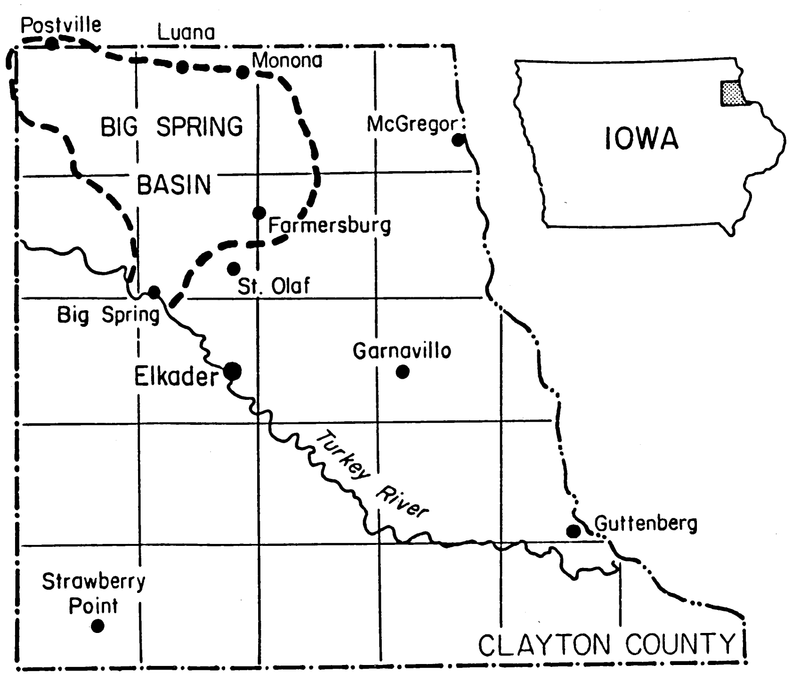
GROUNDWATER MONITORING in the BIG SPRING BASIN 1984-1987: A Summary Review

Technical Information Series 16



Iowa Department of Natural Resources

Larry J. Wilson, Director

November 1989

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A Report of The Big Spring Basin Demonstration Project

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Energy and Geological Resources Division
Geological Survey Bureau

The Big Spring Basin Demonstration Project of the Iowa Department of Natural Resources is supported, in part, through the Iowa Groundwater Protection Act and Petroleum Violation Escrow accounts, and other sponsoring agencies: The U.S. Department of Agriculture, Soil Conservation Service, the U.S. Environmental Protection Agency, Region VII, Kansas City, and the Nonpoint Source Programs Office, Washington, D.C., and the Iowa State University Cooperative Extension Service.

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Other cooperating agencies include: the Agriculture and Home Economics Experiment Station, the Departments of Agronomy and Botany, Iowa State University; the University Hygienic Laboratory, the Institute for Agricultural Medicine and Occupational Health, the Departments of Geology and Preventive Medicine, the University of Iowa; the Department of Biology, University of Northern Iowa; the U.S. Geological Survey, Water Resources Division, Iowa City; the Iowa Department of Agriculture and Land Stewardship; and the U.S.D.A. - Agricultural Stabilization and Conservation Service and the Agricultural Research Service.

While the collaboration of all the agencies and institutions noted above is requisite to the success of this project the most important cooperators are the farmers and families living in the Big Spring basin. Without them there is no project; they are, all at once, the focus of the project, the key workers in many of the demonstrations, and hopefully the principal benefactors. They have the gratitude of all the agencies and institutions involved. The level of cooperation and enthusiasm provided by local citizens is the best continuing tribute that the project can receive.

There are many key workers whose efforts contribute to the success of this project and that must be acknowledged, particularly: Jerry Spykerman, Manager of the Big Spring Fish Hatchery for IDNR; Roger Koster, James Hosch, and Kathie Bentley with the Iowa State University Cooperative Extension Service in Clayton County; Dave Gibney, District Conservationist, USDA-SCS, Clayton County; Frank Phippen, USDA-ASCS, Clayton County. Their personal efforts have enabled much of this project to be successful. Jerry Spykerman and the staff of the Big Spring Hatchery, Gary Thurn, Bob Zach, and Logan Rentschler have been instrumental in maintaining the continuous monitoring of the Big Spring for many years.

At times, there was little extrinsic financial support for the Big Spring study. These needed studies were able to continue only because of the analytical support provided by the University Hygienic Laboratory. They provided 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 cooperation of Ivan Schwabbauer, John Kempf, Loren Johnson, Gene Ronald, Lee Friell, Keith Cherryholmes, and Roger Splinter (formerly with UHL).

Over the years nearly the entire staff of the Geological Survey Bureau has been involved with this project, and were helpful in its development; particularly Bernard Hoyer and Art Bettis. Our thanks to their dedication and support. Many individuals from other agencies have worked "beyond the call of duty" to facilitate the coordination of inter-agency activities. Invaluable in these tasks have been: Dr. Gerald Miller, Iowa State University, Cooperative Extension Service; Julie Elfving with the U.S. Environmental Protection Agency; Dan Lindquist and James Gulliford, Director, Division of Soil Conservation, Iowa Department of Agriculture and Land Stewardship; Rick Kelley and Ubbo Agena, with IDNR; Mike Schendel, Stan Mitchem, Roger Link, Lyle Asell, Dennis Miller, and Jim Reel, U.S.D.A. - Soil Conservation Service; and the Clayton County Soil and Water Conservation District.

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.

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ABSTRACT

The Big Spring basin is a 103 mi^2 groundwater basin in Clayton County, Iowa. Precipitation, groundwater discharge, and the concentrations and loads of various chemical contaminants have been monitored at sites within and around the basin since 1981. This reports summarizes the results of monitoring at Big Spring itself and for the Turkey River during water years 1984 through 1987. Annual precipitation during the period varied between 32 inches in water year (WY) 1987 and 37 inches in WY 1986, compared to the long-term average of 33 inches. Groundwater discharge from the basin to the Turkey River ranged from 32,700 acre-feet in WY 1984 to approximately 25,000 acre-feet in WYs 1985 and 1987. Discharge from the Turkey River varied between 555,000 acre-feet in WY 1985 to over 1,000,000 acre-feet in WY 1984. After WY 1985 the timing and intensity of rainfall, while adequate for crop production, was not conducive to produce significant groundwater recharge.

Flow-weighted mean nitrate concentrations at Big Spring varied from 43 mg/L in WYs 1984 and 1986, to a low of 31 mg/L in WY 1985. The total load of nitrate-nitrogen discharged by the groundwater system varied from 843,000 pounds in WY 1984 to 477,000 pounds in WY 1985. On an annual basis, both nitrate concentrations and loads vary with total groundwater discharge. For the Turkey River, flow-weighted nitrate means varied from 16 mg/L in WY 1985 to 28 mg/L in WY 1986. Nitrate-nitrogen loads were lowest in WY 1985, 5,341,000 pounds, and greatest in WY 1984 at 15,175,000 pounds.

Atrazine is the most consistently detected herbicide in the groundwater discharging from Big Spring. Flow-weighted mean atrazine concentrations at Big Spring varied from a high of 0.7 ug/L in WY 1985 to 0.3 ug/L in WY 1987. These years also had the highest and lowest total loads of atrazine discharged from the basin, 47.6 and 17.6 pounds, respectively. The annual mean atrazine concentrations and loads do not vary with discharge in the manner of nitrate. Rather, both annual concentrations and loads increased through WY 1985, and then decreased through the remainder of the period. Atrazine data from the Turkey River are available for WYs 1986 and 1987. Flow-weighted atrazine means were 0.60 and 0.47 ug/L, respectively, for these years, while total loads were 1,407 and 891 pounds.

Maximum concentrations of nitrate in Big Spring groundwater occur during periods of significant infiltration recharge. Maximum concentrations of pesticides occur during periods when the discharge at the Spring is dominated by sinkhole-captured surface runoff, particularly in the months following spring application of these chemicals. Since monitoring at Big Spring began in 1981, 98% of all samples analyzed for pesticides have contained detectable atrazine. The majority of detections of other pesticides occur during the months after application. Cyanazine, alachlor, and metolachlor have been detected in 15%, 15%, and 5% of the analyzed samples, respectively. Maximum annual concentrations of all pesticides follow the trend of annual flow-weighted atrazine concentrations, increasing through WY 1985, and then decreasing through the remainder of the period.

Nitrate concentrations at Big Spring during WY 1985 were distinctly lower than other years of similar discharge and appear related to decreased fertilizer applications during the PIK program of 1983. This suggests a two-year lag time for water quality response to changes in nitrogen inputs. Similar changes in pesticide concentrations, or frequency of detections, did not occur in WY 1985. This may suggest a longer lag time for these chemicals. Atrazine concentrations declined in WYs 1986 and 1987. From 1984 to 1987 there was a significant decrease in atrazine usage. The drought conditions that hampered crop production in the area during 1988 began much earlier from a hydrologic standpoint, with little significant groundwater recharge since snowmelt of 1986. Hence, definitive interpretations of these trends are hampered by complex climatic variations, which underscores the need for long-term monitoring of environmental systems.

INTRODUCTION

The Big Spring basin is a 103 square mile (mi^2) groundwater basin located in Clayton County, in northeastern Iowa. The groundwater basin has been defined through extensive hydrologic investigations of the Iowa Department of Natural Resources, Geological Survey Bureau (DNR-GSB) and cooperating agencies. Previous reports have described the hydrologic definition of the basin, the gaging of the groundwater and surface-water discharge, the monitoring of water quality, and the relationships to agricultural landuse and management in the area. Detailed reviews of the water and chemical discharge for water years 1982 and 1983 have been presented by Hallberg and others (1983, 1984a, 1985); these reports include data describing detailed observations of particular hydrologic events from the monitoring of Big Spring, as well as tile lines, monitoring wells, surface waters and groundwater throughout the basin. Such details have provided insights to the hydrologic behavior and contaminant delivery mechanisms. Additional reports have summarized results from water years 1984 and 1985 (Libra et al., 1986, 1987; Hallberg et al., 1987). (Water years are defined as the 12-month period from 1 October through 30 September of the cited year; i.e., Water Year 1983 includes the period from October 1982, through September 1983.)

Since Water Year 1983 the Big Spring Basin Project has expanded significantly. During this interim, preliminary data for water years 1984-1987 have been included in informal progress reports developed for public agencies cooperating in the project or agency officials who have visited the basin (e.g., Hallberg et al., 1988). This report provides a summary review of the monitoring at the Big Spring itself and from the Turkey River, for the water years 1984 through 1987.

DEMONSTRATION PROJECT STATUS

The Big Spring Basin Demonstration Project (BSBDP) has been underway since 1981; starting as a research project -- the Big Spring Basin Project -- designed to investigate the relationship between agricultural activities and groundwater quality problems related to those activities. In 1986 the "Demonstration" project officially began. The overall program was expanded to develop an intensive, interactive farm demonstration and public education program to help farmers implement improved management practices. The goal of the expanded program was to assist farmers to improve their efficiency and profitability while reducing impacts on the environment: from soil erosion, chemical and nutrient contamination of water supplies, and consumption of non-renewable energy resources. This effort was undertaken in the basin because of the extensive data base developed on the hydrology, water quality, landuse, farm management practices, surveys of attitudes and perceptions of farmers and farm families. These data coupled with the unique hydrogeologic setting of the basin afforded an unparalleled possibility to measure the environmental benefits of improving land and farm management practices, in a real world setting.

The BSBDP involves an integrated, interactive hierarchy of various demonstration, education, research, and monitoring activities, involving the support and effort of many agencies and institutions, as noted in the acknowledgements. In parts of the basin small, detailed research plots are nested within larger, on-farm demonstration fields. The agricultural production, economics, and energy efficiencies are directly measured. The environmental impacts are measured, either on-site, or in aggregate throughout the basin. Water quality is currently monitored at about 50 sites, involving several thousand analyses per year, to provide a detailed chemical-nutrient-energy balance. Other studies are underway concerning the aquatic ecology of the basin, focusing on the impacts of agriculture on the aquatic ecosystem, and assessing the nitrogen dynamics in this ecosystem. Sociological surveys and door-to-door inventories of farm management practices provide other measures of change and point out areas where farmers need further assistance to improve their practices. Public education is stressed in several specific activities, but it is a part of all activities. The BSBDP is committed to conveying research results to the farm community to promote adoption of improved management practices.

The detailed water-quality studies in the basin have been reviewed, and the findings used by the U.S. Environmental Protection Agency (EPA), the U.S.D.A.-Soil Conservation Service (SCS), the National Research Council, the U.S. Geological Survey (USGS), various congressional committees and others. The project has been credited, as well as criticized, with providing the integrated findings that elucidated the impacts of agricultural practices on groundwater quality. The observations more firmly established the relationship, over time, of changes in agricultural practices and agricultural chemical use and the degradation of groundwater quality. These data provided a more complete view of an agricultural ecosystem which highlighted inefficiencies of agricultural management, that perhaps weren't wholly apparent otherwise. This perspective has provided some of the necessary incentive to support the efforts needed to find ways to improve farm management -- to balance the need for efficient and profitable crop production, with the need to improve environmental quality and farm health and safety.

Hydrologic Monitoring Status

Since 1983, during the development of the Demonstration Project, eight new gaging installations were developed on surface water and tile line sites in the basin and more detailed precipitation monitoring was established. The gaging at the Big Spring was improved, and electronic instruments now continuously record some water quality parameters at several sites. Four sets of nested observation wells were installed in the bedrock aquifers and subjacent rock units in the area; these were designed to provide more refined observations on the groundwater hydrology and water-quality relationships among the aquifers in the area.

The expansion of gaging and monitoring necessitated the development of a more refined data management system, as well. Since 1984, efforts have concentrated on developing these installations and data base handling tools, as well as coordinating the implementation of activities in the demonstration programs. The computer data base was finalized in the spring of 1989, for Big Spring, and will be complete for other sites during 1989, as well.

In comparison to previous Big Spring reports, the water and chemical discharge data presented in this report include only the groundwater components, and only the groundwater discharged from the basin to the Turkey River. The loading data do not yet include the surface-water components. Typically the surface-water discharge would add another 80%-150% to the nitrate-nitrogen load discharged from the basin, for example; so values presented are low compared to figures for total basin loads discussed in previous reports (e.g., Hallberg et al., 1984a; Libra et al., 1987). Reports reviewing all basin monitoring are in preparation and these will provide a more complete overview. Many insights into the behavior of nitrate and pesticides in the hydrologic system are incomplete without consideration of the surface-water, tile-line effluent, and well monitoring data.

ANALYTICAL METHODS

All water-quality analyses reported have been performed by the University Hygienic Laboratory (UHL), Iowa City, Iowa. The UHL is fully certified, by the EPA, for all drinking water programs, priority pollutants and pesticides (USEPA, 1982), and has an EPA approved QA/QC program (USEPA, 1984). All analyses are performed by approved standard methods. All nitrogen forms are analyzed by automated methods using Technicon auto-analyzer systems (USEPA, 1983, for methods references): nitrate plus nitrite nitrogen are analyzed by cadmium reduction (Method 353.2); ammonia-nitrogen analyses are performed by phenate reaction (Methods 350.1 and 350.2); and organic-nitrogen is derived from block digestion, Total Kjeldahl procedures (Method 415.1) and subtracting ammonia-N.

Pesticides are analyzed by gas chromatography (GC), (after USEPA, 1980). Pesticide analysis and quantitation utilize GC with dual flame photometric and/or nitrogen-phosphorus (N-P) detectors. Of note for this report is the modification in methods for pesticide analysis that occurred in late 1985. Prior to mid-1985, herbicide analysis and quantitation had been performed by GC using dual columns and electron capture (EC) detectors, with replicate analysis, to quantitate certain analytes, with N-P detectors. This provided excellent control and sensitivity, with a practical quantitation limit of approximately 0.01 ug/L for many common pesticides. (The term practical quantitation limit is used, because the actual method detection limit has a lower value; under UHL's QA/QC and standards analysis program, the minimum value reported is the lowest concentration that the lab confidently quantifies in a given environmental matrix.)

In Water Year 1986 (WY 1986), because of the increasing demand for pesticide analyses, UHL installed additional equipment that utilized dual capillary columns and N-P detectors. While this increased the speed and repeatability of analyses, the N-P detectors are less sensitive; hence, the quantitation limits for pesticide analytes has increased from 0.01 ug/L to 0.1 ug/L. All positive reports require confirmation and quantitation on two columns, with intermittent comparisons with EC detectors and GC-mass spectrometry.

UHL pesticide analysis procedures utilize internal calibration standards to identify and quantitate the following compounds: the herbicide active ingredients alachlor, atrazine, butylate, cyanazine, metolachlor, metribuzin, pendimethalin, and trifluralin; the insecticide active ingredients chlorpyrifos, diazinon, ethoprop, fonofos, malathion, parathion, phorate, and terbufos. Infrequently, samples from this study were also analyzed for the acid-based herbicides which include: 2,4-D, 2,4,5-T, 2,4,5-TP, acifluorfen, chloramben, and dicamba. (Of several hundred samples, the acid-based compounds were only analyzed on a small percentage of samples.) If a significant peak from an unknown compound occurs the lab attempts to identify it with other standards that are not routinely used.

Atrazine, alachlor, cyanazine, and metolachlor are the compounds that have been most frequently detected in the Big Spring basin; their occurrence will be summarized graphically, as well as in the text. The following compounds have not been detected at Big Spring, and can be considered as non-detected (ND, above 0.1 ug/L) for all samples noted in this report: butylate, pendimethalin, and trifluralin; chlorpyrifos, diazinon, ethoprop, malathion, parathion, phorate, and terbufos; 2,4,5-T, 2,4,5-TP, acifluorfen, chloramben, and dicamba.

HYDROGEOLOGIC SETTING

The Big Spring basin is located within the Paleozoic Plateau region of northeast Iowa (Hallberg et al., 1984b). Through most of the basin the landscape is moderately rolling but this ranges to steeply sloping as the Turkey River valley is approached in the southern portion of the area. Total relief within the basin is approximately 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 rocks (and the Silurian escarpment) are evident as wooded promontories standing above the surrounding landscape.

The basin has a well integrated surface drainage network. Most of the groundwater basin coincides with the surface-water basin of Roberts Creek. The landscape is controlled by the configuration of the bedrock. However, the bedrock is mantled by a relatively thin veneer of Quaternary materials, which rarely exceed 25 feet in thickness. Remnants of Pre-Illinoian till occur on upland divides, but largely the surface material dominating the landscape is Wisconsinan loess. Loess-derived soils, primarily Downs, Fayette, and some Tama soils, occupy over 70% of the land surface (Hallberg et al., 1983).

The bedrock of the basin is comprised of the Galena Group carbonate rocks and the overlying Maquoketa Formation of Ordovician age. Locally, on the southwestern portion of the basin divide, outliers of the Silurian-age dolomites occur. The Galena Group dolomites and limestones comprise the Galena aquifer, which supplies the water discharging at Big Spring and the majority of water to wells in the basin. The Galena outcrops low in the landscape and forms the bedrock in only a small portion of the basin (see Hallberg et al., 1983). A series of low permeability shales and shaly carbonate strata underlie the Galena (the Decorah, Platteville, and Glenwood Formations), and mark the effective base of the aquifer.

Over the majority of the basin the Maquoketa Formation overlies the Galena, and is the uppermost bedrock unit. The lower part of the Maquoketa is composed of shaly carbonates, while the upper Maquoketa is shale and claystone.

The shaly carbonates of the lower Maquoketa do not significantly retard water movement, and are generally in open hydrologic connection with the Galena aquifer. Where the Galena aquifer is the bedrock, or is covered by a thin section of the lower Maquoketa, solutional processes have developed sinkholes. The drainage area to most individual sinkholes is relatively small. However, a number of these sinkholes are associated with surface drainage basins, and following extreme rains or snowmelt, runoff from these basins is captured by the sinkholes and diverted into the Galena aquifer. The surface area draining to sinkholes covers about 11% of the Big Spring groundwater basin.

The shales and claystones of the upper Maquoketa Formation are the uppermost bedrock in the western portion of the basin. These low permeability strata retard the downward movement of groundwater towards the Galena aquifer, and in the western portion of the basin the Galena is effectively confined. This area provides a natural background area for the groundwater in the Galena, because the slow recharge through the Maquoketa precludes the occurrence of any modern contaminants related to anthropogenic activities. There are no nitrates (< 0.3 mg/L as NO_3) or pesticides in the Galena groundwater in this region.

BIG SPRING BASIN LANDUSE

Landuse patterns make the Big Spring basin particularly conducive for study of the agricultural ecosystem. The land in the basin is essentially all used for agriculture. There are no significant urban or industrial areas, no landfills or other major point sources to confound the analysis of the groundwater data. The only point sources are surface-water discharges from the Luana creamery and more recently, the addition of the treated waste-water from the new Monona sewage treatment plant. The impact of these sources are monitored.

Table 1 presents landuse information, showing the area and percentage of land in the basin used for various purposes. During the 1980's, landuse in the basin has been relatively stable; with agriculture comprising nearly 97% of the basin. The agricultural acreage has also been relatively stable, with 50-60% of the basin annually devoted to row-crops. The notable exception was in 1983, during the Payment-In-Kind (PIK) program, when substantial land was taken out of row-crop production.

