◆ SIXTH NATIONAL ◆

NONPOINT-SOURCE MONITORING WORKSHOP

FIELD TRIP 2

BIG SPRING BASIN, CLAYTON COUNTY, IOWA
AND
SNY MAGILL WATERSHED, CLAYTON COUNTY, IOWA

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INTRODUCTION TO BIG SPRING

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The Iowa Department of Natural Resources-Geological Survey Bureau began receiving an increasing number of questions and comments regarding nitrate concentrations in the bedrock aquifers of northeast Iowa during the mid-1970s. 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 Geological Survey Bureau 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. 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 (Figure 2). Big Spring is the largest spring in Iowa. Water from the spring has been used to supply a trout-rearing facility since the late 1930s, and the spring has been owned by the Department of Natural Resources for over 30 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

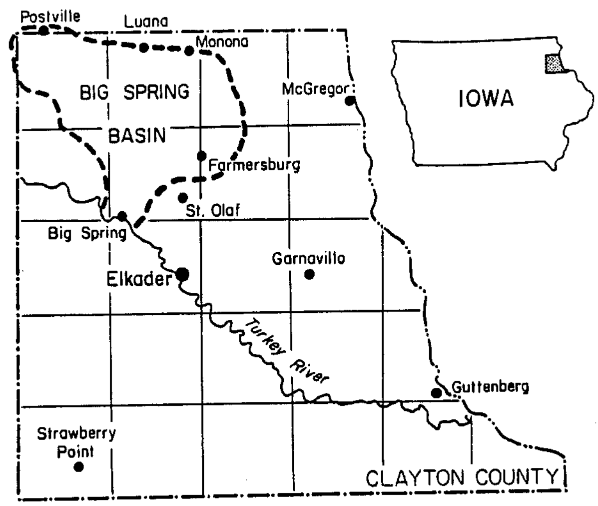


Figure 2. Map showing the location of the Big Spring basin.

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. Expanded and similar education and demonstration efforts continue under the auspices of the Northeast Iowa Demonstration Project. The remainder of this introduction gives background information on the Big Spring basin and associated activities. Miller (this volume) provides an overview of how the water quality demonstration project has evolved through time. Appendix I (located at the end of this article) provides a list of selected references on the Big Spring basin.

STRATIGRAPHIC SETTING

A general stratigraphic column for northeastern Iowa is shown in Figure 1. 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 unconformably overlain by the St. Peter Sandstone, a locally important aquifer in northeast 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. Overlaying the Galena carbonates is the Maquoketa Formation. For mapping and hydrogeologic purposes the Maquoketa is divided into two units (Figure 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 (Figure 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 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 (Figure 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 process during and following deposition of the tills. Extensive erosion in conjunction with downcutting of the Mississippi 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-Wisconsin 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

