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Reconnaissance Survey of Nitrate Concentrations in Ground Water in Howard and Pike Counties, Arkansas

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RECONNAISSANCE SURVEY OF NITRATE CONCENTRATIONS IN GROUND WATER IN HOWARD AND PIKE COUNTIES, ARKANSAS

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Abstract

In recent years, the rapid growth of poultry and hog production in Arkansas has caused concern regarding nitrate contamination of the ground water. In the study area of Pike and Howard Counties, the number of hogs has increased from 3,300 hogs in 1970 to 75,000 hogs in 1990. Poultry production for the area has increased from 38,933,000 per year in 1970 to 62,774,000 per year in 1990. As animal production increases, so does the amount of animal waste that must be disposed. Hog production is of particular concern. Typical hog operations store concentrated animal waste in lagoons prior to land application. If the lagoons are improperly constructed and leak, they can contaminate ground water with bacteria and nitrate. Disposal of chicken litter on pastureland is also a significant source of ground water nitrate. In response to these concerns, a study of nitrate concentrations in rural water wells was conducted for Pike and Howard Counties during "wet" and "dry" seasons in 1991. Approximately fifty samples were collected from each county and analyzed for nitrate as well as other chemical parameters.

Pike and Howard Counties are divided into two distinct physiographic regions; the Ouachita Mountains and the Gulf Coastal Plain. Comparisons of nitrate concentrations indicates that the Gulf Coastal Plain portion of the study area may be more susceptible to surface contamination than the Ouachita Mountain portion. Average mean nitrate plus nitrite (NO_3-N) values for the Gulf Coast portion of the study area was 1.06 mg/L as compared to 0.59 mg/L for the Ouachita Mountains. Also, nitrate data from a 1955 study indicates that the increased animal production in Pike and Howard Counties corresponds with increased levels of ground-water nitrate. In 1955 the average mean NO_3-N value was 0.26 mg/L (Gulf Coastal Plain area) as compared to 1.06 mg/L in 1991. Wet season average mean NO_3-N values for the Gulf Coast region (0.22 mg/L) and the Ouachita Mountain region (0.06 mg/L) were higher than dry season NO_3-N values (0.16 mg/L and 0.02 mg/L, respectively). Nitrate levels in ground water for Pike and Howard Counties were all below the 10 mg/L NO_3-N drinking water standard.

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Introduction

In recent years, the tremendous expansion of hog and poultry production in Arkansas has caused concern regarding nitrate contamination of ground water. Nitrate contamination can occur when animal waste is applied as fertilizer to pastureland. This is of particular concern in rural areas where domestic wells supply most if not all drinking water. It can also affect municipal water systems, which may not adequately treat for nitrate.

While the major source of ground water nitrate in Arkansas is surface application of animal waste, other agricultural practices may contribute to ground water nitrate. The use of commercial fertilizers containing nitrogen, sewage disposal, cattle feeding operations, and the cultivation of virgin soils (leading to oxidation of large quantities of nitrogen existing as organic matter in the soil), have been considered major sources of nitrate contamination.

Nature of Concerns

Nitrate (NO_3) is by far the most dominant nitrogen species in ground water. Measurements of nitrate concentrations are usually reported in one of two ways: nitrate (NO_3) or nitrate-nitrogen (NO_3-N). The current national primary drinking water standard for NO_3-N is 10 mg/L, which is equivalent to 45 mg/L NO_3 (EPA, 1985).

There are two main health effects related to nitrate. The first is methemoglobinemia ("blue baby syndrome"), a type of blood disorder in which oxygen transport in young babies and fetuses is impaired (Craun, 1984). The second health effect is the possibility of forming cancer-causing compounds after drinking contaminated water. Under certain conditions, nitrate is reduced to nitrite in the gastrointestinal tract. It then reacts with secondary amines and amides present in food and water to form N-nitroso compounds, many of which are carcinogenic in animals.

A 1982 epidemiological study found evidence that elevated nitrate in ground water may cause human fetal malformations. The study found a higher death rate due to such congenital malformations in a region that had 10+ mg/l nitrate-N in its drinking water than had occurred in surrounding areas that showed negligible nitrate levels (Scragg et al., 1982).

Previous Investigations

Although a number of nitrate studies have been conducted in other parts of Arkansas, no recent study has examined nitrate levels in well water for this area. A 1955 ground water resource study (Counts et al., 1955) examined an area of southwest Arkansas which included the southern half of Pike and Howard County. The purpose of this study was to gather information about the occurrence and quality of ground water, with emphasis on areas of Cretaceous age.

A water chemistry study was conducted in 1978 by a University of Arkansas graduate student (Sharp, 1978). The goal of this study was to examine the potential of spring water chemistry as a geothermal and mineral exploration tool. Springs in Pike and Howard Counties (as well as Sevier, Polk, Montgomery, and Garland) were analyzed for heavy metals and the normal anion/cation suite, including NO_3-N.

A 1980 study was done to study the chemistry of the spring waters of the Ouachita Mountains (Steele et al., 1980). Ninety-three springs and nine wells were sampled, with twenty-five sample sites located in Pike and Howard Counties. A follow-up study examined these same springs and wells as an evaluation of ground water sampling as a sampling medium for uranium exploration (Steele, 1982). In conjunction with this study, an additional study investigated the seasonal effects on ground water chemistry (Steele et al., 1982).

Study Area

Location and Physiography

The study area, which consists of Pike and Howard Counties, covers 1169 miles^2 (748,160 acres). The two counties are located in southwest Arkansas, as shown in Figure 1. The two county area has a 1990 total population of 23,655, which is down 0.8% from the 1980 population of 23,832 (U.S. Census, 1990). The economy of this area is based primarily on animal production and the timber industry.

Both Pike and Howard Counties are divided by the fall line which separates Arkansas into two physiographic provinces: the northwestern Interior Highlands and the southeastern Gulf Coastal Plain. The study area north of the fall line lies in the Ouachita Mountain region of the Interior Highlands. The study area south of the fall line is located in the Gulf Coastal Plain.

North of the fall line (Interior Highlands) the outcrops are mostly Mississippian and Pennsylvanian in age, and the land surface is hilly to mountainous. The highly folded structure of the Ouachita Mountains produces long, narrow, east-west trending ridges of more resistant sandstone and narrow, parallel valleys of less resistant shale. South of the fall line (Gulf Coastal Plain) the outcrops are primarily Cretaceous in age. The surface expression of the Cretaceous area is characterized by low rounded hills, aligned in a general northeastern direction, the trend conforming to the outcrop bands of the formations. The more resistant formations, such as the Nacatoch Sand and the Tokio Formation, stand up as low ridges (Counts et al., 1955).

Figure 1. Location of study area (Pike and Howard Counties, indicated by oblique lines).

Animal Production Statistics

Pike and Howard Counties have experienced relatively rapid growth in poultry and swine production. Table 1 shows the increase in animal production for each county over the last 20 years.

Pike County

YEAR	BROILERS	SWINE	CATTLE
1970	11,608,000	1,400	18,000
1980	17,200,000	2,700	20,300
1990	17,124,000	18,000	18,000

Howard County

YEAR	BROILERS	SWINE	CATTLE
1970	27,325,000	1,900	28,000
1980	43,369,000	1,500	31,700
1990	45,650,000	57,000	33,000

Table 1. Animal production for Pike and Howard Counties (USDA, 1970, 1980, 1990). Broiler numbers are total production per year, swine and cattle numbers are a one time head count for that year.

In 1990, Howard County ranked fifth of all counties in the state in broiler production and fourth in swine production. Pike County ranked nineteenth in broiler production and eleventh in swine production (USDA, 1990).

General Geology

The Ouachita Mountain portion of the study area is part of a structural belt which extends for more than 1300 miles along the southern edge of North America from northern Mexico across Arkansas, Oklahoma, Texas, and to southwestern Alabama (Flawn et al., 1961) The major exposure of this belt is the Ouachita Mountains of western Arkansas and eastern Oklahoma

A generalized stratigraphic column for the Ouachita Mountain system is shown in Figure 2. The lithologies of the Ouachita Mountain system range in age from Cambrian to Pennsylvanian rocks in the Ouachita Mountains are mostly Paleozoic-age sandstone, shale, and chert deposited in a deep oceanic basin. These rocks were subsequently compressed, folded, and faulted during the late Pennsylvanian and Permian. Small segments of underlying basaltic rock were also folded up into the Ouachita Mountains (Guccione, 1985)

The Gulf Coastal Plain is south of the Ouachita Mountain division and extends across southwestern and south-central Arkansas. The rocks are not folded, and only a few normal faults are present. The sedimentary rocks of the Gulf Coastal Plain were deposited in the shallow sea that covered the southern part Arkansas during the Cretaceous and the shallow Gulf of Mexico covered the same area during the late Mesozoic and the middle Cenozoic. These sedimentary rocks are all poorly lithified and consist mostly of evaporites, sandstones, and shales (Guccione, 1985). A generalized stratigraphic column for the Gulf Coastal Plain is shown in Figure 3

