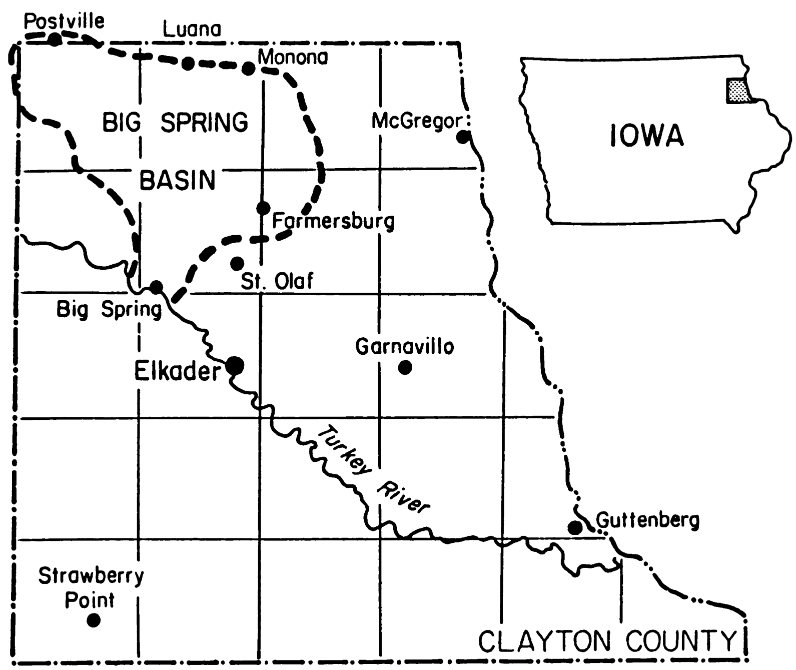
ENVIRONMENTAL GEOLOGY OF THE BIG SPRING GROUNDWATER BASIN, NORTHEAST IOWA

GUIDEBOOK SERIES NO. 15



Iowa Department of Natural Resources
Larry J. Wilson, Director
May 1992

ENVIRONMENTAL GEOLOGY OF THE BIG SPRING GROUNDWATER BASIN, NORTHEAST IOWA

GUIDEBOOK SERIES NO. 15

prepared by

R. D. Libra, G. R. Hallberg, R. D. Rowden, E. A. Bettis III

Iowa Department of Natural Resources
Energy and Geological Resources Division
Geological Survey Bureau

S. J. Kalkoff

U. S. Geological Survey
Water Resources Division

D. G. Baker

The University of Iowa
Department of Geology

May 1992

Prepared for North-Central Section, Geological Society of America
26th Annual Meeting, April 30-May 1, 1992, Iowa City, Iowa
Field Trip No. 7, May 2, 1992

Iowa Department of Natural Resources
Larry J. Wilson, Director

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The Iowa Department of Natural Resources-Geological Survey Bureau (DNR-GSB) began receiving an increasing number of questions and comments regarding nitrate concentrations in the bedrock aquifers of northeast Iowa during the mid-1970's. Some occurrences of nitrate could be linked to obvious, localized sources of contamination. However, much of this largely anecdotal information suggested that more wide-spread contamination might be occurring. In response, the GSB began to evaluate the existing data concerning the distribution of nitrate concentrations in the regionally extensive bedrock aquifers of northeast Iowa, and the hydrogeologic and environmental factors controlling this distribution (Hallberg and Hoyer, 1982). This evaluation yielded several important findings. First, nitrate concentrations were generally low within the bedrock aquifers in "deep bedrock" areas, where they are overlain by greater than fifty feet of relatively low-permeability shales or Quaternary deposits. Second, concentrations in "shallow bedrock" areas, where less than fifty feet of Quaternary cover is present, had statistically higher concentrations and were suggestive of regional contamination. The third finding related to the effects of karst development, as indicated by the presence of sinkholes, on the distribution of nitrate. There was no statistical difference between nitrate concentrations from the karst areas and shallow bedrock areas. This finding was of importance, as the shallow bedrock areas are considerably more extensive than the karst areas. Hallberg and Hoyer (1982) suggested that regional nitrate contamination was linked to the intensive row-cropped agriculture occurring on the land surface of northeast Iowa, and discussed concerns that contamination by commonly-used pesticides might also be occurring.

Investigations began in the Big Spring area following this initial evaluation (Fig.1). Big Spring is the largest spring in Iowa. Water from the spring has been used to supply a trout-rearing facility since the late 1930's, and has the spring been owned by the DNR for over thirty years. The structures used to direct water for the hatchery operations allow gaging of the discharge of groundwater from the spring, and its associated groundwater basin. The area contains deep bedrock, shallow bedrock, and karst areas, using the terminology of Hallberg and Hoyer (1982). Dye tracing in the mid-1970s established that runoff to sinkhole areas several miles to the north discharged via the spring (Heitmann, 1980), and defined part of the groundwater basin. The area is dominantly agricultural, without major industrial or waste disposal operations. These factors made the Big Spring area attractive for further investigations of the interactions of agricultural practices, hydrogeologic settings, and groundwater quality. Efforts began in 1981, and were expanded in 1986 with the formation of the Big Spring Basin Demonstration Project (BSBDP). This project, the result of efforts by a multiplicity of state, federal, and local agencies, is the centerpiece of Iowa's efforts to develop, demonstrate, and generate the implementation of agricultural practices that limit environmental degradation yet are economically viable. The remainder of this introduction gives background information on the Big Spring basin and associated activities. This guidebook contains sections from numerous prior reports, including Hallberg et al., 1983, 1984, 1989, 1991; Hoyer et al., 1986; Libra et al., 1986, 1991; Rowden and Libra, 1990; and Littke and Hallberg, 1991.

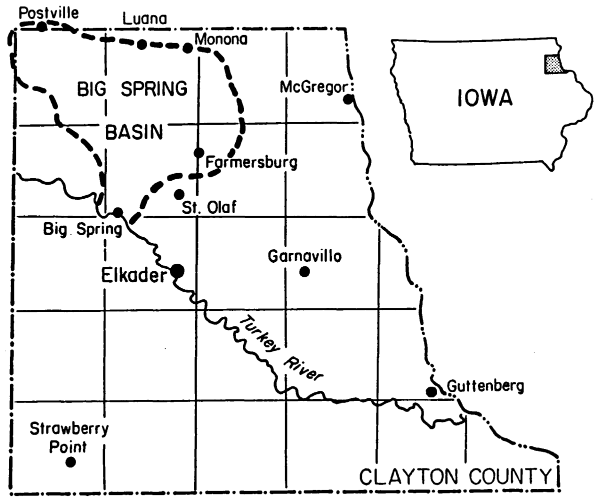


Figure 1. Map showing the location of the Big Spring basin.

Stratigraphic Setting

A general stratigraphic column for northeastern Iowa is shown by Figure 2. Figure 3 shows a bedrock map of the Big Spring basin and adjacent areas. Bedrock units are of Ordovician age unless otherwise noted. The oldest rocks exposed in the area are carbonates of the Shakopee Formation. The Shakopee is

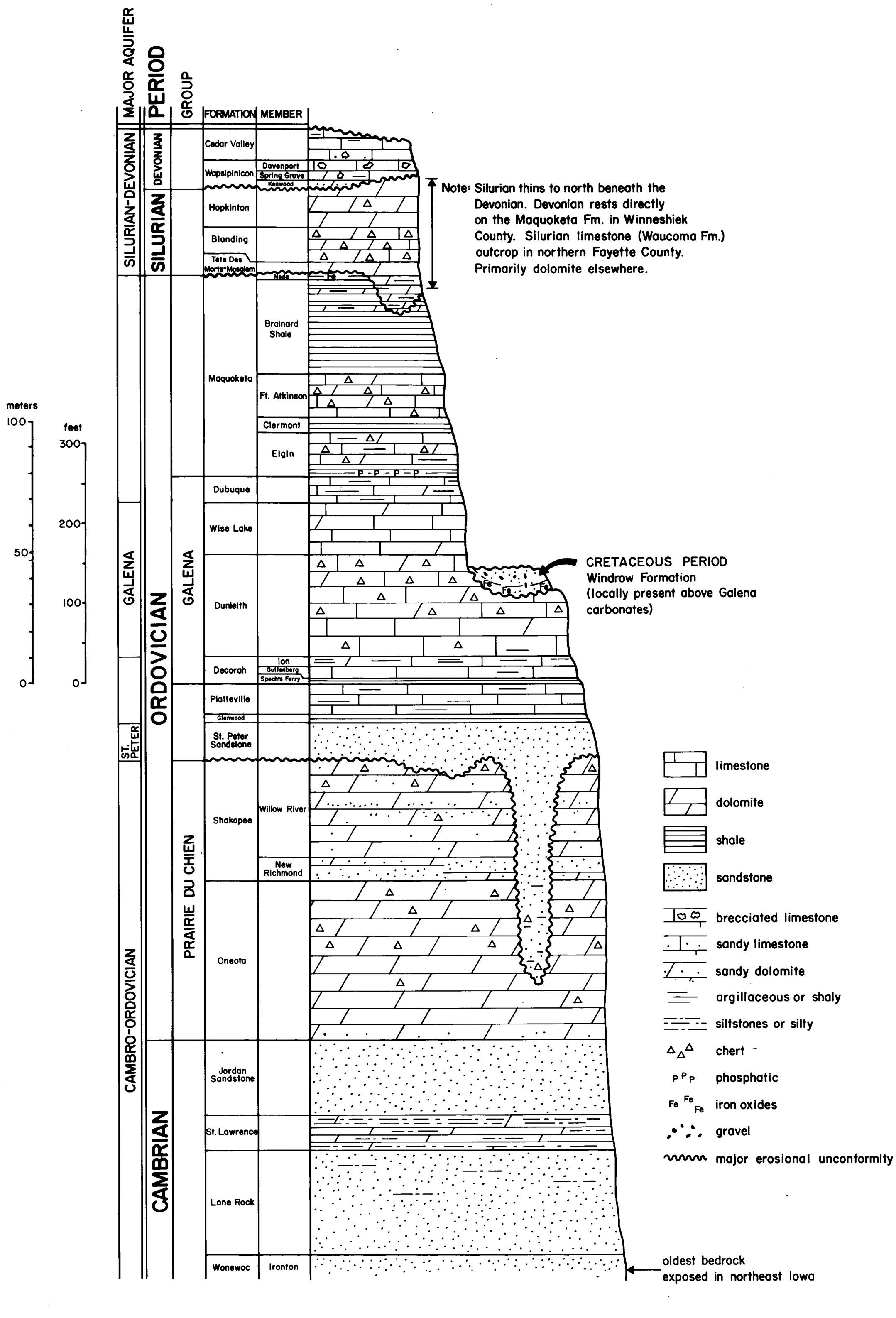
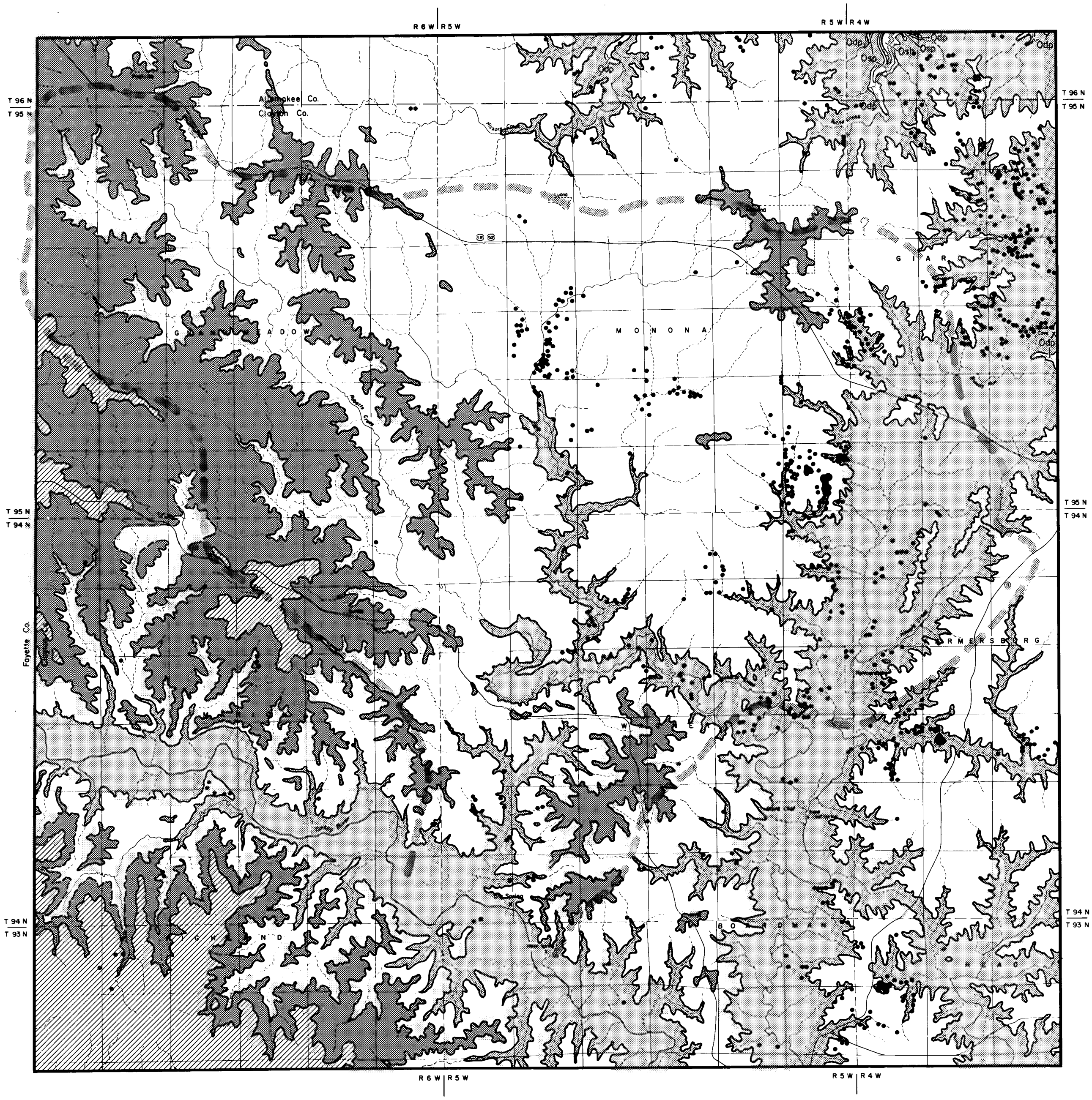


Figure 2. General stratigraphic column for northeast Iowa.



BEDROCK GEOLOGIC MAP
Big Spring Study Area
1982

Compiled by G.A. Ludvigson
(field mapping by G.A. Ludvigson, R.M. McKay,
M.J. Bounk, S.J. Lenker)

SILURIAN

Su-Silurian dolomites
(Blanding, Tete des Morts, Mosalem Frms.)

• Approximate location of sinkholes

ORDOVICIAN

Omb-Maquoketa Frm.
Brainard Shale Member

Og-Galena carbonates
Dubuque, Wise Lake, and Dunleith Frms.

Osp — Osp-St. Peter Sandstone

Omf-Maquoketa Frm.
Ft. Atkinson, Clermont, and Elgin Members

Odp — Odp-Decorah, Platteville, and Glenwood Frms.

Osh — Osh-Shakopee Frm.

Figure 3. Bedrock geologic map of the Big Spring basin area.

unconformably overlain by the St. Peter Sandstone, a locally important aquifer in northeastern Iowa. The St. Peter is overlain by shales, shaley carbonates, and carbonates of the Glenwood, Platteville and Decorah (GPD) formations. These rocks are mapped as a single unit on Figure 3, as they collectively function as an aquitard which confines the St. Peter aquifer.

The GPD confining beds are overlain by the carbonates of the Dunleith, Wise Lake, and Dubuque formations, grouped together here as the Galena aquifer. Most private wells in the area are completed within this aquifer. A number of springs, including Big Spring, discharge from the Galena. Overlying the Galena carbonates is the Maquoketa Formation. For mapping and hydrogeologic purposes the Maquoketa is divided into two units (Fig. 3). The lower unit is comprised of the shaly carbonates of the Elgin Member, the Clermont shale, and the carbonates of the Ft. Atkinson Member. The upper unit is the Brainard Shale Member, a clay-rich shale with minor interbedded carbonates. The lower part of the lower mapping unit, particularly the Elgin, is in hydrologic connection with the Galena Aquifer. The Brainard Shale forms a major confining bed in northeast Iowa.

The youngest rocks in the area are Silurian carbonates. These resistant units form a prominent ridge, the Niagaran Escarpment, south of the Turkey River (Fig. 3). North of the river these units have largely been removed by erosion, and are present only as outliers. The Silurian units form an important regional aquifer across much of the eastern half of Iowa.

Bedrock strata in northeastern Iowa generally dip to the southwest at about 20 feet/mile. Within the Big Spring basin, structure contours drawn on the base of the Galena mimic this general trend, but show a prominent flexure trending north-south through the center of the area (Hallberg et al., 1983). Big Spring itself lies near the southern end of this feature.

Over most of the Big Spring area, a relatively thin cover of Pleistocene deposits mantle the bedrock. The oldest of these are Pre-Illinoian tills and associated materials (Fig. 4). The tills were deposited by continental glaciers prior to 500,000 years ago (Hallberg, 1980) whereas the associated deposits accumulated by glacial-fluvial and erosional processes during and following deposition of the tills. Extensive erosion in conjunction with downcutting of the Misssissippi River and its major tributaries (including the Turkey River) removed most of the tills and associated deposits prior to 20,000 years ago. Today these deposits are found along upland divides where they are buried by late-Wisconsinan loess, and in buried paleovalleys that have not been exhumed by the modern drainage network. Most outcrops of Pre-Illinoian deposits in the Big Spring basin are located in the upper portions of the drainage network where small valleys have encroached on divide areas (Fig. 4).

Late Wisconsinan loess is the most abundant surficial deposit in the area. This deposit consists of aeolian silt and clay-sized materials deposited between 25,000 and 14,000 years ago. The loess is thickest, 15 to 25 feet, on upland divides in the southern and central parts of the basin. Generally the loess thins down slope because of erosion during and following deposition. On these slopes a portion of the silty mantle is re-worked, loess-derived colluvium. Loess-mantled terraces are present along the larger stream valleys within the basin (Fig. 4). Loess thickness in these areas is in the 20 to 30 feet range. Loess-mantled terraces usually form broad, relatively flat surfaces below the uplands and 15 to 30 feet above the modern floodplain.

In the southwest corner of the basin loamy alluvial deposits and associated aeolian sands are found on a high, Late Wisconsinan terrace along the Turkey River (Fig. 4). Silty alluvial deposits are found in the remainder of the stream valleys in the area. These have accumulated by stream migration and overbank flooding during the last 11,000 years. Several low terraces are evident along several of the valleys within the basin. Gravels of unknown thickness underlie the silty alluvium throughout the area.

Hydrologic Setting

Northeast Iowa is characterized by a midcontinental subhumid climate. Mean annual precipitation at the Elkader recording station is about 33 inches (84 cm) with 70 percent of that (23 inches, 54 cm) occurring during the growing season between April and September. Mean annual temperature is 44°F (6.7°C). Winter average temperature is 22°F (-5.6°C) and the summer average is 72°F (22.2°C).

The Big Spring study area is located within the Paleozoic Plateau Landform region in northeast Iowa (Prior, 1976, 1991). The landscape in the Big Spring area ranges from moderately rolling in the northern one-half, to steeply sloping as the Turkey River valley is approached in the southern portion of the area. Local relief within Big Spring basin is about 420 feet. As much as 320 feet of relief is present along the Turkey River valley in the southwest corner of the basin where outliers of Silurian strata (Fig. 3) are evident as wooded promontories standing above the surrounding landscape.

