Iowa Geological Survey
Open File Report 83-3
June, 1983

HYDROGEOLOGY, WATER QUALITY, AND LAND MANAGEMENT IN THE BIG SPRING BASIN, CLAYTON COUNTY, IOWA

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A report on contract number 82-5500-02
of the Iowa Department of Environmental Quality
from the
Iowa Geological Survey
Donald L. Koch, State Geologist and Director
123 North Capitol Street
Iowa City, Iowa 52242

The publication of this document has
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(Contract Report; April 29, 1983)

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EXECUTIVE SUMMARY

The Big Spring study is the second phase of an assessment of groundwater quality in the karst-carbonate aquifers of NE Iowa. The project is jointly funded and conducted by the Iowa Geological Survey (IGS), Iowa Department of Environmental Quality (DEQ Contract No. 85-5500-02), and the U.S.D.A.-Soil Conservation Service (SCS), with assistance from the Iowa Conservation Commission (ICC), University Hygienic Laboratory (UHL), and U.S. Geological Survey. Staff from other institutions have participated in a consultative role, including personnel from Iowa State University, the Cooperative Extension Service, the U.S.D.A.-Agricultural Stabilization and Conservation Service, and the Iowa Department of Soil Conservation.

The Big Spring study was designed to provide a controlled assessment of a karst groundwater basin. This allows a more thorough understanding of the groundwater quality, the processes resulting in groundwater degradation, and evaluation of possible control measures or management practices. The Big Spring area was chosen because: 1) prior knowledge of the groundwater system in the Galena aquifer existed; 2) ICC and SCS had specific concerns with water-quality and landuse in the area; and 3) the ICC Fish Hatchery at Big Spring allowed the direct measurement of groundwater discharge from the basin, which is generally impossible in other areas.

The study was initiated with a basin-wide inventory. Over 320 rural residences were visited and 271 wells were inventoried. About 125 wells were sampled for water-quality analyses. The geology, soils, sinkhole locations, landuse, and piezometric surface of the Galena aquifer were mapped. SCS staff conducted surveys and inventories of ag-chemical use and application rates, as well as land-treatment practices used in the basin. The boundaries of the groundwater basin were defined from the piezometric mapping and dye-trace studies. As defined, the Big Spring basin is about 103 square miles in areas; about 11% of the area drains entirely to sinkholes. Water discharge and quality were monitored at Big Spring from 11/81 through 12/82. Water quality

also was monitored at selected wells, streams, springs, and tile lines. Of prime concern are the water-quality data on nitrates, pesticides, bacteria, and turbidity because of their possible effects on public health.

Results of monitoring groundwater in this study confirm many conclusions of the first phase of this study, which assessed regional water-quality problems in these karst-carbonate aquifers. During an original basin-wide water sampling inventory, the median nitrate concentration from the Galena aquifer was 35 mg/l, with individual analyses as high as 280 mg/l. However, where the Galena aquifer is protected from significant surficial infiltration or sinkhole "run-in" by a cover of Maquoketa shale, nitrates are not detected (<5 mg/l) in the groundwater. For the water year, the mean nitrate concentration in groundwater discharging at Big Spring was 40 mg/l, approaching the U.S.E.P.A. drinking water standard for nitrate (45 mg/l). This is in marked contrast to water-quality analyses from Big Spring from 1951 and 1968 which had a mean nitrate concentration of 13 mg/l. Comparison of these values suggests a 230% increase in nitrate concentrations in groundwater since the late 1960's. During this period, corn acreage increased about 40% and the application rate of fertilizer-N increased about 80%. As the corn acreage and application rate are "additive," the total fertilizer-N applied in the basin increased by about 250% during this same period. Other potential sources of increased nitrate were negligible by comparison. The primary reason for increased nitrate concentrations in the Galena aquifer clearly seems to be the dramatic increase in nitrogen fertilization.

The total discharge of nitrogen (as nitrate-N) from the Big Spring basin for the water-year was 905 tons; 527 tons in groundwater and 378 tons in streamflow. This amounts to 27 lbs-N/acre for the entire basin or, 47 lbs-N/ acre for the row-crop area of the basin. As a matter of perspective, the total N lost from the basin was equivalent to 33% of the total fertilizer-N applied in 1982. This is not to imply that all the N lost was 1982-applied N. Monitoring of the Turkey River indicates that such substantial N-losses occur regionally, and constitute an economic as well as an environmental loss.

Pesticides were not detected in groundwater during the winter and early spring of 1981-82. The herbicide, atrazine, appeared in detectable amounts in groundwater at Big Springs and most monitored wells within two weeks of application. At Big Spring atrazine persisted throughout the remainder of 1982, but it dropped below detectable limits in most wells. Concentrations of atrazine in groundwater ranged from 0.04 to 2.5 μg/l. Three other herbicides, Bladex, Lasso, and Dual were also detected in groundwater, but only during May and June. The pesticide concentrations measured are all very low, well below toxic levels and estimated-safe-average-daily-intake levels. The discharge of pesticides in groundwater during the water-year amounted to only about 14 lbs, approximately 0.04% of that applied in the basin. The total loss of pesticides in groundwater and streamflow is estimated at 0.4 to 4% of the amount applied.

Bacterial contamination of the aquifer was found in association with peak runoff periods. Turbidity and associated problems, such as sediment, soil-attached pesticides (especially dieldrin), and other organics, are also related to peak runoff. Persistent bacteria problems are not necessarily related to the karst-groundwater system, but may be associated with faulty domestic water systems. Cisterns, in particular, were found to be a common source of bacterial contamination in rural drinking water supplies.

Groundwater discharge was separated into two principle components: 1) a "base-flow" or "infiltration" component; and 2) a "peak conduit flow" or "run-in" component, related to surfacewater run-in to sinkholes. The "infiltration" component delivers to groundwater: 1) the highest concentrations and largest mass (94%) of nitrate (and other soluble nutrients); 2) the largest mass (84%) of soluble pesticides, but in very low concentrations; and 3) generally little sediment, turbidity, organic, or bacteria problems. The "run-in" component delivers to groundwater: 1) peak pesticide loadings, with concentrations 10 to 100 times greater than the "infiltration" component; 2) peak turbidity and sediment problems; 3) peak bacteria problems; and 4) generally lower concentrations of nitrates, compared to the "infiltration" component. The respective contributions of these components must be considered in any planning of control measures or management practices.

Health problems related to bacteria and viruses are widely known, and their potential existance in karst aquifers has been a concern of health officials for many years. The health effects of elevated levels of nitrate and persistent low levels of pesticides are not well known, and represent important subjects for further research.

Quantitative and qualitative evaluation of land-treatment changes are being conducted. Soils information (soil types, slopes, etc.), current landuse, geologic, and hydrologic data were all merged together in a computer data base. Using this data base, computer models were used to provide quantitative estimates of soil erosion and surface runoff under various land-treatment practices.

Common soil conservation measures and other land management practices which effect groundwater quality in karst regions were evaluated, based on the quantitative modelling and the qualitative assessment of various practices. Agricultural management practices which could improve groundwater quality are those which will reduce leaching losses of nitrate (e.g., through better N-management, reduced rates of application, and/or reduced acreages), reduce leaching losses of pesticides (e.g., through integrated pest control, use of less soluble products, and/or reduced acreages), and reduce pesticide and sediment delivery to sinkholes (e.g., through conservation measures, especially crop rotations or strip cropping).

Although some aspects of waste-disposal and management can be regulated, the larger concerns with agricultural chemicals must be addressed primarily through public education and further research. People living in karst areas should be made aware of the condition of their groundwater resource, and alerted to potential health hazards. Information on domestic water-treatment and alternative groundwater sources should be developed. Further, a program to promote research and implementation of appropriate land-management practices should be undertaken.

The publication of this document has been financially aided through a grant to the Iowa Department of Environmental Quality from the United States Environmental Protection Agency and a cooperative agreement with the U.S. Department of Agriculture, Soil Conservation Service.

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ACKNOWLEDGEMENTS

This study was possible only because of the hard work and support of many people besides the authors.

Mr. Jerry Spykerman and his staff at the ICC Big Spring Hatchery were instrumental in maintaining the continuous monitoring of the Big Spring. They also made all their facilities available to us. In particular, Jerry Spykerman's personal efforts at the Spring have enabled much of this project to be successful.

Nearly the entire IGS staff have been involved with this project, and were instrumental in its development. The data base analysis would not have been possible without the extensive support of Technical Services Group staff, especially Pete Kollasch and Ross Black, who assembled the software; assisted in entering, processing, and analyzing the information; and taught others to do these activities. Mike Bounk provided much information on karst and supervised the dye tracing. Bedrock geologic mapping was directed by Greg Ludvigson. Graphic arts were prepared by Pat Lohmann, and the manuscript was typed and formatted by Laurie Comstock. The initial water inventory of the basin was organized by Sue Lenker, who died in an auto accident while working on the project. Carol Thompson and Paul Van Dorpe provided special help organizing data at the start of the project. Gale Ressmeyer has provided countless insights and other assistance as a research associate on this project. Other IGS staff who have made significant contributions above and beyond the "call-of-duty," include Bob McKay, Bob Pyle, Mike Farmer, Mary Pat Heitman, and Deborah Quade. Sheila Underwood edited and proofread this report.

The University Hygienic Laboratory has provided excellent support. They provided sampling equipment and all the water-chemical analytical work, as well as timely answers to the many questions which arose during the study. We especially want to acknowledge the help of Patt Cain and Rolf Hahne.

This study was partially funded by the Iowa Department of Environmental Quality through a grant from the U.S. Environmental Protection Agency. Beyond the financial support; the keen interest, cooperation, and assistance of DEQ personnel has been invaluable to this work, particularly the efforts of Darrell McAllister, Rick Kelley, and Ralph Turkle.

Partial funding for this work was also provided through a cooperative agreement with the USDA Soil Conservation Service. As with the DEQ, the support from the Iowa SCS far exceeded financial contributions. We especially want to acknowledge the help received from Roger Koster, Stan Mitchem, Jim Reel, Dave Gibney, Bill Eno, Dennis Miller, Russ Knutson, and Roger Link.

Personnel from the US Geological Survey, Water Resources Division, Iowa City, also provided valuable assistance and advice. Ivan Burmeister and his staff established the gage and rating curve at Big Spring, and gaged the Turkey River and other springs. The study would not have been possible without his help. Oscar Lara provided unpublished information and valuable guidance and insight to our runoff estimates and water budget analysis. Bob Buchmiller assisted in the well inventory in the study area.

Mr. Richard Lively from the Minnesota Geological Survey provided many useful discussions on karst development and analyzed water samples for radon (not included in this report) concentration. Dr. Calvin Alexander, from the University of Minnesota provided information about dye-tracing procedures.

Many other people have discussed or reviewed some aspects of this research. Their ideas, suggestions, and criticisms were all appreciated. These people include Min Amemiya, Tom Fenton, Dick Handy, Stu Melvin, Gerry Miller, Mike Thompson, and Reg Voss from Iowa State University, James Gulliford, Dan Lindquist, and Ed Beardsley from the Iowa Department of Soil Conservation. Special recognition is due to Jim Baker, Department of Agricultural Engineering, Iowa State University, for his comments and insights, and for all his past research which provides much of the foundation for the study.

Jim Hosch, Clayton County Extension Director, and Frank Phippen, County ASCS Executive Director, provided valuable assistance in developing local publicity and cooperation. Steve Helfer, County Sanitarian, has provided local information.

Paul Waite, State Climatologist, and Don Menken, Conservation Officer and weather observer, have provided timely delivery of climatologic data.

Last, but clearly, not least, we must acknowledge the excellent support, cooperation, and encouragement of rural residents in the study area. The hospitality and cooperation we have received, in access to private land and wells, has truly been outstanding. In particular, we must specially thank the following and their families: Harold Kuntz, Kevin Ihde, Harold Vorwalds, Norbert Walz, Norbert Fritz, Donald Steva, Ron Schrader, Eugene Voss, William Eno, Barb Rodas, Al Landt, Elmer Bries, Harold Peterson, Ken Keehner, Francis Meisner, Harley Radloff, Ron Trudow, Franklin Wacker, and Ed Sass.

Even though this list of acknowledgements is lengthy, many other individuals who have contributed have gone unmentioned. A general word of thanks to all those who have helped.

INTRODUCTION

A program to study the hydrogeology of the karst-carbonate aquifer areas in northeast Iowa was undertaken: 1) to provide detailed information about the nature of the degradation of groundwater quality in the sinkhole regions and shallow carbonate aquifer areas in northeast Iowa; 2) to evaluate possible programs to alleviate these problems; and 3) to provide the technical information needed for public use and education. The first phase of this study (Hallberg and Hoyer, 1982; DEQ Contract No. 81-5500-04) provided a regional assessment of the physical nature of the karst regions and documented significant contamination of groundwater by nitrates in the karst areas and regions where the carbonate bedrock aquifers occur at shallow depths below the land surface. Because of the direct interaction between surfacewater runoff and infiltration with groundwater in the karst regions, the introduction of contaminants from the land surface into the groundwater is of great concern. On the regional level, the principal contaminants of concern for public health are nitrates, pesticides, bacteria (and viruses), and turbidity.

This regional assessment left some ambiguities because of a lack of adequate geologic and hydrologic controls in the regional water-quality data and because of the complexity of the karst-groundwater system. Also, to more fully evaluate possible protection programs, it is necessary to look at the nature of the hydrologic system in considerable detail, from the delivery of contaminants into, and their flow through, the karst-groundwater system. This current study, or phase II, was designed to provide a controlled and detailed assessment of a single karst basin. This detailed study will provide a more thorough assessment of the mechanics of groundwater degradation in these areas.

The Big Spring's Area

The area chosen for the detailed analysis was the Big Spring's karst area in northern Clayton County (see figure 1). This area was selected for numerous reasons. The karst in this area is formed primarily in limestone and dolostone of the upper Galena Group (Galena aquifer) of Ordovician age. It is a typical part of one of the three major karst areas of northeast Iowa identified in the first phase of this program (Hallberg and Hoyer, 1982). In addition to DEQ and IGS, the Big Spring's region has been of concern to the USDA, Soil Conservation Service (SCS), and the Iowa Conservation Commission (ICC). The SCS, in its Northeast Iowa River Basin study, identified groundwater quality as the major environmental issue of concern to area residents. The ICC has had past, and continuing, water problems which affect the operation of the Big Spring Fish Hatchery. As a consequence of these mutual interests, DEQ, SCS, and IGS are all contributing money and personnel to the program. ICC is also providing facilities and help from personnel at the Hatchery, which is an invaluable part of the study. (The U.S. Environmental Protection Agency, EPA, is now also providing direct funding which contributed to this report.)

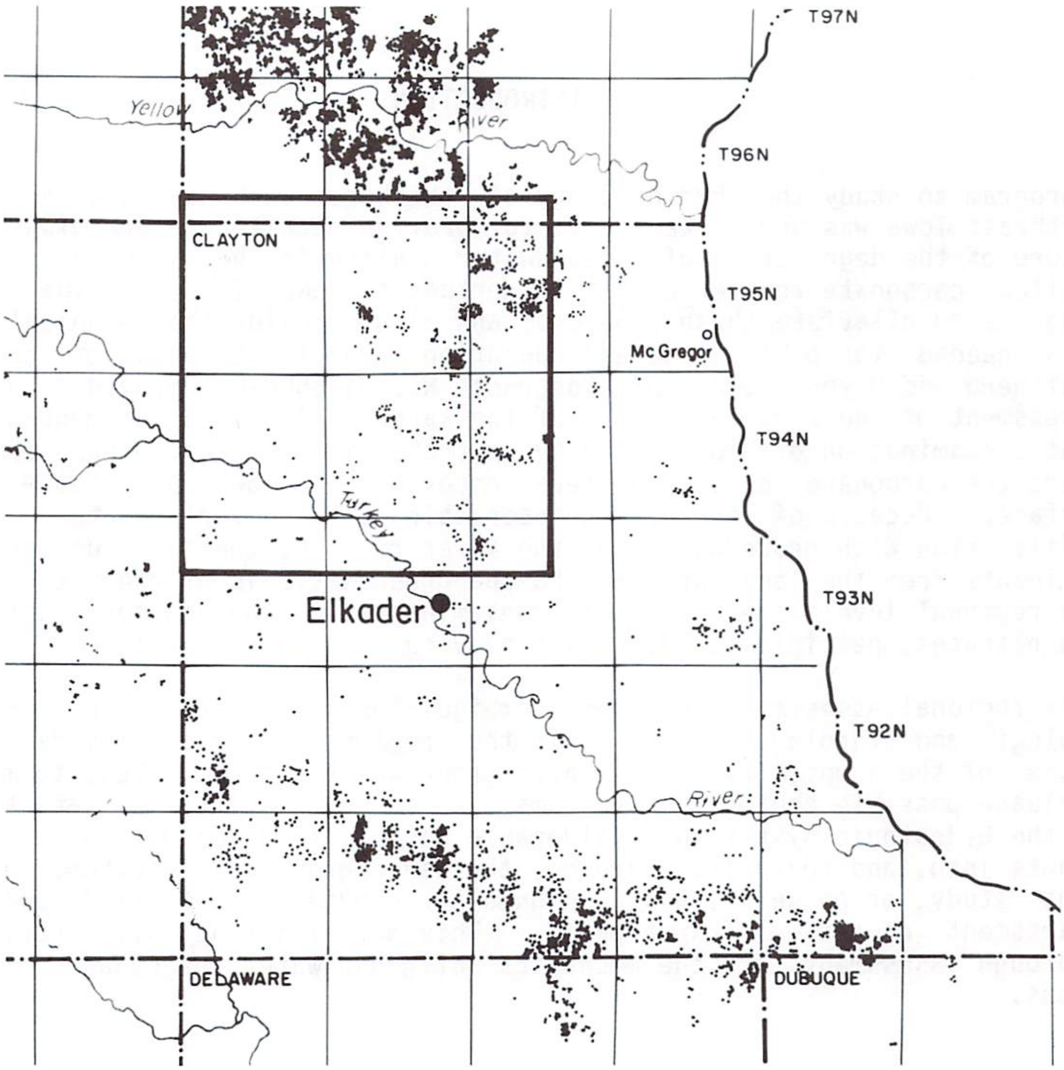


Figure 1. Location of Big Spring study area. Outlined area shows region covered by study area map. Dots indicate locations of sinkholes after Hallberg and Hoyer (1982, plate 1).

Prior studies on the karst-groundwater system of the Big Spring area provided an excellent base of needed information to begin this study. Studies by Steinhilber and others (1961) provided background information on the geology and hydrology of the area. Dye-tracing studies (Heitmann, 1980), which were conducted by ICC, provided significant information toward defining the groundwater basin. The structural control of the discharge of Big Spring at the fish hatchery afforded the opportunity to gage the discharge from the groundwater system. This is generally impossible in most groundwater studies. Big Spring is controlled to provide the constant cool-temperature water necessary for raising the trout. It is the largest karst-groundwater spring known in Iowa.

Water-Quality Concerns

In the first phase of this study, Hallberg and Hoyer (1982) determined that on the regional level the principal groundwater contaminants of concern for public health are nitrates, pesticides, bacteria (and viruses), and turbidity. This initial study documented significant contamination of groundwater by nitrates, to depths of 150 to 200 feet (45-60 m; figure 2) in the karst-carbonate aquifer regions of northeast Iowa (Hallberg and Hoyer, 1982; Hallberg et al., 1983). This and other studies (McDonald and Splinter, 1982; Nielsen et al., 1982; Hill, 1982; Saffinga and Keeney, 1977; Smith et al., 1975) have also shown that the limited data which exists suggests that nitrate concentrations in water have been significantly increasing over the past two decades, and that the principal source of the nitrate is clearly related to surface activities, mainly the widespread use of chemical-N fertilizers. Nitrates were monitored in detail in this study, as well as their relationship with other soluble ions.

There is very little data regarding the occurrence of common, modern pesticides in groundwater. Various reports suggest that pesticides generally do not occur in groundwater (Kim and Stone, 1981; Baker, 1980), or where pesticides have been found in groundwater, they have been related to accidental spills (Morris and Johnson, 1969; Kim and Stone, 1981), or that they may occur, but at very low concentrations (Baker, 1980). However, one study (Richards et al., 1975) showed the presence of low concentrations (<0.5 µg/l) of atrazine in the finished water supplies of several Iowa towns that use shallow alluvial wells for their water supply, as early as 1974. A more recent study in Wisconsin (Rothschild et al., 1982) shows the presence of aldicarb (trade name Temik; a soluble, systemic pesticide used for potatoes in Wisconsin) in a shallow, sandy aquifer.

The widely documented occurrence of pesticides in surfacewater and runoff from agricultural lands shows that pesticides must be entering the karst-groundwater system, carried along with runoff into sinkholes (Hallberg and Hoyer, 1982; Frank et al., 1982; Leung and Richard, 1982; Baker and Johnson, 1979; Morris and Johnson, 1969). There is no data available to suggest what the fate of these pesticides is in the groundwater environment. Additionally, studies of tile-effluent water (Von Stryk and Boston, 1977; Muir and Baker, 1976, Burnside et al., 1971) have shown that at least atrazine (a trizine herbicide) can leach through the soil to depths of at least 5 feet (1.6 m) because it was present in effluent from tile lines buried over five feet (1.6 m) deep (Muir and Baker, 1976). This suggests the possibility that pesticides may also enter the groundwater system through normal (diffuse) infiltration to shallow aquifers, as well as through surfacewater run-in to sinkholes. Where no pesticide-production plant or waste-disposal site occurs (i.e.--a point source) the only source of these chemicals is in non-point sources, from their application on ag-lands. A prime concern of this study was to evaluate the delivery mechanisms and fate of pesticides in groundwater.

The review of bacterial-analysis data from northeast Iowa was equivocal (Hallberg and Hoyer, 1982). No significant trends related to geologic settings were apparent. The data showed that regionally 35% of all analyses were unsafe or unsatisfactory, and it was suggested that many bacterial problems are

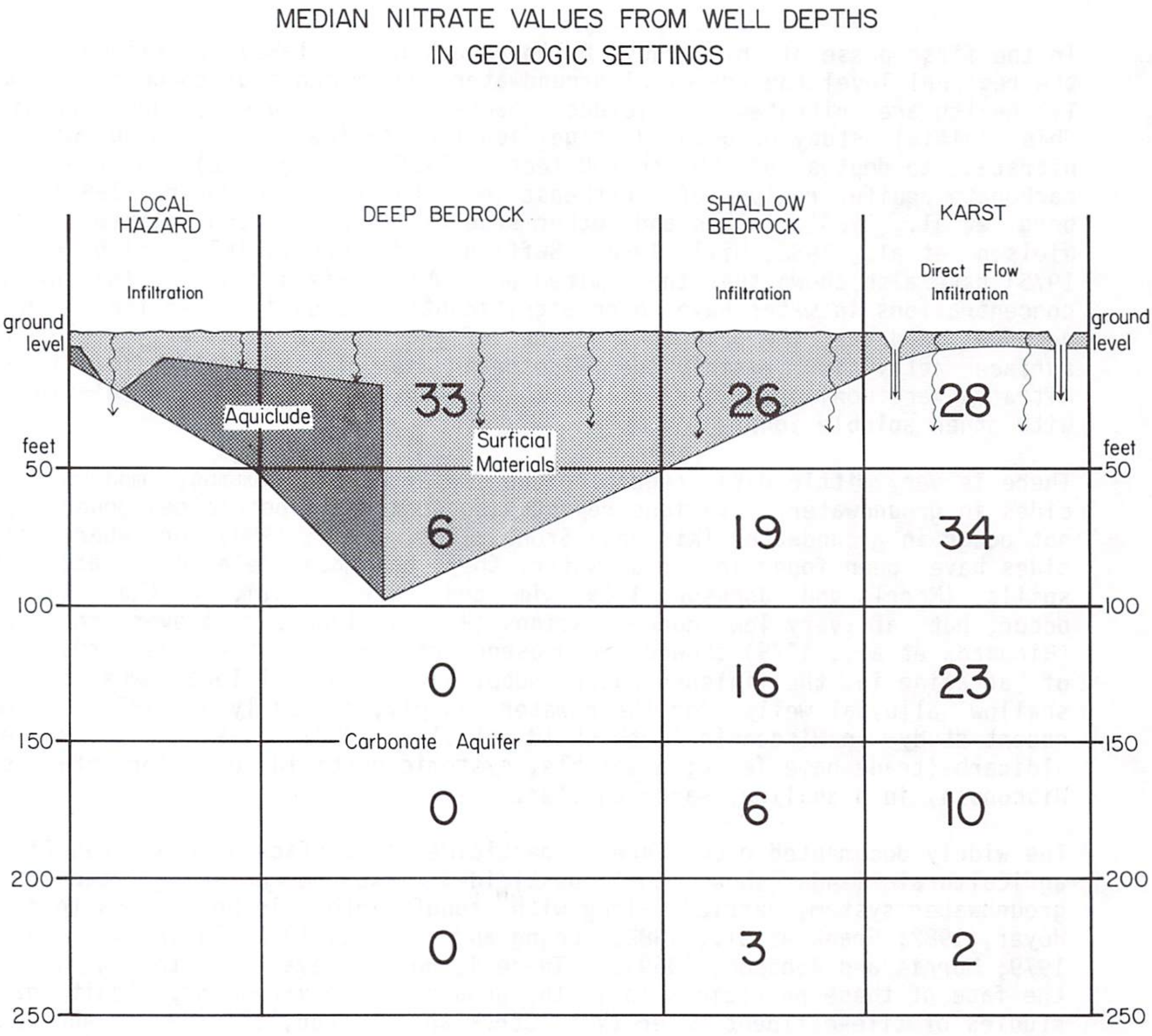


Figure 2. Summary of median nitrate concentrations for the different geologic settings and by well depth in northeast Iowa. In all areas, wells less than 50 feet deep show high levels of nitrate contamination. In the Karst and Shallow Bedrock regions, where the soil cover is less than 50 feet thick over the carbonate bedrock, significant levels of nitrate contamination occur to depths of 150 feet and locally to 200 feet. The problem is most pronounced in the Karst regions where the soil mantle is generally thinner, allowing greater infiltration, and because sinkholes allow the direct in-flow of surface water into the groundwater. Even where an aquiclude (e.g.--shale) covers the carbonate aquifer, local hazards may exist where the soil and aquiclude mantle are thin.

related to local water system problems. However, review of case studies revealed that bacterial contamiation can be a problem in karst areas. In the Big Spring's study, data was collected to evaluate and separate bacterial problems related to water systems from those related to aquifer problems.

Turbidity in groundwater presents two concerns. First, turbidity may be caused by a combination of dissolved solids and particulate matter. The particulate matter is comprised of both mineral and organic matter. These particulates may have a variety of attached chemicals. Thus, the products contributing to turbidity may be a concern for health. The second problem is that the products contributing to turbidity may effect the possible effectiveness of water-treatment, such as chlorination for bacteria. Qualitatively, turbidity is a known problem in carbonate aquifers where wells are open to fractures which are large enough to transmit sediment, etc. (Hallberg and Hoyer, 1982). These problems were also addressed in the Big Spring evaluation. Again, a prime contributor to turbidity in karst areas is the run-in to sinkholes of turbid, sediment-laden surfacewaters, coming off of ag-lands.

Although many point sources can locally contribute to these contaminants to groundwater, non-point sources have to be the prime contributors of the region-wide problems. Another important facet of the Big Spring's study area is that there are essentially no point sources. There is no industry, no landfills, no large feedlots, and only two small municipal sewage systems (Monona and Farmersburg) that discharge in the area. Population has declined in the basin, decreasing the number of septic systems in use. Thus, the basin presents an ideal area to evaluate the non-point source contributions.

This report will detail our analysis of the groundwater system of the Big Spring area in Clayton County. The study will focus on the groundwater flow system of the area, particularly as it relates to the specific nature of groundwater contamination and the relationship of these contaminants to land-use, local environmental factors, and potential land-treatment control programs. The study and report consist of three phases: 1) initial inventory studies defining the hydrogeologic system, water quality, and landuse; 2) temporal monitoring of the hydrogeologic system; and 3) modelling and evaluation of control programs, such as changes in land-treatment practices.

PROCEDURES AND BACKGROUND INFORMATION

A variety of quantitative data will be presented in this report. The following section outlines the principal analytical procedures used.

Well-Water Sampling Procedures

The quality of water within an aquifer is generally investigated through chemical analysis of well-water samples. However, several factors may cause a well sample to be unrepresentative of the water within the aquifer. The presence of metal well casing, the type of pumping mechanism, and an open connection to the surface provided by the well may contribute or adsorb dissolved species, allow for equilibration of dissolved gases with the atmosphere, and alter the eH-pH conditions of the water. The magnitude of chemical changes are generally greatest when water is in storage within the casing, and effectively isolated from the zone of active groundwater flow.

Several methods of overcoming the above problems and obtaining representative groundwater samples are commonly employed. The preferred method involves pumping the well until several casing volumes of water are removed, allowing for movement of representative groundwater into the well (Gibb et al., 1981; Scalf et al., 1981). Alternative methods suggest monitoring changes in a chemical or physical parameter during pumping until a stable condition exists. Specific conductance, temperature, and pH are easily measured parameters that stabilize during pumping (Summers and Branvold, 1967).

Groundwater samples collected for this study were taken from existing domestic water wells. Information about the depth and size of casing, and depth to water, needed to calculate the water-filled casing volume, are not available for most of the wells. Therefore, temperature was monitored while the wells were pumped. Temperature was chosen as the monitoring parameter because of the ease of measurement and because other recommended parameters, such as pH and specific conductance, are temperature dependent and will not stabilize until the temperature is constant. In most cases, a stable temperature was reached within ten minutes of pumping, after which time the samples were collected and other field measurements (conductivity, etc.) were taken.

The water chemistry can also be affected if the water is passed through a cistern, or storage tank, or water-conditioning equipment. Unless specified, no water samples were taken which passed through such devices. All samples were collected directly at the well head, or from the hydrant closest to the well head.

Field Analyses

Some general water-quality parameters were measured in the field or field office. These were conductivity, pH, and turbidity. Temperature was monitored continuously at selected stations.

Conductivity

Conductivity of the water was measured in the field at each sample site. A quart jar was filled with sample water, water temperature was determined with a thermometer, then conductivity was measured using a Beckman RB3 Solu Bridge conductivity meter. Specific conductance was determined in micromhos/ cm, instrumentally corrected to a standard of 25° C.

pH

A Hach model 19000 digital pH meter was used to determine pH of the water samples. Samples were collected in 100 ml jars and returned to the laboratory or field office for analysis. Buffer solutions of pH 9 and 4 were used to standardize the instrument. A glass combination electrode with a calomel reference element was used to measure pH. Hydrogen-ion activity (pH) was determined from a 50 ml sample in which the electrode was allowed to stand until the digital readout stabilized (usually 2-3 minutes).

Turbidity

Turbidity of the water samples was determined using a Hach model 16800 Portable Turbidimeter. A split of the water sample collected for pH determination was used. The method of detection used by this instrument is nephelometric and standardization was accomplished using a latex secondary turbidity standard of known value. Turbidity was determined in Nephelometric Turbidity Units (NTU).

Temperature Monitoring

Water temperatures were monitored continuously at Big Spring, Back Spring, Robert's Creek, and in an abandoned Galena well, during various time periods. The temperatures were recorded on strip charts using submersible Ryan Model J recording thermographs (manufactured by Peabody-Ryan, Kirkland, Washington).

Chemical Analyses

All water chemical analyses were performed by the University Hygienic Laboratory (UHL) using standard analytical methods. Details of the analytical procedures may be obtained from UHL.

Nitrate

Nitrates are analyzed using EPA method 353.2 ("Methods for Chemical Analysis of Water and Wastes," EPA-600/4-79-020) with minor modifications. This is the standard cadmium reduction method for nitrate/nitrite analysis. Results are reported as milligrams per liter, nitrate (mg/l, NO_3).

Bacteria

Total coliform bacteria were determined using the most probable number (MPN) method, in accord with EPA standard methods ("Microbiological Methods for Monitoring the Environment," EPA-600/8-78-017, December, 1978). The data are reported as the statistical MPN of total coliform individuals per 100 ml of water. The MPN classes are 0, 2.2, 5.1, 9.2, 16, and 16+. Any value above 0 is considered unsatisfactory (2.2) or unsafe (>2.2). These data generally exhibit an irregular frequency distribution with the mode at 0, and a secondary mode of 16+ (see Hallberg and Hoyer, 1982, p. 15-19).

Pesticide Analysis

Pesticide concentrations in the water samples were run by standard gas-chromatographic column methods, following EPA guidelines ("Methods for Organochlorine Pesticides and Chlorophenoxy Acid Herbicides in Drinking Water and Raw Source Water," EPA-Interim Methods, July, 1978; and "Manual of Analytical Methods," EPA). Samples were collected in quart-size, wide-mouth, glass mason jars with teflon liners. Samples were refrigerated prior to analysis. Results are reported as micrograms per liter (μg/l). Detection limits vary for individual pesticides, and with other water constituents (miscellaneous organic compounds) which may interfere with the chromatographic peaks.

Discharge Measurements and Records

A variety of water discharge data will be presented, for Big Spring, the Turkey River, and other springs and surfacewater. The procedures used will be outlined below. All gaging was performed by U.S. Geological Survey-Water Resources Division personnel, under the direction of Mr. Ivan Burmeister, using standard methods ("Techniques of Water Procedures Investigations of the U.S. Geological Survey," Applications of Hydraulics handbooks).

Big Spring's Discharge

The discharge of groundwater from Big Spring at the ICC trout hatchery is controlled by a concrete dam, which abuts bedrock surrounding the spring. The water is discharged from this structure through two avenues: 1) directly across a spillway, out of the structure; and 2) part of the water is discharged through a 30-inch (0.76 m) diameter, corrugated-metal pipe into a distribution box. From the distribution box, the water is discharged through another 30-inch corrugated pipe and enters a series of distribution pipes which carry water to the trout raceways. A gate in the distribution box can be opened and closed to stop the discharge.

The discharge through the spillway is calculated using standard Type I flow analysis, relating the slope and cross-sectional area of the spillway to the stage, or height of water in the spring pond discharging through the spillway. The discharge through the spillway has been measured intermittently using a flow-meter to establish an actual rating curve for the spillway. This is necessary because at low-flow aquatic vegetation growing at the head of the spillway alters the volume and roughness of the spillway.

The portion of the discharge passing through the distribution box is calculated using Type 4 flow analysis, for pipe flow through a box with a submerged outlet (and inlet). The discharge is calculated as a function of the difference in stage (head) between the spring pond and the distribution box, and standard functions related to the type and diameter of pipe.

The stages are read manually. The stage in the spring is read by a staff, and the stage in the distribution box is read from a float gage in a stilling-well installed in the box. Stage readings are taken by ICC staff at the hatchery at intervals related to flow conditions, ranging from daily, or twice daily during low-flow, to as often as hourly during peak flow events. During the course of this study, the gate in the distribution box has been kept either fully opened or fully closed to simplify the calculations.

From the stage measurements and rating curves, the discharge is calculated and added together to give the total discharge from Big Spring, in cubic feet per second (cfs).

Turkey River Discharge

The discharge for the Turkey River is measured at Garber, about 25 miles (40 km) downstream from Big Spring. Garber is a standard USGS recording gage station. The data from Garber will be used for the Turkey River hydrograph to compare discharge trends. The discharge of the Turkey River was also computed during relatively low-flow in the Big Spring reach by USGS staff, using standard stream and velocity profiling methods.

Other Discharge Measurements

The discharge of two other springs (Back Spring, at the ICC Hatchery, and Heick Spring) was also measured on separate occasions using standard flumes and flow meter measurements. Partial flow records also exist for Robert's Creek. These were measured by USGS and ICC staff at various times in the past.

Landuse Information

A variety of data was compiled on landuse and land treatment, cropping practices, and chemical application rates for the Big Spring study area. This data will be used for comparison of landuse and water quality, and for analysis and modelling of land-treatment practices.

Landuse Mapping

A landuse map of the study area was made by photo-interpretation of 1:80,000 scale, high-altitude, color-infrared photography taken in November, 1980. The two original photos covering Big Spring Basin were enlarged and printed at a scale of 1:24,000 to aid interpretation and construction of the landuse map. Eight landuse classes were distinguished by color and pattern differences on the photography: 1) cover crop; 2) terraced-cover crop; 3) row crop; 4) terraced-row crop; 5) strip cropping; 6) terraced-strip cropping; 7) forest; and 8) urban/quarry/ road areas. The cover crop and terraced cover crop classes include both alfalfa, hay, and permanent pasture. A landuse inventory conducted by the SCS in the basin indicates that only a very small percentage of this area is permanent pasture and that most of the area included in the cover crop classes are in an alfalfa or hay crop (Table 1), as part of a rotation sequence with corn. Areas designated row crop are in corn. Forest tracts in the basin are generally used as woodlots or are lightly grazed.

The landuse map was originally compiled by hand, and then was digitized and entered into the computer. This data was later used in calculating potential soil loss and runoff.

Field checking of the landuse map during 1982 showed no significant differences between current landuse and that in 1980. Also, SCS statistical data compiled for the National Resources Inventory (NRI), from 1981 sampling, showed no significant difference in landuse.

Crop Rotations

Cropping information for the Big Spring Basin was provided by the SCS from NRI data. This information consisted of a listing of rotations and conservation practices, and the percentage of each rotation/conservation system in use in the basin. All rotations in the area are various forms of a corn-oats-meadow rotation ranging from continuous corn to one year of corn and oats in a seven year rotation with meadow (Table 1).

Ag-Chemical Use

Information on current ag-chemical use was also compiled for the Big Spring study area. The information was compiled from SCS records and informal interviews conducted by SCS and IGS staff with farm operators and chemical dealers, and from a special survey conducted by SCS staff.

From this information, general rates of chemical use for 1982 can be described. Of principal interest are the chemicals applied to land used for corn production. The general rate of nitrogen fertilization on corn was 175 lbs-N/acre (195 kg/ha), applied as anhydrous ammonia. The majority of people interviewed stated their application rate as between 170 and 185 lbs/acre (190-205 kg/ha). The extremes varied from 125 lbs/acre (140 kg/ha) in dry form, to 250 lbs/acre (270 kg/ha) as anhydrous plus dry forms.

The application of other nutrients was much more variable, as expected, in both the timing and rate of application. When applied, phosphorus rates varied from 40 to 80 lbs/acre (45-90 kg/ha), generally applied dry as diammonium phosphate or concentrated superphosphate. Potassium rates vary from 60 to 180 lbs/acre (65-200 kg/ha), generally applied as potassium chloride. Ag-lime, gypsum, and various trace elements are also applied, as are a variety of custom-blends.

Pesticide use can also be generalized from interviews and sale records. The most common herbicides used were atrazine and Lasso (in combination), for weed and grass control. Atrazine application rates averaged 1.5 lbs/acre (1.7 kg/ha). If oats were to follow the corn, the atrazine would be replaced in part or in whole by Bladex. Other herbicides which were also used in lesser amounts were, Sutan, Ramrod, Prowl, Dual, Eradicane, Roundup, Banvel, and 2,4-D.

Table 1. Rotations and management systems currently in use, Big Spring Basin.

Continuous Corn 21%

a) Contour farming and conservation tillage	41%
b) Contouring and terraces and conservation tillage	8%
c) Conservation tillage	46%
d) Conventional tillage	5%
	100%

CCCOMM 32%

a) Contour farming and conservation tillage	25%
b) Contouring and terraces and conservation tillage	10%
c) Contour farming	15%
d) Contour strip cropping and conservation tillage	15%
e) Contour strip cropping	10%
f) Conventional tillage	25%
	100%

CCOMMM 31%

a) Contour farming and conservation tillage	47%
b) Contour strip cropping and conservation tillage	47%
c) Conventional tillage	6%
	100%

COMMMMM 2%

a) Conventional tillage	100%

Permanent Pasture 9%

Kentucky bluegrass with 25% covered by brush and trees (6 1/2 ft. average drop fall height) and 80% ground cover

Forest Land 4%

90% tree canopy and undergrowth, and 90% covered by duff

Planter-applied insecticides are also used on corn following corn. In general order of use, these were; Counter, Amaze, Dyfonate, Thimet, Furadan, Mocap, and Lorsban. Other miscellaneous pesticides used on alfalfa or brush include Malathion, Eptam, Alfatox, 2,4,5,T, Paraquat, and Tordon. All products are believed to be used at recommended application rates.

Geographic-Data Base

A computerized geographic-data base was constructed for the entire Big Spring Basin study area. ELAS data-base software (Junkin et al., 1980), which was developed by NASA, was used to digitize the areal data, to process the areal polygons into the data base, and to manipulate the data within the data base. The ELAS data base system is a cell system: 25 meter cells were used throughout the project. The areal data were digitized as polygons, and then converted to cell data by the software. Geographic control was provided by USGS, 7 1/2 minute quadrangle, topographic maps.

Digitizing was accomplished using a Textronix 4954 MOD AD tablet and 4014-1 Textronix graphics terminal. Processing was done on a Perkin-Elmer 3220 computer while interactive analysis was conducted using a Comtal/3M Vision One/20 image processing system and the ELAS software.

The major digitizing activity involved the data entry of soils mapping units. The Soil Survey of Clayton County, Iowa, Advance Report (Kuehl, 1978) was the source for digitizing the soils. All mapping units were digitized although separate erosion classes were not maintained in the data base. In all, about 5,800 soil polygons were encoded to the data base. Soil maps provided the basis for defining sinkhole basins, as well. About 900 polygons of 1980 landuse were digitized. Landuse digitizing, as well as other digitizing, was done from work maps at various scales.

Nitrates and potentiometric surface-data sets were processed using Surface II Graphics System software (Sampson, 1975) and software developed at IGS.

The data base consisted of the following basic data sets: soils, landuse, bedrock geology, sinkholes, sinkhole basins, nitrates, potentiometric surface, roads, and sample points. These data sets could be displayed individually or in combinations for interpretive analysis. Further, data could be indexed by characteristics for display or computational purposes. For example, all soils mapped on a C slope and/or developed from loess could be selected.

Most data-base analysis consisted of establishing index tables for digitized basic data sets, and computing derived values using algorithms which related one or more of these indexed, basic resource data sets. The most important derivative products involved modelling of 1) runoff, based on 1980 landuse and three alternate land-management schemes, and 2) erosion potential, based on 1980 landuse and current management, as well as five alternate land-management schemes.

Modelling of Soil Erosion and Runoff

Potential soil erosion for the Big Spring Basin and runoff for the sinkhole basins were modelled using the Universal Soil Loss Equation (USLE; Wischmeyer and Smith, 1978) and the Urban Hydrology for Small Watersheds Model (TR-55) developed by the Engineering Division of the U.S. Soil Conservation Service (SCS, 1975). The USLE is used to calculate the expected annual soil loss from a given landuse over a specified area. The model has the general form:

$$A = R\ K\ L\ S\ C\ P$$

in which A = the computed soil loss per unit area, usually expressed in tons per acre, per year; R = a factor expressing the erosion potential of the average annual rainfall in the area; K = the soil erodability factor and represents the average soil loss, in tons per acre, per unit of rainfall factor-R, from a particular soil in cultivated continuous fallow, with a standard plot length of 72.6 feet and 9 percent slope; L = the slope-length factor, the ratio of soil loss from the field slope length to that from a 72.6 foot length under otherwise identical conditions; S = the slope-steepness factor, the ratio of soil loss from the field-slope gradient to that from a 9 percent slope under otherwise identical conditions; C = the cover and management factor which represents the ratio of the soil quantities eroded from land that is cropped under specific conditions, to that which is eroded from clean-tilled fallow under identical slope and rainfall conditions; and P = the support practice factor, the ratio of soil loss with a support practice to that with straight-row farming up and down the slope (P = 1.0 for straight-row farming).

An R factor of 175, (from Wischmeyer and Smith, 1978) was used in calculating A for the Big Spring Basin. K, L, and S factors for each soil series and slope class were obtained from soil-interpretation sheets provided by the SCS. C and P factors were area weighted for the eight landuse classes from data provided by the SCS (Table 2).

That portion of the Soil Survey of Clayton County (Kuehl, 1982) covering the Big Spring Basin was digitized by hand and the data entered into the computer. Appendix 1 shows the soil series, soils mapping unit, corresponding computer soil number and area occupied by each mapping unit in the basin.

Six potential soil-erosion runs were performed for the basin using the IGS Perkin-Elmer 3220 computer. The runs included: 1) current landuse; 2) terracing of all row crop acreage; 3) one year of increased meadow in rotations currently in use; 4) all row-crop areas strip cropped; 5) all row-crop acreage converted to no till; and 6) native vegetation conditions as deduced from the soil-survey interpretations (Kuehl, 1982). Table 3 shows the assumptions concerning cropping and land treatment which were incorporated into these analyses. Area weighted C and P factors used for the row-crop acreages under alternate management systems are presented in Table 4.

Potential runoff from sinkhole basins in the study area was modelled using procedures for model TR-55, outlined in "Urban Hydrology for Small Watersheds" (SCS, 1975) and various amendments to the Engineering Field Manual provided by

Table 2. C and P factors used with the USLE in this study.

Landuse	C	P
strip cropped	0.074	0.3
strip cropped terraced	0.074	0.3
cover crop	0.055	0.68
cover crop terraced	0.055	0.5
row crop	0.125	0.68
row crop terraced	0.125	0.5
forest	0.001	1.0
urban/quarry/roads	excluded	excluded

SCS personnel (Iowa users guide and supplement to TR-55, 1980; chapter 4 of the National Engineering Handbook; amendment IA2 to the Engineering Field Manual, 1981; and amendment IA3 to the Engineering Field Manual, 1981). In this method, a combination of a hydrologic soil group (soil) and a landuse and treatment class (cover) is used to determine the hydrologic soil-cover complex. The effect of the hydrologic soil-cover complex on the amount of rainfall that runs off is represented by a runoff-curve number (CN). The equation used to calculate runoff is:

$$Q = \frac{(P-0.2S)^2}{P + 0.8S}$$

where Q = runoff, in inches; P = the total storm rainfall, in inches; and S the potential abstraction which is all the storm rainfall occurring before surface runoff starts. Potential abstraction is related to the soil-cover conditions of a watershed. As noted, the runoff-curve number, CN, is related to the soil-cover conditions and is related to S by:

$$CN = \frac{1,000}{S + 10}$$

Several factors were compiled to develop runoff-curve numbers for the soils in the basin. The hydrologic-soil group of each soil series was taken from amendment IA2 of the SCS Engineering Field Manual. All Iowa soils fall into

Table 3. Cropping information and assumptions for soil erosion and runoff modelling.

1981 NRI statistics on current landuse

34%	cover crop
9%	strip crop (2/3 cover crop)
44%	row crop
9%	permanent pasture
4%	forest land

47% row crop (including strip-cropped area)

rotations for row-crop area (percentage of total basin):

21%	continuous corn	(21% corn)
32%	CCCOMM	(16% corn)
31%	CCOMMM	(10% corn)
2%	COMMMMM	
	TOTAL	47% corn

Increased Meadow In Rotation

percentage of total basin in various rotations:

21%	CCCOMM	(11% corn)
32%	CCOMMM	(11% corn)
33%	COMMMMM	(5% corn)
	TOTAL	27% corn

All Stripcropped

percentage of total basin in various rotations:

53%	CCCOMM	(27% corn)
33%	CCOMMM	(11% corn)
	TOTAL	38% corn

No Till

assume current rotations; all corn acreage under no till; spring residue 3,400 lb/acre (100-125 bu/ac yield grazed over winter); hay yield 3-5 tons/acre

Terracing

assume same rotations as 1980. Terrace intervals: 2-7% slope - 135 ft.; 7-11% slope - 120 ft.; >11% slope - 100 ft.

one of four hydrologic-soil groups ranging from soils with low runoff potential (group A) to soils with high runoff potential (group D). Next, the landuse (cover factor) was determined for the areas occupied by each hydrologic-soil group and then runoff curve numbers for the various hydrologic soil-cover complexes were read from exhibit 2-2A of amendment IA3, chapter 2 to the SCS Engineering Field Manual. The values used in this study are shown on Table 5. The resulting curve numbers were then area-weighted and a single curve number representing the total sinkhole basin area was generated. The antecedent moisture condition (AMC), a measure of watershed wetness, was then determined using the 1982 24-hour precipitation record from the Elkader station provided by the U.S. Weather Service. Area-weighted curve numbers for the various antecedent moisture conditions were then interpolated from values provided in Table 10 of the Iowa Users Guide and Supplement to TR-55 (SCS, 1980). These area-weighted curve numbers were used to calculate S which was then entered into the runoff equation, along with 24-hour precipitation amounts for the Elkader station to calculate runoff for the sinkhole basins.

An initial run of this model for present landuse conditions over the period of time between 16 March and 28 December 1982 indicated that the model was underestimating the actual runoff, as determined by gaging at Big Spring. The model was adjusted to observed conditions by adjusting antecedent-moisture conditions upward and by using a growing season of 26 June to 1 October. With these modifications, significant runoff predicted by the model coincided with actual runoff events measured at Big Spring, although the predicted amounts were still less than those measured.

Runoff from the sinkhole basins was modelled for the time period between 16 March and 28 December 1982. The early part of 1982 was omitted to avoid uncertainties in modelling runoff resulting from snowmelt. Runoff was modelled for current landuse, terracing of all row-crop acreage, one year of increased meadow in current rotations, strip cropping all row-crop acreage, and no till on all row-crop acreage.

INVENTORY INFORMATION

During November and December of 1981, an initial field survey and well and water-quality inventory was done in the Big Spring Basin. Detailed geologic mapping was also initiated at this time. The inventory provided a baseline survey of information about well construction, water-quality, and head data (from water-level measurements). The survey took about 60 staff days for IGS and USGS personnel, involving interviewing well owners, inventorying the local setting of the wells, measuring water-levels, taking water samples, noting the occurrence of sinkholes, and describing and mapping of rock outcrops. A variety of other background information was compiled on the soils, landuse, sinkhole distribution, water-quality, and hydrology of the area. The varied information was collected to allow the analysis of local environmental effects on water-quality and to provide a detailed spatial overview of water-quality in the area. From this data a set of wells and surfacewater locations were chosen for continued monitoring throughout the year.

Table 4. Area weighted C and P factors used for row crop areas in calculating potential soil loss under alternate management systems.

Management		Management Systems C	P
increased meadow in rotation, row-crop acreage		0.048	0.65
increased meadow in rotation, strip-cropped acreage		0.07	0.3
all rowcrop strip cropped		0.06	0.369
no till		0.082	same as current landuse
native vegetation:	forest	0.001	1.0
	prairie	0.003	1.0

Table 5. Runoff curve numbers for hydrologic soil-cover complexes used in modelling.

Landuse	Cover Treatment or practice	Hydrologic condition	Hydrologic soil group A	B	C	D
Row crop	Contoured	Good	65	75	82	86
Terraced row crop	Contoured and terraced	Good	62	71	78	81
Strip cropped	Contoured	Good	61	73	81	84
Terraced strip cropped	Contoured and terraced	Good	59	70	78	81
Cover crop	Straight row	Good	58	72	81	85
Terraced cover crop	Contoured and terraced	Good	51	67	76	80
Forest		Good	25	55	70	77

Prior to the field survey a considerable effort went into publicizing the inventory. With the help of the Clayton County SCS (Roger Koster, District Soil Conservationist), Extension Service (James Hosch, County Extension Director), and ASCS (Frank Phippen, County Executive Director) officials, many local groups and individuals were contacted and informed about the study. With the use of the ASCS mailing list, all landowners and tenants in the area were informed of the study through a direct mailing which explained the study and particularly the nature of the well inventory. Area newspapers also carried press releases about the study.

As a result of the prior publicity, the well inventory was quite successful and cooperation from local residents has been outstanding. Over 320 rural homesteads were visited. Of these, 271 wells were inventoried. At 60 locations water-level measurements were made, and 125 wells were sampled for water-quality analyses. Some wells finished in aquifers other than the Galena were sampled for background information. Also, several surfacewater sites, tile lines, and springs were sampled. The wells sampled were chosen from those with the most complete or verifiable information available so that the source of the water (aquifer) was known with some certainty.

The following sections will outline the information collected to define the Big Spring groundwater system.

Bedrock Geology

A variety of rock units are exposed in the study area (figure 3). Of principal importance are those rock units which comprise the Galena aquifer. The stratigraphy of the region is summarized on figure 4.

The oldest rocks exposed in the area are the carbonate rocks of the Shakopee Formation of Ordovician age. The Shakopee is unconformably overlain by the St. Peter Sandstone. The St. Peter is variable in thickness and forms an aquifer of local importance in northeast Iowa. The St. Peter is overlain by shales, shaly carbonates, and carbonates of the Glenwood, Platteville, and Decorah Formations. The Decorah-Platteville-Glenwood Formations are lumped together for mapping (figure 3) because these units form an aquiclude which separates the St. Peter aquifer from the Galena aquifer. These rock units (Decorah through Shakopee) are only exposed in the northeast part of the study area, along Hickory Creek, Suttle Creek, and Bloody Run (figure 3).

The Decorah, Dunleith, Wise Lake, and Dubuque Formations are all included in the Galena Group. As noted, for the purposes of this report, the Decorah Formation has been included with the underlying rocks for mapping and discussion. The carbonate rocks of the Dunleith, Wise Lake, and Dubuque Formations are delineated here (figure 3) as the Galena "carbonates" because they form the Galena aquifer. The Galena carbonates outcrop low in the landscape along the valleys of the principal streams in the area.

Overlying the Galena carbonates is the Maquoketa Formation (figure 4). For mapping and hydrogeologic purposes the Maquoketa Formation has been divided into two units (figure 3): a lower unit, comprised of the shaly carbonates of

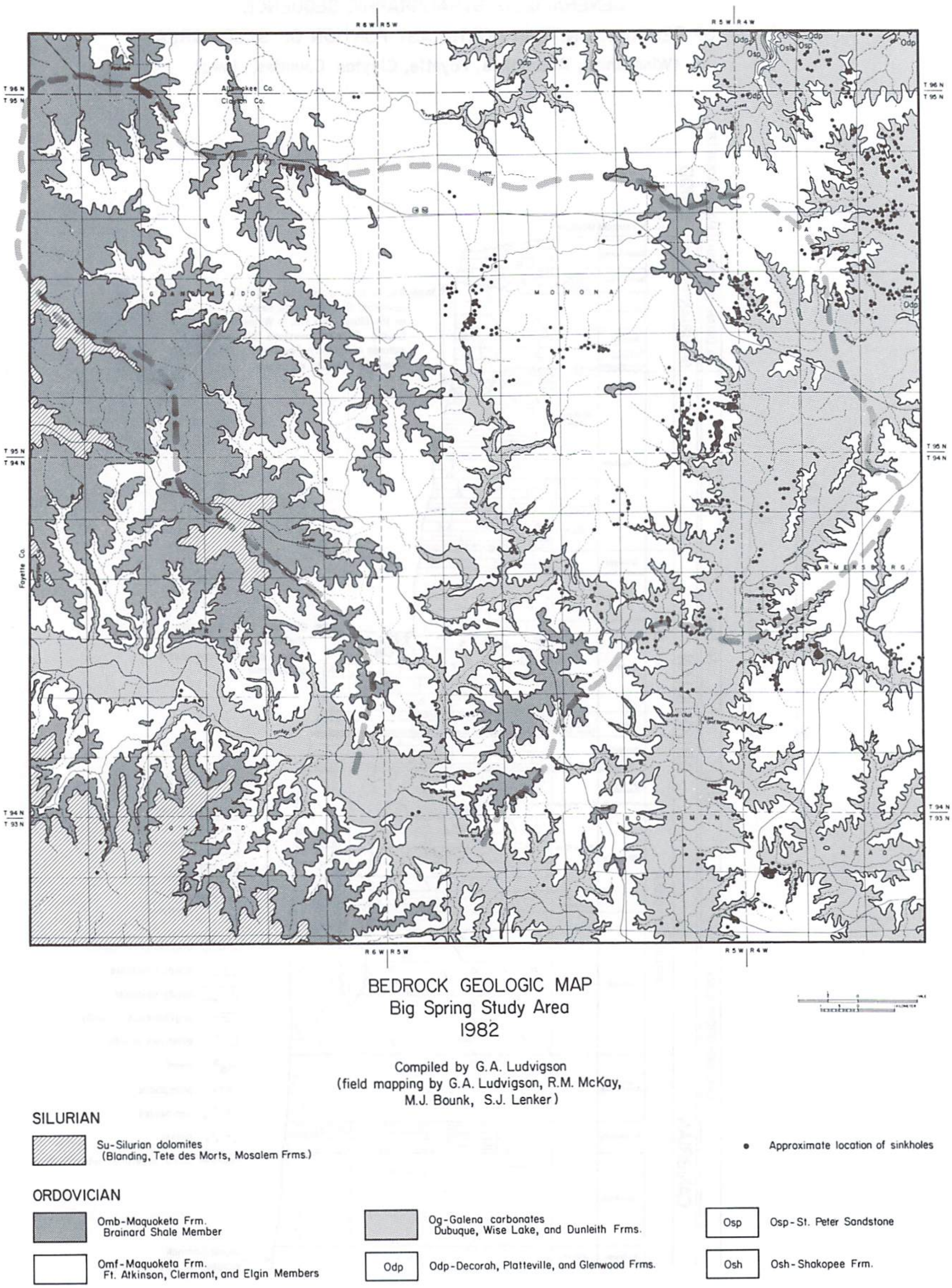


Figure 3. Bedrock geologic map of Big Spring study area.

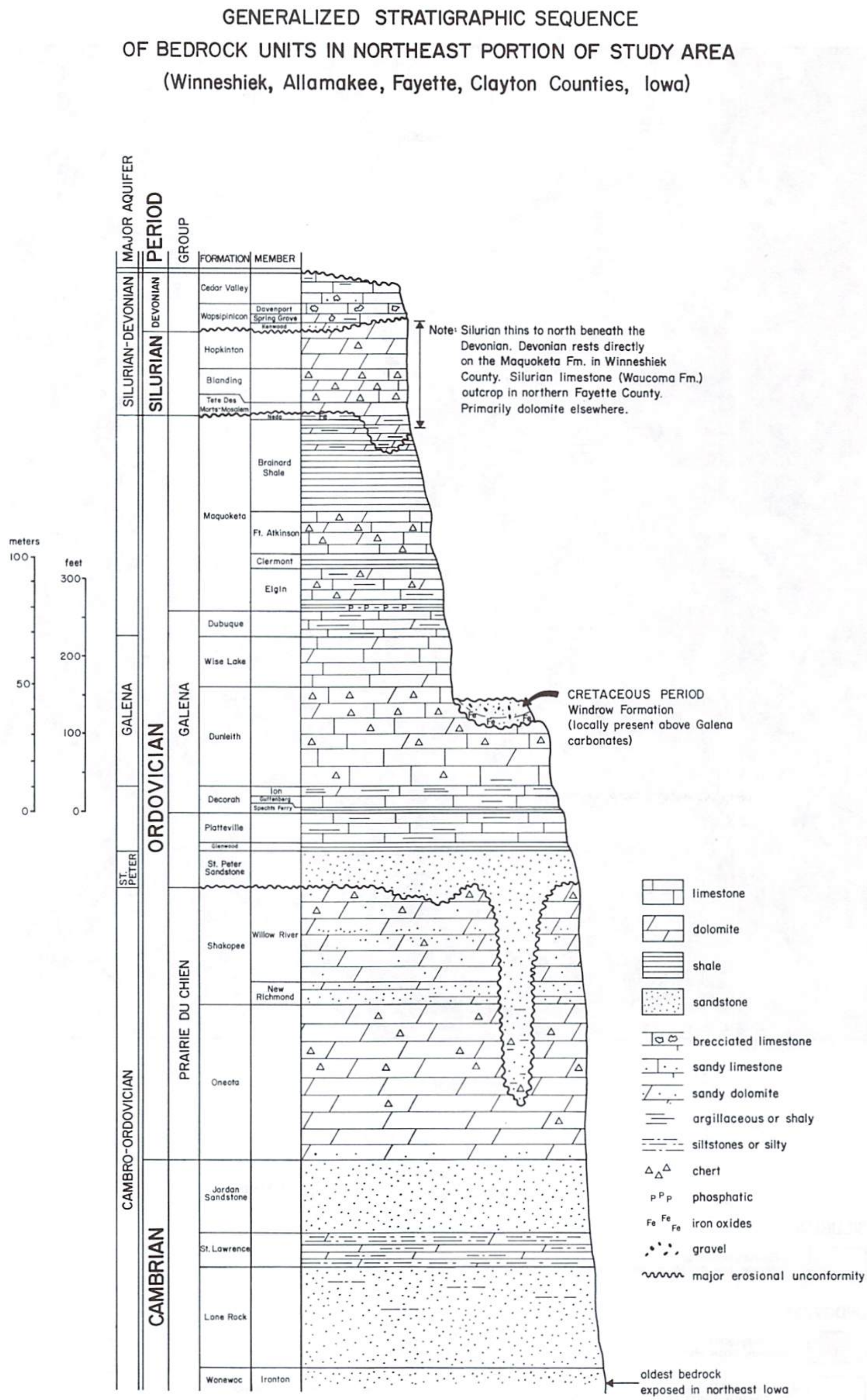


Figure 4. Generalized stratigraphic section for Big Spring study area (from Witzke, unpublished).

the Elgin Member, the Clermont shale, and the carbonates of the Ft. Atkinson Member; and an upper unit, comprised of the Brainard Shale Member, a thick clay-shale, with minor interbedded carbonates, which is a major aquiclude in northeast Iowa. This subdivision allows consistent mapping because the Ft. Atkinson Member, which separates the two mapping units, often forms a prominent topographic ledge, and thus is distinct in the field. The next underlying contact which is prominent enough for consistent recognition occurs at the top of the Galena carbonates. Also, the lowermost portion of the Elgin Member is, in part, hydrologically connected with the Galena carbonates.

The youngest rocks which occur in the study area are the dolomites of Silurian age. These carbonate rocks are part of the regionally important Silurian-Devonian aquifer. The Silurian carbonates also have a karst topography developed on them. The Silurian dolomites outcrop south of the Turkey River along the Silurian Escarpment--the ridge upheld by these resistant rocks. North of the Turkey River only a few outliers of Silurian rocks occur, on the west side of the study area.

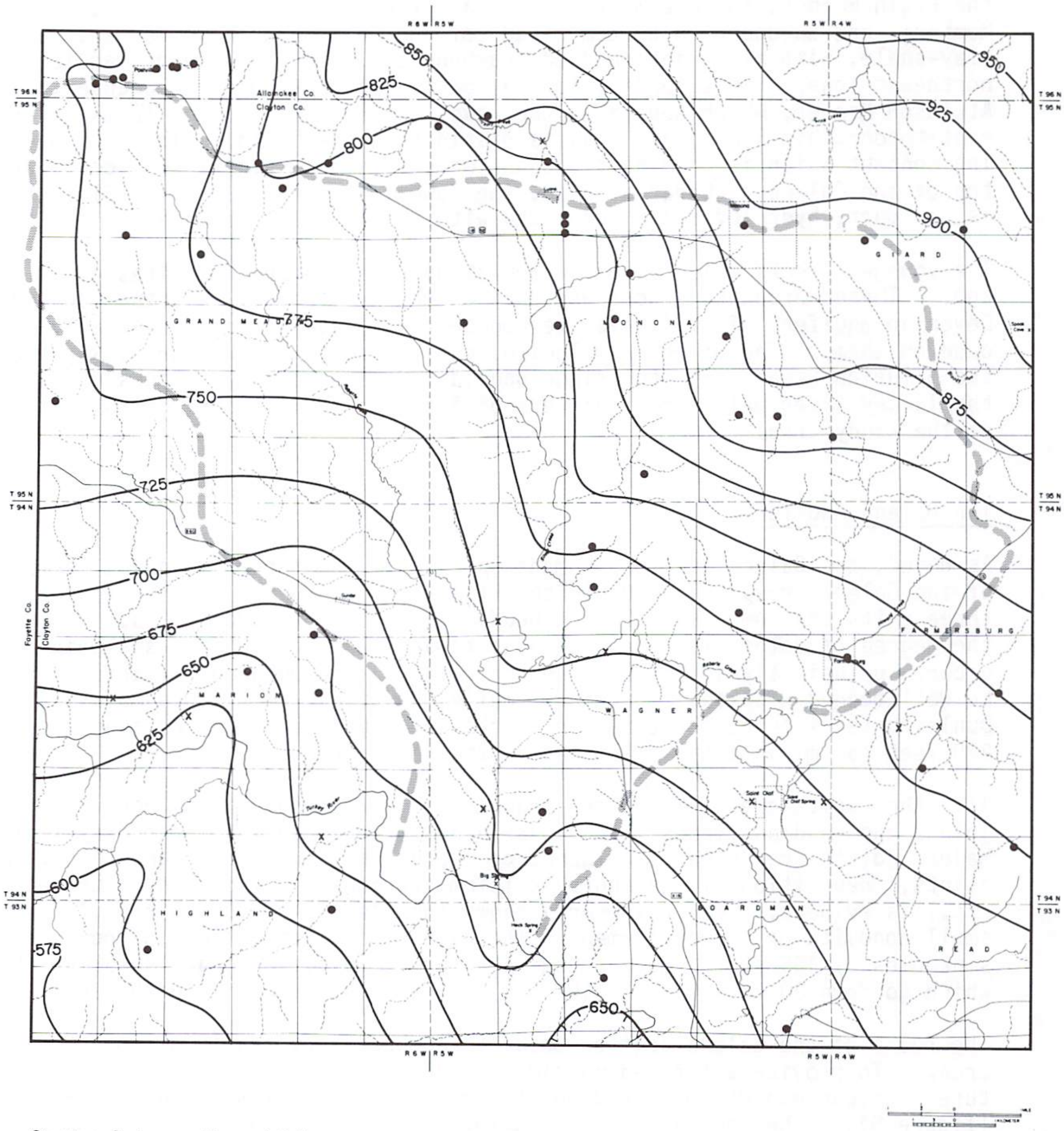
The Galena Aquifer

As noted, the Galena aquifer is made up of only the three youngest Formations of the Galena Group: the Dunleith, Wise Lake, and Dubuque Formations. These three units are comprised of interbedded limestones and dolomites. Regionally the degree of dolomitization decreases toward the north. Some shale interbeds occur, principally in the Dubuque Formation. The Dubuque Formation tends to be well bedded with shaly partings, while the Wise Lake is more massive. The Dunleith tends to be cherty. The rocks of the Galena aquifer average about 220 feet (67 m) in total thickness in the study area.

All the units are jointed or fractured. Karst-solutional activity along joints and bedding planes is obvious in nearly any exposure or quarry visited. Major joints are clearly widened by solutional activity, and along many joints, deposition of secondary calcium carbonate (flowstone, travertine, etc.) is evident. Many exposures show sinkholes, small "dome pits," and even small conduits or caves formed in the rocks. Investigations of newly formed sinkholes by IGS staff have revealed natural, open, vertical solution shafts which go down 30 to 120 feet (10-35 m) below landsurface, into the aquifer.

The rocks of the Galena aquifer occur throughout very nearly all of the study area. To provide a three-dimensional understanding of the aquifer, a structure contour map was prepared on the base of the Galena aquifer carbonates (figure 5). The map was prepared using a variety of data including: wells with complete penetration of the Galena; elevations from outcrops off the base of the Galena; estimated points based on partial penetrations and the average thickness of the Galena; and comparison with other structural datum. The map was compiled on data from a larger area than shown on figure 5.

In general, the base of the aquifer dips from northeast to southwest at about 18 feet/mile (3.5 m/km). One of the more prominent features of the structure contour map is a flexure which occurs in the center of the study area, running roughly north-south from the Big Spring.



Structure Contour on Base of Galena

- ● Subsurface Control Points (outcrop and other control points out of basin area not shown)
- x Estimated Points

Figure 5. Structure contour map on the base of the Galena (by G. A. Ludvigson).

Sinkhole Distribution

The distribution of sinkholes was mapped as part of the initial inventory of the area. The sinkhole locations are shown on figure 6 and figure 3 in relation to the bedrock geology. The sinkhole distribution was mapped from soil-survey maps, IGS field inventory, and review of ICC field-mapping notes.

The sinkholes occur in several stratigraphic settings. Some occur within the Silurian carbonates, and from the examination of exposures of the Silurian, numerous sinkholes which are filled with soil material also occur (but are not shown on the figures). Some other sinkholes are shown near the contact of the upper and lower units of the Maquoketa Formation. These appear to be formed in the Ft. Atkinson Member, a limestone unit within the Maquoketa, and are of local significance only.

The most extensive areas of sinkholes, and those of greatest concern, are found in the Galena carbonates, or near the map-contact of the Galena and lower Maquoketa (Omf) rocks (figure 3). Where the Galena carbonates have a broad outcrop area,numerous sinkholes are found. Where the outcrop belt is narrower,the topography is rather steep and fewer sinkholes are evident. However, in these areas, open fractures and small sinkholes occur in the beds of the stream valleys and often go unnoticed.

The major concentrations of the sinkholes occur near the top of the Galena carbonates, often developed right at the contact between the Galena and the shaly carbonates of the overlying Elgin Member. As shown on figure 3, several prominent clusters of sinkholes occur in the Elgin Member, in the north-central portion of the study area. These sinkholes occur in the lower 5 to 20 feet (2-6 m) of the Elgin, and these karst forms are continuous into the Galena rocks. Thus, in these regions, the lower Elgin and Galena are in direct hydrologic connection. It is not known at this time, because exposures in the area are poor, whether the karst features formed within the lower Elgin by solution or simply by collapse into solutional features in the underlying Galena.

