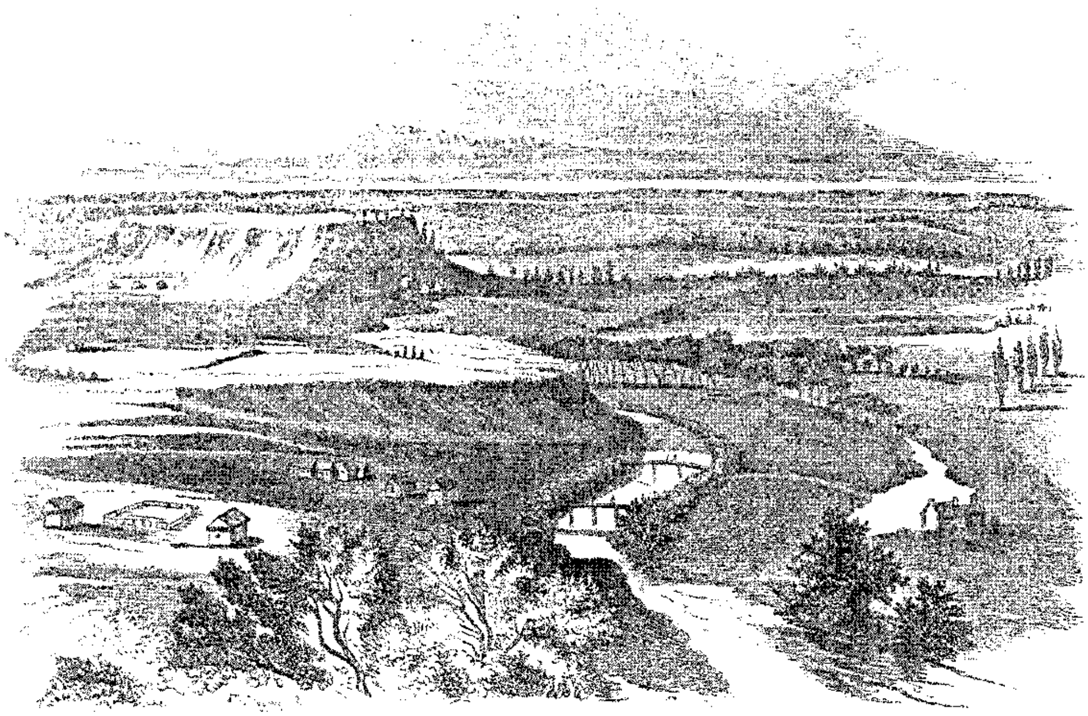
WATER QUALITY AND THE GALENA GROUP IN THE BIG SPRING AREA, CLAYTON COUNTY

B.E. Hoyer E.A. Bettis III B.J. Witzke



SYMMETRICAL FORM OF HILLS, TURKEY RIVER.

Geological Society of Iowa

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There have been so many people who have contributed to the Big Spring research that it is impossible to acknowledge them all. Any list must include George Hallberg. His efforts are probably the single most important ingredient to the overall success of the research. Others who have or are now making major contributions include: Bob Libra, Deb Quade, John Littke, Mike Bounk, Jerry Spykerman, Mike Schendel, Roger Koster, Dave Gibney, Jim Reel, Stan Mitchem, Jerry DeWitt, Gerry Miller, Jim Hosch, Jim Kaap, Frank Phippen, Taun Novak, Julie Elfving, Jim Baker, Fred Blackmer, Ivan Burmeister, Nick Melcher, Rick Kelley, Bill Gasper, Dan Lindquist and Bill Nicholas. These people, and many others, have made major contributions, each in their own way.

Appreciation is extended to the residents of the area who have been so gracious. Special appreciation is extended to Klinges, Inc., Ed Sass, Duane Moon and Ervin Bugenhagen who have graciously allowed us access to view sites on their land.

Appreciation is also extended to Mary Pat Heitman and Pat Lohmann who helped in preparation of this guidebook.

About the cover: The cover is taken from a lithograph in "Reports of a Geological Survey of Wisconsin, Iowa, and Minnesota" by David Dale Owen (1852). The lithograph depicts his impression of the Turkey River Valley (probably in the vicinity of Eldorado in Fayette County, or Elkader or Motor in Clayton County).

INTRODUCTION

Hallberg and Hoyer (1982) reviewed and compiled pertinent geologic and hydrologic information, as well as existing nitrate data, for the years 1977-80 in 22 northeast Iowa counties. In northeast Iowa, local residents and public officials had often voiced concern for the quality of their public and private underground water supplies. In this region many of the important water-bearing units, or aquifers, are shallow limestone formations which often are revealed at the land surface by the occurrence of sinkholes. Over the years, many cases of contaminated water have been documented in these areas and well drillers have described increased difficulty in completing wells without high levels of nitrate in water. Hallberg and Hoyer's research concluded that systematic degradation of water quality existed in northeast Iowa. Water quality systematically improved, in general, with increased well depth and in areas with natural geologic protection, such as would be afforded by shale or thick glacial till deposits. Areas where sinkholes were present, often called karst areas, were found generally to have the highest nitrate levels; areas without sinkholes but with relatively thin protective cover had similar, but somewhat lower levels of nitrate; areas of thicker drift revealed little nitrate in the bedrock aquifers below. This work concluded that the source of most nitrate was normal infiltration processes, not runoff into sinkholes. Table 1 presents the systematic variation in median nitrate values from three natural geologic settings, by well depth classes, for the northeast Iowa regional study area. Natural background levels of nitrate were determined to be essentially zero (less than the routine 5 mg/l detection limit). Combining background levels of nitrate with the systematic distribution of elevated nitrate levels, it was concluded that groundwater nitrate contamination is related to surface sources and recent activities of man.

Research in the Big Spring basin began in the fall of 1981. Hallberg et al. (1983) concentrated on understanding the mechanisms of nitrate and pesticide contamination, the distribution (both in time and space) and concentration of contaminants, and the relationships of water quality to agricultural practices. Landuse and appropriate geologic and hydrologic systems were mapped in detail. Monitoring of wells, springs, tile lines and streams began in 1981 and has continued up to the present. Systematic nitrate contamination in unprotected portions of the aquifer was found in the basin as predicted from the earlier study. However, either intermittent or continuous herbicide contamination, at very low concentrations, was found in these same unprotected aquifer areas. Two conclusions have made the research at Big Spring, perhaps, the most well known evaluation of nonpoint agricultural effects on groundwater.

First, nitrate increases were directly linked to increases in commercial fertilizer use. Intermittent water analyses at Big Spring, dating back to 1951, suggest a tripling of nitrate concentrations since the late 1960's. Nitrate concentrations rose from the range of 10-15 mg/l to 30-45 mg/l. This period of time corresponded to a 2.5 times increase in chemical fertilizer nitrogen applied in the basin. In another report Hallberg et al. (1984a) describe similar rates of nitrate concentration increases between 1976 and 1983 from unprotected carbonate aquifers in northeast Iowa. Recent agronomic research supports the idea that leaching of nitrogen (N) fertilizers may account for the nitrate levels found today in unprotected carbonate aquifers. Studies by Blackmer (1984) using isotopically labeled nitrogen (^{15}N) fertilizers in 1982 and 1983 revealed that a mean of only 17% of the applied N was used by

Table 1. Summary of median nitrate values (in mg/l) from UHL analyses from the 22 county northeast Iowa study area for 1977-1980. (From Hallberg and Hoyer, 1982.)

Well Depth (feet)	Geologic Setting: Karst	Shallow Bedrock	Deep Bedrock
0-49	28	26	33
50-99	34	19	6
100-149	23	16	<5
150-199	10	6	<5
200-249	<5	<5	<5
250-299	<5	<5	<5
300-499	<5	<5	<5
>500	<5	<5	<5
Unknown	(22)	(7)	(<5)
Median (No. of Samples)	19 (1104)	9 (2719)	<5 (2217)

the corn during the year of application; another 0.7% was used the following crop year. Surface applied ^{15}N-labeled urea was found to convert to nitrate and generally leach greater than 25 cm during the period 2 to 6 weeks after application. Recovery of ^{15}N was 100%, 73%, and 42% after 2, 4, and 6 weeks, respectively, and Blackmer concludes that the losses are primarily from nitrate leaching to depths below the root zone. His work indicates that a significant portion of the nitrogen fertilizer Iowa farmers apply for corn production may be lost to groundwater by infiltration through the soil before corn plants have an opportunity to take up this nitrogen. Thus, minimizing these losses could decrease the pollution potential of nitrogen fertilizers without decreasing the profitability of crop production.

Second, Big Spring research showed that pesticides could be delivered to groundwater through normal infiltration recharge mechanisms (Hallberg et al., 1983, 1984b). Subsequent studies have shown this to be widespread and aquifers which are not confined are highly susceptible to low levels of pesticide contamination (Libra et al., 1984; Kelley, 1985; Kelley and Wnuk, 1986; Kelley et al., 1986). Recently, a compilation of pesticide analyses in Iowa reveals that 33% of the wells tested had one or more detectable pesticide residues (Hallberg et al., 1986).

Big Spring research has become widely recognized in the past few years as Congress, the Environmental Protection Agency and people throughout Iowa have begun to recognize the importance of groundwater and the potential threats to its quality. Agriculture's affects on groundwater have been little known, and generally thought to be insignificant. A number of field tours have been presented at Big Spring for officials and researchers with environmental or agricultural interests. These trips have often been their first exposure to geology and hydrology. This Geological Society of Iowa trip will allow the geological community to become more familiar with the research efforts conducted on the Galena aquifer in the Big Spring area over the past five years.

Futher, it will provide a glimpse of what is currently going on and will continue for the next six years through a program called the Big Spring Demonstration Project.

HEALTH CONCERNS

The leaching and delivery of nitrate and pesticides into groundwater-drinking water supplies is a public health concern. The concern is generated because Iowan's depend on groundwater supplies and the persistence of these constituents over ever increasing areas creates the potential for widespread exposure.

Often the potential impacts of nitrates are downplayed; the principle expressed concern is the potential for methemoglobinemia in infants. In general, the current drinking-water standard (45 mg/l) is thought to be a conservative and safe standard. Methemoglobinemia, although rare, does occur. Recent epidemiological research, however, also suggests that nitrates in drinking water (perhaps at even lower concentrations) may contribute to problems such as hyptertension, gastric cancers, and birth defects.

The concentrations of pesticides currently found in groundwater are low. The concentrations are far below toxic levels and even generally below levels considered harmful for longer-term chronic effects for the individual compounds for which pertinent data exists. There are, however, reasonable concerns for long-term health impacts of the exposure to pesticides through drinking water in relation to other environmental factors, especially the co-existence of numerous pesticides and possibly their metabolites, and their general occurrence in combination with nitrates.

THE TRIP

STOP 1: Roadcuts in Galena Group north of Elkader, Hwys. 13 and 128

An understanding of the stratigraphy, lithology, and physical characteristics of Ordovician carbonates in northeast Iowa provides a framework for evaluating the physical container of hydrologic systems like those in the Big Spring basin. The bedrock surface in the area of the Big Spring basin encompasses Middle and Upper Ordovician carbonates and shales of the Galena Group and Maquoketa Formation (Fig. 1). The Galena Group includes, in ascending order, the Decorah, Dunleith, Wise Lake, and Dubuque formations. The Galena Group carbonates, primarily the upper Dunleith, Wise Lake, and Dubuque formations, form steep valley walls in the Turkey River drainage in the field trip area. The lowest unit in the Maquoketa Formation, the Elgin Member, is dominated by limestone and dolomitic limestone, and may be in hydrologic continuity with the underlying Galena Aquifer. This unit is less resistant than the Galena Group rocks and tends to form more gentle slopes. Even less-resistant Maquoketa shales underly more gently sloping surfaces in the upland areas, which are in turn capped, in the highest regions, by resistant Silurian dolomites.

The carbonates of the Galena Group undergo a major diagenetic facies change within the Clayton County outcrop belt. Galena Group carbonates are pervasively dolomitized in the southern sections, but the sequence encompasses progressively more limestone and dolomitic limestone to the north. Apparently, because limestone is more soluble than dolomite, more sinkholes and other karst features are developed in regions where the Galena Group is dominated by limestone than in the dolomite terrains. Original depositional fabrics are more faithfully preserved in the limestone facies than in the severely altered dolomite facies to the south.

We will examine a series of roadcuts (SE sec. 12, T93N, R5W) along Highways 13 and 218 about 3 miles north of our morning rendezvous point (Fig. 2). These cuts display limestone strata of the upper Galena Group, encompassing parts of the Wise Lake and Dubuque formations. The illustrated sequence (Fig. 3) is derived from Delgado (1983), who led an SEPM field trip to these exposures in October, 1983. Roadcut A begins on the north side of Hwy. 128 near the junction with Hwy. 13. Roadcuts B, C, and D proceed to the southwest along the east side of Hwy. 13. The exposed interval is non-cherty (unlike the underlying Dunleith Fm.) and limestone dominated, although dolomitic limestones are concentrated locally in burrow structures. The Wise Lake Formation is generally free of notable argillaceous impurities, although shales and argillaceous partings appear in the upper part. By contrast, the Dubuque Formation is characterized by conspicuous thin shales and shaly partings, reflecting an influx of terrigenous clastics from Transcontinental Arch or Taconic sources during Dubuque deposition. The Middle-Upper Ordovician boundary is drawn near the base of the Wise Lake Formation.