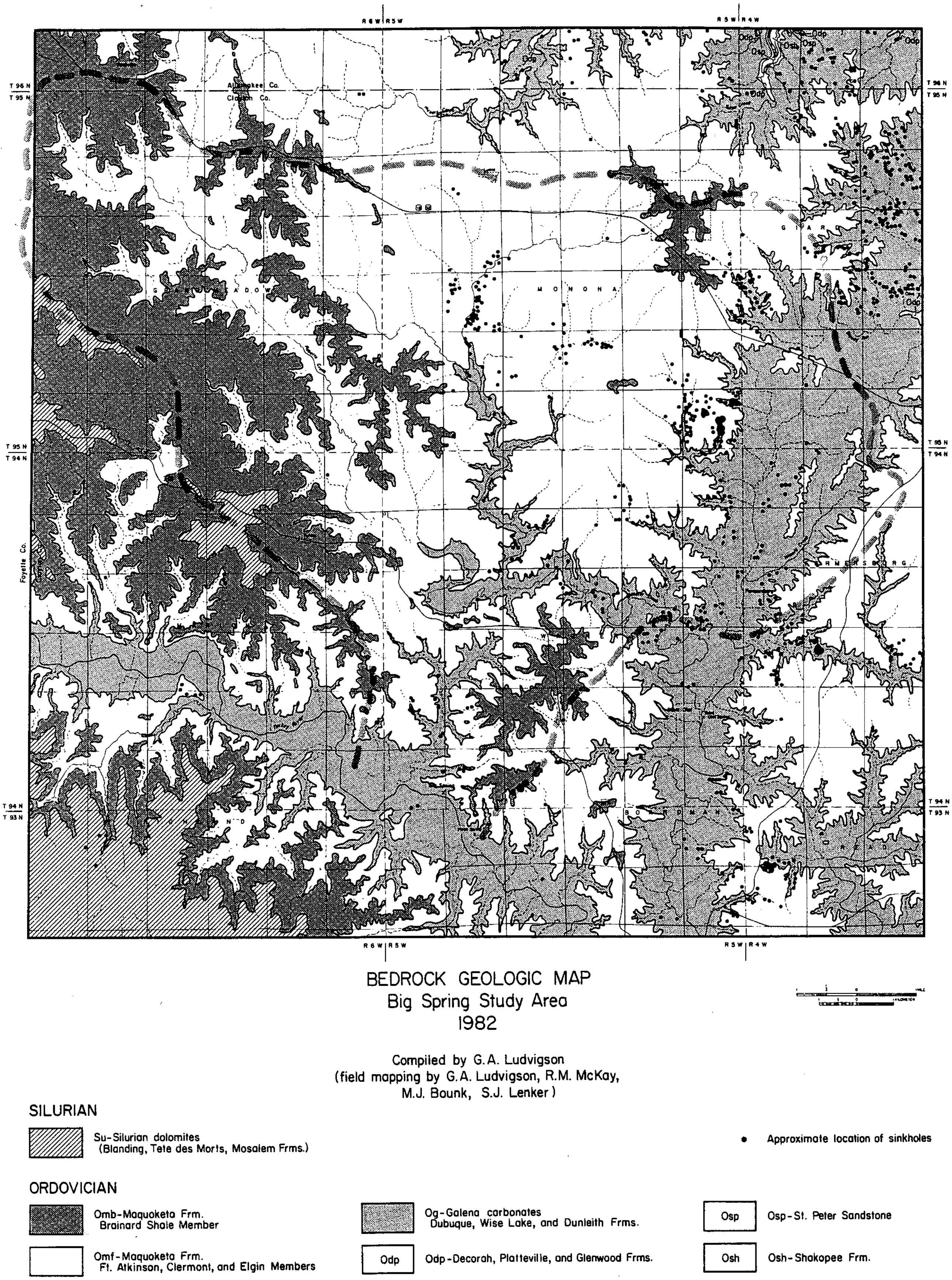


Figure 3. Bedrock geologic map of the Big Spring basin.

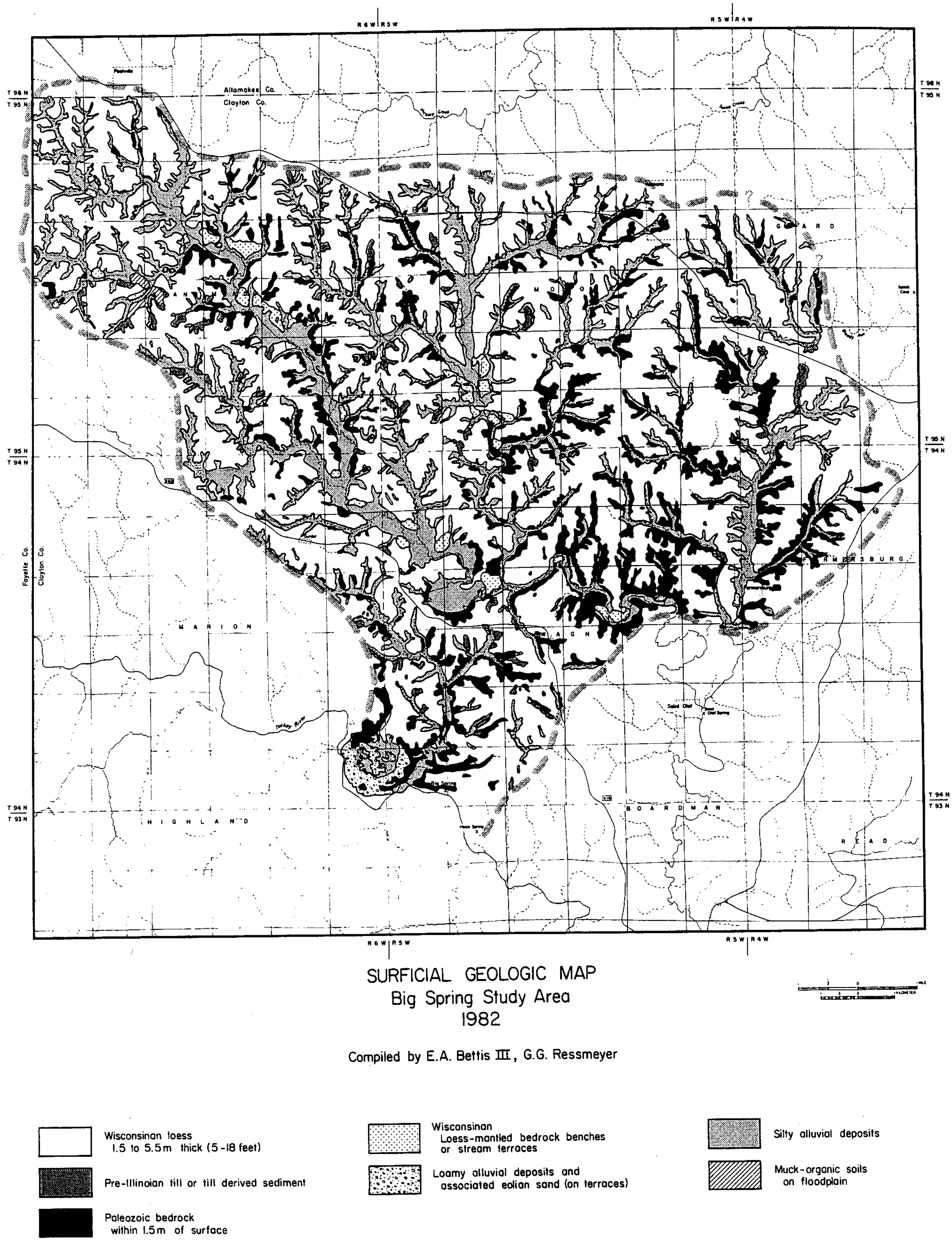


Figure 4. Surficial geologic map of the Big Spring basin.

the drainage network where small valleys have encroached on divide areas (Figure 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 (Figure 4). Loess thickness in these areas is in the 20-30 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 Wisconsin terrace along the Turkey River (Figure 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, 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 (Figure 3) are evident as wooded promontories standing above the surrounding landscape.

