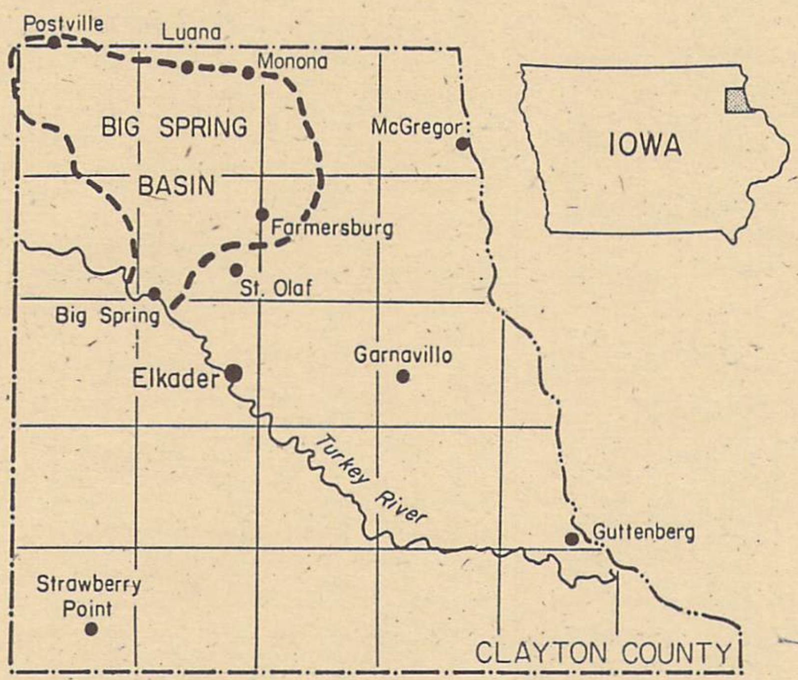
HYDROGEOLOGIC OBSERVATIONS FROM BEDROCK MONITORING WELL NESTS in the BIG SPRING BASIN

Open-File Report 90-1



Iowa Department of Natural Resources

Larry J. Wilson, Director

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A Report of The Big Spring Basin Demonstration Project

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ABSTRACT

The Big Spring basin is a 103 mi^2 (267 km^2) groundwater basin in Clayton County, Iowa. The groundwater discharge and water quality within the basin have been monitored continuously since 1981. Big Spring discharges from the Galena aquifer, the main groundwater source in the basin. It is a carbonate aquifer with moderate karst development. In previous studies, water table/potentiometric data from Galena wells and spring elevations, along with dye tracing and identification of losing- and gaining-stream reaches, were used to define the extent of the groundwater basin.

To refine the three-dimensional understanding of the groundwater-flow system, test holes were drilled at five sites. At four of these sites, cores were taken and nested monitoring wells were installed. Well sites were placed in different regions of the basin to delineate the hydrologic system, and to refine the potentiometric relations within the flow system of the Galena aquifer and bounding aquitards.

Site BS-1 is located in the southernmost portion of the basin near the Big Spring and the Turkey River. In this portion of the basin, the top of the Galena potentiometric surface declines to within 50 to 75 feet (15 to 23 m) of the base of the aquifer. The Turkey River acts as "base-level" for the Galena potentiometric surface. The bedrock dips toward this area and groundwater is discharged through Big Spring and associated smaller springs to the Turkey River. At this location, hydraulic head increases with depth, and the potential for groundwater movement is upward.

Site BS-2 is located near the center of the basin, above an inferred major conduit zone. In this portion of the basin, Robert's Creek and Silver Creek and their associated alluvial valleys are 100 feet (31 m) or more above the Galena potentiometric surface, which lies roughly in the middle of the aquifer. In this portion of the basin the potential for groundwater movement is downward. A complex system of small voids was encountered at this site.

Site BS-3 is located in the north-central portion of the basin near an area of sinkhole development. At this location, the Galena potentiometric surface was expected to be near or above the top of the Galena aquifer. Installation of the lower Galena observation well showed the potentiometric surface to be approximately 125 feet (38 m) below the top of the Galena at this location. This site may be over a conduit zone where the Galena potentiometric surface is locally depressed. The feature may not be large enough to have been reflected in previous assessments of water-level data. At this location, the potential for groundwater movement is also downward from the Galena to the St. Peter.

Site BS-4 is located in the northwest portion of the basin. In this area, Galena carbonates are overlain by the Maquoketa Formation, and the Galena potentiometric surface is located above the top of Galena. At this site, an anomalously thick sequence of Quaternary materials overlie an incomplete Maquoketa section. In this portion of the basin, the potential for groundwater movement is downward; the Quaternary and Maquoketa rocks form an aquitard, and the Galena is a confined aquifer.

For continuous monitoring of the wells, digital recorders were installed and set to register water levels hourly. From January 1989 to September 1989, all monitoring wells exhibited overall declines of mean monthly water levels, reflecting the continued absence of recharge during the drought. The more shallow wells exhibited more immediate response to snow melt and rain fall events than the deeper monitoring wells.

Water-quality sampling of the monitoring wells is expected to begin during the 1990 water year. Ongoing monitoring of water levels in wells will provide detailed three-dimensional observations of changes in the various potentiometric surfaces within the basin, and refine knowledge of potentiometric relations and contaminant transport within the flow system of the Galena aquifer and bounding aquitards.

INTRODUCTION

Since 1980, the Department of Natural Resources, Geological Survey Bureau (GSB), in conjunction with numerous state, federal, and local agencies, and university researchers, have been investigating the impact of agricultural chemicals, particularly nitrogen fertilizers and pesticides, on groundwater. Investigations by Hallberg and Hoyer, 1982; Hallberg et al., 1983, 1984a, 1984b, 1985, 1986, 1989; and Libra et al., 1984 have documented the magnitude of groundwater contamination related to agricultural practices, identified hydrogeologic settings that are susceptible to contamination from agricultural use, and provided insights into the mechanisms that deliver agricultural chemicals to groundwater. A significant portion of this work has focused on the Big Spring basin, a 103 square mile (267 sq. km) groundwater basin located in Clayton County, in northeast Iowa (Figure 1).

To further refine the three-dimensional understanding of the groundwater flow system in the basin, a series of nested monitoring wells were installed in 1988 and 1989. This report will summarize the hydrologic placement of the monitoring wells, the information obtained from the core analysis and will also present initial monitoring results from the wells.

Geologic Setting

The basin is located within the Paleozoic Plateau Landform region in northeast Iowa (Hallberg et al., 1984b). Topographically, the basin varies from moderately rolling in the northern one-half of the area, to steeply sloping near the Turkey River Valley in the southern portion of the area. Total relief in the basin is approximately 420 feet (128 m), with as much as 320 feet (98 m) of relief occurring along the Turkey River Valley in the southwest corner of the basin (Hallberg et al., 1983). Bedrock units in the basin include Silurian and Ordovician strata. The Galena aquifer is the main groundwater source in the basin; Big Spring functions as the main groundwater discharge point for this carbonate aquifer.

The geographic extent of the Big Spring groundwater basin was delineated in previous investigations through defining the water table/potentiometric surface of the Galena aquifer, dye traces, and locating and gaging gaining- and losing-stream reaches. Land use within the basin is essentially all agricultural. There are no major urban or industrial areas, no landfills, commercial feedlots, or other major point sources to significantly affect groundwater quality. The only point sources within the basin are surface-water discharges from a creamery and a new sewage treatment plant. The effects of these discharges are monitored.

As of 1987, about 43% of the basin was in row crop, about 14% was strip cropped, about 35% in cover crops, and about 5% of the basin is forest. The remaining portion of the basin is comprised of small urban areas, quarries, and roads. Up until about 1986, 99% of the row crop acreage was in corn. Since then, there have been small increases in the amount of soybeans and sorghum grown in the area. The cover crops grown within the basin include haycrops, oats, and pasture, and recently small amounts of wheat. Land use is interpreted from aerial photos, ASCS records, staff field notes, and land owner surveys.

Groundwater Flow

The groundwater discharge and water quality at Big Spring, have been monitored continuously since November 1981 (Hallberg et al., 1983). Nearly 90% of the groundwater discharged from the basin to the Turkey River occurs through Big Spring, with the remainder discharged via a few small associated springs. Groundwater also discharges downward from the Galena aquifer to underlying units. The water from Big Spring supplies a Department of Natural Resources, state-operated trout hatchery. The discharge is controlled by a concrete dam, which abuts bedrock surrounding the spring. At low stages, all water is discharged through a 30 inch (0.76 m) diameter, corrugated-metal pipe into the hatchery system. At higher stages, water discharges both through the pipe and through a concrete spillway to the Turkey River. These structures allow the discharge to be gaged.

The Galena is a carbonate aquifer with moderate karst development. Where the Galena

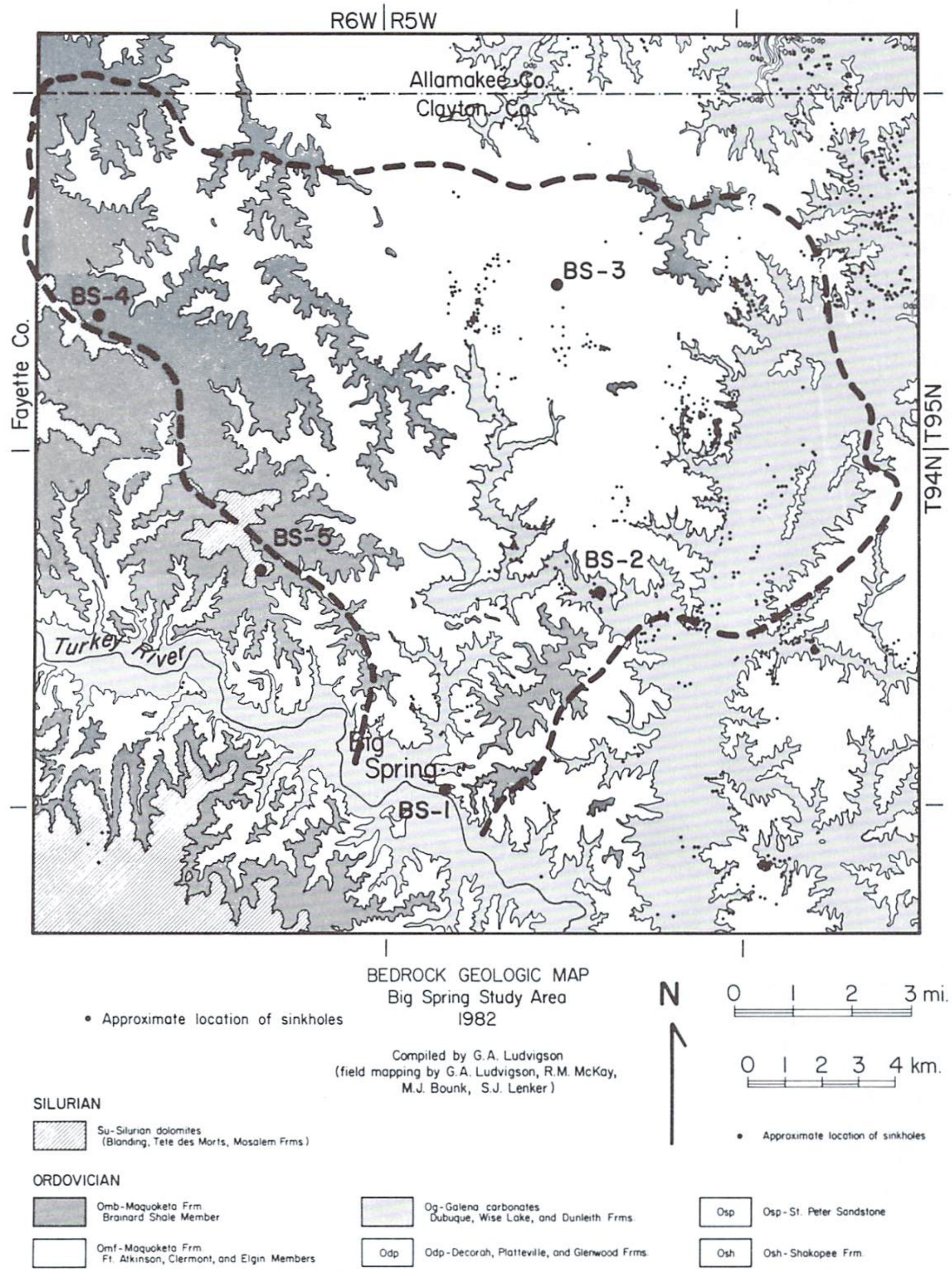

Figure 1. Bedrock geologic map of the Big Spring study area showing monitoring-well sites (adapted from Hallberg et al., 1983).