The distribution of sinkholes on figure 3 reflects conditions as of spring 1982. The karst landscape is a very dynamic system. Since the spring of 1982, numerous new sinkholes have appeared. A few that were open have filled up and become plugged with sediment. As examples; during the early summer of 1982, IGS staff were doing field work near Heick's Spring. They went up a small valley to take water samples from a stream that emptied into a known sinkhole. However, the stream bed at the sinkhole was dry, yet the stream was known to be flowing at its head. Farther up the valley a new sinkhole had opened (that was unknown to the land owner) and was swallowing the stream. Buried in the sinkhole, under about 5 feet of sediment, were farm implements of 1930s or 40s vintage. In addition, twice during this study new sinkholes have formed in cornfields during the short time intervening between combine passes around the field.

These examples are cited to emphasize that the karst system is constantly changing. The mapped distribution is a static product at a given point in time. However, the map does reflect the overall distribution of karst activity, even though the status of an individual sinkhole may change.

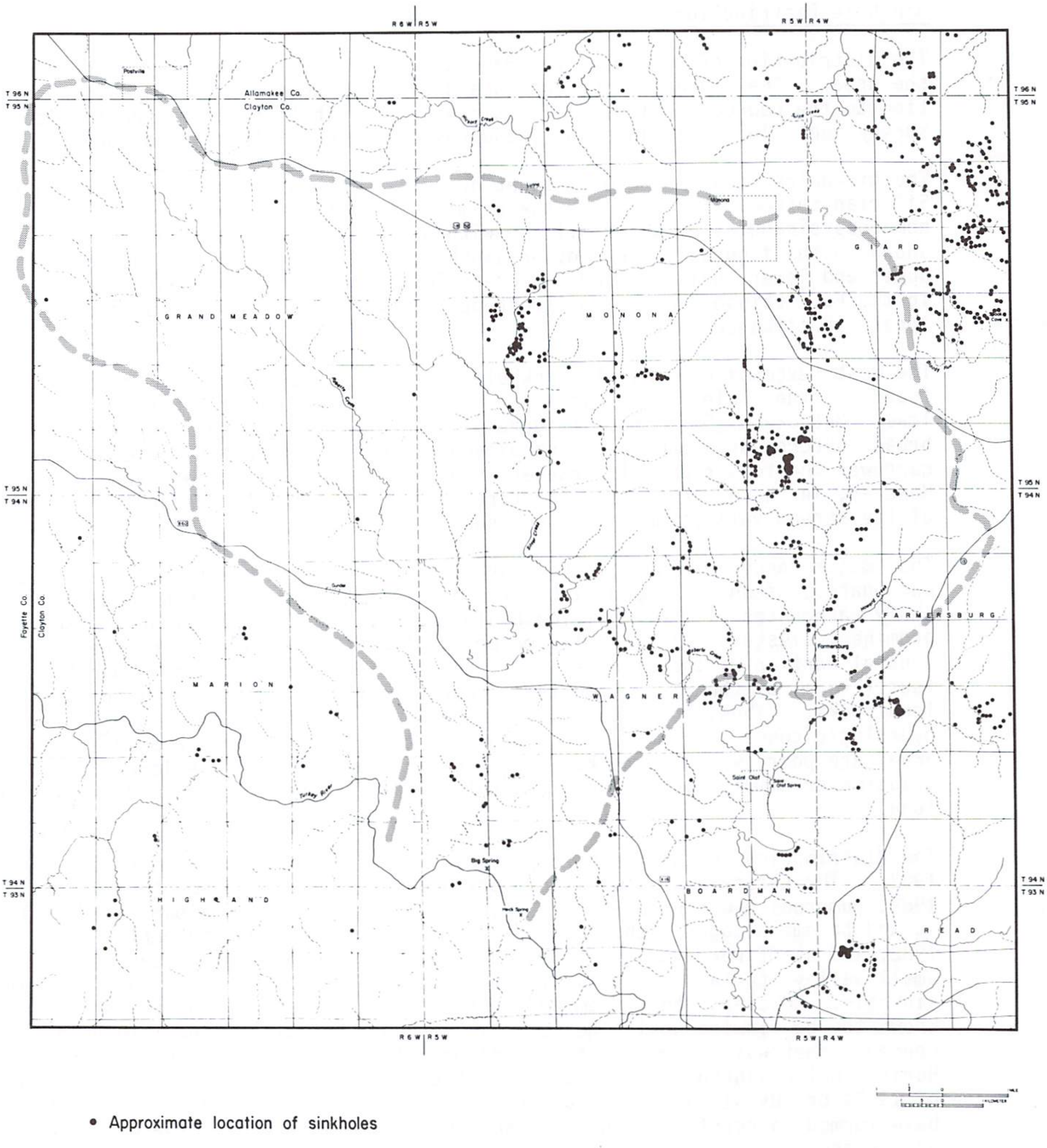


Figure 6. Approximate location of sinkholes in Big Spring study area.

Big Spring Groundwater Basin

The groundwater discharging from Big Spring originates as recharge within a given catchment area or contributing groundwater basin. An important part of the inventory phase of this study was the definition of the Big Spring groundwater basin. The geographic extent of this basin was delineated through dye traces, locations of gaining- and losing-stream reaches, and analysis of the water table/potentiometric surface of the Galena aquifer in the area.

Dye Tracing

Dye traces are used to establish direct connections between sinkhole-recharge points and discharging springs. Traces that produce dye at Big Spring indicate that the sinkhole-input site used for the trace lies within the Big Spring basin. Traces that yield dye only to other springs place the sinkhole and spring involved outside of the basin. Traces that yield dye to more than one spring suggest complex flow paths and must be evaluated in light of other evidence.

Figures 7 and 8 show sinkholes used as dye-input points and springs monitored for dye output. Successful traces are marked with idealized, straight-line flow paths from sinkhole to spring.

ICC Dye Traces

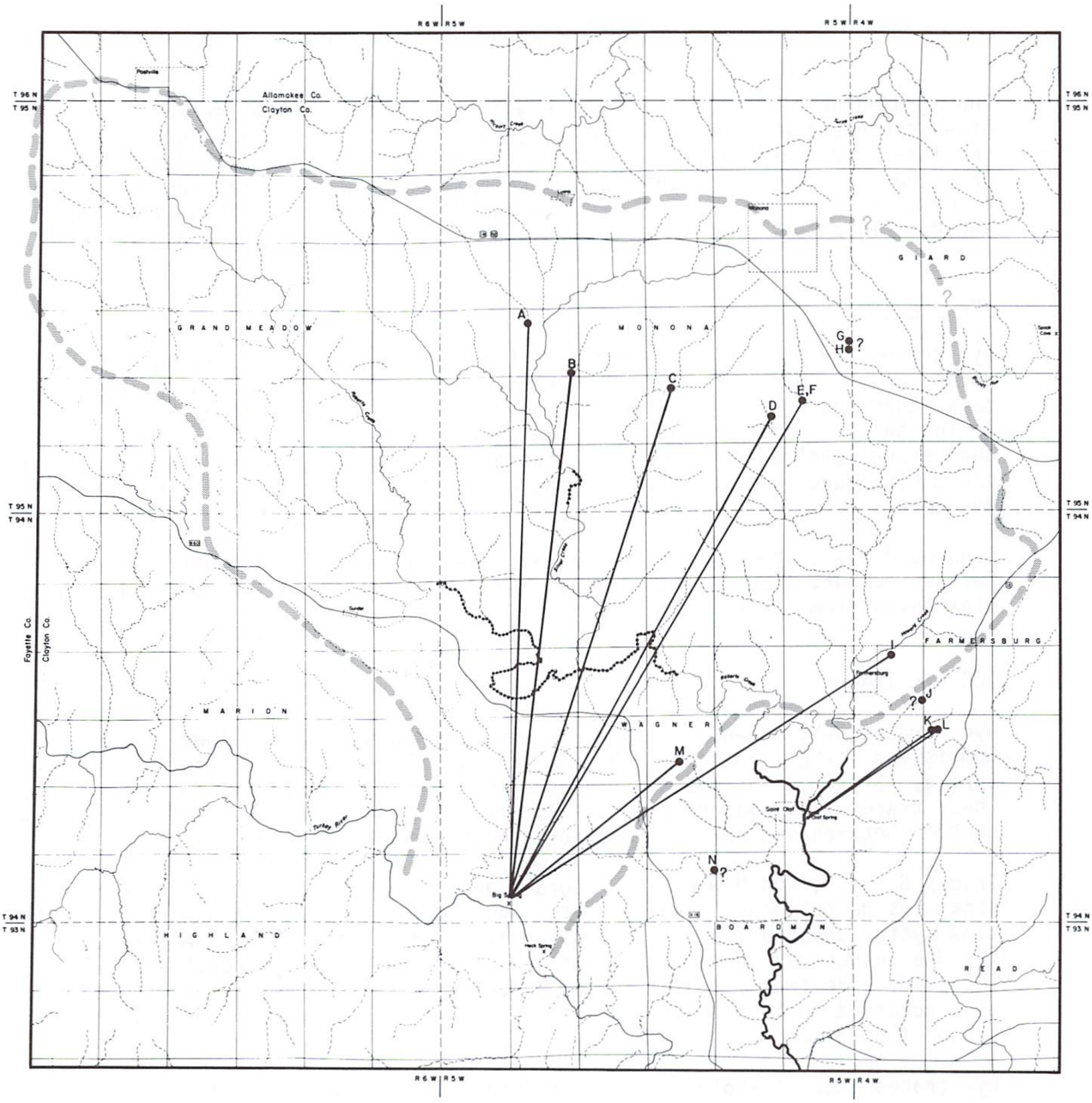
Dye traces A-N, shown on figure 7, were conducted by the Iowa Conservation Commission (ICC) in the 1970s (Heitmann, 1980). Big Spring, Spook Cave Spring, St. Olaf Spring, and one small spring were monitored for dye during these traces. The majority of the ICC traces (A-F, I, and M) indicated a connection between sinkholes used as dye inputs and Big Spring.

Traces G, H, J, and N were not recorded anywhere. It seems likely that these sinkholes do not empty into conduits, but enter into more diffuse parts of the flow system and thus, the dye was diluted and undetectable. Alternatively, the dye output may have occurred at a location that was not monitored. In the ICC study (Heitmann, 1980), during traces A and F, a weakly-positive trace also occurred to Spook Cave. It was not clear if this was the result of background fluorescence.

Dye traces from sinkholes K and L produced dye only at St. Olaf Spring, indicating these sinkholes and St. Olaf Spring are not part of the Big Spring basin. These traces also indicate a groundwater divide between site K (to St. Olaf) and site I (to Big Spring).

IGS Dye Traces

IGS staff conducted two dye traces during the summer of 1982 to: 1) investigate the postulated flow of water from ICC trace A, located in the northeastern section of the Big Spring groundwater basin, to Spook Cave, and 2)



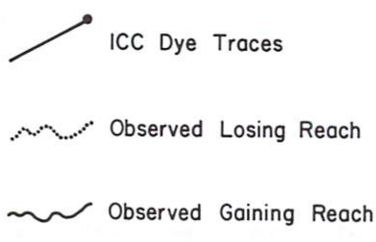


Figure 7. Location of sinkholes used for dye input in ICC dye traces; idealized (straight-line) dye-flow paths; and location of observed losing- and gaining- stream reaches.

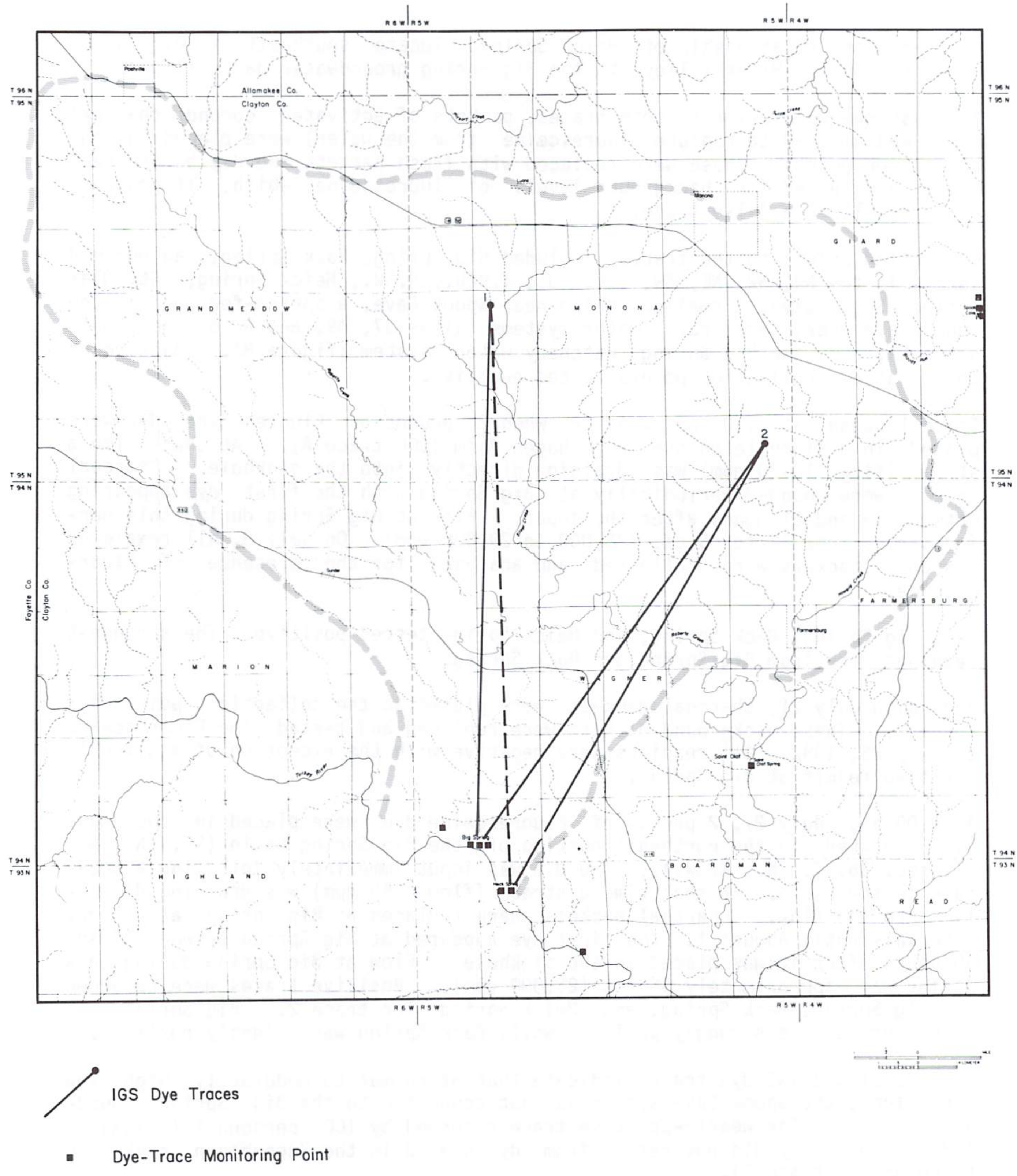


Figure 8. Location of sinkholes used for dye input in IGS dye traces; dye-output monitoring points; and idealized (straight-line) dye-flow paths.

evaluate the relationship of Heick Spring, located southeast of Big Spring along the Turkey River valley, to the Big Spring groundwater basin (figure 8).

At least one week prior to both traces, packets of activated coconut charcoal (the medium used to capture Fluoresceine from the water) were placed at the collection points. These were replaced with fresh packets the day before each trace and tested for background levels of Fluoresceine which, if present, could result in a false trace.

Collection points to the traces included Big Spring, Back Spring, an unnamed spring in the NW, NW, NE, SW, sec. 31, T.94N., R.5W., Heick Spring, St. Olaf Spring, Spook Cave, a smaller spring near Spook Cave, a spring-fed pond in the Spook Cave area, three rural water systems (sites 37, 49, and 81 of the sample network), and the Big Spring Hatchery water system (figure 8). Background levels at all collection points tested negative.

Trace 1 began at 8:30 pm, June 22 when 2 pounds of Fluoresceine dye were placed in a sinkhole on the Bugenhagen farm (ICC trace A). At that time a stream (flow ~10-20 gpm) was draining directly into the sinkhole. Charcoal packets were changed periodically at Big Spring with the first dye appearing between 39 and 51 hours after the input. Flow at Big Spring during this period varied from 62 to 65 cfs (28,000 to 29,000 gpm). On July 8, all remaining charcoal packets were collected and analyzed for the presence of Fluoresceine.

Only Big Spring, Back Spring, and Heick Spring tested positive. The strongest readings were from Big Spring and Back Spring.

Beginning July 21, charcoal packets were placed at the collection points for trace 2. These background packets were replaced and tested for Fluoresceine on July 26, 1982. All readings were negative with the exception of a slightly positive result at Big Spring.

At 9:00 am, July 27, 2 pounds of Fluoresceine dye were placed in the Baade sink, located in the northeast portion of the Big Spring basin (SE, NW, NW, SE, sec. 36, T.95N., R.5W.). The dye was input immediately following a heavy rain in the basin. At that time a stream (flow ~ 50 gpm) was draining directly into the sink. Charcoal packets were replaced at Big Spring at 1/2 day intervals until August 1. The first dye appeared at Big Spring between 44 and 50 hours after it was placed in the sinkhole. Flow at Big Spring during this period was approximately 56 cfs (25,000 gpm). Positive traces were recorded at Big Spring, Back Spring, and Heick Spring for trace 2. Big Spring and Heick Spring were strongly positive while Back Spring was slightly positive.

Results of the IGS dye traces indicate that at normal to moderately high flow conditions, the Spook Cave system is not connected to the Big Spring groundwater basin. The weakly-positive trace recorded by ICC personnel (Heitmann, 1980) apparently did not result from dye placed in the Bugenhagen sink (ICC trace A; IGS trace 1).

IGS trace 2 indicated that Heick Spring is also connected to the Big Spring groundwater basin and takes most of its flow from the eastern portion of the basin.

Other Dye Trace Results

The dye-trace studies provide other valuable information on the nature of the groundwater-flow system. The dye traces indicate groundwater flow from north to south (site A to Big Spring, figure 7) and from east to southwest (site I to Big Spring). These flow directions are directly opposed to surfacewater flow, which is from west to east in Robert's Creek (see figure 7).

The trace studies also suggest that portions of the karst system are quite open and very responsive. Small plastic spheres, 0.4 in. (1.1 cm) diameter, were introduced into several sinkholes (B-F, and L) along with dye. Some of these have been found at Big Spring, over time, on screens in the water system. During high discharges at Big Spring, corn stalks and an occasional beverage can also emerge from the groundwater.

Dye travel times are also informative. Dye from sinkhole A (figure 7) reached Big Spring, 8.6 miles (13.9 km) straight-line distance away, within 24 hours under "moderately high-flow conditions" (Heitmann, 1980). Under lower flow, during the IGS trace (number 1, figure 8) the dye took 39 to 50 hours to traverse this distance. Also, under lower flows, dye from sinkholes B and C, 7.9 miles (12.7 km) away, arrived in 49 hours.

From the east side of the basin, travel times are somewhat slower; dye from sinkhole F, 8.6 miles (13.8 km) away, took 72 hours; dye from I, 6.7 miles (10.8 km), took 134 hours. Dye from IGS trace 2 (figure 8), 7.7 miles (13 km) arrived in 44 to 50 hours. Such travel times are quite fast for groundwater.

During the ICC dye traces, the dye was not only traced at Big Spring, but was also detected in private wells. These wells form the water supply for rural residents. These results point out the potential direct connections between surfacewater run-in to sinkholes and drinking water supplies.

Several other unpublished dye traces, done by spelunkers, ICC, and DEQ staffs, also aided definition of the groundwater basin. These traces were related to flow paths to Spook Cave or springs in Suttle and Hickory Creeks on the north and east sides of the study area. These traces helped to define the basin boundary in these areas.

Losing and Gaining Streams

Losing- and gaining-stream reaches provide further evidence about the extent of the basin. The section of Robert's Creek lying to the north of Big Spring, is observed to lose water to the groundwater system (figure 7). In the 1960s, creamery wastes (whey) were dumped into this reach of Robert's Creek. The stream water and whey then entered the groundwater through fractures in the bed of the stream and sinkholes, discharged at Big Spring, and caused a major fish kill at the hatchery.

After this occurred, ICC personnel took some discharge measurements along Robert's Creek, during winter low-flow periods. Over a 6 mile (9.7 km) reach, Robert's Creek lost about 20% of its flow, or 0.3 cfs; the flow decreasing from 1.6 to 1.3 cfs across the reach. Farther downstream, Robert's Creek lost even more flow into a sinkhole. Standing water in adjacent sinkholes was about 6 feet (2 m) below the level of the Creek. Other observations suggest that, at other times in the past, nearly the entire flow of Robert's Creek has been swallowed by sinkholes in this losing reach (figure 7). At the present time, all the sinkholes along Robert's Creek have been plugged, either by man or by natural activity.

Farther downstream, Robert's Creek is observed to gain water, indicating a groundwater discharge zone. These observations, combined with the dye trace studies, place this reach of Robert's Creek outside of the basin. The gaining stretch of Robert's Creek, St. Olaf Spring and sinkholes K and L (figure 7), are part of a discrete groundwater basin neighboring the Big Spring basin.

During the 1981-82 winter inventory, the authors observed a losing reach on Silver Creek as well (figure 7). In this area, the entire flow of Silver Creek disappeared into the bed of the creek, which was formed on the Galena carbonates. These open fractures later became naturally plugged, and by late spring Silver Creek flowed across this area again.

Water Table/Potentiometric Surface in the Galena Aquifer

Figure 9 is a generalized water table/potentiometric surface map for the Galena aquifer. The map was compiled from various data, including: water-level measurements in Galena wells, and measurements of Galena spring elevations, made by IGS-USGS staff during the November-December 1981 inventory; static-water levels reported by well-driller's during 1979-81; and older static-water levels, in the well-log records of IGS. Many of the older wells that IGS has records of were relocated, and static water levels remeasured. Nearly 80% of the 1981 water levels were in agreement with the older static levels recorded, within the limits of resolution of the elevations. (This is in accord with past IGS surveys as well.) This suggests two things: 1) static-water levels in the Galena have not changed appreciably over the past 20 years; and 2) with prudent, and interpretive judgements, the older records on file at IGS can be used in this data base.

Most of the wells measured are fully open to the Galena. Some, however, are cased to some depth into the Galena, and the casing records of other wells are unknown. Obviously, vertical head differences will occur in the aquifer, but these generally cannot be resolved from this data. Wells in close proximity to the northern (recharge) part of the basin indicate downward flow components with vertical-head differences of 20 to 30 feet (6-9 m) within the Galena. With the 50 foot (15 m) contour interval used, the head data can be used to present a reasonable approximation of the elevation of the water table/potentiometric surface.

The varied data used provide about 120 control points. The contouring of these data was guided by the knowledge of the dye-trace studies, and losing-gaining-stream reaches. The resultant map is shown in figure 9. Groundwater flow is at right angles to contours on the map; the basin divide can be defined and indicates where groundwater will flow towards Big Spring and related springs.

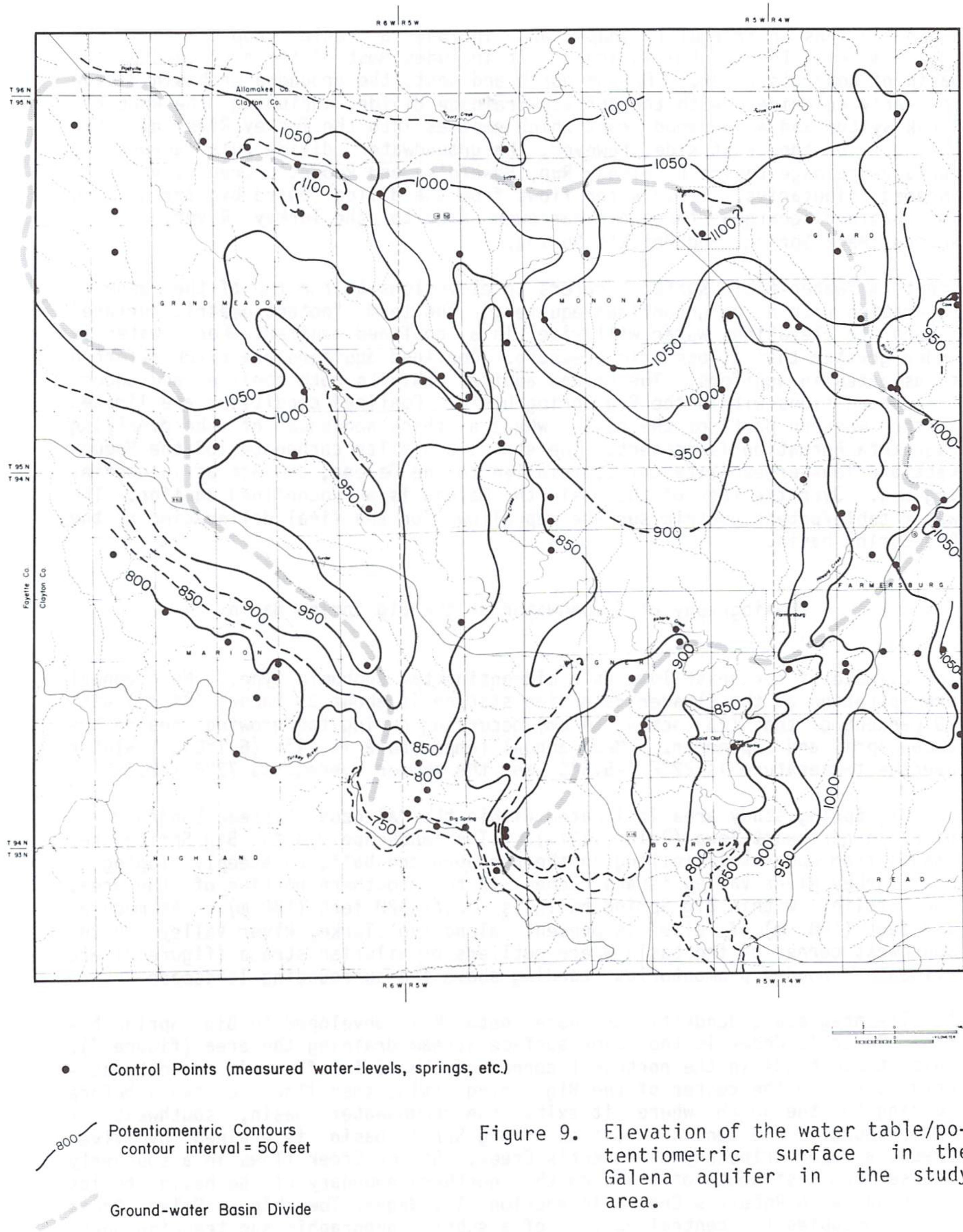


Figure 9. Elevation of the water table/potentiometric surface in the Galena aquifer in the study area.

The basin has an irregular shape, and includes a region approximately 103 square miles (165 sq. km) in area. It includes most of the surface-drainage basin of Robert's Creek. On the north and west, the groundwater-basin divide 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, however, the groundwater divide cuts across the surface-drainage basins of Bloody Run, Howard's, and Robert's Creeks, and some unnamed tributaries. Groundwater flows from the divide toward Big Spring, and the basin discharges through a narrower area to the Turkey River, at Big Spring, Back Spring, and Heick's Spring.

The term "water-table surface" refers to elevations at the top of the zone of saturation within an unconfined aquifer. The term "potentiometric surface" refers to elevations water will rise in a confined aquifer, where water is under greater than atmospheric pressure. Confined aquifers are often referred to as artesian aquifers. The Galena aquifer exhibits both confined and unconfined conditions within the Big Spring basin. Confined conditions are limited to the western part of the basin where a thick sequence of the overlying Maquoketa Formation is present. The shales and silty carbonates of the Maquoketa are low-permeability units, relative to the Galena, and act as a confining bed. Over the rest of the basin the Galena is an unconfined aquifer. The water table/potentiometric surface map allows for the final delineation of the Big Spring basin.

Physiography of Groundwater at the Big Spring Basin

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

The Big Spring study area is located within the Paleozoic Plateau Landform region in northeast Iowa (Prior, 1976). The landscape in the Big Spring area ranges from moderately rolling in the northern one-half, to steeply sloping as the Turkey River Valley is approached in the southern portion of the area. Local relief within Big Spring basin is about 420 feet (130 m). As much as 320 feet (100 m) of relief is present along the Turkey River Valley in the southwest corner of the basin where outliers of Silurian strata (figure 3) are evident as wooded promontories standing above the surrounding landscape.

A well-integrated, dendritic drainage network is developed in Big Spring basin. Robert's Creek is the major surface stream draining the area (figure 7). This stream heads in the northwest corner of the basin, flows in a southeasterly course to the center of the Big Spring basin, then flows eastward before turning to the south where it exits the groundwater basin, southwest of Farmersburg. The central portion of Big Spring basin is drained by Silver Creek, a major tributary of Robert's Creek. Silver Creek flows in a southerly course from just south of Luana on the northern boundary of the basin to its junction with Robert's Creek in section 16, Wagner Township. Silver Creek valley occupies the central portion of a subtle topographic sag trending north to south through Big Spring basin. The axis of this topographic sag follows a prominent flexure in the Galena structure contour mentioned in the discussion of the bedrock geology.

Howard's Creek and an unnamed tributary drain most of the eastern one-third of Big Spring basin. This portion of the drainage network follows a southerly course until it exits the groundwater basin about one-quarter mile south of Farmersburg. Howard's Creek joins Robert's Creek in the village of St. Olaf a few hundred feet upstream of the St. Olaf Spring.

The extreme northeast corner of Big Spring basin is drained by the headwaters of Bloody Run. These drainageways trend northwest to southwest before turning to an easterly course as they leave the groundwater basin.

Big Spring basin's southern boundary is formed by the Turkey River, a major northeast Iowa surface stream. Surface drainage between Robert's Creek and the Turkey River is accomplished by an unnamed tributary to the Turkey River which joins the Turkey just upstream from Big Spring.

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

The major surface-water basins which drain to sinkholes were mapped and are shown on figure 10. The basins were delineated using topographic maps, soils maps, and field observations. The sinkhole basins occupy 11.5 square miles (18.5 km), which is about 11% of the groundwater basin.

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

A mosaic of Paleozoic rocks and Pleistocene deposits make up the present land-surface in Big Spring basin (figures 3 and 11). Paleozoic rocks, primarily shaly carbonates of the Elgin Member of the Maquoketa Formation, and the Galena carbonates crop out along valleys throughout the basin. Rock outcrops are abundant in the eastern and southern portions of the basin (figure 11).

The oldest Pleistocene deposits found in the basin are Pre-Illinoian till and associated deposits. The tills were deposited by continental glaciers throughout northeast Iowa prior to 500,000 years ago (Hallberg, 1980), whereas the associated deposits accumulated by glacial-fluvial and erosional processes during and following deposition of the tills. Extensive erosion in conjunction with downcutting of the Mississippi River and its major tributaries such as the Turkey River, removed most of the till and related deposits from the area prior to 20,000 years ago. Today these deposits are found along upland

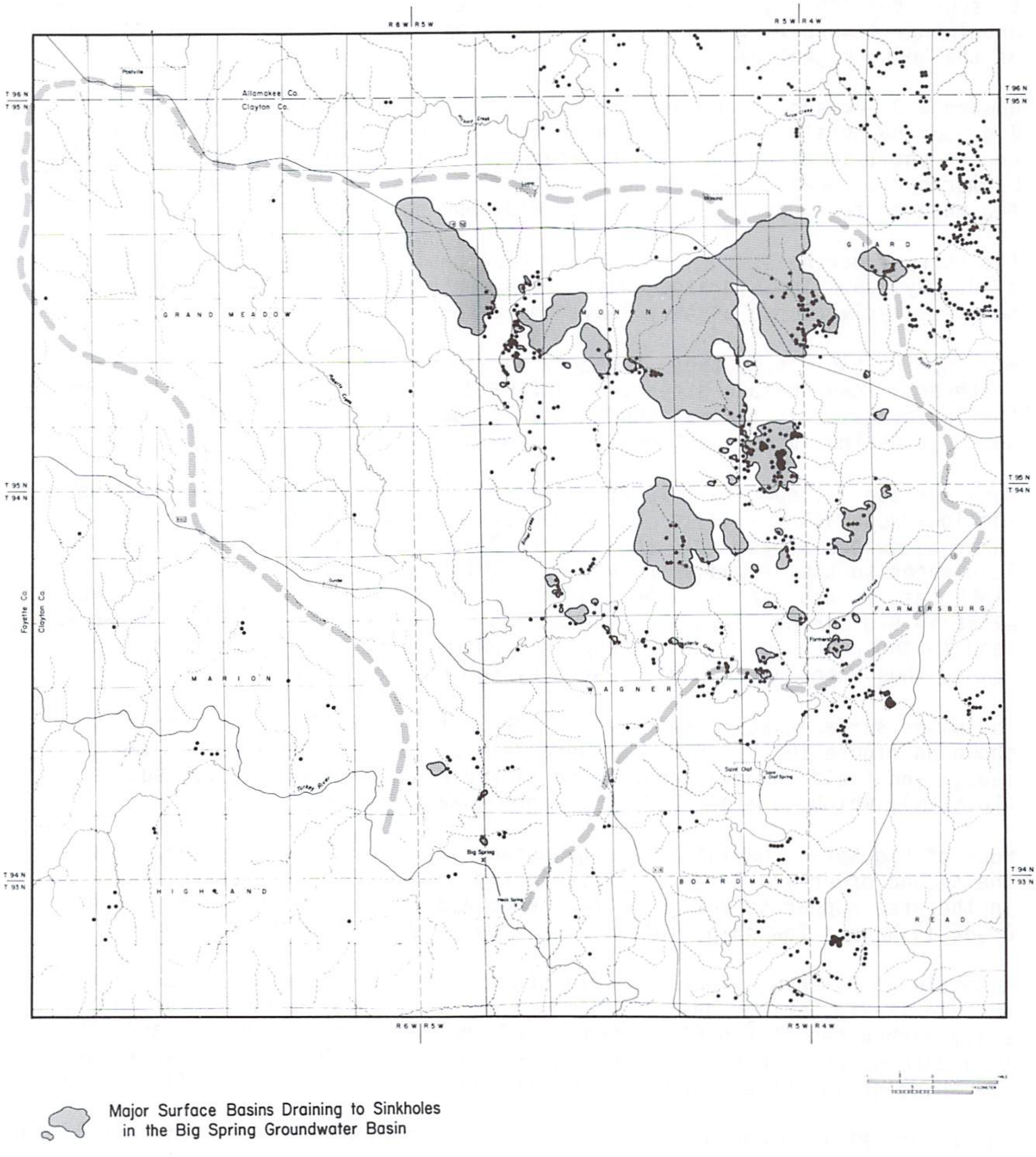


Figure 10. Major surfacewater basins which drain to sinkholes in the Big Spring groundwater basin.

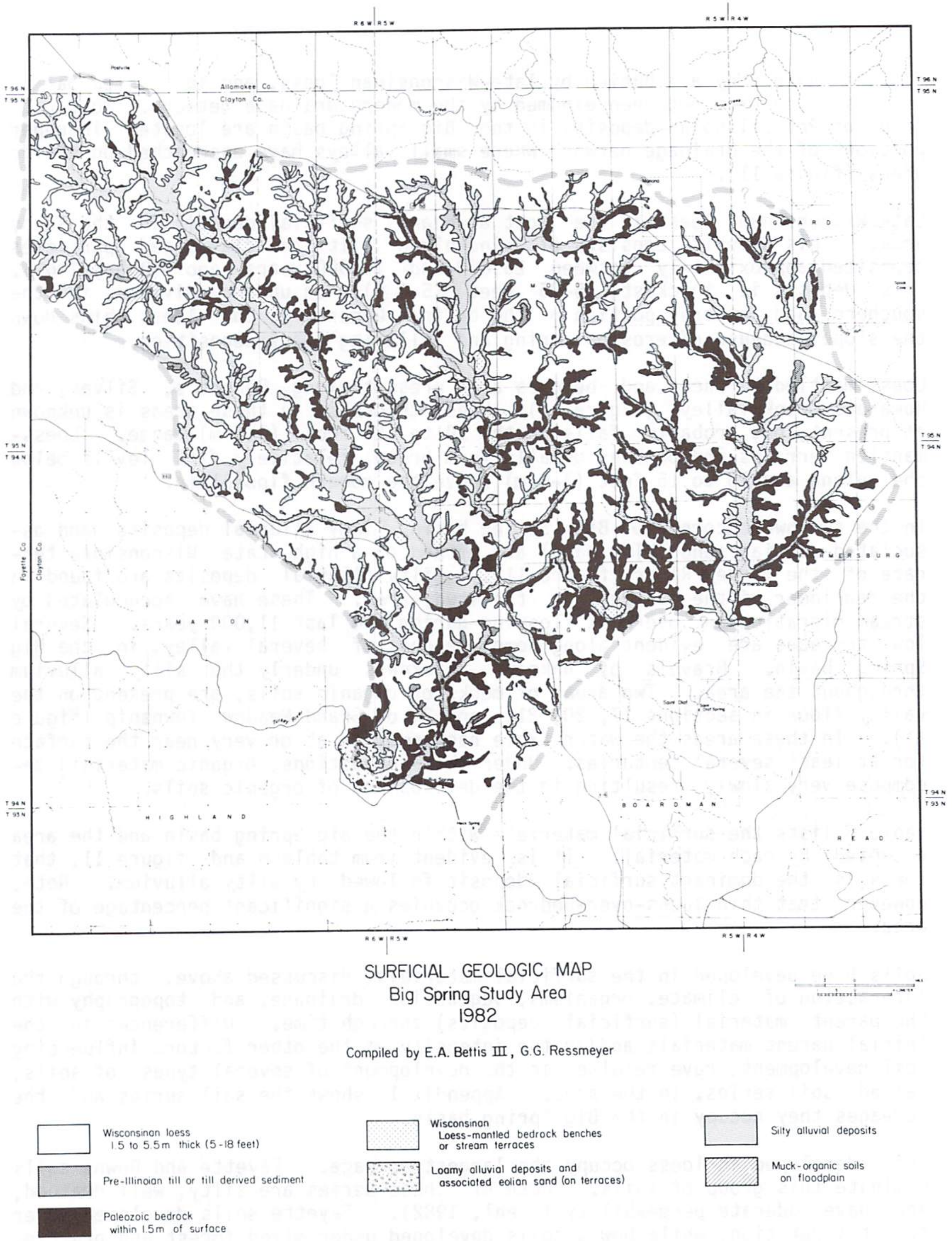


Figure 11. Surficial geologic map of the Big Spring groundwater basin.

divides where they are buried by late-Wisconsinan loess, and in buried paleovalleys which have not been exhumed by the modern drainage network. Most outcrops of Pre-Illinoian deposits in the Big Spring basin are located in upper portions of the drainage network where small valleys have encroached on divide areas (figure 11).

Late Wisconsinan loess is the most abundant surficial deposit in the study area. This deposit consists of wind-blown silt and clay-sized particles deposited approximately between 25,000 and 14,000 years ago (Ruhe, 1969). This deposit is thickest, 15-25 feet (5-8 m), on upland divides in the southern and central portion of the basin. Generally, the loess thins down the slopes because of erosion during and following loess deposition.

Loess-mantled terraces and benches are present along, Robert's, Silver, and Howard's Creek valleys (figure 11). Loess thickness in these areas is unknown at present, but probably falls in the 10 to 20 foot (3-6 m) range. Loess-mantled terraces and benches usually form broad, relatively flat levels below the upland and 10 to 15 feet (3-5 m) above the modern floodplain.

In the southwest corner of Big Spring basin, loamy alluvial deposits and associated aeolian sand (blow sand) are found on a high, Late Wisconsinan terrace of the Turkey River (figure 11). Silty alluvial deposits are found in the remainder of the valleys in the study area. These have accumulated by stream migration and overbank flooding during the last 11,000 years. Several low terraces are evident along some reaches of several valleys in the Big Spring basin. Gravels of unknown thickness underly the silty alluvium throughout the area. Two areas of muck, or organic soils, are present on the valley floor in sections 17, 20, 21, and 24 of Grand Meadow Township (figure 11). In these areas the water table has remained at or very near the surface for at least several centuries. Under these conditions, organic materials decompose very slowly, resulting in the development of organic soils.

Table 6 lists the surficial materials within the Big Spring basin and the area occupied by each material. It is evident from table 6 and figure 11, that loess is the dominant surficial deposit followed by silty alluvium. Note, however, that thin loess-over-bedrock occupies a significant percentage of the area.

Soils have developed in the surficial materials, discussed above, through the interaction of climate, organisms, vegetation, drainage, and topography with the parent material (surficial deposits) through time. Differences in the initial parent materials and/or the intensity of the other factors influencing soil development, have resulted in the development of several types of soils, called soil series, in the area. Appendix 1 shows the soil series and the acreages they occupy in the Big Spring basin.

Soils developed in loess occupy the largest acreage. Fayette and Downs soils dominate this group of soils. Both of these series are silty, well drained, and have moderate permeability (Kuehl, 1982). Fayette soils developed under forest vegetation, while Downs soils developed under mixed forest and prairie. These differences in native vegetation resulted in a darker topsoil with more organic matter in the Downs than the Fayette soils.

Table 6. Surficial materials in Big Spring Basin study area.

Materials	Area (sq. mi.)	Percentage of study area
Loess	73.31	71.0
Loess <5' thick over bedrock or bedrock outcrop	8.45	8.2
Blow sand	0.34	0.3
Glacial till	1.31	1.3
Alluvium		
Silty	17.99	17.4
Sandy and loamy	0.33	0.3
Loess covered terraces or benches	1.13	1.1
Muck	0.16	0.2
Ponds	0.19	0.2
	103.24	100.0%

Soils developed in silty alluvium are the next most abundant in the study area. Numerous soil series fall into this group. Most of these are moderately-well- to somewhat-poorly drained with moderate permeability. They have developed under forest, prairie, and mixed forest and prairie vegetation.

Soils developed in shallow loess over bedrock are the third most abundant group. These are well drained and have moderate- to moderately-rapid permeability. Soils such as Dubuque, Nordness, and Frankville are examples of such soils. Soils developed in the other surficial materials are of minor areal extent in Big Spring Basin.

The distribution of sinkholes in Big Spring basin is also generally related to the thickness of surficial deposits overlying the bedrock surface. In general, sinkholes are found where surficial materials are less than 20 feet thick, over the carbonate bedrock. These areas generally correspond to sideslopes and valleys in the central and eastern portions of the basin (figure 6).

Landuse

Knowledge of current use of the land, as well as past trends, are important for evaluating current groundwater conditions and responses. Most of the Big Spring basin study area is devoted to agriculture. Family-sized crop and livestock farms, many of which have been in the same families for several generations, blanket the rolling landscape. Dairying is an important economic activity. Hog raising is important to many farms and small- to moderate-sized cattle feedlots are frequent. No large feedlots are present. The principal crop grown is corn, followed by hay and oats; soybeans are almost non-existent in the study area.

Table 7 reveals how strong the agricultural influence is for the study area. The class "Urban" covers 3% of the area. This class includes towns, quarries, and all roads. The remaining classes, covering 97% of the study area, are involved in agriculture. Even the forest land is under private management and most is grazed. "Cover crop" on Table 7 includes hay ground, oat fields, and pastures, almost all of which are in rotations with corn. Permanent pastures are rare, usually located in poorly-drained locations. Row-crop area includes land devoted mostly to raising corn, although some oat fields may be included.

Good farm management is the rule in this basin. Terracing is practiced over 10% of the basin to reduce soil erosion. Strip cropping is practiced over an additional 7%. Besides these obvious good-management practices, contour farming and conservation tillage dominate the row-crop acreage. Less than 15% of the area in row crops is managed with conventional tillage techniques. Crop rotations further reveal the good farm management present in the area (Table 1). Almost 90% of the basin is utilized in row-crop agriculture during some years, but of this, only about one-half is planted in corn in any one year. The majority is in rotations of corn followed by oats and then meadow crops, with corn being planted about one-third of the time, on the average.

The intensity of farming and the rotations used in the land management can be seen in Table 8. Assuming that virtually all the land area included in the cover-crop class is in the cover portion of the crop-rotation cycle, note how there is little change in percentages of land in cover crop, strip crop, or row crop on the B, C, and D slope classes, and that the ratio between row crop and cover crop remains essentially 2:1. Even on A slopes, which are restricted almost completely to valley bottoms in this area, the ratio is virtually the same. B, C, and D slopes are managed similarly and are all in well-managed, intensive row-crop agriculture. When slopes exceed 14% (E, F, and G slopes), crop rotations change, less land is devoted to crop production, and significantly more land has been left as forest.

Figure 12 shows the distribution of landuse in the basin. Derived from the computer data base and simplified for display in this report, it reveals three area classes: 1) all row crop, including strip-cropped areas; 2) cover crop, including urban; and 3) forest. There is no striking pattern to the distribution of landuse across the basin, although there are certain tendencies. Row-crop agriculture is most intense in the north-central portion of the study area. This is the region drained by Silver Creek. Slopes tend to be more

Table 7. Landuse in 1980 in the Big Spring basin; given in square miles and percent (%).

	Big Spring Basin	Sinkhole Basins Only
Urban	3.45 (3)	0.49 (4)
Forest	6.50 (6)	0.59 (5)
Cover Crop	26.03 (25)	2.94 (26)
Terraced	2.13 (2)	0.41 (4)
Strip Crop	7.55 (7)	0.72 (6)
Terraced	1.87 (2)	0.15 (1)
Row Crop	49.15 (48)	5.31 (46)
Terraced	6.56 (6)	0.89 (8)
Total	103.24 (100)	11.50 (100)

gentle in that region. Forests are most common on the valley walls of Robert's Creek and in the southern portion of the basin adjacent to the Turkey River Valley. Strip cropping and terracing is most evident in the eastern portion of the basin, and to a lesser extent, along the southwestern-basin divide. These tendencies are likely related to the physiography of the area; in the steepest areas are forests; in the areas of most gentle topography are row crops; in the most rolling areas terracing and strip cropping occur.

These tendencies don't hold up strongly, however, for divisions highly pertinent to evalute the hydrology and water quality of the Galena aquifer. Table 9 compares landuse in the areas of the four bedrock units covering the area. Although there are differences, ratio of row-crop area to cover-crop area remains nearly the same, 2:1; and intensive agriculture is found "across the board" in all the different bedrock areas. Equally important for evaluation of conditions relating to groundwater quality, landuse remains nearly identical when the classes are compared between the sinkhole basins and the entire groundwater basin (Table 7). The landuse within the 11.5 square miles (18.5 sq. km), which drain to sinkholes, is virtually identical in distribution to the landuse within the 103 square mile (165 sq. km) groundwater basin, which drains to Big Spring.

Historical Changes

Enormous changes in the acreage used for corn production have occurred in Iowa in the past 15 years. Clayton County is not different. From 1917 to 1957, land devoted to corn production in Clayton County rose from 76,000 acres (31,000 ha) to about 92,000 acres (37,000 ha). By 1966, it had risen just

Table 8. Landuse by soil slope classes for the Big Spring basin study area, 1980.

Category	A Sq. Mi.	(%)	B Sq. Mi.	(%)	C Sq. Mi.	(%)	D Sq. Mi.	(%)	E Sq. Mi.	(%)	F & G Sq. Mi.	(%)
Urban	0.23	(2)	0.85	(5)	1.18	(4)	0.93	(3)	0.17	(2)	0.08	(2)
Forest	0.63	(6)	0.56	(3)	0.87	(3)	1.75	(5)	1.28	(13)	1.38	(38)
Cover Crop	2.85	(29)	4.25	(25)	6.47	(24)	8.69	(24)	2.79	(29)	0.95	(26)
Terraced	0.04	(0)	0.27	(2)	0.48	(2)	0.91	(3)	0.30	(3)	0.13	(4)
Strip Crop	0.30	(3)	0.77	(5)	2.02	(7)	3.06	(9)	1.17	(12)	0.24	(7)
Terraced	0.04	(0)	0.22	(1)	0.49	(2)	0.89	(2)	0.20	(2)	0.03	(1)
Row Crop	5.49	(56)	8.87	(52)	13.93	(51)	16.91	(47)	3.17	(33)	0.75	(20)
Terraced	0.15	(2)	1.22	(7)	1.95	(7)	2.67	(7)	0.44	(5)	0.12	(3)
Total	9.73		17.02		27.38		35.82		9.52		3.67	

over the 100,000 acre (40,000 ha) mark, increasing about 26,000 acres (11,000 ha) in 50 years. But between 1966 and 1981, corn acreage increased about 58,000 acres (23,000 ha) in only 15 years, up to 160,000 acres (65,000 ha; figure 13).

It is important to notice where much of this increased acreage occurs. Figure 14 shows that in Clayton County, substantial increases are being made in areas where bedrock is very shallow. From 1967 to 1979 such increases have nearly doubled the area of shallow-bedrock soils producing row crops in Clayton County, increasing the acreage from about 8,000 acres (3,200 ha) to almost 14,000 acres (5,700 ha).

Concurrent with this increased corn acreage has been increased yields. Average corn yields moved from the 30-40 bushel-per-acre range in the 1910s and 1920s, to the 60-80 bushel-per-acre range in the 1950s and early 1960s. By 1971, average estimated yields in Clayton County exceeded 100 bushels-per-acre for the first time, and by 1981, a high of 121 bushels-per-acre was recorded county wide (data from Iowa Crop and Livestock Reports). This increase in yields occurred as a result of better hybrids, improved farm management, the use of pesticides, and greatly increased fertilization. It occurred in spite of increased acreages planted on steeper slopes and more "fragile" soils.

Many forms of nitrogen can be applied for corn production. Now the most common form is anhydrous ammonia, applied either in fall or spring. The survey of ag-chemical use in the Big Spring basin showed a range of application rates

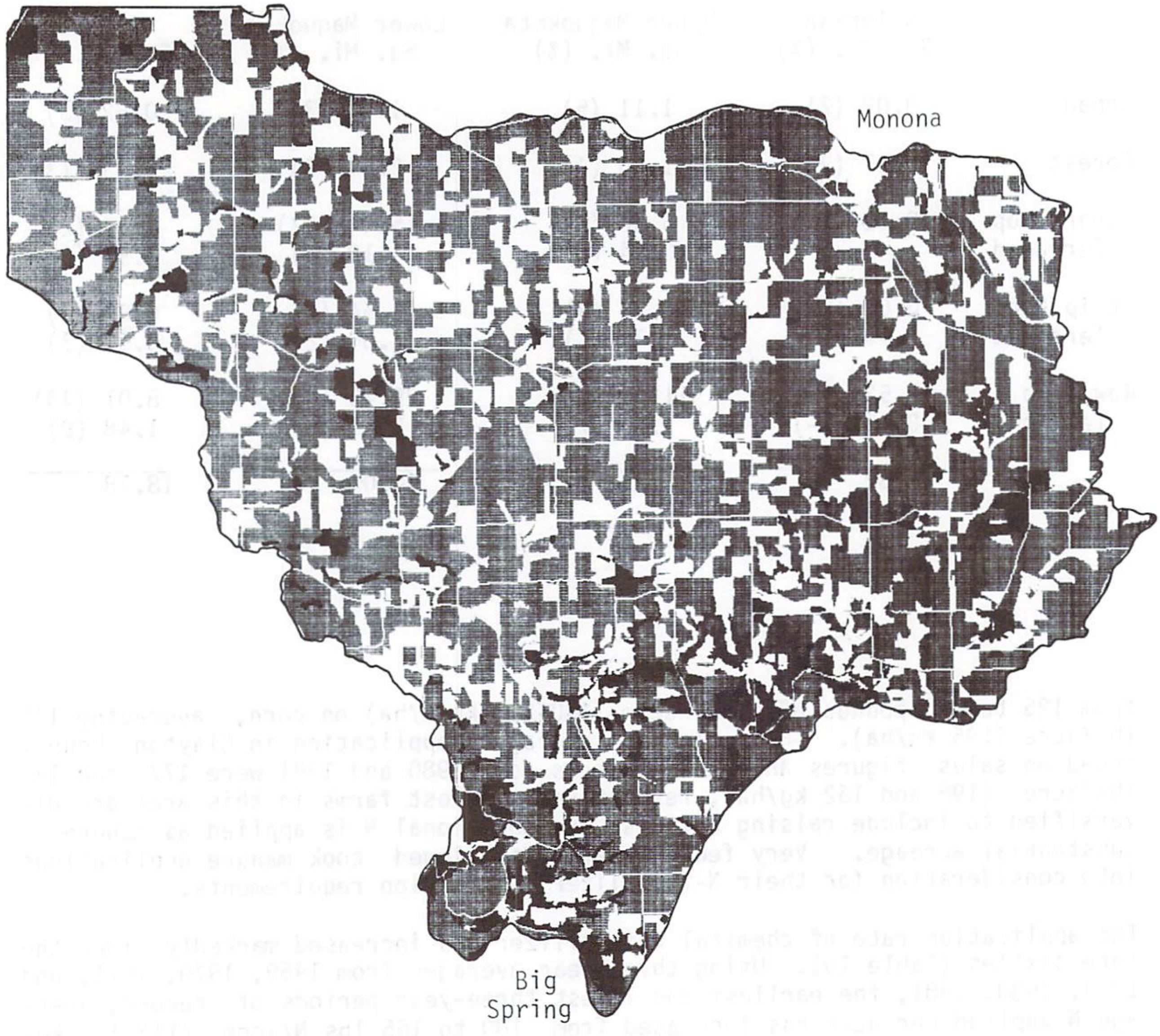


Figure 12. Generalized landuse map of the Big Spring groundwater basin: forest=black areas; cover crop and urban=white; all row crop, including strip-cropped areas=gray.

Table 9. Landuse occurring on bedrock units in Big Spring Basin study area, 1980.

	Silurian Sq. Mi. (%)	Upper Maquoketa Sq. Mi. (%)	Lower Maquoketa Sq. Mi. (%)	Galena Sq. Mi. (%)
Urban	0.02 (2)	1.11 (5)	1.68 (3)	0.62 (3)
Forest	0.07 (9)	1.05 (4)	2.94 (5)	2.43 (13)
Cover Crop	0.12 (15)	5.56 (24)	15.94 (27)	4.40 (23)
Terraced	--	0.44 (2)	1.18 (2)	0.51 (3)
Strip Crop	0.07 (9)	2.15 (9)	4.54 (8)	0.80 (4)
Terraced	--	0.35 (1)	1.00 (2)	0.53 (3)
Row Crop	0.52 (63)	11.22 (48)	29.40 (49)	8.01 (43)
Terraced	0.00 (--)	1.68 (7)	3.40 (6)	1.48 (8)
	0.82	23.55	60.09	18.78

from 125 to 250 pounds of N per acre (140-280 kg-N/ha) on corn, averaging 175 lbs/acre (195 kg/ha). Estimates of average N application in Clayton County based on sales figures and corn acreages for 1980 and 1981 were 177 and 145 lbs/acre (198 and 162 kg/ha), respectively. Most farms in this area are diversified to include raising animals, and additional N is applied as manure on substantial acreage. Very few farmers interviewed took manure applications into consideration for their N-fertilizer application requirements.

The application rate of chemical N-fertilizer has increased markedly since the late sixties (Table 10). Using three-year averages from 1969, 1970, 1971, and 1979, 1980, 1981, the earliest and latest three-year periods of record, average N applied per acre has increased from 100 to 165 lbs N/acre (112-175 kg-N/ha). Before 1969, official records are incomplete, but the existing data suggests that the major increase occurred in the late 1960s and through the 1970s (figure 15). The increased sales is a result of both increased application rates, now approaching 175 lbs N/acre (195 kg/ha) in the Big Spring area, and the increased acreages of corn.

Concurrent with the increase in corn acreage, there was an increase in cattle and hog production in the region. The increase in the cattle population in Clayton County is the most consistent. Cattle and calves increased from about 106,000 head to 140,000 in 1979 (figure 16). Hog populations show sizeable fluctuations but also increased in Clayton County over this time period as well (figure 17).

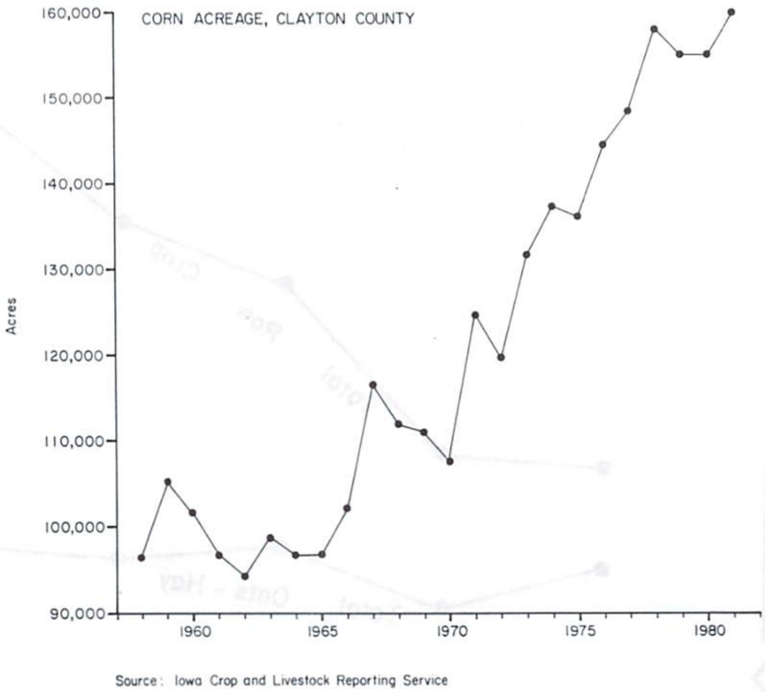


Figure 13. Change in acreage planted to corn in Clayton County, 1958 to 1981.

The Big Spring Hydrogeologic System

For a thorough understanding of the groundwater-quality data, it is necessary to relate this data to the hydrogeologic system. This section will provide a brief review of carbonate aquifers and a description of the Big Spring flow system.

Hydrogeologic Characteristics of Carbonate Aquifers

The nature of the problems of karst-carbonate aquifers has been reviewed in prior reports (Hallberg and Hoyer, 1982). However, a brief review of some of these features is pertinent.

The Galena aquifer, which supplies the water discharging at Big Spring, is composed primarily of dolomite and limestone, collectively termed carbonate rocks. Carbonate-rock aquifers possess two properties that often result in anomalous hydrologic characteristics, relative to clastic–rock aquifers. These properties are: 1) generally low primary permeability; and 2) solubility in water which is undersaturated with respect to carbonate minerals. The low primary permeability results in groundwater recharge and flow being concentrated within fractures and along bedding planes, while the solubility of the carbonate allows for enlargement of these fractures.

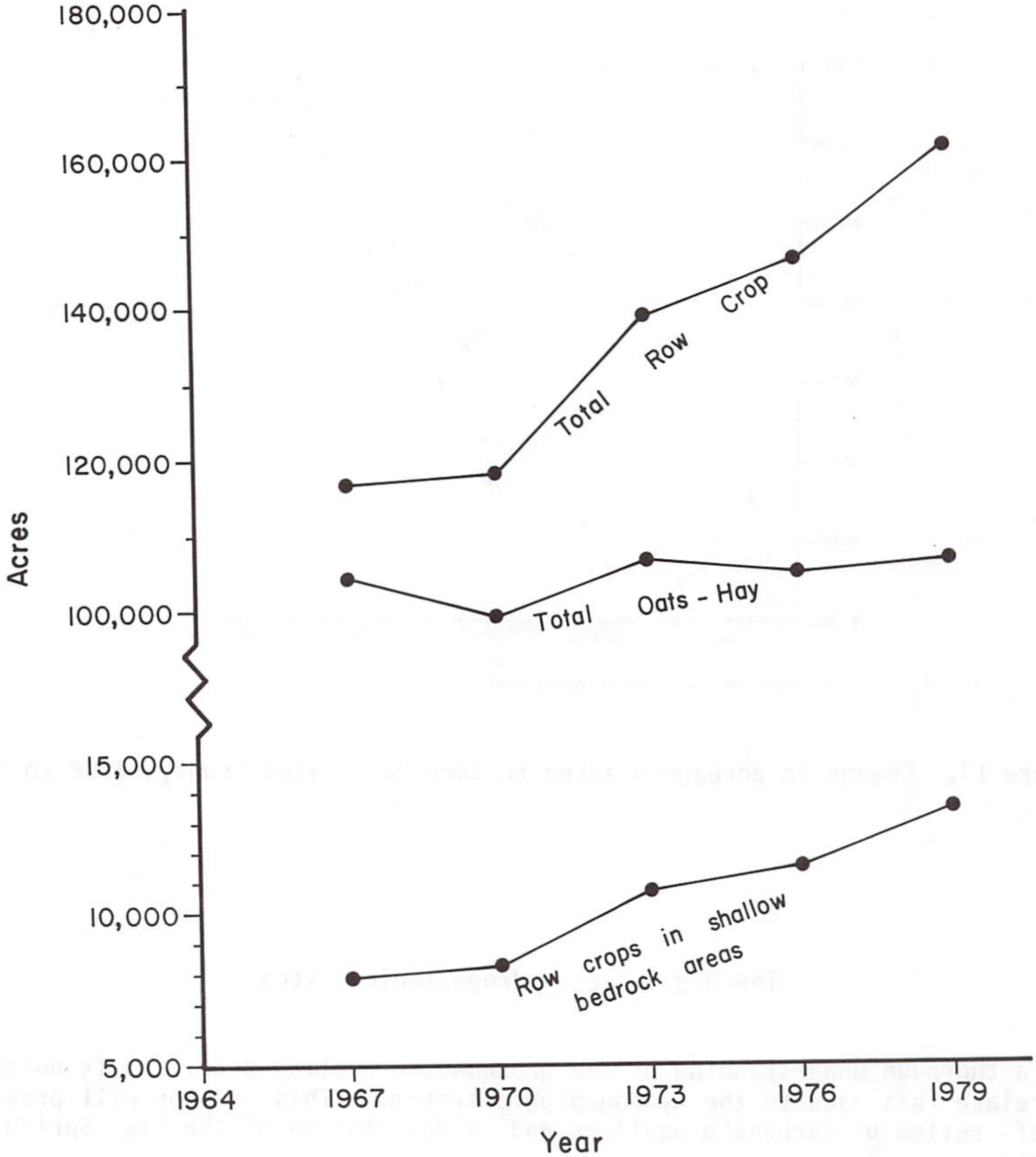


Figure 14. Change in total row crop acreage; acreage of oats and hay; and row-crop acreage on soils with bedrock less than five feet deep (unpublished data provided by G. A. Miller, Iowa State University).

Near-surface carbonate solution may lead to the formation of collapse and solution features such as sinkholes. Sinkholes increase recharge to the aquifer by capturing surface runoff. The additional rapid recharge may promote accelerated enlargement of subsurface voids. The continued solution results in cavernous subsurface openings or conduits linked to recharging sinkholes,

Table 10. Fertilizer N sold, acres of corn, and estimated N application rates in Clayton County, 1958 to 1981. Nitrogen fertilizer sales figures are computed from Iowa Department of Agriculture records. Corn acreage and corn-yield estimate figures are taken from Crop and Livestock Reporting Service reports. Application rate is based on N sold in Clayton County divided by acres of corn planted in Clayton County.

Year	Tons of N Sold	Corn Acreage	N/acre (pounds)	Yield (bushels/acre)
1958	495	96,300	10	64
1959	ND	105,100	---	63
1960	ND	101,900	---	58
1961	ND	96,800	---	74
1962	ND	94,100	---	63
1963	ND	98,900	---	80
1964	ND	96,800	---	62
1965	ND	96,900	---	76
1966	2,730	102,100	53	86
1967	ND	116,600	---	86
1968	ND	112,100	---	94
1969	6,399	111,000	115	93
1970	6,087	117,400	104	94
1971	5,064	124,700	81	100
1972	ND	119,500	---	106
1973	6,980	131,700	106	104
1974	8,619	137,200	126	92
1975	7,429	136,000	109	97
1976	8,997	144,400	125	92
1977	6,612	148,300	89	115
1978	10,480	157,000	133	113
1979	11,405	155,000	147	116
1980	13,743	155,000	177	116
1981	11,636	160,000	145	121

forming an integrated drainage system within the aquifer (see Le Grand and Stringfield, 1973). A conduit system such as this, presents a marked contrast to other parts of the aquifer, where permeable zones may be limited to relatively unmodified fractures and bedding planes. Between these two end-members, all intermediate stages of solutionally-developed permeability may exist.

The wide range of permeabilities that are possible in carbonate aquifers results in varying types of groundwater flow and recharge/discharge mechanisms. White (1977) used the terms conduit flow to describe groundwater movement through large open cavernous zones or conduits, and the term diffuse flow to characterize flow through relatively unmodified fractures and bedding planes

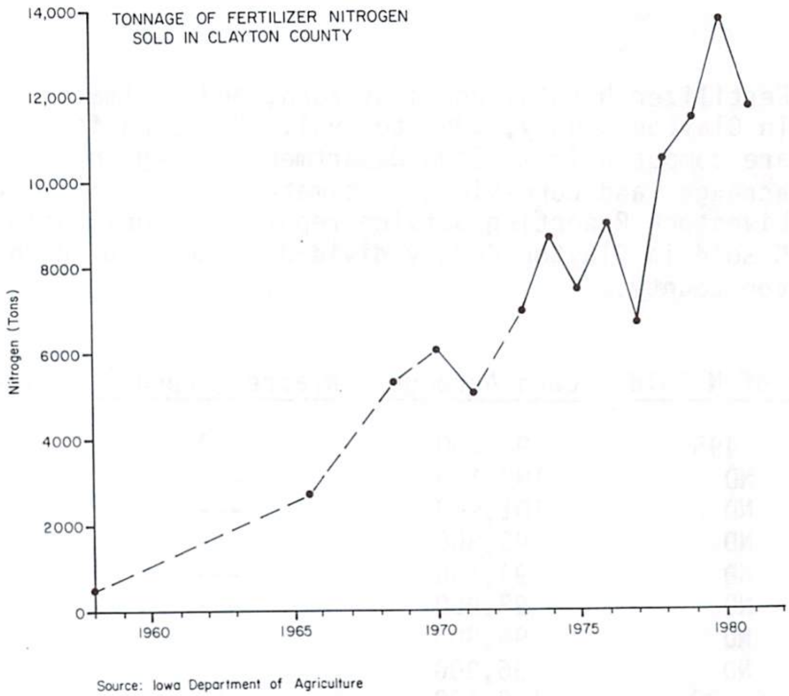


Figure 15. Tons of nitrogen fertilizer sold in Clayton County, 1958 to 1981.

(figure 18). Carbonate aquifers characterized by conduit flow are recharged largely by the partial or complete capture of surface runoff by sinkholes. Flow is exceedingly fast, relative to most groundwater systems, and may be turbulent. Discharge is generally concentrated in a small number of related large springs or gaining-stream reaches. The response of such a system to precipitation is extremely fast, and often analogous to the response of a surface-water system (figure 18).

Diffuse-flow carbonate aquifers receive recharge through infiltration along unenlarged fractures and the low-permeability rock matrix. Flow through the system is generally more analogous to flow in clastic aquifers. Discharge is through numerous small springs, seeps, and gaining-stream reaches. The response of a diffuse-flow system to precipitation is slow, and similar to the response of a clastic aquifer (figure 18).

Within most carbonate aquifers, both diffuse- and conduit—flow systems are present to some degree. Because of the high transmissivity of these conduit zones, more rapid groundwater flow occurs, which draws down the water table/potentiometric surface, in the same manner that a tile-line draws down and drains soil water. This results in enhanced flow from the diffuse-flow system toward the conduit zones. Thus, in these systems, the conduit-bearing parts of the aquifer act as subsurface drains, with much of the diffuse flow discharging into, and flowing through the open cavernous zones to the surface discharge points of the conduit system, usually a spring. In a well-developed karst drainage system the water table is so depressed along these "arterial" conduit zones, that the underground conduits meet the surface stream discharge

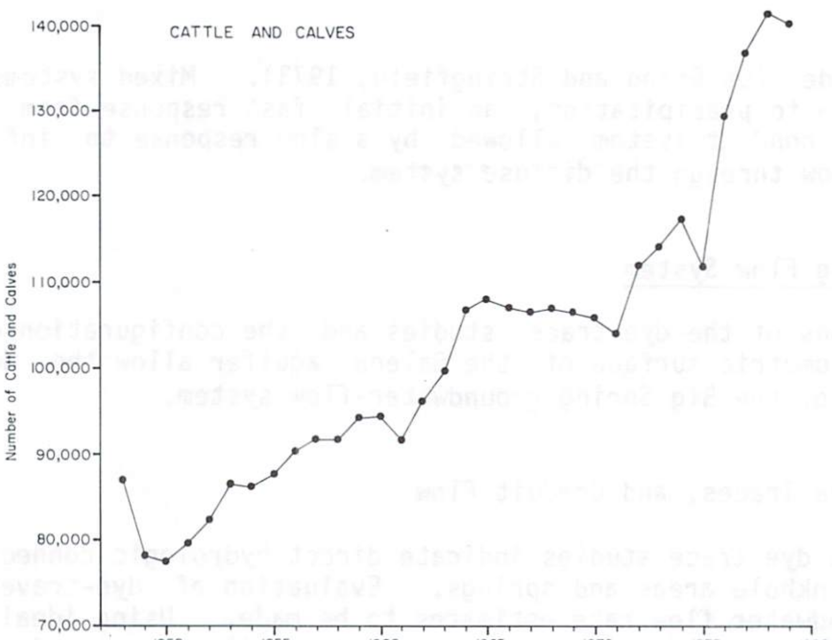


Figure 16. Number of cattle and calves in Clayton County, 1948 to 1979 (data from Iowa Crop and Livestock Reporting Service).