Up until about 1986 the row crop acreage was about 99% corn. In the past few years there has been a minor increase in the amount of soybeans grown in the area, and some small acreages of sorghum planted, as well. The cover crops include oats, hay crops, and pasture, and in the past few years minor amounts of wheat and barley. The landuse has been interpreted from aerial photos, ASCS records, staff field notes, and landowner surveys; these data have been 'digitized' from maps into the DNR-GSB geographic information system, under development for this project.

Other details on annual cropping patterns and annual use of fertilizers and pesticides are also compiled. These data will be presented in subsequent reports.

HYDROLOGIC MONITORING

Groundwater discharge from the Big Spring basin to the Turkey River has been monitored at Big Spring since the fall of 1981. Discharge at Big Spring is a function of recharge within the basin, and therefore is controlled by the amount, timing and intensity of precipitation and snowmelt. This section will present the precipitation record for the basin, and the record of groundwater discharged to the Turkey River, for WYs 1984-1987. Some aspects of the discharge record for the Turkey River will also be discussed. The Turkey River is a high base-flow stream; a large portion of its discharge is derived from groundwater flux. Hence, the record of the Turkey provides some regional perspective on the responses monitored at Big Spring.

The discharge records of other surface water sites and tile-lines, and other data on groundwater hydrology, will be addressed in upcoming reports. Refined interpretations of the data presented in this report requires detailed analysis of all data from the basin, and from associated projects state-wide. Without this further analysis, erroneous conclusions are possible.

Hydrologic data for WY 1988 are not presented. The extreme drought conditions prevailing in 1988 resulted in very low discharges at Big Spring. The established relationships between stage and discharge at Big Spring (Hallberg et al., 1983, 1984a) do not apply under these extreme low flows. A supplemental low-flow stage vs. discharge relationship is currently being established.

PRECIPITATION

Precipitation has been measured at several sites in the basin. Data from the primary weather stations near Elkader, Waukon, and Fayette, which form a triangle around the basin, were also utilized. Precipitation data from these primary weather stations, as well as temperature data used in this report, comes from the Iowa Department of Agriculture and Land Stewardship, State Climatology Office. In August of 1984, a National

Table 1. Landuse in the Big Spring basin; 1970 to 1987. (Computed from DNR-GSB Big Spring basin geographic information system to standardize results.)

	1970			1980		
	acres	square miles	% of basin	acres	square miles	% of basin
Row crop	18,543	29.0	28.1	31,459	49.2	47.6
terraced row crop	4,375	6.8	6.6	4,196	6.6	6.4
Total row crop	22,918	35.8	34.7	35,655	55.7	54.0
Strip crop	2,094	3.3	3.2	4,835	7.6	7.3
terraced strip crop	992	1.6	1.5	1,199	1.9	1.8
Total strip crop	3,086	4.8	4.7	6,034	9.4	9.1
Cover crop	32,481	50.8	49.2	16,656	26.0	25.2
terraced cover crop	1,482	2.3	2.2	1,364	2.1	2.1
Total cover crop	33,963	53.1	51.4	18,020	28.2	27.3
Forest	3,950	6.2	6.0	4,159	6.5	6.3
Urban	306	0.5	0.5	363	0.6	0.6
Roads	1,834	2.9	2.8	1,834	2.9	2.8
Quarries	16	0.02	0.0	9	0.01	0.0
Total urban	2,156	3.4	3.3	2,205	3.5	3.3
TOTAL	66,073	103.2	100.1	66,073	103.2	99.9

	1986			1987		
	acres	square miles	% of basin	acres	square miles	% of basin
Row crop	26,074	40.7	39.5	25,027	39.1	37.9
terraced row crop	3,143	4.9	4.8	3,252	5.1	4.9
Total row crop	29,217	45.7	44.2	28,279	44.2	42.8
Strip crop	10,292	16.1	15.6	8,561	13.4	13.0
terraced strip crop	1,010	1.6	1.5	799	1.3	1.2
Total strip crop	11,302	17.7	17.1	9,360	14.6	14.2
Cover crop	18,614	29.1	28.2	21,165	33.1	32.0
terraced cover crop	1,498	2.3	2.3	1,881	2.9	2.8
Total cover crop	20,112	31.4	30.4	23,046	36.0	34.9
Forest	3,223	5.0	4.9	3,169	5.0	4.8
Urban	388	0.6	0.6	388	0.6	0.6
Roads	1,834	2.9	2.8	1,834	2.9	2.8
Quarries	8	0.01	0.0	8	0.01	0.0
Total urban	2,219	3.5	3.4	2,220	3.5	3.4
TOTAL	66,073	103.2	100.0	66,073	103.2	100.1

Atmospheric Deposition Program station, including various rain gage equipment, was installed at the Big Spring hatchery to collect rain for chemical analysis as a part of the national acid rain monitoring network (National Atmospheric Deposition Program, 1987). Data from this additional station have been used since that time. Data from these sites are evaluated to calculate the basin precipitation (Hallberg et al., 1983, 1984a). Monthly basin precipitation and deviation from normal for WY 1982 through 1988 are shown in Figure 1. ("Normal" is the mean precipitation calculated for the 1951-1980 period.)

The mean annual (WY) precipitation for the area is 32.97 inches (837.4 mm). The annual sum for WY 1984 was 32.81 inches, WY 1985, 1986, and 1987 had annual totals of 35.84, 36.96, and 31.98 inches, respectively. Although annual sums for these water years are close to normal, it is significant to note the distribution pattern of precipitation throughout each year (Table 2). For all four water years, precipitation in June and July was below the norm. In WY 1984, precipitation for the months June through September was below normal for the area. WY 1985 also had four consecutive months of below normal precipitation, April through July. June, July, and August were drier than normal months in WY 1986. In WY 1987 June and July were months with below average precipitation during the growing season.

Overall, rainfall amounts were less than normal during the growing season but greater than normal in the fall during these years. High rainfall occurred in October of WY 1985 following the four dry months which ended WY 1984. In water years 1985-1987, above average rainfall occurred in either August or September. As shown in Figure 1, this trend continued throughout WY 1988. Precipitation deficits also occurred during March and April of WYs 1986-1987, months when significant groundwater recharge often occurs. The timing, intensity, and distribution of rainfall all affect the resultant recharge to the soil-groundwater system.

HYDROLOGY AND THE TRANSPORT OF AGRICULTURAL CONTAMINANTS

Previous reports (Hallberg et al., 1983, 1984a, 1985; Libra et al., 1986, 1987) have documented the relationships between recharge mechanisms and the concentrations and loads of agricultural contaminants in Big Spring basin groundwater. Pertinent findings are summarized below.

Figure 2 shows the groundwater discharge hydrograph from the Big Spring basin for WYs 1984-1987. Periods when discharge rapidly increases, and then just as rapidly decreases, are the result of surface water runoff-recharge to sinkholes. This runoff occurs in small (<2 mile^2, with most <1 mile^2), generally ephemeral headwater drainages, and therefore is short-term (measured in days) and "flashy" in nature. Following such events, the discharge often remains significantly higher than previous to the event, and more slowly decreases to lower flow-rates. This increase indicates that significant infiltration recharge from the event occurred, delivering influent water to the more transmissive parts of the groundwater system, such as conduits or solutionally enlarged fractures and bedding planes. The magnitude of individual recharge events -- from either sinkhole-captured runoff or infiltration -- is controlled by the amount, timing, and intensity of rainfall or snowmelt, and by antecedent discharge and soil-moisture conditions.

During prolonged periods with insignificant recharge, the continuing discharge from Big Spring consists of water that recharged and flowed through the less transmissive parts of the hydrologic system. The hydrograph records this discharge as long, nearly flat lines indicating an extremely gradual decline in flow rates. The less transmissive parts of the system include areas where a thicker cover of Maquoketa Formation and/or Quaternary deposits overlie the Galena aquifer; zones within the Galena dominated by relatively unenlarged fractures and bedding planes, or enlarged fractures and other solutional features that are in-filled with low permeability materials; and the matrix of the Galena aquifer itself. The low permeability of these zones results in low groundwater flow rates, and suggests a considerably longer residence time for groundwater within these zones, relative to the more transmissive parts of the system. For example, where the Galena is covered by a thick Maquoketa section, groundwater age-dates (^{14}C and ^{3}H) suggest recharge occurred a minimum of 35 years ago.

Significant periods of recharge and discharge, from either runoff or infiltration may occur during any time of the year. However, peak instantaneous discharges at Big Spring typically occur during

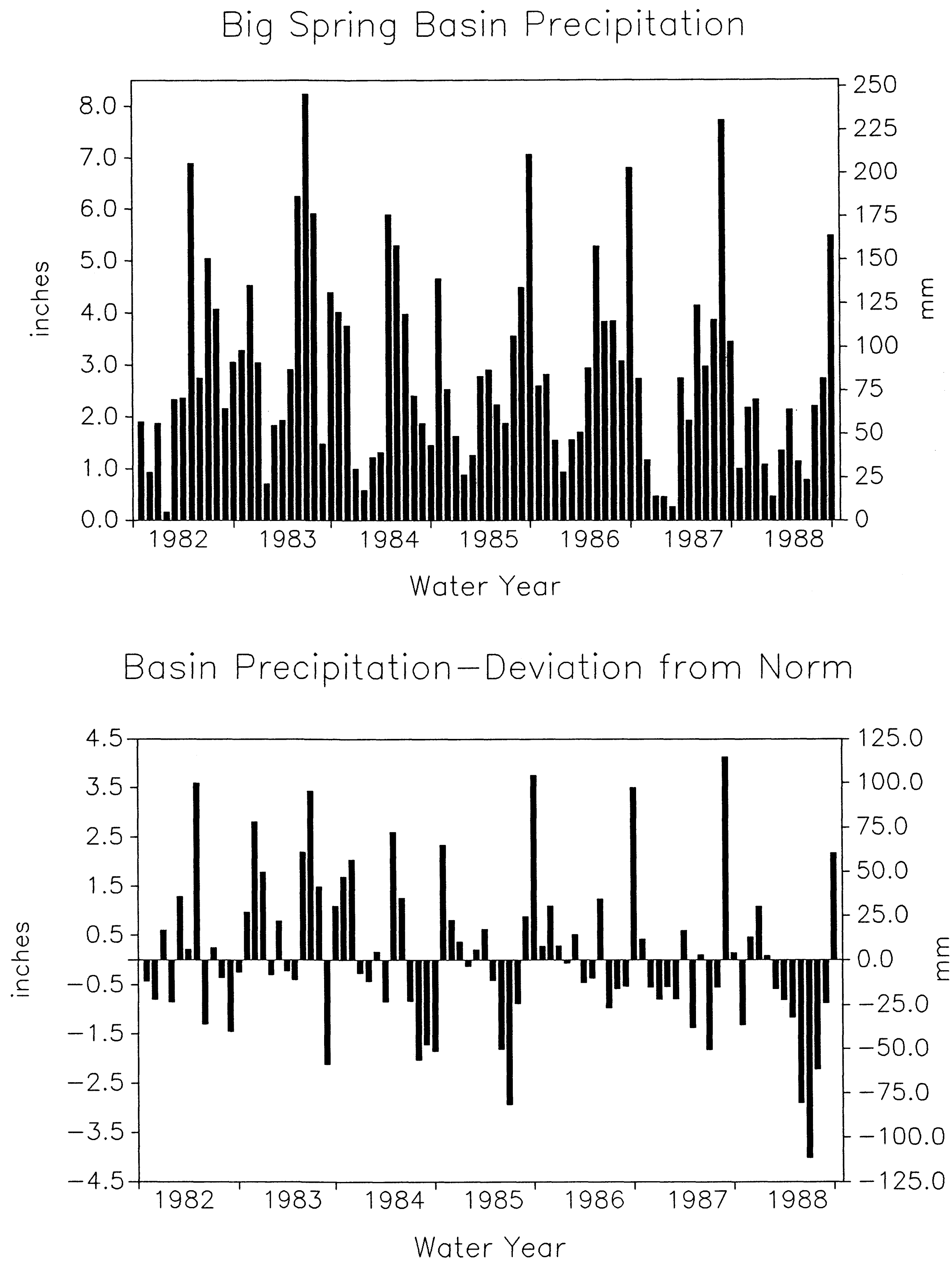


Figure 1. Monthly precipitation totals and deviation from normal for the Big Spring basin, WYs 1982-1988 (Iowa Dept. of Ag. and Land Stewardship, State Climatology Office).

Table 2. Monthly precipitation and departure from normal; Big Spring basin, WYs 1984-1987.

WY 1984	Basin precip inches	Departure from norm inches	% of norm	WY 1985	Basin precip inches	Departure from norm inches	% of norm
Oct-83	4.02	1.70	173.3	Oct-84	4.66	2.34	200.9
Nov-83	3.76	2.04	218.6	Nov-84	2.53	0.81	147.1
Dec-83	1.00	-0.26	79.4	Dec-84	1.63	0.37	129.4
Jan-84	0.58	-0.42	58.0	Jan-85	0.88	-0.12	88.0
Feb-84	1.22	0.17	116.2	Feb-85	1.26	0.21	120.0
Mar-84	1.32	-0.83	61.4	Mar-85	2.78	0.63	129.3
Apr-84	5.90	2.60	178.8	Apr-85	2.90	-0.40	87.9
May-84	5.30	1.26	131.2	May-85	2.23	-1.81	55.2
Jun-84	3.98	-0.82	82.9	Jun-85	1.87	-2.93	39.0
Jul-84	2.40	-2.03	54.2	Jul-85	3.56	-0.87	80.4
Aug-84	1.88	-1.72	52.2	Aug-85	4.48	0.88	124.4
Sep-84	1.45	-1.85	43.9	Sep-85	7.06	3.76	213.9
TOTAL WY 1984	32.81	-0.16	99.5	TOTAL WY 1985	35.84	2.87	108.7

WY 1986	Basin precip inches	Departure from norm inches	% of norm	WY 1987	Basin precip inches	Departure from norm inches	% of norm
Oct-85	2.60	0.28	112.1	Oct-86	2.74	0.42	118.1
Nov-85	2.82	1.10	164.0	Nov-86	1.17	-0.55	68.0
Dec-85	1.55	0.29	123.0	Dec-86	0.47	-0.79	37.3
Jan-86	0.94	-0.06	94.0	Jan-87	0.46	-0.54	46.0
Feb-86	1.56	0.51	148.6	Feb-87	0.27	-0.78	25.7
Mar-86	1.70	-0.45	79.1	Mar-87	2.75	0.60	127.9
Apr-86	2.94	-0.36	89.1	Apr-87	1.93	-1.37	58.5
May-86	5.28	1.24	130.7	May-87	4.15	0.11	102.7
Jun-86	3.84	-0.96	80.0	Jun-87	2.98	-1.82	62.1
Jul-86	3.85	-0.58	86.9	Jul-87	3.88	-0.55	87.6
Aug-86	3.08	-0.52	85.6	Aug-87	7.73	4.13	214.7
Sep-86	6.80	3.50	206.1	Sep-87	3.45	0.15	104.5
TOTAL WY 1986	36.96	3.99	112.1	TOTAL WY 1987	31.98	-0.99	97.0

snowmelt, in February or March. Winter months, when the surface soil is frozen and most precipitation falls as snow, and the summer growing season, when evapotranspiration is at a maximum, are characterized by little recharge and therefore extended periods of discharge recession. Major rains that occur between these periods will often generate significant recharge.

The hydrologic responses to recharge (or the lack of recharge) are important in understanding the transport of agricultural chemicals into and through the groundwater system. Previous reports (Hallberg et al., 1983, 1984a) have shown that the recharge components have unique chemical signatures. These signatures can be traced from monitoring runoff and infiltration within the basin into the Big Spring groundwater system. Infiltration recharge is enriched in nitrate and other chemicals that are mobile in soil (e.g., chloride), relative to runoff recharge, particularly runoff derived from snowmelt. Runoff recharge has lower concentrations of such compounds, but is enriched

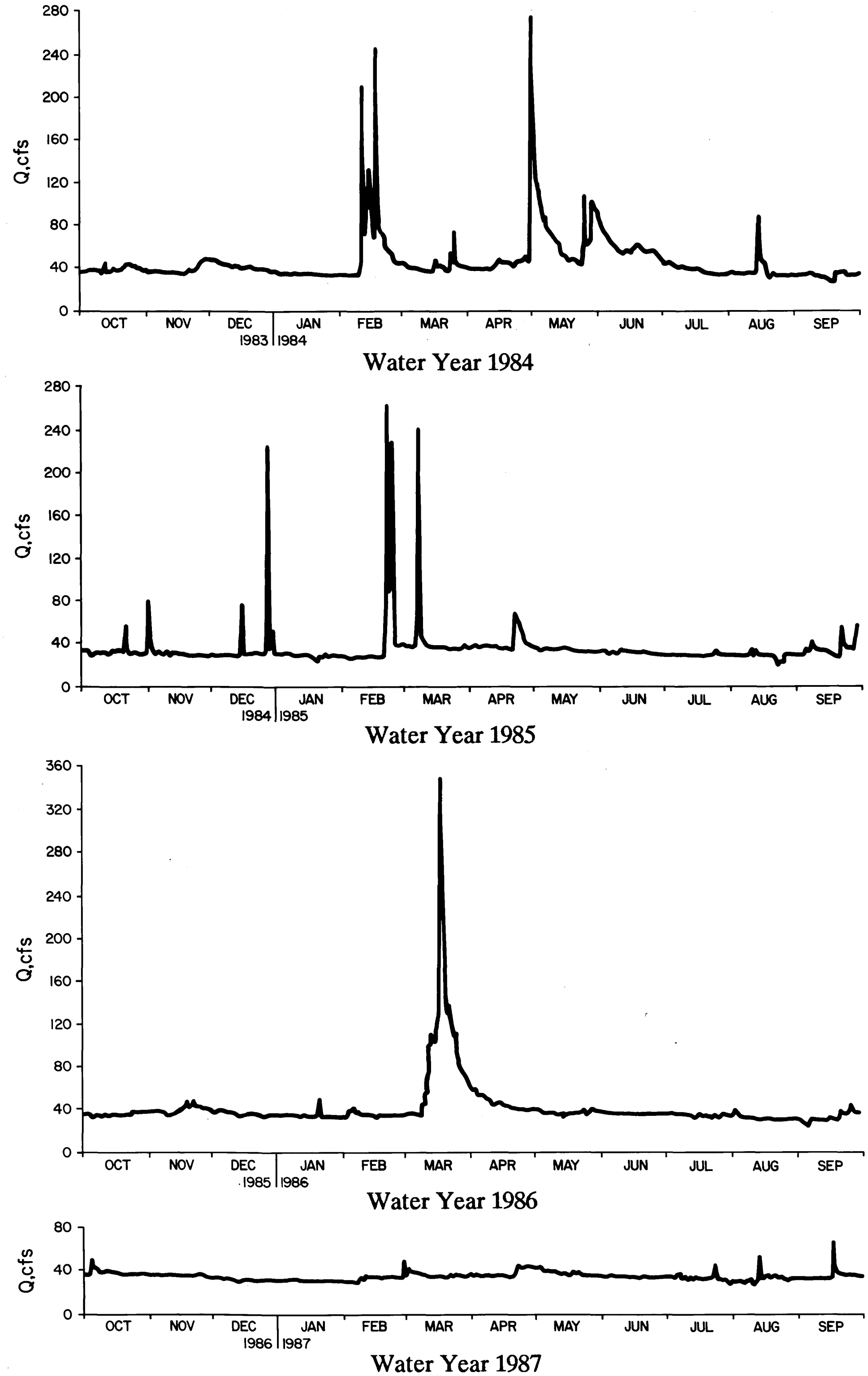


Figure 2. Groundwater discharge hydrographs for the Big Spring basin, WYs 1984-1987.

with herbicides and other chemicals with low soil mobility (e.g., ammonia), relative to infiltration. The characteristic contaminant loads mobilized by these recharge sources define the quality of water discharged at Big Spring. During a recharge event relatively low nitrate and high herbicide concentrations occur when runoff recharge is discharged from the spring. This is typically followed by higher nitrate and lower herbicide concentrations as the associated infiltration recharge moves through the system.

During prolonged recession periods, nitrate and herbicide (particularly atrazine) concentrations generally show a slow, steady decline. This decline likely occurs as an increasing percentage of the discharge is from the less transmissive parts of the flow system. As discussed above, discharge from the less transmissive parts of the system is relatively old and may contain lower or no detectable concentrations of agricultural contaminants. This is a result of landuse and ag-practices at the time of recharge (i.e., lower N-fertilization, limited application of currently-used herbicides), or chemical reactions while in slow transit to Big Spring (i.e., denitrification, herbicide degradation).