carbonates lie close to the land surface, solutional features such as sinkholes and enlarged fractures are present to varying degrees. The groundwater flow system within the Galena consists of both conduit- and diffuse-flow components. The conduit component is recharged by intermittent diversion of surface-water runoff into sinkholes; this recharge typically accounts for about 10% of the total groundwater recharge to the system. The diffuse-flow system contributes about 90% of the recharge, via infiltration through the soil and rock materials underlying the surface. The two systems are complexly related.

Monitoring Wells

The current test drilling was undertaken to further delineate the hydrogeologic system within the Big Spring basin, to help place the Galena flow system in a three-dimensional perspective, and to refine the knowledge of potentiometric relations within the flow system of the Galena aquifer and surrounding aquitards.

To facilitate this, at five sites, (Figure 1) holes penetrating the Galena aquifer were drilled between June 1988 and July 1989. At four sites, cores were taken from various intervals and monitoring wells were installed. The coring allowed for a more detailed hydrostratigraphic analysis of the basin.

Placement of monitoring-well nests at each site will assist further documenting the three-dimensional distribution of potentiometric elevations, and therefore the lateral and vertical components of water flux within the basin. The wells also allow for water-quality sampling within discrete stratigraphic intervals. Figure 1 shows the location of the monitoring-well sites with respect to the bedrock geology in the basin area. In discussing the information obtained from the installation of the wells, the framework of the Big Spring basin hydrogeology is briefly summarized (Hallberg et al., 1983).

Stratigraphic Framework

The oldest rocks exposed in the Big Spring basin area are the carbonate rocks of the Shakopee Formation of Ordovician age (Figures 1 and 2). The Shakopee is unconformably overlain by the St. Peter Sandstone, which is variable in thickness and forms an aquifer of local importance in northeast Iowa. Overlying the St. Peter are the shales, shaly carbonates and carbonates of the Glenwood, Platteville and Decorah formations. The Decorah, Platteville and Glenwood formations form an aquitard which separates the St. Peter aquifer from the Galena aquifer. Overlying the Decorah Formation are the Dunleith, Wise Lake, and Dubuque formations. The Galena Group includes the Decorah, Dunleith, Wise Lake, and Dubuque formations. Overlying the Galena Group are the rocks of the Maquoketa Formation which are, in ascending order, the Elgin Member, the Clermont Shale Member, the Ft. Atkinson Member, and the Brainard Shale Member. The uppermost member of the Maquoketa Formation, the Brainard Shale, forms a major aquitard in eastern Iowa, whereas the lowest member, the Elgin, is in part hydrologically connected with the Galena carbonates. Overlying the Maquoketa Formation are Silurian dolomites, which are the youngest bedrock units in the study area. In the Big Spring basin, the Silurian occurs as scattered erosional remnants, but forms an important regional aquifer to the south and west.

The Galena Aquifer

The Galena aquifer is made up of three formations of the Galena Group: the Dunleith, Wise Lake, and Dubuque formations. The lowest formation in the Galena group, the Decorah, is part of the aquitard separating the Galena aquifer from the St. Peter Sandstone. The Galena aquifer is comprised of interbedded limestones and dolomites, with some shaly interbeds. The shaly interbeds occur primarily in the Dubuque Formation. Regionally, the degree of dolomitization decreases to the north. The Dubuque Formation tends to be well-bedded, with shaly partings, whereas the Wise Lake is more massive, and the Dunleith tends to be cherty. Within the study area, the Galena aquifer is approximately 220 feet (67 m) thick. Structurally, the aquifer exhibits a flexure running roughly north-south through the central portion of the basin and dipping to the southwest at about 18 feet/mile

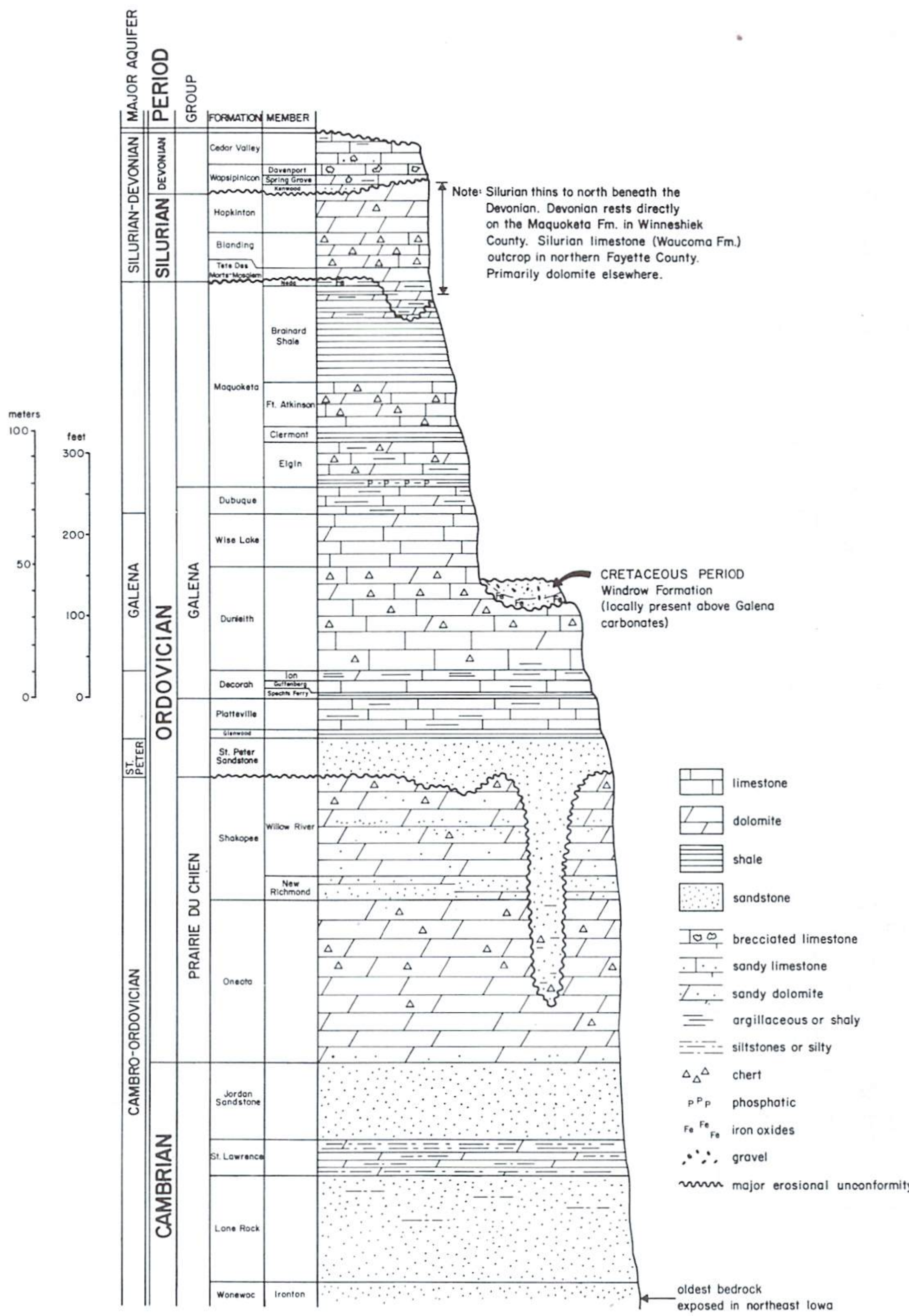

Figure 2. Generalized stratigraphic section for Big Spring study area (from Hallberg et al., 1983).

(3.5 m/km) (Hallberg et al., 1983).

All units within the Galena aquifer are jointed or fractured. At nearly any exposure in the study area, some solutional activity along joints and bedding planes is apparent. Major joints have been widened by solutional activity and contain secondary deposits of calcium carbonate.

Within the Big Spring basin, concentrations of sinkholes are found near the outcrop area of the contact between the Galena Group and lower Maquoketa Formation (Figure 1). Sinkhole development is more prominent in regions where the Galena carbonates have a broad outcrop area and in localities where less than 20 feet (6.1 m) of the lowermost Maquoketa Formation overlies the Galena. Newly formed sinkholes investigated by GSB staff have revealed open, vertical solution shafts penetrating up to 120 feet (37 m) below the land surface, into the aquifer. In areas where the topography is more steep, fewer sinkholes are apparent.

Water Table/Potentiometric Surface in the Galena Aquifer

In previous hydrogeologic studies, a water table/potentiometric surface map for the Galena aquifer was compiled (Figure 3) from water levels in Galena wells and measurements of Galena spring elevations (Hallberg et al., 1983). The contouring, and definition of the basin was assisted by dye-trace studies and defining losing- and gaining-stream reaches. The potentiometric contours define the groundwater basin divide and indicate the general direction of groundwater flow. Interpreted groundwater flow occurs on a regional scale at right angles to the potentiometric contours.

Within the Big Spring basin, the Galena aquifer exhibits confined and unconfined aquifer conditions. In the western part of the basin, where a thick sequence of overlying Maquoketa Formation is present, the Galena acts as a confined aquifer. Within the rest of the basin the Galena is unconfined.

Physiography and Groundwater in the Basin

The Big Spring basin includes an area of approximately 103 square miles (267 sq. km) and contains most of the surface-drainage basin of Robert's Creek. On the north and west, the groundwater-basin divide (Figure 4) is nearly coincident with the surface-drainage divide, including the Robert's Creek system and an unnamed creek which empties into the Turkey River near Big Spring. On the east side of the basin, the groundwater divide cuts across the surface-drainage basins of Bloody Run, Howard and Robert's Creeks and tributaries. Groundwater flows from the divide toward Big Spring, and discharges from the Galena aquifer through a narrow region to the Turkey River, with the major portion concentrated at Big Spring, Back Spring and Heick's Spring. Past work has shown that Big Spring constitutes about 89% of the groundwater discharge.