SYSTEM	SERIES	FORMATION	MEMBER	THICKNESS (METERS)	LITHOLOGY
QUATERNARY		ALLUVIUM			SILT, SAND, AND GRAVEL ALONG STREAM CHANNELS.
		TERRACE DEPOSITS			GRAVEL, SAND, AND SILT OCCURING ALONG MAJOR STREAMS.
CRETACEOUS		TRINITY FORMATION			GRAVEL, SILT, CLAY, SILTSTONE, AND SANDSTONE WITH SOME BARITE IN WESTERN PART OF ITS OUTCROP.
PENNSYLVANIAN	ATOKAN	ATOKA	UPPER MIDDLE LOWER	6000+	SHALE, LIGHT GRAY, SILTY, MICACEOUS, AND FLAKY WITH INTERBEDDED FINE TO COARSE-GRAINED, MICACEOUS SANDSTONE WITH VERY ABUNDANT SOLE MARKINGS. THIN SILICEOUS SHALES NEAR BASE AND IN LOWER PART OF FORMATION.
	MORROWAN	JOHNS VALLEY SHALE		600	SHALE, LIGHT GRAY TO TAN, DARK GRAY NEAR BASE, AND THIN BEDS OF SANDSTONE AND LIMESTONE. LARGE ERRATIC MASSES OF LIMESTONE OR SHALE ARE FOUND NEAR THE BASE OF THE FORMATION, AND EXOTIC BOULDERS, PEBBLES, AND GRANULES OCCUR AT NUMEROUS HORIZONS.
		JACKFORK SANDSTONE		2300	SANDSTONE, MEDIUM TO COARSE GRAINED, HARD, WITH INTERBEDDED SHALE. SOLE MARKINGS ARE ABUNDANT IN THE SANDSTONES. FOUR BEDS OF SILICEOUS SHALE AND ONE BED OF MAROON TO GREEN SHALE ARE IDENTIFIABLE OVER LONG DISTANCES AND FORM MARKER BEDS.
MISSISSIPPIAN	CHESTERIAN	STANLEY GROUP	CHICKASAW CREEK		SHALE, DARK COLORED, MOSTLY GRAY, INTERBEDDED WITH DARK GRAY ARGILLACEOUS SILTSTONE AND VERY POORLY SORTED FINE- TO VERY FINE-GRAINED ARGILLACEOUS CHLORITIC SANDSTONE. BEDS OF SILICEOUS SHALE ARE IDENTIFIABLE OVER LONG DISTANCES IN SEVERAL HORIZONS. CONE-IN-CONE CONCRETIONS ARE ABUNDANT AT PLACES.
	MERAMECIAN		HATTON TUFF	0-30 (STANLEY GROUP: 4000)	FELSIC VITRIC TUFF.
			HOT SPRINGS SANDSTONE	0-20	SANDSTONE, HARD, QUARTZOSE, FINE TO VERY FINE GRAINED, SMALL AMOUNTS OF INTERBEDDED SHALE AND LOCALLY CONGLOMERATIC NEAR BASE. CROPS OUT ONLY IN RELATIVELY SMALL AREA NEAR HOT SPRINGS.
	OSAGEAN KINDERHOOKIAN	ARKANSAS NOVACULITE	UPPER	310	GREEN, BROWN, AND GRAY RADIOLARIAN CHERT AND RADIOLARIAN SHALE.
DEVONIAN	UPPER AND MIDDLE		UPPER MIDDLE		RED AND GREEN RADIOLARIAN SHALE SILICEOUS SHALE RADIOLARIAN CHERT AND BITUMINOUS CHERT.
			LOWER MIDDLE		LIGHT GRAY TO BLACK BITUMINOUS SPORE-BEARING CHERT AND BLACK PAPERY BITUMINOUS SHALE.
			LOWER		WHITE TO GREEN MASSIVE SPICULITIC CHERT AND GREEN LAMINATED SILICEOUS SHALE.
SILURIAN	NIAGARAN	MISSOURI MOUNTAIN SHALE		100	SHALE, HARD, GREEN SILICEOUS, SANDY IN PART. THIN BEDS OF FINELY LAMINATED CHERT AND QUARTZOSE SANDSTONE AND LOCAL LENSES OF SANDY CHERT CONGLOMERATE.
	ALEXANDRIAN	BLAYLOCK SANDSTONE		500	SANDSTONE, GRAY TO GREEN, THIN BEDDED, FINE GRAINED, WITH INTERBEDDED SHALEY MICACEOUS SILTSTONE AND DARK FISSILE SHALES. VEINS OF QUARTZ AND SMOKY QUARTZ ARE ABUNDANT. FORMATION PRESENT ONLY IN PART OF BROKEN BOW-BENTON UPLIFT.
MIDDLE AND UPPER ORDOVICIAN	CINCINNATIAN	POLK CREEK SHALE		68	SHALE, SOFT, BROWN, PLATY IN MOST OF FORMATION; HARD, BLACK, BITUMINOUS, AND SILICEOUS NEAR BASE. ABUNDANT GRAPTOLITES. THIN STREAKS OF QUARTZITIC SANDSTONE AND OOLITIC LIMESTONE.
	TRENTONIAN	BIG FORK CHERT	UPPER	260	BLACK, NONCALCAREOUS, BITUMINOUS CHERT AND BLACK BITUMINOUS PAPERY SHALE.
			LOWER		GRAY TO BROWN CALCAREOUS CHERT, SILICEOUS LIMESTONE, CLASTIC LIMESTONE AND CHERTY SHALE.
	BLACKRIVERIAN	WOMBLE SHALE		1100	SHALE, BLACK TO GREEN, WITH THIN INTERBEDS OF QUARTZOZE SANDSTONE AND LIMESTONE. SOME SILICEOUS BITUMINOUS SHALE NEAR CONTACT WITH BIGFORK CHERT.
LOWER ORDOVICIAN	CHAZYAN				
	CANADIAN	BLAKELY SANDSTONE		130	SHALE, BLACK TO GREEN, INTERBEDDED WITH FINE TO MEDIUM GRAINED QUARTZOSE SANDSTONE. SOME VEINS OF SMOKY QUARTZ.
		MAZARN SHALE		1000	SHALE, BLACK TO GREEN, BANDED, CLAYEY, FISSILE, WITH THIN LAYERS OF GREEN SANDSTONE AND BLUISH-BLACK LIMESTONE VEINS OF QUARTZ AND CALCITE.
		CRYSTAL MOUNTAIN SANDSTONE		280	SANDSTONE, MASSIVE, LIGHT GRAY, CALCAREOUS TO QUARTZITIC. MANY QUARTZ VEINS AND CRYSTALS.
		COLLIER SHALE		330	SHALE, BLACK, GRAPHITIC, AND DARK-COLORED SILICEOUS LIMESTONE. SOME DENSE BLACK CHERT.

Figure 2. Generalized stratigraphic column of the Ouachita Mountain System. Fron Flawn et al., 1961.

Era	System	Series	Group or formation	Thickness (feet)	Character of materials
Cenozoic	Quaternary.		Alluvium and terrace deposits.	0-90	Sand, gravel, silt, and clay.
	Tertiary.	Eocene.	Wilcox formation.	0-600	Lignitic sand and clay.
		Paleocene.	Midway formation.	0-600	Clay, blue plastic. Clay, blue fossiliferous, bottom 30 to 50 feet.
			–Unconformity.–		
Mesozoic	Cretaceous	Upper Cretaceous (Gulf)	Arkadelphia marl.	0-150	Clay, fossiliferous, calcareous with interbedded limestone. Shale, blue in subsurface.
			Nacatoch sand.	0-500	Sand massive cross-bedded, limestone lenses and calcareous clay.
			Saratoga chalk.	0-60	Chalk, hard white with interbedded blue marl. Fossiliferous.
			–Unconformity.–		
			Marlbrook marl.	0-200	Marl, blue to gray, fossiliferous.
			Annona chalk.	0-100	Chalk, massive white.
			–Unconformity.–		
			Ozan formation.	0-250	Clay, bluish to tan and clay and marl, sandy. Sand glauconitic at base from 0-20 feet thick.
			Brownstown marl.	0-200	Clay, gray to tan, fossiliferous calcareous.
			–Unconformity.–		
			Tokio formation.	0-350	Sand, cross-bedded quartz, gravels and clay, gray lignitic.
			–Unconformity.–		
			Woodbine formation.	0-250	Clay, red and gray, sand and gravel, yellowish cross-bedded.
			–Unconformity.–		
		Lower Cretaceous (Comanche)	Kiamichi formation.	0-20	Clay, soft gray, marl fossiliferous and lenses of limestone. Present in very small area in Little River County.
			Goodland limestone.	0-50	Limestone gray sandy and clay gray. Present in very small area in Little River County.
			Trinity group.	0-900	Sand, fine, white, interbedded with red and clay, and limestone.
				0-100	Limestone, interbedded gray, clay and gypsum, gray.
				0-40	Gravel.
				0-400	Clay, red, interbedded with gray sand.
				0-40	Limestone interbedded with dark shale.
				0-50	Gravel.
	Jurassic.			0-?	Red beds and anhydrite.
Paleozoic	Mississippian and Pennsylvanian		Atoka formation. Jackfork sandstone. Stanley shale.	0-?	Sandstone and shale, highly folded.

Figure 3. Generalized stratigraphic column of the Gulf Coastal Plain. From Counts et al., 1955.

