GROUNDWATER QUALITY, HYDROGEOLOGY, AND AGRICULTURAL DRAINAGE WELLS

Floyd and Mitchell Counties, Iowa

Geological Survey Bureau
Technical Information Series 29

Iowa Department of Natural Resources
Larry J. Wilson, Director
April 1994

GROUNDWATER QUALITY, HYDROGEOLOGY, AND AGRICULTURAL DRAINAGE WELLS
Floyd and Mitchell Counties, Iowa

Geological Survey Bureau
Technical Information Series 29

Prepared by:

R.D. Libra[1], D.J. Quade[1], G.R. Hallberg[2], J.P. Littke[3]

[1] Iowa Department of Natural Resources
[2] University Hygienic Laboratory
[3] U.S. Soil Conservation Service

Supported, in part, through grants from the
U.S. Environmental Protection Agency, Region VII

April 1994

Iowa Department of Natural Resources
Larry J. Wilson, Director

In June of 1994, John Littke lost what can only be described as a heroic battle with leukemia. He faced his condition as he faced all of life's tribulations; with a smile, and without complaint. You were one of the good guys, Big John. Your friends will miss you, and you will be in our thoughts as we continue our work with Iowa's soil, rocks, and water.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GROUNDWATER QUALITY, HYDROGEOLOGY, AND AGRICULTURAL DRAINAGE WELLS
Floyd and Mitchell Counties, Iowa

Iowa Department of Natural Resources, Geological Survey Bureau
Technical Information Series 29, 1994, 63p.

R.D. Libra, D.J. Quade, G.R. Hallberg and J.P. Littke

ABSTRACT

Studies in Iowa, based on geological criteria, have defined areas where the underlying aquifers are susceptible to agriculturally-related contamination. In Floyd and Mitchell counties, stratigraphic relationships within the underlying Devonian System aquifers also influence the potential for groundwater contamination. Part of Floyd County contains a concentration of agricultural drainage wells (ADWs), which are potential contaminant delivery mechanisms. ADWs deliver tile drainage and/or surface runoff into the underlying Devonian carbonate strata. An estimated 92 ADWs are present in Floyd County, draining about 11,500 acres, or 4% of the county. Approximately 60% of the ADWs are less than 100 feet deep, while 4% appear to exceed 250 feet in depth. To evaluate the impacts of ADWs and stratigraphic relationships on groundwater quality, four complete core penetrations of the Devonian aquifers were drilled in Floyd and Mitchell counties. Three of these corehole sites were completed as four-piezometer nests to allow for hydrologic and chemical monitoring of specific aquifer intervals. Private wells located near ADWs were also monitored for ADW-related effects. Other private wells, located in analogous geologic settings but distant from ADWs were monitored as a control. Results of the coring and hydrologic analysis confirmed the Devonian strata form a three-part aquifer system in these counties. Results of hydrologic and water-quality monitoring suggest that ADWs do deliver agricultural contaminants— specifically nitrate and commonly-used corn and soybean herbicides— to groundwater. Monitoring at a well nest located 500 feet from a 300 foot-deep ADW showed significant ADW-related contamination at some depths, and negligible contamination at others. Some private wells located within 1 to 2 miles of concentrations of ADWs are impacted by the drainage wells, while others are not. The interplay between private well depth and construction, ADW depth, and stratigraphy is the likely cause of this variability. Discernible effects of ADWs are further limited to areas that have a low natural susceptibility to ag-contamination, including "deep bedrock areas" where the upper Devonian aquifer is overlain by greater than 50 feet of relatively low-permeability glacial deposits and/or shales. ADWs that penetrate the middle or lower Devonian aquifers also cause discernible water-quality effects within these units. Tritium age-dating of upper aquifer groundwater from deep bedrock areas, and groundwater from the middle and lower aquifers, indicates pre-1953 groundwater is present in these units in the absence of ADWs. In susceptible areas, the delivery of ag-contaminants by natural processes masks ADW effects. Tritium and nitrate data suggest denitrification may occur within the Devonian aquifers in the Floyd County ADW area.

INTRODUCTION

Previous investigations in Iowa have identified areas where surficially-derived contaminants, particularly nitrates and commonly used pesticides, have caused degradation of groundwater in regionally extensive bedrock aquifers (Hallberg and Hoyer, 1982; Hallberg et al., 1983, 1984, 1989; Libra et al., 1984, 1991). These studies showed that the depth to bedrock aquifers and the presence or absence of karst features have a major influence on the potential for surficial contaminants to reach groundwater. Geologic regions based on these criteria were delineated. In Floyd County and adjacent areas (Fig. 1), where Devonian system carbonate strata form a widely used multi-aquifer system, stratigraphic relationships influence the extent and degree of groundwater contamination (Witzke and Bunker, 1984; Libra et al., 1984). In addition, areas with significant numbers of agricultural drainage wells (ADWs) are present in parts of Floyd and other counties in northern Iowa. The ADWs have been shown to deliver tile-drainage water and surface waters containing nitrates, pesticides, and microbial contaminants to groundwater (Musterman et al., 1981; Baker and Austin, 1984). To further the evaluation of ADWs as a groundwater contaminant pathway in Floyd County, a refined understanding of the effect of the Devonian stratigraphy on the flow and quality of groundwater was needed. Therefore, four complete core penetrations of the Devonian sequence were drilled during the summer of 1984. The coring and subsequent geophysical logging of the coreholes allowed for detailed stratigraphic analysis and correlation of the Devonian strata. Packer tests were run in three of the coreholes to obtain in-situ information on aquifer hydraulics and the degree of inter-connection of individual aquifers, and to allow for water-quality sampling of individual aquifers. These three core sites were then completed as piezometer nests, to allow for continued monitoring of water levels and quality within individual aquifers and within the surficial, unconsolidated Quaternary System glacial deposits. These glacial deposits function as an aquitard, and overlie the Devonian aquifers. Previous reports (Libra and Hallberg, 1985; Witzke and Bunker, 1985) gave preliminary information on the drilling and testing phases. This report summarizes the monitoring at the piezometers, a network of tile lines, private wells, and surface-water sites. These data, and the results of previous investigations in this region (Libra et al., 1984), are used to evaluate the impacts of ADWs on groundwater quality in Floyd County.

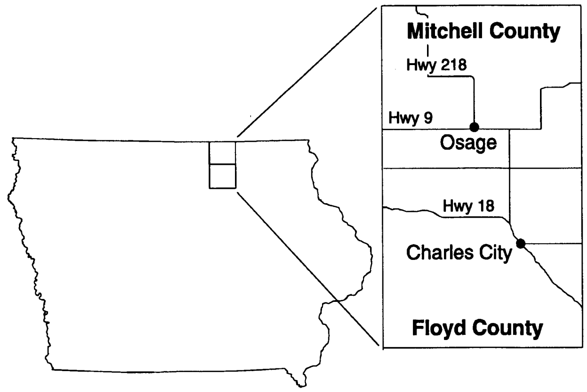

Figure 1. Map showing location of Floyd and Mitchell counties.

Hydrogeology and Agricultural Contamination of Groundwater

Previous investigations in eastern Iowa have helped define various relationships between hydrogeologic settings and the distribution of ag-contaminants in groundwater. These relationships are briefly discussed here. Hallberg and Hoyer (1982) defined geologic regions for 22 counties of northeastern Iowa based on varying susceptibilities to surficially-derived contamination. These regions include: 1) deep bedrock areas where more than 50 feet of low permeability glacial deposits and/or shales overlie the regional bedrock aquifer; 2) shallow bedrock areas where glacial deposits/shales are less than 50 feet thick; and 3) karst areas, where concentrations of sinkholes are present and depth to bedrock is generally less than 25 feet. Hallberg and Hoyer analyzed existing data from these regions and showed that deep bedrock areas were found to be largely protected from surficial contaminants, as generally indicated by low (<5 milligrams per liter [mg/L]) concentrations of nitrate (NO_3). Shallow bedrock and karst areas, in contrast, commonly showed measurable nitrate in wells up to 200 feet deep, and the median nitrate concentrations for shallow wells (<50 feet deep) exceeded half the 45 mg/L U.S. Environmental Protection Agency Health Advisory Level (USEPA-HAL) for nitrate. There was no significant difference in NO_3 concentrations between karst and shallow-bedrock areas, implying normal infiltration recharge as the dominant delivery mechanism in these susceptible geologic environments.

Monitoring in the Big Spring basin area of Clayton County (Hallberg et al., 1983, 1984, 1985, 1989; Libra et al., 1986, 1991) showed similar relationships. These investigations indicated that the highest nitrate concentrations are associated with infiltrating recharge water, rather than runoff to sinkholes. The Big Spring studies also documented the occurrence of pesticides in groundwater, showing that while the highest concentrations are caused by runoff to sinkholes, the greatest mass of the pesticide atrazine is delivered to groundwater via infiltration. Previous study of the Devonian carbonate aquifers in Floyd and Mitchell counties (Libra et al., 1984) also showed nitrates and pesticides delivered to groundwater by infiltrating recharge waters. High nitrate concentrations and detectable pesticides were present in karst and shallow bedrock areas, while there was a general lack of detectable nitrates or pesticides in deep bedrock areas. Data from the investigations cited above showed numerous wells from susceptible (shallow rock or karst) geologic environments with low to non-detectable nitrate concentrations and no detectable pesticides. The variability of ag-contaminants in domestic drinking water wells in three susceptible areas is related to several factors. The interplay of well and casing depths, stratigraphy, and the rates and direction of groundwater flow must all be considered when evaluating the impact of agriculture on groundwater quality under any specific situation or set of conditions (see Libra et al., 1984). For example low permeability units — aquitards or confining beds —may exist within a permeable sequence of rocks, dividing the sequence into multiple aquifers. A well that is located in a susceptible area but drilled and cased below a confining bed may produce water unaffected by ag-chemicals. In such an instance, sufficient time has not passed for recent recharge waters, carrying dissolved nitrates and pesticides, to reach the part of the well open to the aquifer. A nearby well drilled into the zone above the confining bed may produce water with significant amounts of ag-contaminants. In areas where no effective, extensive confining beds are present, deeper wells, with deep casings, may intercept older parts of the groundwater flow system, and also be unaffected by ag-contaminants. As the intensive use of chemical nitrogen fertilizers and pesticides is a relatively recent occurrence, older groundwater, in this context, infiltrated through the soil more than about 25 years ago.

Poor well construction, placement, and maintenance also contributes to the variability of agriculturally-related contaminants in the groundwater produced by private wells. Wells that are unsealed or have inadequate grout, cracked casings, or other defects may allow for inputs of shallow groundwater or surface runoff. This could lead to contamination if the well is located down-flow of a contaminant source. Surface runoff, though infrequent, could deliver relatively high concentrations of pesticides to a well but would commonly contain relatively low concentrations of nitrate (e.g., Hallberg et al., 1983). Shallow groundwater may contain variable concentrations of these contaminants. Both may contain coliform bacteria, and potentially, more harmful bacterial contaminants. If runoff and/or shallow groundwater inputs to a well are volumetrically significant, relative to the hundreds to thousands of gallons produced daily by typical rural wells, they may contribute to contamination of the produced water. A large majority of the private rural wells in eastern Iowa appear to be unaffected by runoff or shallow groundwater inputs, as evidenced by the general lack of nitrate or pesticide contamination of bedrock wells in geologically-protected deep bedrock regions (Hallberg and Hoyer, 1982; Hallberg et al., 1983, 1984; Libra et al., 1984).

Hydrogeologic Setting of Floyd and Mitchell Counties

The hydrogeology and water quality of the Devonian aquifers in Floyd and Mitchell counties were discussed by Libra and others (1984), and is briefly reviewed here. Figure 2 is a map of the geologic regions of Floyd and Mitchell counties. Libra and others (1984) added an additional area, termed incipient karst, to Hallberg and Hoyer's (1982) three original regions. The incipient karst areas are characterized by a very thin (<20 feet) cover of Quaternary material over the carbonate aquifers, and the presence of numerous shallow, closed depressions interpreted as "incipient" sinkholes. These areas occupy broad, low-relief, upland positions and are marked by high rates of infiltration. Using the geologic regions defined in Hallberg and Hoyer (1982), the incipient karst areas would be shallow bedrock areas, and therefore are considered susceptible to surficial contamination. Most of Floyd and Mitchell counties are shallow bedrock or incipient karst regions. The most extensive deep bedrock area occurs along the eastern part of the area (Fig. 2). This area marks the location of a bedrock channel, now filled primarily with low permeability glacial till. Depth to the bedrock aquifer locally exceeds 300 feet in this area. Another large deep bedrock area occurs in central Floyd County, on the upland divide between the Cedar and Shell Rock rivers.

Figure 3 shows the results of an inventory of private wells sampled for nitrate in December, 1982 (from Libra et al., 1984). Wells in the deep bedrock areas contained low and/or non-detectable concentrations of NO_3. Many wells within the other more susceptible areas showed relatively high (>20 mg/L) nitrate concentrations. Table 1 summarizes the results from monitoring a subset of these wells during water year (WY) 1983. Mean nitrate levels were less than 5 mg/L in deep bedrock areas, and exceeded 20 mg/L in other areas. Detectable concentrations of pesticides were rarely found in deep bedrock areas, while occurring at least once in over 70% of the wells in shallow bedrock and karst areas. However, numerous wells within the susceptible areas (Fig. 2) showed low to non-

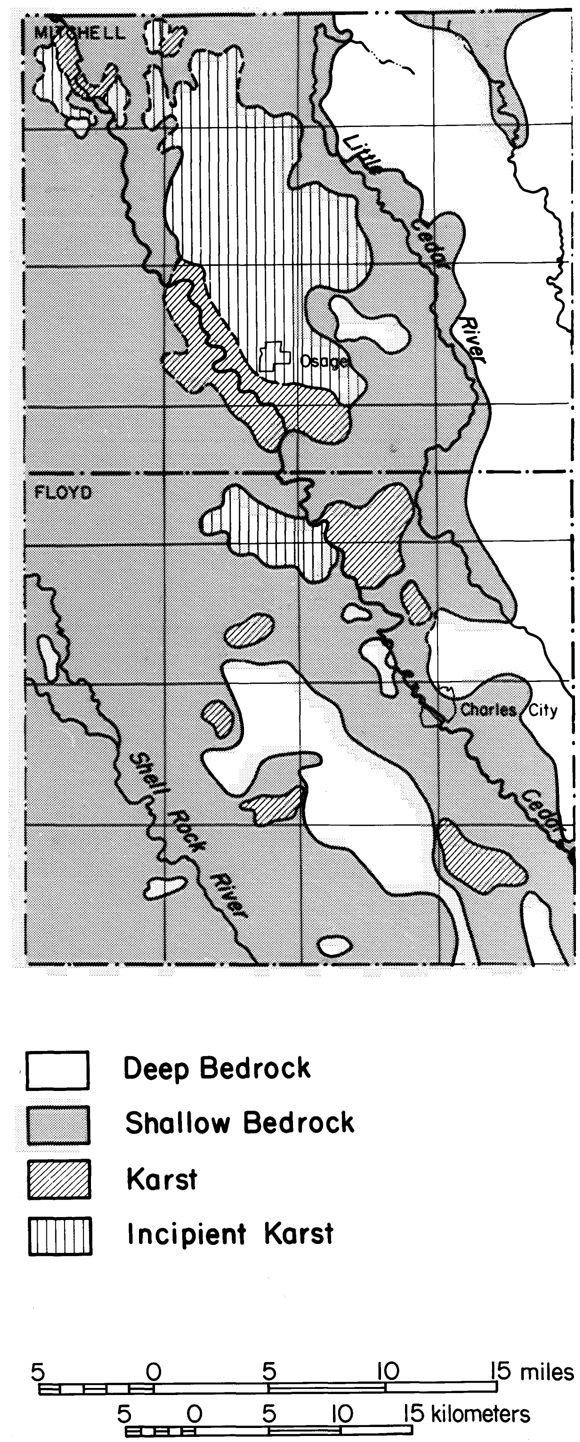

Figure 2. Map showing geologic regions for Floyd and Mitchell Counties (modified from Libra et al., 1984).

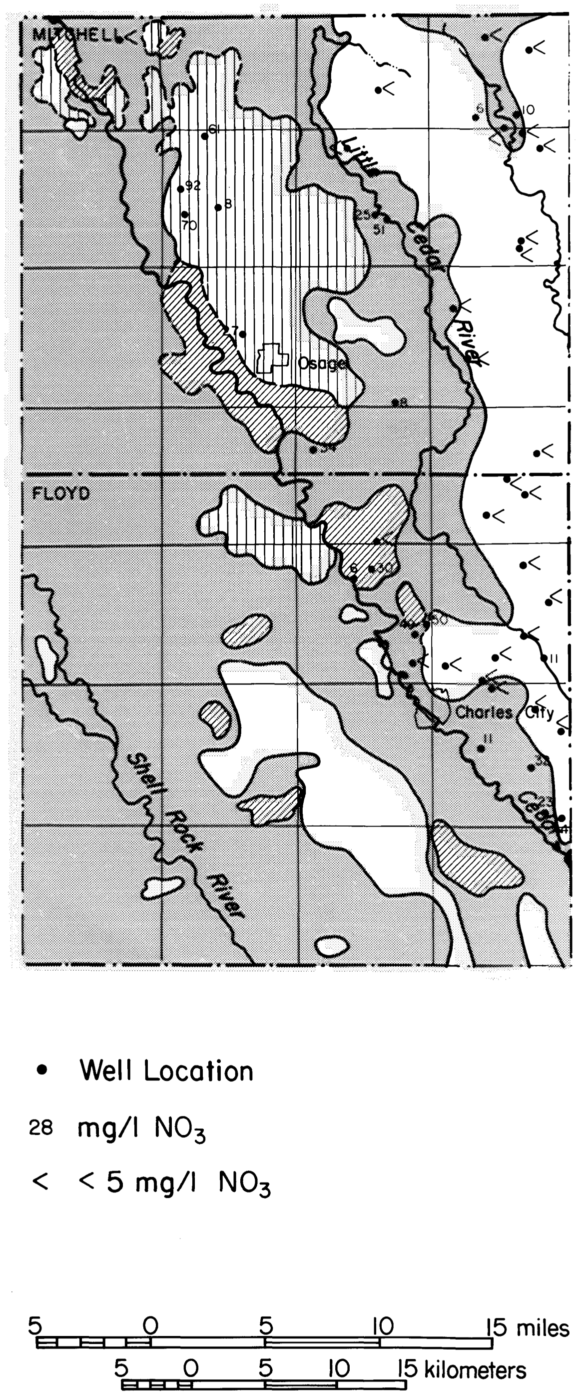

Figure 3. Nitrate concentrations in private wells, December 1982. Geologic regions also shown.

detectable levels of nitrates and pesticides. The factors outlined in the previous section (well and casing depth, presence or absence of extensive, effective confining beds, and position within the groundwater flow-system) are the major cause of this variability within the susceptible areas.

Recent stratigraphic and hydrogeologic studies (Witzke and Bunker, 1984; Witzke et al, 1988; Libra et al., 1984) suggest the Devonian strata in Floyd-Mitchell counties are best described as a three-part aquifer system with the major water-producing carbonate strata separated by intervening shales and shaley carbonates. Figure 4 is an east-west cross-section of the Devonian strata. Three major aquifers are noted on Figure 4, and these are informally termed the "lower," "middle," and "upper" aquifers for purposes of this report. The Spillville Formation forms the lower aquifer, and the Basset Member of the Little Cedar Formation acts as the middle aquifer. The upper aquifer consists of the Hinkle and Eagle Center Members of the Little Cedar Formation, and the Coralville, Lithograph City, and Shell Rock Formations. Major confining beds include the Chickasaw Shale Member of the Little Cedar Formation and the Pinicon Ridge Formation. These confining units are believed to be fairly extensive in north central Iowa (Witzke and Bunker, 1985). Limited water quality sampling of wells completed below the Chickasaw shale generally showed no detectable nitrates or pesticides (Libra et al., 1984). A composite potentiometric surface of the Devonian aquifer was mapped by Horick (1984; see Libra et al., 1984, p. 13), using available water-level data from all wells completed in the Devonian aquifers. Sparsity of well data and lack of stratigraphic control for much of the available data does not allow for a detailed representation of 3-dimensional head distributions. However, the general trends shown by the mapping indicate regional flow from upland positions to the large streams and rivers, which act as discharge zones. Existing vertical head data in upland areas and in major river valleys, though limited, support this conclusion (Munter, 1980; Libra et al., 1984).

Table 1. Summary statistics for private wells, Floyd and Mitchell Counties, water year 1983.

GEOLOGIC REGIONS Wells	No. of Samples	Nitrate mg/L Mean	Nitrate mg/L Range	Coliform Bacteria MPN Median	Coliform Bacteria MPN Range
Deep	44	<5	0 - 5	0	0 - 9.2
Shallow	66	22	<5 - 58	0	0 - 16+
Karst	44	41	16 - 119	5.1	0 - 16+
Incipient Karst	40	68	25 - 132	0	0 - 16+

Agricultural Drainage Wells

Agricultural drainage wells (ADWs) are concentrated in parts of Floyd County. ADWs are wells drilled with the expressed purpose of removing excess drainage water from cropped agricultural fields, and "inject" (using gravity) this water into the underlying aquifers. In Iowa, only fractured carbonate aquifers are used as ADW injection zones (Musterman et al., 1981). ADWs are generally cased to bedrock, and are uncased through the total depth of bedrock penetrated. In essence, ADWs function as artificial sinkholes. Currently, ADWs are registered with both the Iowa Department of Natural Resources (IDNR) and the USEPA. There are 75 state-registered ADWs in Floyd County, with reported locations shown in Figure 5. A merged version of the state and federal registration lists suggests there are 92 ADWs in the county (Libra and Hallberg, 1993). Verification of the actual number of ADWs is limited by the location of many wells in the middle of fields, below fields (i.e., with no surficial expression) or beneath roads (Floyd Co. Engineers Office, personal communication), where they cannot be seen. Some locations may not be exact, some of the registered ADWs may be plugged and no longer accept drainage and several likely represent sinkholes that receive tile drainage. However, the locations serve to delineate the area where ADWs are concentrated. This area occupies the upland divide between the Shell Rock and Cedar rivers in portions of shallow and deep bedrock areas. Registration information concerning locations, depths, and areas drained was supplied by ADW owners, and only some of this information has been field verified. Based on the registration data, roughly 11,500 acres, or 4% of the county, drains to ADWs. About 60% of the ADWs are less than 100 feet deep, and only 4% are greater than 250 feet deep. An estimated 5% of the wells appear to penetrate the Chickasaw Shale confining bed (Libra and Hallberg, 1993).

A previous study of the impact of the Floyd County ADWs on groundwater quality included weekly sampling of the tile drainage delivered to two ADWs during the period October-December 1980 (Musterman et al., 1981). Nitrate concentrations averaged 41 mg/L at one site and 61 mg/L at the other. A one-time sampling for pesticides (November 1980) detected cyanazine, alachlor, and atrazine, at concentrations ranging from 0.1 to 0.5 µg/L. Samples were not collected from private wells in the area. Baker and Austin (1984) and Baker and others (1985) modeled surface and subsurface (i.e., tile drainage) drainage to ADWs, and groundwater response to ADW recharge, in Humboldt County, Iowa. They also sampled water delivered to ADWs and water produced by private domestic wells in nearby areas. They found relatively high (>45 mg/L) nitrate concentrations in many wells located within 1-2 miles of ADW clusters, in areas where depth to bedrock exceeds 50 feet, and where low (<5 mg/L) nitrate concentrations would be expected (Hallberg and Hoyer,

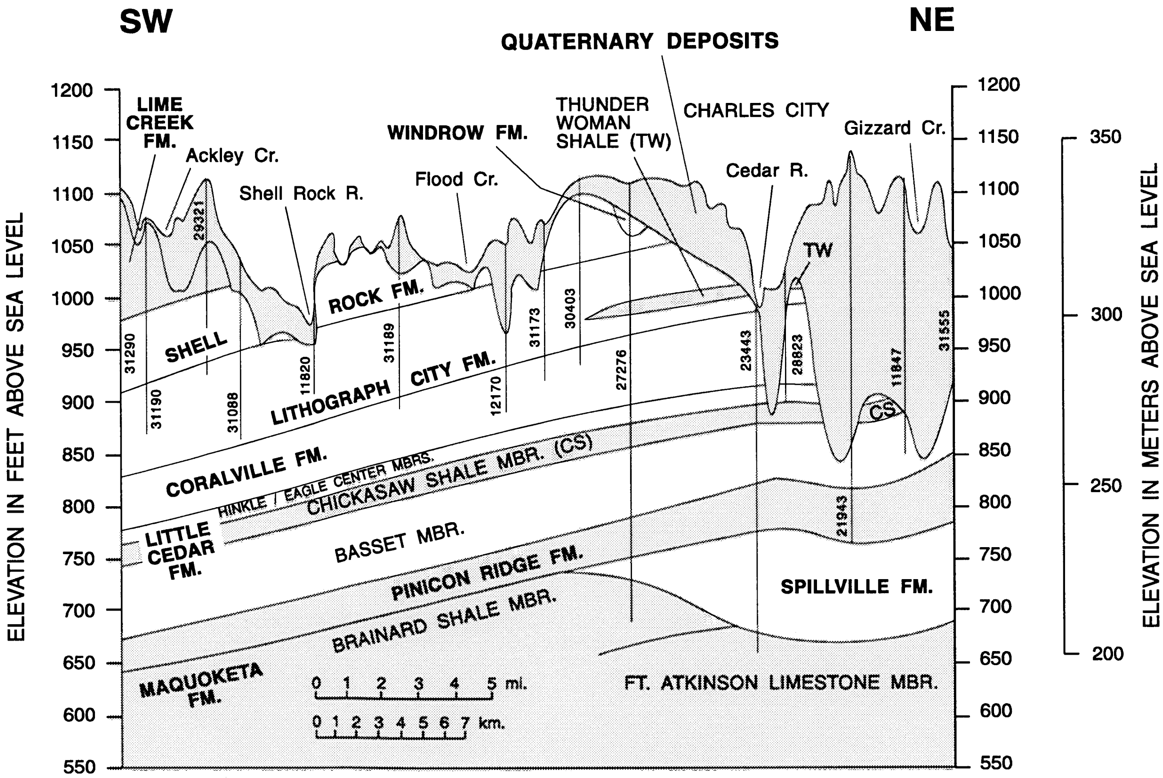

Figure 4. Geologic cross-section of the Devonian system in Floyd and adjacent counties (from Libra and Hallberg, 1993).

1982). Other wells located close to ADWs showed lower nitrate concentrations. Again the interplay between private well casing depths and the position of more permeable rock zones likely explains this variability. Another factor is the depths of the involved ADWs. The general conclusion of Baker and Austin (1984): the ADWs indeed adversely affect groundwater quality, but effects vary greatly and are difficult to predict locally.

The present study was conducted to further evaluate the impact of the ADWs on groundwater quality in Floyd County. The evaluation included several activities: 1) drilling continuous cores of the Devonian rocks in Floyd and Mitchell counties to allow for confirmation and refinement of the stratigraphic framework presented by Witzke and Bunker (1984); 2) packer testing of the coreholes to evaluate aquifer response and confining-bed effectiveness; 3) installation of nested piezometers in the coreholes to allow for the measurement of potentiometric evaluations (i.e., heads) and sampling for water-quality parameters within individual aquifers; 4) sampling of private domestic wells in the ADW area for various water quality parameters; and 5) sampling of private domestic wells located away from ADWs, but in geologically similar environments, to provide a control for the assessment. The sampling of private wells included an initial inventory of numerous wells, and the subsequent monthly sampling of a subset of the wells. This monthly sampling network included several tile lines and streams, providing additional data on contaminants in the hydrologic system. Several piezometers, tile lines, and private wells were sampled for tritium so that groundwater ages could be examined.

