GROUNDWATER MONITORING in the BIG SPRING BASIN 1990-1991: A Summary Review

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Larry J. Wilson, Director
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A Report of the Big Spring Basin Demonstration Project

Prepared by

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Energy and Geological Resources Division
Geological Survey Bureau

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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 chemicals have been monitored within and around the basin since 1981. This report summarizes the results of monitoring at Big Spring and the Turkey River during water years (WYs) 1990 and 1991. This period was characterized by above average precipitation, and followed the driest consecutive two-year period in the state's history. Precipitation totals for the basin increased from 22.94 inches in WY 1988 and 24.32 inches in WY 1989 to 37.87 inches during WY 1990 and 47.27 inches during WY 1991. The WY 1990 and 1991 totals were 115% and 143% of the long-term average precipitation of 32.97 inches. The increased precipitation generated both runoff and infiltration recharge. Groundwater discharge from the basin to the Turkey River totaled 17,500 acre-feet in WY 1990 and 42,500 acre-feet in WY 1991, which was the highest annual discharge measured during the WY 1982 through 1991 period of record at Big Spring. Discharge rates generally increased slowly across the period, with a minimum monthly average of 11 cubic feet per second (cfs) occurring in December 1989 and a maximum monthly average of 141 cfs in June 1991. Annual discharge of the Turkey River at Garber was 631,900 and 1,103,000 acre-feet, for WYs 1990 and 1991, equivalent to 92% and 160% of the long-term average discharge.

Annual flow-weighted (fw) mean nitrate concentrations at Big Spring were 37 mg/L in WY 1990 and 56 mg/L in WY 1991. The total load of nitrate-nitrogen discharged by the groundwater system was 388,500 pounds in WY 1990 and 1,445,500 pounds in WY 1991. Annual fw mean nitrate concentrations and loads for WY 1991 were the highest recorded since monitoring began at Big Spring. Nitrate concentrations increased slowly across the period, in a manner similar to the rate of discharge. For the Turkey River, fw mean nitrate concentrations were 31 mg/L and 44 mg/L, in WYs 1990 and 1991. Total nitrate nitrogen discharged by the river was about 11.7 million pounds in WY 1990 and 29.6 million pounds in WY 1991.

Atrazine is the most consistently detected herbicide in Big Spring groundwater. It was detected in all samples analyzed for pesticides during WYs 1990 and 1991. WY 1991 registered the highest fw mean atrazine concentration (1.17 µg/L), and the highest annual atrazine load (135 pounds), during the period of record. WY 1990 recorded the second highest fw mean atrazine concentration (1.10 µg/L) and the second highest total atrazine load (50.0 pounds) during the period of record. Alachlor, cyanazine, and metolachlor were also detected at Big Spring and the Turkey River during WYs 1990 and 1991. The Turkey River discharged about 3,260 pounds of atrazine at a fw mean concentration of 1.90 µg/L during WY 1990, and about 3,330

pounds of atrazine at a fw mean concentration of 1.11 μg/L during WY 1991.

Analysis of annual data for WYs 1982 through 1991 indicates that while fw mean nitrate concentrations and loads generally parallel discharge, fw mean atrazine concentrations and loads do not. Relatively high concentrations and loads of atrazine have occurred during years with low groundwater discharge. The climatic variations and resulting hydrologic conditions exhibited in the Big Spring basin during WYs 1982 through 1991 have led to variations in discharge rates and contaminant concentrations and loads by factors ranging from two to ten during the period of record. Extreme climatic variations complicate the interpretation of changes in water quality and illustrate the need for detailed, long-term monitoring of nonpoint-source contamination.

INTRODUCTION

The Big Spring basin is a 103 mi^2 groundwater basin located in Clayton County, northeast Iowa. The geographic extent of the groundwater basin was delineated in previous investigations by the Iowa Department of Natural Resources, Geological Survey Bureau and cooperating agencies. Previous reports have documented the magnitude of groundwater contamination related to agricultural practices, identified hydrogeologic settings susceptible to contamination from agricultural use, and provided insights into the mechanisms that deliver agricultural chemicals to groundwater. Reviews of the hydrologic and water-quality monitoring for water years (WYs; October 1 through September 30) 1982 through 1989 have been presented by Hallberg and others (1983, 1984, 1985, 1987, 1989), and Libra and others (1986, 1987, 1991). Data from several monitoring sites within the basin for WYs 1988 through 1990 are presented in Kalkhoff (1989), Rowden and Libra (1990), Kalkhoff and Kuzniar (1991), and Kalkhoff and others (1992). Reviews of rainfall monitoring for pesticides are discussed in Nations (1990), Nations and Hallberg (1992), Goolsby and others (1990), and Capel (1990).The design and implementation of the network of monitoring stations used to quantify changes in water quality in the basin are described in Littke and Hallberg (1991).

This report summarizes Big Spring and Turkey River monitoring data for WYs 1990 and 1991. Analytical methods, landuse, and the current status of the Big Spring Basin Demonstration Project are reviewed in Hallberg and others (1989). Interpretation of data presented in this report requires analyses of data from the network of monitoring sites throughout the basin. Hydrologic and water-quality data from tile lines, wells, and surface-water sites within the basin and sub-basins will be addressed in subsequent reports.

HYDROLOGIC AND WATER QUALITY MONITORING

Groundwater discharge from the Big Spring basin to the Turkey River has been monitored since the fall of 1981. Discharge at Big Spring is a function of recharge within the basin, and is controlled by the amount, timing, and intensity of precipitation and snowmelt. Climatic variations, along with antecedent conditions, exert a major control on the transport, concentrations, and loads of agriculturally-related contaminants. This section will discuss the monitoring of precipitation, discharge, and water-quality at Big Spring, and some aspects of the discharge and water-quality record for the Turkey River. The Turkey River is a high baseflow stream, deriving a significant part of its discharge from influent groundwater. Therefore, data from the Turkey River provide a regional perspective for the hydrologic and water-quality monitoring at Big Spring. All references to the Turkey River or Turkey River basin refer to the basin above Garber, Iowa. Discharge records for the Turkey River at Garber are available for all but seven years since WY 1914, and are continuous since 1933. Discharge data for the Turkey River and Big Spring were supplied by the U.S. Geological Survey, Water Resources Division, (USGS) Iowa City, Iowa.

The Big Spring hydrologic system receives both infiltration and runoff recharge, which have unique chemical signatures (Hallberg et al., 1983, 1984). These signatures can be tracked through the hydrologic system, from the soil zone beneath individual fields to the basin water outlets (Hallberg et al., 1984). Infiltration recharge is enriched in nitrate and other chemicals that are mobile in soil, relative to runoff recharge, particularly runoff derived from snowmelt. Runoff recharge has lower concentrations of such compounds, but is enriched in herbicides and other chemicals with low soil mobility. Typically Big Spring yields groundwater, but following significant precipitation or snowmelt, sinkholes within the basin may direct some surface runoff into the aquifer mixing it with the groundwater. As this runoff recharge moves through the groundwater system and discharges from Big Spring, relatively low nitrate and high herbicide concentrations occur during peak flow periods. 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 relatively older groundwater from the less transmissive parts of the flow system (Hallberg et al., 1984). In general, low discharge periods are accompanied by low contaminant concentrations, yielding small total contaminant loads. Concentrations are generally higher during periods of higher discharge, yielding greater loads, related to both the increased volume of water and greater concentrations.

The nested monitoring network design used in the Big Spring basin allows water and chemical responses to recharge events to be tracked through the hydrologic system, from the soil zone beneath individual fields to the basin water outlets (Hallberg et al., 1984). The design also allows integration and comparison of water quality responses at different scales to assess affects of landuse and landscape-ecosystem processes. Infiltrating recharge water from individual field sites delivers high concentrations of nitrate to shallow groundwater, and this shallow groundwater transports the nitrate laterally to streams and downward to the Galena aquifer and Big Spring. Although the discharge and chemical responses are not as great or immediate at the largest scales monitored, they clearly occur and the nested monitoring design allows the pulse to be followed back through the hydrologic system. The water quality of the Big Spring and Turkey River basins is an integration of the management practices on all the individual parcels of land they contain.

Precipitation

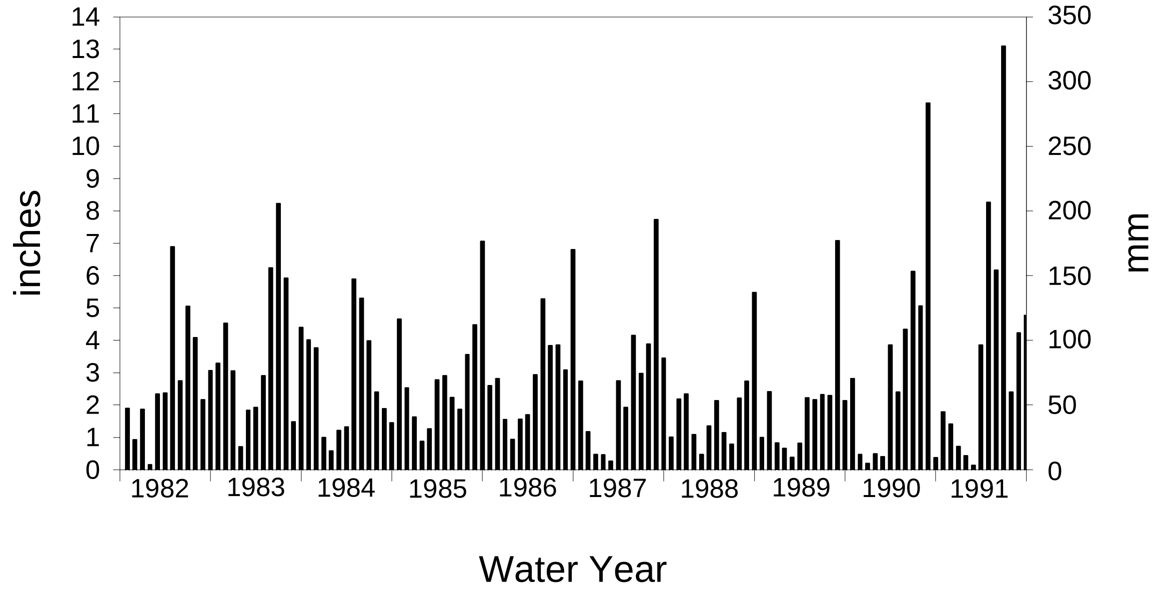
Precipitation data for WYs 1982-1988 were calculated using data from the Elkader, Waukon, and Fayette weather stations, which form a triangle around the Big Spring basin. These data and daily minimum/maximum temperature data are supplied by the Iowa Department of Agriculture and Land Stewardship, State Climatology Office (IDALS, SCO). Precipitation has been recorded at the Big Spring Fish Hatchery since August 1984 as part of the National Atmospheric Deposition Program (NADP). Beginning in WY 1985, this data has also been used to calculate basin precipitation. In the summer of 1988, the USGS installed rain gages at two surface-water gaging stations within the basin. Basin precipitation for WYs 1989 to present are calculated with data from the two USGS stations and the NADP station at the hatchery. Precipitation for the Turkey River drainage basin, which includes a larger area, is estimated using averages for the state's northeast climatic division (IDALS, SCO). The mean annual WY precipitation for the basin area is 32.97 inches, and references to normal precipitation are based on the period 1951-1980.

Monthly precipitation and departures from normal for WYs 1982 through 1991 are shown in Figure 1, and are tabulated for WYs 1990 and 1991 in Table 1. The ten year period of record was characterized by extreme climatic variability. The two driest consecutive years in Iowa's recorded history, WYs 1988 and 1989, preceded the two wettest consecutive water years since the Big Spring project's inception.

Mean annual precipitation increased from 33.56 inches in WY 1982 to 44.53 inches during WY 1983. Water Years 1984, 1985, 1986, and 1987 had annual totals of 32.81, 35.84, 36.96, and 31.98 inches, respectively. Although the annual totals for WYs 1984 through 1987 were near normal, precipitation during June and July of these years was below normal. In general, precipitation amounts were lower than normal during the growing season, and greater than normal during the fall of these years. This trend continued throughout WYs 1988 and 1989. Basin precipitation for WY 1988 was 22.94 inches and for WY 1989, 24.32 inches. These annual totals were 70% and 74% of the long term normal, respectively.

