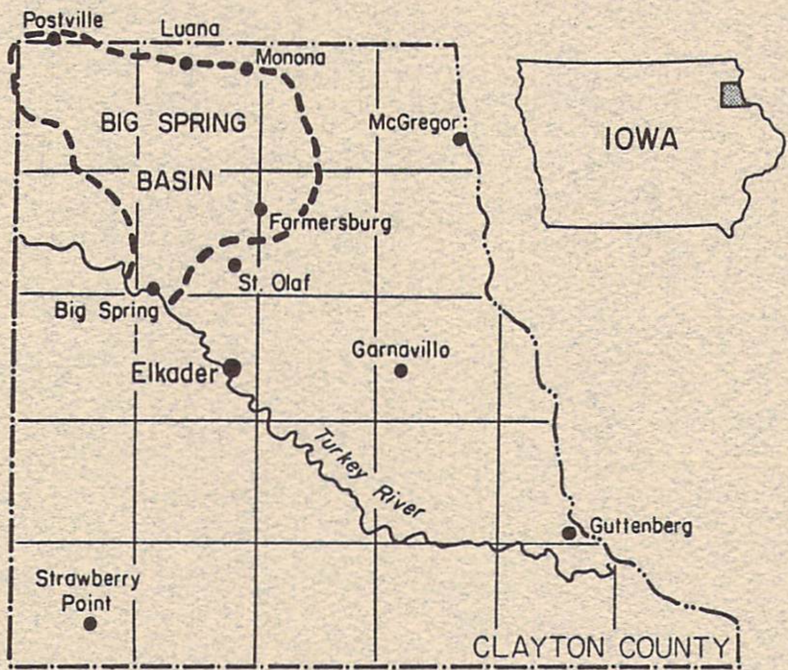
BIG SPRING BASIN WATER-QUALITY MONITORING PROGRAM: DESIGN AND IMPLEMENTATION

Open-File Report 91-1



Iowa Department of Natural Resources

Larry J. Wilson, Director

July 1991

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A Report of The Big Spring Basin Demonstration Project

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TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

ABSTRACT

The agricultural practices, hydrology, and water quality of the Big Spring basin have been studied since 1981. A network of precipitation stations, tile lines, streams, springs, and wells of various depths has been monitored during this period. These investigations documented changes in water quality related to historic changes in cropping practices, nutrient management, and fertilizer and chemical use. Based on this research a multi-agency group initiated the Big Spring Basin Demonstration Project in 1986 to integrate public education with on-farm research and demonstration projects that stress and monitor the environmental and economic benefits of prudent chemical management. The water-quality monitoring network was expanded to over 50 sites, to provide a detailed record of the water-quality changes accompanying improved farm management. The monitoring network is designed in a nested fashion, from small-scale field plots to the basin groundwater and surface-water outlets. Ten key sites have been instrumented for continuous or event-related measurement of water discharge and chemistry and for automated sample collection. Four sites have been instrumented with deep-nested monitoring wells, penetrating the uppermost bedrock aquifer. The development of monitoring sites within the Big Spring basin has been a cooperative effort among the Iowa Department of Natural Resources, the US Geological Survey, Iowa State University, the USDA-Soil Conservation Service, and the US Environmental Protection Agency.

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

From the individual field sites, the nested monitoring scheme follows the natural hierarchy of the drainage system. Watersheds of increasing size are instrumented and monitored, up to the main surface-water and groundwater outlets for the basin (103 mi^2. Water quality at these larger scales is an integration of the management practices of all the individual parcels of land they contain. Water quality improvements at these increasingly larger scales will require longer periods of time to become apparent, relative to field plots.

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

INTRODUCTION

The Big Spring basin is a groundwater basin in northeastern Clayton County, Iowa (Fig. 1). The relationships between agricultural activities and groundwater quality have been studied since 1981 by the Iowa Department of Natural Resources-Geological Survey Bureau (IDNR) and cooperating agencies (Hallberg et al., 1983, 1984, 1985, 1989; Kalhkoff, 1989; Kalhkoff and Kuzniar, 1991). These investigations have shown a relationship between long-term increases in nitrogen-fertilizer use and increasing nitrate concentrations in groundwater; they have also demonstrated the presence of atrazine and other pesticides in groundwater. As an outgrowth of this research, the multi-agency group involved with the Big Spring studies initiated the Big Spring Basin Demonstration Project (BSBDP) in 1986. This effort involves integrating public education and on-farm research and demonstration projects that stress the environmental and economic benefits of prudent chemical management. The project involves various scales of monitoring to evaluate farm management practices that improve efficiency and profitability, while reducing soil erosion and chemical and nutrient contamination of surface-water and groundwater resources. This report describes the network of monitoring stations used to quantify changes in water quality in the basin, and serves as a reference for the design of the various installations in the basin.

Geologic Setting and Land Use

The bedrock exposed in the basin is of Ordovician age and includes the carbonate rocks of the Galena Group and the shales and silty-carbonate rocks of the Maquoketa Formation (Hallberg et al., 1983; Rowden and Libra, 1990). The Galena Group forms the bedrock aquifer used by most basin residents for their water supplies. The bedrock units are mantled by thin Quaternary deposits, but are frequently exposed along the small valleys in the basin. High on the landscape Pre-Illinoian till and glacial-fluvial deposits are preserved. The uplands and hillslopes are draped by loess (wind-blown silt deposits), and loamy alluvial deposits occur in the stream valleys and drainageways.

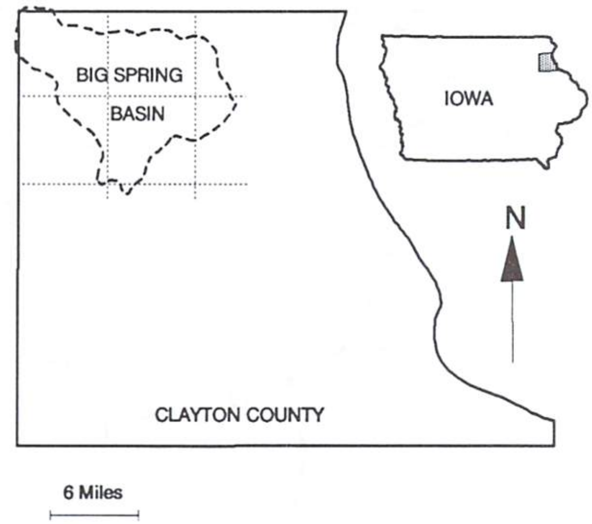

Figure 1. Map showing the location of the Big Spring basin.

Where the Galena aquifer is at or near the surface, the basin exhibits a moderately developed karst landscape, as evidenced by sinkholes, occasional sinking streams, and springs. Big Spring, Iowa's largest spring, discharges from the Galena aquifer in the valley of the Turkey River.

The Big Spring "basin" is a groundwater basin. The catchment area contributing to Big Spring was defined by mapping the potentiometric surface of the Galena aquifer, dye tracing via sinkholes, and gaging gaining and losing stream reaches (Hallberg et al., 1983). As defined, the groundwater basin encompasses 103 mi^2 (Fig. 2). The potentiometric surface indicates the basin's groundwater flow converges on a short reach of the Turkey River near Big Spring. Over 85% of the groundwater discharged from the basin flows through Big Spring. Surface water is discharged by various streams, but dominantly by Robert's Creek, which accounts for 65% of the basin's surface area and about 75-80% of the surface-water flow leaving the basin.