As you examine the upper Galena Group in the roadcut exposures, try to identify some of the following features. 1) A series of nine or more closely-spaced hardgrounds characterize the upper Sinsinawa Member. 2) Thin beds or lenses of skeletal grainstone (SCB - "sparry calcarenite bands" of Levorson and Gerk, 1983), some geographically widespread and stratigraphically significant, can be seen in the Wise Lake and Dubuque formations. These

GENERALIZED STRATIGRAPHIC SEQUENCE
OF BEDROCK UNITS IN NORTHEAST PORTION OF STUDY AREA
(Winneshiek, Allamakee, Fayette, Clayton Counties, Iowa)

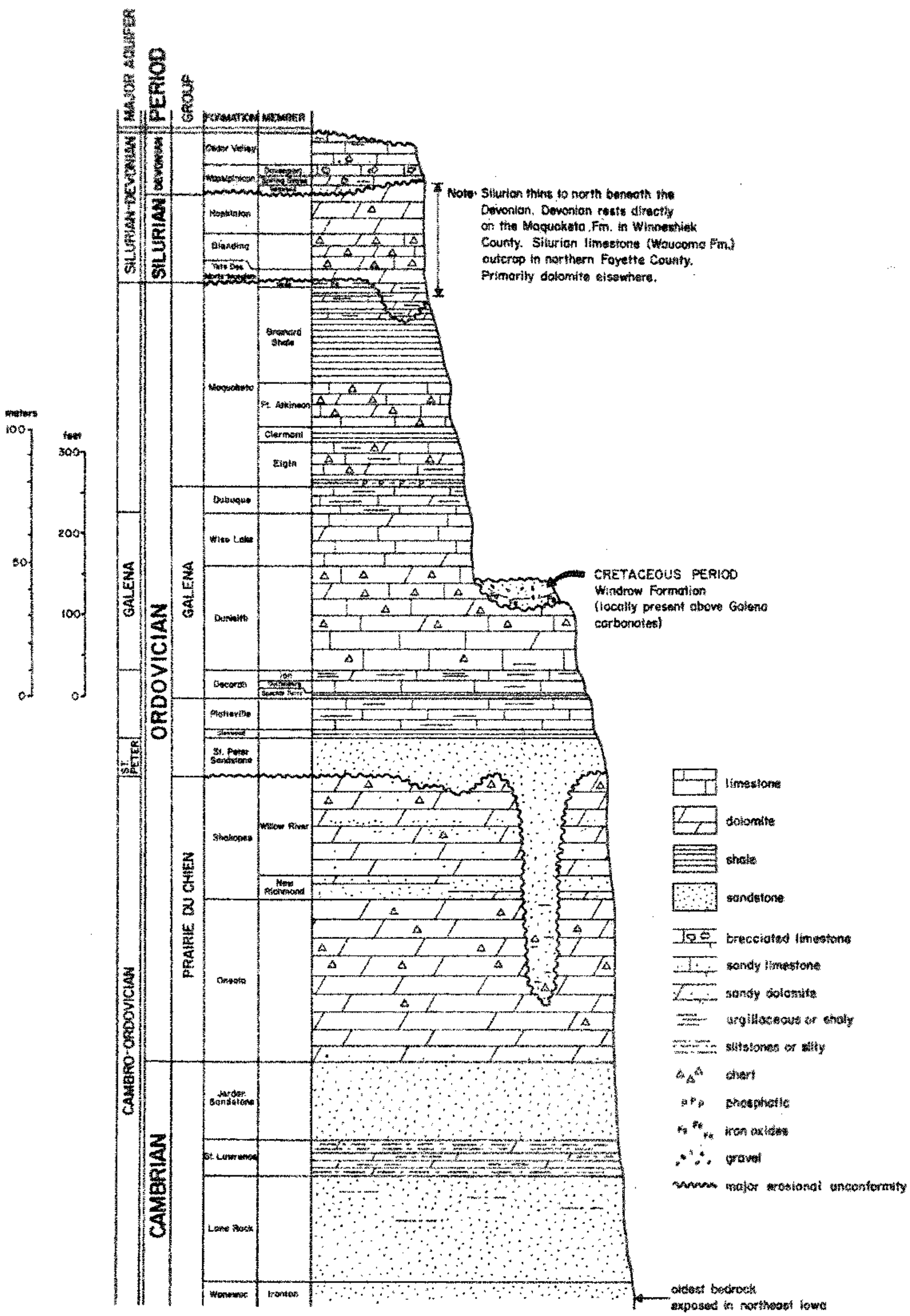


Figure 1. Generalized stratigraphic section for Big Spring study area.

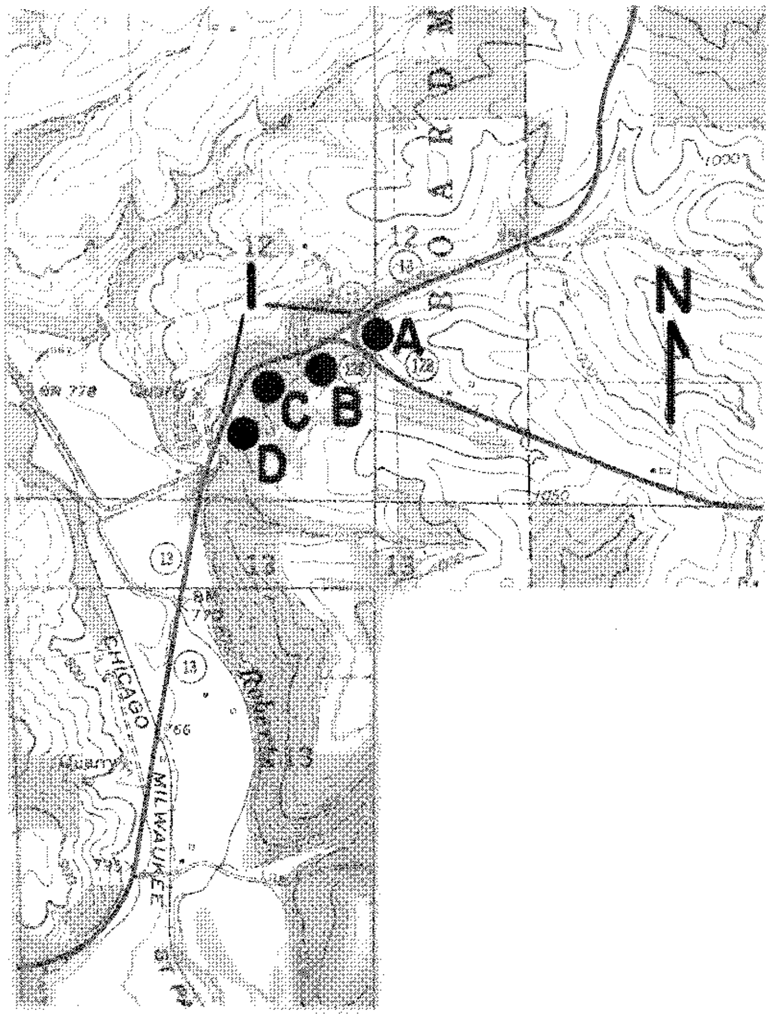


Figure 2. Topographic map showing location of Stop 1 exposures. (From USGS Elkader, St. Olaf, and Farmersburg 7.5 minute quads.) 2.5 inches equals approximately 1 mile.

apparently represent storm deposits. 3) Molluscan fossils are especially prominent in parts of the Wise Lake, primarily gastropods (including large *Maclurites*) and some nautiloids. 4) The "Upper *Receptaculites* Zone" is present in the lower Stewartville Member, and is characterized by an abundance of distinctive calcareous green algae (now assigned to *Fisherites*). 5) The Dubuque-Wise Lake contact is drawn at the base of the lowest shale bed that has widespread geographic continuity (the "marker bed" of Levorson and Gerk, 1983). 6) Observe the upward increase of crinoidal debris within the Dubuque Formation, as well as the prominent shaly partings. 7) Thin shales in the "Luana beds" of the Dubuque yield dalmanellid (*Paucicrura*) and inarticulate (*Pseudolingula*) brachiopods.

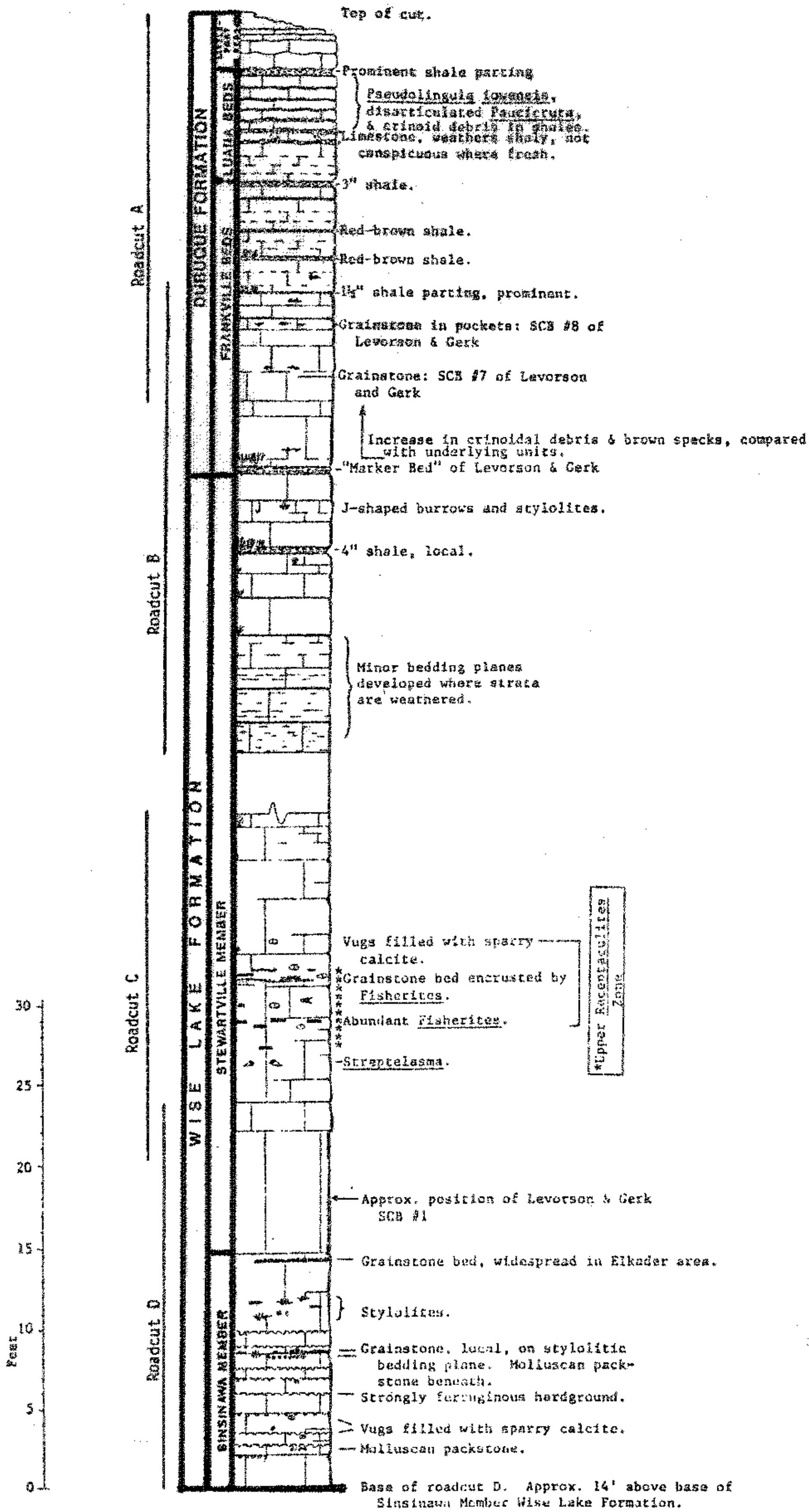


Figure 3. Composite stratigraphic section exposed at Stop 1. (Adapted from Delegado, 1983.)

STOP 2: Roberts Creek Quarry

One characteristic aspect 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 contained carbonates, and portions of the rock are disassociated and dissolved.

In most 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 opening 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 head in response to hydrostatic 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, solutional conduit and cavern development occur along those fracture trends which best facilitate down-head movement (Bounk, 1983a, 1983b).