General Hydrogeology

The Ouachita Mountain portion of the study area is very complex lithologically. This complex lithology, in combination with intense folding and faulting and highly variable hydraulic conductivities and porosities, results in very complex hydrologic systems. The Stanley Formation, which is a turbidite sequence of up to 12,000 feet of alternating sandstones and shales (Flawn et al., 1961), supplies most of the well water in this portion of the study area.

The Gulf Coastal Plain portion of the study area is composed of a wedge of Cretaceous age sedimentary deposits that thin to an edge at the fall line and thicken rapidly to the south. The lower Cretaceous Trinity Group and the Tokio Formation crop out in a band bordering the Interior Highlands.

The Trinity Group consists of alternating beds of sand, clay, gravel, and limestone. The total thickness for the Trinity Group ranges from 20 to 100 feet. The upper sand of the Trinity is the principal source of water in the group (Counts et al., 1955). Trinity water is usually fair to good in chemical quality.

The Tokio Formation consists of sands, gravels, and clays. The Tokio Formation ranges from about 50 feet thick in the study area to as much as 350 feet thick further downdip. It yields moderate amounts of good quality water to domestic, industrial, and public supply wells.

Both the Trinity Group and the Tokio Formation serve as both recharge points and major aquifers for the study area. On the basis of a few pumping tests and an approximation of its gradient, the rate of ground water movement through these units is on the order of about 5 feet per year (Counts et al., 1955).

With the existing data it is difficult to determine which aquifer supplies a given well. While deeper aquifers such as the Atoka, Jackfork, and Stanley may supply water to some wells, they are rarely utilized because of sufficient water yields in shallower aquifers.

Pike County

Most of the wells in the Ouachita Mountain portion of Pike County receive their water from the Stanley Formation. Low volume wells with fair to good quality water can usually be obtained at depths of less than 300 feet.

In the region of the fall line where the Trinity group crops out, little ground water is available. Here the Trinity group is a calcareous clay that bears little water (Veatch, 1906).

Further south, the Tokio formation provides ground water of good chemical quality (suitable for domestic use without treatment), typically at depths of less than 100 feet. However, at the extreme end of Howard County domestic wells may be as much as 500 feet deep.

Howard County

As in Pike County, the Stanley Formation supplies wells in the Ouachita Mountain portion of Howard County. In central Howard County, many wells derive their water from the middle and lower sands of the Tokio Formation. In the extreme south end of the county wells yield water from the upper sand of the Tokio and the

Woodbine Formation. Sands in the upper part of the Trinity group also supply wells in central Howard County (Counts et al., 1955).

Well depth varies from a few feet in the northern end of the county to as much as 700 feet in the southern part. The chemical quality of the Tokio water is generally good. Water supplied by the Trinity group is generally highly mineralized and often requires treatment.

Methodology

Selection of Sample Locations

A total of 100 samples were collected from Pike and Howard Counties. Sample site distribution is shown in Figure 4. Initially, random sampling based on the use of a grid system was planned. After evaluating the two county area; however, it was determined that a grid system would not be practical due to the population concentrations along roadways and the large areas of timber company land. The sample sites in Howard County were selected by spacing fifty sites as evenly as possible over the populated areas of that county. Pike County presented more of a problem. Most of the chicken and hog production for Pike County is located in the upper one-third of the county along Arkansas Highways 84 and 70, both of which run east to west. Of the 50 samples collected, 38 are distributed over this area. The remaining samples are distributed over the lower two-thirds of the county, which is predominantly timber company land (non-populated).

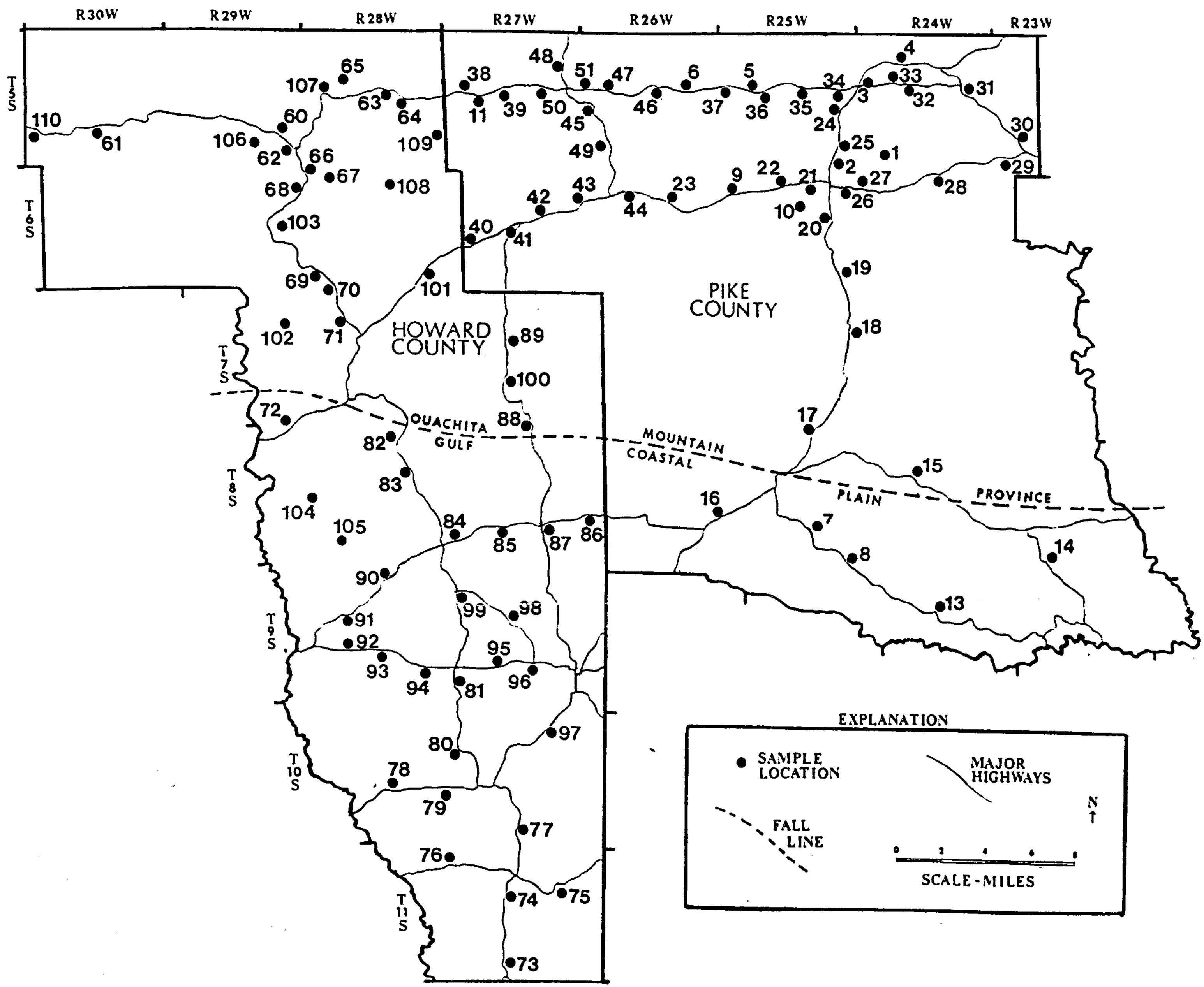

Figure 2. Location of sample sites in Pike and Howard Counties.

Sample Collection and Field Analysis

Residential wells in Howard and Pike Counties were sampled this study. Two rounds of samples were collected during successive wet and dry seasons. Wet season samples were collected between March 21, 1991 and May 25, 1991. Dry season samples were collected between July 17, 1991 and August 10, 1991. A total of 100 samples were collected and analyzed for the wet season, but only 91 samples were collected and analyzed for the dry season. Reasons for fewer dry season samples range from well owners not being home to wells having gone dry.

Samples were collected at each site in a 1000 mL polypropolene bottle. This sample was then filtered through a 0.45 um pore-size cellulose-acetate membrane and placed on ice. At the end of each sampling day the 1000 mL filtered sample was divided into three portions. A 500 mL portion was refrigerated at 4 °C to be analyzed for sulfate (SO_4 and chloride (Cl). A 250 mL portion to be used for the cations was acidified with 1.0 mL of HNO_3 to a pH of <2. The remaining 250 mL portion of the filtered sample was acidified with 1.0 mL of 1:1 H_2SO_4 to a pH of <2 and stored in a polypropolene bottle at 4 °C. This sample was used for nitrate plus nitrite (as N) and ammonia (NH_4 and NH_3).

To minimize contamination problems, samples were collected from the closest outlet to the well. Most samples were collected at the well house faucet. All wells were purged at least five minutes in order to flush the holding tank and well bore.

Water temperature, pH, specific conductance, and total alkalinity as calcium carbonate were determined in the field at collection time. Temperature was determined with a mercury bulb thermometer. Hydrogen ion activity (pH) was measured with an Orion Research Model SA 250 pH meter and a Ross probe. Field conductance was measured with a YSI model 33 conductivity meter and mathematically adjusted to specific conductance at 25°C. Titration to the bromocreosol green/methyl red end point with 0.02 N H_2SO_4 was used to determine total alkalinity.