The relationship between the surface-water system and the groundwater system within the Big Spring basin is very complex. In their headwaters, most of the streams are recharged by shallow-groundwater flow from local seeps, or diffuse groundwater flow from the Maquoketa, Galena, and/or Quaternary deposits. In the central and eastern portions of the basin, the streams and their alluvial valleys are perched well above the Galena potentiometric surface. Here streams lose surface water to the groundwater system through intermittent runoff into sinkholes, and as diffuse seepage in some perennial streams. As the streams leave the basin, in the St. Olaf area, they receive discharge from the Galena aquifer, and again become gaining streams.

Most streams maintain perennial flows through portions of the basin that appear to be losing reaches. This is possible when sustained recharge, provided by shallow groundwater (including tile drainage) in the streams headwaters, is greater than the rate of leakage into the groundwater system downstream. The upper portions of the alluvial deposits and large areas of the stream beds are relatively fine-textured, silty deposits, which provide relatively slow percolation, effectively retarding losses or leakage through the stream bed.

Much of the well-integrated, dendritic drainage network developed in the Big Spring basin is controlled by bedrock, especially the second order and larger valleys in the eastern two-thirds of the basin. Many valleys in this area appear to follow major joint trends. Several small

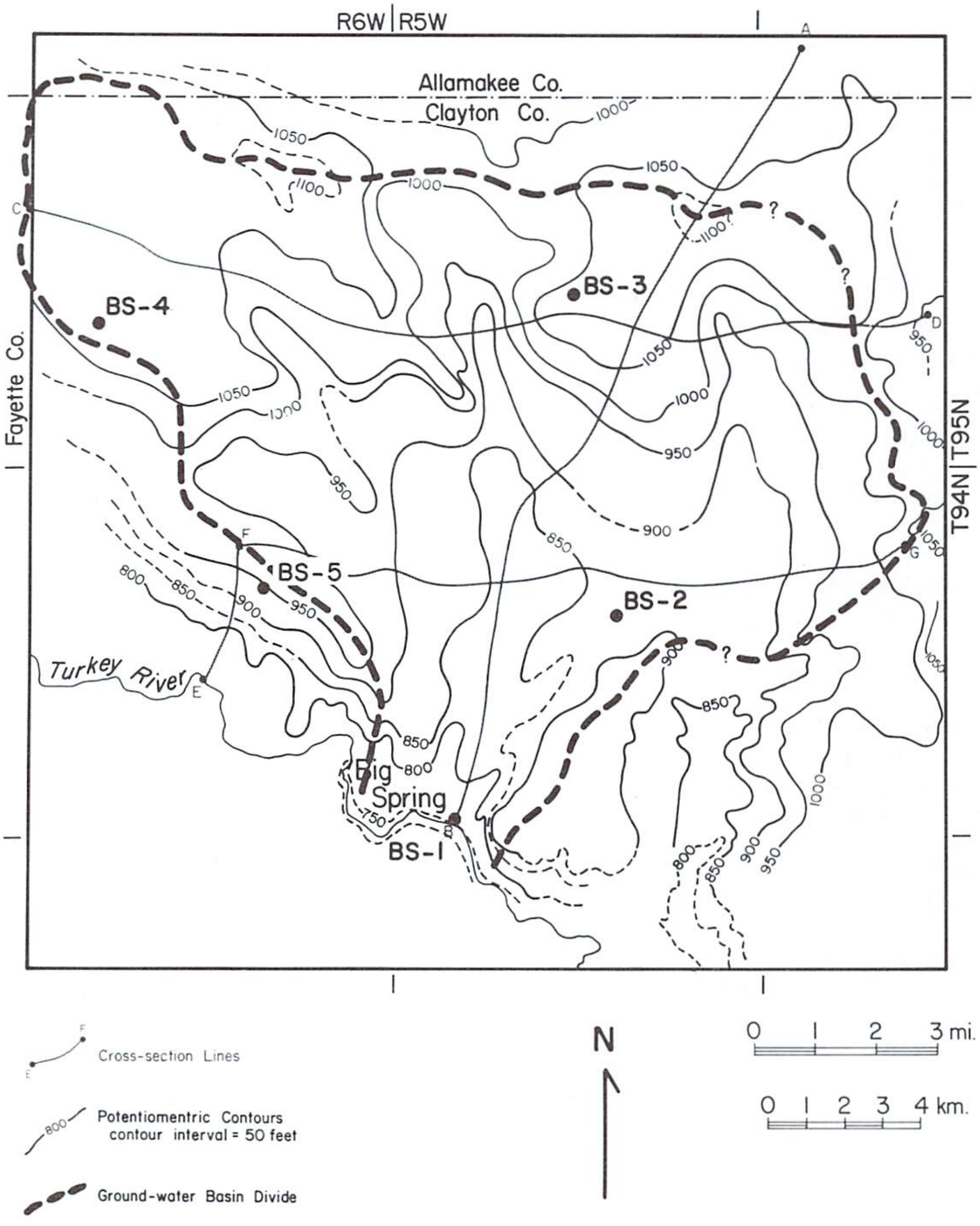

Figure 3. Elevation of the water table/potentiometric surface in the Galena aquifer, and lines of cross-section shown on figures 5 through 7 (adapted from Hallberg et al., 1983).

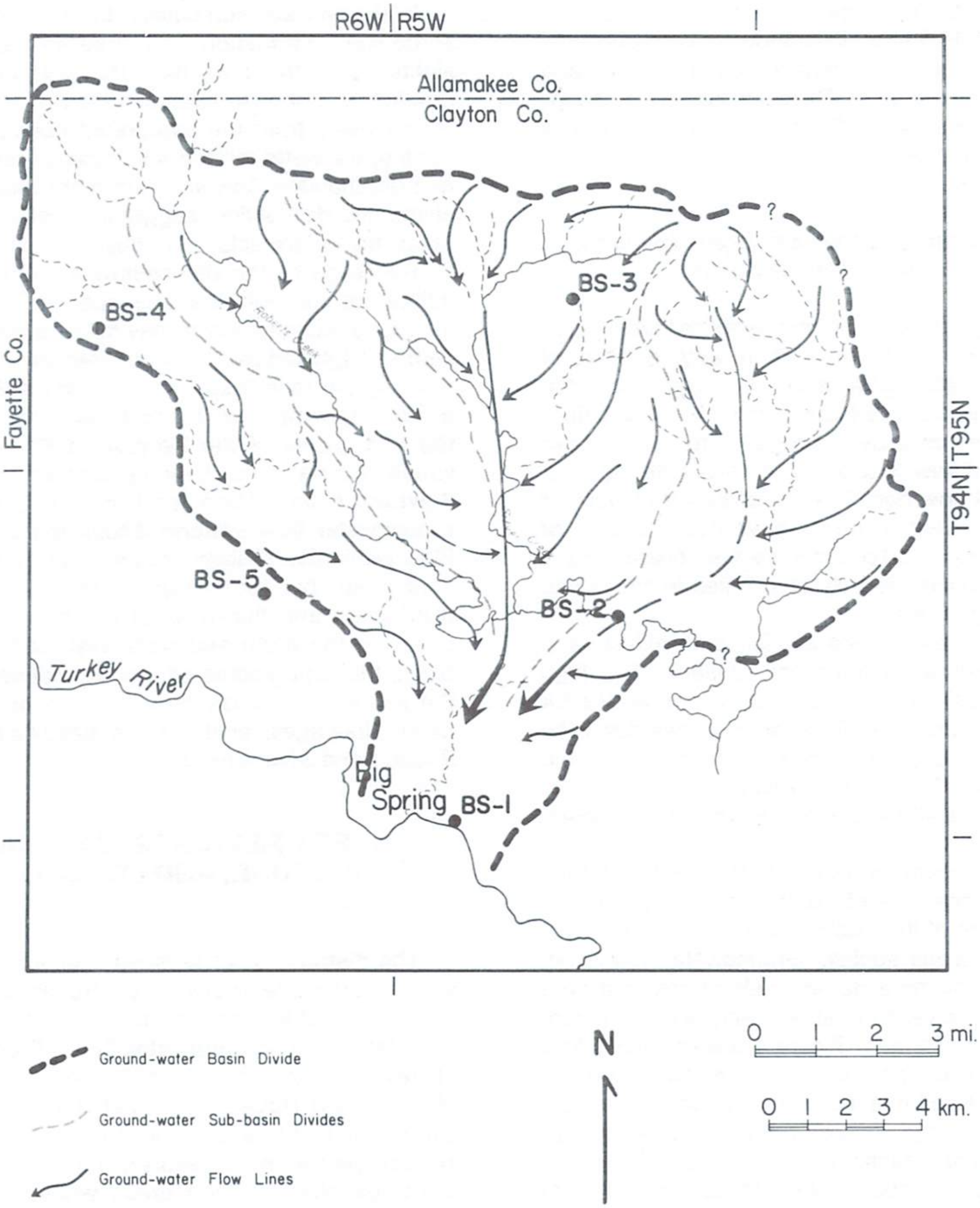

Figure 4. Groundwater basin and subbasin divides, and schematic groundwater flow lines based on the water table/potentiometric surface map (adapted from Hallberg et al., 1983).

blind valleys in this area disrupt the integrated drainage network and lead to the development of hollows which discharge entirely into sinkholes, entering the groundwater system of the Galena aquifer. However, infiltration rates through the soil and rock are relatively high in this area and runoff is infrequent. The sinkhole basins occupy 11.5 square miles (29.8 sq. km), or about 11% of the groundwater basin.

Major Conduit Zones and Groundwater Flow in the Galena Aquifer

The wide range of permeabilities that occur in carbonate aquifers result in varying types of groundwater flow and recharge/discharge mechanisms. The terms conduit flow and diffuse flow were used by White (1977) to describe two types of flow that occur in carbonate aquifers. Conduit flow describes groundwater movement through larger open cavernous zones or conduits. The term diffuse flow characterizes flow through relatively unmodified fractures and bedding planes.

Within the Galena aquifer, both diffuse- and conduit-flow systems are present. The high transmissivity of the conduit zones allows for rapid groundwater flow, which draws down the water table/potentiometric surface within the adjacent diffuse zones. This enhances flow from the diffuse-flow system toward the conduit zones.

The configuration of the water table/ potentiometric surface (Figure 3) provides an indication of the location of major conduit zones in the Galena aquifer. Groundwater flows from high to low potentiometric elevations, and on a regional scale, flows at right angles to the potentiometric contours. Figure 4 is a schematic flow diagram for the Galena aquifer based on the water table/potentiometric surface. The flow lines converge towards pronounced troughs, or lows in the potentiometric contours in the central and eastern sub-basins. These troughs converge and flow toward the groundwater discharge area along the Turkey River, principally at Big Spring. These elongate troughs have relatively high transmissivities, relative to adjacent parts of the aquifer and are interpreted as major "arterial" routes of the conduit-flow system, which transmit groundwater from sinkholes to Big Spring. These troughs likely include a broader zone of solutionally enhanced fracture permeability.