June is typically the wettest month in the Big Spring basin (4.80 inches for 1951-1980). However, for WYs 1985-1989, either August or September were the wettest months (Hallberg et al., 1989). Previous reports (Hallberg et al., 1983, 1984, 1989) have indicated that March through June are typically marked by low evapotransporation and wet antecedent conditions, which are important for groundwater recharge. Precipitation during

A



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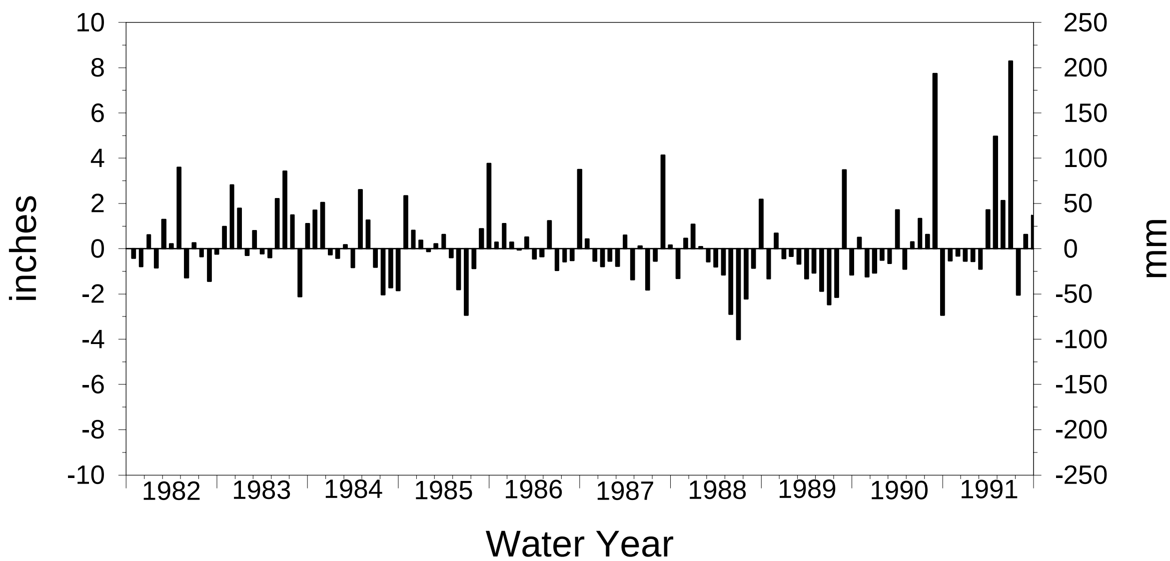

Figure 1. A) Monthly precipitation totals and B) departure from normal for the Big Spring basin, WYs 1982-1991 (Iowa Dept. of Ag. and Land Stewardship, State Climatology Office).

Table 1. Monthly precipitation and departure from normal; Big Spring basin, Water Years 1990-1991.

Water Year 1990	Basin precip inches	Departure from normal inches	% of normal	Water Year 1991	Basin precip inches	Departure from normal inches	% of normal
Oct-89	2.82	0.50	122	Oct-90	1.79	-0.53	77
Nov-89	0.48	-1.24	28	Nov-90	1.41	-0.32	57
Dec-89	0.19	-1.07	15	Dec-90	0.72	-0.54	57
Jan-90	0.49	-0.51	49	Jan-91	0.43	-0.57	43
Feb-90	0.40	-0.65	38	Feb-91	0.14	-0.91	13
Mar-90	3.86	1.71	180	Mar-91	3.86	1.71	180
Apr-90	2.40	-0.90	73	Apr-91	8.27	4.97	251
May-90	4.34	0.30	107	May-91	6.17	2.13	153
Jun-90	6.13	1.33	128	Jun-91	13.09	8.29	273
Jul-90	5.06	0.63	114	Jul-91	2.40	-2.04	54
Aug-90	11.33	7.73	315	Aug-91	4.23	0.63	118
Sep-90	0.37	-2.93	11	Sep-91	4.77	1.47	145
TOTAL	37.87	4.90	115	TOTAL	47.28	14.29	143

these months was below normal during WYs 1984 through 1987, and far below normal during WYs 1988 and 1989.

While there was timely precipitation for crops in WYs 1986 and 1987, the timing and intensity of rainfall was such that almost no runoff occurred, and recharge of any kind was limited after snowmelt in March of WY 1986. Base-flow conditions prevailed for nearly 18 months, depleting groundwater storage in the Galena aquifer during WYs 1987 through 1989.

Precipitation patterns began changing during the spring of WY 1990. Annual precipitation was 4.9 inches above the long term average (Table 1). Monthly precipitation was above normal from May through August. The wettest months were August (11.33 inches) and June (6.13 inches) and the driest months were December (0.19 inches) and September (0.37 inches). Precipitation during August was 7.73 inches above normal, and precipitation during September was 2.93 inches below normal. The largest single rainfall events occurred on August 24 (1.82 inches) and 25 (1.74 inches).

Water Year 1991 had the highest mean annual precipitation during the WY 1982-1991 period. Precipitation for the water year was 14.3 inches or 43% above the long term average. Precipitation was slightly below normal from October through February, far below normal during July, and far above average from March through June. The greatest monthly accumulation of precipitation (13.09 inches) occurred in June, and the largest single rainfall event (local reports of 11 to 13 inches near Monona, Iowa) occurred on June 14. Precipitation during June was 8.29 inches above normal, and precipitation during July was 2.04 inches below normal.

The change in the distribution patterns of precipitation from WYs 1988 and 1989 to WYs 1990 and 1991 was rather dramatic. WYs 1985 through 1989 were characterized by dry growing seasons and wet falls. During WYs 1990 and 1991 rainfall amounts were below normal from October through February, and above normal from March through September. The timing, intensity, and distribution of rainfall all affect the resultant recharge to the soil-groundwater system, and the concentrations of agricultural contaminants transported by surface- and groundwater.

Water Year 1990

Discharge Monitoring

Tables 2 through 8 and Figures 2 through 5 summarize the discharge, climatic, water quality, and chemical loading data for Big Spring and the Turkey River at Garber during WY 1990.

Groundwater discharge from the Big Spring basin was 17,476 acre-feet (ac-ft), at an average rate of 24 cubic feet per second (cfs). Groundwater discharge was equivalent to about 8% of precipitation (Table 2). Discharge for the Turkey River was about 631,900 ac-ft, at an average rate of 873 cfs (Table 3). Surface-water discharge accounted for about 20% of precipitation, and was equal to about 93% of the long-term average.

Figure 2 shows the discharge hydrograph and water temperature for Big Spring, along with daily basin precipitation and maximum/minimum air temperatures from the Elkader weather observation station. Snowmelt events are indicated by sharp drops in Big Spring water temperature. Periods when discharge rapidly increases, and then rapidly decreases are the result of significant surface water runoff-recharge to sinkholes. After such events, the discharge often remains at higher levels than previous to the event, and then slowly decreases to lower flow rates. This sustained increase in discharge indicates that significant infiltration occurred, delivering influent water to the more transmissive parts of the groundwater system, such as conduits or solutionally enlarged fractures or bedding planes (Hallberg et al., 1989). During prolonged periods with insignificant recharge, the discharge from Big Spring consists of water from the less transmissive parts of the hydrologic system. This type of discharge is expressed on the hydrograph as long, nearly flat lines indicating an extremely gradual decline in flow rates. Figure 3 shows the discharge hydrograph, along with plots of nitrate and atrazine concentrations.

The discharge hydrograph for early WY 1990 reflects the continuation of the drought conditions that prevailed during WYs 1988 and 1989. Low flow conditions persisted during the first four months of the water year and mean daily discharge declined

Table 2. Annual summary of groundwater and chemical discharge from the Big Spring basin to the Turkey River for Water Year 1990.

DISCHARGE		
Total		
acre-feet	17,476	
millions cf	761	
millions cm	21.5	
Average		
cfs	24.1	
cms	0.7	
mg/d	15.6	
gpm	10,816	
PRECIPITATION AND DISCHARGE		
Precipitation	37.87 inches (961.9mm)	
Discharge	3.2 inches (81.3mm)	
Discharge as % of precipitation	8%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	37.0	8.2
Mean of analyses	29.7	6.6
	NO_3-N output	**Total N output**
lbs - N	388,479	420,294
kg - N	176,181	190,610
lbs - N/acre	5.89	6.38
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	1.06	
Mean of analyses	0.97	
Total output		
lbs	50.0	
kg	22.7	

Table 3. Annual summary of water and chemical discharge for the Turkey River at Garber for Water Year 1990. (Discharge data are from U.S. Geological Survey, Water Resources Division.)

DISCHARGE		
Total		
acre-feet	631,900	
millions cf	27,526	
millions cm	779	
Average		
cfs	873	
cms	24.7	
mg/d	564	
gpm	391,802	
PRECIPITATION AND DISCHARGE		
Precipitation	38.87 inches (987.3mm)	
Discharge	7.67 inches (194.8mm)	
Discharge as % of precipitation	20%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	30.5	6.8
Mean of analyses	27.4	6.1
	NO_3-N output	**Total N output**
lbs - N	11,649,897	16,724,530
kg - N	5,283,400	7,584,821
lbs - N/acre	11.8	16.9
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	1.90	
Mean of analyses	2.02	
Total output		
lbs	3,259	
kg	1,478	

from about 13 cfs to about 11 cfs from October through December. Snowmelt events in January and February, and precipitation events in March generated runoff but little infiltration recharge, as indicated by the hydrograph quickly returning to base flow. Precipitation events in May, June, and July generated minor runoff, but provided enough infiltration recharge to sustain higher discharge rates (18 to 30 cfs) between events. This indicates the amount of groundwater stored within the hydrologic system was beginning to recover from the relatively low levels that occurred during the drought. The largest runoff event of the water year occurred on August 25 following two days of widespread rainfall, and caused extensive flooding throughout the Turkey River valley. The mean daily discharge declined rapidly from 213 cfs on August 25 to 55 cfs on September 1, and then slowly declined to 26 cfs near the end of the water year.

Table 4 summarizes the discharge data for Big Spring on a monthly basis. The greatest monthly discharge, 2,542 ac-ft, occurred in August, at an average rate of 41 cfs. Monthly discharge remained below 2,400 ac-ft during all other months. The minimum monthly discharge, 683 ac-ft, occurred during December, at an average rate of 11 cfs. This was the lowest monthly average discharge for the period of record for Big Spring (WYs 1982-1987; Hallberg et al., 1983, 1984 ,1989, and WYs 1988-1989; Libra et al., 1991). August and December were also the highest- and lowest-flow months for the Turkey River at Garber, with 222,100 ac-ft discharged, at an average rate of 3,611 cfs in August, and 6,270 ac-ft discharged, at an average rate of 102 cfs in December.

Nitrate Monitoring

Tables 2 and 5 summarize the nitrate and nitrate-nitrogen monitoring at Big Spring for WY 1990. During the water year 147 samples were analyzed for nitrate, and 86 of these were analyzed for other nitrogen species (ammonia- and organic-N). The flow-weighted (fw) mean nitrate concentration (mean concentration per unit volume of discharge) for the water year was 37 mg/L (8.2 mg/L as NO_3-N). A total of 420,300 pounds of

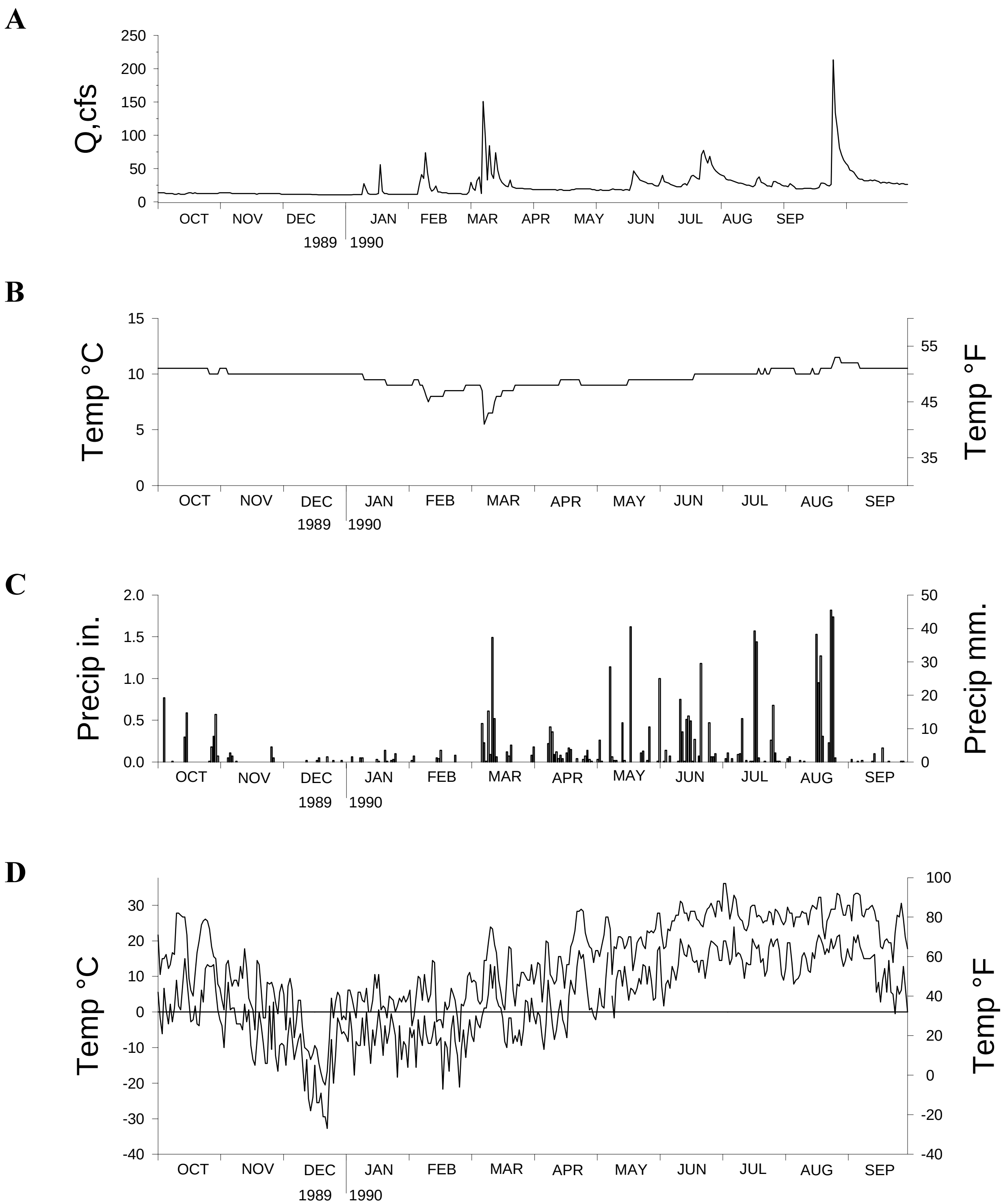

Figure 2. A) Groundwater discharge, B) groundwater temperature and C) daily precipitation for the Big Spring basin; and D) maximum-minimum temperatures for Elkader, IA (Iowa Dept. of Ag. and Land Stewardship, State Climatology Office), for WY 1990.