Laboratory Analysis

Analysis for nitrate followed Hach Company procedures (Hach, 1984). Prior to analysis the nitrate samples were neutralized to a pH of 7.0 using sodium hydroxide (NaOH). The concentrations of the samples were adjusted to compensate for the change in volume during neutralization. Nitrate and nitrite was then analyzed using the cadmium reduction colorimetric method (APHA, 1985) as modified by Hach (1984). A Bauch & Lomb Spectronic 20 Colorimeter was used to measure the transmittance of the nitrate samples. Samples that were below 12% transmittance were diluted and reanalyzed. All the remaining anions and cations were analyzed using EPA approved methods and time constraints (EPA, 1983).

Quality Control

Duplicate samples were analyzed to determine analytical accuracy. For the wet season, ten of one hundred samples (10%) were duplicates, and for the dry season, ten of ninety-one samples (11%) were duplicates. A single pooled precision value of 0.015 mg\L as NO_3-N for both seasons was calculated based on the method of Skoog and West (1974). Appendix B, Table B-1 lists the initial and duplicate analyses for both seasons, as well as pooled precision values for both seasons.

Trip blanks and field duplicates were collected and analyzed as part of the QA/QC program. All field duplicates and trip blanks were collected, filtered, acidified, neutralized, and analyzed by the same procedures as described previously. The results of these analyses are listed in Appendix B, Table B-2.

Various known NO_3 concentrations were used to spike selected samples. These spiked samples were analyzed with the same procedure as the other nitrate samples and are tabulated in Appendix B, Table B-3. The maximum difference between measured

expected values was 0.06 mg/L NO_3-N. A mean percent recovery of 103.91 and a relative standard deviation of 18.06% for the mean percent recovery was calculated for the spiked samples

Additional quality control was ensured by analysis of blind NO_3 samples provided by the water quality lab at the University of Arkansas. All blind sample analyses were within the 90% confidence limit. Data from the blind sample analysis is given in Appendix B, Table B-4

SUMMARY OF STUDY RESULTS

Because animal waste tends to be applied fairly close to the production area, its seems likely that NO_3-N levels in the ground water would increase with increased animal production. As shown in Table 2, Howard County has substantially higher levels of ground water NO_3-N than Pike County. This corresponds with the higher animal production seen in Howard County (Table 1).

PIKE COUNTY			HOWARD COUNTY		
SEASON	STATISTICS	NO_3-N(Mg/L)	SEASON	STATISTICS	NO_3-N(Mg/L)
Wet	High	4.56	Wet	High	8.50
	Low	<0.01		Low	<0.01
	Avg.	0.48		Avg.	1.25
	Median	0.04		Median	0.30
	Std. Dev.	0.99		Std. Dev.	2.05
	# Samples	50		# Samples	50
Dry	High	6.32	Dry	High	7.55
	Low	<0.01		Low	<0.01
	Avg	0.45		Avg.	0.68
	Median	0.03		Median	0.12
	Std. Dev.	1.10		Std. Dev.	1.34
	# Samples	47		# Samples	44

Table 2. NO_3-N statistics of well water samples for Pike and Howard Counties.

Because of the hydrogeologic differences in the study area, the comparisons made in Table 2 may be misleading. Table 3 compares the Gulf Coastal Plain and Ouachita Mountain regions of Pike and Howard Counties. In the Ouachita Mountain Province, median NO_3-N values for both wet (0.56 mg/L) and dry (0.05 mg/L)

OUACHITA MOUNTAINS

PIKE COUNTY

SEASON	STATISTICS	NO_3-N(Mg/L)
Wet	High	3.94
	Low	<0.01
	Avg.	0.33
	Median	0.02
	Std. Dev.	0.74
	# Samples	45
Dry	High	2.70
	Low	<0.01
	Avg	0.25
	Median	0.01
	Std. Dev.	0.56
	# Samples	43

HOWARD COUNTY

SEASON	STATISTICS	NO_3-N(Mg/L)
Wet	High	8.50
	Low	0.03
	Avg.	1.45
	Median	0.56
	Std. Dev.	2.17
	# Samples	23
Dry	High	7.53
	Low	<0.01
	Avg.	0.80
	Median	0.05
	Std. Dev.	1.78
	# Samples	21

OUACHITA MOUNTAINS

(PIKE AND HOWARD COMBINED)

SEASON	STATISTICS	NO_3-N(Mg/L)
Wet	High	8.50
	Low	<0.01
	Avg.	0.76
	Median	0.06
	Std. Dev.	1.68
	# Samples	68
Dry	High	7.50
	Low	<0.01
	Avg	0.41
	Median	0.02
	Std. Dev.	1.15
	# Samples	64

GULF COASTAL PROVINCE

PIKE COUNTY

SEASON	STATISTICS	NO_3-N(Mg/L)
Wet	High	4.56
	Low	0.06
	Avg.	1.88
	Median	1.73
	Std. Dev.	1.62
	# Samples	5
Dry	High	6.32
	Low	0.09
	Avg	2.57
	Median	1.94
	Std. Dev.	2.36
	# Samples	4

HOWARD COUNTY

SEASON	STATISTICS	NO_3-N(Mg/L)
Wet	High	7.30
	Low	<0.01
	Avg.	1.16
	Median	0.19
	Std. Dev.	1.89
	# Samples	28
Dry	High	3.36
	Low	<0.01
	Avg.	0.66
	Median	0.16
	Std. Dev.	0.86
	# Samples	28

GULF COASTAL PROVINCE

(PIKE AND HOWARD COMBINED)

SEASON	STATISTICS	NO_3-N(Mg/L)
Wet	High	7.30
	Low	<0.01
	Avg.	1.27
	Median	0.22
	Std. Dev.	1.87
	# Samples	32
Dry	High	6.30
	Low	<0.01
	Avg.	0.84
	Median	0.16
	Std. Dev.	1.32
	# Samples	27

Table 3. NO_3-N statistics of well water samples by the physiographic regions of Pike and Howard Counties.

seasons in Howard County are higher than the median wet (0.02 mg/L) and dry (0.01 mg/L) NO_3-N values for Pike Counties. As previously noted, this is likely due to the higher levels of animal production in Howard County as compared to Pike County.

In the Gulf Coastal Province, median NO_3-N values for both wet (1.73 mg/L) and dry (1.94 mg/L) seasons in Pike County are much higher than the median NO_3-N wet (0.19 mg/L) and dry (0.16 mg/L) values for Howard County. The higher NO_3-N levels for Pike County were unexepected due to the lower animal production of Pike County. However, it should be pointed out that only five sites are located in the Gulf Coastal portion of Pike County as compared to 28 sites in the Gulf Coastal portion of Howard County. This is not enough sites for a meaningful comparison.

The Gulf Coastal Province combined wet-dry season median NO_3-N value is 0.19 mg/L as compared to 0.04 mg/L for the Ouachita Mountain Province. The higher nitrate levels in the Gulf Coastal Plain Province are very likely due to the nature of the Gulf Coastal Plain sediments which serve as area aquifers. These sediments are in general permeable and susceptible to local contamination; whereas, the Stanley Formation, which serves as the aquifer for the Ouachita portion of the study area, is a relatively impermeable shale unit. However, local areas of fracturing and faulting in the Stanley Formation could be susceptible to surface contamination.

It is also worth pointing out that many poorly cased wells were observed while collecting samples. These wells, which were often located on or near pastureland, would be particularly susceptible to local surface contamination and might even serve as "conduits" for aquifer contamination. The highest NO_3-N values may be the result of surface contamination of poorly cased individual wells or contamination from domestic septic systems.

other comparison that can be made is with historical nitrate data. In the study by Counts et al. (1955), 83 samples from the Gulf Coastal Plain area in Pike and Howard Counties were analyzed for nitrate. Table 4 is a comparison of these analyses without regard to county or season

1955 STUDY
NO_3-N DATA

STATISTICS	NO_3-N(Mg/L)
High	1.19
Low	0.00
Avg.	0.26
Median	0.21
Std. Dev.	0.18
# samples	83

AVERAGE OF ALL GULF COAST
NO_3-N DATA FROM THIS STUDY

STATISTICS	NO_3-N(Mg/L)
High	7.30
Low	<0.01
Avg.	1.06
Median	0.19
Std. Dev.	1.60
# Samples	59

Table 4. Comparison of historical nitrate data to nitrate data collected for this study.

In reference to the 1955 data shown in Table 4, it is worth noting that the study area was farmed in the early to mid 1900's. The nitrate levels seen in the 1955 study are likely the result of fertilizers applied to crop land. Because little or no crop farming now occurs in Pike and Howard Counties, the NO_3-N ground water concentrations in this study are likely the result of surface application of animal waste. Although the median values for the two studies are similar, the higher average value and standard deviation for the present study suggests increased nitrate contamination in some of the ground water.

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APPENDIX A

Results of chemical analyses

Format:

Sample locations - system used shown in Appendix D

Sample numbers - Locations are shown in Figure 4.

Ouachita Mountain samples - Indicated by * beside sample number.

Gulf Coastal Plain samples - Indicated by lack of *

Alk = Total alkalinity as mg/L $CaCO_3$.

Spec. Cond. = uS/cm at 25 C.