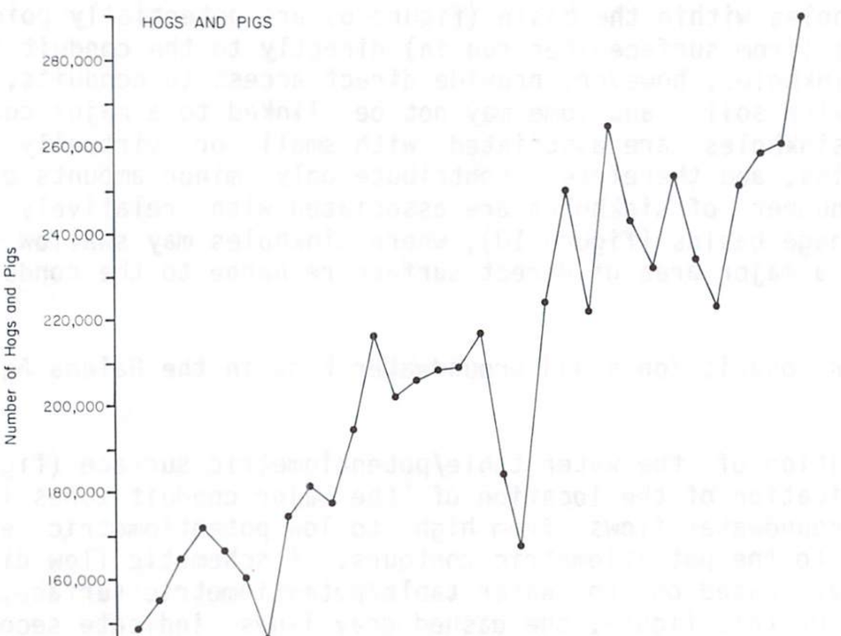


Figure 17. Number of hogs in Clayton County, 1948 to 1979 (data from Iowa Crop and Livestock Reporting Service.

almost at grade (Le Grand and Stringfield, 1973). Mixed systems show a two-phase response to precipitation, an initial fast response from sinkhole recharge of the conduit system followed by a slow response to infiltration recharge and flow through the diffuse system.

The Big Spring Flow System

Interpretations of the dye-trace studies and the configuration of the water table/potentiometric surface of the Galena aquifer allow the description of some aspects of the Big Spring groundwater-flow system.

Sinkholes, Dye Traces, and Conduit Flow

As noted, the dye trace studies indicate direct hydrologic connections between particular sinkhole areas and springs. Evaluation of dye-travel times allow minimum groundwater flow rate estimates to be made. Using idealized straight line travel distances (as shown on figures 7 and 8), or using interpreted flow path distances using the water table/potentiometric surface map (figure 9), results in computed flow rates that vary from about 1.3 to 8.6 miles/day (2.1-14 km/day), and averaging about 3.5 miles/day (5.5 km/day). The upper range of these rates is comparable to surfacewater velocities, and are extremely high for groundwater. The rapid flow rates indicate the sinkholes and Big Spring (and associated springs) are linked by a conduit flow system, and respectively act as recharge and discharge points.

All the sinkholes within the basin (figure 6) are potentially points of fast-flow recharge (from surfacewater run in) directly to the conduit system. Not all of the sinkholes, however, provide direct access to conduits, because many are plugged with soil, and some may not be linked to a major conduit. Further, some sinkholes are associated with small or virtually non-existent drainage basins, and therefore, contribute only minor amounts of direct recharge. A number of sinkholes are associated with relatively large, well-defined drainage basins (figure 10), where sinkholes may swallow small streams and comprise a major area of direct surface recharge to the conduit system.

Major Conduit Zones and Groundwater Flow in the Galena Aquifer

The configuration of the water table/potentiometric surface (figure 19) provides an indication of the location of the major conduit zones in the Galena aquifer. Groundwater flows from high to low potentiometric elevations, at right angles to the potentiometric contours. A schematic flow diagram for the Galena aquifer, based on the water table/potentiometric surface, is shown on figure 20. On this figure, the dashed gray lines indicate secondary groundwater divides within the basin proper. These divides separate the area into discrete sub-basins. Black arrows represent generalized groundwater flow lines, which indicate the direction of groundwater movement. Notice that the flow lines converge towards pronounced troughs, or lows in the potentiometric contours (figure 19), particularly in the central and eastern sub-basins.

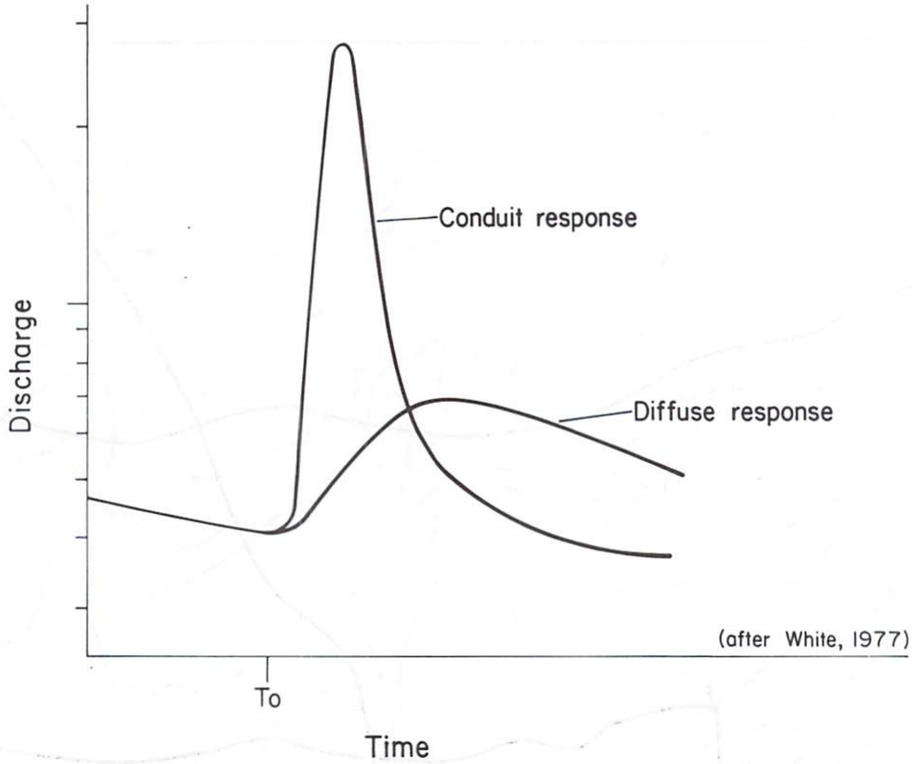


Figure 18. Schematic hydrographs showing the difference between conduit—flow and diffuse-flow discharge in a carbonate aquifer (e.g., at a spring) over time, in response to a recharge event at time, To.

These troughs converge in the southern portion of the basin and flow toward the groundwater discharge area along the Turkey River, principally at Big Spring, Back Spring, and Heick's Springs. Much of the groundwater contained in these sub-basins flows into and through these narrow zones, along the axes of these troughs, indicating that these elongate troughs have very high transmissivities, relative to adjacent parts of the aquifer. These zones are indicated schematically on figure 20 by the long, prominent flow-lines in the eastern and central sub-basins. These zones are interpreted as the major "arterial" routes of the conduit flow system, which transmits groundwater from the sinkholes to Big Spring. The dye-trace minimum flow rates suggest that these major zones of the conduit flow system likely include sizeable conduits, but they also likely include a broader zone of enhanced fracture permeability as well.

Other less-pronounced troughs are present in the western sub-basins, and trend to the northwest (figure 19). These are less well-defined. The thick cap of Maquoketa Formation and lack of sinkholes in this area likely limit the potential for development of open-solution conduits, making interpretation of these troughs in the western sub-basins speculative.

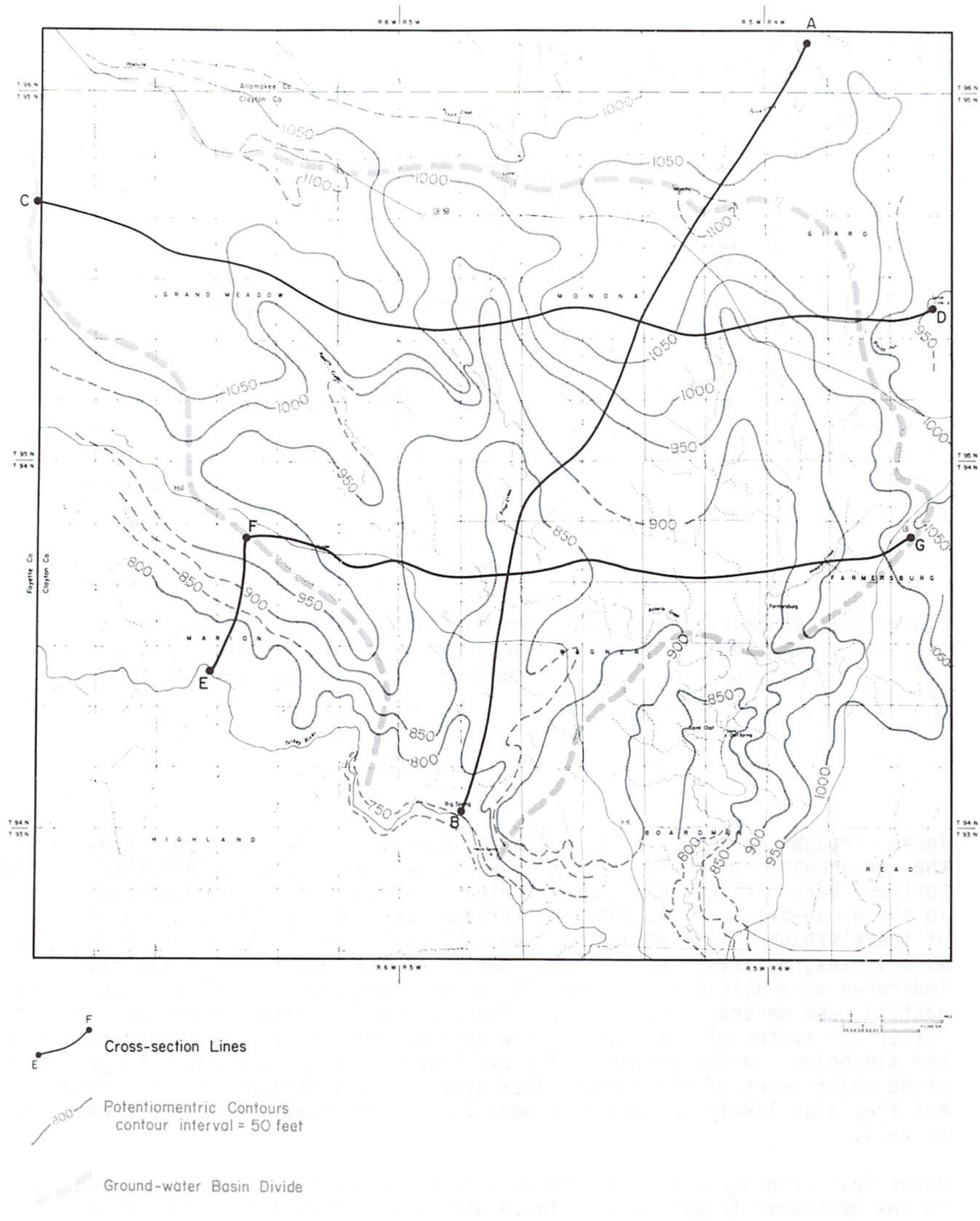


Figure 19. Elevation of the water table/potentiometric surface in the Galena aquifer, and lines of cross section shown on figures 21 through 23.

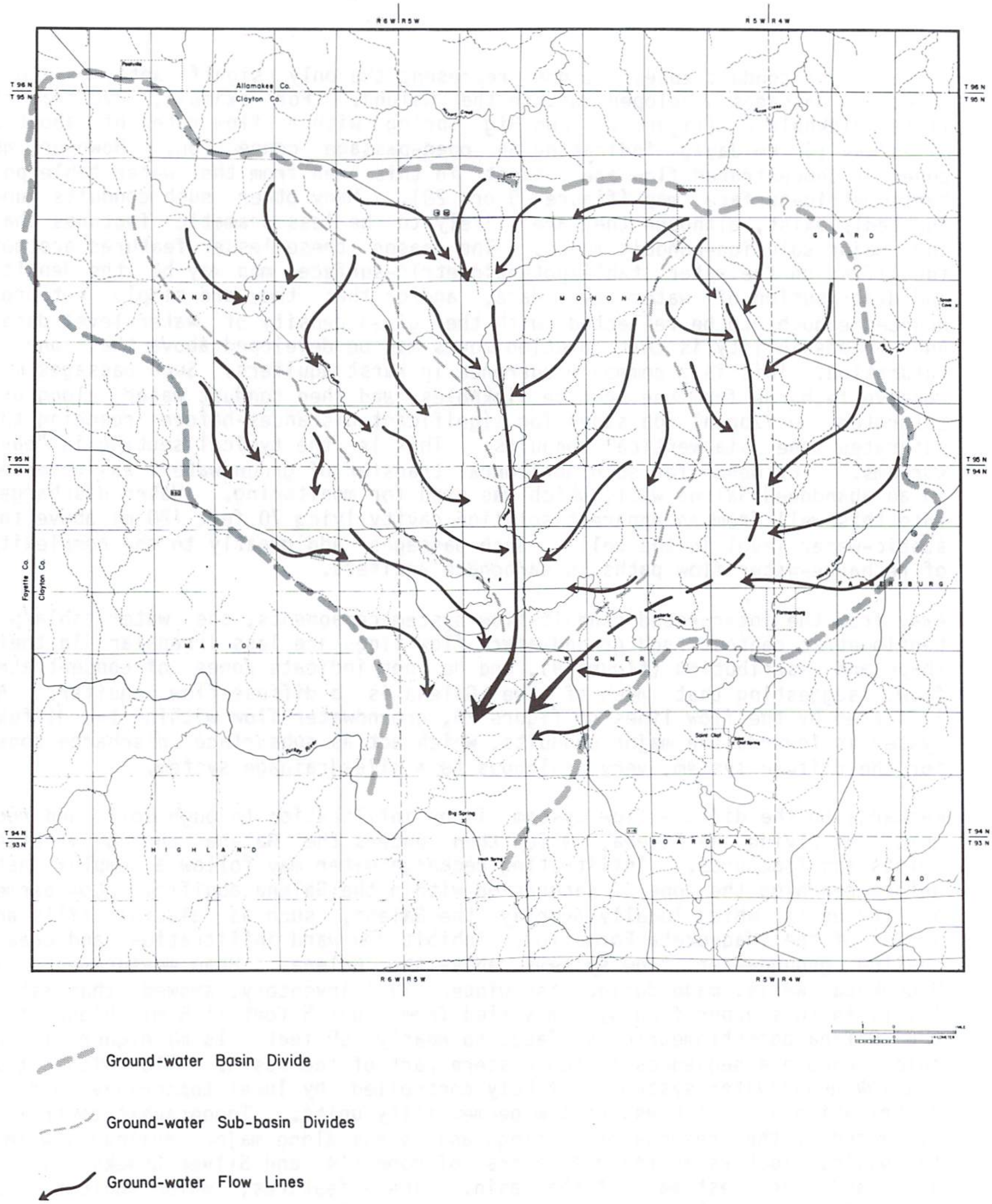


Figure 20. Groundwater basin and subbasin divides, and schematic groundwater flow lines based on the water table/potentiometric surface map.

These major conduit zones do not represent the only significantly enlarged solution passages developed within the Galena. For example, dye tracing linked sinkhole C (figure 7) and Big Spring with a flow rate of about 3 miles/day (5 km/day), indicating an open-passage connection. However, no zones of concentrated flow are evident in this area from the water table/potentiometric-surface map (figure 9 or 20). Many other such conduits undoubtedly exist, although they are likely to be less dramatic features than the major solution-conduit zones. The reason these lesser features are not identified on the water table/potentiometric-surface map may be the density and distribution of water-level data, and/or that they are simply not pronounced enough to be reflected with the given density of water-level data. Another possibility is that solution zones may be developed above the zone of saturation. This is a common occurrence in karst aquifers. Such passages may receive recharge from one or more sinkholes, and then conduct water along unsaturated, horizontal passages for significant distances before reaching the saturated zone via vertical conduits. This is the typical setting in "cave streams." Evidence for such horizontal transfer of groundwater was observed in an abandoned Galena well, which was used for monitoring. Water discharges into this well from an apparent solution cavity lying 70 feet (20 m) above the static-water level in the well. Such passages add greatly to the complexity of recharge-water flow paths in carbonate aquifers.

Away from the interpreted conduit-flow system components, the water table/potentiometric contours and groundwater flow lines are less irregular in their shape and distribution (figure 9), and do not indicate zones of concentrated flow, suggesting that much of the Galena is a diffuse-flow aquifer. As indicated by the flow lines on figure 20, groundwater flow within the diffuse system is towards the major conduits, which act as subsurface discharge zones for the diffuse system, very analogous to a tile-drainage system.

Recharge to the diffuse-flow system is by infiltration through soil and rock units overlying the Galena, which then enters the Galena through vertical joints and fractures. Infiltrating recharge water may follow a complex path before reaching the zone of saturation within the Galena aquifer. Low permeability units which locally overlay the Galena, such as glacial tills and shales of the Maquoketa Formation, inhibit downward infiltration and create shallow groundwater flow systems above the Galena. Head measurements in Maquoketa wells, made during the winter 1981 inventory, showed that water-levels in this upper flow system varied from about 5 feet (1.5 m) higher than the Galena potentiometric surface, to nearly 50 feet (15 m) higher in the thick Maquoketa sequences in the western part of the basin. Flow within this shallow groundwater system is likely controlled by local topography and the distribution and thickness of low permeability units. Topographic control is evidenced by the presence of springs and seeps along major drainages within the basin, such as in the headwaters of Robert's and Silver Creeks, in the north and northwest part of the basin. These features, which indicate discharge from the shallow flow system, are more evident in spring when rates of infiltration into the soil exceed recharge rates, forming a thicker shallow-saturated zone. However, flow in the shallow system is likely towards surface drainages throughout the year. Shallow flow towards surface drainages and partial or complete removal of low-permeability units within the associated valleys make these areas potentially important recharge zones for the Galena aquifer. Aley (1977) estimates that a majority of the "diffuse" recharge to carbonate aquifers in an area of southern Missouri occurs along valleys, although the valleys occupy only a small part of the area under consideration. Additional recharge along valleys occurs more directly from losing streams. Figure 7 shows the observed losing-stream reaches within the basin. Others also exist.

Limited evidence suggests that leakage from the shallow flow system to the Galena may be a continuous process in many parts of the basin. In the thick Maquoketa area, permanent wells are finished within the Maquoketa, and some perennial springs issue from Maquoketa rocks as well. In other parts of the basin, relatively deep (5-6 feet) main tile lines were observed to discharge water throughout 1981-82. This indicates that infiltrating water is present at fairly shallow depths several months after any significant surficial recharge to the area. Likewise, the abandoned well used for monitoring, which was previously described, received recharge from the solution zone (located about 70 feet above the static water level) throughout the winter of 1981-82. As there was little or no surficial recharge during the winter months, the solution passage must have been receiving leakage from the shallow system, demonstrating that leakage recharges conduit parts of the flow system as well as the diffuse flow system. Whether this long term leakage is widespread or local in occurrence cannot be determined.

Downward leakage from the Galena aquifer also must occur. Shales within the Decorah-Platteville-Glenwood Formations act as aquicludes and separate the Galena flow system from the St. Peter Sandstone aquifer (Steinhilber et al., 1961). Head data from properly cased St. Peter wells in the Big Spring basin, and head data from prior studies (Steinhilber et al., 1961; and other unpublished data) show that water levels in the St. Peter vary from about 15 feet (5 m) lower than in the Galena (near the St. Peter outcrop belt to the northeast, or in the conduit zones) to, perhaps, greater than 150 feet (45 m) under portions of the Galena groundwater divides. The average difference in head is about 50 feet (15 m). A few wells finished in the Platteville Formation have intermediate heads.

Summary: Big Spring Groundwater Flow System

To summarize: several lines of evidence indicate that the Big Spring groundwater-basin flow system is comprised of both conduit- and diffuse-flow systems within the Galena aquifer. The conduit flow system is directly recharged by diversion of surfacewater runoff into sinkholes. Flow is through large open solution passages at rates comparable to surfacewater velocities. At least two major conduit zones are identified and tentatively located. Other conduits undoubtedly exist and many may be located above the zone of saturation.

Discharge from the conduit system is through Big Spring and associated springs. The conduits are indirectly recharged by conduit interception of downward leakage from the shallow groundwater systems. The diffuse flow system is recharged by slow infiltration through the overlying materials. Where low-permeability units overlie the Galena, shallow flow systems develop and infiltrating recharge waters may follow complex paths before reaching the saturated zone of the Galena. Flow through the diffuse system is largely along joints, fractures, and bedding planes that have experienced relatively little solutional modification. The diffuse system discharges to the conduit zones and thus ultimately to Big Spring and the other associated springs as well.

Hydrogeologic Cross Sections

Hydrogeologic cross sections were constructed for the Big Spring basin, and help to place the Galena flow system in a three-dimensional perspective. The three cross-section lines are located on figure 19, and shown on figures 21, 22, and 23. Each section delineates the geologic units (abbreviations as on figure 3), the general land-surface topography, streams, the relations to the St. Peter Sandstone (Osp), and the major sinkhole areas. As noted, the main sinkhole areas occur where the Galena (Og) outcrops and where only a thin increment of the lower Maquoketa (Omf) occurs over the Galena.

Cross-section A-B runs roughly north-south across the northern groundwater and surfacewater divide, and then roughly follows a groundwater flow path going south, into the axis of the central conduit zone trough, and on to the discharge area at Big Spring. This section follows the general structural dip of the Galena as well. The cross section illustrates several important features. The water table/piezometric surface declines sharply in elevation in the central conduit-zone trough. In this area the top of the piezometric surface comes within 50 to 75 feet (15-20 m) of the base of the Galena carbonates. LeGrand and Stringfield (1973) note that the water table in karst aquifers becomes so depressed along main "arterial" conduits that the water table related to the conduits join the surface stream almost at grade. Section A-B in figure 21 illustrates this situation in the Galena aquifer in the Big Spring area.

Development of solution conduits in carbonate rocks takes place near the water table and in the upper part of the zone of saturation, and then decreases with depth (Thrailkill, 1968; LeGrand and Stringfield, 1973). The Turkey River is the major discharge stream for the Galena aquifer, and thus the Turkey acts as the 'base-level' for the piezometric suface in the aquifer. Well records and ongoing studies of the alluvial history of the Turkey River valley show that, in the geologic past, the Turkey River was downcut 50 to 60 feet (15-20 m) deeper than the present floodplain. As suggested in figure 21, the river must have cut to (or perhaps through) the base of the Galena carbonates. In relation to the present piezometric surface, this suggests that karst conduits may have been able to develop essentially to the base of the aquifer in this region; karst-conduit flow paths likely penetrate the full thickness of the Galena aquifer, at least in the conduit zones.

Another important feature illustrated by section A-B is the relationship of the Galena piezometric surface to the surface streams. Silver Creek and Robert's Creek, and their alluvial valleys, are 100 feet (30 m) or more <u>above</u> the Galena piezometric surface over the axis of the central conduit trough. This is in the heart of the area where these streams lose water to the groundwater system. Yet in most years these streams flow continuously, even through this reach. However, in this immediate area, adjacent to Robert's Creek, solution openings observed in quarrys in the Galena go down below the level of the floodplain of the Creek and yet are dry. Alluvial wells drilled by IGS

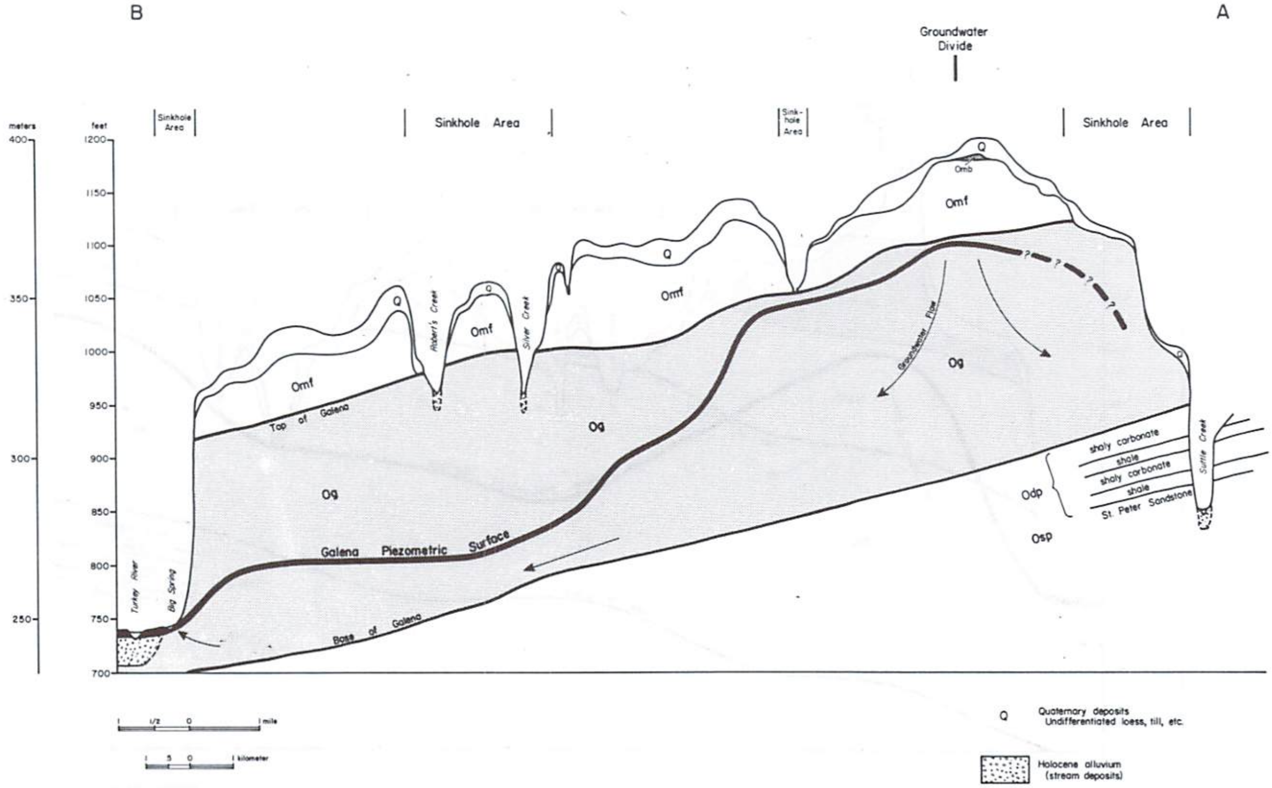


Figure 21. Hydrogeologic cross section A-B; location shown on figure 19.

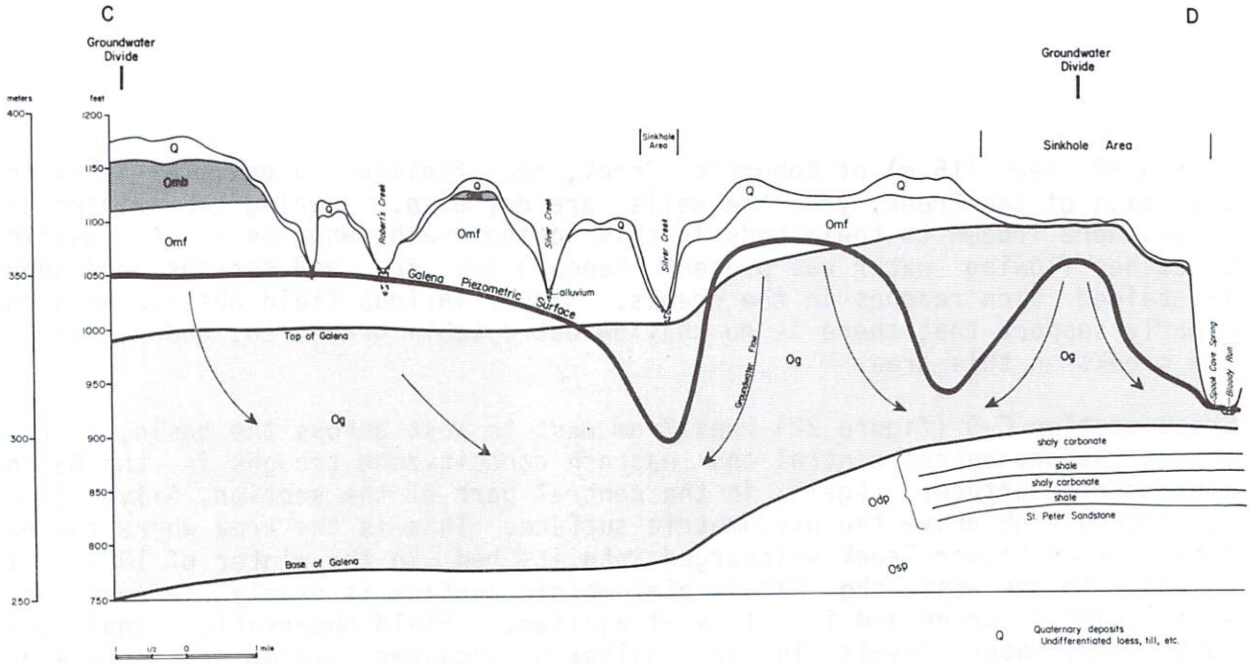


Figure 22. Hydrogeologic cross-section C-D; location shown on figure 19.

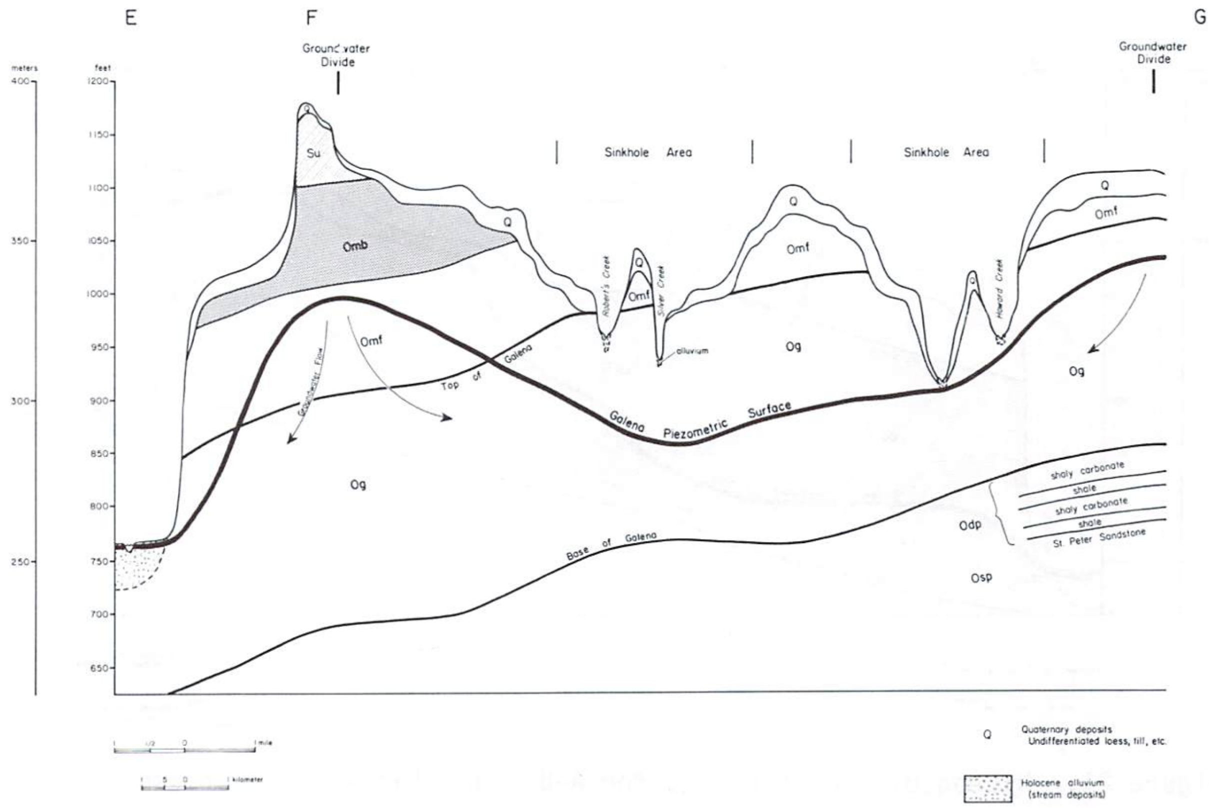


Figure 23. Hydrogeologic cross-section E-F-G; location shown on figure 19.

within 50 feet (15 m) of Robert's Creek, are finished in gravels below the elevation of the Creek, yet the wells are dry also. During the winter the creeks were frozen to their beds in this losing reach, whereas in the gaining stretches flowing water was present beneath the ice, and springs and seeps maintained open reaches in the creeks. Thus, various field observations can clearly support that there is no shallow water table graded to, and recharging the creeks in this area.

Cross-section C-D (figure 22) runs from east to west across the basin, cutting across the pronounced central and eastern conduit-zone troughs in the Galena piezometric surface. Again, in the central part of the section, Silver Creek is perched high above the piezometric surface. This is the area where the entire flow of Silver Creek discharged into its bed in the winter of 1981. In contrast to the west, the Galena piezometric surface is nearly in confluence with Robert's Creek and its alluvial aquifer. Field observations again support this; water levels in the shallow groundwater system (Maquoketa and alluvial wells) are only a few feet (1 m) higher than the Galena, alluvial wells produce water, and the water table in the alluvial aquifer grade to the stream. Observed springs and seeps maintain perennial flow in this area of Robert's Creek. Note also that the central conduit zone trough coincides with the pronounced structural flexure in the Galena carbonates that was discussed previously (figure 5). Near the eastern conduit-zone trough, a new sinkhole formed which was investigated by IGS staff. Beneath the sinkhole was a vertical solution shaft or dome pit that descended about 120 feet (40 m) below ground level, but still did not encounter saturated conditions.

Cross-section E-F-G (figure 23) runs east-west across the southern part of the groundwater basin, traversing the broad low area on the piezometric surface (figure 19) where the east conduit-zone trough flows to the west and south to merge with the central trough (figure 20). This section goes through the outliers of Silurian rocks (Su), which form the highest area in the basin, and the areas with the full thickness of the upper Maquoketa Formation (Omb) over the Galena aquifer. The section again goes through the losing reaches of Robert's and Silver Creeks, but on the east, the section traverses Howard Creek and an unnamed tributary just north of where these creeks are observed to gain discharge from the groundwater.

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

Karst Features, Galena Structure, and Lithology

The distribution of karst-solution features within carbonate rocks is controlled by the structural (Thrailkill, 1968; White, 1977; Powell, 1977; Bounk, 1983) and lithologic (Thrailkill, 1968; White, 1977) properties of the rocks, in relation to groundwater-flow directions (Bounk, 1983; Hallberg and Hoyer, 1982). Structural features such as joints, fractures, and bedding planes, provide avenues for water movement and hence for the initiation and continuation of solutional activity. Faults, flexures, or high fracture densities often provide areas where intense solutional activity may be localized. Joint patterns in the Big Spring area are still being analyzed. However, observations of a few large-scale features are possible. As already noted, the major central conduit zone, apparent in the piezometric map (figure 19), is concident with the north-south trending flexure in the Galena rocks (figures 22 and 5). It is also interesting to note that all the conduit-zone troughs are coincident with major stream-valley systems, even though the piezometric surface is quite deep in the subsurface. The eastern trough coincides with the north-south Howard Creek system; the central trough underlies the north-south trend of Silver Creek; the poorly defined east-west piezometric low connecting these troughs underlies Robert's Creek. Even the northwesterly-trending troughs in the western groundwater sub-basins directly underlie Robert's Creek and an unnamed creek, even though the surface valleys are formed wholly in the Maquoketa Formation. This coincidence of conduit zones, "piezometric valleys," and surface topography, at least suggests that structural features which propagate through the Galena and Maquoketa rocks have guided the development of the stream valleys and prominent solution-conduit zones.

Lithology of the Galena carbonates may also play a role in the distribution of karst features. Limestone is more soluble than dolomite, and more readily develops karst-solution features. In the Big Spring basin both the Dubuque and Dunleith Formations are dominantly limestone, whereas the Wise Lake is more dolomitic. The Wise Lake is also quite massive. In quarries it is apparent that solutional features are better developed in the Dubuque and Dunleith Formations than in the Wise Lake. This is particularly true for horizontal solution features (such as caves or conduits). Solutional features observed in the Wise Lake are generally enlarged vertical joints or fractures, and occasional dome pits.

The distribution of karst features in the basin may reflect the lithologies of these rock units. The major sinkhole concentrations all occur where the top of the Galena (the Dubuque Formation) outcrops in the north-central portion of the basin. Further south, along Robert's Creek for example, where the Dubuque thins and the Wise Lake outcrops, there are fewer sinkholes developed. Also, as noted, the most prominent solutional conduits in the Galena are near the very base of the aquifer, formed in the Dunleith Formation. Refinement of these relationships may provide a better understanding of the karst-hydrogeologic system.

Water Quality Inventory

As previously noted, during the initial phases of the Big Spring study, 271 wells in the area were inventoried by IGS staff. Water samples were collected for nitrate and bacterial analyses from about 125 wells which had the best information and allowed the determination of the aquifer supplying the well. Figure 24 shows the location of sample sites on the study-area map. Table 11 provides an index of IGS site numbers, locations, and a summary of the water-quality data for the sites shown on figure 24. Note that a few sites do not have any data shown. These are sites which will be discussed in later sections of the report, but were not sampled during the 1981 inventory. Also, a number of sites were sampled during the inventory which are located outside of the study-area map. These data are included in the inventory-summary statistics. On Table 11, sites 1-90 are Galena aquifer wells and springs. Sites 91-106 are wells finished in other formations, and sites 107-116 are various surfacewater-sample locations.

Table 12 gives summary statistics for the water-quality data for the Galena wells and springs. Figure 25 shows a histogram of the nitrate concentrations. This is a typical distribution of nitrate data (see Hallberg and Hoyer, 1982); it shows one mode at <5 mg/l (less than detectable) and another mode at higher values, between 35 and 40 mg/l. The median nitrate concentration in groundwater samples from the Big Spring basin is 35 mg/l and the nitrate concentrations range from <5 to 280 mg/l (Table 12).

Table 12 also shows a breakdown of the nitrate data by geologic settings in the Big Spring area. Four categories are broken out. First, is the area where the Galena aquifer has a thick cover of Maquoketa Formation shales in the west-central part of the basin. Second, is an area of intermediate thickness of Maquoketa Formation over the Galena, principally the western and northern part of the basin. The third and fourth areas are where there is only a thin Maquoketa cover or where the Galena is the bedrock; this area constitutes the majority of the basin and is where virtually all the sinkholes occur. The two subdivisions made in this area are: 1) water samples from wells in the zones of the high-transmissivity, conduit zone troughs as defined from the piezometric map; and 2) the remaining Galena aquifer samples. The only significant difference apparent in the data occurs in the nitrate concentration for the area with thick Maquoketa cover. In this area the Galena aquifer is protected from surface contamination by the thick shale cover. The median (and quartiles) nitrate concentration of the aquifer is less than detectable (<5 mg/l). This is the background, or natural concentration of nitrate in the Galena aquifer and agrees with other data compiled in the IGS karst studies (Hallberg and Hoyer, 1982; Hallberg, et al., 1983). Also note there are no bacterial problems in water samples from this area (after local problems, such as cisterns, are removed from the data).

More precise analyses (mineral scans) were performed on water samples during 1982. These data show that the background level of nitrates in the area with thick Maquoketa cover is about 2 mg/l.

The median nitrate concentration in the area of intermediate Maquoketa thickness is only slightly less than in the other areas where the Galena is clearly more open to surface contamination.

The water samples from the high-transmissivity area of the Galena tend to show higher bacteria levels, although the differences are not pronounced. This is logical because in the area where the aquifer is most open, groundwater is least likely to get adequate natural filtration.

Table 13 shows a summary of nitrate and bacteria data for water samples from the other aquifers. Of principle interest are the data from St. Peter wells. Samples from St. Peter wells with deep casing show no detectable nitrates (<5 mg/l). However, St. Peter wells with shallow casing, which are open to the Galena aquifer show a median nitrate concentration of 25 mg/l, and no samples from these wells were <5 mg/l. This again reinforces previous data (Hallberg and Hoyer, 1982) and emphasizes the need for proper well construction. This is of concern for more than just these individual wells, because heads in the St. Peter aquifer in the Big Spring area range from 15 to possibly over 150 feet (5 to 45 m) lower than in the Galena aquifer, averaging about 50 feet (15 m) lower. These head relations indicate that open wells such as these will allow contaminated Galena water to move downward into the St. Peter.

Table 14 shows the summary of nitrate and bacteria data for surfacewater and spring samples. The median nitrate concentration of the stream samples (39 mg/l) is very similar to that of the Galena aquifer (35 mg/l). The nitrate concentration from one tile-line sample was more than double (97 mg/l) the median of the stream samples. An analysis on the stream water about 150 feet (45 m) downstream from the tile line showed 40 mg/l nitrate. All the surfacewater sites and springs had 16+ MPN bacterial analyses, which was expected.

Table 11. Summary of November-December 1981 Water-Quality Inventory Data; nitrate in mg/l; bacteria--MPN numbers.

GALENA WELLS AND SPRINGS

Site No.		T.	R.	Sec.	NO_3	Bac.	C	R	T
1.	PAT-6	95	6	3	29	0			
2.	PAT-1	95	6	3	54	(0)	Spring		
3.	PAT-3	95	6	2	13	0			
4.	B-19	95	4	4	<5	0			
5.	PAT-9	95	6	11	24	16		R	T
6.	PAT-10	95	6	12	31	0			
7.	VD-41	95	6	12	6	2.2			
8.	AB-10	95	5	10	53	0		R	
9.	VD-27	95	6	13	30	0			
10.	VD-26	95	5	18	33	0			
*11.	VD-24	95	5	18	17	0		R	
12.	VD-35	95	5	17	52	16+		R	T
13.	VD-32	95	5	16	36	16+	C	R	T
14.	VD-6	95	5	13	34	16	C	R	T
*15.	B-18	95	4	18	144	0			
*16.	B-32	95	4	17	19	0			
17.	B-11	95	4	17	52	5.1			
18.	PAT-19A	95	6	22	<5	0			
19.	VD-30	95	6	24	23	0			
20.	VD-31	95	6	24	<5	0			
21.	VD-22	95	5	19	8	16	C	R	
22.	VD-21	95	5	20	10	5.1		R	
23.	VD-16	95	5	21	19	0			
24.	VD-15	95	5	21	44	16+		R	
25.	VD-14	95	5	21	60	5.1	C	R	
*26.	VD-12	95	5	22	12	0		R	
27.	VD-11	95	5	22	34	2.2		R	T
28.	VD-2	95	5	24	33	0			
29.	VD-3	95	5	24	33	0			
*30.	B-27	95	4	19	40	9.2		R	
31.	B-10	95	4	20	280	16			
32.	PAT-16	95	6	27	<5	16+		R	
33.	PAT-14	95	6	26	21	0			
34.	L-21	95	5	30	15	16			
35.	L-17	95	5	30	9	0			
36.	L-16	95	5	29	83	0		R	
*37.	VD-18	95	5	29	94	2.2		R	T
38.	L-14	95	5	28	74	16+	C		
*39.	L-7	95	5	27	120	16+		R	
40.	L-4	95	5	27	52	5.1			
41.	L-37	95	5	25	29	16		R	T
42.	B-26	95	5	25	60	16		R	T
43.	B-23	95	4	30	29	0			
44.	B-22	95	4	29	43	16			T
*45.	PAT-20	95	6	34	<5	0			
46.	PAT-28	95	6	34	<5	0			

Table 11. Continued

Site No.		T.	R.	Sec.	NO_3	Bac.	C	R	T
*47.	PAT-18	95	6	35	<5	0			
48.	F-43	95	5	31	9	0		R	
*49.	F-51	95	5	32	11	0		R	T
50.	B-12	95	4	33	38	0			
51.	F-54	94	6	1	<5	2.2		R	
*52.	F-8	94	5	6	64	0		R	
53.	F-40	94	5	4	68	16+			
54.	L-44	94	5	4	58	16			T
55.	L-43	94	5	4	51	(16+)	Spring		
*56.	F-33	94	5	3	35	0			
*57.	T-17	94	4	6	36	2.2			
58.	T-3a	94	4	4	58	2.2		R	
59.	T-24	94	4	4	104	0			
60.	T-26	94	4	4	56	2.2			
*61.	L-42	94	5	10	86	0		R	
62.	T-25	94	4	8	35	16		R	
63.	PAT-26	94	6	15	<5	0			
64.	L-45	94	5	18	<5	0			
65.	F-3	94	5	16	22	2.2	C	R	
66.	E-3	94	5	14	9	0	(?Open to Formations below Galena?)		
67.	E-2	94	5	14	128	16		R	
68.	T-9	94	4	17	36	0			
69.	T-21	94	4	17	53	16+	C	R	
70.	PAT-24	94	6	22	<5	0			
71.	PAT-25	94	6	22	26	16+		R	T
*72.	GL-1	94	6	24	35	5.1			T
73.	GL-2	94	5	20	28	16+	C	R	T
74.	GL-4	94	5	21	36	16	C		
*75.	GL-8	94	5	21	90	0		R	T
76.	GL-7	94	5	28	57	0			
77.	GL-3	94	5	28	23	16+		R	T
78.	S.O.	94	5	25	42	(16+)	St. Olaf Spring		
79.	T-12	94	4	30	22	16+	C	R	T
80.	T-13	94	4	30	69	16+	C		T
*81.	AB-6	94	6	36	33	2.2			
*82.	B.S.	94	5	30	39	(16+)	Big Spring		
83.	J.S.W.	94	5	30					
*84.	AB-3	94	5	31	34	5.1		R	T
85.	E-6	94	5	31	42	2.2		R	T
86.	GL-5	94	5	33	67	16	C		T
87.	GL-6	94	5	33	53	16+	C		T
88.	AB-1	94	5	36	39	0			
89.	H.S.	93	5	5			(Heick Spring)		
90.	BL-1	95	5	31					

Table 11. Continued

OTHER WELLS (Open Formations in parentheses)

(Maquoketa)

Site No.		T.	R.	Sec.	NO_3	Bac.	C	R	T
91.	PAT-22	94	6	12	17	16+		R	T
92.	PAT-17	95	6	35	34	0		R	
	(Galena through St. Peter)								
93.	L-35	95	5	36	25	16			T
94.	T-23	94	4	4	49	0		R	
95.	T-27	94	4	4	43	16+			
96.	F-5	94	5	16	21	0			T
97.	E-1	94	5	13	19	16+	C		
98.	AB-4	94	5	30	28	0			T

Sub-Galena Wells

(Platteville)

99.	F-52	95	5	30	<5	0	
	(St. Peter)						
100.	B-17	95	4	17	<5	16+	C
101.	PAT-19	95	6	22	<5	0	
102.	SW	95	4	21	<5	0	
	SP	95	4	21	<5	16+	(St. Peter Spring)
103.	L-33	94	5	1	<5	0	
104.	E-4	94	5	22	<5	0	
105.	E-5	94	5	27	<5	0	
106.	AB-2	94	5	33	<5	0	

SURFACEWATER AND MISCELLANEOUS SITES

107.	CT-54	95	5	16	61	16+	Stream taking discharge from Luana Creamery
*108.	L-22	95	6	24	97	16+	Tile line
*109.	L-23	95	5	19	40	16+	Silver Creek
*110.	F-45	94	5	7	38	16+	Robert's Creek
*111.	F-47	94	5	15	37	16+	Robert's Creek
112.	DHL	94	4	29	56	16+	Dry Hollow Creek
*113.	TR	94	5	30	25	16+	Turkey River
114.	SC-1	95	5	33			
115.	RC-2	94	5	25			
116.	H-Series	94	5	31			

*--Monthly monitoring stations.
C--Water sample after cistern
R--Well affected by surface run-in
T--Owner reports turbidity problems

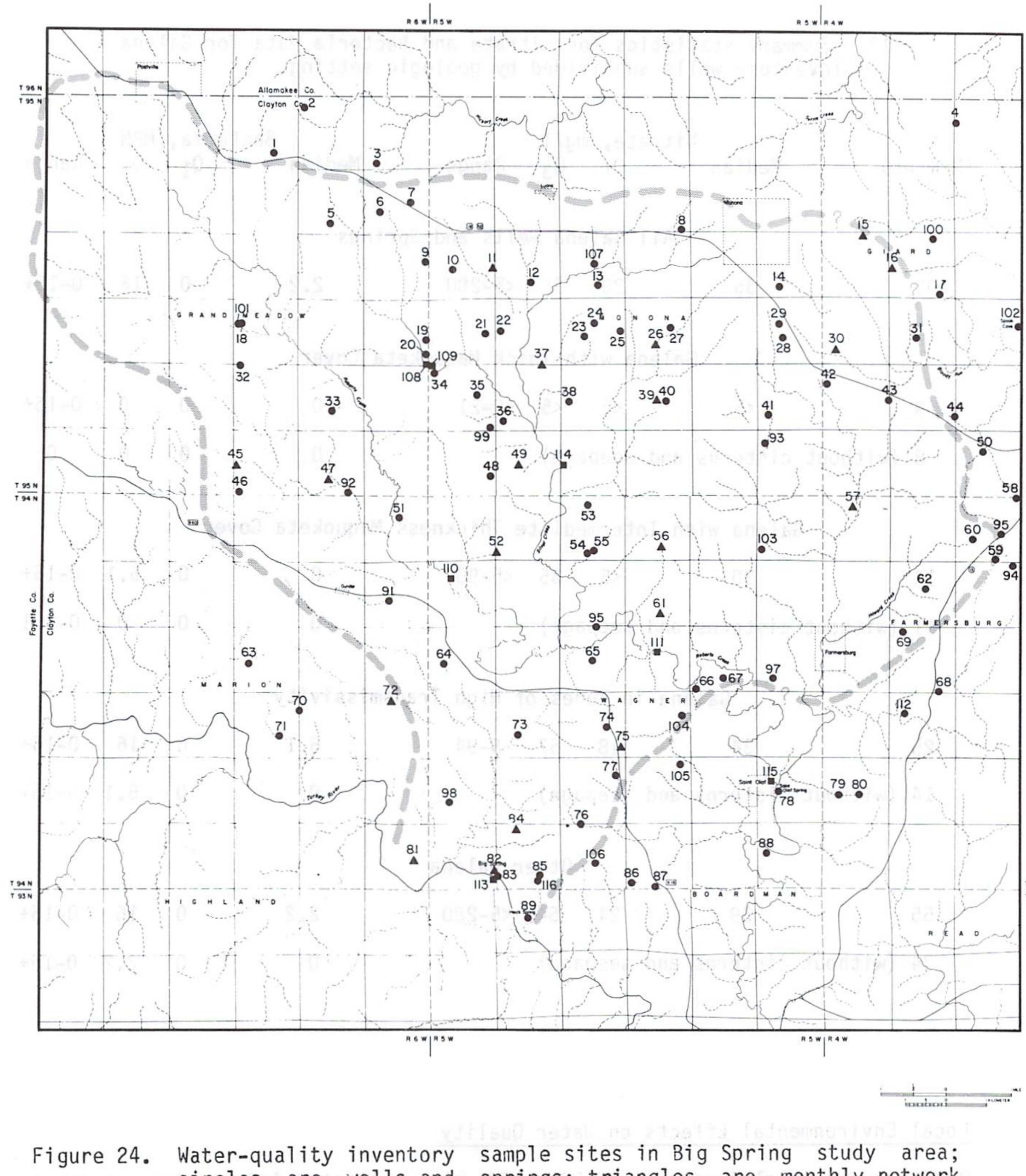


Figure 24. Water-quality inventory sample sites in Big Spring study area; circles are wells and springs; triangles are monthly network wells and springs; squares are surfacewater sites. Shaded line outlines groundwater basin divide.

Table 12. Summary statistics for nitrate and bacteria data for Galena inventory wells subdivided by geologic setting.

N (Number)	Nitrate, mg/l Median	Q_1	Q_3	Range	Bacteria, MPN Median	Q_1	Q_3	Range
All Galena Wells and Springs								
103	35	20	56	<5-280	2.2	0	16	0-16+
Galena with Thick Maquoketa Cover								
9	<5	<5	<5	<5-21	0	0	0	0-16+
8 (without cisterns and seepage)					0	0	0	0
Galena with Intermediate Thickness Maquoketa Cover								
14	30	<5	35	<5-90	0	0	5.1	0-16+
11 (without cisterns and seepage)					0	0	0	0-5.1
Galena in Zones of High Transmissivity								
25	34	18	57	8-94	5.1	0	16	0-16+
14 (without cisterns and seepage)					0	0	5.1	0-16+
Other Galena								
55	39	24	54	<5-280	2.2	0	16	0-16+
34 (without cisterns and seepage)					0	0	2.2	0-16+

Local Environmental Effects on Water Quality

During the initial inventory, IGS staff also collected information on local well construction, well placement, and water-system problems, and interviewed residents about known water-quality problems. Some aspects of well-casing problems have already been discussed in relation to the St. Peter aquifer. Several other items were addressed; the use of cisterns, well placement and/or construction that allowed seepage or run-in of surfacewater into the well,

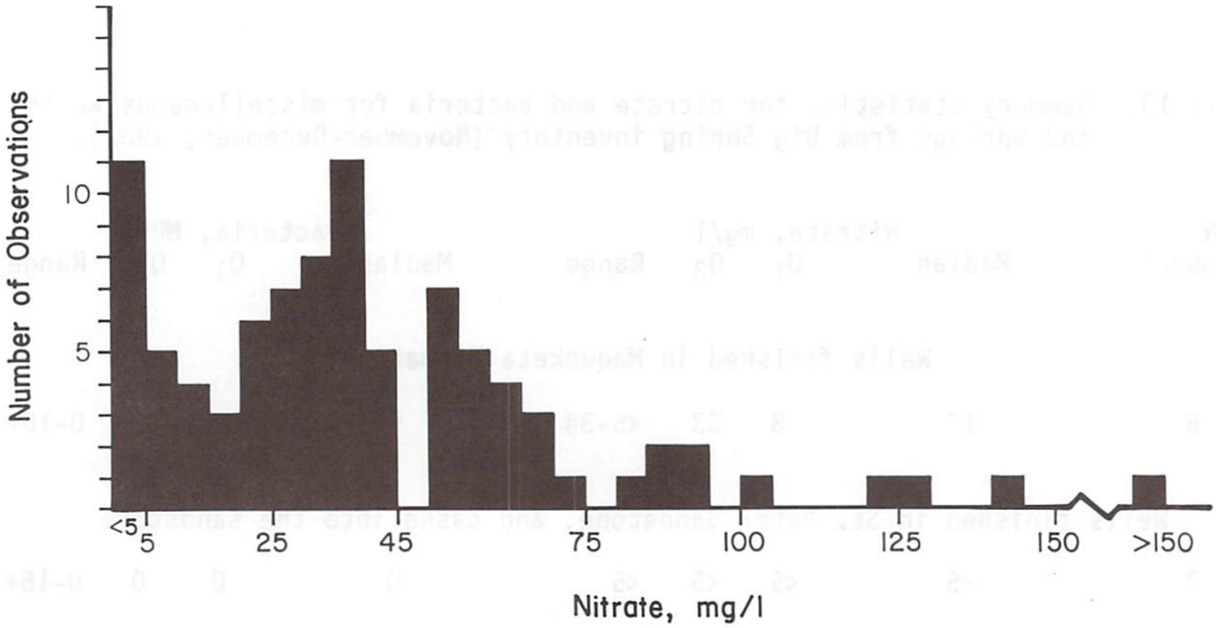


Figure 25. Histogram of nitrate concentration from analyses of water samples from Galena aquifer wells and springs.

placement of the well in relation to feed-lots, septic tanks, etc., known turbidity problems, and known water-quality problems.

The use of cisterns was investigated because it was felt their use may seriously affect the bacterial analyses and resultant interpretations (as well as recommendations on how to deal with individual bacteria problems). Past studies (Hallberg and Hoyer, 1982) suggest that seepage problems likewise may affect the water quality of a well. Turbidity may be another factor of water-quality problems in the karst area because sediment and suspended organics can be transported through solution conduits. Turbidity can be a health problem because it is generally associated with various organic compounds, and various chemicals (such as pesticides) may be attached to clay particles or the organics.

The 1981 inventory of the Big Spring area revealed that a minimium of 25% of the rural well water-supply systems used cisterns; 32% of the wells were affected by seepage problems of one kind or another; and 16% of the well owners reported known turbidity problems. These figures are only minimums because in some instances it was not determined whether a cistern was used or not; some seepage problems cannot be observed, such as cracked or corroded casing below the ground surface; and some well owners didn't really know if they had minor turbidity problems.

Many wells are affected by more than one of these problems. In combination, a minimum of 41% of the water supplies were affected by the use of cisterns and seepage problems, and 47% by cisterns, seepage problems, and turbidity.

Table 13. Summary statistics for nitrate and bacteria for miscellaneous wells and springs from Big Spring inventory (November-December, 1982).

N (Number)	Nitrate, mg/l Median	Q_1	Q_3	Range	Bacteria, MPN Median	Q_1	Q_3	Range
Wells finished in Maquoketa Formation								
5	17	8	33	<5-34	5.1	0	16+	0-16+
Wells finished in St. Peter Sandstone, and cased into the sandstone								
7	<5	<5	<5	<5	0	0	0	0-16+
St. Peter Spring								
1	<5				16+			
Wells finished in St. Peter Sandstone, but with shallow casing, i.e.--well open to Galena (and Decorah-Platteville) aquifer								
9	25	11	46	9-52	5.1	0	16+	0-16+

(Note: 16+ bacteria analysis affected by cistern)

Before reviewing these effects quantitatively, a qualitative look at these problems may be instructive. Table 15 abstracts some selected comments from well owners and from IGS staff noted during the inventory. These comments provide some overview on perceptions and conditions of the rural water-supply system problem.

In the first category on Table 15, many Galena well owners had noted water problems from past water analyses. Unfortunately, none had saved the analyses for actual comparison. In a few instances, owners did note that bacteria problems occurred in the spring (with the spring thaw and runoff) but not at other times. Also, some well owners noted that they had to repeatedly chlorinate their wells to control bacteria. This seems to imply that the bacteria is coming through the karst aquifer, and is not simply a problem for the well. One of the wells on the monitoring network began with no bacteria in December, 1981. As the spring thaw began, the water from this well rose to a 16 MPN bacteria level. The owner then chlorinated the well. About 7 days after chlorination, a large surge of spring meltwater began to move through the karst groundwater system; the water from this well "turned murky, smelled funny, and tasted like old snow," according to the owner. With this surge of

Table 14. Summary statistics for nitrate and bacteria data for surface water samples and springs from Big Spring inventory.

N (Number)	Nitrate, mg/l Median	Q_1	Q_3	Range	Bacteria, MPN Median	Q_1	Q_3	Range
				Streams				
6	39	37	56	25-61	16+	16+	16+	16+
				Tile Line Effluent				
1	97				16+			
				Springs				
				Galena				
4	46	39	54	39-54	16+	16+	16+	16+
				St. Peter				
1	<5				16+			

meltwater, the water from the well decreased sharply in nitrate, but the bacteria rose again to 16+ MPN within about one week of shock chlorination. In these settings, chlorination will have little effect.

The next categories on Table 15 note comments on obvious turbidity and sediment problems from Galena wells, suspected (but undocumented) water-related health problems, and some general comments about Galena wells. The category on Well and Water System Placement, Construction and Maintenance, outlines a sampling of observations of "local enviornmental" problems which also affect water quality. Most of these comments relate to what is classed in this report as seepage problems. These range from problems of well placement to problems of construction and maintenance. Placement problems occur when a well is placed in a setting which promotes seepage of surfacewater into the well. For example, some wells are located in valleys where surfacewater is naturally conducted to it, or the placing of a well in a feed-lot where the local soil water will be highly charged with bacteria, ammonium, and over time, nitrate and other mobile ions. The most common construction problem is the use of well-pits, which are pits dug around the head of the well. These are commonly used with various kinds of working-head pump systems. These pits

Table 15. Selected comments from well owners or by IGS staff about water-quality from Galena wells, or local factors which may effect water-quality in the Big Spring's basin.

General Water-Quality

"Water tastes bad."

"Water smells bad."

"Bacteria problems in past."

"Nitrate problems in past."

"Previous analyses show nitrate and bacteria problems."

"Has bacteria problems in spring."

"Must chlorinate every 6 months or so."

"Water gets oily film on it."

Turbidity

"Water gets turbid when it rains."

"Water gets muddy and tastes funny in spring."

"Pumps sand after heavy rain."

"Pump got plugged with sediment after heavy rain in June, 1974."

"Well across road clouded up when this well was drilled."

Health and Related Problems

"Had health problems with old shallow well. Cleared up after new deep well was drilled."

"Water problems have forced owner and tenant to vacate house."

"Child got ill from water."

"When Luana dumped sewage 2 years ago, water turned gray and livestock wouldn't drink it."

"Well water showed dye during Conservation Commission study."

Comments about Galena Wells

"Galena well no longer used for dairy. Water too bad, drilled St. Peter well."

Table 15. Continued

"Drilled well deeper, because of water-quality problems; but didn't put any more casing in. Too expensive."

"Mentioned contamination when St. Olaf creamery dumped whey."

"Drilled St. Peter well for house and dairy. Galena well just used to water hogs."

"Buys bottled water to drink. Only uses Galena well to water stock."

Well and Water System Placement, Construction, and Maintenance

"Runoff from hog lot can run into well shaft."

"Well in draw and takes runoff from cornfield."

"Well cap is cracked; surfacewater seeps in."

"Well in hog lot."

"Well in middle of feed-lot."

"Cesspool near well."

"Well pump sits in pit which allows water from hog lot to seep into well."

"Casing in pit has holes rusted through."

"Water and garbage in well pit."

"Well pit has 3 inches of murky water in it."

"Dead hog in well pit."

"Snowmelt seeps into cistern."

"Sides of cistern cracked; lets seepage in."

"Cistern takes runoff."

Miscellaneous

"Reportedly struck a 'water-bearing crevice'."

"Farm pond won't hold water."

"Sinkhole opened under farm pond."

invariably allow soil water to seep into the well, and depending on the use of the land surrounding the well, this seepage water can have adverse effects on the water quality. Also, as noted on Table 15, these pits are sometimes used to dispose of various things ("Dead hog in well pit!") which may also contaminate the water in the well shaft.

Quantitatively, these effects are shown on Tables 16 and 17. Table 16 shows the summary statistics for the total number of Galena aquifer inventory water samples affected by cisterns, seepage, and turbidity. Although there are too few data to test statistically, these data clearly show that cisterns (median, 16+ MPN) produce bacterial problems in the water supply (see also Tables 12 and 13). These data also suggest that the samples from cisterns show higher nitrates than the norm of the samples. However, some of these sites are affected by multiple problems (cisterns, plus turbidity for example). Table 17 shows the data from wells which are only affected by seepage, etc. This further reduces the number of data but the same trend is still apparent. The samples which passed through cisterns show very high bacteria, with a median of 16+ MPN, and a total range of 16 to 16+. Next highest in median bacteria levels are the wells affected by turbidity and then those affected by seepage problems. All the bacterial medians are higher than the remaining Galena wells which were not known to be affected by any of these problems. The data in Table 17 also suggest that the water supplies affected by cisterns and seepage also show higher than modal nitrate concentrations.

For all the water samples from Galena wells, 52% had unsatisfactory or unsafe (2.2 MPN or greater) bacteria analyses. This is considerably higher than the 35% noted regionally in northeast Iowa by Hallberg and Hoyer (1982). Even when the local problems, such as cisterns and seepage (which could be corrected) are removed, 30% of the samples are still unsafe or unsatisfactory. This represents a karst-groundwater problem--aquifer contamination--compounded by other local water-system conditions.

To further test these observations on cisterns, special sampling was done at some sites where the water from various places in the water system could be analyzed. These results are shown on Table 18. The water samples from the cisterns always showed higher bacteria than the well samples; generally increasing from 0 MPN at the well, to 16+ MPN in the cistern. These potential bacterial problems are then passed through to the tap water in the house. In systems without cisterns (i.e.--direct-pump systems) the sites with well samples without bacteria also showed 0 MPN from tap water. Each site that showed bacteria in the well-water sample, did show an increase in MPN at the tap after the water had passed through the water system. However, the increases are not as dramatic as with the use of cisterns.

The nitrate data are equivocal. Clearly there is no significant change in the samples from water systems without cisterns. For systems with cisterns, sometimes the cisterns show higher nitrate than the well, but in a few cases the well shows higher nitrates. This variability has many possible sources. Some of the differences may be related to the original nitrate content of the well water which was stored in the cistern before sampling. Cisterns will also take seepage into them; if this seepage water is high in nitrate it will increase the nitrates in the cistern water. Also, evaporation from the cistern may cause increases in the nitrate concentration. Overall, the data suggest

Table 16. Summary statistics for nitrate and bacteria data for Galena wells and springs from Big Spring inventory (November-December, 1982).

N (Number)	Nitrate, mg/l Median	Q_1	Q_3	Range	Bacteria, MPN Median	Q_1	Q_3	Range
All Galena Wells and Springs								
103	35	20	56	<5-280	2.2	0	16	0-16+
Galena Springs								
4	46	29	54	39-54	16+	16+	16+	16+
Galena-with cisterns (total)								
15	51	25	63	8-74	16+	16	16+	2.2-16+
Galena with seepage problems (total)								
38	37	24	59	<5-128	5.1	0	16+	0-16+
Galena with reported turbidity (total)								
23	35	29	56	11-94	16	2.2	16+	0-16+

that a modest increase in nitrates is associated with the use of cisterns, and with seepage (well placement/construction) problems.

Another aspect of "local environmental problems" which was inventoried, was the distance from the well to a possible source of contamination such as a feed-lot, septic tank, manure storage, etc. This was investigated because of suggested relationships from the study by Tjostem and others (1977). The data from the Big Spring inventory show no direct relationship between water quality and distance to such surface sources. Such factors may be important locally, but probably only with improper well placement and construction.

The distribution of nitrates with depth in the Galena wells (exclusive of the area protected by the Maquoketa shales) was also evaluated. Nitrate concentration was analyzed in relation to well depth, well-casing depth (where known), and by structural depth within the aquifer. In contrast to other studies, no relationship between nitrates and depth was found. Significantly,

Table 17. Summary statistics for nitrate and bacteria data for Galena inventory wells with local environmental problems.

N (Number)	Nitrate, mg/l Median	Q_1	Q_3	Range	Bacteria, MPN Median	Q_1	Q_3	Range
				Galena-only affected by cisterns				
8	55	51	69	36-74	16+	16	16+	16-16+
				Galena-only affected by seepage				
24	52	29	83	<5-128	2.2	0	16+	0-16+
				Galena-only affected by turbidity				
6	39	33	49	31-58	5.1	2.2	16	0-16
				Galena-unaffected by problems above				
38	30	13	60	<5-280	0	0	5.1	0-16+

however, as previously discussed, karst-conduit development may penetrate the full thickness of the Galena aquifer in the Big Spring basin. This would allow the penetration of surface-contaminated, nitrate enriched water deep within the aquifer, and thus there are no simple relationships between depth and nitrate concentration within the aquifer.

Areal Distribution of Nitrates

The areal distribution of nitrate concentrations from the Galena inventory (figure 24) was also evaluated. Because there was no relationship to well depth, the nitrate concentrations from the Galena wells were treated as a single-data set and the values were contoured (figure 26). The data represent the conditions in November-December 1981. Several prominent features appear on the nitrate-contour map. On the west side of the basin, a large area occurs with no detectable nitrates (<5 mg/l). This region coincides with the distribution of the thick Maquoketa shales (figure 3), which separate the Galena from interaction with surfacewater and shallow groundwater.

The majority of the basin falls between the 20 and 40 mg/l contours, as would be expected from the data distribution (figure 25; median 35 mg/l). Areas

Table 18. Comparison of water quality between wells, cisterns, and tap-water samples.