A well-integrated, dendritic drainage network is developed in the Big Spring basin (Figure 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, south 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 two-thirds 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

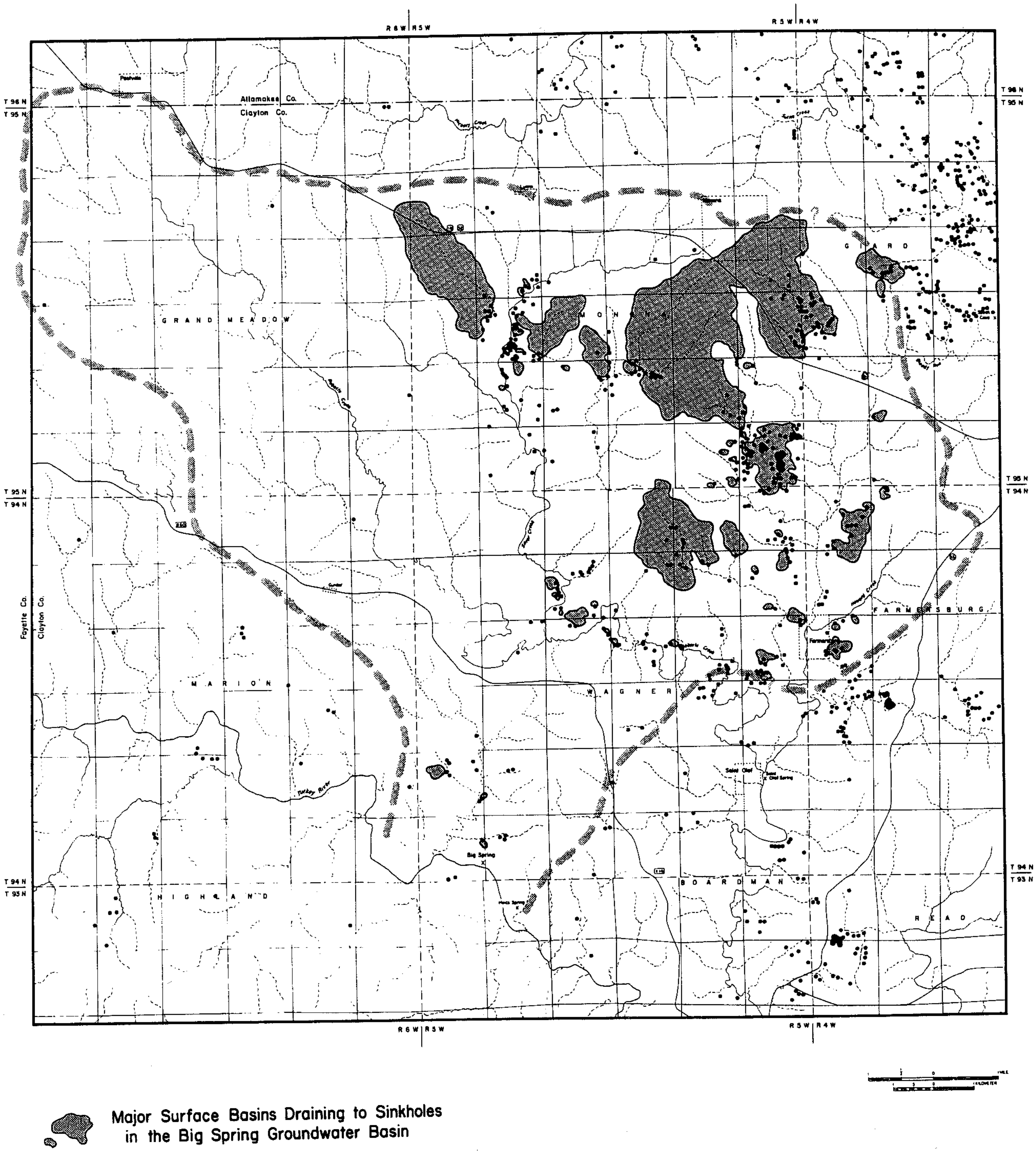


Figure 5. Map showing surface drainage and surface basins that drain to sinkholes.

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 two-thirds 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 (Figure 6), and mapping the potentiometric surface of the Galena aquifer (Figure 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 Figure 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 (Figure 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 part of the zone of saturation, and then decreases with depth (Thrailkill, 1968; LeGrand 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