Appendix A-1: Wet season data for Pike County.

	Date Collected	Well Location	Temp (°C)	Spec. Cond.	pH	Alk (mg/L)	Nitrate (mg/L)	Ammonia (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)
1 *	3/21/91	5S 24W-32bcb	18.0	211	6.6	105	0.06	< 0.01	6.58	5.00	26.80	5.30	12.40	1.10
2 *	3/21/91	5S 25W-36cbb	17.5	316	6.8	155	0.01	< 0.01	< 3.00	15.50	34.80	9.90	18.40	0.80
3 *	3/21/91	5S 24W-18bac	17.0	,160	6.5	102	0.64	< 0.01	< 3.00	----	40.00	37.20	153.60	2.60
4 *	3/21/91	5S 24W-08aad	18.0	245	6.6	98	0.14	< 0.01	< 3.00	3.00	28.80	4.10	16.20	0.90
5 *	3/21/91	5S 25W-17bdb	18.5	215	6.5	110	< 0.01	< 0.01	< 3.00	5.50	20.00	8.10	18.80	1.40
6 *	3/21/91	5S 26W-14acc	17.5	150	6.5	76	< 0.01	< 0.01	< 3.00	2.50	21.20	2.30	10.00	0.50
7	3/23/91	8S 24W-22ccc	17.0	534	8.3	212	0.06	< 0.01	49.36	31.50	7.80	1.95	119.70	3.20
8	3/23/91	8S 24W-26dcc	16.0	106	5.6	14	2.62	< 0.01	8.07	9.00	10.40	1.80	5.20	1.50
9 *	3/23/91	6S 26W-12add	21.0	189	6.5	81	1.07	< 0.01	12.41	7.00	20.80	4.10	12.40	1.50
10 *	3/23/91	6S 26W-04ddb	14.0	433	7.0	219	0.05	< 0.01	28.27	9.50	72.00	7.20	18.40	0.90
11 *	3/23/91	5S 27W-17dcb	17.0	116	6.0	55	0.91	< 0.01	6.17	3.00	13.20	3.80	7.00	0.90
13	4/4/91	9S 24W-09acc	20.0	72	5.0	14	0.44	< 0.01	10.06	5.00	5.70	1.20	2.00	3.20
14	4/4/91	8S 23W-32bab	18.0	,140	6.4	245	4.56	< 0.01	83.99	142.00	----	7.20	25.60	0.80
15 *	4/4/91	8S 23W-08dbb	18.0	342	6.3	69	< 0.01	< 0.01	67.13	17.00	37.20	3.60	22.00	3.70
16	4/4/91	8S 25W-23acc	17.0	58	4.1	0	1.73	< 0.01	< 3.00	7.50	1.20	1.20	3.90	2.00
17 *	4/4/91	7S 25W-34cbb	19.0	476	6.6	143	1.62	< 0.01	< 3.00	61.50	3.40	1.10	119.70	2.00
18 *	4/4/91	7S 25W-11add	19.0	218	6.5	100	0.01	< 0.01	< 3.00	7.50	12.00	9.80	20.20	1.30
19 *	4/4/91	6S 25W-26cda	18.0	114	6.3	48	< 0.01	< 0.01	< 3.00	1.50	2.30	3.80	3.70	0.50
20 *	4/4/91	6S 25W-15add	18.0	325	6.8	160	< 0.01	< 0.01	4.56	8.50	37.20	13.60	15.00	1.00
21 *	4/4/91	6S 25W-10bbb	19.5	344	6.8	174	< 0.01	< 0.01	< 3.00	13.00	37.20	10.20	21.50	1.50
22 *	4/4/91	6S 25W-08aaa	16.5	170	6.9	102	0.03	< 0.01	< 3.00	1.50	22.80	2.95	12.70	0.90
23 *	4/4/91	6S 26W-10ccb	19.5	194	6.0	40	3.94	< 0.01	8.28	16.00	14.00	5.30	15.40	3.40
24 *	4/5/91	5S 25W-24bbc	15.5	36	4.7	12	0.15	< 0.01	4.56	3.00	1.30	1.30	3.10	0.40
25 *	4/5/91	5S 25W-25cac	17.0	46	5.0	5	0.89	< 0.01	< 3.00	5.00	1.00	1.00	4.30	1.20
26 *	4/5/91	6S 25W-02abc	17.0	99	5.9	40	< 0.01	< 0.01	7.00	4.00	2.50	3.10	10.00	0.30
27 *	4/5/91	6S 25W-01bab	17.0	278	6.6	145	< 0.01	< 0.01	11.45	0.00	28.00	9.80	13.50	1.00
28 *	4/5/91	6S 24W-04dac	16.0	201	7.0	107	0.01	< 0.01	< 3.00	2.00	21.00	5.50	16.70	0.70
29 *	4/5/91	5S 23W-31bda	19.0	526	7.0	271	0.08	< 0.01	5.35	8.00	49.80	14.20	53.50	1.50
30 *	4/5/91	5S 23W-29cab	21.0	302	6.8	155	< 0.01	< 0.01	7.21	3.00	36.00	10.00	11.00	0.80
31 *	4/5/91	5S 24W-11daa	17.0	197	7.2	102	0.17	< 0.01	4.56	2.00	26.40	3.40	10.00	0.80
32 *	4/5/91	5S 24W-16bda	19.0	308	7.0	157	0.03	< 0.01	10.06	8.50	39.20	6.40	18.40	0.90
33 *	4/5/91	5S 24W-17bbc	18.5	678	6.7	140	< 0.01	< 0.01	40.01	110.00	76.80	17.20	32.70	1.40
34 *	4/5/91	5S 25W-13bca	17.5	75	6.0	24	0.92	< 0.01	4.56	6.00	3.90	1.20	6.70	0.90
35 *	4/5/91	5S 25W-15acc	18.0	245	6.1	124	< 0.01	< 0.01	< 3.00	6.00	28.00	5.00	17.50	0.90
36 *	4/5/91	5S 25W-17daa	18.0	342	6.5	145	0.02	< 0.01	12.41	20.00	45.00	7.00	17.10	0.90
37 *	4/5/91	5S 25W-18bdc	18.0	228	6.7	124	< 0.01	< 0.01	< 3.00	2.00	29.20	4.10	14.30	1.20
38 *	4/5/91	5S 27W-18daa	18.0	262	7.5	129	< 0.01	< 0.01	5.96	4.00	40.40	3.40	9.70	0.70
39 *	4/5/91	5S 27W-16dbc	20.0	143	5.6	69	0.04	< 0.01	4.75	3.00	9.80	4.70	12.70	0.70
40 *	4/6/91	5S 27W-19ccc	17.5	374	6.5	114	< 0.01	< 0.01	16.48	39.50	23.20	16.00	26.00	1.30
41 *	4/6/91	6S 27W-21bcb	16.5	88	5.4	10	2.45	< 0.01	8.07	6.50	3.80	2.20	5.50	2.70
42 *	4/6/91	6S 27W-15dbb	17.0	52	4.9	7	0.77	< 0.01	6.58	5.50	1.00	1.00	5.00	0.90
43 *	4/6/91	6S 27W-13bbb	18.5	226	6.8	105	< 0.01	< 0.01	7.00	3.00	15.20	4.20	26.00	0.90
44 *	4/6/91	6S 26W-08cbc	15.5	321	6.9	131	0.04	< 0.01	9.16	12.50	17.00	11.00	25.60	1.60
45 *	4/6/91	5S 26W-19bdd	18.0	228	6.4	86	< 0.01	< 0.01	5.15	7.50	5.60	6.00	20.20	0.70
46 *	4/6/91	5S 26W-15bdb	17.5	190	7.1	90	0.04	< 0.01	4.95	3.00	21.20	9.80	12.00	0.90
47 *	4/6/91	5S 26W-17bca	17.5	230	6.6	95	< 0.01	< 0.01	4.75	10.00	22.00	5.00	19.70	1.00
48 *	4/6/91	5S 27W-12bcd	17.5	196	6.8	95	0.02	< 0.01	6.17	2.00	24.40	4.90	11.30	1.00
49 *	4/6/91	5S 26W-30ddc	17.0	220	6.9	102	< 0.01	< 0.01	7.42	3.00	19.80	5.90	19.70	1.40
50 *	4/6/91	5S 27W-14bcd	15.5	83	6.7	79	< 0.01	< 0.01	< 3.00	2.50	14.80	4.20	14.30	0.90
51 *	4/7/91	5S 27W-13bdd	17.0	244	6.6	100	< 0.01	< 0.01	4.56	2.50	16.40	7.30	19.20	0.90

Appendix A-2: Wet season data for Howard County.