The concentration-discharge relationships discussed above define the total loading of agricultural chemicals discharged from the Big Spring groundwater system. In general, low discharge periods are accompanied by low contaminant concentrations, yielding small total loads. Concentrations are generally higher in periods of higher discharge, yielding greater loads. Departures from this simple framework provides further insights into the hydrologic system and contaminant behavior. The following sections will summarize the Big Spring and Turkey River (at Garber) discharge records by water year, and will then discuss the results of nitrate and pesticide monitoring in light of the discharge records. All discharge data for the Turkey River at Garber are from the U.S. Geological Survey, Water Resources Division, Iowa District.

WATER YEAR 1984

Tables 3 through 8 and Figures 3 through 6 summarize the discharge, precipitation, water quality, and chemical loading data for WY 1984. Precipitation for the year was 32.81 inches, about 0.2 inch below average. Groundwater discharge from the basin was 32,696 acre-feet (ac-ft), and the average discharge for the year was 45 cubic feet per second (cfs). This discharge was the greatest for any water year in the 1984-1987 period, in spite of the average total precipitation. A significant snowmelt in February and intense rains during April and May generated major recharge events. The four month February-May period accounted for 42% of the total discharge for the water year. Precipitation for these months was 3.2 inches above average. These events occurring prior to the growing season, coupled with the relatively wet antecedent conditions from WY 1983 (precipitation was 44.5 inches), resulted in significant groundwater recharge. Discharge was equivalent to 18% of precipitation for WY 1984.

Major recession periods, indicative of little or no recharge, occurred during the period from early December through mid-February, and again from July through September (Fig. 3). This latter recession was interrupted by a short period of runoff recharge in August, which appears as a sharp single peak on the hydrograph. Following this event, the discharge falls quickly back to and below pre-event levels, indicating only minor infiltration recharge occurred. Average monthly discharges varied from a high of 73 cfs during May to a low of 31 cfs in September, at the end of the summer baseflow recession period.

Figure 5 shows log-scale discharge hydrographs for Big Spring and the Turkey River at Garber. Tables 7 and 8 summarize data for the Turkey River, which at Garber has a drainage area of 1,545 miles^2. The hydrographs are quite similar in their overall form and seasonal response, as discussed by Hallberg and others (1983; 1984a). Total discharge at Garber was slightly in excess of one million acre-feet, with an average discharge of 1,395 cfs. This discharge was about 37% of the precipitation for the water year, and was about 152% of the long-term (1951-1980) average annual discharge for the Turkey River at Garber.

Nitrate Monitoring

Tables 3 and 5 summarize the results of monitoring at Big Spring for WY 1984; a total of 197 samples for nitrate analysis were collected from Big Spring. The flow-weighted mean nitrate concentration for WY 1984 was 43 mg/L (9.6 mg/L as NO_3-N), just below the U.S.E.P.A. drinking-water standard (45 mg/L as NO_3). A total of 843,000 pounds of nitrate-nitrogen was discharged from the Big Spring basin groundwater system to the Turkey River. Figure 4 shows the discharge hydrograph and nitrate concentrations for Big Spring. At the beginning of WY 1984 nitrate concentrations were about 40 mg/L. Minor recharge events -- mainly from infiltration -- during October and December delivered nitrate to the groundwater, and resulted in concentrations typically above 45 mg/L during much of this period. Nitrate concentrations decreased back to about 40 mg/L during the mid-December to early February period, as little recharge of nitrate-rich infiltration water occurred. Runoff recharge during the mid-February snowmelt delivered a large volume of low-nitrate water to the system, causing the nitrate concentration at Big Spring to fall to a minimum of about 20 mg/L for a short period of time during runoff recharge (Fig. 4). As noted previously, this snowmelt also resulted in significant infiltration recharge. The effects of the infiltration recharge is shown on the nitrate graph by the increase in nitrate concentration in late February. This occurs as discharge decreases, and more slowly recedes, just after the main snowmelt-related discharge maxima (Fig. 4). Nitrate concentrations increase to levels greater than those prior to the snowmelt event, reflecting the addition to the groundwater of recharge that has passed through the soil, mobilizing and transporting nitrate downward (e.g., Hallberg et al, 1984a; Libra et al., 1984; Baker and Johnson 1977, 1981). Such effects -- decreased nitrate concentrations for a short period (several days, at most) during runoff recharge periods, followed by increased nitrate during the infiltration recharge periods that follow -- are key indicators of the recharge mechanisms at work in the basin. Significant runoff and infiltration recharge in late April and early May resulted in another nitrate concentration decrease followed by an increase to greater than pre-event levels (Fig. 4). Smaller recharge events during the remainder of the year had lesser effects, and nitrate concentrations generally decreased from about 50 mg/L in May to about 35 mg/L in September.

Table 5 summarizes average monthly flow-weighted mean nitrate concentrations and nitrate-nitrogen discharge for WY 1984. Concentrations and loads were greatest in May and June; 49 and 47 mg/L nitrate and 130,000 and 100,000 pounds of nitrate-nitrogen, respectively. These two months accounted for about 27% of the total nitrate discharged in WY 1984. Flow-weighted concentrations were lowest -- 34 mg/L -- in February, when large amounts of snowmelt runoff discharged from the basin, and in September, following several months of limited recharge. September also exhibited the lowest nitrate-nitrogen discharge, about 37,000 pounds. These effects are also typical of responses in the basin; runoff water, and particularly snowmelt runoff, has a very low nitrate concentration and dilutes the nitrate in the groundwater system derived from infiltration and storage. During longer recessions nitrate also declines, as the head in the aquifer lowers to deeper in the soil-rock reservoir, where nitrate concentrations tend to be lower, and water coming out of the matrix of the aquifer and confined storage become more important.

Figure 5 and Tables 7 and 8 summarize nitrate concentrations and loads for the Turkey River (at Garber) for the water year. Note that the general trends in nitrate concentrations are similar for the Turkey River and for Big Spring groundwater. Differences in detail occur because of the size difference between the systems, the much larger proportion of surface runoff water in the Turkey River, and the more frequent sampling at Big Spring during recharge-discharge events (see Hallberg et al., 1983, 1984a). A total of 15,000,000 pounds of nitrate-nitrogen was discharged by the Turkey River during WY 1984, at a flow-weighted mean nitrate concentration of 25 mg/L (5.6 mg/L as NO_3-N). As was the case for Big Spring, May and June accounted for the greatest total nitrate-nitrogen discharges, about 3,000,000 and 2,600,000 pounds, respectively (Table 8). The lowest total nitrate-nitrogen flux occurred in September, 167,000 pounds.

Pesticide Monitoring

Tables 3 and 6 and Figures 4 and 6 summarize the results of pesticide monitoring at Big Spring for WY 1984; 47 samples for pesticide analysis were collected from Big Spring. The most commonly occurring pesticide in Big Spring groundwater is atrazine. During WY 1984, about 40 pounds of atrazine were discharged by the basin's groundwater system, at a flow-weighted mean concentration of 0.45 ug/L. Figure 4 shows a plot of atrazine concentrations for WY 1984 at Big Spring. Note that the atrazine graph resembles a subdued

Table 3. **Annual summary of groundwater and chemical discharge from the Big Spring basin to the Turkey River for Water Year 1984; 10/01/83 - 09/30/84.**

DISCHARGE

Total

acre-feet	32,696
millions cf	1,424
millions cm	40

Average

cfs	45.3
cms	1.3
mg/d	29.3
gpm	20,340

PRECIPITATION AND DISCHARGE

Precipitation	32.8 inches	(353mm)
Discharge	5.9 inches	(150mm)
Discharge as % of precipitation	18.0%	

NITRATE DISCHARGE

Concentration - mg/L	As NO_3	As NO_3-N
Flow-weighted mean	43	9.7
Mean of analyses	41	9.1

Total NO_3-N output

lbs - N	843,399
kg - N	382,494

ATRAZINE DISCHARGE

Concentration - ug/L

Flow-weighted mean	0.45
Mean of analyses	0.80

Total output

lbs	40.0
kg	18.1

Table 4. **Monthly summary of groundwater discharge from the Big Spring basin for Water Year 1984.**

	1983 Oct.	Nov.	Dec.	1984 Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.
TOTAL MONTHLY DISCHARGE												
Acre-feet	2,348	2,243	2,529	2,095	3,769	2,457	3,105	4,468	3,489	2,231	2,191	1,772
Cubic feet (millions)	102	98	110	91	159	107	135	195	152	97	95	76
Gallons (millions)	765	731	824	683	1,229	801	1,012	1,456	1,137	727	714	578
Cubic meters (millions)	2.9	2.8	3.1	2.6	4.5	3.0	3.8	5.5	4.3	2.8	2.7	2.2
AVERAGE DISCHARGE												
cfs	38	38	41	34	66	40	52	73	59	38	36	31
cms	1.1	1.1	1.2	1.0	1.9	1.1	1.5	2.1	1.7	1.1	1.0	0.9
mg/d	25	24	27	22	42	26	34	47	38	24	23	20
MAXIMUM												
cfs	43	48	47	37	245	73	274	162	84	45	86	34
cms	1.2	1.4	1.3	1.1	6.9	2.1	7.8	4.6	2.4	1.3	2.4	1.0
MINIMUM												
cfs	34	34	37	33	32	36	37	41	47	32	30	26
cms	1.0	1.0	1.0	0.9	0.9	1.0	1.1	1.2	1.3	0.9	0.8	0.7

Table 5. **Monthly summary of nitrate-N discharged in groundwater from the Big Spring basin to the Turkey River; Water Year 1984.**

	1983 Oct.	Nov.	Dec.	1984 Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.
Flow-weighted mean NO_3 concentration, in mg/L;	45	45	47	42	37	40	38	48	47	44	39	34
as NO_3-N	10.0	10.0	10.5	9.2	8.3	8.9	8.5	10.7	10.5	9.7	8.6	7.7
Mean of NO_3 analyses, in mg/L;	43	45	47	42	34	36	35	49	47	43	39	34
as NO_3-N	9.6	10.0	10.5	9.2	7.7	8.0	7.8	10.9	10.5	9.6	8.6	7.7
Total monthly NO_3 output, thousands lbs	64	61	72	52	85	60	71	130	100	59	51	37
Total monthly NO_3 output, thousands kg	29	28	33	24	38	27	32	59	45	27	23	17

Table 6. **Monthly summary of atrazine discharged in groundwater from the Big Spring basin to the Turkey River; Water Year 1984.**

	1983 Oct.	Nov.	Dec.	1984 Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.
Flow-weighted mean atrazine concentration, in *u*g/L	0.22	0.24	0.16	0.13	0.31	0.23	0.69	1.01	0.91	0.32	0.20	0.14
Mean of atrazine analyses, in *u*g/L	0.22	0.25	0.18	0.13	0.30	0.32	2.95	1.36	0.91	0.30	0.18	0.15
Total monthly atrazine output, lbs	1.4	1.4	1.1	0.7	3.2	1.6	5.9	12.3	8.6	1.9	1.2	0.7
Total monthly atrazine output, grams	644	655	509	336	1,429	706	2,652	5,575	3,899	878	534	302

Table 7. **Annual summary of water and chemical discharge for the Turkey River at Garber for Water Year 1984; 10/01/83 - 09/30/84.** (Discharge data from the U.S. Geological Survey, Water Resources Division.)

DISCHARGE

Total

acre-feet	1,010,100
millions cf	44,000
millions cm	1,246

Average

cfs	1395.2
cms	39.5
mg/d	902.0
gpm	626,445

PRECIPITATION AND DISCHARGE

Precipitation	33.0 inches	(838.2mm)
Discharge	12.3 inches	(312.4mm)
Discharge as % of precipitation	37.0%	

NITRATE DISCHARGE

Concentration - mg/L	As NO_3	As NO_3-N
Flow-weighted mean	25	5.6
Mean of analyses	24	5.3

Total NO_3-N output

thousands lbs - N	15,175
thousands kg - N	6,882

Table 8. **Monthly summary of nitrate-N discharge for the Turkey River at Garber; Water Year 1984.**

	1983 Oct.	Nov.	Dec.	1984 Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.
Flow-weighted mean NO_3 concentration, in mg/L;	22	25	31	27	18	21	24	29	33	24	15	14
as NO_3-N	4.9	10.0	6.9	6.0	4.0	4.7	5.3	6.4	7.3	5.3	3.3	3.1
Mean of NO_3 analyses, in mg/L;	21	25	32	27	21	22	25	29	32	22	14	14
as NO_3-N	4.7	5.6	7.1	6.0	4.7	4.9	5.6	6.4	7.1	4.9	3.1	3.1
Total monthly NO_3-N output, thousands lbs	717	1,087	1,144	523	1,684	1,310	1,753	3,055	2,664	809	281	167
Total monthly NO_3-N output, thousands kg	325	493	519	273	763	594	795	1,386	1,208	367	127	76

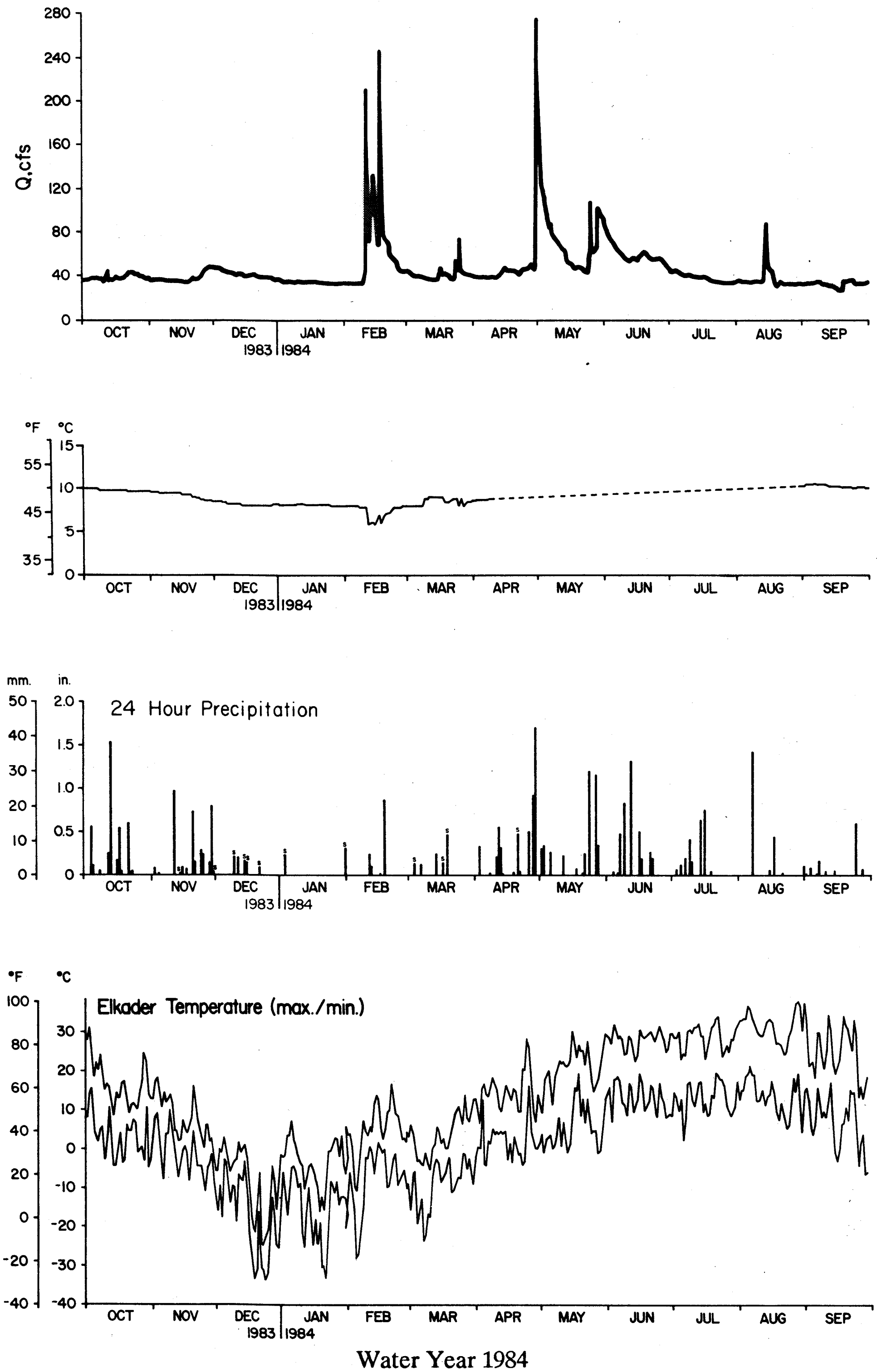


Figure 3. Daily precipitation, groundwater discharge, and groundwater temperature for the Big Spring basin, and maximum-minimum temperatures for Elkader, IA (Iowa Dept. of Ag. and Land Stewardship, State Climatology Office), for WY 1984.

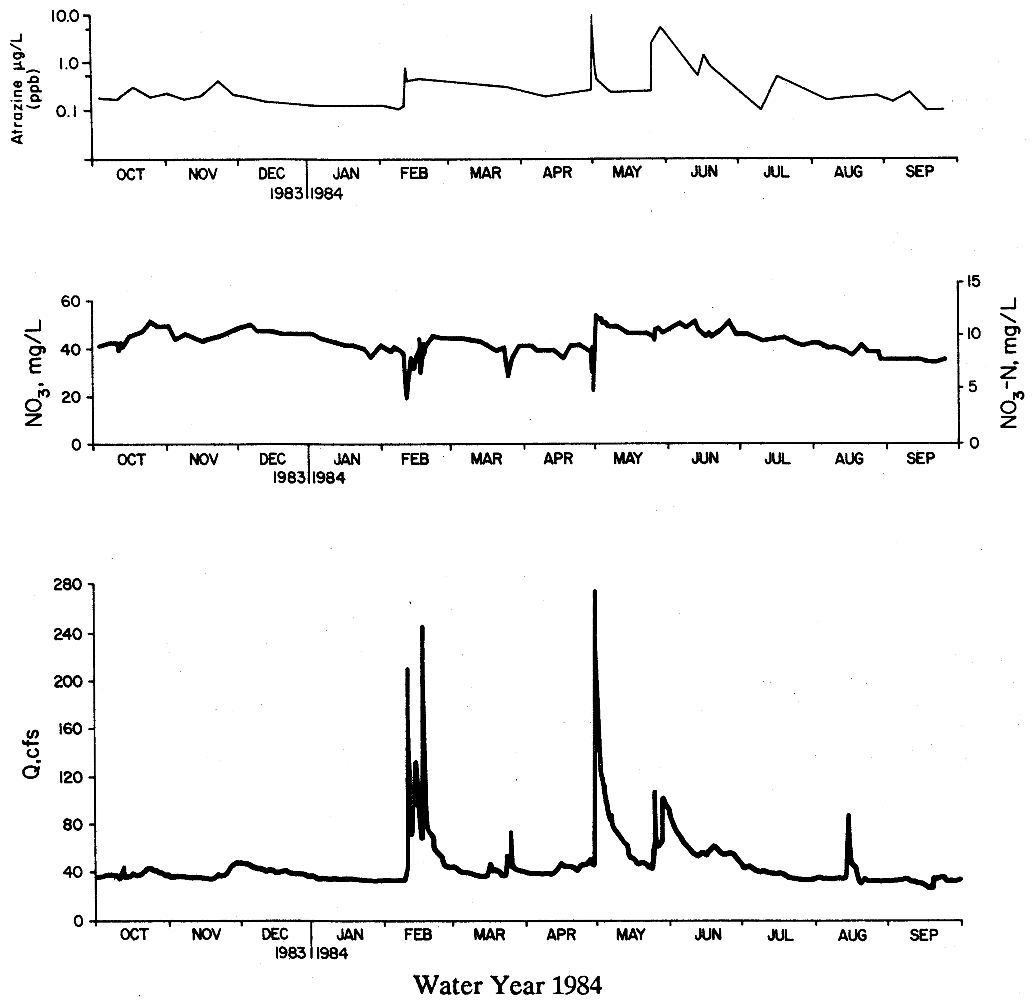
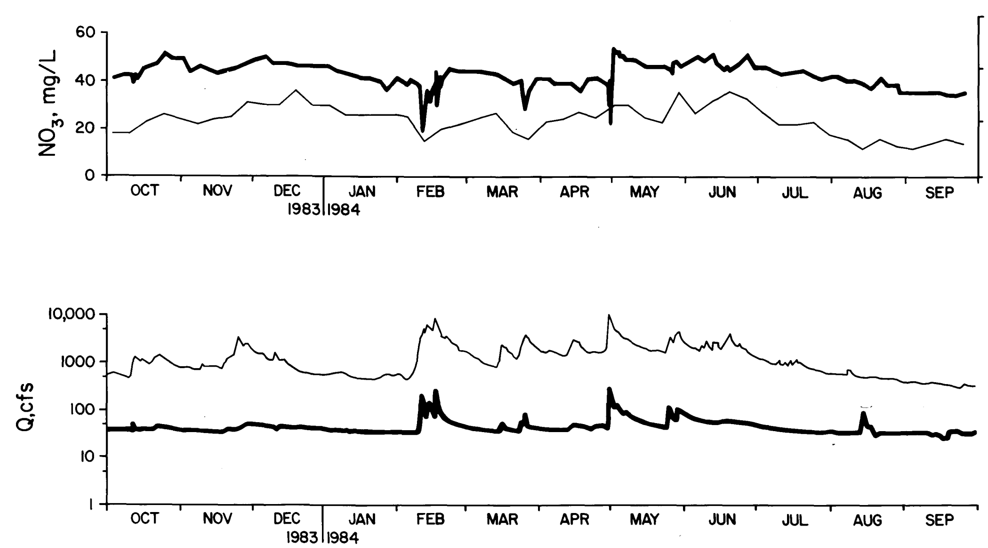
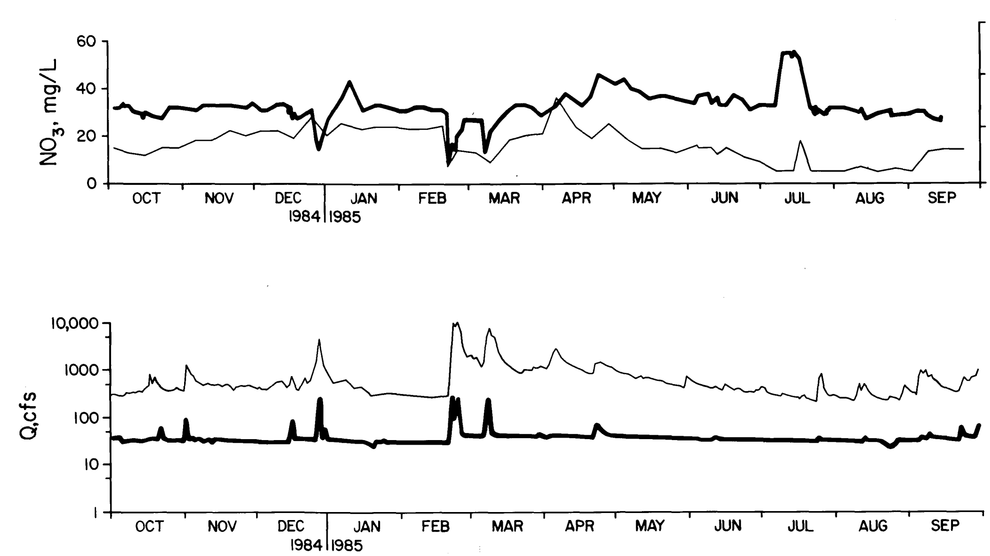


Figure 4. Groundwater discharge, and nitrate and atrazine concentrations at Big Spring for WY 1984.