In the western sub-basins, the thick cap of Maquoketa Formation and resulting lack of sinkholes in the area limit the potential for development of open solution conduits. In areas farther away from the interpreted conduit-flow system, the water table/potentiometric contours and groundwater flow lines are more regular in shape and distribution, suggesting that in these areas, the Galena acts as a diffuse-flow aquifer.

Recharge to the diffuse-flow system is by infiltration through the soil and rock units. Infiltrating recharge water may follow a complex path through vertical joints and fractures before reaching the zone of saturation within the Galena aquifer. Low permeability units such as glacial tills and shales of the Maquoketa Formation, which overlay the Galena aquifer, retard downward infiltration and create shallow groundwater flow systems above the Galena. Flow within this shallow groundwater system is controlled by local topography and the distribution and thickness of low permeability units. In the north and northwest part of the basin, this topographic control is evidenced by the presence of small springs or seeps along major drainages, such as the headwaters of Robert's and Silver Creeks.

KARST FEATURES, GALENA STRUCTURE, AND LITHOLOGY

The distribution of karst-solutional features within carbonate rocks is controlled by the structural, and lithologic properties of the rocks in relation to groundwater-flow directions (Thrailkill, 1968; Powell, 1977; White, 1977; Hallberg and Hoyer, 1982; and Bounk, 1983). Structural features such as joints, fractures, bedding planes, faults, flexures, and high fracture densities often provide areas where intense solutional activity may be localized. For example, the central conduit zone in the Big Spring basin (Figure 4) appears coincident with the north-south trending flexure in the Galena aquifer previously noted. Other conduit-zone troughs are also coincident with major stream-valley systems, even though the potentiometric surface is deep in the subsurface. The coincidence of the conduit zones, or "potentiometric valleys", and surface topography suggests that structural features of the Galena and Maquoketa rocks have influenced the location and development of the stream valleys and prominent solution-conduit zones within the Big Spring basin.

The lithology of the Galena carbonates probably also plays a role in the distribution of karst features. Limestone is more soluble than dolomite, and is more susceptible to the development of karst-solution features. In the Big Spring basin, the Dubuque and Dunleith formations are dominantly limestone, whereas the Wise Lake Formation is more dolomitic and massive. Horizontal solutional features, are better developed in the Dubuque and Dunleith formations. In the Wise Lake Formation, solutional features are generally enlarged vertical joints, fractures, and occasionally dome pits.

In the Big Spring study area, the major sinkhole concentrations occur where the top of the Galena (the Dubuque Formation) outcrops in the north-central portion of the basin. Further south, where the Dubuque has been largely removed by erosion and dissolution and the Wise Lake outcrops, there are fewer sinkholes.

Hydrogeologic Cross-Sections

Hydrogeologic cross-sections of the Big Spring basin have been constructed to help place the Galena flow system in a three-dimensional perspective (Hallberg et al., 1983). The cross-section lines are located on Figure 3, and shown on Figures 5, 6, and 7. The cross-sections delineate the geologic units, the general topography and structure, streams, relations to the St. Peter Sandstone (Osp), and the major sinkhole areas. Also shown are the approximate locations of sites BS-1 through BS-5.

Cross-section A-B (Figure 5) runs across the northern groundwater and surface-water divide, and then roughly parallels a groundwater-flow path into the discharge area at Big Spring. This section also parallels the structural dip of the Galena aquifer. Along this cross-section, the water table/potentiometric surface declines in elevation near the central conduit-zone trough; Silver Creek and Robert's Creek, and their associated alluvial valleys are 100 feet (31 m) or more above the Galena potentiometric surface in some areas. In this area, streams may lose water into the groundwater system.

Cross-section C-D (Figure 6) runs east to west across the central and eastern conduit-zone troughs in the Galena potentiometric surface. In the central portion of the section, Silver and Robert's Creeks are again perched above the Galena potentiometric surface. In the western part of the section, the potentiometric surface is essentially in confluence with Robert's Creek and its associated alluvial aquifer, providing groundwater discharge to the streams.

Cross-section E-F-G (Figure 7) runs east-west within the southern part of the groundwater basin, crossing the potentiometric surface (Figure 3) where the east conduit-zone trough trends to the west and south to merge with the central trough (Figure 4). To the west, this section runs through outliers of Silurian rocks (Su) and areas overlain by rocks of the Maquoketa Formation (Omb and Omf). In the central portion of the section, Robert's and Silver Creeks are losing reaches. To the east, the section traverses Howard Creek and an unnamed tributary just north of where these creeks begin to form gaining reaches again.

HYDROSTRATIGRAPHY OF MONITORING-WELL SITES

The analysis of the cores and cuttings from five drilling sites has supported the assessment of, and allowed refinement of the Big Spring basin hydrologic system. At site BS-1, the geologic log of the stratigraphic sequence is based on drill cuttings; at sites BS-2 through BS-4, the logs of the stratigraphic sequences are based on cuttings and cores. The lithologic key and stratigraphic sequences for the four sites are shown in Figures 8 through 13.

Site BS-1

Site BS-1 is located in the southernmost portion of the basin (Figure 1) on the alluvial plain, within 300 feet (91 m) of Big Spring and the

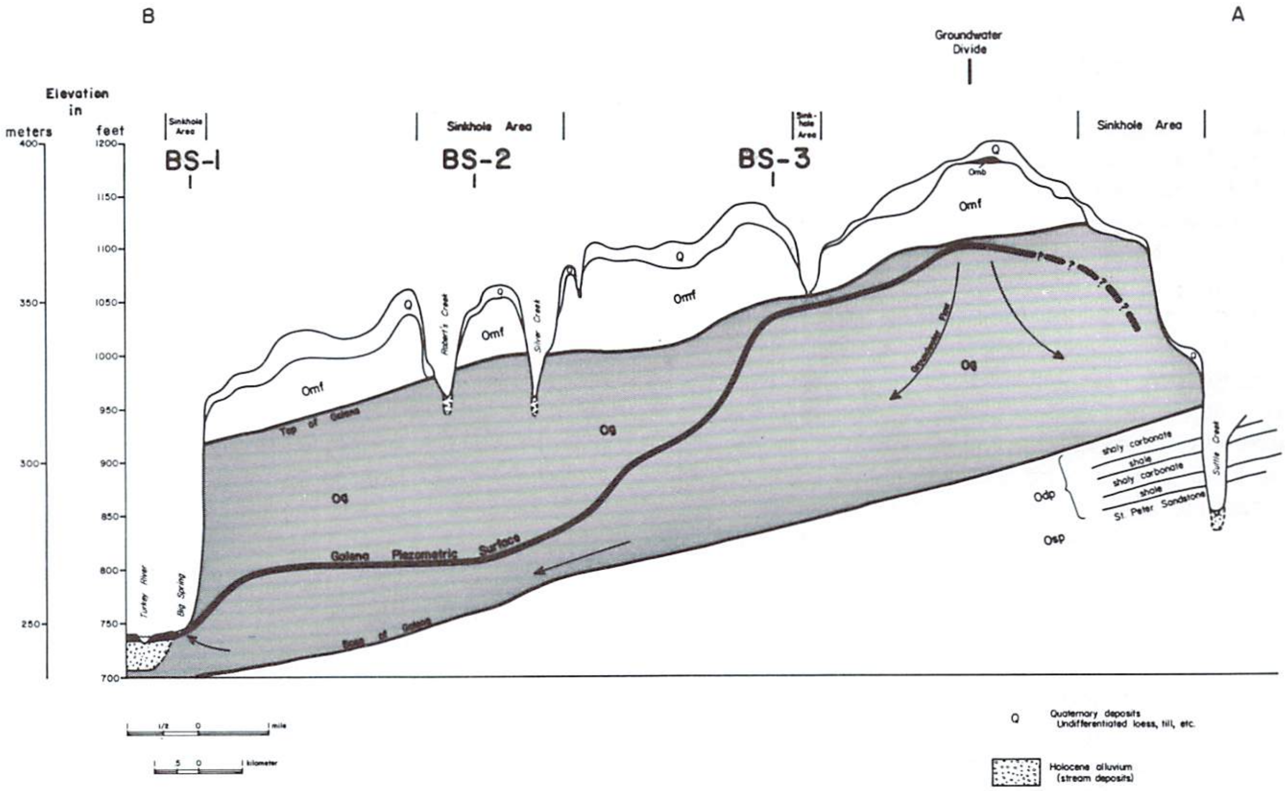

Figure 5. Hydrogeologic cross-section A-B; location shown on figure 3. Also shown are projected locations of monitoring-well sites (adapted from Hallberg et al., 1983). See figure 1 for legend.

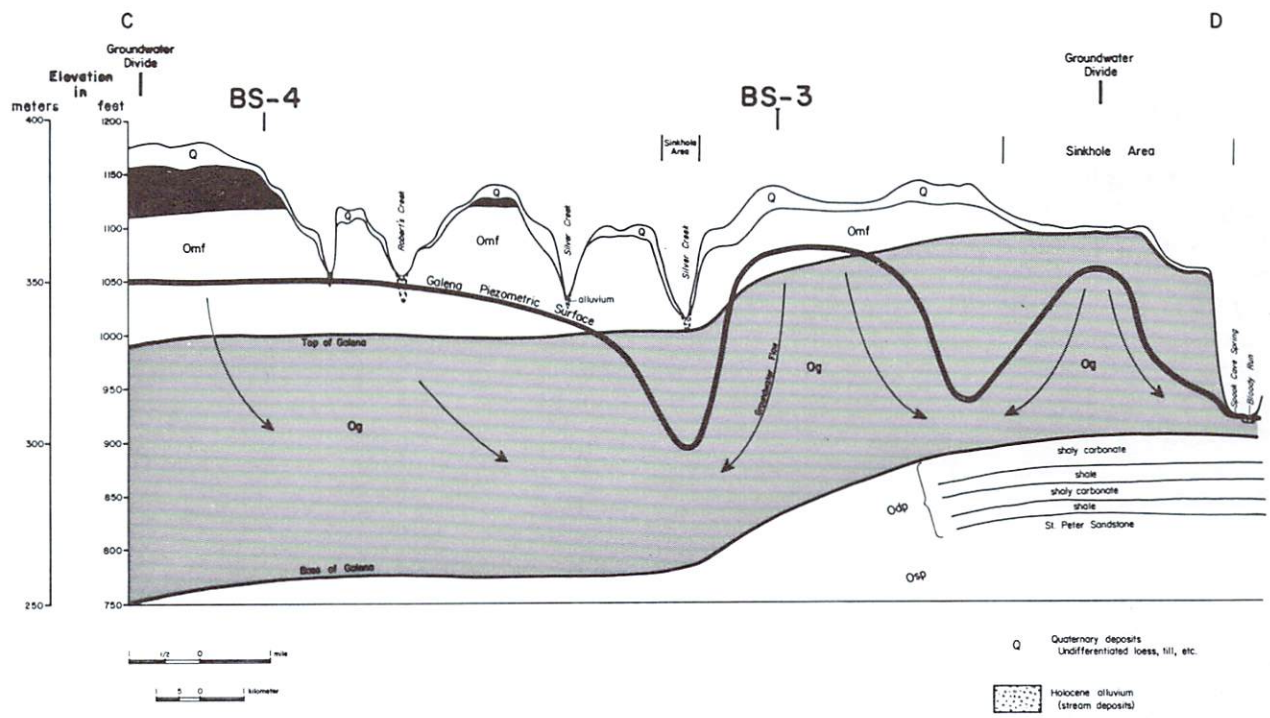

Figure 6. Hydrogeologic cross-section C-D; location shown on figure 3. Also shown are projected locations of monitoring-well sites (adapted from Hallberg et al., 1983). See figure 1 for legend.