Land use in the basin is almost entirely agricultural. There are no significant point sources that impact groundwater quality. These conditions allow unambiguous study of the agricultural ecosystem. By monitoring water quality and discharge of surface water and groundwater in the basin, the mass flux of

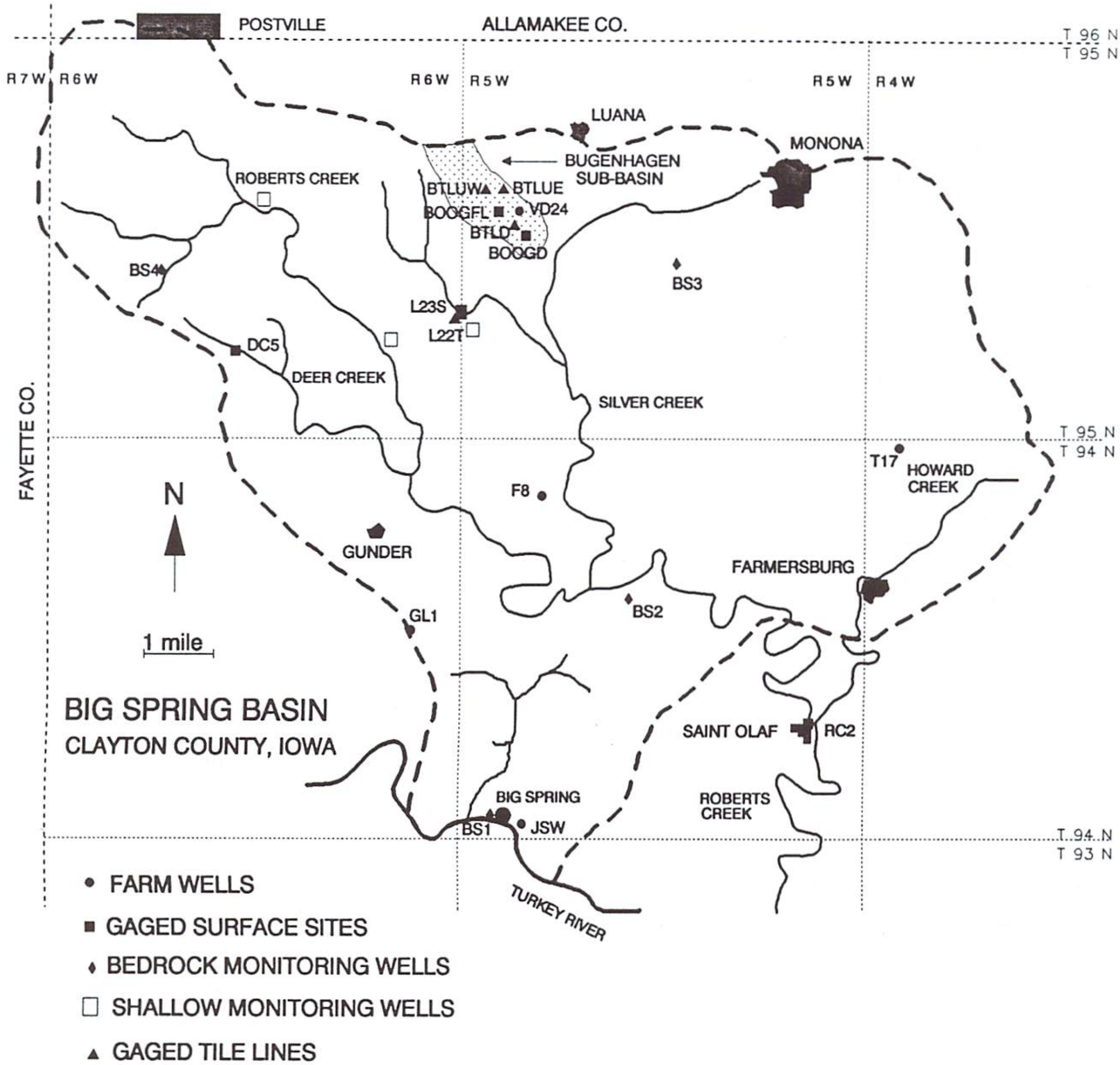

Figure 2. Map of Big Spring basin showing location of monitoring sites.

nutrients and chemicals applied within the basin can be quantified, allowing assessment of chemical balances on a basin-wide scale.

With the thin mantle of glacial deposits and the local karst development, the Galena aquifer is highly responsive to recharge events and to changes in land and chemical management practices, as well. In a majority of the basin, the aquifer's proximity to the land surface makes it susceptible to a relatively rapid influx of contaminants carried by infiltration recharge. Typically infiltration recharge delivers highly soluble ions, such as nitrate, from the soils to the aquifer. In the few areas with open sinkholes, surface runoff can immediately recharge the aquifer, carrying characteristic contaminants such as suspended matter and sediment. The appearance of contaminants in Big Spring groundwater discharge can be related to different recharge mechanisms, since they are distinct in their transport time and chemical signatures. Consequently, monitoring Big

Spring's discharge and water quality makes possible an estimation of the chemical loads delivered to the aquifer by infiltration and runoff recharge.

MONITORING NETWORK INSTRUMENTATION AND DESIGN

A network of over 50 sites in the basin is routinely monitored for water quality. Precipitation, surface water, and groundwater from tiles, shallow piezometers, bedrock wells and springs are included in the network. Instrumentation which continuously monitors discharge and initiates event-related sampling has been installed at key sites. This supplements routine observations and samples collected by field personnel. The development of monitoring sites within the Big Spring basin has been a cooperative effort. Staff from the U.S. Geological Survey, Water Resources Division, Iowa City office, designed, constructed, and maintain the stream gaging stations (RC2, L23S, BOOGD, and the Turkey River at Garber) and also cooperate in water-quality monitoring. Tile-monitoring installations (BTLUE, BTLUW, L22T, and BTLD) and a surface-water flume (BOOGFL) were designed and constructed under the direction of Dr. James Baker, Department of Agricultural Engineering, Iowa State University, Agriculture and Home Economics Experiment Station. The following sections describe the equipment used for monitoring purposes within the Big Spring basin. The configurations of equipment used at specific sites will be briefly discussed in later sections.

Discharge Measurement Equipment

H- and HL-flumes were developed by the USDA, Soil Conservation Service during the 1930's to measure runoff from experimental plots. They can be described as a flat-bottomed spout with converging sidewalls that uniformly decrease in height towards the nose. The cross-sectional area controlling the water outflow, is always a similar rectangle. As discharge increases, the depth of water in the flume increases, causing water to top the sidewalls increasingly toward the rear of the flume. There is a numerical relationship (rating) between the depth of water (stage) in the flume and discharge. The design of H- and HL-flumes allows for accurate discharge measurements over a greater range of discharge than other flumes and weir designs (Table 1).

Table 1. Types of H-flumes used in the Big Spring basin, and their ratings.

Type of flume	Depth (feet)	Rated Flow Range (cubic feet/second)
1. H-	0.75	0.001 - 0.957
	1.50	0.001 - 5.330
2. HL-	4.00	0.005 - 117.
	3 X 4.00	0.015 - 351.