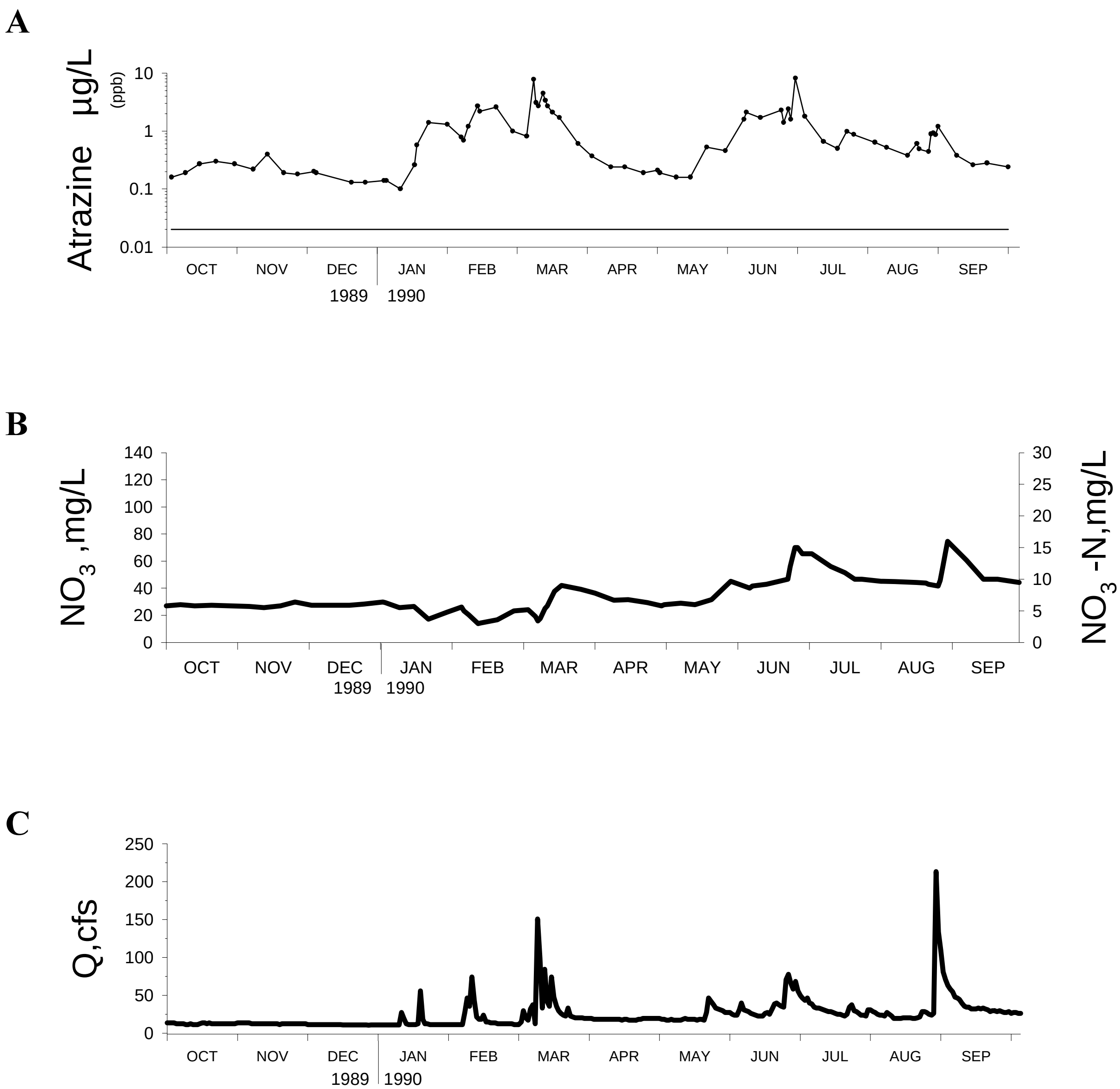

Figure 3. A) Atrazine and B) nitrate concentrations; and C) groundwater discharge at Big Spring for WY 1990.

nitrogen were discharged by groundwater from the basin during the water year; of this total, 388,500 pounds, or 92%, was in the form of nitrate.

Figure 3 shows the discharge hydrograph and a plot of nitrate concentrations for Big Spring. During the first three months of the water year, nitrate concentrations remained below 30 mg/L (6.7 mg/L as NO_3-N). Nitrate concentrations remained relatively low from October through February, as a result of the continuing drought conditions and resulting lack of infiltration recharge. Snowmelt in January and February generated runoff recharge and caused short-term dilution of nitrate concentrations during peak discharge. The lowest nitrate concentration sampled, 6 mg/L (1.3 mg/L as NO_3-N), occurred in March, during peak discharge following precipitation events. Concentrations then increased to 40 mg/L (8.9 mg/L as NO_3-N) as

Table 4. Monthly summary of groundwater discharge from the Big Spring basin for Water Year 1990.

	1989 Oct	Nov	Dec	1990 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
TOTAL MONTHLY DISCHARGE												
Acre-feet	777	754	683	848	1,069	2,189	1,092	1,448	2,303	1,813	2,542	1,949
Cubic feet (millions)	34	33	30	37	47	95	48	63	100	79	111	85
Gallons (millions)	253	246	223	276	348	714	356	472	750	591	829	635
Cubic meters (millions)	1.0	0.9	0.8	1.0	1.3	2.7	1.4	1.8	2.8	2.2	3.1	2.4
AVERAGE DISCHARGE												
cfs	13	13	11	14	19	36	18	24	39	30	41	33
cms	0.4	0.4	0.3	0.4	0.5	1.0	0.5	0.7	1.1	0.8	1.2	0.9
mg/d	8	8	7	9	12	23	12	15	25	19	27	21
MAXIMUM												
cfs	14	14	11	56	74	150	19	46	78	41	213	55
cms	0.4	0.4	0.3	1.6	2.1	4.3	0.5	1.3	2.2	1.2	6.0	1.5
MINIMUM												
cfs	11	11	11	11	11	13	17	17	23	23	19	26
cms	0.3	0.3	0.3	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.5	0.7

discharge receded, indicating that significant infiltration recharge had occurred. Concentrations then declined until precipitation events in May generated minor infiltration recharge and nitrate concentrations increased as discharge generally increased. During the remainder of the water year, nitrate concentrations followed discharge. As discharge events occurred, nitrate concentrations would decrease during peak discharge, then increase as discharge began to recede, then decrease as discharge continued to recede. Comparison of the nitrate plot with the hydrograph shows peaks in nitrate concentrations closely following peaks in discharge. In addition, both discharge rates and nitrate concentrations showed a general increasing trend during the last half of the water year, as relatively nitrate-rich water recharged the aquifer. The highest concentration sampled during the water year, 65 mg/L (14.4 mg/L as NO_3-N), occurred following precipitation events in late June.

Table 5 summarizes fw mean nitrate concentrations and nitrate-N loads on a monthly basis for WY 1990. The highest monthly fw mean, 51 mg/L (11.3 mg/L as NO_3-N), occurred in July and the lowest, 19 mg/L (4.1 mg/L as NO_3-N) was recorded during February. Monthly fw means remained below 30 mg/L from October through April. From June through September, fw mean nitrate concentrations exceeded the 45 mg/L (10 mg/L as NO_3-N) drinking water standard for nitrate. The greatest monthly N-load, about 70,000 pounds, occurred in August, the month with greatest groundwater discharge. The lowest N-load, 11,000 pounds, occurred during November and December, the months with the second lowest and lowest groundwater discharge, respectively. The nitrate-N discharged with groundwater during these two months was the lowest measured in the basin during the WY 1982 through

Table 5. Monthly summary of nitrate-N discharged in groundwater from the Big Spring basin to the Turkey River; Water Year 1990.

	1989 Oct	Nov	Dec	1990 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean NO_3 concentration, in mg/L;	26	24	26	26	19	27	29	30	46	51	46	52
as NO_3-N	5.7	5.4	5.7	5.7	4.1	6.0	6.4	6.6	10.3	11.3	10.2	11.6
Mean of NO_3 analyses, in mg/L;	25	24	26	22	15	27	28	24	49	51	26	48
as NO_3-N	5.6	5.4	5.8	4.8	3.4	5.9	6.2	5.4	11.0	11.3	5.8	10.7
Total monthly NO_3-N output, thousands lbs	12	11	11	12	12	36	19	26	65	56	70	60
Total monthly NO_3-N output, thousands kg	5	5	5	6	5	16	9	12	29	25	32	27

WY 1991 period of record.

Figure 4 and Tables 3 and 6 summarize nitrate concentrations and loads for the Turkey River basin for WY 1990. During WY 1990, 47 samples were analyzed for nitrate, and 16 of these were also analyzed for ammonium- and organic-N. A total of about 17 million pounds of nitrogen were discharged by the Turkey River during the water year; of this total, about 12 million pounds, or 70%, was in the form of nitrate. The annual fw mean nitrate concentration was 30.5 mg/L (6.8 mg/L as NO_3-N).

Comparison of the hydrographs and nitrate plots for Big Spring and the Turkey River shows similar trends in both discharge and nitrate concentrations. Differences in detail occur because of the size difference between the systems, the larger proportion of surface runoff water in the Turkey River, in-stream processes that affect surface water, and the higher frequency of sampling at Big Spring.

Nitrate concentrations were relatively constant through December, at about 22 mg/L (4.9 mg/L as NO_3-N) and generally decreased through January and most of February to 9 mg/L (2.0 mg/L as NO_3-N) following snowmelt. The lowest concentration sampled, 4 mg/L (0.9 mg/L as NO_3-N) coincided with the lowest concentration sampled at Big Spring in March during peak discharge following precipitation. Concentrations increased to 45 mg/L (10.0 mg/L as NO_3-N) in mid-March then declined to 13 mg/L (2.9 mg/L as NO_3-N) at the end of April. During the remainder of the water year, both nitrate concentrations and discharge generally increased. As with Big Spring, nitrate concentrations generally decreased during peak discharge, increased as discharge receded, and then decreased again as discharge continued to recede. The highest nitrate concentration sampled during the water year, 74 mg/L (16.4 mg/L as NO_3-N) occurred in late June, coinciding with the highest concentration sampled at Big Spring.