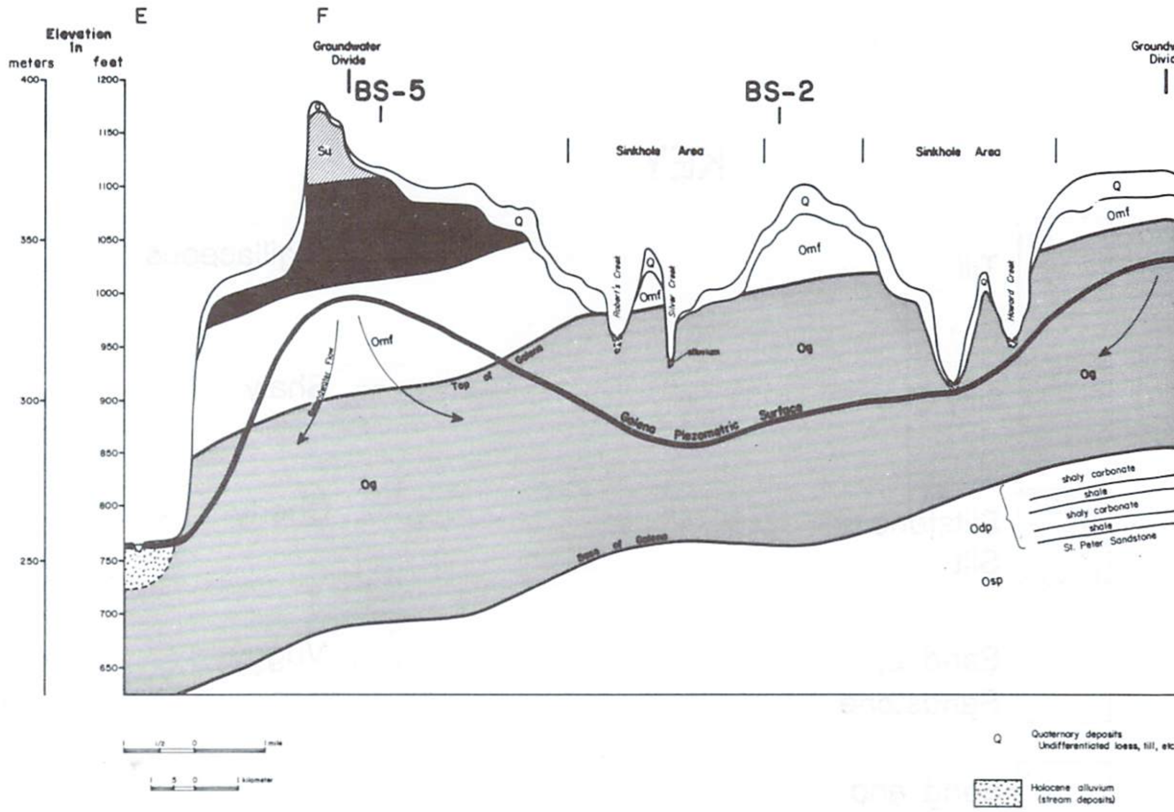

Figure 7. Hydrogeologic cross-section E-F-G; location shown on figure 3. Also shown are projected locations of monitoring-well sites (adapted from Hallberg et al., 1983). See figure 1 for legend.

Turkey River. The land surface at this site is about 13 feet (4.0 m) above the Turkey River at base flow, and about 5 feet (1.5 m) above the Big Spring pool at base flow. In this portion of the basin, the top of the Galena potentiometric surface declines to within 50 to 75 feet (15 to 23 m) of the base of the aquifer (Figure 5), and the Turkey River acts as "base-level" for the Galena potentiometric surface. Well records and previous and ongoing studies of the alluvial history of the Turkey River Valley have shown that in the geologic past, the Turkey River was downcut 50 to 60 feet (15 to 18 m) deeper than the present floodplain (Hallberg et al., 1983). In this area, the river probably cut to, or perhaps through, the base of the Galena carbonates. This suggests that conduits may have developed to the base of the aquifer, and that karst-conduit flow paths may penetrate the full thickness of the Galena aquifer in parts of the basin.

Figure 9 shows the stratigraphic sequence and monitoring-well installations for site BS-1. At this location, the Dubuque, Wise Lake and much of the Dunleith formations have been truncated by downcutting of the Turkey River. Four monitoring wells, BS-1A through BS-1D were installed at various depths above, within and below the Galena aquifer (Table 1). BS-1A is screened into unconsolidated sand, gravel and limestone boulders, which are overlying the Dunleith Formation. These deposits are thought to be a combination of alluvial stream deposits and colluvium from downcutting along the valley wall. Water levels in this well are about 13 to 15 feet (4.0 to 4.6 m) below land surface. BS-1B is open into the bottom of the Galena aquifer in the Dunleith Formation. In this well, the water level is about 8 to 10 feet (2.4 to 3.1 m) below land surface. The observation that the water level in BS-1A is about 5 feet (1.5 m) lower than the water level in BS-1B suggests that at this site, groundwater from the lower portion of the Galena is discharging upward to the Turkey River and its alluvial aquifer.

Monitoring well BS-1C is open to the Pecatonica Member of the Platteville Formation.

Figure 8. Lithologic key for figures 9 through 13.

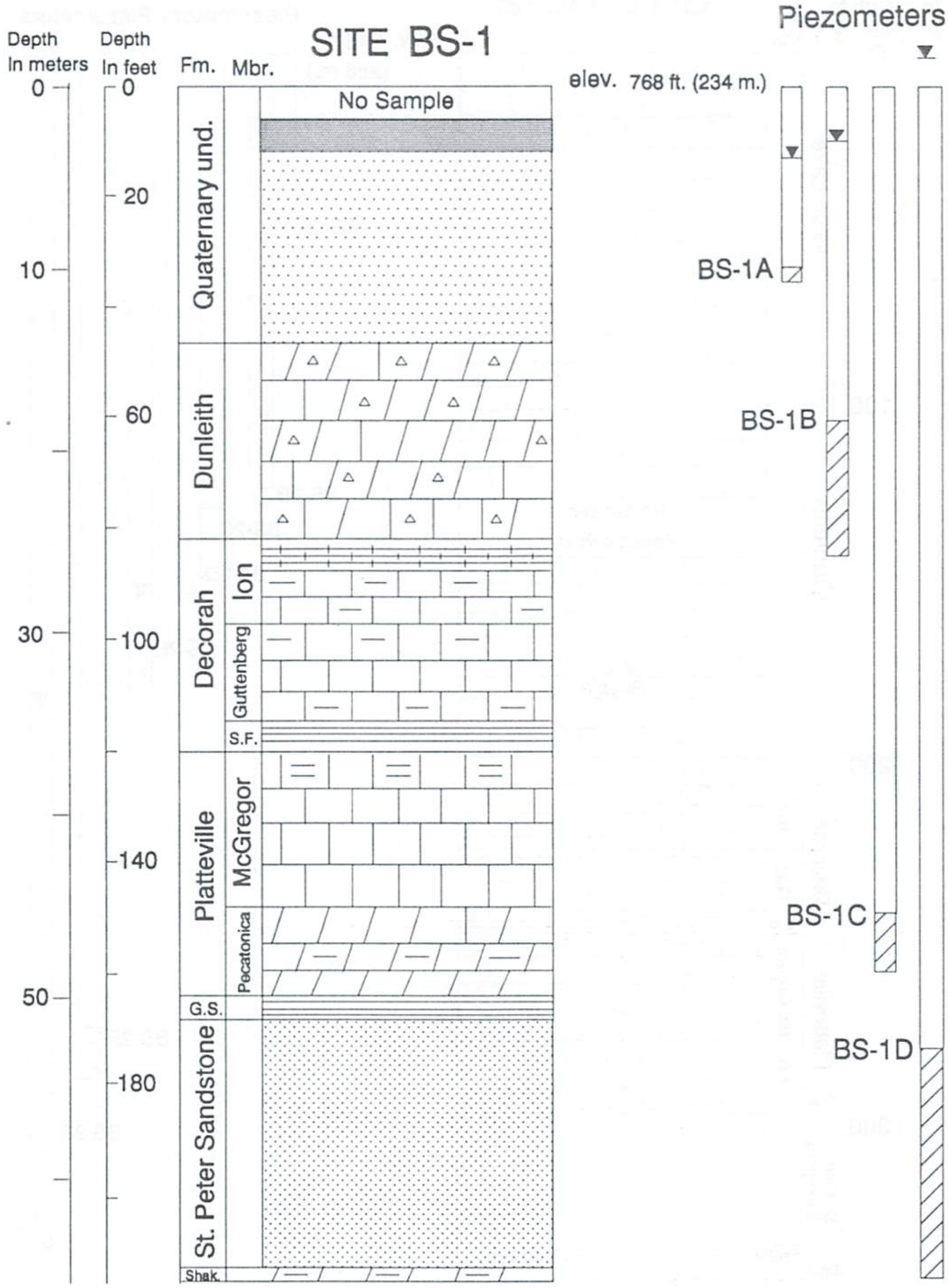

Figure 9. Stratigraphic sequence and monitoring-well installations at site BS-1 (cuttings logged by M. J. Bounk).

