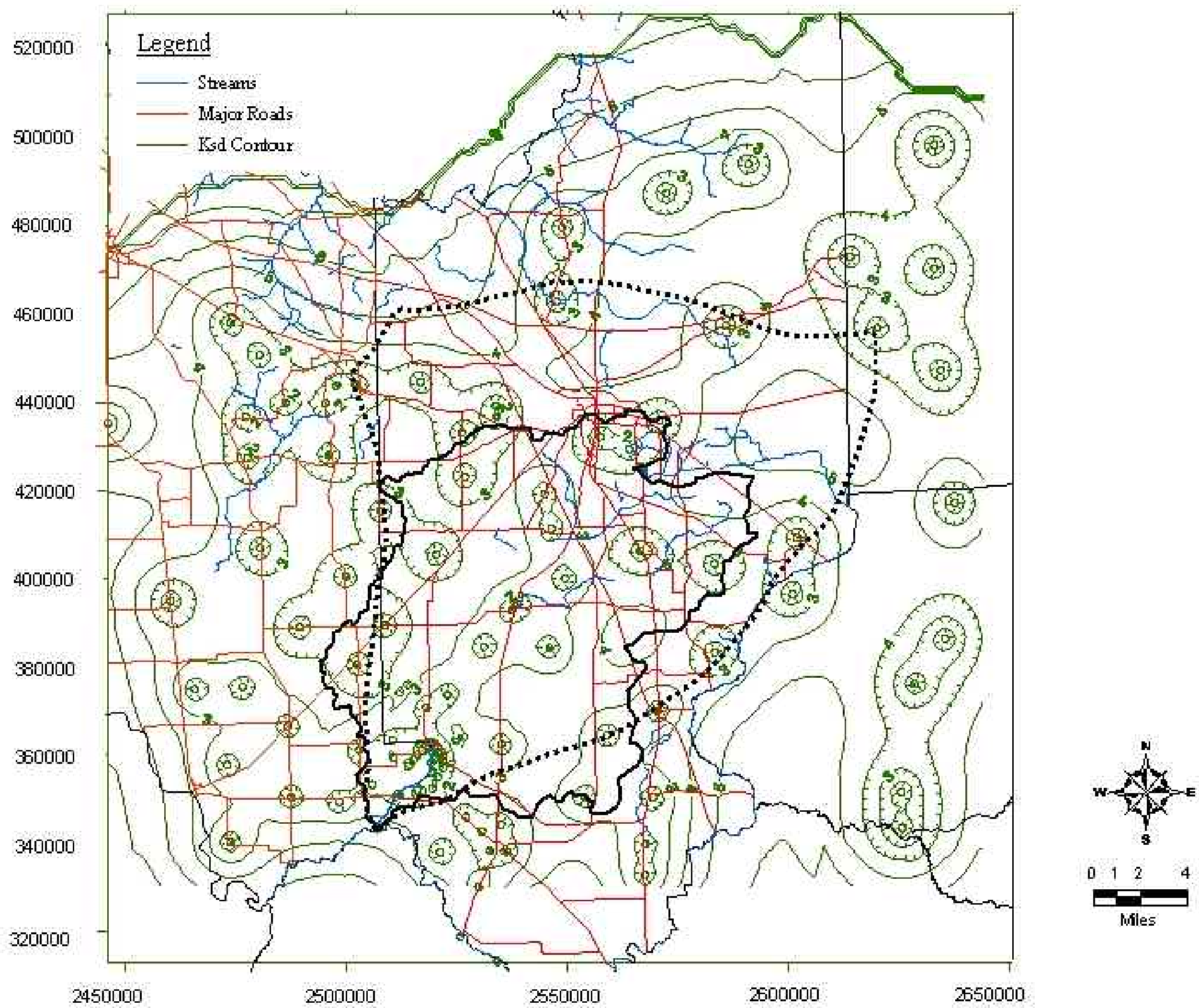

Figure 6. September 2002 potentiometric Ksd map for the Ichetucknee springshed.

