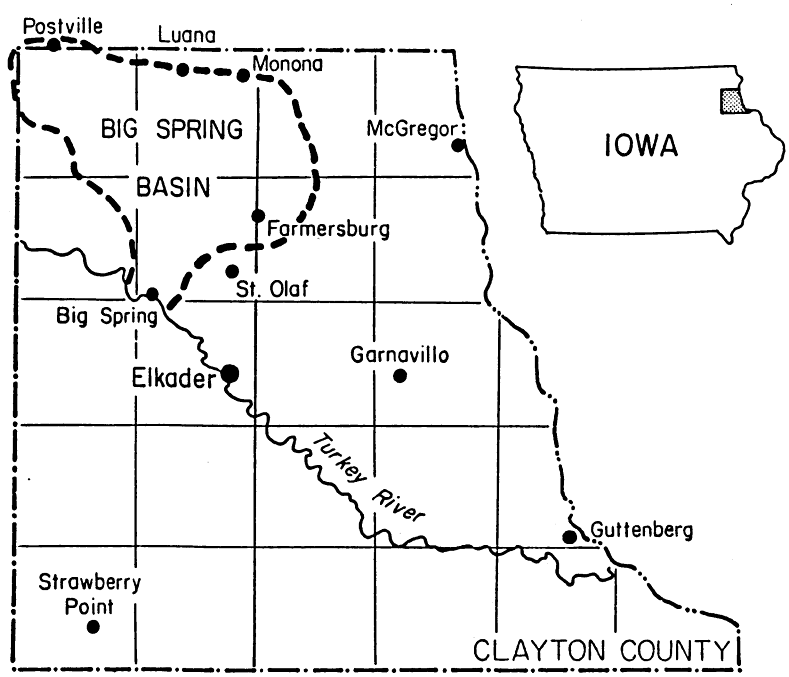
GROUNDWATER MONITORING in the BIG SPRING BASIN 1988-1989: A Summary Review

Technical Information Series 21



Iowa Department of Natural Resources

Larry J. Wilson, Director

June 1991

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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 US Geological Survey, Water Resources Division, Iowa City; the Iowa Department of Agriculture and Land Stewardship; and the USDA-Agricultural Stabilization and Conservation Service and the Agricultural Research Service.

While the collaboration of all 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 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 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.

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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 itself and for the Turkey River during water years (WYs) 1988 and 1989. This period was characterized by extreme drought, and was the driest consecutive two-year period in the state's history. Precipitation totals for the basin were 22.94 inches in WY 1988 and 24.32 inches in WY 1989. These totals were 70% and 74% of the long-term average precipitation of 32.97 inches. The drought conditions severely limited groundwater recharge and runoff. Groundwater discharge from the basin to the Turkey River totalled 26,000 acre-feet in WY 1988 and 12,700 acre-feet in WY 1989, the latter figure being the lowest annual discharge measured during the WY 1982 through 1989 period of record. Discharge rates generally declined slowly across the period, with a minimum monthly average of 12 cfs occurring in July 1989. Average discharge of the Turkey River at Garber was 436,000 and 220,000 acre-feet, for WYs 1988 and 1989, equivalent to 65% and 32% of the long-term average discharge.

Flow-weighted mean nitrate concentrations at Big Spring were 43 mg/L in WY 1988 and 25 mg/L in WY 1989. The total load of nitrate-nitrogen discharged by the groundwater system was 672,000 pounds in WY 1988 and 195,000 pounds in WY 1989. The nitrate concentration and load for WY 1989 was the lowest recorded since monitoring began at Big Spring. Nitrate concentrations in general declined slowly across the period, in a manner similar to the rate of discharge. For the Turkey River, flow-weighted mean nitrate concentrations were 23 mg/L and 12 mg/L in WYs 1988 and 1989. Total nitrate-nitrogen discharged by the river was about 6 million pounds in WY 1988 and 1.6 million pounds in WY 1989.