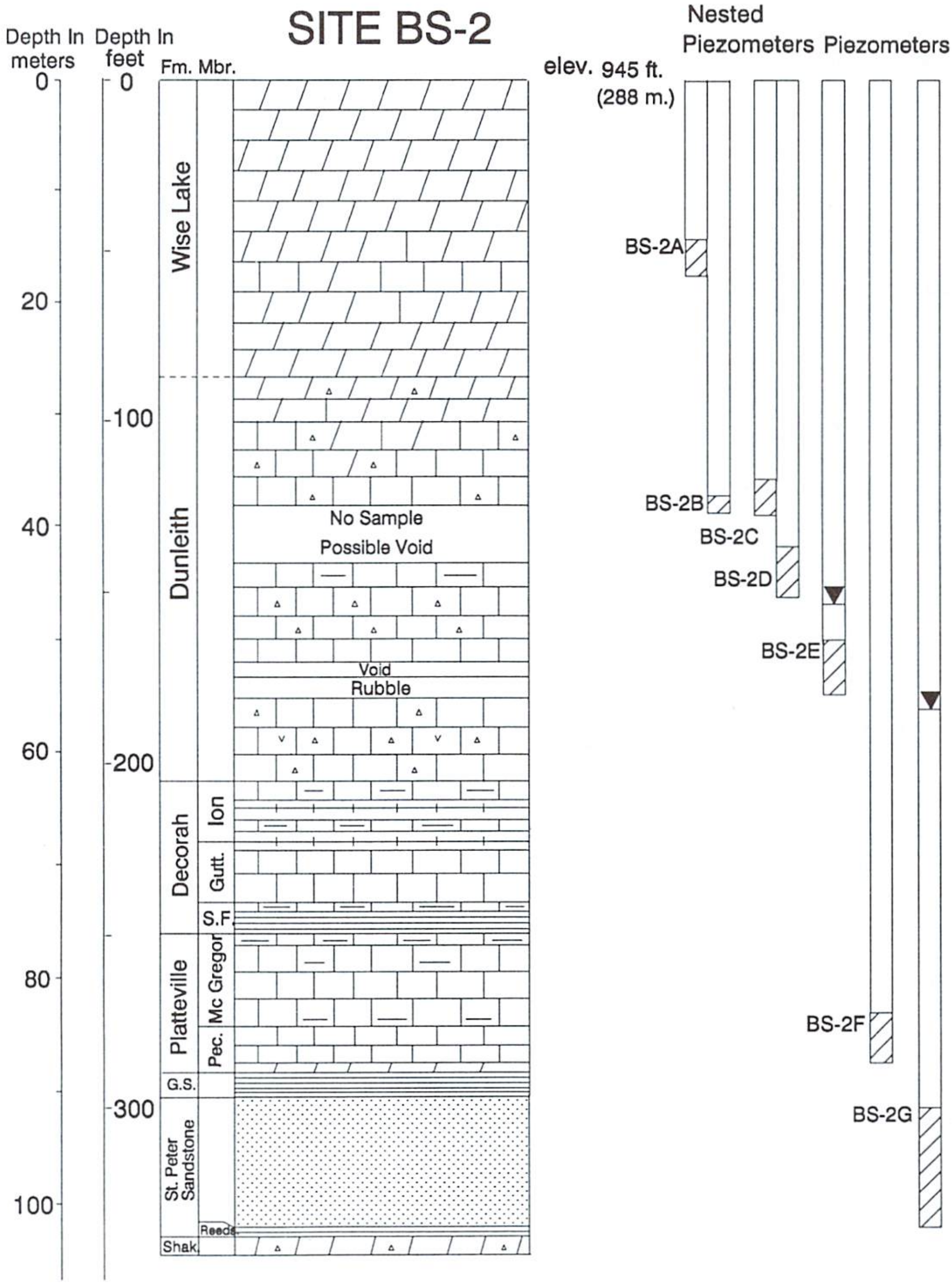

Figure 10. Stratigraphic sequence and monitoring-well installations at site BS-2 (core logged by M. J. Bounk).

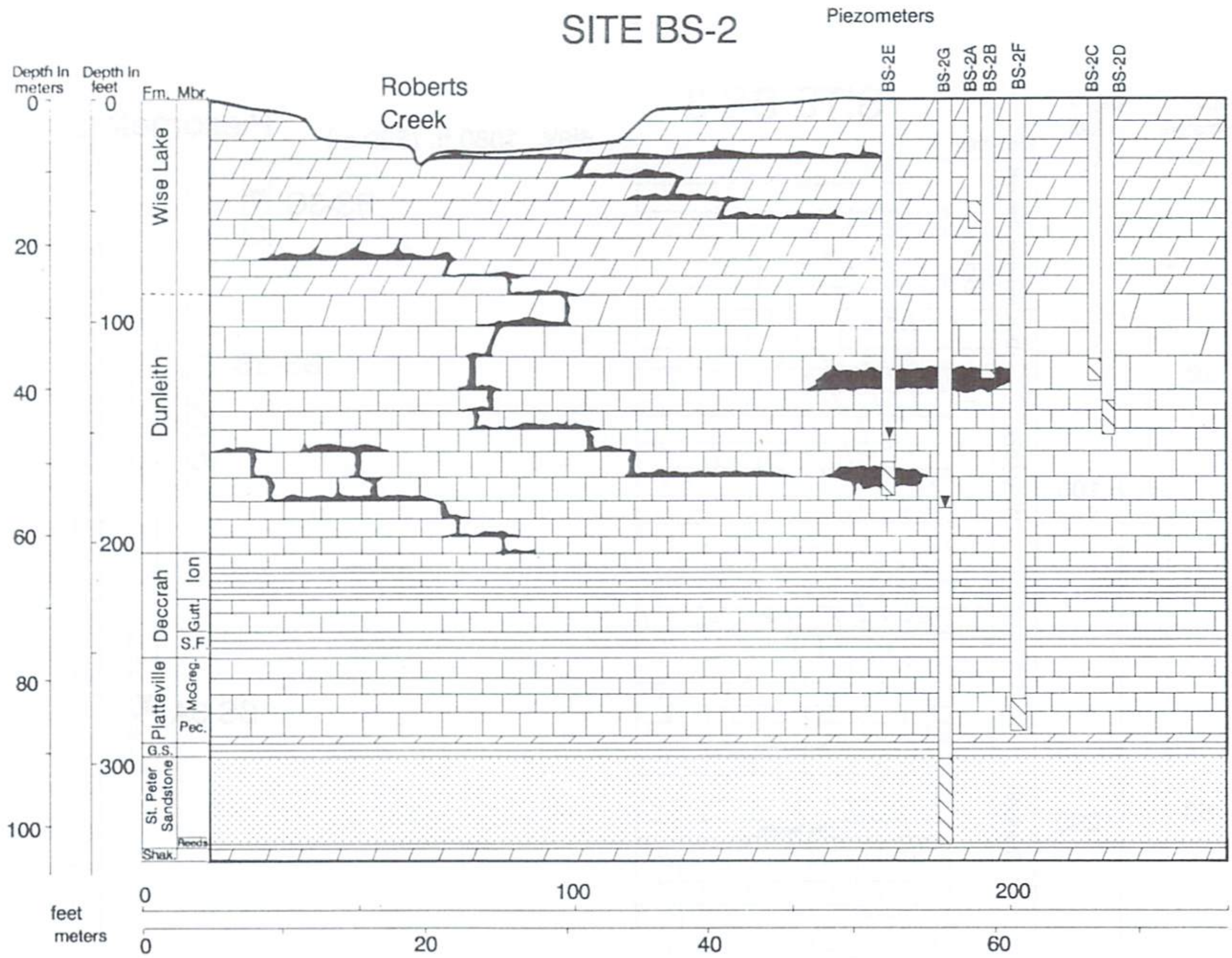

Figure 11. Geologic cross-section and monitoring-well installations at site BS-2. Shaded areas represent documented or inferred solution voids and solutionally enhanced fractures and bedding planes (core logged by M. J. Bounk).

When BS-1C was installed, drilling fluid was lost, near the top of the Decorah Formation, suggesting a zone of high conductivity, perhaps a local fracture and/or conduit zone at the bottom of the Galena aquifer. As previously mentioned, the Glenwood Shale, the Platteville and Decorah formations comprise an aquitard that separates the St. Peter Sandstone from the Galena aquifer. To date, BS-1C contains only a few feet of water, suggesting that at this site, the aquitard has extremely low conductivity, at least when fractures and/or solutional conduits are not encountered. This also suggests that where unfractured, the aquitard is very effective, affording little leakage through the rock matrix upward from the St. Peter Sandstone to the Galena aquifer.

Monitoring well BS-1D is open to the St. Peter Sandstone. At this site, the St. Peter Sandstone acts as a confined aquifer and exists under flowing artesian conditions; the head in this well is 6 to 7 feet (1.8 to 2.1 m) above land surface, and it flows at about 2 to 3 gallons per minute (7.6 to 11.4 liters per minute).

This portion of the basin is topographically lower than sites BS-2 through BS-5. The bedrock also dips toward this area and groundwater is discharged through Big Spring and associated

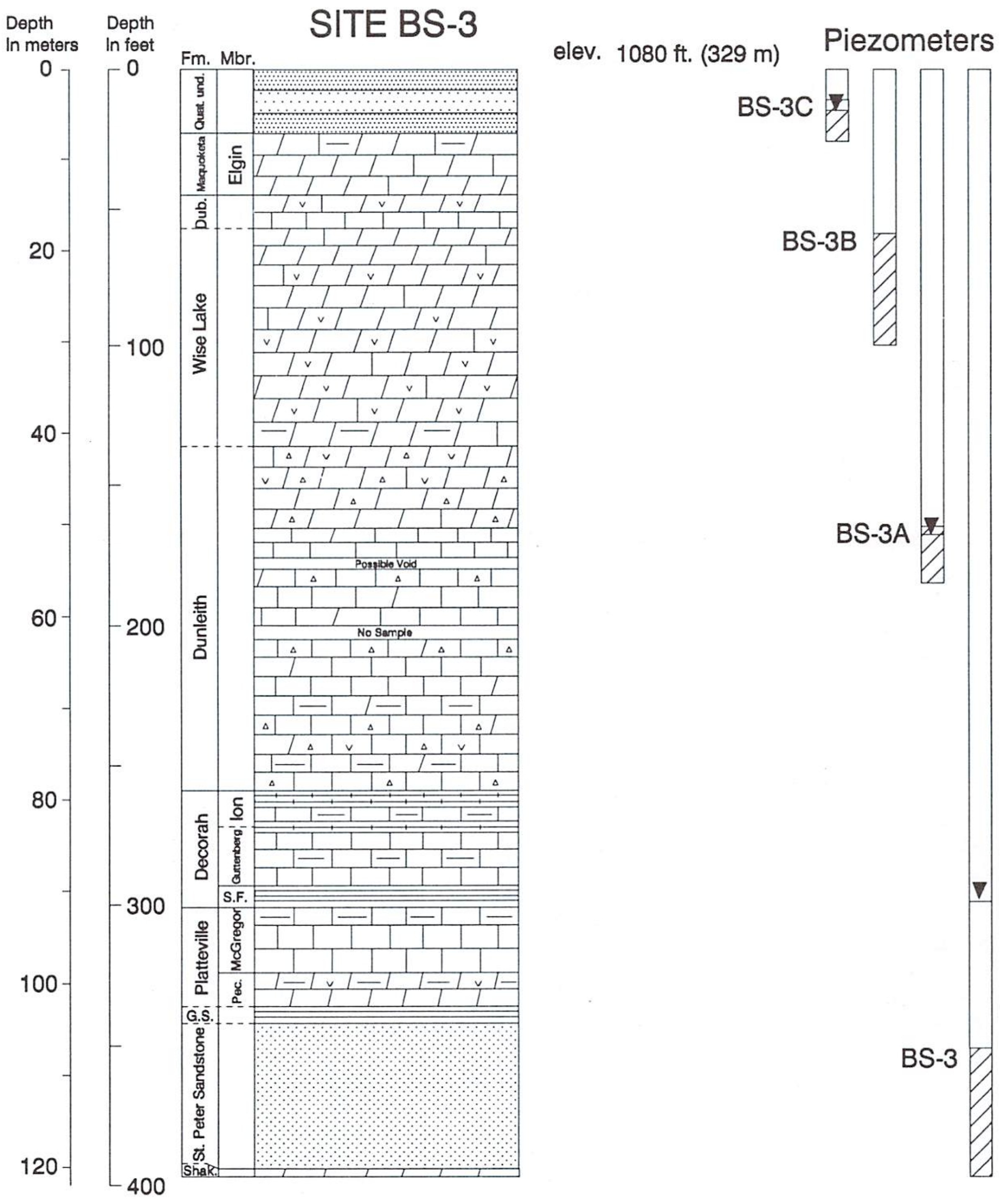

Figure 12. Stratigraphic sequence and monitoring-well installations at site BS-3 (core logged by M. J. Bounk).