Instrument Specialty Company, Inc. (ISCO), model 1870 and 2870 flow meters are used to calculate and record instantaneous flow through the H-and HL-flumes. The flow meter supplies air to a bubbling tube placed in either stilling wells or baffle boxes attached to the flumes. The pressure needed to emit a bubble corresponds to the stage above the tube opening. The stage is converted to discharge from the rating for the flume . Discharge is continuously recorded on a strip chart, and totaled on an analog dial. The flow meters are powered by 12-volt direct current.

Where continuous power is not available, mechanical stage-recorders are used with the H-and HL-flumes to record the instantaneous stage through time. A rotating drum-chart is operated by a precision 8-day mechanical clock. A pen, connected to a float and tape assembly in the flume stilling-well, continuously scribes the stage on the rotating chart.

Water Samplers

ISCO models 2100 and 2700 water samplers are used for automatic sample collection for water-quality analysis. The samplers can be programmed to extract a sample at equal time-intervals, or they can be linked with a flow meter to sample after a predetermined flow volume has passed. Samples are extracted from the water passing through the flume by a

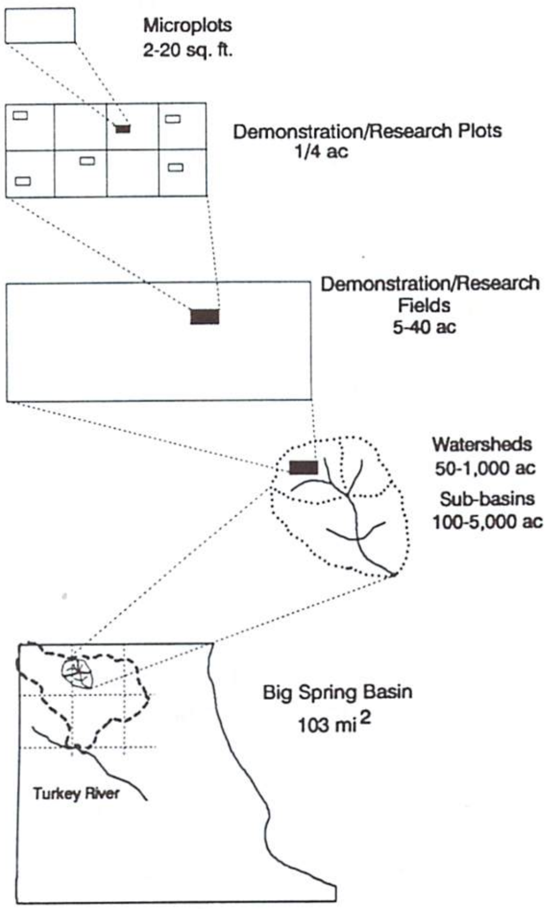

Figure 3. Schematic diagram of nested monitoring network design.

peristaltic pump, which draws the water through Teflon tubing and delivers it to 1000 ml polypropylene bottles. The samplers contain 24 bottles and can be programmed to place one discrete sample into one bottle, to composite several small samples per bottle, or to fill several bottles per sample interval. The tubing is automatically purged before and after each sample. The samplers are powered by 12-volt direct current.

Serco water samplers were used at sampling sites without a power source. The sampler is a two-tiered rack of twenty-four, 350 ml glass bottles enclosed in an insulated aluminum case. A separate Tygon sampling tube is attached to the stopper of each sample bottle. The bottles are evacuated with a hand pump, and each tube is pinched with a clamp mechanism that is released by the trigger of a precision 8-day, spring-wound clock. The sampling nozzle of the tubing is submerged in the water passing through the flume. Two gear settings are used to actuate sample collection, either every hour for one day, or every 8 hours for 8 days. The amount of sample collected is dependant on the elevation above the water that the vacuum must act against and is usually between 200 to 300 ml.

USGS Stream Gaging Stations

At perennial stream sites, standard USGS gaging facilities have been constructed. Stage is monitored continuously with bubble-gage sensors (manometers) and recorded by digital and analog recorders. The digital recorders are controlled by solid state timers set to record stage at 15 minute intervals. Stevens A-35 strip-chart recorders also register stage continuously. The recording instruments are housed in 5 by 5 foot metal buildings. The equipment is powered by 12 volt gell-cell batteries which are recharged by solar panels or battery chargers run by external power. Reference elevations for all USGS gage stations are surveyed in from USGS benchmarks. Stage recording instruments are referenced to outside staff plates placed in the streambeds, or to type-A wire-weights attached to the adjacent bridges.

Stream discharge is computed from the rating developed for each site. The stream-gaging and calibration is performed by USGS personnel, using standard methods (e.g., "Techniques of Water Procedures Investigations of the U.S. Geological Survey", Applications of Hydraulics handbooks). Current-meter methods and portable Parshall flumes are used periodically to measure stream discharge and refine the station ratings. The data is stored in the USGS Automatic Data Processing System (ADAPS) and published annually.

Monitoring Network Design

The basin monitoring network is designed in a nested fashion, affording hydrologic and water-quality measurements at different scales (Fig. 3). Instrumentation at key sites adds significant detail to these observations. The smallest areas monitored with instrumentation are individual fields or land-use tracts (5 to 40

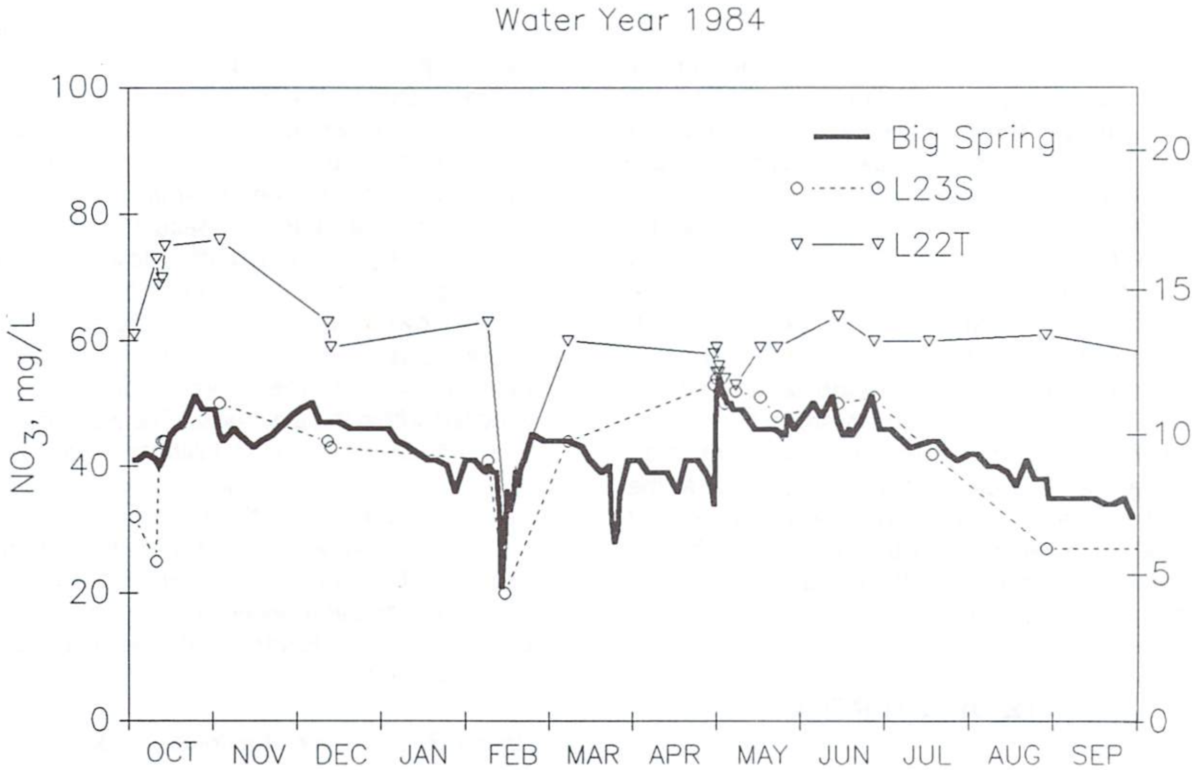

Figure 4. Graph of nitrate concentrations from three monitoring sites within the Big Spring basin.