Atrazine is the most consistently detected herbicide in Big Spring groundwater. WY 1988 showed the lowest flow-weighted mean atrazine concentration (0.13 μg/L), the lowest total atrazine load (9.2 pounds), and the lowest frequency of atrazine detections (75%) for the WY 1982 through 1989 period of record. During WY 1989 these parameters increased to 0.61 μg/L, 21.2 pounds, and 88%, respectively. Cyanazine was the only other herbicide detected in WY 1988; cyanazine, alachlor, and metolachlor were detected in WY 1989. Concentrations and frequency of detection for herbicides did not follow the generally slow declining trend exhibited by discharge rates and nitrate concentrations. During WY 1988, the Turkey River discharged about 407 pounds of atrazine at a flow-weighted mean concentration of 0.34 μg/L. During WY 1989, the atrazine load was 571 pounds at a flow-weighted mean concentration of 0.95 μg/L.

An overview of groundwater discharge, nitrate, and atrazine data for the WY 1982 through 1989 period indicates that while nitrate concentrations and loads vary in a parallel fashion with discharge, atrazine concentrations and loads do not. Rather, relatively higher concentrations and loads have occurred during years with lower discharges. Discharge rates and contaminant concentrations and loads have varied by factors of two to six across the period of record at Big Spring, underscoring the need for long-term monitoring for the understanding of natural systems.

INTRODUCTION

The Big Spring basin is a 103 mi^2 groundwater basin located in Clayton County, northeast Iowa. The groundwater basin has been defined through extensive hydrologic investigations by the Iowa Department of Natural Resources, Geological Survey Bureau and cooperating agencies. Previous reports have described the hydrogeologic setting and the hydrologic definition of the basin, the gaging of groundwater and surface-water discharge, the monitoring of water quality, and the relationships to agricultural land use and management in the area for water years (WYs; October 1 through September 30) 1982 through 1987 (Hallberg et al., 1983, 1984, 1985, 1987, 1989; Libra et al., 1986, 1987). Kalkoff (1989) and Kalkoff and Kuzinar (1991) presented data from several monitoring stations within the basin for WYs 1988 and 1989. This report is a companion volume to Hallberg and others (1989); it summarizes Big Spring and Turkey River monitoring data for WYs 1988 and 1989. Analytical methods, land use, and the current status of the Big Spring Basin Demonstration Project are reviewed in Hallberg and others (1989). Hydrologic and water-quality data from tile lines, wells, and surface waters within the basin will be addressed in subsequent reports. Further interpretation of the data presented in this report requires detailed analysis of data from all monitored parts of the basin's hydrologic system.

HYDROLOGIC AND WATER QUALITY MONITORING

Groundwater discharge from the Big Spring basin to the Turkey River has been monitored since early in WY 1982. Discharge at Big Spring is a function of recharge within the basin, which is controlled by the amount, timing, and intensity of precipitation, along with antecedent conditions. These factors therefore exert a major control on the transport, concentration, and load of agriculturally related contaminants in groundwater. This section discusses precipitation, discharge, and water quality at Big Spring; some aspects of the discharge and water-quality record for the Turkey River are also addressed. The Turkey River is a "high baseflow" stream, deriving a significant part of its discharge from influent groundwater. Data from the Turkey River therefore provide a regional perspective for the hydrologic and water-quality monitoring at Big Spring. All references to the Turkey River discharge or to the Turkey River basin refer to the basin above Garber, Iowa, which is located about 15 miles downstream from Big Spring. As defined, the Turkey River basin contains 1545 mi^2. Discharge data for the Turkey River were supplied by the U.S. Geological Survey, Water Resources Division (USGS), Iowa City, Iowa.