Monthly fw mean nitrate concentrations varied from 11 mg/L (2.4 mg/L as NO_3-N) in October to 50 mg/L (11.0 mg/L as NO_3-N) in May (Table 6). The highest monthly fw mean nitrate concentration previously recorded for the Turkey River was 34 mg/L (7.6 mg/L as NO_3-N), occurring in November and December of WY 1986. The greatest monthly nitrate-N discharge, about 3.6 million pounds, oc-

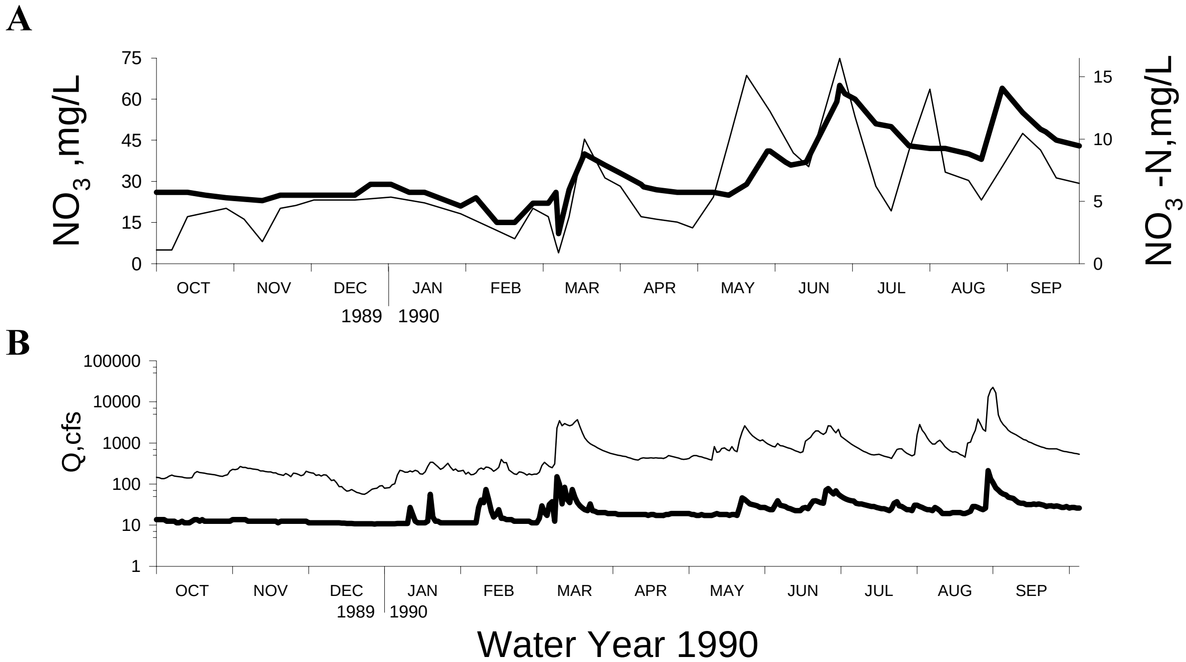

Figure 4. A) Nitrate concentrations and B) discharge hydrographs for Big Spring (bold lines) and the Turkey River (lighter lines) at Garber for WY 1990. (Turkey River discharge data are from U.S.Geological Survey, W.R.D., IA Dist.)

curred in August, the month with the highest monthly discharge, and accounted for 31% of the annual nitrate-N discharge for WY 1990. Only 66,000 pounds of nitrate-N were discharged in October, the month with the lowest fw mean, representing less than 0.6% of the annual nitrate-N discharge. In-stream nitrate losses, nitrate losses from streambed denitrification, and uptake by aquatic plants also must be considered when trying to assess nitrogen balances on a watershed scale (e.g., Bachmann et al., 1990; Isenhart and Crumpton, 1989).

Pesticide Monitoring

Figures 3 and 5 and Tables 2 and 7 summarize the results of pesticide monitoring at Big Spring for WY 1990. Eighty-five samples from Big Spring were analyzed for pesticides. *All* samples collected contained detectable levels of atrazine (>0.1 µg/L). A total of 50.0 pounds of atrazine were discharged, at a fw mean concentration of 1.06 µg/L. This was the highest annual fw mean atrazine concentration and annual load observed at Big Spring during the WY 1982 through 1990 period of record. Figure 3 shows atrazine concentrations and the discharge hydrograph from Big Spring. Concentrations were relatively stable during the first three months of the water year, varying from 0.16 µg/L in early October to 0.40 µg/L in mid-November, to 0.10 µg/L in mid-January. Snowmelt in January and February and precipitation in March generated significant runoff. Atrazine concentrations exceeded 1.0 µg/L during most of February and March, increasing to 7.80 µg/L in early March. As discharge receded through April and May, atrazine concentrations declined to less than 0.2 µg/L in mid-May. From late May through September, atrazine concentrations generally increased, exceeding 1.0 µg/L during June. Atrazine concentrations reached 8.20 µg/L at the end of June, then slowly declined across the remainder of the water year to less than 0.3 µg/L in late September. Monthly fw mean atrazine concentrations and loads were highest in June at 2.38 µg/L, and 14.9 pounds, and lowest in December at 0.16 µg/L, and 0.3 pounds.

Table 6. Monthly summary of nitrate-N discharge for the Turkey River at Garber; Water Year 1990.

	1989 Oct	Nov	Dec	1990 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean NO_3 concentration, in mg/L;	11	17	23	20	12	20	18	50	42	37	27	40
as NO_3-N	2.4	3.8	5.0	4.5	2.6	4.3	4.0	11.0	9.4	8.3	5.9	8.8
Mean of NO_3 analyses, in mg/L;	12	16	23	21	14	20	18	48	50	41	30	37
as NO_3-N	2.6	3.6	5.1	4.7	3.0	4.5	4.0	10.6	11.1	9.1	6.7	8.2
Total monthly NO_3-N output, thousands lbs	66	126	86	162	87	1,002	283	1,744	2,001	1,111	3,578	1,403
Total monthly NO_3-N output, thousands kg	30	57	39	74	39	454	129	791	908	504	1,623	636

Figure 5 summarizes detections and concentrations of atrazine, cyanazine, alachlor, and metolachlor for the water year (a list of pesticides not detected at Big Spring are included in Table 16). The occurrence of non-detections of atrazine or other pesticides is indicated by concentration bars ending at "ND." All samples collected contained detectable levels of atrazine (the detection limit for pesticides is usually >0.1 µg/L, although the detection limit may be increased to >0.2 µg/L, depending on lab variations and quantity of water sampled). Thirty samples, or 35% of those collected from Big Spring, contained detectable cyanazine; fifteen, or 18% contained detectable alachlor; and seven, or 8% contained detectable metolachlor. The highest concentration of pesticides detected during the water year included atrazine at 8.20 µg/L; cyanazine at 0.94 µg/L; alachlor at 0.91 µg/L; and metolachlor at 0.61 µg/L. All maximum pesticide detections occurred in June. Cyanazine was detected during January, February, March, May, June, July, and August; alachlor was detected in November, January, February, March, May, and June; and metolachlor was detected in March and June. All of these herbicides were detected in samples collected several weeks and in some cases months prior to chemical applications for the 1990 growing season.

Tables 3 and 8 summarize atrazine data for the Turkey River for WY 1990. During the water year, twenty samples from the Turkey River were analyzed for pesticides. An estimated 3,259 pounds of atrazine were discharged, at a fw mean concentration of 1.90 µg/L. Monthly fw mean atrazine concentrations were highest in June at 4.88 µg/L, and lowest in December at 0.14 µg/L. Atrazine loads were highest in August with 1,236 pounds of atrazine being discharged, and lowest in December when 2.4 pounds were discharged. About 38% of the annual total of atrazine was discharged during August. All samples collected contained detectable levels of atrazine. Eight samples, or 40% of those collected from the Turkey River, contained detectable cyanazine; seven, or 35% contained detectable metolachlor; and six, or 30% contained detectable alachlor. The highest concentration of pesticides detected during the water year included atrazine at 20.00 µg/L; cyanazine at 6.80 µg/L; alachlor at 13.00 µg/L; and metolachlor at 2.90 µg/L. All maximum detections occurred in mid-June.

Cyanazine was detected during October, March, May, June, July, and August; alachlor was detected in March, May, June, July, and August; and metolachlor was detected in October, March, May, June, July, and August. All of these herbicides were detected in samples collected several weeks and in some cases months prior to chemical applications for the 1990 growing season.

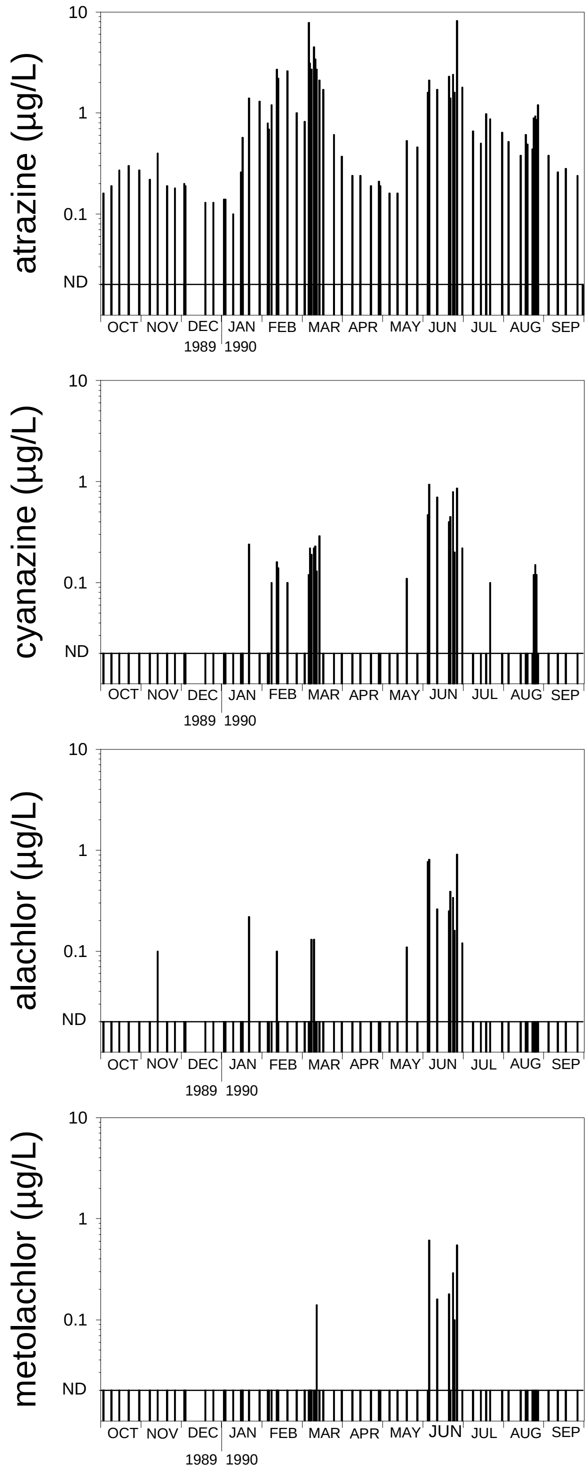

Figure 5. Bar graphs of pesticide concentrations at Big Spring for WY 1990. ND represents not detected.

Table 7. Monthly summary of atrazine discharged in groundwater from the Big Spring basin to the Turkey River; Water Year 1990.

	1989 Oct	Nov	Dec	1990 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean atrazine concentration, in µg/L	0.24	0.28	0.16	0.60	1.69	2.31	0.26	0.33	2.38	1.05	0.68	0.34
Mean of atrazine analyses, in µg/L	0.20	0.25	0.16	0.35	1.40	2.54	0.26	0.25	2.70	0.96	0.50	0.30
Total monthly atrazine output, lbs	0.5	0.6	0.3	1.3	4.9	13.8	0.8	1.3	14.9	5.2	4.7	1.8
Total monthly atrazine output, grams	225	258	138	596	2,231	6,243	354	594	6,767	2,340	2,124	806

Table 8. Monthly summary of atrazine discharge for the Turkey River at Garber; Water Year 1990.

	1989 Oct	Nov	Dec	1990 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean atrazine concentration, in µg/L	0.26	0.26	0.14	0.47	0.85	1.28	0.20	0.50	4.88	3.19	2.05	0.68
Mean of atrazine analyses, in µg/L	0.31	0.18	0.0	0.44	0.85	1.10	0.18	0.39	11.75	3.00	1.79	0.26
Total monthly atrazine output, lbs	7.2	8.4	2.4	17.2	28.2	294	13.9	78.9	1,037	427	1,236	109
Total monthly atrazine output, kg	3.3	3.8	1.1	7.8	12.8	133	6.3	35.8	470	194	560	49.4

Water Year 1991

Discharge Monitoring

Tables 9 through 15 and Figures 6 through 9 summarize the discharge, climatic, water quality, and chemical loading data for Big Spring and the Turkey River for WY 1991. Groundwater discharge from the Big Spring basin was 42,481 ac-ft, at an average rate of 59 cfs. Groundwater discharge accounted for about 16% of precipitation. The annual discharge and precipitation for WY 1991 were the highest recorded for the WY 1982 through 1991 period of record at Big Spring.

Annual discharge from the Turkey River at Garber was 1,103,000 ac-ft, at an average rate of 1,524 cfs. Discharge accounted for 28% of precipitation, and was 160% of the long-term average. The maximum instantaneous discharge for the period of record at Garber was 49,900 cfs, and occurred on June 15, 1991.