These principles are displayed in the Roberts Creek Quarry (SW 1/4, NW 1/4, sec. 14, T94N, R5W; Fig. 4). 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. Lithologic properties of the rocks here are very similar to those viewed at Stop 1. 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°E; N23°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 as a result of downward movement of surface-derived water along them. 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 in 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 intersection 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 also 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

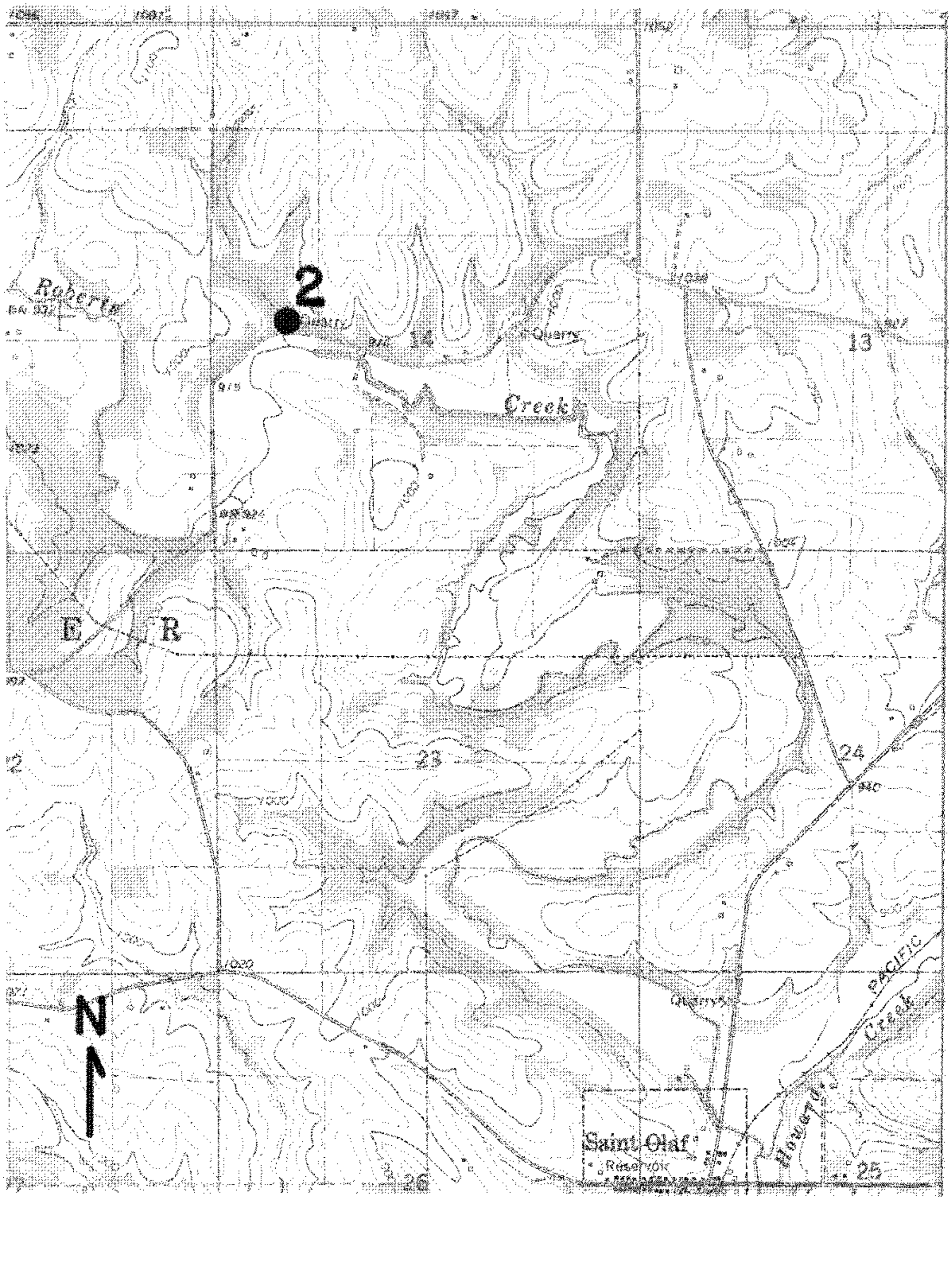


Figure 4. Topographic map showing the location of Stop 2. (From USGS St. Olaf 7.5 minute quad.) 2.5 inches equals approximately 1 mile.

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 unlithified Quaternary materials readily transmit soil water to the karstified bedrock surface where it travels down solutionally-enlarged joints into the Galena aquifer.

STOP 3: Big Spring and the Big Spring Hatchery

Big Spring (Fig. 5) was purchased by the Iowa Conservation Commission in 1961 to provide water for a trout rearing facility. Annually, about 220,000 rainbow trout and 40,000 brown trout are raised for stocking in northeast Iowa streams. The spring issues from the Dunleith Formation of the Galena Group and provides a reliable source of water to the hatchery.

The U.S. Geological Survey established the means to gage the discharge of the spring in the fall of 1981. Using manual techniques, the spring has been gaged daily by staff at the hatchery. During periods of rapid change, recordings may occur at hourly intervals. For water-years 1982-1985, the spring has averaged a discharge of 47 cubic feet per second (cfs) (21,150 gallons per minute) (gpm). A maximum flow of 360 cfs (162,000 gpm) was achieved on 19 March 1986; a minimum flow of 21 cfs (9,450 gpm) was recorded on 24 August 1985.

Normally the water is clean and cool (48°F)--excellent for fish rearing. During periods of normal base flow, sediment concentrations may be about 10 mg/l, but during runoff from a series of storms which occurred between June 27 and July 3, 1983 sediment concentrations of 4000 mg/l were recorded. This delivered 96 tons of sediment per hour to the hatchery. Such episodes can quickly create a life threatening situation for the trout in the raceways and a major cleanup problem for hatchery staff. Turbidity is the major water quality problem for the operation of the hatchery. Other water quality problems which affect the trout include ammonia, especially during the spring snow-melt season, and perhaps nitrate. The worst water quality problem ever recorded was a severe condition of chemical oxygen demand which killed the entire hatchery fish population in December 1963. Creamery wastes were dumped into a stream which entered a sinkhole near Luana, about 14 miles north of the hatchery. The sink was connected to Big Spring.

Determination of the subsurface drainage in a karst area can be treacherous because surface and subsurface drainge basins may be unconnected in karst areas. Heitmann (1980) used dye-tracing to connect sinkholes hydrologically with Big Spring. Hallberg, et al. (1983) combined Heitmann's work with water level measurements and additional dye-tracing (1984b) to establish the groundwater basin. Figure 6 interprets groundwater flow from water table/potentiometric surface isometric maps of the Galena aquifer. Two major north-south flow paths drain the eastern and central portions of the basin and connect the major areas of sinkholes to Big Spring. Water tables are depressed along these trends by as much as 150 feet. Hydraulic conductivity is very high along these joint controlled trends. Heitmann (1980) recorded flows as high as 579 meters/hour (0.2 m/s) and Hallberg et al., (1984b) recorded similar minimum flow velocities as high as 10.9 miles/day (0.2 m/s). Such conductivity, potentiometric gradients and drainage network clearly represent a major conduit or cave system developed in the central and eastern basin. The conduits bring water beneath Roberts Creek and directly to the Turkey River via Big Spring.

The bedrock geology of the basin is interpreted in Figure 7. The Galena forms bedrock in the vicinity of Silver Creek, Howard Creek, and Roberts Creek from near its junction with Silver Creek. The lower portion of the Maquoketa Formation (Elgin, Clermont, Ft. Atkinson members) form bedrock over the majority of the basin (58%). In the western portion, the upper Maquoketa (Brainard Shale), or the Silurian above it on the divide, form bedrock. Fifteen to thirty feet of Quaternary deposits commonly overly bedrock in the region.

Sinkholes are formed where the Galena is either bedrock, or more commonly,

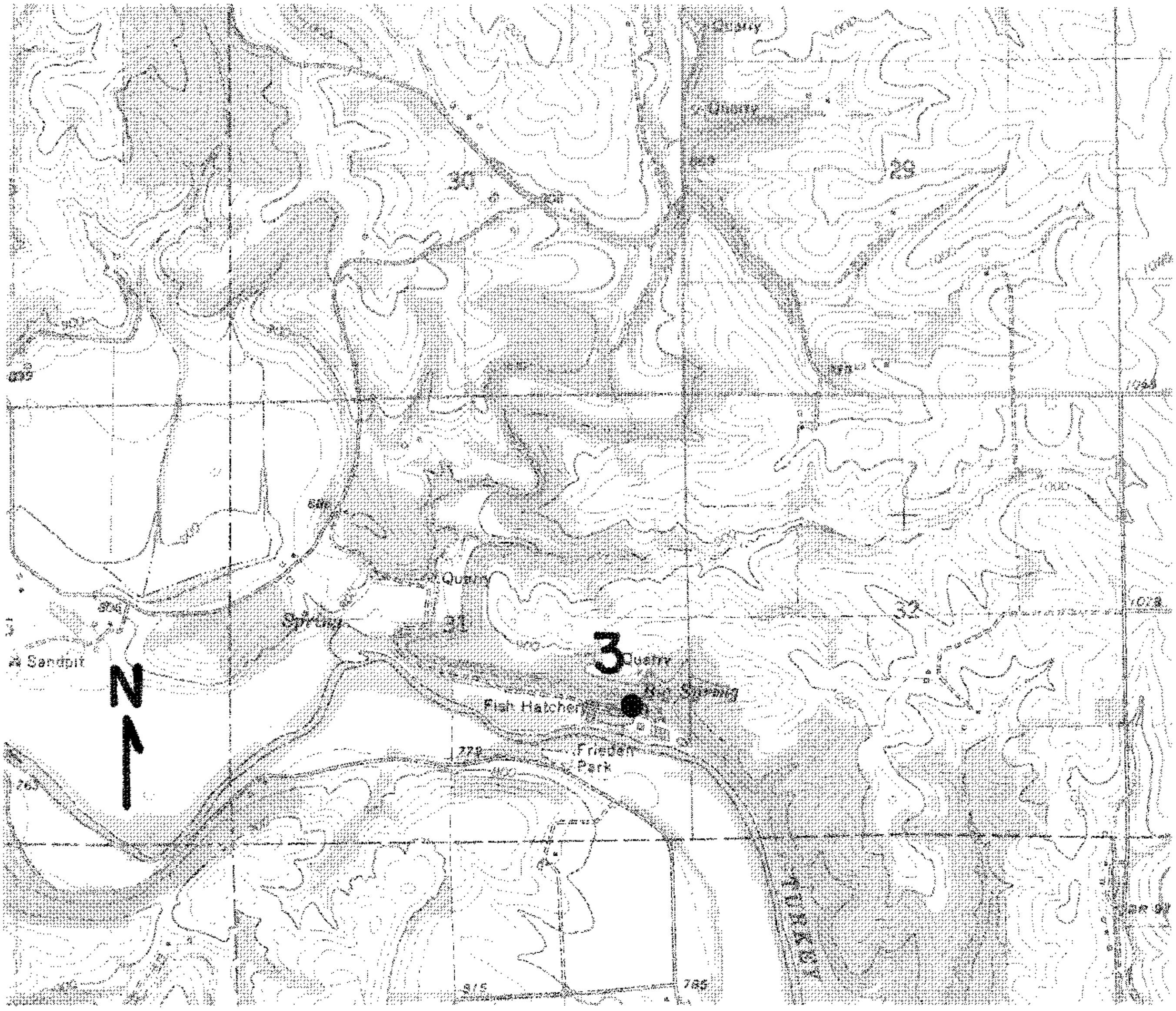


Figure 5. Topographic map showing the location of Stop 3. (From USGS St. Olaf 7.5 minute quad.) 2.5 inches equals approximately 1 mile.

where the Elgin above it is rather thin, and the water table/potentiometric surface is depressed because of the high hydraulic conductivity along the conduits. Over 250 sinkholes have been counted in the basin. They drain 11.5 square miles of the watershed (11%) and most are associated with the two major conduits developed in the Galena. Since study began in 1981 several new sinkholes have formed and been documented. Most watersheds draining to sinks remain dry, except during episodes of very wet conditions. Only one watershed

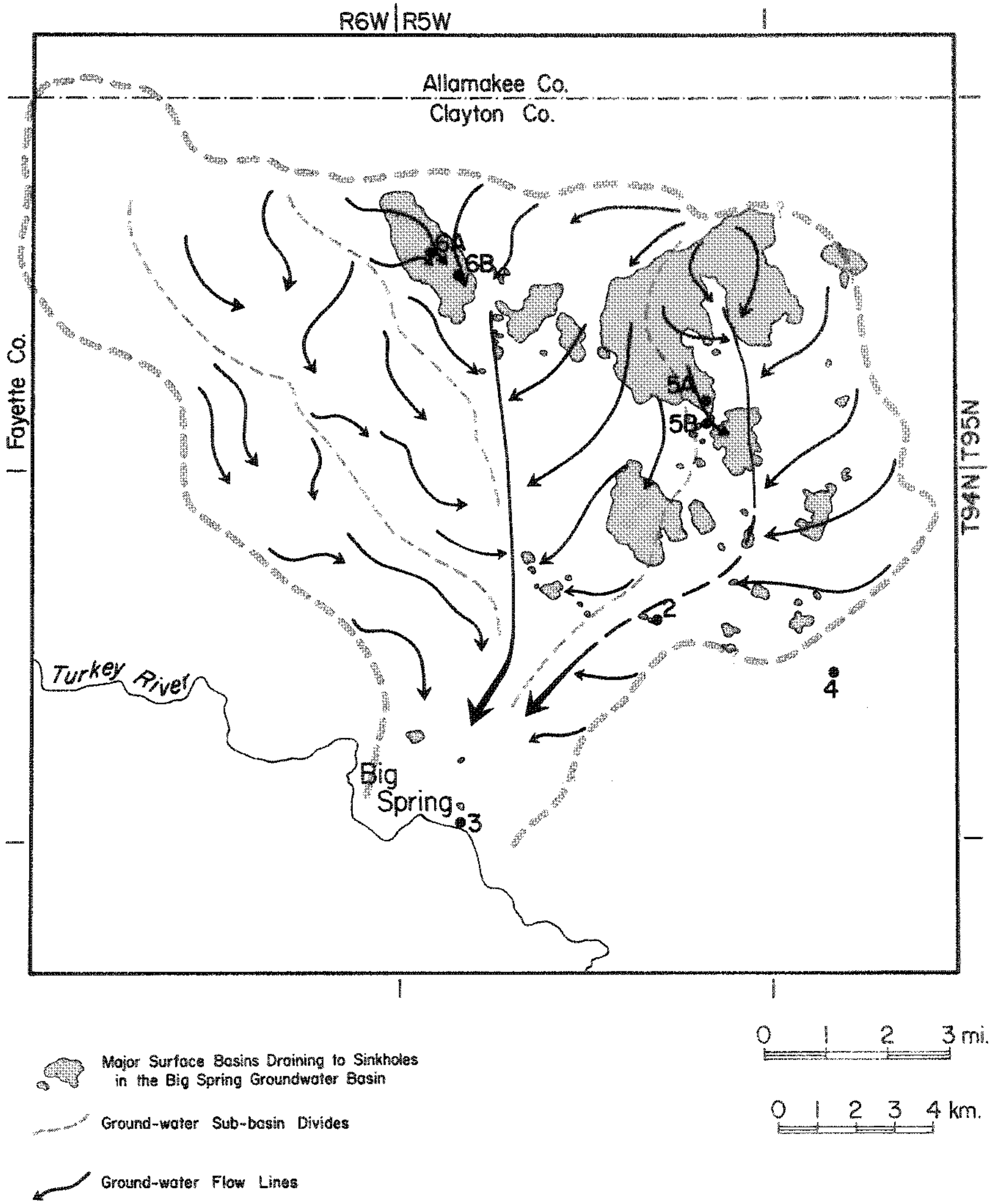


Figure 6. Schematic groundwater flow lines and watersheds draining to sinkholes in the Big Spring basin. Numbered dots are field trip stops. Thick dashed line outlines Big Spring groundwater basin. (From Hallberg et al., 1983).