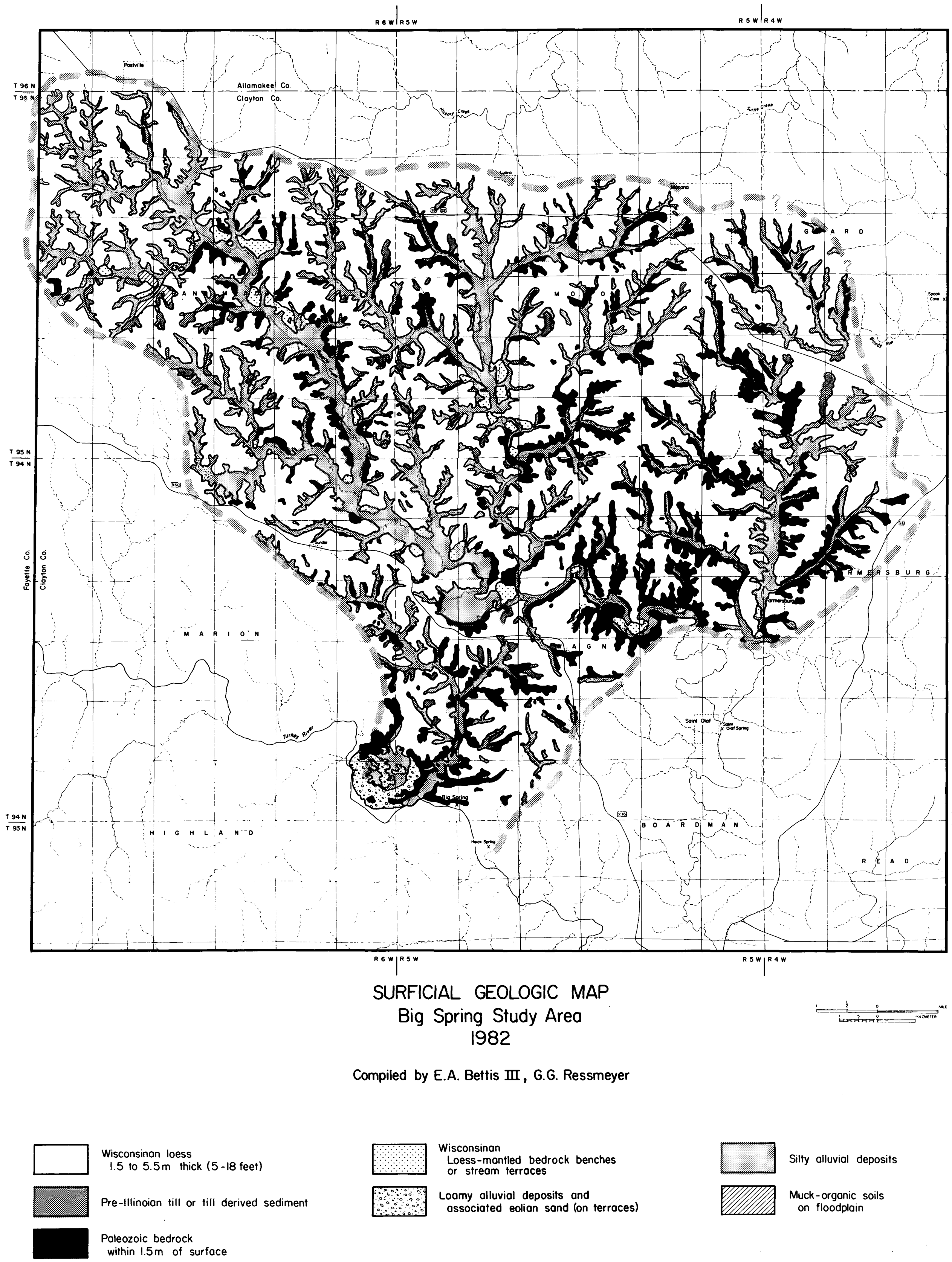


Figure 4. Surficial geologic map of the Big Spring basin.

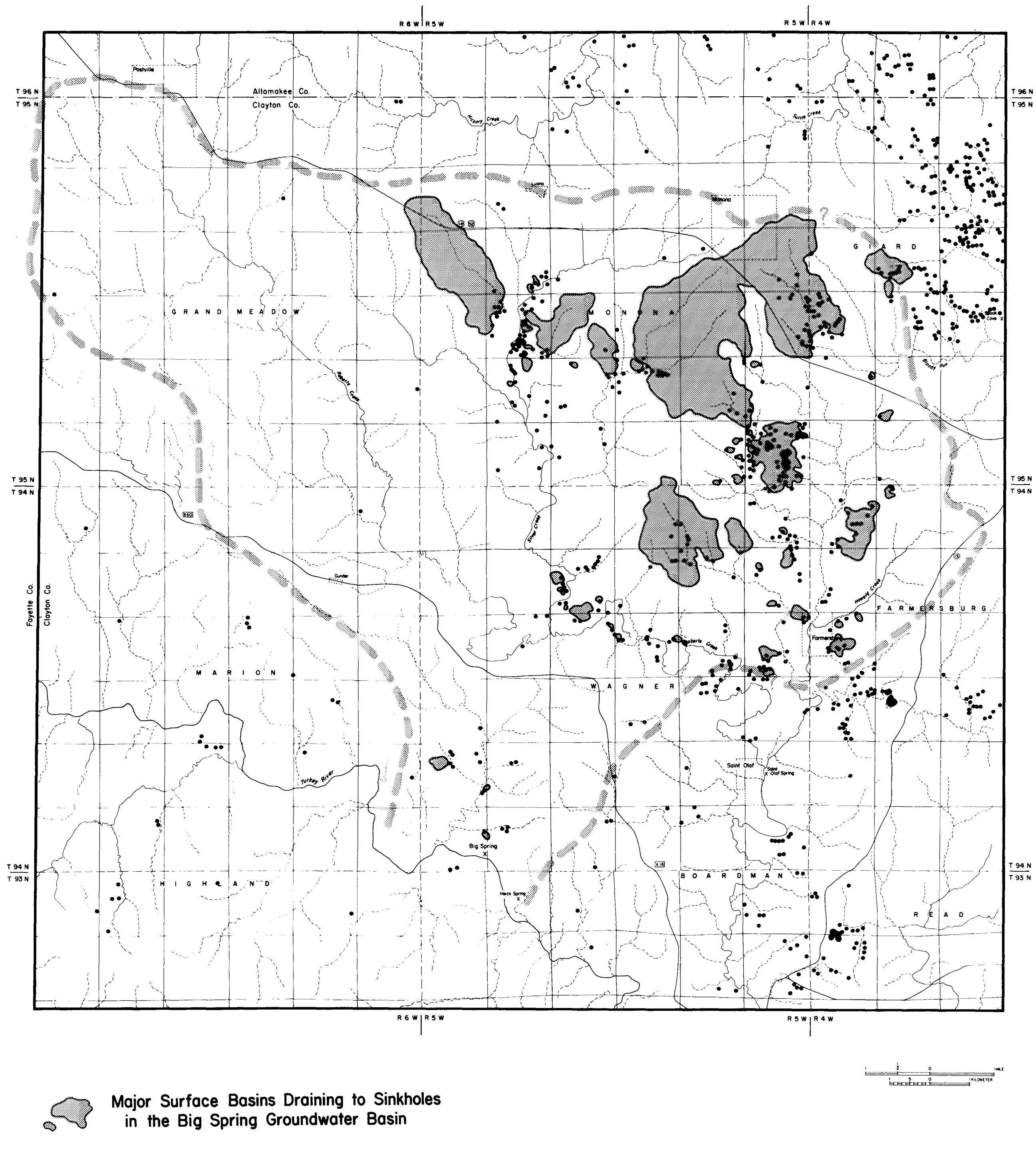


Figure 5. Map showing surface drainage and surface basins that drain to sinkholes.

A well-integrated, dendritic drainage network is developed in the Big Spring basin (Fig. 5). Roberts Creek is the major surface stream in the area, draining about 70% of the basin. This stream heads in the northwest corner of the basin, flows in a southeasterly course to the center of the basin, then flows eastward before turning to the south where it exits the groundwater basin, southwest of Farmersburg. The central portion of the basin is drained by Silver Creek, a major tributary of Roberts Creek. Silver Creek flows in a southerly course from just south of Luana on the northern boundary of the basin to its junction with Roberts Creek in section 16, Wagner Township. Silver Creek valley occupies the central portion of a subtle topographic sag trending north to south through Big Spring basin. The axis of this topographic sag follows a prominent flexure in the Galena structure contour mentioned in the discussion of the bedrock geology.

Howards Creek and an unnamed tributary drain most of the eastern one-third of the Big Spring basin. This portion of the drainage network follows a southerly course until it exits the groundwater basin about one-quarter mile south of Farmersburg. The basin's southern boundary is formed by the Turkey River, a major northeast Iowa surface stream. Surface drainage between Roberts Creek and the Turkey River is accomplished by an unnamed tributary to the Turkey River which joins the Turkey just upstream from Big Spring.

Many surface streams in this area are fed by springs and seeps issuing from shallow-groundwater flow in the Maquoketa, Galena, or Quaternary deposits in their headwater areas. In the eastern 2/3 of the basin, the Galena or the lowermost Maquoketa Formation is the uppermost bedrock. Here, karst features such as sinkholes are present and most of the streams lose water to the groundwater system. This loss occurs through fractures and sinkholes in and near the bed of the streams. Several blind valleys also exist in the Big Spring basin. These disrupt the integrated drainage network and lead to the development of enclosed hollows which discharge entirely to sinkholes, thus entering the groundwater system of the Galena aquifer.

The major surface-water basins which drain to sinkholes were mapped and are shown on Figure 5. The basins were delineated using topographic maps, soils maps, and field observations. The sinkhole basins occupy 11.5 square miles (18.5 km), which is about 11% of the groundwater basin.

Much of Big Spring basin's drainage network is bedrock controlled, especially the second order and larger valleys in the eastern 2/3 of the basin. Valleys in the area appear to follow joint trends and in some cases, such as Roberts Creek in Wagner Township, follow a tortuous course along these trends.

Big Spring discharges groundwater from a 103 mi^2 groundwater basin. The basin was defined by a combination of dye tracing from sinkholes to springs, identification of losing and gaining stream reaches (Fig. 6), and mapping the potentiometric surface of the Galena aquifer (Fig. 7). The potentiometric surface contains two pronounced north-south trending troughs that extend from sinkhole basin areas towards Big Spring. These indicate that highly transmissive "conduit" zones are present and acting as drains for the aquifer. Dye traces indicate that flow rates within these zones exceed 1,500 feet/hour under high-flow conditions, when sinkhole-captured surface-runoff is directly recharging the conduits. Under low flow conditions flow rates of less than 250 feet/hour have been measured in the same zones. The dye traces also indicate that several small springs are associated with Big Spring. The largest of these is located about two hundred yards east of Big Spring, and formed when Big Spring was originally dammed for use as a water source.

Figure 7 shows the locations of three cross-sections given on Figures 8, 9, and 10, superposed on the potentiometric map. Each section delineates the geologic units (abbreviations as on Fig. 3), the general land-surface topography, streams, the relations to the St. Peter Sandstone (OSP), and the major sinkhole areas. As noted, the main sinkhole areas occur where the Galena (Og) outcrops and where only a thin increment of the lower Maquoketa (Omf) overlies the Galena.

Cross-section A-B (Fig. 8) runs roughly north-south across the northern groundwater and surface-water divide, and then roughly follows a groundwater flow path going south, into the axis of the central conduit zone trough, and on to the discharge area at Big Spring. This section follows the general structural dip of the Galena as well. The cross section illustrates several important features. The potentiometric surface declines sharply in elevation in the central conduit-zone trough. In this area the potentiometric surface comes within 50 to 75 feet of the base of the Galena carbonates. LeGrand and Stringfield (1973) note that the water table in karst aquifers becomes so depressed along main "arterial" conduits that the water table, related to the conduits, joins surface streams almost at grade. Section A-B illustrates this situation in the Galena aquifer in the Big Spring area.

Development of solution conduits in carbonate rocks takes place near the water table and in the upper

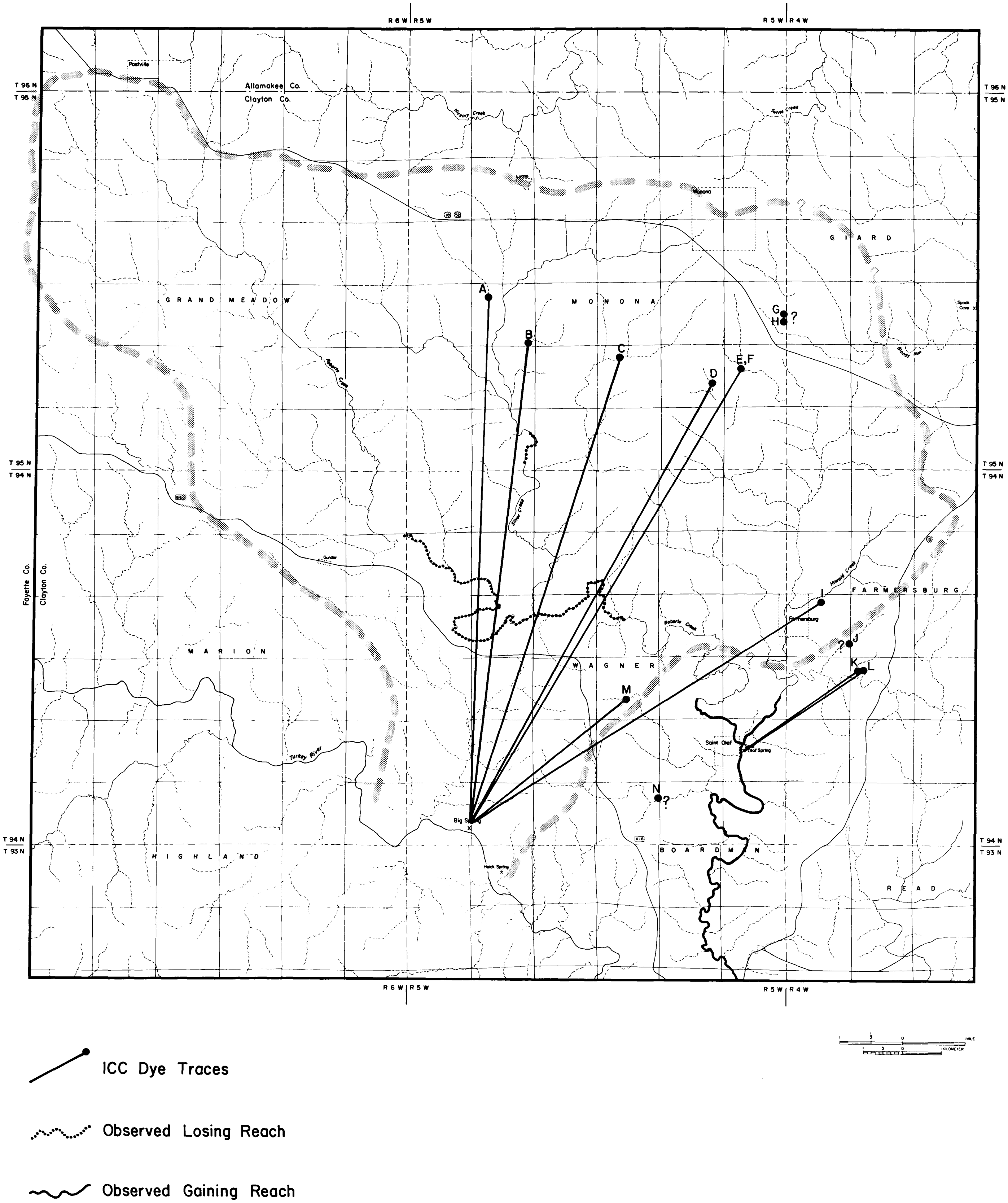


Figure 6. Map showing dye traces and gaining and losing stream reaches in the Big Spring basin.

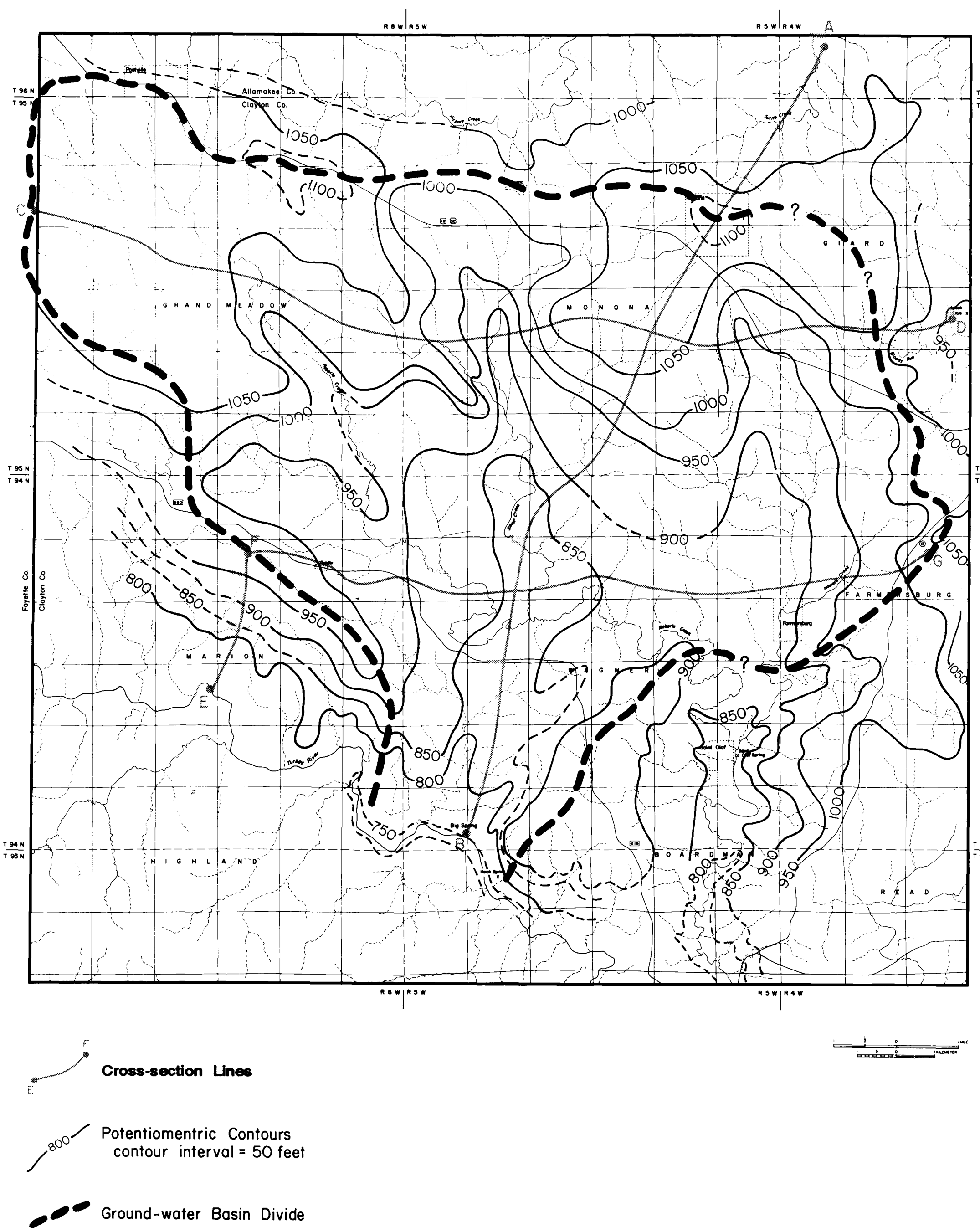


Figure 7. Map showing the potentiometric surface of the Galena aquifer. Cross-section lines for Figures 8, 9, and 10 are also shown.

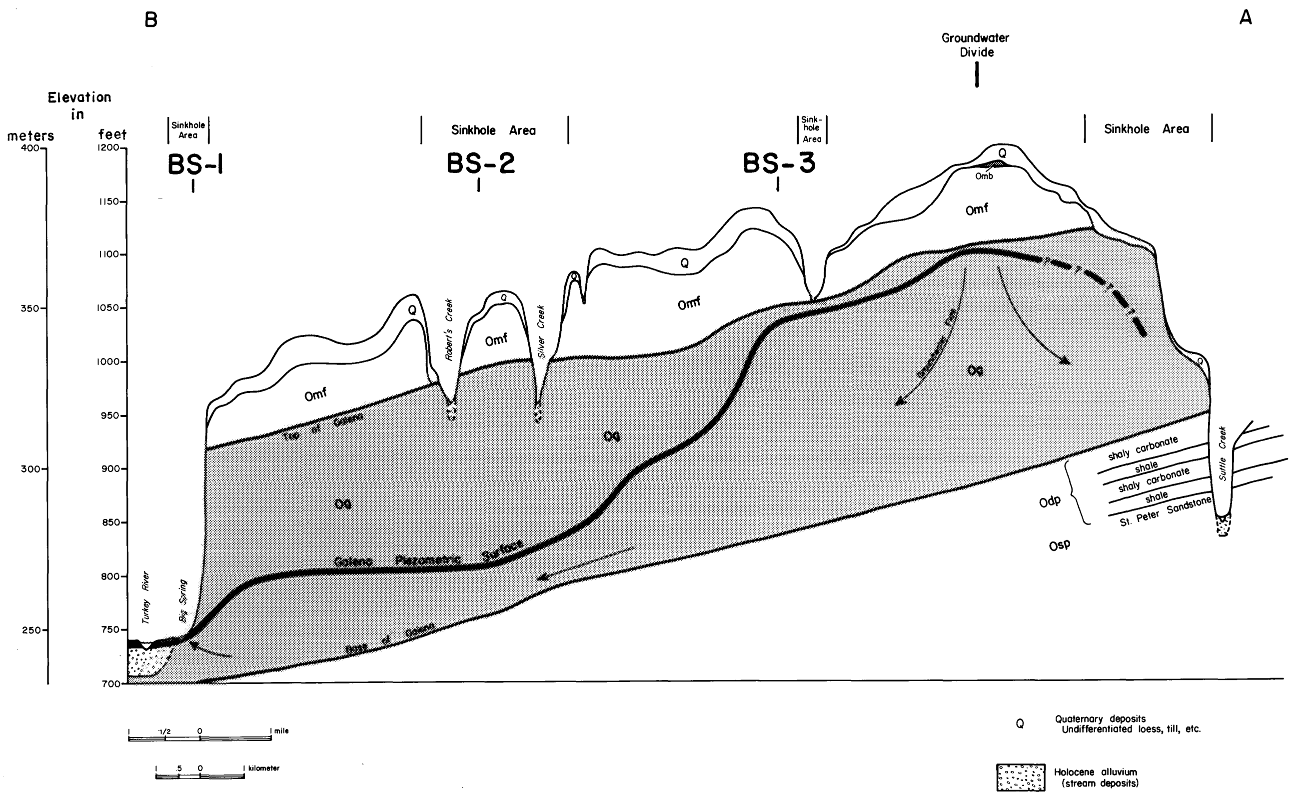


Figure 8. Hydrogeologic cross-section A-B. Location given on Figure 7.