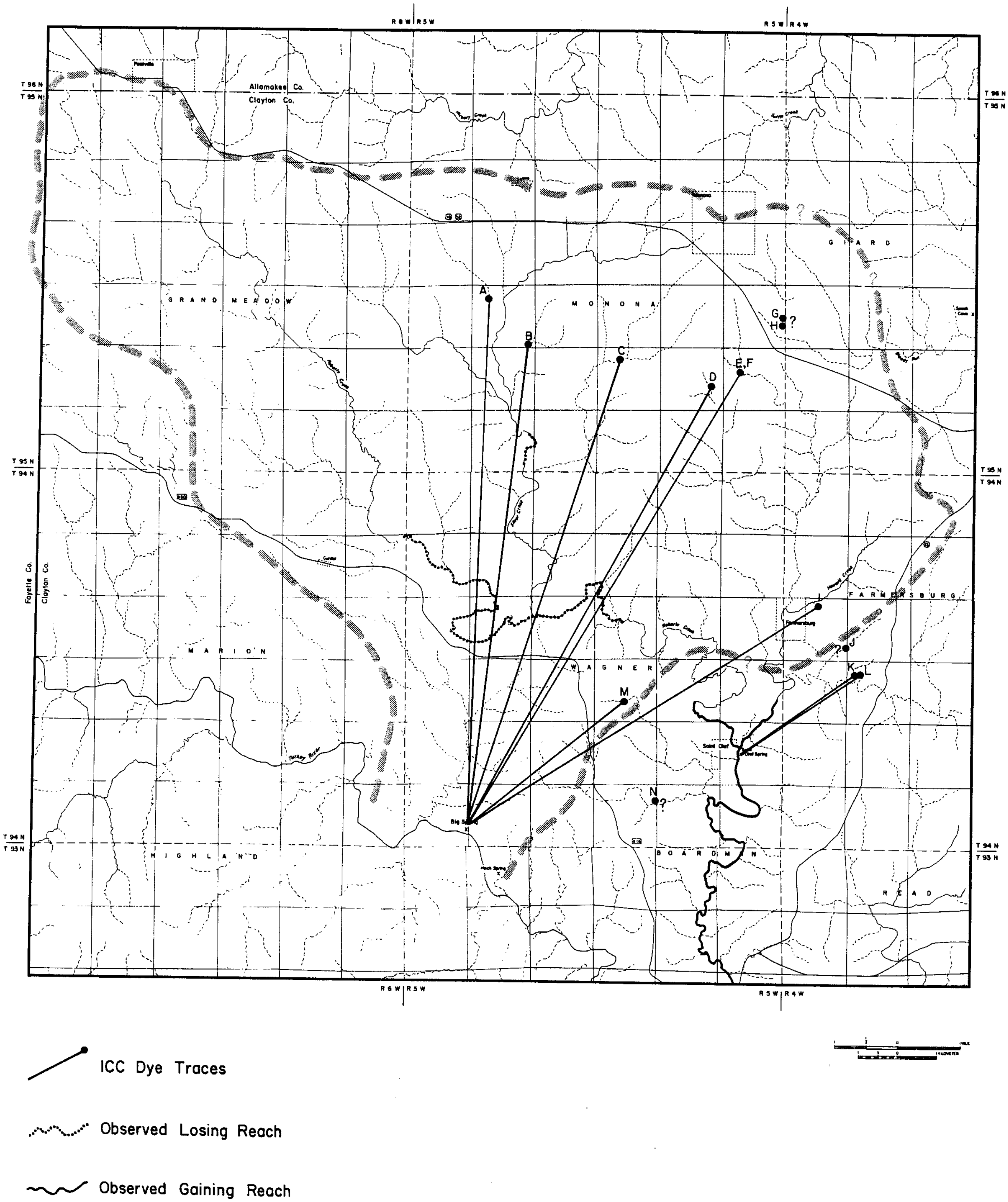


Figure 6. Map showing dye traces and gaining and losing stream reaches in the Big Spring basin.

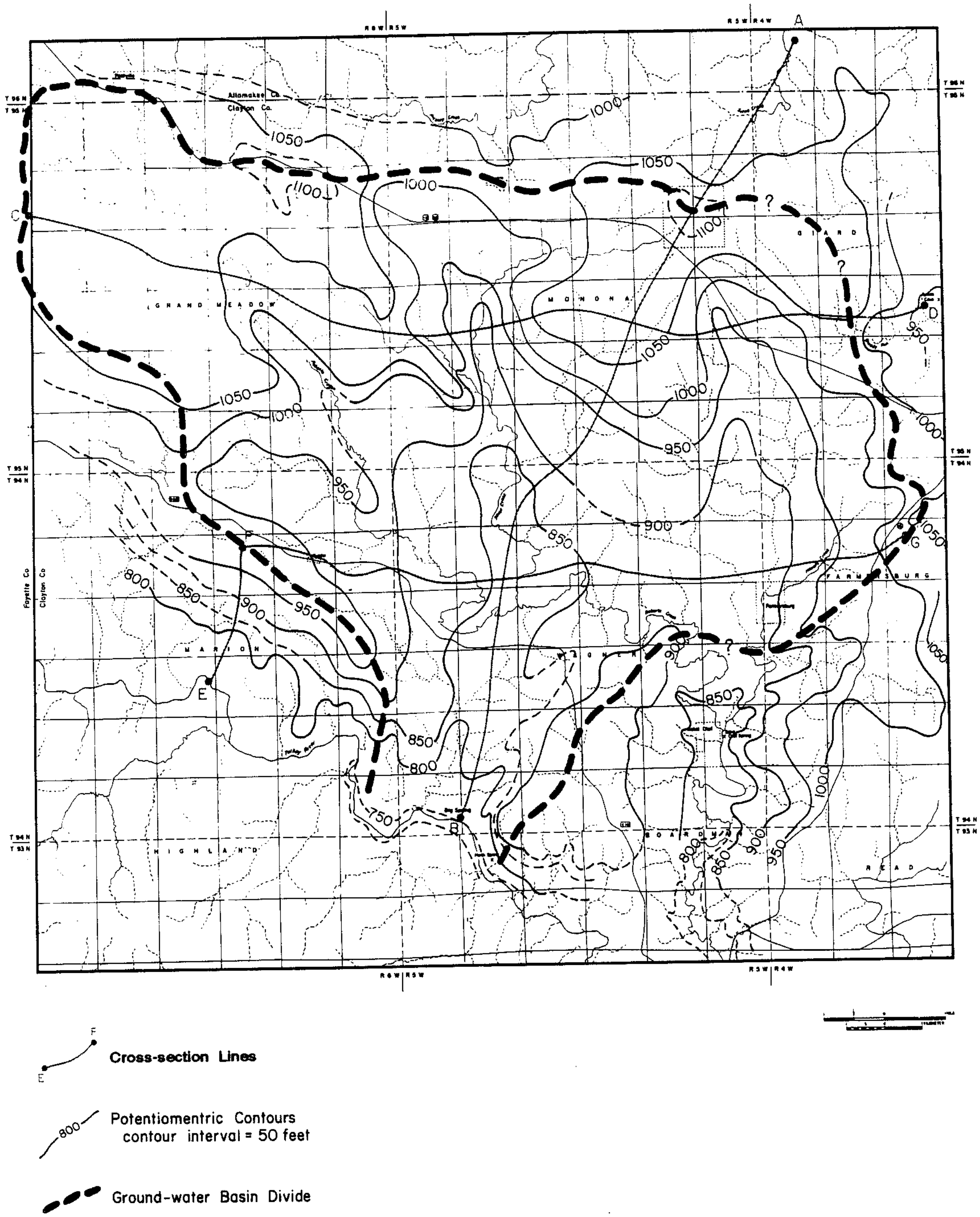


Figure 7. Map showing the potentiometric surface of the Galena aquifer. Cross-section lines for Figures 8, 9, and 10 are also shown.