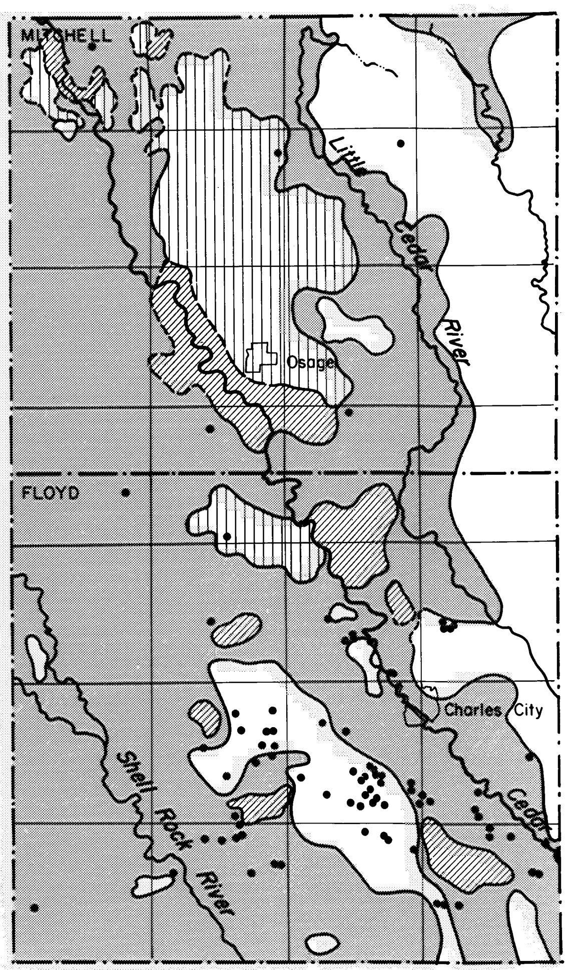

Figure 5. Location of registered ADWs, Floyd County. Geologic regions also shown.

COREHOLE SITES, PACKER TESTING, AND PIEZOMETER CONSTRUCTION

Site Locations

Figure 6 gives the location of three of the corehole sites with respect to the geologic regions mapped in Floyd and Mitchell counties. Site #1 is in a shallow bedrock area on the north fringe of an open karst area. Site #2 is in a generally shallow bedrock area, although depth to the water-yielding carbonate bedrock is 45 feet at the site. Site #3 is in a deep bedrock area where concentrations of ADWs are known to occur; the closest ADW is approximately 500 feet from Site #3. (Site #4 lies in a shallow bedrock region to the west of the mapped area, and was cored to provide stratigraphic control. It was not packer tested or completed as a piezometer nest.)

Geological Analysis

Geological analysis of the core material has supported and allowed the refinement of the stratigraphic framework for the Devonian aquifers originally presented by Witzke and Bunker (1984) and reported by Witzke et al., (1988). The stratigraphic terminology of the latter authors will be used in this report. Graphic geologic logs of the cores are given on Figures 7 through 10. The "lower" aquifer, the Spillville Formation, is present at all sites. The Spillville is 60-70 feet thick at Sites #1 and #2, and 25 and 45 feet at Sites #3 and #4, respectively. Thinning of the Spillville from Sites #1 and #2 towards Sites #3 and #4 is consistent with the framework of Witzke and Bunker (1984), who showed that the Spillville Formation pinches out to the south and west in the area. At all sites the Spillville Formation is overlain by the Pinicon Ridge Formation, a suspected confining bed consisting of 30-40 feet of shale, carbonates, and shaley carbonates. Driller's observations, core analysis, and geophysical logging indicate that at Site #3 the Spring Grove Member of the Pinicon Ridge (Fig. 10) is a broken or brecciated, possibly

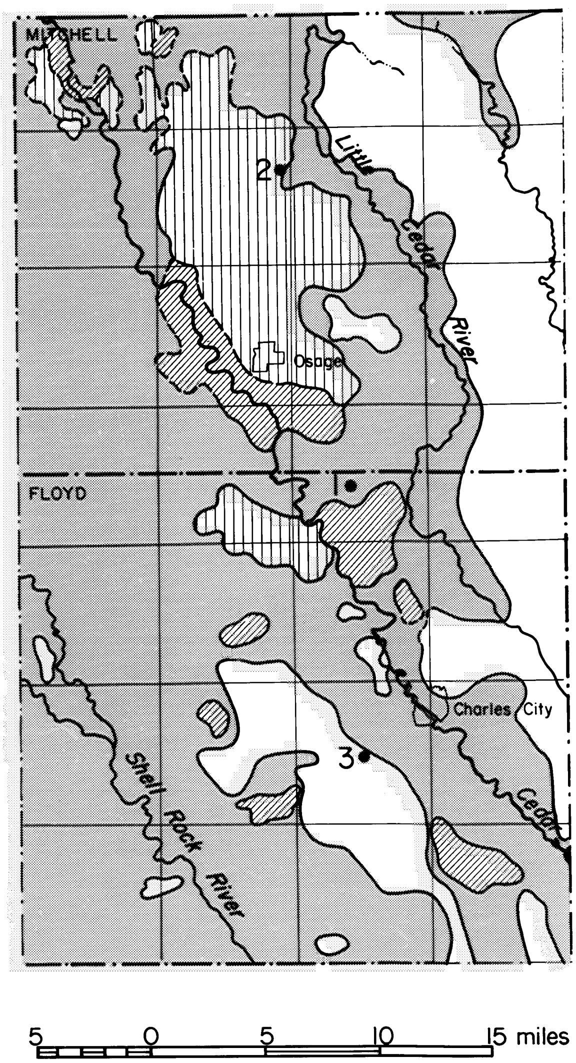

Figure 6. Location of corehole sites. Geologic regions also shown.

cavernous zone. Where present, the broken nature of these rocks may change their hydrologic role from a confining bed to an aquifer. The middle aquifer (Figs. 7-10), the Basset Member of the Little Cedar Formation, is present at all sites and varies in thickness from 60 to 75 feet. The middle aquifer is overlain and confined by the Chickasaw Shale, which has a thickness of about 20 feet at all sites (this unit was informally termed the "Rapid" shale in reports about the LaBounty waste site at Charles City (i.e., Munter, 1980)). The overlying Devonian carbonates, consisting of the Eagle Center through the Shell Rock Formation, are grouped together as the upper aquifer, because no regionally persistent confining bed is present within these strata. However, shales or shaley carbonate horizons are present locally and may act to subdivide the upper aquifer into relatively isolated hydrologic units in restricted areas. Of these, the Thunder Woman Shale Member of the Lithograph City Formation (Fig. 10) appears to be the most extensive. Thickness of the upper aquifer varies from 120 to 180 feet at the core sites (Figs. 7-10).

Packer Tests

Packer tests were conducted on individual aquifers at each site, as identified from the core analysis, geophysical logging, and driller's observations. The tests were run during the week of 9/10/84. Packer tests are used to hydraulically evaluate individual aquifers. Two rubber inflatable packers were used to isolate individual aquifers for testing. A 5-horsepower submersible pump placed between the packers was used to stress each isolated aquifer. Each zone was pumped for a minimum of one hour. At the end of each pumping period, water samples were collected and analyzed for major ions and commonly-used pesticides (see Libra and Hallberg, 1985). Tested intervals are shown on Figures 8 through 10. During the packer tests heads were monitored, using airlines, within the aquifer being pumped, and in the zones immediately above and below. Monitoring of heads above and below the pumped zone insured that the packers had properly inflated and isolated the pumped zone. This monitoring also allowed for an evaluation of the confining beds that separate the aquifers. No head losses occurred outside the pumped zone during testing, indicating the confining beds effectively isolated the aquifers, under the conditions tested (one to two hours of pumping at low-to-moderate rates). Quantitative analysis of leakage through the confining beds would have required significantly longer pumping periods and/or higher pumping rates.

Results from monitoring of drawdowns and pumping rates are given in Table 2; these data are

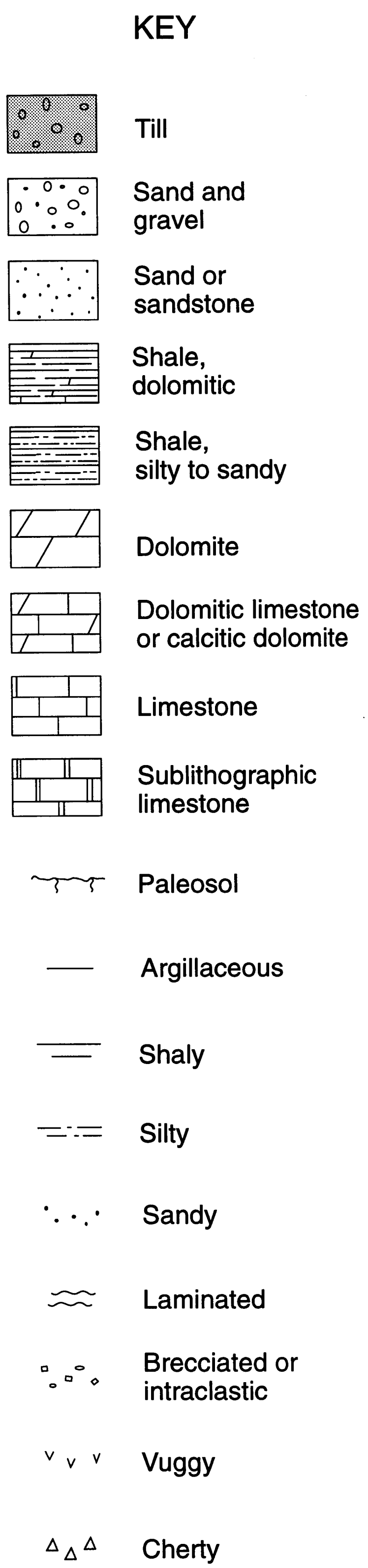

Figure 7. Key to geologic logs, Figures 8 through 10.

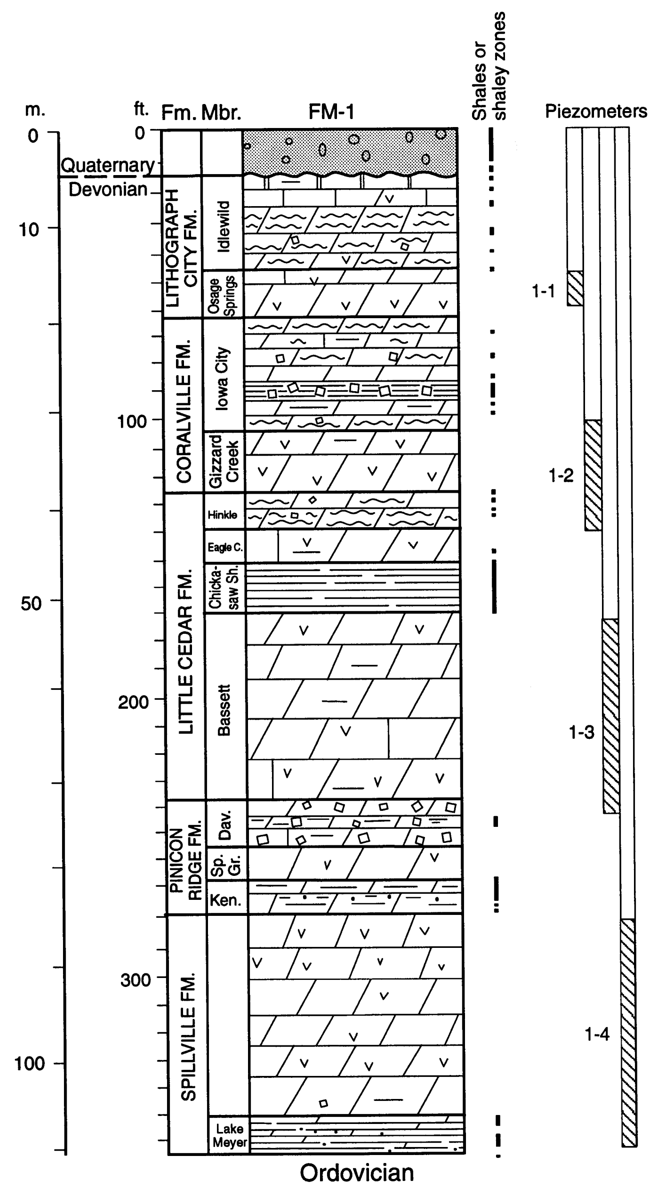

Figure 8. Geologic log, packer-test intervals, and piezometer completions, Site #1.

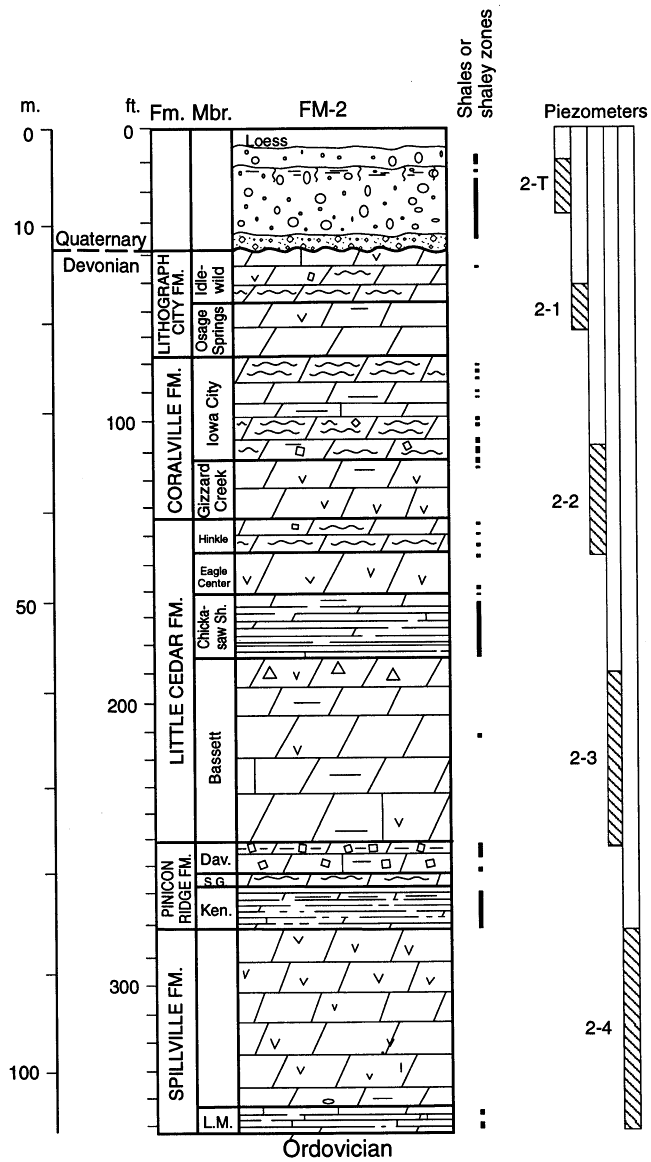

Figure 9. Geologic log, packer-test intervals, and piezometer completions, Site #2.

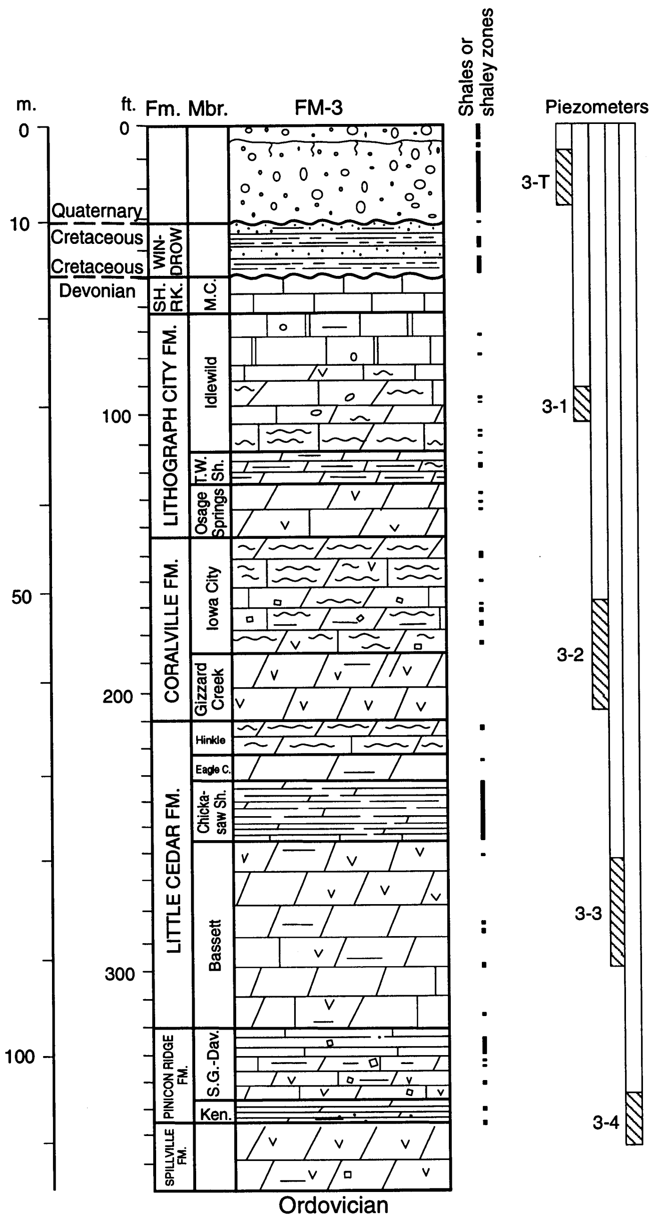

Figure 10. Geologic log, packer-test intervals, and piezometer completions, Site #3.

Table 2. Results of packer tests at corehole sites.

INTERVAL	DEPTH (ft)	PUMPING RATE (gal/min)	DRAW-DOWN (ft.)	SPECIFIC CAPACITY (gal/min/ft drawdown)	TRANS-MISSIVITY (gal/day/ft)	HYDRAULIC CONDUCTIVITY (gal/day/ft2)
			SITE # 1			
1-1	138 - and above	17	62.4	0.27	200	*
1-2	165 - 245	68	9.2	10.65	15,000	190
1-3	275 - 355	65	27.7	2.35	13,000	40
			SITE # 2			
2-1	110 - and above	73	2.0	36.1	62,000	690
2-2	110 - 145	55	49.7	1.11	1,400	40
2-3	145 - 180	64	25.4	2.52	3,500	100
2-4	175 - 250	41	97	0.42	500	6
2-5	275 - 350	33	111	0.30	300	4
			SITE # 3			
3-1	175 - and above	30	79.7	0.38	300	*
3-2	170 - 245	65	6.9	9.4	15,000	195
3-3	245 - 320	60	*	>60	>105,000	>1,420
3-4	320 - 380	45	*	>45	>78,000	>1,300

* No measurable drawdown

also expressed as specific capacities. Specific capacities of the test zones varied from less than 0.3 to over 60 gallons per minute per foot of drawdown (gpm/ft). Such variance is typical in many carbonate aquifers, where most of the permeability is secondary in the form of fractures, joints, and bedding planes that have been solutionally enlarged to varying degrees. The highest specific capacities recorded during the tests were from the middle and lower aquifers at Site #3 (Fig. 10), where no drawdown was noted during testing. These aquifers showed moderate to low specific capacities at Sites #1 and #2. The higher specific capacities of the units at Site #3 may result from a number of factors. First, a higher degree of fracturing and solutional activity may be present within these units at Site #3. Second, driller's observations, geophysical logs and core analysis all indicated a very open, broken, cavernous zone within the Spring Grove Member of the Pinicon Ridge Formation at Site #3 (Fig. 10). Previous investigation had suggested that the Pinicon Ridge should act as a confining bed because of the presence of shales in the upper and lower parts of the formation, the Davenport and Kenwood members, respectively (Witzke and Bunker, 1984; Libra et al., 1984). At Site #3, however, the cavernous nature of the Spring Grove Member suggests it is a highly productive zone and may have contributed water to the packer tests on the middle and lower aquifers. Therefore, the specific capacity data from these tests may not be strictly applicable to the middle and lower aquifers, but the data does indicate that highly productive aquifers occur below the Chickasaw Shale at Site #3. Moderately high specific capacities, varying from 10 to 40 gpm/ft, also occurred in the middle aquifer at Site #1; and in parts of the upper aquifer at Sites #2 and #3. Specific capacities for all other horizons were less than 2.5 gpm/ft, with the lowest, 0.3 gpm/ft, from the upper aquifer at Site #1. Site #1 is near the edge of a karst area where open sinkholes, caves, springs, and other indications of secondary permeability occur. A well intersecting zones of secondary permeability should have a very high specific ca-

Table 3. Estimated hydrologic parameters for Devonian Aquifers, Charles City area.

Well	Location	Aquifer	Open Interval Elevation	TRANS-MISSIVITY (gal/day/ft)	HYDRAULIC CONDUCTIVITY (gal/day/ft2)
Charles City #5	NW NE NE 1-16-95	Middle	858-826	67,000	2,080
Charles City #7	NW NE NE 1-16-95	Middle	868-828	88,000	2,200
Salsbury Labs #4	? 11-16-95	Middle-Lower	?	5,000	30
Sherman Nursery	SW SE NE 11-16-95	Upper	938-890	23,000	480
Salsbury LaBounty Site # 2	SW SW 7-15-95	Upper	987-962	18,000	720
Charles City Creamery	SE NE SE 1-16-95	Upper	901-833	13,000	235
F/M # 3-1	SW NE 22-16-95	Upper	1025-930	300	---
F/M #3-2	SW NE	Upper	930-855	15,000	190
F/M #3-3	SW NE 2-16-95	Middle	855-780	<106,000	<1,400
F/M #3-4	SW NE 22-16-95	Lower	700-720	<78,000	<1,300

pacity relative to that measured for the upper aquifer at Site #1. This indicates that the core hole at Site #1 is not in direct hydrologic connection to the adjacent karst system.

The specific capacity data were used to estimate transmissivities and hydraulic conductivities, using the method of Walton (1962). Estimated transmissivities vary from 200 to over 100,000 gallons per day per foot (gpd/ft). Hydraulic conductivities vary from about 5 to 1400 gallons per day per square foot (gpd/ft^2). All measured and estimated hydrologic parameters vary over 3 orders of magnitude. Existing information, from near the test sites, was examined to evaluate the applicability of the packer test data to the surrounding area. No wells with reliable production-drawdown data, geologic data, and well-completion information are located in the area around Sites #1 and #2. More information is available near Site #3, because it is near Charles City, the largest community in Floyd and Mitchell counties. Table 3 summarizes estimated transmissivities and hydraulic conductivities from existing municipal, industrial, and monitoring wells in the Charles City area completed within the Devonian sequence. These estimates were derived using the same method (Walton, 1962) applied to the packer test data. Results from Site #3 are included for comparison. While these estimates show the typical variability expected for carbonate aquifers, most data suggest that the lower and middle aquifers have relatively high permeabilities, while overlying units have moderate to low permeabilities.

Piezometer Construction

Following the packer tests, piezometer nests were completed in the coreholes. Completed intervals and piezometer designations are given in Figures 8 through 10. The three deepest piezometers at

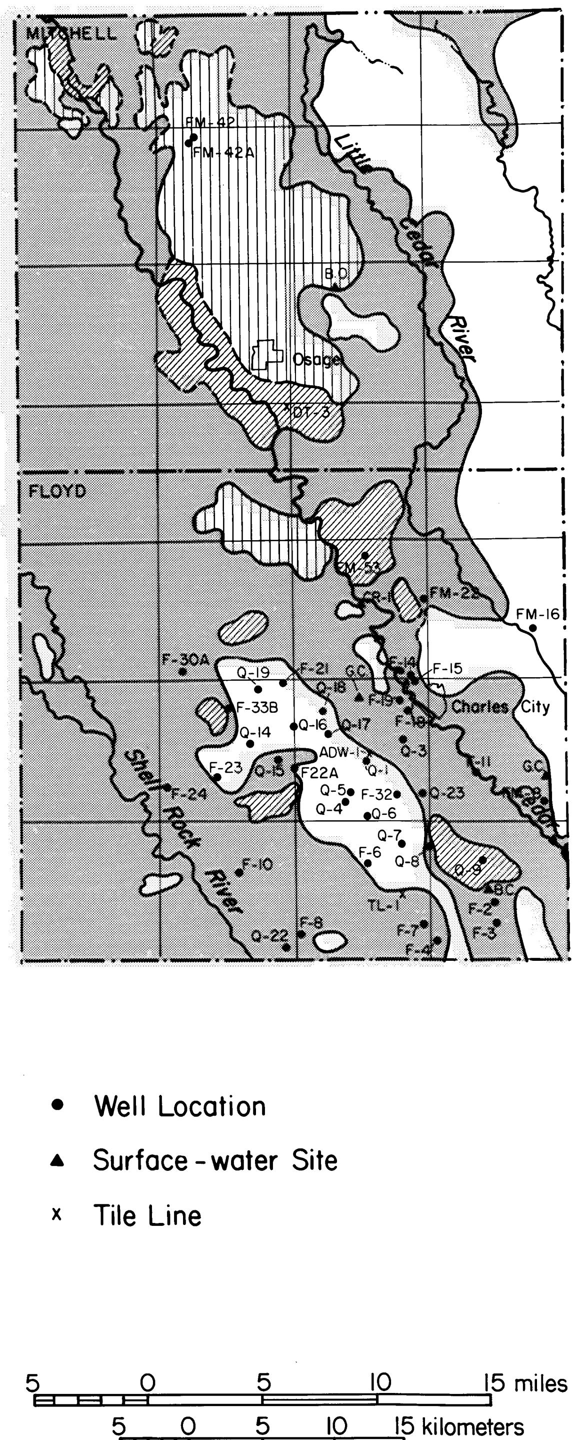

Figure 11. Location of sampling sites, November 1984 inventory. Geologic regions also shown.

each site were constructed with 1.5" I.D. PVC, the uppermost bedrock piezometers with 1.0" I.D. PVC; and the till piezometers at Sites #2 and #3 with 2.0" I.D. PVC. All the PVC pipe used was flushed-jointed and threaded, so that no glues or cements were used. The piezometers were gravel packed opposite the slotted intervals, and bentonite and cement were used to isolate the intervals. The piezometers were developed by air-lifting.

SAMPLING SITE INVENTORY

An inventory of 41 private wells, 2 tile lines, and 2 surface streams from the Floyd County ADW area was carried out in November, 1984; locations of all are shown on Figure 11. Water samples were collected for bacterial and nitrate analysis. Well placement and construction were examined, and potential point sources of contamination (pesticide and fertilizer handling and storage areas, septic systems, manure storage areas, etc.) were noted. Several sites that had been sampled by Libra and others (1984) were re-sampled during the inventory to allow for comparison (all samples collected during this investigation were analyzed by the University Hygienic Laboratory, except as noted. Sampling procedures and analytical methods are given in Libra et al., 1984). Table 4 gives the results of the inventory, and Table 5 summarizes these results by geologic region. The median nitrate concentration for all wells sampled was 22 mg/L; for deep bedrock wells, <5 mg/L; and for shallow bedrock (and karst) wells, 29 mg/L. Previous reports showed similar results (Hallberg and Hoyer, 1982; Hallberg et al., 1983; Libra et al., 1984), with higher nitrate concentrations found in shallow bedrock and karst areas, relative to deep bedrock areas. However, five of the fourteen deep bedrock wells contained greater than 5 mg/L nitrate. Figure 12 shows the distribution of nitrate concentrations in private wells from the inventory, superimposed on the geologic regions map. The deep bedrock wells that have detectable nitrates are generally located near clusters of ADWs (Fig. 5) and may reflect the input of high-nitrate water via the ADWs. However, other factors, such as lateral groundwater flow from susceptible areas into the deep bedrock areas, and sparsity of sufficient mapping data makes conclusions based on the inventory results tentative.

Samples from tile lines and surface water contained nitrate concentrations generally similar to those found in previous studies in Iowa (Hallberg et al., 1983, 1984; Libra et al., 1984) during late fall periods. Note that tile line ADW-1 (Table 4) contained only 18 mg/L nitrate. This tile line empties into a 305-foot deep ADW located about 500 feet from corehole Site #3. This site was also sampled by Musterman and others (1981). Coliform bacteria were detected at 32% of the inventoried wells (Table 5). Fourteen percent of the deep bedrock wells and 41% of the shallow bedrock wells had bacterial problems.