Water Year 1984



Water Year 1985

Figure 5. Discharge hydrographs and nitrate concentrations for Big Spring (bold lines) and the Turkey River (lighter lines) at Garber for WYs 1984-1985; Turkey River data. (Turkey River discharge data from U.S.G.S., W.R.D., IA Dist.)

concentrations of atrazine -- exceeding 1 ug/L -- roughly coincide with maximum discharges, reflecting the transport of relatively high concentrations of atrazine into and through the system with runoff recharge. Atrazine concentrations decrease rapidly as runoff inputs decline and infiltration-derived water begins to dominate the discharge from Big Spring. Atrazine concentrations during infiltration-dominated parts of the February-June recharge period are higher than those occurring before or after the period, and indicate infiltration transport of atrazine. Concentrations during non-runoff periods were generally 0.2 to 0.5 ug/L. (As discussed in past reports, the relative recharge components of chemical solutes are evaluated against other monitoring in the basin. These data will be presented in subsequent reports.)

Table 6 summarizes the atrazine data for WY 1984 by month. Flow-weighted mean atrazine concentrations are highest in May and June, when significant runoff recharge water was discharged from the basin. Mean concentrations were 1.01 and 0.91 ug/L, respectively, for these months. The lowest monthly mean concentrations occurred during January and September, and were 0.13 and 0.14 ug/L, respectively. These months marked the end of the most extensive baseflow periods of the water year. The largest total flux of atrazine occurred during May, when 12.3 pounds was discharged by the groundwater system. By contrast, only 0.7 pound was discharged during January and September.

In addition to atrazine, the herbicides cyanazine, metolachlor, and alachlor were detected in Big Spring groundwater. Figure 6 shows concentrations of these four herbicides for WY 1984. Atrazine was detected in every sample analyzed; the other herbicides were only detected when shown. Detection of these other chemicals occurred between the end of April and mid-June. Maximum concentrations of atrazine, alachlor, cyanazine, and metolachlor were 10.0, 4.0, 1.7, 4.5 ug/L, respectively. These herbicides were detected in 100%, 26%, 23%, and 19% of the samples analyzed. Additionally, the insecticide fonofos was detected once, at a concentration of 0.3 ug/L.

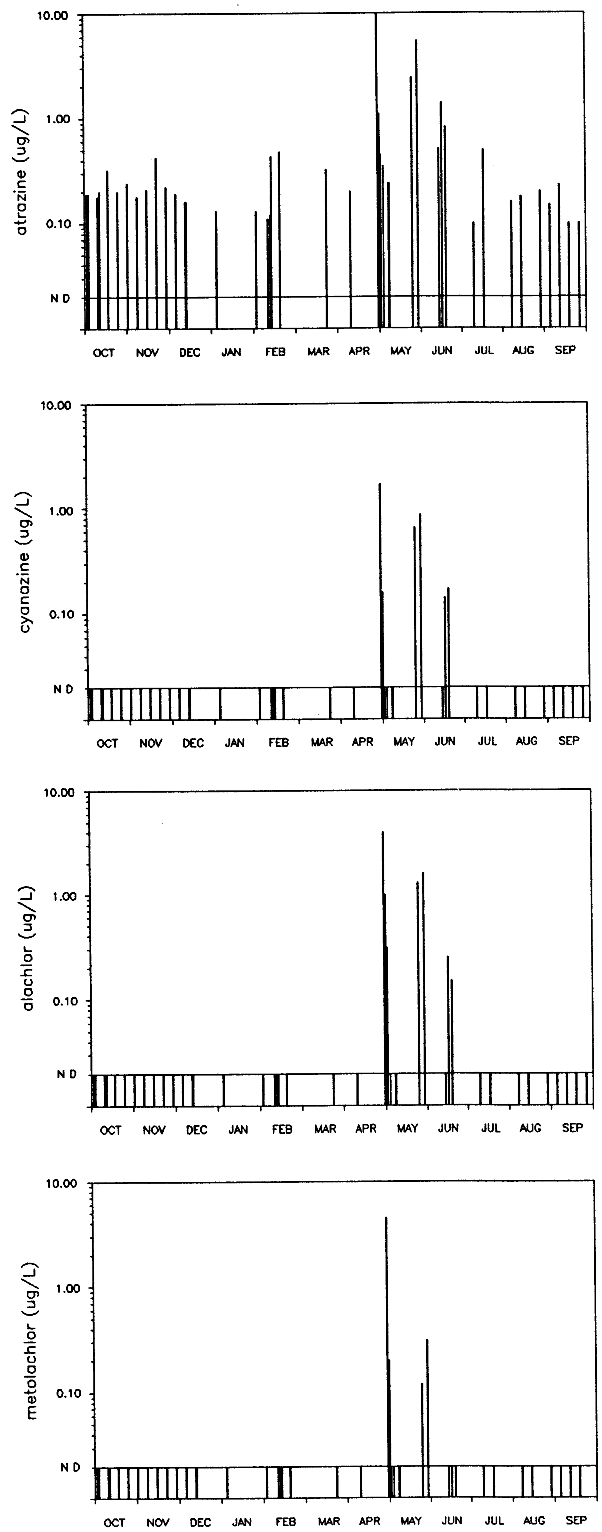


Figure 6. Schematic diagram of pesticide concentrations at Big Spring for WY 1984. ND represents not detected.

WATER YEAR 1985

Tables 9 through 14 and Figures 5, 7, 8, and 9 summarize the discharge, precipitation, water quality, and chemical-load data for WY 1985. Precipitation for the year was 35.84 inches, about 2.9 inches above average. Groundwater discharge from the basin was 25,122 ac-ft, and the average discharge for the year was 35 cfs. Though precipitation was greater than WY 1984, discharge in WY 1985 was equivalent to 13% of the year's precipitation, compared to 18% during WY 1984. During the October-April period, the hydrograph (Fig. 7) shows numerous peaks, indicating runoff recharge. Following these peaks, discharge returned to, or only slightly above, the pre-event rate, indicating a lack of significant infiltration recharge during much of this period. The hydrographs from WYs 1984 and 1985 are in marked contrast in this respect (Fig. 2).

During the remainder of WY 1985 (late April-September), a few small recharge events occurred. In general, this was a recession period. While a summer baseflow recession is typical at Big Spring, in WY 1985 the recession was under way by mid-March. Precipitation was 5.1 inches below normal during the April-June period. This precipitation deficit in the late spring-early growing season acted to limit groundwater recharge throughout the remainder of WY 1985.

Average monthly discharge varied from a high of 49 cfs during February, when snowmelt occurred, to 29 cfs in August, at the end of the summer baseflow recession. Average discharge exceeded 40 cfs only in February and March.

Figure 5 shows log-scale discharge hydrographs for Big Spring and the Turkey River at Garber. Tables 13 and 14 summarize WY 1985 data for the Turkey River. Total discharge for the water year was about 556,000 ac-ft, little more than half that of WY 1984. The average flow-rate was 770 cfs, or 84% of the long-term average. Discharge was equivalent to 19% of total precipitation.

Nitrate Monitoring

Tables 9 and 11 and Figures 5 and 8 summarize the results of nitrate monitoring at Big Spring for WY 1985; the nitrate record for WY 1985 consists of 209 separate analyses. The flow-weighted mean nitrate concentration for WY 1985 was 31 mg/L (6.9 mg/L as NO_3-N), the lowest for the WYs 1984-1987 period of record. A total of 477,000 pounds of nitrate-nitrogen was discharged from the Big Spring basin groundwater system to the Turkey River.

Figure 8 shows the discharge hydrograph and nitrate concentrations for Big Spring. At the beginning of WY 1985 nitrate concentrations were relatively low, generally less than 35 mg/L. Significant snowmelt events during December, February, and March resulted in runoff recharge and corresponding periods of low nitrate concentrations. Three of these events caused nitrate concentrations to fall below 20 mg/L for short periods of time. Following this dilution effect caused by runoff, nitrate concentrations rise to levels somewhat higher then those occurring previous to these events, indicating infiltration delivery of recently leached nitrate. Minor recharge events in late March and April were accompanied by an increase in nitrate concentrations, to about 40 mg/L. Nitrate concentrations decreased during the summer baseflow recession, to below 30 mg/L by September.

A period of 10 to 14 days in mid-July (Fig. 8) was marked by anomalously high nitrate concentrations. Nitrate concentrations were above 50 mg/L during this period, compared to 30 to 35 mg/L before and after. Similar increases in nitrate concentrations have been noted in the past (see Hallberg et al., 1984a), but these generally occur during periods of more notable infiltration recharge. The discharge hydrograph gives little indication of any recharge during this period (Fig. 8). Field observations did not suggest significant recharge either. Precipitation during the previous week was approximately 0.5 inch. The period of high nitrate concentrations is defined by eight separate analyses, (from two different labs and two different methods) and therefore analytical problems are unlikely. The exact cause of this anomaly cannot be determined at present.

Table 11 summarizes the nitrate concentration and load data by month. The highest flow-weighted mean nitrate concentration, 39 mg/L, occurred during May, while the lowest occurred during the snowmelt-dominated month of February, 23 mg/L. The largest monthly fluxes of NO_3 discharged from the basin were 52,000 pounds in April and 51,000 pounds in May. The lowest monthly discharge occurred in August and totalled 29,000 pounds of NO_3-N.

Figure 5 and Tables 13 and 14 summarize nitrate concentrations and loads for the Turkey River (at Garber) for the water year. In total, 5.3 million pounds of nitrate-nitrogen were discharged by the Turkey River, at a flow-weighted mean nitrate concentration of 16 mg/L (3.6 mg/L as NO_3-N). April and March accounted for the greatest nitrate-nitrogen discharges, about 1.2 and 0.9 million pounds, respectively (Table 14). The lowest nitrate flux occurred in August, 58,000 pounds of NO_3-N.

Pesticide Monitoring

Seventy-eight samples were analyzed for pesticides from Big Spring during WY 1985. Tables 9 and 12 and Figures 8 and 9 summarize these results. During WY 1985, about 48 pounds of atrazine were discharged by the basin's groundwater system at a flow-weighted mean concentration of 0.70 ug/L. Figure 8 is a plot of atrazine concentrations through WY 1985 at Big Spring. Relatively high atrazine concentrations -- from 1.0 to 5.0 ug/L -- accompanied the occurrence of numerous runoff recharge events during the October-March period. Concentrations were generally around 0.2 ug/L between these events. Peak atrazine concentrations occurred in early January, February, and early April, as well as June. Concentrations ranged from the water year maximum of 6.1 ug/L in June, and then decreased to about 0.3 ug/L in September, although major recharge events were lacking. Both the hydrologic analysis and field monitoring indicate that the period of relatively high concentrations of atrazine in June and July coincides with a period dominated by infiltration recharge or recession, with water coming out of storage from the aquifer.

Table 12 summarizes the atrazine data on a monthly basis. Flow-weighted mean concentration and total atrazine discharge were greatest in June, and were 1.93 ug/L and 10.2 pounds, respectively. The lowest concentration (0.26 ug/L) and load (1.4 pounds) were in November.

Figure 9 shows concentrations of atrazine, cyanazine, alachlor, and metolachlor for WY 1985. Atrazine was detected in every sample analyzed. (The occurrence of non-detections of the other chemicals are indicated by concentration bars ending at "ND".) Detection of these other chemicals began on April 2 and continued intermittently until earliest July. The peak detections of all these compounds that occurred in earliest April, preceded nearly all 1985 pesticide application in the basin. (Field observations and surveys noted only two areas where any herbicides were applied during or prior to this time.) Late March was marked by snowfall and wet conditions which precluded field work from beginning. The new snow and rain that fell on the soils of the basin, which had thawed in most areas by then, did afford some infiltration recharge.

Maximum concentrations of atrazine, alachlor, cyanazine, and metolachlor were 6.1, 5.0, 4.6, 4.5 ug/L, respectively (Table 30). These herbicides were detected in 100%, 14%, 15%, and 4% of the sample analyses, respectively. Metribuzin, 2,4-D, and fonofos were also detected in one sample each during the spring of 1985.

Table 9. **Annual summary of groundwater and chemical discharge from the Big Spring basin to the Turkey River for Water Year 1985; 10/01/84 - 09/30/85.**

DISCHARGE

Total

acre-feet	25,122
millions cf	1,094
millions cm	31

Average

cfs	35.2
cms	1.0
mg/d	22.7
gpm	15,796

PRECIPITATION AND DISCHARGE

Precipitation	35.84 inches	(910.34mm)
Discharge	4.6 inches	(116.8mm)
Discharge as % precipitation	13.0%	

NITRATE DISCHARGE

Concentration - mg/L	As NO_3	As NO_3-N
Flow-weighted mean	31	7.0
Mean of analyses	29	6.5

Total NO_3-N output

lbs - N	476,827
kg - N	216,248

ATRAZINE DISCHARGE

Concentration - ug/L

Flow-weighted mean	0.70
Mean of analyses	0.76

Total output

lbs	47.6
kg	21.6

Table 10. **Monthly summary of groundwater discharge from the Big Spring basin for Water Year 1985.**

	1984 Oct.	Nov.	Dec.	1985 Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.
TOTAL MONTHLY DISCHARGE												
Acre-feet	1,985	1,913	2,234	1,793	2,701	2,598	2,361	2,132	1,931	1,877	1,586	1,969
Cubic feet (millions)	86.5	83.3	97.3	78.1	117.7	113.1	102.8	92.9	84.1	81.8	69.1	85.8
Gallons (millions)	647	623	728	584	880	847	769	695	629	612	517	642
Cubic meters (millions)	2.4	2.4	2.8	2.2	3.3	3.2	2.9	2.6	2.4	2.3	2.0	2.4
AVERAGE DISCHARGE												
cfs	32	32	36	29	49	44	40	35	33	31	29	34
cms	0.9	0.9	1.0	0.8	1.4	1.2	1.1	1.0	0.9	0.9	0.8	1.0
mg/d	21	21	24	19	31	28	26	22	21	20	19	22
MAXIMUM												
cfs	55	80	223	31	262	240	69	38	35	34	35	58
cms	1.5	2.3	6.3	0.9	7.4	6.8	1.9	1.1	1.0	1.0	1.0	1.6
MINIMUM												
cfs	29	28	28	23	27	35	34	32	31	29	21	28
cms	0.8	0.8	0.8	0.6	0.8	1.0	1.0	0.9	0.9	0.8	0.6	0.8

Table 11. **Monthly summary of nitrate-N discharged in groundwater from the Big Spring basin to the Turkey River; Water Year 1985.**

	1984 Oct.	Nov.	Dec.	1985 Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.
Flow-weighted mean NO_3 concentration, in mg/L;	31	31	28	33	23	26	36	39	35	38	31	29
as NO_3-N	6.9	6.9	6.2	7.3	5.1	5.8	8.0	8.7	7.8	8.4	6.9	6.4
Mean of NO_3 analyses, in mg/L;	31	33	27	32	20	24	36	39	35	39	30	29
as NO_3-N	6.9	7.3	6.0	7.1	4.4	5.3	8.0	8.7	7.8	8.7	6.7	6.4
Total monthly NO_3-N output, thousands lbs	37	36	38	36	37	41	52	51	41	43	29	34
Total monthly NO_3-N output, thousands kg	17	16	17	16	17	19	24	23	19	19	13	15

Table 12. **Monthly summary of atrazine discharged in groundwater from the Big Spring basin to the Turkey River; Water Year 1985.**

	1984 Oct.	Nov.	Dec.	1985 Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.
Flow-weighted mean atrazine concentration, in *u*g/L	0.29	0.26	0.90	0.34	1.31	1.00	0.37	0.22	1.93	0.46	0.52	0.45
Mean of atrazine analyses, in *u*g/L	0.24	0.19	0.23	0.33	1.48	0.60	0.33	0.22	2.22	0.47	0.54	0.43
Total monthly atrazine output, lbs	1.6	1.4	5.4	1.7	9.6	7.0	2.4	1.3	10.2	2.3	2.3	2.4
Total monthly atrazine output, grams	720	619	2,467	758	4,371	3,193	1,079	586	4,607	1,056	1,024	1,095

Table 13. Annual summary of water and chemical discharge for the Turkey River at Garber for Water Year 1985; 10/01/84 - 09/30/85. (Discharge data from the U.S. Geological Survey, Water Resources Division.)