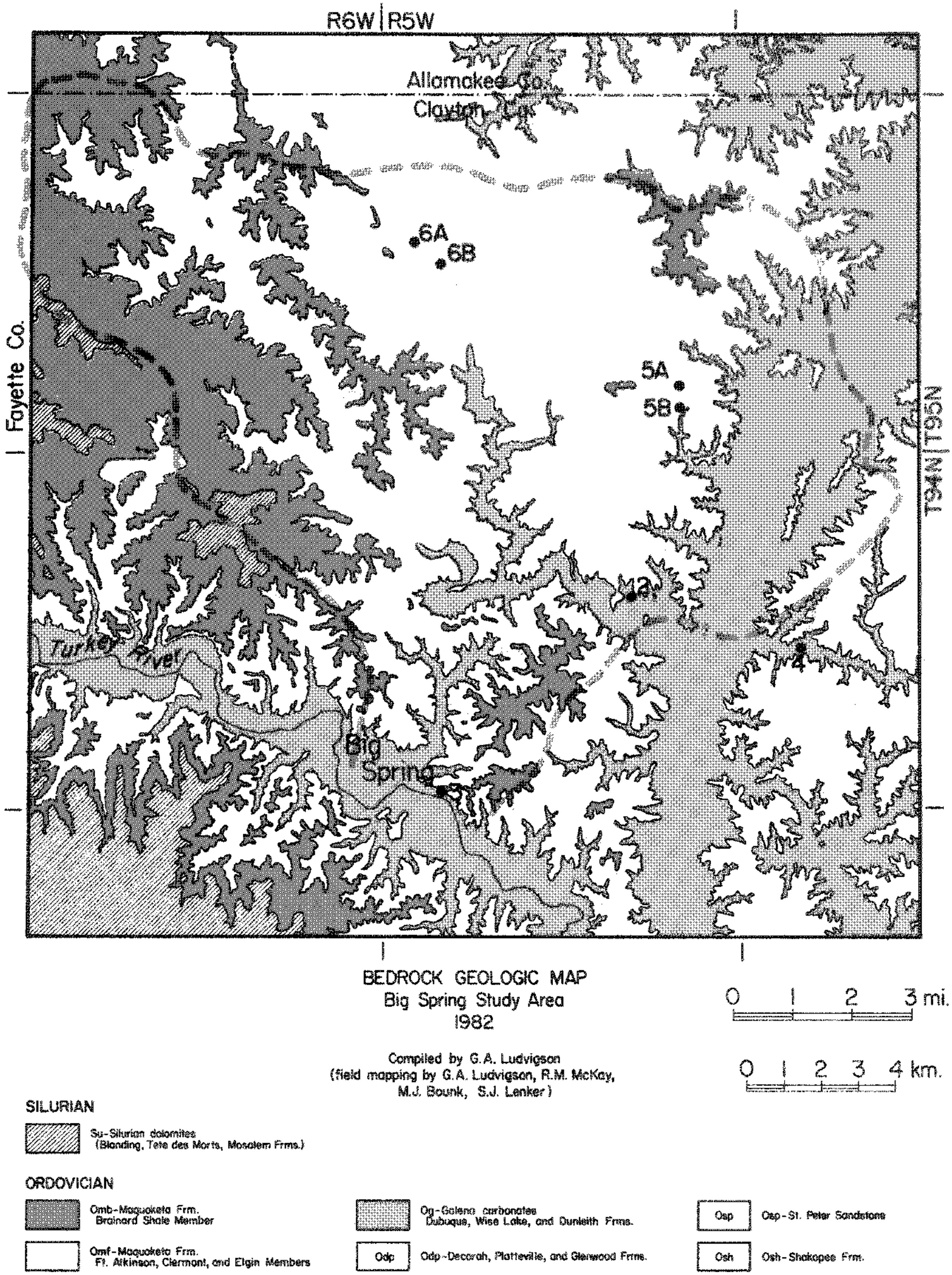


Figure 7. Bedrock geologic map of Big Spring basin. Dashed line is outline of the Big Spring groundwater basin. (From Hallberg et al., 1983)

provides nearly perennial flow to a sinkhole. It is the largest, and it probably occurs where the Elgin begins to thicken and impede infiltration recharge to the Galena.

One-time monitoring for nitrate of 132 wells developed in the Galena aquifer in the basin in November 1981 is revealed in Figure 8. This monitoring revealed significant nitrate contamination: 30 wells (23%) contained nitrate levels above the public health standard of 45 mg/l. However, contamination was not uniform, and as Hallberg and Hoyer (1982) found earlier, geology controlled the distribution. Figure 9 generalizes the nitrate contamination found in the basin during that monitoring. Nitrate was not elevated in the region where the Brainard Shale acts as an aquitard and confines the aquifer below. Where the Elgin Member is present, or the Galena itself is bedrock, contamination is widespread. Limited sampling for pesticides in 1982 revealed that atrazine, a commonly used corn herbicide was also widely present in the areas where elevated nitrate concentrations were found. However, beneath the Brainard, atrazine was not found in the Galena.

Repetitive sampling of a selected network of sixteen wells, and the mass sampling of 132 wells, revealed that through time the nitrate concentrations at Big Spring were representative of conditions throughout the Galena aquifer. Big Spring water was simply an integration of water flowing out of each portion of the aquifer. This is important because Big Spring sampling can be used to evaluate contributions everywhere in the basin. Such sampling is far more efficient in terms of data collection time and analytical costs. For this reason, water quality sampling since 1981 has been concentrated at Big Spring, although a few other locations, including the Turkey River, Roberts and Silver Creeks, a few selected tile lines, and three wells, have received considerable sampling frequency throughout the five years of research so that comparisons can be made. Between November, 1981, and April 15, 1986, 620 nitrate analyses and 254 pesticide analyses have been made from water obtained at Big Spring.

Nitrate has been recorded as high as 75 mg/l (4 July 1983) and as low as 9 mg/l (22 February 1985); pesticides have been recorded as high as 20.3 µg/l (30 April 1984) and on five occasions pesticides were found to be below analytical limits of detection. Table 2 summarizes monitoring data.

Six herbicides and one insecticide have been identified from Big Spring waters. Atrazine is easily the most common herbicide found. It has been present throughout most of the monitoring period. Since May, 1982 it has been absent only once--on 7 January 1986 following a long recession. It has been detected in 98% of the samples collected. Dyfonate, the lone insecticide, is rare, occuring in only 2% of the samples analyzed from Big Spring. Table 3 identifies the pesticides and the maximum concentrations that have occurred for each compound by year. Note that the concentrations have generally increased through four years--an increase that cannot be explained by sampling design or rainfall and runoff characteristics. Sampling frequency decreased in water years 1984 and 1985, yet maximum concentrations increased. Similarly, refering back to Table 2, note that discharge decreased in water years 1984 and 1985, yet, the flow-weighted mean for atrazine increased and maximum concentrations of each pesticide except for atrazine went up. The data suggests that pesticide concentrations are increasing, but a longer record is necessary to assess any hydrologic system.

Hydrograph separation analysis has played a key role in all interpretations at Big Spring. Through time, Big Spring undergoes considerable fluctuation in discharge as well as physical and chemical properties. The evaluation of these physical and chemical properties together with discharge data allow interpretations to be made about recharge mechanisms. The contribution of

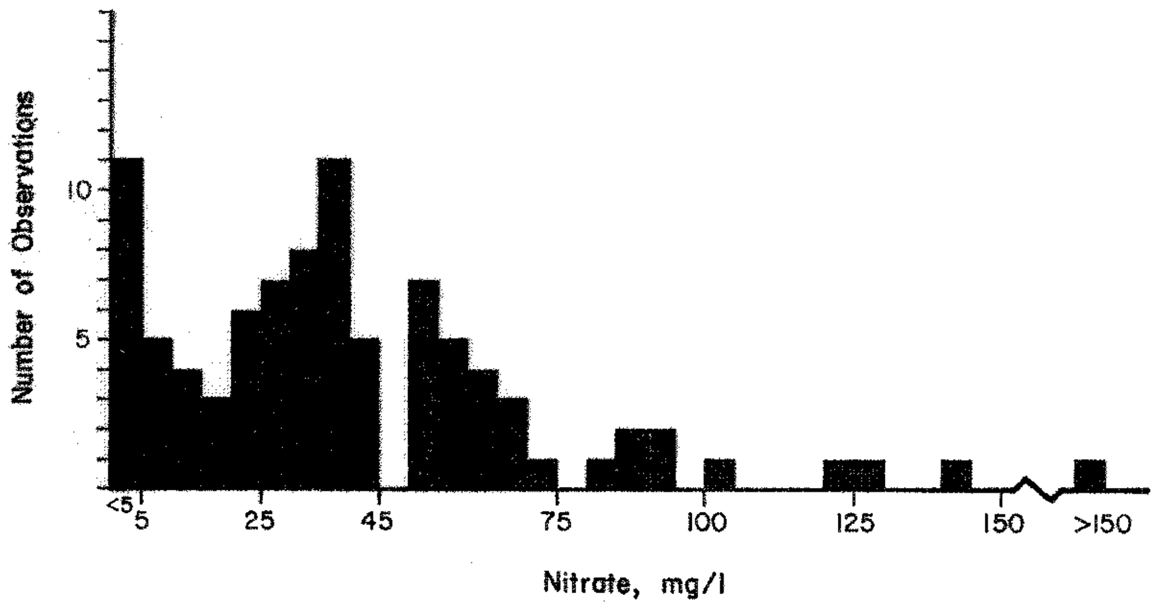
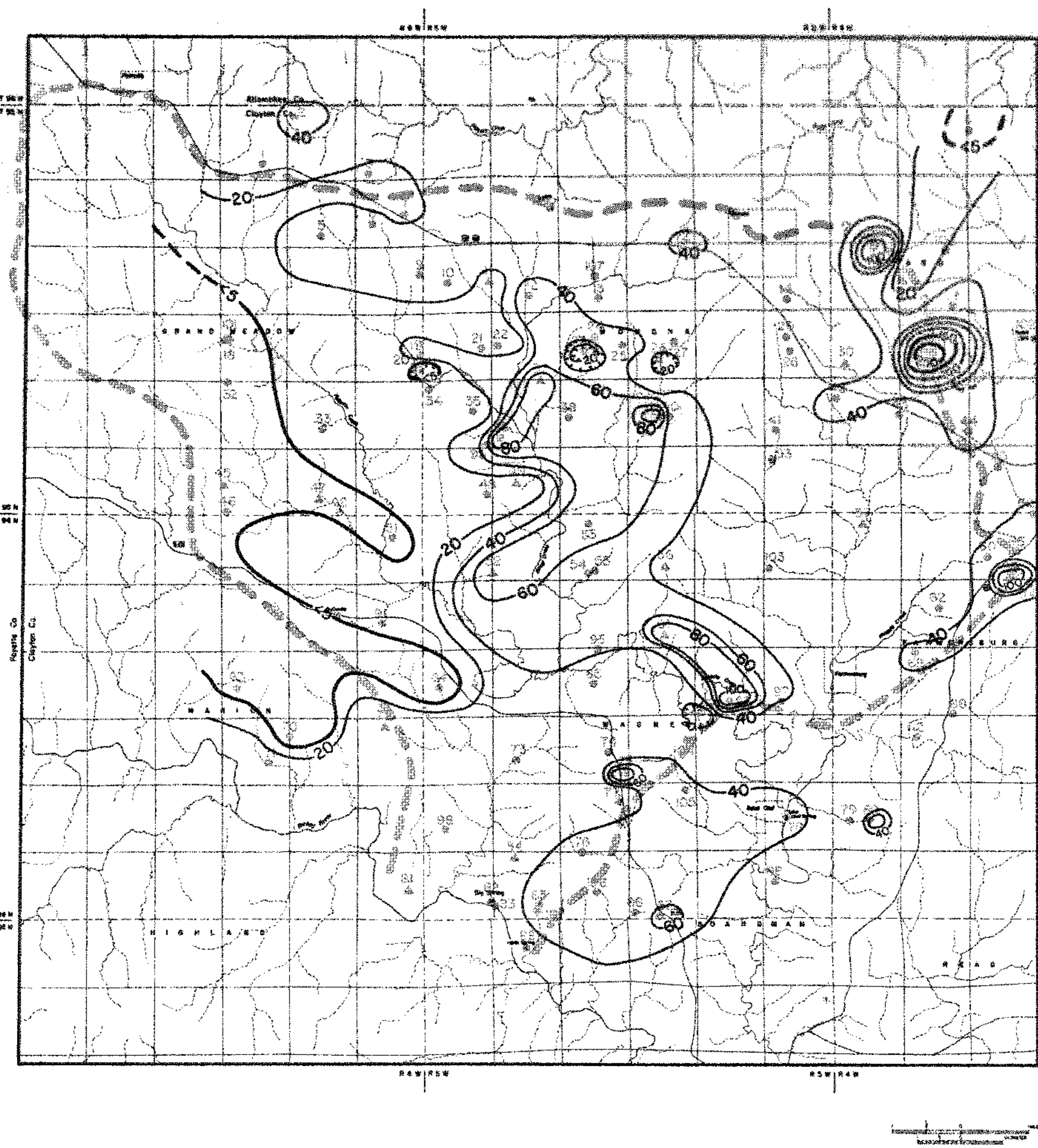


Figure 8. Histogram of nitrate concentration from analyses of water samples from Galena aquifer wells and springs, November-December, 1981. (From Hallberg et al., 1983.)

sinkholes to recharging the Galena can be determined, as well as the chemicals or sediment which enter the aquifer through them. Similarly, the total role of infiltration to recharge, both water and chemical loading, can be evaluated through time.