Following the initial inventory, a subset of the inventory sites were selected as a sampling network (two other wells, Q-22 and Q-23, were added to the network). The network was chosen to give geographic coverage of the study area; all network sites are shown on Figure 11. These wells, surface waters, and tiles, along with the piezometer sites and several previously sampled sites (Libra et al., 1984) were sampled monthly during the period December 1984 through May 1986. Nitrate concentrations were analyzed monthly, with pesticide and nitrogen series (nitrate-N, ammonia-N, organic-N) analyses performed less frequently. About 720 nitrate and 470 pesticide samples were analyzed during the project. The potentiometric elevations of the Devonian aquifers were measured monthly at the piezometer sites. Results of the water quality and potentiometric monitoring, climatic data from local weather stations, and discharge data for the Cedar River at Charles City, are presented in the following sections.

Table 4. Results of water-quality inventory data, November 1984.

Site No.	NO3 mg/L	Bacteria MPN
	Karst Area Wells	
FM-22	46	0
FM-53	22	16+
Q-8	29	16+
Q-9	39	16+
	Shallow Bedrock Wells	
FM-8	22	0
F-2	70	0
F-3	30	0
F-4	30	0
F-7	<5	0
F-8	101	9.2
F-10	<5	0
F-11	24	5.1
F-14	<5	0
F-15	<5	0
F-18	32	5.1
F-19	13	0
F-22A	<5	0
F-23	29	0
F-24	26	16+
F-30A	48	0
F-32A	16	16+
F-33B	51	16+
Q-3	<5	0
Q-14	12	0
Q-15	56	5.1
	Deep Bedrock Wells	
FM-16	<5	0
F-6	<5	0
F-21	<5	0
F-32	16	16+
Q-1	6	0
Q-4	<5	0
Q-5	<5	16
Q-6	<5	0
Q-7	<5	0
Q-14	12	0
Q-16	26	0
Q-17	67	0
Q-18	<5	0
Q-19	<5	0
	Surface Sites	
Cedar River	22	16+
Goose Creek	7	16+
Burr Oak	28	16+
Beaver Creek	50	16+
Wildwood Creek	9	16+
	Tile Lines	
TL-1	41	16+
DT-3	63	16+
ADW-1	18	16+

HYDROLOGIC MONITORING

Climatic Data

Table 6 summarizes climatic data for Charles City (Floyd Co.) and Osage (Mitchell Co.), for the December 1984 - May 1986 period of study. Climatic data were obtained from the Iowa Department of Agriculture and Land Stewardship-Office

Table 5. Summary of private well inventory data by geologic region.

	Nitrate, mg/L				Bacteria, MPN			
Number	Q1	Median	Q3	Range	Q1	Median	Q3	Range
				ALL WELLS				
41	<5	12	33	<5 - 101	0	0	5.1	0 - 16+
				DEEP BEDROCK WELLS				
14	<5	<5	12	<5 - 67	0	0	0	0 - 16+
				SHALLOW BEDROCK AND KARST WELLS				
27	<5	29	39	<5 - 101	0	0	5.1	0 - 16+

of the State Climatologist. Temperatures for the period were near normal, excepting October 1985 - February 1986, when temperatures were below normal. Also, several anomalous precipitation trends occurred. For example, May-August 1985 was dry, with precipitation at Charles City being only 57% of the long term average (based on 1951-1980 data). During the same period in 1986, precipitation was about average. September was very wet in both 1985 and 1986, with precipitation amounts nearly three times the average. The late-fall and winter months were wetter in 1985-86, relative to 1984-85. This, combined with the below normal temperatures during October 1985 through February 1986, resulted in significantly more snow accumulation and a significantly greater spring snow melt in 1986, than in 1985. In sum, more precipitation water was available to become ground-water and surface water recharge during March-August 1986 than during much of the preceding study period.

Cedar River

Discharge data for the Cedar River at Charles City were obtained from the U.S. Geological Survey. The drainage area of the Cedar River at Charles City is 1504 square miles and the average discharge for the twenty-one year period ending in 1985 was 732 cubic feet per second (cfs). Comparison of the Charles City discharge record (1964-1980) with downstream stations that have a longer period of record suggests an average long-term discharge of about 500 cfs (Tom Dahl, USEPA, personal communication). Average discharge during WYs 1985 and 1986 was 425 cfs and 740 cfs, respectively. Figure 13 shows the discharge hydrograph for the Cedar River, along with daily precipitation at Charles City. In general, precipitation during periods of low evapotranspiration and above-freezing temperatures, such as October through December, and March through June, cause sharp increases in discharge. Melting of the snow accumulated during winter months contributes significantly to early spring discharge. Rains falling during the July-September growing season generally cause lesser increases. The sharp increase in discharge immediately following precipitation events results from surface runoff, in-channel precipitation, and subsurface storm flow. The greater discharges persisting between precipitation events result from increased groundwater discharge to the Cedar River and its tributaries. Increased groundwater discharge is caused by rising potentiometric levels related to precipitation that recharged the carbonate aquifers and overlying deposits. Rising potentiometric elevations impose steeper hydraulic gradients between the carbonate aquifers and the river, causing increased groundwater discharge to the river. The Cedar River discharge record for the study period of interest reflects the seasonal climatic factors discussed above. During March-August 1986 particularly high peak discharges occurred, related to significant surface runoff, and generally high baseflows resulting from significant groundwater inputs. By contrast, the hydrograph for the March-August 1985 indicates lesser amounts of both surface runoff and groundwater inputs.

Potentiometric Monitoring

Figures 14 through 18 show potentiometric elevations for the Devonian aquifers at the bedrock piezometers and within the overlying tills at Sites #2 and #3. Note that the general seasonal trends of potentiometric elevations are similar to the discharge hydrograph from the Cedar River (Fig. 13), indicating the interrelationship of groundwater and surface water in the area. Rising groundwater levels indicate recharge water has, via infiltration or other processes, reached and raised the water table surface and that the rate of recharge exceeds the rate of groundwater discharge to streams and rivers. The potentiometric surface of deeper, confined aquifers rise in response to the pressure increase caused by the addition of recharge water. Falling groundwater levels indicate that groundwater discharge exceeds recharge, with a net loss of groundwater in storage within the aquifer.

Potentiometric elevations decrease with depth at all sites, indicating that these sites are located in recharge areas, where the potential for downward groundwater movement exists. Maximum and minimum downward gradients measured within the bedrock sequence are given in Table 7. Maximum/minimum gradients are similar at all sites, except for Site #3, where occasionally no potential for downward movement exists. While the potential for downward groundwater movement usually exists at all sites, the presence of confining beds between the aquifers drastically limits the actual volume of water transferred downward. Comparison of water levels within, and depth to the upper aquifer indicates it is confined at Site #2, but unconfined at Site #1 and Site #3. Unconfined conditions were expected at Site #1, where the

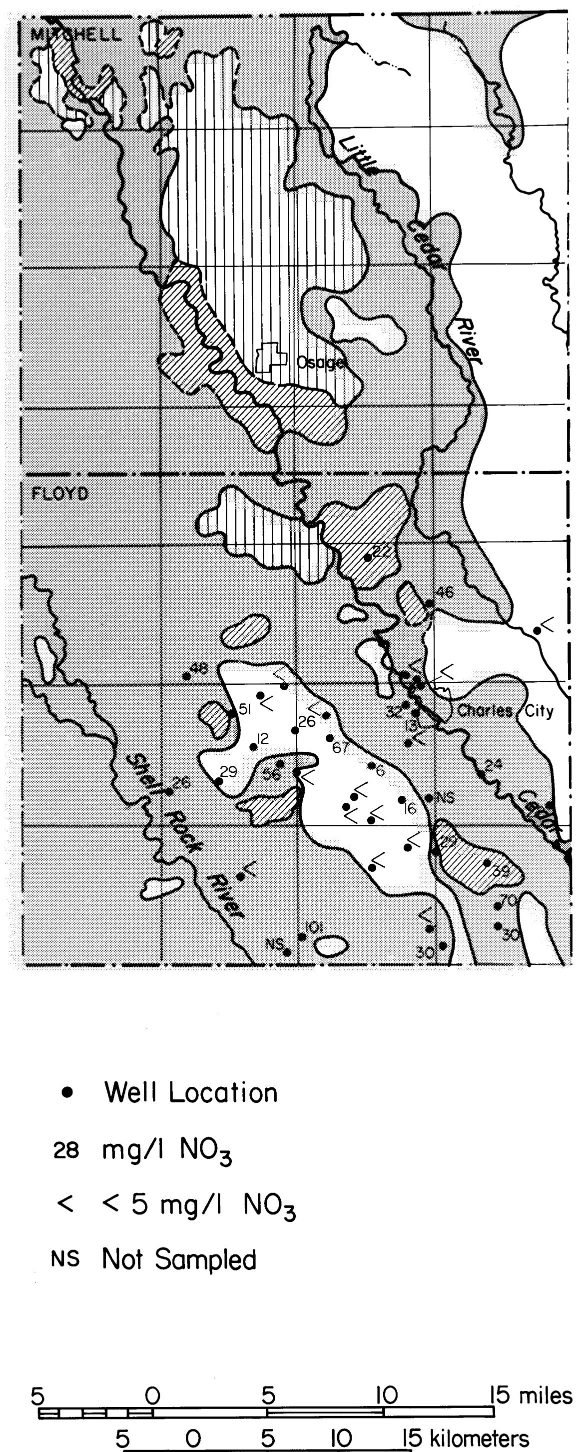

Figure 12. Nitrate concentrations from wells sampled in the November 1984 inventory. Geologic regions also shown.

Table 6. Monthly climatic data for Charles City and Osage, Iowa.

Water Year	CHARLES CITY Total Precip	Departure From Norm	% of Norm	Avg Temp	Long Term Avg Temp	OSAGE Total Precip	Departure From Norm	% of Norm	Avg Temp	Long Term Avg Temp
Oct-84	4.43	2.11	191	53	52	4.91	2.67	219	52	51
Nov-84	3.12	1.68	217	36	36	2.45	1.07	178	35	35
Dec-84	1.39	0.37	136	23	22	1.24	0.20	119	22	21
Jan-85	0.59	-0.25	70	14	14	0.71	-0.17	81	13	13
Feb-85	1.13	0.21	123	18	21	0.60	-0.32	65	17	20
Mar-85	2.30	0.13	106	38	32	1.91	-0.33	85	37	31
Apr-85	2.84	-0.50	85	54	48	3.82	0.87	129	53	47
May-85	1.56	-2.54	38	64	60	1.36	-2.55	35	63	59
Jun-85	5.45	0.78	117	66	69	3.94	-0.54	88	66	68
Jul-85	0.80	-3.41	19	72	73	1.50	-2.93	34	72	72
Aug-85	3.21	-0.92	78	68	71	3.22	-1.31	71	67	70
Sep-85	8.16	4.56	227	62	62	10.35	6.97	306	62	61
Annual Summary	34.98	2.22	107	47	47	36.01	3.63	111	47	46
Oct-85	1.92	-0.40	83	50	52	1.22	-1.02	54	49	51
Nov-85	2.08	0.64	144	28	36	2.85	1.47	207	27	35
Dec-85	1.56	0.54	153	9	22	1.76	0.72	169	8	21
Jan-86	0.71	-0.13	85	19	14	0.57	-0.31	65	18	13
Feb-86	1.10	0.18	120	18	21	0.51	-0.41	55	18	20
Mar-86	1.86	-0.31	86	38	32	1.96	-0.28	88	36	31
Apr-86	3.98	0.64	119	52	48	4.15	1.20	141	50	47
May-86	5.42	1.32	132	61	60	4.65	0.74	119	61	59
Jun-86	2.07	-2.60	44	71	69	1.78	-2.70	40	70	68
Jul-86	7.08	2.87	168	74	73	5.80	1.37	131	74	72
Aug-86	2.56	-1.57	62	67	71	4.60	0.07	102	66	70
Sep-86	4.30	0.70	119	64	62	9.87	6.49	292	62	61
Annual Summary	34.64	1.88	106	46	46	39.72	7.34	123	45	46

upper aquifer lies within ten feet of the land surface. Such conditions were not expected at Site #3, where the upper aquifer lies beneath approximately 50 feet of till and Cretaceous shales and shaley sandstone. The existence of unconfined conditions at Site #3 suggests that the downward flux of groundwater through the glacial and Cretaceous deposits is small, relative to the lateral movement of groundwater in the upper aquifer. Therefore, the upper aquifer is capable of laterally discharging the downward flux of groundwater without becoming completely saturated. The presence of nearby, deep ADWs may also be a factor. The upper aquifer at Site #3 generally has a higher head than the underlying aquifers. Therefore, groundwater from the upper aquifer will flow down the borehole of any ADW that is drilled into the underlying aquifers. This discharge of upper aquifer groundwater to deeper aquifers lowers the head in the upper aquifer, and likely contributes, to some degree, to the unconfined conditions within the upper aquifer at Site #3.

The potentiometric elevations fluctuated with time at the three sites. At Site #1, total head change varied from 17.5 feet in the uppermost part of the bedrock aquifer to 10.0 feet in the lower aquifer. At Site #2, head changes ranged from 4.8 feet in the uppermost bedrock to 7.1 feet in the lower aquifer. The largest head changes were at Site #3. Here, measured changes were about 20 feet in the two upper aquifer piezometers, and about 30 feet in the middle and lower aquifers. Water levels in the till piezometers (Figs. 16 and 18) varied about 4 feet.

Heads were measured additional times in the bedrock piezometers at Site #3, as part of another investigation. Head changes of almost 1 foot/day were noted during close-spaced measurements of all Site #3 piezometers, and exceeded 2 feet/day in the uppermost bedrock (piezometer FM3-1). When very high heads occur, heads within the uppermost bedrock aquifer and the lower and middle aquifers are essentially equal at Site #3 (Fig. 17), whereas at the other sites, high heads are associated with the largest head differences between aquifers (see Figs. 14 and 15). High heads and rapid changes in head at Site #3, such as occurred during the relatively wet March-June 1986 period, are reflecting inputs from nearby ADWs. Significant tile inflow at site ADW-1, a 305-foot-deep ADW located about 500 feet from Site #3, was noted several times during the period March June 1986. During snow melt (late March 1986), pulses of water discharged upward through a hole on the top of ADW-1, indicating the head at that point was above the land surface, and 60-70 feet above heads measured at Site #3. During this period, turbulent water could be heard in the piezometers at Site #3, suggesting cavernous zones are present. Heads at Site #3 declined rapidly after snow melt and after heavy rains in May 1986 (Fig. 17), indicating that the cone of impression (or areal head increase) caused by ADWs after major recharge events disappears on a time scale of weeks.

Water levels were measured at Site #3 in early September, 1986. Precipitation during the June-September 1986 period was above average, and significantly greater than the previous year (Table 6). Heads remained relatively high through September, and in fact, were higher than any measured in 1985.

WATER-QUALITY MONITORING

ADWs deliver shallow groundwater (i.e., tile drainage water) and occasionally surface runoff water directly into underlying aquifers. These waters are, or have recently been, in direct contact with the soils of row-cropped fields; therefore, they may contain relatively high concentrations of nitrates and pesticides. As shallow groundwater and surface water represent the main inputs to ADWs, the result of monitoring these hydrologic components will lead this section. Data from the bedrock piezometers, for which the most accurate stratigraphic control is available, follows. Finally, the

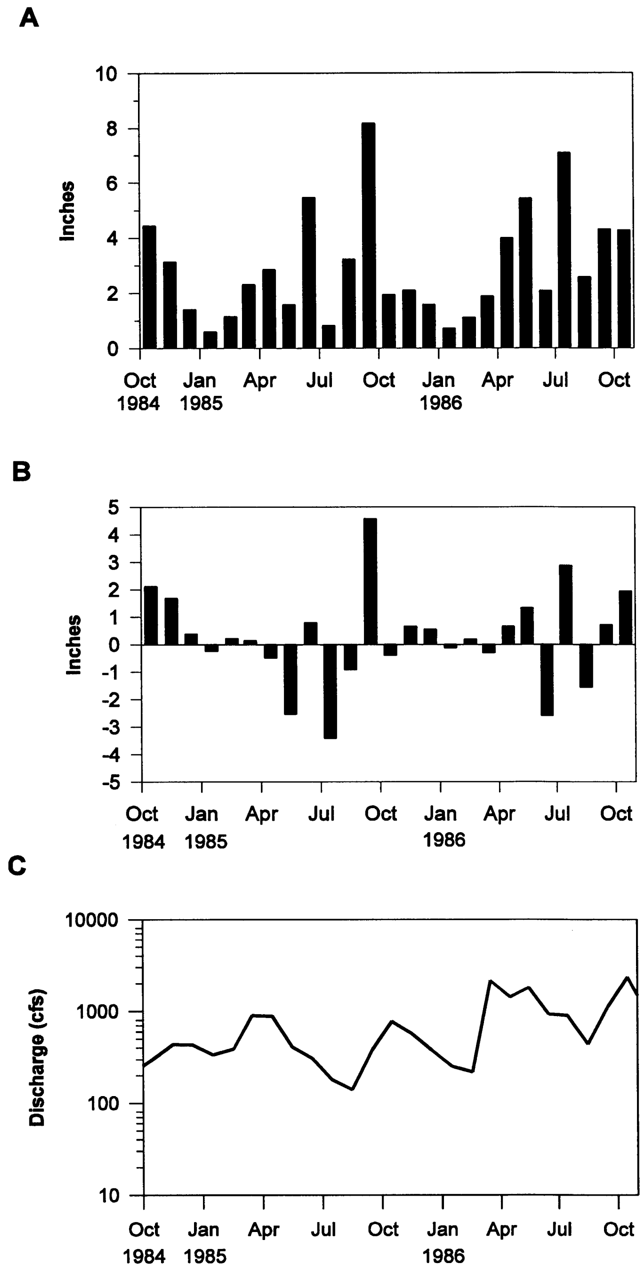

Figure 13. A) Charles City precipitation, B) departure from normal precipitation, and C) discharge hydrograph of the Cedar River at Charles City.

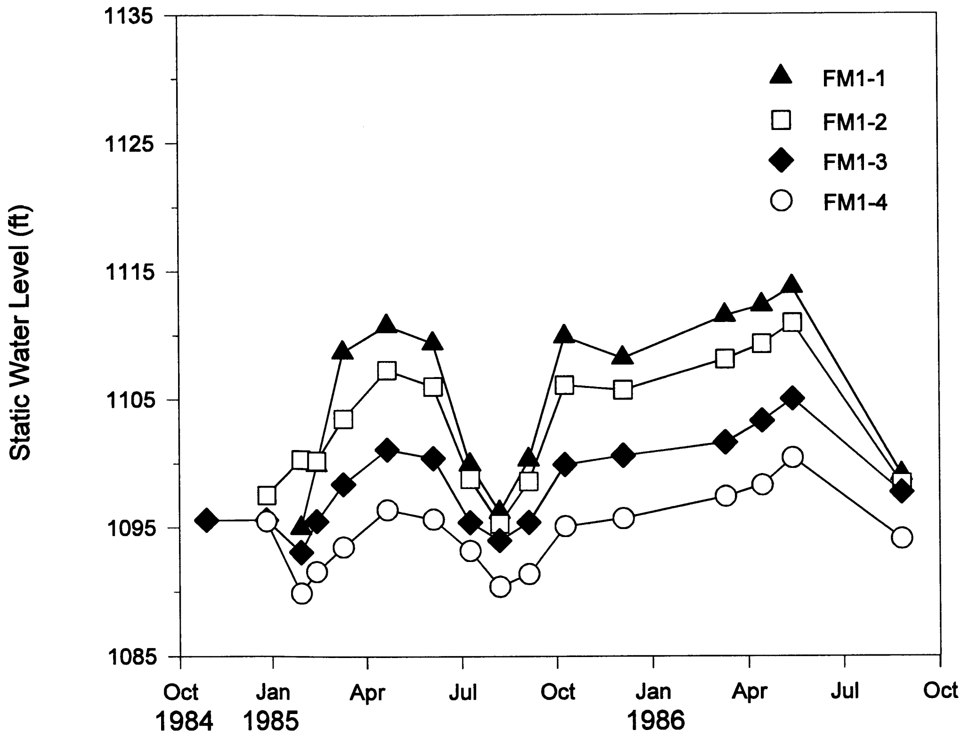

Figure 14. Potentiometric elevations at Site #1 bedrock piezometers.

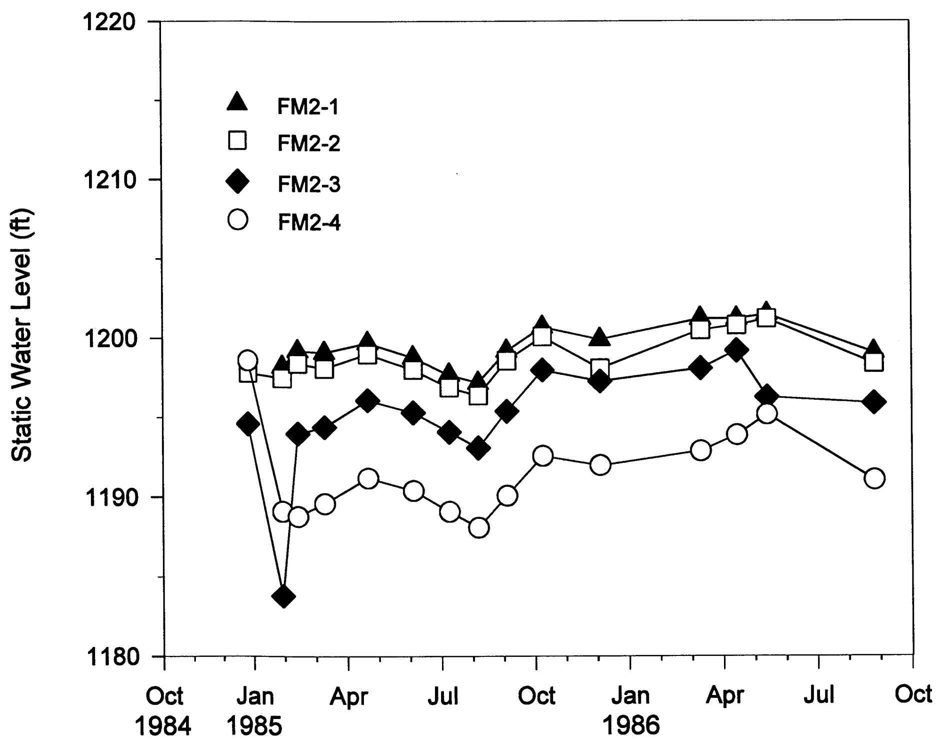

Figure 15. Potentiometric elevations at Site #2 bedrock piezometers.

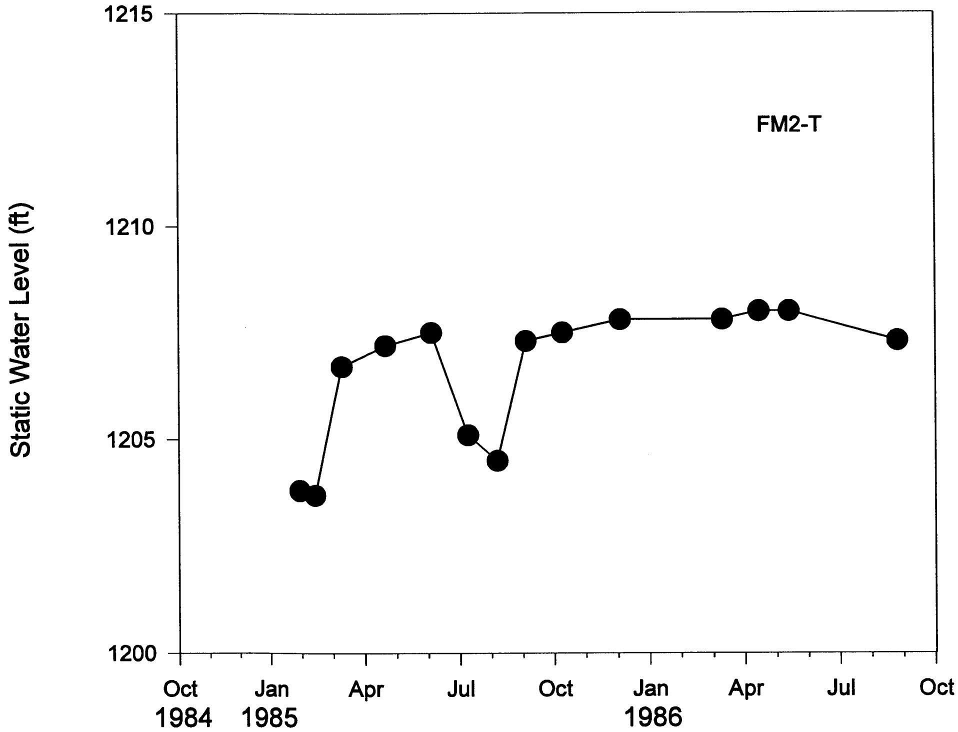

Figure 16. Potentiometric elevations at FM2-T.

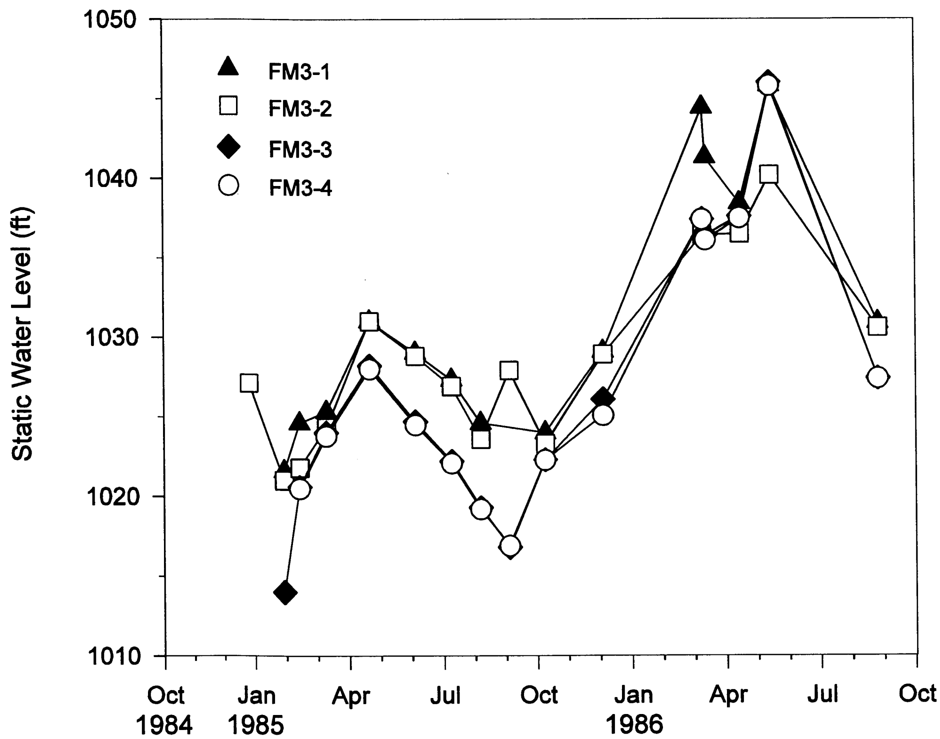

Figure 17. Potentiometric elevations at Site #3 bedrock piezometers.