	Date Collected	Well Location	Temp (°C)	Spec Cond	pH	Alk (mg/L)	Nitrate (mg/L)	Ammonia (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)
60 *	4/28/91	5S 29W-25bab	18.0	91	5.3	17	3.28	< 0.01	< 3.00	14.00	7.80	2.30	9.00	2.10
61 *	4/28/91	5S 30W-27bca	17.0	195	6.5	102	0.03	< 0.01	< 3.00	4.00	24.40	3.00	15.40	0.90
62 *	4/28/91	5S 29W-36bab	17.0	290	6.7	133	0.04	< 0.01	12.17	8.50	42.00	4.80	15.40	0.70
63 *	4/28/91	5S 28W-15dbb	17.0	145	6.1	64	0.53	< 0.01	< 3.00	4.00	16.20	2.50	13.10	1.00
64 *	4/28/91	5S 28W-16cca	17.0	162	6.6	81	1.18	< 0.01	< 3.00	4.00	19.30	3.50	12.70	1.50
65 *	4/28/91	5S 28W-17abb	17.0	60	4.9	10	7.08	< 0.01	< 3.00	9.50	3.50	2.10	8.10	2.80
66 *	4/28/91	5S 28W-36daa	17.0	220	6.5	110	0.58	< 0.01	< 3.00	4.00	23.80	6.00	18.40	1.20
67 *	4/28/91	5S 28W-01dda	19.0	159	5.9	62	0.51	< 0.01	< 3.00	13.50	10.00	4.10	23.00	1.00
68 *	4/29/91	6S 29W-12bcd	15.0	84	6.1	29	0.63	< 0.01	4.56	4.56	9.90	2.80	6.20	0.70
69 *	4/29/91	6S 29W-36bad	18.0	234	7.2	140	0.10	< 0.01	4.75	2.50	31.20	8.90	16.70	0.90
70 *	4/29/91	6S 28W-31cdd	19.0	202	7.2	136	0.42	< 0.01	13.38	4.50	30.40	10.00	25.60	1.30
71 *	4/29/91	7S 28W-07aca	18.0	353	6.4	164	0.09	< 0.01	11.93	11.00	40.40	8.80	32.70	1.00
72	4/29/91	7S 29W-35cba	19.0	549	6.8	198	0.01	< 0.01	18.40	58.00	47.70	11.20	63.00	2.80
73	5/20/91	11S 27W-32adb	24.0	765	8.7	319	0.19	< 0.01	4.36	50.50	0.90	0.10	190.80	0.90
74	5/20/91	11S 27W-17abc	22.0	583	8.7	352	0.06	< 0.01	< 3.00	26.00	1.10	0.40	190.80	1.00
75	5/20/91	11S 27W-14bbd	25.0	300	8.2	133	0.23	< 0.01	21.93	7.50	0.50	0.30	89.50	1.10
76	5/20/91	11S 28W-01cba	22.0	636	8.7	333	0.18	< 0.01	20.72	6.00	0.70	0.20	175.50	0.90
77	5/20/91	10S 27W-33bab	23.0	624	9.1	371	0.22	< 0.01	6.17	2.50	0.80	0.20	179.30	0.60
78	5/20/91	10S 28W-21dab	22.0	636	8.1	252	0.13	< 0.01	87.12	7.00	1.50	0.20	168.10	1.40
79	5/20/91	10S 28W-23bca	20.5	545	8.6	224	0.15	< 0.01	75.86	4.50	1.90	0.10	139.60	1.80
80	5/20/91	10S 28W-12ddc	24.0	84	4.4	17	6.97	< 0.01	8.28	8.00	2.00	1.70	9.00	1.80
81	5/20/91	9S 28W-25dcc	24.0	255	3.5	0	< 0.01	< 0.01	81.09	4.00	24.80	3.10	2.90	1.80
82	5/21/91	8S 28W-03bbd	21.0	594	6.9	207	0.11	< 0.01	17.29	64.50	30.60	13.00	101.10	3.20
83	5/21/91	8S 28W-10dcb	22.0	429	7.1	195	1.47	< 0.01	7.42	20.00	48.60	16.60	21.10	4.50
84	5/21/91	8S 28W-25dcb	24.0	66	6.1	29	1.84	< 0.01	4.56	3.00	8.50	1.40	2.30	1.50
85	5/21/91	8S 27W-29aab	23.0	224	6.4	105	0.60	< 0.01	12.89	7.50	32.80	4.40	9.00	4.20
86	5/21/91	8S 27W-24cab	25.0	375	7.6	171	0.11	< 0.01	31.28	5.50	50.40	11.80	7.00	4.10
87	5/21/91	8S 27W-27bab	20.5	185	6.0	33	1.48	< 0.01	4.36	32.50	16.00	4.10	10.30	3.90
88 *	5/21/91	7S 27W-33dac	22.0	355	6.5	100	1.13	< 0.01	41.00	27.50	25.20	11.00	36.50	3.00
89 *	5/21/91	7S 27W-17dab	24.0	51	4.7	5	3.68	< 0.01	< 3.00	5.00	2.30	1.40	1.50	1.50
90	5/23/91	9S 28W-04ada	26.0	372	6.7	98	2.50	< 0.01	67.13	16.00	40.40	9.50	23.50	0.70
91	5/23/91	9s 28W-18abc	24.0	82	6.5	24	2.76	< 0.01	< 3.00	6.50	7.80	2.20	2.80	1.20
92	5/23/91	9S 28W-19acc	22.5	17	6.0	62	0.14	< 0.01	11.22	9.50	20.40	5.00	5.00	2.40
93	5/23/91	9S 28W-21cac	23.0	114	6.1	43	0.22	< 0.01	4.95	5.50	12.00	3.00	4.50	2.30
94	5/23/91	9S 28W-26bdb	23.0	437	7.6	210	0.38	< 0.01	19.54	16.00	20.00	4.70	83.90	5.00
95	5/23/91	9S 27W-20bac	22.0	217	6.8	86	0.01	< 0.01	19.83	5.50	26.40	3.00	7.60	3.30
96	5/23/91	9S 27W-28aba	24.0	479	7.4	219	0.15	< 0.01	32.07	4.00	26.40	2.50	86.70	4.20
97	5/23/91	10S 27W-03dcb	21.0	702	8.8	243	0.12	< 0.01	78.39	7.50	1.50	0.20	175.50	1.20
98	5/23/91	9S 27W-17aaa	23.0	99	5.1	19	2.01	< 0.01	12.17	3.50	10.70	1.00	2.60	2.30
99	5/23/91	9S 28W-12aba	21.0	227	6.6	98	0.03	< 0.01	7.64	18.00	22.80	5.50	21.50	3.30
100 *	5/23/91	7S 27W-29aab	21.0	43	4.9	7	0.84	< 0.01	4.95	4.00	2.40	0.80	2.30	2.50
101 *	5/23/91	6S 28W-35bac	20.0	369	7.0	140	1.39	< 0.01	25.81	18.50	43.20	11.80	11.70	0.90
102 *	5/23/91	7S 29W-11cbb	21.0	378	6.3	98	8.50	< 0.01	21.02	29.50	19.60	16.00	26.00	7.40
103 *	5/23/91	6S 29W-15ddd	23.0	385	7.3	171	0.33	< 0.01	16.21	7.50	42.60	13.00	23.00	1.10
104	5/24/91	8S 29W-13cdc	26.0	147	5.4	17	2.99	< 0.01	25.47	10.00	18.80	2.00	3.90	0.90
105	5/24/91	8S 29W-30cdd	25.0	135	6.0	21	7.30	< 0.01	4.95	13.50	11.80	1.50	9.70	4.30
106 *	5/24/91	5S 29W-27ddb	24.0	224	7.1	114	0.27	< 0.01	< 3.00	3.00	33.20	3.60	14.30	0.70
107 *	5/24/91	5S 28W-18daa	24.0	255	7.3	136	0.11	< 0.01	< 3.00	3.50	40.80	3.30	14.30	0.80
108 *	5/25/91	6S 28W-09adc	24.0	326	7.3	183	0.22	< 0.01	5.56	5.00	38.00	9.50	32.70	0.90
109 *	5/25/91	6S 28W-25dac	23.0	62	5.8	26	1.56	< 0.01	< 3.00	2.00	6.60	1.60	3.70	0.70
110 *	5/25/91	5S 30W-30bcb	24.0	41	4.7	5	0.83	< 0.01	4.56	3.50	0.90	0.60	3.70	0.50

Appendix A-3: Dry season data for Pike County.