DISCHARGE

Total

acre-feet	555,713
millions cf	24,207
millions cm	686

Average

cfs	769.7
cms	21.8
mg/d	497.6
gpm	345,595

PRECIPITATION AND DISCHARGE

Precipitation	35.1 inches	(891.5mm)
Discharge	6.7 inches	(170.2mm)
Discharge as % of precipitation	19.0%	

NITRATE DISCHARGE

Concentration - mg/L	As NO_3	As NO_3-N
Flow-weighted mean	16	3.6
Mean of analyses	16	3.6

Total NO_3-N output

thousands lbs - N	5,341
thousands kg - N	2,422

Table 14. **Monthly summary of nitrate-N discharge for the Turkey River at Garber; Water Year 1985.**

	1984 Oct.	Nov.	Dec.	1985 Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.
Flow-weighted mean NO_3 concentration, in mg/L; as NO_3-N	14 3.1	18 4.0	21 4.7	23 5.1	12 2.7	13 2.9	25 5.6	18 4.0	14 3.1	7 1.6	6 1.3	11 2.4
Mean of NO_3 analyses, in mg/L; as NO_3-N	14 3.1	20 4.4	23 5.1	23 5.1	17 3.8	14 3.1	25 5.6	16 3.6	14 3.1	6 1.3	6 1.3	12 2.7
Total monthly NO_3-N output, thousands lbs	204	350	614	371	732	907	1,197	430	199	78	58	200
Total monthly NO_3-N output, thousands kg	93	159	278	168	332	411	543	195	90	35	27	91

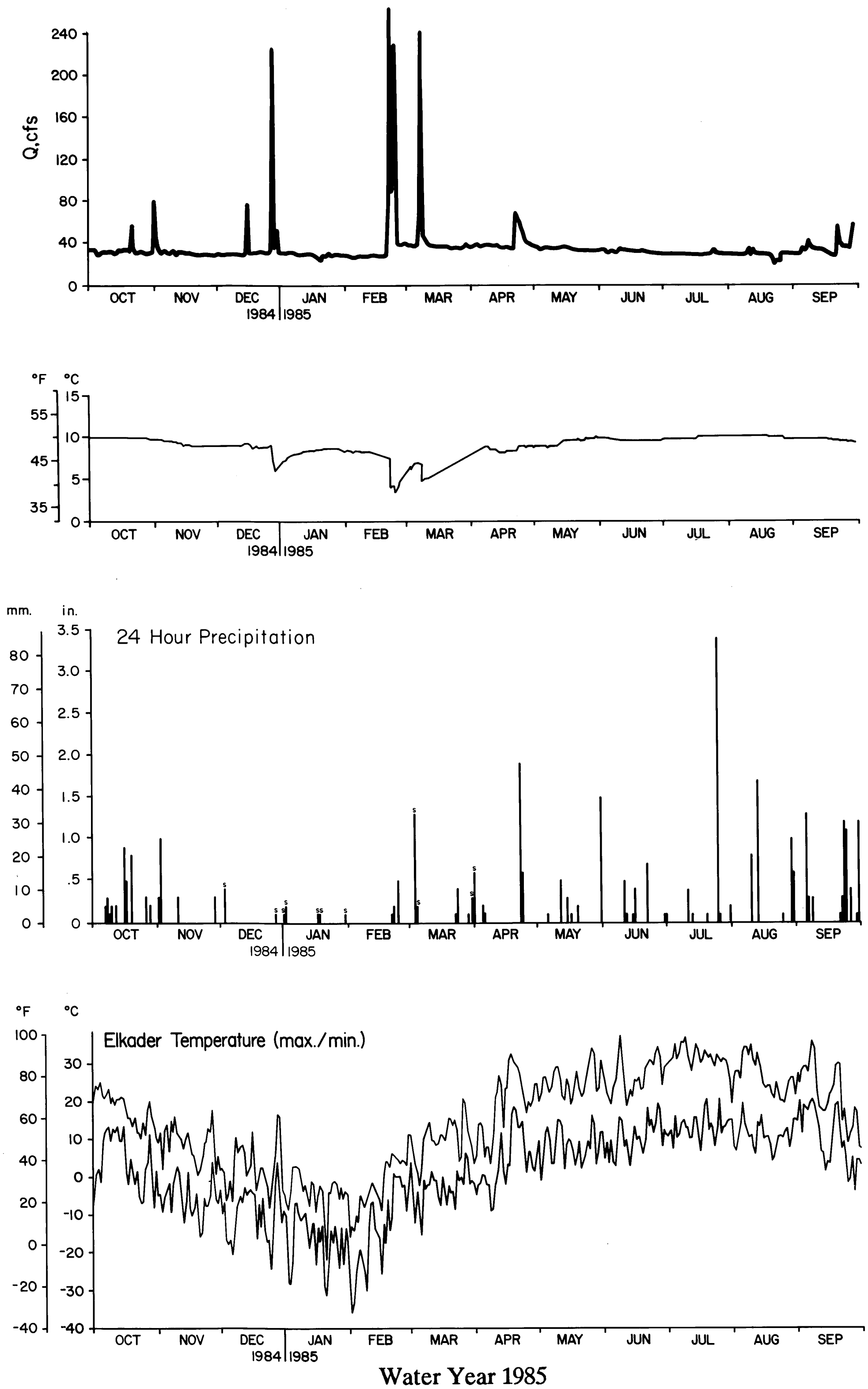


Figure 7. Daily precipitation, groundwater discharge, and groundwater temperature for the Big Spring basin, and maximum-minimum temperatures for Elkader, IA (Iowa Dept. of Ag. and Land Stewardship, State Climatology Office), for WY 1985.

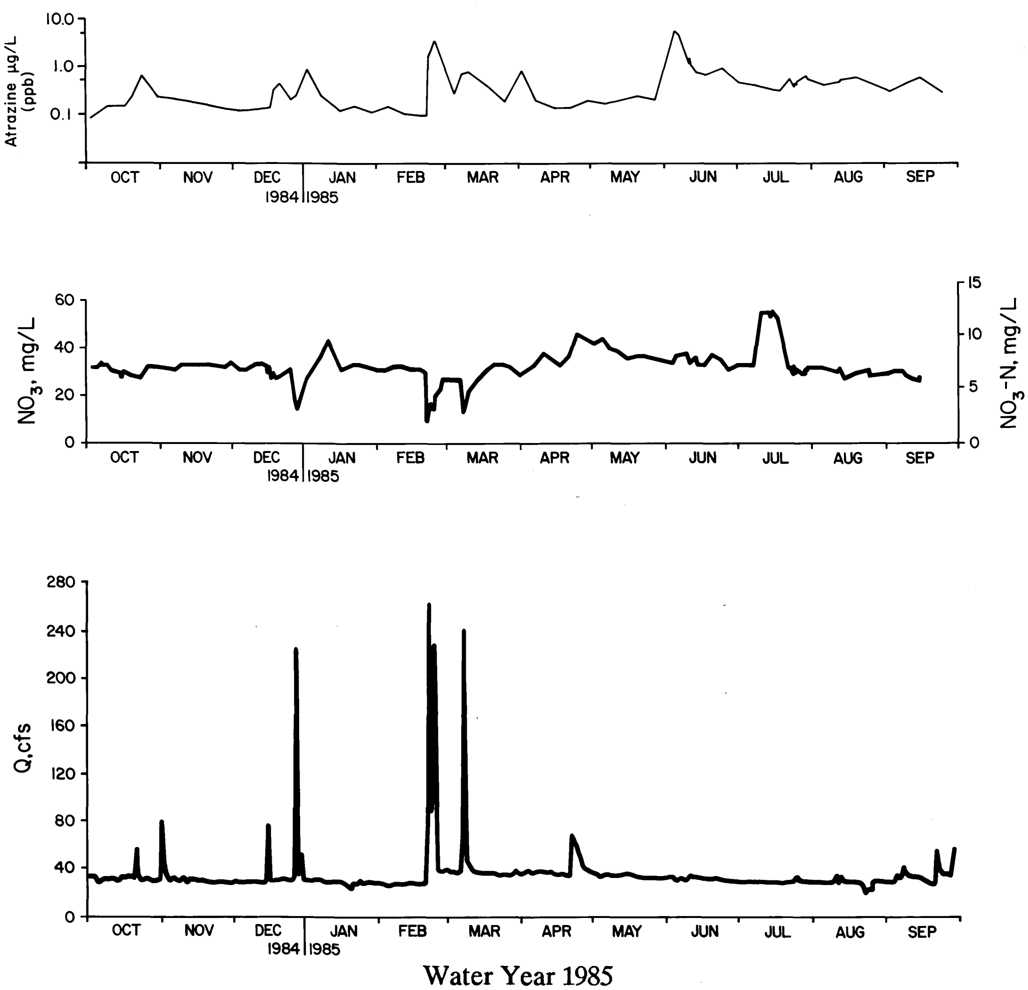


Figure 8. Groundwater discharge, and nitrate and atrazine concentrations at Big Spring for WY 1985.

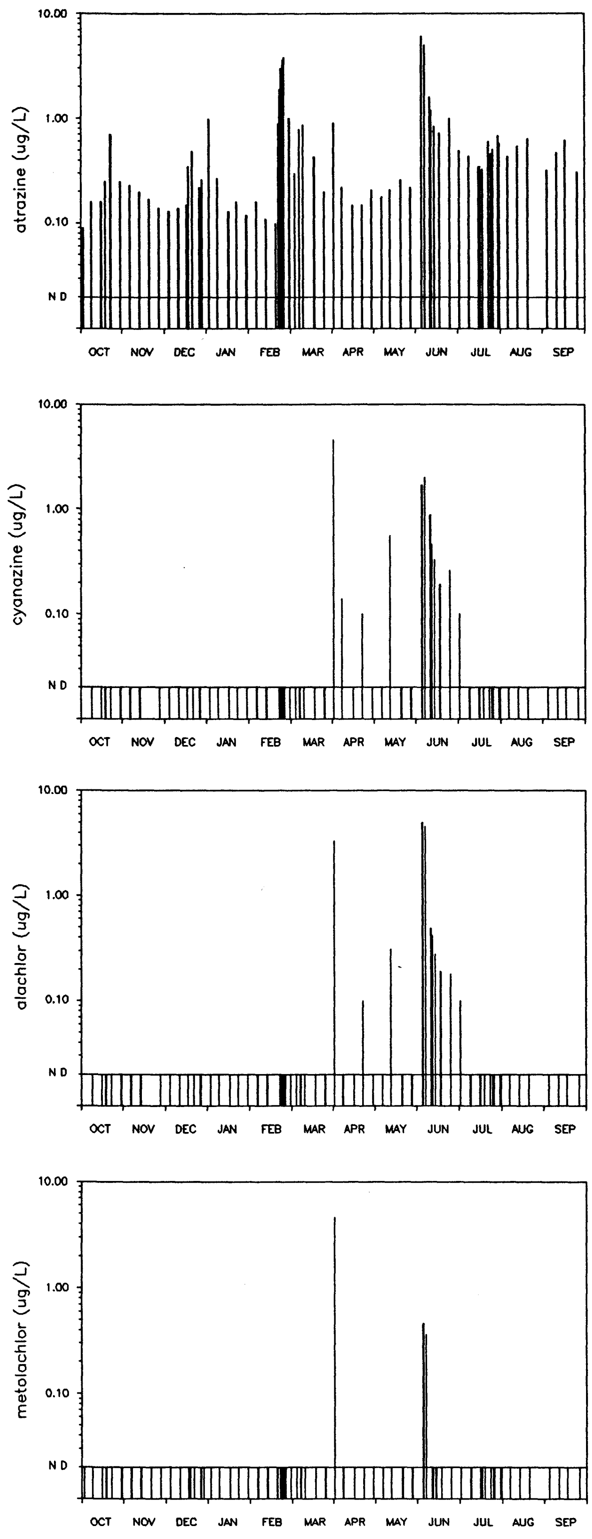


Figure 9. Schematic diagram of pesticide concentrations at Big Spring for WY 1985. ND represents not detected.

WATER YEAR 1986

Tables 15 through 21 and Figures 10 through 13 summarize the discharge, precipitation, water quality, and chemical-load data for WY 1986. Precipitation for the year was 36.96 inches, about 4.0 inches above average. Groundwater discharge from the basin was 30,290 ac-ft, and the average discharge for the year was 42 cfs. Discharge during WY 1986 was equivalent to 15% of the total precipitation. The discharge hydrograph for WY 1986 is dominated by the very large peak event that occurred in March. A major snowmelt accompanied by significant, intense rains, generated instantaneous discharge in excess of 360 cfs, the highest discharge observed at Big Spring during the period of monitoring. Significant infiltration was associated with this event, sustaining relatively high discharge rates through April. Discharge during March and April was about 8,700 ac-ft, or 29% of the years total; March alone accounted for 19% of the total. Only minor recharge occurred prior to or following this major event. While May was wetter than normal (Fig. 1; Table 2), rainfall intensity was low. The June-August period had about 2.0 inches less rain than normal. March showed the highest average monthly discharge for the water year, 95 cfs. Average monthly discharge declined to a low of 33 cfs by August and September; discharge varied from 35 to 40 cfs before the March snowmelt (Table 16).

Figure 12 shows log-scale discharge hydrographs for Big Spring and the Turkey River at Garber. Tables 19 through 21 summarize WY 1986 data for the Turkey River. Total discharge for the water year was about 858,000 ac-ft. The average flow-rate was 1,185 cfs, or 129% of the long-term average. Discharge was equivalent to 27% of total precipitation.

Nitrate Monitoring

Tables 15 and 17 and Figures 11 and 12 summarize the results of 137 nitrate analyses, and 23 nitrogen series analyses (nitrate-N; organic-N; and ammonia-N) of Big Spring discharge in WY 1986. The flow-weighted mean nitrate concentration for WY 1986 was 43 mg/L (9.6 mg/L as NO_3-N). A total of 790,000 pounds of nitrate-nitrogen was discharged from the Big Spring basin groundwater system to the Turkey River. If concentrations of organic-N and ammonia-N in Big Spring discharge are considered, the total nitrogen output from the groundwater system was 840,000 pounds.

Figure 11 shows the discharge hydrograph and nitrate concentrations for Big Spring. At the beginning of WY 1986 nitrate concentrations were relatively low, generally less than 35 mg/L. Minor recharge events resulted in a general rise in concentrations to about 50 mg/L in early December. Nitrate concentrations -- and groundwater discharge -- followed a declining trend until the major snowmelt-rainfall recharge event of March. Nitrate concentrations show less of a dilution effect during the maximum discharge periods of this event relative to other snowmelt periods. Concentrations increased to almost 50 mg/L following this event and then generally declined, to about 35 mg/L, by mid-September (Fig. 11). Very heavy rains at the end of the water year generated recharge, and increased nitrate concentrations to almost 45 mg/L as the period ended.

Table 17 summarizes the nitrate data for WY 1986 on a monthly basis. The highest monthly flow-weighted mean concentration, 49 mg/L, occurred in April after the major March recharge event. The lowest mean -- 37 mg/L -- occurred in August and September, following the summer baseflow period. These months also had the lowest total discharges of nitrate-N, 45,000 and 43,000 pounds, respectively. In contrast, during the month of March 165,000 pounds of nitrate-N were discharged. This accounted for about 21% of the total nitrate-N discharge for WY 1986; this was the greatest monthly discharge of nitrate-N during WYs 1984-1987 and was equivalent to over one-third of the nitrate-N discharged during all of WY 1985.

Figure 12 and Tables 19 and 20 summarize nitrate concentrations and loads for the Turkey River (at Garber) for WY 1986. A total of 14,300,000 pounds of nitrate-nitrogen was discharged by the Turkey River during WY 1986, at a flow-weighted mean nitrate concentration of 28 mg/L (6.2 mg/L as NO_3-N). As was the case with Big Spring, the greatest monthly nitrate-N discharge occurred in March, and was about 3.8 million pounds (Table 20). The nitrate-N discharged in March accounted for about 27% of the total for WY 1986, and was equal to 71% of the total discharged in WY 1985. The lowest monthly nitrate-N discharge occurred in August, 365,000

Table 15. **Annual summary of groundwater and chemical discharge from the Big Spring basin to the Turkey River for Water Year 1986; 10/01/85 - 09/30/86.**

DISCHARGE

Total

acre-feet	30,290
millions cf	1,319
millions cm	37

Average

cfs	42.0
cms	1.2
mg/d	27.1
gpm	18,838

PRECIPITATION AND DISCHARGE

Precipitation	36.96 inches	(938.78mm)
Discharge	5.5 inches	(139.7mm)
Discharge as % of precipitation	15.0%	

NITRATE DISCHARGE

Concentration - mg/L	As NO_3	As NO_3-N
Flow-weighted mean	43	9.7
Mean of analyses	44	9.8

	NO_3-N total output	Total N output
lbs - N	790,454	839,790
kg - N	358,482	380,857

ATRAZINE DISCHARGE

Concentration - ug/L

Flow-weighted mean	0.35
Mean of analyses	0.38

Total output

lbs	29.0
kg	13.1

Table 16. **Monthly summary of groundwater discharge from the Big Spring basin for Water Year 1986.**

	1985 Oct.	Nov.	Dec.	1986 Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.
TOTAL MONTHLY DISCHARGE												
Acre-feet	2,202	2,367	2,264	2,174	1,987	5,860	2,833	2,337	2,289	2,168	2,007	1,904
Cubic feet (millions)	95.9	103.1	98.6	94.7	86.6	255.3	123.4	101.8	99.7	94.5	87.4	82.9
Gallons (millions)	718	772	738	790	648	1,910	923	762	746	707	654	621
Cubic meters (millions)	2.7	2.9	2.8	2.7	2.5	7.2	3.5	2.9	2.8	2.7	2.5	2.3
AVERAGE DISCHARGE												
cfs	36	40	37	35	36	95	48	38	39	35	33	33
cms	1.0	1.1	1.0	1.0	1.0	2.7	1.4	1.1	1.1	1.0	0.9	0.9
mg/d	23	26	24	23	23	62	31	25	25	23	21	21
MAXIMUM												
cfs	38	47	40	49	42	360	65	41	88	37	40	45
cms	1.1	1.3	1.1	1.4	1.2	10.2	1.8	1.2	2.5	1.0	1.1	1.3
MINIMUM												
cfs	34	35	35	33	33	34	41	33	36	33	31	24
cms	1.0	1.0	1.0	0.9	0.9	1.0	1.2	0.9	1.0	0.9	0.9	0.7

Table 17. **Monthly summary of nitrate-N discharged in groundwater from the Big Spring basin to the Turkey River; Water Year 1986.**

	1985 Oct.	Nov.	Dec.	1986 Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.
Flow-weighted mean NO_3 concentration, in mg/L;	38	46	46	40	38	47	48	45	45	41	37	37
as NO_3-N	8.4	10.2	10.2	8.9	8.4	10.4	10.7	10.0	10.0	9.1	8.2	8.2
Mean of NO_3 analyses, in mg/L;	37	46	44	40	39	48	49	45	43	41	37	36
as NO_3-N	8.2	10.2	9.8	8.9	8.7	10.7	10.9	10.0	9.6	9.1	8.2	8.0
Total monthly NO_3-N output, thousands lbs	50	65	62	53	45	165	83	64	60	54	45	43
Total monthly NO_3-N output, thousands kg	23	30	28	24	21	75	38	29	27	25	21	19

Table 18. **Monthly summary of atrazine discharged in groundwater from the Big Spring basin to the Turkey River; Water Year 1986.**

	1985 Oct.	Nov.	Dec.	1986 Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.
Flow-weighted mean atrazine concentration, in *u*g/L	0.62	0.55	0.28	0.18	0.20	0.43	0.24	0.38	0.31	0.27	0.30	0.32
Mean of atrazine analyses, in *u*g/L	0.80	0.57	0.29	0.14	0.19	0.48	0.23	0.43	0.30	0.26	0.27	0.30
Total monthly atrazine output, lbs	3.7	3.5	1.7	1.1	1.1	6.9	1.8	2.4	1.9	1.6	1.6	1.6
Total monthly atrazine output, grams	1,683	1,599	783	492	493	3,140	822	1,099	848	727	719	746

Table 19. **Annual summary of water and chemical discharge for the Turkey River at Garber for Water Year 1986; 10/01/85 - 09/30/86.** (Discharge data from the U.S. Geological Survey, Water Resources Division.)

DISCHARGE

Total

acre-feet	857,620
millions cf	37,358
millions cm	1,058

Average

cfs	1,184.6
cms	33.5
mg/d	765.8
gpm	531,885

PRECIPITATION AND DISCHARGE

Precipitation	40.7 inches	(1,033.8mm)
Discharge	10.4 inches	(264.2mm)
Discharge as % of precipitation	26.0%	

NITRATE DISCHARGE

Concentration - mg/L	As NO_3	As NO_3-N
Flow-weighted mean	28	6.2
Mean of analyses	27	6.0

Total NO_3-N output

thousands lbs - N	14,306
thousands kg - N	6,488

ATRAZINE DISCHARGE

Concentration - ug/L

Flow-weighted mean	0.60
Mean of analyses	0.70

Total output

lbs	1,407.0
kg	638.4

Table 20. **Monthly summary of nitrate-N discharge for the Turkey River at Garber; Water Year 1986.**

	1985 Oct.	Nov.	Dec.	1986 Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.
Flow-weighted mean NO_3 concentration, in mg/L;	31	34	34	26	25	27	31	31	29	18	19	22
as NO_3-N	6.9	7.6	7.6	5.8	5.6	6.0	6.9	6.9	6.4	4.0	4.2	4.9
Mean of NO_3 analyses, in mg/L;	30	36	32	25	25	26	30	31	26	17	20	19
as NO_3-N	6.7	8.0	7.1	5.6	5.6	5.8	6.7	6.9	5.8	3.8	4.4	4.2
Total monthly NO_3-N output, thousands lbs	958	1,252	639	542	527	3,793	1,789	1,955	1,101	385	365	1,001
Total monthly NO_3-N output, thousands kg	434	568	290	246	239	1,720	811	887	499	175	164	454

Table 21. **Monthly summary of atrazine discharge for the Turkey River at Garber; Water Year 1986.**

	1985 Oct.	Nov.	Dec.	1986 Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.
Flow-weighted mean atrazine concentration, in *u*g/L	0.76	0.60	0.67	0.26	0.21	0.26	0.63	1.20	0.75	0.54	0.65	0.92
Mean of atrazine analyses, in *u*g/L	0.74	0.46	0.14	0.21	0.20	0.59	1.20	1.20	0.49	0.58	0.80	1.20
Total monthly atrazine output, lbs	107.9	101.4	56.4	23.7	20.1	165.5	165.0	342.7	127.7	51.2	57.4	188.8
Total monthly atrazine output, kg	48.9	46.0	25.6	10.7	9.1	75.1	74.8	155.4	57.9	23.2	25.4	85.6