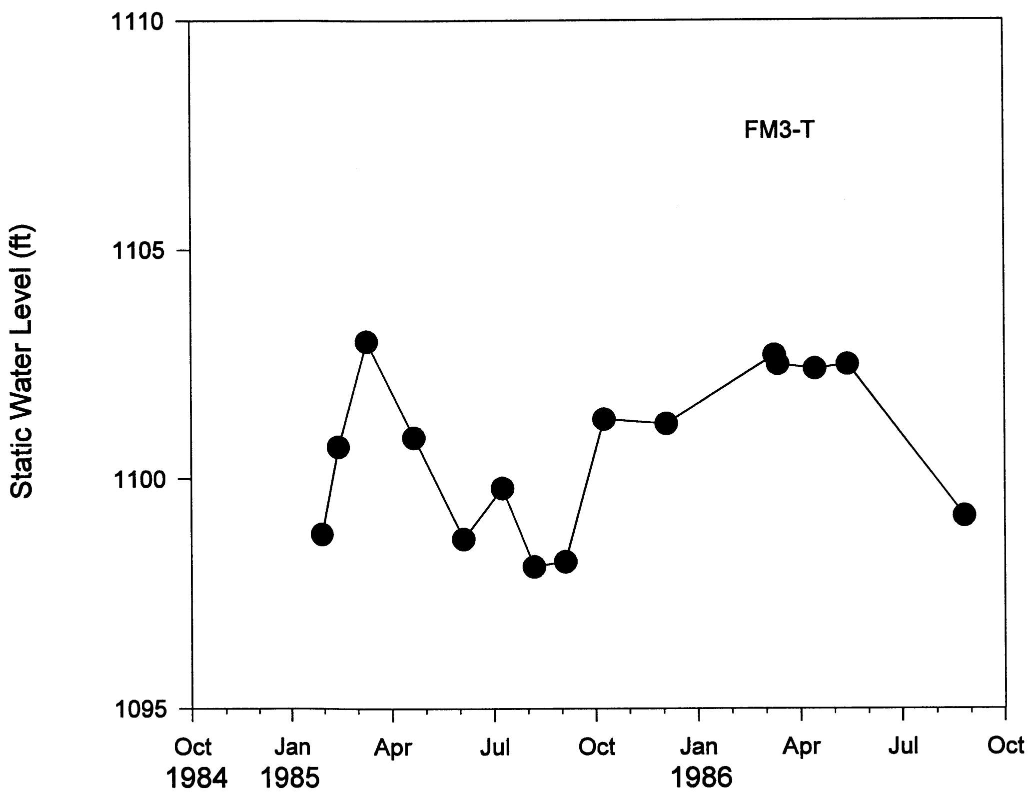

Figure 18. Potentiometric elevations at FM3-T.

results obtained from monitoring the private well network will be discussed. Nitrate monitoring will be reported first, followed by the results of pesticide monitoring. Nitrate samples were collected monthly, pesticide samples less frequently, because of costs.

Nitrate

Shallow Groundwater

Shallow groundwater samples were obtained from three tile lines (ADW-1, TL-1, DT-3), and from the till piezometers at Sites #2 and #3, piezometers FM2-T and FM3-T, respectively. Tile line samples are representative of water quality at the top of the water table, while the till piezometer samples are characteristic of water within the glacial till at depths between 10 and 25 feet below the land surface. Tile-line and till-piezometer locations are given on Figures 6 and 11, respectively. Nitrate data from shallow groundwater are given on Table 8; nitrate data from all sites is summarized in Tables 9 and 10. Data from tile line ADW-1 are samples collected from a large main tile that discharges into an ADW located about 500 feet south of Site #3. None of the tile lines were running during the dry months of July and August 1985, indicating the water table had dropped below typical tile depth (4 to 6 feet). During such periods there is little or no delivery of infiltrating recharge to the water table, or to ADWs. Similar conditions also exist during the coldest parts of the year (i.e., December 1985), when frozen soil conditions, and precipitation falling as snow do not allow recharge to occur. During periods when the tiles were discharging, nitrate concentrations varied between 18 and 77 mg/L, with most samples containing 30-65 mg/L (Table 8). At ADW-1, the highest concentrations occurred in samples collected during March-May 1986, a major recharge period. During times when significant recharge occurs, nitrate is mobilized and carried by infiltrating recharge water down to the water table. Previous studies (Hallberg et al., 1983; 1984; Libra et al, 1984) have documented a general increase in nitrate concentrations in shallow groundwater during such recharge periods, with lower concentrations occurring during drier periods. This trend is apparent in the data from ADW-1, but is somewhat less clear in the data from the other tiles (Table 8). Data from piezometer FM2-T show a generally decreasing trend in nitrate concentrations, from over 100 mg/L during the beginning of the study to 30-55 mg/L later in the sampling period (Table 8). The decrease is not constant, with concentrations sometimes increasing. Comparing the nitrate data from FM2-T (Table 8) with measured water levels (Fig. 16) suggests a correspondence of high nitrate concentrations during periods when water levels are lowest (non-recharge periods). A mechanism causing this can be suggested. Site #2 is located within a small non-cropped area 100 to 500 feet from adjacent row-cropped fields. Lateral groundwater movement from adjacent fields, as opposed to downward movement from the soil zone, delivers nitrate-rich water to FM2-T. During recharge periods, water infiltrating the non-cropped area around FM2-T may actually dilute the nitrate concentrations in the underlying groundwater. This suggestion is speculative, and confirmation would require a longer period of monitoring and additional monitoring wells. Additionally, this does not explain the overall decrease in nitrate observed at FM2-T.

Nitrate concentrations were much lower at FM3-T, relative to FM2-T (Table 8). Nitrate concentrations exceeded 5 mg/L in only two samples, and were below 0.1 mg/L at times. A factor that may account for the observed difference in nitrate concentrations is the presence of a paleosol at both Sites #2 and #3. A paleosol often contains a horizon with a relatively high clay content. This clay-rich horizon may act as a low permeability barrier, limiting downward groundwater movement. FM2-T is constructed such that the open interval extends above the paleosol, while FM3-T is completed entirely below the paleosol. Therefore, FM3-T may be in a locally "protected" zone, where groundwater tends to move laterally, with only slow downward movement across the paleosol.

Table 7. Range of vertical potentiometric gradients at the piezometer sites.

Site #	Geologic Region	Maximum	Minimum
1	Karst	0.055	0.024
2	Shallow Bedrock	0.050	0.030
3	Deep Bedrock (ADW)	0.050	0.00

Cherryholmes and Gockel (1987) monitored tile drainage entering eight ADWs in Floyd County during June, July, and September 1986; ADW-1 was one of these sites. Nitrate concentrations during June and July varied between 31 and 112 mg/L; only one of these tiles discharged drainage water with less nitrate than ADW-1. In September 1986, five of the tiles were dry. Two of the three remaining tiles had nitrate concentrations below 5 mg/L, while the other contained 140 mg/L nitrate. This latter ADW (Well #2 of Cherryholmes and Gockel, 1987) is located within the same section as ADW-1.

Surface Water

Average nitrate concentrations in surface water varied between 21 mg/L and 49 mg/L (Table 10). The Cedar River, with by far the largest drainage area (1504 mi^2), had the lowest concentrations. The other sites have drainage basins that vary from 10 to 20 mi^2, and did not display a relationship between basin size and nitrate concentrations. Maximum concentrations at these sites varied from 41 mg/L to 83 mg/L, and minimums from <5 mg/L to 18 mg/L (Table 10). Maximum concentrations for all sites occurred in May 1986, a relatively wet but non-runoff period (Table 6). Minimum concentrations typically occurred during February 1985, a period dominated by snow-melt runoff, which is relatively dilute with respect to nitrate (e.g., Hallberg et al., 1983). Low concentrations also occurred during the relatively dry summer months of 1985. These reflect both a lack of nitrate inputs to streams, caused by the dry conditions, and in-stream pro-

Table 8. Nitrate concentrations in shallow groundwater.

Sites:	ADW-1	TL-1	DT-3	FM 2-T	FM 3-T
DATE					
11-10-84	18	41	63	113	<5
1-9-85	NA	49	77	109	<5
2-12-85	NA	NA	55	111	<5
2-27-85	NA	18	50	105	<5
3-25-85	32	33	54	92	<5
5-6-85	39	49	67	34	10
6-19-85	30	47	66	69	<5
7-24-85	Dry	Dry	Dry	83	2.4
8-21-85	Dry	Dry	Dry	80	0.3
9-18-85	Dry	42	57	84	<5
10-23-85	24	44	51	65	<5
12-18-85	Frozen	Frozen	51	33	<0.5
3-25-86	54	40	50	54	<0.5
4-29-86	35	44	58	59	20
5-28-86	63	26	76	38	<0.5
9-9-86	Dry	Dry	20	32	3.2

NA-- Not accessible

cesses that consume or transform nitrate (e.g., Isenhart and Crumpton, 1989). In sum, nitrate concentrations in surface water and shallow groundwater sources, from which ADW inputs are derived, vary significantly, both temporally and spatially. This variation in the quality of input water is one of the factors which complicates the evaluation of the impact of ADWs on groundwater.

Bedrock Piezometers

The piezometer sites were sampled on approximately a monthly basis for nitrates from November 1984 through May 1986. The results are given on Figures 19 through 21, and summarized in Table 10. Examination of the nitrate and potentiometric data (Figs. 14, 15 and 17) from the piezometers indicates a general seasonal concurrence of high heads and high nitrate concentrations. This occurs particularly in the upper aquifer (monitored by the two upper most bedrock piezometers), where the impact of nitrate-rich recharge water is volumetrically more important. Nitrate concentrations at Sites #1 and #2 are consistent with their respective hydrogeologic settings and piezometer completions. At Site #1 (karst, shallow bedrock region) nitrate concentrations in the upper piezometer, FM1-1, vary from about 20 to 45 mg/L, while in the deeper piezometers concentrations are usually are less than 10 mg/L nitrate. At Site #2 (where about 45 feet of low permeability materials overlie the aquifer), piezometers in the upper aquifer, FM2-1 and FM2-2, vary from near zero to about 10 mg/L NO_3 (Fig. 20). Samples from the middle and lower aquifer piezometers FM2-3 and FM2-4, are generally below 5 mg/L, although occasional samples showed 10 to 30 mg/L NO_3. The significance of these higher concentrations is difficult to evaluate. The results may represent the input of discrete pulses of fairly recent recharge water, which is unlikely to reach these lower confined aquifers. No reasonable mechanism for this delivery can pres-

Table 9. Nitrate and coliform bacteria data from network sites, by geologic region or site type.

GEOLOGIC REGIONS Wells	No. of Samples	Nitrate mg/L Mean	Nitrate mg/L Range	Coliform Bacteria MPN Median	Coliform Bacteria MPN Range
Deep	153	14	<0.5 - 73	2.2	0 - 16+
Shallow	180	42	<0.5 - 121	2.2	0 - 16+
*Karst	70	38	<0.5 - 60	5.1	0 - 16+
Tile Lines/Till Piezometers	65	42	<0.5 - 113	16+	2.2 - 16+
Surface Water Sites	45	31	<5 - 83	16+	9.2 - 16+

*Includes 2 incipient karst wells.

ently be proposed, however. The anomalously high values may represent laboratory, sampling, or labeling errors, although there is no evidence for these alternatives, either. Nitrate concentrations at Site #3 (greater than 50 feet to bedrock) vary widely (Fig. 21). During relatively dry periods, the uppermost piezometer, FM3-1, generally produced water with less than 10 mg/L nitrate. During such periods, the tile line draining to ADW-1 (and other observed tile outlets) was dry or supplying only a trickle of water. However, during the wet December 1985 to May 1986 period, when heads at Site #3 increased dramatically, nitrate concentrations in piezometer FM3-1 exceeded 100 mg/L at times, and changes in concentrations occurred very quickly. Piezometer FM3-4 also showed increased nitrate levels, to about 20 mg/L. Piezometers FM3-2 and FM3-3 showed little or no increases in nitrate, although the potentiometric response at these piezometers was similar to that which occurred in FM3-1 and FM3-4 (Fig. 17).

The increases in nitrate concentrations in some of the Site #3 piezometers are interpreted as resulting from inputs from nearby ADWs during wet periods. The more significant response in the piezometer FM3-1, relative to others at Site #3, may occur for several reasons. First, some nearby ADWs may not penetrate significantly deeper than FM3-1, and the water they deliver may only affect the upper part of the upper aquifer. Also, the uppermost bedrock at Site #3 is unsaturated. ADW water entering this unsaturated zone is not subject to mixing and dilution with pre-existing water, as is the case with water entering deeper, saturated zones. May 1986 marked the end of regular sampling for this project. However, the piezometers and several private wells were sampled again during September 1986. As noted, rainfall during the period June 1986 through September 1986 was above normal, and although ADW-1 was not monitored during this period, drainage to ADWs continued (Cherryholmes and Gockel, 1987). Nitrate concentrations at piezometers FM3-1 and FM3-4 remained relatively high into September 1986, at about 50 and 10 mg/L, respectively, while concentrations at FM3-2 and FM3-3 were below 1 mg/L. The high nitrate concentrations in water from FM3-1 and FM3-4 are probably related to continued inputs of ADW water during the period. Additionally, these concentrations may be indicating the longer-term affects of the large March-May 1986 snow melt and spring rain recharge.

Comparison of the nitrate concentrations in the tile effluent at ADW-1 and in groundwater from the piezometers FM3-1 and FM3-4 (Fig. 22) yields insights about the complexity of the ADW-carbon-

Table 10. Summary of nitrate data from individual network sites. Data from bedrock piezometers included for comparison.

Site Number	Average Nitrate mg/L	Standard Deviation*	Range mg/L	Coefficent of Variation
Karst Wells				
FM-22	48	6.6	31 - 54	14
FM-53	28	4.7	23 - 40	17
Q-8	32	9.4	25 - 59	29
Q-9	38	8.95	19 - 57	23
Q-22	45	10.7	24 - 60	24
FM 1-1	28	9	16 - 50	32
FM 1-2	<5	--	0.9 - 10	--
FM 1-3	<5	--	0.5 - 16	--
FM 1-4	<5	--	<0.5 - <5	--
Shallow Bedrock Wells				
FM-8	22	3.1	16 - 29	14
FM-42**	69	10.9	45 - 83	16
FM-42A**	45	12.6	20 - 79	28
F-2	53	6.2	43 - 64	12
F-8	102	14.7	74 - 121	14
F-10	7	10.7	0.5 - 31	157
F-11	42	10	23 - 54	24
F-18	35	5.1	26 - 42	15
F-19	19	5.5	8 - 26	29
F-23	28	3.2	23 - 37	11
Q-3	<5	--	<0.5 - 6	--
Q-14	15	3.2	13 - 26	21
Q-15	54	5.2	45 - 65	10
FM 2-1	<5	--	1.6 - 9	--
FM 2-2	<5	--	<5 - 11	--
FM 2-3	<5	--	<0.5 - 15	--
FM 2-4	<5	--	<0.5 - 31	--

*Standard deviations and coefficients of variation not calculated for sites which were consistently below 5 mg/L; lower detection limits for nitrate varied from 0.5 to 5.0 mg/L.

**Incipient karst wells.

Table 10. (Continued)

Site Number	Average Nitrate mg/L	Standard Deviation*	Range mg/L	Coefficent of Variation
Deep Bedrock				
FM-16	<5	---	<0.5 - 9	--
F-6	<5	---	<0.5 - 32	--
F-21	<5	---	<0.5 - 9	--
F-32	20	9.9	<5 - 50	--
Q-1	5	---	<5 - 8	--
Q-4	<5	---	<0.5 - <5	--
Q-5	<5	---	<0.5 - 20	--
Q-6	9	13.3	<0.5 - 44	146
Q-16	28	3.6	24 - 38	13
Q-17	66	3.2	61 - 73	5
Q-18	<5	---	<0.5 - 9	--
Q-23	37	10.8	26 - 59	29
FM 3-1	37	40.3	<5 - 135	108
FM 3-2	<5	---	<0.5 - 8	--
FM 3-3	<5	---	<0.5 - <5	--
FM 3-4	7	7.55	<0.5 - 27	115
Surface water Sites				
Cedar River	21	9.3	<5 - 41	44
Goose Creek	24	13.4	7 - 50	55
Burr Oak Creek	32	10.8	18 - 50	33
Beaver Creek	34	21.6	11 - 61	63
Wildwood Creek	49	22.8	9 - 83	46
Tile Lines/Till Piezometers				
TL-1	39	9.4	18 - 49	24
DT-3	57	13.6	19 - 77	24
ADW-1	37	14	18 - 63	38
FM 2-T	72	18.3	32 - 113	25
FM 3-T	<5	---	<0.5 - 20	--

*Standard deviations and coefficients of variation not calculated for sites which were consistently below 5 mg/L; lower detection limits for nitrate varied from 0.5 to 5.0 mg/L.

**Incipient karst wells.

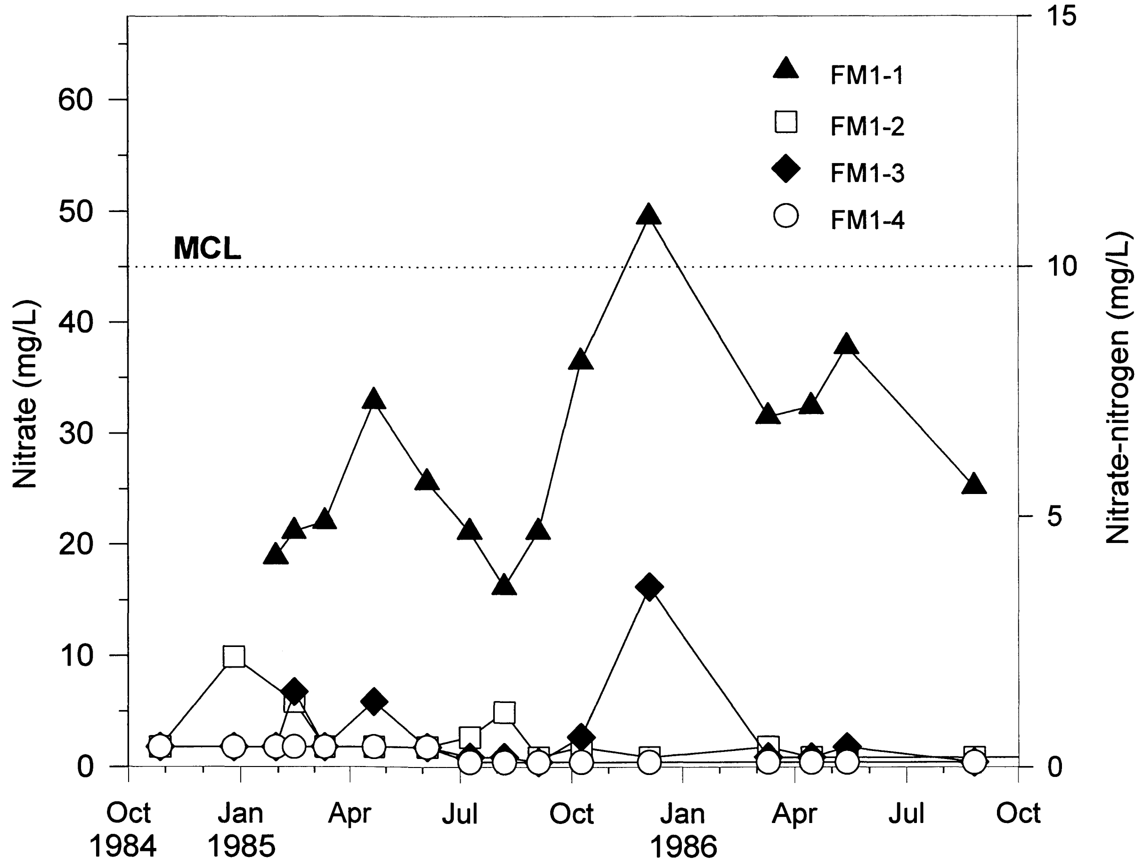

Figure 19. Nitrate concentrations at Site #1 bedrock piezometers.

ate aquifer system. Note that the concentrations of nitrate measured going into ADW-1 during March through May 1986 are less than that yielded by piezometer FM3-1. Also, concentrations and species of pesticides differ between the piezometers and ADW-1 (Appendix A). This suggests that other ADWs, located farther away from Site #3 than ADW-1 (such as well #2 of Cherryholmes and Gockel, 1987) are significantly impacting water quality at Site #3.

Private Well Network

Table 9 summarizes the results of nitrate (and bacterial) monitoring at the network sites, by site type and/or geologic region; Table 10 summarizes results from individual sites. Data from the bedrock piezometers and shallow groundwater and surface-water sites are included for comparison. Average nitrate concentrations are similar for karst, shallow bedrock, and shallow groundwater, about 40 mg/L, which is 90% of the USEPA-MCL for nitrate, 45 mg/L. Surface water averaged 31 mg/L NO_3 during the period. Deep bedrock area wells showed lower nitrate concentrations, averaging 14 mg/L. These results are generally similar to those reported in other studies in Iowa (Hallberg and Hoyer, 1982; Hallberg et al., 1983, 1984; Libra et al., 1984). A major difference is the nitrate concentrations in deep bedrock areas; previous studies showed most deep bedrock groundwaters contain less than 5 mg/L NO_3. Nitrate concentrations at the network sites follow the same general seasonal variability as the piezometer sites (Figs. 19-21), with higher concen-

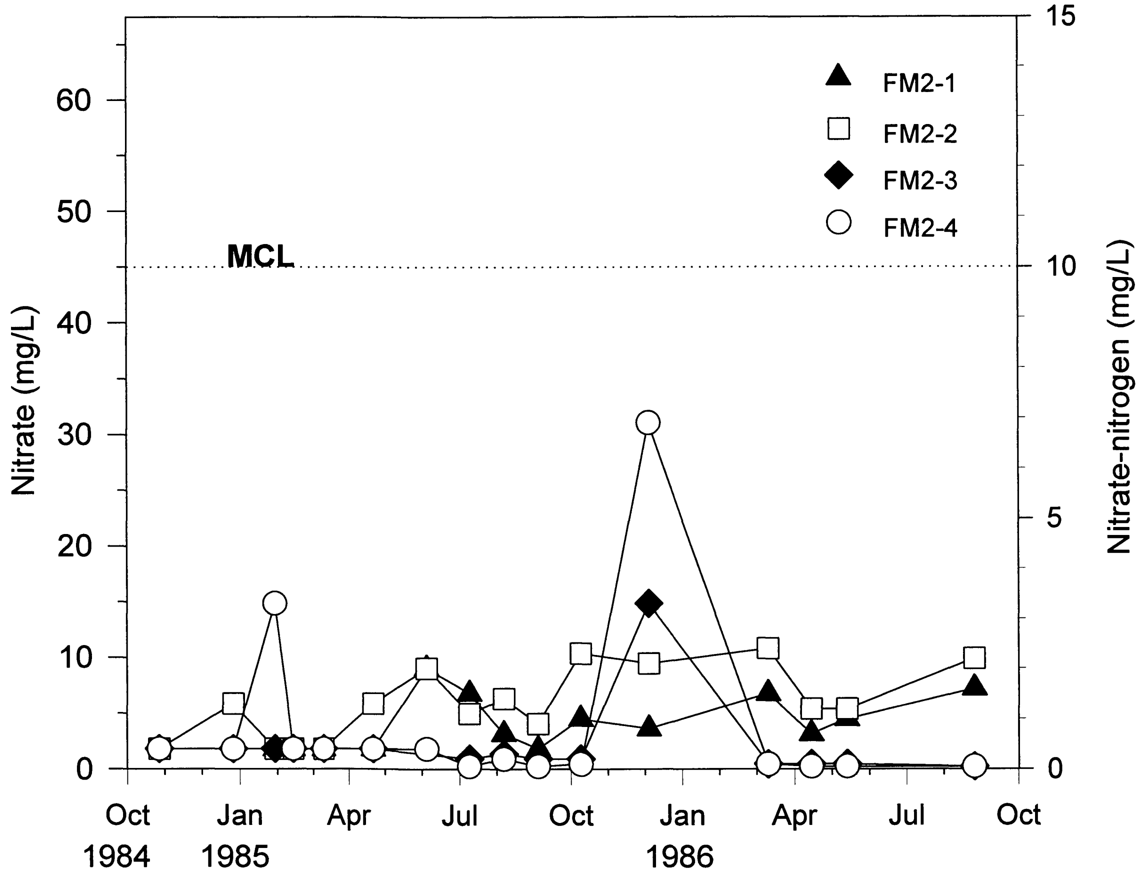

Figure 20. Nitrate concentrations at Site #2 bedrock piezometers.

trations occurring after groundwater recharge events. However, variability ranges widely from site to site. Table 10 gives the coefficient of variation (C.V.) of nitrate concentrations (where the data allowed calculation - see footnotes for Table 10). In general, nitrate variability is highest in surface water (C.V. ~50), followed by shallow groundwater (C.V. ~30), and groundwater from private wells in karst (C.V. ~25), and shallow bedrock (C.V. ~20) areas. In intensively agricultural areas, nitrate variability is largely a function of how rapidly and directly a given part of the hydrologic system is affected by runoff and/or infiltration processes. Surface waters are rapidly affected by overland flow, which is generally low in nitrate. Surface water also receives significant inputs of shallow groundwater, which is generally high in nitrate. Therefore, streams are mixtures of relatively high-and-low nitrate water. The proportions of high and low nitrate inputs change through time, generating quite variable nitrate concentrations. In contrast groundwater from private wells in deep bedrock areas is relatively protected and only slowly affected by infiltration water, and therefore should not display highly variable nitrate concentrations.

Nitrate concentrations in half of the deep bedrock wells were too low, and detection limits too variable, to calculate C.V. values. Where values could be calculated, they range from 5 to over 150 (Table 10). Note that piezometers FM3-1 and FM3-4, where ADW effects occur, have nitrate C.V. values greater than 100. Therefore, deep bedrock wells with highly variable nitrate concen-

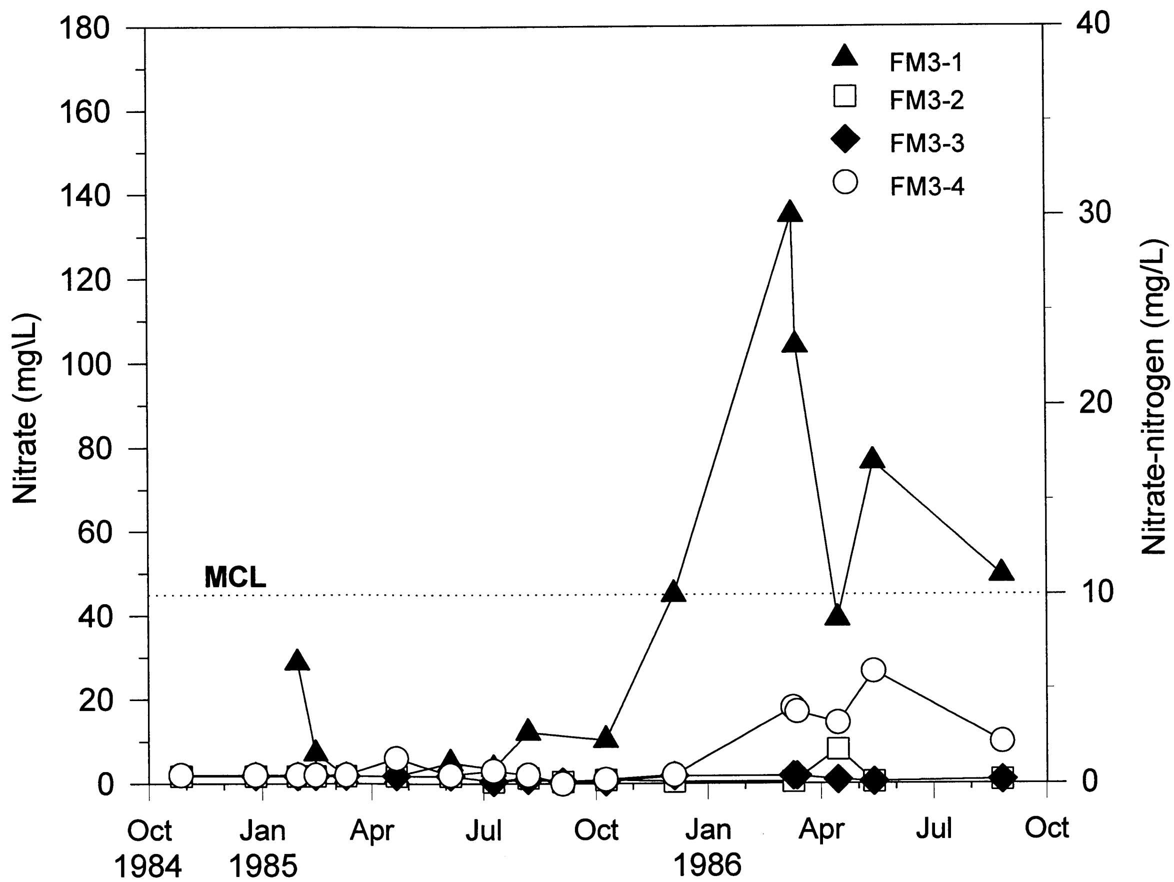

Figure 21. Nitrate concentrations at Site #3 bedrock piezometers.

trations, such as F-32 an Q-6, may indicate nitrate-rich ADW recharge into otherwise low-nitrate groundwater. Nitrate concentrations in these wells vary from less the 5 mg/L to over 50 mg/L. Wells F-6 and Q-23 also have rather variable nitrate levels (Table 10). These wells are all located within the area where ADWs could cause both the magnitude and variability of the observed nitrate concentrations. Two other deep bedrock wells, Q-16 and Q-17, have relatively high nitrate concentrations but show little variability (C.V. = 5 and 13, respectively). This combination of low variability with moderate to high nitrate concentrations (20 mg/L and 66 mg/L at wells Q-16 and Q-17, respectively) is inconsistent with the ADW effects noted at piezometers FM3-1 and FM3-4.