Bacteria MPN			Nitrate mg/l		
Well	Cistern	Tap	Well	Cistern	Tap
0	16+	16+	27	69	69
(*Pipe from well to cistern at this site: 0 MPN; 31 mg/l)					
0	9.2	0	12	16	30
0	16+	16+	35	30	31
16	16+	16+	86	77	
16	16+	16+	66	56	49
0	16+	16+	<5	24	9
0	16+		<5	16	
16+	16+	16+	60	39	41
0	16+	9.2	35	36	31
Systems Without Cisterns					
0		0	63		63
0		0	33		34
0		0	34		32
0		0	<5		<5
0		0	<5		<5
0		0	19		18
5.1		16	25		22
5.1		9.2	148		140
0		0	<5		9
2.2		5.1	65		65

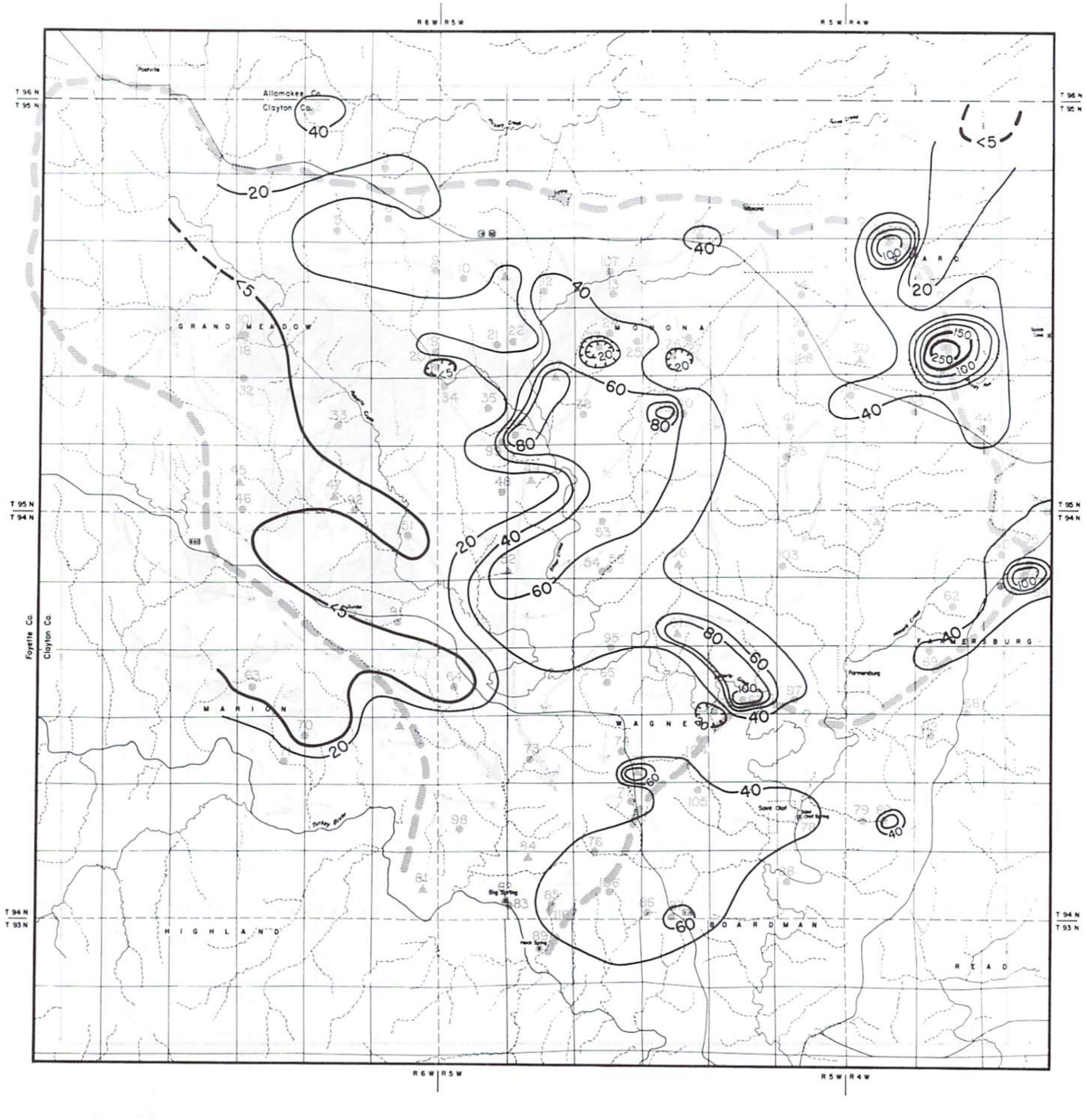
with concentrations above 40 mg/l occur in two settings. First, a series of high nitrate areas occur intermittently along the basin groundwater divide. These areas should have the strongest vertical-head gradients, and thus the strongest components of downward groundwater flow. This would promote leaching and downward movement of soluble ions such as nitrate. However, in part, the eastern basin boundary coincides with surface divides which have the thickest sections of Quaternary materials which might be thought to afford some measure of protection to the aquifer. As discussed though, these Quaternary materials are not very thick, generally less than 25 feet (8 m), and thus may not be much of a factor. Further, the landscape has enough relief that these deposits thin rapidly, and in fact, sinkholes are abundant even around the eastern divide (figure 6). The extreme, local nitrate concentration (>250 mg/l) value in the northeast comes from a single well which is poorly constructed and poorly located; factors which may contribute to this value. To double check this analysis, the well was resampled during 1982 and had approximately the same concentration (about 280 mg/l).

The second major region with over 40 mg/l occurs as an irregular area in the central part of the basin. Compare the location of this area with figure 27. Figure 27 shows the sinkhole basins (from figure 10) in relation to the groundwater-flow paths. This area of higher nitrates occurs just on the down-flow side of the major sinkhole basins. The area also coincides with the Robert's and Silver Creek areas where the Galena is shallow, and the streams lose water to the groundwater system. This high nitrate region would seem to coincide with areas where the highest potential for direct infiltration of shallow groundwater to the Galena aquifer occurs.

It is interesting to also note that south of this area, toward Big Spring, the areal nitrate concentrations are lower, falling between the 20 and 40 mg/l contours. Again, compare this to the groundwater flow paths depicted on figure 27. This area of lower concentration occurs where the western-derived low nitrate groundwater would enter the narrow part of the basin, flowing toward the discharge area at Big Spring. The flow paths and nitrate data suggest that some diffusion and mixing of groundwater from the various sub-basins takes place, moderating and integrating the nitrate concentrations in the discharge area.

Water-Quality Monitoring Network

From the data collected during the initial inventory, a network of sites was selected for water-quality monitoring throughout the duration of the project. Eighteen wells were selected for monitoring. They were selected to represent the spectrum of geologic and hydrologic conditions in the basin, and to be representative of the range of water quality found during the inventory. Also, on the monitoring network is Big Spring, and a few surfacewater sites including tile-lines, the Turkey River, Robert's Creek, and Silver Creek. The monitoring sites are shown on figure 24 and annotated on Table 11. A number of other sites have been monitored intermittently. These sites will be included with the discussions of the monitoring data. The monitoring network was established to understand: 1) the inputs into the groundwater system by measuring the water quality of losing streams, surfacewater runoff into sinkholes, and infiltration and tile-drainage water; 2) the water quality in



Nitrate Concentration (Nov.-Dec., 1981)

Contour Interval - 20 Mg/l

Departure from Stated Contour Interval

Figure 26. Contour map of nitrate concentrations recorded from Galena aquifer inventory water samples.

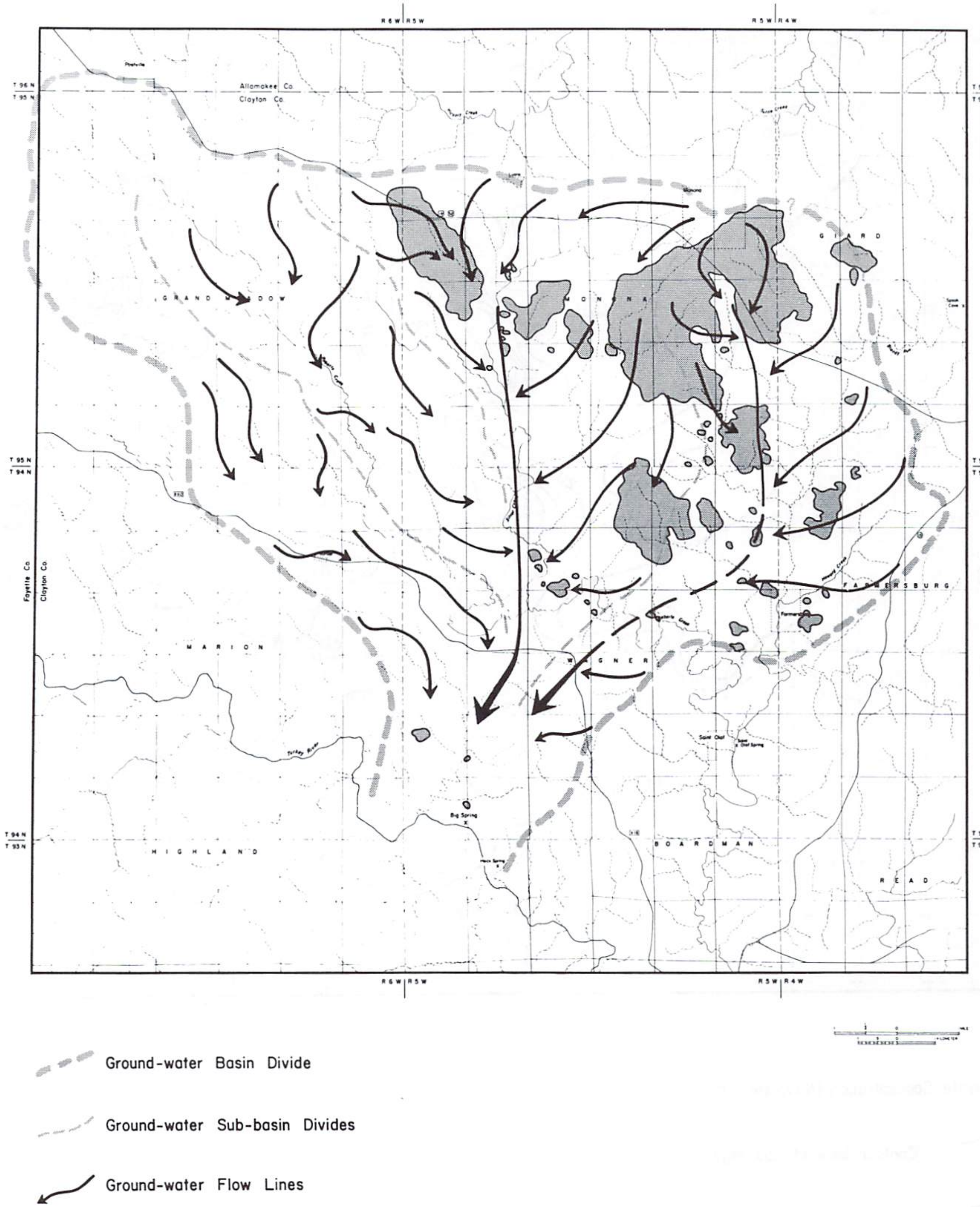


Figure 27. Schematic groundwater flow lines (from figure 20) and sinkhole basins (from figure 10).

transit through the system using the wells; 3) monitoring the water quality where the groundwater system discharges at Big Spring; and 4) to analyze changes and variations in the water quality through time.

The well network, as shown on figure 24, provides a good spatial cross section of the Big Spring system. Two wells, numbers 45 and 47, serve as background wells where the Galena aquifer is protected by thick Maquoketa shales. Sites 15, 16, 30, 52, 72, 75, and 81, are wells located on the divides and periphery of the basin. The remaining wells, sites 11, 26, 37, 39, 49, 52, 56, 61, and 84, are located in the zones of high transmissivity or sub-basin divides.

A summary of the water quality of the monitoring network is shown on Table 19, in comparison to the total Galena inventory and Big Spring. As obvious on Table 19, the network selected provides an adequate representation of the total data set, both in terms of medians and overall range.

Historic Records of Water Quality

Historic changes in water quality are difficult to document because of a lack of unequivocal data (Hallberg and Hoyer, 1982). For most locations there are generally not enough data to sort out the effects of seasonal variations in nitrate from other trends. However, data collected from the Big Spring area over time provide some insights.

Comments from Dairy Farmers

Discussions with the many dairy farmers in the area provide, at least, some qualitative insights. Grade A dairies have strict requirements on the quality of the milk produced, which is influenced by the quality of water and feed they use for their cattle. The majority of grade A diary farmers interviewed reported drilling new wells to the St. Peter Sandstone during the past 10 years because of the increase in nitrates in their Galena well water. They have had to change water sources to maintain the quality of their produce.

Records from Big Spring

Some water-quality data has been collected over time from Big Spring. As will be documented in this report, the water-quality at Big Spring presents a good integrated representation of the water quality for this 103 square mile (165 sq. km) region. Thus, these data provide some interesting insights.

In Table 20, nitrate concentrations are shown from the water analyses from Big Spring, which were collected on the dates listed. The 1951 sample was collected during an inventory of water resources in Clayton County conducted by USGS and IGS (Steinhilber et al., 1961). The 1968 samples were collected the year after some major water-quality problems at the fish hatchery. The 1982 data are from this study. All samples were analyzed by UHL, using the same methods.

Table 19. Summary of statistics for nitrate and bacteria data for Galena inventory wells; all data, and monthly monitoring network.

N (Number)	Nitrate, mg/l Median	Q_1	Q_3	Range	Bacteria, MPN Median	Q_1	Q_3	Range
				All Galena Wells and Springs				
103	35	20	56	<5-280	2.2	0	16	0-16+
				Monitoring Network				
18	35	17	86	<5-144	2.2	0	5.1	0-16+
				Big Spring				
1	39				16+			

Although there are only 5 samples during 1968, they were taken at times through the year which should adequately reflect the seasonal variation in nitrate concentration. These values range from 7.8 to 14 mg/l, with a mean of 12 mg/l (median of 13 mg/l). Although there was only one sample from 1951, the concentration, 13 mg/l, is essentially at the mean (equal to the median) for 1968, suggesting very little change between 1951 and 1968. Perhaps just as important, the 1951 sample was collected in September, toward the end of the growing season, generally a period of base-flow at the spring, which should reflect rather "average" conditions (see later discussion of monitoring at Big Spring). In sharp contrast, nitrate concentrations recorded for the same seasonal span in 1982 range from 23 to 50 mg/l, with a mean (and median) of 40 mg/l. The 1982 data do not even overlap with the older data.

Precipitation trends may influence the amount of nitrate which is leached into groundwater. Particularly, if a dry period is followed by a wet period, nitrate concentrations may be increased (see Hallberg and Hoyer, 1982, p. 71). In relation to these water-quality observations, 1951 was one of the wettest years on record in the area, with nearly 12 inches (30 cm) above average precipitation at Elkader. July through September precipitaion was about normal, however. In 1967, the area had a little below average precipitation, but 1968 was nearly 5 inches (13 cm) above normal. The precipitation records suggest, if anything, that nitrate concentrations might be higher than typical for this time period. In contrast, 1982 was a near-normal precipitation year in the region recording only about 1.5 inches (4 cm) above normal. However, 1982 was preceeded by two very different years; 1980 was relatively dry, about 4 inches (10 cm) below normal, and 1981 was relatively wet, nearly 7 inches (18 cm)

Table 20. Nitrate concentrations (mg/l) in water from Big Spring, 1951-1982.

1951 Date	1951 NO_3	1968 Date	1968 NO_3	1982 Date	1982 NO_3
				2/16	33
				2/23	30
		2/27	7.8	2/26	32
				3/2	35
				3/16	23
		3/26	10	3/23	38
				4/6	39
				4/29	42
		4/24	14	4/28	42
				5/11	40
				5/18	48
		5/27	13	5/27	46
				6/3	47
				6/8	45
				6/23	50
				6/29	45
				7/7	46
				7/21	40
		8/5	14	8/3	41
				8/10	37
				8/17	38
				8/25	35
9/4	13			9/7	37
MEAN	13		12		40
SD			3		6

above normal. Thus, any wet-dry cycle phenomena that would strongly affect the nitrate data should have preceded 1982.

All things considered, these water-quality data clearly suggest more than a three-fold increase in the concentration of nitrate in groundwater in the Big Spring basin between 1968 and 1982.

Surfacewater-Quality Surveys

Various surfacewater-quality surveys conducted by UHL for DEQ were also reviewed. Of particular interest are the studies on Robert's Creek-Silver Creek (UHL, 1977) within the Big Spring basin and a survey of the Turkey River (UHL, 1976).

The survey on Robert's Creek-Silver Creek and their tributaries, was performed during June of 1977 during relatively low-flow conditions. In general, these stream systems were noted to have "average" water quality (UHL, 1977). Two problems were noted. Discharge from the Mississippi Valley Milk Producer's Association creamery near Luana was noted as producing elevated stream temperatures of 35°C (95°F) in a tributary to Silver Creek. However, this temperature anomaly was dissipated within the next mile downstream. This was also noted in this study by IGS personnel. In January, 1982, a temperature of 24°C (75°F) was noted in the reach below the creamery (figure 24, station 107), while air temperatures were nearly -30°C (-20°F). However, within about 1 mile downstream, the creek was frozen over again.

A second problem that was noted was that the effluent discharged from Monona's sewage-treatment plant produced significant increases in the stream's ammonia-N, BOD, and fecal coliforms. This is significant because these streams eventually lose water into the groundwater system. However, according to regional DEQ personnel, this problem has been corrected.

The Turkey River survey was conducted during October of 1975, again during relatively low-flow conditions. Water quality in general, was very good. Trace amounts of DDE and DDT (0.003-0.007 ppb) were detected.

Of interest are the nitrate data collected during these studies. In the Robert's Creek system, values ranged from <0.5 to 13 mg/l nitrate, and in the Turkey River, values ranged from 0.5 to 12 mg/l nitrate. During the course of this present study (10/27/81-12/31/82) the nitrate concentration of the Turkey River at Big Spring has ranged from 12 to 43 mg/l. Surfacewater monitored in the Robert's Creek-Silver Creek system have ranged from 20 to 61 mg/l nitrate.

Again, in relation to climatic trends, 1974 averaged about 5 inches (13 cm) over normal precipitation, while 1975 was about average. 1976 was quite dry in this area, nearly 8 inches (20 cm) below normal in precipitation, while 1977 was about 3 inches (8 cm) over normal. Again, the direction of precipitation trends would seem to give these comparisons of nitrate concentrations the 'benefit of the doubt.'

Similar to the groundwater-quality data, the nitrate concentrations recorded from the mid-1970s and 1982 do not overlap. Because of differences in stream flow though, these data from the UHL survey and the current study may not be directly comparable, but once again these data suggest a sharp increase in nitrate concentration; a 2-3 fold increase or greater over the past 5 to 7 years.

HYDROLOGIC MONITORING OF THE BIG SPRING BASIN

Following the inventory and definition of the Big Spring basin, various aspects of the hydrologic system of the basin were monitored throughout 1982. These include climatological data, groundwater discharge, Turkey River discharge, and various aspects of surfacewater and groundwater quality, as previously outlined. Certain aspects of the system continue to be monitored in 1983.

Climate and Discharge

Before discussing the water-quality aspects of the basin, the water balance of the system will be described. These data include the inputs of precipitation, and outputs from the system from groundwater and surfacewater discharge, and estimates of changes in groundwater storage. Data will also be summarized on a water-year basis, for the first 12-month period of monitoring, from 11/1/81 through 10/31/82.

Climatic Data

Climatic data for the Big Spring area, including daily precipitation records and temperature extremes, were compiled from the Elkader, Fayette, and Waukon weather stations. These stations form a triangle that encloses the Big Spring basin. Monthly and annual precipitation data from the weather stations are listed in Table 21, along with long-term average precipitation amounts. Precipitation at the Fayette station during the period 11/1/81-10/31/82 was approximately 15% greater than normal. At the Elkader and Waukon stations, which lie closest to the basin, precipitation was 3% greater and slightly below the long-term averages for these locales, respectively. Therefore, precipitation during the period was considered to be just slightly above normal over the basin area. Data from the Elkader station most closely parallels the mean precipitation amounts for the three stations, and is used to represent average conditions within the basin.

Precipitation amounts for individual storms were quite uniform and similar at all three stations throughout the year. Although precipitation was just slightly above normal in northeast Iowa during this period, water yields and streamflow discharges were considered higher than expected for the rainfall received. This was a function of the timing of precipitation events and antecedent moisture conditions, more than the absolute amount of precipitation.

Groundwater Discharge Monitoring

Groundwater discharge from the Big Spring basin to the Turkey River was monitored at Big Spring on a daily basis, or more frequently when conditions warranted. The discharge hydrograph from Big Spring is shown on figure 28 (plotted on a linear scale), along with precipitation and temperature data from Elkader.

Table 21. Climatic data for stations near Big Spring basin.

	Elkader in (mm)	Fayette in (mm)	Waukon in (mm)	Mean in (mm)
1981				
Nov.	2.81 (71.4)	1.72 (43.7)	1.17 (29.7)	1.90 (48.3)
Dec.	1.00 (25.4)	1.14 (29.0)	0.64 (16.3)	0.93 (23.6)
1982				
Jan.	2.65 (67.3)	1.85 (47.0)	1.12 (28.4)	1.87 (47.5)
Feb.	0.27 (6.9)	0.16 (4.1)	0.05 (1.3)	0.16 (4.1)
Mar.	2.12 (53.8)	2.98 (75.7)	1.93 (49.0)	2.34 (59.4)
Apr.	2.75 (69.9)	2.40 (61.0)	2.33 (59.2)	2.37 (60.2)
May	6.10 (154.9)	7.30 (185.4)	7.26 (184.4)	6.89 (179.0)
June	2.38 (59.4)	3.18 (80.8)	2.69 (68.3)	2.75 (69.9)
July	5.34 (135.6)	6.15 (156.2)	3.65 (92.7)	5.05 (128.3)
Aug.	3.07 (78.0)	3.59 (91.2)	5.58 (141.7)	4.08 (103.6)
Sept.	2.29 (58.2)	2.64 (67.1)	1.55 (39.4)	2.16 (54.9)
Oct.	3.29 (83.6)	3.06 (77.7)	2.83 (71.9)	3.06 (77.7)
12-month summary	34.07 (865.4)	36.17 (918.7)	30.80 (782.3)	33.56 (852.4)
Nov.	4.53 (115.1)	4.01 (101.9)	4.07 (103.4)	4.20 (106.7)
Dec.	3.05 (77.5)	3.99 (101.3)	2.17 (55.1)	3.07 (78.0)
Long-term Annual Average				
Precip. in. (mm)	33.1 (840.7)	32.5 (825.5)	30.7 (779.8)	
Temp. °F	45	46	45	
°C	7.2	7.8	7.2	

The dye-trace studies showed that groundwater also discharges to the Turkey River through two smaller springs--Back Spring and Heick's spring. The discharge from these springs cannot be continuously monitored as can the Big Spring. These two smaller springs were gaged, by USGS-WRD personnel in September and October of 1982. During this time, Big Spring was discharging at a low, base-flow level, about 33 to 39 cubic feet per second (cfs). Back

Spring discharge was gaged at 3.9 cfs and Heick's Spring at just over 1.0 cfs. Back Spring discharge averaged about 10.9% of the Big Spring discharge, while Heick's Spring was about 3.2%. To complete the total groundwater discharge from the three springs, the discharge of Back and Heick's Springs was simply computed as 14.1% of the Big Spring discharge over time. The two values were then added together.

In addition to discrete spring-conduit flow, some discharge from the Big Spring basin may also occur through more diffuse flow from the Galena aquifer into the alluvial aquifer of the Turkey River. To assess the significance of this discharge, the Turkey River was gaged by USGS-WRD personnel in October 1982, when the Turkey River was at its lowest discharge of the fall. However, this was not a low-flow condition (see figure 29). The river was gaged at the upstream and downstream points in the reach where the Big Spring groundwater basin discharges to the river (see figures 19 or 20). Each location was gaged twice, by two different people. The average of the measured discharge values was 418 cfs (11.8 cms) on the upstream side of the basin and 433 cfs (12.3 cms) at the downstream edge where the Turkey River leaves the Big Spring basin. Thus, the average-computed increase in discharge through this reach was 15 cfs (0.4 cms); the increase computed from all the data ranged from 0 to 29 cfs (0-0.8) cms). However, in this same reach at this same time the springs were discharging 36.6 cfs (1.0 cms) to the river. In effect, the discharge measurements suggest a possible loss of water by the Turkey River. Head relations clearly show that the Galena aquifer is discharging to the river. It is perhaps possible that some stream flow is lost (or transferred downstream) as local, shallow flow through permeable fluvial deposits (sand and gravel) which occur in the banks of the river. These differences are also within the range of error of the measurement (3-5%) at this discharge, however, and this seems the most likely cause of the difference. As a consequence diffuse discharge from the Galena aquifer to the Turkey River is considered as negligible.

Table 22 summarizes the total, average, maximum, and minimum groundwater discharges on a monthly basis; computed from the Big Spring monitoring and adjusted for discharge from Heick's Spring and Back Spring as described.

Discharge rates and responses at Big Spring reflect the effects of recharge to the Galena aquifer within the contributing basin. The relationship between precipitation, recharge, and discharge events is complex, but shows definite seasonal trends. During the winter months (November-February) at the beginning of the study, discharges from Big Spring were fairly constant, usually 35-40 cfs (1.0-1.1 cms), and followed a slowly decreasing trend. Temperatures during this period generally remained well below freezing, and precipitation fell as snow. As a result, little recharge occurred, and flow from the spring represented water draining from storage within the diffuse-flow parts of the aquifer. The gradual decrease in discharge is caused by declining heads, and therefore declining hydraulic gradients, within the aquifer, as groundwater storage is depleted. This is analagous to baseflow-recession conditions in a surface stream.

A minor amount of winter recharge did occur during late November-early December, and was caused by a minor snowmelt event. IGS staff in the field at that time noted that little or no runoff occurred during the snowmelt. Therefore, most of the recharge water entered the system as slow infiltration, mainly to

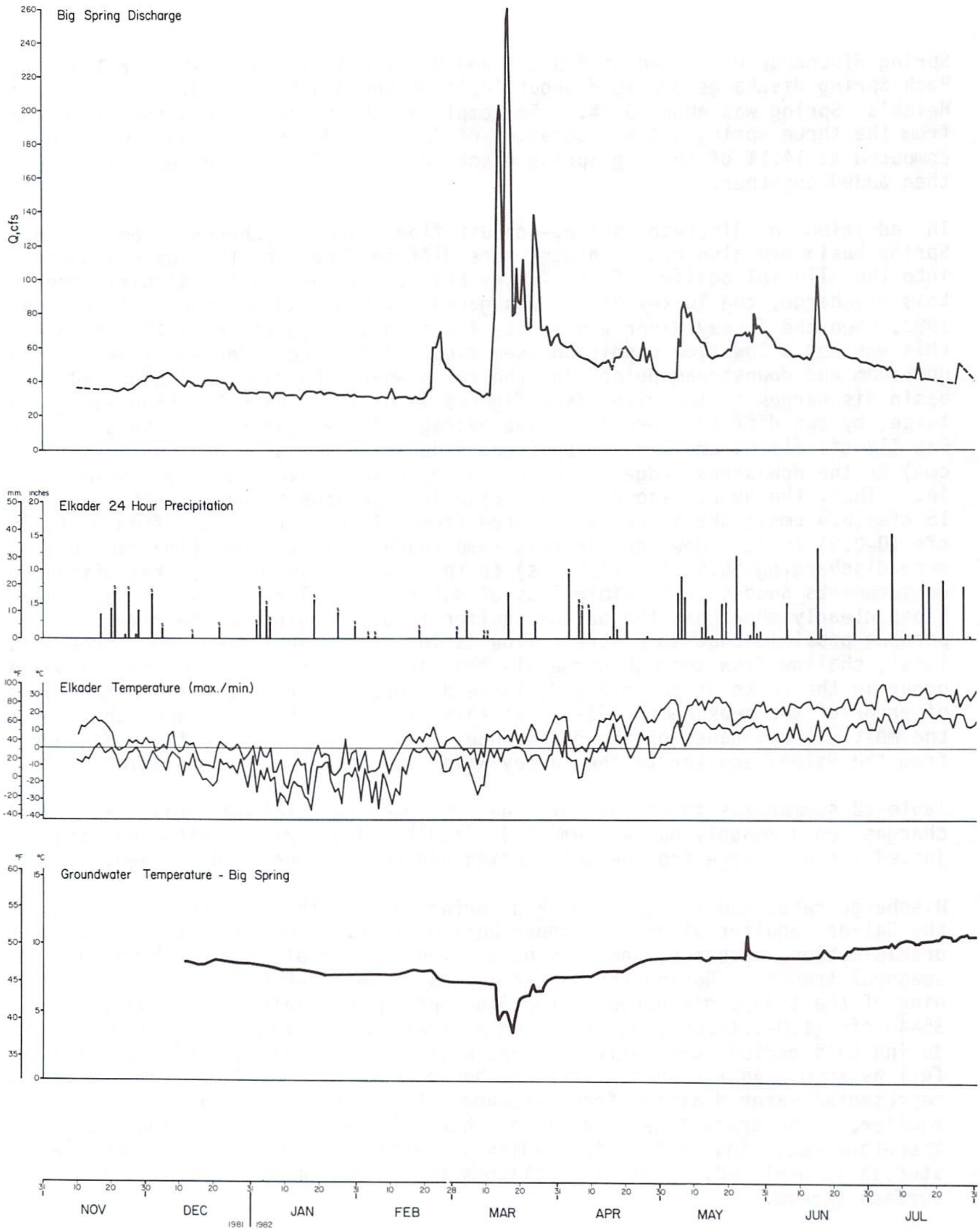


Figure 28. Discharge hydrograph from Big Spring; 24 hour precipitation, maximum and minimum daily temperatures from Elkader; and temperature of groundwater discharging at Big Spring; for 1981-1982.

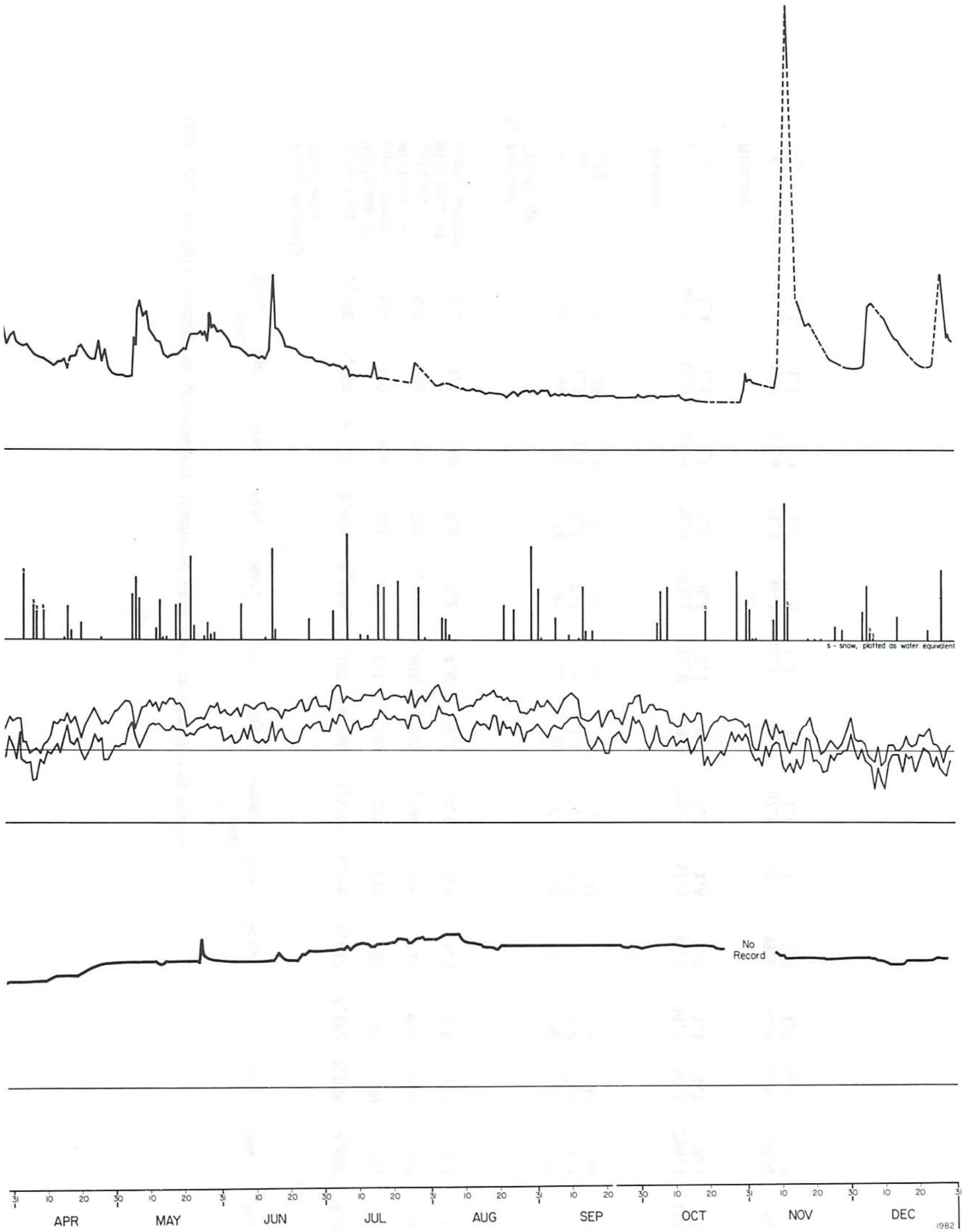


Figure 28, con't. April through July overlaps with page 84.

Table 22. Monthly summary of groundwater discharge data for the Big Spring basin.

	1981		1982											
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1. Total Monthly Discharge														
Acre-feet	2,590	2,755	2,306	2,324	5,854	3,707	4,200	3,973	3,056	2,427	2,142	2,038	4,602	4,400
Millions of cubic feet	113	120	100	101	255	161	183	173	133	106	93	89	201	192
Millions of gallons	845	898	748	755	1,907	1,204	1,369	1,294	995	793	696	666	1,504	1,438
Millions of cubic meters	3.2	3.4	2.8	2.9	7.2	4.6	5.2	4.9	3.8	3.0	2.6	2.5	5.7	5.4
2. Average Discharge														
cfs	44	45	38	42	95	62	68	67	50	40	36	33	78	71
cms	1.2	1.3	1.1	1.2	2.7	1.8	1.9	1.9	1.4	1.1	1.0	0.9	2.2	2.0
mg/d	28	29	24	27	62	40	44	43	32	26	23	21	50	46
3. Maximum														
cfs	48.8	52.0	39.0	78.9	297.1	72.8	98.3	115.7	57.9	44.1	39.2	40.5	295.3	117.6
cms	1.4	1.5	1.1	2.2	8.4	2.1	2.8	3.3	1.6	1.2	1.1	1.1	8.4	3.3
Minimum														
cfs	39.5	37.7	33.9	34.4	36.1	49.5	48.1	57.5	44.2	35.0	35.0	31.9	41.0	54.7
cms	1.1	1.1	1.0	1.0	1.0	1.4	1.4	1.6	1.3	1.0	1.0	0.9	1.2	1.5

the diffuse-flow part of the aquifer. The discharge response at Big Spring to this primarily infiltration-recharge event was a minor, prolonged increase in flow rates (figure 28), and is fairly typical of a diffuse-flow system response to recharge (see figure 18; also White and White, 1974; White, 1977).

Spring snowmelt, sometimes accompanied by rainfall, occurred during March and April. Rapid snowmelt generated significant runoff, and yielded large volumes of direct recharge to the conduit-flow system. Discharge at Big Spring responds rapidly to this direct conduit recharge, and the resulting hydrograph (figure 28) during these months is punctuated by numerous high-flow peaks, with a maximum discharge of about 260 cfs (7.4 cms). During May and June, rain storms produced similar results, though of lesser magnitude. Wet conditions prevailed throughout the entire March-June period, and total basin discharge remained generally high, averaging over 60 cfs (1.7 cms; Table 22); this four month interval accounted for nearly 50% of the total discharge for the water year (11/81-10/82).

While the extremely high peak-discharge events that occurred during March through June resulted from runoff recharge to sinkholes and the conduit system, the persistantly elevated flows between peak events are, to a large degree, the result of significant infiltration recharge to the diffuse-flow system. This infiltration recharge increases the amount of groundwater in storage within the Galena aquifer, and therefore raises water table/potentiometric elevations and imposes steeper hydraulic gradients upon the system. This results in increased discharge from the diffuse-flow parts of the aquifer.

The hydrograph for the late summer-fall (July-October) period contrasts markedly with that for the preceeding months (figure 28). Although numerous rainfalls greater than 0.75 inches (19 mm) occurred, no significant discharge events resulted, indicating the conduit-flow system received little direct runoff recharge. Additionally, discharge-flow rates steadily decreased across this period, indicating base-flow conditions with little infiltration recharge taking place. As in the winter months, discharge from the Spring during July-October was primarily groundwater released from storage within the aquifer. The lack of recharge to the aquifer during these months is caused by high-water uptake by crops and other plants and hot summer temperatures. These factors result in very high rates of evapotranspiration and relatively low soil moisture levels, leaving little or no precipitation available for runoff or infiltration.

November and December of 1982 experienced very different climatic conditions compared to the same months of the preceding water year. Daily maximum temperatures were generally well above freezing, and most precipitation fell as rain. Several fairly intense rain storms occurred and generated high-flow events, with the largest storm resulting in discharges greater than 250 cfs (7.1 cms). The high discharges are partially related to the size and intensity of the preceding storms, but also reflect the effects of rainfall on harvested fields during a period of low evapotranspiration potential. These factors allow for a significant amount of the precipitation to run off, causing direct recharge to the conduit-flow system, resulting in the high discharges at Big Spring.

Water-Temperature Monitoring

For various periods of the water year, groundwater and surfacewater temperatures were recorded continuously, using Ryan recording thermographs. Groundwater temperatures were monitored at Big Spring, Back Spring, and in an abandoned Galena well. Surfacewater temperatures were monitored in the losing reach of Robert's Creek just upstream from sampling station 111 (figure 24).

The Big Spring and Back Spring records were essentially identical, except that Back Spring showed a few warm temperature "spikes," of short duration during run off events in early summer. Back Spring receives some runoff from a small valley above the ICC Fish Hatchery. The thermograph in the Big Spring malfunctioned, and so the Back Spring record for late May, June, and early July was used to plot the groundwater-temperature curve shown in figure 28. (Since late July only the Big Spring temperature has been monitored.)

As shown in figure 28, there is little variation in the groundwater temperature discharged at Big Spring. When monitoring began in December, 1981, groundwater temperature was at about 8.8°C (48°F), and over the winter it gradually declined to about 7.2°C (45°F)--the mean annual air temperature. With spring snowmelt, the large conduit-flow discharges caused the only significant temperature changes of the year. The cold snowmelt water dropped the groundwater temperatures to 4.4°C (40°F) and 3.3°C (38°F) during the two meltwater discharge peaks (see figure 28).

After the snowmelt season the water temperatures gradually rose. The warm temperature "spike" in late-May is likely an artifact of the Back Spring thermograph. Over the summer months there are sharp--but very slight--increases in temperature (less than 0.5°C) which did coincide with runoff events. Overall, the temperature gradually rose to a high of 10°C (50°F) in August. After this the temperatures gradually declined to about 8.8°C (48°F) again. A few subtle changes in groundwater temperature occurred with the large runoff-conduit flow events that occurred in November and December, 1982. The change in temperature that occurred with conduit-flow events lagged behind the beginning of the discharge rise on the hydrograph by 24 to 48 hours.

The thermograph from the abandoned Galena well showed very little change. The groundwater temperature was essentially constant at 8.8°C (48°F) from January through June, even though this well admitted water from a vadose conduit during runoff events. Only during the beginning of the first snow melt event, in late February, did it show any change. Then it showed a sudden 4°C drop in temperature, that lasted for about 2 hours. Thus, the various groundwater temperature records show, as would be expected, that the temperature of the surface water entering the Galena reaches equilibrium quite quickly, with some travel in the aquifer, except during extreme events.

The temperature of Robert's Creek was monitored from early February through July. In essence, the thermograph mimics the diurnal air temperatures from Elkader (figure 28) with two exceptions. While ice-covered and during the first snowmelts (until about March 20th) the water temperatüre remained between 0.5 and 1.0°C (32.9-33.8°F). Also, during runoff events the surfacewater temperature would generally decline sharply (2 to 4°C) and then remain relatively constant for 12 to 36 hours.

Total Groundwater Basin and Turkey River Discharges

The hydrograph in figure 28 shows only the measured discharge from the gaging at Big Spring. The total discharge to the Turkey River system, from the Big Spring groundwater basin is the sum of the Big Spring, Back Spring, and Heick's Spring discharge (Table 22) as noted. Figure 29 shows the hydrograph for this total basin discharge, plotted on a semi-logarithmic scale so it can be compared with the Turkey River discharge. The log-scale plot of discharge damps the amplitude of the hydrograph, but the significant events are still discernable.

The Turkey River hydrograph (figure 29) shows the average daily discharge, in cfs, from data at the USGS gaging station at Garber (#4125). The Garber station is 27 miles (43 km) downstream from Big Spring, and at this point drains an area (1,545 sq. miles--4,000 sq. km) 15 times larger than the Big Spring basin. Even with the distance separating the Garber gage and Big Spring, the parallelism in the hydrographs is striking. Peak conduit flows at Big Spring are coincident with peak events on the Turkey River, although the peaks are offset at Garber by a short time lag, generally about 24 hours. Periods of peak flows and periods of general recession are in phase.

The principal reasons for this parallelism is that the Turkey River is a "high" base-flow stream, i.e., a high proportion of its total flow is contributed by groundwater. This is typical for all the major streams in northeast Iowa draining the Paleozoic Plateau area (e.g.--the Turkey, Volga, Yellow, and Upper Iowa Rivers). Hydrograph separation and base-flow indexing (discussed in a following section) show that over the long-term, the discharge of the Turkey River at Garber is comprised of about 70% groundwater in-flow (Oscar Lara, USGS-WRD, Iowa City, pers. comm.), such as from the Big Spring basin. As noted earlier, surfacewater discharges in northeast Iowa were higher than usual during the water year. Base-flow indexing for this period shows that the Turkey River discharge was comprised of about 50 to 55% groundwater (Oscar Lara, USGS, pers. comm.) contributions. Surfacewater inputs were higher than normal.

The correspondence between the Turkey River and Big Spring hydrographs clearly suggest that the response and behavior of the Big Spring basin hydrologic system is typical of the much larger area drained by the Turkey river.

Water Balance

From the various hydrologic data collected, a water balance was established for the Big Spring basin for the water year.

Groundwater Balance

In its simplest form, a groundwater balance for the Galena aquifer may be written in the following manner:

$$\text{Recharge} = \text{Discharge} + \Delta \text{ storage}$$

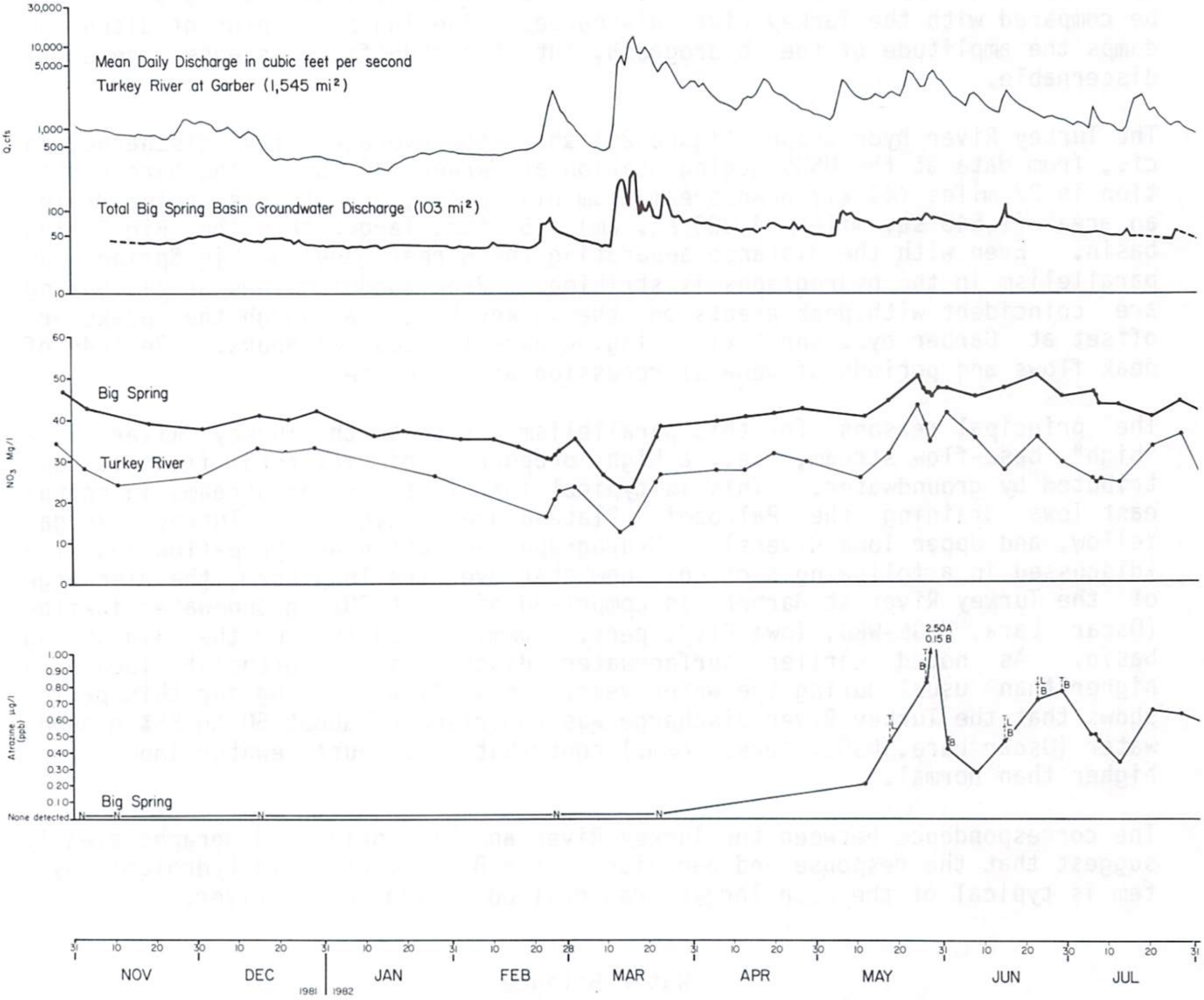


Figure 29. Discharge hydrographs from the Turkey River at Garber and the Big Spring groundwater basin; nitrate concentrations from the Big Spring and Turkey River; and atrazine concentration from Big Spring, for 1981-1982.

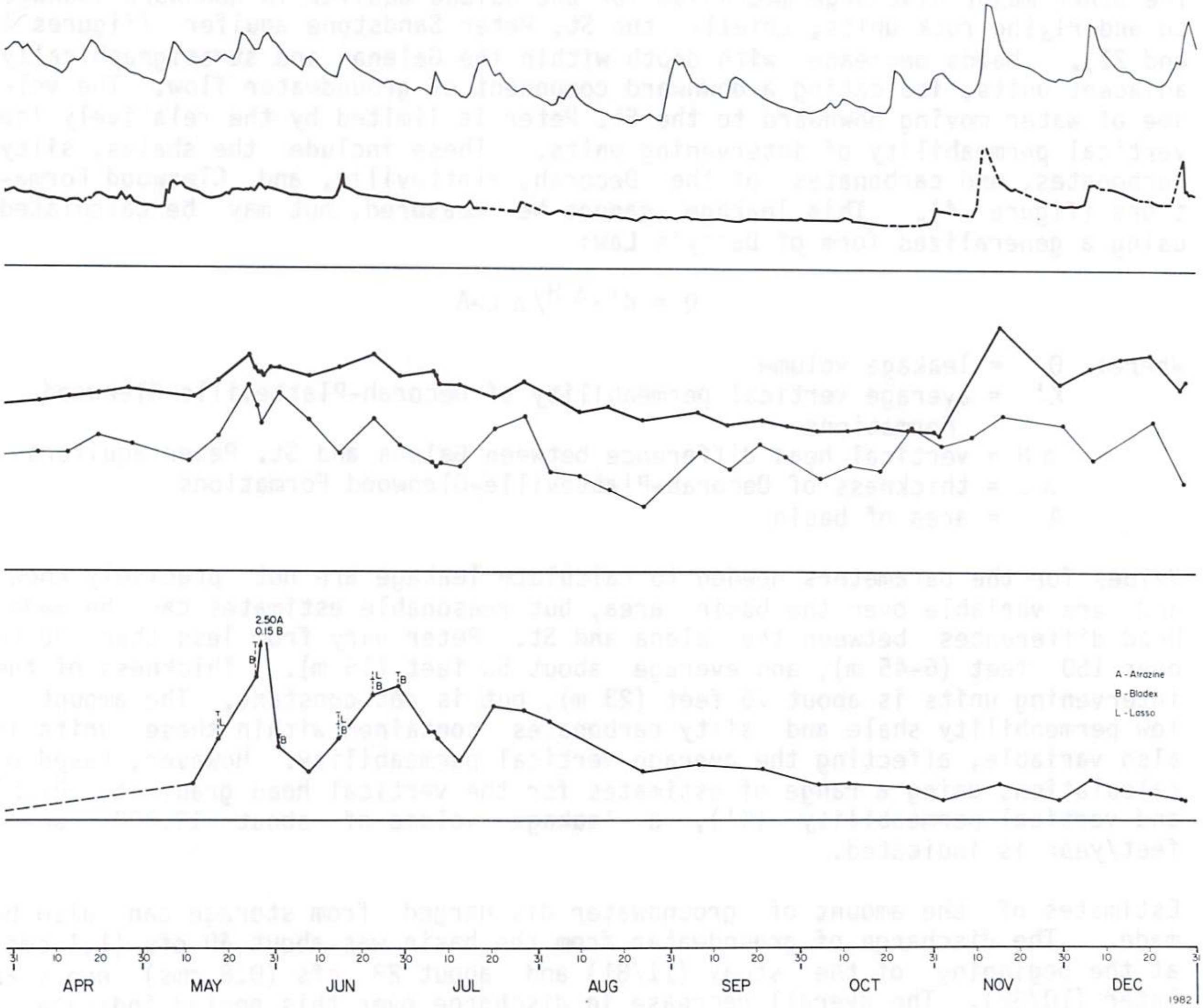


Figure 29, con't. April through July overlaps with page 90.

where, over the period of concern, recharge is all water entering the aquifer, discharge is all water leaving the aquifer, and Δ storage is the change in the amount of water contained ("stored") within the aquifer. Significant amounts of groundwater are discharged from the Galena in two ways. First, as surficial discharge to the Turkey River, through Big Spring and associated springs; discharge to the Turkey River during the period 11/81-10/82 was about 37,400 acre-feet (46 million cubic meters).

The other major discharge mechanism for the Galena aquifer is downward leakage to underlying rock units, chiefly the St. Peter Sandstone aquifer (figures 4 and 21). Heads decrease with depth within the Galena and stratigraphically adjacent units, indicating a downward component of groundwater flow. The volume of water moving downward to the St. Peter is limited by the relatively low vertical permeability of intervening units. These include the shales, silty carbonates, and carbonates of the Decorah, Platteville, and Glenwood Formations (figure 4). This leakage cannot be measured, but may be calculated using a generalized form of Darcy's Law:

$$Q = K' \cdot \Delta H / \Delta L \cdot A$$

Where:
- Q = leakage volume
- K' = average vertical permeability of Decorah-Platteville-Glenwood Formations
- ΔH = vertical head difference between Galena and St. Peter aquifers
- ΔL = thickness of Decorah-Platteville-Glenwood Formations
- A = area of basin

Values for the parameters needed to calculate leakage are not precisely known and are variable over the basin area, but reasonable estimates can be made. Head differences between the Galena and St. Peter vary from less than 20 to over 150 feet (6-45 m), and average about 50 feet (15 m). Thickness of the intervening units is about 75 feet (23 m), but is not constant. The amount of low permeability shale and silty carbonates contained within these units is also variable, affecting the average vertical permeability. However, based on calculations using a range of estimates for the vertical head gradient ($\Delta H / \Delta L$) and vertical permeability (K'), a leakage volume of about 10,000 acre-feet/year is indicated.

Estimates of the amount of groundwater discharged from storage can also be made. The discharge of groundwater from the basin was about 40 cfs (1.1 cms) at the beginning of the study (11/81) and about 28 cfs (0.8 cms) one year later (10/82). The overall decrease in discharge over this period indicates a decrease in the volume of water in storage within the Galena. The decrease in storage is equivalent to the volume of water released from storage as discharge drops from 40 cfs (1.1 cms) to 28 cfs (0.8 cms) during base-flow recession (Atkinson, 1975). Using the basin discharge hydrograph for base-flow recession periods (November 1981-February 1982 and July-October 1982), a storage decrease of about 10,000 acre-feet (12.3 million cm) is indicated from the observed decrease in discharge.

Using the measured and estimated discharge and storage change volumes, recharge to the Galena within the basin may be calculated:

$$\text{Recharge} = \text{Discharge} + \Delta\ \text{storage}$$
$$= (37{,}400\ \text{a-f} + 10{,}000\ \text{a-f}) + (-10{,}000\ \text{a-f})$$
$$= 37{,}400\ \text{acre-feet}$$

Distributed equally across the basin, groundwater recharge for the 12 month period was 6.8 in. (173 mm). Assuming 34.0 in (864 mm) of precipitation fell on the basin during the period, about 20% of the precipitation recharged the Galena aquifer. Data used in the groundwater balance is summarized in Table 23.

Another source of groundwater removal from the basin is the withdrawal of water from Galena wells. From the inventory data and from general population and livestock statistics, estimates were made of the amount of Galena water withdrawn for human and livestock consumption. Standard values for water-use of 75 gpd-per person and 20 gpd-per head cattle, were used in the calculations. Using even the highest population estimates the estimated water consumed from Galena wells was still less than one percent of groundwater discharge. Thus, this factor was treated as negligible.

Surfacewater Discharge

In addition to groundwater discharge, there was, of course, surfacewater discharged from the Big Spring basin. In a karst basin, such as this, some surface water enters the groundwater system and is discharged by conduit flow. This, however, is common for much of the Turkey River basin. As previously described about 11% of the land surface in the basin currently drains to sinkholes. Thus, surfacewater discharge constitutes a substantial, additional portion of the water yield for the basin.

As previously described, the 103 square mile (267 sq. km) area of the Big Spring groundwater basin does not entirely coincide with the Robert's Creek drainage basin. Other surface waters leave the groundwater basin in the southern and northeastern portions of the area in particular. It is not possible to gage all this discharge, but various methods can be used to provide good estimates of the surfacewater discharge.

From long-term gaging records the USGS-WRD has developed quantitative relationships for estimating long-term average discharges. The regional relationship which includes the study area is:

$$Qa = 0.68\ A^{0.97}$$

where Qa = average discharge in cfs, and A is the drainage area (Oscar Lara, USGS, pers. comm.). Such estimates are usually within 10% of measured values. For example, there are 11 years of gage records from Robert's Creek where its draining area is 101 square miles (262 sq. km). The average discharge was 60 cfs (1.7 cms), which is the same as the value predicted by the equation. Thus, during periods when Robert's Creek is not losing significant portions of its discharge to sinkholes, it has a typical stream output for this region.

Table 23. Total Water Yield from Big Spring Basin for Water-Year (11/81-10/82).

	Acre-feet	(millions cubic meters)
GW discharge to Turkey River	37,400	(46.1)
GW leakage to St. Peter	10,000	(12.3)
(change in storage)	(-10,000)	(-12.3)
Streamflow discharge	34,750	(42.8)
Total	82,150	(101.3)
Precipitation	34 inches	(864 mm)
Water Yield (less change in storage)	13.1 inches	(333 mm)
Water Yield as % of precipitation	38%	

The long-term average discharge for the Turkey River at Garber is 917 cfs (26 cms), or about 0.59 cfs/sq. mile (0.07 cms/sq. km), which equals about 8.06 inches (205 mm) of runoff per year--about 25% of the average precipitation for the basins. As noted, the strong correspondence between the Big Spring and Turkey River hydrographs point to the strong interrelationship between discharge from the study area and the Turkey River hydrologic system as a whole. All lines of evidence show that the Big Spring's region is a typical contributor to the Turkey River. Thus, various regional parameters can also be used to guide estimates of water-yield from the Big Spring basin, with reasonable accuracy.

Numerous methods were used to estimate the surfacewater discharge, which all produced similar values. The long-term averages for contributions to the Turkey River (e.g., 0.59 cfs/sq. mi) include both groundwater and surfacewater discharge to the Turkey River system. Similar parameters can be computed for the water year to estimate the total discharge to the Turkey River from the Big Spring basin. The groundwater discharge from the basin is measured, and thus, the surface-water discharge can be computed by the difference.

For the water year, the average discharge to the Turkey River was 1.06 cfs/sq. mile of drainage area. For a 103 sq. mile basin, the average discharge would be 109 cfs (3.1 cms) or a total contribution of 78,900 acre-feet for the water year. As noted (see Table 23) the groundwater discharge to the Turkey River for the water year was measured at 37,400 acre-feet, or an average discharge of 51.6 cfs (1.5 cms). This value includes, however, the surfacewaters diverted through sinkholes into the groundwater discharge. Applying separation techniques to the Big Spring hydrograph (discussed in a later section) suggests that about 9% of the groundwater is comprised of peak-conduit flow (essentially a surface-water component), which amounts to 3,360 ac-ft, or an average discharge of 4.6 cfs (0.1 cms). This leaves 91% as the "normal" groundwater component. This amounts to 34,040 ac-ft or an average discharge of 47 cfs (1.3 cms).

This procedure thus estimates an average discharge of 57 cfs (1.6 cms) for surface water out-flow from the basin. If combined with the surfacewater discharge draining to the sinkholes, the average total for surfacewater discharge is 62 cfs (1.8 cms). These values represent 55 and 52%, respectively, of the estimated total discharge to the Turkey River.

The results from other approaches will be briefly outlined, for comparative purposes. As noted, base-flow indexing for the water-year suggests that 50-55% of the Turkey River discharge was comprised of groundwater base flow, and thus, 45-50% was surface runoff. Applying these values to the Big Spring basin, results in estimates of the average discharge ranging from 85 to 94 cfs (2.4-2.7 cms). Base-flow indexing and hydrograph separation applied to monthly flow data suggest an average discharge of about 102 cfs (2.9 cms). Simply balancing the increase above normal average discharge, for all the Turkey River and nearby gage stations, suggests an average of 105 cfs (3.0 cms). Similarly, using regional runoff-to-precipitation relationships for all northeast Iowa gage stations suggests a range from 97 to 109 cfs (2.7-3.0 cms). In short, nearly all the methods used resulted in a very narrow range of estimates.

One last method which is worthy of further mention, was the use of the hydrograph separations from the Big Spring discharge data. As noted, an average discharge of 4.6 cfs (0.1 cms) was computed for the surfacewater component (peak-conduit flow). This discharge comes from only 11% of the total basin, and as previously described, this 11% is very typical of the slopes and soils in the entire basin. Thus, if these values are expanded to the entire 103 sq. mile (267 sq. km) area, it suggests surfacewater runoff was about 42 cfs (1.2 cms), for a total average discharge of 99 cfs (2.8 cms). At peak flows some of the surface runoff escapes the sinkhole basins, and thus, the value is likely low, but still falls in the middle of all the other estimates.

The mean of all the estimates gave an average basin discharge of 100 cfs (2.8 cms). This value was used for computing the total water-yield for the basin. This amounts to an average stream-flow discharge of 48 cfs (1.4 cms) or a total of 34,750 ac-ft (Table 23). With the close corroboration of all the methods used, this value is probably within 10% of what would be measured (Oscar Lara, USGS, pers. comm.).

Water-Balance Summary

Table 23 summarizes the total water-yield from the Big Spring groundwater basin for the water year. The figures, as outlined, amount to 13.1 inches

(333 mm) of water yield (groundwater and surfacewater) for 34 inches (864 mm) of precipitation, which is higher than the normal 25% for northeast Iowa streams. Although this value is quite high for Iowa, it is typical, or even low, relative to many karst terrains (Bassett, 1976; Atkinson, 1975). A review of data from all the gaging stations in northeast Iowa for this and the preceding water year, show a range from 34 to 44%. Again, the value for the Big Spring basin falls in the middle of the measured conditions. Also, from long-term records, the occurrence of this high a mean discharge has a 10% probability (Oscar Lara, USGS, pers. commun.) and thus, is not unusual for northeast Iowa.

Water-Quality Monitoring

A variety of water-quality parameters were also monitored during the period of study in 1981 and 1982. As noted earlier, a network of wells, surfacewater sites, and tile lines were selected for monthly monitoring. These sites are identified on Table 11 and figure 24. The water-quality data from the monitoring period is tabulated in Appendix 2, listed by site number, and then by date. Water-quality data from samples collected from other miscellaneous sites is tabulated in Appendix 3.

Nitrate Data

Water samples from Big Spring (site 82) and the Turkey River (site 113) were analyzed weekly for nitrate, or more often during some runoff events (Appendix 2). Samples from other sites on the monitoring network were analyzed monthly or more often (Appendix 2). The nitrate concentration data are summarized in Table 24. Also, a variety of other samples were collected from other wells, from surface waters and tile lines draining to sinkholes, and other springs (Appendix 3). The miscellaneous samples corroborate other findings and support the representative nature of the monitoring network results.

Nitrate was the only form of nitrogen-species compounds for which the samples were analyzed. This was a matter of time and money, and because nitrate is the principal N-species of concern in groundwater.

The resultant concentration data were in accord with past studies (see Baker et al., 1978; Baker and Johnson, 1981; Hallberg and Hoyer, 1982). Samples from direct land-surface runoff, such as sheetwash coming off corn fields, showed less than detectable amounts of nitrate (<5 mg/l). Even runoff from feedlots showed <5 mg/l. Such samples are usually high in organic-N and ammonia, but not nitrate. Once water begins to infiltrate the soil it then picks up the oxidized and mobile nitrates. Very shallow subsurface-seepage water (sampled in newly collapsed sinkholes, for example) and water in very small, ephemeral streams draining to sinkholes, whose flow was contributed by runoff and shallow-soil stormflow, ranged from 6 to 48 mg/l in nitrate concentration. Tile-line effluent water is more typical of a shallow-infiltrating soil water. The nitrate concentrations from various tile lines ranged from 32 to 98 mg/l, with a mean of 74 mg/l. (Note: for many sites with nitrates persistently present, the data distribution approaches a "bell-shaped" distribution, and the use of means is reasonable. For well networks, and other data

Table 24. Summary statistics for nitrate data (in mg/l) for monthly monitoring network.

Site No.	Site ID Wells	Mean	S.d.	Range mg/l
11	VD-24	27	12	10-57
15	B-18	143	8	132-158
16	B-32	17	3	12-21
26	VD-12	16	20	<5-63
30	B-27	36	13	23-72
37	VD-18	84	32	27-152
39	L-7	100	29	45-142
45	Pat-20	<5 (2)	0	<5
47	Pat-18	<5 (2)	0	<5
49	F-51	25	14	10-52
52	F-8	62	6	55-79
56	F-33	35	9	18-48
57	T-17	46	7	36-58
61	L-42	80	17	41-104
72	GL-1	32	10	9-40
75	GL-8	85	14	60-101
81	AB-6	34	3	29-39
84	AB-3	31	16	5-60
Tile Line				
108	L-22	72	17	32-97
Surfacewater				
109	L-23	39	10	23-61
111	F-47	35	12	20-57
110	F-45	35	10	21-54
113	Turkey River	28	7	12-43
Big Spring				
82	BS	40	7	23-57

with numerous <5 values medians will still be used.) The larger, permanent streams within the basin (such as Robert's and Silver Creek and smaller unnamed tributaries), whose flows are sustained by runoff, tile drainage, and shallow sub-soil flow, had nitrate concentrations ranging from 20 to 61 mg/l, with a mean of 37 mg/l. Nearly all Galena spring samples were within the range recorded at Big Spring, 23 to 57 mg/l nitrate, except the St. Olaf Spring (site 78), which peaked at 68 mg/l. The Big Spring data was representative of all the Galena springs discharging to the Turkey River. The median value for the Big Spring samples was 40 mg/l.

The Turkey River shows lower concentrations, as expected. A river of this size generally dilutes the nitrate concentrations because of the large area it drains, and because of the large runoff (low nitrate) component to its flow. Nitrate values for the Turkey River ranged from 12 to 43 mg/l with a mean of 28 mg/l.

The data from the Galena well network is more difficult to summarize. As in the initial inventory, the median of the well samples tends to be a few mg/l less than the Big Spring value (Table 19) for any month. For the monitoring period, the values ranged from <5 mg/l in the background wells under the Maquoketa, to 158 mg/l in site 15 (Table 24; Appendix 2, Table 2-2).

Big Spring Nitrate Concentrations

Weekly samples from Big Spring provide a good basis to view the trends in nitrate concentration over the water year. The nitrate concentrations at Big Spring are plotted in figure 29, for comparison with the Big Spring hydrograph.

In the early winter of 1981-82, nitrate concentrations from Big Spring were between 40-47 mg/l. As discharge gradually recessed, so did the nitrate concentration, decreasing to about 30 mg/l. The high discharge peaks, which accompanied snowmelt in March, diluted the nitrate concentration, and caused a sharp decline to 23 mg/l. After the snowmelt period, the discharge declined. High peaks of runoff-conduit flow mark the record through early June. During this time nitrates gradually rose and varied from 47 to 50 mg/l. This was followed by the summer and early fall recession in both discharge and nitrate concentrations. Nitrate concentrations again gradually declined (as did discharge) to 33-34 mg/l in late October, 1982. This marks the end of the first water year. As previously discussed, November and December 1982, were quite unusual because they were marked by warm temperatures, rain, and runoff, which produced the large discharges at Big Spring (figure 28-29). High infiltration rates also accompanied these events, and the nitrate concentration in the groundwater at Big Spring rose to its highest level of the year, 57 mg/l, and remained between 43 and 50 mg/l during this time.

Thus, as expected from past studies, the nitrate concentration varies seasonally at Big Spring, but in a predictable manner. As described, it generally also varies with discharge. Figure 30 graphically shows that there is a roughly linear relationship between increasing discharge and increasing nitrate concentration, except during large peak-conduit flow, runoff events,

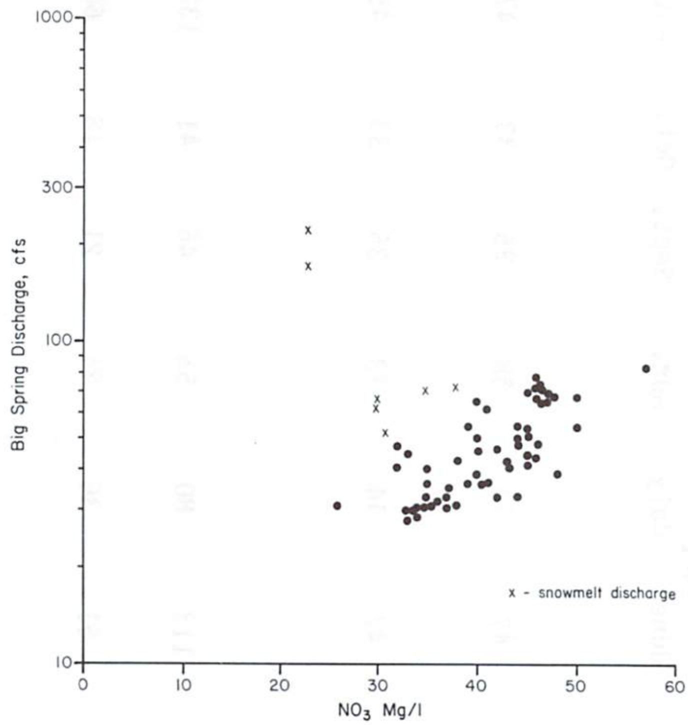


Figure 30. Big Spring discharge versus nitrate concentration for 1981-82 data.

such as snowmelt. As noted, runoff water, particularly snowmelt, is low in nitrate, and thus, these runoff related conduit-flow discharges cause the nitrate concentrations to decrease.

With the detailed monitoring of discharge and nitrate concentrations, it is also possible to compute the mass of nitrate being discharged with the groundwater from the Big Spring basin. Table 25 summarizes these calculations by month, for the 1981-82 monitoring period. Using the discharge and nitrate data, flow-weighted concentrations were calculated, and then the mass, expressed as N, was calculated for a given period of discharge. There is little difference between the flow-weight means and the arithmetic means of the analysis, because of the detail of sampling. This average monthly discharge of N from groundwater was 81,000 lbs. (37,000 kg) or 40.5 tons of N.

The mass of N discharged is a function of both the nitrate concentration and the volume of water discharged. Thus, for the water year, May and June record the highest mass output, but the third highest month is March. In spite of the low concentrations associated with snowmelt, the large discharges also put out a large mass of N. November and December, 1982, provide a perspective on how unique weather conditions may promote large leaching losses of N. The high discharges, and high nitrate concentrations yielded exceptionally large amounts of N, over 65 tons of N in November alone.

Table 25. Monthly summary of nitrate-N output with groundwater discharged from the Big Spring basin to the Turkey River.

	1981 Nov.	Dec.	1982 Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1. Flow-weighted mean NO_3 concentration, in mg/l	41	40	38	33	30	40	44	47	43	38	35	33	47	47
2. Mean of NO_3 analyses, in mg/l	41	40	36	32	30	41	46	47	44	38	35	33	45	47
3. Total monthly NO_3-N output														
Thousand lbs-NO_3-N	64	66	52	47	107	91	112	113	80	55	46	41	132	127
Thousands kg-NO_3-N	29	30	24	21	49	41	51	51	36	25	21	18	60	57

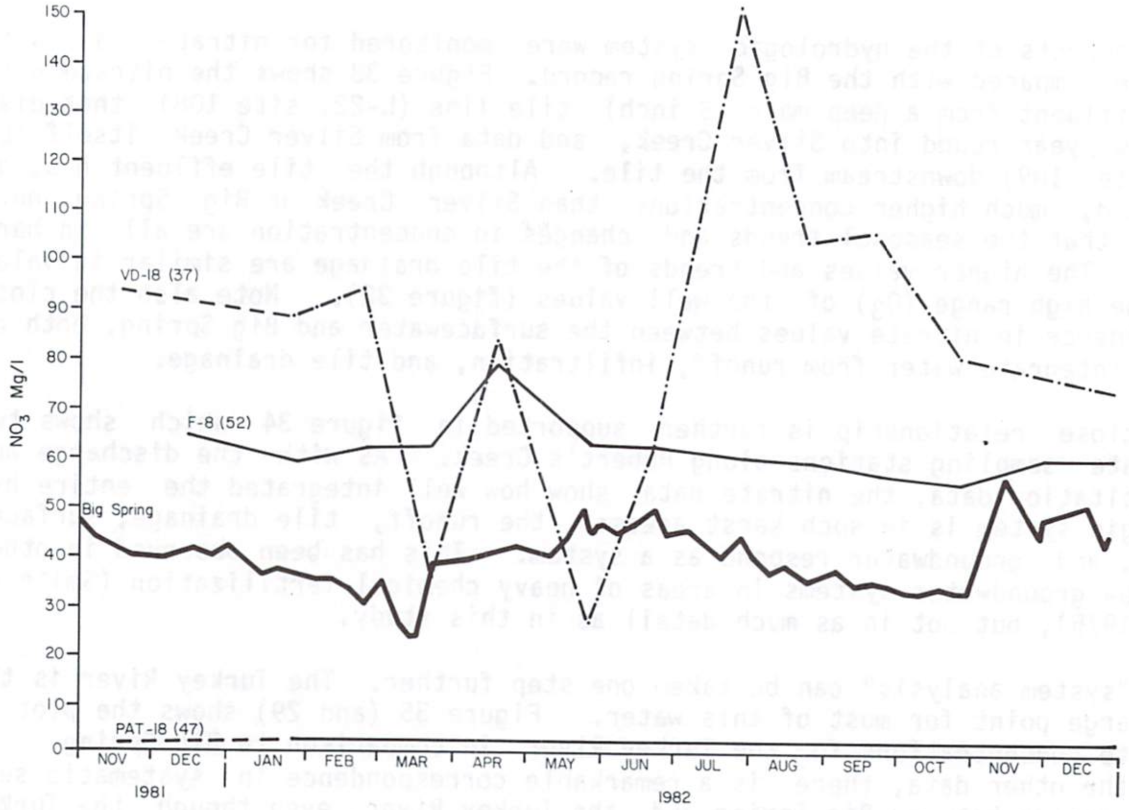


Figure 31. Nitrate concentration over time for Big Spring, and from three monitoring network wells.