Water which flows into sinkholes moves rapidly through conduits to discharge at Big Spring. Such water shows on a hydrograph as a very rapid change in discharge. Water entering the aquifer from infiltration, affects discharge modestly and slowly. Figure 10 idealizes such changes and compares them. Hydrograph analytical techniques allow the separation of the sources of recharge. Water quality analyses conducted on samples collected to represent each recharge mechanism, reveal the chemical contribution of each mechanism.

Table 4 summarizes the mechanisms and their relative contribution to the Galena aquifer in the Big Spring basin. Several major conclusions can be drawn from the hydrograph separation analysis. First, even in a karst region, such as the Big Spring area, most aquifer recharge results from normal infiltration. About 90% of the recharge of Big Spring results from infiltration through the soil; only 10% results from surface flow into sinkholes. Second, nitrate which is a very soluble chemical, enters the aquifer through the soil during normal infiltration recharge. Ninety-five percent of the nitrate is delivered to Big Spring with normal infiltration water. Thus, any aquifer that receives significant recent recharge could develop nitrate problems. Third, the majority of at least one herbicide, atrazine, is delivered to the Galena aquifer through normal infiltration recharge. Although surface waters entering sinkholes deliver the highest concentrations of atrazine, and may deliver much of the other



Nitrate Concentration (Nov.-Dec., 1981)

Contour Interval - 20 Mg/l

Departure from Stated Contour Interval

Figure 9. Map contouring nitrate concentrations recorded from Galena aquifer inventory water samples. Numbered dots and triangles are sampling sites. (From Hallberg et al., 1983.)

Table 2. Summary of annual monitoring data from Big Spring. (Modified from Hallberg et al., 1983; Hallberg et al., 1984a,b; Hallberg, 1985.)

	Water Year			
	1982	1983	1984	1985
Mean Discharge (cfs)	51.4	56.9	44.9	35.0
Total Discharge (inches)	6.8	7.5	5.9	4.6
Flow-weighted Mean NO_3 Concentration (mg/l)	39	46	43	31
Flow-weighted Mean Atrazine concentration (μg/l)	0.2	0.3	0.5	0.7

Table 3. Maximum pesticide concentratrions and percent pesticide detections from Big Spring discharges, Clayton County, Iowa in northeastern Iowa studies, 1981-1985 (Modified from Hallberg, 1985 and Kelley et al., 1986).

Common Name Active Ingredient	Typical Trade Name	Maximum Concentration μg/l (ppb)				Percent Detections from all samples (percent)
		Big Spring Basin				
Herbicides		WY-82	WY-83	WY-84	WY-85	
atrazine	AAtrex, Atrazine	2.5	5.1	10.0	6.1	98
alachlor	Lasso	0.2	0.6	4.0	5.0	20
cyanazine	Bladex	0.7	1.2	1.7	4.6	22
metolachlor	Dual	---	0.6	4.5	4.6	7
metribuzin	Sencor/Lexone	---	---	---	3.6	<1
2,4-D	2,4-D	NA	NA	NA	0.2	<1
Insecticides						
fonofos	Dyfonate	---	0.1	0.3	0.4	2

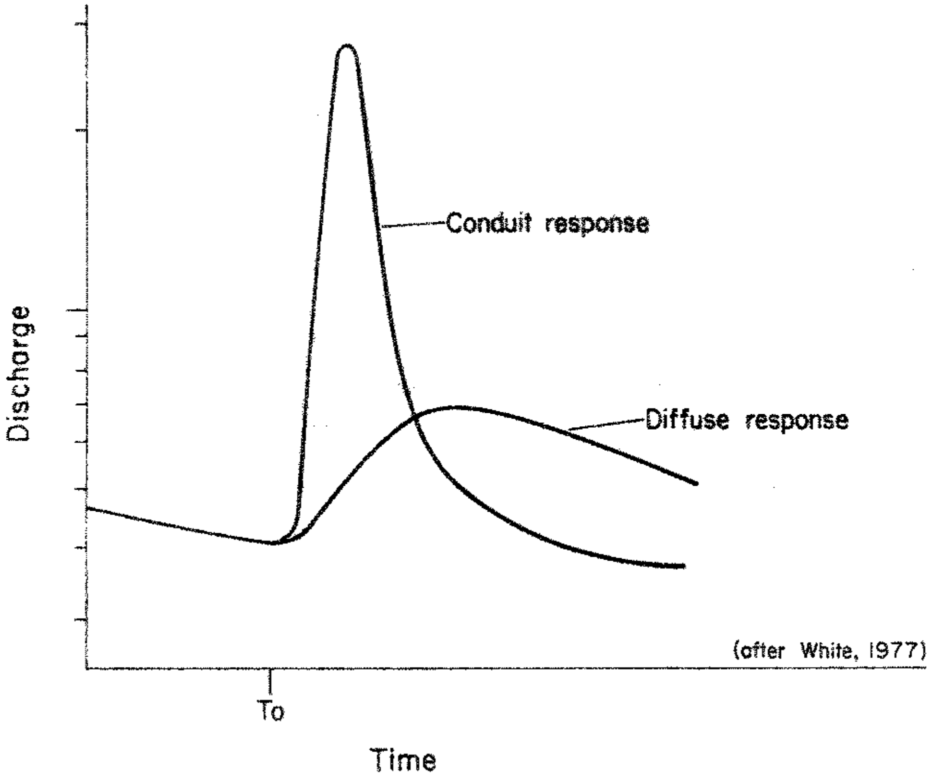


Figure 10. Schematic hydrographs showing the difference between conduit-flow (sinkhole recharge) and diffuse-flow (infiltration recharge) discharge from a carbonate aquifer over time in response to a recharge event at time To.

pesticides at Big Spring, substantial amounts of atrazine, and possibly other herbicides can be delivered via normal infiltration. Statewide sampling has confirmed that some pesticides get into groundwater through normal infiltration. Nine of the eleven most commonly used herbicides in Iowa have been found in groundwaters where recharge occurs only via normal infiltration (Kelley et al., 1986).

However, runoff into sinkholes has been shown to produce special water quality problems including: high concentrations of sediment, higher concentrations of pesticides, high concentrations of ammonia, rapid temperature fluctuations at certain times of the year, intermittent bacterial contamination and the potential for temporary contamination from spills or improper disposal of materials, such as occurred in 1963 when creamery wastes were disposed of improperly and a fish kill resulted.

The Big Spring groundwater basin encompasses an area of 103.24 square miles. It is intensely utilized for agriculture and contains Clayton County's finest cropland. Eighty percent of the soils are developed in loess parent

Table 4. Recharge mechanisms to the Galena aquifer in the Big Spring basin. (Modified from Hallberg et al., 1983; Hallberg et al., 1984b; unpublished data).

	1982		1983		1984	
	Conduit	Infiltration	Conduit	Infiltration	Conduit	Infiltration
Water Total Discharge (Acre-feet)	3,360 9%	34,080 91%	4,502 11%	36,871 89%	2,050 6%	30,565 94%
Nitrate Nitrogen (lbs.)	52,000 6%	821,000 94%	57,000 5%	1,093,000 95%	35,000 4%	806,000 96%
Atrazine (lbs.)	2.3 16%	11.9 84%	14.5 47%	16.7 53%	13.2 33%	26.8 67%

material and only 13% of the area contains hillslopes graded steeper than 14 percent. Ninety-one percent of the land area is cropped: 54% is planted to corn; 9% is strip cropped; 27% is in a rotation of alfalfa, oats, or pasture. Only 6% of the land area is forested; 3% is classified as roads, towns, or quarries. Thus, in a typical year 60% of the land is planted to corn and about 30% is in a cover crop rotation (Hallberg et al., 1983).

Dairy cow populations, hogs and cattle populations are high for northeast Iowa and livestock populations have shown increases of about 30 percent over the past 15 years. Row crop production has also increased in the past 15 years, up 40 percent. Much of this increase has occurred over more marginal soils--soils with less water holding capabilities because they are developed where limestone or shaley limestone occurs within the solum. However, nitrogen fertilization rates have increased about 80% over all the corn acreage, both old and new (Hallberg et al, 1983). Currently corn is fertilized in the basin at an average rate of 240 lbs/acre including 70 lbs. manure, 20 lbs. alfalfa, and 150 lbs. commercial fertilizer (Padgett, 1985).

The combination of natural nitrogen sources (rainfall, soil organic matter, decaying plant matter, manure) plus the added nitrogen sources of the past 15 years (more manure and especially more commercial fertilizer) have apparently lead to a rapid rise in nitrate levels. Currently, fertilizer N accounts for 56% of the available N in the Big Spring basin, manure and soil N account for 25%, rainfall accounts for 10%, and rotated crops account for 9% (Hallberg, 1986). Figure 11 relates changing nitrogen sources with nitrate increase in Big Spring waters. The apparent linear increase in nitrate concentration with increased fertilization is supplemented by agronomic field studies where tile lines are monitored (Gast et al., 1978; Kanwar et al., 1983).

Monitoring of Big Spring and surface streams leaving the basin allows estimates of nitrate-nitrogen losses to be estimated. For the water years 1982, 1983, and 1984 nitrogen losses, as nitrate only, were equivalent to the

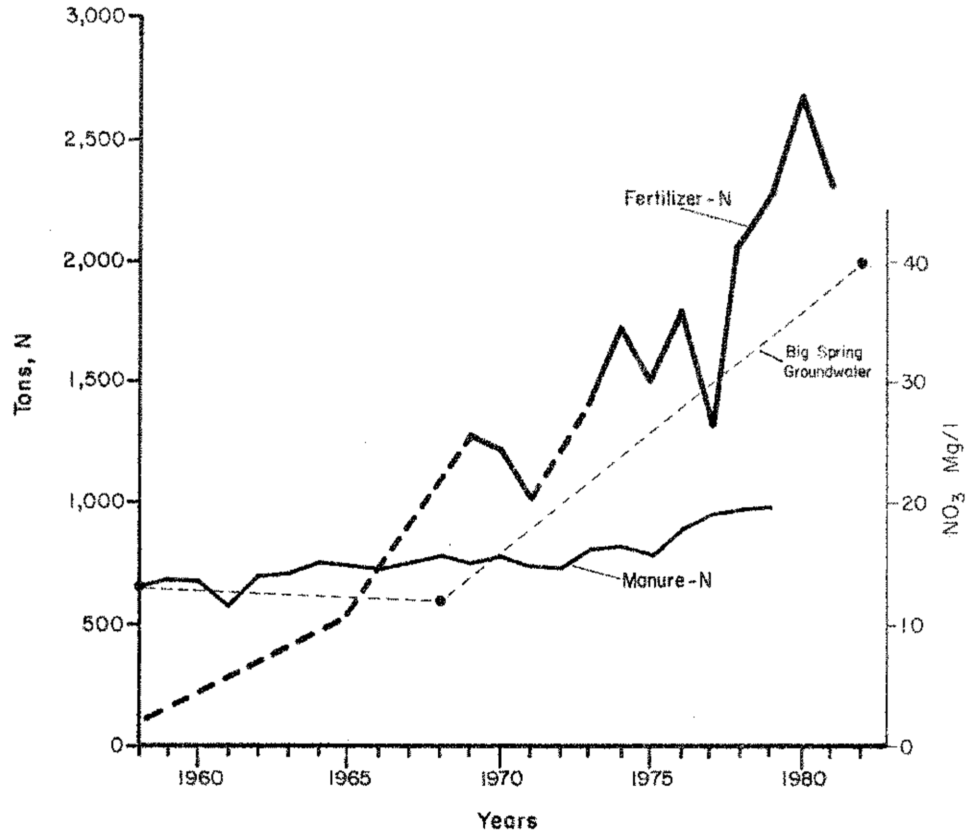


Figure 11. Estimated tons of fertilizer N and manure-N applied in the Big Spring Basin and average NO_3 concentration (dashed line, right axis for scale) in groundwater at Big Spring (from Hallberg et al., 1983).

range of 33% to 55% of all the fertilizer nitrogen applied. Such losses represent a major economic impact on the farming community as well as a major environmental impact on the state's groundwater. It is such results that have recently influenced Iowa agencies to try and develop both economically and environmentally sound practices for agriculture through programs such as the Big Spring Demonstration Project which will be discussed at Stop 6 on this trip.