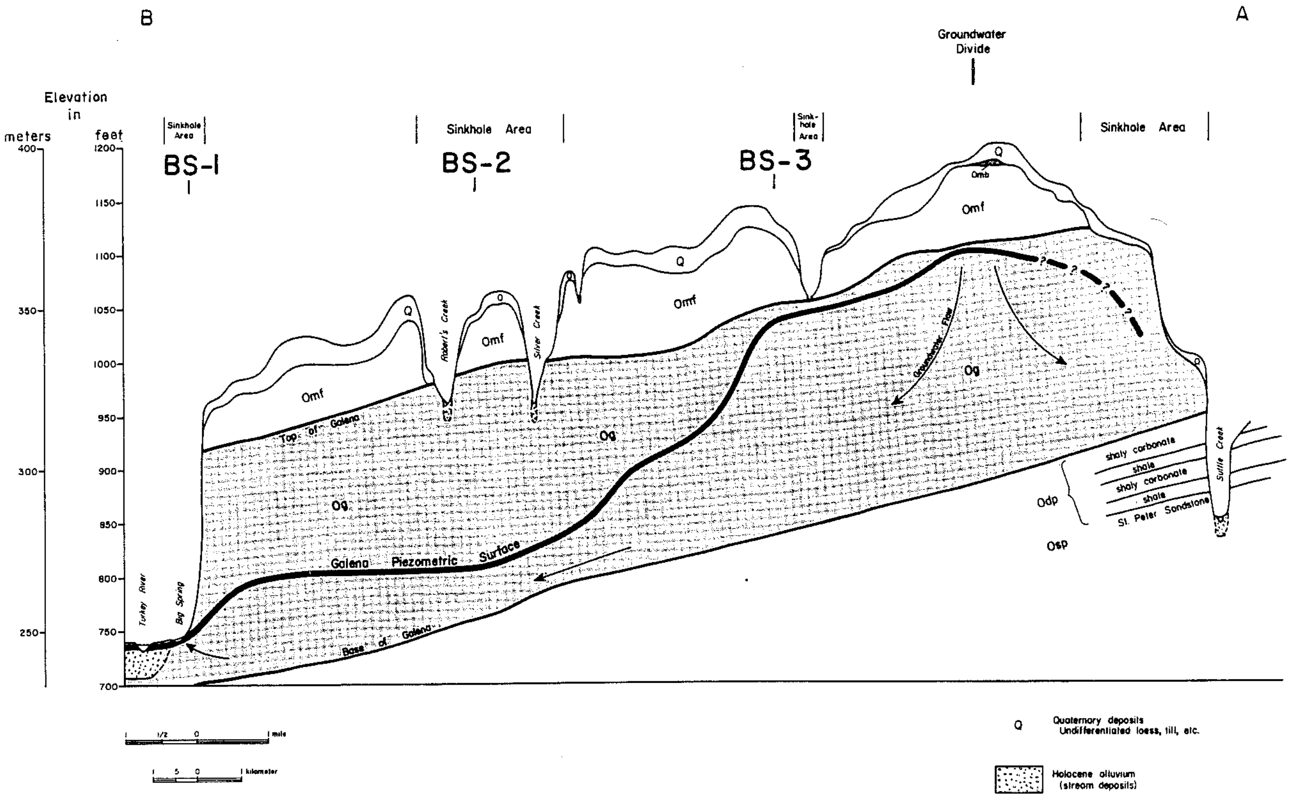


Figure 8. Hydrogeologic cross-section A-B. Location given on Figure 7.