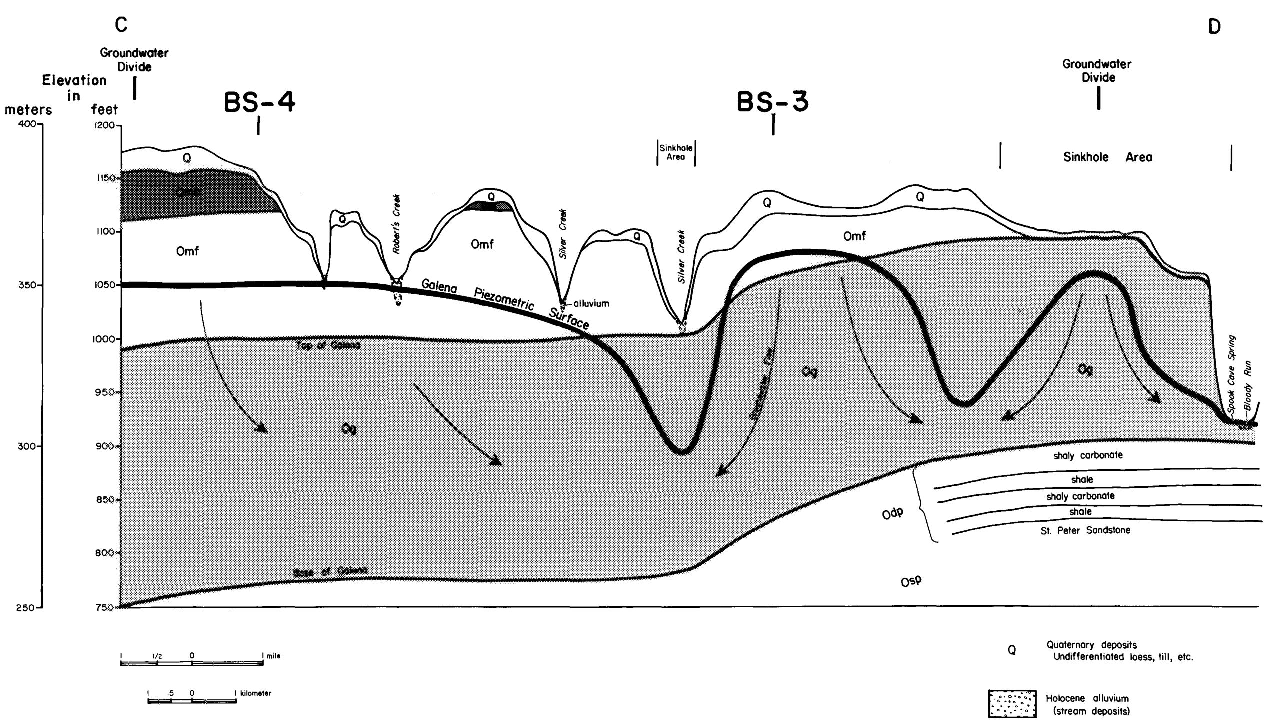


Figure 9. Hydrogeologic cross-section C-D. Location given on Figure 7.

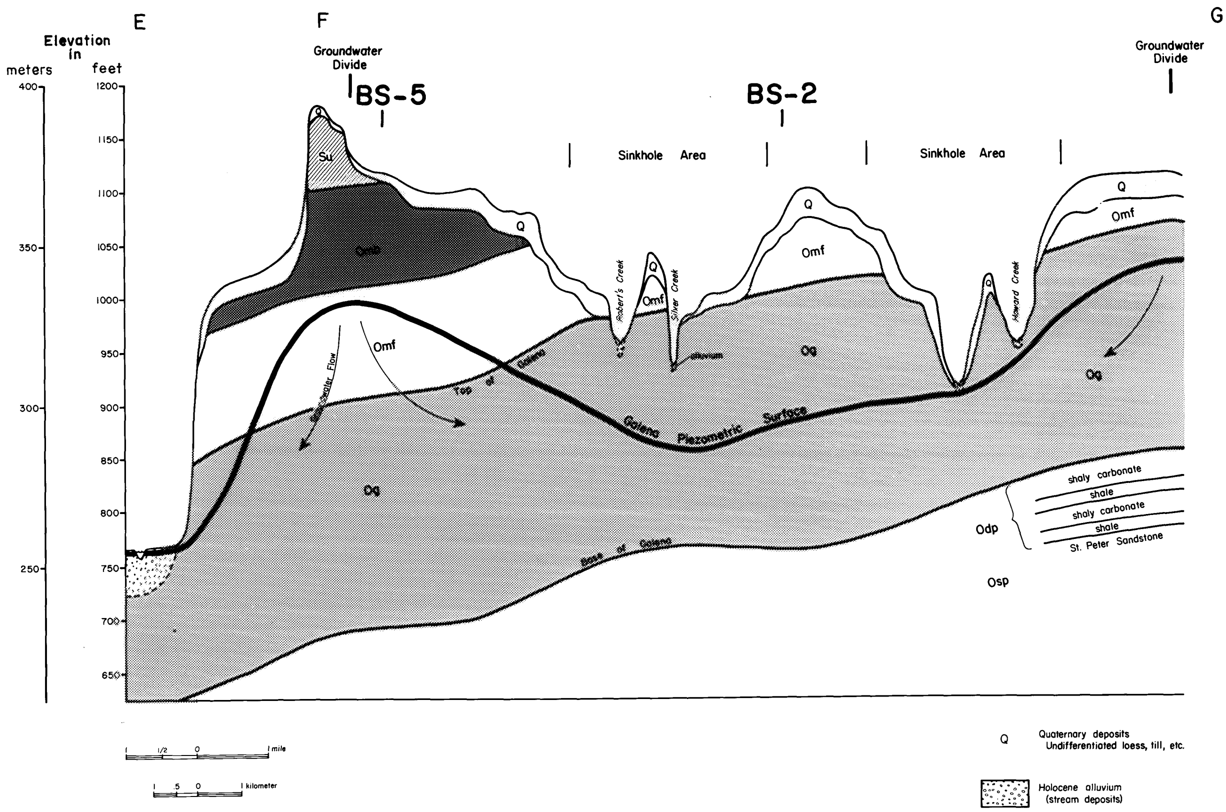


Figure 10. Hydrogeologic cross-section E-F-G. Location given on Figure 7.

part of the zone of saturation, and then decreases with depth (Thrailkill, 1968; Le Grand and Stringfield, 1973). The Turkey River is the major discharge stream for the Galena aquifer, and thus acts as the "base-level" for the potentiometric surface in the aquifer. Well records and ongoing studies of the alluvial history of the Turkey River valley show that, in the geologic past, the Turkey River was downcut 50 to 60 feet deeper than the present floodplain. As suggested in Figure 8, the river must have cut to (or perhaps through) the base of the Galena carbonates. In relation to the present potentiometric surface, this suggests that karst conduits may have been able to develop essentially to the base of the aquifer in this region.

Another important feature illustrated by section A-B is the relationship of the Galena potentiometric surface to surface streams. Silver Creek and Roberts Creek, and their alluvial valleys, are 100 feet or more *above* the Galena potentiometric surface over the axis of the central conduit trough. In this immediate area, adjacent to Roberts Creek, solution openings observed in quarries in the Galena go down below the level of the floodplain of the creek and are dry. Alluvial wells drilled by GSB within 50 feet of Roberts Creek are finished in gravels below the elevation of the creek, and are also dry. During the winter the creeks at times are frozen to their beds in this losing reach, whereas in the gaining stretches flowing water is present beneath the ice, and springs and seeps maintain open reaches. Thus, various field observations can clearly support that there is no shallow water table graded to and recharging the creeks in this area. Yet in most years these streams flow across this area continuously.

Cross-section C-D (Fig. 9) runs from east to west across the pronounced central and eastern conduit-zone troughs in the Galena potentiometric surface. In the central part of the section, Silver Creek is perched high above the potentiometric surface. In this area the entire flow of Silver Creek sinks into its bed during extremely low-flow periods. In contrast, to the west the Galena potentiometric surface is nearly in confluence with Roberts Creek and its alluvial aquifer. Field observations again support this; water levels in the shallow groundwater system (Maquoketa and alluvial wells) are only a few feet higher than the Galena potentiometric surface, alluvial wells produce water, and the water table in the alluvial aquifer grades to the stream. Observed springs and seeps maintain perennial flow in this area of Roberts Creek. Note also that the central conduit zone trough coincides with the pronounced structural flexure in the Galena carbonates that was discussed previously. Near the eastern conduit-zone trough, a new sinkhole formed which was investigated by GSB staff. Beneath the sinkhole was a vertical solution shaft or dome pit that descended about 120 feet below ground level without encountering saturated conditions.

Cross section E-F-G (Fig. 10) runs east-west across the southern part of the groundwater basin, traversing the broad low area on the potentiometric surface (Fig.7) where the east conduit-zone trends to the west and south to merge with the central trough. This section goes through the outliers of Silurian rocks (Su), which form the highest areas in the basin, where the full thickness of the upper Maquoketa Formation (Omb) overlies the Galena aquifer. The section goes through the losing reaches of Roberts and Silver Creeks, and to the east, traverses Howard Creek and an unnamed tributary just north of where these creeks are observed to gain discharge from the groundwater.

As described, the surface streams within the basin have a very complex relationship with the groundwater system. Most of the streams are recharged by shallow-groundwater flow in their headwaters. They then pass into losing reaches where they are over the Galena carbonates in the center of the basin. As they leave the basin, they become gaining streams once again, receiving discharge from the Galena in the St. Olaf area. Even in reaches that appear to be losing to the groundwater, intermittent tile drainage from shallow infiltrating groundwater is discharged into the streams. As noted, these streams generally have perennial flows, indicating their recharge, provided by shallow groundwater in their headwaters and tile drainage, is greater than their rate of leakage to the groundwater system.

Landuse

Landuse patterns make the Big Spring basin particularly conducive to the study of the agricultural ecosystem. The land in the basin is essentially all used for agriculture. There are no significant urban or industrial areas, no landfills or other major point sources to confound the analysis of the groundwater data. The only point sources are surface-water discharges from a creamery near Luana and from a new sewage treatment plant near Monona (Fig. 1). The impact of these sources are monitored.

Table 1 presents landuse information, showing the area and percentage of land in the basin used for various purposes. During the 1980s, landuse in the basin has been relatively stable; with agriculture comprising nearly 97% of the basin. The agricultural acreage has also been relatively stable, with 50-60% of the basin annually devoted to row-crops. The notable exception was in 1983, during the Payment-In-Kind (PIK) program, when substantial land was taken out of row-crop production.

Up until about 1986 the row crop acreage was about 99% corn. In the past few years there has been a minor increase in the amount of soybeans grown in the area, and some small acreages of sorghum have been planted. Major cover crops include oats, hay crops, and pasture, and in some years minor amounts of wheat and barley. The landuse has been interpreted from aerial photos, ASCS records, staff field notes, and landowner surveys; these data have been 'digitized' from maps into the DNR-GSB geographic information system.

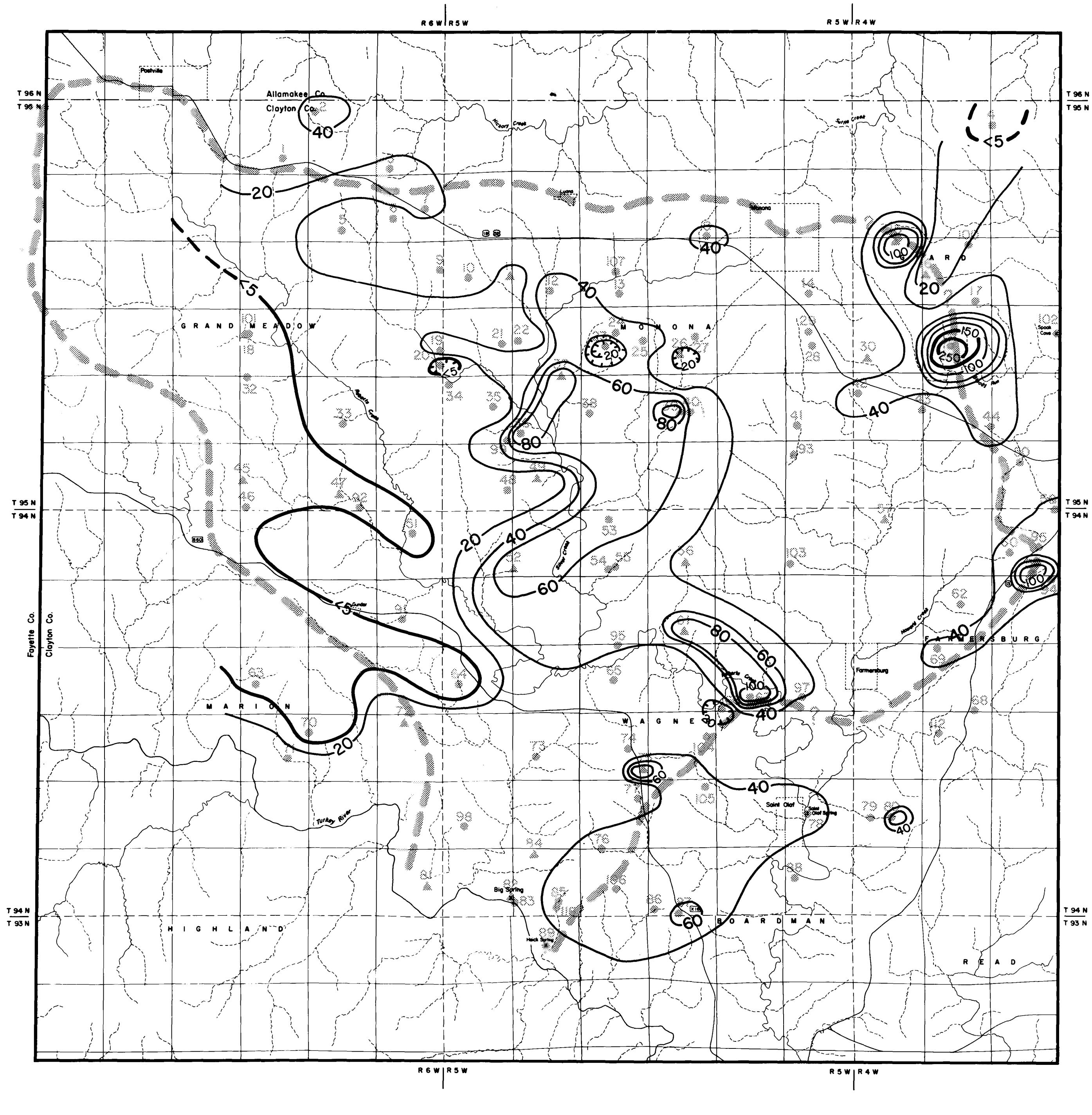
Water Quality Monitoring

During November and December of 1981, an initial field survey, including a private well inventory and sampling, was conducted in the basin. Data for geologic, potentiometric, and other mapping were collected during this period. Over 270 farm sites were visited, and about 125 wells were sampled for nitrate and coliform bacteria. The nitrate data are shown on Figure 11. Note that in the western part of the basin, a significant thickness of the upper Maquoketa Formation overlies the Galena aquifer (Fig. 3) and here, nitrate concentrations are below 5 mg/L; elsewhere, concentrations average about 40 mg/L. The upper Maquoketa confining bed protects the underlying Galena from surficial contaminants in the western part of the basin; groundwater age-dating indicates the Galena in this area recharged prior to the intensive use of chemical fertilizers, and possibly before European settlement.

Since the initial survey, a network of precipitation stations, tile lines, streams, springs, and wells of various depths has been monitored. These investigations documented the concurrent increase in N-fertilizer applications and nitrate concentrations in groundwater, and have noted the presence of atrazine and other herbicides in surface water and groundwater. Based on

Table 1. Landuse in the Big Spring basin, 1970 to 1987. (Computed by DNR-GSB Big Spring geographic information system to standardize results.)

	------- 1970 -------			------- 1980 -------		
	acres	square miles	% of basin	acres	square miles	% of basin
Row crop	18,543	29.0	28.1	31,459	49.2	47.6
terraced row crop	4,375	6.8	6.6	4,196	6.6	6.4
Total row crop	22,918	35.8	34.7	35,655	55.7	54.0
Strip crop	2,094	3.3	3.2	4,835	7.6	7.3
terraced strip crop	992	1.6	1.5	1,199	1.9	1.8
Total strip crop	3,086	4.8	4.7	6,034	9.4	9.1
Cover crop	32,481	50.8	49.2	16,656	26.0	25.2
terraced cover crop	1,482	2.3	2.2	1,364	2.1	2.1
Total cover crop	33,963	53.1	51.4	18,020	28.2	27.3
Forest	3,950	6.2	6.0	4,159	6.5	6.3
Urban	306	0.5	0.5	363	0.6	0.6
Roads	1,834	2.9	2.8	1,834	2.9	2.8
Quarries	16	0.02	0.0	9	0.01	0.0
Total urban	2,156	3.4	3.3	2,205	3.5	3.3
TOTAL	66,073	103.2	100.1	66,073	103.2	99.9
	------- 1986 -------			------- 1987 -------		
	acres	square miles	% of basin	acres	square miles	% of basin
Row crop	26,074	40.7	39.5	25,027	39.1	37.9
terraced row crop	3,143	4.9	4.8	3,252	5.1	4.9
Total row crop	29,217	45.7	44.2	28,279	44.2	42.8
Strip crop	10,292	16.1	15.6	8,561	13.4	13.0
terraced strip crop	1,010	1.6	1.5	799	1.3	1.2
Total strip crop	11,302	17.7	17.1	9,360	14.6	14.2
Cover crop	18,614	29.1	28.2	21,165	33.1	32.0
terraced cover crop	1,498	2.3	2.3	1,881	2.9	2.8
Total cover crop	20,112	31.4	30.4	23,046	36.0	34.9
Forest	3,223	5.0	4.9	3,169	5.0	4.8
Urban	388	0.6	0.6	388	0.6	0.6
Roads	1,834	2.9	2.8	1,834	2.9	2.8
Quarries	8	0.01	0.0	8	0.01	0.0
Total urban	2,219	3.5	3.4	2,220	3.5	3.4
TOTAL	66,073	103.2	100.0	66,073	103.2	100.1



Nitrate Concentration (Nov.-Dec., 1981)

Contour Interval - 20 Mg/l

Departure from Stated Contour Interval

Figure 11. Nitrate concentrations in Galena aquifer groundwater, November-December 1981.

this research the multi-agency group involved with these studies initiated the Big Spring Basin Demonstration Project in 1986. This effort integrates public education with on-farm research and demonstration projects that stress the environmental and economic benefits of efficient chemical management. As part of the project, the water-quality monitoring network was expanded to over 50 sites, to provide a detailed record of the water-quality changes accompanying improved farm management. The monitoring network is designed in a nested fashion, from small-scale field plots to the basin water outlets at Big Spring and Roberts Creek. Key sites are instrumented for continuous or event-related measurement of water discharge and chemistry, and for automated collection of samples for laboratory analysis. Selected sites are shown on Figure 12. The development of monitoring sites within the Big Spring basin has been a cooperative effort. USGS staff designed, constructed, and maintain the stream gaging stations and cooperate in water-quality monitoring. Tile-monitoring installations and a surface-water flume for runoff monitoring were designed and constructed under the direction of Dr. James Baker, Department of Agricultural Engineering, Iowa State University. Water samples collected within the basin are submitted for analysis to the University Hygienic Laboratory; analytical methods are summarized in Hallberg et al., 1989.

The network design and instrumentation allows a detailed view of the hydrologic system, at a variety of scales. The smallest areas with instrumented tile lines and/or shallow piezometers are individual fields or land-use tracts (5 to 40 acres) with known management. Nested within some of the individual fields are research and demonstration plots (<1/4 acre) of varied farm management, and within selected research plots, microplots (3 ft^2) are used to study nitrogen movement. Monitoring at the field scale allows observation and interpretation of the processes of water and chemical-transport in relation to soil properties and agricultural management. Water quality improvements caused by changes in agricultural practices will most quickly and clearly become apparent at the field scale.

From the individual field sites, the nested monitoring scheme follows the natural hierarchy of the drainage system. Watersheds of increasing size are instrumented and monitored, up to the main surface-water and groundwater outlets for the basin. Water quality at these larger scales is an integration of the management practices of all the individual parcels of land they contain. Water quality improvements at these increasingly larger scales will require longer periods of time to become apparent, relative to field plots.

The hydrologic and chemical responses of the individual fields to recharge events can be tracked through the larger groundwater and surface-water systems. While the concentration changes are not as great or as immediate at the largest scales monitored, they are clearly apparent and the nested monitoring design employed allows the pulse to be interpreted in relation to their source. Through this hierarchy responses to changes in management practices can also be tracked at various scales, and a detailed record of the chemical flux through the basin is being established. This will afford, over time, an assessment of the water-quality improvements resulting from changes in agricultural practices.