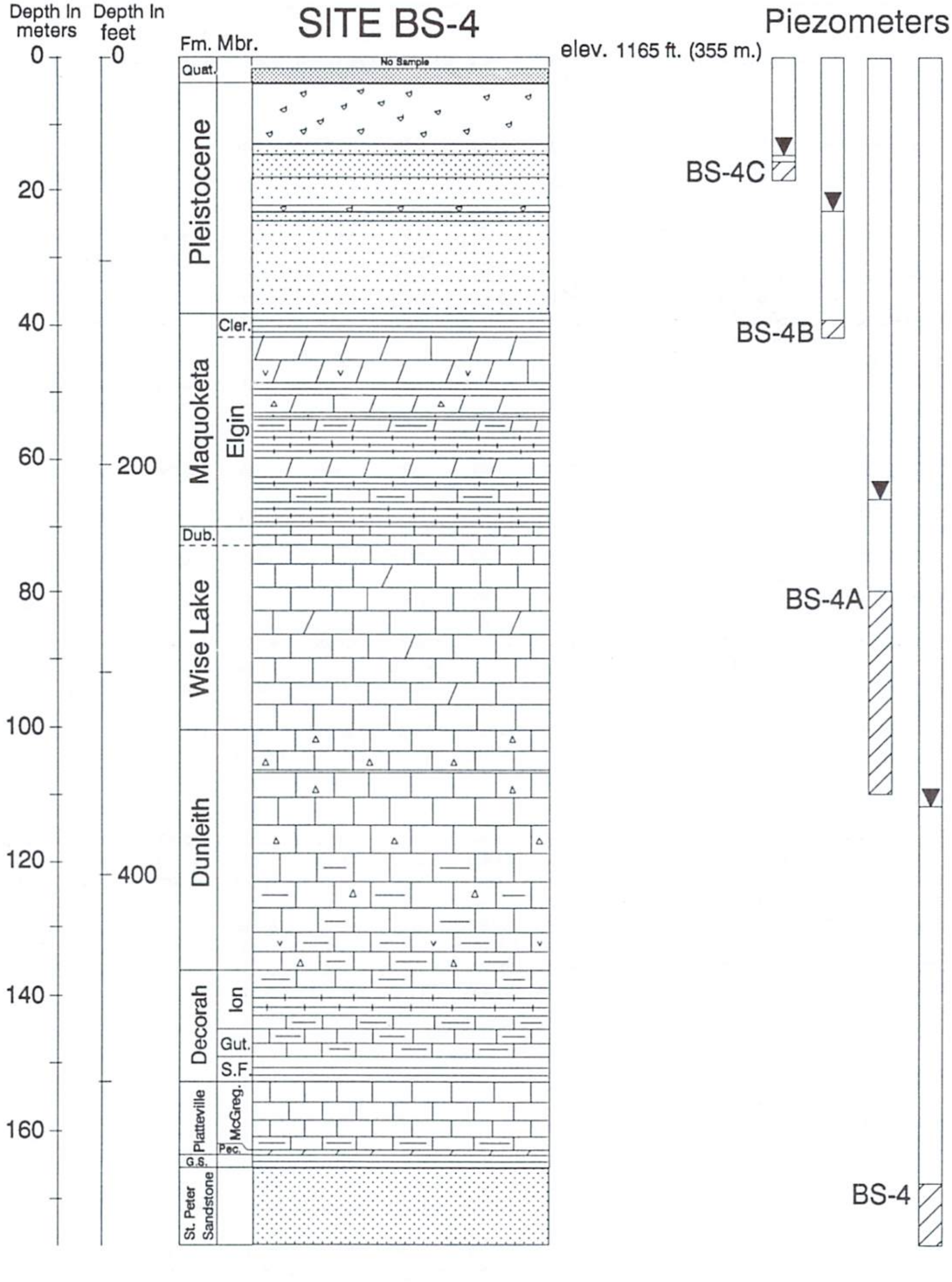

Figure 13. Stratigraphic sequence and monitoring-well installations at site BS-4 (core logged by M. J. Bounk).

Table 1. Potentiometric elevations from monitoring wells at sites BS-1 through BS-4. Also shown are formations screened and depth of screened interval below land surface.

MEAN WATER LEVEL DEPTH BELOW LAND SURFACE, IN FEET (METERS), 1989 WATER YEAR
((+) feet above land surface, (-----) no observations)

PIEZOMETER	FORMATION	SCREENED INTERVAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
BS-1A	QUATERNARY	33.0-36.0	14.07	13.76	12.91	13.90	14.14	14.41	14.78	14.73	14.38
		(10.1-11.0)	(4.29)	(4.19)	(3.94)	(4.29)	(4.31)	(4.39)	(4.51)	(4.49)	(4.38)
BS-1B	DUNLEITH	61.0-85.0	8.94	9.00	7.91	8.77	9.13	9.64	-----	9.84	-----
		(18.6-25.9)	(2.73)	(2.74)	(2.41)	(2.67)	(2.78)	(2.94)		(3.00)	
BS-1C	PLATTEVILLE	150.0-161.0	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
		(45.7-49.1)									
BS-1D	ST. PETER	173.0-215.0	-----	-----	-----	-----	-----	+5.29	+4.55	+4.02	-----
		(52.7-65.5)						(1.61)	(1.39)	(1.23)	
BS-2A	WISE LAKE	47.0-57.0	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
		(14.3-17.4)									
BS-2B	DUNLEITH	122.0-127.0	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
		(37.2-38.7)									
BS-2C	DUNLEITH	118.0-128.0	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
		(36.0-39.0)									
BS-2D	DUNLEITH	137.0-151.0	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
		(41.8-46.0)									
BS-2E	DUNLEITH	165.0-180.0	153.92	154.41	-----	154.31	154.39	154.48	154.80	154.49	154.43
		(50.3-54.9)	(46.92)	(47.06)		(47.03)	(47.06)	(47.09)	(47.18)	(47.09)	(47.07)
BS-2F	PLATTEVILLE	272.0-286.0	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
		(82.9-87.2)									
BS-2G	ST. PETER	300.0-335.0	183.95	184.24	184.31	184.33	184.56	184.73	185.23	185.20	185.29
		(91.4-102.1)	(56.07)	(56.16)	(56.18)	(56.18)	(56.25)	(56.31)	(56.46)	(56.45)	(56.48)
BS-3C	QUATERNARY	11.0-26.0	-----	15.28	15.97	16.40	14.77	15.31	15.65	15.78	14.88
		(3.4-7.9)		(4.66)	(4.87)	(5.00)	(4.50)	(4.67)	(4.77)	(4.81)	(4.54)
BS-3B	WISE LAKE	60.0-100.0	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
		(18.3-30.5)									
BS-3A	DUNLEITH	165.0-185.0	-----	167.86	167.82	-----	-----	167.89	167.86	167.82	167.87
		(50.3-56.4)		(51.16)	(51.15)			(51.17)	(51.16)	(51.15)	(51.17)
BS-3	ST. PETER	351.0-397.0	-----	299.97	299.95	300.07	300.11	300.08	-----	300.15	300.80
		(107.0-121.0)		(91.43)	(91.43)	(91.46)	(91.47)	(91.46)		(91.49)	(91.68)
BS-4C	QUATERNARY	50.0-61.0	-----	-----	-----	-----	-----	-----	-----	-----	56.23
		(15.2-18.6)									(17.14)
BS-4B	QUATERNARY/	130.0-139.0	-----	-----	-----	-----	-----	-----	-----	-----	72.94
	CLERMONT	(39.6-42.4)									(22.23)
BS-4A	DUNLEITH/	261.0-361.0	-----	214.94	215.51	215.83	216.69	217.57	218.87	219.50	219.72
	WISE LAKE	(79.6-110.0)		(65.51)	(65.69)	(65.79)	(66.05)	(66.32)	(66.71)	(66.90)	(66.97)
BS-4	ST. PETER	550.0-580.0	-----	366.97	367.58	367.25	367.62	368.18	368.95	369.34	369.92
		(167.6-176.8)		(111.85)	(112.04)	(111.94)	(112.05)	(112.22)	(112.46)	(112.58)	(112.75)

smaller springs to the Turkey River. Hydraulic head increases with depth, and the potential for groundwater flow is upward.

Site BS-2

Figures 10 and 11 show the stratigraphic sequence and monitoring-well installations for site BS-2. This site is located about 100 feet (31 m) south of Robert's Creek, above an inferred major conduit zone. In this portion of the basin, Robert's Creek and Silver Creek and their associated alluvial valleys are 100 feet (31 m) or more above the Galena potentiometric surface, which lies roughly in the middle of the aquifer. This site contains seven monitoring wells (BS-2A through BS-2G) (Table 1). BS-2A is screened into the middle of the Wise Lake Formation. BS-2B is screened into a 1 foot (0.31 m) 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 (2.7 m) 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 (9.1 m) lower in the Dunleith Formation. This void is approximately 5 feet (1.5 m) thick and overlies a rubble zone that is also about 5 feet (1.5 m) thick. The water level in BS-2E is about 154 feet (47 m) 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, again suggesting extremely low conductivity within the matrix of the aquitard. Monitoring well BS-2G is open to the St. Peter Sandstone. BS-2G penetrated the void encountered in wells BS-2B and BS-2E, but did not penetrate the lower void which BS-2E is screened into. The water level in BS-2G rises from the St. Peter to approximately 185 feet (56 m) below land surface, exhibiting confined aquifer conditions. Since the head of the St. Peter aquifer is lower than the head of the Galena aquifer, the potential for groundwater flow 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 into the hole from the upper void and running down the side of the hole before combining with water in 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 Robert's Creek.

The documentation of water seeping into BS-2E, coupled with observations that show wells BS-2A through BS-2D have remained essentially dry, suggest that Robert's 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.

Site BS-3

Site BS-3 is located in the north-central portion of the Big Spring basin near an area of sinkhole development (Figure 1). In this part of the basin the Galena potentiometric surface is near, or above the top of the Galena carbonates (Figure 6).