Monitoring Network Data

The nitrate data from the monthly monitoring network is summarized in Table 24. The wells sampled can be classed into three basic groups, those whose nitrate concentrations did not vary much over the period of monitoring, those wells that showed high variability, and those in between. Figure 31 shows examples of each group, plotted in comparison to Big Spring. Well site 47 is a Galena well beneath the thick Maquoketa shale, and thus shows <5 mg/l nitrate all year. However, wells even at the other extreme, such as site 15 which has the highest nitrate values, also show very little variation. In contrast, wells such as site 37, varied more than 100 mg/l over the year. Site 52 is an example of one of the wells of moderate variation.

Even with the variations that occur, the well data can be summarized to show some important features. Figure 32 shows the median and quartiles from the monthly well-water nitrate analyses, plotted in relation to the nitrate data from Big Spring. The coincidence in seasonal trend, and actual value, between the median nitrate concentration from the well network and the Big Spring, again points out how well Big Spring integrates the groundwater discharging from this basin. This relationship enhances all the interpretations that can be made from the detailed observations at Big Spring.

Other aspects of the hydrologic system were monitored for nitrates and will also be compared with the Big Spring record. Figure 33 shows the nitrate data from effluent from a deep main (8 inch) tile line (L-22, site 108) that discharges year round into Silver Creek, and data from Silver Creek itself (L-23, site 109) downstream from the tile. Although the tile effluent has, as expected, much higher concentrations than Silver Creek or Big Spring, note again that the seasonal trends and changes in concentration are all in harmony. The higher values and trends of the tile drainage are similar in value to the high range (Q_3) of the well values (figure 32). Note also the close coincidence in nitrate values between the surfacewater and Big Spring, both of which integrate water from runoff, infiltration, and tile drainage.

This close relationship is further supported in figure 34 which shows two separate sampling stations along Robert's Creek. As with the discharge and precipitation data, the nitrate data show how well integrated the entire hydrologic system is in such karst areas: the runoff, tile drainage, surfacewater, and groundwater respond as a system. This has been observed in other shallow groundwater systems in areas of heavy chemical fertilization (Smith et al., 1975), but not in as much detail as in this study.

This "system analysis" can be taken one step further. The Turkey River is the discharge point for most of this water. Figure 35 (and 29) shows the plot of nitrate concentrations for the Turkey River in comparison to Big Spring. As with the other data, there is a remarkable correspondence in systematic seasonal trends between Big Spring and the Turkey River, even though the Turkey is draining an area 10 times larger than the Big Spring basin. As noted earlier, the actual nitrate concentrations are lower from the Turkey River (for all but one sample). There is, perhaps, a good analogy between Big Spring and the Turkey River, and the nitrate data from tile line site 108 (L-22) which empties into Silver Creek, site 109 (L-23; figure 33).

As with Big Spring, there is a positive relationship between discharge and nitrate concentrations, except for snowmelt periods (figure 36). Figure 37 shows a plot of the nitrate concentration from the Big Spring versus that for the Turkey River. This relationship (r^2=0.69) emphasizes the correspondence in trends between these two members of the Turkey River hydrologic system. All these close interrelationships between the Big Spring and the Turkey River suggest that the findings from Big Spring are applicable to much of the larger area of the Turkey River basin.

Nitrates and Hydrogeologic Setting

As described, nitrate concentrations varied greatly in some wells. Generally, there were wells with reported or observed turbidity problems, etc. Thus, it was suggested that these wells were open to portions of the fracture or conduit-flow system. To evaluate this, figure 38 shows a map contouring the coefficient of variation of the nitrate analyses for the Galena well and spring monitoring network. The coefficient of variation is the standard deviation divided by the mean of the analyses, times 100. This is used to normalize the data and remove the effects of differences in absolute values of the analyses.

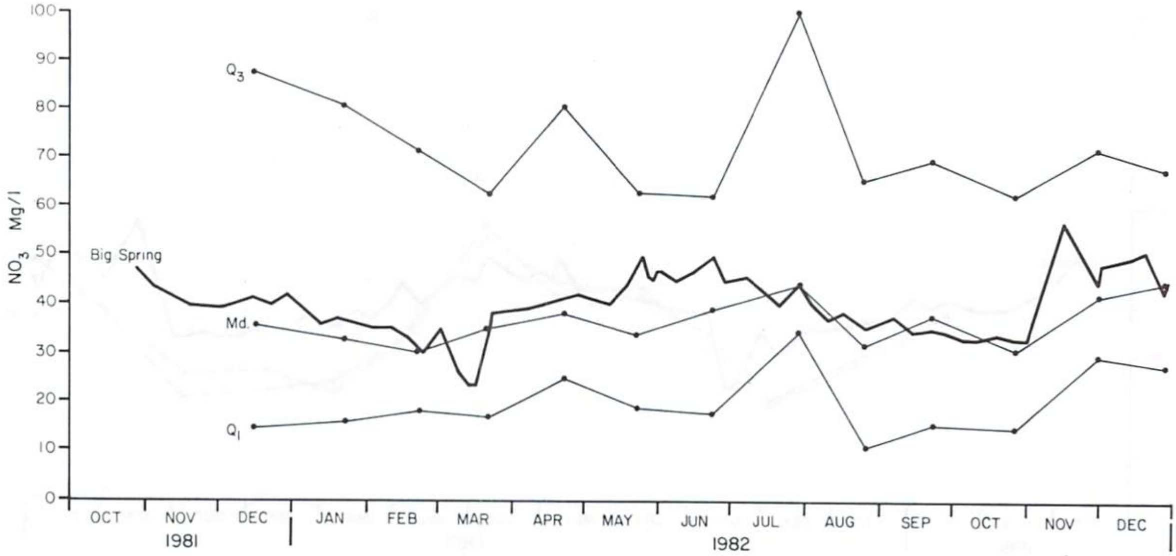


Figure 32. Nitrate concentrations over time for Big Spring, Md.-median concentration from well network, Q_1 and Q_3-quartiles, 25th and 75th percentiles of well network.

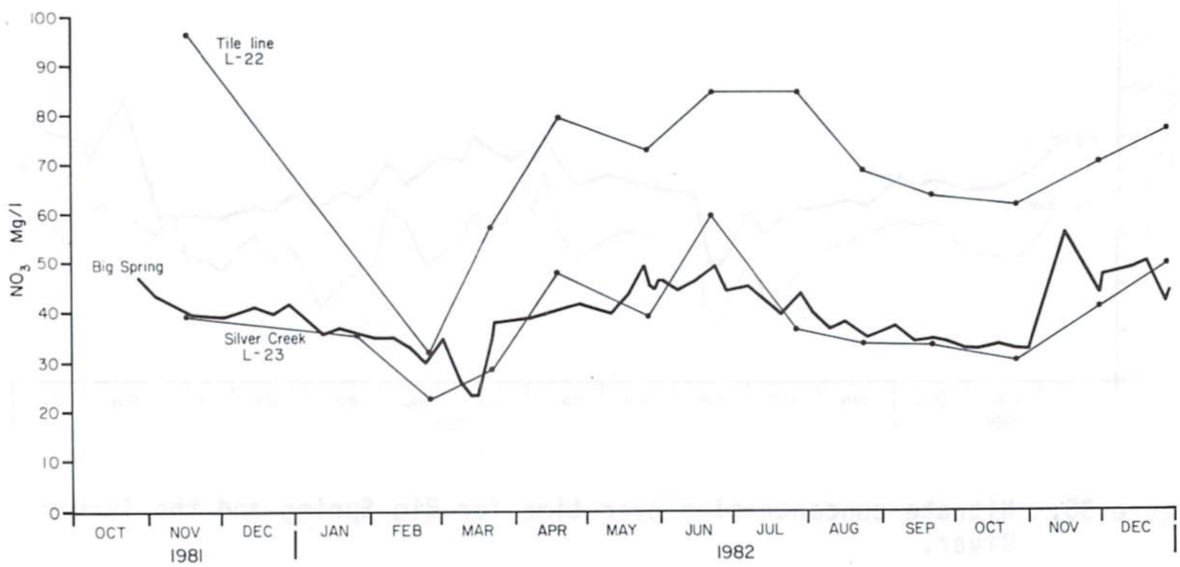


Figure 33. Nitrate concentrations over time for Big Spring, tile-line effluent (site 108, L-22), and Silver Creek (site 109, L-23).

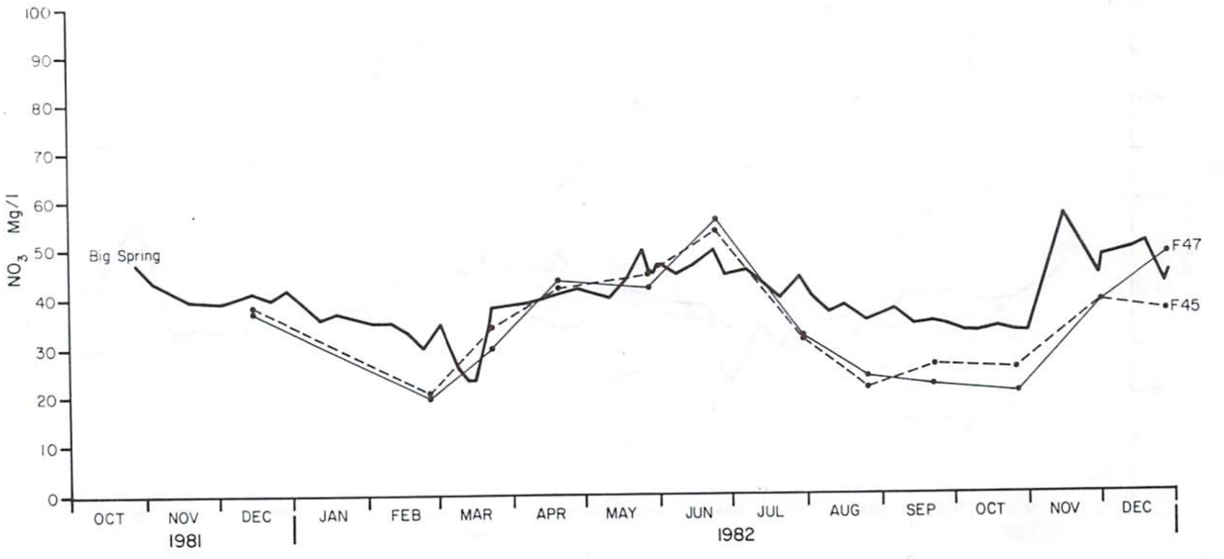


Figure 34. Nitrate concentrations over time for Big Spring and two monitoring stations along Robert's Creek (site 110, F-45 and site 111, F-47).

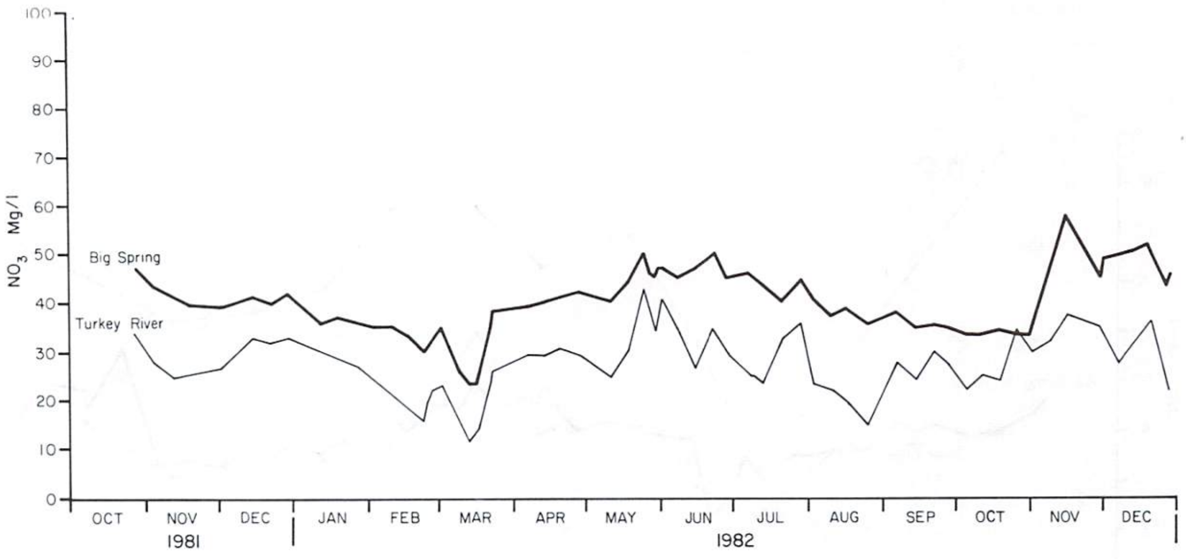


Figure 35. Nitrate concentration over time for Big Spring and the Turkey River.

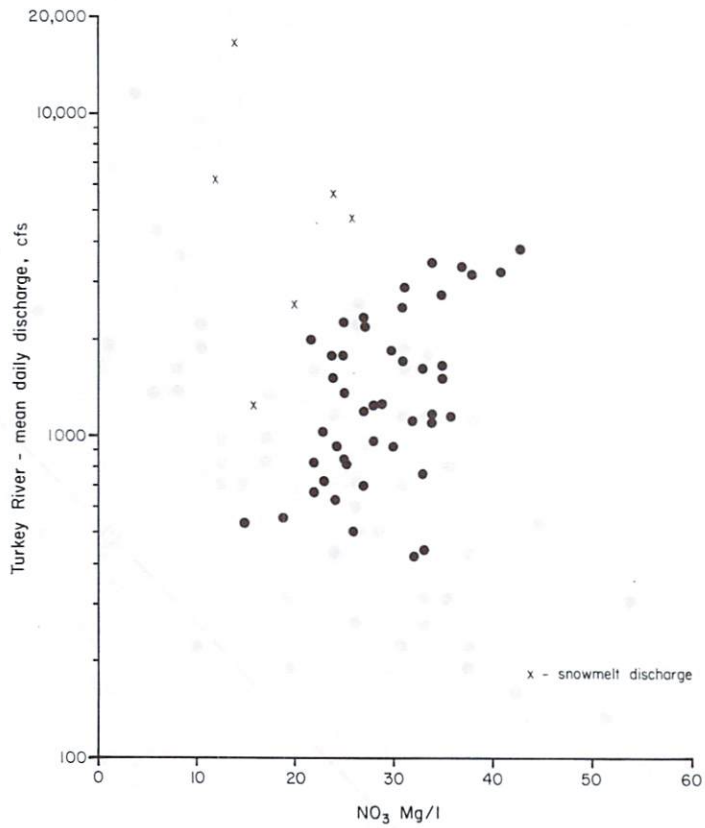


Figure 36. Mean daily discharge versus nitrate concentration for the Turkey River for 1981-82.

The wells with the highest variations occur within the heart of the basin where the karst is best developed. The area of highest variation lies along the axis of the north-south major conduit-zone trough (see figure 9), where fracture and conduit permeability in the aquifer is the highest. The water-quality data fits well with the hydrogeologic assessment of the region.

Nitrate-N Discharge

The monthly mass of nitrate-N discharged with groundwater was tabulated in Table 25. Tables 26 and 27 summarize the water and chemical discharge for the water year, for groundwater discharging to the Turkey River and for total groundwater and surfacewater discharged from the basin, respectively. The total calculated mass of nitrate-N lost from the basin in water has been used to calculate N loss in pounds-per-acre from the basin, under different assumptions: 1) using the total acreage for the basin; 2) using just the acres of row crop in the basin, which is where N-fertilizers have been applied over time; and for perspective 3) using the current acreage for corn in the basin, where N-fertilizers are being actively applied; and 4) using a reduced acreage for corn, assuming no N is applied to corn following meadow in rotation (although this assumption is likely not valid). Also, for perspective, the mass

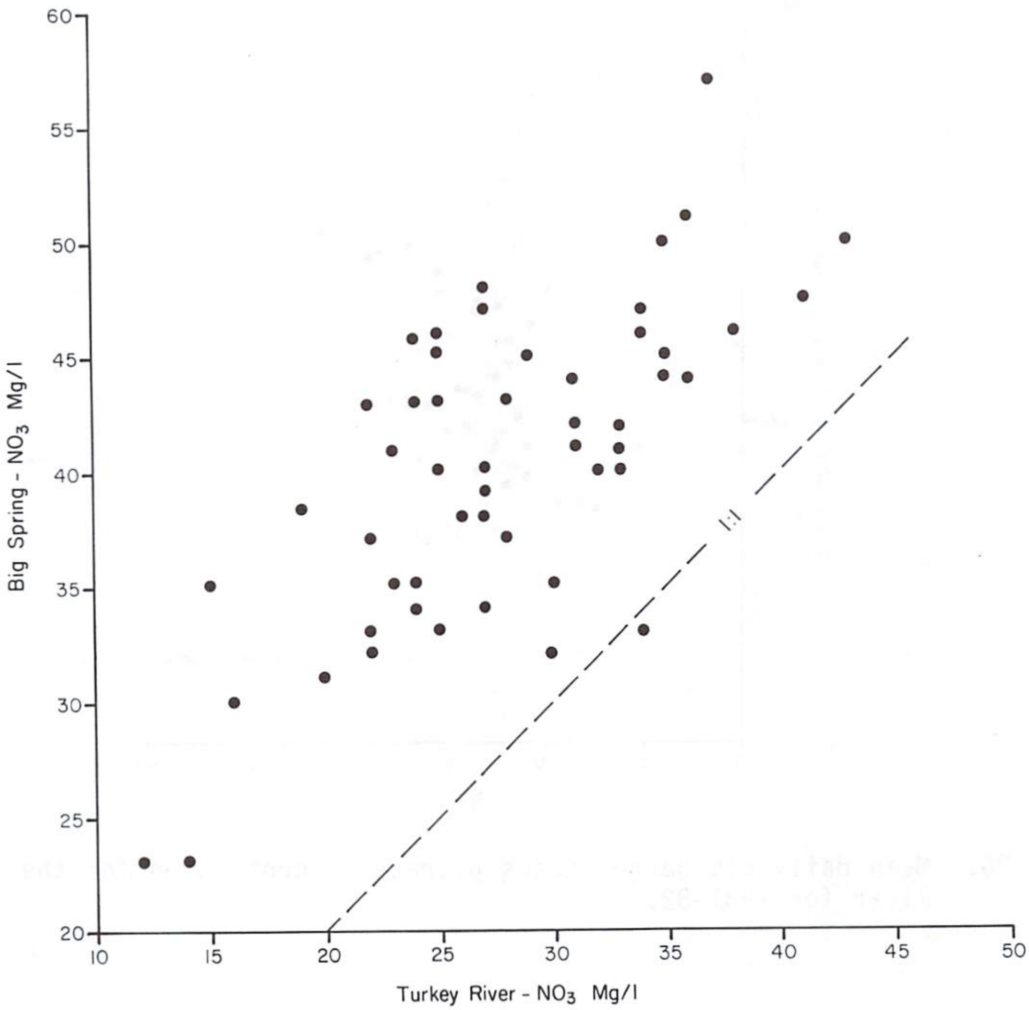
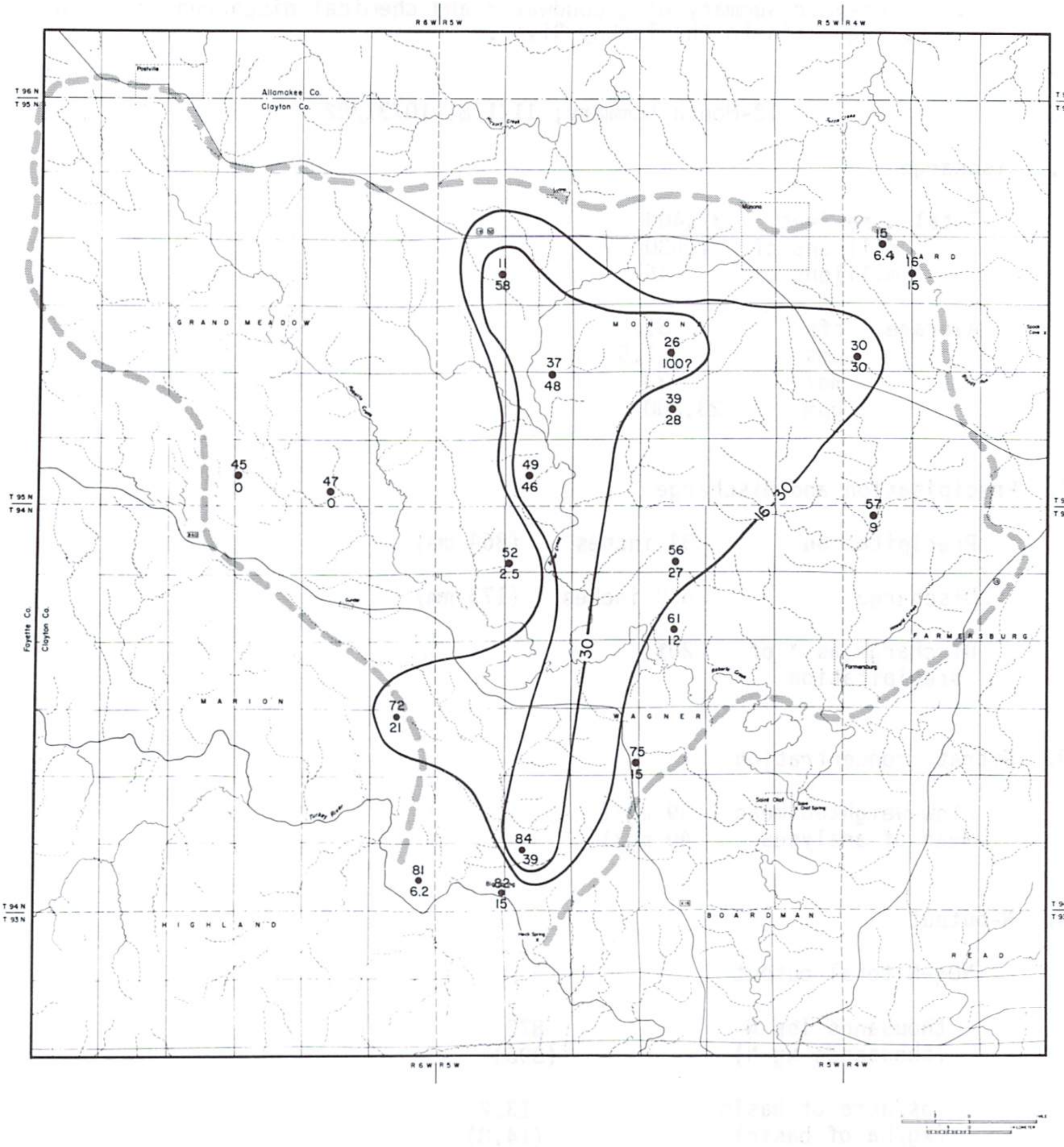


Figure 37. Nitrate concentrations at Big Spring versus nitrate concentration in the Turkey River. The 1:1 line points out that concentrations are nearly always lower in the Turkey River.

of N lost was calculated as a percentage of the chemical N-fertilizer applied in 1982 (estimated from chemical-use survey data and observed land use), and as a percentage of the applied fertilizer plus the estimated N-generated from manure production in the basin.

The total output of N in groundwater discharged to the Turkey River (Table 26) during the water year was 873,000 pounds (396,000 kg). For the total output in groundwater, however, leakage must also be considered. The mass of N lost in leakage was calculated conservatively because much of the estimated leakage occurs where the head difference between the Galena and St. Peter is greatest, which is in the western portion of the basin, under the thick Maquoketa cover. In this region there are very low nitrate concentrations present, or often



81 Site Number
15 Coefficient of Variation Nitrate Data

Figure 38. Coefficient of variation of nitrate analyses from Galena monitoring well and spring-water samples (through July, 1982).

Table 26. Water-year summary of groundwater and chemical discharge from Big Spring basin to the Turkey River.

12-Month Summary; 11/1/81-10/31/82

1. Discharge

Total	acre-feet	37,400
	millions cf	1,630
	millions cm	46

Average -	cfs	51.6
	cms	1.5
	mg/d	33
	gpm	23,200

2. Precipitation and Discharge

Precipitation	34 inches	(864 mm)
Discharge	6.8 inches	(173 mm)
Discharge as % of precipitation	20%	

3. Nitrate concentration

Flow-weighted mean	39 mg/l
Mean of analyses	40 mg/l

4. N-output

NO_3-N total output

thousands lbs N	873
(thousands kg N)	(396)
lbs/acre of basin	13.2
(kg/ha of basin)	(14.8)
lbs/acre-row crop	22.6
(kg/ha-row crop)	(25.3)
lbs/acre-corn	28.2
(kg/ha-corn)	(31.6)
% of applied N (1982)	17%
% of applied and manure N (1982)	(12%)

Table 26, con't.

Assuming no N applied to corn after meadow

lbs/acre-corn	35.7
(kg/ha-corn)	(40.0)
% of applied N (1982)	20%
% of applied and manure N (1982)	(14%)

5. Atrazine output (5/6/82-10/31/82)

Concentration--	
Flow-weighted mean	0.31 µg/l
Mean of analyses	0.52 µg/l
Total Output	
pounds	14.2
(kg)	(6.5)
lbs/acre-corn	5.8×10^{-4}
(kg/ha-corn)	(6.5×10^{-4})
% of applied (1982)	0.04%

they are undetectable. When the estimated N-loss with leakage is added in (Table 27), the total N lost with groundwater is over 1,053,000 pounds (478,000 kg)--nearly 527 tons of nitrogen.

The discharge of N with surfacewater was calculated by multiplying the mean nitrate concentration in surfacewaters (from the monitoring samples) by the volume of surfacewater discharged. The same procedure was compared to the more detailed data from Big Spring. Only the concentrations of the monthly samples at Big Spring (taken at the same time as the surfacewater samples) were averaged, and then multiplied times the total volume discharged. The value calculated in this manner was about 3% higher than the more detailed flow-weighted calculations. Thus, to be conservative, the calculated N lost in surface water was reduced by 5%. The N lost in surfacewater for the water year amounted to 756,000 pounds (343,000 kg) or nearly 378 tons.

The total nitrate-N lost from the basin for the water year is calculated as 1,809,000 pounds (821,000 kg)--about 905 tons of nitrogen. It must again be emphasized that nitrate is only one form (albeit, generally the most abundant) of N being discharged from the basin. Other forms such as organic N, ammonia,

Table 27. Total water and nitrate yield from Big Spring basin for the water-year; 10/31/81-11/1/82.

1. Water Yield	Ac-ft	
A. Groundwater discharge to Turkey River	37,400	
B. Groundwater leakage (to St. Peter)	10,000	
C. Change in groundwater storage	(-10,000)	
Total Groundwater Discharge (1A+1B)	47,400	
D. Streamflow discharge	34,750	
Total Water-Yield	82,150 Ac-ft	
2. Precipitation and Discharge		
A. Precipitation	34 inches (173 mm)	
B. Water Yield, less change in gw storage	13.08 inches (351 mm)	
C. Water yield (as 2B) as % of precipitation	38%	
3. N-output	Thousands Pounds-N (Thousands kg-N)	
A. NO_3-N, gw output to Turkey River	873 (396)	
B. NO_3-N, gw leakage	180 (82)	
NO_3-N output in groundwater	1,053 (478)	
C. NO_3-N, in surfacewater discharge	756 (343)	
Total NO_3-N output	1,809 (821)	

4. N and Landuse	Total	GW	SW
A. lbs-N/acre of basin (kg-N/ha of basin)	27.4 (30.7)	16.0 (17.9)	11.4 (12.8)

Table 27, con't.

B.	lbs-N/acre of row crop	46.7	27.2	19.5
	(kg-N/ha of row crop)	(52.3)	(30.5)	(21.8)
C.	lbs-N/acre-corn	58.4	34.0	24.4
	(kg-N/ha-corn)	(65.4)	(38.1)	(27.3)
D.	% of applied N (1982)	33%	19%	14%
	% of applied and manure N (1982)	(25%)	(15%)	(10%)
E.	Assuming no N applied to corn after meadow			
	lbs-N/acre-corn	74.0	43.1	30.9
	(kg-N/ha-corn)	(82.9)	(48.3)	(34.6)
	% of applied N (1982)	42%	25%	17%
	% of applied and manure N (1982)	(29%)	(17%)	(12%)
5.	N and Landuse-with groundwater discharge adjusted (decreased) for change in storage.			
A.	lbs-N/acre of basin	23.8	12.4	11.4
	(kg-N/ha of basin)	(26.7)	(13.9)	(12.8)
B.	lbs-N/acre of row crop	40.6	21.1	19.5
	(kg-N/ha of row crop)	(45.5)	(23.7)	(21.8)
C.	lbs-N/acre of corn	50.8	26.4	24.4
	(kg-N/ha of corn)	(56.9)	(29.6)	(27.3)
D.	% of applied N (1982)	29%	15%	14%
	% of applied and manure N (1982)	(21%)	(11%)	(10%)
E.	Assuming no N applied to corn after meadow			
	lbs-N/acre-corn	64.3	33.4	30.9
	(kg-N/ha-corn)	(72.1)	(37.5)	(34.6)
	% of applied N (1982)	36%	19%	17%
	% of applied and manure N (1982)	(25%)	(13%)	(12%)

and nitrite are being discharged along with nitrate. These other N-species ions are often in much lower concentrations than nitrate (particularly in groundwater). Data from studies in Iowa by Schuman et al. (1975), and Burwell et al. (1976) suggest that subsurface discharge of nitrate accounted for 84 to 95% of the total soluble N in streamflow. Over the period of a water year, however, these other species would add substantially to the total N lost.

In relation to the land area of the basin, this amounts to a loss of over 27 lbs-N/ac (31 kg-N/ha). This is a minimum figure though because much of the basin is not cultivated. The most valid assumption is to consider the N lost in terms of the land involved in row-crop (almost solely corn in this area) rotations, which have been fertilized over the years. In this case the loss is about 47 lbs-N/ac (52 kg-N/ha). The other figures presented in Table 27 (such as 4D, which assumes total N lost in relationship to actual corn acreage, etc.) present the worst case assumptions. Again, as a matter of perspective only, the amount of N lost from the basin amounts to a mass of N equivalent to 33% of the chemical fertilizer-N applied in 1982.

These figures are not intended to imply that all the N lost during the water year is from 1982 fertilizer-N. Obviously, this is not the case. But over many years the N applied to the land (with associated application losses), natural sources of N, N removal by plants, dentrification, and N loss in water must balance out. Many studies have shown that nitrate will build up in the soil in micropores, and will move intermittently when conditions for leaching are appropriate (Rose et al., 1983; Hubbard and Sheridan, 1983; Baker and Johnson, 1981; Gast et al., 1978).

These figures are also not intended to imply that all the nitrate ions discharged are derived from fertilizer-N. Clearly, the nitrate lost comes from a mix of all the available sources. However, the ultimate cause for the N losses is the use of N-fertilizers, which, in total with other sources of N, puts more N on the land than can be used by the plants. Excess N can then be leached below the rooting zone and eventually into groundwater, particularly in areas of high infiltration, and into surfacewater through shallow groundwater flow, tile drainage, or interflow (shallow sub-soil storm flow). Fertilizer-N application rates of 175 lbs/ac (195 kg/ha), as currently used in the Big Spring basin, are 2 to 6 times higher than natural sources of N (see review in Hallberg and Hoyer, 1982). Even with the relatively large livestock populations in this region, N-fertilization rates are at least 3 to 4 times higher than potential N generated from manure.

Studies from various parts of the midwest and other parts of the world, have documented (or at least been able to strongly imply) that the increase in nitrates in groundwater supplies in rural areas in the past decades is related to increased use of N-fertilizers (Singh and Sekhon, 1978; Piskin, 1974; Saffinga and Keeney, 1977; Smith et al., 1975; Hill, 1982; Nielsen et al., 1982; McDonald and Splinter, 1982; Hallberg and Hoyer, 1982). Other groundwater studies, such as this study, have shown positive correlations between fertilizer usage and shallow groundwater nitrate, and have also shown, just as in this study, that in areas where an aquifer is protected (e.g.--overlain by natural forest cover or permanent pasture) from such surface inputs, or where land has been idle, that nitrate concentrations in groundwater are low or nonexistent (Saffigna and Keeney, 1977; Baker and Johnson, 1977; Hill, 1982).

Several field and model studies in Iowa suggest that, over time, nitrate accumulation in soils, below the rooting zone, or the rate of nitrate leaching from soils in soil and groundwater, is directly proportional to the N-fertilizer application rate (Jolly, 1974; Burwell et al., 1975; Baker and Johnson, 1981; Baker and Austin, 1982). Numerous studies from other areas also show that the amount of nitrate-N leached below the soil rooting zone and into groundwater, tile-drains, or experimental lysimeters, is a direct function of the rate of fertilizer-N applied and the amount of water percolated through the soil (e.g., Baker, 1980; Baker and Johnson, 1977, 1981; Saffinga and Keeney, 1977; Gast et al., 1978, Gerwing et al., 1979; Timmons and Dylla, 1981; Hill, 1982; Herget et al., 1982; Hubbard and Sheridan, 1983).

The Big Spring data from November and December 1982, suggest the kinds of variation that can take place during unusually wet periods (Table 28). The nitrate-N loss, only in groundwater, to the Turkey River during this period was over 259,000 lbs. (117,000 kg). This amounts to 30% of the N lost in groundwater discharge to the Turkey River for the entire previous water year. Substantial fall application of anhydrous ammonia took place in the basin prior to these rains. At this time, it is difficult to evaluate what effect this had on the high nitrate-N losses.

Reported rates of N lost to the subsoil, and to seepage and groundwater, in applicable studies, range from 6 lbs/ac (7 kg/ha) to over 107 lbs/ac (120 kg/ha); the rate, again, dependent on fertilization rate and the amount of percolate water, which is in part, related to soil properties (Meisinger, 1976; Cameron et al., 1978; Saffinga et al., 1977; Baker et al., 1975; Baker and Johnson, 1981; Mielke et al., 1979; Smika et al., 1977; Gast et al., 1978; Bolton et al., 1970; Burwell et al., 1976). Two studies are of particular interest.

Baker and Johnson (1981) report that in north-central Iowa a corn plot receiving 80-90 lbs/ac (90-100 kg/ha) N-fertilizer, every other year, lost an average of 24 lbs-N/ac (27 kg-N/ha) in tile drainage water, whereas a plot receiving 210-220 lbs/ac (240-250 kg/ha) of N-fertilizer lost an average of 43 lbs-N/ac (48 kg-N/ha). Even three years after differential fertilization ceased, the difference in nitrate-N concentrations in the water were apparent. In Minnesota, Gast et al. (1978) measured the nitrate-N losses in tile drainage from plots in continuous corn that received differential N-fertilization ranging from 18 lbs/ac (20 kg/ha) to 400 lbs/ac (448 kg/ha). Average annual losses in tile water ranged from 12 to 54 lbs-N/ac (14-16 kg-N/ha) depending on the fertilization rate. At the end of the study, however, soil sampling showed a substantial build-up of nitrate-N in the 0-10 foot (0-3 m) soil profile for the two highest levels of fertilization. In the 400 lbs/ac (448 kg/ha) plots about 690 lbs NO_3-N/ac (770 kg NO_3-N/ha) had accumulated, and under the 200 lbs/ac (224 kg/ha) plots about 380 lbs NO_3-N/ac (425 kg NO_3-N/ha) had accumulated.

By comparison, the estimated N loss in the Big Spring basin, of 47 lbs NO_3-N/ac (52 kg NO_3-N/ha) for 175 lbs-N/ac (196 kg-N/ha) fertilization rate may seem high. Several things must be considered. First, there is only one year of record from Big Spring. Second, northeast Iowa, because of abundant forest-derived soils and the shallow karst-carbonate aquifers, is a high-infiltration, high water-yield region, which may promote more leaching of soluble ions. Third, but very important, is that these previous studies could

Table 28. Summary statistics of groundwater and chemical discharge from Big Spring basin to the Turkey River for November-December, 1982.

Summary of 11/1/82-12/31/82 data

1. Discharge		
A. Total;	acre-feet	9,002
	millions cf	393
	millions cm	11.1
	% of bi-monthly average (11/1/81-10/31/82)	144%
B. Peak Conduit Flow;	acre-feet	2,153
	millions cf	94
	millions cm	2.7
	% total	24%
	(% total November)	(31%)
	(% total December)	(17%)
C. Base Flow;	acre-feet	6,849
	millions cf	299
	millions cm	8.4
	% total	76%
	(% total November)	(69%)
	(% total December)	(83%)
2. N-Output		
A. Total NO_3-N;	thousand lbs	259
	(thousand kg)	(117)
	% of bi-monthly average	178%
	% of 12-month total	30%
B. Peak Conduit Flow;	thousand lbs	63
	(thousand kg)	(28)
	% total	24%
C. Base Flow;	thousand lbs	196
	(thousand kg)	(89)
	% total	76%
D. N output and landuse		
	lbs-N/acre of basin	3.9
	(kg-N/ha of basin)	(4.4)
	lbs-N/acre-row crop	6.7
	(kg-N/ha-row crop)	(7.5)

Table 28, con't.

lbs-N/acre - corn	8.4
(kg-N/ha - corn)	(9.4)
% of applied N (1982)	5%
% of applied and manure N (1982)	(4%)

Assuming no N applied to corn after meadow

lbs-N/acre-corn	10.6
(kg-N/ha-corn)	(11.9)
% of applied N (1982)	6%
% of applied and manure N (1982)	(4%)

3. Atrazine output

A. Concentration-Total discharge

Flow-weighted mean	0.15 µg/l
Mean of analyses	0.14 µg/l

B. Total output

pounds	3.7
(kg)	(1.7)

C. Peak Conduit Flow

Flow-weighted mean concentration	0.24 µg/l
Total pounds	1.4
(Total kg)	(0.6)
% total	38%

D. Base Flow

Flow-weighted mean concentration	0.12 µg/l
Total pounds	2.3
(Total kg)	(1.1)
% total	62%

not measure the nitrate-N losses to groundwater. They only measured losses in tile drainage, and additionally showed a build-up in the soil profile. The Big Spring monitoring provides detailed control on a major aspect of the hydrologic system--namely groundwater--which is not and often cannot be measured in controlled agricultural experiments. From this perspective, the nitrate-N losses from the Big Spring basin may simply be more completely documented than in other studies.

On this note, it is worthy of mention, that many studies invoke high ranges of "denitrification" and "volatilization" of N-fertilizer to explain unaccounted for N in N-balance studies. These studies generally have not measured leaching losses (e.g.--Rice and Smith, 1982) and sometimes do not even admit its existence. Another problem with many small plot studies, in particular, is that they are conducted over a short (one year) time span. As noted, it may take several years to account for the N applied during a particular year (Rose et al., 1983; Baker and Johnson, 1981). However, various data suggest that in high infiltration regions the groundwater system may respond rapidly (Saffinga and Keeney, 1977).

Regional Nitrate-N Discharge From the Turkey River

Nitrate concentration and discharge were also monitored for the Turkey River. Thus, the mass of nitrate-N discharged for the entire Turkey River basin to Garber (drainage area, 1,545 sq. miles; 2,486 sq. km) can also be calculated. The mass of nitrate-N discharged by the Turkey River was about 18,800,000 lbs. (8,500,000 kg)--nearly 9,400 tons of N.

On an areal basis for this regional basin, this amounts to 19 lbs/ac (21 kg/ha) for the entire basin. In considering losses related to agriculture, this is a minimum value, in many respects, because the Turkey River nitrate discharge includes a high percentage of nitrate-poor runoff and rainfall water, and because the acreage figure includes all the land area. This compares favorably with the 27 lbs/ac (30 kg/ha) calculated using the entire Big Spring land area. Again, this suggests that the results and conclusions from Big Spring are clearly useable on a regional basis in northeast Iowa.

Major Ion Analyses

The Big Spring well network, two surfacewater sites, and a nearby spring were sampled for major ion analyses in late July, 1982. Results of the analyses, along with equilibrium CO_2 pressures and saturation indices for calcite and dolomite, are given in Table 29. CO_2 pressures and saturation indices were calculated using the USGS computer program, WATEQF (Plummer et al., 1976). The concentrations and relative proportions of major ions, and the calculated parameters, are typical of shallow carbonate groundwaters. Calcium, magnesium, and bicarbonate are the dominant dissolved ions, on an equivalent (charge) basis. Calcium and magnesium account for 56-65% and 31-41% respectively, of the cation (positively charged) species. Bicarbonate accounts for 50-97% of the anion (negatively charged) species. The wide range in bicarbonate percentages reflects variable concentrations of other anions: nitrate, chloride, and sulfate. In samples from the western part of the basin (well sites 47 and 45), where a thick cover of Maquoketa shale protects the Galena aquifer from interaction with the land surface, bicarbonate accounts for 95% of the anions, clearly suggesting a surficial source for the other anions.

The relative proportions of cations are less variable and show a general geographic distribution. Molar ratios of Ca/Mg increase from 1.2-1.4 in the southeast part of the basin to over 2.0 in the northwest. This may reflect a lithologic change that occurs within the Galena aquifer. The Galena varies from primarily dolomite south and east of the basin to primarily limestone towards the north and west (Witzke, 1983). Limestones are composed mainly of calcium carbonate (calcite), while dolomite is a calcium-magnesium carbonate. Dissolution of limestone releases greater amounts of calcium than magnesium into the groundwater. The increased amount of limestone present in the northwest part of the basin may cause the higher Ca/Mg ratios observed there.

Total dissolved solids concentrations in the network-well samples range from 250-850 mg/l, and average about 480 mg/l. Dissolved-solids levels significantly greater than 500 mg/l are caused mainly by increased nitrate, chloride, and sulfate concentrations.

Calculated saturation indices indicate that, under midsummer conditions, groundwater within the basin is generally undersaturated with respect to calcite and dolomite, and therefore is capable of dissolving these minerals. Dolomite saturation varies from 3 to 90%, and calcite saturation from 24 to 118%.

Calculated pCO_2 values (partial pressure of dissolved CO_2 gas) vary between $10^{-1.63}$ and $10^{-1.09}$ atmospheres, 70 to 250 times greater than atmospheric CO_2 levels. These values are typical for groundwater, which obtains elevated CO_2 levels from decaying organic matter during infiltration through shallow soil horizons.

The concentration of chloride, and to a lesser extent sulfate, in the network samples, shows a strong relationship to nitrate levels. The lowest measured concentrations of chloride and sulfate occurred in well sites 47 and 45, located in the western part of the basin where a thick cover of Maquoketa is present, and nitrate levels are consistently less than 5 mg/l. Increased levels of nitrate within the rest of the basin are generally associated with increased chloride and sulfate (figures 39 and 40). While shallow carbonate aquifers often contain natural sources of sulfate, natural chloride sources in such aquifers are rare. Chloride concentrations in excess of a few milligrams per liter are usually caused by surficial inputs, such as leaky sewer/septic systems, salting of roads, and the application of potassium chloride (KCl) fertilizers. The occurrence of corresponding nitrate and chloride concentrations indicates a common source, and the basin-wide occurrence of elevated nitrate-chloride levels suggests that N and KCl fertilizers act as this source.

Table 29. Chemical analyses of Big Spring basin groundwaters and surfacewaters, 7/28/82.[1]

Site	Field Temp.	Ca^{++}	Mg^{++}	Na^{+}	K^{++}	Mn^{+}	Fe	HCO_3^-	$SO_4^=$	Cl^-	NO_3^-	F^-	pH
57	12°	96	36	6	0.3	ND[2]	0.04	351	32	24	43	0.1	6.95
72	11°	110	38	4.4	ND	ND	0.02	378	41	32	40	0.2	6.9
49	11°	93	30	7.0	0.6	0.03	0.02	332	49	22	18	0.3	7.05
83	11°	92	35	7.1	2.8	0.01	0.05	370	26	16	27	0.2	6.85
61	11°	150	74	25	2.2	0.05	4.3	532	70	82	98	0.2	6.95
26	10°	100	44	4.2	0.9	0.01	1.4	414	80	10	10	0.3	7.1
78	15°	91	38	5.9	2.0	0.05	0.39	353	28	18	38	0.2	7.1
16	10°	81	35	7.2	0.8	0.03	2.9	344	44	12	20	0.2	7.15
30	10°	83	37	4.3	ND	ND	0.5	403	15	4	23	0.2	7.0
11	11°	94	33	5.2	0.9	ND	0.02	349	46	14	17	0.2	6.9
45	11°	100	29	6.2	3.5	0.01	7.4	436	8.4	1	2	0.4	6.8
47	11°	82	26	3.8	1.3	0.06	4.5	394	12	0.5	2.1	0.3	6.85
75	14°	130	50	10	0.9	ND	0.05	414	47	46	100	0.2	6.9
56	12°	91	38	8.1	0.3	ND	0.02	364	42	12	37	0.2	7.1
52	10.5°	93	33	6.2	0.4	ND	ND	328	40	16	58	0.2	6.95
15	10.5°	130	54	14	0.1	ND	ND	328	55	74	140	0.2	6.5
82	11.5°	88	34	9.4	2.6	ND	0.05	362	26	20	39	0.2	6.95
39	12°	140	61	19	1.5	0.01	0.03	392	64	99	120	0.2	6.9
81	9°	61	18	3.2	0.8	ND	0.27	222	16	6	34	0.2	7.0
37	10°	120	41	16	1	0.01	1.6	368	48	54	62	0.3	6.8
84	10°	96	37	8.6	2.9	0.23	2.7	323	32	19	34	0.2	----
Surfacewater Sites													
111	24.5°	80	32	7.4	5.0	0.17	0.17	318	23	22	30	0.2	7.75
114	22°	80	33	11	4.9	0.25	1.2	327	29	26	33	0.2	7.7

[1]All analyses expressed as milligrams per liter except: Temperature - degrees centigrade; pH - standard units

[2]ND indicates not detected

Table 29, con't.

Site	SiO_2	Hardness	Alkalinity	TDS	Lab Conductivity	Field Conductivity	Log pCO_2	SIC	SID
57	17	388	288	446	770	755	-1.50	.61	.19
72	28	431	310	499	830	855	-1.42	.63	.18
49	20	356	272	412	720	705	-1.63	.68	.20
83	16	374	303	397	720	750	-1.38	.48	.11
61	18	687	436	833	1300	1350	-1.34	1.18	.90
26	18	441	339	489	830	830	-1.59	.92	.48
78	17	384	289	413	720	720	-1.63	.91	.52
16	16	352	282	423	700	700	-1.72	.75	.31
30	22	360	330	360	690	700	-1.50	.65	.23
11	15	370	286	399	720	705	-1.46	.51	.12
45	17	382	357	374	680	680	-1.26	.55	.11
47	19	320	323	323	600	590	-1.35	.47	.09
75	21	530	339	624	1000	1010	-1.38	.85	.41
56	18	384	298	434	750	750	-1.63	.84	.40
52	19	368	433	433	740	745	-1.53	.53	.13
15	23	557	259	742	1100	1200	-1.09	.24	.03
82	17	360	297	405	740	670	-1.49	.57	.17
39	17	600	321	808	720(?)	1200	-1.40	.78	.37
81	16	227	182	249	450	560	-1.75	.28	.03
37	22	471	302	550	970	980	-1.34	.50	.11
84	22	397	302	508	740	710	-----	---	---
Surface Water Sites									
111	17	333	261	425	670	650	-2.28	4.43	15.2
114	19	338	268	460	690	670	-2.23	3.71	10.4

Log pCO_2 - Atmospheres
SIC, SID - Dimensionless
Lab - Field conductivity μmhos/cm[2]

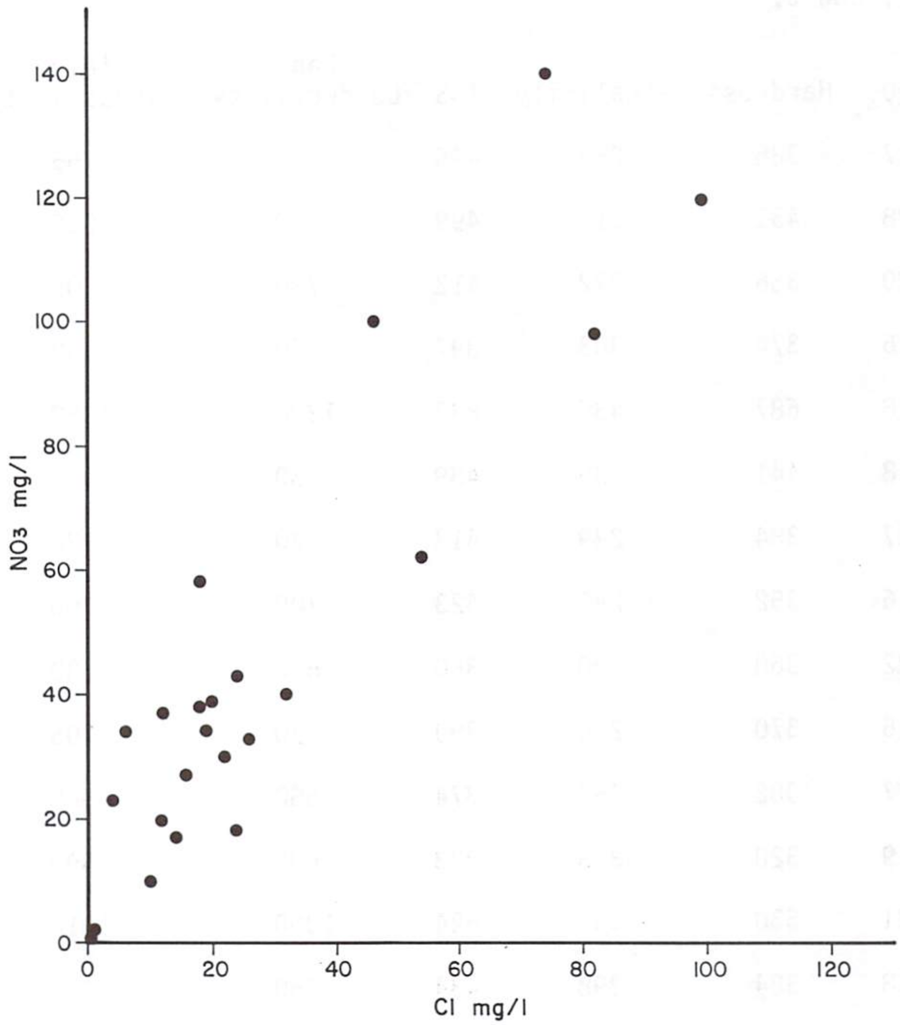


Figure 39. Nitrate and chloride concentrations for Galena aquifer groundwater samples in the Big Spring basin.

Fertilizers have been suggested as the source of elevated nitrate and chloride concentrations in shallow groundwaters in agricultural areas in Wisconsin (Saffigna and Keeney, 1977), and correlated with N and KCl applications in Ontario (Hill, 1982). In both areas, roughly equivalent amounts of N and KCl were applied annually to fields. Weight ratios of Cl/NO_3-N in underlying shallow groundwaters, were generally greater than one, and varied between 0.8 and 3.5. The relatively small variation in Cl/NO_3-N ratios over a wide range of chloride and nitrate concentrations, implies a common source for these constituents. The values of these ratios were considered consistent with the suggested fertilizer sources, as dentrification and plant uptake of N greatly exceeds plant uptake of chloride, leaving an excess of chloride available for leaching, thus causing Cl/NO_3-N to be greater than one.

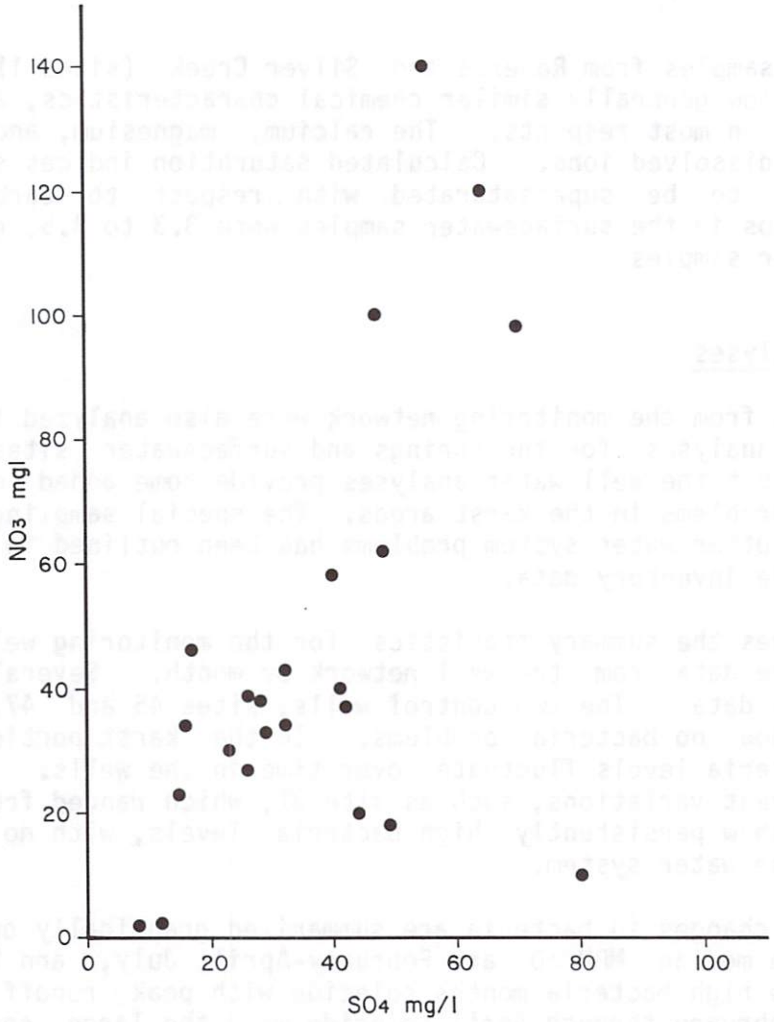


Figure 40. Nitrate and sulfate concentrations for Galena aquifer groundwater samples in the Big Spring basin.

Cl/NO_3-N ratios from the Big Spring network samples varied from 0.8 to 5.5, with a mean of 2.7. Seventy-five percent of the ratios were between 1.2 and 3.9. These values are generally in agreement with those from Saffigna and Keeney (1977) and Hill (1982), and also suggest a fertilizer source for these constituents. The somewhat wider range of ratios in the Big Spring area, relative to the Wisconsin and Ontario studies, is caused by differences in agricultural practices. The Wisconsin and Ontario areas are cropped with potatoes, are heavily fertilized with annual applications of both N and KCl, and experience large leaching losses. Additionally, the Wisconsin area is irrigated in late summer months, thereby increasing potential leaching losses. By contrast, the fields in the Big Spring area are not irrigated, are cropped with corn, and do not receive KCl annually. Further, when KCl is applied, a wide range of application rates may be used. The less consistent KCl applications would cause a wider range of Cl/NO_3-N ratios.

Surfacewater samples from Roberts and Silver Creek (sites 111, and 114, respectively) show generally similar chemical characteristics, and resemble area groundwaters in most respects. The calcium, magnesium, and bicarbonate are the dominant dissolved ions. Calculated saturation indices show the surfacewater samples to be supersaturated with respect to carbonate minerals. Cl/NO_3-N ratios in the surfacewater samples were 3.3 to 3.5, generally similar to groundwater samples.

Bacterial Analyses

Water samples from the monitoring network were also analyzed for coliform bacteria. The analyses for the springs and surfacewater sites are meaningless (always 16+) but the well water analyses provide some added insights into the groundwater problems in the karst areas. The special sampling work to isolate cisterns and other water system problems has been outlined in a previous section, with the inventory data.

Table 30 gives the summary statistics for the monitoring wells and Table 31 summarizes the data from the well network by month. Several things are apparent in the data. The two control wells, sites 45 and 47, under the thick Maquoketa, show no bacteria problems. In the karst portion of the basin, coliform-bacteria levels fluctuate over time in the wells. Over time, some wells show great variations, such as site 81, which ranged from 0 to 16+ MPN. Some wells show persistently high bacteria levels, with no obvious reasons related to the water system.

The temporal changes in bacteria are summarized graphically on figure 41. The months with a median MPN >0 are February-April, July, and November-December 1982. These high bacteria months coincide with peak runoff and conduit-flow periods. February through April coincide with the large conduit flows associated with spring snowmelt and rainfall. The November and December periods coincide with the unusual rainfall-runoff events which occurred at this time. Although July was generally a month of base-flow recession, the sampling coincided with the runoff, conduit-flow event at the end of July (see figure 28). It is during these periods that the variable wells (such as site 81) showed their peak MPN values.

It is also interesting to note how the peak bacterial problems and peak nitrate problems can be out of phase. With spring snowmelt runoff (March, in particular) nitrate concentrations decreased while bacterial counts increased, markedly in some instances. In the discussion of the inventory data (p. 66) a well problem was noted where, 7 days after shock-chlorination, bacteria counts in the well water rose back to 16+, related to snowmelt runoff. This occurred at site 75, and is typical of the type of bacterial problems affecting this karst aquifer.

Figure 42 contours the maximum MPN value recorded from the wells during the monitoring period. As with the coefficient of variation of nitrate, the maximum MPN region occurs coincident with the karst portions of the basin, where wells are likely open to portions of the conduit-flow system.

Table 30. Summary statistics of MPN bacteria data for monthly-monitoring wells.

Site No.	(Well No.)	Median	Q_1	Q_3
11.	VD-24	0	0	0
15.	B-18	2.2	0	5.1
16.	B-32	0	0	0
26.	VD-12	0	0	0
30.	B-27	5.1	0	9.2
37.	VD-18	2.2	0	2.2
39.	L-7	0	0	5.1
45.	PAT-20	0	0	0
47.	PAT-18	0	0	0
49.	F-51	0	0	2.2
52.	F-8	0	0	0
56.	F-33	2.2	0	5.1
57.	T-17	16	5.1	16+
61.	L-42	5.1	2.2	16
72.	GL-1	2.2	0	5.1
75.	GL-8	5.1	0	16+
81.	AB-6	0	0	16+
84.	AB-3	16+	16+	16+

The wells which show persistently high bacteria counts are wells which, from most lines of evidence, are likely open to large conduits. Site 84, in particular, recorded dye in the well water during the dye traces to Big Spring. This well shows high turbidity, and its water chemistry is always similar to the Big Spring.

Table 31. Summary of MPN coliform bacteria data for network wells by month.

Month	Median	Q_1	Q_3
1981			
Nov.-Dec.	0	0	2.2
1982			
Jan.	0	0	5.1
Feb.	2.2	0	9.2
March	2.2	0	16+
April	2.2	0	5.1
May	0	0	5.1
June	0	0	9.2
July	2.2	0	5.1
Aug.	0	0	9.2
Sept.	0	0	5.1
Oct.	0	0	5.1
Nov.	5.1	0	16+
Dec.	2.2	0	16+

The UHL also did some special analytical work to compare broth and agar membrane filter methods of bacterial analysis with the MPN methods. The results are complex and many of the samples with high MPN values (>5.1) were too numerous to count by these other methods. One interesting note, however, was that two of these open, high-bacteria wells also showed copious growths of non-coliform organisms.

As documented in this report, many bacteria problems are associated with local water-system problems. The data presented here, however, outlines bacteria problems which are related to the nature of the aquifer itself.

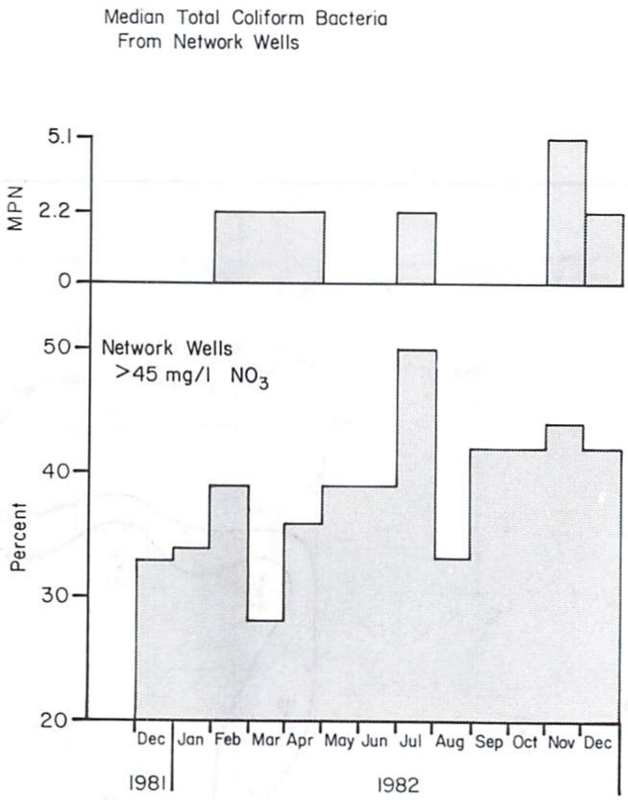


Figure 41. Monthly summary of median coliform-bacteria MPN, and percent of nitrate analyses over 45 mg/l for monthly-monitoring wells in the Big Spring basin.

Turbidity, pH, and Conductivity Analyses

Turbidity, pH, and conductivity was also measured on the monthly monitoring samples. The NTU turbidity data shows a wide variation (Appendix 2), and is complex to interpret. The background wells (sites 45 and 47), under the thick Maquoketa, show persistent, moderate values for NTU turbidity. These values are likely related to the higher iron content in the water from these wells, compared to the wells in the karst portion of the basin (Table 29). The high iron interferes with the NTU, light-transmission readings.

For the remaining wells in the karst portion of the basin, the turbidity shows patterns similar to the other data. The wells with the most persistent and highest turbidity, are the wells which are open to large conduits and show persistent, and generally high, bacteria counts. Well-site 84, again, consistently shows the highest turbidity. (The sample submitted for major ion analyses was noted, by UHL, to have a strong-colored sediment in the water samples).

The greatest variation in turbidity occurred, again, in the wells in the midst of the karst terrain, particularly in those associated with the north-south conduit zone. The highest values of turbidity in the wells occurred in March,

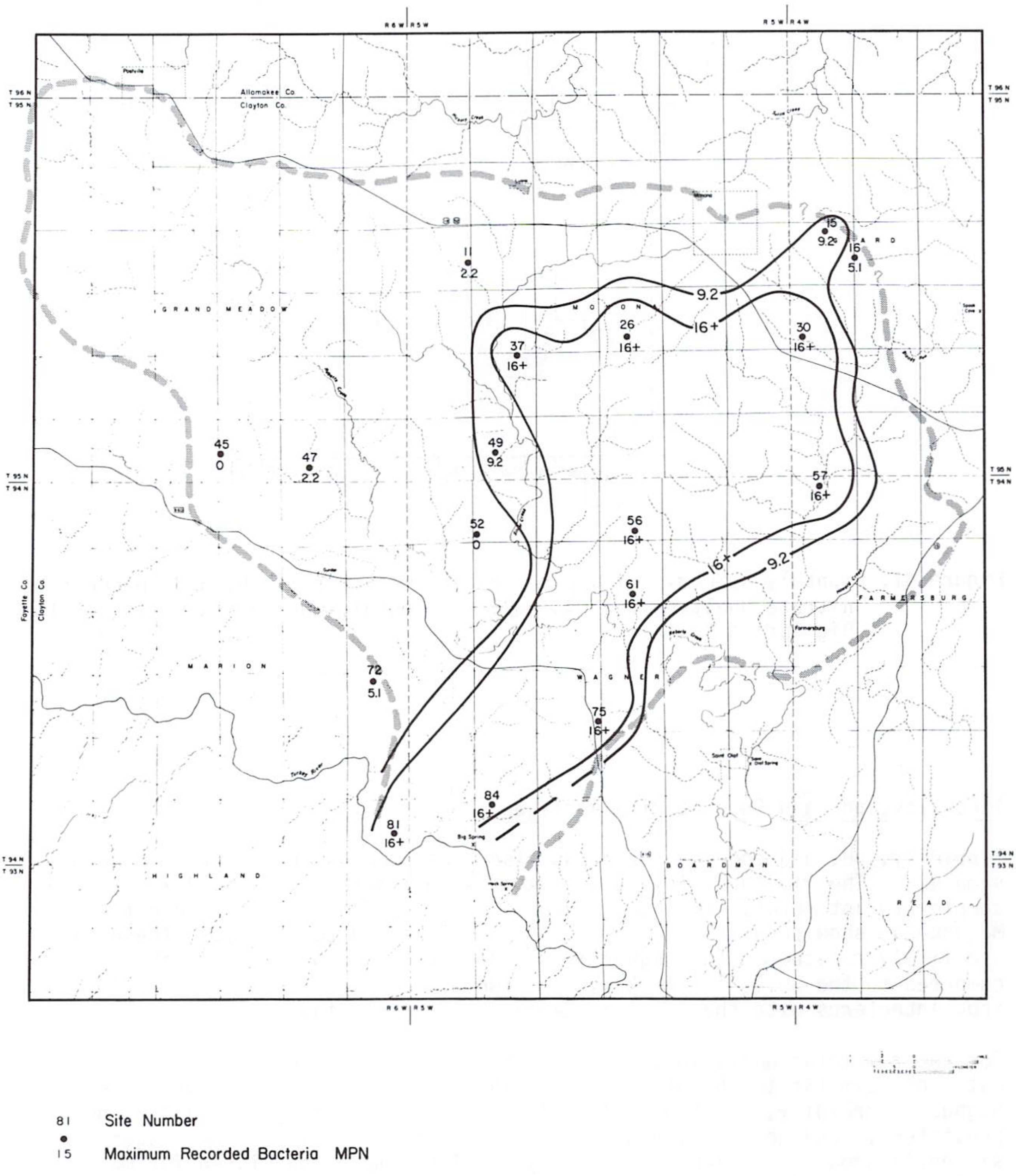


Figure 42. Map of maximum MPN coliform bacteria recorded in 1981-82 from monitoring-well network.

July, November, and December, 1982, coincident with the high runoff, conduit-flow periods, and high bacteria counts.

No direct quantitative relationship could be found between particular NTU analyses, and bacteria, conductivity, pH, nitrate, or pesticide analyses on the same samples. However, pesticides attached to the particulates contributing to turbidity is an item of concern. This will be discussed in a later section.

Hydrogen ion activity, or pH, showed little significant variation in the monitoring samples. All the pH data show the waters in the basin to be near neutral to slightly alkaline. Tile-line waters ranged in pH from 6.8 to 7.3 with a mean of 7.0, while surfacewaters in the basin ranged from 7.3 to 8.5, with a mean of about 7.6. Well waters ranged from pH 6.9 to 8.1 with a mean of 7.3. Big Spring showed a very narrow range of pH, from 7.1 to 7.5, with a mean of 7.3. The Turkey River showed the largest range in pH, varying from 7.1 to 8.8, with a mean of 7.8.

Specific conductance values (in micromhos/cm) are proportional to the total dissolved solids (TDS) in the water samples. Conductivity values from the well-water samples ranged from 475 to 1350; the highest values being associated with the wells with the highest nitrate and TDS levels (including Cl and SO_4). The mean for the wells was approximately 720.

The background wells (sites 45 and 47) under the Maquoketa shale showed a narrow range, on the low side of the well values, and ranged from 585 to 700, with means of 600 and 670. The well at site 81 shows very low values also, ranging from 450 to 560. This well is completed near the very base of the Galena aquifer and may receive substantial portions of its groundwater from the projected region of the Galena, under the Maquoketa shale.

Tile-line conductivities ranged from 590 to 675, with a mean of 610. Surfacewaters in the basin ranged from 420 to 720 with a mean of about 640. The Turkey River exhibited much lower conductivities, ranging from 275 to 600, and a mean of 530.

Over the period of time that specific conductance was measured (since May, 1982), the conductivity at Big Spring has only ranged from 600 to 780, with a mean of 700. Some of the lower readings occurred during runoff, conduit-flow periods, but in general the values at the spring varied from 640 to about 740 with no apparent pattern.

The coefficient-of-variation of the conductivity shows a pattern similar to the variation in nitrate and bacteria. The highest variations are shown in the midst of the karst area of the basin, particularly aligned along the conduit-zone regions (see figures 38 and 89).

Pesticide Monitoring

Water samples were collected for pesticide analysis at varying time intervals from Big Spring, the monitoring well network, various surfacewater sites, tile lines, and a number of other miscellaneous sites. Additionally, a number of sediment samples were collected from Big Spring and analyzed for soil-attached pesticides or pesticide derivatives. Most of the commonly-used pesticides and chlorinated-hydrocarbon compounds are identified by these analyses. A short description of the chemistry, solubility, toxicity, and other characteristics of the pesticides detected during the study are given in Appendix 4.