Pesticides

Results of the pesticide analysis of water collected during this investigation are tabulated in Appendix A. Analyses were run on 42 samples of shallow groundwater, 33 samples of surface water, 239 samples from private wells, and 125 samples from the bedrock piezometers.

Shallow Groundwater and Surface water

Table 11 summarizes the results from shallow groundwater and surface water. Pesticides were detected in shallow groundwater from all sites at least once during the study, and were present in 43% of the samples collected. More than one pesticide was present in 12% of the samples. Atra-

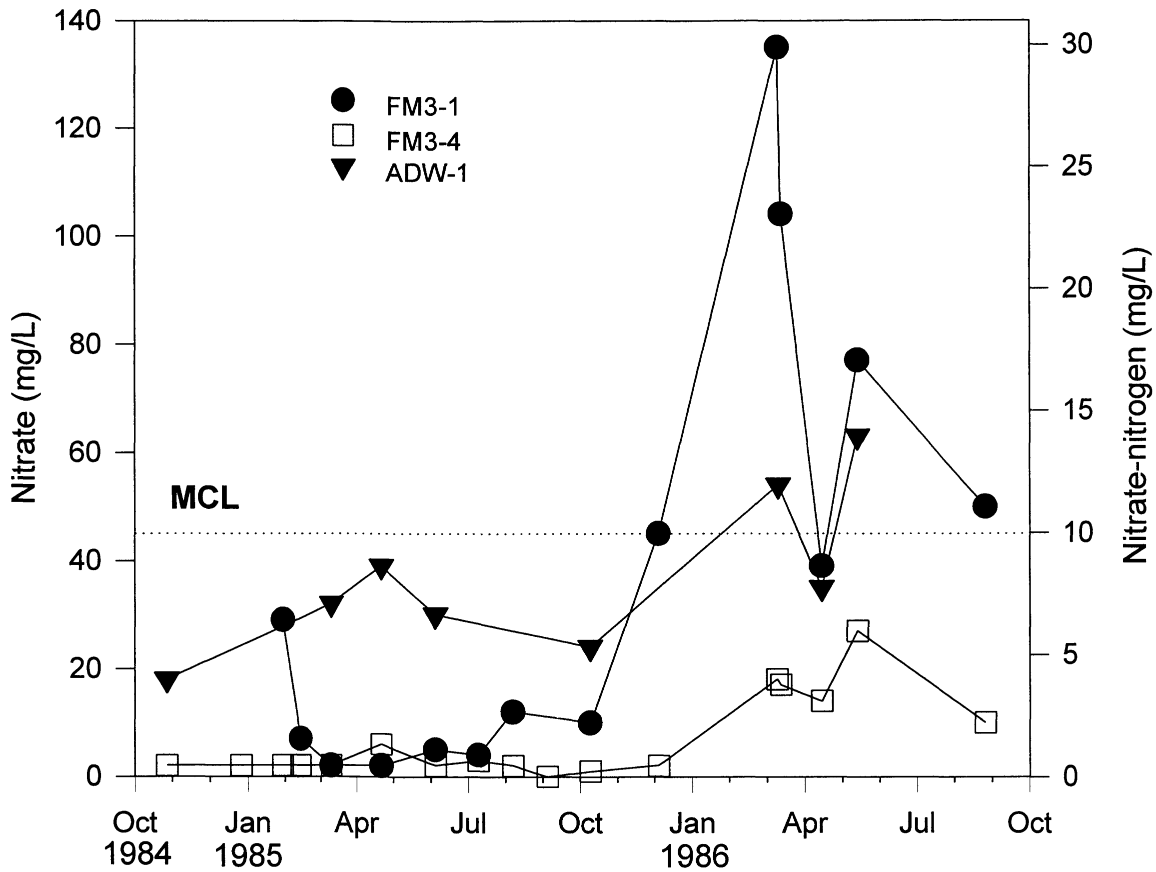

Figure 22. Nitrate concentrations at FM3-1, FM3-4, and ADW-1.

zine was most commonly detected, with a maximum concentration of 1.1 µg/L. Cyanazine, alachlor, metolachlor, and metribuzin were also detected with maximum concentrations of 2.8, 1.8, 5.9, and 0.73 µg/L, respectively. Detections were more common, concentrations were higher, and more types of pesticides were present in samples collected from tile lines, compared to those from till piezometers. Tiles drain water from near the top of the water table, immediately below cropped fields where pesticides have been applied. By contrast, the till piezometers are completed about 15 feet below the water table. Piezometer FM2-T is located several hundred feet from cropped fields, and FM3-T is completed immediately beneath a paleosol (as previously discussed). These factors likely explain the lesser occurrence of pesticides at the piezometers relative to the tiles.

Thirty-two of 33 samples of surface water contained detectable pesticides, with 60% of the samples containing more than one chemical (Table 11). Concentrations were generally similar to those found in tile line samples. The one sample that did not contain detectable pesticides was from the Cedar River, in October 1985. Concentrations in other surface waters were also at their lowest during that period.

Bedrock Piezometers

One hundred twenty-five samples for pesticide analysis were collected from the bedrock piezometers. Results are tabulated in Appendix A; Table 12 summarizes the pesticide results from the pi-

Table 11. Pesticide detections in shallow groundwater and surface water.

Site	Number of Samples	Number of Detections	Number of Multiple Detections	Maximum* µg/L
		SURFACE WATERS		
Cedar River	9	8	6	1.4
Goose Creek	7	7	5	15.2
Burr Oak Cr.	6	6	3	1.3
Beaver Cr.	2	2	2	1.4
Wildwood Cr.	9	9	3	7.2
TOTAL	33	32	19	---
		TILE LINES / TILL PIEZOMETERS		
FM2-T	9	1	0	0.28
FM3-T	10	1	0	0.11
TL-1	8	7	3	3.3
DT-3	10	7	1	2.8
ADW-1	5	2	1	9.5
TOTAL	42	18	5	---

* Maximum is sum of all pesticide products detected.

ezometers. Figures 23 through 25 show concentrations of atrazine in the bedrock piezometers. One feature of these data stand out clearly: during August and September, 1985, anomalously high concentrations of atrazine occur within virtually all piezometers. These August-September data are questionable for several reasons. First, concentrations begin rising in August, in the midst of an extended dry period. During that time, heads at all sites were at or near their lowest measured levels (Figs. 14, 15, and 17), and the tile lines on the sampling network had been dry for over a month.

Atrazine concentrations increased in September, a very rainy month. Heads at most sites increased in September, but of the three tile lines included in the sampling network, only one had resumed flow. This suggests recharge was limited, with most precipitation replenishing soil moisture rather than reaching the water table. The August through September samples cannot be interpreted as pulses of recent, unmixed recharge water, for several reasons: first, most of the samples with anomalously high pesticides contained no nitrate; second, it is extremely difficult, if not impossible, to postulate a mechanism that would deliver such water to all three aquifers at the same time (especially given the preceding dry conditions). For the rest of this discussion, the August-September pesticide data are considered erroneous, and unrepresentative of actual aquifer conditions.

Disregarding the August-September 1985 analyses, the atrazine data indicated a general correspondence of higher concentrations during wet, recharge conditions; a similar relationship for nitrate and recharge was previously discussed. The highest and most persistent concentrations of atrazine occurred in piezometer FM1-1 (Fig. 23). Ten of eleven samples contained detectable atrazine (Table 12), and five samples also contained more than one pesticide. Two of eight sampled collected at FM1-2 also contained pesticides. The highest concentrations noted in FM1-1 and FM1-2 occurred in May 1986. This period followed a relatively wet, recharge period, and was 2 to 6

Table 12. Pesticide detections in bedrock piezometers.

Site	Number of Samples	Number of Detections	Number of Multiple Detections	Maximum* µg/L
FM 1-1	11	10	5	6.1
FM 1-2	8	2	1	1.39
FM 1-3	8	3	0	0.06
FM 1-4	7	1	0	0.1
FM 2-1	10	1	1	0.31
FM 2-2	8	1	0	1.4
FM 2-3	8	0	0	---
FM 2-4	6	0	0	---
FM 3-1	12	10	4	0.98
FM 3-2	10	1	1	0.46
FM 3-3	9	0	0	---
FM 3-4	8	5	3	1.43

* Maximum is sum of all pesticides present.

weeks after chemicals were applied to fields. FM1-1 yielded water with 3.9 µg/L atrazine, and with 0.5 to 1.0 µg/L cyanazine, metolachlor and alachlor. Water from FM1-2 contained 0.85 µg/L atrazine and 0.54 µg/L metolachlor. Atrazine was detected three times in FM1-3, completed in the middle Devonian aquifer, and once in FM1-4, at concentrations of 0.1 - 0.2 µg/L.

Data from the upper aquifer piezometers (FM1-1 and FM1-2) at Site #1 are comparable to those from private wells in karst or shallow bedrock areas (to be discussed). The mode of delivery of pesticides to these piezometers - via surface runoff to sinkholes, or infiltration through the thin (<15 feet) cover of unconsolidated materials - is not clear. Several factors argue against sinkhole inputs as the source. First, Site #1 is located upgradient of most of the sinkhole development in the immediate area. The majority of the sinkholes in the area are of minor hydrologic significance as they have little or no drainage basin associated with them. Packer testing of the upper aquifer at Site #1 indicated a low permeability, relative to the other packer tests (see Table 2) and to all other existing data for the Devonian aquifers in the area (see Table 3). This is not the result expected from a well in hydrologic connection with karst "conduits," or with a fracture network that has undergone significant solutional enlargement (see Hallberg et al., 1983; 1984).

Pesticides were detected only once at Site #2 (Fig. 24 and Table 12), in the upper Devonian aquifer in piezometers FM2-1 and FM2-2, during June 1985. At this site, the cover of low permeability materials overlying the upper Devonian aquifer is about 45 feet, indicating at least some local "protection" from surficial contaminants. The lack of detectable pesticides in most samples is consistent with the geologic setting, and with the generally low nitrate concentrations noted at the site (<10 mg/L). At Site #3 (Fig. 25 and Table 12), pesticides were detected in 10 of 12 samples from piezometers FM3-1 and 5 of 8 samples from FM3-4. More than one compound was present in four and five of the samples from these piezometers, respectively. Only

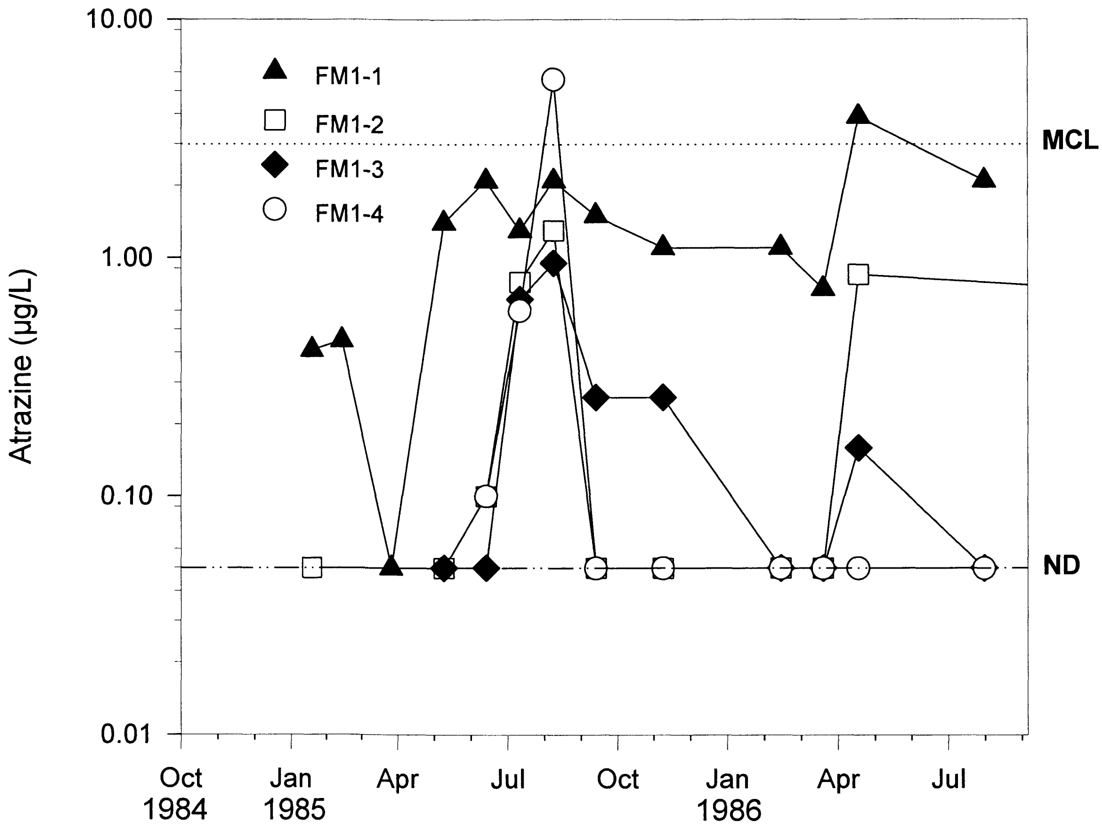

Figure 23. Atrazine concentrations at Site #1 bedrock piezometers.

one of 12 samples from piezometers FM3-2, and zero of 11 from FM3-3, contained detectable pesticides. These data parallel those found for nitrate: surficial contaminants were primarily found in piezometers FM3-1 and FM3-4. As with nitrates, the highest pesticide concentrations at FM3-1 and FM3-4 occurred during wet periods when tiles were discharging and high heads occurred (Figs. 17, 21, and 25). Atrazine, cyanazine, alachlor, and metolachlor were detected during wetter periods in piezometers FM3-1 and FM3-4 (Table 12). As this site is located in, and is downgradient from, protected, deep bedrock areas, ADWs are believed to be the source of agricultural chemicals in the groundwater samples collected there.

Private Well Network

Two hundred thirty-nine samples of groundwater from the private well network were analyzed for pesticides. Table 13 summarizes the results. Forty-nine samples were collected from private wells in karst areas, and virtually all contained detectable pesticides. Atrazine was the most commonly detected pesticide, but over one third of the samples contained more than one compound. Maximum concentrations detected were: atrazine, 13 µg/L; cyanazine, 1.8 µg/L; metolachlor, 14 µg/L; alachlor, 250 µg/L; metribuzin, 7.5 µg/L. All maximum concentrations, with the exception of metribuzin, were from well Q-8 in May 1986. Previous samples from this well collected during the extended dry period in the summer of 1985, also contained atrazine and alachlor, but at concentrations below 1 µg/L (Appendix A). These previous samples did not contain coliform bacteria, while samples collected in May 1986 were bacterially contaminated (MPN 16+). May 1986 was charac-

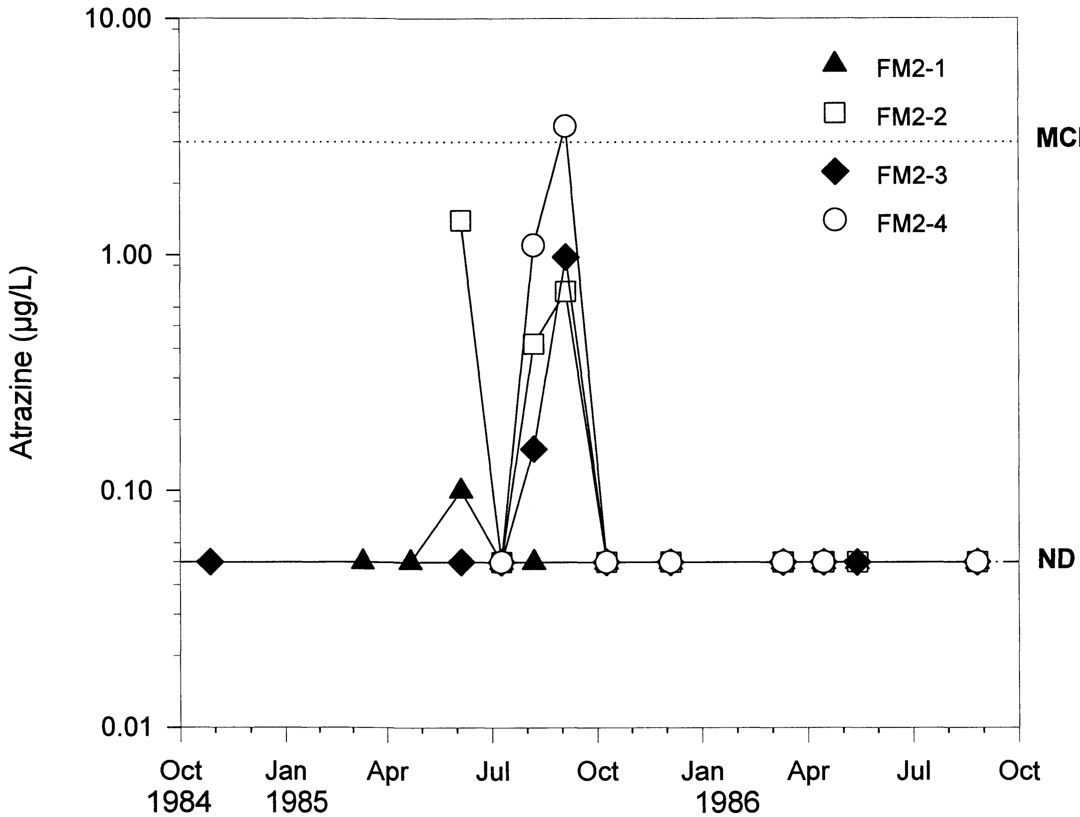

Figure 24. Atrazine concentrations at Site #2 bedrock piezometers.

terized by wet, recharge conditions, and chemicals were applied to fields in the weeks prior to sample collection. Sinkholes occur in the midst of cropped fields within several hundred feet of well Q-8. Runoff from recently treated fields to sinkholes may have caused the high concentrations noted in the May 1986 samples. A spill of chemicals could also have been involved, although the owner reported that none had occurred.

One-hundred two samples were collected from shallow bedrock areas. Pesticides were detected in 64% of the samples, and 12 of the 13 wells sampled contained detectable pesticides at least once. Atrazine was the pesticide most frequently detected in water from these wells, but three wells produced water with more than one compound at least once. Maximum concentrations for specific pesticides included: atrazine, 0.53 µg/L; cyanazine, 4 µg/L; alachlor, 65 µg/L; and metribuzin, 30 µg/L. Maximums, other than for atrazine, occurred at well FM-42. This well has been sampled intermittently during the period from December 1982 through September 1987 (see Libra et al., 1984). Alachlor concentrations have generally exceeded 5 µg/L during this period, and were usually above 10 µg/L during the January 1985-September 1987 period (Appendix A). Results and further investigations at this site will be discussed in a future report.

Ninety-six samples were collected from private wells in deep bedrock areas. Twenty-five percent contained detectable pesticides, and virtually all detections were of atrazine. Two samples also contained metolachlor. Maximum concentrations detected were 5 µg/L atrazine, and 2.8 µg/L metolachlor. Previous work in Floyd and Mitchell counties indicated a lack of pesticide occurrences in private wells from deep bedrock areas (Libra et al., 1984). Therefore, detections in the wells sampled

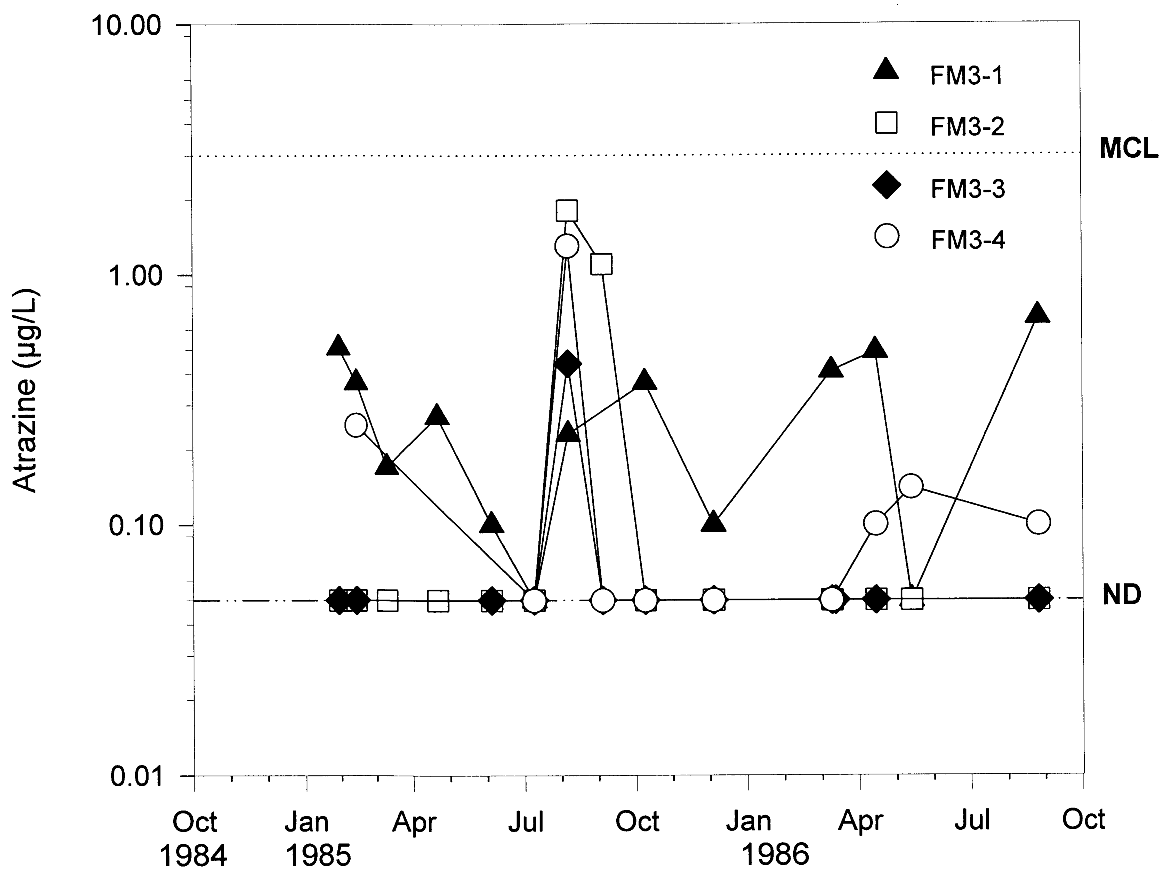

Figure 25. Atrazine concentrations at Site #3 bedrock piezometers.

in this study that are located in deep bedrock areas with ADWs present, may be related to inputs of drainage water via the ADWs. Table 14 summarizes the private well data in terms of pesticide detections per monthly sampling period. During six periods more than 20 wells were sampled for pesticides, and the percentage of wells with detectable pesticides are given for these periods. In general, 50-60% of the private wells produced groundwater with detectable pesticides. The lowest percentage of detections, 48%, occurred in August, 1985, following quite dry conditions (see Table 6), with little or no groundwater recharge occurring. Note that 58% of the wells contained detectable pesticides in March 1986. This is 10-11 months after the most recent application of pesticides (i.e., prior to the 1985 growing season), and indicates the chemicals detected persist in the environment for periods approaching one year.

TRITIUM MONITORING AND GROUNDWATER AGES

Tritium (^3H) is a radioactive isotope of hydrogen, produced naturally in the atmosphere by the interaction of cosmic rays and nitrogen gas (N_2). Tritium is incorporated into water molecules and has a relatively short half-life of 12.3 years. Concentrations of tritium in water are generally reported in Tritium Units (T.U.); 1 T.U. is equal to 1 tritium atom in 10^{18} hydrogen atoms. Natural generation is sufficient to produce tritium in precipitation at concentrations of 5-20 T.U. (Payne, 1972). During 1953-1963, atmospheric testing of

Table 13. Summary of pesticide data from individual network sites.

Site	Number of Samples	Number of Detections	Number of Multiple Detections	Maximum * µg/L
		KARST WELLS		
FM-22	10 (6)***	9 (3)***	0 (0)***	0.26 (0.25)***
FM-53	7 (5)***	7 (2)***	2 (2)***	.7 (0.25)***
Q-8	7	6	3	279
Q-9	12	12	4	2.8
Q-22	13	13	8	8.1
TOTAL	49	47	17	---
		SHALLOW BEDROCK WELLS		
FM-8	5 (5)***	1 (0)***	0 (0)***	0.1
FM-42**	15 (6)***	15 (6)***	14 (6)***	97 (20.8)***
FM-42A**	14 (1)***	9 (1)***	6 (0)***	11.1 (0.3)***
F-2	8	6	0	0.53
F-8	8	4	1	3.2
F-10	6	1	0	0.53
F-11	6	1	0	0.13
F-18S	6	4	0	0.2
F-23	9	8	0	0.42
Q-3	9	0	0	---
Q-14	8	1	0	0.17
Q-15	8	8	0	0.23
F-19	7	7	0	0.31
TOTAL	109	65	21	---
		DEEP BEDROCK WELLS		
FM-16	5 (5)***	0 (0)***	0 (0)***	-- (--)***
F-6	5	0	0	---
F-21	6	0	0	---
F-32	11	5	1	8.6
Q-1	11	1	0	0.1
Q-4	10	0	0	---
Q-5	6	0	0	---
Q-6	8	1	0	0.2
Q-16	9	1	0	0.1
Q-17	10	7	0	0.23
Q-18	6	0	0	---
Q-23	9	9	1	1.5
TOTAL	96	24	2	---

* Maximum is sum of all pesticide products detected.
**Incipient karst wells
***Value in parentheses is data for 1982-1983, from Libra et al., 1984.

Table 14. Pesticide detections in network wells, summarized by month.

Month	Number Sampled	Number of Detections
1/85	4	3
2/85	14	7
2/85	14	6
3/85	13	7
5/85	16	11
6/85	29	17 (59%)
7/85	26	15 (58%)
8/85	29	12 (48%)
9/85	5	5
10/85	29	15 (58%)
12/85	8	3
3/86	29	15 (58%)
4/86	10	7
5/86	22	14 (64%)
9/86	7	6

nuclear weapons released large quantities of tritium, resulting in precipitation over North America containing over 1000 T.U. (Freeze and Cherry, 1979). The low natural concentrations of tritium in pre-1953 precipitation, and the relatively short half-life of tritium, make this isotope useful for groundwater age determinations. Precipitation that fell and recharged the groundwater system before 1953 has very little tritium (<5 T.U.) remaining. Therefore, the tritium content of groundwater allows for a simple age classification into either pre-1953 or post-1953 water.

For this investigation, samples for tritium analysis were collected from the Site #2 and Site #3 bedrock and till piezometers, three private wells, and two tile lines. The piezometers were sampled twice — in August 1985, following an extended dry period, and in March 1986, within 1-2 weeks of snow melt and accompanying heavy rains. The private wells and tile lines were only sampled in March 1986. The samples were analyzed at the Environmental Isotope Laboratory, Department of Earth Sciences, University of Waterloo. Samples were collected from Site #3 piezometers to evaluate the age of groundwater from the various aquifers in the deep bedrock-ADW area. Samples from Site #2 were collected for comparison. Tritium concentrations in shallow groundwater (i.e., tile-line samples) are considered indicative of current recharge. Two of the private wells sampled were near ADW clusters, and generally produced water with <0.5-10 mg/L nitrate. The other private well is located in a deep bedrock area with no known ADWs. Results of the tritium analyses are given in Table 15, along with corresponding nitrate concentrations.