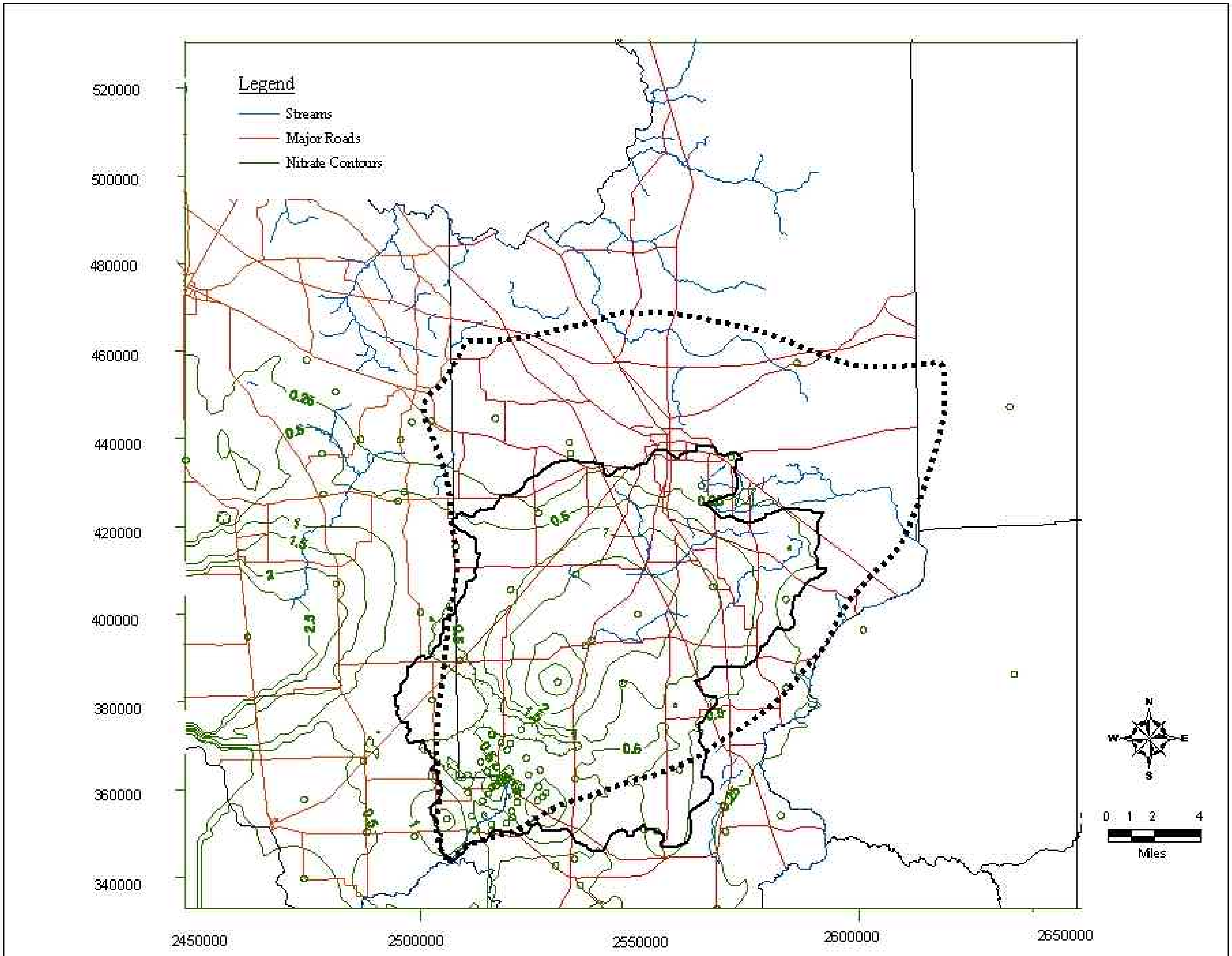

Figure 7. Nitrate concentrations in the Ichetucknee springshed. Concentrations in mg/l.

southwestward to near Columbia City. Highest concentrations are just southeast of the Rose Creek sink system. There is also a high nitrate area immediately east of the springs.

Figure 8 depicts the K_{SD} map for nitrate + nitrite. The units are natural logarithms in mg/L. Greatest uncertainty is, therefore, between 0.8 and 1.0 lm mg/L, or 2.2 to 2.7 mg/L. These uncertainties may be acceptable to the District, in which case the basin is well monitored for nitrate. If not, the areas indicated as having K_{SD} values in excess of 0.6 ln mg/L (1.8 mg/L) are extensive and considerable additional monitoring will be required to lower the uncertainty. Note that the uncertainties are for interpolations between data points, not for the monitoring data itself, so measured concentrations can be relied upon to indicate contamination.