Figure 29 shows a plot of pesticide concentrations in Big Spring water through time. Table 32 shows sample dates and concentrations at Big Spring. Samples were collected at roughly one-month intervals during the first six months of the study (November 1981-April 1982). Pesticides were not detected during this period, which correlates with winter base-flow and spring-snowmelt conditions. Atrazine was first detected in Big Spring samples in early May, 1-2 weeks after chemicals were applied to fields within the basin. Through May and June, months characterized by rains that produced runoff and infiltration, atrazine, Bladex, and Lasso were present in the water at the spring. Atrazine concentrations ranged from 0.2 to 2.5 µg/l, and were usually greater than 0.50 µg/l. Bladex and Lasso levels through this period did not exceed 0.2 µg/l. During the late summer-fall base-flow recession, when little or no groundwater recharge occurred, Bladex and Lasso concentrations fell below detection limits. However, atrazine was present throughout the remainder of the year, at concentrations that slowly decreased to about 0.1 µg/l. The intense rains that occurred in November-December 1982 caused only slight increases in atrazine levels, although samples were not collected at peak flows. The presence of atrazine, months after Bladex and Lasso concentrations fell below detectable limits is an indicator of both the relatively greater use and greater stability of atrazine.

Sediment carried in the groundwater discharging at Big Spring was analyzed for attached pesticides on several occasions. Atrazine and Dieldrin were present on sediment at various times, at concentrations as high as 5.1 and 8.1 µg/l, respectively. Results and dates of all water and sediment pesticide analyses from Big Spring are given on Table 32.

Network Wells

Table 33 summarizes results of pesticide analyses from the network wells. Atrazine was first detected in well waters in late May-early June samples. Thirteen of eighteen samples contained detectable amounts of atrazine. The highest atrazine concentration detected, 0.45 µg/l, was from site 49, with the other well waters having 0.05-0.25 µg/l atrazine. The only other pesticide detected in the well samples was Bladex at site 84, which dye tracing has shown to be in direct connection with the major conduit system associated with Big Spring. Subsequent samples from the well network generally indicated decreasing atrazine levels, with most sites falling below detection limits. Atrazine was present in all samples from wells 49 and 84, however.

Figure 43 shows the geographic distribution of atrazine concentrations from samples collected in early June (6/7/82). No atrazine was detected at sites 45 and 47 (PAT-20 and PAT-18, respectively) which are located beneath a thick cover of the Maquoketa shale, or in several wells lying along the groundwater

Table 32. Results of UHL analyses for pesticides in water and sediments from Big Spring.

Date	Analysis µg/l (ppb)		
10/27/81	N.D. in water, or sediments in raceway.		
11/10/81	N.D. in water, or sediments in raceway.		
12/15/81	N.D. in water.		
2/25/82	N.D. in water (or any wells or surface water).		
3/22/82	N.D. in water; 0.65 Dieldrin in sediments collected from spring.		
	Atrazine	Bladex	Lasso
5/12/82	0.18		
5/18/82	0.44		0.15
5/27/82	0.8	0.2	
5/28/82	2.5	0.15	
6/1/82	0.4	0.07	
6/8/82	0.26		
6/15/82	0.45	0.08	0.08
6/23/82	0.70	0.09	0.05
6/29/82	0.75	0.07	
7/6/82	0.49		
7/7/82	0.49		
7/8/82	0.45		
7/13/82	0.31		
7/21/82	0.63		
7/28/82	0.62		

Table 32, con't.

8/3/82	0.55
8/25/82	0.26
9/7/82	0.30
9/22/82	0.28 (sediment-8.0 Dieldrin)
10/5/82	0.19
10/12/82	0.20
10/26/82	0.18
11/3/82	0.10 (sediment-3.6 Dieldrin; 5.1 Atrazine)
11/16/82	0.19
11/30/82	0.11 (sediment-1.1 Dieldrin; 5.0 Atrazine)
12/7/82	0.22
12/14/82	0.17
12/21/82	0.16
12/28/82	0.12
12/29/82	0.11

basin divide. The highest atrazine concentrations occur near the major conduit zones leading to Big Spring (see figures 19 and 20), reflecting the relatively open connection between these zones and the land surface.

By 7/28/82, atrazine levels in the network wells had decreased, and many well samples declined below detection limits (figure 44). However, along the major conduit zones, atrazine still persisted, generally at concentrations above 0.1 µg/l. The persistence of atrazine along these zones, during a period when little or no recharge occurred, may be caused by two factors. First, the open connection of these zones to the surface, through fractures and sinkholes, probably allows for significant leakage from streams and the shallow groundwater/tile drainage system. Second, groundwater flow within the Galena aquifer is towards these zones, and may cause the movement of atrazine-bearing water toward wells located near the major conduits.

One sample from well 83 (JSW) and from well 81 (AB-6), contained about 0.1 µg/l of atrazine. These wells are completed near the very base of the Galena aquifer, and the presence of atrazine in these wells indicates that surficial contaminants may be present through the entire saturated thickness of the aquifer.

Surface Water

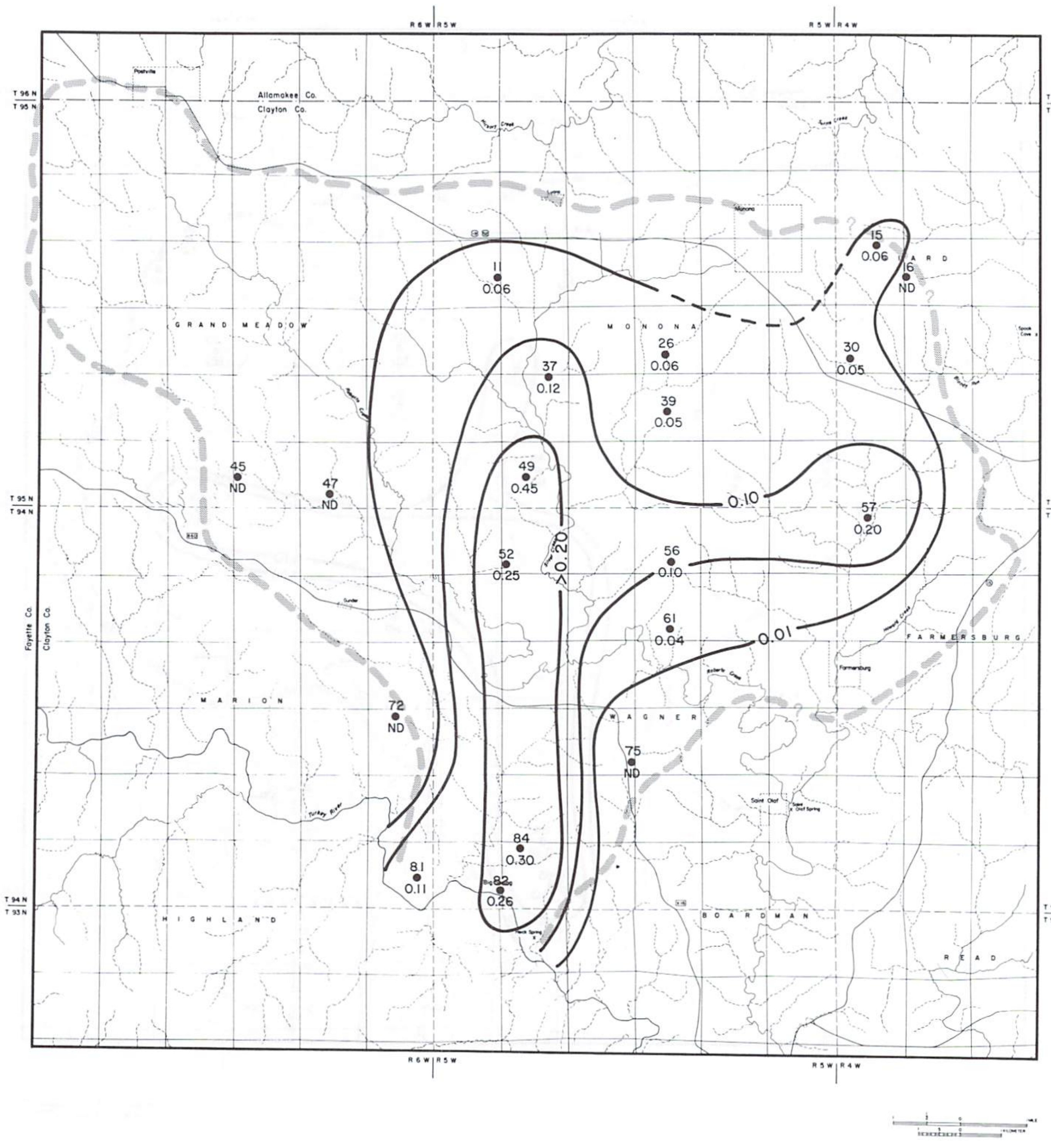
Pesticide concentrations were monitored in perennial streams at the Turkey River (TR, site 113), at two sites along Roberts Creek (F-45, site 110; F-47, site 111), and one site along Silver Creek (L-23, site 111). Results of the analyses are listed in Table 34. No pesticides were detected in February samples collected during an early snowmelt event. The extremely cold conditions that occurred during the months preceding this snowmelt resulted in a deep frost; this, in combination with an incomplete melting of the snowpack, likely limited the interaction of meltwaters with the soil zone. Pesticides were detected in the next surface-water samples collected in late May and early June, and included atrazine, Lasso, Bladex, Dual, and the insecticide Dyfonate. The June 7-8 samples contained the highest levels and greatest variety of pesticides, with total pesticide concentrations of about 60 µg/l in the Turkey River and 30 µg/l at Roberts Creek (site 110, F-45). As with the samples from Big Spring and the network wells, atrazine was the pesticide present in the highest concentrations. Subsequent sampling showed considerably lower levels of pesticides. At site 111 (F-47) on Roberts Creek, monthly analyses through late summer/fall indicated decreasing levels of all pesticides, with only atrazine present in detectable amounts during the last four months of 1982. As little runoff occurred during the period July-October, the presence of pesticides in Roberts Creek indicates that pesticides are also present in the shallow groundwater system supplying base flow to the stream.

Runoff Samples

During runoff periods, surface runoff and surfacewaters in small streams which drain to sinkholes were also sampled. These are surfacewaters from much smaller drainage basins and thus more closely related to the source of the pesticides. Consequently, concentrations of pesticides are higher (Table

Table 33. Pesticide concentrations in groundwater samples from Big Spring study wells. All values in μg/l (micrograms per liter). Values are for atrazine unless noted as follows: B-Bladex; L-Lasso. Big Spring data given for comparison.

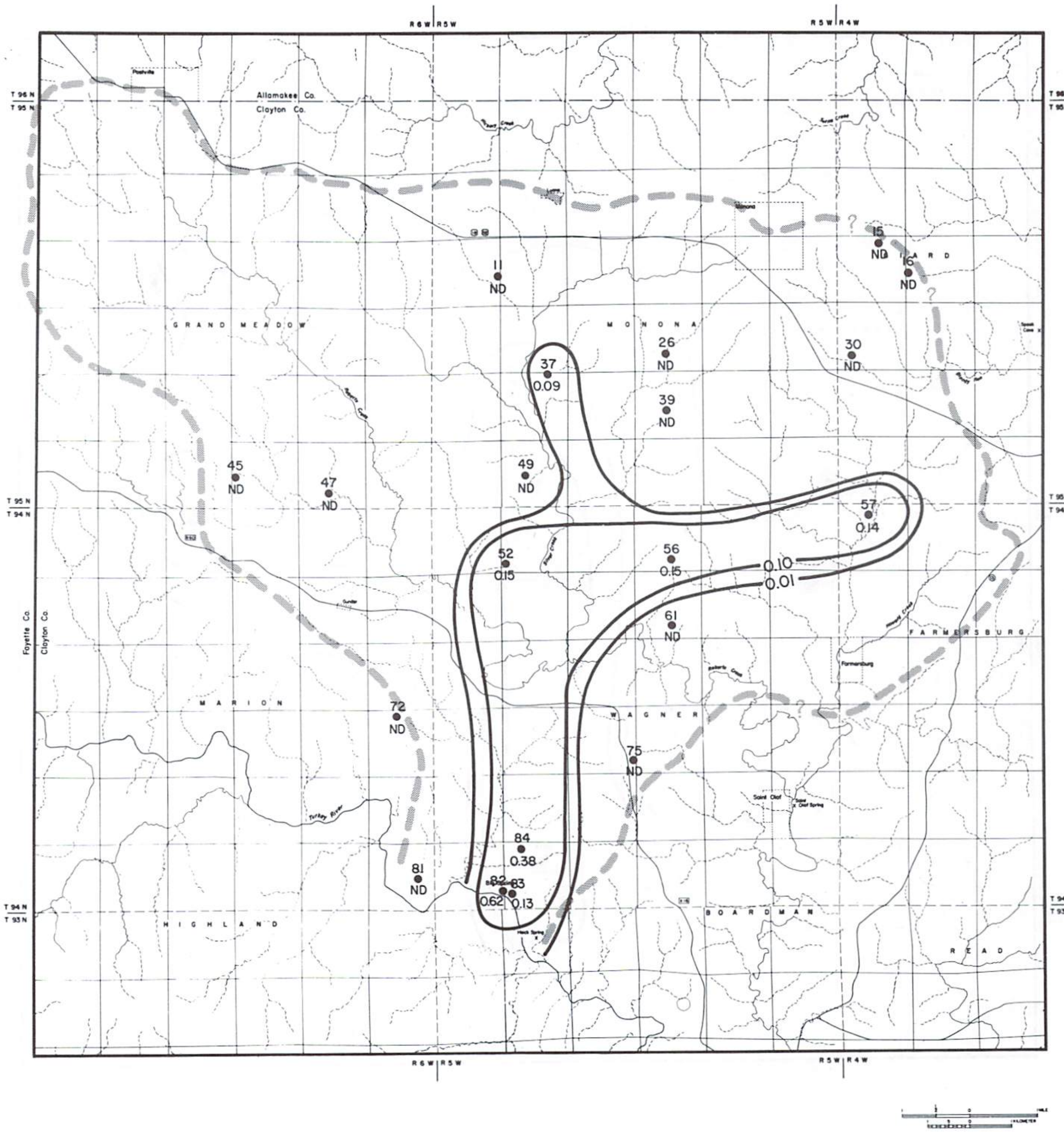
Site No.	2/24-25/82	5/27/82	Date of Sampling 6/7-8/82	6/22-23/82	7/28/82	11/30/82
11. VD-24			0.06		N.D.	
15. B-18	N.D.		0.06	0.10	N.D.	
16. B-32			N.D.		N.D.	
26. VD-12			0.06		N.D.	
30. B-27			0.05		N.D.	
37. VD-18	N.D.		0.12	0.10	0.09	
39. L-7			0.05		N.D.	
45. PAT-20			N.D.		N.D.	
47. PAT-18	N.D.		N.D.	N.D.	N.D.	N.D.
49. F-51			0.45		N.D.	0.16
52. F-8			0.25		0.15	0.13
56. F-33			0.10		0.15	
57. T-17			0.20		0.14	
61. L-42	N.D.		0.04	N.D.	N.D.	
72. GL-1		N.D.	N.D.		N.D.	
75. GL-8	N.D.	N.D.		N.D.	N.D.	
81. AB-6			0.11		N.D.	
82. Big Spring	N.D.	0.8 0.2B	0.26	0.7 0.09B 0.05L	0.62	0.11
83. JSW					0.13	N.D.
84. AB-3	N.D.	0.3 0.2B		0.64 0.11B	0.38	



81 Site Number

0.11 Atrazine in µg/l

Figure 43. Atrazine concentration (µg/l) in groundwater from monitoring-well network in Big Spring basin, June 7, 1982.



84 Site Number

0.38 Atrazine in µg/l

Figure 44. Atrazine concentration (µg/l) in groundwater, from monitoring-well network in Big Spring basin, July 28, 1982.

Table 34. Pesticide concentrations in surfacewater samples from Big Spring study; all values in µg/l (micrograms per liter). A-atrazine; B-Bladex; L-Lasso; D-Dual; F-Dyfonate.

Site No.	Date of Sampling 2/24-25/82	5/26-27/82	6/7-8/82	6/22-23/82	7/28/82	8/25/82	9/21/82	10/26/82	12/29/82
113 (TR)	N.D.	3.30A	37.00A	1.30A					
		0.15B	5.00B	0.10B					
		0.40L	20.00L	0.17L					
			1.60D	0.10D					
			0.36F						
110 (F-45)	N.D.		17.00A	1.50A					
			2.60B	0.41B					
			3.00L	0.12L					
			6.00D	0.05D					
			0.09F						
110 (F-47)	N.D.		4.50A		2.50A	2.50A	0.35A	0.31A	0.30A
			1.30B		0.39B	0.65B			
			1.50L		0.06L	0.31L			
			0.70D		0.25D				
109 (L-23)	N.D.	0.64A		0.82A					
		0.15L							

Table 35. Pesticide concentrations in surfacewater draining into sinkholes, in Big Spring bain. All values in µg/l (micrograms per liter). A-Atrazine; B-Bladex; L-Lasso; D-Dual; F-Dyfonate; S-Sencor.

Site No.	5/6/82	Date of Sampling 5/27/82	7/28/82
BSW-1	6.30A 31.00B 12.70L 1.50S		
BGN-S	1.40A 8.00B 4.00L 0.10S		0.13A
ES-1	1.90A 7.20B 3.30L		
Miscellaneous Surface-Runoff Samples			
R-10		55.00A (Sheetwash-Runoff from 0.30L cornfield.)	

35) than in the Roberts Creek-Silver Creek samples (Table 34). Bladex concentrations are quite high in these stream samples. These streams all drain fields where combinations of Bladex, atrazine, and Lasso were applied. In the BSW and BGN samples, Sencor was detected. No soybeans are planted in the area, and the origin of the Sencor is not known.

The BGN site was resampled on 7/28/82, and only atrazine was present in the sample. At this time, most of the flow of the stream was sustained by tile drainage.

One sample, R-10, was collected from sheetwash, running off a cornfield during a rain storm. This sample provides at least an impression of the concentrations of atrazine present in the direct runoff water.

Tile Lines

Pesticide concentrations from several tile lines are given in Table 36. Tile lines are useful sample points, as tile-discharge water is a reasonable indicator of the quality of infiltrating soil water and groundwater in the shallow flow system. Tile-line site 108 (L-22), which empties into Silver Creek, was

Table 36. Pesticide concentrations in water from tile lines in Big Spring study. All values in µg/l (micrograms per liter); A-atrazine B-Bladex, and L-Lasso.

	Date of Sampling										
Site No.	11/17/81	2/25/82	5/06/82	5/26-27/82	6/7-8/82	6/22/82	7/28/82	8/24/82	9/21/82	10/26/82	12/29/82
108 (L-22)	0.3A	N.D.		0.51A	1.0A N.D.B 0.16L	1.4A		0.49A	0.15A	0.30A	0.30A
BTL-1			0.9A	1.0A 6.5B 1.5L			0.24A 0.08B N.D.L		N.D.		
Cannon				0.51A							
HBH-SO				0.26A							
HBH-W				0.26A							
BTL-2									N.D.		
ESTL-2				0.70A					N.D.		

part of the monthly monitoring network and has the most complete record of analyses. In November 1981, 0.3 µg/l of atrazine was present in discharge from this tile but no pesticides were detected in the February samples. Again, the cold conditions of the preceeding months limited infiltration through the soil, and therefore likely did not allow significant leaching for atrazine to be detected. The highest concentrations of atrazine occurred in May and June, and ranged between 0.5 and 1.5 µg/l. Low levels of Lasso were present in an early June sample. From August through December, atrazine concentrations varied between 0.15 and 0.50 µg/l. Miscellaneous analyses from other tile lines indicate pesticide concentrations similar to those found at site 108 (L-22), with minor exceptions. Site BTL-1 drains fields to which Bladex and Lasso were applied, and discharge water from this tile shows elevated levels of these chemicals (Table 36). No pesticides were detected at this site in a September sample, indicating the less persistant nature of Bladex and Lasso relative to atrazine. Two other samples collected in September from sites ESTL-2 and BTL-2, also showed no detectable pesticides; the latter of these sites drains a field which has been in pasture for several years and has not received chemical applications in recent years.

The concentrations of pesticides in the shallow soil and groundwater discharging from the tile lines are similar to the levels seen in the groundwater samples from the wells.

Discussion of Pesticide-Monitoring Results

Results of the pesticide sampling of Big Spring, network wells, surface waters, and tile lines, indicates similar trends exist in these different parts of the basin's hydrologic system, in terms of pesticide occurrence, persistence, and relative concentrations. Winter 1981-82 samples from all components of the system contained no detectable levels of pesticides. As previously mentioned, the winter of 1981-82 was extremely cold, with a deep frost and thick snow cover, limiting the leaching of pesticides from the soil zone; however, it is possible that more intensive sampling during the winter months would have detected pesticides within parts of the system. During May and June, pesticides were present in virtually all parts of the system sampled, with the exception of groundwaters from the background wells, under the thick sequence of the Maquoketa shales, and those wells along the groundwater-basin divide. The concentrations and variety of pesticides were greatest during this period, a result of spring chemical applications and rains that produced runoff and infiltration. The highest pesticide levels were found in surface streams and field runoff, indicating that overland flow is responsible for most pesticide mobilization. This is in agreement with previous studies (Johnson and Baker, 1978; Baker and Johnson, 1979; Baker, 1980). Total pesticide concentrations in surfacewaters were generally in the tens of µg/l range. Runoff to sinkholes provides recharge water, with relatively high pesticide levels, to the Galena aquifer. The sinkhole inputs may direct this recharge into either the conduit or diffuse-flow parts of the aquifer, depending upon the degree of hydrologic connection of the sink to major integrated conduits. The highest concentrations of pesticides recorded at Big Spring occurred during runoff, conduit-flow periods. Runoff recharge to the conduit-flow system resulted in atrazine concentrations in excess of 0.5 µg/l, with lesser amounts of Bladex and Lasso, at Big Spring during May and June. Both runoff and infiltration recharge the diffuse flow system, with infiltration likely providing the greatest volume of water. Pesticide levels in infiltration may be inferred from tile-line analyses, where total pesticide concentrations generally measured a few μg/l or less. Basin-wide, atrazine is the dominant pesticide species in infiltrating waters recharging the diffuse flow system. In carbonate aquifers, well samples are often considered to be good indicators of the chemical quality in diffuse flow systems; well samples collected during May and June generally contained 0.05-0.25 μg/l of atrazine.

Although pesticide concentrations were generally much lower in groundwater than surfacewater, the potential exists for much higher concentrations to occur in well waters. If a well was tapping a conduit directly downflow from a connected sinkhole, the well could tap water with pesticide concentrations more analagous to surfacewaters. During the June 7, 1982 runoff event, a water sample was collected for analysis from Dutton's Cave Spring, in Fayette County (see Hallberg and Hoyer, 1982, p. 55-59 for discussion of Dutton's Cave area). Dutton's Cave Spring is fed, in part, by water which runs off cropped fields into sinkholes within 0.5 to 1 miles (0.8-1.6 km) from the spring. The pesticide concentrations from this sample are shown in Table 37. The concentrations recorded at Dutton's are 4 to 100 times higher than the groundwater samples from the Big Spring region, and resemble surfacewater concentrations. These values are exemplary of what groundwater concentrations of pesticides would probably be in the proximity of surfacewater entry into the karst groundwater system during runoff events.

During the summer and fall base-flow periods, pesticide levels generally decreased in all parts of the hydrologic system, and only atrazine persisted through this period. This decrease reflects the breakdown of a portion of the pesticides remaining in the soil zone, and climatic conditions which limited any significant runoff or infiltration. Concentrations of atrazine decreased by roughly an order of magnitude in surface streams, and by a lesser amount in tile lines and at Big Spring. Most well samples contained no detectable pesticides. The persistence of low levels of atrazine at Big Spring and a few wells may be caused by leakage from surface streams and/or infiltration from the shallow groundwater system. The persistence of atrazine during this base-flow-recession period indicates that atrazine does enter the base-flow, diffuse-flow system. The similar seasonal responses and trends of pesticide concentrations in water samples from the basin again points out the well-integrated nature of the Big Spring basin hydrologic system, and the strong interrelationships between the various parts of the system.

The monitoring results also provide implications on the persistence of various pesticides. Most modern herbicides, in particular, are considered to degrade rapidly in the soil environment. Bladex and Lasso are considered to have very short half-lives, and only persist in the soil for 1 to 3 months. Atrazine, on the other hand, is known to be more persistent, and commonly is stated to persist in the soil from 2 to 8 months. Unfortunately, very little is known about the longevity of such chemicals once they leave the environment of the plow zone and reach the groundwater environment.

The monitoring from the Big Spring basin clearly support the short persistence of herbicides such as Bladex, Lasso, and Dual. Except for atrazine, all other

Table 37. Pesticide concentrations in water from Dutton's Cave Spring, Fayette County, 6/7/82. Values in µg/l (micrograms per liter).

Atrazine	10.00 µg/l
Bladex	0.50
Lasso	6.00
Dual	0.25

pesticides ceased to be detected by July or August, 3 to 4 months after application. Atrazine, however, persisted in groundwater samples, albeit in very low concentrations, throughout 1982, and into 1983 (as shown by continued monitoring).

The persistence of atrazine is well-documented in various studies (Frank et al., 1982; Von Stryk and Boton, 1977; Burnside et al., 1971; Jones et al., 1982; Armstrong et al., 1967). The half-life of atrazine is an item of varied opinions. Various studies suggest anywhere from 37 days (Dao et al., 1979) to 3 to 5 years (Armstrong et al., 1967). Recent well-documented studies suggest a half-life of about one year in the soil environment (Jones et al., 1982). The Big Springs data clearly show the persistence of atrazine in groundwater. The fluctuations in concentrations of atrazine at Big Spring, related to changes in flow regime, do not allow estimates of a half-life to be made. The Big Spring data do clearly suggest its persistence is much longer than the 2 to 8 months commonly attributed to it.

Atrazine Discharge

Atrazine concentrations in Big Spring water and measured groundwater discharge from the spring were used to sum the total mass of atrazine discharged in groundwater from the basin, for the period 5/6/82-10/31/82. This represents the period of the water year for which atrazine was present at detectable levels in Big Spring water. The amount of atrazine discharged was calculated in the same manner used to calculate the annual amount of the NO_3-N discharged. The concentration of atrazine was multiplied times the applicable volume of groundwater discharged during a period of time. Atrazine discharged during these discrete periods was then summed to give a total for the period 5/6/82-10/31/82. The total calculated atrazine output in groundwater (Table 26) is 14.2 lbs. (6.5 kg). The flow-weighted mean atrazine concentration was 0.31 µg/l, while the mean of all atrazine analyses from Big Spring was 0.52 µg/l. The flow-weighted mean and the mean of analyses do not correspond as well for atrazine as did those means for nitrate. This is a reflection of the fewer number of pesticide samples collected from the spring.

Using the 14.2 lbs (6.5 kg) atrazine output, an average atrazine application rate of 1.5 lbs/acre-corn, and the acreage of corn within the basin, atrazine loss in groundwater was about 5.8 x 10^{-4} lbs/acre (6.5 x 10^{-4} kg/ha), or about 0.04% of the atrazine applied during 1982 (Table 26).

Discharge and atrazine data for November-December 1982, were used to calculate the atrazine discharge for those months (Table 28) which were characterized by unusually warm conditions and intense rainfall and runoff-producing rain storms. The estimated atrazine loss for this period was 3.7 lbs (1.7 kg), with a flow-weighted mean and mean of analyses of 0.15 μg/l and 0.14 μg/l, respectively (Table 28). Although these means are considerably lower than those calculated for the preceding period (5/6/82-10/31/82), the high discharges recorded during this period resulted in a relatively significant atrazine discharge.

The density of surfacewaters sampled for pesticides was considered insufficient for calculation of the amount of atrazine discharged from the basin in surfacewater. However, a qualitative estimate of this discharge can be made. As previously discussed, surfacewater discharge from the basin was roughly equal to the measured groundwater discharge, and atrazine concentrations in surfacewater were 10-100 times greater in surfacewater than at Big Spring. Therefore, the amount of atrazine discharged in surfacewater was in range of 140-1400 lbs. for the period, representing 0.4 to 4% of the atrazine applied in 1982. As surfacewater losses are considerably greater than groundwater losses, the total basin pesticide discharge, and pesticide losses probably fall into the above ranges.

Previous studies have indicated atrazine losses, from surface runoff and tile-line discharge, ranging between 0.5-5% of the annual application rate (Baker, 1980; Baker and Johnson, 1982; Frank et al., 1982; Jones et al., 1982) in generally good agreement with the range indicated by this study. The timing and intensity of rainfall events following application of pesticides, is a major control on pesticide losses. If no significant rains occur for several weeks after application of chemicals, losses may be less than 1%. However, intense rainfalls occurring immediately following applications may generate losses of up to 15% (Baker, 1980).

Hydrograph Separation: Runoff and Infiltration Components

Hydrograph separation is a technique used by surfacewater hydrologists to identify the contribution of basic flow components to stream discharge during major, runoff-producing events. Various, generally similar basic methods for hydrograph separation are given in most standard engineering hydrology textbooks. While hydrograph separations have proved useful in describing the response of surfacewater systems to recharge events, it should be kept in mind that partitioning the hydrograph into two flow components is generally an oversimplification of the complex processes that contribute to streamflow. The same may be said, to an even greater degree, when applying separation methods to karst-spring hydrographs.

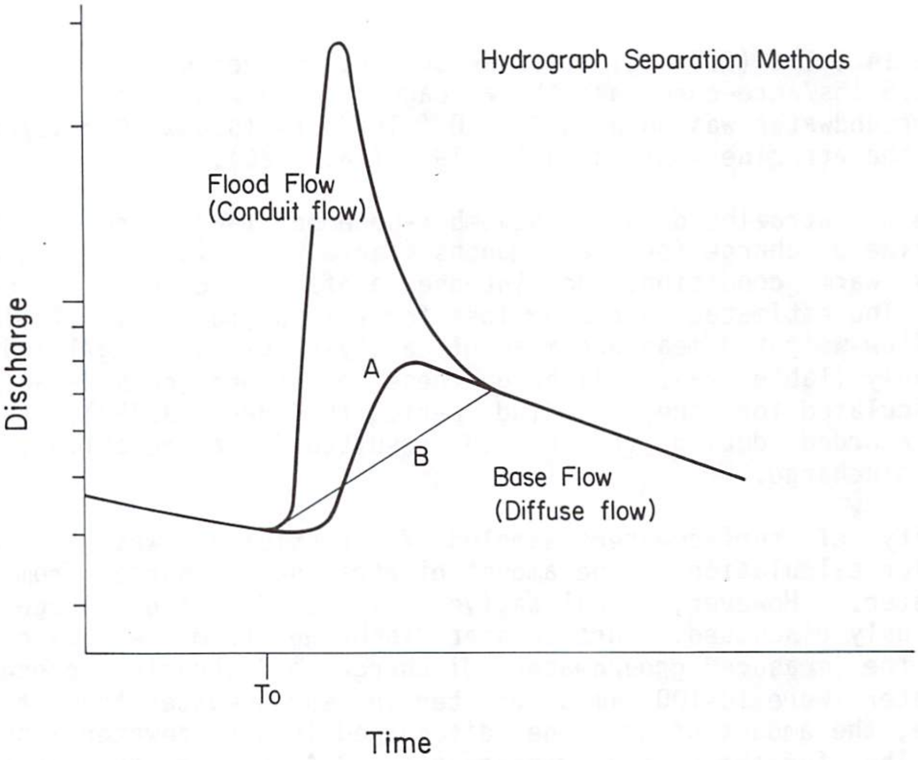


Figure 45. An idealized hydrograph separated into flow components using two numerical methods discussed in this report.

The two flow components addressed by most hydrograph-separation techniques are given various names, but are often termed flood flow (surface runoff, storm flow, etc.) and base flow. These components are separated on an idealized hydrograph by two methods on figure 45; the separation methods used are discussed in the next section. Flood flow corresponds to water derived from rapid overland runoff to streams, and only occurs after significant rainfall or snowmelt events. The hydrograph reponse to flood-flow contributions is a rapid rise and fall in discharge, forming a pronounced peak in the discharge record. The base-flow component is comprised of groundwater discharged to streams, which is a virtually constant process in perennial streams, and supplies essentially all streamflow during rainless periods. When rainfall recharges a groundwater-stream system, the water table rises in recharge zones and imposes steep hydraulic gradients on the system. This increases the flow of groundwater to the stream and raises stream discharge. As groundwater recharge and groundwater flow are generally slow processes, relative to surface runoff, changes in base-flow contributions to streams are less rapid and dramatic than flood-flow contributions.

The rapid rise of stream levels in response to flood flow, relative to groundwater levels, may reverse the hydraulic gradient between the stream and the groundwater system. Water from the stream will then recharge the adjoining groundwater system (e.g., alluvial aquifer). As flood-flow contributions quickly diminish, the gradients will again reverse, and the water which entered the adjoining aquifer will return to the stream. This water is termed bank storage, and in many hydrograph-analysis methods is considered part of base flow. The degree to which bank storage affects the hydrograph is dependent upon several factors, such as permeability of the stream bed, the size and permeability of adjacent alluvial aquifers, and the intensity of the specific precipitation event. Streams associated with little or no bank-storage capacity will have very pronounced flood-flow peaks, with rapid rises and falls of discharge. Streams associated with significant bank-storage capacity will, all other factors held equal, have a less-pronounced, lower peak discharge, because of stream water entering the adjacent aquifer. Also, discharge decreases more slowly following the flood peak, as the bank-storage water is discharged back into the stream. This is shown schematically in figure 46.

Figure 47 is an example of an idealized flood event and two generalized hydrograph separations. T_0 represents the time of the rainfall generating the flood event. Prior to T_0, discharge decreases slowly, in a response to the declining base-flow contributions provided by the groundwater system (i.e., base-flow recession). Following T_0, discharge increases dramatically as runoff contributes flood flow to the stream. As the flood flow peaks and falls, discharge drops quickly, though not as dramatically as it initially rose. The rate of discharge decline slows as the last of the runoff, flood-flow water, is contributed to the stream, and a base-flow recession begins again. The hydrograph separations point out the effect of bank storage on groundwater inflow to the stream. The groundwater-inflow hydrograph (dashed line) shows a gentle rise as water-table elevations increase, followed by a characteristic, slow decline. In contrast, the bank storage plus groundwater-inflow hydrograph (lower solid line) first decreases, with the decrease corresponding to the flood-flow peak, and resulting from streamflow entering the groundwater system as bank storage. Discharge from groundwater plus bank storage increases sharply as the flood-flow peak passes in response to rising groundwater levels and the release of bank-storage water back to the stream.

Several analogies can be drawn between surfacewater systems and an integrated conduit-flow system in a karst-carbonate aquifer. Flood flow is analogous to peak-conduit flow, which is fed by the flood flow of streams draining into sinkholes, and is transmitted through the carbonate aquifer via large open passages to discrete discharge points. In such a system, base flow is supplied to the conduits by the diffuse-flow groundwater system (figure 45). In the karst aquifer, responses of peak-conduit flow and diffuse groundwater-base flow to precipitation are similar to the responses of their surfacewater analogs (figure 18).

The concept of a bank-storage component is also applicable to a karst system. Conduit-flow response to rainfall is much faster than diffuse, base-flow response, and may result in elevated water levels along conduit zones and thus reverse the hydraulic gradients along these zones. This, therefore, would cause water from the conduit system to flow into the adjacent parts of the diffuse-flow system. As conduit flow decreases and hydraulic gradients again reverse, diffuse flow and "bank-storage" waters would again flow towards the highly transmissive conduit zones. As the bank-storage water is flowing into

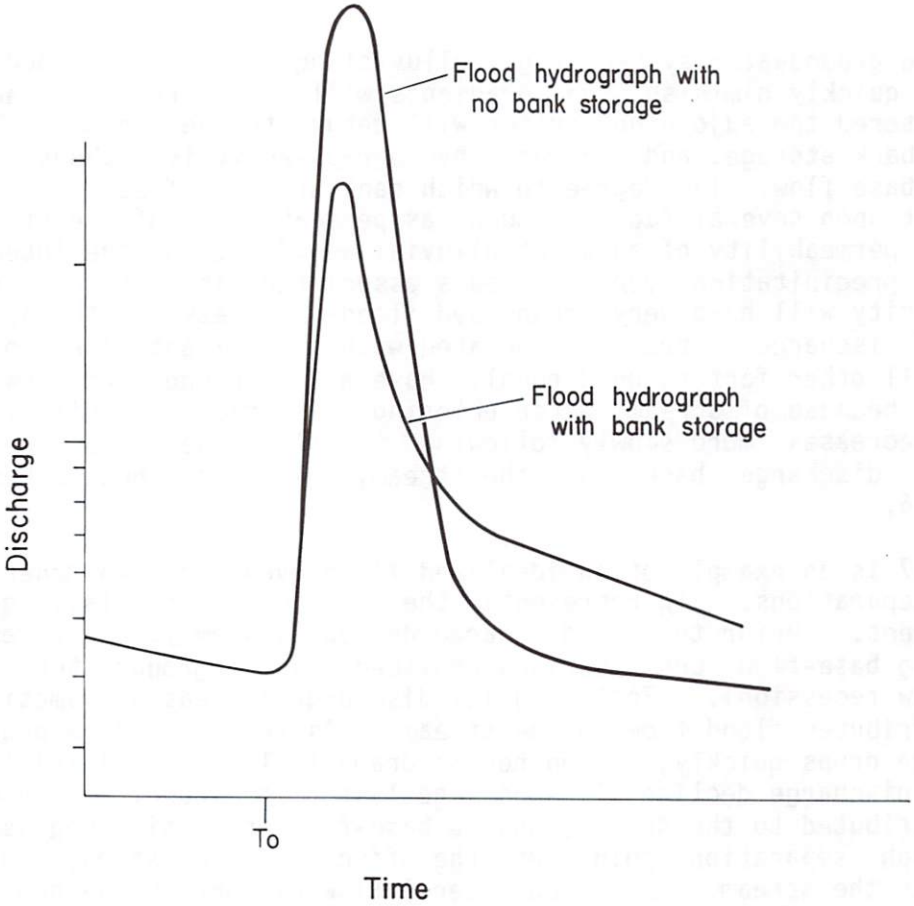


Figure 46. Idealized surfacewater-flood hydrographs, showing the effects of bank storage.

and then out of the diffuse flow part of the aquifer, its hydrologic response is similar to diffuse flow.

Hydrograph-Separation Methods

The Big Spring basin groundwater-discharge hydrograph was separated into base flow and peak conduit-flow components using two analytical methods. Figure 45 shows an idealized stream hydrograph, separated by these methods. The first method (method A, figure 45) was modified from Singh and Stall (1971). This method utilizes base-flow recession parameters (flow-rate decay constants) to calculated conduit-flow recession parameters. These parameters describe the recessions of the two flow components as linear responses. Several initial estimates of the base-flow recession parameter are used to generate corresponding conduit, flood-flow parameters, until a combination of base-flow and conduit-flow recessions are generated that best fit the observed discharge

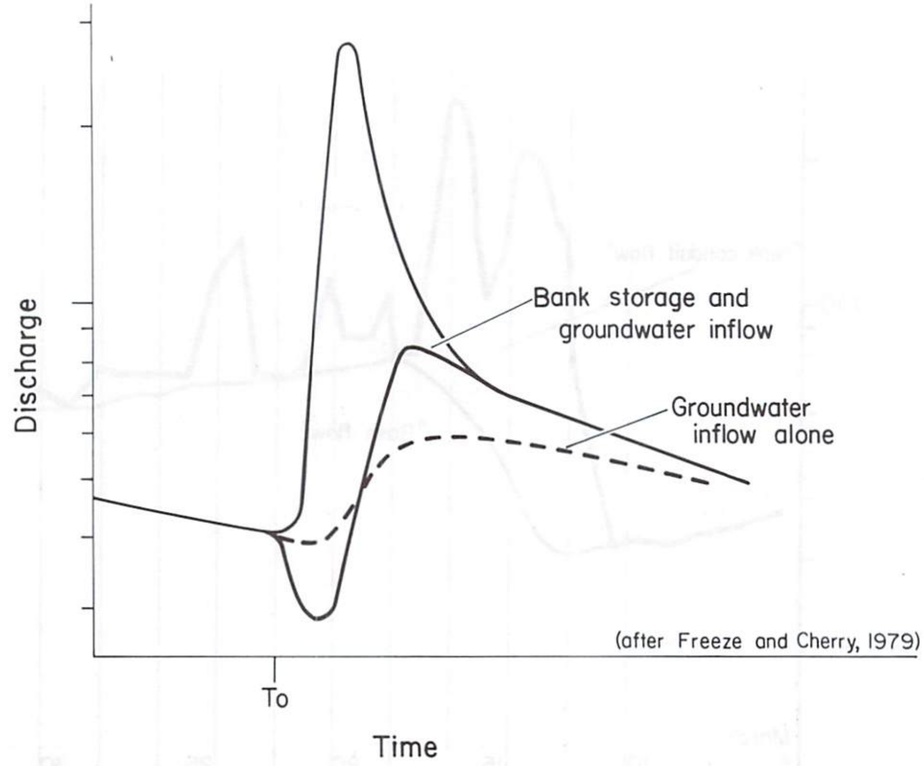


Figure 47. Generalized hydrograph illustrating the relative relations of flood flow, groundwater, and bank storage (after Freeze and Cherry, 1979).

hydrograph. This method is most readily utilized with well-defined, single-peaked discharge events, although the general concepts and mathematical basis are applicable to complex hydrographs as well. An example of the hydrograph separation using this method, the Big Spring hydrograph from March 1982, is shown in figure 48. Singh and Stall (1971) give stepwise examples of the application of this method.

The second analytical method (method B, figure 45) used was developed by the Institute for Hydrology (1980). Daily discharges are separated into five-day sets, and the minimum flow for each set is identified. The minima are then compared sequentially in groups of three. Where the central values of the three compared is less than 90% of one of the outer values, this discharge and the date it occurred are considered a base-flow "turning point." These turning points are plotted on the hydrograph and connected, forming the base-flow hydrograph. The hydrograph separation for Big Spring using this method, for March 1982, is shown on figure 48. While this method is less accurate for single-discharge events than the theoretically-based approach of Singh and Stall (1971), the two methods yielded nearly identical results over the span of the water year for the Big Spring basin.

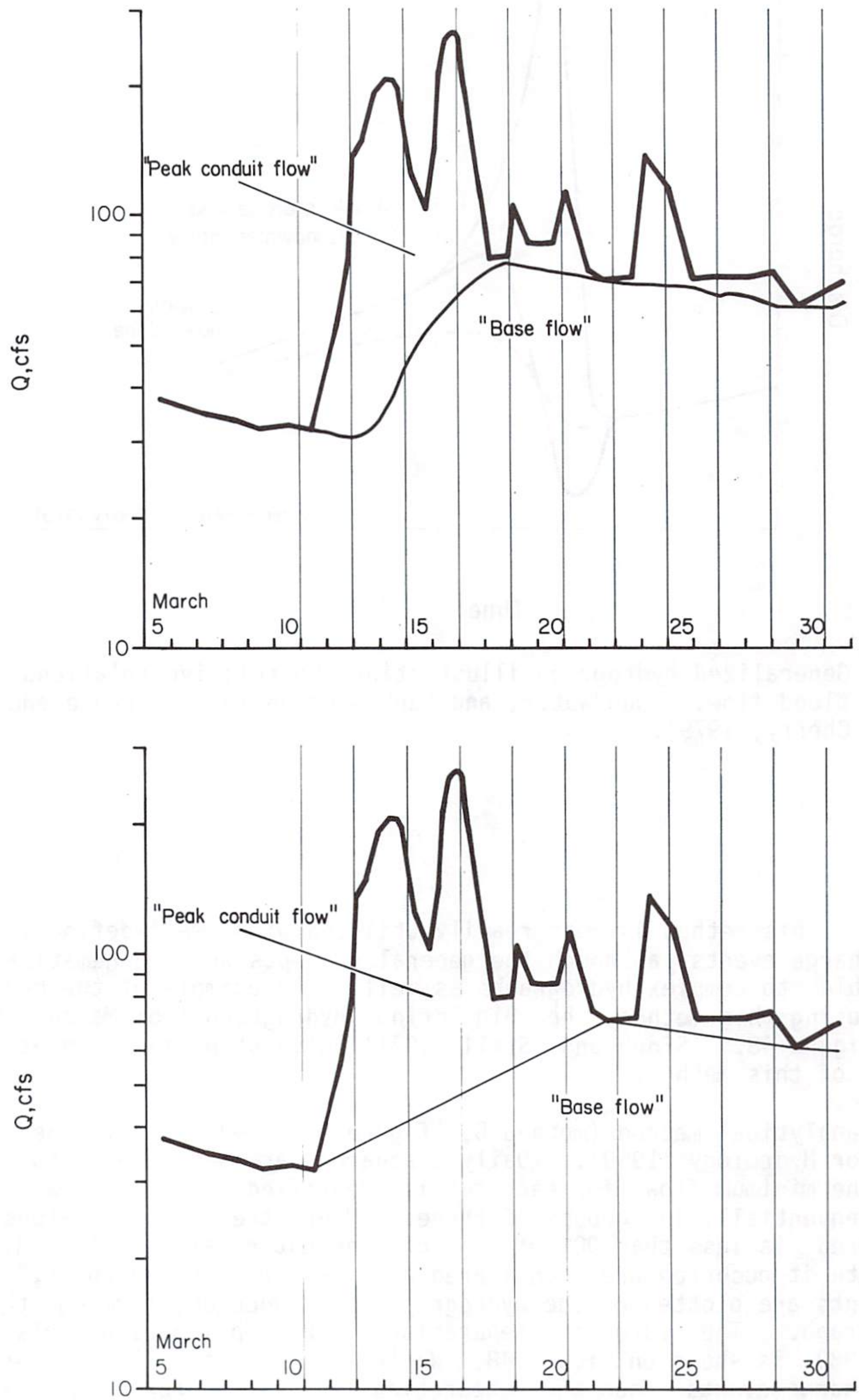


Figure 48. Big Spring hydrograph for March 1982, separated by numerical methods used in this report (method A, top; B, below).

Hydrograph components can be analyzed from changes in the water chemistry as well as the physical-numerical means outlined above. If the concentrations of a particular constituent are known in the groundwater base flow and in the runoff, flood-flow component, and their resultant, mixed concentrations are measured in the outflow during a discharge event, the respective water-discharge components can be separated by resolving the simple proportions of the constituents, as shown below (after Freeze and Cherry, 1979):

$$Qg = Qt \left(\frac{C_t - C_r}{C_g - C_r}\right)$$

Where Q_g = groundwater, or base-flow, diffuse-flow component in this case;

Q_t = total discharge, as measured during the hydrograph event;

C_g = concentration of the constituent in groundwater;

C_r = concentration of the constituent in the stormflow, or runoff-conduit flow;

and C_t = resultant concentration of the constituent, as measured in Q_t.

This approach was used for some events monitored at Big Spring. Unfortunately, during many events that were monitored in detail, chemical parameters did not change enough to be useful. The most successful use of this approach was from data in the spring of 1982, during the snowmelt-runoff events. Water temperatures were monitored constantly and this data provided a very detailed record. Nitrates were also monitored. The hydrograph for March 5-25, the water temperature record, and nitrate data from Big Spring are shown on figure 49. Also shown on the hydrograph is the detailed separation of "conduit-flow" and "base-flow" components from the analysis of the temperature data. This can be contrasted with the numerical separations for this same hydrograph shown on figure 48. Both numerical methods indicate a discharge mix of 60% base flow and 40% conduit flow for this time period. The detailed temperature separation suggests a mix of 75% base flow and 25% conduit flow. (The graphic differences on the hydrographs appear greater than this because of the logarithmic plot.) However, temperatures were rising slightly across this period, and the water temperatures also can adjust rapidly. Therefore, the separation was also calculated for gradual temperature mixing which suggested 70% base flow and 30% conduit flow for this period. Nitrate concentrations were also used and they indicated almost identical values with the numerical methods. All the methods provided reasonable agreement; the principal difference resulted from the level of detail available for the temperature record.

The numerical methods were used for separating the hydrograph for the entire period of monitoring. There was no significant difference between the results of the two methods. This analysis indicated that the discharge at Big Spring over the span of the water year was comprised of 91% diffuse flow and only 9% conduit flow. All the methods suggested that during any 24-hour period (during runoff) that the maximum conduit-flow component would be between about 57 and 68%. During base-flow recession (see August and September, figure 28) there is no conduit-flow component.

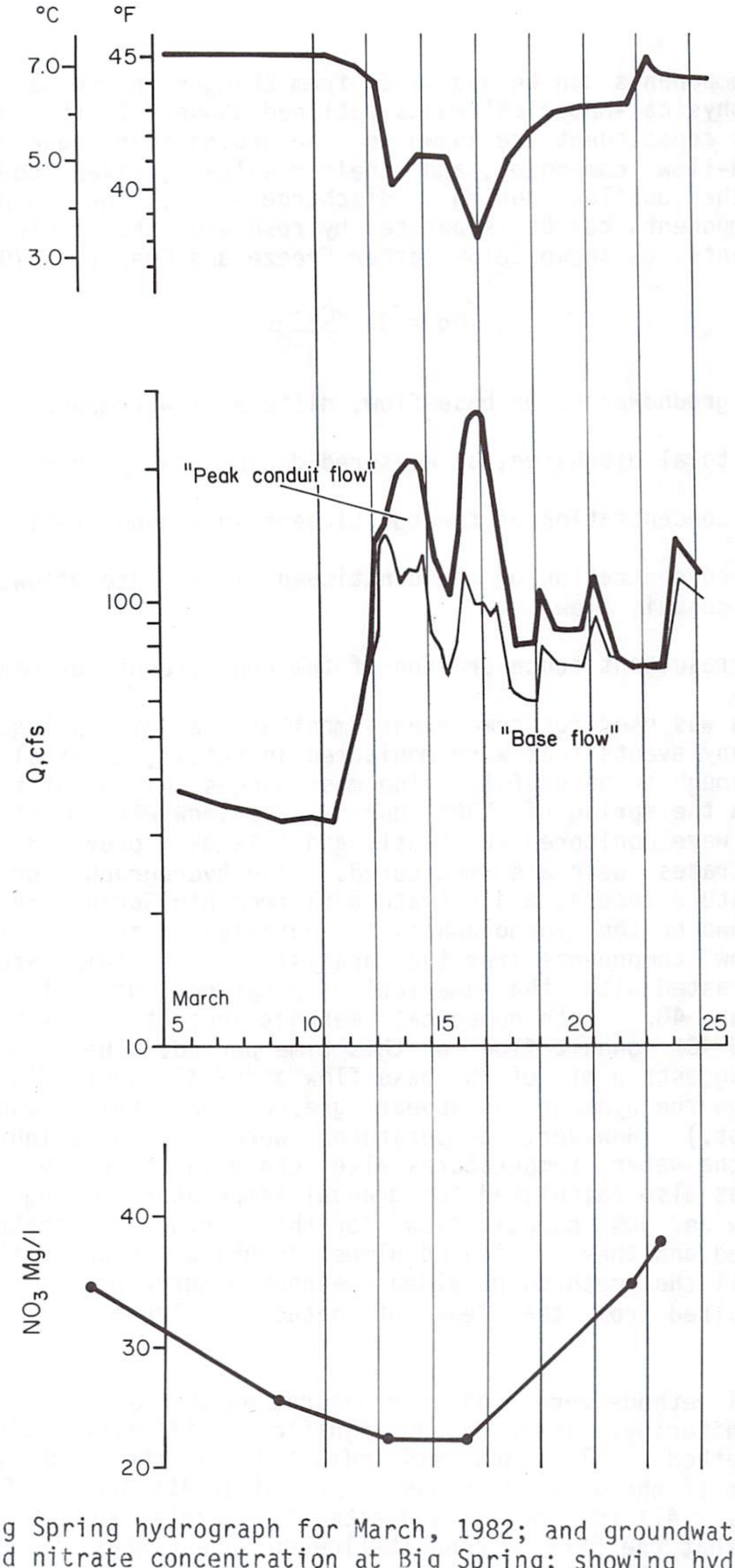


Figure 49. Big Spring hydrograph for March, 1982; and groundwater temperature and nitrate concentration at Big Spring; showing hydrograph separation derived from temperature data.

Processes Contributing to Peak Conduit and Base Flow

As previously described, partitioning of a karst spring hydrograph, such as the Big Spring hydrograph, into two flow components is a simplification of a complex process. Both base flow and conduit flow are comprised of several subcomponents which, because of similar or overlapping ranges of response times to recharge, are not easily separated from one another. These subcomponents are important, however, as their different origins and recharge paths may impart different water-quality characteristics.

Peak conduit flows discharging at Big Spring occur only after major rainfall/snowmelt events, and include all water rapidly transmitted to sinkholes connected with major conduit systems. Rapid recharge to these sinkholes includes water derived from overland flow, or sheet flow, from fields, and storm flow in streams swallowed by sinkholes. Additionally, rainfall generates shallow subsurface flow to sinkholes and associated streams. This flow subcomponent is often termed interflow, and is augmented by tile discharge to sinkhole streams. Peak discharges of interflow/tile-drainage water occurs quickly following rains, and contributes to the surface flood-flow input to sinkholes. Table 38 summarizes the subcomponents included in peak-conduit flows.

Base flow at Big Spring is largely derived from slow infiltration of precipitation through the soil, followed by slow, diffuse groundwater flow through the aquifer. Through time, this flow enters major conduits and is discharged at Big Spring. Several other mechanisms also contribute slow recharge to the Galena aquifer, and therefore, to base flow at Big Spring. Infiltrating precipitation may enter sinkholes, collapse features, or major fractures which are buried or filled with soil, and therefore, supply slow recharge to the conduit-flow system. The base flow of perennial streams drain into sinkholes year round and thus, contribute to base flow at Big Spring. Sinking-stream base flow is supported by tile drainage and shallow groundwater discharge. Even where sinkholes do not actually drain streams, leakage from streams (such as Robert's Creek), and the shallow groundwater system, adds to Big Spring base flow. Additionally, storm runoff may enter sinkholes that do not connect with the main conduit-flow system, but end rather abruptly within parts of the diffuse-flow system. Runoff to these sinkholes therefore recharges the diffuse-flow system, and also augments base flow at Big Spring. Subcomponents contributing to base flow at Big Spring are summarized in Table 39.

Interpretation of Subcomponents of Karst Groundwater Flow at Big Spring

As inferred, the water components contributing to the karst groundwater are complex. The separation of the hydrograph into the two components of conduit flow and base flow (diffuse flow) is not a clean separation, but does provide a reasonable approximation of the water and chemical inputs from various sources.

The analysis of various hydrograph events over the entire monitoring period and the details provided by the temperature separations do provide some insights into the complexity of the hydrograph. Note that on figure 49 the temperature record is complex and that the temperature drops do not correspond

Table 38. Components of "Peak Conduit Flow" groundwater.

"Peak Conduit Flow" groundwater component includes:
All rapid flow into sinkholes, which connect into conduits that allow rapid flow through system (i.e.-within 12 to 48 hours, sometimes to 72 hours, of a runoff-producing event). This includes: A. Sheet flow - overland flow. B. Stream - stormflow. C. Peak interflow - shallow subsurface stormflow; 1. as subsoil stormflow, and 2. peak tile discharge.

exactly with the rises in discharge. Also, note that within a single discharge rise and fall there appear two peaks of diffuse flow (or conduit flow). From such analyses and study of the hydrograph shapes (Rogers, 1972), some general interpretations can be made.

Figure 50 shows a generalized Big Spring hydrograph and an interpreted sequence of the various components that may contribute to it. The general Big Spring hydrograph (when analyzed in detail) has a steep-rising limb and often has a "shoulder" on the gradual-falling limb.

Within six to eight hours of the beginning of a precipitation event that generates runoff (T_0) the discharge at Big Spring will begin to rise. By twelve hours it is usually into the steep-rising limb. However, no changes in water chemistry or temperature occur until 24 to 36 hours after T_0. This first mass of water that is discharged during the event is interpreted as "displaced conduit water." This is basically "diffuse-flow" groundwater in its properties that must be displaced out of the saturated conduits before the new water, that has run off the land surface into sinkholes and the conduit system, can arrive at Big Spring. The increase in discharge occurs because the run-in of surface water through sinkholes produces a head increase, principally over the conduit system, which in turn increases the hydraulic gradient and, thus, the discharge. As this water is displaced, the properties of the

Table 39. Components of "Base Flow" groundwater.

"Base Flow" groundwater component includes:

1. Normal slow infiltration and percolation through soil and rock to aquifer.

2. Rapid infiltration through soil to fractures and "buried" or filled sinkholes.

3. Slow, continuous leakage from streams, and alluvial aquifers, such as Robert's, Silver, and Howard's Creeks.

4. Tile-line base flow to sinkholes and losing streams.

5. Surface runoff into sinkholes which end in diffuse-flow areas of the aquifer (i.e.-where the sinkhole is not connected by large rock-openings to main conduit system).

discharging water change rapidly marking the arrival of the new discharge, conduit-flow water, resulting from surfacewater run in. The hydrograph peak and the peak of the first slug of new conduit water coincide. This water is mainly transported down the main conduit zone which trends north-south from Big Spring. Dye traces from this area show the fastest travel times, with dye arriving at Big Spring in 24 hours; the same time lag inferred from temperature and chemical changes.

The multiple temperature peaks and the shape of the hydrographs though, suggest that an additional peak of new conduit-flow water arrives somewhat later in time. The timing is likely related to the conditions of individual events, but interpretations of some data suggest that this may occur between 40 to 72 hours. This conduit-flow water may be delivered either through portions of the conduit system which are simply further away (Rogers, 1972), such as from the eastern conduit zone, which generally shows longer dye-trace travel times and/or portions of the conduit systems which simply have slower travel times because of differences in hydraulic gradient or hydraulic conductivity. After this, conduit-flow components decrease relatively rapidly.

The remaining recession portion of the falling limb is maintained by true infiltration, and other components of diffuse flow into the aquifer, and possibly a component analagous to "bank storage." With the rapid head increases

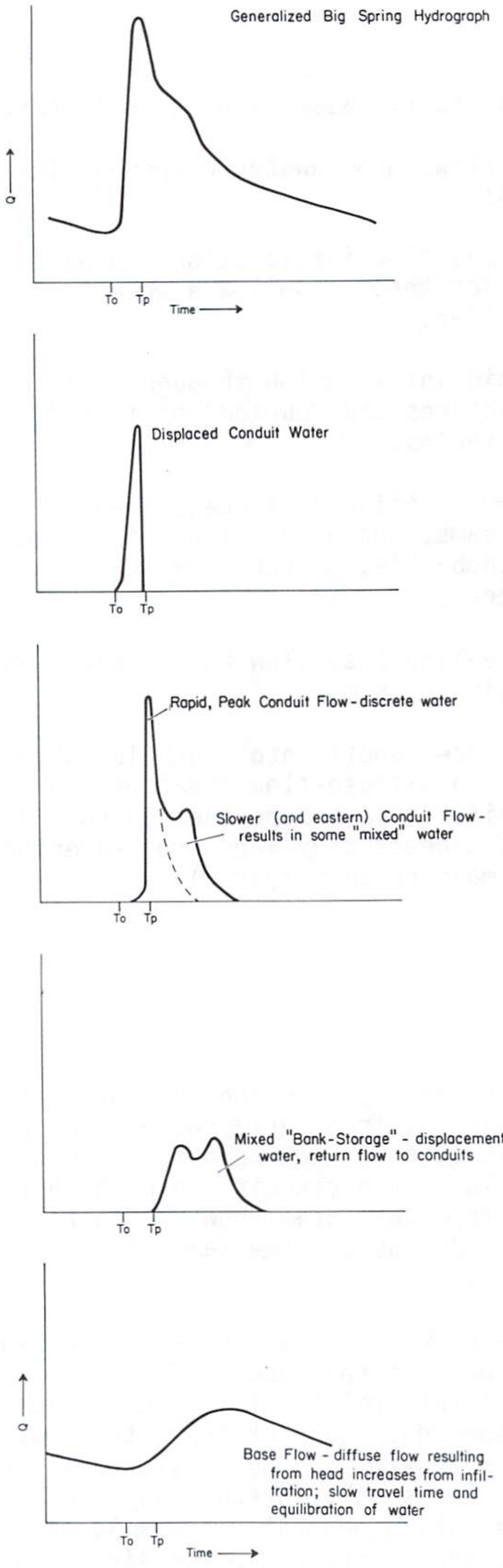


Figure 50. Generalized Big Spring hydrograph and interpretations of the hydrograph for various flow components.

imposed on the conduit system in the initial phases of the event, some groundwater is likely displaced into the aquifer, as well as down the conduits. As the relative head difference between the conduits and the adjacent (more diffuse) aquifer decrease, some of this water reenters the conduit system as "return flow," just as in bank storage with a stream. Such effects are supported by the complex head changes that occur in karst aquifers (White, 1977). These components are interpretive, and will clearly vary from event to event with different rainfall intensities, rainfall distribution, prior base-flow levels, etc. These observations do serve to place in perspective the complexity of the karst-aquifer flow system.

Results of Hydrograph Separation

Following separation of the basin hydrograph into base-flow and peak conduit-flow components, the discharge contribution of these components may be summed. The amount of NO_3-N and atrazine carried by these components may also be estimated. These data are summarized in Table 40, and shown schematically in figure 51. For the water year (11/1/81-10/31/82), total groundwater discharge from the basin was 37,400 acre-feet (46 million cm). Results of the hydrograph separation indicates that base flow contributed about 91%, or 34,040 acre-feet (41 million cm), of the discharge during this period. The remaining 9% of the groundwater discharge, totalling about 3,360 acre-feet (5 million cm) was contributed by peak conduit flows, virtually all of which occurred during the period mid-February to June.

Using the calculated volumes of peak conduit and diffuse discharge, and the flow-weighted chemical data of Big Spring waters, the amount of nitrate-N and atrazine discharged by the two flow components may also be calculated. Total NO_3-N output for the period was 873,000 lbs. (396,000 kg). Base flow delivered about 821,000 lbs. (372,000 kg), or 94% of the total groundwater output. Peak conduit flows delivered 52,000 lbs. (24,000 kg) of NO_3-N, 6% of the total. Note that the percentage of total NO_3-N output accounted for by base flow, 94%, is larger than the percentage of total water discharge which is base flow, 91%. This indicates that base-flow waters are enriched in NO_3-N, relative to peak conduit-flow waters. Note the calculated, flow-weighted mean nitrate concentration for conduit flow is only 22 mg/l (Table 40). This value is so low primarily because of the dilution effects of the low-nitrate snowmelt runoff, which constitutes the major portion of the total conduit flow. This is consistent with the observations that nitrate is lost mainly through infiltration, as opposed to runoff.

Base flow contributed 84%, or about 11.9 lbs. (5.4 kg), of the total amount of atrazine discharged from the basin during the period 5/6/82-10/31/82. Peak conduit flows delivered about 2.3 lbs. (1.1 kg) of atrazine, 16% of the total for the period. Peak conduit flows, which account for 9% of the water discharged from the basin, deliver 16% of the atrazine discharged. Again, this is consistent with observations that higher concentrations of atrazine occur in runoff. In terms of total output, however, the constant low levels of atrazine present in base flow account for the largest portion of this pesticide discharged from the basin.

Table 40. Components of groundwater and chemical discharge for water year, from Big Spring basin.

12-month Summary; 11/1/81-10/31/82

1. Discharge

Peak Conduit Flow	
acre-feet	3,360
millions cf	146
millions cm	5
% total	9%
Base Flow	
acre-feet	34,040
millions cf	1,484
millions cm	41
% total	91%

2. Nitrate Output

Peak Conduit Flow; NO_3-N (flow-weighted mean NO_3-22 mg/l)	
thousand lbs	52
(thousand kg)	(24)
% total	6%
Base Flow; NO_3-N (flow-weighted mean NO_3-41 mg/l)	
thousand lbs	821
(thousand kg)	(372)
% total	94%

3. Atrazine Output (5/6/82-10/31/82)

Peak Conduit Flow	
Flow-weighted mean concentration	0.92 µg/l
Total pounds	2.3
(Total kg)	(1.1)
% Total	16%
Base Flow	
Flow-weighted mean concentration	0.27 µg/l
Total pounds	11.9
(Total kg)	(5.4)
% Total	84%

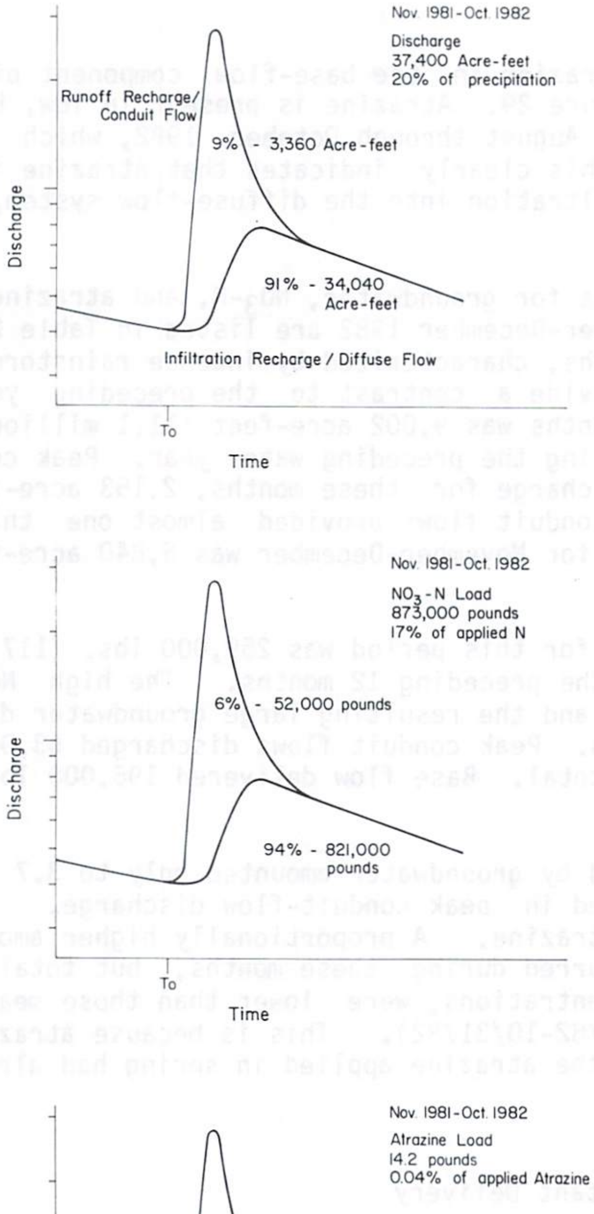


Figure 51. Schematic hydrographs summarizing the relative contributions of groundwater, nitrate, and atrazine from conduit flow and base flow in the Big Spring basin.

The presence of atrazine in the base-flow component of the groundwater is clearly seen in figure 29. Atrazine is present in low, but consistent concentrations throughout August through October 1982, which is a period of base-flow recession. This clearly indicates that atrazine is being delivered to the aquifer by infiltration into the diffuse-flow system, as well as by runoff into sinkholes.

Similar calculations for groundwater, NO_3-N, and atrazine discharged from the basin during November-December 1982 are listed in Table 28 (in an earlier section). These months, characterized by intense rainstorms and high discharge at Big Spring, provide a contrast to the preceding year. Total discharge during these two months was 9,002 acre-feet (11.1 million cm), 144% of the bimonthly average during the preceding water year. Peak conduit flows accounted for 24% of the discharge for these months, 2,153 acre-feet (94 million cm), during December, conduit flows provided almost one third of the total discharge. Base flow for November-December was 6,840 acre-feet (8.4 million cm), 76% of the total.

Total NO_3-N output for this period was 259,000 lbs. (117,000 kg), equal to 30% of the total for the preceding 12 months. The high NO_3-N output relates to the intense rains, and the resulting large groundwater discharge that occurred during these months. Peak conduit flows discharged 63,000 lbs. (28,000 kg) of NO_3-N, 24% of the total. Base flow delivered 196,000 lbs. (89,000 kg) of NO_3-N.

Atrazine discharged by groundwater amounted only to 3.7 lbs. (1.7 kg), 38% of which was delivered in peak conduit-flow discharge. Base flow carried 2.3 lbs. (1.1 kg) of atrazine. A proportionally higher amount of runoff and peak conduit flows occurred during these months, but total atrazine losses, and mean atrazine concentrations, were lower than those measured during the preceding period (5/6/82-10/31/82). This is because atrazine is not applied in fall, and most of the atrazine applied in spring had already been utilized or removed.

Chemical and Pollutant Delivery

Based on analyses of chemical and physical water-quality parameters from the various hydrologic components of the Big Spring basin, several conclusions can be made concerning groundwater delivery of chemicals and other pollutants. The largest volume of groundwater transmitted through the system is the infiltration derived, diffuse-flow water that supports base flow at Big Spring. As leaching of nitrates (chlorides, etc.) is primarily an infiltration process, the highest concentrations, as well as the greatest mass, of these ions is carried in the base-flow component. The large volume of base-flow discharge, relative to peak conduit flows, also carries the largest mass of soluble pesticides, but in lower concentrations than conduit flows. Infiltration and diffuse-flow processes generally exclude the transport of sediment, bacteria, and organic solids. Table 41 summarizes the water-quality effects of base flow.

Peak conduit flows are generated by surface runoff, the major mechanism causing pesticide losses from cropped fields. Peak conduit flows, therefore, are

Table 41. Contaminant input from "Base flow."