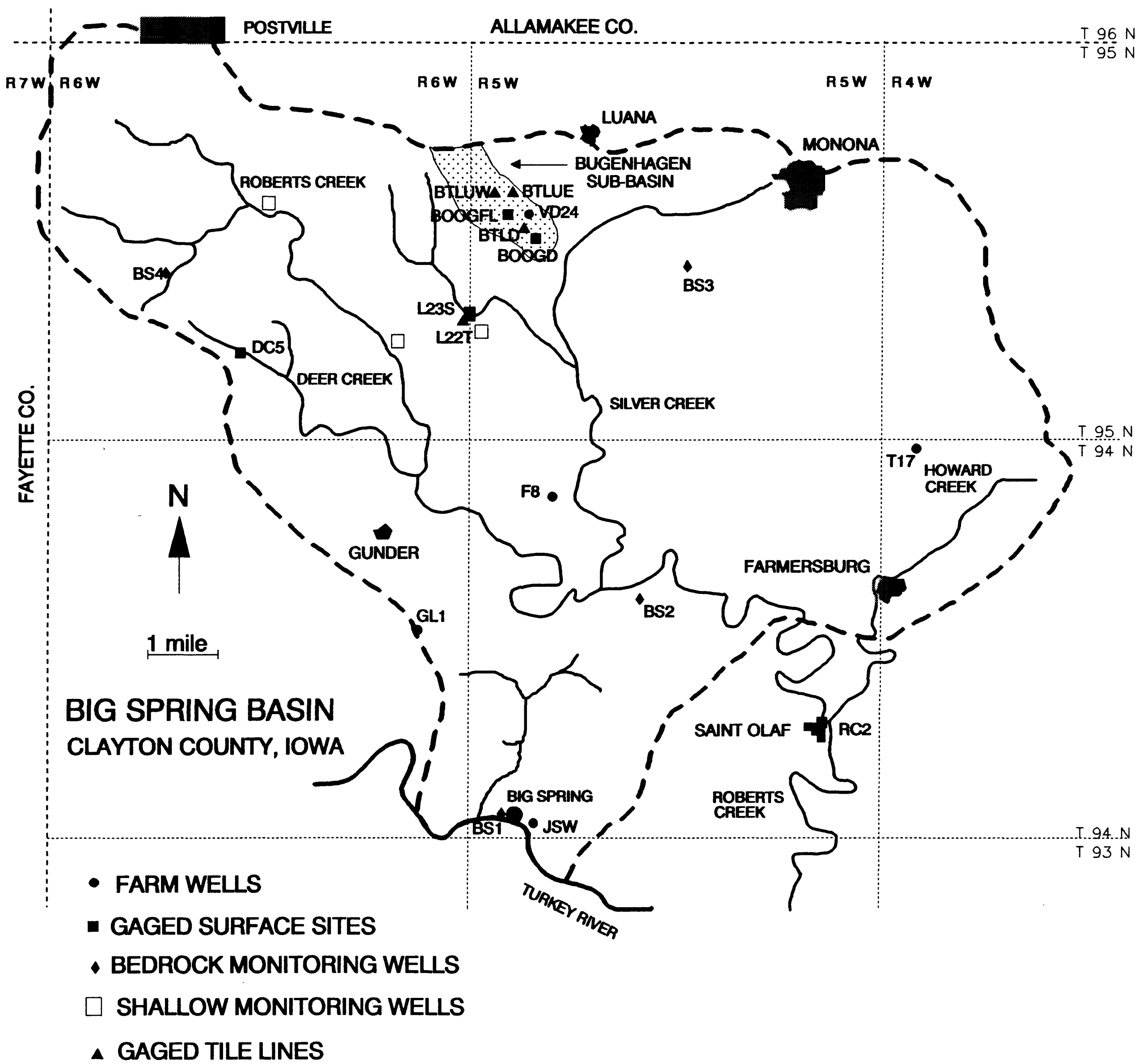


Figure 12. Map showing selected sites in the Big Spring basin monitoring system.

FRIDAY

STOP 1: CHICKEN RIDGE OVERLOOK

At Stop 1, en route to Elkader and the Big Spring basin area, we will pull off Iowa Highway 13 at the crest of Chicken Ridge. From this vantage point we can view the relationships of the bedrock stratigraphy (Fig. 2) and the landscape in the Paleozoic Plateau (Prior, 1991; Hallberg et al., 1984). Chicken Ridge forms part of the Silurian or "Niagaran" Escarpment, which winds its way throughout the midwest and Great Lakes regions. Portions of the Silurian section are exposed in the road cuts along the ridge crest. Cross sections of sinkholes and other enlarged fractures in the cherty Silurian carbonates of the Blanding Formation are exposed. The sinks and other fracture openings are in part solutional and in part mechanically induced. The instability of the landscape has promoted some mechanical movement, separation and widening of fractures and other openings, in addition to solutional enlargement (Hansel, 1976; Bounk, 1983a). The ridge is capped with 5-6 feet of Wisconsinan Peorian Loess.

The ridge crest, above the road level, is at an elevation of approximately 1165 feet. Looking to the southwest, the landscape descends in stepped fashion to the Volga River, at an elevation of 740 feet; to the north it descends to the Turkey River at an elevation of 700 feet along Highway 13. Looking to the southwest provides a landscape view of the local stratigraphy. The entire area has a thin mantle of loess and loess-derived colluvium and hence outcrops are not common, except on the steeper slopes. The steep wooded scarp along the ridge crest is upheld by the resistant Silurian dolostones, approximately 75-85 feet thick. Below the Silurian, a series of stepped erosion surfaces occur, related to the lithologies of the underlying strata. The more gentle slopes flaring out along the interfluves below the Silurian are underlain by the Brainard Shale (about 120 feet thick) of the Maquoketa Formation. The Brainard Shale forms an effective aquitard separating the Silurian aquifer from the Galena. Along with the topographic break is a marked change in landuse, with row crops, hay crops and pasture on the more gentle Maquoketa slopes. These slopes continue to flatten out, then terminate in steeper slopes, in the middle distance, formed on the Ft. Atkinson Member, another resistant carbonate unit.

This steeper backslope descends onto another more gently sloping surface, below about 900 feet, underlain by the Clermont Shale and the Elgin Member of the Maquoketa, comprised of silty, shaly dolomitic rocks. These surfaces end again in steeper slopes as the top of the resistant Galena Group carbonate rocks are encountered at about 825 feet elevation. Portions of the Dubuque and Wise Lake Formations are exposed in cuts near the Volga and Turkey Rivers; these slopes coincide with the wooded areas in the lower portion of the landscape that we can see from here. The steeper, loess-mantled Galena slopes descend to Wisconsinan and Holocene alluvial surfaces and deposits along the valleys.

As we proceed north on Highway 13, we will descend and ascend through this landscape. Outcrops of the Silurian are visible on the next ridge segment and as we approach the Turkey River valley outcrops of the Galena occur. On the other side of the Turkey we will pass by large roadcuts in the Galena Group rocks. The primary aquifer in the Big Spring basin is comprised by the Galena Group rocks, but the Elgin Member is hydrologically connected.

SATURDAY

STOP 2: ROBERTS CREEK QUARRY

One characteristic of carbonate rocks located near the land surface is the development of secondary porosity through dissolution by meteoric water. Rainwater passing through the atmosphere and upper parts of the soil profile reacts with carbon dioxide and organic compounds to form weak acids which are transported to the rock with downward percolating water. When it reaches the rock the weakly acidic water reacts with the carbonates, and portions of the rock are dissolved.

In many carbonate rocks there is relatively little intergranular porosity compared to, for example, sandstones. For this reason most water movement in carbonates follows vertical fractures or joints, and horizontal bedding planes. As water moves through these openings, it dissolves some of the confining rock, thus enlarging the openings and allowing greater flow. This diverts flow from smaller adjacent openings and concentrates flow in the larger conduits causing them to increase in diameter.

The overall direction of groundwater flow in carbonate rock is down gradient in response to potentiometric pressure as it is in a hydrologically more isotropic rock such as sandstone. In carbonates, however flow is concentrated along zones of high hydraulic conductivity; the water readily moves along the enlarged fractures and bedding planes. Thus, solution conduit and cavern development occur along those fracture trends which best facilitate down-gradient water movement (Bounk, 1983a, 1983b).

These principles are displayed in the Roberts Creek Quarry. This quarry is developed in the lower portion of the Dubuque Formation (Frankville Beds) and upper portions of the Wise Lake Fm. (Stewartville Member) of the Galena Group. The "Upper *Receptaculites* Zone" of Levorson and Gerk (1983) is evident four to six feet above the quarry floor. Dolomitized burrows are very evident on fresh and slightly weathered faces. Five prominent joint trends are developed in the rocks in this quarry (N42°E, N60°W; N4°W; and E-W). These are prominent trends throughout the Big Spring area. Several of the quarry walls are developed along these trends. These walls show abundant solutional pitting, widening, and reddening a result of downward movement of surface-derived water. The joint faces are significantly enlarged at some joint intersections in the lower and middle parts of the quarry walls. These appear to widen downward and may be the top of dome pits entering a large conduit network at a lower stratigraphic level. Solutional widening of these rocks is also evident along horizontal bedding planes. In this case, water moving horizontally along these zones has dissolved some of the rock. Additional widening is usually noted at the intersections of the joints and bedding planes.

Other karst features have been observed in this quarry. Occasionally, there are cracks in the quarry floor which open into small caverns. These features are dry and have been observed extending approximately six feet below the quarry floor. Sinkholes, usually filled with reddish brown loamy and clayey sediment, have been observed high on the quarry walls. These are present where solutionally-enlarged joints intersect the top of the bedrock surface. Close examination of the materials filling these sinkholes shows that they contain occasional erratics. Materials filling the sinkholes are very similar in appearance to "Late-Sangamon" Paleosols which developed long after the last Pre-Illinoian glaciation of northeastern Iowa. It seems likely that the karst fill is "Late Sangamon" Paleosol-derived material which has slumped and washed into the sinkhole. If this is the case, these sinkholes are younger than Pre-Illinoian in age (Hallberg and Bettis, 1985).

Further evidence for the age of the karst is provided by U-series dating of flowstone associated with the karst (Lively, 1983). The flowstone can accumulate only after solutional widening has occurred, and therefore flowstone dates provide minimum ages for the karst features they are associated with. Flowstone collected from the western south-facing wall of Roberts Creek Quarry yielded a Uranium-Thorium date of 7,900 ±200 years (R. Lively, Minnesota Geological Survey, personal communication). This flowstone was accumulating during the early middle Holocene.

The Galena group rocks are buried by ten to twenty feet of Quaternary deposits at the Roberts Creek Quarry. The bulk of this thickness is made up of Wisconsinan-age Peoria Loess. In addition, patches of a once continuous Pre-Illinoian-age glacial till cover are occasionally exposed during the quarrying operation. These weathered, unlithified Quaternary materials readily transmit recharge water and dissolved contaminants to the karstified bedrock surface where it travels down solutionally-enlarged joints within the Galena aquifer.

STOP 3: WELL NEST BS-2

Nests of wells have been installed in several different hydrogeologic settings within the Big Spring basin (see Fig. 12). Figures 13 and 14 show the stratigraphic sequence and monitoring-well installations for the nest at site BS-2. This site is located about 100 feet south of Roberts Creek, above an inferred major conduit zone. In this portion of the basin, Roberts Creek and Silver Creek and their associated alluvial valleys are 100 feet or more above the Galena potentiometric surface, which lies roughly in the middle of the aquifer. This site contains seven monitoring wells designated BS-2A through BS-2G. BS-2A is screened into the middle of the Wise Lake Formation. BS-2B is screened into a one foot-thick void within the Dunleith Formation. BS-2C is screened at approximately the same depth as BS-2B, but did not encounter the void found in BS-2B. BS-2D is also screened into the Dunleith Formation about 9 feet lower than BS-2C. Monitoring wells BS-2A through BS-2D have all remained essentially dry since completion. BS-2E penetrates the same void that was encountered in BS-2B, and is screened into a larger void approximately 30 feet lower in the Dunleith Formation. This void is approximately 5 feet thick and overlies a rubble zone that is also about 5 feet thick. The water level in BS-2E is about 154 feet below land surface. BS-2F is open to the Pecatonica Member of the Platteville Formation, within the aquitard which separates the Galena aquifer from the St. Peter Sandstone aquifer. BS-2F has remained essentially dry since installation, suggesting extremely low conductivity within the matrix of the aquitard. Similar conditions were encountered within the aquitard in wells drilled at Big Spring. Monitoring well BS-2G penetrated the void encountered in wells BS-2B and BS-2E, but did not penetrate the lower void that BS-2E is screened into. The water level in BS-2G rises from the St. Peter to approximately 185 feet below land surface, exhibiting confined aquifer conditions. Since the head in the St. Peter aquifer is lower than the head in the Galena aquifer, the groundwater gradient is downward from the Galena to the St. Peter aquifer in this portion of the basin.

After BS-2E was partially completed water could be heard discharging into the hole. To investigate this, a downhole camera was utilized, and water was seen discharging from the upper void and running down the side of the hole and into the lower void. The upper void appears to be a solutionally enlarged bedding plane. The morphology of the lower void could not be determined, as its dimensions were greater than the camera lights could penetrate. A small volume of water was also noted seeping into the hole from small fractures, voids and/or enlarged bedding planes at approximately the same level as the bottom of the channel of Roberts Creek.

The documentation of water seeping into BS-2E, coupled with observations that show wells BS-2A through BS-2D had remained essentially dry, suggest that Roberts Creek is actively loosing water at this site. The distribution of voids in the monitoring wells demonstrates the complex distribution of fractures and/or voids within the Big Spring groundwater flow-system. At this location, some water is conducted along minor unsaturated horizontal passages from the stream bed and shallow alluvial aquifer system before reaching the saturated zone through vertical fractures and voids. Water is also being channeled through the upper solutionally enlarged bedding plane, above the water table/ potentiometric surface. Passages such as these demonstrate the complexity of recharge-water flow paths associated with the Galena aquifer.

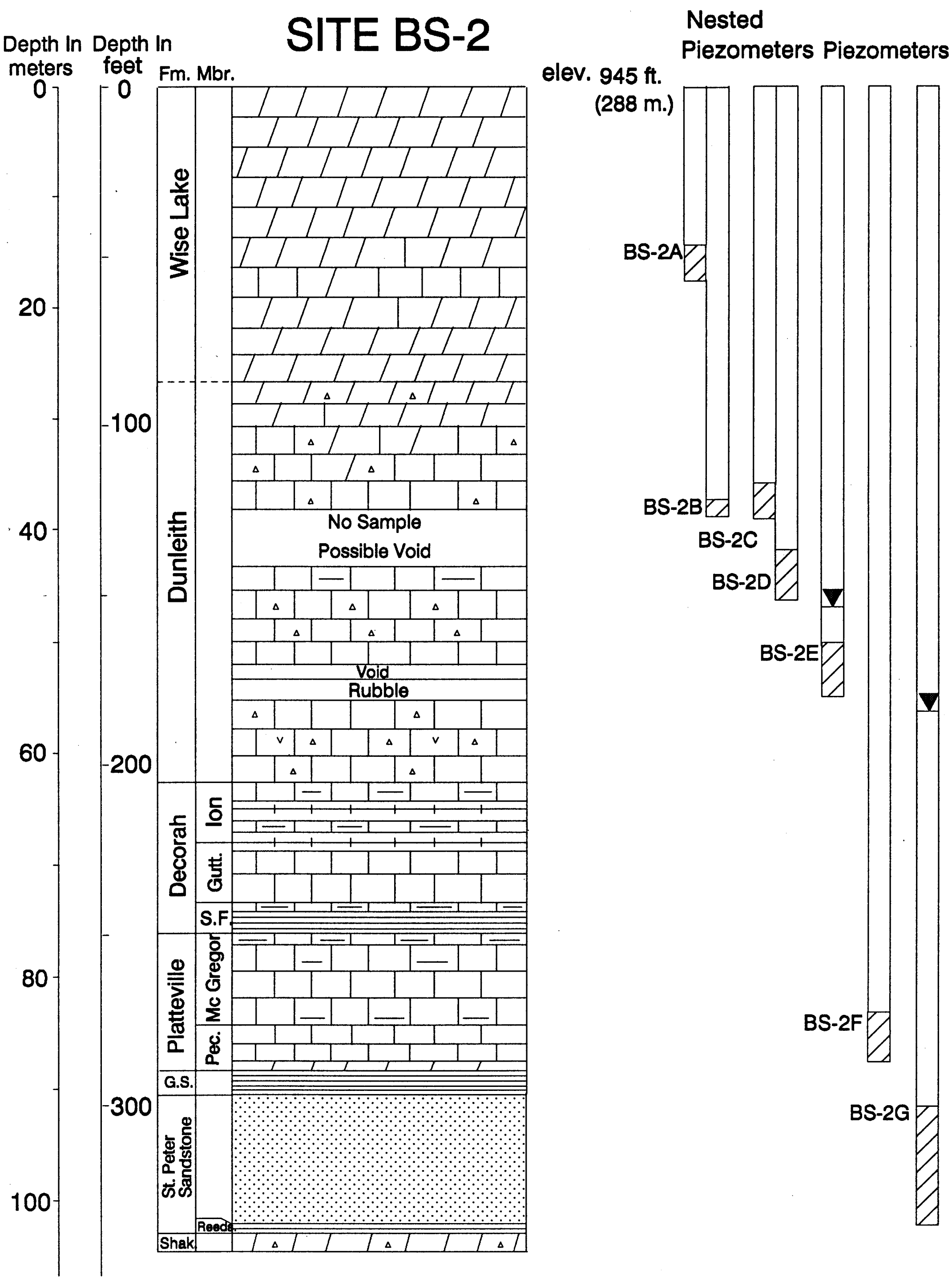


Figure 13. Stratigraphic sequence and monitoring-well installations at Site BS-2 (core logged by M.J. Bounk).

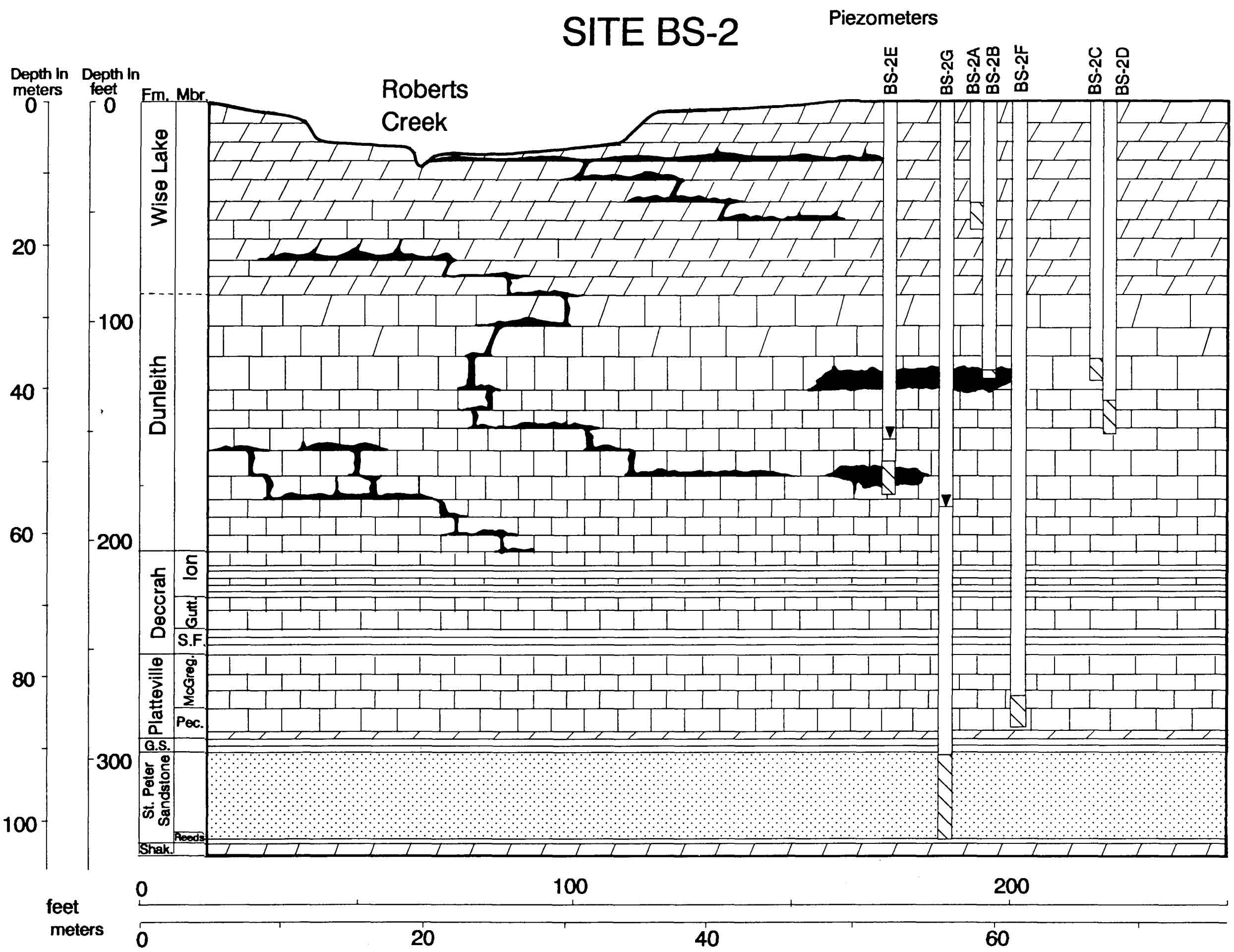


Figure 14. Geologic cross-section and monitoring-well installations at site BS-2. Shaded areas represent documented or inferred solution voids and solutionally enlarged fractures and bedding planes.

STOP 4: SASS FARM AREA

Sinkholes are the most prevalent surficial expression of karst development in northeastern Iowa, but sinkholes are not randomly distributed throughout the region. Karst features are concentrated in the outcrop belt of the Galena Group and Devonian carbonates in Dubuque, Clayton, Allamakee, Fayette, and Winneshiek counties, and along the outcrop belt of Devonian carbonates in Mitchell and Floyd counties. Another area of regional sinkhole concentration is along the Silurian Escarpment in Clayton and Dubuque counties.

Stop 4 is located in one of the areas of sinkhole concentration in the east-central part of the Big Spring basin (Figs. 3 and 5). Other karst features, such as sinking streams and blind valleys are present in this area. An area of several square miles around this stop contains more surfical expression of karst than any other part of the basin. Even here, there is a noteable lack of such surficial expression of karst, relative to many carbonate-rock areas.