Summary

The data presented herein clearly indicate that the Ichetucknee ground-water basin can be delineated by use of a high-resolution monitoring program. The ground-water elevation data depict details that assist in identification of ground-water divides and contrasts in hydraulic conductivity as interpreted from the patterns of isopotential lines. If there is a need to drive the uncertainty down, there is an area just north of the spring system where additional monitoring points are indicated.

Nitrate + nitrite can also be adequately monitored with the existing monitoring plan. Uncertainties for extrapolation between data points are somewhat high, but not to the point of negating contouring of the data. The data can be utilized for delineation of high nitrate water, and high concentration areas were detected north and east of the springs.

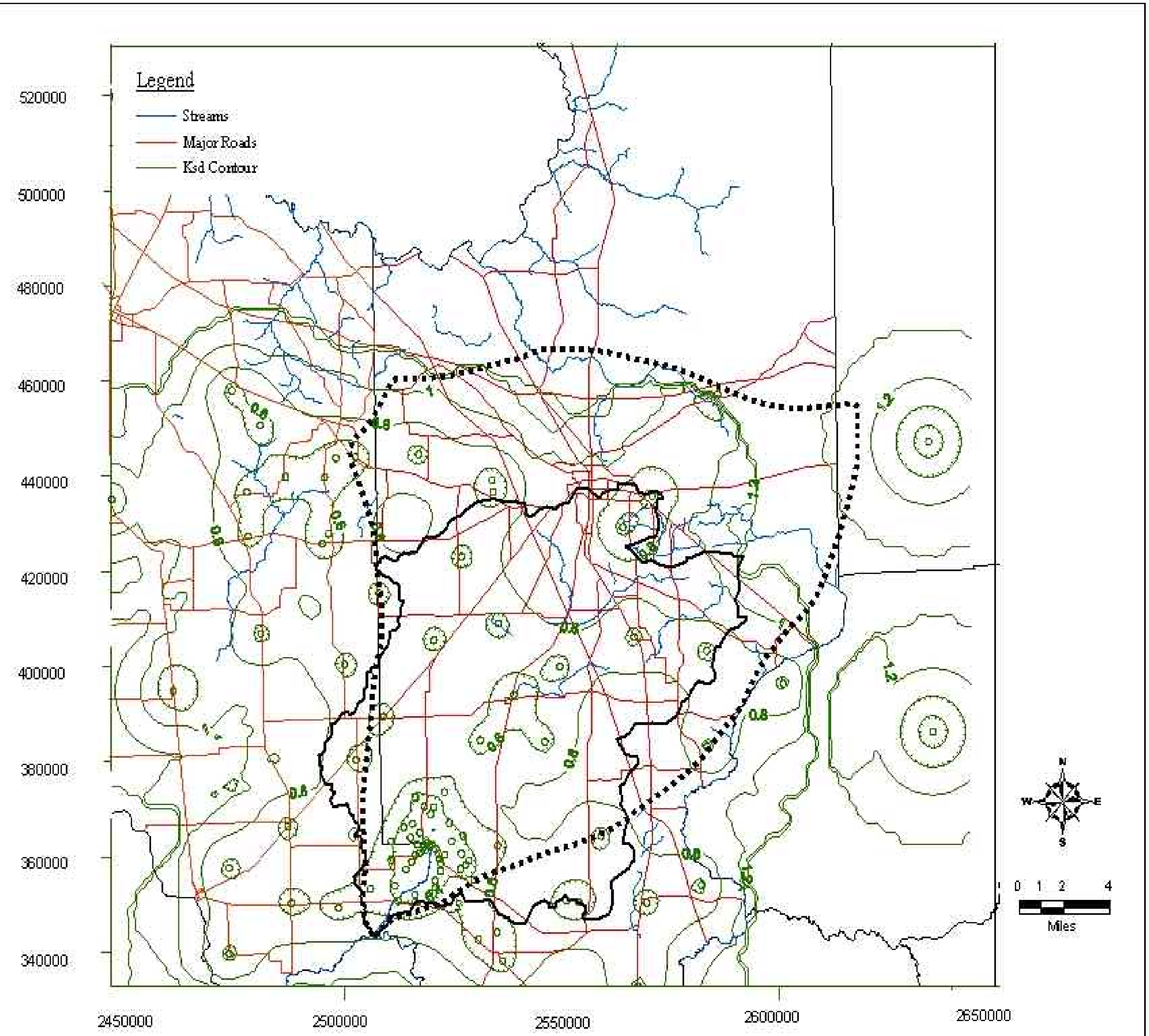

Figure 8. Nitrate Ksd map for the Ichetucknee springshed.