Tritium concentrations in shallow groundwater range from 17-52 T.U. (Table 15). Piezometer FM2-T showed rather high values, 45 T.U. in August 1985, and 52 T.U. in March 1986. The other shallow groundwater falls within a narrow range, 17-26 T.U. Thompson (1986) found similar values, 20 to 30 T.U., for the uppermost saturated zone of alluvial aquifers in western Iowa. During 1986, recharge in the Big Spring area of northeast Iowa contained 30 to 40 T.U. (I.D.N.R., unpublished data). Based on these data current recharge is estimated to contain 20 to 40 T.U. At Site #2, groundwater from the upper aquifer piezometers (FM2-1 and FM2-2) contained 7-18 T.U. The middle and lower aquifers (piezometers FM2-3 and FM2-4) contained <1 T.U. These data indicate the upper aquifer at this site contains post-1953 water, although tritium contents are somewhat low compared to shallow groundwater. The middle and lower aquifers contain insignificant post-1953 recharge water. Corresponding nitrate concentrations in the upper aquifer were 3-11 mg/L and <2 mg/L in the middle and lower aquifers.

The tritium data from the Site #2 bedrock piezometers appear consistent with the geologic setting. Depth to bedrock is 45 feet at Site #2 but is considerably less in much of the surrounding area; Site #2 lies on the border between a shallow bedrock area and an incipient karst area, and the incipient karst area in particular has a relatively thin (<20 feet) cover of low permeability materials overlying the upper aquifer. Post-1953 recharge has penetrated the surficial cover, and currently is a component of the groundwater contained in the

Table 15. Tritium and corresponding nitrate data from selected sampling sites.

		AUGUST 1985		MARCH 1986	
SITE TYPE	SITE	NITRATE (mg/L)	TRITIUM (T.U.)	NITRATE (mg/L)	TRITIUM (T.U.)
BEDROCK PIEZOMETERS	FM2-1	3.1	18	7	7
	FM2-2	6.5	12	11	14
	FM2-3	1.5	4	0.5	<1
	FM2-4	0.9	<1	<0.5	<1
	FM3-1	12	6	135	20
	FM3-2	1.5	25	<0.5	21
	FM3-3	0.9	24	<0.5	18
	FM3-4	1.7	24	17	16
SHALLOW GROUNDWATER	ADW-1	NOT FLOWING		54	17
	DT-3	NOT FLOWING		50	26
	FM2-T	80	45	54	52
	FM3-T	0.3	6	<.5	19
PRIVATE WELLS ADW AREA	Q-1	6	---	5	13
	Q-3	<5	---	<0.5	<1
PRIVATE WELL DEEP BEDROCK NON-ADW AREA	FM-16	<5	---	<5	<1

upper aquifer at Site #2. By contrast, the middle and lower aquifers at Site #2 lack pathways that would allow the delivery of post-1953 recharge. These aquifers subcrop below areas with a thin surficial cover, but these subcrop areas are tens of miles upgradient from Site #2 (see Fig. 4). Post-1953 recharge entering the middle and lower aquifer in such areas has yet to flow downgradient to Site #2. Potentiometric data indicate the potential for groundwater flow from the upper aquifer to the middle, and eventually, lower aquifer. However, the intervening confining beds, particularly the Chickasaw shale (Fig. 9), has sufficiently limited downward flow, restricting tritiated, post-1953 recharge water to the upper aquifer.

At Site #3, water from the uppermost bedrock piezometer (FM3-1) contained 6 and 20 T.U. in the August 1985 and March 1986 samples, respectively. Water from the other piezometers contained 16-25 T.U. during both sample collections. The presence of post-1953 water in all of the Devonian aquifers, in both wet and dry periods, is significant. As was described for Site #2, the middle and lower aquifer have no apparent natural pathways capable of delivering post-1953 recharge to Site #3. The upper aquifer at Site #3 is overlain by over 50 feet of low permeability materials and lies downgradient from similar deep bedrock areas. It is unlikely that large volumes of post-1953 recharge have penetrated this surficial cover. Given the hydrogeologic setting, the source of tritiated water in Site #3 piezometers is the nearby ADWs.

The March 1986 tritium data from Site #3, collected after snow melt and significant rain, fall within a narrow range, 16-21 T.U. (Table 15). This is consistent with the significant ADW inputs that had just occurred in the area. The samples collected in August 1985 followed an extended dry period, during which potentiometric elevations at Site #3 had declined for four months (Fig. 17). These samples indicate tritiated water had persisted in the aquifers, particularly in lower and middle aquifers (FM3-3 and FM3-4), and the lower part of the upper aquifer (FM3-2; Table 15). Only the shallow-most piezometer, FM3-1, produced water with a relatively low tritium content, 6 T.U. These data suggest that ADW inputs may be a volumetrically important form of recharge to the Devonian aquifers in the Site #3 area.

While significant tritium concentrations persisted in groundwater at Site #3 following an extended dry period, note that corresponding nitrate concentrations are relatively low (Table 15). Piezometers FM3-2, FM3-3, and FM3-4, with significant tritium contents (24-25 T.U.), contain less than 2 mg/L NO_3 (pesticide data are not available for this sample period; see pesticide monitoring section for explanation). If ADWs are responsible for the delivery of tritiated water to these piezometers, higher nitrate concentrations might also be expected. A possible explanation for the presence of tritiated, low nitrate water in piezometers FM3-2, FM3-3, and FM3-4 is the delivery of drainage water through ADWs, followed by denitrification. Denitrification involves the bacterially mediated reduction of nitrate to nitrous oxide (N_2O) or molecular nitrogen gas (N_2; Broadbent and Clark, 1965). In addition to a bacterial catalyst, denitrification requires the presence of organic carbon — either dissolved or suspended in the water or contained within the aquifer matrix itself — and anaerobic conditions. Numerous studies have discussed the occurrence and significance of denitrification in groundwater (e.g., Whitelaw and Rees, 1980; Hendry et al., 1983; Edmonds and Walton, 1983; Hallberg et al., 1983; Thompson, 1984; Howard, 1985; Trudell et al., 1986). The present study was not intended to address denitrification in groundwater. However, several lines of evidence suggest denitrification may affect nitrate concentrations in groundwater receiving ADW recharge. First, significant ADW inputs to the groundwater system originate as tile drainage following major recharge events. These events often cause waterlogged soils, and local ponding of water on fields. High moisture contents and ponding promote anaerobic conditions denitrification (Broadbent and Clark, 1965). Therefore, tile lines likely deliver anaerobic soil water — containing nitrate, organic carbon, and denitrifying bacteria — to groundwater via ADWs. Whether, and to what degree, this is occurring in the Floyd County ADW area cannot be stated at this time.

Samples for tritium analysis were collected from three private wells in March 1986 (Table 15). Well Q-1 (Fig. 11) is located within a concentration of ADWs, is in a deep bedrock area, and is completed in the upper aquifer. This well produced water with 13 T.U. and 5 mg/L NO_3. Well Q-3 (Fig. 11) is located on the downgradient edge of the same ADW cluster, is in a shallow bedrock area, and is completed in the middle aquifer. This well produced water with <1 T.U. and <0.1 mg/L NO_3. These data (and other data from these wells, Appendix A), suggest minor, but observable ADW effects at Q-1 — detectable ^3H and NO_3; ADW effects are not apparent at Q-3.

Well F-16 (Fig. 11) is located away from ADWs, is in a deep bedrock area, is completed in the middle aquifer, and is a flowing, discharge area well. This well has been sampled for nitrate and pesticides intermittently since 1982 (see Libra et al., 1984, and Appendix A, this report), and its hydrogeologic setting suggests it produces pre-1953 water (Libra et al., 1984). Detectable pesticides, or nitrate concentrations above 5 mg/L, have not been found in water from this well. The tritium content in March 1986 was <1 T.U., confirming the age of the water, and the utility of this well for quality control and assurance purposes (i.e., detection of pesticides, or nitrates above 5 mg/L, in water from this well would be considered erroneous).

IMPACT OF ADWs ON GROUNDWATER QUALITY

This section will evaluate the hydrogeologic and water-quality monitoring data from the Floyd-Mitchell county area, relative to the affects ADWs have on groundwater quality. Many of the ADWs in Floyd County are located in a deep bedrock area. During this investigation, relatively high (>5 mg/L) concentrations of nitrate, and detectable amounts of pesticides, were found to occur in water from private wells in this "ADW/deep-bedrock" area. Previous investigations in Iowa (Hallberg and Hoyer, 1982; Hallberg et al., 1983, 1984; Libra et al., 1984) have shown that private wells in deep bedrock areas are largely protected from surficially-derived contamination. Therefore, the presence of agricultural contaminants in private wells in the Floyd County ADW/deep-bedrock area may be related to ADW inputs. Data from these wells will be compared to the ADW-derived effects on groundwater quality documented at the Site #3 piezometers. In the ADW/deep-bedrock area, complete and reliable construction information for most of the private wells monitored is not available. The available data — largely from the individual landowners' knowledge or records — suggests that most wells are 150-200 feet deep, and cased only to bedrock (50 to 80 feet). (Past field surveys suggest that 75-80% of owners' knowledge or records are accurate.) The open interval of most of these wells is in the upper aquifer, and is comparable to the combined open intervals of piezometers FM3-1 and FM3-2 (Fig. 10). The response of these two piezometers to ADW recharge, in terms of water quality, is very different; FM3-1 shows a dramatic impact, while FM3-2 is virtually unaffected. Most private wells are open to larger stratigraphic intervals than the bedrock piezometers, and samples from these wells integrate groundwater quality from all contributing strata. Therefore, ADW effects at private wells may be less dramatic than these noted at FM3-1, but more so than those at FM3-2.

Data from the 11 private wells in the ADW/deep-bedrock area are summarized in Table 16. Data from five of these wells, F-6, F-21, Q-4, Q-5, and Q-18, do not appear to indicate ADW effects. Pesticides were not detected at these wells and nitrates concentrations rarely exceeded 5 mg/L. The occasional higher nitrate concentrations may or may not be related to ADWs. Note that wells Q-4 and Q-5 are located within 1/4 mile of several ADWs (see Figs. 5 and 11), yet appear unaffected by the ADWs. Two of the wells summarized in Table 16, Q-16 and Q-17, had relatively high (24-73 mg/L) and constant (NO_3 C.V. = 5-13) concentrations of nitrate. Q-17 also showed relatively constant pesticide occurrences, with 7 of 10 samples containing detectable atrazine, ranging from 0.1 to 0.23 µg/L. These consistent concentrations are very different from the ADW effects documented at Site #3, where variable nitrate and pesticide concentrations are characteristic. The source of contamination in these wells is not obvious. The construction and location of these wells does not appear to be the cause.

Well Q-1 is shallower than the other private wells summarized in Table 16. The owner's comments regarding the well indicate it is about 75 feet deep, and cased to about 55 feet. This well is located about 1/2 mile from Site #3, and is similar in construction to piezometer FM3-1. Nitrate concentrations averaged 5 mg/L, atrazine was detected once, and tritiated water was present in March 1986. Data from this well are not comparable to those seen at piezometer FM3-1 and are inconclusive with respect to ADW effects. Any such effects appear minimal.

Wells F-32 and Q-23 lie southeast of the main concentration of ADWs (Figs. 5 and 11) in a generally downgradient direction. F-32, in particular, is within about one mile of several ADWs. Nitrates were quite variable at F-32, ranging from <5-50 mg/L (NO_3 C.V. = 49). Pesticides were detected in about one-half of the samples collected with a maximum concentration over 8 µg/L (Table 16). All other analyses were below 0.3 µg/L. High nitrate and pesticide concentrations occurred during wetter months, March-May of 1985 and 1986, when significant ADW inputs occurred. The highest pesticide concentration is similar to those present in tile lines, surface waters, and piezometer FM3-1. The location and data from F-32 suggest ADW inputs reach this well.

Table 16. Summary of monitoring data from the ADW/deep-bedrock area.

SITE	AVERAGE NITRATE mg/L	RANGE NITRATE mg/L	NITRATE C.V.	PESTICIDES DETECTIONS/ SAMPLES	PESTICIDES MAXIMUM µg/L
F-6	<5	<0.5 - 32	---	0/5	---
F-21	<5	<0.5 - 9	---	0/6	---
F-32	20	<5 - 50	49	5/11	8.6
Q-1	5	<5 - 8	---	1/11	0.1
Q-4	<5	<0.5 - 5	---	0/10	---
Q-5	<5	<0.5 - 20	---	0/6	---
Q-6	9	<0.5 - 44	146	1/8	0.2
Q-16	28	24 - 28	13	1/9	0.1
Q-17	66	61 - 73	5	7/10	0.23
Q-18	<5	<0.5 - 9	---	0/6	---
Q-23	3	26 - 59	29	9/9	1.5

Well Q-23 lies about one mile further from ADWs than F-32. Q-23 has less variable nitrate concentrations (C.V. = 29) than F-32, and pesticides were detected in all analyzed samples with a maximum concentration of 1.5 µg/L (Table 16). This well lies near the mapped boundary between the deep- and shallow-bedrock regions; these boundaries do not represent a sudden change from a susceptible to a protected environment. Therefore, it is difficult to assess whether the ag-contaminants observed at Q-23 are related to ADWs, to the natural delivery of agricultural chemicals in shallow bedrock areas, or to a combination of both.

The last well possibly impacted by ADWs is Q-6. During relatively dry periods, nitrate concentrations at Q-6 were consistently less than 5 mg/L, and below 0.5 mg/L when lower detection limits were used (Table 16). During wet periods, nitrate often exceeded 20 mg/L (maximum 43 mg/L NO_3), and pesticides were detected once (May 1986, 0.2 µg/L). This well is 1-2 miles from the main concentration of ADWs (Figs. 5 and 11). The range of nitrate concentrations, from undetectable during dry periods to approaching the MCL during wet periods, is suggestive of the ADW impacts noted at the Site #3 piezometers.

SUMMARY

1. Data from the Site #3 bedrock piezometers clearly show that ADWs negatively affect groundwater quality. Monitoring of these piezometers indicates complex hydrogeologic controls affect the movement of water and agricultural chemicals delivered by ADWs. Within certain stratigraphic intervals ADW recharge delivers pesticides, and may generate nitrate concentrations several times the MCL; other horizons are virtually unaffected.

2. Delivery of contaminants via ADW is variable, and is most prominent following major recharge events. In this, ADWs are similar to other contaminant delivery mechanisms, such as infiltration to shallow aquifers or runoff to sinkholes. During extended dry periods, the effects of ADWs become increasingly less prominent.

3. Some private wells located within approximately one mile of a concentration of ADWs receive agricultural chemicals via ADW inputs. These wells have variable nitrate and pesticide concentrations that are consistent with occasional inputs of nitrate-and pesticide-bearing tile drainage (and possibly surface water) into otherwise naturally

protected aquifers. Other private wells located within one mile of some ADWs are virtually unaffected by ADWs. This occurs even though the private wells monitored are completed within the upper aquifer, which is completely penetrated by some ADWs. The groundwater flow paths in fractured carbonate aquifers are complex and make prediction of ADW effects at a given well difficult.

4. Concentrations of nitrate and pesticides in groundwater affected by ADWs are similar to the concentrations generated by natural processes in groundwater from shallow bedrock and karst areas.

5. Where numerous ADWs exist, the volume of water they deliver to receiving aquifers may be significant. Limited data suggest the delivery of ADW water to aquifers may result in conditions favorable for denitrification within the groundwater system.

ACKNOWLEDGMENTS

The efforts and cooperation of many individuals and agencies were instrumental to the completion of this project and the preparation of this report. Retired U.S.D.A.-S.C.S. soil scientists Kermit Voy and Russ Buckner, with their many years of experience in the area, contributed insights concerning soils, sinkholes, and the Floyd County landscape, as well as the locations of karst features, ADWs, and previously unknown bedrock exposures. S.C.S. staff, along with staff from the Iowa State University-Cooperative Extension Service, provided local support and many contacts with Floyd County residents. The University Hygienic Laboratory performed the water quality analyses; in particular we wish to acknowledge Gene Ronald, Lee Friell, and Lauren Johnson and their staffs for their assistance and helpful discussions. Financial support for the project was provided by the U.S.E.P.A.-Region VII; we are particularly grateful for the efforts of Ralph Langemier and Julie Elfving.

Many GSB staff aided in the completion of this project and report. Bernie Hoyer contributed to the original project design, and has provided leadership and support for many of GSBs environmental monitoring efforts. The coreholes were drilled and the monitoring wells constructed by Darwin Evans, former Research Driller with GSB. His observations during the drilling and testing of the holes were, as always, invaluable. The efforts of Bill Bunker and Brian Witzke to reinterpret the Devonian stratigraphy of Iowa were crucial to the authors understanding of the hydrology of these rocks. Tim Kemmis, Eve Watson, Carol Thompson, and Mary Skopec provided editorial reviews of the manuscript; it was improved as a result. Pat Lohmann oversaw the design, layout, and production of the report, and prepared many of the graphics it contains.

Last, but far from least, we wish to acknowledge the cooperation of the many Floyd and Mitchell county residents we have encountered during more than a decade of investigations in the region. They have given freely of their time, provided information on water and drainage wells, geologic features and agricultural practices, and allowed access to their property. Without such freely-given cooperation, we could not increase our knowledge of the natural resources that we all share.

REFERENCES

Baker, J.L., and Austin, T.A., 1984, Impact of Agricultural drainage wells on groundwater quality: Project 2450, I.S.U.-E.R.I. - Ames - 85183, 238 p.

Baker, J., Kanwar, R., and Austin, T., 1985, Impact of agricultural drainage wells on groundwater quality: Journal of Soil and Water Conservation, v. 40, p. 516-520.

Broadbent, F.E., and Clark, F., 1965, Denitrification, *in* Bartholomew, ed, W.V., Soil Nitrogen, Agronomy Monograph #10, Madison, WI, American Society of Agronomy, p. 344-359.

Cherryholmes, K.L., and Gockel, M.L., 1987, Iowa agricultural drainage well assessment report: U.S.E.P.A., Contract Report #G007273010, University Hygienic Laboratory, Iowa City, IA, 26 p.

Edmonds, W.M., and Walton, N.R.G., 1983, The Lincolnshire Limestone-hydrochemical evolution over a ten-year period: Journal of Hydrology, v. 61, p. 201-211.

Freeze, A., and Cherry, J., 1979, Groundwater: Prentice-Hall, N.J., 604 p.

Hallberg, G., 1986, Overview of agricultural chemicals in groundwater, *in* Agricultural Impacts on Groundwater: Dublin, OH, National Water Well Association, p. 1-66.

Hallberg, G.R., and Hoyer, B.E., 1982, Sinkholes, hydrogeology, and groundwater quality in northeast Iowa: Iowa Geological Survey, Open-File Report 82-3, 120 p.

Hallberg, G.R., Hoyer, B.E., Bettis, E.A., III, and Libra, R.D., 1983, Hydrogeology, water quality, and land management in the Big Spring basin, Clayton County, Iowa: Iowa Geological Survey, Open-File Report 83-3, 191 p.

Hallberg, G.R., Libra, R.D., Bettis, E.A. III, and Hoyer, B.E., 1984, Hydrogeologic and water quality investigations in the Big Spring basin, Clayton County, Iowa - 1983 water year: Iowa Geological Survey, Open-File Report 84-4, 231 p.

Hallberg, G., Libra, R., and Hoyer, B., 1985, Non-point source contamination of groundwater in karst-carbonate aquifers in Iowa, *in* Perspectives On Non-point Pollution: Washington, D.C., U.S.E.P.A. - Office of Water Regulations and Standards, p. 109-114.

Hallberg, G.R., Libra, R. D., Quade, D. J., Littke, J., and Nations, B., 1989, Groundwater monitoring in the Big Spring basin 1984-1987: a summary review: Iowa Department of Natural Resources Technical Information Series 16, 68 p.

Hendry, M., Gilham, R., and Cherry, J., 1983, An integrated approach to hydrogeologic investigations - a case history: Journal of Hydrology, v. 63, p. 211-232.

Horick, P., 1984, Silurian-Devonian aquifer of Iowa: Iowa Geological Survey, Miscellaneous Map Series #10.

Howard, K.W.F., 1985, Denitrification in a major limestone aquifer: Journal of Hydrology, v. 76, p. 265-280.

Isenhart, T.M., and Crumpton, W.G., 1989, Transformation and loss of nitrate in an agricultural stream: Journal of Freshwater Ecol., v. 15, p. 123-129.

Libra, R.D., Hallberg, G.R., Ressmeyer, G.G., and Hoyer, B.E., 1984, I. Groundwater quality and hydrogeology of Devonian-carbonate aquifers in Floyd and Mitchell counties, Iowa: Iowa Geological Survey, Open-File Report 84-2, p. 1-106.

Libra, R., and Hallberg, G., 1985, I. Hydrogeologic observations from multiple core holes and piezometers in the Devonian-carbonate aquifers in Floyd and Mitchell counties, Iowa: Iowa Geological Survey, Open-File Report 85-2, p. 1-19.

Libra, R., Hallberg, G., Hoyer, E., and Johnson, L., 1986, Agricultural Impacts on groundwater quality: the Big Spring basin study, *in* Agricultural Impacts on Groundwater: Dublin, OH, National Water Well Association, p. 253-273.

Libra, R.D., Hallberg, G.R., Littke, J.P., Nations, B.K., Quade, D.J., and Rowden, R.D., 1991. Groundwater monitoring in the Big Spring basin 1988-1989: a summary review: Iowa Department of Natural Resources, Technical Information Series 21, 29 p.

Libra, R.D. and Hallberg, G.H., 1993, Agricultural drainage wells in Iowa: hydrogeologic settings and water-quality implications: Iowa Department of Natural Resources, Technical Information Series 24, 39 p.

Munter, J., 1980, Evaluation of the extent of hazardous waste contamination in the Charles City area: Iowa Geological Survey, Contract Report, 74 p.

Musterman, J.L., Fisher, R.A., and Drake, L., 1981, Underground injection control in Iowa, project termination: Office of Drinking Water, Environmental Protection Agency, Department of Environmental Engineering, University of Iowa.

Payne, B., 1972, Isotope Hydrology: Advances in Hydroscience, v. 8, p. 95-138.

Thompson, C., 1984, Hydrogeology and water quality of the upper Des Moines River alluvial aquifer: Iowa Geological Survey, Open-File Report 84-5, 169 p.

Thompson, C., 1986, Water Resources of the Ocheyedan-Little Sioux alluvial aquifer: Iowa Department of Natural Resources, Open-File Report 86-3, 90 p.

Trudell, M., Gilham, R., and Cherry, J., 1986, An in-situ study of the occurrence and rate of denitrification in a shallow unconfined sand aquifer: Journal of Hydrology, v. 83, p. 251-268.

Walton, W.C., 1962, Selected analytical methods for well and aquifer evaluation: Illinois State Water Survey Bull. 49, 81 p.

Whitelaw, K., and Rees, J.F., 1980, Nitrate-reducing and ammonium-oxidizing bacteria in the vadose zone of the Chalk Aquifer of England: Geomicrobiology Journal, v. 2, no. 2, p. 179-187.

Witzke, B.J., and Bunker, B.J., 1984, II. Devonian stratigraphy of north-central Iowa: Iowa Geological Survey, Open-File Report 84-2, p. 107-149.

Witzke, B.J., and Bunker, B.J., 1985, II. Stratigraphic framework for the Devonian aquifers in Floyd and Mitchell counties, Iowa: Iowa Geological Survey, Open-File Report 85-2, p. 21-32.

Witzke, B.J., Bunker, B.J., and Rogers, F.S., 1988, Eifelian through Lower Frasnian Stratigraphy and deposition in the Iowa area, central midcontinent, U.S.A., *in* Devonian of the World, v.1, Canadian Journal of Petroleum Geologists Memoir 14, p. 221-250.