STOP 4: Dry Hollow Swallow

Disappearing streams or "swallow holes" are common occurrences in the highly karstified areas of northeastern Iowa. Along with sinkholes and open fractures at the landsurface, they provide avenues for the direct input of surface water into the groundwater. These landsurface openings are the primary locus for the input of sediment and sediment-attached chemicals into the groundwater.

Several karst features are evident at this stop (Fig. 12). Immediately east of the road on the north side of Dry Hollow is a reactivated sinkhole. During the 1950s and 1960s this sinkhole was used as a garbage dump. Today the fill is collapsing into the sinkhole and the debris is being introduced into the groundwater system. This is not an isolated incident, sinkholes have been a favorite location for the disposal of domestic and farm waste for a long time. Recent public education programs coupled with rural waste collection areas are significantly reducing this aspect of groundwater contamination.

The portion of Dry Hollow we will visit flows across the Dubuque Formation and the upper portion of the Wise Lake Formation (Stewartville Member) of the Galena Group. The stream pattern is controlled by joints in the rock. Solutionally enlarged joint faces and bedding planes, as well as abundant vugs and larger karst conduits are evident along the valley walls. Portions of the stream course we will walk along have a U-shaped crossection and the adjacent exposed rock is very weathered. It is possible that portions of the stream course are occupying a collapsed karst conduit. Other streams and valleys in the area display similar features.

Usually Dry Hollow's stream doesn't flow the full length of the valley. The location of an often-active swallow is shown on the accompanying topographic map. At that location the stream veers to the east and drops into an opening in the eastern valley wall. Spelunkers have explored the opening and report that it drops between ten and fifteen feet nearly vertically and then sumps (is water filled; M. Bounk, personal communication).

Dye tracings by the Iowa Conservation Commission in the 1970s in nearby sinkholes indicate that Dry Hollow and other karst southeast of Farmersburg are connected to the conduit network which issues at the St. Olaf Spring along Roberts Creek about 1.2 miles southwest of the Dry Hollow swallow. During dry periods, Dry Hollow's stream doen't flow as far as the swallow. During these intervals the stream gradually sinks into its bed, which is connected to the karst-conduit system through solutionally enlarged joints and bedding planes. This phenomena of surface water loss through the bed is very common throughout the Big Spring basin where stream levels are above the potentiometric surface of the Galena aquifer.

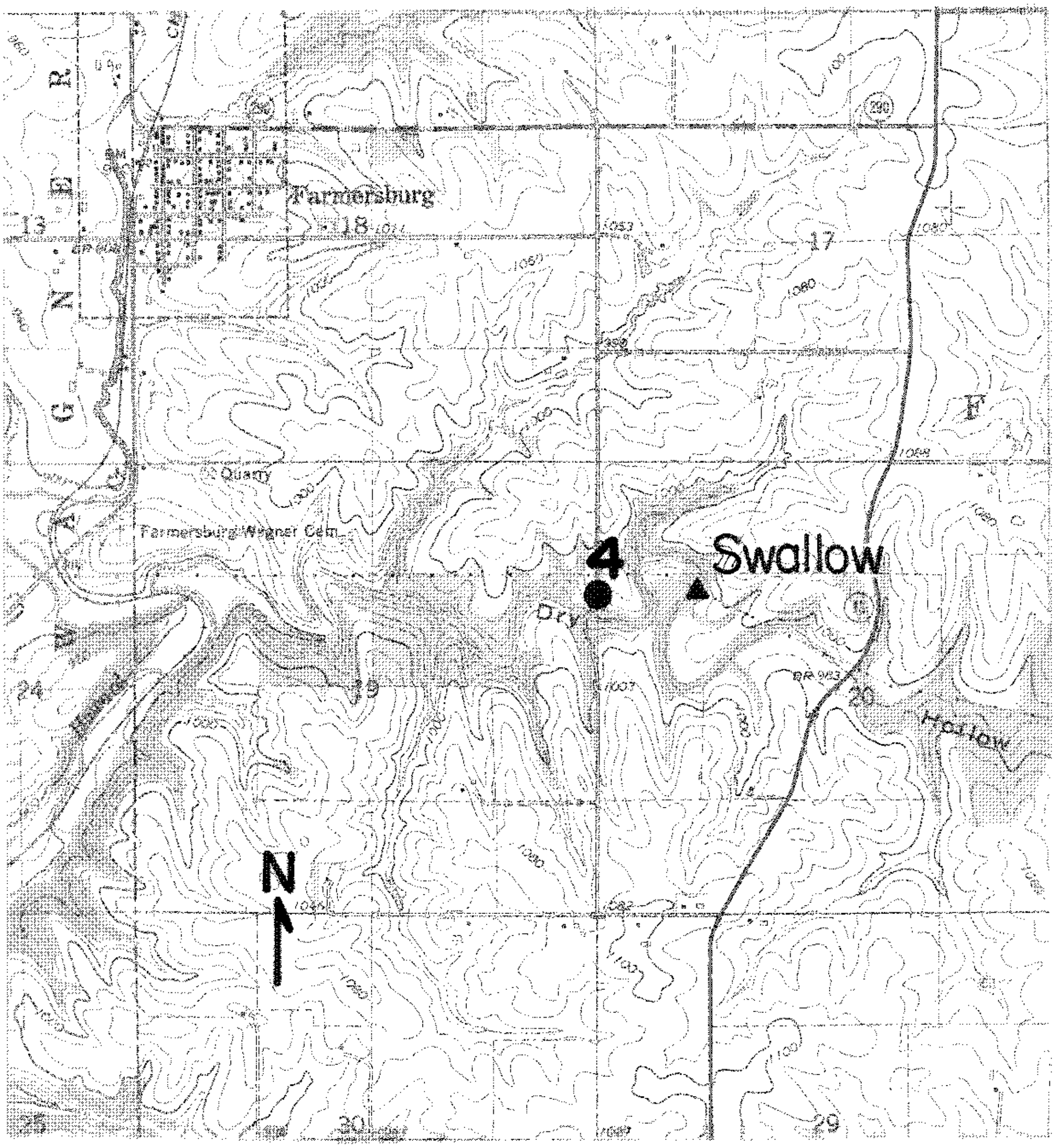


Figure 12. Topographic map showing the location of Stop 4 and the Dry Hollow swallow. (From USGS Farmersburg 7.5 minute topographic quad.) 2.5 inches equals approximately 1 mile.

STOP 5: Sass Area

Sinkholes are the most prevalent surficial expression of karst development in northeastern Iowa. Figure 13 presents a summary of a sinkhole survey of northeastern Iowa undertaken in 1980. It is evident from the figure that 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.

Sinkholes also exibit a non-random distribution on a local scale. Examination of figure 14 reveals that within the Big Spring basin there are areas of sinkhole concentration and other areas where sinkholes are rare or absent. Sinkholes are concentrated where the Elgin Member of the Maquoketa Formation is relatively thin or absent over the Galena Group rocks. On the west side of the Big Spring basin sinkholes are not present. The Brainard Shale of the Maquoketa Fm. is present above the Elgin Member in this area, and forms an aquiclude which greatly retards the development of solutional karst in this area.

Stop 5 is located in one of the areas of sinkhole concentration in the east-central part of the Big Spring basin (Fig. 15). Other karst features, such as sinking streams and blind valleys are present in this area. 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, peronsal 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 or 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 about 0.5 miles south of Stop 5A (5B on Figure 15) 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.

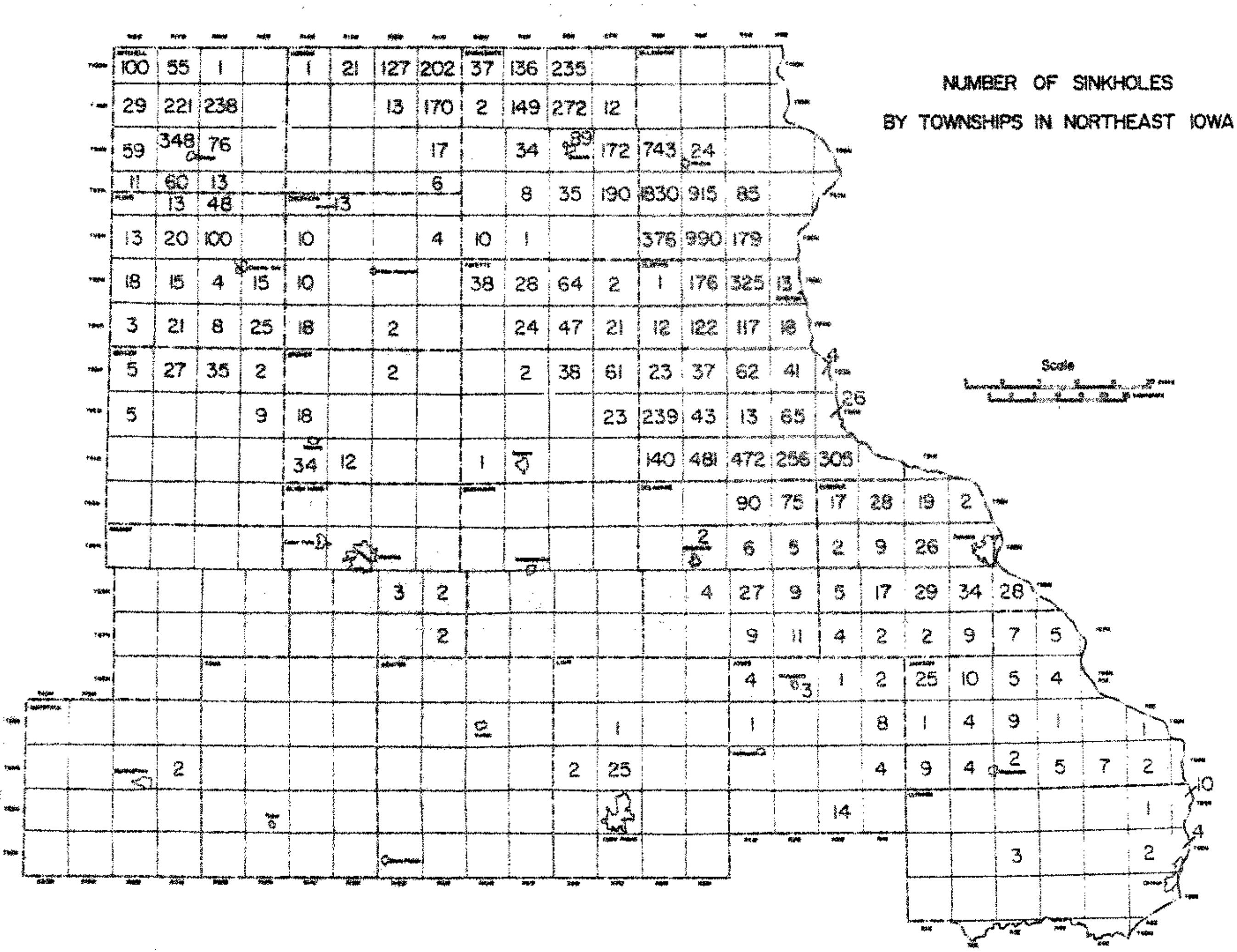


Figure 13. Summary of the distribution of sinkholes in northeastern Iowa. Numbers indicate the number of sinkholes in each township. (From Hallberg and Hoyer, 1982.)