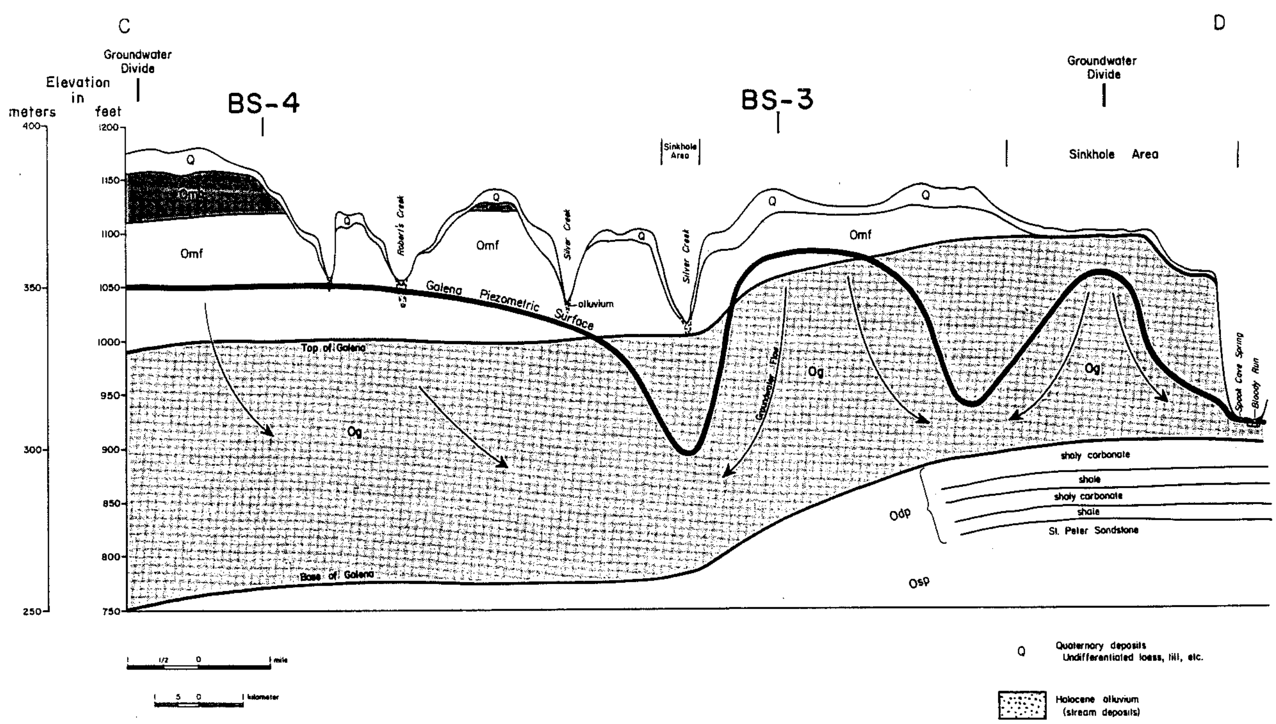


Figure 9. Hydrogeologic cross-section C-D. Location given on Figure 7.

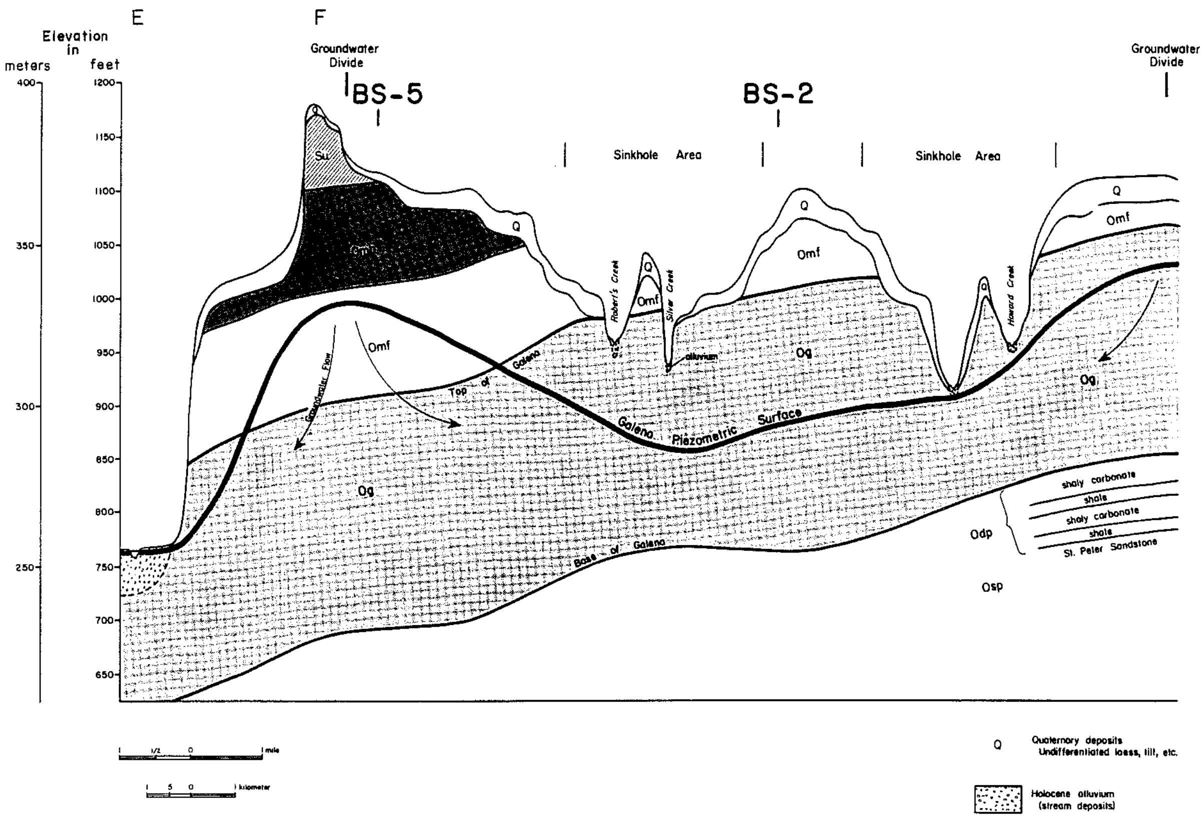


Figure 10. Hydrogeologic cross-section E-F-G. Location given on Figure 7.

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 the Geological Survey Bureau (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 clearly support that there is no shallow water table graded to and recharging creeks in this area. Yet in most years these streams flow across this area continuously.