APPENDIX

Monitoring Network Data

ABBREVIATIONS USED IN THIS APPENDIX

mg/L	milligrams per liter
N	Nitrate (NO_3)
Total Coliform	Most Probable Number (MPN) count for Total Coliform Bacteria
μg/L	micrograms per liter
N.A.	not available

						Herbicides				
Site Name	Date	Nitrate (mg/L)	Organic N	NH4 N	Total Coliform	Atrazine (µg/L)	Cyanazine (µg/L)	Metolachlor (µg/L)	Alachlor (µg/L)	Metribuzin (µg/L)
Private Wells										
Deep Bedrock Region										
F-06	01/09/85	<5			0					
F-06	02/12/85	<5			0					
F-06	02/27/85	<5			0					
F-06	03/25/85	<5			0					
F-06	05/06/85									
F-06	06/19/85	<5			0					
F-06	07/24/85	<5			0	<0.1	<0.1	<0.1	<0.1	<0.1
F-06	08/21/85	<5			0	<0.1	<0.1	<0.1	<0.1	<0.1
F-06	09/18/85	0.1								
F-06	10/23/85	0.0	0.01	0.01		<0.1	<0.1	<0.1	<0.1	<0.1
F-06	12/18/85	0.0			0					
F-06	03/25/86	4.0	0.01	0.01		<0.1	<0.1	<0.1	<0.1	<0.1
F-06	04/29/86	32.0			2.2					
F-06	05/28/86	14.0			>16	<0.1	<0.1	<0.1	<0.1	<0.1
F-21	01/09/85	<5			16					
F-21	02/12/85	<5			0					
F-21	02/27/85	<5			0					
F-21	03/25/85	<5			0					
F-21	05/06/85	<5			0					
F-21	06/19/85	<5			0	N.A.	<0.1	<0.1	<0.1	<0.1
F-21	07/24/85	0.7			0	<0.1	<0.1	<0.1	<0.1	<0.1
F-21	08/21/85	<5			0	<0.1	<0.1	<0.1	<0.1	<0.1
F-21	09/18/85	<5								
F-21	10/23/85	0.0	0.01	0.04		<0.1	<0.1	<0.1	<0.1	<0.1
F-21	12/18/85	<5			0					
F-21	03/25/86	<5			0	<0.1	<0.1	<0.1	<0.1	<0.1
F-21	04/29/86	9.0			0					
F-21	05/28/86	<5			16	<0.1	<0.1	<0.1	<0.1	<0.1
F-32	01/09/85	19.0			0					
F-32	02/12/85	17.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
F-32	02/27/85	16.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
F-32	03/25/85	19.0			0					
F-32	05/06/85	16.0			0	5.00	0.82	2.80	<0.1	<0.1
F-32	06/19/85	19.0			0	<0.1	<0.1	0.28	<0.1	<0.1
F-32	07/24/85	<5			0	<0.1	<0.1	0.15	<0.1	<0.1
F-32	08/21/85	19.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
F-32	09/18/85	19.0			0	0.13	<0.1	<0.1	<0.1	<0.1
F-32	10/23/85	17.0			0	0.16	<0.1	<0.1	<0.1	<0.1
F-32	12/18/85	19.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
F-32	03/25/86	50.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
F-32	04/29/86	28.0			0					
F-32	05/28/86	26.0			0					
FM-16	01/09/85	<5			16					
FM-16	02/12/85	<5			0					
FM-16	02/27/85	<5			2.2	<0.1	<0.1	<0.1	<0.1	<0.1
FM-16	03/25/85	<5			0					
FM-16	05/06/85	<5			0					
FM-16	06/19/85	<5			0	<0.1	<0.1	<0.1	<0.1	<0.1
FM-16	07/24/85	7.0			0					
FM-16	08/21/85	<5			0	<0.1	<0.1	<0.1	<0.1	<0.1
FM-16	09/18/85	0.0								
FM-16	10/23/85	0.5	0.08	1		0.10	<0.1	<0.1	<0.1	<0.1
FM-16	12/18/85	0.0	0.03	1.1						
FM-16	03/25/86	<5			0	<0.1	<0.1	<0.1	<0.1	<0.1
FM-16	04/29/86	9.0								
FM-16	05/28/86	0.0	1.02	1.2		<0.1	<0.1	<0.1	<0.1	<0.1
Q-01	01/09/85	6.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-01	02/12/85	6.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-01	02/27/85	5.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-01	03/25/85	5.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-01	05/06/85	<5			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-01	06/19/85	5.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-01	07/24/85	8.0			2.2	<0.1	<0.1	<0.1	<0.1	<0.1
Q-01	08/21/85	6.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-01	09/18/85	5.3								
Q-01	10/23/85	4.5	0.01	0.01		0.10	<0.1	<0.1	<0.1	<0.1
Q-01	12/18/85	5.9	0.01	0.01	0	<0.1	<0.1	<0.1	<0.1	<0.1

						Herbicides				
Site Name	Date	Nitrate (mg/L)	Organic N	NH4 N	Total Coliform	Atrazine (µg/L)	Cyanazine (µg/L)	Metolachlor (µg/L)	Alachlor (µg/L)	Metribuzin (µg/L)
Deep Bedrock Region-cont.										
Q-01	03/25/86	5.0	0.01	0.01		<0.1	<0.1	<0.1	<0.1	<0.1
Q-01	04/29/86	5.0	0.01	0.05						
Q-01	05/28/86	6.8	0.21	0.17						
Q-04	01/09/85				0					
Q-04	02/12/85	2.0				<0.1	<0.1	<0.1	<0.1	<0.1
Q-04	02/27/85	2.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-04	03/25/85	2.0			0					
Q-04	05/06/85	2.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-04	06/19/85	2.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-04	07/24/85	2.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-04	08/21/85	2.0			2.2	<0.1	<0.1	<0.1	<0.1	<0.1
Q-04	09/18/85	0.0								
Q-04	10/23/85	0.5	0.01	0.28		<0.1	<0.1	<0.1	<0.1	<0.1
Q-04	12/18/85	0.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-04	03/25/86	0.0	0.01	0.27		<0.1	<0.1	<0.1	<0.1	<0.1
Q-04	04/29/86	0.0	0.4	0.4						
Q-04	05/28/86	0.0	0.01	0.33		<0.1	<0.1	<0.1	<0.1	<0.1
Q-05	01/09/85	2.0			0					
Q-05	02/12/85									
Q-05	02/27/85	2.0			0					
Q-05	03/25/85	2.0			0					
Q-05	05/06/85	2.0			0					
Q-05	06/19/85	2.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-05	07/24/85	20.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-05	08/21/85	2.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-05	09/18/85	0.0			0					
Q-05	10/23/85	0.0	0.01	0.26	0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-05	12/18/85	0.0	0.09	0.32	0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-05	03/25/86	0.0	0.01	0.38		<0.1	<0.1	<0.1	<0.1	<0.1
Q-05	04/29/86	0.0	0.4	0.41						
Q-05	05/28/86	0.0	0.01	0.35		<0.1	<0.1	<0.1	<0.1	<0.1
Q-06	01/09/85	2.0			0					
Q-06	02/12/85	2.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-06	02/27/85	2.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-06	03/25/85	11.0			5.1					
Q-06	05/06/85									
Q-06	06/19/85	2.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-06	07/24/85	2.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-06	08/21/85	2.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-06	09/18/85	0.0								
Q-06	10/23/85	0.5	0.01	0.01		<0.1	<0.1	<0.1	<0.1	<0.1
Q-06	12/18/85	24.0			2.2					
Q-06	03/25/86	0.0	0.01	0.07		<0.1	<0.1	<0.1	<0.1	<0.1
Q-06	04/29/86	43.7	0.01	0.03						
Q-06	05/28/86	28.0	0.01	0.15	5.1	0.19	<0.1	<0.1	<0.1	<0.1
Q-17	11/10/84	67.0			0					
Q-17	01/09/85	66.0			0					
Q-17	02/12/85	63.0			0	0.12	<0.1	<0.1	<0.1	<0.1
Q-17	02/27/85	65.0			0	0.13	<0.1	<0.1	<0.1	<0.1
Q-17	03/25/85	64.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-17	05/06/85	68.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-17	06/19/85	61.0			0	0.11	<0.1	<0.1	<0.1	<0.1
Q-17	07/24/85	63.0			0	0.23	<0.1	<0.1	<0.1	<0.1
Q-17	08/21/85	65.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-17	09/18/85	63.0			0		<0.1	<0.1	<0.1	<0.1
Q-17	10/23/85	63.0			0	0.18	<0.1	<0.1	<0.1	<0.1
Q-17	12/18/85	64.0			0		<0.1	<0.1	<0.1	<0.1
Q-17	03/25/86	66.0			>16	0.13	<0.1	<0.1	<0.1	<0.1
Q-17	04/29/86	72.0			0					
Q-17	05/28/86	73.0			0	0.15	<0.1	<0.1	<0.1	<0.1
Q-18	11/10/84	<5			0					
Q-18	01/09/85				0					
Q-18	02/12/85	<5			0					
Q-18	02/27/85	<5			0					
Q-18	03/25/85	<5			0					
Q-18	05/06/85	<5			>16					
Q-18	06/19/85	<5			0	<0.1	<0.1	<0.1	<0.1	<0.1

Site Name	Date	Nitrate (mg/L)	Organic N	NH4 N	Total Coliform	Herbicides Atrazine (µg/L)	Cyanazine (µg/L)	Metolachlor (µg/L)	Alachlor (µg/L)	Metribuzin (µg/L)
Deep Bedrock Region-cont.										
Q-18	07/24/85	<5			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-18	08/21/85	<5			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-18	09/18/85	<0.1								
Q-18	10/23/85	0.5	0.1	0.37		<0.1	<0.1	<0.1	<0.1	<0.1
Q-18	12/18/85	<5			0					
Q-18	03/25/86	<5			9.2	<0.1	<0.1	<0.1	<0.1	<0.1
Q-18	04/29/86	9.0			2.2					
Q-18	05/28/86	<5			2.2	<0.1	<0.1	<0.1	<0.1	<0.1
Q-16	11/10/84	26			0					
Q-16	01/09/85	31			0					
Q-16	02/12/85	26			0	<0.10	<0.10	<0.10	<0.10	<0.10
Q-16	02/27/85	25			0	<0.10	<0.10	<0.10	<0.10	<0.10
Q-16	03/25/85	26			0	<0.10	<0.10	<0.10	<0.10	<0.10
Q-16	05/06/85	25			0					
Q-16	06/19/85	24			0	0.16	<0.10	<0.10	<0.10	<0.10
Q-16	07/24/85	31			0	<0.10	<0.10	<0.10	<0.10	<0.10
Q-16	08/21/85	28			0	<0.10	<0.10	<0.10	<0.10	<0.10
Q-16	09/18/85	28			0					
Q-16	10/23/85	25			0	0.10	<0.10	<0.10	<0.10	<0.10
Q-16	12/18/85	26			0					
Q-16	03/25/86	27			0	<0.10	<0.10	<0.10	<0.10	<0.10
Q-16	04/29/86	38			0					
Q-16	05/28/86	32			0	<0.10	<0.10	<0.10	<0.10	<0.10
Q-23	02/12/85	33.0			0					
Q-23	02/27/85	31.0			16					
Q-23	03/25/85	29.0			5.1					
Q-23	05/06/85	29.0			5.1	0.34	<0.1	<0.1	<0.1	<0.1
Q-23	06/19/85	26.0			>16	0.34	<0.1	<0.1	<0.1	<0.1
Q-23	07/24/85	34.0			>16	0.50	<0.1	<0.1	<0.1	<0.1
Q-23	08/21/85	30.0			0	0.40	<0.1	<0.1	<0.1	<0.1
Q-23	09/18/85	54.0			5.1	0.64	<0.1	<0.1	<0.1	<0.1
Q-23	10/23/85	32.0			>16	0.61	<0.1	<0.1	<0.1	<0.1
Q-23	12/18/85	27.0			>16					
Q-23	03/25/86	43.0				0.65	<0.1	0.12	<0.1	<0.1
Q-23	04/29/86	55.0			0	0.80	<0.1	<0.1	<0.1	<0.1
Q-23	05/28/86	59.0			>16	<0.1	<0.1	<0.1	<0.1	<0.1
Q-23	09/09/86	40.5	0.13	0.04		1.30	<0.1	0.24	<0.1	<0.1
Incipient Karst Region										
FM-42	11/10/84	79.0			0					
FM-42	01/09/85	74.0			5.1	0.10	0.75	<0.1	60.00	16.00
FM-42	02/12/85	82.0			0	<0.1	2.00	<0.1	46.00	9.00
FM-42	02/27/85	82.0			2.2	<0.1	<0.1	<0.1	50.00	20.00
FM-42	03/25/85	75.0			0	<0.1	0.51	<0.1	25.00	3.70
FM-42	05/06/85	57.0			0	<0.1	0.93	<0.1	19.00	18.00
FM-42	06/19/85	72.0			0	<0.1	1.10	<0.1	41.00	9.90
FM-42	07/24/85	79.0			0	<0.1	1.00	<0.1	44.00	7.00
FM-42	08/21/85	83.0			9.2	<0.1	2.10	<0.1	65.00	30.00
FM-42	09/18/85	71.0			9.2	<0.1	1.10	<0.1	44.00	27.00
FM-42	10/23/85	60.0			0	<0.1	<0.1	<0.1	15.00	<0.1
FM-42	12/18/85	68.0	0.15	0.03		<0.1	4.00	<0.1	65.00	<0.1
FM-42	03/25/86	54.0	0.01	0.01		<0.1	0.57	0.10	12.00	3.80
FM-42	04/29/86	66.0				<0.1	0.16	<0.1	8.9	<0.1
FM-42	05/28/86	61.0			0	<0.1	0.41	<0.1	10.0	3.00
FM-42	09/09/86	45.0	0.57	0.13		<0.1	1.30	<0.1	47.00	10.00
FM-42A	01/09/85	79.0								
FM-42A	02/12/85				0	<0.1	<0.1	<0.1	<0.1	<0.1
FM-42A	02/27/85	54.0			2.2	<0.1	<0.1	<0.1	<0.1	<0.1
FM-42A	03/25/85	52.0			9.2	0.18	<0.1	<0.1	<0.1	<0.1
FM-42A	05/06/85	20.0			0	0.15	<0.1	<0.1	0.43	0.36
FM-42A	06/19/85	38.0			0	0.10	<0.1	<0.1	4.40	0.32
FM-42A	07/24/85	44.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
FM-42A	08/21/85	53.0			>16	<0.1	<0.1	<0.1	0.68	<0.1
FM-42A	09/18/85	43.0			2.2	0.14	0.13	<0.1	8.00	2.80
FM-42A	10/23/85	34.0			9.2	<0.1	<0.1	<0.1	1.70	1.10
FM-42A	12/18/85	45.0	0.01	0.01		<0.1	0.22	<0.1	0.30	<0.1
FM-42A	03/25/86	45.0	0.1	0.01		<0.1	<0.1	<0.1	3.10	0.52
FM-42A	04/29/86	37.0	0.1	0.01		<0.1	<0.1	<0.1	3.10	0.52
FM-42A	05/28/86	42.0			5.1	<0.1	<0.1	<0.1	<0.1	<0.1
FM-42A	09/09/86	41.9	0.09	0.15		<0.1	<0.1	<0.1	0.21	<0.1

Site Name	Date	Nitrate (mg/L)	Organic N	NH4 N	Total Coliform	Herbicides Atrazine (µg/L)	Cyanazine (µg/L)	Metolachlor (µg/L)	Alachlor (µg/L)	Metribuzin (µg/L)
Karst Region										
FM-22	01/09/85	49.0			0	0.17	<0.1	<0.1	<0.1	<0.1
FM-22	02/12/85	52.0			0	0.26	<0.1	<0.1	<0.1	<0.1
FM-22	02/27/85	51.0			0	0.21	<0.1	<0.1	<0.1	<0.1
FM-22	03/25/85	51.0			0	0.20	<0.1	<0.1	<0.1	<0.1
FM-22	05/06/85	52.0			0	0.25	<0.1	<0.1	<0.1	<0.1
FM-22	06/19/85					0.20	<0.1	<0.1	<0.1	<0.1
FM-22	07/24/85	53.0			0					
FM-22	08/21/85	51.0			0	0.18	<0.1	<0.1	<0.1	<0.1
FM-22	09/18/85	54.0			0					
FM-22	10/23/85	47.0			2.2	<0.1	<0.1	<0.1	<0.1	<0.1
FM-22	12/18/85	48.0			0					
FM-22	03/25/86	31.0			>16	0.20	<0.1	<0.1	<0.1	<0.1
FM-22	04/29/86	45.0			0	0.15	<0.1	<0.1	<0.1	<0.1
FM-22	05/28/86	36.0			0	0.26	<0.1	<0.1	<0.1	<0.1
FM-53	01/09/85	26.0			0					
FM-53	02/12/85	23.0			0					
FM-53	02/27/85	23.0			>16					
FM-53	03/25/85	25.0			9.2					
FM-53	05/06/85	24.0			0					
FM-53	06/19/85	25.0			>16	0.28	<0.1	<0.1	<0.1	<0.1
FM-53	07/24/85	31.0			5.1	0.23	<0.1	<0.1	<0.1	0.10
FM-53	08/21/85	27.0			2.2	0.24	<0.1	<0.1	<0.1	<0.1
FM-53	09/18/85	26.0			16					
FM-53	10/23/85	25.0			5.1	0.21	<0.1	<0.1	<0.1	<0.1
FM-53	12/18/85	27.0	0.06	0.01	0					
FM-53	03/25/86	29.0			5.1	0.45	<0.1	<0.1	<0.1	0.11
FM-53	04/29/86	40.0			0	0.35	0.35	<0.1	<0.1	<0.1
FM-53	05/28/86	35.0			0	0.44	<0.1	<0.1	<0.1	<0.1
Q-08	02/12/85	25.0			0					
Q-08	02/27/85	27.0			2.2					
Q-08	03/25/85	30.0			2.2					
Q-08	05/06/85	25.0			>16					
Q-08	06/19/85	25.0			0	<0.1	<0.1	<0.1	0.56	<0.1
Q-08	07/24/85	31.0			0	<0.1	<0.1	<0.1	0.62	<0.1
Q-08	08/21/85	29.0			0	<0.1	<0.1	<0.1	0.26	<0.1
Q-08	09/18/85	28.0			0					
Q-08	10/23/85	29.0			0	<0.1	<0.1	<0.1	6.90	<0.1
Q-08	12/18/85	32.0			2.2					
Q-08	03/25/86	28.0			>16	0.15	<0.1	<0.1	30.00	<0.1
Q-08	04/29/86	49.0			>16					
Q-08	05/28/86	59.0			>16	13.00	1.80	14.00	250.00	<0.1
Q-08	09/09/86	32.0	0.18	0.13		0.27	<0.1	<0.1	3.30	<0.1
Q-09	01/09/85	35.0			>16	0.22	<0.1	<0.1	<0.1	<0.1
Q-09	02/12/85	35.0			5.1	0.18	<0.1	<0.1	<0.1	<0.1
Q-09	02/27/85	19.0			>16	0.29	<0.1	<0.1	<0.1	<0.1
Q-09	03/25/85	25.0			9.2	0.23	<0.1	0.15	<0.1	<0.1
Q-09	05/06/85	37.0			0	0.17	<0.1	<0.1	<0.1	<0.1
Q-09	06/19/85	32.0			0	0.23	<0.1	<0.1	<0.1	<0.1
Q-09	07/24/85	42.0			2.2	0.84	<0.1	0.25	<0.1	<0.1
Q-09	08/21/85	35.0			0	0.10	<0.1	<0.1	<0.1	<0.1
Q-09	09/18/85	36.0			0					
Q-09	10/23/85	46.0			>16	0.60	<0.1	<0.1	<0.1	<0.1
Q-09	12/18/85	43.0			>16					
Q-09	03/25/86	41.0	0.1	0.01		0.34	<0.1	<0.1	<0.1	<0.1
Q-09	04/29/86	49.0			>16	0.42	<0.1	<0.1	<0.1	<0.1
Q-09	05/28/86	57.0			>16	0.49	<0.1	0.67	1.60	<0.1
Q-09	09/09/86	41.0	0.06	0.07		0.60	<0.1	<0.1	<0.1	<0.1
Q-22	01/09/85									
Q-22	02/12/85	56.0			5.1	1.30	<0.1	<0.1	<0.1	<0.1
Q-22	02/27/85	24.0			>16	1.40	<0.1	0.20	<0.1	<0.1
Q-22	03/25/85	27.0			5.1	1.40	<0.1	<0.1	<0.1	<0.1
Q-22	05/06/85	41.0			>16	0.59	<0.1	<0.1	<0.1	7.50
Q-22	06/19/85	51.0			>16	2.20	<0.1	0.55	0.40	1.80
Q-22	07/24/85	55.0			>16	1.50	<0.1	0.23	<0.1	1.50
Q-22	08/21/85	60.0			>16	1.50	<0.1	<0.1	<0.1	<0.1
Q-22	09/18/85	50.0			>16	1.80	<0.1	<0.1	<0.1	0.66
Q-22	10/23/85	44.0			>16	1.00	<0.1	<0.1	<0.1	<0.1
Q-22	12/18/85	41.0			>16	0.81	<0.1	<0.1	<0.1	0.12

Site Name	Date	Nitrate (mg/L)	Organic N	NH4 N	Total Coliform	Herbicides Atrazine (μg/L)	Cyanazine (μg/L)	Metolachlor (μg/L)	Alachlor (μg/L)	Metribuzin (μg/L)
Karst Region--cont.										
Q-22	03/25/86	60.0	0.1	0.06	>16	0.36	<0.1	<0.1	<0.1	<0.1
Q-22	04/29/86	41.0				0.91	<0.1	<0.1	<0.1	<0.1
Q-22	05/28/86	40.0			>16	1.10	0.10	0.24	24.00	<0.1
Q-22	09/09/86	40.1	0.24	0.01		0.86	<0.1	<0.1	0.10	<0.1
Shallow Bedrock Region										
F-02	01/09/85	64.0			0					
F-02	02/12/85	62.0			0					
F-02	02/27/85	62.0			0					
F-02	03/25/85	51.0			0	0.32	<0.1	<0.1	<0.1	<0.1
F-02	05/06/85	47.0			0	0.37	<0.1	<0.1	<0.1	<0.1
F-02	06/19/85	43.0			0	0.42	<0.1	<0.1	<0.1	<0.1
F-02	07/24/85	49.0			0	0.51	<0.1	<0.1	<0.1	<0.1
F-02	08/21/85	52.0			0	0.53	<0.1	<0.1	<0.1	<0.1
F-02	09/18/85	57.0			0					
F-02	10/23/85	51.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
F-02	12/18/85	50.0			0					
F-02	03/25/86	46.0			9.2	<0.1	<0.1	<0.1	<0.1	<0.1
F-02	04/29/86	54.0			5.1					
F-02	05/28/86	48.0			2.2	0.48	<0.1	<0.1	<0.1	<0.1
F-08	01/09/85	117.0			2.2					
F-08	02/12/85	114.0			0					
F-08	02/27/85	99.0			0					
F-08	03/25/85	111.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
F-08	05/06/85	104.0			16					
F-08	06/19/85	107.0			16	<0.1	<0.1	<0.1	<0.1	<0.1
F-08	07/24/85	110.0			>16	<0.1	<0.1	0.11	<0.1	<0.1
F-08	08/21/85	111.0			>16	<0.1	<0.1	<0.1	<0.1	<0.1
F-08	09/18/85	104.0			>16					
F-08	10/23/85	74.0	0.01	0.01	>16	0.14	<0.1	<0.1	<0.1	<0.1
F-08	12/18/85	121.0			2.2					
F-08	03/25/86	106.0			5.1	0.20	<0.1	<0.1	<0.1	<0.1
F-08	04/29/86	103.0			9.2					
F-08	05/28/86	74.0			>16	0.12	<0.1	3.00	0.10	<0.1
F-08	09/09/86	76.5	0.05	0.02		<0.1	<0.1	<0.1	<0.1	<0.1
F-10	01/09/85	<5			0					
F-10	02/12/85	<5			0					
F-10	02/27/85	<5			0					
F-10	03/25/85	<5			0					
F-10	05/06/85	<5			0					
F-10	06/19/85	<5			0	<0.1	<0.1	<0.1	<0.1	<0.1
F-10	07/24/85	<5			0	<0.1	<0.1	<0.1	<0.1	<0.1
F-10	08/21/85	<5			0	<0.1	<0.1	<0.1	<0.1	<0.1
F-10	09/18/85	0.7								
F-10	10/23/85	0.5	0.01	0.01		<0.1	<0.1	<0.1	<0.1	<0.1
F-10	12/18/85	<5			0					
F-10	03/25/86	26.0			0	0.47	<0.1	<0.1	<0.1	<0.1
F-10	04/29/86	26.0			0					
F-10	05/28/86	31.0			9.2	<0.1	<0.1	<0.1	<0.1	<0.1
F-11	01/09/85	50.0			0					
F-11	02/12/85	50.0			0					
F-11	02/27/85	45.0			16					
F-11	03/25/85	46.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
F-11	05/06/85	49.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
F-11	06/19/85	37.0			>16	<0.1	<0.1	<0.1	<0.1	<0.1
F-11	07/24/85	51.0			0					
F-11	08/21/85	46.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
F-11	09/18/85	38.0			5.1					
F-11	10/23/85	29.0			2.2	0.13	<0.1	<0.1	<0.1	<0.1
F-11	12/18/85									
F-11	03/25/86	25.0			16					
F-11	04/29/86	54.0			2.2					
F-11	05/28/86	23.0			16	<0.1	<0.1	<0.1	<0.1	<0.1
F-18	01/09/85	30.0			>16					
F-18	02/12/85	34.0			0					
F-18	02/27/85	32.0			>16					
F-18	03/25/85	30.0			5.1					

						Herbicides				
Site Name	Date	Nitrate (mg/L)	Organic N	NH4 N	Total Coliform	Atrazine (µg/L)	Cyanazine (µg/L)	Metolachlor (µg/L)	Alachlor (µg/L)	Metribuzin (µg/L)
Shallow Bedrock Region--cont.										
F-18	05/06/85	30.0			0					
F-18	06/19/85	31.0			2.2	0.17	<0.1	<0.1	<0.1	<0.1
F-18	07/24/85	40.0			0	0.20	<0.1	<0.1	<0.1	<0.1
F-18	08/21/85	42.0			0	0.17	<0.1	<0.1	<0.1	<0.1
F-18	12/18/85	37.0			0					
F-18	03/25/86	26.0				0.10	<0.1	<0.1	<0.1	<0.1
F-18	04/29/86	41.0			0					
F-18	05/28/86	41.0			>16	0.10	<0.1	<0.1	<0.1	<0.1
F-19	01/09/85	14.0			0					
F-19	02/12/85	17.0			5.1	0.20	<0.1	<0.1	<0.1	<0.1
F-19	02/27/85	17.0			>16	0.25	<0.1	<0.1	<0.1	<0.1
F-19	03/25/85	14.0			5.1					
F-19	05/06/85	8.0			0	0.14	<0.1	<0.1	<0.1	<0.1
F-19	06/19/85	18.0			0	0.10	<0.1	<0.1	<0.1	<0.1
F-19	07/24/85	26.0			2.2	0.20	<0.1	<0.1	<0.1	<0.1
F-19	08/21/85	23.0			0					
F-19	09/18/85	26.0			2.2					
F-19	10/23/85	25.0			0	0.31	<0.1	<0.1	<0.1	<0.1
F-19	12/18/85	16.0			0					
F-19	03/25/86	18.0			>16	0.27	<0.1	<0.1	<0.1	<0.1
F-19	04/29/86	26.0			2.2					
F-23	01/09/85	28.0			0					
F-23	02/12/85	27.0			0	0.15	<0.1	<0.1	<0.1	<0.1
F-23	02/27/85	29.0			0					
F-23	03/25/85	23.0			0	0.10	<0.1	<0.1	<0.1	<0.1
F-23	05/06/85	30.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
F-23	06/19/85	25.0			0	0.10	<0.1	<0.1	<0.1	<0.1
F-23	07/24/85	26.0			0	0.18	<0.1	<0.1	<0.1	<0.1
F-23	08/21/85	30.0			0	0.10	<0.1	<0.1	<0.1	<0.1
F-23	09/18/85	30.0			0					
F-23	10/23/85	29.0			0	0.27	<0.1	<0.1	<0.1	<0.1
F-23	12/18/85	25.0			0					
F-23	03/25/86	30.0			0	0.42	<0.1	<0.1	<0.1	<0.1
F-23	04/29/86	37.0			0					
F-23	05/28/86	30.0			0	0.13	<0.1	<0.1	<0.1	<0.1
FM-08	01/09/85	23.0			0					
FM-08	02/12/85	23.0			0					
FM-08	02/27/85	18.0			0					
FM-08	03/25/85	22.0			0					
FM-08	05/06/85	22.0			0					
FM-08	06/19/85	20.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
FM-08	07/24/85	22.0			0					
FM-08	08/21/85	25.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
FM-08	09/18/85	24.0			9.2					
FM-08	10/23/85	21.0			16	0.10	<0.1	<0.1	<0.1	<0.1
FM-08	12/18/85									
FM-08	03/25/86	16.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
FM-08	04/29/86	29.0			0					
FM-08	05/28/86	20.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-03	01/09/85	<5			0					
Q-03	02/12/85	<5			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-03	02/27/85	<5			0	<0.1	<0.1	<0.1	<0.1	
Q-03	03/25/85	<5			0					
Q-03	05/06/85	<5			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-03	06/19/85	<5			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-03	07/24/85	6.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-03	08/21/85	<5			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-03	09/18/85	0.5								
Q-03	10/23/85	0.5	0.01	0.19		<0.1	<0.1	<0.1	<0.1	<0.1
Q-03	12/18/85									
Q-03	03/25/86	0.0	0.01	0.24		<0.1	<0.1	<0.1	<0.1	<0.1
Q-03	04/29/86	0.0	0.01	0.1						
Q-03	05/28/86	0.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-14	02/12/85	14.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-14	02/27/85	13.0			0					
Q-14	03/25/85	13.0			0					
Q-14	05/06/85	14.0			0	<0.1	<0.1	<0.1	<0.1	<0.1