Precipitation

Several precipitation monitoring stations have been installed in the Big Spring basin since the project's inception. This has allowed more refined calculation of precipitation inputs to the area. Precipitation for WY 1988 and previous years was calculated using data from the Elkader, Waukon, and Fayette weather stations, which form a triangle around the basin. These data, along with daily maximum/minimum temperatures, are supplied by the Iowa Department of Agriculture and Land Stewardship, State Climatology Office (IDALS, SCO). Beginning in WY 1985, data from the National Atmospheric Deposition Program (NADP) station located at Big Spring have also been used. In the summer of 1988, the USGS installed two rain-gage stations within the basin. Precipitation for WY 1989 was 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 than the Big Spring basin, is estimated using averages for the state's northeast climatic division (IDALS, SCO). References to normal precipitation are based on the period 1951-1980.

Monthly precipitation and departures from normal for the Big Spring basin during WYs 1982 through 1989 are shown in Figure 1, and are tabulated for WYs 1988 and 1989 in Table 1. Precipitation in WY 1988 and WY 1989 was dramatically below normal, the drought conditions comprising the two driest consecutive years in Iowa's recorded history. Precipitation for WY 1988 was 22.94 inches (10.03 inches below normal) and for WY 1989, 24.32 inches (8.65 inches below normal). These annual totals were 70% and 74% of the long-term normal, respectively. Precipitation for the northeast Iowa climatic district was 23.34 inches in WY 1988 (9.60 inches below normal) and 24.85 inches in WY 1989 (8.09 inches below normal).