Figure 6 shows the distribution of surface basins draining to sinkholes in the Big Spring basin as of 1983. Several other surface basins not shown on the map now drain to sinkholes in the area. A blind valley (a small valley ending abruptly at a joint face approximately perpendicular to the valley trend) is present on the east side of the road at this stop. West of the road several sinkhole locations are evident as roughly circular clumps of trees in the southeasterly-trending drainageway passing through the Ed Sass Farm. All the flow from this intermittent stream enters one of the large sinkholes northwest of the barn. This swallow has been active for at least several decades (Ed Sass, personal communication). In 1982 several small sinkholes were present in the drainageway down valley of the large sinkholes. These were filled with rock and Quaternary materials using a bulldozer in 1983 and 1984. Two of the filled sinkholes just west of the road and south of the lane into the Sass Farm have reopened. It is interesting to note that the road at this location was relocated over a filled sinkhole in 1985.

Quaternary deposits (thin Pre-Illinoian till and Peoria Loess) which bury the bedrock surface are generally less than 20 feet thick in this area. An exposure in a road cut on the west side of the gravel road shows a typical sequence of deposits in this area. At this location three to six feet of Peoria Loess bury a Farmdale Paleosol developed on older Wisconsinan loess (Roxana equivalent) which, in turn, buries a "Late Sangamon" Paleosol developed on Elgin Member carbonates. A stone line, which contains occasional erratics, rests on top of the "Late-Sangamon" Paleosol. The stone line is a lag deposit which originated during cutting of an extensive upland erosion surface prior to deposition of the Wisconsinan loesses.

Several feet of Elgin Member carbonates are present here. A thin phosphatic zone containing a depauperate fauna is present at the base of the Elgin Member in this outcrop. The top of the Dubuque Formation of the Galena Group is exposed at the base of the cut.

Comparison of the bedrock geologic map, the location of sinkholes, and the Galena potentiometric surface (Figs. 3 and 7) yields several insights into the karstification process and resulting hydrology of the Sass area and of geologically similar parts of the basin. First, sinkholes tend to form where all or most of the lowermost Maquoketa Formation has been erosionally removed. Second, the pronounced troughs in the Galena potentiometric surface tend to follow the Galena/lowermost Maquoketa outcrop belt in the major stream valleys. Potentiometric data from GSB-installed wells indicates troughs are present below some smaller valleys as well. These relationships indicate that as the Maquoketa is erosionally removed, the solutional process generates sinkholes at the surface These are linked to the extremely transmissive conduits that act as drains for the bulk of the aquifer, generating prominent troughs on the potentiometric surface.

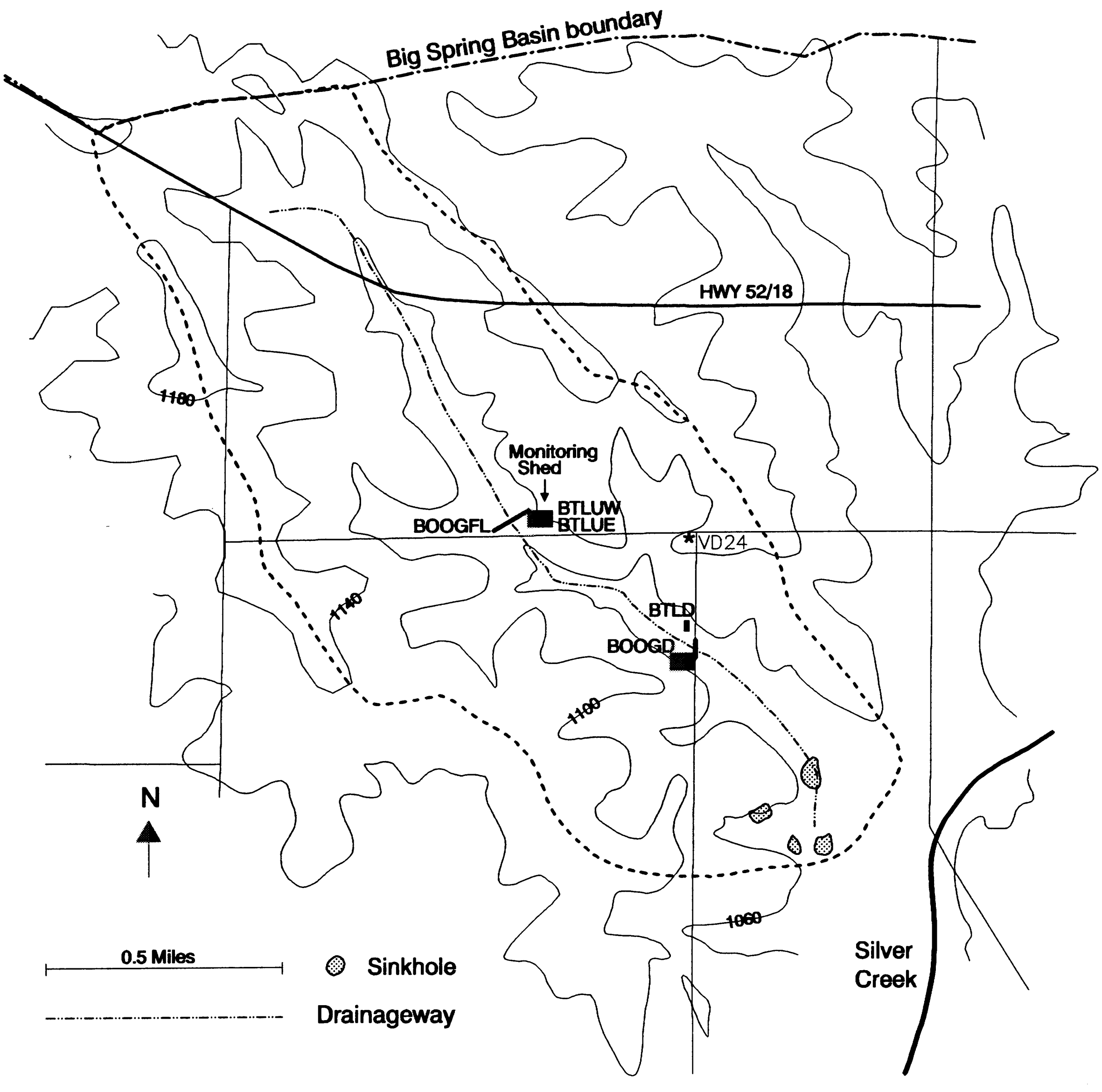


Figure 15. Topographic map of the Bugenhagen sub-basin showing monitoring site locations.

STOP 5: BUGENHAGEN SUB-BASIN

The Bugenhagen sub-basin has been the site of routine water-quality monitoring of tile lines, surface water, and groundwater since 1981. The sub-basin was selected early in the project to be a model area for implementation of improved farm management and soil conservation. Landowners within the watershed were enrolled in 7-year cooperative agreements involving cost-sharing to implement Best Management Practices (BMP). These BMPs stress soil conservation, and fertilizer and pest management through one-on-one technical assistance. The principle goals of the sub-basin efforts are to implement integrated farm management practices that improve profitability and environmental efficacy. The monitoring equipment within the sub-basin is used to document changes in discharge and water quality related to the implementation of BMPs.

The sub-basin area of 1,100 acres generally has a small surface-water discharge, which drains towards a complex of soil-filled sinkholes on the margin of the Silver Creek floodplain (Fig. 15). The uplands consist of loess, over remnants of glacial till and carbonate bedrock which crops out on the steeper slopes. The drainageways are filled with loamy alluvium that progressively thins, down drainage, over the bedrock. During low flow, surface water seeps into the alluvium of the streambed and the underlying bedrock before reaching the sinkholes. Intermittently, small openings or fractures in the bedrock swallow the discharge more directly. During higher flow conditions, discharge reaches the sinkhole complex located farther downstream. These sinkholes are large depressions that are generally filled with alluvium. They are not open directly into the bedrock, nor is bedrock exposed within the sinkholes. During extreme runoff events the stream may overflow the sinks, beyond which there is no defined channel. Excess streamflow bypassing the sinkholes has been observed to spread out over the floodplain of Silver Creek and infiltrate into the alluvial soils.

Dye tracing has established the connection between the Bugenhagen sinks and Big Spring (see Fig. 6, site A). Under relatively high-flow conditions travel times from the sinks to Big Spring are about 24 hours, indicating that a highly transmissive conduit zone underlies at least part of the sub-basin. There is a marked spatial variability in the presence of such features, as indicated by monitoring at farm well VD-24 (Fig. 15). VD-24 is about 200 feet deep, is cased to about 100 feet, and is located less than 1,000 feet from the sub-basin drainageway. Under normal-to-wet climatic conditions, groundwater from this well contains 20 to 40 mg/L nitrate, detectable atrazine (>0.1 ug/L), and 20 to 30 units of tritium (3H). However, concentrations of these parameters decline during drier periods. Nitrate concentrations fall to less than 5 mg/L, atrazine is not detectable, and tritium concentrations are less than 10 T.U. This indicates that during periods of limited recharge, groundwater that is more than 20 years old and largely unaffected by agrichemicals is pumped from within 1,000 feet of conduit zones. Similar groundwater likely discharges to the conduit zone, and ultimately resurfaces at Big Spring.

Upper Bugenhagen monitoring sites

Approximately 1/2 mile above the sinkhole complex is the sub-basin instrument shed (Fig. 15). The instrumentation here is designed to monitor the water discharge from the upper half of the sub-basin (approximately 400 acres). Both subsurface drainage from tile lines (BTLUE and BTLUW) and surface flow (BOOGFL) are monitored. The instrument shed is constructed of corrugated metal on an 8 by 12 foot deep foundation/sump, made of 5/8-inch exterior plywood (Fig. 16). Power for the instruments was originally supplied by a 12-volt lead-acid battery that was replaced on a weekly basis. This proved unsatisfactory, as the battery was prone to total discharge from increased sampling during runoff events. Insufficient power reserve during cold weather was also a problem. In addition, temperature fluctuations and humidity build-up within the shed caused problems with the electronic equipment. As a result, electrical service was extended to the shed, the upper compartment was sealed and insulated with 3 1/2-inch faced fiberglass insulation, and the sump was insulated with 2-

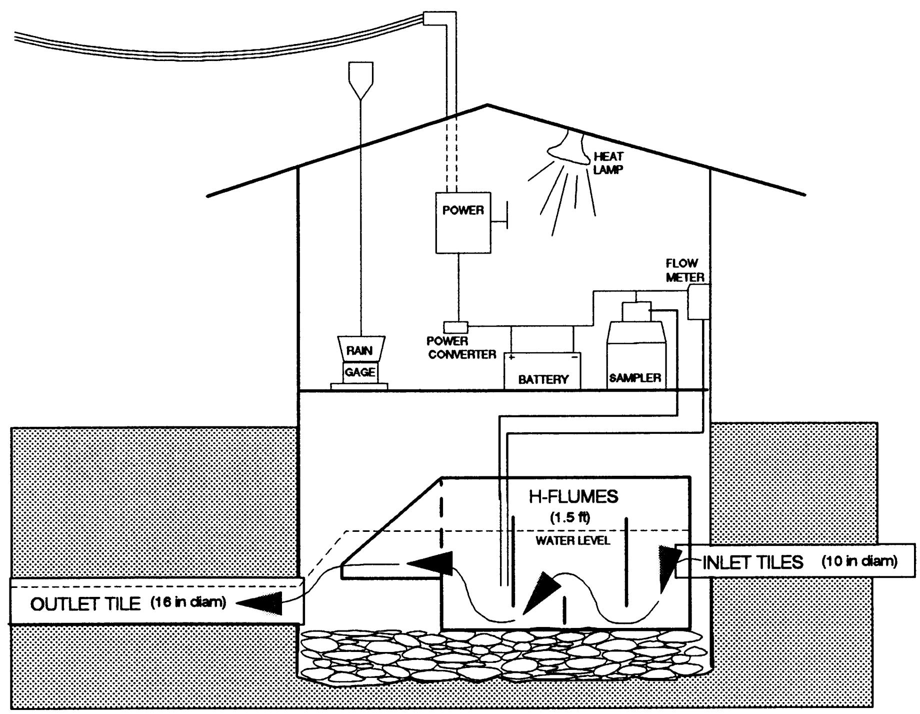


Figure 16. Diagram of the Bugenhagen sub-basin instrument shed.

inch styrofoam. The power supply for the electrical equipment was reconfigured to provide 12-volt direct current from a lead-acid battery under a constant low-amp charge. This arrangement provides power for the equipment during periods of frequent sampling and the battery functions as a backup during power outages. A 250-watt infrared heat lamp is used to offset extreme low temperatures and to decrease the humidity within the shed.

BOOGFL measures the intermittent surface-water flow in the upper part of the basin. Three stainless steel HL-flumes, four feet high, were joined side by side and installed in the main drainageway of the upper sub-basin (Fig. 15). They are set on 6 by 6-inch treated posts. To prevent surface water from flowing around the outside of the flumes, skirts made of 5/8-inch treated plywood were attached. Each HL-flume is capable of measuring up to 117 cfs and together have a maximum capacity of 351 cfs. An extension was constructed to direct surface water through the center flume, increasing stage-measurement precision during low flow. Stage is recorded in each flume using float recorders set on stilling wells that are open to individual flumes. An ISCO model 2870 flow meter continuously measures stage in the center-flume stilling well. During runoff it initiates an ISCO model 2700 sampler. The sampling tube is fixed to a hinge in the middle of the center flume allowing it to pivot, avoiding plugging and damage from rafted debris.

Tile lines BTLUW and BTLUE have been sampled by IDNR for water quality since 1981. They are installed in Otter and Worthen silt loams, poorly drained soils present in the gently sloping upland drainage basin. Otter soils occupy the drainageway and are flanked by Worthen soils at the base of the upland slopes.

The original diameters of BTLUW and BTLUE were 5 and 6 inches, respectively. Both tiles had a single surface inlet immediately down-drainage from the box culvert beneath Highway 52/18 (Fig. 15), but these stopped functioning during 1982. The culvert directs overland runoff and discharge from the tile-line drainage system north of the highway into the drainageway. During the summer of 1986, BTLUW and BTLUE were routed into separate 1.5-foot H-flumes, in the instrument-shed sump (Fig. 16) The flumes are monitored by ISCO model 1870 flow meters and sampled by ISCO model 2100 and model 2700 samplers.

Tile-outlet terraces have been installed in the sub-basin beginning in 1987, as part of soil conservation BMP implementation. The addition of the new tile outlets has increased the drainage areas of BTLUW and BTLUE. To increase flow capacities, 10-inch diameter tile lines parallel to the existing tiles were added and retrofitted to the H-flumes in the instrument shed. BTLUE now drains the eastern portion of the sub-basin north of the instrument shed, and the sub-basin area north of Highway 52/18. BTLUW drains the western part of the sub-basin, north of the equipment shed, but only south of the highway. The addition of the tile-outlet terraces changes the nature of the water discharge. During dry periods the tiles yield shallow groundwater. Following significant precipitation the tile intakes in the terraces direct surface runoff into the tiles, mixing it with the groundwater.

Lower Bugenhagen monitoring sites

The sites BOOGD and BTLD are located approximately 1/4 mile downstream from the upper Bugenhagen sites. BOOGD monitors the intermittent surface-water discharge from 722 acres of the sub-basin (Fig. 15). The site is equipped with a standard USGS gaging station, with continuous discharge records beginning May, 1986. The station is just upstream of an elliptical, corrugated culvert-road crossing that the stream flows through. A rectangular-notched weir was welded onto the upstream side of the culvert to increase the precision of stage measurements during low-flow periods. In May of 1988, a mini-monitor that measures water temperature, pH, and specific conductance was added. The data is recorded at 15 minute intervals with a multiple-parameter data-logger and is downloaded weekly by telephone modem to the USGS office in Iowa City. Samples for sediment and nutrient analysis are taken by an ISCO water sampler that is activated by changes in flow. The sediment samples are supplemented with periodic and event-related sediment samples collected by local observers (sub-basin cooperators).

BTLD is located on the north bank of the sub-basin drainageway, immediately above BOOGD (Fig. 15). BTLD is a 5-inch tile line buried at a depth of approximately 3 1/2 feet in Otter silt loam. The Otter series is a poorly drained, moderately permeable soil formed in silty alluvium in upland drainage basins. The drained field has been in pasture for over 30 years, with little chemical application. This site provides a baseline for comparison with groundwater from fields more intensely cropped. There are no surface-water intakes connected to BTLD.

The GSB has sampled this site since 1981. In 1986, the tile was routed into a sump through a 0.75 foot H-flume. Stage in the flume is measured by a float connected to an FW-1 clock-driven stage-recorder. Both Serco and ISCO water samplers have been used in time-sampling mode. A solar cell recharges a 12-volt battery that powers the ISCO sampler. The pasture drained by BTLD is relatively small, and discharge has been intermittent, with no flow occurring during the drought of 1988-89.

STOP 6: SILVER CREEK SITES

At this stop the discharge and water quality from Silver Creek (4.4 mi^2 drainage basin) and a tile line are monitored (sites L23S and L22T, respectively, of Hallberg et al., 1983). Some of the results of this monitoring will be discussed at our final stop. Here, we will focus on a dye trace that was conducted at this site. Unlike most dye traces in a karst area, this trace did not involve slugging a sinking stream with dye and monitoring the outflow from associated springs. The dye trace at this site was conducted on 6/27/90, and was a collaborative effort between GSB, Dr. Calvin Alexander and Mr. Scott Alexander, Department of Geology and Geophysics, University of Minnesota, and students under their direction.

Figure 17 is a schematic diagram of the site area. L22T lies about six feet below the land surface in this area. It is installed in alluvium mapped as Otter and Worthen soils; poorly drained soils formed in silty alluvium. For purposes of the dye trace the red dye rhodamine WT (RWT) was surface-applied to a 20 by 60 foot portion of the corn field overlying the tile, at a rate equivalent to 1.5 lbs/acre. 1200 gallons of water containing 55 mg/L of the green dye fluorescein and 322 mg/L bromide were irrigated onto the same area using sprinkler hoses. The dyes are organic chemicals, with adsorption characteristics that are generally similar to herbicides (Everts, 1989), while bromide is considered a conservative ion that essentially moves with the water, similar to NO_3. The water and tracers were delivered in 130 minutes, beginning at 17:05 hours, simulating a 1.6 inch rainfall. Samples of tile water were collected both manually and by an automatic sampler and analyzed to determine tracer concentrations. Unfortunately, the automatic sampler did not collect samples during the period of greatest interest, so the details of the tile response to the tracer input were lost. However, the data provide interesting insights, and are shown on Figure 18. First, all three tracers are present in detectable concentrations after the field had received water for less than 90 minutes (fluorescein was visibly present in the discharge at this point). Second, fluoroscein concentrations were generally two orders of magnitude higher than RWT concentrations, and when normalized on input concentrations were still more than one order of magnitude higher. Third, concentrations of all the tracers decline rapidly after the irrigation input stops. Tile discharge throughout the test stayed at 16.2 gallons/minute; only a miniscule volume of our irrigation input discharged from L22T. However, rapid water and chemical transport to the water table occurred. This demonstrates the importance, and gives insights into the process of flow through macropores. Macropores are elongated zones of secondary permeability, and are formed by roots, burrowing insects and animals, dessication, and other processes. In addition to providing avenues for rapid water movement, macropores allow infilration recharge to bypass near-surface organic-rich horizons, where adsorption of organic dyes—and herbicides—is most likely to occur.

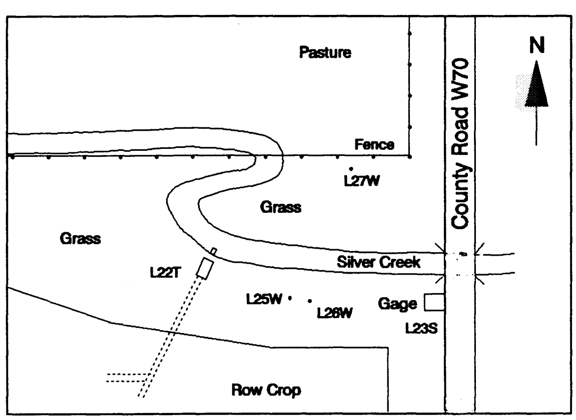


Figure 17. Diagram of Silver Creek monitoring sites.

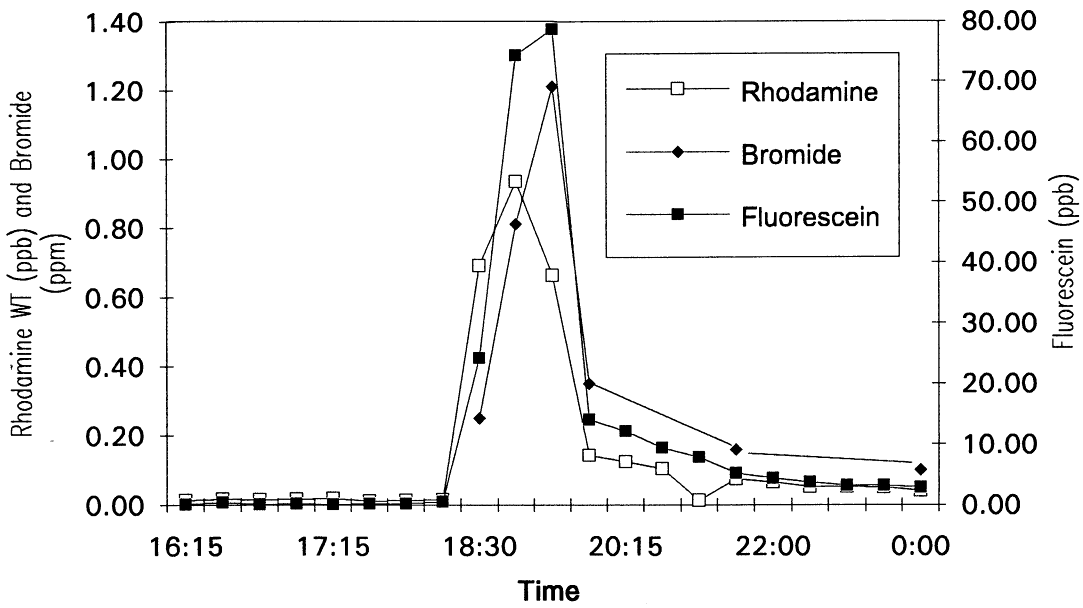


Figure 18. Concentrations of tracers in the discharge from L22T during irrigation dye trace, 6/27/90.