Site Name	Date	Nitrate (mg/L)	Organic N	NH4 N	Total Coliform	Herbicides Atrazine (µg/L)	Cyanazine (µg/L)	Metolachlor (µg/L)	Alachlor (µg/L)	Metribuzin (µg/L)
Shallow Bedrock region--cont.										
Q-14	06/19/85	13.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-14	07/24/85	15.0			2.2	0.17	<0.1	<0.1	<0.1	<0.1
Q-14	08/21/85	16.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-14	09/18/85	16.0			0					
Q-14	10/23/85	14.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-14	12/18/85	15.0			0					
Q-14	03/25/86	16.0	0.01	0.03	0	<0.1	<0.1	<0.1	<0.1	<0.1
Q-14	04/29/86	26.0			0					
Q-14	05/28/86	15.0			0	0.11	<0.1	<0.1	<0.1	<0.1
Q-15	01/09/85	53.0			>16					
Q-15	02/12/85	52.0			0					
Q-15	02/27/85	51.0			16	0.22	<0.1	<0.1	<0.1	<0.1
Q-15	03/25/85	53.0			0					
Q-15	05/06/85	54.0			>16	0.23	<0.1	<0.1	<0.1	<0.1
Q-15	06/19/85	49.0			>16					
Q-15	07/24/85	60.0			2.2	0.22	<0.1	<0.1	<0.1	<0.1
Q-15	08/21/85	58.0			>16	0.10	<0.1	<0.1	<0.1	<0.1
Q-15	09/18/85	47.0			>16					
Q-15	10/23/85	45.0			>16	0.20	<0.1	<0.1	<0.1	<0.1
Q-15	12/18/85	59.0			16					
Q-15	03/25/86	56.0			>16	0.18	<0.1	<0.1	<0.1	<0.1
Q-15	04/29/86	56.0			>16					
Q-15	05/28/86	65.0			>16	0.21	<0.1	<0.1	<0.1	<0.1
Research Well Sites										
Karst Region										
FM1-1	01/09/85									
FM1-1	02/12/85	19.0			>16					
FM1-1	02/27/85	21.0			>16	0.41	<0.1	<0.1	<0.1	<0.1
FM1-1	03/25/85	22.0			>16	0.45	<0.1	0.2	<0.1	<0.1
FM1-1	05/06/85	33.0			16	0.00	<0.1	<0.1	<0.1	<0.1
FM1-1	06/19/85	26.0			>16	1.40	<0.1	0.42	0.1	<0.1
FM1-1	07/24/85	21.0				2.10	<0.1	<0.1	<0.1	<0.1
FM1-1	08/21/85	16.0				1.30	<0.1	<0.1	<0.1	<0.1
FM1-1	09/18/85	21.0				2.10	<0.1	<0.1	<0.1	<0.1
FM1-1	10/23/85	36.5	0.47	<0.01		1.50	<0.1	<0.1	<0.1	<0.1
FM1-1	12/18/85	50.0	0.29	0.1		1.10	<0.1	<0.1	<0.1	<0.1
FM1-1	03/25/86	32.0	0.1	0.05		1.10	<0.1	0.13	<0.1	<0.1
FM1-1	04/29/86	32.4	2.8	<0.01		0.74	<0.1	<0.1	<0.1	<0.1
FM1-1	05/28/86	37.8	0.1	0.13		3.90	1.6	0.49	0.67	<0.1
FM1-1	09/09/86	25.2	0.42	0.04		2.10	0.1	<0.1	<0.1	<0.1
FM1-2	11/10/84	<5			0					
FM1-2	01/09/85	10.0			0					
FM1-2	02/12/85				0					
FM1-2	02/27/85	6.0			0	<0.1	<0.1	<0.1	<0.1	<0.1
FM1-2	03/25/85	<5			0					
FM1-2	05/06/85	<5			0					
FM1-2	06/19/85	<5			0	<0.1	<0.1	<0.1	<0.1	<0.1
FM1-2	07/24/85	3.0				0.10	<0.1	<0.1	<0.1	<0.1
FM1-2	08/21/85	5.0				0.79	<0.1	<0.1	<0.1	<0.1
FM1-2	09/18/85	1.0				1.30	<0.1	<0.1	<0.1	<0.1
FM1-2	10/23/85	1.8	18	0.66		<0.1	<0.1	<0.1	<0.1	<0.1
FM1-2	12/18/85	1.0	0.6	0.28		<0.1	<0.1	<0.1	<0.1	<0.1
FM1-2	03/25/86	<5	<0.1	0.34		<0.1	<0.1	<0.1	<0.1	<0.1
FM1-2	04/29/86	0.9	0.7	0.34		<0.1	<0.1	<0.1	<0.1	<0.1
FM1-2	05/28/86	0.9	1.9	0.58		0.85	<0.1	<0.1	<0.1	<0.1
FM1-2	09/09/86	0.9	1.2	0.73						
FM1-3	11/10/84	<5			5.1					
FM1-3	01/09/85	<5			5.1					
FM1-3	02/12/85	<5			2.2					
FM1-3	02/27/85	7.0			>16					
FM1-3	03/25/85	<5			>16					
FM1-3	05/06/85	6.0			16					
FM1-3	06/19/85	<5			16	<0.1	<0.1	<0.1	<0.1	<0.1
FM1-3	07/24/85	0.7				<0.1	<0.1	<0.1	<0.1	<0.1
FM1-3	08/21/85	1.1				0.67	<0.1	<0.1	<0.1	<0.1
FM1-3	09/18/85	0.5				0.95	<0.1	<0.1	<0.1	<0.1

Site Name	Date	Nitrate (mg/L)	Organic N	NH4 N	Total Coliform	Herbicides Atrazine (µg/L)	Cyanazine (µg/L)	Metolachlor (µg/L)	Alachlor (µg/L)	Metribuzin (µg/L)
Karst Region--cont.										
FM1-3	10/23/85	2.7	1.9	0.21		0.26	<0.1	<0.1	<0.1	<0.1
FM1-3	12/18/85	16.0	0.4	0.1		0.26	<0.1	<0.1	<0.1	<0.1
FM1-3	03/25/86	1.0	<0.1	0.2		<0.1	<0.1	<0.1	<0.1	<0.1
FM1-3	04/29/86	1.0	1.1	0.2		<0.1	<0.1	<0.1	<0.1	<0.1
FM1-3	05/28/86	1.8	<0.1	0.79		0.16	<0.1	<0.1	<0.1	<0.1
FM1-3	09/09/86	0.5	1.1	0.32		<0.1	<0.1	<0.1	<0.1	<0.1
FM1-4	11/10/84	<5			0					
FM1-4	01/09/85	<5			0					
FM1-4	02/12/85	<5			>16					
FM1-4	02/27/85	<5			>16					
FM1-4	03/25/85	<5			5.1					
FM1-4	05/06/85	<5			0					
FM1-4	06/19/85	<5			16					
FM1-4	07/24/85	0.0				0.10	<0.1	<0.1	<0.1	<0.1
FM1-4	08/21/85	0.5				0.60	<0.1	<0.1	<0.1	<0.1
FM1-4	09/18/85	0.0				5.60	<0.1	<0.1	<0.1	<0.1
FM1-4	10/23/85	0.5	1.2	0.19		<0.1	<0.1	<0.1	<0.1	<0.1
FM1-4	12/18/85	<0.5	0.54	0.17		<0.1	<0.1	<0.1	<0.1	<0.1
FM1-4	03/25/86	<0.5	<0.1	0.24		<0.1	<0.1	<0.1	<0.1	<0.1
FM1-4	04/29/86	1	0.42	0.24		<0.1	<0.1	<0.1	<0.1	<0.1
FM1-4	05/28/86	1	<0.1	0.42		<0.1	<0.1	<0.1	<0.1	<0.1
FM1-4	09/09/86	1.0	0.12	0.55		<0.1	<0.1	<0.1	<0.1	<0.1
Shallow Bedrock Region										
FM2-1	01/09/85									
FM2-1	02/12/85	<5			0					
FM2-1	02/27/85	<5			0					
FM2-1	03/25/85	<5			>16	<0.1	<0.1	<0.1	<0.1	<0.1
FM2-1	05/06/85	<5			0	<0.1	<0.1	<0.1	<0.1	<0.1
FM2-1	06/19/85	9.0			2.2	0.10	<0.1	0.21	<0.1	<0.1
FM2-1	07/24/85	6.6				<0.1	<0.1	<0.1	<0.1	<0.1
FM2-1	08/21/85	3.1				<0.1	<0.1	<0.1	<0.1	<0.1
FM2-1	09/18/85	1.6								
FM2-1	10/23/85	4.5	0.4	0.23		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-1	12/18/85	3.6	0.28	0.25		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-1	03/25/86	7.0	0.2	0.05		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-1	04/29/86	3.2	0.48	0.19		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-1	05/28/86	4.5	0.1	0.14		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-1	09/09/86	7.2	0.1	0.11		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-2	11/10/84	<5			0					
FM2-2	01/09/85	6.0								
FM2-2	02/12/85	<5								
FM2-2	02/27/85	<5								
FM2-2	03/25/85	<5								
FM2-2	05/06/85	6.0								
FM2-2	06/19/85	9.0				1.40	<0.1	<0.1	<0.1	<0.1
FM2-2	07/24/85	4.9				<0.1	<0.1	<0.1	<0.1	<0.1
FM2-2	08/21/85	6.5				0.42	<0.1	<0.1	<0.1	<0.1
FM2-2	09/18/85	3.8				0.70	<0.1	<0.1	<0.1	<0.1
FM2-2	10/23/85	10.4	0.02	<0.01		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-2	12/18/85	9.5	0.07	<0.01		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-2	03/25/86	11.0	0.01	<0.1		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-2	04/29/86	5.4	0.01	<0.01		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-2	05/28/86	5.4				<0.1	<0.1	<0.1	<0.1	<0.1
FM2-2	09/09/86	10.4	0.02	0.04		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-3	11/10/84	<5			0					
FM2-3	01/09/85	<5								
FM2-3	02/12/85	<5								
FM2-3	02/27/85	<5			0					
FM2-3	03/25/85	<5			0					
FM2-3	05/06/85	<5			0					
FM2-3	06/19/85					<0.1	<0.1	<0.1	<0.1	<0.1
FM2-3	07/24/85	0.7				<0.1	<0.1	<0.1	<0.1	<0.1
FM2-3	08/21/85	1.5				0.15	<0.1	<0.1	<0.1	<0.1
FM2-3	09/18/85	1.0				0.98	<0.1	<0.1	<0.1	<0.1
FM2-3	10/23/85	0.9	0.89	1.5		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-3	12/18/85	14.9	0.32	0.84		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-3	03/25/86	.5	<0.1	0.73		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-3	04/29/86	0.5	0.85	1.3		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-3	05/28/86	<1	1.4	0.01		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-3	09/09/86	<1	1.1	1.1		<0.1	<0.1	<0.1	<0.1	<0.1

Site Name	Date	Nitrate (mg/L)	Organic N	NH4 N	Total Coliform	Herbicides Atrazine (µg/L)	Cyanazine (µg/L)	Metolachlor (µg/L)	Alachlor (µg/L)	Metribuzin (µg/L)
Shallow Bedrock Region--cont.										
FM2-4	11/10/84	<5			9.2					
FM2-4	01/09/85	<5			0					
FM2-4	02/12/85	15.0								
FM2-4	02/27/85	<5								
FM2-4	03/25/85	<5			9.2					
FM2-4	05/06/85	<5			5.1					
FM2-4	06/19/85	<5			5.1					
FM2-4	07/24/85	<0.1				<0.1	<0.1	<0.1	<0.1	<0.1
FM2-4	08/21/85	0.9				1.10	<0.1	<0.1	<0.1	<0.1
FM2-4	09/18/85	0.4				3.50	<0.1	<0.1	<0.1	<0.1
FM2-4	10/23/85	0.5	8.1	0.63		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-4	12/18/85	31.0	0.17	0.23		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-4	03/25/86	<.5	<0.1	0.34		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-4	04/29/86	<1	0.07	0.4		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-4	05/28/86	<1	0.36	0.58		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-4	09/09/86	<1	0.94	0.55		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-T	11/10/84	113.0			>16	0.12	<0.1	<0.1	<0.1	<0.1
FM2-T	01/09/85	109.0								
FM2-T	02/12/85	111.0			>16					
FM2-T	02/27/85	105.0			>16	<0.1	<0.1	<0.1	<0.1	<0.1
FM2-T	03/25/85	92.0			>16	<0.1	<0.1	<0.1	<0.1	<0.1
FM2-T	05/06/85	34.0			16	<0.1	<0.1	<0.1	<0.1	<0.1
FM2-T	06/19/85	69.0			>16	<0.1	<0.1	<0.1	<0.1	<0.1
FM2-T	07/24/85	83.0				<0.1	<0.1	<0.1	<0.1	<0.1
FM2-T	08/21/85	80.0				<0.1	<0.1	<0.1	<0.1	<0.1
FM2-T	09/18/85	84.0			>16	0.28	<0.1	<0.1	<0.1	<0.1
FM2-T	10/23/85	65.0			>16	<0.1	<0.1	<0.1	<0.1	<0.1
FM2-T	12/18/85	32.9	1.4	0.13		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-T	03/25/86	54.0	0.4	0.11		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-T	04/29/86	54.0			5.1	<0.1	<0.1	<0.1	<0.1	<0.1
FM2-T	05/28/86	38.3	0.1	0.24		<0.1	<0.1	<0.1	<0.1	<0.1
FM2-T	09/09/86	32.0	0.8	0.46		<0.1	<0.1	<0.1	<0.1	<0.1
ADW/Deep- Bedrock Region										
FM3-1	01/09/85									
FM3-1	02/12/85	29.0			16	0.51	<0.1	<0.1	<0.1	<0.1
FM3-1	02/27/85	7.0			>16	0.37	<0.1	<0.1	<0.1	<0.1
FM3-1	03/25/85	<5			>16	0.17	<0.1	<0.1	<0.1	<0.1
FM3-1	05/06/85	<5			>16	0.27	0.16	0.3	<0.1	<0.1
FM3-1	06/19/85	5.0			>16	0.10	0.2	0.2	<0.1	<0.1
FM3-1	07/24/85	3.6				<0.1	<0.1	<0.1	<0.1	<0.1
FM3-1	08/21/85	12.0				0.23	<0.1	<0.1	<0.1	<0.1
FM3-1	09/18/85									
FM3-1	10/23/85	10.4	0.6	<0.01		0.37	<0.1	<0.1	<0.1	<0.1
FM3-1	12/18/85	45.0	0.15	<0.01		0.10	<0.1	<0.1	<0.1	<0.1
FM3-1	03/24/86	135.0	0.8	0.03						
FM3-1	03/27/86	104.0	1.1	0.04		0.41	<0.1	<0.1	<0.1	<0.1
FM3-1	04/29/86	39.2	0.8	0.01		0.49	<0.1	0.49	0.14	<0.1
FM3-1	05/28/86	76.5	0.5	0.11		<0.1	<0.1	<0.1	<0.1	<0.1
FM3-1	06/01/86									
FM3-1	06/02/86									
FM3-1	06/03/86									
FM3-1	09/09/86	49.5	0.75	0.06		0.67	<0.1	0.12	<0.1	<0.1
FM3-2	11/10/84	<5			9.2					
FM3-2	01/09/85	<5			2.2					
FM3-2	02/12/85	<5			2.2	<0.1	<0.1	<0.1	<0.1	<0.1
FM3-2	02/27/85	<5			>16	<0.1	<0.1	<0.1	<0.1	<0.1
FM3-2	03/25/85	<5			16	<0.1	<0.1	<0.1	<0.1	<0.1
FM3-2	05/06/85	<5			>16	<0.1	0.31	<0.1	0.15	<0.1
FM3-2	06/19/85	<5			16	<0.1	<0.1	<0.1	<0.1	<0.1
FM3-2	07/24/85	<0.1				<0.1	<0.1	<0.1	<0.1	<0.1
FM3-2	08/21/85	1.5				1.80	<0.1	<0.1	<0.1	<0.1
FM3-2	09/18/85	<0.1				1.10	<0.1	<0.1	<0.1	<0.1
FM3-2	10/23/85	0.9	0.37	0.05		<0.1	<0.1	<0.1	<0.1	<0.1
FM3-2	12/18/85	<.5	0.17	0.03		<0.1	<0.1	<0.1	<0.1	<0.1
FM3-2	03/24/86	<.5	0.8	0.06						
FM3-2	03/27/86		0.8	0.06		<0.1	<0.1	<0.1	<0.1	<0.1
FM3-2	04/29/86	8.1	0.2	<0.01		<0.1	<0.1	<0.1	0.11	<0.1
FM3-2	05/28/86	<.5	0.6	0.11		<0.1	<0.1	<0.1	<0.1	<0.1

Site Name	Date	Nitrate (mg/L)	Organic N	NH4 N	Total Coliform	Herbicides Atrazine (µg/L)	Cyanazine (µg/L)	Metolachlor (µg/L)	Alachlor (µg/L)	Metribuzin (µg/L)
ADW/Deep- Bedrock Region--cont.										
FM3-2	06/01/86									
FM3-2	06/02/86									
FM3-2	06/03/86									
FM3-2	09/09/86	0.9	<0.01	0.1		<0.1	<0.1	<0.1	<0.1	<0.1
FM3-3	11/10/84	<5			0					
FM3-3	01/09/85	<5			0					
FM3-3	02/12/85	<5			9.2	<0.1	<0.1	<0.1	<0.1	<0.1
FM3-3	02/27/85	<5			>16	<0.1	<0.1	<0.1	<0.1	<0.1
FM3-3	03/25/85	<5			0					
FM3-3	05/06/85	<5			0					
FM3-3	06/19/85	<5			>16	<0.1	<0.1	<0.1	<0.1	<0.1
FM3-3	07/24/85	0.1				<0.1	<0.1	<0.1	<0.1	<0.1
FM3-3	08/21/85	0.9				0.44	<0.1	<0.1	<0.1	<0.1
FM3-3	09/18/85	0.4				<0.1	<0.1	<0.1	<0.1	<0.1
FM3-3	10/23/85	0.5	1	0.39		<0.1	<0.1	<0.1	<0.1	<0.1
FM3-3	12/18/85	<.5	0.06	0.49		<0.1	<0.1	<0.1	<0.1	<0.1
FM3-3	03/24/86	<.5	1.3	0.32						
FM3-3	03/27/86	<.5	0.4	0.32		<0.1	<0.1	<0.1	<0.1	<0.1
FM3-3	04/29/86	<.5	1	0.33		<0.1	<0.1	<0.1	<0.1	<0.1
FM3-3	05/28/86	<.5	0.1	0.4						
FM3-3	06/01/86									
FM3-3	06/02/86									
FM3-3	06/03/86									
FM3-3	09/09/86	<.5	0.32	0.5		<0.1	<0.1	<0.1	<0.1	<0.1
FM3-4	11/10/84	<5			0					
FM3-4	01/09/85	<5								
FM3-4	02/12/85	<5								
FM3-4	02/27/85	<5			0	0.25	<0.1	<0.1	<0.1	<0.1
FM3-4	03/25/85	<5			0					
FM3-4	05/06/85	6.0			>16					
FM3-4	06/19/85	<5			>16					
FM3-4	07/24/85	2.6				<0.1	<0.1	0.18	<0.1	<0.1
FM3-4	08/21/85	1.7				1.30	0.63	<0.1	0.48	<0.1
FM3-4	09/18/85	0.4				<0.1	<0.1	<0.1	<0.1	<0.1
FM3-4	10/23/85	0.9	0.16	<0.01		<0.1	<0.1	<0.1	<0.1	<0.1
FM3-4	12/18/85	1.8	0.04	<0.01		<0.1	0.12	0.12	<0.1	<0.1
FM3-4	03/24/86	18.0	0.2	0.01						
FM3-4	03/27/86	17.0	0.3	0.01		<0.1	<0.1	<0.1	<0.1	<0.1
FM3-4	04/29/86	14.4	<0.1	0.01		0.10	<0.1	0.17	<0.1	<0.1
FM3-4	05/28/86	26.6	0.01	0.06		0.13	0.42	0.87	<0.1	<0.1
FM3-4	06/01/86									
FM3-4	06/02/86									
FM3-4	06/03/86									
FM3-4	09/09/86	9.9	0.16	0.03		0.10	0.23	0.45	<0.1	<0.1
FM3-T	11/10/84	<5			>16	<0.1	<0.1	<0.1	<0.1	<0.1
FM3-T	01/09/85	<5			>16					
FM3-T	02/12/85	<5			>16					
FM3-T	02/27/85	<5			>16	<0.1	<0.1	<0.1	<0.1	<0.1
FM3-T	03/25/85	<5			>16	<0.1	<0.1	<0.1	<0.1	<0.1
FM3-T	05/06/85	10.0			>16					
FM3-T	06/19/85	<5			>16					
FM3-T	07/24/85	2.4				<0.1	<0.1	<0.1	4.4	0.32
FM3-T	08/21/85	0.3				<0.1	<0.1	<0.1	<0.1	<0.1
FM3-T	09/18/85	<5			>16	0.11	<0.1	<0.1	<0.1	<0.1
FM3-T	10/23/85	<5			2.2	<0.1	<0.1	<0.1	<0.1	<0.1
FM3-T	12/18/85	0.0	2.3	0.35		<0.1	<0.1	<0.1	<0.1	<0.1
FM3-T	03/24/86									
FM3-T	03/27/86	<.5	0.5	0.09		<0.1	<0.1	<0.1	<0.1	<0.1
FM3-T	04/29/86	19.8	1.1	0.02		<0.1	<0.1	<0.1	<0.1	<0.1
FM3-T	05/28/86	<.5	<0.1	0.09		<0.1	<0.1	<0.1	<0.1	<0.1
FM3-T	09/09/86	3.2	<0.1	0.22		<0.1	<0.1	<0.1	<0.1	<0.1
Surface Water Sites										
BURR OAK CK.	11/10/84	28.0			>16					
BURR OAK CK.	02/27/85	18.0			>16	0.89	<0.1	<0.1	<0.1	<0.1
BURR OAK CK.	03/25/85	22.0			9.2	0.19	<0.1	0.4	<0.1	<0.1
BURR OAK CK.	05/06/85	30.0			>16	0.35	0.33	<0.1	<0.1	<0.1
BURR OAK CK.	06/19/85					0.37	<0.1	<0.1	<0.1	<0.1
BURR OAK CK.	09/18/85	23.0			>16					

						Herbicides				
Site Name	**Date**	**Nitrate (mg/L)**	**Organic N**	**NH4 N**	**Total Coliform**	**Atrazine (µg/L)**	**Cyanazine (µg/L)**	**Metolachlor (µg/L)**	**Alachlor (µg/L)**	**Metribuzin (µg/L)**
Surface Water Sites--cont.										
BURR OAK CK.	10/23/85	37.0			>16	0.39	<0.1	<0.1	<0.1	<0.1
BURR OAK CK.	03/25/86	35.0			>16					
BURR OAK CK.	04/29/86	49.0			>16					
BURR OAK CK.	05/28/86	50.0			>16	0.61	0.11	0.35	0.21	<0.1
CEDAR RIVER	11/10/84	22.0			>16					
CEDAR RIVER	01/09/85	24.0			>16					
CEDAR RIVER	02/27/85	14.0			>16	0.54	<0.1	0.3	<0.1	<0.1
CEDAR RIVER	03/25/85	17.0			>16	0.16	<0.1	<0.1	<0.1	<0.1
CEDAR RIVER	05/06/85	24.0			16	0.29	0.26	0.13	0.12	<0.1
CEDAR RIVER	06/19/85	19.0			>16	0.43	0.24	0.29	0.22	<0.1
CEDAR RIVER	07/24/85	12.0			9.2	0.21	<0.1	<0.1	<0.1	<0.1
CEDAR RIVER	08/21/85	<5			>16					
CEDAR RIVER	09/18/85	16.0			>16	0.80	0.21	<0.1	0.17	<0.1
CEDAR RIVER	10/23/85	28.0			>16	<0.1	<0.1	<0.1	<0.1	<0.1
CEDAR RIVER	03/25/86	27.0				0.83	<0.1	0.13	<0.1	0.26
CEDAR RIVER	04/29/86	30.0			>16	0.60	<0.1	0.33	0.32	<0.1
CEDAR RIVER	05/28/86	41.0			>16					
BEAVER CK.	11/10/84	50.0			>16					
BEAVER CK.	02/27/85	11.0			>16	1.20	<0.1	0.25	<0.1	<0.1
BEAVER CK.	06/19/85	15.0			>16					
BEAVER CK.	05/28/86	61.0			>16	0.31	<0.1	.12	.25	<0.1
GOOSE CK.	11/10/84	7.0			>16					
GOOSE CK.	01/09/85	16.0			>16	0.12	<0.1	<0.1	<0.1	<0.1
GOOSE CK.	02/27/85	12.0			>16	1.60	<0.1	1.4	<0.1	<0.1
GOOSE CK.	03/25/85	21.0			>16					
GOOSE CK.	05/06/85	12.0			>16	0.28	0.13	0.19	<0.1	<0.1
GOOSE CK.	10/23/85	35.0			>16	0.34	<0.1	<0.1	<0.1	<0.1
GOOSE CK.	03/25/86	33.0			>16	0.49	<0.1	0.19	<0.1	<0.1
GOOSE CK.	04/29/86	34.0			>16	0.88	<0.1	0.51	0.16	<0.1
GOOSE CK.	05/28/86	50.0			>16	4.00	1.8	5.8	2.6	1.0
GOOSE CK.	09/09/86									
WILDWOOD CK.	11/10/84	9.0			>16					
WILDWOOD CK.	01/09/85	34.0			>16	0.21	<0.1	<0.1	<0.1	<0.1
WILDWOOD CK.	02/27/85	18.0			>16	1.80	<0.1	1.4	<0.1	<0.1
WILDWOOD CK.	03/25/85	37.0			>16	0.26	<0.1	<0.1	<0.1	<0.1
WILDWOOD CK.	05/06/85	67.0			>16	0.22	<0.1	<0.1	<0.1	<0.1
WILDWOOD CK.	06/19/85	63.0			>16	0.30	<0.1	<0.1	<0.1	<0.1
WILDWOOD CK.	10/23/85	50.0				0.31	<0.1	<0.1	<0.1	<0.1
WILDWOOD CK.	03/25/86	62.0			>16	0.42	<0.1	<0.1	<0.1	<0.1
WILDWOOD CK.	04/29/86	69.0			>16	0.35	<0.1	<0.1	<0.1	<0.1
WILDWOOD CK.	05/28/86	83.0			>16	2.40	0.18	3.0	1.2	0.34
Tile Line Sites										
ADW-1	11/10/84	18.0			>16					
ADW-1	03/25/85	32.0			>16	<0.1	<0.1	<0.1	<0.1	<0.1
ADW-1	05/06/85	39.0			>16	<0.1	<0.1	0.12	<0.1	<0.1
ADW-1	06/19/85	30.0			>16	<0.1	<0.1	<0.1	<0.1	<0.1
ADW-1	10/23/85	24.0			>16	<0.1	<0.1	<0.1	<0.1	<0.1
ADW-1	03/25/86	54.0	0.5	0.06						
ADW-1	04/29/86	35.0			>16					
ADW-1	05/28/86	63.0			>16	<0.1	2.8	5.9	0.12	0.73
DT-03	11/10/84	63.0			>16					
DT-03	01/09/85	77.0			>16	0.10	<0.1	<0.1	<0.1	<0.1
DT-03	02/12/85	55.0			16					
DT-03	02/27/85	50.0			>16					
DT-03	03/25/85	54.0			>16	0.11	<0.1	<0.1	<0.1	<0.1
DT-03	05/06/85	67.0			>16	0.00	<0.1	<0.1	<0.1	<0.1
DT-03	06/19/85	66.0			>16	0.19	<0.1	<0.1	<0.1	<0.1
DT-03	09/18/85	57.0			>16					
DT-03	10/23/85	51.0			>16	<0.1	<0.1	<0.1	<0.1	<0.1
DT-03	12/18/85	51.0			>16	<0.1	<0.1	<0.1	<0.1	<0.1
DT-03	03/25/86	50.0	0.4	0.01		0.10	<0.1	<0.1	<0.1	<0.1
DT-03	04/29/86	58.0			>16	0.10	<0.1	<0.1	<0.1	<0.1
DT-03	05/28/86	76.0			>16	0.10	<0.1	0.88	1.8	<0.1
DT-03	09/09/86	20.0	0.25	0.05		0.14	<0.1	<0.1	<0.1	<0.1

Site Name	Date	Nitrate (mg/L)	Organic N	NH4 N	Total Coliform	Herbicides Atrazine (µg/L)	Cyanazine (µg/L)	Metolachlor (µg/L)	Alachlor (µg/L)	Metribuzin (µg/L)
Tile Line Sites--cont.										
TL-1	11/10/84	41.0			>16					
TL-1	01/09/85	49.0			>16	0.10	<0.1	<0.1	<0.1	<0.1
TL-1	02/27/85	18.0			>16	0.10	<0.1	0.2	<0.1	<0.1
TL-1	03/25/85	33.0			>16					
TL-1	05/06/85	49.0			>16	<0.1	<0.1	<0.1	<0.1	<0.1
TL-1	06/19/85	47.0			>16	0.10	<0.1	0.55	<0.1	1.8
TL-1	09/18/85	42.0			>16					
TL-1	10/23/85	44.0			>16	1.90	<0.1	<0.1	<0.1	<0.1
TL-1	03/25/86	40.0	0.5	0.05		0.14	<0.1	<0.1	<0.1	<0.1
TL-1	04/29/86	44.0			>16	0.18	<0.1	<0.1	<0.1	<0.1
TL-1	05/28/86	26.0			16	1.10	0.58	<0.1	1.6	<0.1

Iowa Department of Natural Resources
Energy and Geological Resources Division
Geological Survey Bureau
109 Trowbridge Hall
Iowa City, Iowa 52242-1319
(319) 335-1575