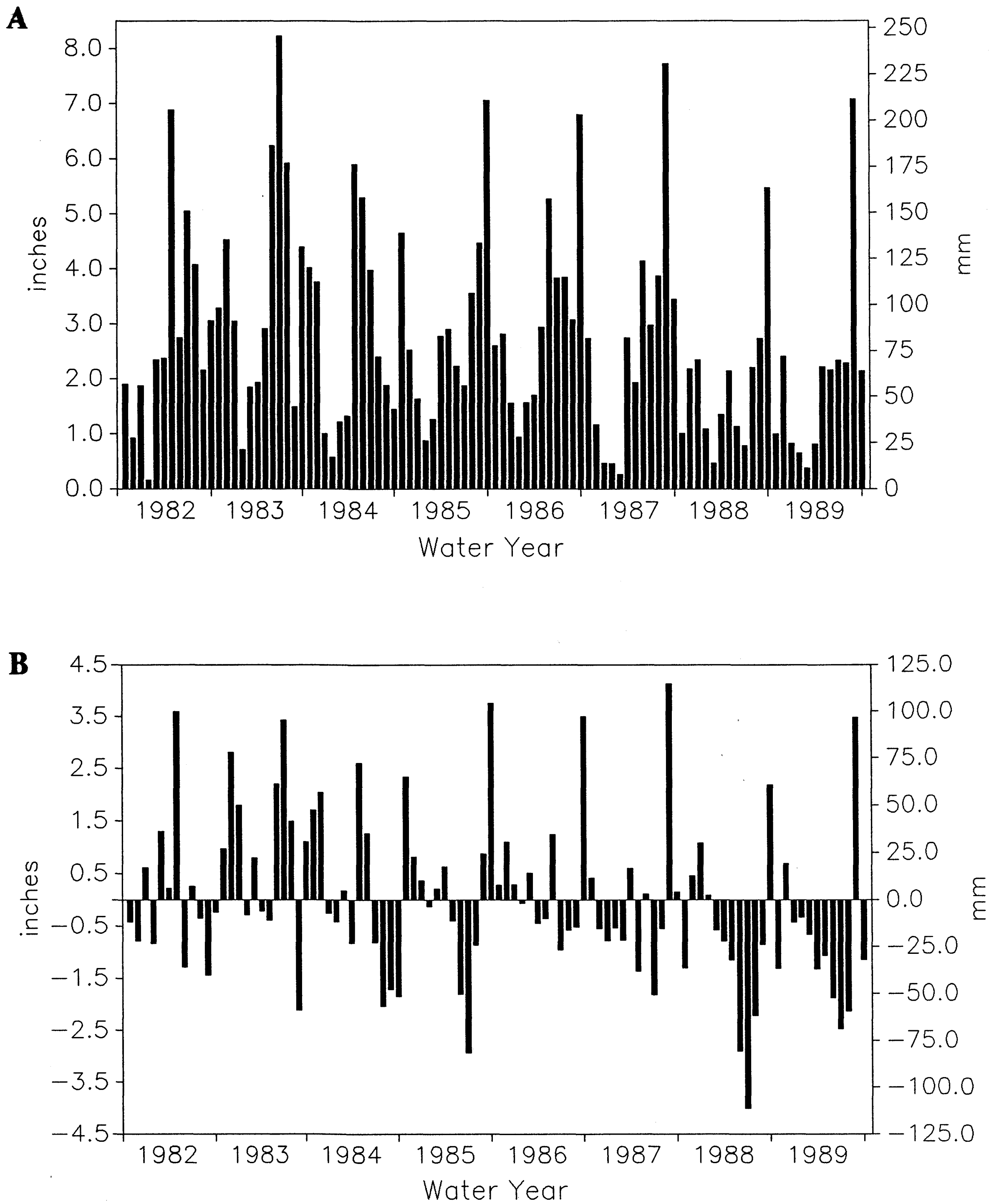

Figure 1. A) Monthly precipitation totals and B) departure from normal for the Big Spring basin, WYs 1982-1989 (Iowa Dept. of Ag. and Land Stewardship, State Climatology Office).

Table 1. Monthly precipitation and departure from normal; Big Spring basin, Water Years 1988-89.

Water Year 1988	Basin precip inches	Departure from normal inches	% of normal	Water Year 1989	Basin precip inches	Departure from normal inches	% of normal
Oct-87	1.01	-1.31	43.5	Oct-88	1.00	-1.32	43.1
Nov-87	2.18	0.46	126.7	Nov-88	2.41	0.69	140.1
Dec-87	2.34	1.08	185.7	Dec-88	0.83	-0.43	65.9
Jan-88	1.09	0.09	109.0	Jan-89	0.66	-0.34	66.0
Feb-88	0.47	-0.58	44.8	Feb-89	0.38	-0.67	36.2
Mar-88	1.35	-0.80	62.8	Mar-89	0.82	-1.33	38.1
Apr-88	2.14	-1.16	64.9	Apr-89	2.22	-1.08	67.3
May-88	1.14	-2.90	28.2	May-89	2.16	-1.88	53.5
Jun-88	0.79	-4.01	16.5	Jun-89	2.33	-2.47	48.5
Jul-88	2.21	-2.22	49.9	Jul-89	2.29	-2.14	51.7
Aug-88	2.74	-0.86	76.1	Aug-89	7.08	3.48	196.7
Sep-88	5.48	2.18	166.1	Sep-89	2.14	-1.16	64.9
TOTAL	22.94	-10.03	69.6	TOTAL	24.32	-8.65	73.8

These were 71% and 75%, respectively, of the long-term normal.

Previous reports (Hallberg et al., 1983, 1984, 1989) indicate the March through June period, typically marked by low evapotranspiration and wet antecedent conditions, is important for groundwater recharge. Precipitation in the Big Spring basin during this period was 8.87 inches below normal in WY 1988, and 6.76 inches below normal in WY 1989. These periods were also characterized by relatively small rainfalls; no daily rainfall exceeded one inch. The wettest months were September of WY 1988, when precipitation was 5.48 inches, and August of WY 1989, when 7.08 inches of rain fell. Less than 3.0 inches of precipitation were recorded during any other month. Normal or above normal precipitation occurred only in the fall and winter months (Table 1). Typically, June has been the wettest month in the Big Spring basin (the 1951-1980 average is 4.80 inches). However, since WY 1985, either August or September have been the wettest months (Hallberg et al., 1989).