STOP 7: HOLOCENE ALLUVIAL STRATIGRAPHY AND VEGETATION HISTORY OF ROBERTS CREEK BASIN

Introduction

The purpose of this stop is threefold; 1) to examine lithlogic properties and stratigraphic relationships of Holocene alluvium along Roberts creek that typify conditions over a large part of the Midwest, 2) to discuss paleoecological records associated with the alluvium and how these records bear on the vegetation history of eastern Iowa, and 3) to discuss how lithologic properties of the alluvium may influence some aspects of the quality of shallow groundwater in valley settings.

In Iowa, Holocene valley-fill sediments are called the DeForest Formation (Bettis, 1990; Bettis et al., 1992). The formation is divided into four members that have distinctive lithologic properties (texture, color, bedding structures, pedogenic alterations) and landscape associations. Table 2 outlines the properties of the four members of the DeForest Formation in eastern Iowa. The type area for the Roberts Creek and Gunder Members is the Roberts Creek basin of northeast Iowa, and we will see typical examples of these two members and the historic-age Camp Creek Member at this stop.

Each member of the DeForest Formation was deposited during a restricted time range during the Holocene (Bettis, 1990). In valleys the size of Roberts Creek the Gunder Member accumulated between about 10,500 and 4000 B.P.(radiocarbon years before present), the Roberts Creek Member from 3500 to about 500 B.P., and the Camp Creek Member from about 150 B.P. to the present. The Corrington Member, is found in alluvial fans in large valleys and is not usually present in valleys as small as Roberts Creek.

In valley reaches where the groundwater table was never lowered below the bed of the stream during the Holocene well-preserved pollen, plant macrofossil, and fossil beetle records are present in the lower reduced or unoxidized part of the alluvium. An extensive study of such paleoecological sites in Roberts Creek basin has revealed a very detailed picture of northeast Iowa's Holocene vegetation history (Chumbley et al., 1990). This history indicates that prairie invaded eastern Iowa much later than in central Iowa and Minnesota. The prairie expanded eastward in central Iowa during the early Holocene when mesic forest still covered eastern Iowa. Prairie expansion along the axis of the "Prairie Peninsula" occurred only after about 5500 yr. B.P. (Baker et al., in press). The period of dominant prairie vegetation was relatively short (2000 years) in eastern Iowa relative to its duration in central Iowa and Minnesota. After about 3500 yr. B.P. increases in oak pollen percentages signal the establishment of oak savanna in northeastern Iowa, and the development of the prairie-oak savanna-forest mosaic vegetation pattern that occurred in the area in the early Historic period.

Stratigraphy, lithology, and paleoecology

This stop is located along the left bank of Roberts Creek downstream of its junction with Deer Creek in the SE1/4 SW1/4 sec. 1 T94 N R6W. At this location Roberts Creek meanders into the eastern valley wall, then passes southwestward across the floodplain, exposing a sequence of valley margin, low terrace, and floodplain deposits.

In valleys outside thick loess areas the Holocene alluvial fill occurs as a horizontal sequence where successively younger cut and fills are distributed horizontally across the valley floor. The geometry of the alluvial fills at this stop shows this relationship. The oldest unit, the Gunder Member grades to the adjacent valley wall, the Roberts Creek Member, forming a low terrace, is inset into and finally completely cuts out the Gunder, and the Camp Creek Member cuts out the Roberts Creek Member in the floodplain area on the downstream end of the exposure.

The oxidized Gunder Member buries Ordovician-age shaley carbonates of the Elgin Member (Maquoketa Fm.) along the valley margin. Moving away from the valley margin the upper part of

Table 2. Generalized characteristics of DeForest Formation members in eastern Iowa.

Camp Creek Member

Very dark grayish brown to yellowish brown (10YR3/2-5/4) silt loam to loam (sandy loam if sandy source materials are common) grading to sand and gravel in the channel belt; usually noneffervescent; horizontally stratified where greater than 0.25 meters in thickness; surface soils are Entisols (A-C profiles); unit often buries pre-settlement surface soil; thickest in and adjacent to modern channel belt, and at the base of steep slopes; ranges in age from 400 B.P. to modern.

Roberts Creek Member

Very dark gray to dark grayish brown (2.5Y3/0 to 10YR3/1-3/2) silt loam, silty clay loam and loam grading downward to sand and gravel; usually noneffervescent; thick sections are stratified at depth; detrital organic matter in lower part; relatively thick Mollisol (A-C or A-Bw-C profile) developed in upper part; strong brown and yellowish red (7.5YR5/8 and 5YR5/8) mottles may occur throughout unit; found within the present floodplain, usually parallels the modern channel, also found in fan trenches; ranges in age from about 4000 to 500 B.P.

Gunder Member

Brown to yellowish brown to grayish brown (10YR4/3-5/4 to 2.5Y5/2) silt loam, silty clay loam, or loam grading to sand and gravel at depth; usually noneffervescent; lower part may be stratified; detrital organic matter often present in lower, stratified, coarse part of unit; moderately well to somewhat poorly drained Mollisols and Alfisols (A-Bw-C, A-Bt-C, or A-E-Bt-C profile) developed in upper part; C horizons usually contain strong brown, yellowish red, or dark brown (7.5YR5/8, 5YR5/8, or 10YR3/3) mottles; usually comprises low terrace that merges with sideslope in a smooth concave upward profile; ranges in age from 10,500 to about 3000 B.P.

Corrington Member

Dark grayish brown to yellowish brown to olive brown (10YR4/2-5/4 to 2.5Y4/2-4/4) loam and silty clay loam with sandy loam, pebbly sandy loam, and gravelly interbeds; noneffervescent grading to effervescent at depth; upper part of unit has thick Mollisol or Alfisol (A-Bw-C, A-Bt-C, or A-E-Bt-C profile) developed in it; at least one and often several buried paleosols within unit; unit consists of several upward-fining sequences, most having paleosols developed in their upper part; brown mottles common; found in alluvial fans and colluvial slopes along the margins of large to moderate-size valleys; unit ranges in age from about 9000 to 2500 B.P.

the Gunder retains its oxidized brown color, but the lower part becomes reduced to a gray or greenish gray color with abundant strong brown mottles. The reduced color and accompanying mottles indicate that the lower part of the Gunder was oxidized sometime after deposition, then later reduced as the long-term water table rose. Because it was once oxidized, pollen and other organic remains are not preserved in the Gunder Member here.

The Roberts Creek Member is inset into the Gunder Member and forms a low terrace/high floodplain in the valley. The Roberts Creek Member is dark colored throughout because of a relatively high content of organic matter. The lower part of the Roberts Creek Member, having remained below the water table since deposition, contains abundant organic remains. Four radiocarbon ages from the organic-rich part of this exposure average about 2900 yr. B.P., and the entire organic-rich section was probably deposited over a span of 100-200 years.

Pollen in this Roberts Creek Member exposure is dominated by nonarboreal taxa (63%), with grass (29%), sedge (18%) and composite (10%) pollen most abundant (Chumbley, 1989; Chumbley et al., 1990). Tree pollen is primarily oak (14%), with other riparian trees such as willow (7%), green ash (6%) and boxelder (1%). This pollen spectrum suggests that the surrounding area was predominantly prairie and oak savanna 2900 yr. B.P.

Plant macrofossils in the deposit give a much clearer picture of the local vegetation. Thirty one indicator taxa, mostly identified to the species level, indicate that prairie was well developed at the site. The woody-plant macrofossils reinforce the idea that riparian trees were scattered on the floodplain. Wet-ground plant macrofossils are also abundant, indicating that wet meadows were common on the floodplain. In summary, about 2900 years ago the Roberts Creek area was largely covered by prairie, with oak on the valley walls, oak savanna in some upland areas, and wet meadow and riparian forest scattered on the floodplain.

Near the downstream end of this exposure the Camp Creek Member cuts out the Roberts Creek Member. The Camp Creek Member also laps up onto and buries the early Historic surface soil developed on the Roberts Creek Member in the central part of the exposure. Historic artifacts and high percentages of ragweed pollen point to an Historic age for the unit. Our studies suggest that most of the Camp Creek Member overbank deposits in Roberts Creek basin accumulated between about 1890 and 1930 as the channel adjusted to runoff and sediment load changes brought on by dramatic, agriculture related land use changes (Baker et al., in review).

Lithologic influences on the quality of shallow groundwater in small valleys

Throughout the state the Roberts Creek Member consistently contains a higher content of organic carbon (OC) than the Gunder Member. The Camp Creek Member is more variable in OC content, sometimes being high, at other times low depending on local source materials and the intensity of slope erosion during the early Historic period. The high OC content of the Roberts Creek Member occurs throughout the vertical extent of the unit, including that part at and below the water table.

Hallberg et al. (1983) compared nitrate concentrations from tile lines, their receiving streams and adjacent piezometers completed within the Roberts Creek Member in the Big Spring basin. Significantly lower nitrate concentrations were consistently present in shallow ground water from the piezometers, compared to the streams and tiles, leading Hallberg et al. (1983) to suggest that denitrification was occurrring within the Roberts Creek Member. Data from shallow wells in DeForest Formation alluvium at Bluegrass Watershed in Audubon County, Iowa also suggest that denitrification may be occurring in groundwater passing through the Roberts Creek Member (Siegley and Hallberg, 1991). Transects of wells perpendicular to shallow groundwater flow show that nitrate levels decrease from water in Gunder Member alluvium to water in adjacent, down-gradient Roberts Creek Member alluvium. Thompson (1986; 1984) has also suggested that denitrification may also be occurring in alluvial aquifers associated with some of the larger valley systems in Iowa.

The high OC content of Roberts Creek Member alluvium is conducive to the denitrification process. The greatest potential for denitrification occurs in oxygen-deficient, water-saturated materials (Rolston, 1981). The denitrification process is also dependent on an available supply of bio-degradable organic carbon, a requirement easily met by Roberts Creek Member alluvium.

Roberts Creek member alluvium occurs as a strip of variable width roughly paralleling the present channel belt, essentially a buffer strip between the valley floor and the channel discharge zone. The unit occurs throughout a large part of the Upper Midwest (Bettis, 1990; 1992; Mandel and Bettis, 1992), and may be important in assessing the fate of nitrogen in the shallow groundwater systems discharging to streams in the region's valleys.

STOP 8: BIG SPRING

Our last stop is at Big Spring, where most of the groundwater from the basin discharges to the surface and the Turkey River. Our discussion here will focus on: 1) the monitoring system utilized at the site; 2) "typical" seasonal variations in the hydrology and water quality of the basin; 3) data collected during major recharge/discharge events; 4) the results of hydrologic and water quality monitoring at the spring since the project began in 1981; and 5) the impact of education and demonstration programs on reducing chemical inputs.

Monitoring System

The IDNR uses the naturally cool water from Big Spring (Fig. 19) for trout rearing. The spring is impounded by a concrete wall that pools the spring water. Underground, a 30-inch diameter metal culvert directs flow from the pool to a distribution pipe that supplies 24 trout raceways. After passing through the raceways the water is collected and routed to the Turkey River. Excess groundwater from the spring flows through a concrete spillway to the river. These water-control structures allow for gaging the groundwater discharge at the spring.

Stage-discharge relationships for the spring were developed during the first year of the project by the USGS and GSB (Hallberg, 1983). Stage was measured manually until mid-1986, when the USGS installed a Stevens A-35 recorder. A datalogger, which records stage, pH, conductivity, and temperature of the spring was added in 1988 and is accessible by phone modem.

A small spring, referred to as Back Spring, is approximately 200 yards east of Big Spring. Back Spring was formed by the damming of Big Spring, which raised the potentiometric surface of the Galena aquifer in the immediate area. The hydrologic relationship between Big Spring and Back Spring has been further documented by dye-tracing (Hallberg, et al., 1983; 1984). Flow from Back

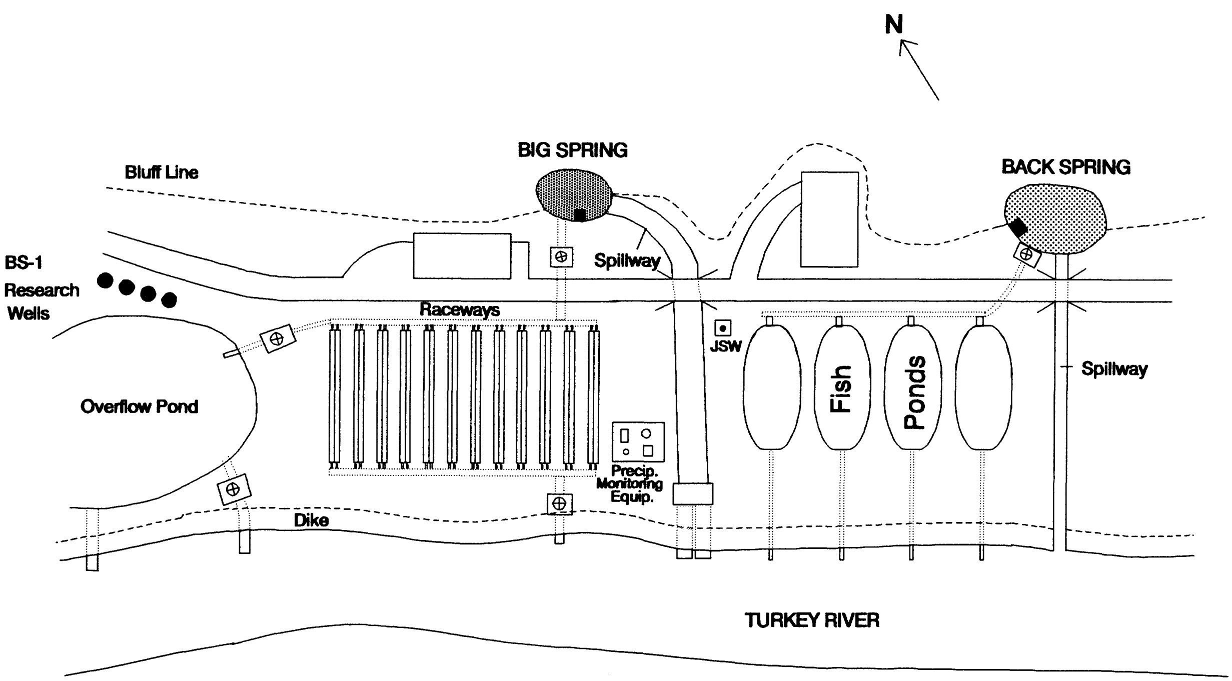


Figure 19. Diagram of Big Spring Hatchery and monitoring system. Dotted lines indicate structures that are underground.

Spring is directed to four earthen ponds used for brown trout. Water-control structures allowing for continuous gaging were built for Back Spring in 1985, and a Steven's A-35 recorder was installed by the USGS the summer of 1986. Drought-related low-flow conditions during much of 1987 through 1989 hampered establishment of a stage-discharge relationship for Back Spring. Intermittent gaging during 1981 through 1983 indicated it's flow is about 11% of Big Springs (Hallberg et al., 1983).

Precipitation has been measured at Big Spring since August 1984 as a part of the National Atmospheric Deposition Program (NADP). Rain gages were added to the USGS stream-gaging stations at BOOGD and RC2 in the spring of 1986 (Fig. 12). Estimates of total basin precipitation are calculated primarily from these sites. An additional rain gage is located at the instrument shed in the upper Bugenhagen sub-basin. Data from this gage, and from weather bureau stations at the nearby towns of Waukon, Fayette, and Elkader, are reviewed as part of this process. The weather bureau stations also supply daily maximum and minimum temperatures for the surrounding area.

At Big Spring, an automatic sampler collects rainfall that is analyzed weekly for major ions (including nutrients) by NADP laboratories (NAPD, 1990). Basin rainfall has been sampled for pesticide analysis since November 1987. The more commonly used corn herbicides are detected in precipitation here, at concentrations ranging to several ug/L. Concentrations are highest in rains falling immediately after application, and decline to below detection limits (typically 0.1 ug/L) by fall (Nations, 1990). As a part of this study, automatic precipitation samplers (Aerochem Metrics model 301) were installed at Big Spring, and in the Silver Creek and Bugenhagen sub-basins in the spring of 1991. An additional sampler was placed in Elkader (outside the basin) for comparison purposes. Pesticide data has also been collected from the NADP sampler at the hatchery by USGS since 1989 (Goolsby et al., 1990, Capel, 1990).

Seasonal variations in hydrology and water quality

Discharge rates and responses at Big Spring reflect the effects of recharge to the Galena aquifer within the contributing basin. Recharge from precipitation or snowmelt enters the groundwater system as either sinkhole-captured surface runoff or as infiltration through the soil zone. These differing recharge modes generate different hydrologic responses at Big Spring. They also give the water recharged by either method distinct chemical signatures. The relationships between precipitation (or snowmelt), recharge, discharge, and water quality are complex, but follow general seasonal trends. Figure 20 shows the discharge hydrograph for Big Spring from WY 1984, which will be used as an example. Groundwater temperature and climatic data are also shown. As WY 1984 began, discharge was about 40 cubic feet per second (cfs). Slight increases in discharge rates occurred following minor rains in October and November. The rather muted response to these rains suggests they generated little runoff, and therefore are largely a result of infiltration. During December and January, temperatures plunged and precipitation fell as snow—if at all. Frozen ground and precipitation falling as snow do not generate recharge, and discharge rates recessed in response. Snowmelt, accompanied by rain, occurred in February. The extremely flashy nature of the hydrograph during this period is in marked contrast to that of the preceding months. Several large peaks in discharge occurred, with the largest exceeding 240 cfs. The rapid increases and declines in discharge are caused by the transient inputs of surface runoff to sinkholes. These inputs result in drops in the temperature of the groundwater. Discharge rates did not fall immediately to pre-snowmelt rates, indicating that infiltration recharge was also occurring. Rains during the March through June period also generated runoff recharge at times. The generally higher discharges during this period reflect the inputs of infiltration recharge. These inputs, largely to the more diffuse-flow parts of the aquifer, sustain the base flow discharge of the spring. Recharge occurs during the March through June period because of relatively low temperatures and rates of evapotranspiration. During the remainder of the summer growing season high temperatures and evapotranspiration rates limit recharge, even after relatively large and intense rainfalls. Discharge rates recess during this period as a result.

Figure 21 also shows the hydrograph from Big Spring, along with plots of nitrate and atrazine concentrations, which vary with changes in discharge rates. At the beginning of WY 1984, nitrate

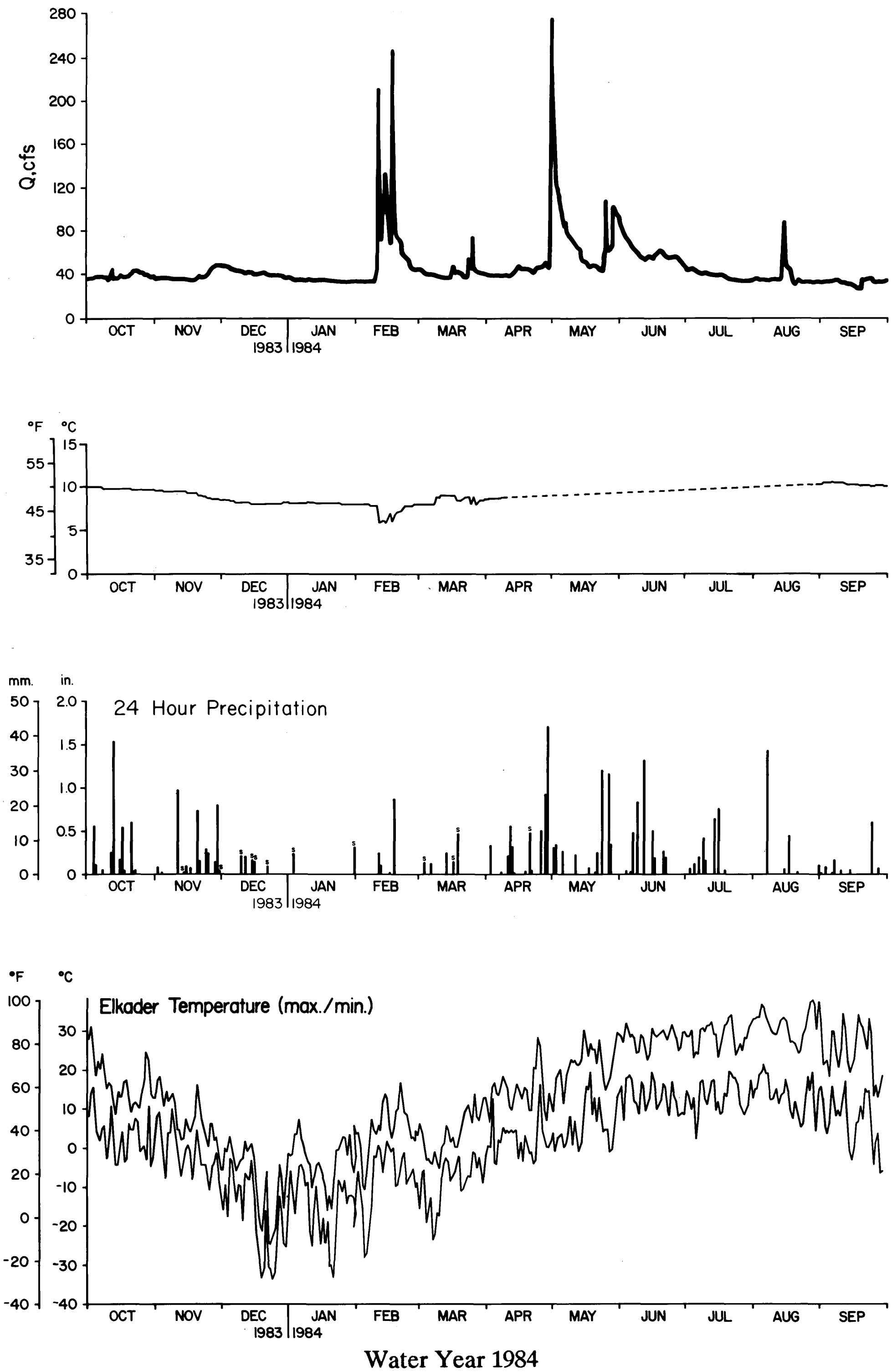


Figure 20. Daily precipitation, groundwater discharge, and temperatures for the Big Spring basin, and maximum-minimum temperatures for Elkader, IA, for WY 1984.