Figure 6 shows the discharge hydrograph and water temperature for Big Spring, along with basin precipitation and daily maximum/minimum air temperatures from the Elkader weather observation station. Figure 7 also shows the hydrograph, along with nitrate and atrazine concentrations. Mean daily discharge generally declined from about 25 cfs at the beginning of WY 1991 to about 11 cfs near the end of January. This is approaching the low levels of discharge recorded at the end of the drought, a year earlier. During February, snowmelt generated minor recharge and daily discharge gradually increased to about 22 cfs near the end of the month. Small amounts of rainfall in late February and March generated minor runoff and infiltration recharge. Above average rainfall during April, May, and June generated significant runoff and infiltration recharge. Mean daily discharge peaked at about 420 cfs in mid-June, following intense rains and then generally receded to about 36 cfs near the end of the water year. The peak daily discharge recorded in mid-June was the highest observed at Big Spring during the period of record. The sustained, general increase in mean daily discharge during the latter half of the water year indicates a net increase in overall storage in the basin's hydrologic system.

Table 11 summarizes discharge data from Big Spring for WY 1991 on a monthly basis. During WY 1991, all months except February had monthly discharges exceeding those registered in WY 1990. The greatest monthly discharge measured at Big Spring during the period of record, 8,413 ac-ft, occurred in June, at an average rate of 141 cfs. The record monthly discharge was produced largely by a single intense precipitation event that occurred on June 14 (local reports of 11 to 13 inches) and caused extensive flooding throughout the Big Spring basin area. Discharge during the month of June accounted for about 20% of the annual total. The lowest monthly discharge during WY 1991, 858 ac-ft, occurred in January, at an average rate of 14 cfs. June and January also had the highest and lowest monthly discharge, respectively for the Turkey River. About 263,000 ac-ft were discharged during June, at an average rate of 4,420 ac-ft. During January, 14,730 ac-ft were discharged, at an average rate of 240 cfs.

Nitrate Monitoring

During WY 1991, 136 samples of Big Spring groundwater were analyzed for nitrate; 80 of these were also analyzed for ammonium- and organic-N. Table 9 summarizes nitrate and nitrate-nitrogen data for the water year. A total of about 1.6 million pounds of nitrogen were discharged with groundwater. Of this total, about 1.4 million pounds, or 93%, was in the form of nitrate, at a fw mean concentration of 56.4 mg/L (12.5 mg/L as NO_3-N). The annual fw mean nitrate concentration and annual nitrate-N output during WY 1991 were the highest documented during the WY 1982 through 1991 period of record at Big Spring.

Figure 7 is a plot of nitrate concentrations at Big Spring for WY 1991. Nitrate concentrations declined from the beginning of the water year to mid-February, decreasing from about 42 mg/L to 30 mg/L (9.3 mg/L to 6.7 mg/L as NO_3-N), a trend similar to that displayed by the discharge record. The lowest nitrate concentration sampled during the water year, 27.0 mg/L (6.0 mg/L as NO_3-N), occurred in early January. Precipitation events

Table 9. Annual summary of groundwater and chemical discharge from the Big Spring basin to the Turkey River for Water Year 1991.

DISCHARGE		
Total		
acre-feet	42,481	
millions cf	1,850	
millions cm	52.4	
Average		
cfs	58.7	
cms	1.7	
mg/d	37.9	
gpm	26,345	
PRECIPITATION AND DISCHARGE		
Precipitation	47.27 inches (1,201mm)	
Discharge	7.72 inches (196.1mm)	
Discharge as % of precipitation	16%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	56.4	12.5
Mean of analyses	49.1	10.9
	NO_3-N output	**Total N output**
lbs - N	1,445,506	1,561,450
kg - N	655,558	708,141
lbs - N/acre	21.9	23.7
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	1.17	
Mean of analyses	0.75	
Total output		
lbs	135	
kg	61.0	

Table 10. Annual summary of water and chemical discharge for the Turkey River at Garber for Water Year 1991. (Discharge data are from U.S. Geological Survey, Water Resources Division.)

DISCHARGE		
Total		
acre-feet	1,103,000	
millions cf	48,047	
millions cm	1,360	
Average		
cfs	1,524	
cms	43.2	
mg/d	985	
gpm	683,971	
PRECIPITATION AND DISCHARGE		
Precipitation	47.27 inches (1,201mm)	
Discharge	13.39 inches (340.1mm)	
Discharge as % of precipitation	28%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	44.4	9.9
Mean of analyses	38.4	8.5
	NO_3-N output	**Total N output**
lbs - N	29,591,638	34,244,926
kg - N	13,420,244	15,530,579
lbs - N/acre	29.9	34.6
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	1.11	
Mean of analyses	0.52	
Total output		
lbs	3,325	
kg	1,508	

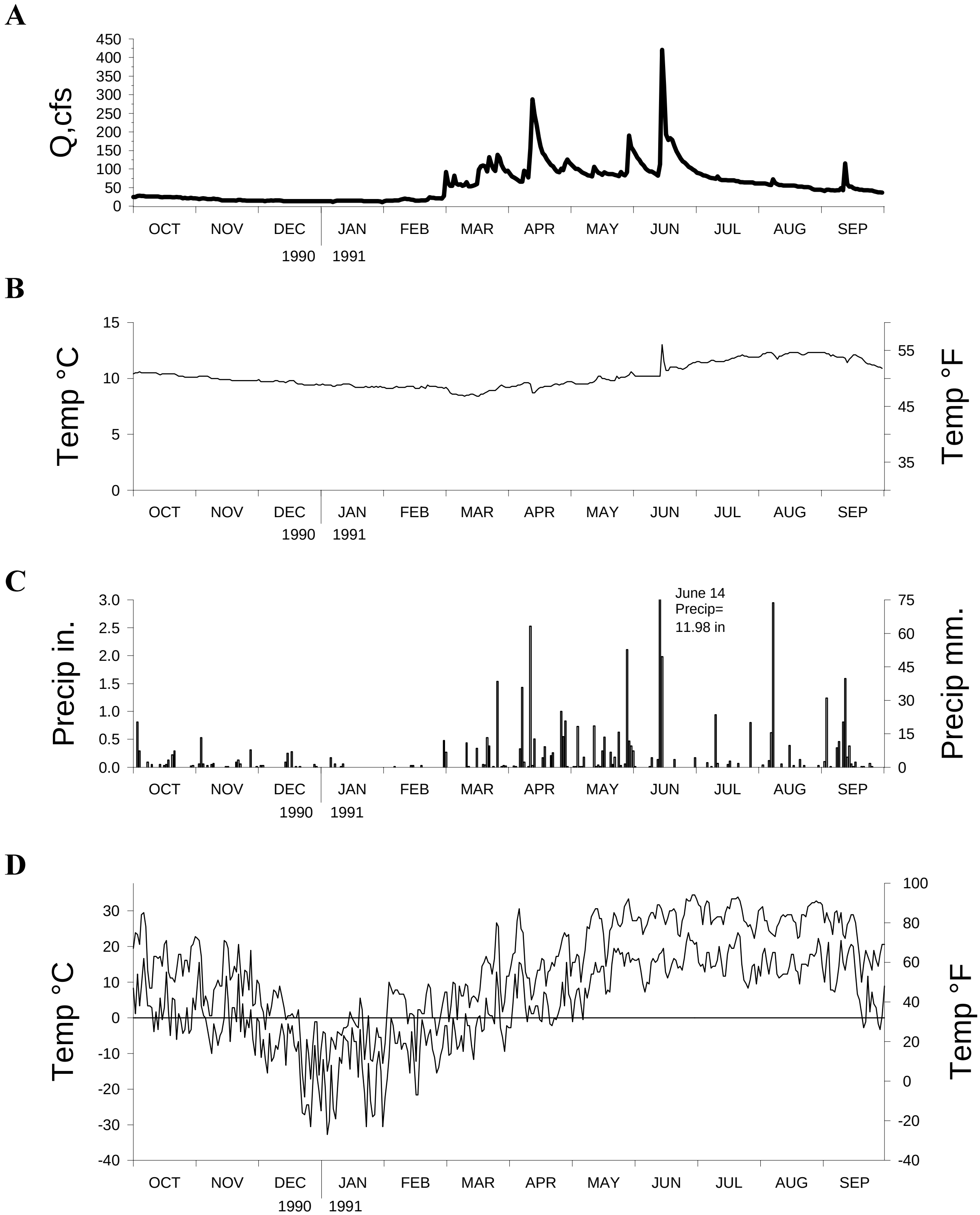

Figure 6. A) Groundwater discharge, B) groundwater temperature and C) daily precipitation for the Big Spring basin; and D) maximum-minimum temperatures for Elkader, IA (Iowa Dept. of Ag. and Land Stewardship, State Climatology Office), for WY 1991.

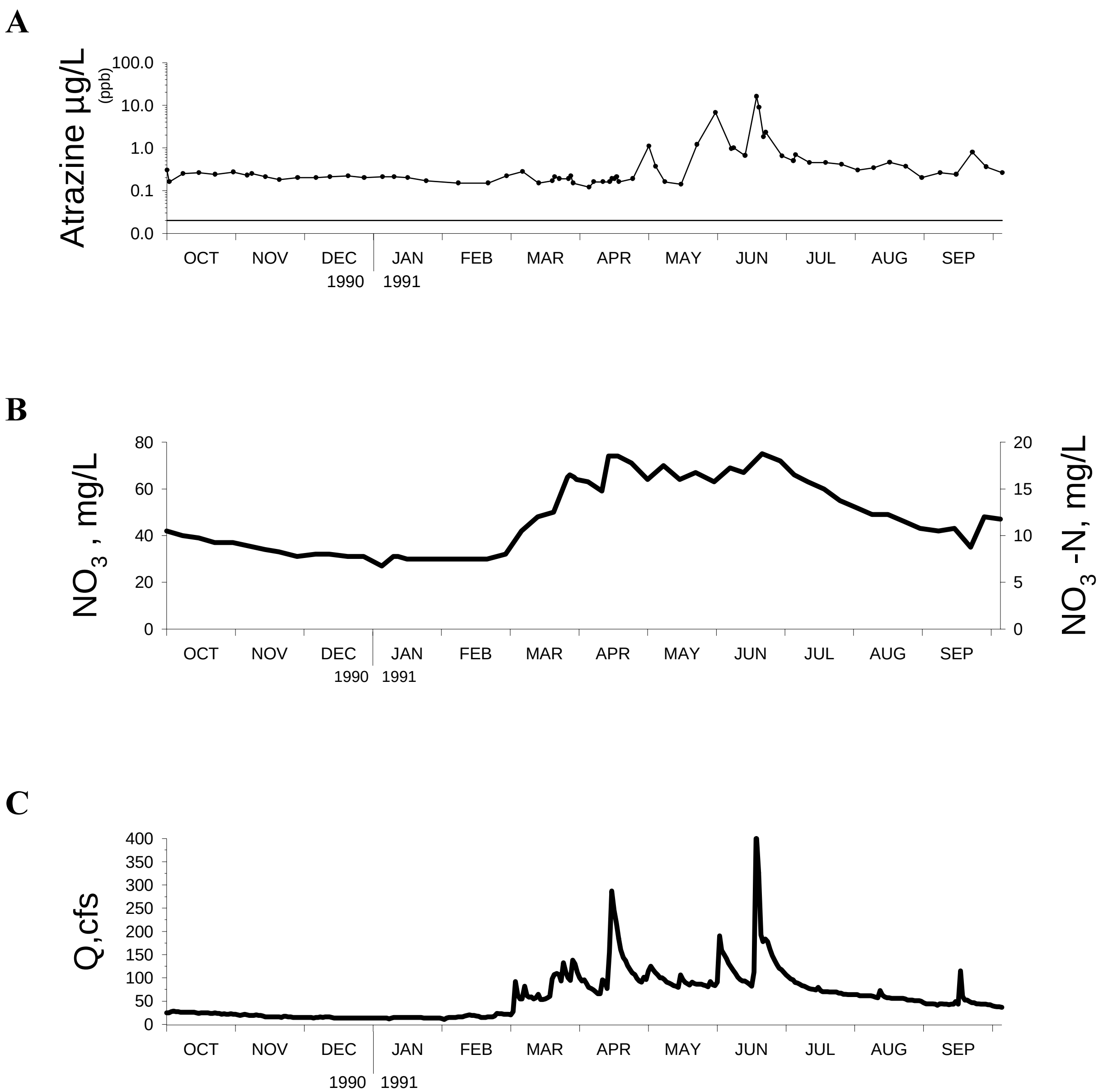

Figure 7. A) Atrazine and B) nitrate concentrations; and C) groundwater discharge at Big Spring for WY 1991.

Table 11. Monthly summary of groundwater discharge from the Big Spring basin for Water Year 1991.