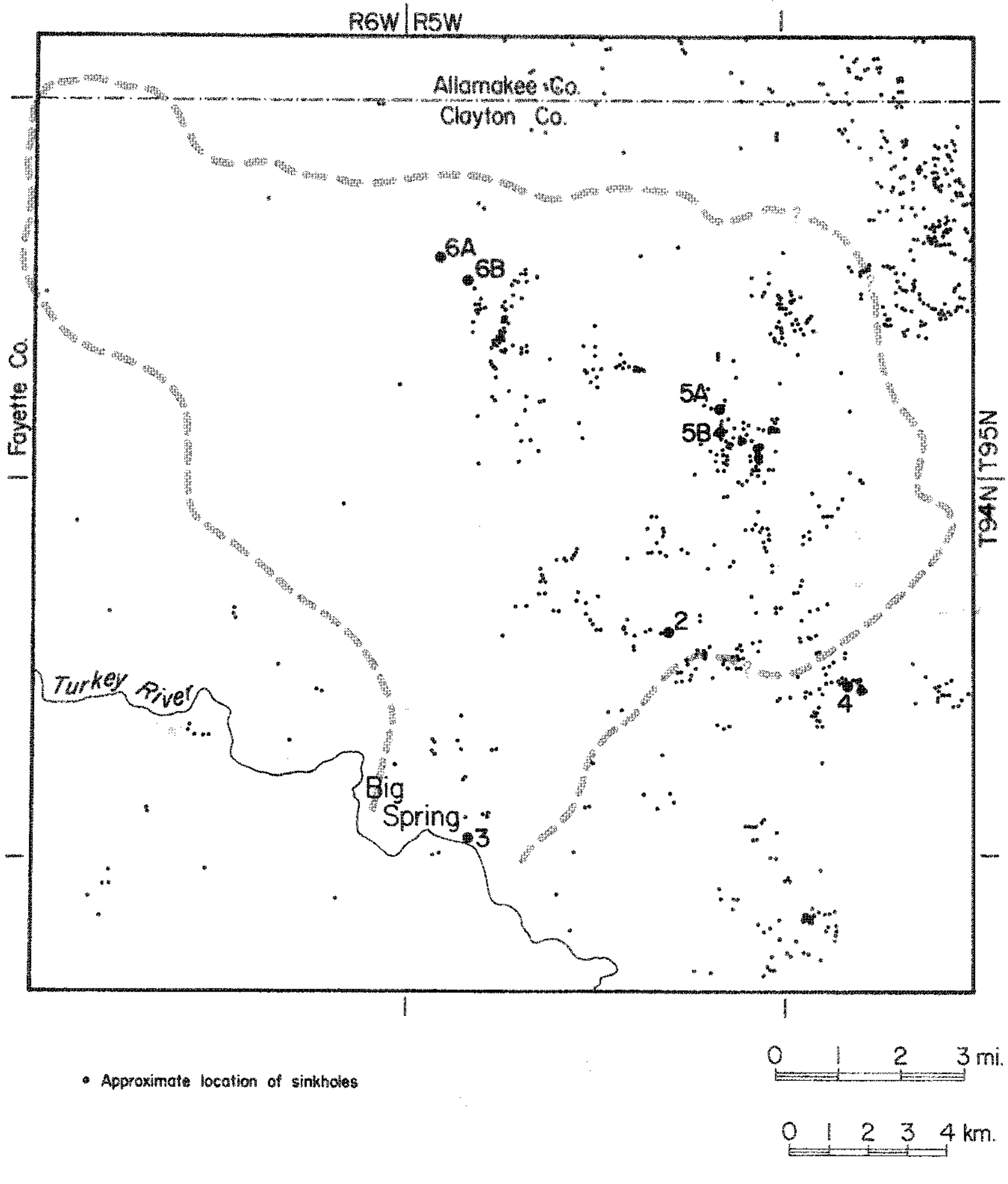


Figure 14. Approximate location of sinkholes in the Big Spring study area. (From Hallberg et al., 1983).

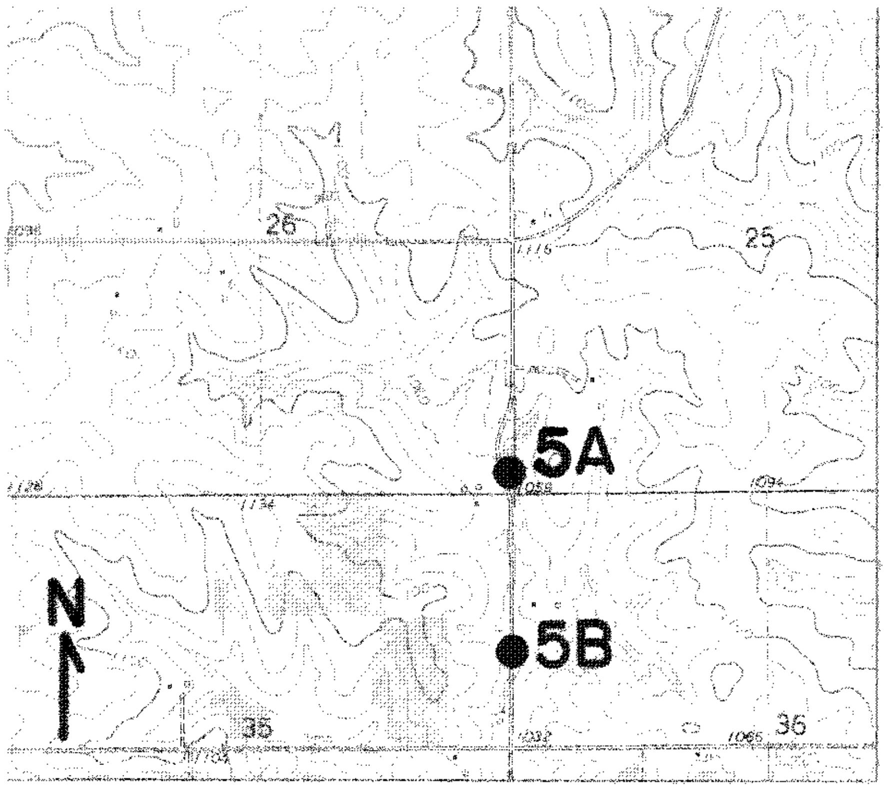


Figure 15. Topographic map showing the location of Stop 5. (From USGS Monona 7.5 minute quad.) 2.5 inches equals approximately 1 mile.

STOP 6: Big Spring Basin Demonstration Project: Bugenhagen Basin

The Big Spring Basin Demonstration Project is a cooperative, interagency program designed to demonstrate and document economically viable techniques to protect groundwater from the non-point source contamination of agricultural chemicals. The project addresses the question: How can current farming practices be changed to protect groundwater quality while maintaining profitability? The seven-year program which began in 1986 is being conducted in a 103 square mile basin in northwest Clayton County because previous research and the area's geology provide a unique opportunity to measure and assess groundwater quality in relation to agriculture. The basin functions as a large, natural, outdoor laboratory. Throughout the project agricultural activities and groundwater quality will be monitored within the basin. The Big Spring Fish Hatchery, where most of the basin's groundwater discharges from the aquifer, will receive special monitoring attention. Such control will provide assurance that conclusions drawn about the movement of agricultural chemicals into groundwater are applicable to protect groundwater throughout Iowa. Groundwater protection is expected to occur as more efficient ag-chemical management is documented and farm managers voluntarily employ alternative management practices in their farming operations. Agency participants believe the adoption of better chemical management practices should result in more efficient, economical crop production as well as groundwater protection. Successful ag-chemical management research, combined with special educational programs, form the core of the Demonstration Project. Experimental farm plots will be developed to document management practices and to demonstrate their potential to area farm managers. Drawing upon research results, education programs will assist farm managers to employ efficient fertilizer and pesticide management techniques within their farming systems. These programs will be combined with special assistance in the areas of soil conservation, and nutrient and pesticide management. The project also includes economic analyses of management practices, a careful evaluation of surface-and groundwater quality, and an evaluation of how effective educational programs can be to implement a non-point source groundwater-protection strategy. The entire project is projected to cost 6.8 million dollars.

The project includes the active cooperation and participation of the following agencies: Agricultural Experiment Station (ISU), Clayton County Soil Conservancy District, Cooperative Extension Service (ISU), Department of Agronomy (ISU), Institute of Agricultural Medicine (U of I), University Hygienic Laboratory (U of I), Iowa Department of Natural Resources, Iowa Department of Agriculture and Land Stewardship, Northeast Iowa Conservancy District, U. S. Agricultural Stabilization and Conservation Service, U. S. Environmental Protection Agency, U.S. Geological Survey, and U.S. Soil Conservation Service.

One of the cornerstones of the project is the sub-basin implementation project being conducted in the "Bugenhagen Basin." The watershed was selected to act as a focal point for the documentation of "best management practices" and their effects on groundwater. This portion of the overall project was designed to help researchers evaluate practical farm-owner experience with practices and allow agencies some experience integrating soil conservation techniques with better fertilizer and pesticide management. Further, it acts as a focal point for educational activities such as field tours and as a center from which techniques can diffuse, farmer to farmer, into the larger Big Spring basin.

"Bugenhagen Basin" is 1.7 square miles in size and drains entirely to a series of sinkholes (Fig. 16). Since 1981, it has been the site of routine water

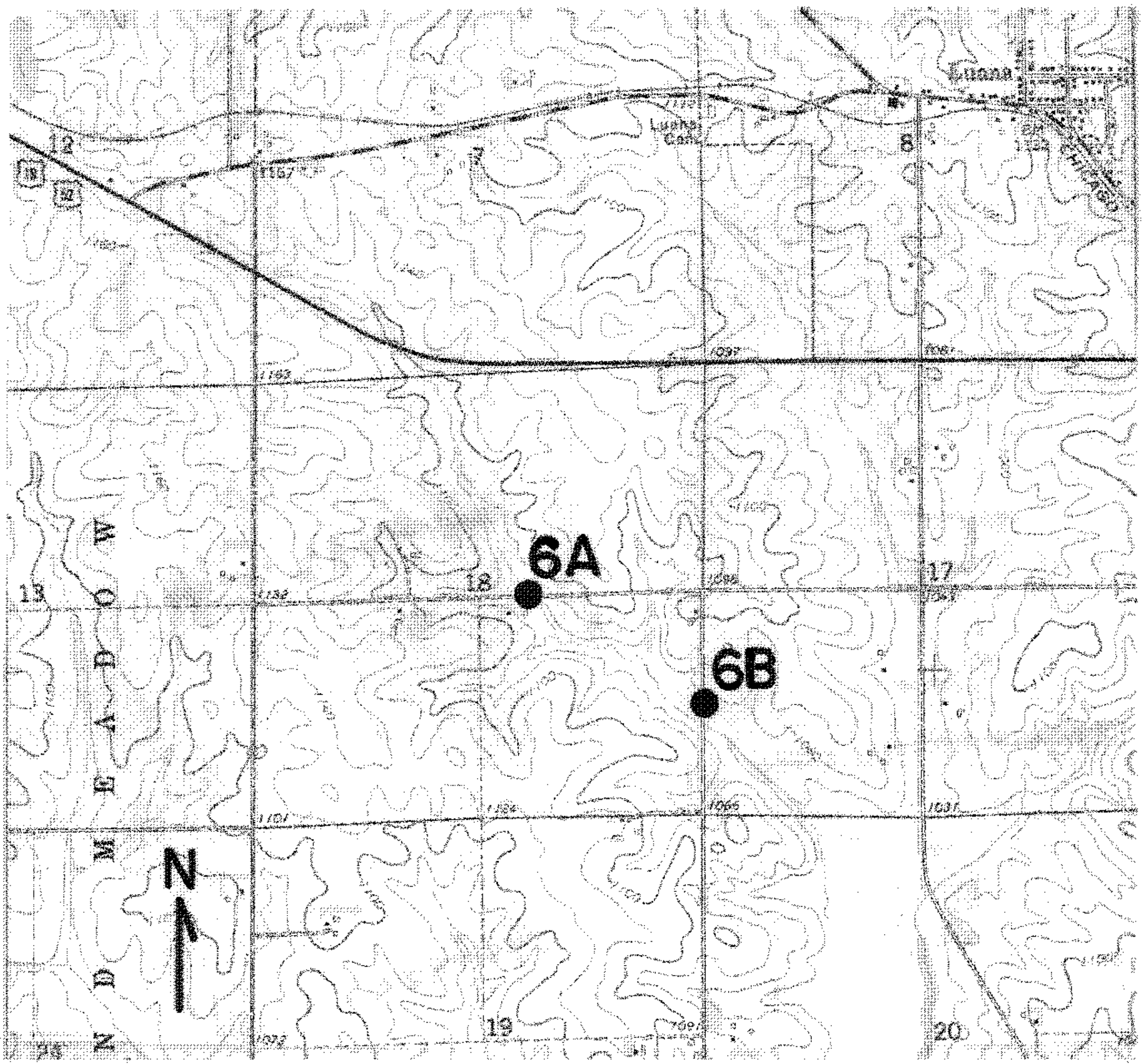


Figure 16. Topographic map showing the location of Stop 6. (From USGS Monona 7.5 minute quad.) 2.5 inches equals approximately 1 mile.

quality monitoring of tile lines, surface water, and groundwater. It is the only watershed in the Big Spring Basin which drains entirely to a sinkhole and generally maintains surface flow. Most watersheds flowing to sinkholes rarely exhibit surface flows, and thus become almost useless for monitoring. The combination of size (the largest) and location (probably having the thickest Maquoketa cover) make it suitable for water quality monitoring because water can be collected! Larger streams, Silver Creek and Roberts Creek, have been reported to disappear into sinks or their stream beds, but normally they flow past the major conduit zones upon their silty stream-bed deposits.

A special cost-share program was offered in the watershed. This was funded by the Division of Soil Conservation (Ia. Dept. of Ag. and Land Stewardship), U.S. Agricultural Stabilization and Conservation Service, and the U.S. Soil Conservation District and administered through the Clayton County Soil Conservation District. To meet project objectives in a timely manner, farmers recieved higher cost share rates, special cost share programs for some practices not usually a part of soil conservation programs, such as for pasture management, and the assurance of rapid farm plan development. Farmers also recieved special consultation from ISU Agricultural Extension Service staff on fertilization, manure handling techniques, weed and insect control, and econmics. In return, farmers were required to use specified rates of fertilization, utilize integrated pest management techniques, keep soil erosion rates below 5 tons per acre, and provide production records to researchers. They were prohibited from applying nitrogen in the fall and from spreading manure on frozen ground. Further, they were expected to allow researchers and visitors to use their land as a laboratory and classroom.

Landowner response has been enthusiastic and very cooperative. In the first year, ninety percent of the basin is covered by special long term agreements (7 years) which include soil conservation and nutrient and pesticide management plans. Most of the soil conservation practices will be in place before the end of the second year. Further, first year crop yields are expected to be excellent in spite of signficant reductions in fertilizer application rates.