"Base Flow" delivers to groundwater:

1. Highest concentrations of nitrate (and other soluble chemicals).

2. Largest mass of nitrates, etc.

3. Largest mass of soluble pesticides--but in very low concentrations.

4. Generally little sediment, turbidity, organic, or bacteria (and viral) problems

associated with the highest concentrations of soluble pesticides. The openess of the major conduit-sinkhole systems allows for the influx of sediment, turbidity, and soil-attached chemicals (such as Dieldrin), and readily transports bacteria and organic matter. The dilution effects of runoff water will often diminish the concentrations of nitrates, chloride, and other soluble ions associated with leaching from the soil. Table 42 summarizes the contaminants delivered to groundwater in peak conduit flows.

In contrast to many prior assumptions about the karst areas, runoff into sinkholes is not the dominant factor creating groundwater-quality problems, at least as far as total chemical delivery is concerned. The proportions of chemicals delivered to groundwater by the conduit flow (runoff) and base flow (infiltration), and the other water-quality effects these components contribute (Tables 41 and 42), must guide the assessment of possible management changes considered to improve water quality. The infiltration component of chemical delivery is a major factor which must be accounted for, and balanced with the concerns of peak pesticide and bacteria loadings delivered by runoff.

Historical Changes in Water Quality and Land Treatment in the Big Spring Basin

As reviewed in the inventory of the basin (p. 39 and 77), dramatic changes have taken place in groundwater quality and landuse in the Big Spring basin during the past 30 years. Historic water-quality records, from a discrete water source, such as Big Spring, are difficult to find (Hallberg and Hoyer, 1982). Based on this study, it is obvious that Big Spring provides a very good, integrated sample of groundwater quality from its 103 sq. mile (267 sq. ha) basin. It is appropriate to review these historic records to see what insights they may provide.

As noted (Table 20), prior to this study, the water-quality measurements at Big Spring in 1951 and 1968 (by USGS and UHL staff) showed an average nitrate concentration of 12-13 mg/l. Though more data would be preferable, the data

Table 42. Contaminant input from "Peak Conduit flow."

"Peak Conduit Flow" delivers to groundwater:

1. Peak pesticide loading.
2. Peak sediment and turbidity problems (includes soil attached chemicals--insecticides, Dieldrin, etc.).
3. Peak organic and bacteria (and Viral) problems.
4. Generally dilutes concentration of nitrates (chlorides, etc.), but, because of high discharge may discharge large total mass.

available was collected at times that should have been representative of water quality in those periods. In 1982, the average nitrate concentration at Big Spring was 40 mg/l and the range was 23-57 mg/l. The 1982 low (during snowmelt) does not even overlap with the 1968 high (14 mg/l). This three-fold increase in the past 14 years is clearly significant, and suggests a 230% increase in nitrates in the Big Spring basin groundwater over the late 1960s levels.

As reviewed previously, other sparse data and other studies support this same trend. As an example, during the course of this study a private well (outside of the Big Spring basin) in the karst-shallow carbonate aquifer area of northeast Iowa was inventoried. In this rare instance, the well owner had recorded UHL water-quality analyses dating back to 1964 (Table 43). These data show a nearly identical trend to the Big Spring data.

A review of various research studies (notably Baker and Johnson, 1977) suggests that the values of 8-14 mg/l nitrate in groundwater is in the range of what would be expected from the less intensive agricultural practices in northeast Iowa before 1970.

Landuse and farming statistics were also compiled for this period of time (see p. 39, figure 13-17; Table 10), and dramatic increases in the acreage of land used for row crops and the rates of nitrogen fertilizer use occurred in Clayton County (figures 13-15 Table 10) and state-wide (Harmon and Duncan, 1978). This data was used to evaluate the impact of these changes in the Big Spring basin. The changes in corn acreage and cattle and hog populations for Clayton County were simply porportioned to the area of the Big Spring basin. This, according to most authorities (and comparing to other landuse statistics), provides a conservative estimate, underpredicting corn acreage (and thus, fertilizer use) and overpredicting cattle population in the Big Spring basin, relative to the rest of the county. From late 1960 values to present, hog

Table 43. Nitrate concentrations and date of sampling, from private well in the karst-shallow carbonate aquifer area in northeast Iowa.

Date	Nitrate, mg/l
4/6/64	14
8/30/71	30
3/15/73	35
4/19/78	42
6/30/81	47
3/23/83	45

to present, hog populations increased about 10% and cattle populations increased about 30%. Using standard estimates of the amount of manure and manure-N generated by cattle and hogs (Vanderholm et al., 1974; S. W. Melvin, ISU Ag-Engineering Extension, pers. comm.), these population figures were converted to tons of manure-N produced in the Big Spring basin over time (figure 52). The resultant increase in manure-N, from the late 1960s to present, was about 30%.

During this time period, corn acreage increased about 40%, but the application rate of fertilizer-N increased about 80%. The corn acreage and fertilizer rate increases are "additive" factors, and the total of fertilizer-N applied increased about 250% over late 1960s values (figure 52).

Figure 52 graphically summarizes the increases in tons of N applied to the Big Spring basin with the average increase in nitrate concentration in groundwater at Big Spring. The coincidence of trends between groundwater nitrates and fertilizer-N applied is obvious and striking. Such data does not prove cause and effect, but with all the other data that has been compiled and the various other studies that have been reviewed, the implications seem obvious. The primary reason for the increase in nitrates in groundwater is the dramatic increase in nitrogen-fertilizer application.

As reviewed earlier, all the N delivered to groundwater as nitrate is clearly not derived solely from N-fertilizers. Some of the N must come from other sources--manure, rainfall, and natural mineralization. Isotopic fractionation studies in Illinois suggest that, on the average, about 55% of the N delivered to water is isotopically fertilizer-N (Smith et al., 1975). Again, however, the reason that the various forms of N are being leached as nitrate is because the high rates of fertilization produce levels of N in the soil which are not fully used by plants or lost by other mechanisms. The strong interrelationship between nitrates and chlorides and pesticides, which have no natural

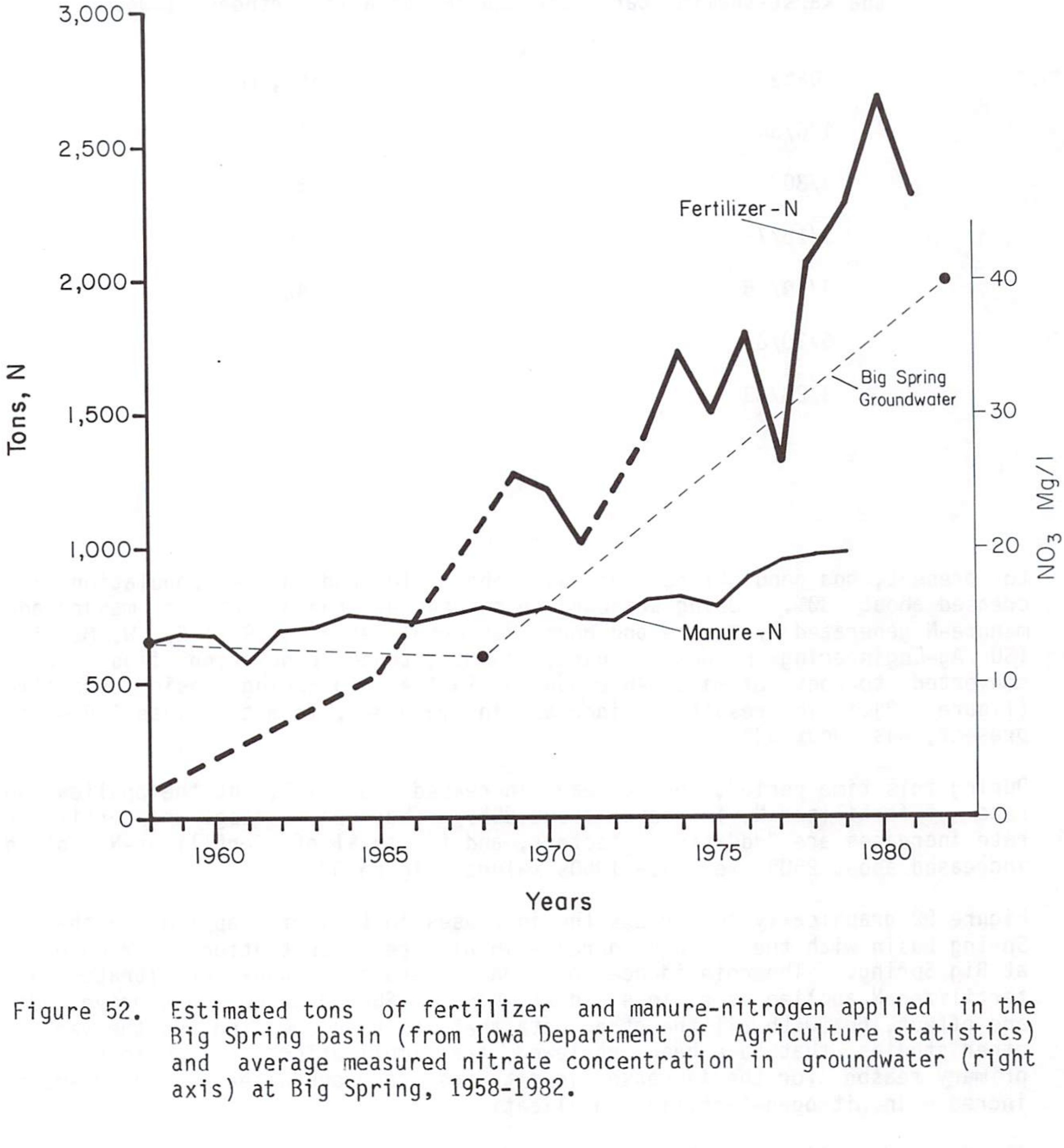


Figure 52. Estimated tons of fertilizer and manure-nitrogen applied in the Big Spring basin (from Iowa Department of Agriculture statistics) and average measured nitrate concentration in groundwater (right axis) at Big Spring, 1958-1982.

sources in these areas support this. In particular, the pesticides have no other source except the application to agricultural lands in the Big Spring basin. The solubilities of these chemicals are many orders of magnitude less than nitrate and there is no rationale to deny leaching of nitrate from N-fertilizers.

Several questions are raised by the apparent trends in figure 52. The change in water quality in relation to fertilizer-N implies a very rapid response time and a proportionally linear increase between groundwater nitrate and fertilizer applied. Different studies have shown, in high-infiltration regions in particular, that changes in surface-chemical practices may rapidly (within the same year), although incompletely, effect groundwater (Saffinga and Keeney, 1977; Gerwing et al., 1979).

The linear response indicated in figure 52 is also supported by several studies. Some studies have found a proportionally linear increase in the build-up of excess nitrogen (and nitrate-N) in the soil in relation to differential fertilization (Jolly, 1974; Gast et al., 1978). Drainage studies and modelling studies in Iowa also suggest a proportionally linear increase in nitrate leaching related to increased fertilization (Baker and Johnson, 1977).

From these observations, the question arises of whether or not groundwater nitrates are at equilibrium with current agricultural practices, or will they continue to rise for some time even if land treatment remains constant? This can only be answered with continued monitoring. However, all available evidence does suggest that if nitrate leaching losses could be reduced, either by more efficient use or simply through less application, this should result in a proportionally linear decrease in groundwater nitrate, at least over a period of years.

Water Quality and Public Health

The karst-carbonate aquifers of northeast Iowa are very susceptible to contamination from a variety of point sources such as spills from hazardous chemicals, or waste-disposal problems. On the regional level, non-point sources degrade groundwater quality and, as addressed in this study, these sources contribute contaminants of concern for public health. These are bacteria (and viruses), turbidity, and dissolved solids--principally nitrates and pesticides.

Bacteria and viruses may produce the most obvious and severe health problems in the short term. When water-borne, pathogenic microbes enter a groundwater supply, the effects are immediate. The analysis of bacteria data in the Big Spring region, as well as other case studies (Harvey and Skelton, 1968; Allen and Morrison, 1973), clearly show that bacteria can be transmitted through the karst aquifers. As shown in this study, many bacteria problems are related to local water-system construction, but during runoff events in particular, bacteria may be widely transmitted through the karst-groundwater system.

This study, as most others, has principally dealt with bacteria. Recent reviews suggest, however, that at least 55% of water-borne diseases during the last 30 years in the U.S. were likely of viral etiology (Keswick and Gerba, 1980). Viral organisms are very difficult to detect and isolate from water supplies and thus, water samples are not routinely analyzed for them. Viruses are potentially much more hazardous than bacteria, because studies suggest that viruses may survive and migrate much further through soil than bacteria, may survive much longer in groundwater than pathogenic bacteria, and may also survive common treatments for bacteria, such as chlorination (see Keswick and Gerba, 1980). Further, the presence or absence of bacteria may not be an indicator of viral contamination. Further study is needed in this area, to provide adequate detection methods.

Most problems of this nature arise because of improper sewage treatment and disposal. Human sewage and livestock wastes must be treated adequately and carefully in these areas. Land disposal of sewage wastes, an increasingly common practice, must be avoided or handled with great care in the karst regions.

Turbidity can be a health problem, dependent on the constituents contributing to the turbidity. The most obvious concern, identified in this study, is the pesticides Dieldrin and atrazine, which may be attached to particulates transmitted in the karst groundwater system. The relative concentrations these might occur in (in terms of ingested amounts) and problems these might cause are not known.

The items of most concern for long-term health problems are the dissolved solids, particularly nitrates and pesticides. As noted, however, where nitrates are high, chloride and sulfate usually follow, and total dissolved solids often exceed the recommended level of 500 mg/l.

Nitrate in groundwater has been of concern for many years, particularly for human infants. The drinking-water standard of 45 mg/l nitrate was set as a safe level to prevent methemoglobinemia in infants (Comley, 1945; Walton, 1951; NRC, 1978; Fraser and Chilvers, 1981). This problem is well known.

Review of recent health studies provide implications that ingested nitrate (of which high-nitrate water is a major source in humans) may contribute to many other problems. Some studies suggest that concentrations over 100 mg/l, nitrates may contribute to: 1) central-nervous system, motor reflex problems in children; 2) hypertension and cardiovascular problems in adults; and 3) gastric cancers (see Fraser and Chilvers, 1981). These studies are not conclusive, and again, more research is clearly needed. The concentration of nitrate in groundwater is approaching, or already exceeds 100 mg/l in local areas in northeast Iowa.

The levels of pesticides found in the groundwater samples are orders of magnitude below toxic levels.

A major unknown is the possible long-term health effects, and possible carcinogenic effects of the pesticides in groundwater. Three issues are of concern: 1) the infrequent, moderate concentrations (10-50 µg/l) of pesticides that may occur during peak runoff, conduit-flow events; 2) the persistent, but very low concentrations (0.1-5 µg/l) of pesticides such as atrazine; and 3) the occurrence of Dieldrin (and possibly other insecticides) attached to particulates ("turbidity") in the karst-area groundwater. None of these issues can be adequately addressed now. The peak load concentrations may be of greater concern if significant amounts of insecticides occur. Although few insecticides were found in the sampling for this study, moderate concentrations of insecticides clearly could occur during conduit-flow events.

The health-related aspects of atrazine in drinking-water supplies are currently unclear. Toxicity of atrazine is low; the oral LD_{50}, or amount of ingested atrazine which is lethal to 50 percent of a test animal population, is 3,080 mg/kg of body weight, about 1.5 times higher than aspirin (see Appendix 4 and 5). However, the long-term effects of low-level atrazine ingestion are unknown. Atrazine is a secondary amine, a class of chemicals which may react with nitrite (NO_2) to form nitrosamines (Sander et al., 1968). Nitrosamines are suspected carcinogens, although current knowledge on the carcinogenic potential of nitrosamines towards man is somewhat inconclusive (Kearney, 1980). The presence of atrazine and nitrate, a potential nitrite source, is therefore a matter of concern, though not a proven health hazard.

Nitrosamines have been formed from atrazine and nitrite in the laboratory, under pH and temperatures typical of the human stomach (Eisenbrand et al., 1975), and in soils treated with atrazine and sodium nitrite. Nitrosamine formation also occurs during the synthesis of many pesticide compounds, probably by reacting with nitrite contained in industrial rust inhibitors (Ross et al., 1977).

In all reported formations of nitrosamines from atrazine, nitrite was required for the synthesis; nitrate and atrazine did not produce nitrosamines. Reduction of nitrate to nitrite may occur in soils, and under alkaline soil conditions may persist and accumulate (Stojanovic and Alexander, 1958). However, most research has indicated that nitrite levels in aerobic soils are extremely low, except for transient conditions. Reduction of nitrate to nitrite within the human body is also limited to unusual conditions (Hill and Hawksworth, 1972). However, nitrite itself may be introduced to the human body, as this chemical is used as a perservative in meats and other food products.

While the potential for nitrosamine formation from atrazine exists, both in the environment or the human body, nitrosamine levels generated from atrazine are probably low. However, nitrosamines formed in this manner would contribute to the total exposure of the population to this potentially carcinogenic class of chemicals.

In summary, for every health concern expressed about groundwater quality, there are many unknowns and questions which cannot be answered. This is particularly true for long-term health effects. Further research in this area must be pursued.

EVALUATION OF LAND MANAGEMENT

It seems clear that the source of the nitrates and herbicides in the groundwater in the karst and unprotected portions of the Galena aquifer in the Big Spring basin are the result of recent and current agricultural practices. If present practices continue with the same technology, the Galena aquifer will, at best, remain the same, but it may deteriorate somewhat further. Presently, the usefulness of Galena groundwater is marginal, and locally it is uanccept-able for many purposes. Through time, the Galena aquifer's degradation will lead to degradation of deeper, alternate water sources, especially the St. Peter Sandstone aquifer. Water-quality improvement seems possible only through altered agricultural practices.

It seems appropriate, therefore, to begin an analysis and discussion of how such land-treatment practices might affect water quality. Difficulty in analysis comes from two sources, 1) there are so many practices, and 2) the complex nature of the karst groundwater system, which includes both surface flow into sinkholes and normal infiltration through soils. Complete evaluations of various ag-management practices are far beyond the scope of the research at hand, and should only be done by researchers with expertise in other disciplines. This analysis will concentrate on the effects of some conventional soil-conservation practices. In contrast to other studies, this analysis will attempt to evaluate the impacts of land-treatment practices on groundwater quality, as well as on soil erosion, runoff, and surfacewater quality. In most cases, however, only an estimate of the direction of change that a particular practice may impart on the groundwater quality will be attempted. These "directions" are, in some cases, merely best guesses based on both imperfect understanding of agricultural practices and how these practices interact with the natural systems at the land surface and beneath the ground. These discussions on the effects of various practices, combined with a backdrop now provided by documented water-quality conditions, provide a forum for researchers in many disciplines--conservationists, environmentalists, farmers, chemical dealers, government officials, politicians, homeowners, and others, to begin serious discussions about the problems of water quality in Iowa, how serious these problems are, and what might be done about them.

Soil-Conservation Measures

Much is known about reducing soil erosion, and as programs exist to reduce it, these methods are obvious ones to consider. Standard soil-conservation practices are often suggested to help improve water quality in northeast Iowa. Clearly, they can aid in improving surfacewater quality, but their impact on groundwater has not been fully considered.

Soil-conservation measures are widely practiced in the Big Spring study area (Tables 7 and 8). This is indicated by the average potential soil-loss erosion figure computed for the study area using the USLE model: 7.3 tons/ acre. This value, in an area considered to have high erosion potential (Harmon and Duncan, 1978) because of forest-derived, loess soils and steeply sloping land, is below the state average, computed to be about 9.9 tons/ acre (USDA, 1980) for cropland. Figure 53 shows the distribution of potential erosion, computed using Universal Soil Loss Equation (USLE) with current landuse and management practices in the Big Spring basin.

Significant reductions in soil erosion can be obtained using accepted soil-conservation measures on cropland. Those measures evaluated with the USLE model include minimum tillage ("no till"), terracing, increased meadow in rotations, and strip cropping. Each was tested separately, none were modelled in combination. The results of computing the average annual soil loss with USLE on the basin, using these alternatives, yield basin-wide results ranging from 2.5 to 5.2 tons/acre (Table 44). Note that erosion figures are very comparable between the basins draining to sinkholes and the entire study area. Figures 54, 55, 56, and 57 reveal the geographic distribution of potential soil erosion classes. While the current management of soils in the basin is certainly good, altered management in various forms would clearly reduce soil erosion further.

Table 45 reflects how these management alternatives affect soil erosion on different slopes. Widespread implementation of any of these alternatives would reduce erosion below T (an acceptable level, usually 5 tons/acre) on C slopes, but cropping D slopes provides some problems. Only strip-cropping and meadow rotations would seem to reduce erosion below T on these D slopes, which cover about one-third of the basin, and are cropped extensively throughout. Steeper slopes would require very careful management to keep erosion below T, if they are cropped. Such data-base manipulations offer potential for soil-conservation programs.

The potential changes in sheet and rill soil erosion are important considerations in the selection of land-treatment alternatives. However, it is the effects on groundwater quality that are the principal concern of this study. Thus, the importance of each land-management alternative is its affects on water-flow paths and what the water may carry with it: how much chemical is applied with various land treatments, how much soil and chemical runs off into sinkholes, how much water and chemical percolates into the soil only to exit as tile drainage (entering sinkholes), or enters the aquifer as diffuse recharge? To begin to understand these relationships, modelling of runoff was also conducted using these same standard soil conservation measures.

Runoff Modelling

Modelling runoff with the Urban Hydrology for Small Watersheds model (TR-55; SCS 1975) permitted evaluation of the effect that three alternate management systems (all row-crop acreage strip cropped, one year of increased meadow in all rotations, and all cropland terraced) will have on surface runoff, compared to current land management. In this analysis, only those portions of the Big Spring basin draining directly into sinkholes (the sinkhole basins) were considered. It has been shown above that these areas are representative of the basin as a whole and their small size (11.5 sq. miles) makes them more applicable to the TR-55 model than the 103 sq. mile Big Spring basin. Table 46 lists the minimum 24-hour rainfall needed to produce runoff under the various landuse systems with antecedent moisture conditions II and III. Only with terracing is significantly more rainfall needed to produce runoff than under current landuse.

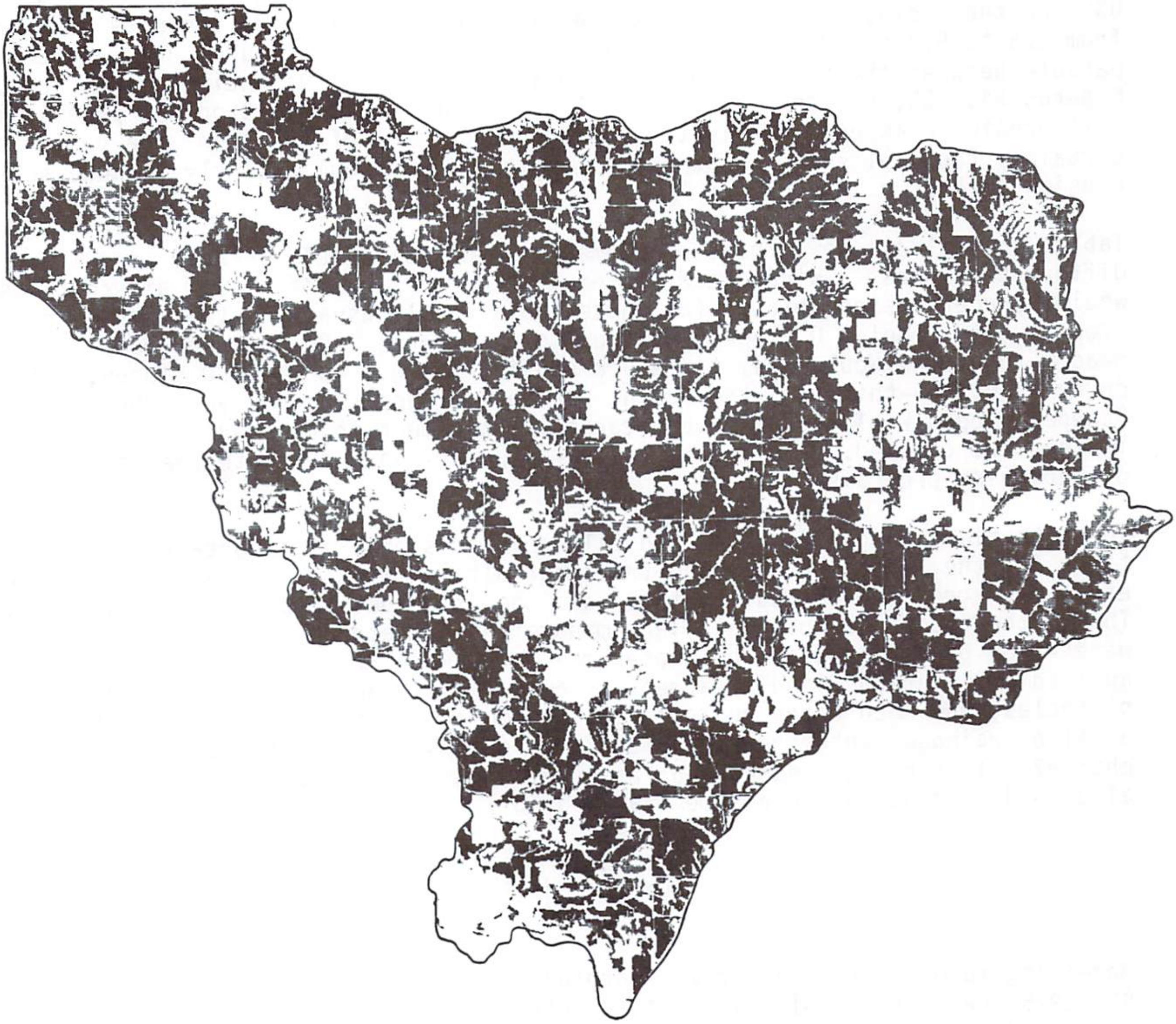


Figure 53. Potential soil erosion for 1980 in Big Spring basin as estimated using Universal Soil Loss Equation (USLE) and current land-use and management practices. White = 0-5 tons/acre; gray = 5-10 tons/acre; black = more than 10 tons/acre.

Table 44. Management effects on potential soil erosion calculated with the Universal Soil Loss Equation in Big Spring basin study area.

Management Practice	Big Spring Study Area (Tons/Acre)	Sinkhole Basins Only (Tons/Acre)
Existing Practices (1980)	7.3	7.2
No Till	5.2	5.1
Terrace all cropland	4.4	4.4
Increased Meadow in crop rotations	3.9	3.7
Strip crop all cropland	2.5	2.3
Native Vegetation	0.5	0.4

Table 47 presents the acre-feet of runoff calculated for these basins, which would be produced by various amounts of rainfall under antecedent moisture conditions II and III. Less total runoff is produced, for a given amount of rainfall (in excess of the minimum amount needed to produce runoff), as the amount of meadow or cover crop in the management system increases. The most significant decrease in runoff is attained by terracing all cropland. Runoff reduction as a percentage of that predicted under 1980 landuse is greatest for small precipitation events under all these alternate management systems.

TR-55 was used to model runoff in the sinkhole basins using the recorded 24-hour rainfall data, for the period March 16, 1982 to December 31, 1982. Model runs were made for current landuse as well as the three alternate management systems. These results are tabulated in Appendix 6. Table 48 summarizes the results of these analyses. Terracing is the most effective means for reducing runoff and direct run-in to sinkholes in these analyses. This management practice would be effective in reducing the peak loading of pesticides and turbidity associated with runoff events. However, terracing is costly and might necessitate changes in row-crop (increases) and cover-crop acreage to offset the expense incurred in building the terraces.

As a consequence of decreased runoff, infiltration would increase under these three alternate systems. This increase would probably be greatest under the terraced cropland system. Increased infiltration would promote increased leaching of nitrate, pesticides, and other applied agricultural chemicals. Thus, although these practices would reduce soil erosion and run-in to sinkholes (reducing the conduit-flow component), they would also increase infiltration, potentially increasing the delivery of chemicals in the diffuse-flow component of groundwater. Infiltration is the major component in the problems

Figure 54. Potential annual soil erosion in Big Spring basin using USLE and minimum tillage on all cropland. White = 0.5 tons/acre; grey = 6-10 tons/acre; black = more than 10 tons/acre.

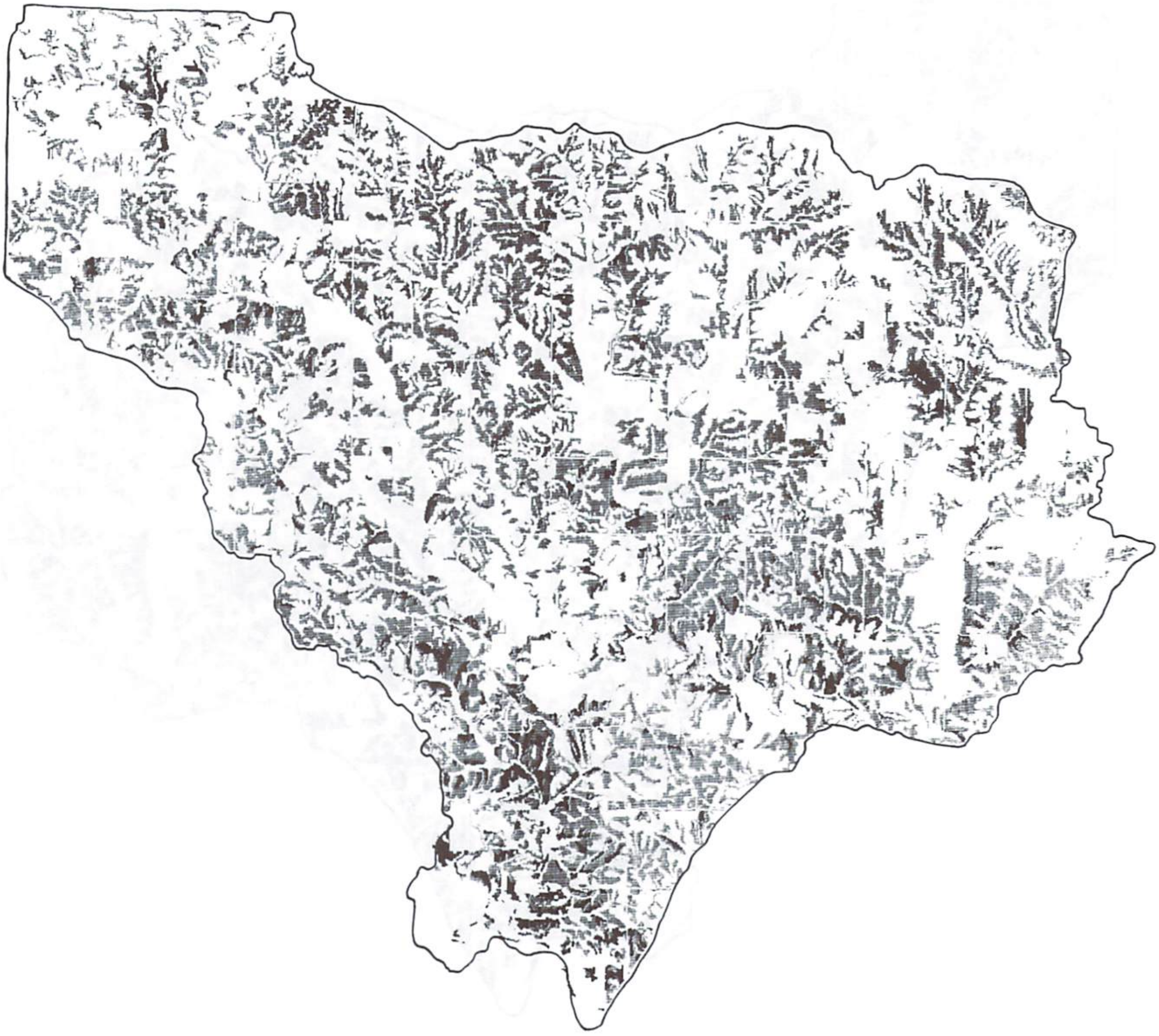


Figure 55. Potential annual soil erosion in Big Spring basin using USLE and terracing on all cropland. White = 0.5 tons/acre; grey = 6-10 tons/acre; black = more than 10 tons/acre.

Figure 56. Potential annual soil erosion in Big Spring basin using USLE and an additional year of meadow in all crop rotations. White = 0.5 tons/acre; grey = 6-10 tons/acre; black = more than 10 tons/acre.

Figure 57. Potential annual soil erosion in Big Spring basin using USLE and all cropland strip cropped. White = 0.5 tons/acre; grey = 6-10 tons/acre; black = more than 10 tons/acre.

Table 45. Effect of management practices on potential soil erosion for soil-slope classes in the Big Spring basin study area.

Potential Soil Erosion (Tons/Acre)

Slope Class	Area (sq. mi.)	Existing Management	No Till	Terraced Cropland	Increased Meadow in crop Rotations	Strip-Cropped Cropland
A	9.73	---	---	---	---	---
B	17.02	1.4	0.9	1.2	0.9	0.5
C	27.38	5.8	4.0	3.4	3.0	1.7
D	35.82	10.6	7.5	6.4	4.9	3.5
E	9.52	13.8	10.8	8.2	7.9	5.4
F & G	3.67	17.4	13.9	9.7	10.9	7.4

with groundwater quality, and thus increasing infiltration may drive the system in the wrong direction.

When the various alternatives are applied, however, certain assumptions were made which change the percentage of cropland planted to corn, oats, or meadow in any one year. Table 49 presents the rotations used for each alternative. No till and terracing alternatives can maintain the same rotations, but the strip cropping and increased meadow in rotations must reduce the area planted to corn annually. In addition to changes in erosion potential, surface runoff, and infiltration, the alternatives provide changes in cropping patterns leading to expected alterations in fertilization and chemical application. Estimated acreage changes in nitrogen application are shown on Table 49.

Effects and Evaluation of Land-Treatment Changes

A summary of projected management effects on the groundwater system are included in Table 50. This table also includes a summary of some pertinent, current practices and conditions. As stated earlier, it is not within the scope of the present research to fully evaluate these practices. Not enough is known in many cases about the effects of the various land-treatment practices on the complexities of the karst groundwater system to fully evaluate their impact. These are "best-guess" effects based on technical literature, the current research, and consultation with various agricultural experts.

Table 46. Minimum rainfall needed to produce runoff with model presented in TR-55.

Landuse	Antecedent moisture condition II	Antecedent moisture condition III
1980	0.75 inches	0.25 inches
All cropland strip cropped	0.75 inches	0.25 inches
Increased meadow in rotation	0.75 inches	0.25 inches
All cropland terraced	1.0 inches	0.5 inches

The brief narratives, presented below, on various management practices, will summarize the projected impacts on the karst-groundwater system, and hopefully can serve as a point of discussion which can then lead to constructive action: education, further research on various practices or products, regulation, and integrated soil, surfacewater- and groundwater-conservation programs.

Structural Practices

1. Terrace construction is a capital-intensive, soil-erosion measure, which has a major impact on water flow and infiltration. Terrace construction reduces the movement of soil (erosion) and as such, will reduce the delivery of sediment to sinkholes. Sediment, itself, is a significant problem at Big Spring, and pesticides reach their highest concentrations concurrent with runoff and high turbidity. Dieldrin is found attached to soil particles in suspension in the groundwater. The association of peak loading of pesticides, turbidity, and bacteria is a serious cause for concern in wells showing intermittent turbidity problems. As discussed, during runoff periods, local wells could exhibit much higher concentrations of pesticides than recorded in this study. Terraces should reduce such loading, and probably the total herbicide delivery, and should also reduce sediment accumulations at Big Spring. Unfortunately, terraces are least effective during times of highest runoff, when contaminant delivery is greatest.

   Another drawback of terraces is their effect on rainfall-soil water flow paths. Terraces will promote increased infiltration. As shown, this infiltrating water delivers high concentrations and the largest mass of nitrate as well as persistent but low concentrations of herbicides. These chemicals may be the most serious, long-term water-

Table 47. Acre-feet of runoff in sinkhole basins produced by given amounts of precipitation based on the model presented in TR-55.

Rainfall (inches)	Antecedent Moisture Condition	1980 landuse	All cropland strip cropped	Increased meadow	All cropland terraced
0.75	II	0.01	0.17	0.33	---
1.0	II	8.92	7.04	6.09	1.64
1.5	II	74.56	68.26	64.85	45.15
2.0	II	188.10	177.33	174.42	136.00
*5.5	II	1616.76	1582	1562.56	1439.05
**6.5	II	2121.81	2082.42	2060.33	1919.18
0.5	III	12.38	11.54	11.54	4.79
0.75	III	58.84	56.80	56.80	38.33
1.0	III	129.06	125.86	125.86	95.83
1.5	III	314.87	309.62	309.62	258.75
2.0	III	537.88	530.97	530.97	462.74
*5.5	III	2446.10	2433.31	2433.31	2301.40
**6.5	III	3030.86	3017.27	3017.27	2876.24

*50 year 24-hour rainfall
**100 year 24-hour rainfall

quality problems. Terracing will likely increase nitrate concentrations in the Galena aquifer. For perspective, though, if all the cropped area draining to sinkholes were terraced, and if all the reduced runoff became infiltration-recharge (which it would not), there would only be a potential, maximum increase in infiltration recharge to the Galena of about 3-5%. However, basin-wide terracing could increase potential recharge by a maximum of about 30-50%. Another important facet of terracing is an economic one. With the

Table 48. Modelled runoff for sinkhole basins 3/16/82-12/31/82 using TR-55. Total rainfall from 3/16/82 to 12/31/82 was 34.08 inches. The growing season was between 6/26 and 10/31.

Management	Runoff (acre feet)	Percent Decrease
Existing management	1,846	----
All cropland strip cropped	1,337	28
Increase meadow in rotation by one year	1,333	28
All cropland terraced	1,030	46

high capitalization involved there is a necessity to recover costs. Terracing leads to increase corn acreage, reducing the meadow rotations, and in turn, substantially increases the amount of N-fertilizer and other chemicals applied. Increased chemical application combined with the increased infiltration would have an adverse impact on groundwater quality.

2. Tiling is done, in general, to improve soil drainage in order to increase crop production acreage. It is associated with more intensive land utilization, thus, adding to the total fertilization and chemical application. It may now have a significant impact on nitrates and herbicides entering sinkholes. Tile drainage enhances the leaching of nitrate from the soil (Baker and Johnson, 1977; Harmon and Duncan, 1978). The resulting discharge, high in nitrate and containing some pesticides contributes to "base flow" in the intermittent and perennial streams feeding sinkholes, and other losing streams. In so altering flow and chemical composition, tile flow can function as a major portion of "point discharges" entering the aquifer at sinkholes. Their water quality may, therefore, strongly affect groundwater quality during "base flow" periods, especially along major fractures.

3. Detention structures could be constructed to reduce peak flow into sinkholes during runoff. As such, they could reduce sediment delivery. However, their location could be critical because numerous examples are available of shortened effectiveness caused by a new sinkhole opening behind the detention structure. Apparently, as water is ponded, the increased head (hydraulic gradient) and infiltration leads to sinkhole formation, defeating its purpose. Constructed in areas of local aquifer discharge or above shales, they could prove somewhat beneficial.

Table 49. Percentage of total basin in various crop rotations and percentage of total basin to which N fertilizer is applied for present land management and three alternatives.

Present conditions or all cropland terraced	Percent of basin in corn	Percent fertilized
21% CCCCCC*	21	21
32% cCComm	16	11
31% cCommm	10	5
2% commmmm	--	--
Total	47	37
All cropland strip cropped		
53% cCComm	27	18
33% cCommm	11	6
Total	38	24 (9 percent decrease over present)
Increased meadow in rotation		
21% cCComm	11	7
32% cCommm	11	5
33% commmmm	5	--
Total	27	12 (20 percent decrease over present)

*it is assumed that there is no N fertilization in corn after meadow. Fertilized corn years are indicated with a capital letter.

4. Filling sinkholes has also been proposed. This is only feasible, and has only been successful, with relatively small sinkholes. Generally, this is only a temporary solution, as the sinkholes will often reopen. There are numerous examples of such failures in northeast Iowa. Filling sinkholes and diverting drainage has also prompted the development of new sinkholes nearby.

Land Management Systems

1. Strip cropping proved the most effective practice for reducing erosion, based on USLE modelling in the study basin. It should also be one of the most effective practices for reducing groundwater degradation. This alternative is attractive because it reduces erosion and runoff to sinkholes, and therefore, peak sediment and peak pesticide loads. It should also decrease nitrate infiltration because it reduces the acreage on which nitrogen or herbicides are applied (Table 49).

2. Increased meadow rotations are similarly effective. However, corn acreage is reduced even more than with strip cropping. Thus, the total nitrogen and pesticide application would be further reduced, which might further reduce groundwater degradation.

3. The effects of minimum tillage on runoff and infiltration are unclear. Some studies suggest that no till may increase nitrate losses, through leaching and/or denitrification (e.g., Rice et al., 1982). Probably its effects are minimal. Further, it should have little effect on insecticide and herbicide acreage and applications of such chemicals can be expected to increase with these practices. However, as minimum tillage reduces soil erosion, it should reduce soil-attached chemicals, such as many insecticides, but will likely have little effect on water-soluble chemicals (Barisas et al., 1978; Ameniypa, 1977; Hubbard et al., 1982).

4. The effect of buffer zones around sinkholes would be small. However, allowing trees, grass, and weeds to grow up around sinkholes could reduce the sediment load, and presumably the pesticide load, entering the sinkholes. Careful selection of grass species for high nitrogen use, etc., might further reduce nutrient loads.

Fertilization Management

Reducing the losses of nitrogen, particularly in the form of nitrate, must be a prime objective to improve groundwater quality. This can be accomplished through many means--by reducing application rates, by finding ways that crops will use N more efficiently (using new hybrids, other forms of N), or finding N-forms that are more stable, for example. This is an area of needed research. Clearly, better N-management is needed; the losses reported in this study are substantial. A few pertinent points can be addressed below.

1. Lower N-application rates will clearly result in less nitrate build-up in soils and less leaching of nitrate, and thus should reduce

Table 50. Projected changes of management practices.[1]

Management Practice	Conduit Peak Flow	Base Flow	Sheet and Rill Erosion	Corn Acreage	Meadow Acreage	Nitrogen Applied
Existing Management Nov. 1981-Oct. 1982	3,360 acre-feet; 9% ground-water discharge	34,040 acre-feet; 91% ground-water discharge	7.3 tons/acre	31,000 acres; 47% Big Spring Basin	26,000 acres 40% Big Spring Basin	2740 Tons N; 175 lbs/acre on corn following corn
Structural						
Terracing[3]	-	+	-	+	-	+
Tiling[3]	-	+	+	+	-	+
Detention Structures[4]	-	+	0	0	0	0
Land Management						
Strip Cropping	-	+	-	-	+	-
Increased Meadow in Rotation	-	+	-	-	+	-
No Till	0(?)	0(?)	-	0	0	0
Buffer Zones Around Sinkholes	0	0	0	0	0	0
Fertilization Mgmt.						
Decrease N application			+[5]			-
Multiple N applications[6]			-[7]			-
N-stabilizers[6]			-[7]			-
Total N Management			-[8]			-
Integrated Pest Management						
Livestock Production						
Increased Pasture Acreage	-	+	-	-	+	-
Increase in Feedlot Animals[3]			+	+	-	+

[1]Assumes conventional good management.

[2]No judgements are made because none was found in study area. However, outside of the study area, Dyfonate was found in a local-flow spring system.

[3]Assumes that it will cause an increase in corn acreage.

Table 50, con't.

Nitrate in Groundwater	Herbicide Applied	Herbicide in Groundwater	Insecticide Applied	Insecticide in Groundwater[2]	Suspended Sediment	Bacteria
527 Tons N; 6% delivered in conduit peak flow; 94% delivered in base flow	Brands applied most widely: Atrazine Lasso Bladex Rate: 1.5 lbs/acre for Atrazine	Lasso & Bladex: May & June only, Atrazine: May-October; 03% of applied; 16% delivered in conduit peak flow; 84% delivered in base flow	Dyfonate Counter Thimet Amaze Mocap Lorsban Furadan Malathion Alfatox	Not found in Big Spring Basin	Problems found in some wells and at Big Spring during periods of high discharge	Problems found in some wells especially during periods of high discharge
+	+	-	+		-	-
+	+	-	+			
0	0	-	0		-	-
-		-			-	-
-	-	-			-	-
0(?)	+	?	+		-	-
0	0	-(0)	0		-	-
-						
-						
-						
	-	-				
-	-	-	-		-	+
+	+	+	+		+	+

[4]This practice may promote new sinkhole formation.
[5]Decreases N, decreases residue.
[6]Assume constant yield.
[7]Assume an increase of crop residue.
[8]Improves tilth.

nitrate concentrations recharging groundwater. Reducing N-application rates in the Big Spring basin from 175 lbs/ac to rates (generally considered more economical) of 150-120 lbs/ac could reduce N-losses by 15 to 30%.

2. Various studies show that multiple applications of N (versus one large application) during the growing season can reduce leaching losses of N by 20 to 40% (e.g.-Arora and Juo, 1982; Baker and Austin, 1982) and improve crop yields as well. Thus, if the same total amount of N was applied in three applications, it would increase yields and reduce N leaching to groundwater. Current yields could be maintained while reducing the amount of N applied, which would provide even greater benefits for water quality.

3. The effects of nitrogen stabilizers are unclear. Their real effects need further research, but potentially could be of benefit. Some forms of stabilization are effective for such a short time, and under such limited soil conditions that their effects on long-term leaching losses may be negligible.

4. Total N-management is an obvious, cost-effective place to begin reducing nitrate losses. All sources of N contributing to crop production should be considered before fertilizer application rates are established. N production resulting from crop rotations, organic material and manure application should be estimated and figured into the total N budget, so that applied chemical-N might be reduced to help reduce nitrate leaching losses. Nitrate losses are not simply the result of fertilization. Nitrate losses are the result of fertilization in excess of the usage by crops.

5. Better N-management must also include better management of manure and livestock wastes. Manure should be accounted for in N-budget requirements (also see discussion of Livestock and Waste Handling).

Pesticide Management

Although pesticide losses are low, compared to nitrate, the possible health effects of these chemicals are of concern. The largest concentrations of pesticides occur in runoff and thus shallow incorporation of pesticides, where appropriate, may help reduce these losses (Baker, 1980). Integrated pest management can also help to reduce insecticide use by as much as 50%, according to some estimates. Use of less persistent pesticides would also decrease the total concentrations in groundwater.

Livestock Production and Waste-Handling Systems

Livestock production and the wastes generated contribute to the long-term nitrate problems and to organic and bacterial-microbial problems in the groundwater in the region.

1. Better feedlot and waste disposal management should be promoted, particularly better manure collection and storage procedures. When limestone is very shallow, lots or storage areas should be paved.

2. Excessive manure applications to the same fields should be avoided, especially in shallow-to-bedrock areas.

3. Reduce runoff from feedlots and areas where manure and animal wastes are frequently used (particularly in sinkhole areas). Combinations of structural practices with vegetative filter strips could be useful to reduce runoff and organic loading to sinkholes. Other possibilities exist such as incorporating manure and not spreading manure during runoff periods or winter. In unconfined livestock operations, keep animals out of sinkholes and losing streams by using fences, buffer strips, watering systems, etc.

4. Reduce N-fertilizer applications by accounting for manure applications in fertilizer requirements.

5. Consider recycling manure for feed or energy production.

6. Increased animal production could have a generally beneficial affect on the leaching of chemicals to groundwater, if expansion comes from grazing. Such expansion would increase the pasture areas, thus reducing corn acreage and amount of chemicals applied. However, increased feedlot populations could deteriorate water quality further. Increased numbers of animals might require increased grain production resulting in expansion of corn acreage. However, it is not certain that this would happen, because grain is presently being exported from the area. Feedlot areas would need adequate protection against runoff into surfacewater and sinkholes.

Other Remedial Measures

In addition to the major discussion on recommendations and impacts of various agricultural land-treatment measures and chemical management changes, there are many other less-complicated changes that must be addressed. These are outlined below by topical area. In all these areas, various practices may be implemented through education, regulation in some instances, and perhaps through the development of new or innovative cost-share programs or other economic incentives (e.g., tax credits, etc.).

Rural Wells and Water Systems

Some problems of water quality, particularly on the local level, are related to well construction or well-placement problems. Thorough education or regulation improvements should be promoted such as:

1. Better well construction, especially proper, grouted casing. Wells should not allow the interchange of contaminated water in shallow

aquifers, with deeper protected aquifers; i.e.-St. Peter wells open to the Galena aquifer allow contaminated water direct access into the St. Peter aquifer.

2. Better well-location criteria. Wells located in low areas that receive surface run-on may allow surface drainage into the well and become contaminated (and possibly contaminate the aquifer).

3. Proper well-abandonment and plugging procedures. Abandoned wells may allow contaminated surfacewater into aquifers (see Van Eck, 1971).

4. Water testing to detect problems.

5. The abandonment of cisterns, and/or innovative ways to treat cistern problems. Cisterns contribute to microbial problems in rural water systems.

6. Mandatory use of anti-siphoning devices on wells for tank filling and chemical-formulating equipment.

7. Where possible, plug ag-drainage (injection) wells, or develop buffer-filter strips around them to reduce sediment and chemical discharge into them.

Home-Sewage Disposal

Through education and enforcement of regulations:

1. Eliminate direct discharges into sinkholes or waterways draining to sinkholes.

2. Promote alternatives (such as mound systems) to conventional septic tank-lateral leaching fields for new installations, and perhaps as replacements for leaching fields in thin soil areas.

3. Promote proper system maintenance, and proper disposal of sewage.

Waste Disposal

Improper disposal of waste may also contribute to groundwater-quality problems in the karst-carbonate aquifer regions. Improperly disposed hazardous materials could spread very quickly through the groundwater supplies of a large area. Such point-source problems clearly should be controlled as much as possible:

1. Prevent disposal of wastes in sinkholes and sinkhole areas.

2. Carefully scrutinize plans and permits for landfills in the carbonate-rock areas of northeast Iowa. Marginal sites should be avoided.

3. Carefully review existing and future discharges from municipal waste-treatment plants and industrial facilities in karst areas. Discharges into losing streams should be frequently monitored or reviewed.

4. Wherever possible, waste-disposal facilities should be sited outside of the karst-shallow bedrock areas to avoid possible problems.

5. Road ditches and culverts that empty directly into sinkholes should be redesigned, where possible, or utilize buffer strips to reduce sediment and chemical loads.

A Final Note on Management Changes

Projecting management changes and their effects is hazardous. Hopefully, new technological developments, such as new plant hybrids, new chemicals, etc. will assist in balancing the needs of modern agriculture and maintaining safe water quality. At the present time, the suggested land-management alternatives suggest substantive changes in style. Many factors will affect whether any changes take place. The farm economy, technological changes, capital investment, government programs--all affect what is done on the farm.

The obvious, most important factor is the response of independent farm operators. Potentially, the most benefical practices--strip cropping, increased meadow rotations, reduced N application, multiple N applications, total N management, and integrated pest management--all have economic consequences and most require complicated, difficult decisions, and implementation by the individual farm operator. The operator and his neighbors are also the ones being affected by the water-quality problem. This underscores the need for people in these regions to be: 1) informed about the quality of their water; 2) educated as to how their groundwater is being adversely affected; and 3) informed how their groundwater quality can be improved.

REFERENCES CITED

Aley, T., 1977, A model for relating land use and ground-water quality in southern Missouri; *in* Dilamarter, R. R., and Csallany S. C., *Hydrologic Problems in Karst Regions*, West. Kent. Univ., Bowling Green, Ken., p. 323-332.

Allen, M. J., and Morrison, S. M., 1973, Bacterial movement through fractured bedrock: *Ground Water*, v. 11, p. 6-12.

Amemiya, M., 1977, Conservation tillage in the western corn belt: *Jour. Soil and Water Conserv.*, v. 32, no. 1, p. 29-36.

Armstrong, D. E., Chesters, C., and Harris, R. F., 1967, Atrazine hydrolysis in soil: *Soil Sci. Soc. Am. Proc.*, v. 31, p. 61-66.

Arora, Yagesh, and Juo, A. S. R., 1982, Leaching of fertilizer ions in a kaolinitic ultisol in the high rainfall tropics: leaching of nitrate in field plots under cropping and bare fallows: *Soil Sci. Soc. Am. Jour.*, v. 46, p. 1212-1218.

Atkinson, T. C., 1977, Diffuse flow and condit flow in limestone terrain in the Mendip Hills, Somerset (Great Britain): *Jour. Hydrol.*, v. 35, p. 93-110.

Baker, J. L., 1980, Agricultural areas as nonpoint sources of pollution; *In* Overcash, M. R. and Davidson, J. M., eds: *Environmental Impact of Nonpoint Source Pollution*, Ann Arbor Science Publishers, Inc., Ann Arbor, MI, p. 275-310.

Baker, J. L., and Austin, T. A., 1982, Impact of agricultural drainage wells on groundwater quality: U.S. Env. Prot. Agency, Contract Rept., EPA Rept. No. G007228010, 126 p.

Baker, J. L., and Johnson, H. P., 1977, Impact of subsurface drainage on water quality: *Proc. Third Nat'l. Drainage Symp.*, Am. Soc. Ag. Eng., St. Joseph, MO.

Baker, J. L., and Johnson, H. P., 1979, The effect of tillage systems on pesticides in runoff from small watersheds: *Trans. Am. Soc. Ag. Eng.*, v. 22, p. 554-559.

Baker, J. L., and Johnson, H. P., 1981, Nitrate-nitrogen in tile drainage as affected by fertilization: *Jour. Environ. Qual.*, v. 10, p. 519-522.

Baker, J. L., Campbell, K. L., Johnson, H. P., and Hanway, J. J., 1975, Nitrate phosphorus, and sulfate in subsurface drainage water: *Jour. Environ. Qual.*, v. 4, p. 406-412.

Baker, J. L., Johnson, H. P., Borcherding, M. A., and Payne, W. R., 1978, Nutrient and pesticide movement from field to stream: a field study; *In* Loehr, R. C., Haitn, D. A., Walter, M. F., and Martin, C. S.., eds.: *Best Management Practices for Agriculture and Silviculture*, Ann Arbor Science Publishers, Inc., Ann Arbor, MI, p. 213-246.

Barisas, S. G., Baker, J. L., Johnson, H. P., and Laflen, J. M., 1978, Effect of tillage systems on runoff losses of nutrients, a rainfall simulation study: *Trans. Am. Soc. Ag. Eng.*, v. 21, p. 893-897.

Bassett, J. L., 1976, Hydrology and geochemistry of the upper Lost River drainage basin, Indiana: *The Natl. Speleo. Soc. Bull.*, v. 38, no. 4, p. 79-87.

Bolton, E. F., Nylesworth, J. W., and Hare, F. R., 1970, Nutrient losses through tile drains under three cropping systems and two fertility levels on a Brookston clay loam: *Can. Jour. Soil Sci.*, v. 50, p. 275-279.

Bounk, M. J., 1983, Some factors influencing phreatic cave development in the Silurian strata of Iowa: *Proc. Iowa Acad. Sci.*, v. 90, no. 1, p. 19-25.

Burnside, O. C., Fenster, C. R., and Wicks, G. A., 1971, Soil persistence of repeated annual applications of atrazine: *Weed Sci.*, v. 19, p. 290-293.

Burwell, R. E., Timmons, D. R., and Holt, R. F., 1975, Nutrient transport in surface runoff as influenced by soil cover and seasonal periods: *Soil Sci. Soc. Am. Proc.*, v. 6, p. 369-373.

Burwell, R. E., Schuman, G. E., Saxton, K. E., and Heinemann, H. E., 1976, Nitrogen in subsurface drainage from agricultural watersheds: *Jour. Environ. Qual.*, v. 5, p. 325-329.

Cameron, D. R., De Jong, R., and Chong, C., 1978, Nitrogen inputs and losses in tobacco, bean and potato fields in a sandy loam watershed: *Jour. Environ. Qual.*, v. 7, no. 4, p. 545-550.

Comly, Hunter, H. M. D., 1945, Cyanosis in infants caused by nitrates in well water: *Jour. Am. Medical Assoc.*, v. 129, no. 2, p. 112-116.

Dao, T. H., Lany, T. L., and Sorensen, R. C., 1979, Atrazine degradation and residue distribution in soil: *Soil Sci. Soc. Am. Jour.*, v. 43, p. 1129-1134.

Eisenbrand, G., Ungerer, O., and Preussmann, R., 1975, Formation of N-nitroso compounds from agricultural chemicals and nitrite; *In* Bogovski, P., and Walker, E. A., eds: N-Nitroso Compounds in the Environment: *IARC Sci. Pub. no. 9*, p. 71-74, Int. Agency for Research on Cancer, Lyon, France.

Frank, R., Braun, H. E, Van Hove Holdrinet, M., Sirons, G. J., and Ripley, B. D., 1982, Agriculture and water quality in the Canadian Great Lakes Basin: V. pesticide use in 11 agricultural watersheds and presence in stream water, 1975-1977: *Jour. Environ. Qual.*, v. 11, p. 497-505.

Fraser, P., and Chilvers, C., 1980, Health aspects of nitrate in drinking water: *The Science of the Environ.*, Water Supply and Health, *Studies in Environ. Sci.*, v. 12, p. 103-116.

Freeze, R. A., and Cherry, J. A., 1979, *Groundwater*: Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 604 p.

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

Gerwing, J. R., Caldwell, A. C., Goodroad, L. L., 1979, Fertilizer nitrogen distribution under irrigation between soil, plant, and aquifer: *Jour. Environ. Qual.*, v. 8, p. 281-284.

Gibb, J. P., Schuller, R. M., and Griffin, 1981, Procedures for the collection of representative water quality data for monitoring wells: *Ill. State Water Survey and Ill. Geo. Survey Coop. Ground Water Report 7*, 61 p.

Hallberg, G. R., 1980, Pleistocene stratigraphy in east-central Iowa: *Ia. Geol. Surv. Tech. Info. Ser. no. 10*, 168 p.

Hallberg, G. R., and Hoyer, B. E., 1982, Sinkholes, hydrogeology, and groundwater quality in northeast Iowa: *Ia. Geol. Surv., Contract Rept.*, 6/31/82, #81-5500-04, 120 p.

Hallberg, G. R., Hoyer, B. E., Libra, R. D., Bettis, E. A., III, and Ressmeyer, G. G., 1983, Additional regional groundwater quality data from the karst-carbonate aquifers of northeast Iowa: *Ia. Geol. Surv., Contract Rept.*, 4/15/83, #82-5500-02, 16 p.

Harmon, L., and Duncan, E. R., 1978, A technical assessment of nonpoint pollution in Iowa: Contract Report 77-001 to the Iowa Dept. Soil Conserv., College of Agric., Iowa State Univ., 427 p.

Harvey, E. J., and Skelton, J., 1968, Hydrologic study of a waste disposal problem in a karst area at Springfield, Missouri: *U.S. Geol. Surv., Prof. Pap.*, 600-C, p. C217-220.

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

Hergert, G. W., Watts, D. G., and Powers, W. L., 1982, Detection of nitrate beneath agricultural land and its long term implications for ground water pollution in Nebraska: *Ninth Annual Conference of the Groundwater Management Districts Association*, Scottsdale, Arizona, 20 p.

Hill, M. J., and Hawksworth, G., 1972, Bacterial production of nitrosamines in vitro and in vivo; N-nitroso Compounds analysis and formation: *IARC Sci. Pub. no. 3*, p. 116-121, Int. Agency for Research on Cancer, Lyon, France.

Hill, A. R., 1982, Nitrate distribution in the ground water of the Alliston region of Ontario, Canada: *Ground Water*, v. 20, no. 6, p. 696-702.

Hubbard, R. K., Erickson, A. E., Ellis, B. G., and Walcott, A. R., 1982, Movement of diffuse source pollutants in small agricultural watersheds of the Great Lakes basin: *Jour. Environ. Qual.*, v. 11, p. 117-123.

Hubbard, R. K., and Sheridan, J. M., 1983, Water and nitrate-nitrogen losses from a small, upland, coastal plain watershed: *Jour. Environ. Qual.*, v. 12, p. 291-295.

Johnson, H. P., and Baker, J. L., 1978, Development and testing of mathematical models as management tools for agricultural non point pollution control, v. 1, Dept. of Ag. Engineering, Iowa State University, 121 p.

Jones, T. W., Kemp, W. M, Stevenson, J. C., and Means, J. C., 1982, Degradation of atrazine in estuarine water/sediment systems and soils: *Jour. Environ. Qual.*, v. 11, p. 632-637.

Junkin, Bubby G., Pearsen, Ronnie W., Seyforth, Benjamin R., Kalcic, Maria T., and Graham, Marcelus H., 1980, ELAS, a geobased information system: *National Aeronautics and Space Administration, National Space Technology Laboratories, Earth Resources Laboratory, Mississippi, Report No. 183*, 467 p.

Kearney, P. C., 1980, Nitrasamines and pesticides: A special report on the occurrence of nitrosamines as terminal residues resulting from agricultural uses of certain pesticides (10): *Pure and Appl. Chem.*, v. 52, p. 499.

Keswick, B. H., and Gerba, C. P., 1980, Viruses in groundwater: *Environ. Sci. and Tech.*, v. 14, no. 11, p. 1290-1297.

Kim, N. K., and Stone, D. W., 1981, *Organic Chemicals and Drinking Water:* New York State Dept. of Health, 140 p.

Kuehl, R. J., 1978, Soil Survey of Clayton County--advance report: USDA, SCS, advance report, 184 p., plus field soil survey sheets.

Kuehl, R. J., 1982, *Soil Survey of Clayton County, Iowa;* USDA, SCS, 238 p.

LeGrand, H. E., and Stringfield, V. T., 1973, Concepts of karst development in relation to interpretation of surface runoff: *U.S. Geol. Surv. Jour. Res.*, v. 1, p. 351-360.

Leung, S. Y. T., and Richard, J. L., 1982, Pesticide accumulation in a new impoundment in Iowa: *Water Resources Bull.*, v. 18, no. 3, p. 485-493.

McDonald, D. B., and Splinter, R. C., 1982, Long-term trends in nitrate concentration in Iowa water supplies: *Research and Tech. Jour. AWWA*, v. 74, no. 8, p. 437-440.

Morris, R. L., and Johnson, L. G., 1969, Pollution problems in Iowa; *in* Horick, P. J., ed., *Water Resources of Iowa*, Ia. Acad. Sci., Cedar Falls, Ia., p. 89-109.

Meisinger, J. J., 1976, Nitrogen application rates consistent with environmental constraints for potatoes on Long Island: *Search Agriculture*, v. 6, no. 7, p. 1-19.

Mielke, L. N.,, Schepers, J. S., and Richards, K. A., 1979, Nitrogen leaching under center pivot irrigation on sandy loam soil: *Proc. Irrigation Assoc. Ann. Tech. Conf. 8-21 Feb. 1979,* San Francisco, Calif., The Irrigation Assoc., Silver Spring, Md., p. 85-94.

Muir, D. C., and Baker, B. E., 1976, Detection of triazine herbicides and their degradation products in tile-drain waters from fields under intensive corn (maize) production: *Jour. Agric. Food and Chem.,* v. 24, p. 122-125.

National Research Council, 1978, Nitrates: An environmental assessment. Environmental Studies Board, Commission on Natural Resources, Coordinating Committee for Scientific and Technical Assessment of Environmental Pollutants. National Academy of Sciences, Washington, D.C.

Neilsen, G. H., Culley, J. L. B., and Cameron, D. R., 1982, Agriculture and water quality in the Canadian Great Lakes Basin: IV. Nitrogen: *Jour. Environ. Qual.,* v. 11, p. 493-496.

Piskin, R., 1974, Evaluation of nitrate content of groundwater in Hall County, Nebraska: *Ground Water,* v. 11, no. 6, p. 4-13.

Plummer, L. N., Jones, B. F., and Truesdell, A. H., 1976, WATEQF - A FORTRAN IV version of WATEQ, a computer program for calculating chemical equilibrium of natural waters: *U.S. Geol. Surv. Water Resources Inv.,* 76-13 63 p.

Powell, R. L., 1977, Joint patterns and solution channel evolution in Indiana; *in* Tolson, J. S., and Doyle, F. L., eds., *Proc. 12th Int. Cong. Karst Hydrogeology,* Int. Assoc. of Hydrogeologists, Univ. Alabama-Huntsville, p. 255-269.

Prior, J. C., 1976, A regional guide to Iowa landforms: *Ia. Geol. Surv., Educ. Ser. No. 3,* 72 p.

Rice, C. W., and Smith, M. S., 1982, Denitrification in no-till and plowed soils: *Soil Sci. Soc. Am. Jour.,* v. 46, p. 1168-1173.

Richard, John J., Junk, G. A., Avery, M. J., Nehring, N. L., Fritz, J. S., and Svec, H. J., 1975, Analysis of various Iowa waters for selected pesticides: atrazine, DDE, and Dieldrin--1974: *Pesticides Monitoring Jour.,* v. 9, no. 3, p. 117-123.

Rogers, W. F., 1972, New concepts in hydrograph analysis: *Water Resources Research,* v. 8, no. 4, p. 973-981.

Rose, C. W., Chichester, F. W., and Phillips, I., 1983, Nitrogen-15-labeled nitrate transport in a soil with fissured shale substratum: *Jour. Environ. Qual.,* v. 12, p. 249-252.

Ross, R. D., Morrison, J., Rounbeher, D. P., Fan, S., and Fine, D. H., 1977, N-Nitroso compound impurities in herbicide formulations: *Jour. Agric. and Food Chem.*, v. 25, p. 1416-1418.

Rothschild, E. R, Mauser, R. J., and Anderson, M. P., 1982, Investigation of Aldicarb in ground water in selected areas of the Central Sand Plain of Wisconsin: *Ground Water*, v. 20, no. 4, p. 437-445.

Ruhe, R. V., 1969, *Quaternary Landscapes in Iowa:* Iowa State Univ. Press, Ames, Iowa, 255 p.

SCS, Engineering Div., 1975, Urban hydrology for small watersheds: Tech. Release no. 55, 98 p.

SCS, 1980, Iowa users guide and supplement to TR-55 urban hydrology for small watersheds: Des Moines, Iowa, 43 p.

Saffinga, P. G, and Keeney, D. R, 1977, Nitrate and chloride in ground water under irrigated agriculture in central Wisconsin: *Ground Water*, v. 15, no. 2, p. 170-177.

Saffinga, P. G, Keeney, D. R., and Tanner, C. B., 1977, Nitrogen, chloride and water balance with irrigated Russet Burbank potatoes in a sandy soil: *Agron. Jour.*, v. 69, p. 251-257.

Sampson, R. J., 1975, *Surface II Graphics System:* Kansas Geol. Surv., Lawrence, Kansas, 240 p.

Sander, J., Schweinberg, F,. and Menz, H. P., 1968, Unterschungen uber die Entstehung cancerogenes Nitrosamine im Magen: *Hoppe-Seyler's Z. physiol. Chem.*, v. 349, p. 1691-1697.

Scalf, M. J., McNabb, J., Dunlap, W., Cosby, R, and Fryberger, J., 1981, *Manual of Groundwater Quality Sampling Procedures*, National Groundwater Center, Ada, Oklahoma.

Schuman, G. E., McCalla, T. M., Saxton, K. E., and Knox, H. T., 1975, Nitrate movement and its distribution in the soil profile of differentially fertilized corn watersheds: *Soil Sci. Soc. Am. Proc.*, v. 39, p. 1192-1197.

Singh, B., and Sekhon, G. S., 1978, Nitrate pollution of groundwater from farm use of nitrogen fertilizers--a review: *Agric. and Environment*, v. 4, p. 207-225.

Singh, K. P., and Stall, J. B., 1971, Derivation of base flow recession curves and parameters: *Water Resources Research*, v. 7, no. 2, p. 292-303.

Smika, D. E., Heermann, D. F, Duke, H. R., Batchelder, A. R., 1977, Nitrate-N percolation through irrigated sandy soil as affected by water management: *Agron. Jour.*, v. 69, p. 623-626.

Smith, H. F., Harmeson, R. H., and Larson, T. E., 1975, The effect of commercial fertilizer on the quality of groundwater: Proc. Moscow Symposium. Groundwater Pollution: *IAHS-AISH Publ. No. 103*, p. 96-102.

Steinhilber, W. L., Van Eck, O. J, and Feulner, A. J., 1961, Geology and ground-water resources of Clayton County, Iowa: *Ia. Geol. Surv. Water-Supply Bull. No. 7*, 142 p.

Stojahovic, B. J., and Alexander, M., 1958, Effect of inorganic nitrogen on nitrification: *Soil Sci.*, v. 86, no. 4, p. 208-216.

Summers, W. K., and Brandvold, C. A., 1967, Physical and chemical variations in the discharge of a flowing well: *Ground Water*, v. 5-6, no. 1

Thrailkill, J., 1968, Chemical and hydrologic factors in the excavation of limestone caves: *Geol. Soc. Am. Bull.*, v. 79, p. 19-46.

Timmons, D. R, and Dylla, A. S, 1981, Nitrogen leaching as influenced by nitrogen management and supplemental irrigtion level: *Jour. Environ. Qual.*, v. 10, p. 421-426.

Tjostem, J. L., Young, Y., Hoilein, C., and Iverson, R. E., 1977, Bacterial and nitrate contamination of well water in northest Iowa: *Proc. Ia. Acad. Sci.*, v. 84, p . 14-22.

UHL, 1976, Water quality survey of the Turkey River basin: Univ. Hygienic Lab. Rept. #76-19, 27 p.

UHL, 1977, Water quality survey of Robert's Creek-Silver Creek: Univ. Hygienic Lab. Rept. #78-7, 16 p.

Van Eck, O., 1971 Optimal well-plugging procedures: *Ia. Geol., Surv., Public Info. Circ. 1*, 7 p.