	1990 Oct	Nov	Dec	1991 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
TOTAL MONTHLY DISCHARGE												
Acre-feet	1,528	1,031	876	858	1,002	5,039	7,148	5,951	8,413	4,480	3,386	2,770
Cubic feet (millions)	67	45	38	37	44	219	311	259	366	195	147	121
Gallons (millions)	498	336	286	280	327	1,643	2,330	1,940	2,743	1,460	1,104	903
Cubic meters (millions)	1.9	1.3	1.1	1.1	1.2	6.2	8.8	7.3	10	5.5	4.2	3.4
AVERAGE DISCHARGE												
cfs	25	17	14	14	18	82	120	97	141	73	55	47
cms	0.7	0.5	0.4	0.4	0.5	2.3	3.4	2.7	4.0	2.1	1.6	1.3
mg/d	16	11	9	9	12	53	77	63	91	47	36	30
MAXIMUM												
cfs	29	22	16	15	24	138	287	190	421	96	73	115
cms	0.8	0.6	0.5	0.4	0.7	3.9	8.1	5.4	11.9	2.7	2.1	3.3
MINIMUM												
cfs	22	15	14	11	15	27	66	80	82	62	44	36
cms	0.6	0.4	0.4	0.3	0.4	0.8	1.9	2.3	2.2	1.7	1.3	1.0

beginning in March generated infiltration recharge, and concentrations generally increased, reaching 75.0 mg/L (16.7 mg/L as NO_3-N) in mid-June, three days after the maximum daily discharge occurred. Nitrate concentrations declined from June, to 35 mg/L (7.8 mg/L as NO_3-N) in mid-September, then increased to 48 mg/L (10.7 mg/L as NO_3-N) as discharge receded from a small recharge event earlier in the month.

Table 12 summarizes the nitrate data from Big Spring for WY 1991 on a monthly basis. The highest monthly fw mean nitrate concentrations to occur during the WY 1983 through 1991 period of record were recorded in April, May, June, and July of WY 1991. Concentrations decreased from 70 mg/L in April to 61 mg/L in July (15.5 mg/L to 13.6 as NO_3-N). The highest monthly fw mean nitrate concentrations previously recorded occurred during WY 1983, and were 54 mg/L in April and 56 mg/L in July (12.0 mg/L and 12.4 mg/L as NO_3-N). The lowest monthly fw mean nitrate concentration during WY 1991, 30 mg/L (6.7 mg/L as NO_3-N), occurred in January and February. Monthly nitrate-N loads varied from 15,000 pounds in January, the month with the lowest groundwater discharge, to 326,000 pounds in June, the month with the greatest groundwater discharge. The monthly nitrate-N discharges during April, May, June, and July were the highest recorded during WYs 1982 through 1991.

During WY 1991, 61 samples from the Turkey River were analyzed for nitrate; 14 of these were also analyzed for ammonia- and organic-N. A total of about 34 million pounds of nitrogen were discharged, at a fw mean concentration of 44.4 mg/L (9.9 mg/L as NO_3-N; Table 10). About 30 million pounds, or 86% of the nitrogen discharged was in the form of nitrate. Figure 8 shows a plot of nitrate

Table 12. Monthly summary of nitrate-N discharged in groundwater from the Big Spring basin to the Turkey River; Water Year 1991.

	1990 Oct	Nov	Dec	1991 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean NO_3 concentration, in mg/L;	39	34	31	30	30	51	70	64	64	61	48	39
as NO_3-N	8.7	7.6	7.0	6.6	6.7	11.3	15.5	14.1	14.2	13.6	10.6	8.6
Mean of NO_3 analyses, in mg/L;	39	33	32	30	31	57	68	66	71	59	47	43
as NO_3-N	8.6	7.3	7.0	6.6	6.8	12.7	15.0	14.7	15.7	13.2	10.4	9.6
Total monthly NO_3-N output, thousands lbs	36	21	17	15	18	154	302	229	326	165	98	63
Total monthly NO_3-N output, thousands kg	16	10	8	7	8	70	137	104	148	75	44	29

concentrations for the Turkey River and Big Spring; their discharge hydrographs are also shown. Nitrate concentrations from the Turkey River followed the same general trend as Big Spring. During the first five months of WY 1991, concentrations were relatively stable, ranging from 38 mg/L (8.4 mg/L as NO_3-N) in mid-October to 29 mg/L (6.4 mg/L as NO_3-N) in late February. Fluctuations in nitrate concentrations, similar to those at Big Spring, occurred following minor runoff events in March, April, May, and June. Concentrations increased to 58 mg/L (12.9 mg/L as NO_3-N) in late March, then generally declined to 33 mg/L (7.3 mg/L as NO_3-N) in early September. Concentrations increased to 41 mg/L (9.1 mg/L as NO_3-N) during a small runoff event later in September. Monthly fw mean nitrate concentrations varied from 22 mg/L (4.9 mg/L as NO_3-N) in January to 49 mg/L (10.9 mg/L as NO_3-N) in March (Table 13). Monthly fw mean nitrate concentrations remained above 40 mg/L (8.9 mg/L as NO_3-N) from March through July, decreasing to 35 mg/L (7.8 mg/L as NO_3-N) in August, then increasing to 36 mg/L (8.0 mg/L as NO_3-N) in September. Monthly nitrate-N discharge varied from 198,000 pounds in January to about 7.4 million pounds in April, which accounted for about 25% of the annual total for WY 1991. The monthly nitrate-N discharge remained well above 4 million pounds during March through June. Previously the greatest monthly nitrate-N discharge was about 3.8 million pounds in March of WY 1986.

Pesticide Monitoring

Figures 7 and 9 and Tables 9 and 14 summarize the results of pesticide monitoring at Big Spring for WY 1991. One hundred and thirty-five pounds of atrazine were discharged in Big Spring groundwater, at a fw mean concentration of 1.17 µg/L. This was by far the highest annual fw mean atrazine concentration and annual load observed at Big Spring during WYs 1982 through 1991. During WY 1991, all seventy-seven samples of Big Spring groundwater that were analyzed for pesticides contained detectable levels of atrazine (>0.1 µg/L).

During the first five months of the water year, atrazine concentrations were relatively stable, varying from 0.30 µg/L in October to 0.15 µg/L in mid-February (Fig. 7). Atrazine concentrations in-

Table 13. Monthly summary of nitrate-N discharge for the Turkey River at Garber; Water Year 1991.

	1990 Oct	Nov	Dec	1991 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean NO_3 concentration, in mg/L;	33	29	29	22	28	49	48	44	47	43	35	36
as NO_3-N	7.4	6.4	6.5	5.0	6.3	10.9	10.7	9.9	10.5	9.6	7.8	8.1
Mean of NO_3 analyses, in mg/L;	32	29	30	22	29	49	48	47	48	41	35	37
as NO_3-N	7.0	6.4	6.6	4.8	6.5	10.8	10.8	10.4	10.7	9.2	7.7	8.1
Total monthly NO_3-N output, thousands lbs	593	407	377	198	328	4,496	7,369	5,465	7,505	1,354	799	702
Total monthly NO_3-N output, thousands kg	269	185	171	90	149	2,039	3,342	2,478	3,404	614	362	318

creased during runoff events in April, May, and June, and decreased along with discharge between events. Concentrations reached 16.0 µg/L in mid-June, then generally declined to 0.27 µg/L in early August as discharge continued to recede from the largest runoff event to occur at Big Spring during the period of record. Atrazine concentrations increased to 0.79 µg/L during a small runoff event in mid-September, then decreased during the remainder of the year.

Table 14 summarizes the atrazine data for Big Spring on a monthly basis. Monthly fw mean concentrations varied from 3.32 µg/L in June to 0.16 µg/L in February. The highest monthly atrazine load occurred during June, when 76.0 pounds of atrazine were discharged, and the lowest monthly atrazine discharge, 0.4 pounds, occurred in February. Atrazine discharge during June accounted for about 56% of the annual total. The monthly fw means and loads registered during May and June of WY 1991 exceeded all previous monthly means and totals during the period of record at Big Spring.

Figure 9 is a bar plot of atrazine, cyanazine, alachlor, and metolachlor concentrations for WY 1991. Atrazine was detected in all of the samples collected; alachlor was detected in fourteen samples, or 18% of those collected; cyanazine in ten, or 13%; and metolachlor in three, or 4% of the samples collected. The highest concentration of pesticides detected during the water year included atrazine at 16.0 µg/L in June; cyanazine at 2.60 µg/L in May; alachlor at 5.50 µg/L in May; and metolachlor at 2.20 µg/L in June. Cyanazine was detected in April, May, and June; alachlor was detected in December, April, May, and June; and metolachlor was detected only during June.

Tables 10 and 15 summarize the results of atrazine monitoring for the Turkey River during WY 1991. The total atrazine load for the water year was 3,325 pounds, at a fw mean concentration of 1.11 µg/L. The highest monthly fw mean atrazine concentration and discharge occurred in June, at 2.94 µg/L, and 2,102 pounds, while the lowest occurred during January, at 0.21 µg/L, and 8.5 pounds. Over 63% of the annual atrazine output occurred during June. During the water year, fifteen samples from the Turkey River were analyzed for pesticides. All samples collected contained detectable levels of atrazine (>0.1 µg/L). Two samples, or 13% of those collected from the

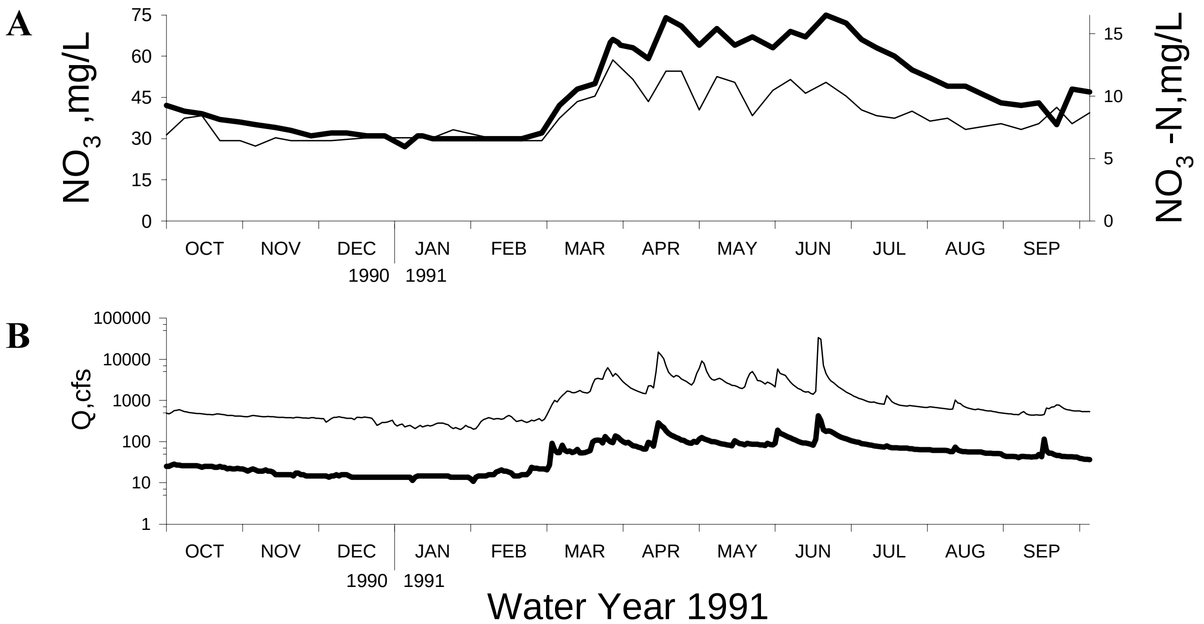

Figure 8. A) Nitrate concentrations and B) discharge hydrographs for Big Spring (bold lines) and the Turkey River (lighter lines) at Garber for WY 1991. (Turkey River discharge data are from U.S.Geological Survey, W.R.D., IA Dist.)

Turkey River, contained detectable cyanazine; two, or 13% contained detectable alachlor; and three, or 20% contained detectable metolachlor. The highest concentration of pesticides detected during the water year included atrazine at 2.90 µg/L; cyanazine at 0.51 µg/L; alachlor at 1.90 µg/L; and metolachlor at 1.20 µg/L. For pesticides other than atrazine, all detections occurred in May and June, and all maximum detections occurred in mid-June. The annual fw mean atrazine concentration and load observed at the Turkey River at Garber during WY 1991 exceeded all previous annual fw means and loads registered during the WY 1986 through 1991 period of record.

DISCUSSION

Monitoring during WYs 1990 and 1991 showed the effects of significant increases in precipitation and resultant recharge on the Big Spring basin's hydrologic system, and on the transport of contaminants within the system, following the drought conditions of WYs 1988 and 1989. The change in the volume and distribution patterns of precipitation from WYs 1988 and 1989 to WYs 1990 and 1991 was dramatic. Annual precipitation increased from being about 30% below the long term average during WYs 1988 and 1989 to 115% of the long term average in WY 1990 and 143% of the long term average in WY 1991. Water Years 1985 through 1989 were characterized by dry growing seasons and wet falls. During WYs 1990 and 1991 rainfall totals were below normal from October through February, and above normal from March through September. The discharge hydrographs and nitrate and atrazine concentration plots for WYs 1990 and 1991 are shown on Figures 3 and 7, respectively. The hydrographs show that discharge decreased very slowly during the first three months of both water years. Nitrate concentrations remained below 30 mg/L during the first five months of WY 1990 and generally decreased from 42 mg/L to 32 mg/L during the first five months of WY 1991. Atrazine concentrations and the frequency and magnitude of detections of other herbicides also remained relatively low during the first few months of WYs 1990 and 1991.