acres) with known management. These areas have instrumented tile lines and/or shallow piezometers. Nested within some of the individual fields are research plots (<1/4 acre) to compare small variations in management, and to monitor any resulting variations in chemical and nutrient concentrations within the soil profile. Within some research plots, microplots (3 ft^2) are used to track nitrogen movement. Monitoring at the field scale is an important part of the network design. Water quality improvements caused by changes in agricultural practices will most quickly and clearly become apparent at the field scale.

From the individual field sites, the nested monitoring scheme follows the natural hierarchy of the drainage system. Watersheds of increasing size are instrumented and monitored, up to the main surface-water and groundwater outlets for the basin, Robert's Creek and Big Spring, respectively. Water quality improvements at these increasingly larger scales will require longer periods of time to become apparent, relative to field plots. Within field plots, management practices can be radically altered at the beginning of any crop year, and water quality is monitored immediately below the field. Within increasingly larger surface-water and groundwater basins, changes in management will be more gradual, and water quality is measured farther away, at the basin outlet. It is the water quality of these larger basins that is of ultimate environmental concern, and their quality is an integration of the management practices on all the individual parcels of land they contain.

The monitoring design allows for tracking of water and chemical responses to recharge events through the hydrologic system, from the soil and water beneath individual fields to the basin water outlets (Hallberg et al., 1984). This provides both an integration and a comparison of scales to assess different affects of landuse and landscape-ecosystem processes. Figure 4 shows nitrate concentrations from three sites : 1) L22T, a tile line discharging shallow groundwater from beneath a 30 acre corn field; 2) L23S, a site along Silver Creek (which L22T discharges to) with a drainage area of 4.4 mi^2; and 3) Big

Spring, the basin's groundwater discharge point. Similar seasonal trends, and pronounced short-term changes in nitrate concentrations, are seen at all three sites. The pronounced short-term changes in nitrate concentrations are responses to significant recharge events. Figure 4 illustrates how the recharge response at the water table beneath a row-cropped field is propagated through the hydrologic system. Infiltrating recharge water delivers high concentrations to shallow groundwater, and this shallow groundwater transports the nitrate laterally to streams and downward to the Galena aquifer and Big Spring. The concentration changes are not as great or as immediate at the largest scales monitored. They are clearly apparent however, and the nested monitoring design employed allows the pulse to be followed back to their source.

SITE DESCRIPTIONS

Bugenhagen Sub-Basin

The Bugenhagen sub-basin has been the site of routine water-quality monitoring of tile lines, surface water, and groundwater since 1981 (Fig. 2). The sub-basin was selected early in the Big Spring Basin Demonstration Project to be a model area for implementation of improved farm management and soil conservation. Landowners within the watershed were enrolled in 7-year cooperative agreements involving cost-sharing to implement Best Management Practices (BMP). These BMPs stress soil conservation, and fertilizer and pest management through one-on-one technical assistance. The principle goals of the sub-basin efforts are to implement integrated farm management practices that improve profitability and environmental efficacy. The monitoring equipment within the sub-basin is used to document changes in discharge and water quality related to the implementation of BMPs.

The sub-basin area of 1,100 acres generally has a small surface-water discharge, which drains towards a complex of soil-filled sinkholes on the margin of the Silver Creek floodplain (Fig. 5). The uplands consist of loess, over remnants of glacial till and carbonate bedrock which crops out on the steeper slopes. The drainageways are filled with loamy alluvium that progressively thins, down drainage, over the bedrock. During low flow, surface water seeps into the alluvium of the streambed and the underlying bedrock before reaching the sinkholes. Intermittently, small openings or fractures in the bedrock swallow the discharge more directly. During higher flow conditions, discharge reaches the sinkhole complex located farther downstream. These sinkholes are large depressions filled with alluvium. They are not open directly into the bedrock, nor is bedrock exposed within the sinkholes. The water draining to the filled depressions infiltrates through the soil and into the groundwater system. During extreme runoff events the stream may overflow the sinks, beyond which there is no defined channel. Excess streamflow bypassing the sinkholes has been observed to spread out over the floodplain of Silver Creek and infiltrate into the alluvial soils.

Upper Bugenhagen Monitoring Sites

Approximately 1/2 mile above the sinkhole complex is the sub-basin instrument shed (Fig. 5). The instrumentation here is designed to monitor the water discharge from the upper half of the sub-basin (approximately 400 acres). Both subsurface drainage from tile lines (BTLUE and BTLUW), and surface flow (BOOGFL) are monitored. The instrument shed is constructed of corrugated metal on an 8 by 12 foot wood frame. This is set on a 7 foot deep foundation/sump, made of 5/8-inch exterior plywood (Fig. 6). Power for the instruments was originally supplied by a 12-volt lead-acid battery that was replaced on a weekly basis. This proved unsatisfactory, as the battery was prone to total discharge from increased sampling during runoff events. Insufficient power reserve during cold weather was also a problem. In addition, temperature fluctuations and humidity build-up within the shed caused problems with the electronic equipment. To remedy these problems, in November, 1988, electrical service was extended to the shed, the upper compartment was sealed and insulated with 3 1/2-inch faced fiberglass insulation, and the sump was insulated with 2-inch styrofoam. The power supply for the electrical equipment was reconfigured to provide 12-volt direct current