Cross-section C-D (Figure 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 (Figure 10) runs east-west across the southern part of the groundwater basin, traversing the broad low area on the potentiometric surface (Figure 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 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

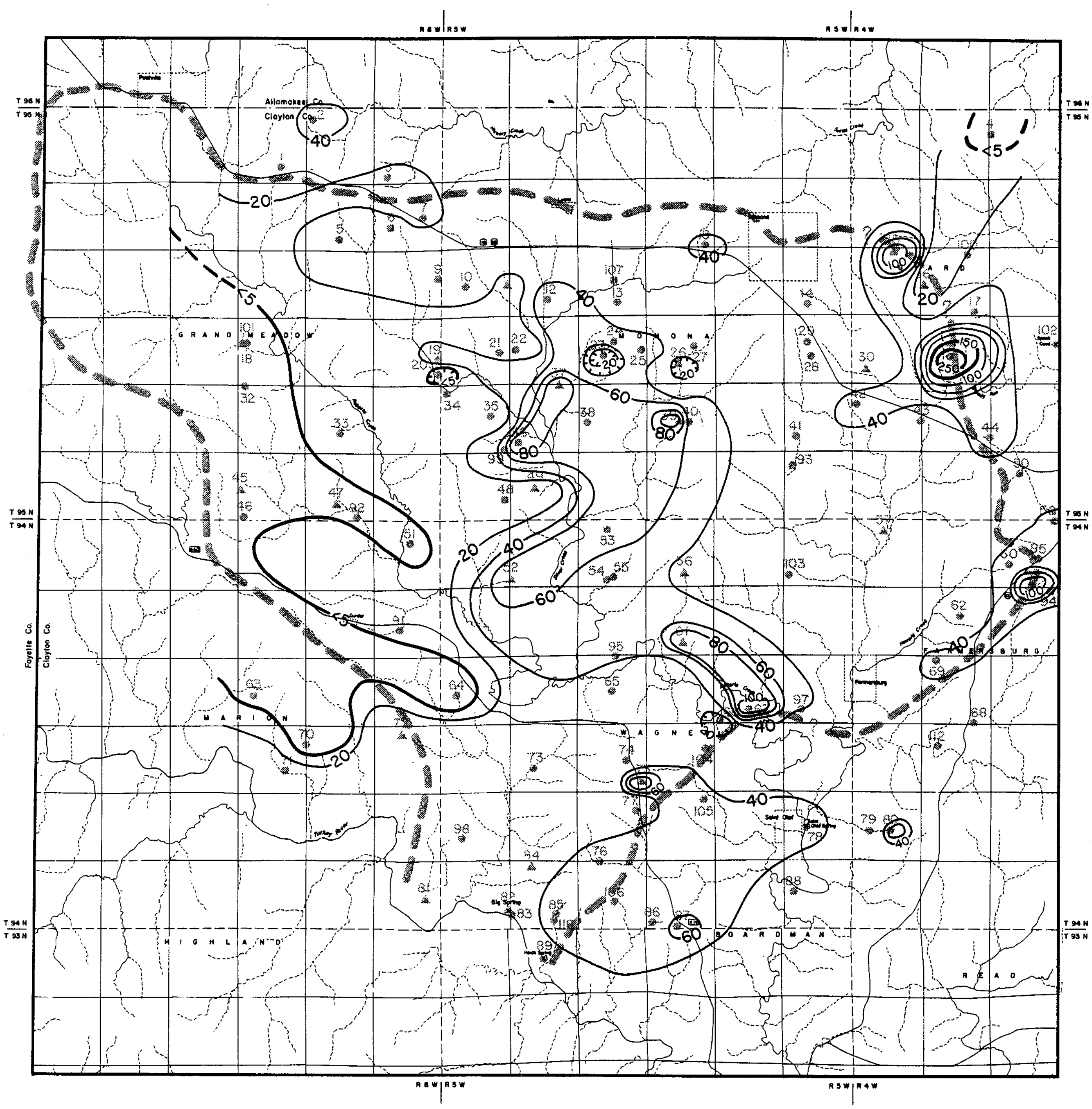
Landuse patterns make the Big Spring basin particularly conducive to the study of the agricultural ecosystem. The land in the basin is essentially all used (97%) for agriculture, and is divided into roughly 200 farms. There are not significant urban or industrial areas, no landfills or other major point 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 sewage treatment plant near Monona (Figure 2). The impacts of these sources have been monitored.

Landuse in the basin has been interpreted from aerial photos, USDA Farm Service Agency records, staff field notes, and landowner surveys; these data have been 'digitized' from maps into the Geological Survey Bureau's geographic information system. Row-cropped fields account for 50-60% of the basin area, with corn production typically accounting for virtually all row crops. Corn is often raised in rotation with alfalfa, an important crop for the numerous small- to moderate-sized dairy operations in the basin. On average, about 25% of the basin is planted to alfalfa. Pasture lands are common and some additional cover crops are grown. Hog production is also an important component of the basin's farm operations. During the mid-1990s, the basin livestock herd included roughly 40,000 hogs and 13,000 cattle and calves.

While year-to-year variations in land use occur within the basin, the overall pattern has remained relatively stable during the monitoring period. More significant changes occurred during the 1960s and 1970s, when the corn crop acreage increased by about 50%, with a coincident decline in amount of land in pasture or cover crops. This increase in corn acreage occurred during a period marked by sharply increasing N-fertilizer application rates on corn. In sum, fertilizer-N inputs to the basin increased three-fold between 1960 and 1980 (Hallberg et al., 1983).