During WY 1990, mean daily discharge declined from about 13 cfs in October to about 11 cfs near the end of December, while nitrate concentrations remained at about 25 mg/L and atrazine concentrations ranged between 0.40 µg/L in November and 0.13 µg/L in December. Atrazine concentrations increased and nitrate concentrations were temporarily diluted during runoff from snowmelt in January and February. Precipitation events in March generated runoff and atrazine concentrations increased to 7.80 µg/L, while nitrate concentrations increased to 26 mg/L. Both atrazine and nitrate concentrations decreased as discharge receded through April and most of May. Increased precipitation during the remainder of WY 1990 generated a number of small runoff events and provided limited infiltration recharge. Nitrate concentrations gradually increased, reaching maximum concentrations of about 65 mg/L following recharge in June and August. Atrazine concentrations increased to 8.20 µg/L in June, then generally declined through mid-August. Atrazine and nitrate concentrations increased in late August following the largest runoff event of the water year. Concentrations then decreased through the end of September as discharge continued to recede.

During WY 1991, mean daily discharge declined from 25 cfs to 14 cfs from October through January. Nitrate concentrations decreased from 42 mg/L to about 30 mg/L, while atrazine concentrations dropped from about 0.3 µg/L to about 0.2 µg/L. A series of minor precipitation events in late February and March generated significant infiltration, but little runoff, and nitrate concentrations increased from 30 mg/L to about 65 mg/L, while atrazine concentrations remained relatively low. Above average rainfall totals during April, May, and June generated significant runoff and infiltration recharge. The infiltration recharge sustained increased daily discharge and increased nitrate concentrations. Mean daily discharge remained above 66 cfs from April through most of July, while nitrate concentrations fluctuated between 59 mg/L and 75 mg/L. Atrazine concentrations and the frequency of detections of other herbicides also generally increased. Atrazine concentrations

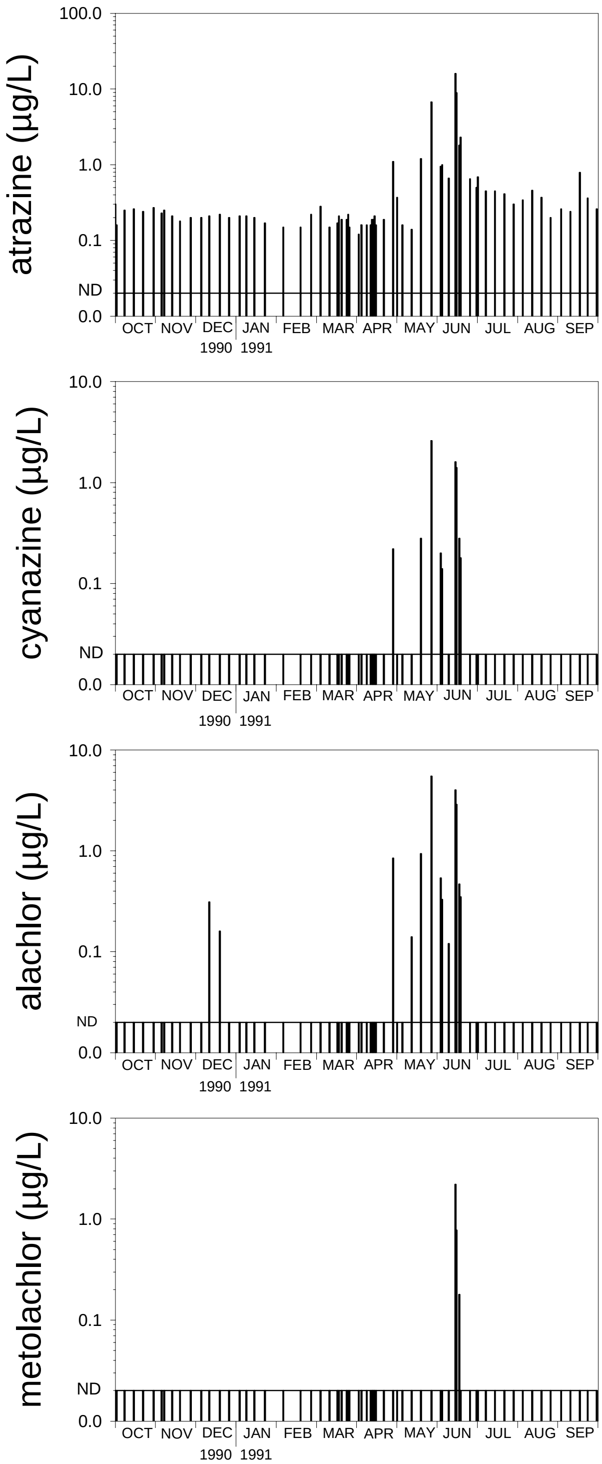

Figure 9. Bar graphs of pesticide concentrations at Big Spring for WY 1991. ND represents not detected.

Table 14. Monthly summary of atrazine discharged in groundwater from the Big Spring basin to the Turkey River; Water Year 1991.

	1990 Oct	Nov	Dec	1991 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean atrazine concentration, in µg/L	0.24	0.22	0.21	0.19	0.16	0.21	0.21	2.22	3.32	0.46	0.36	0.51
Mean of atrazine analyses, in µg/L	0.25	0.21	0.20	0.20	0.17	0.20	0.25	1.61	4.03	0.47	0.33	0.35
Total monthly atrazine output, lbs	1.0	0.6	0.5	0.5	0.4	2.9	4.1	36.0	76.0	5.6	3.3	3.7
Total monthly atrazine output, grams	441	282	223	206	198	1,297	1,861	16,317	34,451	2,557	1,511	1,690

Table 15. Monthly summary of atrazine discharge for the Turkey River at Garber; Water Year 1991.

	1990 Oct	Nov	Dec	1991 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean atrazine concentration, in µg/L	0.26	0.26	0.22	0.21	0.22	0.32	0.43	1.10	2.94	0.46	0.31	0.24
Mean of atrazine analyses, in µg/L	0.26	0.23	0.20	0.24	0.17	0.35	0.31	1.10	1.75	0.41	0.24	0.00
Total monthly atrazine output, lbs	20.9	16.4	12.6	8.5	11.3	132	294	611	2,102	64.2	31.9	20.9
Total monthly atrazine output, kilograms	9.5	7.4	5.7	3.9	5.1	59.7	133	277	953	29.1	14.5	9.5

closely followed discharge, reaching maximum concentrations during runoff events and decreasing along with discharge between events. The highest atrazine concentration sampled during the water year, 16.0 µg/L, occurred in mid-June, coincident with the largest runoff event recorded during the period of record at Big Spring (mean daily discharge of about 420 cfs). Nitrate and atrazine concentrations generally decreased as discharge receded from June through August. The recession was interrupted by a small runoff event in mid-September and atrazine concentrations temporarily increased and nitrate concentrations temporarily decreased.

The sustained, slowly declining discharge during WYs 1988, 1989 and the first few months of WY 1990 was relatively slow-moving groundwater that flows from storage in the less transmissive parts of the basin's hydrologic system (see Hallberg et al., 1989 and Libra et al., 1991). As discharge continued to slowly decline during the first few months of WY 1990, nitrate concentrations remained at the low levels seen during WY 1989. These low nitrate concentrations may be the result of several factors. Typically, a large part of Big Spring's discharge is relatively recent, nitrate-rich recharge water. As drought conditions continued, a large proportion of the discharge was relatively older water from the less transmissive parts of the groundwater system. A portion of this water infiltrated the land surface prior to the major increases in nitrogen fertilizer applications of the 1960s and 1970s, and therefore has relatively low nitrate concentrations (Hallberg et al., 1983, 1984).

Denitrification and instream nitrogen uptake may also be contributing to low nitrate concentrations at Big Spring. Denitrification may occur within some of the less transmissive parts of the hydrologic system, resulting in lower nitrate concentrations. Leakage of surface water from streams into the groundwater within the basin may also affect nitrate concentrations. Denitrification and nitrogen uptake by aquatic vegetation are significant instream processes within the basin, particularly under low flow, high temperature conditions (Crumpton and Isenhart, 1987; Isenhart and Crumpton, 1989). The portion of Big Spring's discharge that may be supplied by leakage from streams under very low flow conditions would also contribute to low nitrate concentrations, at least during warm-weather periods. Future reports will incorporate monitoring data from streams, tile lines, and wells to further evaluate these possibilities.

Previous reports (Hallberg et al., 1983, 1984, 1985, 1987, 1989, and Libra et al., 1986, 1987, 1991) have shown that increases and decreases in annual discharge have been accompanied by increases and decreases in annual fw mean nitrate concentrations and nitrate loads (Fig 10). Annual fw mean atrazine concentrations and loads have shown no consistent relationship to annual discharge, although atrazine concentrations increase with increasing runoff on a short-term basis. During WY 1989, groundwater discharge and annual fw nitrate concentrations declined to the lowest values recorded during the WY 1982-1991 period of record at Big Spring. From WY 1990 to WY 1991, groundwater discharge, annual fw mean nitrate and atrazine concentrations, and annual nitrate and atrazine loads all increased to the highest values recorded during the period of record.

The annual data from WYs 1989, 1990 and 1991 show the general relationship between groundwater discharge and fw mean nitrate concentrations and loads. Relative to WY 1989, WY 1990 had 56% more precipitation, 37% greater groundwater discharge, a 45% higher fw mean nitrate concentration, a 101% greater nitrate load, an 80% higher fw mean atrazine concentration and a 135% greater atrazine load. Relative to WY 1989, WY 1991 had 94% more precipitation, 235% greater groundwater discharge, a 122% higher fw mean nitrate concentration, a 642% greater nitrate load, a 92% higher fw mean atrazine concentration and a 535% greater atrazine load. While the increase in the annual fw mean nitrate concentration from WY 1990 to WY 1991 was proportional to the increase in discharge, the increase in the annual fw mean atrazine concentration was not. Water Years 1990 and 1991 had similar fw mean atrazine concentrations, and the difference in annual atrazine loads is proportional to the difference in discharge. Some of the increase in atrazine loading during WY 1991 can be attributed to a very large runoff event in

August. Monthly discharge during August accounted for 20% of the annual groundwater discharge and 56% of the annual atrazine load. The difference in nitrate loads between WY 1990 and WY 1991 is related to a combination of increased fw mean nitrate concentrations and increased groundwater discharge. These data show a relationship between precipitation, groundwater discharge, and fw mean nitrate concentrations and loads and a lack of any clear relationship between annual fw mean atrazine concentration and groundwater discharge. These data also show a time lag between increases in precipitation and increases in groundwater discharge as storage in the Galena aquifer is slowly replenished. Even with the above average precipitation that occurred during WY 1990, mean daily discharge declined to drought levels during the first four months of WY 1991. The timing, intensity, and distribution of rainfall all affect the resultant recharge to the soil-groundwater system, and therefore affect long-term trends in the transport of agricultural contaminants.

The increases in nitrate concentrations and loads during WYs 1990 and 1991 may be the result of several factors. The affects of denitrification and nitrogen uptake by aquatic vegetation were probably less pronounced under the relatively higher-flow conditions of WYs 1990 and 1991. In addition, the below normal precipitation and resultant lack of significant recharge during WYs 1988 and 1989 would have led to less leaching, leaving a greater than normal mass of nitrate in storage in the soil system available for transport to the hydrologic system with the increased recharge during WYs 1990 and 1991.

The increases in atrazine concentrations and loads during WYs 1990 and 1991 are probably also in part related to the drought. Pesticide degradation rates vary with environmental factors, such as soil moisture. The low soil moisture conditions during WYs 1988 and 1989 may have inhibited hydrolysis and microbial activity, which are important degradation processes (USEPA, 1986). The dry conditions may also have left a greater than normal mass of herbicide available for mobilization and transport to groundwater during WYs 1990 and 1991. Ongoing analysis of monitoring data from streams, tile lines, and wells may provide a better understanding of the trends observed at Big Spring.

OVERVIEW OF MONITORING RESULTS FOR WYs 1982 THROUGH 1991

Figure 10 and Tables 16 and 17 summarize the results of hydrologic and water quality monitoring at Big Spring for WYs 1982 through 1991. During the period, precipitation has varied from 22.9 inches (WY 1988) to 47.3 inches (WY 1991), and groundwater discharge has ranged between 12,700 ac/ft (WY 1989) and 42,500 ac/ft (WY 1991). The highest annual fw mean nitrate concentration, 56 mg/L, and the greatest nitrate-N load, 1,446,000 pounds, occurred in WY 1991. The lowest annual fw mean and nitrate-N load, 25 mg/L and 195,000 pounds, occurred in WY 1989. The highest annual fw mean atrazine concentration, 1.17 µg/L, and the greatest atrazine load, 135 pounds, also occurred during WY 1991. During WY 1988, only 9 pounds of atrazine were discharged, at fw mean concentration of 0.13 µg/L. Maximum atrazine concentrations analyzed varied from 0.4 µg/L in WY 1988 to 16.0 µg/L in WY 1991. The extreme variability of these annual parameters over a short period of time underscores the need for long-term monitoring of nonpoint-source contamination.