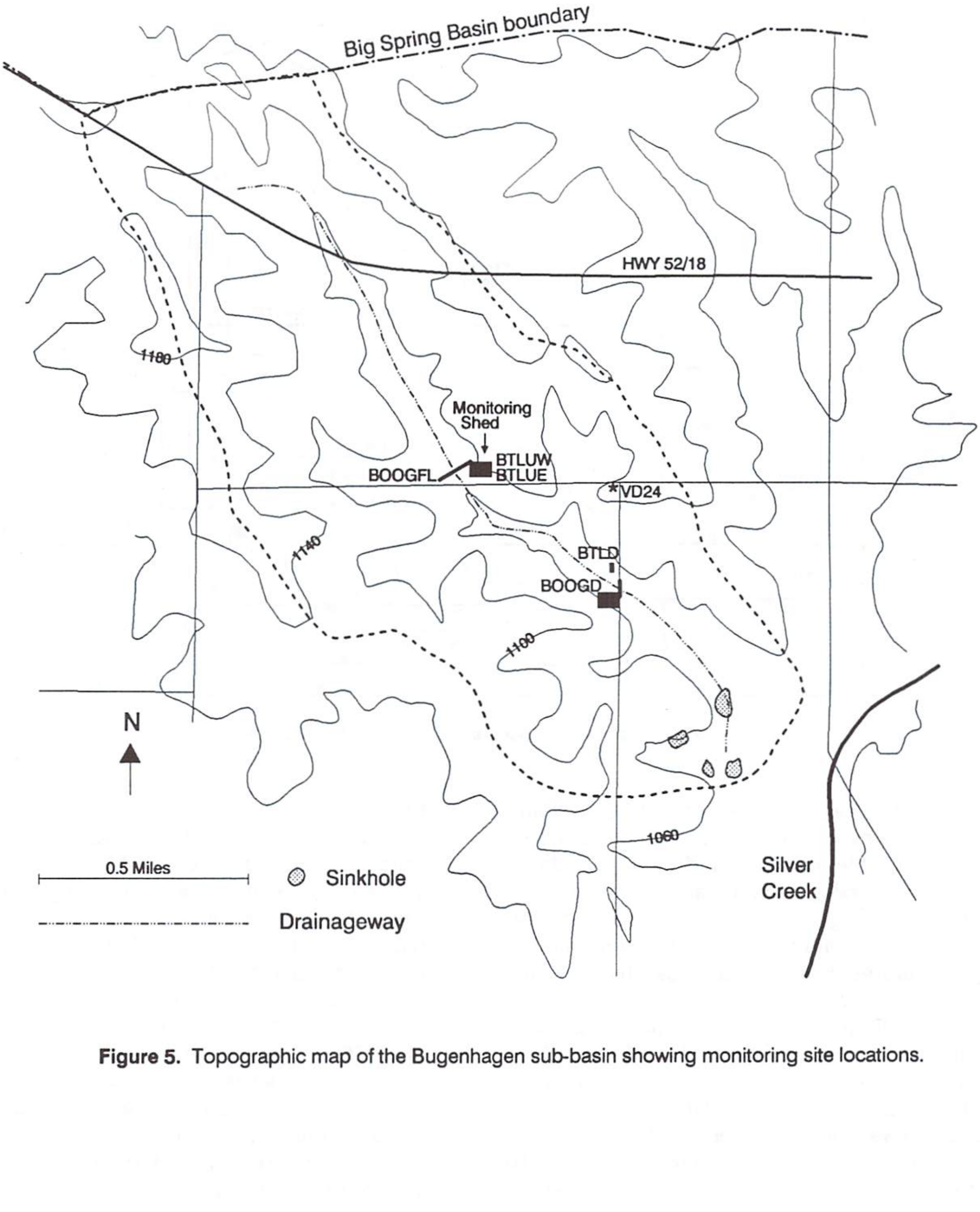

Figure 5. Topographic map of the Bugenhagen sub-basin showing monitoring site locations.

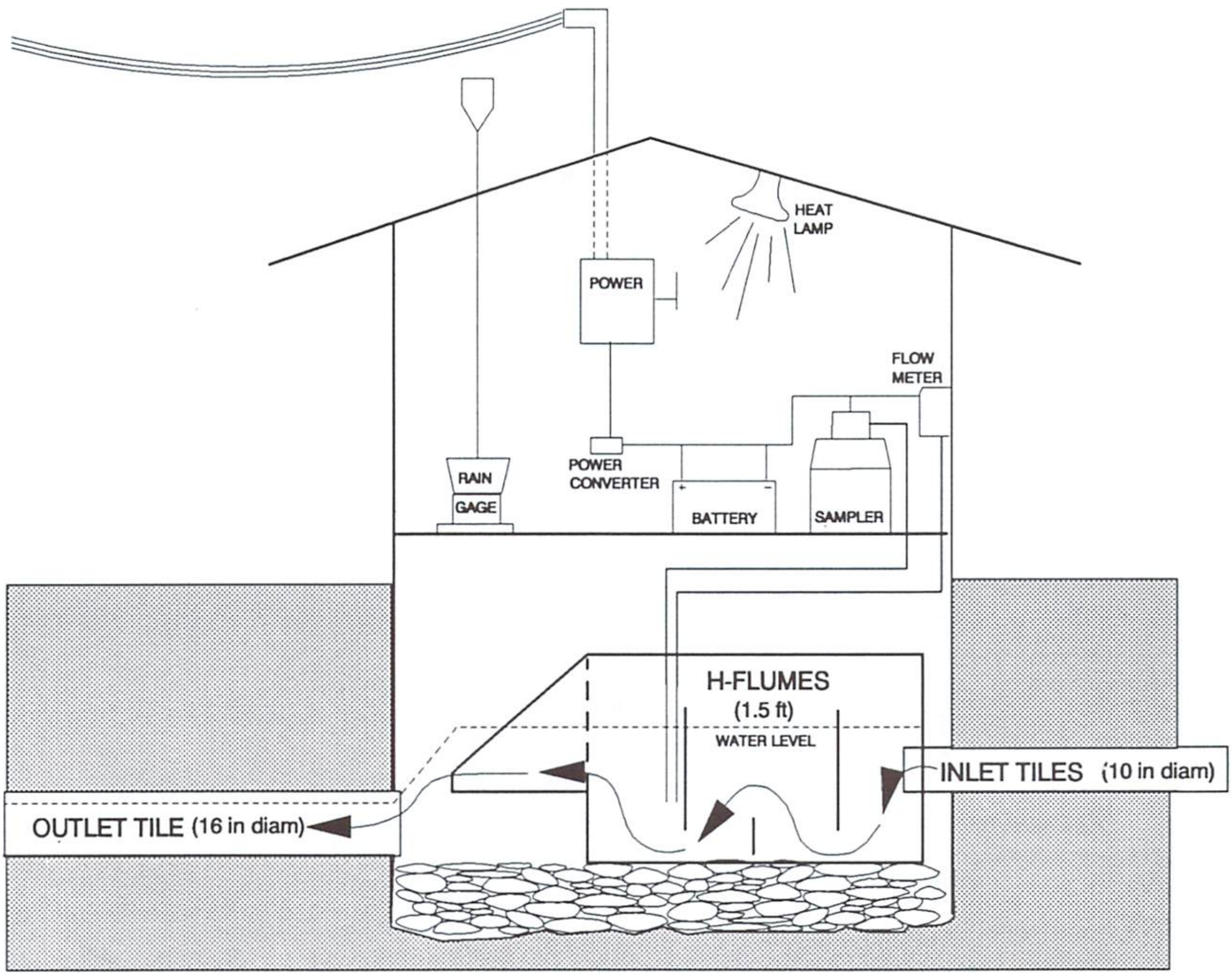

Figure 6. Diagram of Bugenhagen sub-basin instrument shed.

from a lead-acid battery under a constant low-amp charge. This arrangement provides power for the equipment during periods of frequent sampling and the battery functions as a backup during power outages. A 250-watt infrared heat lamp is used to offset extreme low temperatures and to decrease the humidity within the shed.

BOOGFL measures the intermittent surface-water flow in the upper part of the basin. Three stainless steel HL-flumes, four feet high, were joined side by side and installed in the main drainageway of the upper sub-basin (Fig. 7). They are set on 6 by 6-inch treated posts. To prevent surface water from flowing around the outside of the flumes, skirts made of 5/8-inch treated plywood were attached. Each HL-flume is capable of measuring up to 117 cfs and together have a maximum capacity of 351 cfs. An extension was constructed to direct surface water through the center flume, increasing stage-measurement precision during low flow. Stage is recorded in each flume using float recorders set on stilling wells that are open to individual flumes. An ISCO model 2870 flow meter continuously measures stage in the center-flume stilling well. During runoff it initiates an ISCO model 2700 sampler. The sampling tube is fixed to a hinge in the middle of the center flume allowing it to pivot, avoiding plugging and damage from rafted debris.