Monitoring equipment has been installed to assist in the documentation of water quality within the basin (Fig. 17). Although fragmentary discharge records have been collected by hand since 1981, a continuously recording gaging station was constructed by the U.S. Geological Survey in May, 1986. Special flumes were conducted during July and August, 1986, by ISU Agricultural Experiment Station engineers. These will be used to record tile flows from selected areas and surface runoff from the upper half of the area. They serve as positive signals that the Big Spring Basin Demonstration Project is moving ahead despite only partial funding through the cooperation of the participating groups. Such flow records, combined with sampling, are the basis for evaluating the best management practices. Brief records and limited analytical results have not been interpreted as of this date.

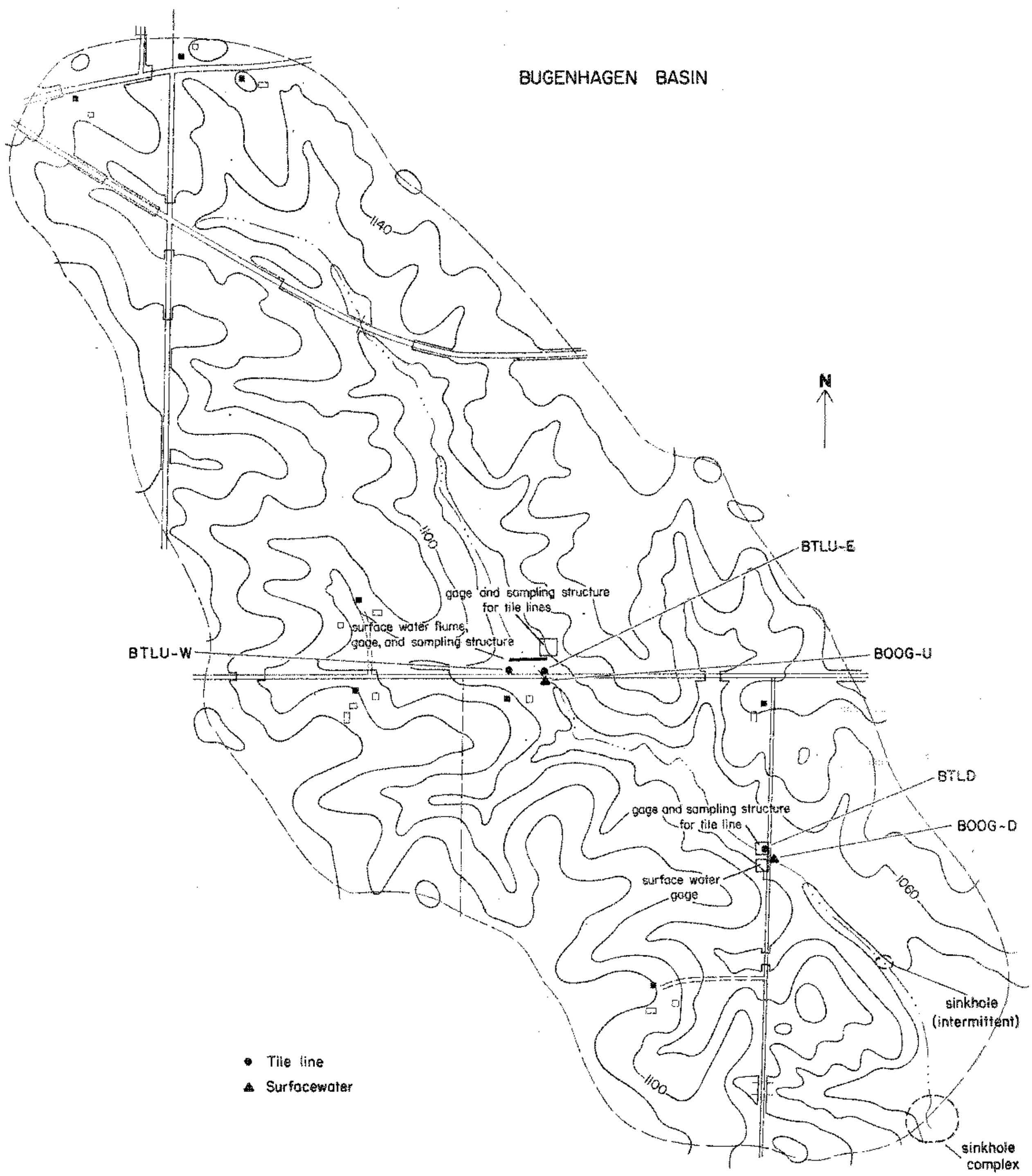


Figure 17. Topographic map of the Bugenhagen Watershed, sampling sites, and location of special demonstrations of best management practices in the Big Spring Basin Demonstration Project.

REFERENCES

Blackmer, A.M., 1984, Losses of fertilizer N from soils: *in* Proc. IA 37th Ann. Fert. and Ag-Chem. Dealers Conf., *Ia. St. Univ., Coop. Ext. Ser., CE-2081*; 4 p. (20811).

Bounk, M.J., 1983a, Some factors influencing phreatic cave development in the Silurian strata of Iowa, *Proc. Iowa Acad. Sci. 90*, pp. 19-25.

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

Delgado, D.J. ed., 1983, Ordovician Galena Group of the Upper Mississippi Valley--Deposition, Diagenesis, and Paleoecology: *Guidebook* 13th Annual Field Conf., Great Lakes Sec., Soc. Econ. Paleon. Mineral.

Gast, R.G., Nelson, W.W., and Randall, G.W., 1978, Nitrate accumulation in soils and loss in tile drainage following nitrogen application to continuous corn: *Jour. Environ. Qual.*, v. 7, p. 258-262.

Hallberg, G.R., 1985, Agricultural chemical and groundwater quality in Iowa: status report 1985: in *Proc. IA. 38th Ann. Fert. and Ag-Chem. Dealers Conf.* Ia. St. Univ. Coop. Ext. Serv., Ames, IA., CE-2158 9215q), 11 pp.

Hallberg, G.R., 1986, Nitrates in groundwater in Iowa, *Proc. Nitrogen and Ground Water Conf.*, Ia. Fert. and Chemical Assoc., Des Moines, IA, 36 pp.

Hallberg, G.R. and Bettis E.A. III, 1985, Overview of landscape evolution in northeastern Iowa I: Pre-Wisconsinan, Pleistocene Geology and 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 ground-water quality in northeast Iowa: *Ia. Geol. Surv., Open-File Rept. 82-3*, 120 p.

Hallberg, G.R., Baker, J.L., and Randall, G.W., 1986, Utility of tile-line effluent studies to evaluate the impact of agricultural practices on ground water, In *Proceedings from the Agricultural Impacts on Groundwater Conference*, National Water Well Association, in press.

Hallberg, G.R., Hoyer, B.E., Bettis, E.A. III, and Libra, R.D., 1983, Hydro-geology, water quality, and land management in the Big Spring basin, Clayton County, Iowa: *Ia. Geol. Surv., Open-File Rept. 82-3*, 120 p.

Hallberg, G.R., Libra, R.D., Ressmeyer, G.G., Bettis, E.A. III, and Hoyer, B.E., 1984a, Temporal changes in nitrates in groundwater in northeastern Iowa: *Iowa Geol. Surv., Open-File Rept. 84-1*, 10 p.

Hallberg, G.R., Libra, R.D., Bettis, E.A. III, and Hoyer, B.E., 1984b, Hydro-geologic and water-quality investigations in the Big Spring basin, Clayton County, Iowa: 1983 Water-Year: *Ia. Geol. Surv., Open-File Rept. 84-4*, 231 p.

Heitmann, N, 1980, Water source of Big Spring Trout Hatchery, Clayton County, Iowa: *Proc. Ia. Acad. Sci.*, v. 87, p. 143-147.

Kanwar, R.S., Johnson, H.P., and Baker, J.L., 1983, Comparison of simulated and measured nitrate losses in tile effluent: *Trans. Am. Soc. Agric. Eng.*, v. 26, p. 1451-1457.

Kelley, R.D., 1985, Synthetic organic compound sampling survey of public water supplies, *Ia. DWAWM Rept.*, April 1985, 32 pp.

Kelley, R.D. and Wnuk, M., 1986, Little Sioux River synthetic organic compound municipal well sampling survey, *Ia. DWAWM Rept.*, March, 1986, 24 pp.

Kelley, R., Hallberg, G., Johnson, L., Libra, R., Thompson, C., Splinter, R., and Detroy, M., 1986, Pesticides in groundwater in Iowa, In *Proceedings from the Agricultural Impacts on Groundwater Conference*, National Water Well Association, in press.

Levorson, C.O. and Gerk, A.J., 1983, Field recognition of stratigraphic position within the Galena Group of northeast Iowa (limestone facies), pp. C1-C11, In Delgado, D.J. (ed.), 1983, Ordovician Galena Group of the Upper Mississippi Valley--Deposition, Diagenesis, and Paleoecology: *Guidebook* 13th Annual Field Conf., Great Lakes Sec., Soc. Econ. Paleon. Mineral.

Libra, R.D., Hallberg, G.R., Ressmeyer, G.R., and Hoyer, B.E., 1984, Groundwater quality and hydrogeology of Devonian-Carbonate aquifers in Floyd and Mitchell Counties, Iowa, *Ia. Geol. Surv., Open-File Rept. 84-2*, 106 pp.

Lively, R.S., 1983, Late Quaternary U-series speleothem growth record from southeastern Minnesota, *Geology* 11: p. 259-262.

Padgitt, S., 1985, Farming operations and practices in Big Spring Basin: CRD 229, Coop. Ext. Serv., Ia. St. Univ., Ames, 48 p.

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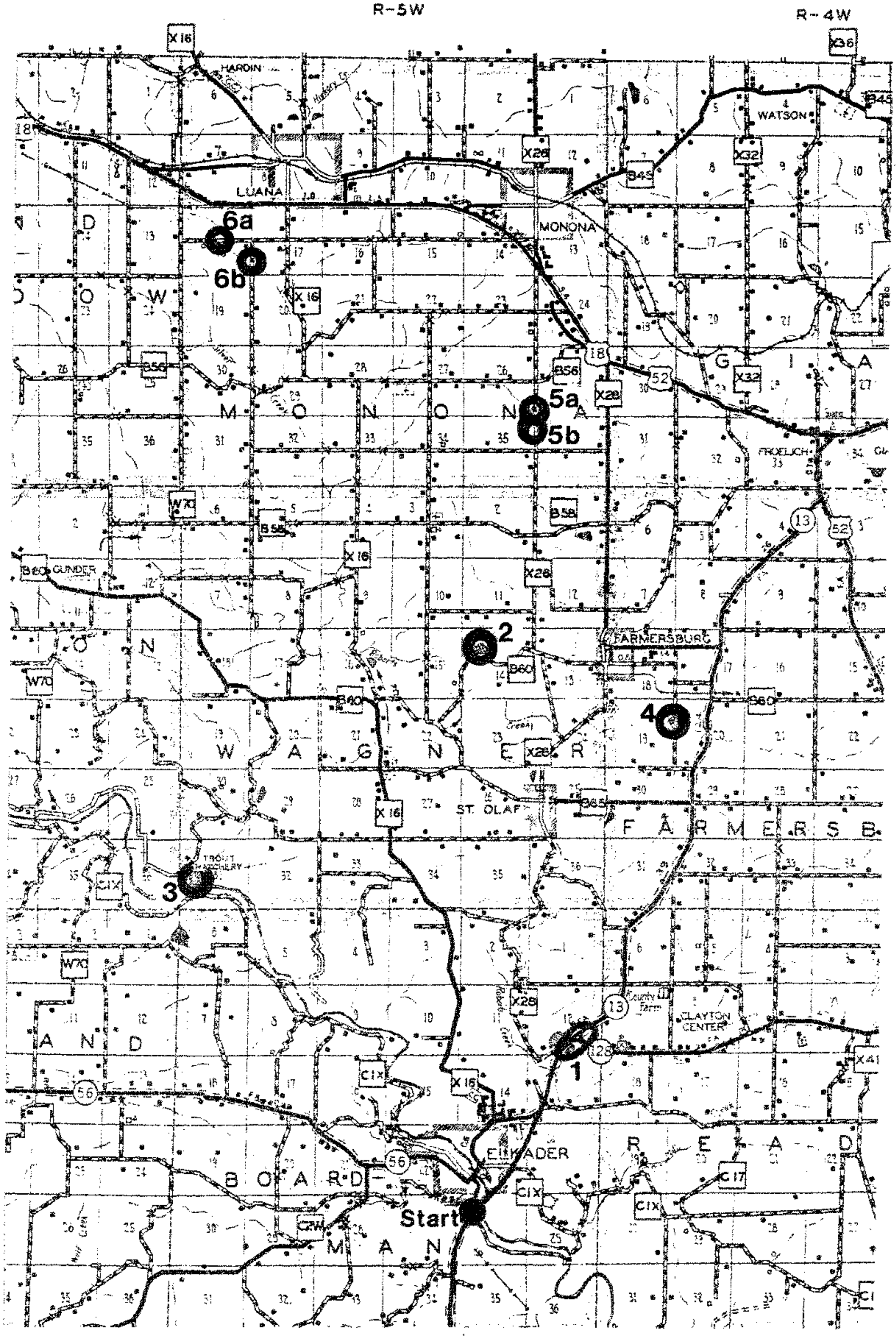
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