Figure 12 shows the stratigraphic sequence and monitoring-well installations at site BS-3. At this location, the Elgin Member of the Maquoketa Formation, overlies a complete sequence of the Galena Group. Monitoring well BS-3C is screened into the top of the Elgin Member, and the overlying Quaternary deposits. Water levels in BS-3C have been about 15 feet (4.6 m) below land surface, suggesting that at this site the top of the Elgin Member and/or the overlying Quaternary deposits may be acting as an aquitard, allowing a shallow groundwater system to develop. Monitoring well BS-3B is open into the top of the Wise Lake Formation, and has remained essentially dry since installation. This indicates that the Galena potentiometric surface is below the top of the Galena aquifer at this location. When BS-3A was drilled, the driller lost fluid in a weathered zone near the base of the Elgin Member at about 42 feet (13 m). This suggests that there may be a zone of very high transmissivity located near the bottom of the Elgin Member and/or near the top of the Galena aquifer at this location. As drilling of BS-3A continued, the driller encountered a cavity or rubble zone between 176 and 180 feet (54 and 55 m), within the Dunleith Formation. This cavity or rubble zone may be part of a collapsed conduit developed at this level. Monitoring well BS-3A is screened into the Dunleith Formation from 165 to 185 feet (50 to 56 m), with the water level at about 168 feet (51 m) below land surface, exhibiting unconfined aquifer conditions. At this location, the Galena potentiometric surface was expected to be near, or above the top of the Galena aquifer, at an elevation similar to the water level in monitoring well BS-3C (Figure 6). This site appears to be over a conduit-zone where the Galena potentiometric surface is locally depressed. This feature may not be large enough to have been reflected in previous assessments of water-level data.

Monitoring well BS-3 is open to the St. Peter Sandstone. The water level in BS-3 has been about 300 feet (91 m) below land surface, exhibiting confined aquifer conditions. Since heads show a decrease with depth, in this portion of the basin, potential for groundwater movement is downward from the Galena to the St. Peter aquifer.

Site BS-4

Site BS-4 is located in the northwest portion of the basin, near the western edge of the basin (Figure 1). In this area, Galena carbonates are overlain by the Maquoketa Formation, and the Galena potentiometric surface is located above the top of the Galena aquifer (Figure 6).

Figure 13 shows the stratigraphic sequence and monitoring-well installations for site BS-4. At this site, Pleistocene sediments overlie the Clermont and Elgin members of the Maquoketa Formation, which in turn, overlie a complete sequence of the Galena Group. Monitoring well BS-4C is screened into unconsolidated, stratified Pleistocene deposits and has a water level approximately 56 feet (17 m) below land surface. Monitoring well BS-4B is open to the Clermont Member, with a water level at about 76 feet (23 m) below land surface. When BS-4B was drilled, the driller noted the loss of fluid near the bottom of the Clermont Member, at around 139 feet (42 m). Well BS-4A is open to about the middle of the Galena aquifer, with a water level approximately 217 feet (66 m) below land surface, exhibiting confined aquifer conditions. During the drilling of BS-4A, the driller noted the loss of fluid at about 100 feet (31 m), and again at about 134 feet (41 m), within the Pleistocene deposits overlying the Clermont Member. Monitoring well BS-4 is open to the St. Peter Sandstone, with a water level about 367 feet (112 m) below land surface, exhibiting confined aquifer conditions. During the drilling of BS-4, the driller lost fluid just above the Clermont Member at 132 to 134 feet (40 to 41 m), and after casing to 149 feet (45 m), again lost fluid at 151 feet (46 m). As drilling of BS-4 continued, no voids were encountered within or below the Galena aquifer.

The loss of fluid, both above and immediately below the Clermont Member, in conjunction with observations of differing water levels in monitoring wells BS-4B and BS-4C, suggest that there may be shallow flow systems developed within the Maquoketa Formation and the overlying Pleistocene deposits at this location. Conversely, the apparent lack of voids within the Galena aquifer at this location, suggest that the overlying Maquoketa Formation limits the development of solution conduits in this portion of the Big Spring basin. The potential for groundwater movement is downward in this portion of the basin, since heads decrease with depth at this site.

Site BS-5

Site BS-5 was drilled to obtain a more complete sequence of the Maquoketa Formation than was present at site BS-4. No monitoring wells were installed at this location.

WELL MONITORING INSTALLATIONS

To allow continuous monitoring of water levels within the wells, digital stage recorders, driven by float and tape assemblies and powered by 12 volt gell cell batteries were installed. The recorders are controlled by solid-state timers, set to register water levels at 1 hour intervals. The recorders are housed in wooden boxes, mounted on the well casings. The digital tapes are removed on a weekly basis by USGS personnel and the data is processed and stored in the USGS, Automatic Data Processing System (ADAPS) data base. The monitoring wells that have remained essentially dry since installation were not instrumented.

Monitoring wells were constructed as consistently as possible using similar installation techniques, and materials. All wells were grouted above the screens with bentonite and cement.

At site BS-1, monitoring wells BS-1A and BS-1B are constructed with 4 inch (10.2 cm) steel casing, and are instrumented with digital recorders. BS-1C is constructed with 6 inch (15.2 cm) steel casing to 61 feet (19 m), then 4 inch (10.2 cm) steel casing to 150 feet (46 m). BS-1D, which is a flowing artesian well, is constructed with 6 inch (15.2 cm) steel casing to 61 feet (19 m), and 4 inch (10.2 cm) steel casing from 47 feet to 173 feet (14 m to 53 m). It is fitted with a pressure gage and dial. Dial readings are monitored by GSB and USGS personnel, and are converted to feet of head by a conversion factor.

At site BS-2, monitoring wells BS-2A/BS-2B and BS-2C/BS-2D are constructed with 2 inch (5.1 cm) PVC casing, nested inside of 6 inch (15.2 cm) steel casing. BS-2F is constructed with 4 inch (10.2 cm) steel casing. Monitoring wells BS-2E and BS-2G are constructed with 4 inch (10.2 cm) steel casing, and are instrumented.

At site BS-3, monitoring wells BS-3C and BS-3B are constructed with 4 inch (10.2 cm) steel casing. BS-3A is cased to 42 feet (13 m) with 6 inch (15.2 cm) steel casing, then with 4 inch (10.2 cm) steel casing to 198 feet (60 m). BS-3A and BS-3C are instrumented for continuous monitoring. Monitoring well BS-3 is cased to 41 feet (13 m) with 6 inch (15.2 cm) steel casing, then with 4 inch (10.2 cm) steel casing to 351 feet (107 m). Instrumentation of well BS-3 has been replaced by monthly measurement by USGS personnel.

At site BS-4, all wells are instrumented for continuous monitoring. BS-4C is constructed with 4 inch (10.2 cm) steel casing. BS-4B is cased to 76 feet (23 m) with 5 inch (12.7 cm) steel casing, then to 130 feet (40 m) with 4 inch (10.2 cm) steel casing. BS-4A is cased to 134 feet (41 m) with 5 inch (12.7 cm) steel casing, then 4 inch (10.2 cm) steel casing to 261 feet (80 m). Monitoring well BS-4 is cased to 133 feet (41 m) with 6 inch (15.2 cm) steel casing, then 4 inch (10.2 cm) steel casing to 550 feet (168 m).

PRELIMINARY WATER-LEVEL DATA
(January 1989 to September 1989)

As previously mentioned, 1988 and 1989 were two of the driest consecutive years in Iowa's recorded history; state-wide, average precipitation was more than 18 inches (45.7 cm) below normal. Precipitation in the Big Spring area was about 10 inches (25.4 cm) below normal during the 1988 Water Year and about 8.7 inches (22.1 cm) below normal during the 1989 Water Year.

From January 1989 to September 1989, all monitoring wells exhibited an overall decline of mean monthly water levels, reflecting the continued absence of recharge during this drought period. The shallower wells exhibited more immediate responses to snow melt and rain fall events than the deeper monitoring wells.

At site BS-1 all wells exhibited overall declining mean monthly water levels (Table 1). Monitoring wells BS-1A and BS-1B rose in response to snow melt in February, and BS-1A also showed an increase in August in response to rain fall. Mean monthly water levels in BS-1A declined from 14.07 feet (4.29 m) in January to 14.25 feet (4.34 m) in September. The largest change in mean daily water levels in BS-1A was a decline of 4.42 feet (1.35 m) that occurred from March 8 to March 14. Mean monthly water levels in BS-1B have declined 0.90 feet (0.27 m) from January to August. The largest fluctuation of mean daily water levels in BS-1B was an increase of 4.33 feet (1.32 m) that occurred from March 5 to March 15. Monitoring well BS-1C contains only a few feet of water since installation. When BS-1D was installed, mean monthly water levels were approximately 7 feet (2.1 m) above land surface. Near the end of the 1989 water year, mean monthly water levels in BS-1D were about 4 feet (1.2 m) above land surface.

At site BS-2, monitoring wells BS-2A, BS-2B, BS-2C, BS-2D, and BS-2F have all remained essentially dry since installation (Table 1). BS-2E, exhibited a decline in mean monthly water levels of 0.51 feet (0.16 m) from January to September. The largest change in mean daily water levels in BS-2E, was an increase of 3.13 feet (0.95 m) that occurred from January 18 to January 30. Monitoring well BS-2G exhibited a decline in mean monthly water levels of 2.18 feet (0.67 m) from January to September. The largest fluctuation of mean daily water levels in BS-2G, was a decline of 1.59 feet (0.49 m) that occurred between September 1 and September 12.

At site BS-3, mean monthly water levels in monitoring well BS-3C have declined 0.40 feet (0.12 m) from February to September (Table 1). The largest fluctuation of mean daily water levels occurred in BS-3C; an increase of 1.50 feet (0.46 m) occurred between September 3 and September 13. BS-3B has remained essentially dry since installation. Mean monthly water levels in BS-3A declined from 167.86 feet (51.16 m) in February to 167.87 feet (51.17 m) in September. The largest change in mean daily water levels in BS-3A, was an increase of 1.43 feet (0.44 m) that occurred from March 12 to March 17. Mean monthly water levels in monitoring well BS-3 dropped from 299.97 feet (91.43 m) in February, to 300.80 feet (91.68 m) in September.

At site BS-4, all wells exhibited declining mean monthly water levels from February to September (Table 1). In BS-4C, the mean monthly water level was 56.23 feet (17.14 m) in September. The mean monthly water level in BS-4B was 72.94 feet (22.23 m) in September. BS-4A exhibited a decline in mean monthly water levels of 4.78 feet (1.46 m) from February to September. The largest fluctuation of mean daily water levels in BS-4A was a decline of 1.47 feet (0.45 m) that occurred from July 1 to July 31. Mean monthly water levels in monitoring well BS-4 dropped from 366.97 feet (111.85 m) in February to 369.92 feet (112.75 m) in September. The largest fluctuation of mean daily water levels in BS-4 was a decrease of 1.09 feet (0.33 m) that occurred from September 1 to September 27.

PLANNED WATER-QUALITY AND WATER-LEVEL DATA

Water-quality sampling of the monitoring wells is expected to begin during the 1990 water year. All wells will probably be sampled once for major ion concentrations, commonly used pesticides, heavy metals, and nitrates. Sampling of the Galena and alluvial wells will probably continue on a quarterly basis for common pesticides and nitrates. Ongoing monitoring of water levels in the wells will provide detailed three-dimensional observations of changes in the various potentiometric surfaces within the basin. Periodic monitoring of the essentially dry wells in the Platteville Formation, will document the effectiveness of the aquitard between the Galena and St. Peter aquifers. Monthly monitoring of the essentially dry wells in the Wise Lake and Dunleith formations at site BS-2, will hopefully afford the opportunity to observe the effects of recharge events on the groundwater flow system.

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