Water Year 1988

Discharge Monitoring

Groundwater discharge from the Big Spring basin was 26,000 acre-feet (ac-ft), at an average rate of 36 cubic feet per second (cfs; Table 2). This groundwater discharge was equivalent to 20% of precipitation. Discharge for the Turkey River was about 436,000 ac-ft, at an average rate of 600 cfs (Table 3). Discharge was equivalent to 23% of precipitation, and was about 65% of the long-term (1951-1980) average.

Discharge at Big Spring declined during October and November, and was relatively stable during December and January, indicating minor recharge from late November rains and minor snow-melt periods (Fig. 2). Major groundwater recharge, as indicated by large rises in discharge at Big Spring (see Hallberg et al., 1983, 1984, 1989), occurred only in the February through April period, and to a lesser degree during the relatively wet September.

Discharge of snow melt-related recharge exceeded 80 cfs on several occasions during February and March, including a peak instantaneous discharge of about 122 cfs. These were the first discharges from Big Spring to exceed 80 cfs since March 1986. A major recession period followed as drought conditions returned during the summer months. Discharge declined from an average of 40 cfs during April to 20 cfs in September. The lowest daily discharge, 16 cfs, occurred in September, prior to minor runoff recharge periods in the latter part of the month. While September was the wettest month of WY 1988, the extremely dry antecedent conditions limited groundwater recharge.

Table 2. Annual summary of groundwater and chemical discharge from the Big Spring basin to the Turkey River for Water Year 1988.

DISCHARGE

Total

acre-feet	26,008
millions cf	1,133
millions cm	32

Average

cfs	35.8
cms	1.0
mg/d	23.2
gpm	16,067

PRECIPITATION AND DISCHARGE

Precipitation	22.94 inches (582.7 mm)
Discharge	4.7 inches (119.4 mm)
Discharge as % of precipitation	20.5%

NITRATE DISCHARGE

Concentration - mg/L	As NO_3	As NO_3-N
Flow-weighted mean	43	9.5
Mean of analyses	41	9.2

	NO_3-N output	Total N output
lbs - N	672,023	700,617
kg - N	304,772	317,740

ATRAZINE DISCHARGE

Concentration - ug/L

Flow-weighted mean	0.13
Mean of analyses	0.14

Total output

lbs	9.2
kg	4.2

Table 3. Annual summary of water and chemical discharge for the Turkey River at Garber for Water Year 1988. (Discharge data from the U.S. Geological Survey, Water Resources Division).

DISCHARGE

Total

acre-feet	436,100
millions cf	18,996
millions cm	538

Average

cfs	601
cms	17
mg/d	388
gpm	269,729

PRECIPITATION AND DISCHARGE

Precipitation	23.34 inches (592.84mm)
Discharge	5.29 inches (134.37mm)
Discharge as % of precipitation	23%

NITRATE DISCHARGE

Concentration - mg/L	As NO_3	As NO_3-N
Flow-weighted mean	23.0	5.1
Mean of analyses	18.7	4.2

	NO_3-N output	Total N output
lbs - N	6,052,690	6,248,173
kg - N	2,744,980	2,833,634