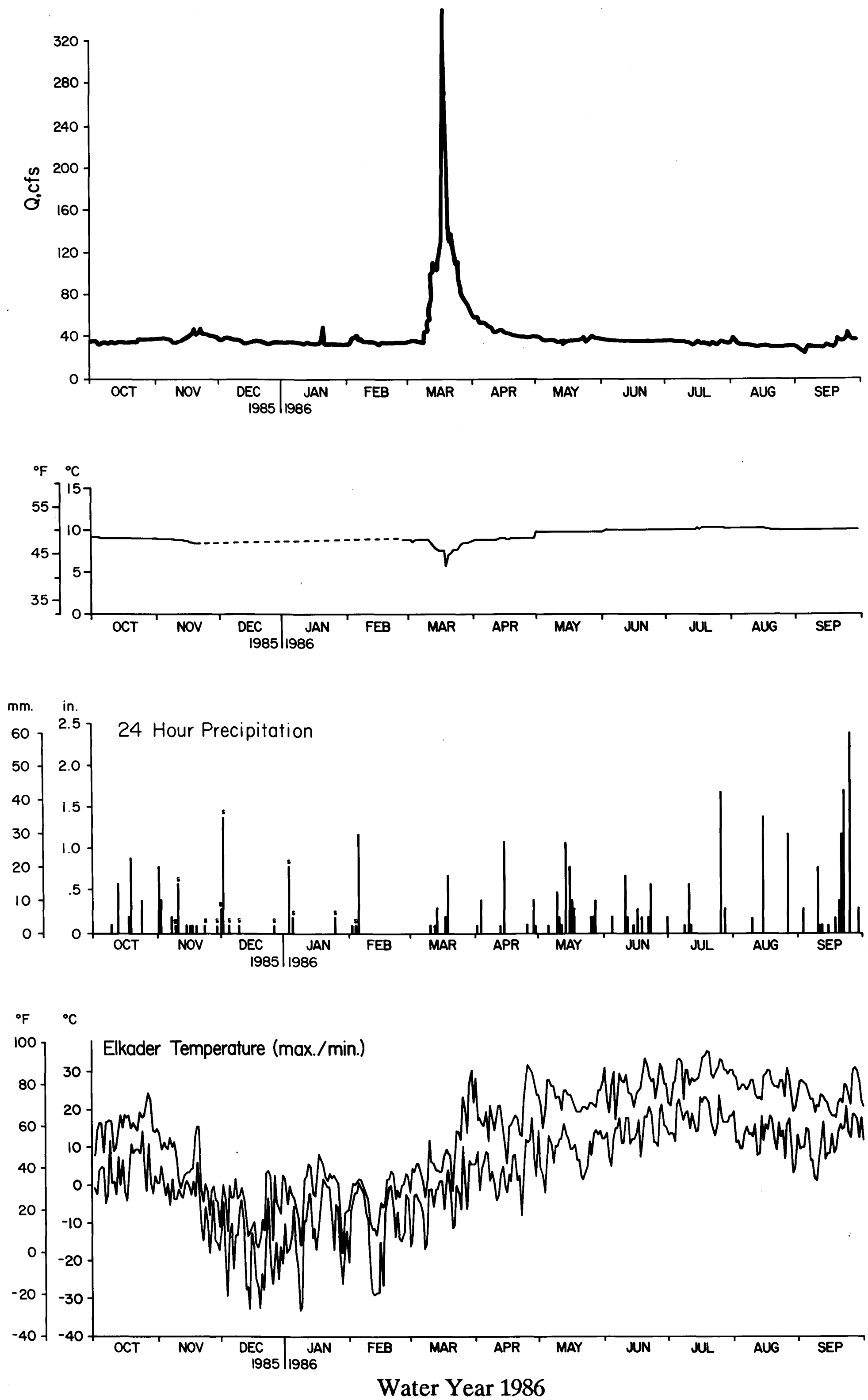


Figure 10. Daily precipitation, groundwater discharge, and groundwater temperature for the Big Spring basin, and maximum-minimum temperatures for Elkader, IA (Iowa Dept. of Ag. and Land Stewardship, State Climatology Office), for WY 1986.

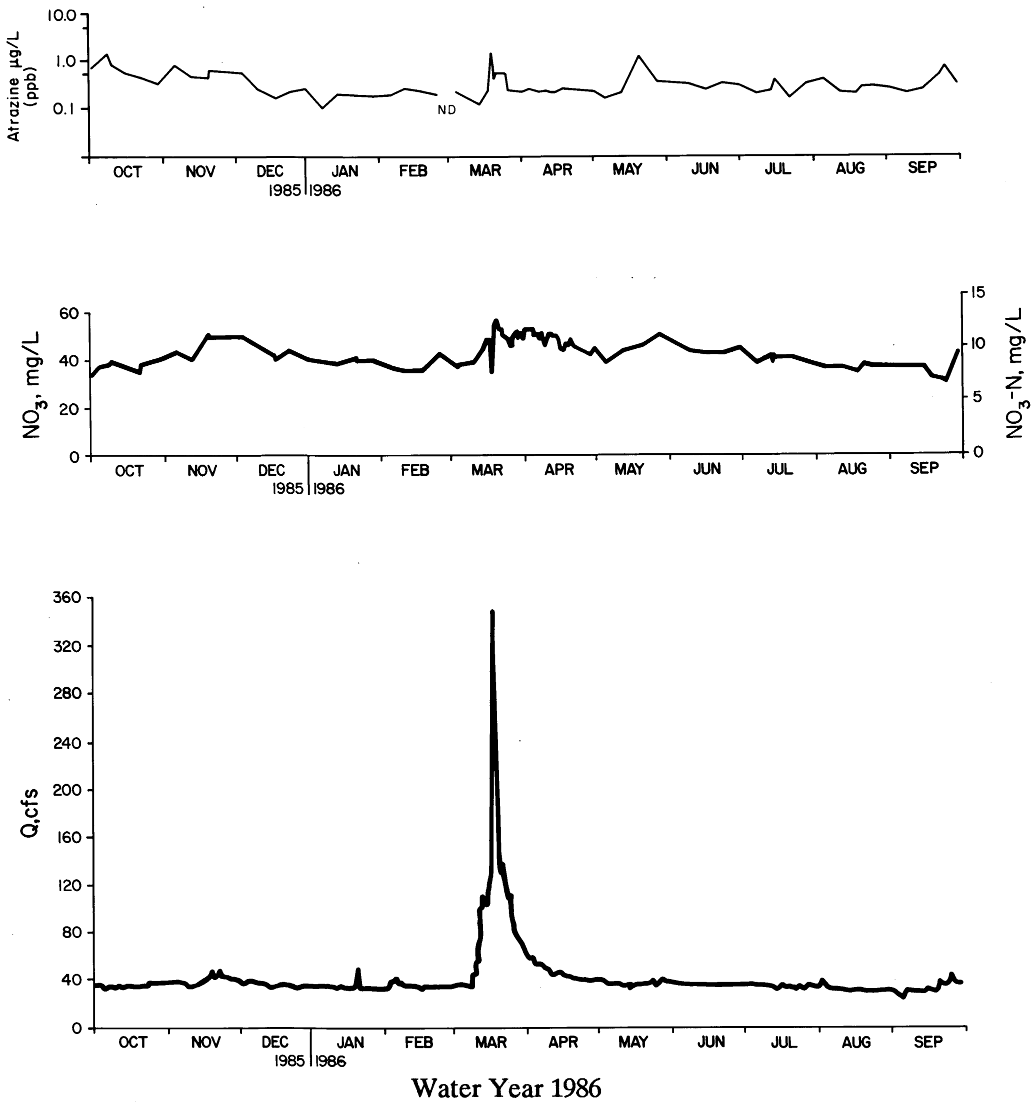


Figure 11. Groundwater discharge, and nitrate and atrazine concentrations at Big Spring for WY 1986.

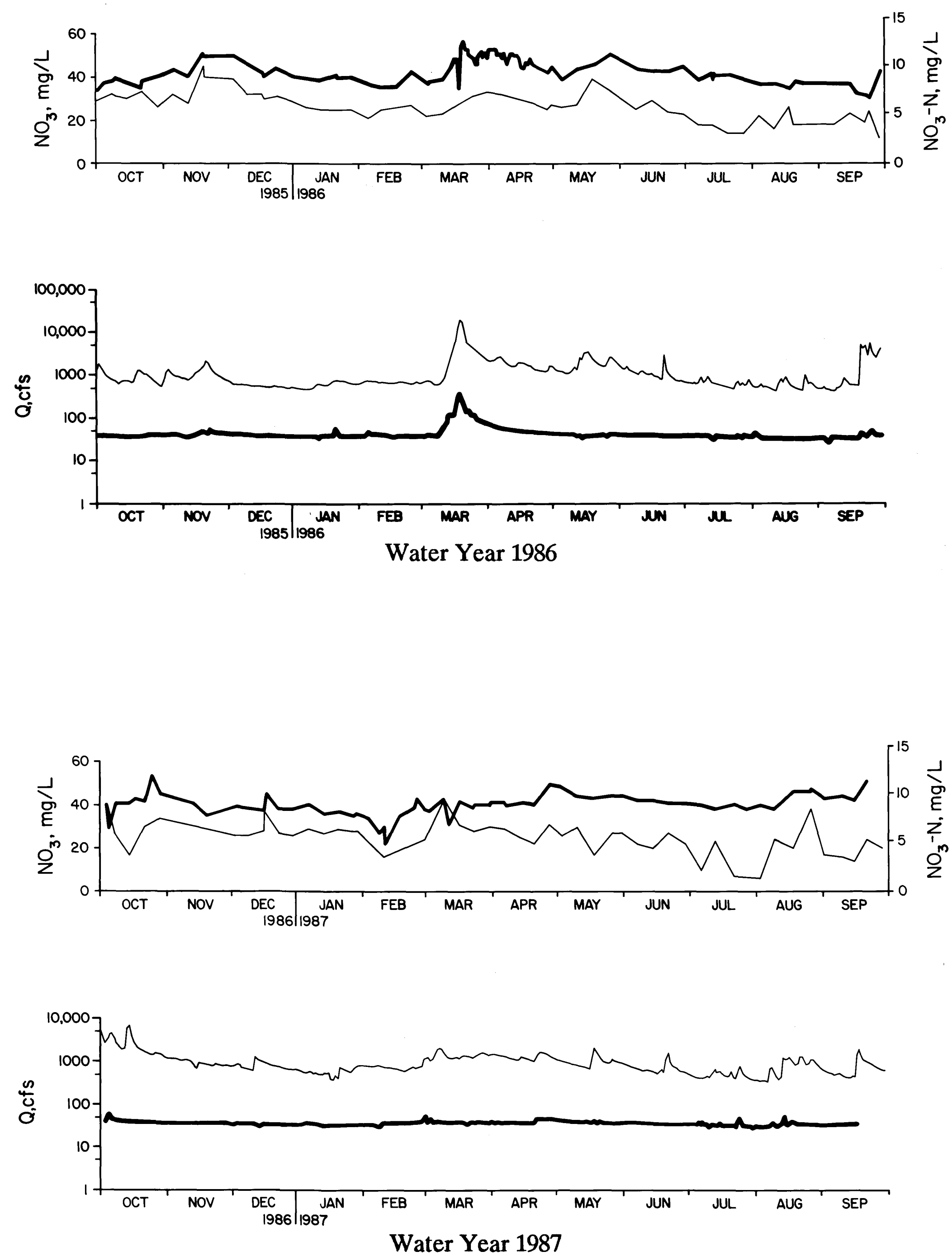


Figure 12. Discharge hydrographs and nitrate concentrations for Big Spring (bold lines) and the Turkey River (lighter lines) at Garber for WYs 1986-1987; Turkey River data. (Turkey River discharge data from U.S.G.S., W.R.D., IA Dist.)

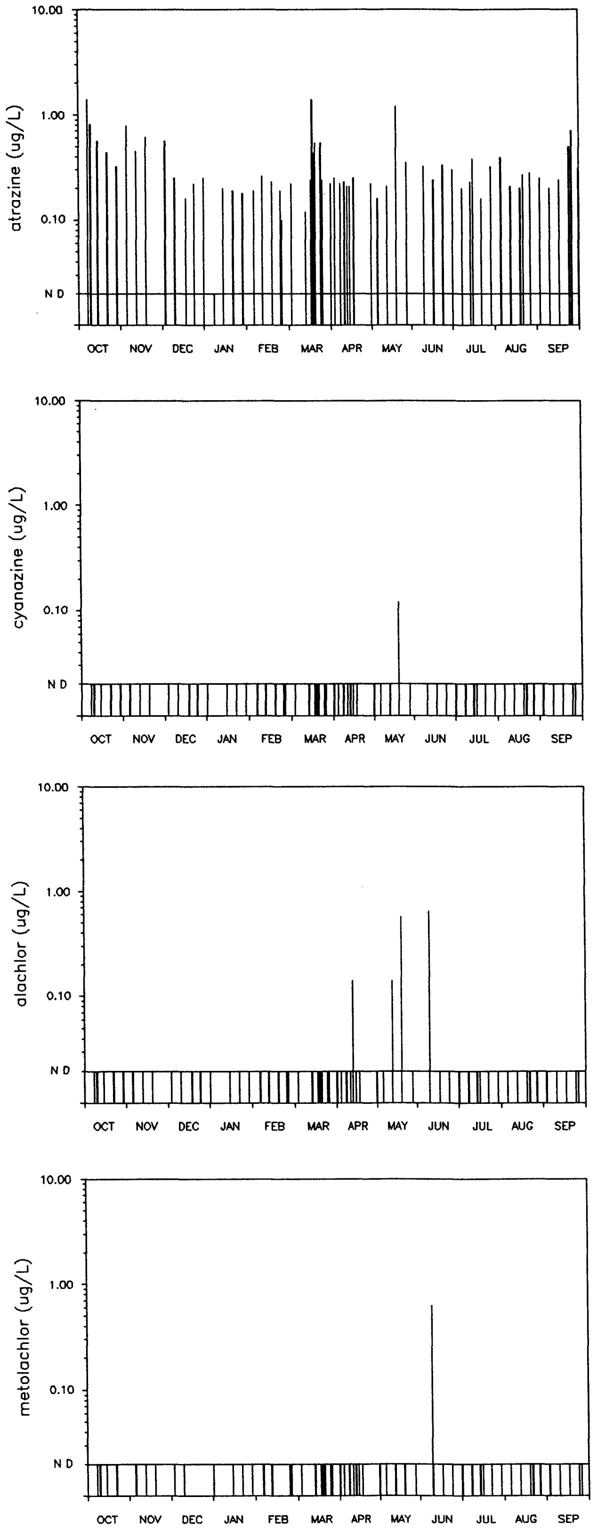


Figure 13. Schematic diagram of pesticide concentrations at Big Spring for WY 1986. ND represents not detected.

pounds. Flow-weighted monthly mean nitrate concentrations varied from 36 mg/L in November to 17 mg/L in July.

Pesticide Monitoring

Tables 15 and 18 and Figures 11 and 13 summarize the results of pesticide monitoring at Big Spring for WY 1986, which consisted of 65 analyses. During WY 1986 about 29 pounds of atrazine were discharged by the basin's groundwater system at a flow-weighted mean concentration of 0.35 ug/L. Figure 12 shows a plot of atrazine concentrations through WY 1986 at Big Spring. The relatively high atrazine concentrations noted during late WY 1985 continued into early WY 1986. Concentrations showed a general decline, from above 1.0 ug/L to about 0.2 ug/L, prior to the March snowmelt-rainfall event. Atrazine concentrations exceeded 1.0 ug/L during this event, and again during minor recharge periods in May. Concentrations were generally in the 0.2 to 0.4 ug/L range for the rest of the water year.

Table 18 summarizes the atrazine data on a monthly basis. Flow-weighted mean monthly concentrations varied from 0.62 ug/L during March to 0.18 ug/L in January, following the winter recession. During March, 6.9 pounds of atrazine were discharged by the basin's groundwater system, the maximum for any month of WY 1986. Minimum atrazine discharges -- 1.1 pounds -- occurred during the winter months of January and February.

Figure 13 shows concentrations of atrazine, cyanazine, alachlor, and metolachlor for WY 1986. Atrazine was detected in all but one sample analyzed; the occurrence of non-detections of atrazine or other pesticides are indicated by concentration bars ending at "ND". (As discussed, near the beginning of WY 1986 the quantitation limit for the pesticide analyses changed for most analytes from about 0.01 to 0.1 ug/L.) Detections of alachlor occurred between mid-April and mid-June. Cyanazine was detected once in May, and metolachlor once in June. Maximum concentrations of atrazine, alachlor, cyanazine, and metolachlor were 1.4, 0.65, 0.12, and 0.62 ug/L, respectively. These herbicides were detected in 98%, 8%, 2%, and 2% of the samples analyzed.

WATER YEAR 1987

Tables 22 through 28 and Figures 12, 14, 15, and 16 summarize the discharge, precipitation, water quality and chemical-load data for WY 1987. Total basin precipitation was 31.98 inches, about 1.0 inch less then average. Total groundwater discharge was 25,554 ac-ft, at an average rate of 35 cfs. This discharge was equivalent to 14% of the total precipitation.

The discharge hydrograph for WY 1987 is relatively featureless when compared to all previous years (Fig. 2; Hallberg et al, 1983; 1984a). No major peaks depicting runoff recharge occurred; maximum instantaneous discharge never exceeded 70 cfs. Following a minor recharge event in October, discharge declined until mid-February. Minor snowmelt and rainfall recharge occurred during March and April, but maximum discharge even in this period was below 50 cfs. May through July was again a recession period. A few minor runoff and infiltration recharge events occurred in August and September.

While total precipitation for the year was only one inch below average, several factors acted to more seriously limit groundwater recharge. First, about 7.7 inches of precipitation -- about 24% of the year's total -- fell during August. Precipitation for the rest of the year was more than 5.0 inches below normal. There was an insignificant snowpack available in spring, as the November-February period had about 2.7 inches less precipitation than average. Finally, the late spring-early summer months -- typically an important recharge period -- showed a precipitation deficit of several inches (Table 2; Fig. 1).

Figure 12 shows log-scale discharge hydrographs for Big Spring and the Turkey River at Garber. Tables 26 and through 28 summarize WY 1987 data for the Turkey River. Total discharge for the water year was about 699,000 ac-ft. The average flow-rate was 970 cfs, or 106% of the long-term average. Discharge was equivalent to 27% of total precipitation.

Nitrate Monitoring

Tables 22 and 24 and Figures 12 and 15 summarize the results of nitrate monitoring at Big Spring for WY 1987. Ninety-nine samples from the spring were analyzed for nitrate, and 30 of these were also analyzed for other nitrogen species. The flow-weighted mean nitrate concentration for WY 1987 was 41 mg/L (9.1 mg/L as NO_3-N). A total of 629,000 pounds of nitrate-nitrogen was discharged from the Big Spring basin groundwater system to the Turkey River. If concentrations of organic-N and ammonia-N in Big Spring discharge are considered, the total nitrogen output from the groundwater system was 649,000 pounds.

Figure 15 shows the discharge hydrograph and nitrate concentrations for Big Spring. As previously discussed, the discharge hydrograph is relatively featureless compared to other years. The nitrate concentration record is also relatively uniform, with concentrations hovering around 40 mg/L throughout the water year. Minor recharge events caused concentration increases during October, late April, and the end of September. The dilution effects of the rather insignificant February snowmelt, which caused only a small discharge increase, are visible as lower nitrate concentrations during that month.

Table 24 summarizes the nitrate data for WY 1987 on a monthly basis. Flow-weighted monthly mean concentrations varied from 45 mg/L in September to 34 mg/L in February. The relatively constant discharge and nitrate concentrations resulted in fairly constant monthly nitrate-N loads, varying from 64,000 pounds in May to 38,000 pounds in February.

Figure 12 and Tables 26 and 27 summarize nitrate concentrations and loads for the Turkey River (at Garber) for WY 1987. A total of 11.1 million pounds of nitrate-nitrogen was discharged by the Turkey River during WY 1987, at a flow-weighted mean concentration of 26 mg/L (5.8 mg/L as NO_3-N). Table 27 summarizes the nitrate data on a monthly basis. Flow-weighted mean monthly nitrate concentrations varied from 31 mg/L in March to 14 mg/L in July. The greatest one-month discharge of nitrate-N occurred at the beginning of the WY 1987 in October, and totalled 2.5 million pounds. The lowest monthly discharge occurred during July, and amounted to 249,000 pounds of nitrate-N.