Sample Number	Date Collected	Well Location	Temp (°C)	Spec. Cond.	pH	Alk (mg/L)	Nitrate (mg/L)	Ammonia (mg/L	Sulfate (mg/L)	Chloride (mg/L	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)
1 *														
2 *	7/15/91	5S 25W-36cbb	19.5	316	6.9	152	< 0.01	< 0.01	< 3.00	14.50	32.80	10.80	17.80	0.90
3 *	7/15/91	5S 24W-18bac	20.5	1,145	6.5	100	1.01	< 0.01	4.89	-----	28.80	28.80	126.00	2.70
4 *	7/15/91	5S 24W-08aad	25.0	250	7.0	138	0.06	< 0.01	0.00	2.50	28.00	4.40	16.30	1.60
5 *	7/15/91	5S 25W-17bdb	21.0	275	6.9	133	0.03	< 0.01	9.25	6.00	21.60	9.00	18.60	1.50
6 *	7/15/91	5S 26W-14acc	20.5	134	6.9	79	< 0.01	< 0.01	7.95	2.50	18.80	2.40	6.90	0.50
7	7/15/91	8S 24W-22ccc	20.5	545	8.1	200	0.09	< 0.01	45.58	30.50	7.20	2.00	117.30	3.20
8	7/15/91	8S 24W-26dcc	24.0	128	5.5	17	2.75	< 0.01	8.59	13.50	9.80	1.80	5.50	2.10
9 *	7/15/91	6S 26W-12add	29.0	230	6.9	107	0.01	< 0.01	13.17	6.00	28.40	4.70	14.90	1.10
10 *	7/15/91	6S 26W-04ddb	18.0	507	7.0	224	0.02	< 0.01	26.06	9.00	72.00	7.00	18.60	0.90
11 *	7/15/91	5S 27W-17dcb	19.5	200	7.1	114	0.06	< 0.01	4.50	2.50	29.20	7.00	11.60	0.90
13	7/16/91	9S 24W-09acc	21.0	54	5.1	5	1.12	< 0.01	7.95	4.50	3.80	1.00	2.80	2.00
14	7/16/91	8S 23W-32bab	21.5	1,075	6.2	257	6.32	< 0.01	85.60	144.50	134.40	7.10	85.40	2.30
15 *	7/16/91	8S 23W-08dbb	19.5	483	6.8	155	0.01	< 0.01	64.10	27.50	64.00	8.80	20.20	3.80
16														
17 *	7/16/91	7S 25W-34cbb	22.0	1,219	7.7	405	0.65	< 0.01	28.52	133.00	4.80	1.20	324.50	1.80
18 *	7/16/91	7S 25W-11add	21.0	216	7.0	102	< 0.01	< 0.01	10.59	6.00	11.40	9.50	18.60	1.30
19 *	7/16/91	6S 25W-26cda	24.0	117	6.2	50	< 0.01	< 0.01	7.32	1.00	2.40	4.00	4.40	0.50
20 *														
21 *	7/16/91	6S 25W-10bbb	21.0	351	6.9	162	< 0.01	< 0.01	< 3.00	13.50	36.00	10.10	21.00	1.40
22 *	7/16/91	6S 25W-08aaa	18.5	186	7.1	110	0.03	< 0.01	4.50	1.50	21.20	3.00	12.90	0.90
23 *	7/16/91	6S 26W-10ccb	23.0	250	6.6	88	2.70	< 0.01	9.03	10.50	22.40	4.80	18.60	1.80
24 *	7/16/91	5S 25W-24bbc	20.0	66	5.8	14	0.20	< 0.01	9.47	5.50	2.20	1.80	4.40	0.50
25 *	7/16/91	5S 25W-25cac	19.5	47	5.5	10	1.70	< 0.01	< 3.00	5.00	1.20	1.00	4.20	1.10
26 *	7/16/91	6S 25W-02abc	20.0	110	6.4	48	< 0.01	< 0.01	5.68	4.50	2.00	3.20	6.70	0.40
27 *	7/17/91	6S 25W-01bab	20.0	264	6.8	148	< 0.01	< 0.01	< 3.00	3.50	25.60	9.40	13.50	0.90
28 *	7/17/91	6S 24W-04dac	23.0	198	7.2	119	< 0.01	< 0.01	< 3.00	1.50	20.40	5.60	17.10	0.70
29 *	7/17/91	5S 23W-31bda	21.0	513	7.4	286	< 0.01	< 0.01	9.03	7.00	48.00	13.20	36.00	1.60
30 *	7/17/91	5S 23W-29cab	23.0	369	6.8	210	< 0.01	< 0.01	< 3.00	2.00	46.40	13.20	13.50	0.70
31 *	7/17/91	5S 24W-11daa	20.5	191	7.4	95	0.09	< 0.01	< 3.00	2.50	25.60	3.60	11.00	0.70
32 *	7/17/91	5S 24W-16bda	25.0	285	7.0	148	0.07	< 0.01	4.89	9.50	34.00	5.90	17.10	0.90
33 *	7/17/91	5S 24W-17bbc	22.0	742	6.7	152	< 0.01	< 0.01	46.15	113.50	77.60	17.80	27.70	1.40
34 *	7/17/91	5S 25W-13bca	19.0	140	6.7	62	1.72	< 0.01	5.09	5.00	15.00	2.50	6.70	0.90
35 *	7/17/91	5S 25W-15acc	20.0	253	7.0	129	< 0.01	< 0.01	< 3.00	5.50	27.60	5.00	17.10	0.90
36 *	7/18/91	5S 25W-17daa	21.0	346	6.8	171	0.14	< 0.01	13.42	14.50	44.00	7.00	15.60	0.90
37 *	7/18/91	5S 25W-18bdc	19.0	252	7.3	143	< 0.01	< 0.01	4.50	3.00	31.20	4.10	14.20	1.10
38 *	7/18/91	5S 27W-18daa	21.0	270	7.7	138	0.05	< 0.01	6.90	3.00	40.00	3.30	10.30	0.70
39 *	7/18/91	5S 27W-16dbc	21.5	159	6.7	79	< 0.01	< 0.01	4.70	3.00	11.20	5.10	13.50	0.70
40 *	7/18/91	5S 27W-19ccc	22.0	339	6.4	105	< 0.01	< 0.01	16.21	36.50	19.40	17.80	22.60	1.30
41 *	7/18/91	6S 27W-21bcb	20.0	88	5.5	10	0.82	< 0.01	6.90	6.50	3.20	2.20	4.90	2.70
42 *	7/18/91	6S 27W-15dbb	19.5	67	5.4	10	0.95	< 0.01	9.91	4.00	1.80	1.30	5.10	0.90
43 *	7/18/91	6S 27W-13bbb	19.5	222	6.8	119	< 0.01	< 0.01	7.32	3.00	16.00	4.30	24.30	0.90
44 *	7/18/91	6S 26W-08cbc	26.5	306	7.2	148	< 0.01	< 0.01	10.82	12.00	14.60	9.40	25.20	1.30
45 *	7/20/91	5S 26W-19bdd	20.5	218	6.9	110	< 0.01	< 0.01	5.68	7.50	13.20	5.90	21.00	0.70
46 *	7/20/91	5S 26W-15bdb	20.0	187	7.3	110	0.03	< 0.01	< 3.00	3.00	20.00	5.80	12.20	0.80
47 *	7/20/91	5S 26W-17bca	20.0	275	7.1	114	< 0.01	< 0.01	4.70	9.00	22.80	4.90	19.40	0.90
48 *	7/20/91	5S 27W-12bcd	21.5	225	7.2	129	< 0.01	< 0.01	5.09	7.50	26.80	5.00	13.50	1.00
49 *	7/20/91	5S 26W-30ddc	23.0	244	7.0	124	< 0.01	< 0.01	10.36	3.00	18.40	5.80	20.20	1.30
50 *	7/20/91	5S 27W-14bcd	18.5	170	6.7	90	0.01	< 0.01	< 3.00	2.00	15.80	4.40	15.60	0.90
51 *	7/20/91	5S 27W-13bdd	19.0	246	6.8	110	< 0.01	< 0.01	4.50	3.00	17.20	7.10	18.60	0.70

Appendix A-4: Dry season data for Howard County.