ATRAZINE DISCHARGE

Concentration - ug/L

Flow-weighted mean	0.34
Mean of analyses	0.42

Total output

lbs	407.1
kg	184.7

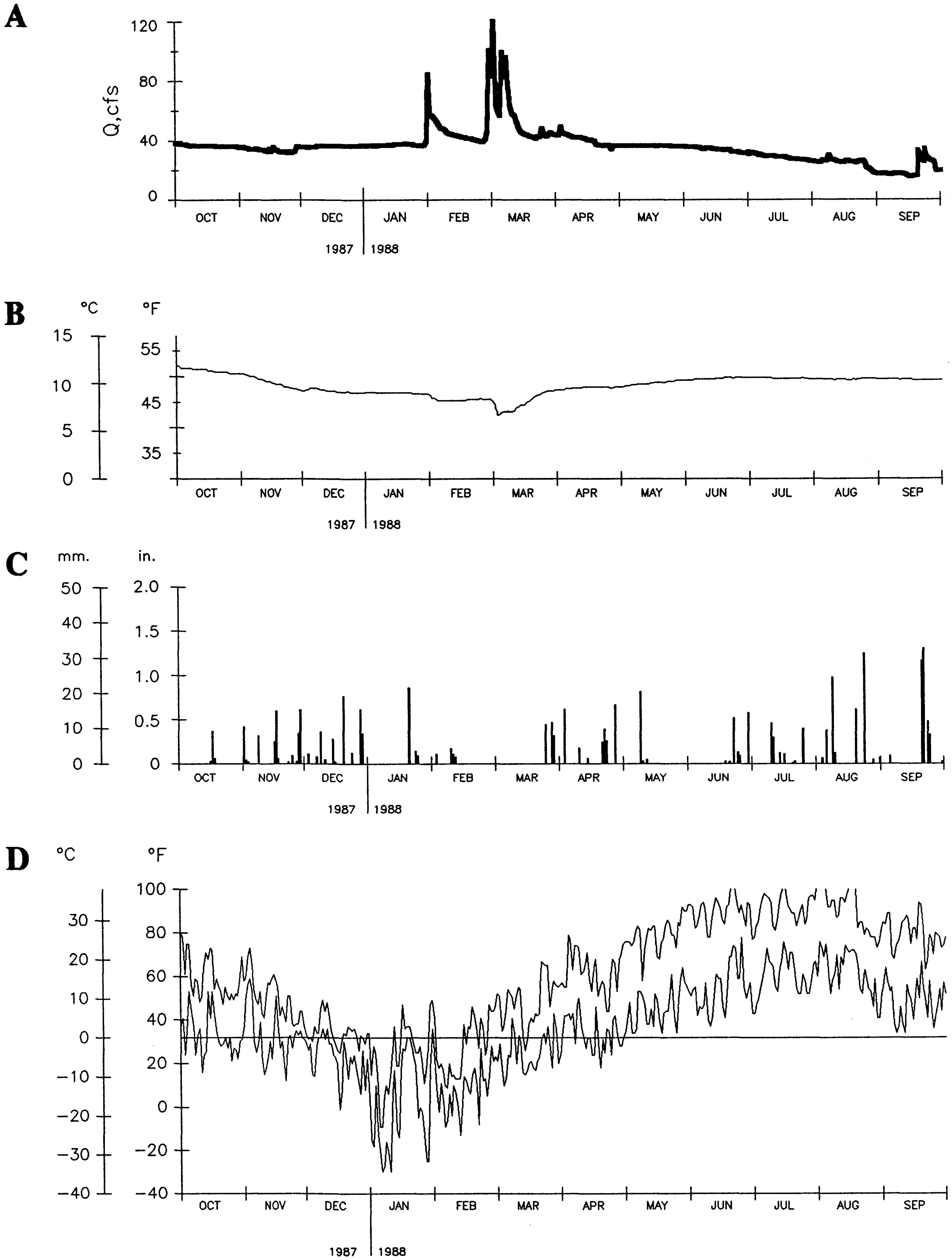

Figure 2. A) Groundwater discharge, B) groundwater temperature and C) daily precipitation for the Big Spring basin, and D) maximum-minimum temperatures for Elkader, IA (Iowa Dept. of Ag. and Land Stewardship, State Climatology Office), for WY 1988.

Table 4. Monthly summary of groundwater discharge from the Big Spring basin for Water Year 1988.