Pesticide Monitoring

Tables 22 and 25 and Figures 15 and 16 summarize the results of pesticide monitoring at Big Spring for WY 1987. Sixty samples were collected during WY 1987. About 18 pounds of atrazine were discharged by the basin's

Table 22. **Annual summary of groundwater and chemical discharge from the Big Spring basin to the Turkey River for Water Year 1987; 10/01/86 - 09/30/87.**

DISCHARGE

Total

acre-feet	25,554
millions cf	1,113
millions cm	32

Average

cfs	35.4
cms	1.0
mg/d	22.9
gpm	15,892

PRECIPITATION AND DISCHARGE

Precipitation	31.98 inches	(812.29mm)
Discharge	4.6 inches	(116.8mm)
Discharge as % of precipitation	14.0%	

NITRATE DISCHARGE

Concentration - mg/L	As NO_3	As NO_3-N
Flow-weighted mean	41	9.1
Mean of analyses	40	8.9

Total NO_3-N total output		Total N output
lbs - N	628,614	649,413
kg - N	285,086	294,518

ATRAZINE DISCHARGE

Concentration - ug/L

Flow-weighted mean	0.25
Mean of analyses	0.24

Total output

lbs	17.6
kg	8.0

Table 23. **Monthly summary of groundwater discharge from the Big Spring basin for Water Year 1987.**

	1986 Oct.	Nov.	Dec.	1987 Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.
TOTAL MONTHLY DISCHARGE												
Acre-feet	2,346	2,243	2,529	2,095	3,652	2,457	3,105	4,468	3,489	2,231	2,191	1,743
Cubic feet (millions)	102	98	110	91	159	107	135	195	152	97	95	76
Gallons (millions)	775	704	645	631	618	750	751	761	671	673	673	675
Cubic meters (millions)	2.9	2.8	3.1	2.6	4.5	3.0	3.8	5.5	4.3	2.8	2.7	2.2
AVERAGE DISCHARGE												
cfs	39	36	32	32	34	37	39	38	35	34	34	36
cms	1.1	1.0	0.9	0.9	1.0	1.1	1.1	1.1	1.0	1.0	1.0	1.0
mg/d	25	24	21	20	22	24	25	25	22	22	22	23
MAXIMUM												
cfs	51	37	34	33	36	49	46	43	36	45	53	67
cms	1.4	1.1	1.0	0.9	1.0	1.4	1.3	1.2	1.0	1.3	1.5	1.9
MINIMUM												
cfs	36	33	29	31	30	35	35	35	34	29	27	34
cms	1.0	0.9	0.8	0.9	0.9	1.0	1.0	1.0	1.0	0.8	0.8	1.0

Table 24. **Monthly summary of nitrate-N discharged in groundwater from the Big Spring basin to the Turkey River; Water Year 1987.**

	1986 Oct.	Nov.	Dec.	1987 Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.
Flow-weighted mean NO_3 concentration, in mg/L;	43	39	39	37	34	38	42	45	42	39	42	46
as NO_3-N	9.6	8.7	8.7	8.2	7.6	8.4	9.3	10.0	9.3	8.7	9.3	10.2
Mean of NO_3 analyses, in mg/L;	42	37	39	37	33	39	42	45	42	39	43	46
as NO_3-N	9.3	8.2	8.7	8.2	7.3	8.7	9.3	10.0	9.3	8.7	9.6	10.2
Total monthly NO_3-N output, thousands lbs	61	51	47	44	38	53	58	64	53	49	52	57
Total monthly NO_3-N output, thousands kg	28	23	21	20	17	24	26	29	24	22	24	26

Table 25. **Monthly summary of atrazine discharged in groundwater from the Big Spring basin to the Turkey River; Water Year 1987.**

	1986 Oct.	Nov.	Dec.	1987 Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.
Flow-weighted mean atrazine concentration, in *u*g/L	0.34	0.22	0.17	0.16	0.23	0.25	0.26	0.21	0.23	0.31	0.38	0.27
Mean of atrazine analyses, in *u*g/L	0.30	0.20	0.15	0.16	0.23	0.28	0.25	0.22	0.27	0.35	0.32	0.21
Total monthly atrazine output, lbs	2.2	1.3	0.9	0.8	1.2	1.6	1.6	1.4	1.3	1.7	2.2	1.5
Total monthly atrazine output, grams	987	574	416	375	528	712	745	614	597	777	978	694

Table 26. Annual summary of water and chemical discharge for the Turkey River at Garber for Water Year 1987; 10/01/86 - 09/30/87. (Discharge data from the U.S. Geological Survey, Water Resources Division.)

DISCHARGE

Total

acre-feet	698,980
millions cf	30,447
millions cm	862

Average

cfs	970.8
cms	27.5
mg/d	627.6
gpm	435,889

PRECIPITATION AND DISCHARGE

Precipitation	31.4 inches	(797.6mm)
Discharge	8.5 inches	(215.9mm)
Discharge as % of precipitation	27.0%	

NITRATE DISCHARGE

Concentration - mg/L	As NO_3	As NO_3-N
Flow-weighted mean	26	5.8
Mean of analyses	24	5.6

Total NO_3-N output

thousands lbs - N	11,120
thousands kg - N	5,043

ATRAZINE DISCHARGE

Concentration - ug/L

Flow-weighted mean	0.47
Mean of analyses	0.73

Total output

lbs	890.7
kg	403.9

Table 27. **Monthly summary of nitrate-N discharge for the Turkey River at Garber; Water Year 1987.**

	1986 Oct.	Nov.	Dec.	1987 Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.
Flow-weighted mean NO_3 concentration, in mg/L;	27	28	29	28	22	31	28	25	24	14	25	22
as NO_3-N	6.0	6.2	6.4	6.2	4.9	6.9	6.2	5.6	5.3	3.1	5.6	4.9
Mean of NO_3 analyses, in mg/L;	30	25	28	28	22	31	27	25	24	13	22	18
as NO_3-N	6.7	5.6	6.2	6.2	4.9	6.9	6.0	5.6	5.3	2.9	4.9	4.0
Total monthly NO_3-N output, thousands lbs	2,541	916	815	579	521	1,523	1,254	875	612	249	699	535
Total monthly NO_3-N output, thousands kg	1,152	415	370	263	236	691	569	397	278	113	317	243

Table 28. **Monthly summary of atrazine discharge for the Turkey River at Garber; Water Year 1987.**

	1986 Oct.	Nov.	Dec.	1987 Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.
Flow-weighted mean atrazine concentration, in *ug*/L	0.74	0.33	0.26	0.24	0.23	0.32	0.30	0.56	1.16	0.33	0.32	0.31
Mean of atrazine analyses, in *ug*/L	0.60	0.27	0.25	0.20	0.27	0.27	0.26	0.70	5.20	0.32	0.32	0.28
Total monthly atrazine output, lbs	312.2	48.1	33.2	22.7	24.4	71.4	60.9	87.7	130.9	25.8	39.6	33.7
Total monthly atrazine output, kg	141.6	21.8	15.1	10.3	11.1	32.4	27.6	39.8	59.3	11.7	17.9	15.3

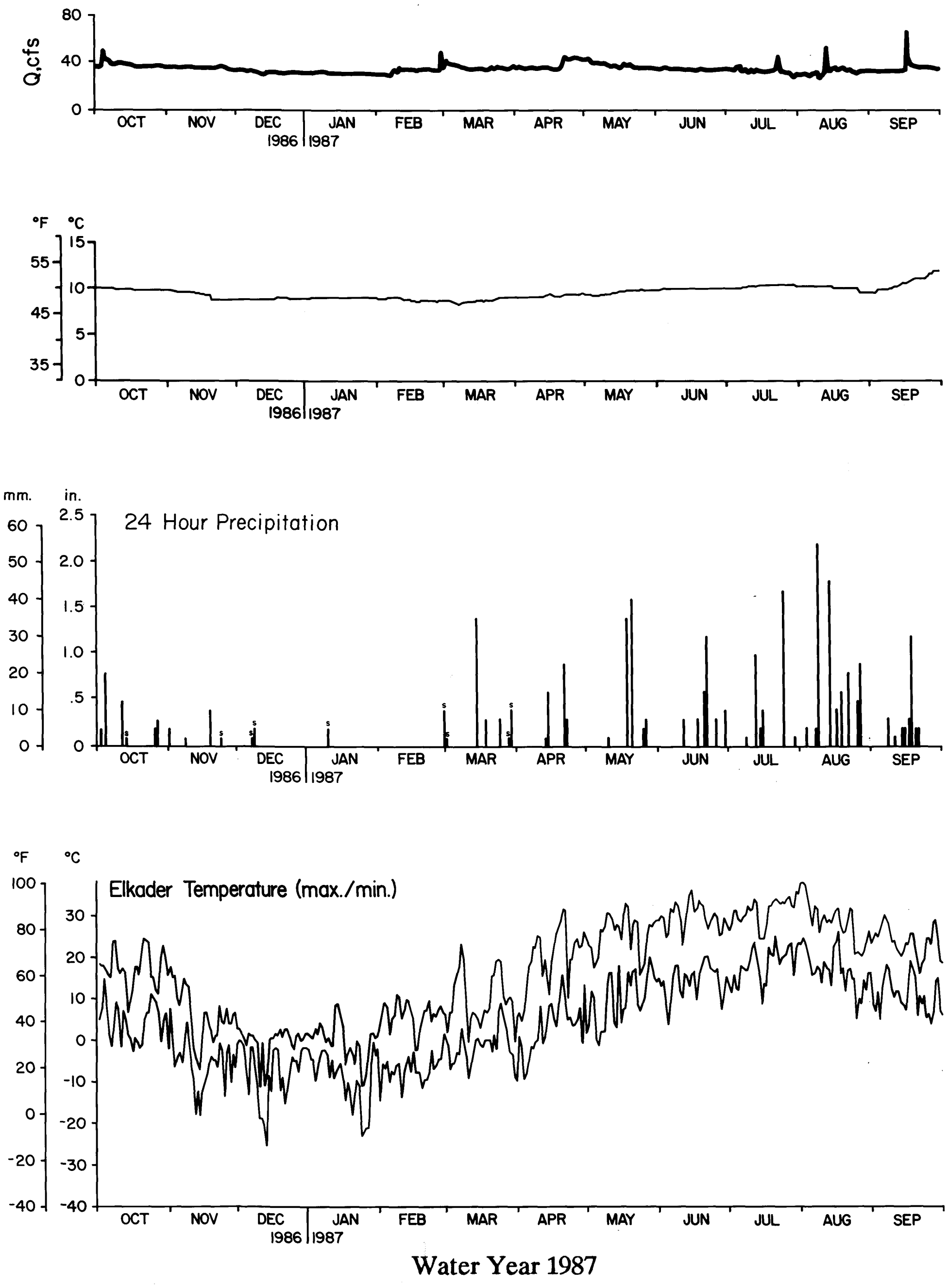


Figure 14. Daily precipitation, groundwater discharge, and groundwater temperature for the Big Spring basin, and maximum-minimum temperatures for Elkader, IA (Iowa Dept. of Ag. and Land Stewardship, State Climatology Office), for WY 1987.

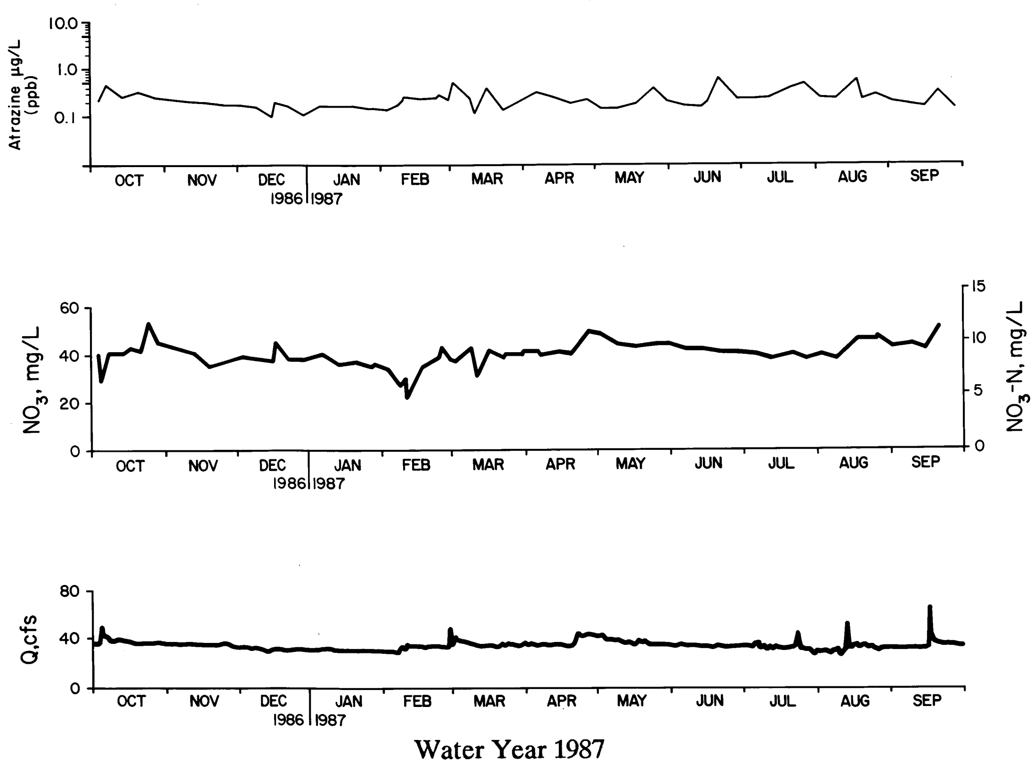


Figure 15. Groundwater discharge, and nitrate and atrazine concentrations at Big Spring for WY 1987.

groundwater system at a flow-weighted mean concentration of 0.25 ug/L. Figure 15 is a plot of atrazine concentrations through WY 1987 at Big Spring. As with the discharge and nitrate record for this water year, the atrazine plot is relatively featureless, with most analyses giving concentrations between 0.2 and 0.4 ug/L. Recharge was so limited in WY 1987 that there could not be any significant transport of new atrazine to the groundwater system.

Table 25 summarizes the atrazine data for WY 1987 by month. Flow-weighted mean monthly concentrations were lowest during the winter months of December and January at 0.17 and 0.16 ug/L, respectively. The highest monthly mean, 0.38 ug/L, occurred in August. The lowest monthly atrazine discharges -- again occurring in December and January -- were 0.9 and 0.8 pound respectively. October and August witnessed the highest fluxes, 2.2 pounds.

Figure 16 shows concentrations of atrazine, cyanazine, alachlor, and metolachlor for WY 1987. Atrazine was detected in every sample analyzed; the occurrence of non-detections of the other chemicals are indicated by concentration bars ending at "ND". Metolachlor was not detected during the water year. Cyanazine was detected twice during May at a maximum concentration of 0.2 ug/L. Alachlor was detected once in August at 0.1 ug/L. The maximum atrazine concentration for the year was 0.7 ug/L. The percentage of detections for these compounds for WY 1987 was: atrazine, 100%; cyanazine, 3%; alachlor, 2%; and metolachlor, 0%.

Tables 26 and 28 summarize atrazine data for the Turkey River (at Garber) for WY 1987. A total of 891 pounds of atrazine was discharged during the year at a flow-weighted mean concentration of 0.47 ug/L. October accounted for over one-third of the total atrazine discharge, with a flux of 312 pounds. By contrast, only 23 pounds were discharged during January. Flow-weighted monthly concentrations varied from 1.16 ug/L during June to 0.2 ug/L in January.

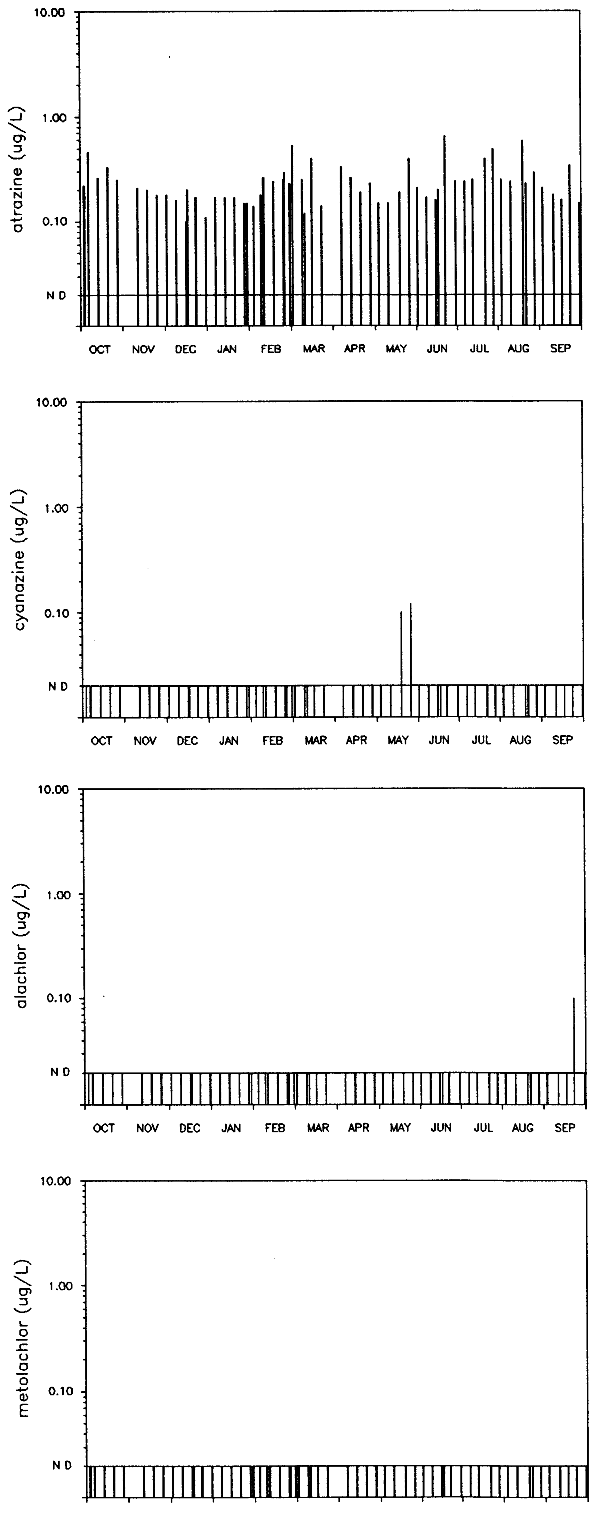


Figure 16. Schematic diagram of pesticide concentrations at Big Spring for WY 1987. ND represents not detected.

SUMMARY AND CONCLUSIONS

The Big Spring basin water and chemical discharge data discussed in this report include only the groundwater components discharged to the Turkey River; they do not yet include the surface water components, or the components of groundwater leakage to geologic units underlying the Galena aquifer. The surface water data are still being reviewed while discharge estimates are being improved. Typically the surface water discharge would add another 80%-150% to the nitrate discharged from the basin. The values presented are considerably less than the total basin loads. Basin-wide monitoring will be described in a series of subsequent reports.

The groundwater data from the Big Spring are important by themselves; it is the gaging of the groundwater discharge that allows the calculation of the hydrologic, chemical and nutrient, and energy mass balances for this basin far more completely than possible in most other areas. Past detailed studies show that over 90% of the groundwater that discharges from the basin to the Turkey River discharges at Big Spring (and associated springs).

The variable climatic and hydrologic conditions exhibited in the Big Spring basin during water years 1984-1987 illustrate the challenge of environmental monitoring, and the need for such detailed, and long-term studies. The climatic -- and therefore hydrologic -- variations complicate understanding the significance of changes in the water chemistry. Table 29 (and Fig. 18) summarizes the groundwater and chemical discharge and precipitation data from Big Spring for the report period; data from the first two years of the project (WYs 1982-1983) are included for perspective. Over the total six year period, annual groundwater discharge, and therefore overall water flux through the basin, though fluctuating year-to-year, has followed an overall declining trend. The review of the Big Spring monitoring record shows various consistent patterns.

HYDROLOGIC REGIMEN

Over the six year period of monitoring, annual precipitation has varied from 32 to 44.5 inches, and groundwater discharge ranged from 25,100 to 41,400 acre-feet per year. Nitrate-N loads have varied between 477,000 and 1,115,000 pounds. Increases and decreases in discharge are accompanied by increases and decreases in N-loads. Atrazine loads have varied from 14 to 48 pounds, with no consistent relationship to discharge. Rather, annual loads increased yearly through WY 1985, and then decreased through WY 1987.

Rainfall and snowmelt resulted in numerous runoff and infiltration recharge events in WY 1984 (Fig. 2). WY 1985 was also characterized by numerous events, although infiltration components following major runoff events were relatively less significant than in previous years. From the latter part of WY 1985 through the end of WY 1987, significant recharge was rare. From March 1985 through WY 1987, groundwater-discharge exceeded 100 cfs only once. As discussed, only WY 1987 was below average in terms of total precipitation. However, the timing and intensity of precipitation, and the antecedent moisture conditions severely limited groundwater recharge.

During the report period, maximum instantaneous and monthly total discharges typically occurred in February or March during snowmelt, particularly when coupled with rainfall. These are periods marked by large quantities of runoff-recharge; i.e., surface water that runs off of the slopes in the area and into sinkholes where it can enter the groundwater system. Such events are short-lived, with rapid increases in discharge, followed by equally rapid declines in discharge (i.e., the large peaks, or spikes on the hydrographs, Fig. 1). These are analogous to short-lived flood-peaks in streams. Many such events do little to recharge the bulk of the aquifer; they often appear to simply pass through the cavernous parts of the system. Following such events discharge returns to the same base-flow rate that was present before the event began (e.g., Fig. 8).

The lowest flows occurred during the recessions of late summer (August through early October) or of mid-winter (December and January). These are periods when groundwater comes out of storage from within the less transmissive parts of the aquifer. These base-flow periods are marked on the hydrographs by the long, nearly flat lines, indicating the very gradual decline in discharge. The more gentle rises and declines on the hydrographs, as well as the more gradual declines following some of the peak runoff-recharge events, are periods dominated by infiltration recharge

Table 29. Water year summary data for groundwater discharge from the Big Spring basin to the Turkey River.