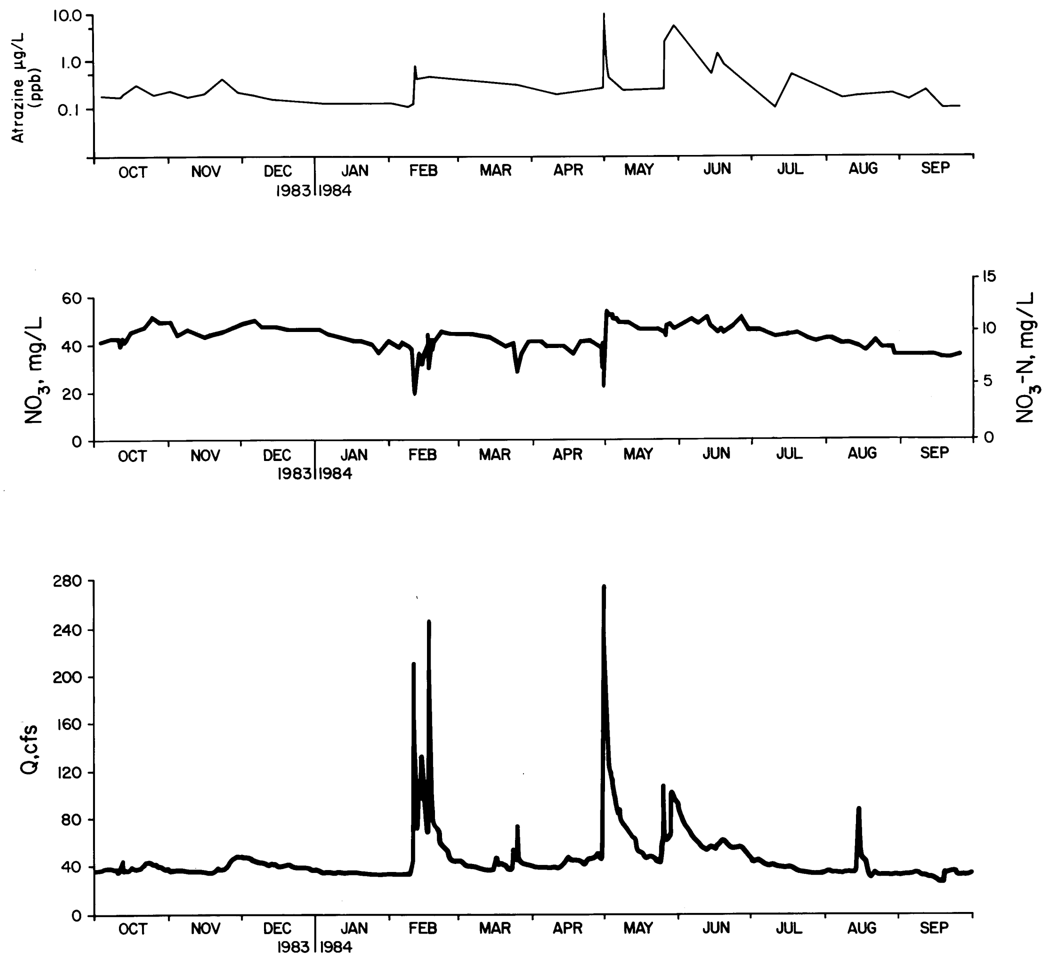


Figure 21. Groundwater discharge, and atrazine and nitrate concentrations at Big Spring for WY 1984.

concentrations were around 40 mg/L. The minor infiltration-derived recharge periods that occurred during October and November generated nitrate concentrations in the 45 to 50 mg/L range. During the winter discharge recession, concentrations declined back to about 40 mg/L. The February snowmelt generated large volumes of relatively low-nitrate runoff recharge. Concentrations at Big Spring responded by falling as low as 20 mg/L for a short period, as the dilute snowmelt runoff passed rapidly through the conduit-dominated parts of the groundwater system. Concentrations rise to somewhat above pre-melt levels, reflecting the infiltration recharge that occurred. Runoff recharge during March and particularly in late April caused short-term dilution of nitrate concentrations. Note the large increase in nitrate concentrations immediately following the late April recharge event. Concentrations rise abruptly to over 50 mg/L; pre-event concentrations were about 40 mg/L. This shows the impact of major infiltration recharge and nitrate leaching from the soil zone on groundwater quality. Recharge during May and June kept concentrations relatively high, while concentrations decline with the discharge during the remainder of the water year, to about 35 mg/L. The decreases in nitrate concentrations that occur during such periods result from a lack of inputs from the nitrate source in the soil/shallow groundwater zone. As less recent recharge is discharged from the spring, an increasing proportion of the discharge is relatively older water from the more diffuse, less transmissive parts of the system. Some component of this water is relatively unaffected

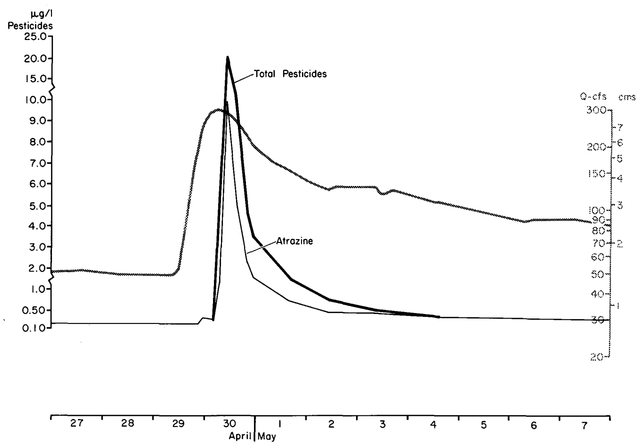


Figure 22. Groundwater discharge, and atrazine and total pesticide concentrations at Big Spring, April/May 1984.

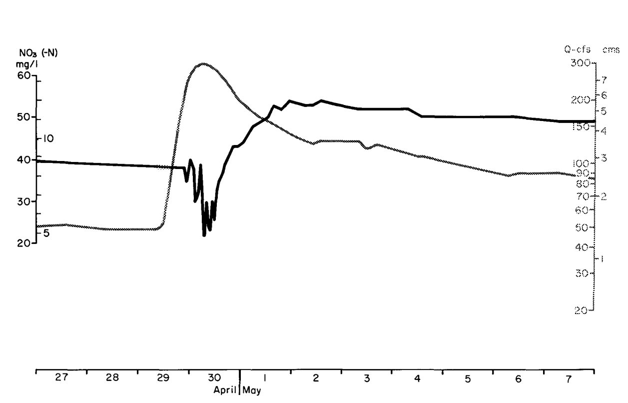


Figure 23. Groundwater discharge and nitrate concentrations at Big Spring, April/May 1984.

by modern agriculture (refer to discussion of well VD-24, stop 5), and therefore causes a decrease in nitrate concentrations at Big Spring.

The plot of atrazine concentrations (Fig. 21) resembles a subdued version of the discharge hydrograph. During no-recharge periods, such as December and January, concentrations were around 0.2 ug/L, and showed a slowly declining trend. Periods marked by infiltration recharge resulted in increases to the 0.5 to 1.0 ug/L range, while major runoff recharge generated concentrations approaching 10 ug/L. Atrazine generally occurs year-round in Big Spring groundwater, but the highest concentrations occur following application. The "older water" discussion concerning nitrate concentrations during dry periods is equally applicable to atrazine.

Anatomy of a recharge event

A number of large recharge/discharge events have been monitored in considerable detail. This has provided refined understanding of the relationships between recharge mechanisms and contaminant mobilization and transport, and of the hydrology of the groundwater system within the basin. Big Spring itself has been the focus of most of the event monitoring; wells, tiles, and streams have also been sampled but with less frequency.

Figure 22 shows the Big Spring hydrograph for parts of April and May 1984; atrazine and total pesticide concentrations are also shown. Discharge at the beginning of this period was about 45 cfs. About 2.9" of rain fell during the afternoon and evening of 4/29. The discharge rate began increasing in the evening, peaking at about 280 cfs on the morning of 4/30. Flow-rates decreased sharply following the peak, falling to about 160 cfs twenty-four hours after peak. Discharge from Big Spring was measured manually at this time; measurements were taken hourly across the discharge peak. Samples for pesticide analysis were collected every 4 hours across the discharge peak. Atrazine concentrations were about 0.2 ug/L prior to the rain storm. Concentrations did not increase immediately with increases in discharge, and were still below 0.30 ug/L 2 hours before peak, although discharge had exceeded 265 cfs. The highest measured atrazine concentrations, 10 ug/L, occurred five hours after peak. Prior to this runoff recharge input, atrazine was the only herbicide present in the discharge from Big Spring. During the event, alachlor, cyanazine, and metolachlor were present with maximum concentrations of 4.0, 1.7, and 4.5 ug/L, respectively. The total detected herbicide concentration reached a maximum of over 20 ug/L. Atrazine concentrations declined quickly with the discharge, falling to 1.1 ug/L as discharge slowed to about 160 cfs, twenty-four hours after discharge had peaked. Concentrations reached pre-event values 5-6 days after peak. Note that this recharge event occurred prior to the application of herbicides for the 1984 crop season.

Nitrate concentrations show a different response to recharge, relative to atrazine (Fig. 23).

Samples for nitrate analysis were collected hourly across the discharge peak. Nitrate concentrations, which had been 39 to 40 mg/L prior to the event, begin dropping as peak discharge is approached. The minimum measured nitrate concentration occurred about one hour past the discharge peak, at 22 mg/L. Concentrations are variable during this period, showing increases and decreases of 5 to 10 mg/L between many hourly samples. Concentrations increase quickly as the discharge falls, and pre-event concentrations are exceeded only 14 hours after the discharge peak. Nitrate concentrations continued to climb, reaching 48 mg/L by the morning of 5/1, 24 hours after the peak (Q=160 cfs; atrazine=1.1 ug/L). By late in the day of 5/1 concentrations were at about 55 mg/L, and exceeded 50 mg/L—20% above pre-event conditions—until 5/7, a week after the discharge peak.

The recharge/discharge event described above is relatively typical of significant recharge periods in the basin. Discharge generally begins to increase 6 to 12 hours after a major rain, peaking 24 to 36 hours later. Atrazine and nitrate concentrations, as well as those of other water quality and geochemical parameters, do not show significant changes until at or after the discharge maximum is reached. This indicates that a significant volume of "pre-event" groundwater is being flushed out of the system prior to the arrival of "new" recharge water. Soon after the discharge peak atrazine concentrations increase by 1 to 2 orders of magnitude as sinkhole-captured surface runoff begins to discharge from the spring. This atrazine-rich runoff is also low in nitrate, relative the pre-event groundwater, and nitrate concentrations fall as a result. This water dominates the discharge from Big Spring for 12 to 30 hours. At the end of this period atrazine concentrations have declined to 1 to 5 ug/L, and nitrate concentrations have recovered to pre-event levels. Significant infiltration recharge has occurred by this point, as evidenced by a continued rise in nitrate concentrations to 10 to 50% above those in pre-event groundwater. This nitrate-rich infiltration recharge represents a significant volume of water; concentrations during the 1984 event reached 50 mg/L when the discharge rate from Big Spring was still high, above 150 cfs. The infiltration recharge reaches Big Spring quickly; concentrations reached 50 mg/L 48 hours after rains began, and 30 hours after peak discharge during the 1984 event. This indicates that large volumes of infiltration water are delivered efficiently to conduit zones where they can be quickly transported to Big Spring. A significant amount of this water likely originates from sinkhole drainage basins and other very shallow rock areas that overlie conduit zones.

The relationships between precipitation (or snowmelt), recharge, discharge, and water quality discussed above for Big Spring groundwater apply to other parts of the basins hydrologic system. As an example, Figure 24 shows nitrate concentrations for WY 1984 from Big Spring, site L23S on Silver Creek, and tile line L22T (the latter two sites are located at Stop 6). L22T discharges shallow groundwater from beneath a 30 acre cornfield; at L23S, Silver Creek has a 4.4 mi^2 drainage area; and the Big Spring groundwater basin is 103 mi^2. In spite of the differences in scale, similar seasonal trends and pronounced short-term changes in nitrate are evident at all sites. While not shown on Figure 24, the same trends are evident in nitrate concentrations from the Turkey River, which has a drainage area of 875 mi^2 at Big Spring. Infiltrating recharge water delivers relatively high nitrate concentrations to the water table below row-cropped, fertilized fields. This shallow groundwater discharges laterally to streams and downward to the Galena aquifer. These streams and groundwater within the Galena aquifer ultimately deliver water with increased nitrate concentrations to the Turkey River. The concentration changes that occur are not as great or immediate at larger scales, but are clearly evident as a recharge-induced pulse throughout the hydrologic system.

Results of long-term monitoring at Big Spring

Evaluation of the long-term impacts of agriculture on groundwater quality is difficult, because of the paucity of historic data. Big Spring was sampled for nitrate in September of 1951, and again in 1968, when monthly samples were collected from January through September. Nitrate concentrations in these samples were 7 to 14 mg/L, averaging 12 mg/L. Relatively "normal" climatic years during the present monitoring at Big Spring have yielded flow-weighted (fw) mean nitrate concentrations of about 40 mg/L (Libra et al., 1991), indicating a three-fold increase in nitrate

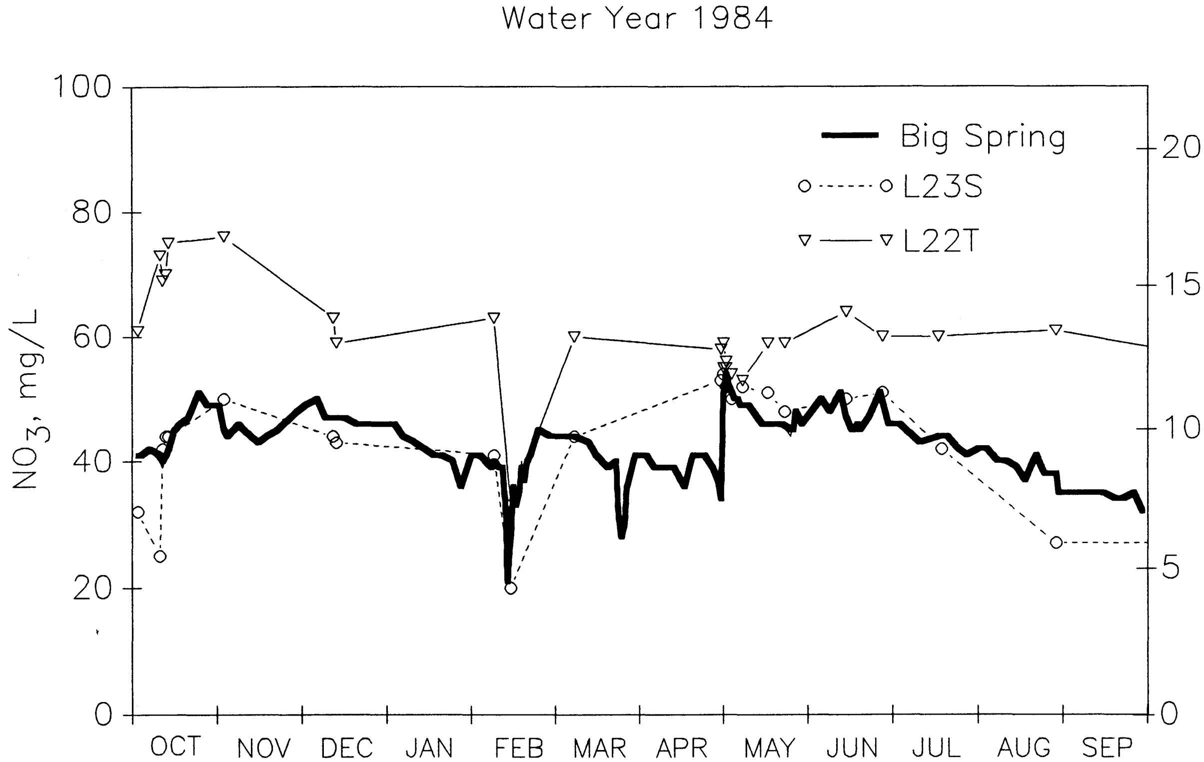


Figure 24. Nitrate concentrations at Big Spring, L22T, and L23S for WY 1984.

concentrations. More detailed records from private wells in the area show similar trends (Hallberg et al., 1985). Estimates of annual nitrogen inputs from chemical fertilizer and manure applications for the basin during the last several decades have been derived from crop and livestock reporting data (see Hallberg et al., 1983,1984). Increases in livestock populations suggest a 30% increase in manure-N from about 1960 to 1980. During the same period, a combination of increased corn acreage and higher rates of chemical fertilization of those acres resulted in a 250% increase in fertilizer-N inputs. These data and nitrate concentrations at Big Spring are summarized in Figure 25, and indicate a direct, parallel increase of nitrate concentrations in response to the increased N-loading.

Figure 26 shows the annual groundwater discharge from Big Spring, along with fw-mean nitrate and atrazine concentrations for WYs 1982 through 1990. These figures and data on annual precipitation and chemical loads are summarized in Table 3. During this period, annual precipitation has varied from 23 inches (WY 1988) to 44.5 inches (WY 1983) and groundwater discharge has ranged between 12,700 acre-feet (WY 1989) and 41,400 acre-feet (WY 1983). The highest annual fw-mean nitrate concentration, 46 mg/L, and the greatest N-load, 1,150 thousand pounds, occurred in the wettest year, WY 1983. The lowest values, 25 mg/L nitrate and 195 thousand pounds of nitrate-N occurred in WY 1989, the second year of an extreme drought. WY 1990 registered an atrazine load of about 50 pounds, at a fw-mean concentration of 1.1 ug/L. The relatively high values for atrazine in WY 1990 were likely the result of drought-induced "carry-over" from the previous years applications. In contrast, only nine pounds of atrazine, at a fw-mean concentration of 0.1 ug/L, were discharged during WY 1988. Annual variations in these parameters, by factors ranging from two to six, complicate interpretations concerning agricultures effects on groundwater quality, and therefore the impact of changes in agricultural practices on groundwater quality. This underscores the need for long-term monitoring to aid in understanding the effects of nonpoint-source contami-

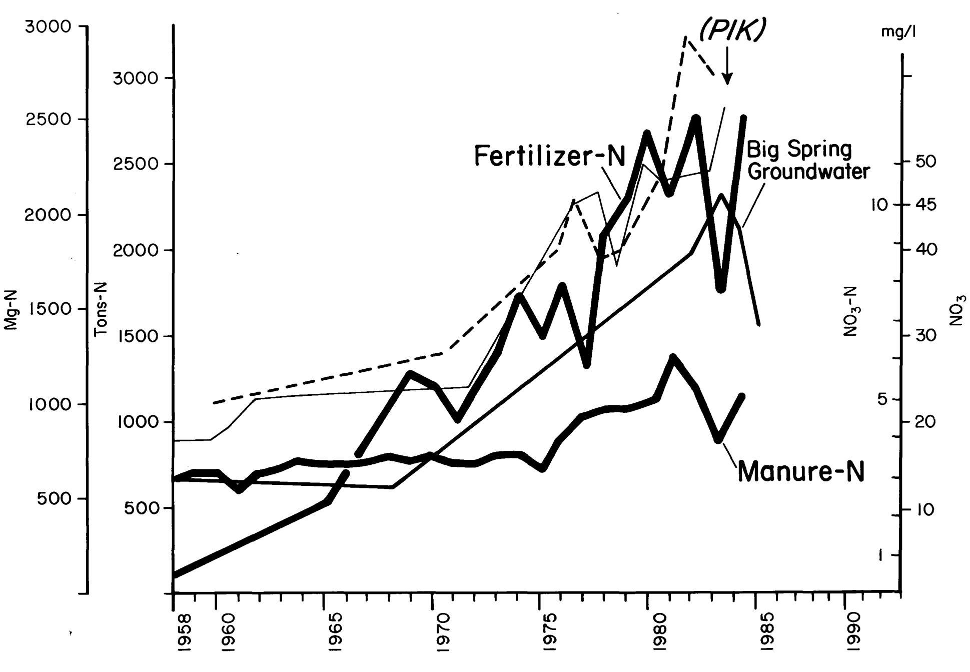


Figure 25. Estimated inputs of fertilizer and manure nitrogen to the Big Spring basin and nitrate concentrations at Big Spring, 1958-1985.

nation on natural systems.