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

The original diameters of BTLUW and BTLUE were 5 and 6 inches, respectively. Both tiles had a single surface inlet immediately down-drainage from the box culvert beneath Highway 52/18, but these stopped functioning during 1982. The culvert directs overland runoff and discharge from the tile-line drainage system north of the highway into the drainageway.

During the summer of 1986, BTLUW and BTLUE were routed into separate 1.5-foot H-flumes, in the instrument-shed sump (Fig. 6). The flumes are monitored by ISCO model 1870 flow meters and sampled by ISCO model 2100 and model 2700 samplers.

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

Lower Bugenhagen Monitoring Sites

The sites BOOGD and BTLD are located approximately 1/4 mile downstream from the upper Bugenhagen sites. BOOGD monitors the intermittent surface-water discharge from 722 acres of the sub-basin (Fig. 5). The site is equipped with a standard USGS gaging station, with continuous discharge records beginning May, 1986 (Kalkhoff, 1989). The station is just upstream of an elliptical, corrugated culvert-road crossing that the stream flows through. A rectangular-notched weir was welded onto the upstream side of the culvert to increase the precision of stage measurements during low-flow periods. In May of 1988, a mini-monitor that

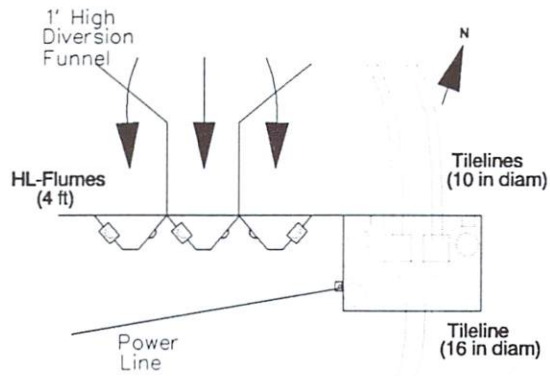

Figure 7. Diagram of Upper Bugenhagen sub-basin monitoring sites.

measures water temperature, pH, and specific conductance was added. The data is recorded at 15 minute intervals with a multiple-parameter data-logger and is downloaded weekly by telephone modem to the USGS, WRD in Iowa City. Samples for sediment and nutrient analysis are taken by an ISCO water sampler that is activated by changes in flow. The sediment samples are supplemented with periodic and event-related sediment samples collected by local observers (sub-basin cooperators).

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

The IDNR has sampled this site since 1981. In 1986, the tile was routed into a sump and through a 0.75 foot H-flume (Fig. 8). Stage in the flume is measured by a float connected to an FW-1 clock-driven stage-recorder. Both Serco and ISCO water samplers have been used in time-sampling mode. A solar cell recharges a 12 volt battery that powers the ISCO sampler. The pasture drained by BTLD is relatively small, and discharge has been intermittent, with no flow occurring during the drought of 1988-89.

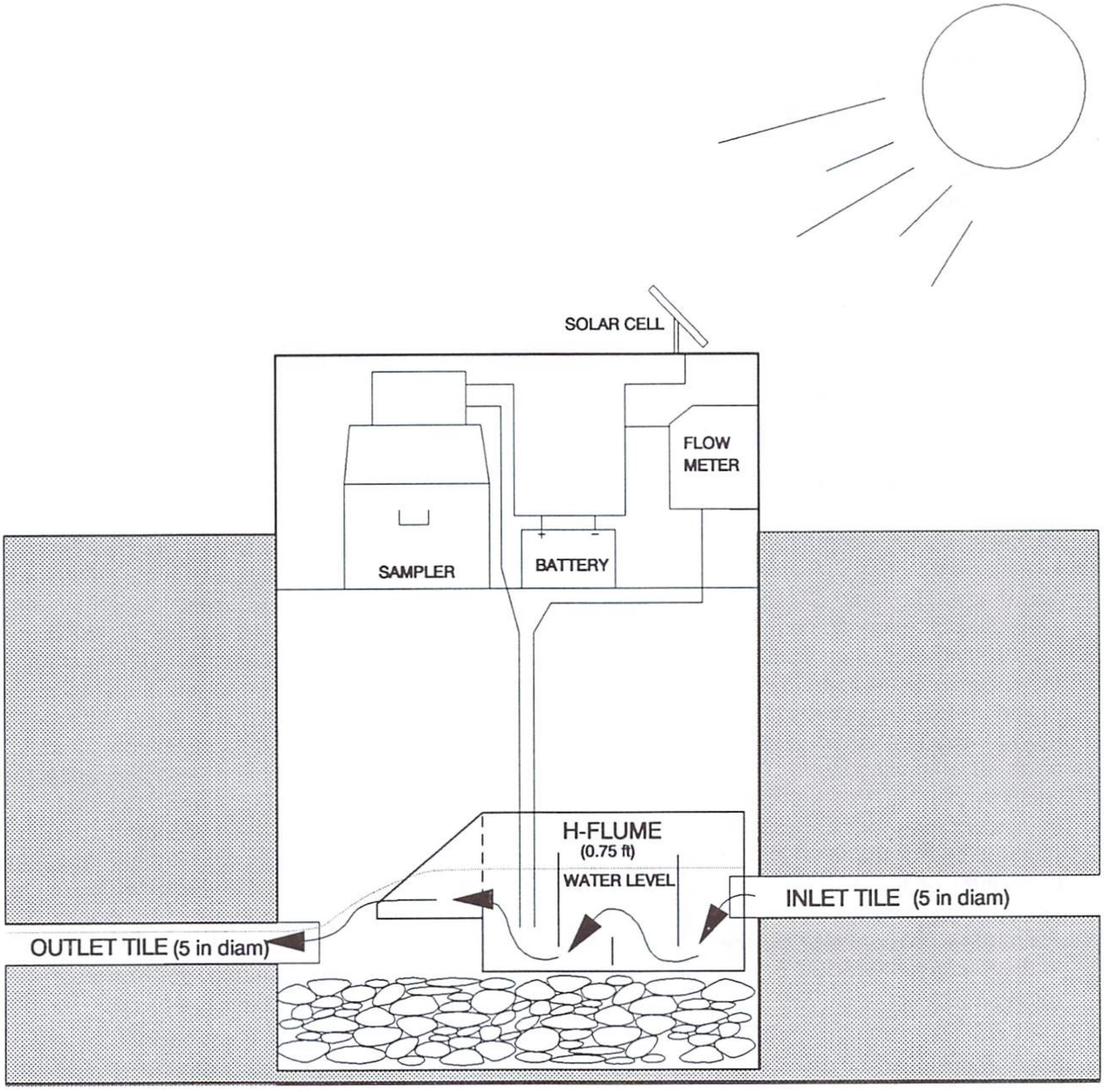

Figure 8. Diagram of monitoring sumps at L22T and BTLD.

Silver Creek Sub-Basin

Site L23S monitors the surface water from a 4.4 mi^2 watershed of the west branch of Silver Creek (Fig. 2). The site has been sampled by IDNR since 1981. The site is equipped with a standard USGS gaging station, with continuous discharge records since May, 1986. L23S is located at a bridge crossing on a county road (Fig. 9). A V-notched weir is attached to the upstream side of the bridge for increased stage measurement precision during low-flow periods.