	1987 Oct	Nov	Dec	1988 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
TOTAL MONTHLY DISCHARGE												
Acre-feet	2,243	2,008	2,230	2,376	2,654	3,383	2,399	2,230	2,014	1,762	1,504	1,206
Cubic feet (millions)	98	88	97	104	116	147	105	97	88	77	66	53
Gallons (millions)	731	654	727	774	865	1103	782	727	656	574	490	393
Cubic meters (millions)	2.8	2.5	2.8	2.9	3.3	4.2	3.0	2.8	2.5	2.2	1.9	1.5
AVERAGE DISCHARGE												
cfs	36	34	36	39	46	55	40	36	34	29	24	20
cms	1.0	1.0	1.0	1.1	1.3	1.6	1.1	1.0	1.0	0.8	0.7	0.6
mg/d	24	22	23	25	30	36	26	24	22	19	16	13
MAXIMUM												
cfs	38	36	37	84	101	122	49	36	36	32	30	34
cms	1.1	1.0	1.0	2.4	2.9	3.5	1.4	1.0	1.0	0.9	0.8	1.0
MINIMUM												
cfs	35	32	35	36	39	41	34	36	31	26	17	16
cms	1.0	0.9	1.0	1.0	1.1	1.2	1.0	1.0	0.9	0.7	0.5	0.5

The greatest monthly discharge from the Big Spring basin occurred in March, 3,383 ac-ft, at an average rate of 55 cfs (Table 4). Discharge was below 2,500 ac-ft in all other months. The minimum monthly discharge was 1,206 ac-ft, at an average rate of 20 cfs, in September. This was the lowest monthly average discharge for the period of record for Big Spring (WYs 1982-1988; Hallberg et al., 1983, 1984, 1989). March and September were also the highest-and lowest-flow months, respectively, for the Turkey River. Over 90,000 ac-ft were discharged in March, and less than 11,000 ac-ft were discharged in September.

Nitrate Monitoring

During WY 1988, 129 samples of Big Spring groundwater were analyzed for nitrate, and 60 of these were also analyzed for other nitrogen species, ammonia-and organic-N. The flow-weighted (fw) mean nitrate concentration (the mean concentration in each unit volume of discharge) for the water year was 43 mg/L (9.5 mg/L as NO_3-N). A total of 701 thousand pounds of nitrogen was discharged by groundwater from the basin during the water year; of this total, 672 thousand pounds, or 96%, was in the form of nitrate (Table 2).

Nitrate concentrations at Big Spring declined from about 50 mg/L to 40 mg/L (11 to 9 mg/L as NO_3-N) during the October-November discharge recession (Fig. 3), and increased slightly following the minor recharge events in late November and January. The February and March snow melt caused short-term dilution of nitrate concentrations. Concentrations declined with the drought-related recession, falling from about 50 mg/L (11 mg/L as NO_3-N) in April to less than 35 mg/L (8 mg/L as NO_3-N) in September. One