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



Nitrate Concentration (Nov. - Dec., 1981)

Contour Interval - 20 Mg/l

Departure from Stated Contour Interval

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

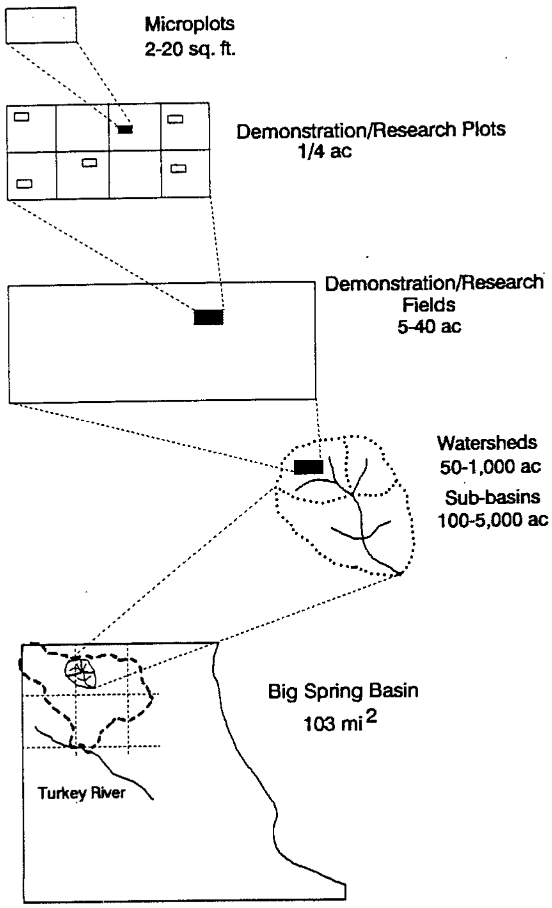


Figure 12. Schematic diagram of nested monitoring network design.

significant thickness of the upper Maquoketa Formation overlies the Galena aquifer (Figure 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 this research the multi-agency group involved with these studies initiated the Big Spring Basin Demonstration Project in 1986. This effort integrated 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 (Figure 12), from small-scale field plots to the basin water outlets at Big Spring and Roberts Creek (Littke and Hallberg, 1991). 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 13. 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 and others (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

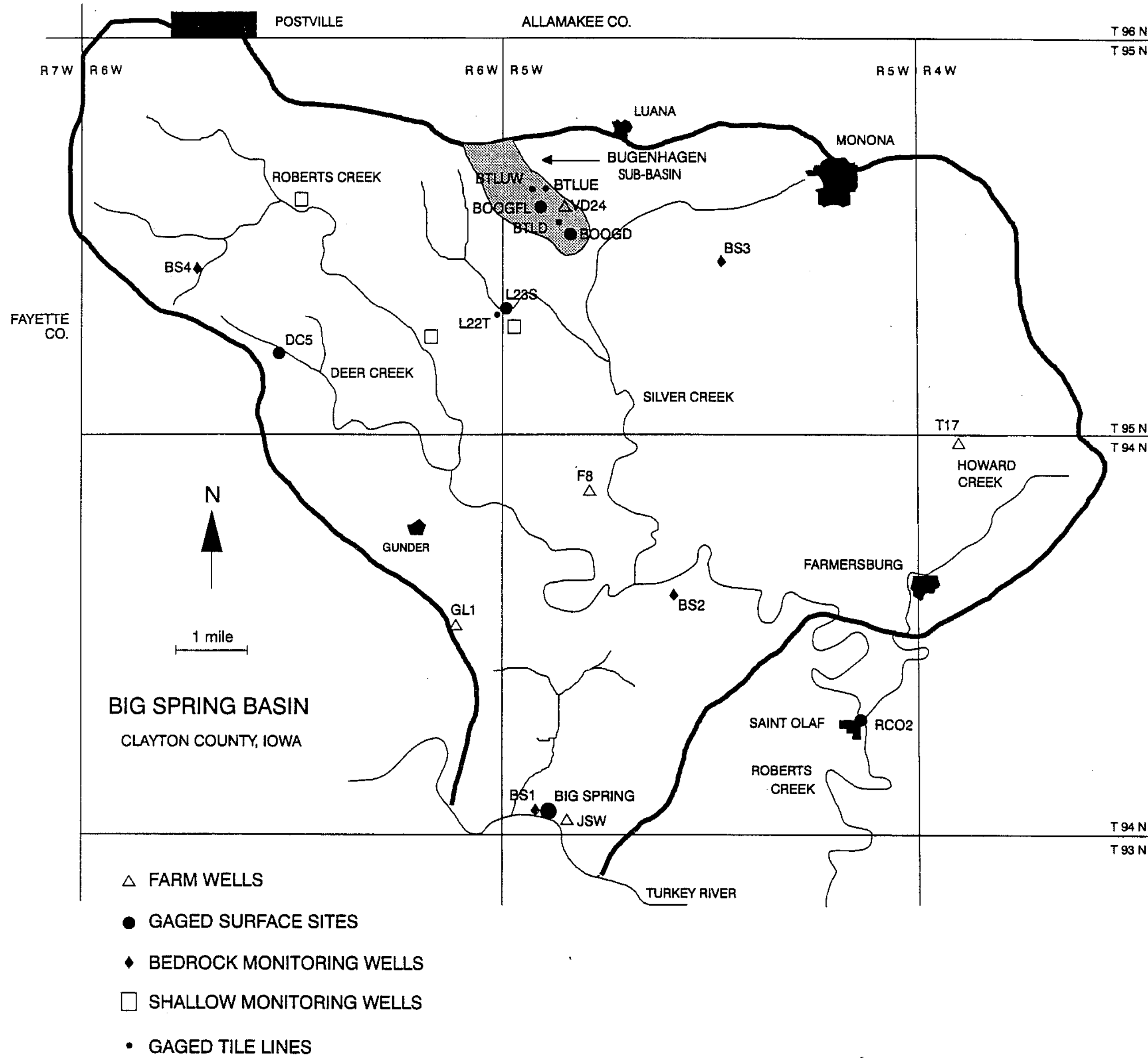


Figure 13. Map showing selected sites in the Big Spring basin monitoring system.

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 affords, over time, an assessment of the water-quality improvements resulting from changes in agricultural practices.

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APPENDIX I.
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