Vanderholm, D. H., Lorimor, J. C., Melvin, S. W., 1974, Field performance of selected beef feedlot waste-handling systems: *Proc. Annual Meeting Am. Soc. of Agric. Engineers*, Stillwater, Oklahoma, 9 p.

Von Stryk, F. G., and Bolton, E. F., 1977, Atrazine residnue in tile drain water from corn plots as affected by cropping practices and fertility level: *Can. Jour. Soil Sci.*, v. 57, p. 249-253.

Walton, Graham, 1951, Survey of literature relating to infant methemoglobinemia due to nitrate-contaminated water: *Am. Jour. Public Health*, v. 41, p. 986-995.

White, W. B., 1969, Conceptual models for carbonate aquifers: *Ground Water*, v. 7, p. 15-21.

White, W. B., 1977, Conceptual models for carbonate aquifers: revisited; *in* Dilamarter, R. R, and Csallany, S. C., eds., *Hydrologic Problems in Karst Regions*, West. Kent. Univ., Bowling Green, Ken., p. 176-187.

White, E. L., and White, W. B., 1974, Analysis of spring hydrographs as a characterization tool for karst aquifers, *In* Rauch, H. W., and Werner, E., eds.: *Fourth Conference on Karst Geology and Hydrology Proceedings*, p. 103-106, West Virginia Geological and Economic Survey.

Witzke, B. J., 1983, Ordovician Galena Group in Iowa subsurface, in Delgado D. J., ed., Ordovician Galena Group--Deposition, Submarine and Later Diagenesis, and Paleoecology: *Soc. Econ. Paleon. Mineral., Great Lakes Sec., 13th Ann. Field Conf.*, in press.

Wischmeier, W. H., and Smith, D. D., 1978, Predicting rainfall erosion losses--a guide to conservation planning: *U.S. Dept. of Agric., Agric. Handbook no. 537*, 58 p.

APPENDIX 1:

Area of Soils Found in Big Spring Basin

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Area of Soils Found in Big Spring Basin

Material	Soil Series	Mapping Unit	Computer Soil Number	Acres	Sq. Mi.
Loess					
	Downs silt loam	162B	55	3198	5.00
		162C&C2	56	10452	16.33
		162D&D2	57	10001	15.63
		162E2	58	189	.29
	Fayette silt loam	163B	59	1028	1.61
		163C&C2	60	6667	10.42
		163D&D2	61	10873	16.99
		163E&E2	62	3241	5.06
		163F&F2 &F3	63	598	.93
	Exette silt loam	763D2&D3	97	195	.30
		763E2&E3	98	86	.13
		763F2&F3	99	35	.05
	Tama silt loam	120B	108	301	.47
		120C	109	35	.06
Eolian Sand					
	Lamont fine sandy loam	110C	38	2	.00
	Sparta loamy fine sand	41B	44	89	.14
		41C	45	43	.07
	Chelsea loamy fine sand	63B	47	7	.01
		63C	48	34	.05
		63E	49	42	.07
Glacial Till					
	Lindley loam	65D2	50	317	.49
		65F2&F3	51	523	.82
Limestone and Shaly Limestone Bedrock Influence					
	Rock outcrop-Nordness complex	478G	77	348	.54

Appendix 1, continued

Nordness silt loam	499B	88	18	.03
	499D	89	60	.09
	499F	90	751	1.17
Fayette silt loam, karst	40	43	72	.11
Fayette silt loam, karst	863D	102	45	.07
Dubuque silt loam	183C	66	13	.02
	183D&D2	67	202	.32
	183E&E2 &E3	68	1464	2.29
	183F	69	86	.13
Frankville silt loam	483D2	83	35	.05
	483E2	84	225	.35
Fayette-Dubuque silt loams	497E	86	5	.01
	497F	87	4	.01
Mottland silt loam	612D2	93	180	.28
	612E2	94	845	1.32
Luana silt loam	902C	103	15	.02
	902D2	104	1009	1.58
Marlean loam	512D2	112	3	.00
Shale Bedrock Influence				
Jacwin loam	444C	75	3	.00
Alluvium--Silty				
Huntsville silt loam	98	12	938	1.47
	98B	13	954	1.49
Arenzville-Chaseburg silt loam	129B	14	769	1.20
Colo silty clay loam	133	15	75	.12
Chaseburg silt loam	142	16	74	.12
	142B	17	97	.15
Dorchester silt loam	158	18	129	.20
	158C	19	18	.03
Camden silt loam	193	20	11	.02
Arenzville silt loam	320	22	817	1.28
Lawson silt loam	484	23	611	.95
Otter-Worthen silt loams	487B	24	3131	4.89
Ossian silt loam	489	25	632	.99
Dorchester-Volney complex	496B	27	73	.11
Otter silt loam	589	28	1374	2.15
Bertrand silt loam	793	29	153	.24
Rowley silt loam	826	30	259	.40

Appendix 1, continued

Canoe silt loam	926	31	309	.48
Orion silt loam	930	32	149	.23
	930B	33	599	.94
Richwood silt loam	977	34	103	.16
Festina silt loam	978	35	234	.37
Alluvium--Loamy				
Terril loam	323B	2	51	.08
Loamy Orthents	5040	8	43	.07
Spillville loam	485	9	13	.02
Saude loam	177	3	9	.01
Waukee loam	178	5	31	.05
Alluvium--Sandy				
Flagler sandy loam	284	39	34	.05
Lilah sandy loam	776	42	12	.02
Ankeny fine sandy loam	136	107	17	.03
Loess Covered Alluvium				
Fayette silty loam	463B	64	476	.74
benches	463C	65	248	.39
Muck				
Palms muck	221A	116	8	.01
	221B	115	97	.15
Miscellaneous				
Made land	---	114	25	.04
Quarries	---	113	38	.06
Ponds	---	110	123	.19
TOTAL	---	---	66073	103.24

APPENDIX 2

Water-Quality Data For Monitoring Sites, Listed by Site and Date of Sampling

Table 2-1. Water analyses for well VD-24 (site 11).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromhs/cm^2 @ 25°C	Other P or M	Notes
<u>1981</u>									
11/17	17	0							
<u>1982</u>									
1/26	10	0							
2/25	28	2.2	600$\pm$59	7.3	0.64				
3/23	26	2.2	--	7.3	0.41				
4/19	20	0	350$\pm$34	7.4	1.1				
5/26	19	0	510$\pm$50	7.4	1.5	11.0	700		
6/8								P	
6/22	18	0	450$\pm$48	7.4	0.57	11.0	740		
7/28	57	0	810$\pm$80	7.2	0.48	11.0	705	M & P	
8/24	24	0	400$\pm$45	6.9	1.6	13.5	720		
9/22	38	0	380$\pm$45	7.5	1.5	10.0	760		
10/26	36	0	490$\pm$59	-----	-----	12.0	760		
11/30	31	0	290$\pm$35	7.4	1.45	10.0	670		
12/28	24	0	310$\pm$37	7.3	0.69	7.5	700		
N	13			10	10		8		
$\overline{X}$	27			7.3	0.99		720		
S	12				0.48		32		

Table 2-2. Water analyses for well B-18 (site 15).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromhs/cm^2 @ 25°C	Other P or M	Notes
<u>1981</u>									
11/17	144	0							W-17703
<u>1982</u>									
1/26	137	0							
2/24	134	5.1	--	7.2	0.90			P	
3/23	134	5.1	--	7.2	0.55				
4/19	140	2.2	--	7.3	1.1				
5/26	148	5.1	990±91	7.3	3.6				
6/7								P	
6/22	154	2.2	1300±120	7.4	0.56	11.0	1110	P	
7/28	158	0	1100±103	7.3	0.58	10.5	1200	M & P	
8/25	141	9.2	900±88	7.1	8.7	10.0	1090		
9/22	132	0	1700±160	7.4	0.78	9.0	1050		
10/26	144	0	660±74	--	--	10.0	1090		
11/30	142	5.1	790±78	7.5	1.10	9.0	1100		
12/28	153	9.2	------	7.1	0.85	9.0	1100		
N	13			7.0	10		10		
$\overline{X}$	143			7.3	1.9		1100		
S	8			---	2.6		46		

Table 2-3. Water analyses for well B-32 (site 16).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromhs/cm^2 @ 25°C	Other P or M	Notes
<u>1981</u>									
11/18	19	0							
<u>1982</u>									
1/26	19	5.1							
2/24	17	0	--	7.5	39				
3/23	16	0	--	7.4	22				
4/19	15	0	--	7.6	6.3				
5/26	12	0	150±17	7.6	20	9.0	605		
6/7								P	
6/22	18	0	440±48	7.6	10.5	9.4	700		
7/28	19	0	300±30	7.4	0.35	10.0	700	M & P	
8/25	14	0	140±21	7.3	54	9.0	680		
9/22	18	0	140±20	7.6	2.75	9.0	685		
10/26	17	0	91±26			10.0	680		
11/30		out of order							
12/28	21	0	------	7.4	21	7.0	675		
N	12			9	9		7		
$\overline{X}$	17			7.5	20		675		
S	3				18		32		

Table 2-4. Water analyses for well VD-12 (site 26).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromhs/cm^2 @ 25°C	Other P or M	Notes
<u>1981</u>									
11/16	12	0							
<u>1982</u>									
1/26	26	16+							sampled at cistern
2/15	<5	0	320±34	7.4	>100				
3/23	<5	0	490±50	7.3	58				
4/19	--	--	--	--	--	--	--		
5/26	<5	0	870±84	7.4	78	10.5	810		
6/7								P	
6/22	<5	0	260±27	7.4	63.5	9.7	840		
7/28	36	2.2	820±75	7.2	3.55	10.0	830	M & P	
8/25	<5	0	390±44	7.1	42	9.5	800		
9/22	<5	0	480±53	7.4	21	9.5	780		
10/26	63	0	590±68	---------		9.0	790		
11/30	10	0	730±74	7.2	34.5	9.0	675		
12/28	34	16+	-----	7.2	5.1	9.0	890		
N	12			9	9		8		
$\overline{X}$	16			7.3	45		800		
S	20			---	33		62		

Table 2-5. Water analyses for well B-27 (site 30).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromhs/cm^2 @ 25°C	Other P or M	Notes
1981									
11/18	40	9.2							
1982									
1/26	43	0							
2/24	72	9.2	--	7.3	27				
3/23	38	0	--	7.3	0.91				
4/19	31	0	--	7.6	14				
5/26	35	0	1100±100	7.5	14	9.0	700		
6/7								P	
6/22	38	0	940±91	7.4	15	9.7	720		
7/28	41	16+	1200±110	7.4	1.2	10.0	700	M & P	
8/25	24	5.1	560±60	7.1	14	9.5	700		
9/22	23	5.1	760±81	7.4	7.4	8.5	710		
10/26	30	0	630±72	-----	-----	9.5	710		
11/30	27	9.2	750±74	7.4	78	9.0	690		
12/28	28	5.1	------	7.3	9.5	7.0	675		
N	13			10	10		8		
$\overline{X}$	36			7.4	18		700		
S	13			---	22		14		

Table 2-6. Water analyses for well VD-18 (site 37).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromhs/cm^2 @ 25°C	Other P or M	Notes
<u>1981</u>									
11/17	94	2.2							
<u>1982</u>									
1/26	88	2.2							
2/25	94	0	1000±95	7.2	31			P	
3/23	36	16+	1200±110	7.2	2.6				
4/19	84	16	800±82	7.3	3.4				
5/26	27	0	850±81	7.3	8.9	10.0	745		
6/7								P	
6/22	62	2.2	1100±100	7.4	7.8	10.2	900	P	
7/28	152	2.2	810±77	7.2	3.3	10.0	950	M & P	
8/24	114	0	930±94	7.0	3.0	10.0	980		
9/22	106	2.2	1100±110	7.3	5.2	10.0	960		
10/26	81	0	840±89	-----	-----	9.0	1000		
11/30	77	2.2	770±77	7.2	25	10.0	900		
12/28	74	0	-----	7.3	33	9.0	930		
N	13			10	10		8		
$\overline{X}$	84			7.2	12		920		
S	32			---	12		79		

Table 2-7. Water analyses for well L-7 (site 39).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromhs/cm^2 @ 25°C	Other P or M	Notes
1981									
11/16	120	16+							
1982									
1/26	142	0							
2/24	71	0	--	7.4	0.76				
3/23	108	16+	--	7.4	3.7				
4/19	109	0	--	7.3	1.8				
5/26	109	0	750±73	7.3	1.4	10.0	1075		
6/7								P	
6/22	--	--	--	--	--	11.6	610		
7/28	59	2.2	420±40	7.3	0.53	12.0	1200	M & P	
8/25	123	0	230±33	6.4	10	11.0	1275		
9/22	84	5.1	280±36	7.5	0.89	10.0	1150		
10/26	120	5.1	350±46	-------		10.5	1330		
11/30	108	16+	550±58	7.5	0.98	9.0	1100		
12/28	45	0	-----	7.4	0.95	8.5	535		
N	12			9	9		8		
$\overline{X}$	100			7.1	2		1030		
S	29			---	3		300		

Table 2-8. Water analyses for well PAT-20 (site 45).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromhs/cm[2] @ 25°C	Other P or M	Notes
1981									
11/18	<5	0							
1982									
1/26	<5	0							
2/25	<5	0	250±28	7.1	5.5				
3/23	<5	0	--	7.2	>100				
4/19	<5	0	210±23	7.2	22				
5/26	<5	0	260±30	7.3	4.5	11.5	650		
6/7								P	
6/22	<5	0	290±35	7.3	26	11.4	680		
7/28	<5	0	170±24	7.3	2.0	11.0	680	M & P	
8/24	<5	0	240±34	6.9	12	11.5	655		
9/22	<5	0	210±31	7.8	2.7	10.0	680		
10/27	<5	0	200±30	-----	-----	11.0	700		
11/30	<5	0	180±20	7.2	5.9	10.0	665		
12/28	<5	0	------	7.2	3.0	9.0	655		
N	13			10	10		8		
$\overline{X}$	<5			7.2	18		670		
S	0			---	30		17		

Table 2-9. Water analyses for well PAT-18 (site 47).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromhs/cm^2 @ 25°C	Other P or M	Notes
1981									
11/18	<5	0							
1982									
1/26	<5	0	83±12						
2/25	<5	2.2	110±15	7.3	11			P	
3/23	<5	0	130±17	7.3	37				
4/19	<5	0	120±15	7.4	57				
5/26	<5	0	110±17	7.4	9.5	9.5	585		
6/7								P	
6/22	<5	0	170±24	7.5	34	10.4	600	P	
7/28	<5	0	180±23	7.4	10	11.0	590	M & P	
8/24	<5	0	150±24	7.3	61	11.0	600		
9/22	<5	0	110±17	7.5	5.5	10.0	600		
10/27	<5	0	130±20	----------		10.0	620		
11/30	<5	0	110±15	7.4	32	9.0	605	P	
12/28	<5	0	52±12	7.3	55	8.0	610		
N	13			10	10		8		
$\overline{X}$	<5			7.4	31		600		
S	0			---	22		11		

Table 2-10. Water analyses for well F-51 (site 49).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromhs/cm[2] @ 25°C	Other P or M	Notes
<u>1981</u>									
12/15	11	0							
<u>1982</u>									
1/26	12	0							
2/25	26	0	1300±120	7.3	3.1				
3/23	17	0	1800±160	--	--				
4/19	42	2.2	1700±150	7.2	2.5				
5/26	25	5.1	--	7.2	10	10.0	695		
6/7								P	
6/22	39	9.2	790±74	7.5	4.9	10.5	810		
7/28	35	0	1100±110	7.4	0.78	11.0	705	M & P	
8/24	11	0	2100±190	7.2	3.2	11.0	650		
9/22	10	0	1800±180	7.8	0.90	10.0	630		
10/26	10	0	1700±160	-----	-----	10.0	665		
11/30	52	5.1	790±78	7.2	32	10.0	825	P	
12/28	30	2.2	------	7.1	2.1	8.0	600		
N	13			9	9		8		
$\overline{X}$	25			7.3	7		690		
S	14			---	10		81		

Table 2-11. Water analyses for well F-8 (site 52).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromhs/cm^2 @ 25°C	Other P or M	Notes
1981									
12/14	64	0							
1982									
1/26	59	0							
2/25	62	0	1200±110	7.3	0.56				
3/23	63	0	1300±130	7.3	0.42				
4/19	79	0	1000±96	7.0	3.4				
5/26	63	0	1500±130	7.6	0.90	10.5	735		
6/7								P	
6/22	63	0	1600±150	7.5	0.50	11.2	775		
7/28	61	0	1400±130	7.5	0.56	10.5	745	M & P	
8/25	60	0	1100±124	7.3	1.4	10.0	745		
9/22	57	0	1400±140	7.6	0.79	10.0	740		
10/26	55	0	1200±120	-----	------	10.0	760		
11/30	60	0	1100±110	8.0	1.3	9.0	725	P	
12/28	60	0	------	7.5	2.8	8.0	740		
N	13			10	10		8		
$\overline{X}$	62			7.4	1.3		750		
S	6			---	1		16		

Table 2-12. Water analyses for well F-33 (site 56).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromhs/cm^2 @ 25°C	Other P or M	Notes
<u>1981</u>									
12/14	35	0							
<u>1982</u>									
1/26	30	0							
2/25	18	16+	980±93	7.3	1				
3/23	34	16+	420±43	7.3	2.5				
4/19	36	2.2	730±69	7.3	1.9				
5/26	48	5.1	920±86	7.3	4.3	--	795		
6/7								P	
6/23	44	0	670±62	7.4	0.53	10.1	800		
7/28	47	2.2	240±28	7.5	0.47	12.0	750	M & P	
8/25	29	0	500±50	7.3	3.7	11.5	710		
9/22	30	0	520±62	7.8	1.7	11.0	710		
10/26	23	0	530±60	-----	-----	10.0	700		
11/30	39	16	790±77	7.3	1.35	9.0	750		
12/29	43	2.2	-----	7.6	2.0	9.0	800		
N	13			10	10		8		
$\overline{X}$	35			7.4	1.9		750		
S	9			---	1.3		43		

Table 2-13. Water analyses for well T-17 (site 57).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromhs/cm[2] @ 25°C	Other P or M	Notes
<u>1981</u>									
11/17	36	2.2							
<u>1982</u>									
1/26	41	2.2							
2/25	38	9.2	1200±110	7.4	0.82				
3/23	44	16+	330±34	7.7	0.82				
4/19	40	2.2	1000±95	7.5	1.1				
5/26	40	16+	900±83	7.5	1.2	--	745		
6/7								P	
6/22	45	16+	980±90	7.5	0.54	10.5	750		
7/28	46	16	780±76	7.5	0.55	12	755	M & P	
8/25	49	16+	880±84	7.4	1.5	9.5	775		
9/22	46	16	1300±130	7.9	0.83	9.0	750		Chlorinated well 1 week ago
10/26	58	5.1	1200±120	-----	-----	10.0	760		
11/30	58	5.1	1100±110	7.5	0.98	9.0	750		
12/29	52	16+	------	7.7	1.2	7.0	780		
N	13			10	10		8		
$\overline{X}$	46			7.5	0.95		760		
S	7			---	0.30		13		

Table 2-14. Water analyses for well L-42 (site 61).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromhs/cm^2 @ 25°C	Other P or M	Notes
1981									
11/18	86	0							
1982									
1/26	88	5.1							
2/25	74	5.1	520±51	7.0	4.4			P	
3/23	72	2.2	800±75	7.0	4.0				
4/19	79	0	770±73	7.0	3.4				
5/26	86	16	580±56	7.1	>100.0	--	1260		
6/7								P	
6/23	89	16+	600±42	7.3	19.0	10.1	1280	P	
7/28	104	5.1	570±57	7.1	4.6	11.0	1350	M & P	Well across road from L-42
8/25	41	16+	340±43	7.2	77.0	10.0	1010		
9/22									dismantled
N	9			7	7		4		
$\overline{X}$	80			7.1	30		1220		
S	17			---	41		150		

Table 2-15. Water analyses for well GL-1 (site 72).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromhs/cm[2] @ 25°C	Other P or M	Notes
1981									
12/14	35	5.1							
1982									
1/26	19	0							
2/25	29	0	460±47	7.2	0.89				
3/23	38	0	930±86	7.2	0.36				
4/19	38	2.2	840±77	7.3	1.3				
5/26	33	0	720±69	7.4	0.87	9.0	690	P	
6/7								P	
6/22	39	0	750±74	7.4	0.5	11.5	800		
7/28	40	5.1	--	7.4	0.46	11.0	855	M & P	
8/24	25	16+	400±46	6.9	2.5	14.0	850		
9/22	39	16+	500±59	7.3	0.87	13.0	850		
10/27	9	16+	400±47	-----	-----	10.0	940		
11/30	40	2.2	660±66	7.4	0.87	9.0	800		
12/28	36	0	710±73	7.3	0.77	7.0	825		
N	13			10	10		8		
$\overline{X}$	32			7.3	0.94		830		
S	10			---	0.61		71		

Table 2-16. Water analyses for well GL-8 (site 75).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromhs/cm^2 @ 25°C	Other P or M	Notes
<u>1981</u>									
12/15	90	0							
<u>1982</u>									
1/26	75	16	270±28						
2/25	101	16+	70±11	7.8	10.0			P	
3/23	76	16+	580±57	7.0	0.45				
4/19	88	5.1	460±45	7.2	1.0				
5/27	65	2.2	400±39	7.2	1.4	--	755	P	
6/23	92	16+	210±27	7.4	0.44	13.7	1040	P	
7/28	100	0	--	7.4	0.51	14.0	1010	M & P	
8/25	101	0	220±32	7.6	2.1	14.0	1090		
9/22	83	0	450±53	7.3	1.0	14.0	1000		
10/27	60	5.1	540±61	-----	-----	12.5	925		
11/30	80	16+	530±55	7.1	0.90	10.0	950		
12/29	97	16+	76±14	7.5	1.0	8.0	990		
N	13			10	10		8		
$\overline{X}$	85			7.3	1.9		970		
S	14			---	2.9		100		

Table 2-17. Water analyses for well AB-6 (site 81).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromhs/cm^2 @ 25°C	Other P or M	Notes
1/27	33	2.2							
2/25	32	0	--	7.5	15.0				
3/23	35	16+	--	7.5	2.0				
4/19	33	9.2	--	7.6	2.3				
5/26	34	0	780±74	7.7	2.5	13.0	450		
6/7								P	
6/23	38	0	590±61	7.6	1.4	11.8	500		
7/28	36	0	690±69	7.5	1.45	9.0	560	M & P	
8/24	36	0	550±61	7.2	3.7	12.0	460		
9/22	29	0	720±78	8.1	1.8	11.0	475		
10/27	29	0	690±73	-----	-----	11.0	490		
11/30	35	16+	650±61	7.7	2.9	10.0	490		
12/28	39	16+	400±44	7.5	2.1	8.0	495		
N	12			10	10		8		
$\overline{X}$	34			7.5	3.5		490		
S	3			---	4.1		33		

Table 2-18. Water analyses for Big Spring (site 82).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromohs/cm^2 @ 25°C	Other P or M
10/27/81	47	16+						
11/3/81	43	16+						
11/10/81								P
11/18/81	39	16+						
12/01/81	38	16+						
12/15/81	41	16+						P
12/22/81	40	16+						
12/29/81	42	16+						
1/12/82	36	16+						
1/19/82	37	16+						
1/26/82			200±22					
2/02/82	35	16+						
2/10/82	35	16+						
2/16/82	33	16+						
2/23/82	30	16+						
2/24/82	30	16+	290±28					
2/25/82	31	16+	230+24 240±24					P
2/26/82	32	16+	260±26	7.3	9			
3/02/82	35	16+						
3/09/82	26	16+						
3/13/82	23	16+						
3/16/82	23	16+						

Table 2-18, con't.

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromohs/cm² @ 25°C	Other P or M
3/22/82	35	16+	350±41					
3/23/82	38	16+		7.2	13			
4/06/82	39	16+						
4/13/82	40	16+						
4/20/82	41	16+	260±27	7.3	8.7			
4/28/82	42	16+						
5/12/82	40	16+						
5/18/82	44	16+						
5/25/82	50	16+						
5/27/82 7:50 am	47	16+						
5/27/82 1:15 pm	46	16+						
5/27/82 2:30 pm	46	16+						
5/27/82 9:50 pm	46	16+	240±28					
5/28/82 9:00 am	46	16+	350±37	7.4	2.9	9.1	700	P
5/28/82 10:45 am	46	16+						
5/28/8 12:00 pm	45	16+	370±38					
5/30/82	47	16+						
6/01/82	47	16+						P
6/07/82			320±36					
6/08/82	45	16+	290±29					P
6/15/82	47	16+						P

Table 2-18, con't.

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromohs/cm^2 @ 25°C	Other P or M
6/23/82	50	16+	310$\pm$36	7.4	3.7	9.4	780	P
6/29/82	45	16+						P
7/06/82								P
7/07/82 8:00 am	46	16+						P
7/07/82 3:10 pm	46	16+						
7/08/82 7:50 am	45	16+						
7/08/82 12:50 pm	45	16+						P
7/08/82 3:35 pm	43	16+						
7/13/82	43	16+						P
7/21/82	40	16+						P
7/28/82	36	16+	240$\pm$29	7.2	1.75	11.0	670	M & P
8/03/82	41	16+						P
8/10/82	37	16+						
8/17/82	38	16+						
8/25/82	35	16+		7.1	5.6	11.0	700	P
9/07/82	37	16+						P
9/14/82	34	16+						
9/22/82	35	16+		7.3	2.0	10.0	745	P
9/28/82	34	16+						
10/5/82	33	16+						P
10/12/82	33	16+						P
10/19/82	34	16+						

Table 2-18, con't.

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromohs/cm² @ 25°C	Other P or M
10/26/82	33	16+	150±23			10.5	750	P
11/1/82	33	16+						
11/3/82								P
11/9/82					sample bottle broken			
11/16/82	57	16+						P
11/30/82	44	16+	290±29	7.4	4.8	9.0	740	P
12/1/82	48	16+						
12/14/82	50	16+						
12/21/82	51	16+						
12/28/82 10:45 am	43	16+	250±30			9.0	705	
12/28/82 12:25 pm			270±32			8.5	610	
12/28/82 1:20 pm			270±31			9.0	725	
12/28/82 2:25 pm			230±28			9.0	705	
12/28/82 3:20 pm			300±34			8.5	680	
12/28/82 4:20 pm			230±28			8.5	650	
12/28/82 5:20 pm			290±34			8.5	660	
12/28/82 7:10 pm			270±32			9.0	700	
12/28/82 8:10 pm			240±31			9.0	710	
12/28/82 9:10 pm			280±34			9.0	600	

Table 2-18 con't.

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromohs/cm^2 @ 25°C	Other P or M
12/28/82 10:15 pm			330±37			9.0	705	
12/28/82 11:10 pm			240±31			9.0	700	
12/29/82 12:10 am			320±36			9.0	700	
12/29/82 4:00 am			240±30			8.0	675	
12/29/82 6:15 am			240±30			8.0	675	
12/29/82 10:10 am	45	16+	300±36	7.2	42.5	9.0	655	
N	71	71	32	11	11		23	
$\overline{X}$	40	NA	272	7.3	9		700	
S	7	NA	47		12		40	

Table 2-19. Water analyses from well AB-3 (site 84).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromhs/cm^2 @ 25°C	Other P or M	Notes
1982									
1/27	14	5.1							
2/25	30	16+	230±27	7.1	11			P	
3/23	35	16+	320±34	7.3	>100				
4/19	38	16+	--	7.3	62				
5/27	60	16+	340±35	7.8	4.0	10.0	955	P	
6/23	49	16+	310±36	7.4	23	10.3	910	P	
7/28	33	16+	--	7.4	10	11.0	750	M & P	
8/24	5	16+	160±26	7.4	16	10.0	710		
9/22	16	16+	250±36	8.1	>100	10.0	710		
10/26	18	16+	460±54	-----	-----	11.0	750		
11/30	31	16+	630±60	7.5	24.5	10.0	875		
12/29	46	16+	------	7.9	2.7	9.0	890		
N	12			10	10		8		
$\overline{X}$	31			7.4	35		820		
S	16			---	38		99		

Table 2-20. Water analyses for tile line L-22 (site 108).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromhs/cm^2 @ 25°C	Other P or M	Notes
1981									
11/17	97	16+						P	
1982									
1/26	--	--	--	--	--	--	--	--	Not flowing
2/25	32	16+	--	6.9	11.0			P	
3/22	58	16+	--	6.9	5.1				
4/19	81	16+	--	7.0	2.0				
5/26	74	16+	--	7.0	3.2	11.0	575	P	
6/7								P	
6/22	86	16+	730±72	7.1	0.61	11.7	675	P	
7/28	86	16+	--	6.8	0.55	--	--		
8/24	70	16+	590±64	6.8	0.81	14.5	590	P	
9/22	65	16+	840±86	7.3	0.78	13	600	P	
10/26	63	16+	830±88	-----	------	12.0	600	P	
11/30	72	16+	870±85	7.0	0.83	9.0	615		
12/28	79	16+	------	6.90	1.7	5.0	625	P	
N	12			10	10		7		
$\overline{X}$	72			7.0	2.7		610		
S	17			---	3.3		32		

Table 2-21. Water analyses for surface water L-23 (site 109).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromhs/cm^2 @ 25°C	Other P or M	Notes
1981									
11/17	40	16+							
1982									
1/26	36	16+	--	--	--	2			
2/25	23	16+	--	7.5	13.0			P	
3/22	29	16+	--	7.5	21.0				
4/19	49	16+	--	7.9	10.0				
5/26	40	16+	120±17	7.6	19.0	11.5	625	P	
6/22	61	16+	85±17	7.9	5.9	18.5	645	P	
7/28	37	16+	87±17	7.9	10.0	18.0	675		
8/24	34	16+	120±22	7.4	32.0	18.0	700		
9/22	34	16+	130±23	7.3	8.0	11.0	705		
10/26	31	16+	180±30	-----	-----	10.0	705		
11/30	42	16+	120±20	7.9	5.5	6.0	620		
12/28	51	16+	------	7.6	18.5	3.0	535		
N	13			10	10		8		
$\overline{X}$	39			7.6	14.3		650		
S	10			---	8.3		58		

Table 2-22. Water analyses for surface water F-45 (site 110).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromhs/cm^2 @ 25°C	Other P or M	Notes
1981									
12/15	38	16+							
1982									
1/26	--	--	--	--	--	--	--	--	Frozen
2/25	21	16+	100±15	7.4	26				
3/23	35	16+	160±25	7.7	48				
4/19	43	16+	64±12	7.9	25				
5/26	46	16+	60±10	8.0	16	13.0	650		
6/7								P	
6/23	54	16+	70±10	8.2	10.3	15.7	710		
7/28	32	16+	41±8	8.2	20	22.0	675		
8/25	22	16+	45±10	7.5	14.0	17.0	570		
9/22	27	16+	49±11	7.2	8.3	16.0	695		
10/26	26	16+	60±14	----------		10.0	710		
11/30	40	16+	61±10	8.0	14	4.0	705		
12/28	38	16+	------	7.6	>100	3.0	420		
N	12			10	10		8		
$\overline{X}$	35			7.7	36		640		
S	10			---	32		101		

Table 2-23. Water analyses for surface water F-47 (site 111).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromhs/cm^2 @ 25°C	Other P or M	Notes
1981									
12/15	37	16+							
1982									
1/26	--	--	--	--	--	--	--	--	Frozen
2/25	20	16+	44±12	7.5	24.0			P	
3/23	31	16+	45±10	7.8	65.0				
4/19	44	16+	14±17	8.1	23.0				
5/26	43	16+	25±7	8.1	49.0	--	635		
6/8								P	
6/23	57	16+	0	8.4	27.0	16.4	720		
7/28	33	16+	------	8.3	20.0	24.5	650	M & P	
8/25	24	16+	------	7.4	85.0	17.5	660	P	
9/21	23	16+	6±.6	8.5	10.1	13.5	655	P	
10/26	21	16+	13±11	-----	-----	9.5	695	P	
11/30	40	16+	51±11	8.1	10.0	5.0	680		
12/29	50	16+	------	7.8	42.0	-0.5	510	P	
N	12			10	10		8		
$\overline{X}$	35			7.9	36		650		
S	12			---	25		63		

Table 2-24. Water analyses for Turkey River (TR-1) (site 113).

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromohs/cm^2 @ 25°C	Other P or M
10/27/81	34	16+						
11/03/81	28	16+						
11/11/81	25	16+						
12/04/81	27	16+						
12/15/81	33	16+						
12/22/82	32	16+						
12/29/82	33	16+						
1/27/82	26	16+						
2/23/82	16	16+						
2/25/82	20	16+						P
2/26/82	22	16+	40$\pm$10	7.8	19			
3/02/82	23	16+						
3/13/82	12	16+						
3/16/82	14	16+						
3/22/82	24	16+						
3/23/82	26	16+	14$\pm$16	7.7	80			
4/06/82	27	16+						
4/13/82	27	16+						
4/20/82	31	16+	10$\pm$5	8.8	91			
4/28/82	29	16+						
5/11/82	25	16+						
5/18/82	31	16+						
5/25/82	43	16+						

Table 2-24, con't.

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromohs/cm² @ 25°C	Other P or M
5/27/82	38	16+						P
5/28/82	34	16+	25±5	8.0	49	14.0	545	
6/01/82	41	16+						
6/08/82	35	16+						P
6/15/82	27	16+						
6/23/82	35	16+	40±11	8.3	24	19.9	600	P
6/29/82	29	16+						
7/07/82 8:00 am	25	16+						
7/07/82 3:10 pm	24	16+						
7/08/82 7:50 am	25	16+						
7/08/82 12:55 pm	25	16+						
7/08/82 3:35 pm	25	16+						
7/13/82	24	16+						
7/21/82	33	16+						
7/28/82	36	16+	47±9	7.9	19.5	21.0	545	
8/03/82	23	16+						
8/10/82	22	16+						
8/17/82	19	16+						
8/25/82	15	16+		7.1	74	17.0	505	
9/7/82	28	16+						
9/14/82	24	16+						

Table 2-24, con't.

Date	NO_3 mg/l	Bac. MPN	Radon piCi/l	pH	Turbid NTU	Temp. °C	Cond. micromohs/cm^2 @ 25°C	Other P or M
9/22/82	30	16+		7.3	11.0	15.0	585	
9/28/82	27	16+						
10/05/82	22	16+						
10/12/82	25	16+						
10/19/82	24	16+						
10/26/82	34	16+	31±3			10.0	575	
11/02/82	30	16+						
11/09/82	32	16+						
11/16/82	37	16+						
11/30/82	35	16+	26±6	7.4	15	5.0	585	
12/07/82	27	16+						
12/14/82	6?	16+						
12/21/82	36	16+						
12/28/82	22	16+		7.8	>100	0.0	275	
N	58	58	9	10	10		8	
$\overline{X}$	28	16+	29	7.8	48		525	
S	7	NA	13	0.5	35		100	

APPENDIX 3

Miscellaneous Water-Quality Data From Samples Collected During Monitoring Period

Table 3-1. Water-quality data from miscellaneous samples collected during 1982.

Galena Wells

Site	Date	NO_3 mgl	Bact MPN	Comments
	1/26/82			
88. AB-1		39	0	
AB-5		6	0	
	2/25/82			
8. AB-10		53	0	
AB-9		7	0	
	5/28/82			
83. JSW		26	0	
116. H-Series				
JH-1		26	16	
JH-4		33	0	
JH-5		43	2.2	
	7/28/82			
83. JWS		62	0	
90. BL-1		17	9.2	
	8/25/82			
83. JSW		28	0	
		28	0	
	10/25/82			
18. PAT-19A		<5	0	
31. B-10		290	0	
32. PAT-16		<5	16	
46. PAT-28		<5	0	
63. PAT-26		<5	2.2	

Galena Springs

Site	Date	NO_3 mgl	Bact MPN	Comments
	1/26/82			
78. SO		42	16+	St. Olaf Spring

Table 3-1, con't.

4/28/82			
89. JH-8	50	16+	Heick Springs (W)
89. JH-9	28	16+	" (E)
5/28/82			
116. JH-2	32	16+	Hi level Heick Spring
89. JH-8	44	16+	Heick Spring (W)
89. JH-9	30	16+	" (E)
6/23/82			
102. SC	30	16+	Spook Cave Spring
8/25/82			
78. SO	33	16+	St. Olaf Spring
11/30/82			
78. SO	54	16+	"
	56	16+	"
12/29/82			
78. SO	68	16+	"
1/15/83			
Coldwater Cave Series			
	35	16+	Cave Stream
	32	16+	"
	6	0	Water dripping in through roof of cave
	Other Wells		
1/26/82			
106. AB-2	<5	0	St. Peter Well
98. AB-4	28	0	Open to Galena thorugh St. Peter
6/23/82			
102. SW	<5	0	St. Peter Well
102. SP	<5	16+	St. Peter Spring

Table 3-1, con't.

8/25/82			
61. L-42N	<5	0	New St. Peter Well
106. AB-2	5	0	St. Peter Well
10/26/82			
91. PAT-22	18	16	Maquoketa Well
92. PAT-17	47	9.2	"

Surfacewater and Sinkholes

1/26/82			
107. CT-54	26	16+	
3/22/82			
D. Ihde Sink	<5	16+	Overland flow into new sinkhole
5/28/82			
116. H-Series; small streams, spring fed in upper reaches; discharge to sinkholes in lower reaches			
JH-3	13	16+	
JH-6	9	16+	
JH-9	10	16+	
8/25/82			
115. RC-2	23	16+	
11/30/82			
114. SC-1	44	16+	
115. RC=2	42	16+	
1/16/83			
Fuelling sinkhole - Water seeping into, and running through new sinkhole			
	33	16+	

Table 3.2. Water-quality data from surfacewater and tile-line discharge which drains into sinkholes.

I. Buggenhagen Basin

Streams draining from cornfields to sinkholes

	5/6/82			5/27/82			7/28/82		
	NO_3 mg/l	Bact. MPN	Pesticides mg/l	NO_3 mg/l	Bact. MPN	Pesticides mg/l	NO_3 mg/l	Bact. MPN	Pesticides mg/l
BSW-1	27	16+	6.30A 31.00B 12.70L 1.50S	43	16+				
BSW-2	51	16+	1.40A 8.00B 4.00L 3.30S	14	16+		25	16+	0.13A
BSW-3	--	--		35	16+		(Run-in to new sinkhole)		

Tile line draining cornfield adjacent to BSW-1.

	5/6/82			5/27/82			7/28/82		
BTL-1	72	16+	0.90A	70	16+	1.00A 6.50B 1.50L	79	16+	0.24A 0.08B

II. Sass Basin

Streams draining from cornfields to sinkholes.

	5/6/82			5/27/82		
	NO_3 mg/l	Bact. MPN	Pesticides mg/l	NO_3 mg/l	Bact. MPN	Pesticides mg/l
ES-1	8	16+	1.90A 7.20B	18	16+	

Table 3.2,con't.

ES-2	30	16+	43	16+	
ES-4	--	--	24	16+	
ES-5	--	--	27	16+	
			Tile line draining cornfield		
ESTL-1	51	16+	60	16+	
			Tile line draining alfalfa and small cornfield		
ESTL-2	88	16+	96	16+	0.70A

III. Miscellaneous Sheetwash (overland flow)

	Samples		
1. Sheetwash collecting in road ditch;	<5	16+	
2. Dark turbid runoff from cornfield;	<5	16+	55.00A 0.30L
3. Runoff from feedlot;	<5	16+	
4. Runoff from feedlot;	<5	16+	

APPENDIX 4

Properties of Common Pesticides Found in Water Samples in the Big Spring Study

The following section contains a short discussion of the pesticides detected in groundwater within the Big Spring basin and nearby areas of northeast Iowa. Included are chemical formulas of the various pesticides, the biochemical effects of these compounds on pests, and data concerning pesticide persistence in soils, solubility in water, and acute toxicity. Toxicity is expressed as the lethal dose 50 (LD_{50}), the dosage that is lethal to 50% of a test animal population. LD_{50} values are expressed as milligrams of pesticide per kilogram of body weight, and are usually determined from tests on laboratory rats. As a comparison for the LD_{50} values of the pesticides, the LD_{50} for aspirin and table salt are 2500 and 3320 mg/kg, respectively.

Data for this discussion are taken from Ware (1982), McEwen and Stephenson (1979), and the Cooperative Extension Service, Iowa State University (1981).

<u>Atrazine</u> (2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine)

Atrazine is a triazine, a class of chemicals that act as strong inhibitors of photosynthesis in certain plants. Atrazine is the pesticide most commonly applied to corn. The LD_{50} toxicity of atrazine in laboratory rats is 3080 mg/kg body weight. The solubility of atrazine in water is about 33 mg/l at room temperature. Atrazine is strongly adsorped onto soil colloids. Persistence in soils varies between two and eight months at common application rates.

Bladex (2-(4-chloro-6-ethylamino-5-triazine-2-ylamino)-2-methyl propionitrile)

Bladex is a trade name for cyanazine. Cyanazine, like atrazine, is a triazine applied to corn, and selectively inhibits photosynthesis. The LD_{50} of Bladex in laboratory rats is 334 mg/kg. 171 mg/l of Bladex are soluble in water at room temperature. Bladex is strongly adsorped onto soil colloids. Soil persistence is commonly two to three months.

Lasso (2-chloro 2',6'-diethyl-N-(methoxymethyl) acetanilde)

Lasso is a trademark for alachlor, a substituted amide. Lasso inhibits protein synthesis in seedlings of grasses and broadleaf weeds. The LD_{50} of Lasso in laboratory rats is 1800 mg/kg. The solubility of Lasso is 242 mg/l at room temperature. Soil colloid adsorptivity is strong. With common rates of application, Lasso will persist one to two months in soils.

Dual 2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2 methoxy-1-methylethyl) acetamide

Dual is a trade name for metoachlor, a member of a class of chemicals termed chloracetamides. Dual inhibits nucleic acid metabolism and protein synthesis in grasses and some broadleaf weeds. Dual is applied to both corn and soybeans. The LD_{50} for Dual in laboratory rats is 2780 mg/kg. Water solubility is 530 mg/l at room temperature. Dual is strongly adsorped onto soil colloids. Dual generally persists for 1-3 months in soils.

Sencor 4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5-(4H)-one

Sencor is a trade name for metribuzin, which, like atrazine and Bladex, is a triazin. Sencor is applied mainly to soybeans and wheat. The LD_{50} toxicity of Sencor in laboratory rats is 1940 mg/kg. Solubility is 1200 mg/l at room temperature. Sencor is moderately adsorped onto soil colloids. Persistence in soils is generally two to four months.

Dieldrin 1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8a-octahydro-1,4-endo-exo-5,8-dimethanonapthalene

Dieldrin is a cyclodiene member of the organochlorine class of chemicals. Organochlorines were banned from most agricultural uses between 1975 and 1980. Dieldrin was used as an insecticide on a variety of crops, although much of the dieldrin found in the environment is formed from the breakdown of aldrin, a similar but more widely used insecticide. Dieldrin acts as a neurotoxicant in insects. LD_{50} toxicity is about 45 mg/kg body weight in laboratory rats. Dieldrin is soluble in water, but is adsorped onto soils to an extremely high degree. Dieldrin is extremely stable in soils, with a persistence measured in years.

Dyfonate O-ethyl-S-phenyl-2-3-ethyl phosponodithoate

Dyfonate is a trade name for the chemical fonofos. Dyfonate is used as an insecticide, primarily against corn rootworm and wireworm. Dyfonate is highly toxic, with a LD_{50} of 8-15 mg/kg in laboratory rats. Persistence in soils is usually on the order of two to three months.

APPENDIX 5

Pesticides in the Groundwater of the Big Spring Basin

\- 1982 -

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Iowa Department of Environmental Quality

Abstract:

Low levels of pesticides were detected in the groundwater of the Big Springs basin during the course of studies being conducted by the DEQ and IGS. The levels of the pesticides found - Atrazine, Bladex, Lasso and Dual - were determined to be quite low. While acute toxicity was not of concern, chronic toxicity has never been determined for two of the chemicals - Bladex and Dual. The paper reviews the relative toxicity of all four chemicals, and recommends a number of activities to ensure that the occurrence of more toxic chemicals does not become a problem in the future.

pmr/OCQ265H07.02

Background:

On July 16th Dr. George Hallberg of the Iowa Geological Survey (IGS) called this office. Dr. Hallberg wanted to relay to the Program Development Section (PDS) the analytical results of the pesticide analysis of samples taken at the Big Springs Study Site. He also requested that a meeting be set up between IGS staff and PDS staff to discuss, among other things, the significance of the occurrence of pesticides in the wells of the area, and the approach that should be taken in informing the well owners.

On July 21st Dr. Hallberg and IGS staff from the study site met with PDS staff in Des Moines. It was decided at that meeting that the most logical and most rational approach, considering the low levels being detected, was to take the following actions.

1. Continue to sample, analyze and evaluate pesticides in the groundwater at the study site.

2. Conduct an extensive evaluation of the possible impacts to human health that may result from long term exposure to low levels of pesticides.

3. Insure that this Department and IGS staff can provide the most accurate and up-to-date information to area residents that is available.

It was strongly felt that it was inappropriate and improper to inform area residents of the problem while not being able, at the same time, to inform them of the significance of the presence of pesticides, how the levels compare to other areas or what possible actions can be taken to remove the pesticides from the water.

mac/OCQ265H07.06

4. Have IGS staff at the study site inform individuals in the study area personally of the test results.

5. Have this Department provide to individuals in the study area, through a letter, the information necessary for those individuals to make knowledgable decisions on what actions they could take to help deal with the problem.

Problem:

Water quality data is collected at the Big Springs study site from the Springs, the Turkey River and 18 wells within the basin. Two of the wells lie along the western boundary of the basin; are capped by Maquoketa shale and are used as control wells. Two other wells are on the basin's boundaries and their hydrology is not clear. The remaining 14 wells are clearly within the basin. Although Atrazine was detected in tile line drainage in November, pesticides were first detected at the Springs in the sediment samples taken in late March. By mid-May detectable levels of pesticides had appeared in all 14 wells within the basin, and have persisted in some as late as mid-June. No pesticides have been detected in the control wells.

Figure 1 shows the analytical results for the sampling at Big Springs.

Figure 1

	Pesticide µg/l					
Date	Dieldrin	Atrazine	Bladex	Lasso	Dual	Remarks
March 22, 1982	.65					Sediment
May 12, 1982		.18				
May 18, 1982		.44		.15		
May 27, 1982		.8	.2			

pmr/OCW265H07.06

Figure 1 - Continued

Date	Dieldrin	Atrazine	Bladex	Lasso	Dual	Remarks
	Pesticide µg/l					
May 28, 1982		2.5	.15			
June 1, 1982		.4	.07			
June 7, 1982		10.0	.05	6.0	.25	Dutton's Cave
June 8, 1982		.26				
June 15, 1982		.45	.08	.08		
June 23, 1982		.7	.09	.05		
June 29, 1982		.75	.07			
July 6, 1982		.49				
July 7, 1982		.49				
July 8, 1982		.45				
July 13, 1982		.31				
July 21, 1982		.63				
July 28, 1982		.62				

Figure 2 shows the pesticide levels detected in the well samples.

Figure 2

Date	Atrazine	Bladex	Remarks
	Pesticide µg/l		
May 27, 1982 - June 8, 1982	0.04 - 0.5	.2	14 of 18 wells. 4 N.D. are control wells or on GW divides
June 27, 1982	0.1 - 0.5		3 of 6 wells. 3 N.D. are control wells or on GW divides

Samples were taken from the surface streams within the basin as well. These surface waters either drain directly to a "sink" or are known to be losing streams. Figure 3 gives the analytical results from this sampling.

Figure 3

	Pesticide µg/l						
Date	Atrazine	Bladex	Lasso	Dual	Sencor	Dyfonate	Remarks
Feb. 4, 1982			None Detected				
May 6, 1982	1.4-6.3	7.2-31	3.3-12.7		0.1-1.5		
May 26, 1982	.64		.15				streams
June 8, 1982	1.0-17.0	1.3-2.6	.1-3.02	.70-6.0		.09-.36	streams
June 23, 1982	1.3-1.5	.10-.41	.12-.17	.05-1.0			streams

Atrazine and Bladex are among the most prevalant pesticides in use in the state. Their presence in the groundwater at Big Springs is, therefore, not a surprise. Nor should we expect their presence in groundwater to be unique to that basin, or even that area of the state. For that reason, an attempt was made to determine their relative toxicity and collect any relavent information available. What follows is a discussion of each of these commonly used pesticides and their relative toxicity.

Atrazine:

Atrazine is a Triazine; specifically, 2 - chloro - 4 - ethylamino - 6 - isopropylamino - 1,3,5 - triazine. It is a selective herbicide used largely in pre-emergence application for corn. Atrazine is the most heavily used pesticide in the United States. Approximately 90 million pounds are produced in the U.S. annually.

Atrazine has been found in the water supplies of New Orleans (4.7 - 5.1 µg/l), Cedar Rapids (.483 µg/l), Davenport (.405 mg/l), Iowa City (.20 mg/l) and Des Moines (.03 mg/l). As early as 1974 Atrazine was being found in Iowa's groundwater (Richards et al.).

Rats have been shown to produce 20 metabolites from Atrazine. In model ecosystem studies, using carbon - 14 ring-labeled Atrazine, there was only a slight degree of food-chain transfer of the pesticide or any of its degradation products. An ecologic magnification of 11 times was observed in fish (Metcaf and Sanborn, 1975).

The oral LD_{50} for Atrazine is 3,080 mg/kg in rats and 1,750 mg/kg in mice. Atrazine, in two-year chronic-feeding studies at 100 mg/l in the diet of rats, produced no gross or microscopic signs of toxicity (WSSA 1974). However, data on the mutagenicity of Atrazine strongly suggests that corn plants can metabolize the pesticide into a mutagenic agent. This causes some concern about the ubiquitous Triazine residues in water supplies. The incidences of hepatomas (tumors in the Liver) in carcinogenicity tests were 5.6% in Atrazine treated mice as opposed to 4.24% in the control mice. No cases of human toxicity have been recorded.

The National Academy of Sciences has established a recommended acceptable daily intake (ADI) value for a number of pesticides. This value is based upon chronic-feeding studies with considerations being made for data (or a lack of) on mutagenicity, teratogenicity, and information on sex and strain. The ADI value reflects the value at which no-observed-adverse-health-effects are seen, over some factor of uncertainty or safety factor. The safety factor represents the level of confidence that was judged by the academy to be justified on the basis of the animal and human toxicity data. Thus, if the data indicated that no-observed-adverse-health-effects were seen below a value of 25 mg/kg/day and the safety factor of 1,000 was used, the ADI would be 25/1,000 or .025 mg/l/kg. This ADI value can be used to establish a suggested level or concentration of a pollutant in drinking water. In calculating the value for drinking water it is assumed that the average weight of a human is 70 kg; the average daily intake of water for that human is two liters; and, that 20% of those two liters is taken in directly as drinking water. Therefore, in the example above we would say that the maximum level of the pollutant we would allow in the drinking water to consider it safe would be .7 mg/l (25/1,000 = .025 (ADI) x 70 x 0.4 = .7 mg/l).[1]

For atrazine the recommended acceptable daily intake is .0215 mg/kg/day. Thus, the highest value of Atrazine in the drinking water which can be considered safe is .602 mg/l or 602 µg/l (.0215 (ADI) x 70 x 0.4 = 0.602 mg/l).

Bladex:

Bladex is a Cyanazine; specifically 2 - (4 - Chloro - 6 - ethylamino - S - triazine - 2 - ylamino) - 2 - methylpropionitrile. Bladex, like Atrazine, is a selective herbicide in wide use across the state. Although, of the triazines it is the smallest production herbicide of the group with only about one million pounds manufactured annually.

As in the case of Atrazine, Cyanazine has been identified in finished water in the United States. However, beyond degradation, primarily by hydrolysis, little work has been done on the pesticide. Because it is in the Triazaine group it is likely that it behaves in the environment in much the same manner as Atrazine.

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1 It should be noted that the use of the value 0.4 to represent 20% of 2 liters of water is not in agreement with the National Academy of Sciences. The Academy uses a value of 0.1 in their calculations. Thus, their value for the maximum acceptable level of any pollutant in the drinking water is slightly lower.

Bladex is mildly toxic. The oral LD_{50} in rats is 334 mg/kg. In two years chronic toxicity test on rats and dogs, no signs of toxic effects were observed up to levels of 25 mg/l. Acute toxicity test have been run on a number of fish species by the National Fisheries Research Laboratory. The LD_{50} values are given in Figure 4. No studies on mutagenicity, carcinogenicity or reproduction have been published to date. No cases of human toxicity have been reported.

Figure 4

Species	96-hour LD_{50} (mg/l)
Fathead Minnow	16.3
Channel Catfish	17.4
Fathead Minnow	17.5
Channel Catfish	11.3
Rainbow Trout	9.0
Fathead Minnow	21.3
Channel Catfish	10.4
Bluegill	22.5

No ADI has been established for Cyanazine because of insufficient data.

Lasso:

Lasso is 2 - Chloro - 2' - 6' - diethyl - N - (methoxymethyl) - acetamide. This Alachlor is a selective preemergence herbicide for corn and soybeans.

Again, little work has been done on Alachlor. It has been reported that Alachlor is liable in an aquatic environment, and there is no evidence to indicate that the metabolites or degradation products accumulate in the biota. However, Alachlor has been found in water supplies near New Orleans (2.9 μg/l). No work has been reported on its carcinogenicity, mutagenicity or teratogenicity. Further, no observations in man have been reported.

The oral LD_{50} for rats, as obtained with emulsifiable concentrate, is 1,800 mg/kg. Besides this acute toxicity, chronic and subchronic toxicity values are available. Subchronic toxicity in rats is over 2,000 mg/l in the diet. The growth patterns of both rats and dogs have been shown to be normal for up to 2,000 mg/l, for a 90-day period; some growth decreases have been observed at higher rates of feeding.

The toxicity of Alachlor was studied by the National Fisheries Research Lab. The 96-hour LD_{50} values for Rainbow Trout and Bluegill were 1.4 - 2.4 mg/l and 3.2 - 4.3 mg/l, respectfully.

Although toxicity data on Alachlor is limited, it appears to be fairly well tolerated by mammals. Interestingly, tolerance levels for Alachlor have been set for soybeans and fresh corn (kernels) at 0.2 - 0.75 ppm and .05 ppm respectfully. A negligible residue (.02 ppm) applies to meat, eggs, and milk.

The existing data on Alachlor is largely that produced by the manufacture for registration purposes. However, because rats apparently tolerate up to 100 mg/kg/day in their diet, an ADI of .1 mg/kg/day has been established. Thus, the recommended no-adverse-effect level for drinking water is 2.8 mg/l (100/1000 = .1 (ADI) x 70 x 0.4 = 2.8 mg/l).

Dual:

Dual is 2 - Chloro - N - (2 - ethyl - 6 - methylphenyl) - N - (2 - methoxy - 1 - methylethyl) - acetamide. It is a Metholochlor that is marketed in two forms; Dual and Dual 8E. Dual is a relatively new pesticide and, as such, little is known or available. No toxicity, carcinagenicity, mutagenicity or human health effects data are available.

The oral LD_{50} values established when the pesticides were registered are 2,780 mg/kg for Dual and 2,500 mg/l for Dual 8E. Both values were obtained using rats.

Discussion:

The insidious effects of chronic exposure to low levels of a toxic agent are difficult to recognize. Often by the time early warning signs are recognized the effects are irreversible. Unfortunately, there are at present no easy or straight forward methods for extrapolating chronic-exposure experimental data to calculate a risk to the human population. As classical toxicology does not provide a reliable means for assessing long-term toxic effects by extrapolation from animal data, the rather novel use of the internationally established standard for toxicological evaluation of food additives and contaminants has been used to establish an acceptable daily intake (ADI).

It should be kept in mind, however, that the ADI values do not consider interactions (i.e., synergism, antagonism) among possible contaminants. The ADI values are by no means an assurance of absolute or guaranteed safe levels. They are a good indication that exposure to the single chemical in question, at that ADI value or less, is not likely to produce an observable toxic response in man.

On the other hand, assessing acute toxicity by means of establishing an LD_{50} is known to be an accurate and valid procedure. LD_{50}'s are generally found to be quantitatively similar among animals. On the basis of dose-per-unit of body surface, toxic effects in man are in the same range as those in experimental animals, such as mice, rats and dogs. On a body-weight basis, man is generally more vulnerable than the experimental animals, probably by a factor of 6-12.

The pesticides discussed in this paper do not represent, by any means, the entire range of pesticides in use across the State. Nor do they represent the most toxic of the pesticides in use in Iowa; although, they are among the most toxic of the herbicides. They are fairly representative of the herbicides, and they represent some of the largest selling herbicides in Iowa.

The toxicity of the insecticides in use today, in Iowa, is significantly greater. The three most commonly used insecticides in the State are Furadan, Counter and Dyfonate. The LD_{50} values on these three pesticides are 11 mg/l, 3.5 - 6.3 mg/l and 8 - 17.5 mg/l, respectively. ADI values have not been established for these insecticides. However, the extremely toxic nature of these chemicals would indicate that the ADI values, if established, would be very low.

Conclusions and Recommendations:

The appearance of pesticides in the groundwater of Northeastern Iowa is not particularly surprising. Detection of low levels of pesticides in groundwater is neither new in Iowa, nor is it unique to Iowa. However, it is not recommended that their presence be ignored. Little is known about the fate of pesticides in groundwater, and their presence in shallow aquifiers now may represent a serious problem in the future if our dependence upon pesticides continues to increase.

The selective herbicides detected at the Big Springs study site are emzymatic inhibitors of low to moderate toxicity. Of the four herbicides identified, Bladex is the most toxic. However, in all cases the levels detected are well below the levels considered to be unsafe. Indeed, the levels detected in the groundwater are about 1,000 times less than the levels a local farmer would likely be exposed to in the mixing and application of the chemical. Removal of pesticides from drinking water is possible. One of the most effective and inexpensive means for home use is with activated charcoal filters. However, it is not necessarily recommended that these homes use units be encouraged. Quite often the health effects resulting from their use are every bit as great as those from the pollutants they are intended to remove. Further, their use does not solve the problem, it only postpone having to deal with it.

Based upon the information available the following actions are recommended:

1. Continued monitoring of the Big Springs basin in conjunction with the third year of the study.

2. A public information program in northeastern Iowa, in conjunction with others involved in the study.

   a. To make people in the area aware of the findings of the study.
   b. To educate people on the problem and the cause of the problem.
   c. To advise people on actions they can take to help solve the problem.
   d. To advise people to monitor their drinking water once a year for pesticides.

3. Contact, via letter, those people in the Big Springs basin and inform them of the health significance of pesticides in drinking water.

4. Contact local health officials to educate them on the problem.

5. Incorporate these activities and the results of the Big Springs study into the groundwater protection strategy (i.e., standards for pesticides in groundwater).

References

DeKraay, Warren H., Pesticides and Lymphoma in Iowa, J. Iowa Medical Society, 68:50-53.

Drinking Water and Health, National Academy of Sciences, 1977.

Johnson, Waynon W., Handbook of Acute Toxicity of Chemicals to Fish and Aquatic Invertebrates, 1980.

Pesticides in Soil and Water, W.D. Guenzi (ed.), 1974.

A Rational Evaluation of Pesticides vs. Mutagenic/Carcinogenic Action, Ronald Hart (ed.) 1976.

Herbicide Handbook, Weed Science Society of America, 1974.

Metcalfe, R.L. and Sanborn, J.R., Pesticides and Environmental Quality in Illinois, ILL. Nat. Hist. Sur. Bull., 1975, 31(9):381-436.

Richard J., Junk, Avery, Nehring, Fritz and Svec., Analysis of Various Iowa Waters for Selected Pesticides: Atrazine DDE and Dieldrin - 1974, Pectic. Monit. J., 9:117-123.

Water Supply and Health, H. Vonlelyveld (ed.), 1981.

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APPENDIX 6

Results of Runoff Modelling (TR-55)

For 1982 Precipitation Data From the Sinkhole Basins

CURRENT LAND USE

Date	Antecedent Moisture Condition	Rainfall (inches)	Q (inches)	ac ft	ft^3
3/16	III	.66	.06340	38.886	1,692,702
3/20	III	.65	.06012	36.874	1,605,120
4/3	III	.93	.17523	107.477	4,678,459
4/6	III	.46	.01280	7.851	341,753
4/9	III	.44	.00968	5.937	258,437
4/15	II	.02	--------		
4/16	II	.48	--------		
4/17	III	.16	--------		
4/20	III	.24	--------		
4/26	II	.02	--------		
5/5	II	.69	--------		
5/6	III	.93	.17523	107.477	4,678,459
5/7	III	.62	.05072	31.1089	1,354,166
5/12	III	.18	--------		
5/13	II	.58	--------		
5/14	III	.03	--------		
5/15	III	.05	--------		
5/18	III	.49	.01820	11.163	485,924
5/19	III	.53	.02669	16.37	712,584
5/22	III	1.19	.31602	193.83	8,437,393
5/23	III	.20	--------		
5/26	III	.07	--------		
5/27	III	.38	.00283	1.7358	75,559
5/28	III	.06	--------		
5/29	III	.10	--------		
6/7	II	.52	--------		
6/13	II	.04	--------		
6/15	II	1.36	.08258	50.65	2,204,783
6/16	III	.14	--------		
6/27	II	.32	--------		
7/3	II	.43	--------		
7/7	I	1.54	--------		
7/11	III	.09	--------		
7/13	II	.06	--------		
7/16	II	.81	.00071	.435	18,935
7/18	II	.77	.00004	.025	1,088
7/22	II	.85	.00219	1.343	58,461
7/28	II	.76	.0000013	.001	43
8/4	II	.33	--------		
8/5	II	.30	--------		
8/6	II	.09	--------		
8/22	II	.53	--------		
8/25	II	.45	--------		
8/30	I	1.37	--------		

Date	Antecedent Moisture Condition	Rainfall (inches)	Q (inches)	ac ft	ft^3
9/1	III	.75	.096	528.212	22,993,010
9/2	III	.04	--------		
9/6	II	.34	--------		
9/10	II	.08	--------		
9/13	II	.03	--------		
9/14	II	.77	.0004	.025	1,088
9/15	II	.13	--------		
9/17	II	.15	--------		
10/6	II	.28	--------		
10/7	II	.74	--------		
10/9	II	.78	.00013	.08	3,482
10/20	II	.46	--------		
10/29	II	1.03	.01824	11.187	486,968
11/1	II	.61	--------		
11/2	III	.49	.01820	11.163	485,924
11/9	II	.34	--------		
11/10	II	.60	--------		
11/12	III	2.0	.87697	537.884	23,414,024
11/19	II	.03	--------		
11/21	II	.03	--------		
11/23	II	.05	--------		
11/28	II	.21	--------		
11/29	II	.17	--------		
12/5	II	.45	--------		
12/6	II	.83	.00135	.828	36,043
12/7	III	.11	--------		
12/8	III	.05	--------		
12/24	II	.19	--------		
12/25	II	.37	--------		
12/28	III	1.05	.23686	145.277	6,323,887
TOTAL				1,845.82	80,348,292

ALL STRIP CROPPED

Date	Antecedent Moisture Condition	Rainfall (inches)	Q (inches)	ac ft	ft^3	Percent Decrease Over Present Conditions
3/16	III	.66	.06078	37.28	1,622,793	4
3/20	III	.65	.05758	35.32	1,537,475	4
4/3	III	.93	.17053	104.59	4,552,789	3
4/6	III	.46	.01174	7.2	313,415	8
4/9	III	.44	.00878	5.38	234,191	9
4/15						
4/16						
4/17						
4/20						
4/26						
5/5						
5/6	III	.93	.17053	104.59	4,552,789	3
5/7	III	.62	.04842	29.7	1,292,837	5
5/12						
5/13						
5/14						
5/15						
5/18	III	.49	.01691	10.37	451,405	7
5/19	III	.53	.02509	15.39	669,925	6
5/22	III	1.19	.30946	189.81	8,262,404	2
5/23						
5/26						
5/27	III	.38	.00237	1.45	63,118	17
5/28						
5/29						
6/7						
6/13						
6/15	II	1.36	.074	45.6	1,984,958	10
6/16						
6/27						
7/3						
7/7						
7/11						
7/13						
7/16	II	.81	.0002	.12	5,224	72
7/18	II	.77	--------			100
7/22	II	.85	.00115	.71	30,906	47
7/28	II	.76	--------			100
8/4						
8/5						
8/6						
8/22						
8/25						
8/30						

Date	Antecedent Moisture Condition	Rainfall (inches)	Q (inches)	ac ft	ft³	Percent Decrease Over Present Conditions
9/1	III	.75	.093	56.798	2,472,419	89
9/2						
9/6						
9/10						
9/13						
9/14	II	.77	--------			100
9/15						
9/17						
10/6						
10/7						
10/9	II	.78	--------			100
10/20						
10/29	II	1.03	.01476	9.05	393,945	19
11/1						
11/2	III	.49	.01691	10.37	451,405	7
11/9						
11/10						
11/12	III	2.0	.866	531.16	23,121,323	1
11/19						
11/21						
11/23						
11/28						
11/29						
12/5						
12/6	II	.83	.00058	.36	15,671	57
12/7						
12/8						
12/24						
12/25						
12/28	III	1.05	.23128	141.85	6,174,711	2
TOTAL				1,337.098	58,203,703	

INCREASED MEADOW

Date	Antecedent Monitor Conditions	Rainfall (inches)	Q (inches)	ac ft	ft ^{3}	Percent Decrease Over Present Conditions
3/16	III	.66	.06078	37.28	1,622,793	4
3/20	III	.65	.05758	35.32	1,537,475	4
4/3	III	.93	.17053	104.59	4,552,789	3
4/6	III	.46	.01174	7.2	313,415	8
4/9	III	.44	.00878	5.38	234,191	9
4/15						
4/16						
4/17						
4/20						
4/26						
5/5						
5/6	III	.93	.17053	104.59	4,552,789	3
5/7	III	.62	.04842	29.7	1,292,837	5
5/12						
5/13						
5/14						
5/15						
5/18	III	.49	.01691	10.37	451,405	7
5/19	III	.53	.02509	15.39	669,925	6
5/22	III	1.19	.30946	189.81	8,262,404	2
5/23						
5/26						
5/27	III	.38	.00237	1.45	63,118	17
5/28						
5/29						
6/7						
6/13						
6/15	II	1.36	.06993	42.89	1,866,996	15
6/16						
6/27						
7/3						
7/7						
7/11						
7/13						
7/16	II	.81	.00005	.03	1,306	93
7/18	II	.77	---------			100
7/22	II	.85	.00072	.44	19,153	67
7/28	II	.76	---------			100
8/4						
8/5						
8/6						
8/22						
8/25						
8/30						

Date	Antecedent Monitor Conditions	Rainfall (inches)	Q (inches)	ac ft	ft^3	Percent Decrease Over Present Conditions
9/1	III	.75	.093	56.798	2,472,419	89
9/2						
9/6						
9/10						
9/13						
9/14	II	.77	--------			100
9/15						
9/17						
10/6						
10/7						
10/9	II	.78				100
10/20						
10/29	II	1.03	.01297	7.95	346,062	29
11/1						
11/2	III	.49	.01691	10.37	451,405	7
11/9						
11/10						
11/12	III	2.0	.866	531.16	23,121,323	1
11/19						
11/21						
11/23						
11/28						
11/29						
12/5						
12/6	II	.83	.00028	.17	7,400	80
12/7						
12/8						
12/24						
12/25						
12/28	III	1.05	.23128	141.85	6,174,711	2
TOTAL				1,332.74	58,013,916	

ALL TERRACED

Date	Antecedent Moisture Conditions	Rainfall (inches)	Q (inches)	ac ft	ft³	Percent Decrease Over Present Conditions
3/16	III	.66	.0376	23.06	1,003,799	41
3/20	III	.65	.03517	21.57	938,941	42
4/3	III	.93	.12675	77.74	3,384,012	28
4/6	III	.46	.00368	2.26	98,337	71
4/9	III	.44	.00218	1.34	58,330	78
4/15						
4/16						
4/17						
4/20						
4/26						
5/5						
5/6	III	.93	.12675	77.74	3,384,012	28
5/7	III	.62	.02831	17.36	755,678	44
5/12						
5/13						
5/14						
5/15						
5/18	III	.49	.00664	4.07	177,167	64
5/19	III	.53	.01183	7.26	316,027	46
5/22	III	1.19	.24691	151.44	6,592,163	22
5/23						
5/26						
5/27	III	.38	.00237	1.45	63,118	17
5/28						
5/29						
6/7						
6/13						
6/15	II	1.36	.04497	27.57	1,200,118	46
6/16						
6/27						
7/3						
7/7						
7/11						
7/13						
7/16	II	.81	--------			100
7/18	II	.77	--------			100
7/22	II	.85	--------			100
7/28	II	.76	--------			100
8/4						
8/5						
8/6						
8/22						
8/25						
8/30						

Date	Antecedent Moisture Conditions	Rainfall (inches)	Q (inches)	ac ft	ft^3	Percent Decrease Over Present Conditions
9/1	III	.75	.062	38.332	1,668,571	93
9/2						
9/6						
9/10						
9/13						
9/14	II	.77	-------			100
9/15						
9/17						
10/6						
10/7						
10/9	II	.78	-------			100
10/20						
10/29	II	1.03	.00429	2.63	114,481	76
11/1						
11/2	III	.49	.00664	4.07	177,167	64
11/9						
11/10						
11/12	III	2.0	.754	462.46	20,130,821	14
11/19						
11/21						
11/23						
11/28						
11/29						
12/5						
12/6	II	.83	--------			100
12/7						
12/8						
12/24						
12/25						
12/28	III	1.05	.17866	109.58	4,770,003	25
TOTAL				1,029.932	44,832,745	