Sample Number	Date Collected	Well Location	Temp (°C)	Spec. Cond.	pH	Alk (mg/L)	Nitrate (mg/L)	Ammonia (mg/L	Sulfate (mg/L)	Chloride (mg/L	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)
60 *	4/28/91	5S 29W-25bab	23.0	291	7.5	171	0.09	< 0.01	4.89	2.50	44.80	3.80	14.20	0.90
61 *														
62 *	4/28/91	5S 29W-36bab	21.0	308	7.5	148	0.02	< 0.01	10.36	9.50	42.40	4.70	14.90	0.90
63 *	4/28/91	5S 28W-15dbb	19.0	157	6.7	90	< 0.01	< 0.01	4.31	4.50	16.20	2.50	13.50	1.10
64 *	4/28/91	5S 28W-16cca	20.0	198	7.1	110	0.01	< 0.01	< 3.00	4.00	22.00	3.80	12.90	1.30
65 *	4/28/91	5S 28W-17abb	20.0	165	6.5	57	3.09	< 0.01	< 3.00	9.00	9.60	4.00	12.20	2.00
66 *	4/28/91	5S 28W-36daa	26.0	225	7.2	119	< 0.01	< 0.01	7.74	4.00	22.80	5.90	15.60	1.10
67 *	4/28/91	5S 28W-01dda	21.0	173	6.7	76	0.00	< 0.01	4.50	11.50	9.80	3.80	20.20	0.90
68 *	4/29/91	6S 29W-12bcd	20.0	330	7.7	176	0.08	< 0.01	< 3.00	5.50	36.80	6.40	22.60	1.10
69 *	4/29/91	6S 29W-36bad	29.0	322	7.7	143	< 0.01	< 0.01	< 3.00	2.50	31.20	9.00	14.90	0.90
70 *	4/29/91	6S 28W-31cdd	21.0	362	7.5	157	0.15	< 0.01	11.28	3.50	30.80	10.10	26.50	1.30
71 *	4/29/91	7S 28W-07aca	21.0	454	7.8	205	0.12	< 0.01	12.45	10.50	42.40	9.30	26.50	1.10
72	4/29/91	7S 29W-35cba	21.0	594	7.4	224	0.05	< 0.01	15.69	51.50	48.00	11.00	39.90	2.90
73	5/20/91	11S 27W-32adb	25.0	750	8.5	352	0.37	< 0.01	< 3.00	42.50	0.80	0.30	217.90	0.90
74	5/20/91	11S 27W-17abc	22.0	689	8.7	348	0.06	< 0.01	< 3.00	27.00	2.00	0.50	186.00	1.30
75	5/20/91	11S 27W-14bbd	26.0	309	8.1	129	0.11	< 0.01	24.72	8.50	0.60	0.30	85.30	1.10
76	5/20/91	11S 28W-01cba	21.5	663	8.9	367	0.12	< 0.01	20.67	6.00	0.80	0.30	178.30	0.90
77	5/20/91	10S 27W-33bab	21.0	702	9.2	386	0.14	< 0.01	15.17	1.00	0.80	0.30	186.00	0.70
78	5/20/91	10S 28W-21dab	22.0	742	8.4	262	0.07	< 0.01	62.31	7.50	1.40	0.30	170.80	1.40
79	5/20/91	10S 28W-23bca	26.0	588	8.9	252	0.06	< 0.01	77.03	4.00	1.60	0.30	166.60	1.80
80														
81	5/20/91	9S 28W-25dcc	28.0	400	7.0	148	0.16	0.10	67.94	5.00	60.00	6.00	14.90	6.30
82	5/21/91	8S 28W-03bbd	21.0	648	7.4	229	0.02	< 0.01	15.69	61.00	32.00	13.00	89.50	3.20
83	5/21/91	8S 28W-10dcb	25.0	550	7.4	262	0.58	< 0.01	9.91	13.00	57.60	19.00	25.20	4.80
84	5/21/91	8S 28W-25dcb	25.0	65	5.9	33	2.62	< 0.01	< 3.00	4.50	5.00	1.20	3.50	1.30
85														
86	5/21/91	8S 27W-24cab	25.0	365	7.4	176	0.22	< 0.01	33.13	4.00	52.80	11.20	5.80	6.30
87	5/21/91	8S 27W-27bab	20.5	202	6.0	71	0.55	< 0.01	4.89	20.00	20.80	4.30	6.40	4.50
88 *	5/21/91	7S 27W-33dac	27.0	446	6.7	105	0.71	< 0.01	58.96	31.50	30.80	13.00	27.10	2.90
89 *	5/21/91	7S 27W-17dab	31.0	62	4.3	5	3.36	< 0.01	4.50	5.00	2.00	1.20	2.60	1.40
90														
91	5/23/91	9s 28W-18abc	27.0	77	6.3	33	1.88	< 0.01	4.50	5.50	7.80	2.20	3.00	0.90
92	5/23/91	9S 28W-19acc	27.0	125	6.3	57	0.06	< 0.01	9.03	6.00	14.00	3.70	3.30	2.10
93	5/23/91	9S 28W-21cac	27.0	130	6.4	67	0.01	< 0.01	4.89	6.00	12.40	3.20	4.40	2.30
94														
95	5/23/91	9S 27W-20bac	26.0	289	6.5	100	< 0.01	< 0.01	48.51	6.00	32.00	3.90	14.90	3.60
96	5/23/91	9S 27W-28aba	27.0	480	7.5	238	0.41	< 0.01	39.38	2.50	25.20	2.40	89.50	4.30
97	5/23/91	10S 27W-03dcb	21.0	702	9.3	295	0.15	< 0.01	86.00	3.00	1.40	0.10	170.80	1.20
98	5/23/91	9S 27W-17aaa	21.5	112	6.0	19	1.32	< 0.01	26.36	5.50	12.00	1.20	3.30	2.10
99	5/23/91	9S 28W-12aba	24.0	398	6.6	105	0.64	< 0.01	4.63	27.00	24.00	6.00	16.80	3.60
100 *	5/23/91	7S 27W-29aab	21.0	65	5.1	10	1.22	< 0.01	3.59	6.50	2.40	0.80	3.00	1.10
101 *	5/23/91	6S 28W-35bac	20.5	382	7.8	162	0.14	< 0.01	18.54	14.00	40.80	10.10	19.40	0.90
102 *	5/23/91	7S 29W-11cbb	23.0	354	6.3	95	7.53	< 0.01	23.25	26.00	16.60	15.60	25.20	5.90
103 *	5/23/91	6S 29W-15ddd	24.0	403	7.8	205	0.06	< 0.01	12.24	5.00	43.20	12.20	22.60	1.10
104	5/24/91	8S 29W-13cdc	31.0	176	5.3	19	1.83	< 0.01	33.83	9.50	20.00	2.10	4.00	0.90
105	5/24/91	8S 29W-30cdd	26.0	162	5.4	10	1.73	< 0.01	< 3.00	17.50	6.00	1.40	11.60	3.90
106 *	5/24/91	5S 29W-27ddb	21.0	243	7.3	129	0.03	< 0.01	< 3.00	3.50	33.60	3.60	12.90	0.70
107 *	5/24/91	5S 28W-18daa	25.0	265	7.3	138	0.03	< 0.01	< 3.00	4.00	40.00	3.20	12.90	0.90
108 *	5/25/91	6S 28W-09adc	18.0	353	7.3	195	< 0.01	< 0.01	< 3.00	5.00	39.20	9.50	25.20	1.10
109 *	5/25/91	6S 28W-25dac	26.0	162	6.4	100	0.02	< 0.01	< 3.00	3.50	19.00	2.60	11.00	0.90
110 *														

APPENDIX B

Quality-Control / Quality-Assurance

Table B-1: Nitrate plus nitrite (mg/L as N) values obtained from duplicate sample analysis.

SAMPLE	SEASON	INITIAL	DUPLICATE	MEAN	% DIFFERENCE
11	WET	0.88	0.95	0.92	3.16
31	WET	0.24	0.15	0.20	25.00
40	WET	<0.01	<0.01	0.00	0.00
42	WET	0.76	0.72	0.74	2.70
51	WET	<0.01	<0.01	0.00	0.00
88	WET	0.53	0.52	0.53	1.89
91	WET	2.62	2.78	2.70	2.88
94	WET	0.27	0.31	0.29	6.45
104	WET	0.56	0.57	0.56	1.75
106	WET	0.33	0.30	0.32	6.25
11	DRY	0.18	0.21	0.20	10.00
21	DRY	0.14	0.12	0.13	7.14
31	DRY	0.20	0.20	0.20	0.00
38	DRY	0.17	0.17	0.17	0.00
46	DRY	0.16	0.15	0.16	0.00
79	DRY	0.30	0.19	0.25	16.67
86	DRY	0.30	0.27	0.29	3.33
99	DRY	0.59	0.53	0.56	5.08
107	DRY	0.16	0.16	0.16	0.00
109	DRY	0.15	0.15	0.15	0.00

Pooled standard deviation - wet season = +/- 0.019
Pooled standard deviation - dry season = +/- 0.010
Pooled standard deviation - both seasons = +/- 0.015

Table B-2: NO_3-N values obtained from field duplicates and trip blanks.

Sample Number	Initial Conc.	Duplicate Conc.	Mean Value	Percent Difference
10	0.05	0.07	0.06	-14.29
14	4.56	4.75	4.66	+1.89
34	0.92	0.85	0.89	-4.49
64	1.18	1.05	1.12	-6.25
69	0.10	0.10	0.10	0.00

Trip Blank Number	Concentration (mg/L)
1	< 0.01
2	< 0.01
3	< 0.01
4	< 0.01

Table B-3: Summary of spiked sample analyses. Values shown indicate NO_3-N (mg/L).

SAMPLE NUMBER	ACTUAL NO_3 AFTER SPIKE	EXPECTED NO_3 AFTER SPIKE	PERCENT RECOVERY
73	0.16	0.19	84.21
77	0.20	0.22	90.91
78	0.13	0.13	100.00
79	0.15	0.15	100.00
92	0.15	0.14	107.14
93	0.17	0.22	77.27
97	0.15	0.12	125.00
99	0.04	0.03	133.33
103	0.31	0.33	93.94
108	0.28	0.22	127.27

Mean percent recovery = 103.91 %

Relative standard deviation for mean percent recovery = +/- 18.06%

Table B-4: Blind sample analyses of NO_3-N.

PARAMETER	TRUE VALUE (mg/L)	95% CONFIDENCE INTERVAL	ANALYTICAL VALUE (mg/L)
Nitrate-N	0.2	0.16 - 0.24	0.23 *
Nitrate-N	0.5	0.44 - 0.55	0.57 **
Nitrate-N	0.5	0.44 - 0.55	0.51 *

* Within 95% confidence limit
** Within 90% confidence limit

Appendix C: Sample collection field check-list.

LOCATION INFORMATION

DATE COLLECTED :

WELL LOCATION :

SAMPLE NUMBER :

SURFACE ELEVATION :

LAND OWNER

WELL INFORMATION

AGE OF WELL :

DEPTH OF WELL :

AMOUNT OF FLOW :

DISTANCE/DIRECTION TO SEPTIC SYSTEM :

ODORS/MINERALIZATION :

FIELD TESTS

TEMPERATURE :

CONDUCTIVITY :

ALKALINITY :

pH

LOCAL GEOLOGY :

NOTES/MAPS

Appendix D: Diagram showing well location system.