L22T is twenty yards west of L23S, on the south bank of Silver Creek. This tile line has been monitored since 1981 by IDNR. It is installed in alluvium mapped as Otter and Worthen soils; poorly drained soils formed in silty alluvium. The field has been cropped to corn most of the years it has been monitored. L22T has flowed continuously since monitoring began.

There are no surface intakes associated with the tile.

During the summer of 1986, the 5-inch tile line was routed into a sump and through a 0.75-foot H-flume (Fig. 8). The sump is 3-by-5 by 7 feet deep and constructed of treated lumber. The line enters the sump at a depth of 6 feet. Originally the flume stage was monitored by a clock-driven stage-recorder, and samples were taken with a Serco water sampler. During October, 1988 solar cells were installed to charge a 12 volt, lead-acid battery and power an ISCO model 2870 flow meter and a model 2800 sampler. The sump's interior is insulated with styrofoam to stabilize temperatures during the winter months.

Deer Creek Sub-Basin

Deer Creek is a perennial tributary of Robert's Creek. It has been monitored at site DC5 (Fig. 2) since 1988 by the USGS. At DC5, the creek has a 1.1 mi^2 drainage basin. Discharge of the creek is measured with a V-notch weir. Tile lines, transects of shallow piezometers, and nested suction lysimeters are installed at this site. These are used to monitor groundwater movement and quality beneath an intensively cropped field, and to investigate interactions between the shallow groundwater and Deer Creek. Kahlkoff and Kuzinar (1991) provide further details on this site.

Robert's Creek

Site RC2 on Robert's Creek is located at St. Olaf, on the perimeter of the Big Spring basin (Fig.2). Robert's Creek has a drainage area of 70.7 mi^2 above RC2; most surface water exits the Big Spring basin here. The USGS maintains a standard gage station at this location, constructed in the spring of 1986. Continuous discharge records are available since March of 1986. Intermittent streamflow measurements have been made since the 1970's. In 1988 pH, conductivity, temperature probes, and a standard rain gage were installed. Samples for sediment and nutrient analyses are taken by an ISCO water sampler that is activated by changes in flow. Manual stage readings and routine samples for sediment analysis are collected by local observers.

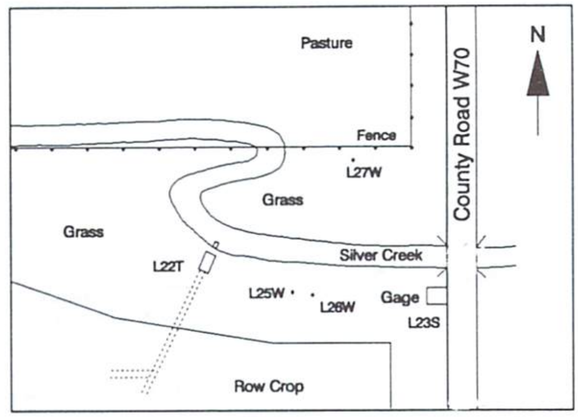

Figure 9. Diagram of sites L22T and L23S and associated monitoring wells.

Big Spring

The IDNR uses the naturally cool water from Big Spring (Fig. 2) for trout rearing. The spring is impounded by a concrete wall that pools the spring waters. Underground, a 30-inch diameter metal culvert directs flow from the pool to a distribution pipe that supplies 24 trout raceways (Fig. 10). After passing through the raceways the water is collected and routed to the Turkey River. Excess groundwater from the spring flows through a concrete spillway to the river. These water-control structures allow for gaging the groundwater discharge at the spring.

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

A small spring, referred to as Back Spring, is approximately 200 yards east of Big Spring (Fig. 10). Back spring was formed by the impoundment of Big Spring, which raised the potentiometric surface of the Galena aquifer locally. The hydrologic relationship between Big Spring and Back Spring has been further documented by dye-tracing (Hallberg et al., 1983; 1984). Flow from Back Spring is directed to four earthen ponds used for brown trout. Water-control structures allowing for continuous

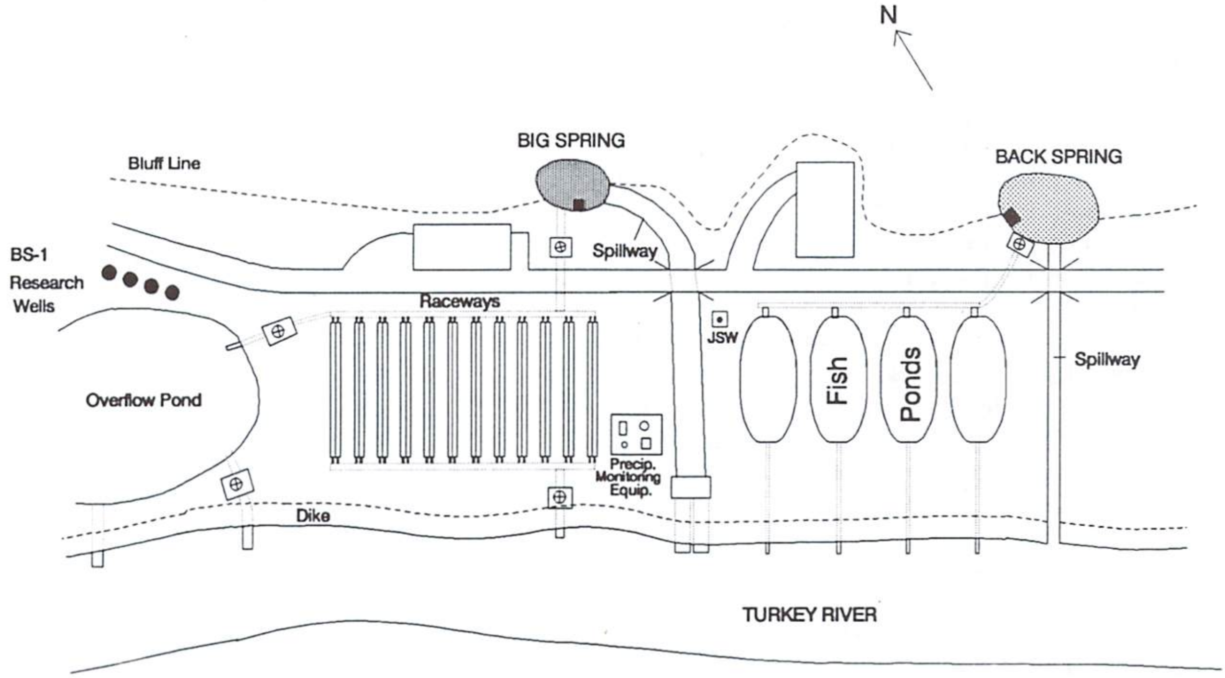

Figure 10. Diagram of Big Spring Hatchery. Dotted lines indicate structures that are underground.

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

Turkey River at Garber

The USGS maintains a standard gage station on the Turkey River at Garber, about 15 miles downstream from Big Spring. The drainage basin above Garber is 1,545 mi^2. Complete discharge records are available since 1932, with partial records available since 1914. Since the Turkey River receives a large portion of its flow from groundwater, the monitoring record here provides a regional perspective on the responses observed at Big Spring.