Annual fw-mean nitrate concentrations vary in a parallel fashion with groundwater discharge (Fig. 26). This results in years with high groundwater discharge producing exceptional N-loads (Table 3). In contrast, the annual fw-mean concentrations of atrazine (and the frequency and magnitude of detections of other herbicides) do not vary with discharge. Rather, higher concentrations occur during years with lower flow-rates (the carry-over effects noted for WY 1990 generating the only break with this trend). The reasons for this difference are not well understood. Retardation of atrazine transport to and through the groundwater system, by adsorption and degradation processes, may be causing a several year lag in the atrazine response to recharge inputs to the system. Some degree of lag might be expected when dealing with a groundwater basin the size of Big Spring's. Data from the smaller watersheds and tile-drained areas within the basin are currently being reviewed, to establish whether similar trends are occurring at smaller scales.

Big Spring Basin Demonstration Project results

Various educational efforts have been underway in the Big Spring basin area since 1982. These have included contacts with the approximately 200 farmers in the basin through farm census surveys, newsletters, and local press and media coverage. On-farm demonstration and implementation projects began in earnest in 1984, and were greatly expanded with the 1987 crop season under the BSBDP.

Alfalfa is a common component of crop rotation sequences in the basin. Alfalfa "fixes" nitrogen from the atmosphere and adds it to the soil. Therefore, a key focus of N-management programs in the BSBDP has been providing appropriate N-credits to corn following alfalfa in a crop rotation. Results from 5 years of on-farm demonstration projects show that farmers lost money using more N than contained in a starter fertilizer (0 to 24 lbs-N/acre rate) on corn following a good multi-year stand of alfalfa. Maximum yields are often obtained with no added nitrogen. Longer-term data from northeast Iowa Experiment Station farms support this. When the project began in 1981, basin inventories showed that area farmers applied an average of 123 lbs of fertilizer-N per acre on corn after good alfalfa stands - at a loss averaging about $18/acre.

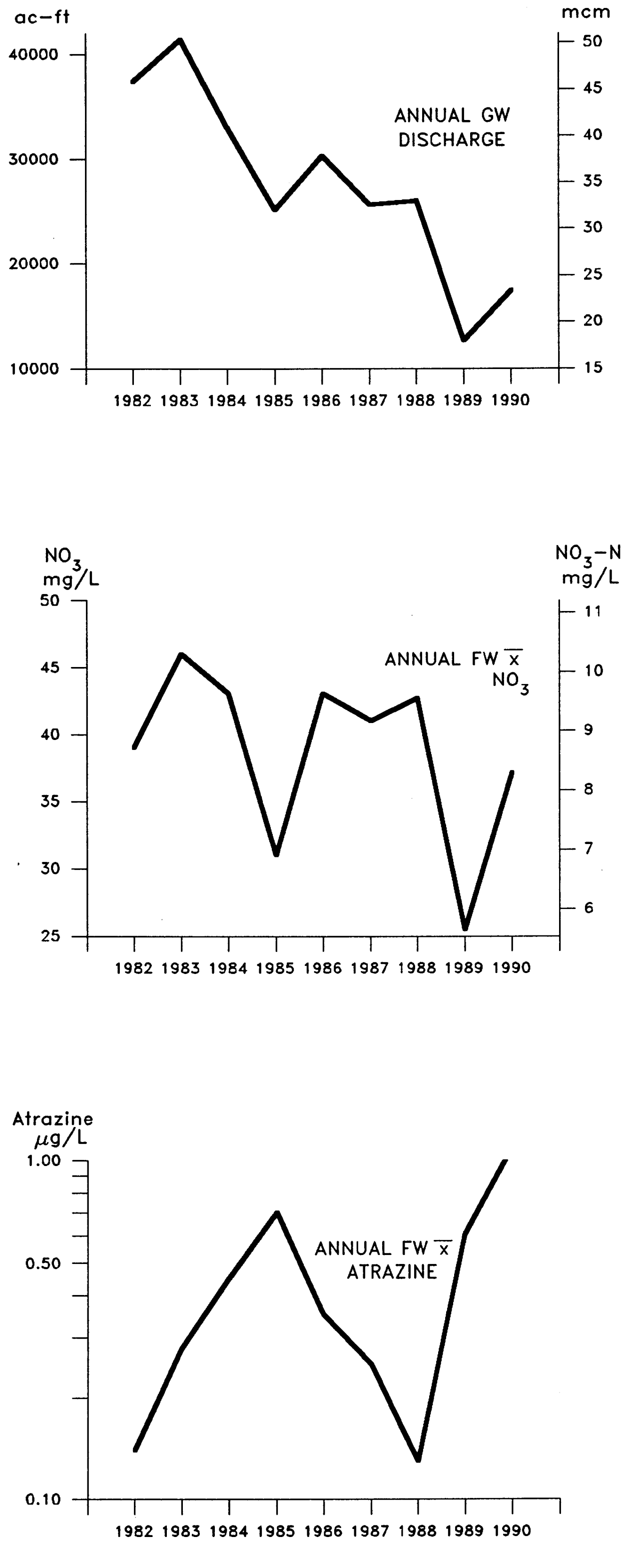


Figure 26. Annual groundwater discharge and flow-weighted mean nitrate and atrazine concentrations at Big Spring, WYs 1982-1990.

Table 3. Water year summary data for groundwater discharge from the Big Spring basin to the Turkey River.

	Water Year								
	'82	'83	'84	'85	'86	'87	'88	'89	'90
Precipitation									
water inches	34.0	44.5	32.8	35.8	36.7	32.0	22.9	24.3	37.9
Groundwater discharge (Q) to the Turkey River									
mean Q, cfs	51.4	56.9	45.3	35.2	42.0	35.4	35.8	17.6	24.1
total Q, inches									
acre-feet, 1000's	37.4	41.4	32.7	25.1	30.3	25.5	26.0	12.7	17.4
Nitrogen discharged with groundwater:									
flow-wtd mean concentration, mg/L									
as nitrate (NO3)	39	46	43	31	43	41	43	25	37
as nitrate-N (NO3-N)	8.8	10.3	9.7	7.0	9.7	9.1	9.6	5.7	8.2
ammonia-N *	*	*	*	*	0.1	0.1	0.1	0.6	0.1
organic-N *	*	*	*	*	0.5	0.2	0.3	0.8	0.6
nitrogen load;									
(nitrate-N + nitrite-N)									
1,000's lbs-N	873.0	1150.0	843.4	476.8	796.8	636.1	672.0	194.9	390.9
lbs-N/acre	13.2	17.4	12.8	7.2	12.1	9.6	10.2	3.0	6.0
(for total basin area)									
Atrazine discharged with groundwater:									
flow-wtd mean concentration, mg/L									
atrazine, ug/L	0.2	0.3	0.5	0.7	0.4	0.3	0.1	0.6	1.1
atrazine load;									
lbs - atrazine	14.2	31.2	40.0	47.6	29.0	17.6	9.2	21.2	49.9

*Prior to WY 1986 ammonia-N and organic-N were not analyzed frequently enough to calculate annual flow-weighted means.

In 1987, several years into the education and marketing efforts, 52% of farmers surveyed noted reducing fertilizer nitrogen rates since 1982. While such responses are promising, annual inventories of farm practices (and area sales records) provide additional information (Table 4). From 1981 to 1989, basin farmers reduced fertilizer-N rates by 33% for first-year corn after alfalfa, by about 22% for second-year corn, and by 15% on continuous corn (3 or more years corn), giving an aggregate reduction of about 21% on all corn acres. Yields generally increased during this time (Table 4). While the yield differences are largely related to weather, the yield data has helped area farmers understand they can address both environmental concerns and profitability.

For farmers in the Big Spring basin the reductions from 1981 to 1989 translate to: a reduction of over 1.2 million lbs. of N applied per year; a savings of about $200,000 per year (or an average of about $1,000 per farm); and an energy savings equivalent to over 250,000 gallons of diesel fuel per year. Even so, there are many producers who can still make substantial improvements.

Table 4. Fertilizer nitrogen (FN) rates used for corn and continuous corn yields, from farm census inventories in the Big Spring basin; inventories consist of personal enumeration surveys, conducted with the farm families in the basin; response rate averages about 90% from the approximately 200 farm operators in the basin.

	Basin average fertilizer-N rates				Ave Yield
Rotation	All corn	1st-yr corn after alfalfa	2nd-yr corn after alfalfa	Continuous corn	Continuous corn yields
Year	------	lbs-FN/acre		------	bu/acre
1981	174	123	160	178	128
1982	174	123	---	178	138
1984	158	115	155	169	130
1986	147	96	---	153	149
1987	149	84	121	157	141
1988	141	84	124	151	79
1989	138	82	125	151	147

Other projects in the region provide an assessment of the effect of the Big Spring demonstrations and marketing efforts. In 1987, Blackmer and others (El-Hout and Blackmer, 1990) conducted on-farm surveys of N-management in areas surrounding the Big Spring basin, including corn stalk and tissue tests and nitrogen soil tests. Farmers in these adjacent areas averaged 121 lbs fertilizer-N/acre on first-year corn after alfalfa, essentially the same rate used by Big Spring basin (BSB) farmers in 1981. But by 1987, BSB farmers had reduced rates to about 84 lbs-N/acre, illustrating the effects of the BSBDP educational programs. Poor alfalfa stands may provide little available-N, necessitating fertilization. However, the plant and soil-test data from the adjacent areas indicated many of these fields had 2 to 3 times the N needed to maximize corn yields (El-Hout and Blackmer, 1990).

While declines in nitrogen application rates on the order of 20% can be documented over the last decade, relating these changes to nitrate concentrations at Big Spring is problematic. The effects of reduced inputs are, at present, largely lost in the year-to-year variations caused by the climatic factors that control the magnitude of groundwater recharge. While the Big Spring basin would be described by most observers as a relatively responsive groundwater system, it is also a 103 mi. sq. basin, and therefore exhibits some degree of lag-time. Continued monitoring and refined statistical analysis of the results of the project will hopefully allow the recognition and quantification of water quality changes resulting from more efficient chemical management.

REFERENCES

Baker, R.G., Maher, L.J., Chumbley, C.A., and Van Zant, K.A., *in press*, Patterns of Holocene environmental change in the Midwest: Quaternary Research.

Baker, R.G., Schwert, D.P., Bettis, E.A., and Chumbley, C.A., *in review*, Impact of Euroamerican settlement on the environment in northeast Iowa, midwestern USA: The Holocene.

Bettis, E.A. III, 1990, Holocene alluvial stratigraphy of western Iowa, *in* Bettis, E.A. III, editor, Holocene alluvial stratigraphy and selected aspects of the Quaternary history of western Iowa: Midwest Friends of the Pleistocene Field Trip Guidebook, p. 1-72.

Bettis, E.A. III, 1992, Soil morphologic properties and weathering zone characteristics as age indicators in Holocene alluvium in the Upper Midwest: chapter 4 *in* Holloday, V.T. (ed.), Soils in Archaeology: Washington, Smithsonian Institution Press, p. 119-144.

Bettis, E.A. III, Baker, R.G., Green, W.R., Whelan, M.K., and Benn, D.W., 1992, Late Wisconsinan and Holocene alluvial stratigraphy, paleoecology, and archaeological geology of east-central Iowa: Iowa Department of Natural Resources, Geological Survey Bureau, Guidebook Series No. 12, 82 p.

Bounk, M.J., 1983a, Some factors influencing phreatic cave development in the Silurian strata of Iowa: Proceedings of Iowa Academy of Science, 90, p. 19-25.

Bounk, M.J., 1983b, Karstification of the Silurian Escarpment in Fayette County, Northeastern Iowa: Geological Society of Iowa Guidebook 40, 26 p.

Capel, P.D., 1990, Atmospheric Deposition of Herbicides in the Mid-Continental United States (abs): Eos, Trans. AGU, v. 71, no. 43, p. 1329.

Chumbley, C.A., Baker, R.G., and Bettis, E.A. III, 1990, Midwestern Holocene paleoenvironments revealed by floodplain deposits in northeastern Iowa: Science, v. 249, p. 272-274.

El-Hout, N.M., and Blackmer, A.M., 1990, Nitrogen status of corn after alfalfa in 29 Iowa fields: Journal of Soil and Water Conservation, v. 45, p. 115-117.

Everts, C.J., 1989, Role of preferential flow on water and chemical transport in a glacial till soil: unpublished Ph.D. dissertation, Iowa State University, Ames, Iowa.

Goolsby, D.A., Thurman, E.M., Pomes, M.L., Majure, J.J., 1990, Herbicides in Atmospheric Wet Deposition-Preliminary Results: National Atmospheric Deposition Program Technical Committee Meeting Abstracts of Papers, NADP/NTN Coordination Office, Colorado State University, Fort Collins, Co., p. 7

Hallberg, G.R., 1980, Pleistocene stratigraphy in east-central Iowa: Iowa Geological Survey Technical Information Series no. 10, 168 p.

Hallberg G.R., and Bettis, E.A. III, 1985, Overview of landscape evolution in northeastern Iowa I: Pre-Wisconsinan, Pleistocene Geology and Evolution of the Upper Mississippi Valley: A Working Conference, Program, Abstracts, Field Guide, Winona State University, p. 15-19.

Hallberg G.R. and Hoyer, B.E., 1982, Sinkholes, hydrogeology, and groundwater quality in northeast Iowa: Iowa Geological Survey, Open-File Report 82-83, 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, Hydrologic and water-quality investigations in the Big Spring basin, Clayton County, Iowa: 1983 Water-Year: Iowa Geological Survey Report 84-4, 231 p.

Hallberg, G.R., Libra, R.D., and Hoyer, B.E., 1985, Nonpoint source contamination of groundwater in karst-carbonate aquifers in Iowa: *in* Perspectives on Nonpoint Source Pollution: Washington, D.C., United States Environmental Protection Agency, Environmental Protection Agency 440/5 85-001, 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.

Hallberg, G.R., Contant, C.K., Chase, C.A., Miller, G.A., Duffy, M.D., Killorn, R.J., Voss, R.D., Blackmer, A.M., Padgitt, S.C., DeWitt, J.R., Gulliford, J.B., Lindquist, D.A., Asell, L.W., Keeney, D.R., Libra, R.D., Rex, K.D., 1991, A Progress review of Iowa's agricultural-energy-environmental initiatives: Nitrogen management in Iowa: Iowa Department of Natural Resources, Technical Information Series 22, 29 p.

Hansel, A.K., 1976, Mechanically induced karst development along the Silurian Escarpment in northeastern Iowa: unpublished M.A. thesis, University of Northern Iowa, 102 p.

Hoyer, B.E., Bettis, E.A. III, Witzke, B.J., 1986, Water quality and the Galena Group in the Big Spring area, Clayton County: Geological Society of Iowa, Guidebook 45, 35 p.

LeGrand, H.E., and Stringfield, V.T., 1973, Concepts of karst development in relation to interpretation of surface runoff: U.S. Geological Survey Journal of Research, v. 1, p. 351-360.

Levorson, C.O., and Gerk, A.J., 1983, Field recognition of stratigraphic position within the Galena Group of northeast Iowa (limestone facies): p. C1-C11, In Delgado, D.J. (ed.), 1983, Ordovician Galena Group of the Upper Mississippi Valley-Deposition, Diagenesis, and Paleoecology, Guidebook 13th Annual Field Conference, Great Lakes Section, Society of Economic Paleontologists and Mineralogists

Libra, R.D., Hallberg, G.R., Hoyer, B.E., and Johnson, L.G., 1986, Agricultural impacts on groundwater quality: the Big Spring Basin study: *in* Agricultural Impacts on Ground Water, National Water Well Association, Worthington, OH, 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.

Littke, J.P., and Hallberg, G.R., 1991, Big Spring Basin water-quality monitoring program; design and implementation: Iowa Department of Natural Resources, Open-File Report 91-1, 19 p.

Mandel, R.D., and Bettis, E.A. III, 1992, Recognition of the DeForest Formation in the east-central Plains: Implications for archaeological research, Geological Society of America North-Central Section Meeting, Abstracts with Program, v. 24 (abstract #105034).

Nations, B.K., 1990, Pesticides in Iowa precipitation: National Atmospheric Deposition Program Technical Committee Meeting Abstracts of Papers, NADP/NTN Coordination Office, Colorado State University, Fort Collins, Co., p. 7.

Prior, J.C., 1976, A regional guide to Iowa landforms: Iowa Geological Survey Educational Series 3, 71 p.

Prior J.C., 1991, Landforms of Iowa: University of Iowa Press, Iowa City, IA, 153 p.

Rolston, D.E., 1981, Nitrous oxide and nitrogen gas production in fertilized land: *in* Delwiche, C.C., editor, Denitrification, Nitrification, and Atmospheric Nitrous Oxide, New York, John Wiley.

Rowden R.D., and Libra, R.D., 1990, Hydrogeologic Observations from Bedrock Monitoring Well Nests in the Big Spring Basin: Iowa Department Natural Resources, Geological Survey Bureau, Open-File Report 90-1, 27 p.

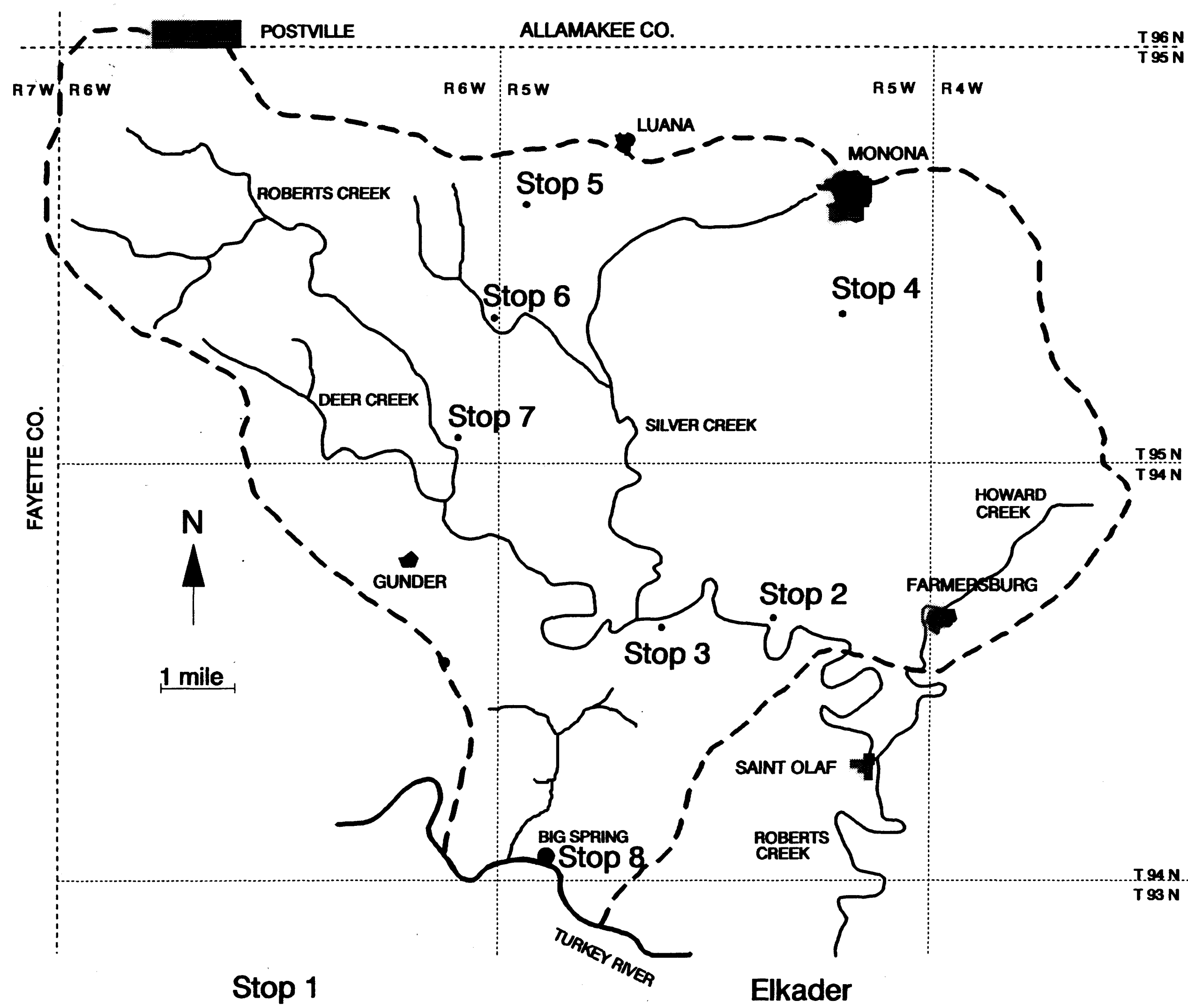
Siegley, L.S, and Hallberg, G.R., 1991, Groundwater quality observations from the Bluegrass Watershed, Audubon County, Iowa: Iowa Department of Natural Resources, Geological Survey Bureau, Technical Information Series 20.

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

Thompson, C.A., 1986, Water resources of theOcheyedan-Little Sioux alluvial aquifer: Iowa Department of Natural Resources, Geological Survey Bureau, Open-File Report 86-3.

Thrailkill, J., 1968, Chemical and hydrologic factors in the excavation of limestone caves: Geological Society of America Bulletin, v. 79, p. 19-46.

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



Big Spring Basin Field Trip Stops