	Water Year					
	'82	'83	'84	'85	'86	'87
Precipitation:						
water ar, inches	34.0	44.5	32.8	35.8	36.7	32.0
Groundwater discharge (Q) to the Turkey River:						
mean Q, cfs	51.4	56.9	45.3	35.2	42.0	35.4
total Q, inches	6.8	7.5	5.9	4.6	5.5	4.6
acre-feet, 1,000s	37.4	41.4	32.7	25.1	30.3	25.5
Nitrogen discharged with groundwater: flow-wtd mean concentration, mg/L						
as nitrate (NO_3)	39	46	43	31	43	41
as nitrate-N (NO_3-N)	8.8	10.3	9.7	7.0	9.7	9.1
ammonia-N *	*	*	*	*	0.1	0.1
organic-N *	*	*	*	*	0.5	0.2
nitrogen load; (nitrate-N + nitrite-N)						
1,000s lbs - N	873.0	1,150.0	843.4	476.8	796.8	636.1
lbs-N/acre (for total basin area)	13.2	17.4	12.8	7.2	12.1	9.6
Atrazine discharged with groundwater: flow-wtd mean concentration,						
atrazine, ug/L	0.2	0.3	0.5	0.7	0.4	0.3
atrazine load; lbs - atrazine	14.2	31.2	40.0	47.6	29.0	17.6

* Prior to WY 1986 ammonia-N and organic-N were not analyzed frequently enough to calculate annual flow-weighted means.

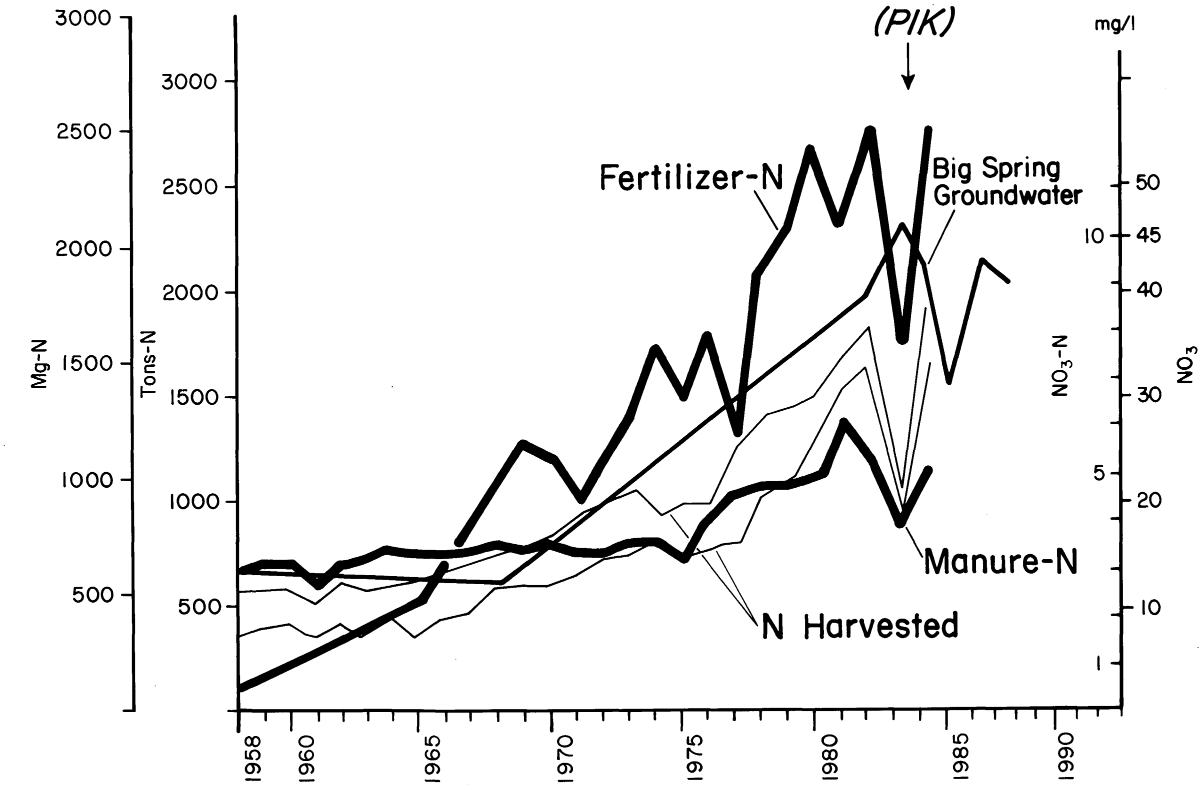


Figure 17. Mass of fertilizer-N and manure-N applied in the Big Spring basin, annual average nitrate concentration (right axis for scale) in groundwater at Big Spring through WY 1987, and estimated mass of N harvested in corn grain from the basin (after Halllberg, 1987; Hallberg et al., 1984a).

(Fig. 1).

The maximum groundwater flow recorded was in March of 1986, at 360 cfs. The lowest flow occurred in August of 1985 and was about 21 cfs. These same two periods account for the maximum and minimum months for NO_3-N discharges. During March of 1986, 165,000 lbs of NO_3-N were discharged; during August of 1985, only 29,260 lbs of NO_3-N were discharged. The mass of N discharged is a function of the volume of water and the concentration of NO_3-N in the water. Particularly at the extremes, the volume of water discharged is the principle controlling factor on the resultant mass discharge. Concentration relations are somewhat more complex.

Drought Effects

From a crop production standpoint, 1988 is referred to as the drought year, however, from a hydrologic standpoint the drought began much earlier. The dry conditions of 1988 and early 1989 were building for several years. While there was good, timely precipitation for crops in 1986 and 1987, the timing and intensity of rainfall was such that almost no runoff occurred, and recharge of any

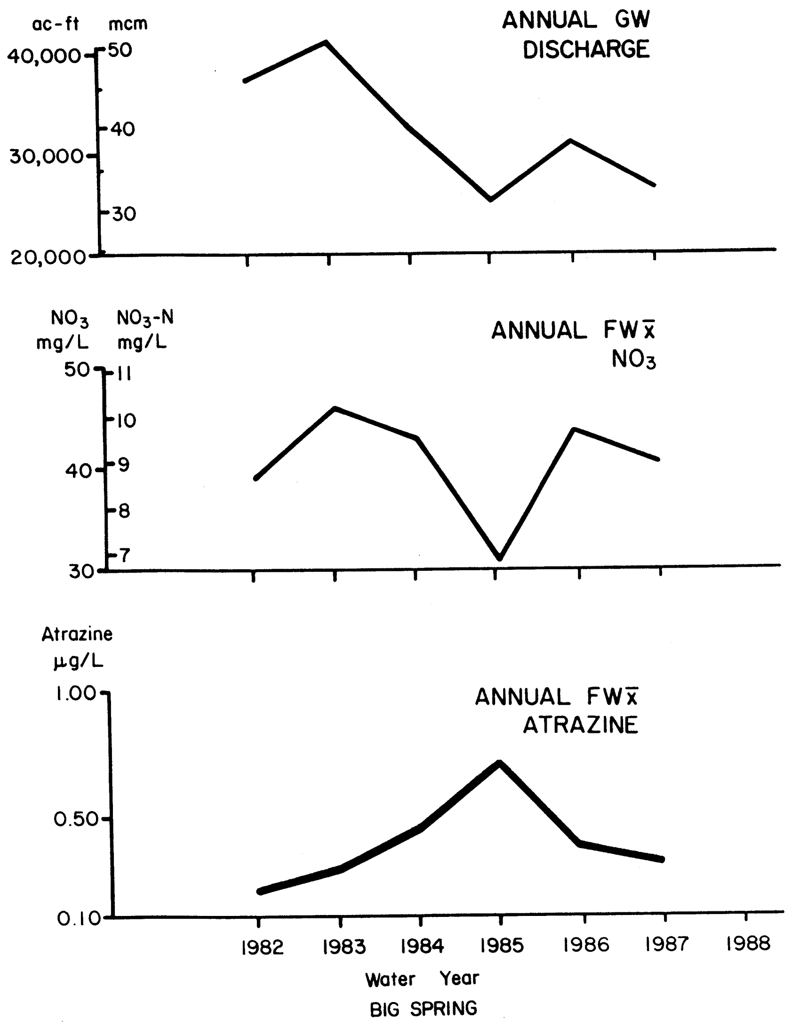


Figure 18. Summary of groundwater discharge, flow-weighted mean NO_3, and flow-weighted mean atrazine concentrations from Big Spring groundwater.

kind was very limited after snowmelt in 1986. Low flow, dominantly base-flow conditions prevailed for nearly 18 months; from the major snowmelt runoff event of March, 1986, continuing through WY 1987. Ongoing analysis indicates that the runoff recharge was less than 1% of the annual WY 1987 discharge (see Fig. 2 or 14). While some infiltration recharge occurred, groundwater was depleted from storage in the aquifer during WY 1987. Such conditions continued through WY 1988, with even more severe precipitation deficits (Fig. 1).

With the drought, the record of WY 1987 does not follow some of the typical patterns described above. In WY 1987, the maximum instantaneous discharge occurred in September, at 67 cfs; but September also had the lowest total monthly discharge. The difference between the lowest and highest discharge was only 40 cfs (low of 27 cfs in August).

WATER QUALITY

The primary focus of the Big Spring basin study has been on nitrate in groundwater. Prior reports have well established the direct relationship

Table 30. Summary of annual maximum concentrations for pesticides in groundwater at Big Spring.

	------- Water Year -------						
	'82	'83	'84	'85	'86	'87	
Pesticide common chemical name	maximum concentration, ug/L						% detections
Herbicides							
atrazine	2.5	5.1	10.0	6.1	1.4	0.7	98%
alachlor	0.2	0.6	4.0	5.0	0.7	0.2	15%
cyanazine	0.7	1.2	1.7	4.6	0.1	0.2	15%
metolachlor	nd	0.6	4.5	4.6	0.6	nd	5%
metribuzin	nd	nd	nd	3.6	nd	nd	<1%
2,4-D	na	na	na	0.2	nd	na	<1%
Insecticides							
fonofos	nd	0.1	0.3	0.4	nd	nd	<1%

na - not analyzed; nd - not detected

The following compounds were not detected: butylate, pendimethalin, trifluralin, chlorpyrifos, diazinon, ethoprop, malathion, parathion, phorate, and terbufos; 2,4,5-T, 2,4,5-TP, acifluorfen, chloramben, and dicamba.

between nitrate and agricultural landuse; Figure 17 updates and illustrates the increase in nitrate in groundwater in the basin that occurred in response to more intensive cultivation and N-fertilization changes over time (Hallberg, 1986; 1987; Hallberg et al., 1984a). Figure 18 summarizes discharge, nitrate, and atrazine concentration data. Table 30 presents further pesticide data.

Nitrate

The total mass of nitrogen discharged with groundwater is strongly related to the total volume of groundwater discharged from the system. Concentration relationships are more complex. As described in this and other reports, nitrate is predominantly contributed to the groundwater system through infiltration recharge. Runoff recharge, particularly from snowmelt, always lowers the nitrate concentration in the groundwater. In simple fashion, nitrate forms in the soil from fertilizer and manure applications, and organic-N mineralization. This nitrate is leached downward by the water that infiltrates through the soil and rock to recharge the groundwater. Hence, following periods of infiltration recharge, nitrate concentrations in Big Spring groundwater increase. During long base-flow recession, nitrate concentrations decline as groundwater levels fall. Increasing proportions of the discharge is older water from storage within the less transmissive parts of the groundwater system. During such periods biologic activity, such as denitrification, may be relatively more effective.

The months with the highest nitrate concentrations are months of significant infiltration recharge, most typically May and June, but the fall and early winter months may be high also. The greatest monthly flow-weighted mean nitrate concentration occurred in July, 1983, at 56 mg/L; the second greatest monthly average has been 48 mg/L, in May, 1984, and April, 1986. The lowest monthly concentrations have occurred in snowmelt months, February and March (the lowest monthly concentration was 23 mg/L in February, 1985), or during late-summer recessions.

The largest monthly load of nitrate-nitrogen was discharged in March, 1986, which was not only a snowmelt runoff event, but a rainy period with significant infiltration recharge as well. The combination of high flow and high concentration discharged over 160,000 tons of nitrogen from the basin during the month.

Pesticides

The greatest pesticide concentrations in groundwater in the basin are typically related to periods of runoff recharge. However, some occurrences are related to infiltration recharge periods, as well. Atrazine in particular, follows recession patterns and concentration fluctuations similar to nitrate during infiltration recharge. Monitoring in the Big Spring basin, and elsewhere, show that a number of commonly used herbicides are also delivered to groundwater through infiltration recharge.

When the Big Spring studies were initiated, the prevailing wisdom was that pesticides would not likely be found in groundwater, except perhaps during the relatively brief periods of runoff recharge. Early in these studies it became apparent that the active ingredient in the widely used herbicide atrazine was detectable in the groundwaters of the basin, not simply during brief events, but it occurred persistently year-around. These were some of the earliest studies on herbicide occurrence in groundwater. At this time it was not felt that atrazine's behavior was much different than many other herbicides. Today it is apparent that atrazine is considerably more persistent in the environment than once presumed, and that atrazine is more persistent than many other herbicides. This is apparent in the graphics summarizing the detection of the herbicides by water year (e.g., Figs. 6 and 9). In the Big Spring groundwater 98% of all samples analyzed, since the fall of 1981, have contained detectable atrazine (Table 30).

The herbicides detected in groundwater in the basin commonly exhibit maximum concentrations during, or shortly after, the period of their application, early in the growing season. In WY 1984, for example, atrazine concentrations show peaks in late April, May, and June, and then decline during the remainder of the water year. Alachlor, cyanazine, and metolachlor were only detected in latest April, May, and June (Fig. 6). Exceptions to these typical trends can be important clues to the overall behavior of these compounds in the soil-groundwater system.

The greatest monthly mean atrazine concentrations, and the greatest monthly loads are generally in May and June. An exception to this indicates the persistence of atrazine; the second greatest monthly mean concentration (1.31 ug/L) and the third greatest load occurred in February, 1985. The persistence of atrazine is also well illustrated by its continued presence, albeit declining concentrations, throughout the prolonged, drought induced recession of late WY 1986 and WY 1987. Clearly atrazine is persistent and in storage in the soil-groundwater system for it to be detected during such long periods without runoff recharge.

The occurrence of alachlor, cyanazine, and metolachlor in earliest April, 1985, during a period of apparent infiltration recharge suggest that they also may persist in the system. Alachlor and cyanazine have been the second most commonly detected herbicides in Big Spring groundwater, but they typically appear intermittently and are detected much less frequently then atrazine. As summarized on Table 30, their maximum concentrations are similar to atrazine's but they have only been detected in 15% of the samples over time. This is typical in many tile-line and well monitoring studies in Iowa and other states. Their detection in tile line and piezometer monitoring has shown that they leach through the soil to groundwater; they are not solely delivered by runoff recharge. For example, Helling et al. (1988; Isensee et al., 1988), of the U.S.D.A., Agricultural Research Service, have been conducting detailed controlled plot studies at the National Agricultural Research Center, at Beltsville, Maryland. In these studies atrazine, alachlor, and cyanazine were detected in 75%, 18%, and 13% of shallow groundwater samples, respectively. These relationships of detections and persistence are very analogous to Iowa findings. Also, they noted that: the rapid vertical transport to the shallow groundwater suggested preferential flow through the soil was an important mechanism; the occurrence of intermittent detections and late-season maxima of the less persistent herbicides did occur during periods of water-flux; and that detections in groundwater occurred after shallow subsoil concentrations had declined to non-detectable levels.

The analyses to date has only been for the parent pesticide compounds; metabolites of atrazine and these herbicides may also occur. The intermittent appearance of these compounds in the groundwater system suggests that some residue is likely left in storage in the system, but these may appear as degradates/metabolites which are not detected by routine analysis (see Hallberg, 1989).

From continued field observations in the Big Spring basin, it is apparent that only during the largest of events is there much direct run-in to the aquifer (i.e., surface water running into a sinkhole with an opening into the Galena aquifer). Most of the sinkholes in the basin are filled with soil; and also have a growth of trees, brush, and grasses. During most smaller events runoff water often doesn't reach the sinkholes, it soaks into the soils in the water ways. In either case much of the 'runoff' water also has to infiltrate through some thickness of soil before it enters the aquifer, in a strict sense. This is analogous to what may happen in other settings as well. In all of Iowa, with moderate rainfall events, some water may begin to run off the upper slopes of the landscape, only to infiltrate into the alluvial soils in the lower part of a waterway system. Considerable research in various environments has also shown that much of the water that is discharged in a stream during a 'runoff' event may actually be comprised of shallow groundwater flow (see Sklash and Farvolden, 1979, and Kennedy et al., 1986, for summaries). Such event water, or through-flow, water passes through the shallow subsoil and moves laterally to streams during recharge events. Hence there is a considerable groundwater component, even in such event related water flux.

The soil materials that fill sinkholes may afford some storage of pesticides (adsorbed to soil particles, or in matrix water), in pendants that penetrate the irregular surface of the aquifer. Also, some sediment runs into open sinkholes and this may afford storage sites within the aquifer itself from which pesticides could be contributed to the groundwater through desorption. However, the volume of sediment that has entered the aquifer in the past 20 years is undoubtedly insignificant compared to the volume that has entered the system over the past 100,000 years or more this landscape has been evolving. There is far more sediment in the system with the capacity for adsorption than sediment with adsorbed pesticides.

The complete record of monitoring from tile-lines, monitoring wells, and surface waters will afford more detailed discussion of the inter-relationship of groundwater and surface-water quality, recharge mechanisms, and farming practices in the basin. Past interpretations of the flux of pesticides to groundwater in the basin have always been based on the data recorded from these various components of the hydrologic system, and from insights garnered from pertinent studies in other areas. It is clear, however, that inferences about the delivery of pesticides to groundwater in the Big Spring basin will never be unequivocal. Yet, the findings from these efforts have clearly contributed to the development of other needed initiatives to address these issues. The principle focus of the Big Spring Basin Demonstration Project will continue to be to document the improvements in water quality that can take place with improved farm management practices.

TEMPORAL CHANGES IN WATER QUALITY

Figure 18 and Table 29 summarize Big Spring groundwater data on a water year basis. As described, the flow-weighted mean nitrate concentrations generally change in a parallel fashion to the groundwater discharge/flux through the system. Nitrate concentrations dropped significantly in WY 1985, as discharge declined. In WY 1986 water flux increased, and concentrations increased as well. They have continued to hover between 40 and 45 mg/L nitrate, just below the recommended drinking water standard of 45 mg/L (10 mg/L as NO_3-N).

Comparisons of the data from the wettest and driest years, WYs 1983 and 1987, are instructive. For the six year period, WY 1983 had the highest precipitation, groundwater discharge, nitrate concentrations, and nitrate-N loads. Relative to WY 1987, WY 1983 had 39% more precipitation, 61% greater groundwater discharge, a 12% higher flow-weighted mean nitrate concentration, and an 80% greater nitrate-N load. These water years had essentially the same flow-weighted mean atrazine concentrations, and the difference in atrazine loads is proportional to the difference in discharge. These data show the general relationship between precipitation, groundwater discharge, and nitrate-N concentrations and loads, and the lack of any such clear relationship involving atrazine.

A similar comparison between WYs 1985 and 1987 gives further insights. Relative to WY 1987, WY 1985 recorded 12% more precipitation, but an essentially equal discharge of groundwater occurred. Yet the flow-weighted mean nitrate concentration and nitrate-N load were significantly greater in WY 1987 than in WY 1985; approximately 33% greater, and nearly 80 tons more nitrogen was discharged with groundwater. However, the flow-weighted mean atrazine concentration was twice as high in WY 1985.

With the perspective of the WY 1986 and 1987 data, the major drop in 1985 appears clearly related to landuse changes, and reductions in fertilizer-nitrogen loading associated with PIK, in 1983, as well as declining water flux. This also suggests that, for nitrate, there is approximately a two-year time lag between major changes in landuse and the appearance of their affects in the groundwater. Further statistical review of these data is underway.

Atrazine flux is somewhat out-of-phase with these other parameters. Atrazine concentrations rose steadily from WY 1982 to WY 1985, in spite of declining water-flux. It declined in 1986 as discharge increased, and further declined during the recession of 1987. The reasons for the out-of-phase trend of atrazine are not clear. The response of a compound such as atrazine may be retarded in the hydrologic system behind other responses. The declines in WYs 1986-1987 may be related to the reduction in runoff recharge and, perhaps more importantly, the reduction of recharge of any kind during this period.

Atrazine concentrations decline during recession, just as nitrate does. With the prolonged recession that occurred from spring 1986 through 1987, some decline in atrazine concentrations would be expected. Also, some significant changes in atrazine use have occurred: farm operations inventories of the basin show that between 1984 and 1987 atrazine use by basin farmers has decreased by more than 25% (report in preparation). Under the current hydrologic regime it is difficult to attribute much of the atrazine decline in groundwater to these changes in farm-chemical use, at this time. When there is little flux of water through the soil/hydrologic system, little flux of dissolved chemicals can occur. Just as with the major drop in nitrate in WY 1985 that can be related to the PIK program landuse changes, the significance of these changes can only be evaluated through the continued record of monitoring over the coming years.

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