Monitoring Wells

A number of shallow piezometers and bedrock research wells have been completed within the basin, and are used for water-level and water-quality monitoring. Additionally, a number of domestic water-supply wells are routinely sampled. The shallow piezometers have been installed in a variety of landscape positions to investigate the hydrogeology of the basin's Quaternary materials. In particular, piezometers are completed within alluvial deposits along the upper reaches of Robert's Creek above its confluence with Deer Creek; and near site L23S (Fig. 2). These are used to investigate interactions between shallow groundwater and surface water, and to assess the effects of the riparian zone and alluvial aquifer on contaminant degradation.

Four sets of nested monitoring wells were installed in the basin between June, 1988 and July, 1989 (Rowden and Libra, 1990). At each site, wells are screened into the Galena aquifer and surrounding bedrock and unconsolidated units. The sites BS1, BS2, BS3 and BS4 (Fig. 2) were placed in different hydrogeologic regions of the basin to help delineate the hydrologic system, and refine the potentiometric relations within the flow system of the Galena aquifer and bounding aquitards. The monitoring-well nests at each site will further document the three-dimensional distribution of potentiometric elevations, and therefore the lateral and vertical components of water flux within the basin. The wells also allow for water-quality sampling within discrete stratigraphic intervals.

For continuous monitoring of water levels within the wells, digital stage recorders, driven by float and tape assemblies and powered by 12 volt gell-cell batteries were installed. The recorders are controlled by solid-state timers, set to register water levels at 1 hour intervals. The recorders are housed in wooden boxes, mounted on the well casings. The digital tapes are removed on a weekly basis by USGS personnel and the data is processed and stored in the USGS-ADAPS data base. The monitoring wells that have remained essentially dry since installation were not instrumented (Rowden and Libra, 1990).

Water quality samples are routinely collected from five domestic water-supply wells. These wells are completed within the Galena aquifer and are located across the basin in a variety of hydrogeologic settings (Fig. 2). These wells were part of the initial basin inventory and well network, and therefore have a monitoring record that dates back to the fall of 1981 (Hallberg et al., 1983). They were chosen for continued monitoring because they collectively exhibit a range of nitrate concentrations, while generally showing limited individual variability.

Precipitation

Precipitation has been measured at Big Spring since August 1984 as a part of the National Atmospheric Deposition Program (NADP). Rain gages were added to the USGS stream-gaging stations at BOOGD and RC2 in the spring of 1986 (Fig. 2). Estimates of total basin precipitation are calculated primarily from these three sites. An additional rain gage is located at the instrument shed in the upper Bugenhagen sub-basin. Data from this gage, and from weather bureau stations at Waukon, Fayette, and Elkader, are reviewed as part of this process. The weather bureau stations also supply daily maximum and minimum temperatures for the surrounding area.

At Big Spring, an automatic sampler collects rainfall that is analyzed weekly for major ions (including nutrients) by NADP laboratories (NAPD, 1990). Basin rainfall has been sampled for pesticide analysis since November 1987 (Nations, 1990). As a part of this study, automatic precipitation samplers (Aerochem Metrics model 301) were installed at Big Spring, and in the Silver Creek and Bugenhagen sub-basins in the spring of 1991. An additional sampler was placed in Elkader (outside the basin) for comparison purposes. Pesticide data has also been collected from the NADP sampler at the hatchery by USGS since 1989 (Goolsby et al., 1990, Capel, 1990).

SUMMARY

The agricultural practices, hydrology, and water quality of the Big Spring basin have been studied since 1981. A network of precipitation stations, tile lines, streams, springs, and wells of various depths has been monitored during this period. These investigations documented the concurrent increase in N-fertilizer application and nitrate concentrations in groundwater, and have noted the presence of atrazine and other herbicides in surface water and groundwater. Based on this research the multi-agency group involved with these studies initiated the Big Spring Basin Demonstration Project in 1986. This effort integrates public education with on-farm research and demonstration projects that stress the environmental and economic benefits of prudent chemical management. As part of the project, the water-quality monitoring network was expanded to over 50 sites, to provide a detailed record of the water-quality changes accompanying improved farm management. The monitoring network is designed in a nested fashion, from small-scale field plots to the basin water outlets at Big Spring and Roberts Creek. Key sites are instrumented for continuous or event-related measurement of water discharge and chemistry, and for automated collection of samples for laboratory analysis. The development of monitoring sites within the Big Spring basin has been a cooperative effort. USGS staff designed, constructed, and maintain the stream gaging stations and cooperate in water-quality monitoring. Tile-monitoring installations and a surface-water flume for runoff monitoring were designed and constructed under the direction of

Dr. James Baker, Department of Agricultural Engineering, Iowa State University.

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

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

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

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There are many key workers whose efforts have contributed to the success of this project. Dr. James Baker, Department of Agricultural Engineering, Iowa State University, designed and supervised the construction of the tile-line monitoring stations and the surface-water flumes in the Bugenhagen sub-basin. Dr. Baker and Dr. Rameshwar Kanwar continue to provide support for various project activities and maintenance of the monitoring network. Personnel from the U.S. Geological Survey, Water Resources Division, Iowa City, Iowa have been responsible for providing various instrumentation and processing of monitoring data. Thanks in particular to Stephen Kalkhoff and Ron Kuzniar for their hard work and support.

Nearly the entire Geological Survey Bureau staff has been involved with the Big Spring Demonstration Project at one time or another. Much of the background information contained in this report is a result of their combined efforts. In particular, Brenda Nations, Bob Rowden, and Bob Libra have contributed significantly to the monitoring network design and provided major assistance in the development and completion of this report.

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REFERENCES

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

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

Hallberg, G.R., Hoyer, B.E., Bettis, E.A., III, and Libra, R.D., 1983, Hydrogeology, water quality, and land management in the Big Spring basin, Clayton County, Iowa: Iowa Geological Survey, Open-File Report 83-3, 191 p.

Hallberg, G.R., Libra, R.D., Bettis, E.A., III, and Hoyer, B.E., 1984, Hydrologic and water-quality investigations in the Big Spring basin, Clayton County, Iowa: 1983 Water-Year: Iowa Geological Survey Report 84-4, 231 p.

Hallberg, G.R., Libra, R.D., and Hoyer, B.E., 1985, Nonpoint source contamination of groundwater in karst-carbonate aquifers in Iowa, *In:* Perspectives on Nonpoint Source Pollution: Washington, D.C., United States Environmental Protection Agency, Environmental Protection Agency 440/5 85-001, p. 109-114.

Hallberg, G.R., Libra, R.D., Quade, D.J., Littke, J., and Nations, B., 1989, Groundwater Monitoring in the Big Spring Basin 1984-1987: A Summary Review: Iowa Dept. of Natural Resources Technical Information Series 16, 68 p.

Kalkhoff, S.J., 1989, Hydrologic data for the Big Spring Basin, Clayton County, Iowa, Water Year 1988: U.S. Geological Survey Open-File Report 89-230, 44 p.

Kalkhoff, S.J., and Kuzniar, R.L., 1991, Hydrologic data for the Big Spring Basin, Clayton County, Iowa, Water Year 1989: U.S. Geological Survey Open-File Report 91-63, 66 p.

National Atmospheric Deposition Program, 1990, NADP/NTN Annual Data Summary: Precipitation Chemistry in the United States, 1989: Fort Collins, CO, Natural Resource Ecology Laboratory, Colorado State University, 482 p.

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

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