As discussed in previous reports (Libra et al., 1986, and 1991; Hallberg et al., 1989), annual fw mean nitrate concentrations tend to parallel annual groundwater discharge, or flux through the hydrologic system. Higher nitrate concentrations occur during years with greater groundwater discharge. Annual fw mean atrazine concentrations, and the frequency and magnitude of detections of other herbicides, do not tend to parallel annual discharge. Relatively high fw mean atrazine concentrations have occurred during years with low groundwater discharge, for reasons that are currently unclear. While annual groundwater discharge and fw nitrate concentrations decreased from WY 1983 to WY 1985 and from WY 1988 to WY 1989, annual fw mean atrazine concentrations and loads increased from WY 1982 to WY 1985 and from WY 1988 to WY 1991. The second highest annual fw mean atrazine concentration, 1.10 µg/L, and the second

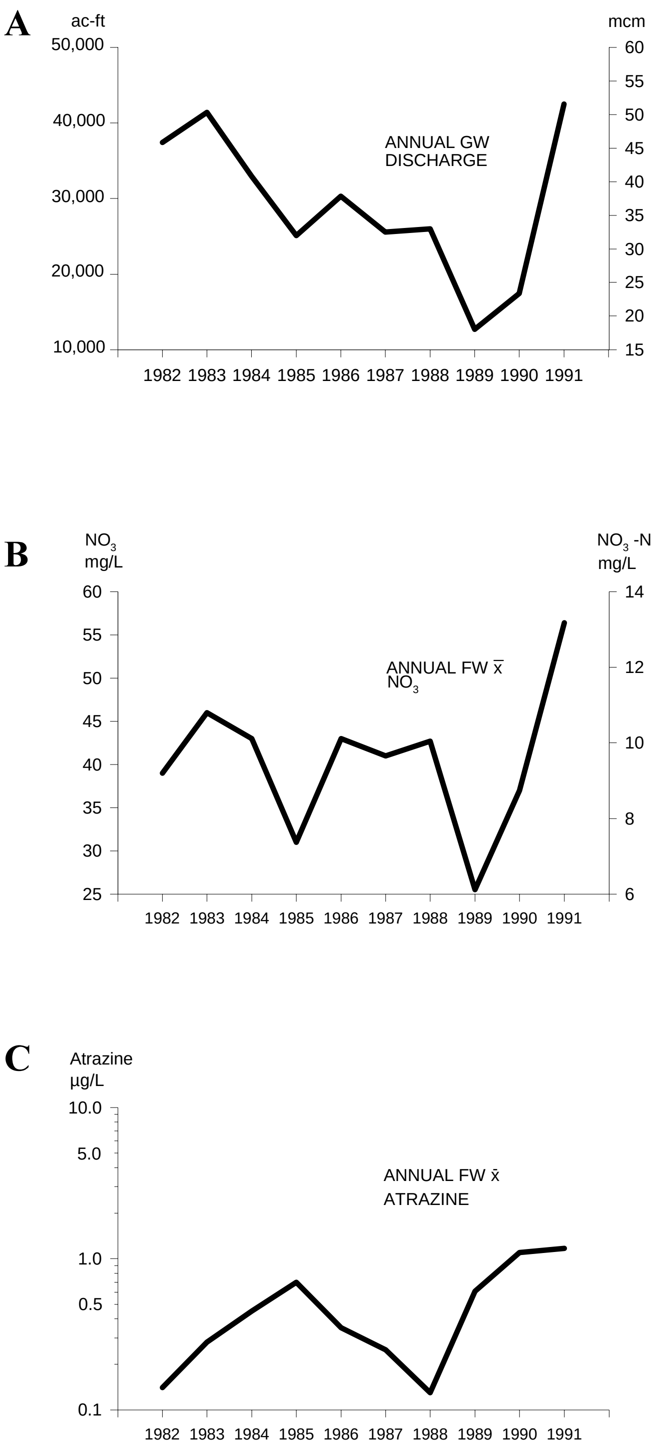

Figure 10. Summary of annual A) groundwater discharge, B) flow-weighted mean NO_3 and C) atrazine concentrations from Big Spring groundwater.

greatest atrazine load, 49.9 pounds, occurred during WY 1990, a year with the second lowest annual groundwater discharge, 17,476 ac-ft, during the period of record. Retardation of atrazine transport to and through the groundwater system, and annual changes in the mass of atrazine present on the land surface, are likely important factors. While the mass of atrazine present is largely a function of the amount applied in a given year, climatic factors may significantly vary degradation rates, leaving a larger percentage of the amount applied available for transport. The low soil moisture from the drought conditions during WYs 1988 and 1989 may have inhibited hydrolysis and microbial activity, important to degradation processes and left a greater than normal mass of herbicide available for mobilization and transport to groundwater during WYs 1990 and 1991.

SUMMARY

WYs 1990 and 1991 were characterized by above average precipitation, and followed the driest consecutive two-year period in the state's history. Precipitation patterns changed significantly from WYs 1988 and 1989 to WYs 1990 and 1991. The increased precipitation generated both runoff and infiltration recharge, although discharge rates generally increased slowly across the period as a net increase in overall storage within the basin's hydrologic system occurred.

Analysis of annual data for WYs 1982 through 1991 indicates that while fw mean nitrate concentrations and loads generally parallel discharge, fw mean atrazine concentrations and loads do not. Relatively high concentrations and loads of atrazine have occurred during years with low groundwater discharge. The variable climatic and resulting hydrologic conditions exhibited in the Big Spring basin during WYs 1982 through 1991 complicate interpretation of changes in water quality and illustrate the need for detailed, long-term monitoring projects for the understanding of nonpoint-source contamination.

Table 16. Summary of annual maximum concentrations for pesticides in groundwater at Big Spring.

Pesticide common chemical name	Water Year 82	83	84	85	86	87	88	89	90	91	% detections (total record)
	maximum concentration, ug/L										
Herbicides											
atrazine	2.5	5.1	10.0	6.1	1.4	0.7	0.4	3.3	8.2	16.0	96%
alachlor	0.2	0.6	4.0	5.0	0.7	0.1	nd	0.2	0.9	5.5	19%
cyanazine	0.7	1.2	1.7	4.6	0.1	0.2	1.0	3.0	0.9	2.6	24%
metolachlor	nd	0.6	4.5	4.6	0.6	nd	nd	0.2	0.6	2.2	15%
metribuzin	nd	nd	nd	3.6	nd	nd	nd	nd	nd	nd	<1%
2,4-D	na	na	na	0.2	nd	na	na	na	na	na	*
Insecticides											
fonofos	nd	0.1	0.3	0.4	nd	nd	na	na	nd	nd	<1%

na- not analyzed; nd- not detected * four analyses, one detection

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.

Table 17. Water Year summary data for groundwater discharge from the Big Spring basin to the Turkey River.

	Water Year									
	82	83	84	85	86	87	88	89	90	91
Precipitation:										
water inches	34.0	44.5	32.8	35.8	36.7	32.0	22.9	24.3	37.9	47.3
Groundwater discharge (Q) to the Turkey River:										
mean Q, cfs	51.4	56.9	45.3	35.2	42.0	35.4	35.8	17.6	24.1	58.7
total Q, inches	6.8	7.5	5.9	4.6	5.5	4.6	4.7	2.3	3.2	7.7
acre-feet, 1000s	37.4	41.4	32.7	25.1	30.3	25.5	26.0	12.7	17.5	42.5
Nitrogen discharged with groundwater:										
flow-wtd mean concentration, mg/L										
as nitrate (NO3)	39	46	43	31	43	41	43	25	37	56
as nitrate-N (NO3-N)	8.8	10.3	9.7	7.0	9.7	9.1	9.6	5.7	8.2	12.5
ammonia-N*	*	*	*	*	0.1	0.1	0.1	0.6	0.1	0.1
organic-N*	*	*	*	*	0.5	0.2	0.3	0.8	0.6	0.9
nitrogen load:										
(nitrate-N + nitrite-N)										
1,000s lbs-N	873.0	1150.0	843.4	476.8	796.8	636.1	672.0	194.9	388.5	1446.0
lbs-N/acre	13.2	17.4	12.8	7.2	12.1	9.6	10.2	3.0	5.9	21.9
(for total basin area)										
Atrazine discharged with groundwater:										
flow-wtd mean concentration,										
atrazine, ug/L	0.2	0.3	0.5	0.7	0.4	0.3	0.1	0.6	1.1	1.2
atrazine load;										
lbs - atrazine	14.2	31.2	40.0	47.6	29.0	17.6	9.2	21.2	50.0	135.0

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

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The development of monitoring sites within the Big Spring basin has been a cooperative effort. The U.S, Geological Survey, Water Resources Division designed, constructed and maintains the stream gaging stations and also cooperates in water-quality monitoring. Tile monitoring sites and a surface-water flume site were designed and constructed by Dr. James Baker, Department of Agricultural Engineering, Iowa State University, Agriculture and Home Economics Experiment Station. Other cooperating agencies include the departments of Agronomy and Botany, Iowa State University, the University Hygienic Laboratory, the Institute of Agricultural Medicine and Occupational Health, the departments of Geology and Preventive Medicine, the University of Iowa, and the Department of Biology, University of Northern Iowa.

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There are undoubtedly individuals whom have contributed to this report that are not acknowledged. Please accept our apologies for forgetting and our thanks for your contributions.

REFERENCES

Bachmann, R.W., Crumpton, W.G., and Hallberg, G.R., 1990, Nitrogen losses in an agricultural stream: Verh. Internat. Verein. Limnol., vol. 24, p. 18-22.

Capel, P.D., 1990, Atmospheric deposition of herbicides in the mid-continental United States (abs): Eos, Trans. AGU, vol. 71, no. 43, p. 1329.

Crumpton, W.G. and Isenhart, T.M., 1987, Nitrogen balance in a stream ecosystem: the role of algal assimilation: Jour. of Water Poll. Control Fed., vol. 50, p. 2043-2046.

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

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

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

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

Hallberg, G.R., Libra, R.D., Long, K.R., and Splinter, R.C., 1987, Pesticides, groundwater, and rural drinking water quality in Iowa, *in* Pesticides and Groundwater: A Health Concern for the Midwest: Navarre, MN, The Freshwater Foundation and the USEPA, p. 83-104.

Hallberg, G.R., Libra, R.D., Quade, D.J., Littke, J., and Nations, B., 1989, Groundwater monitoring in the Big Spring basin 1984-1987: a summary review: Iowa Department of Natural Resources, Geological Survey Bureau, Technical Information Series 16, 68 p.

Isenhart, T.M., and Crumpton, W.G., 1989, Transformation and loss of nitrate in an agricultural stream: Jour. of Freshwater Ecol., vol. 5, p. 123-129.

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

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

Kalkhoff, S.J., Kuzniar, R.L., Kolpin, D.L., and Harvey, C.A., 1992, Hydrologic data for the Big Spring basin, Clayton County, Iowa, Water Year 1990: U.S. Geological Survey Open-File Report 92-67, 80 p.

Libra, R.D., Hallberg, G.R., Hoyer, B.E., and Johnson, L.G., 1986, Agricultural impacts on groundwater quality: the Big Spring basin study *in* Agricultural Impacts on Ground Water, National Water Well Association, Worthington, OH, p. 253-273.

Libra, R.D., Hallberg, G.R., Hoyer, B.E., 1987, Impacts of agricultural chemicals on groundwater quality in Iowa, *in* Fairchild, D.M. (ed.), Ground Water Quality and Agricultural Practices: Chelsea, MI, Lewis Publ. Inc., p. 185-217.

Libra, R.D., Hallberg, G.R., Littke, J.P., Nations, B.K., Quade, D.J., Rowden, R.D., 1991, Groundwater monitoring in the Big Spring basin 1988-1989: a summary review: Iowa Department of Natural Resources, Geological Survey Bureau, Technical Information Series 21, 29 p.

Littke, J.P., and Hallberg, G.R., 1991, Big Spring basin water-quality monitoring program; design and implementation: Iowa Department of Natural Resources, Open-File Report 91-1, 19 p.

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

Nations, B.K., and Hallberg, G.R., 1992, Pesticides in Iowa precipitation: *Journal of Environmental Quality*, Vol. 21, no. 3, July-September, p. 486-492.

Rowden, R.D., and Libra, R.D., 1990, Hydrogeologic observations from bedrock monitoring well nests in the Big Spring basin: Iowa Department of Natural Resources, Geological Survey Bureau, Open-File Report 90-1, 27 p.

U.S. Environmental Protection Agency, 1986, Pesticides in groundwater: background document: U.S.E.P.A., Office of Pesticide Programs, Washington, D.C.

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