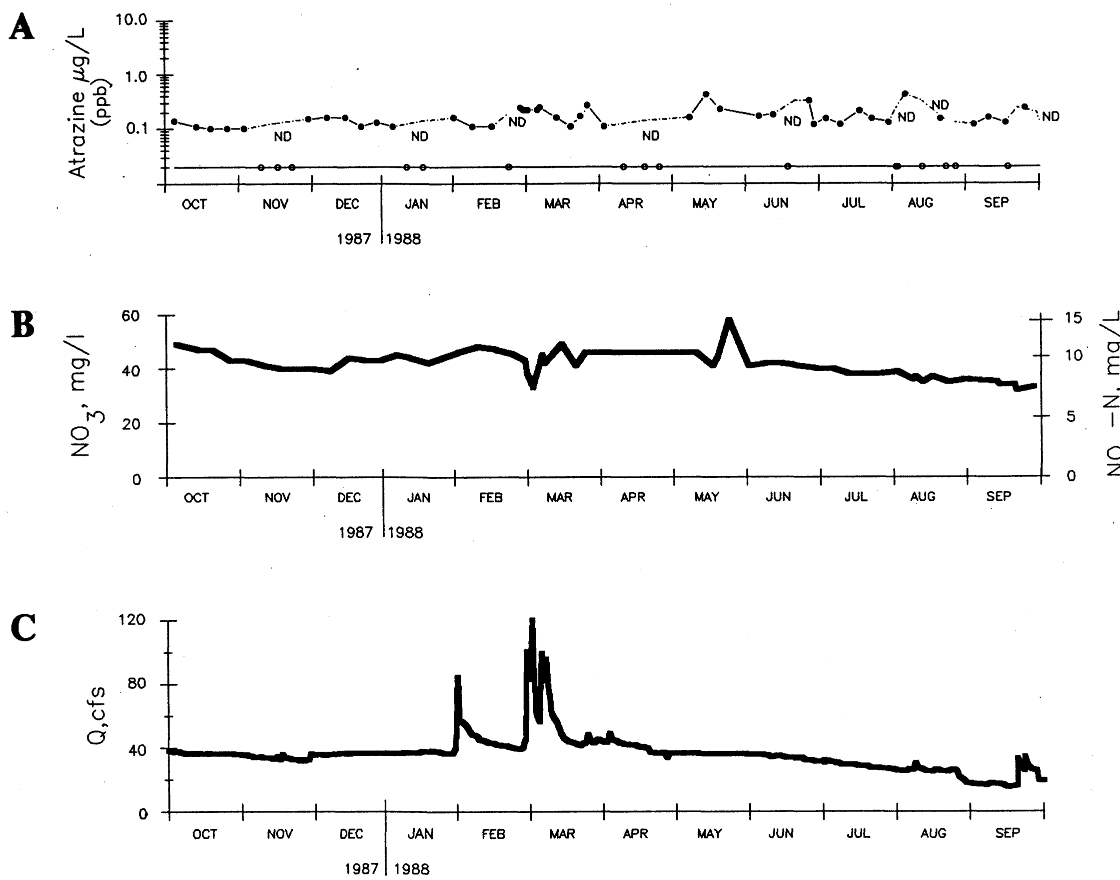

Figure 3. A) Atrazine and B) nitrate concentrations, and C) groundwater discharge at Big Spring for WY 1988.

sample from late May stands out from this decline (Fig. 3), and is 10-15 mg/L higher than the bracketing weekly samples. As there was essentially no precipitation or changes in discharge during this period (Fig. 3), this sudden change in nitrate concentration cannot be readily explained. The rains and minor recharge in September had little effect on nitrate concentrations.

The highest monthly fw mean occurred in October, at 47 mg/L (10.4 mg/L as NO_3-N), while the lowest was recorded during the following September at 34 mg/L (8 mg/L as NO_3-N; Table 5). During October, February, April, and May, fw means exceeded the 45 mg/L (10 mg/L as NO_3-N) drinking water standard for nitrate. The greatest monthly N-load occurred in March, the month with greatest groundwater discharge, and was about 86 thousand pounds. September had the lowest N-load, 25 thousand pounds, as a consequence of both the lowest groundwater discharge and the lowest nitrate concentrations. The nitrate-N discharged with groundwater during this last month of WY 1988 was the lowest measured in the basin during the WY 1982 through WY 1988 period of record.

During WY 1988, 62 water samples from the Turkey River were analyzed for nitrate; 13 of these were also analyzed for ammonium-and organic-N. Roughly 6 million pounds of nitrate-N were discharged by the Turkey River at a fw mean concentration of 23 mg/L (5.1 as NO_3-N; Table 3). Nitrate concentrations followed a generally increasing trend from October through early April, rising from about 20 mg/L to around 30 mg/L (4.4 mg/L to 6.7 mg/L as NO_3-N). Concentrations decreased for the remainder of the year, to less than 5 mg/L (1.1 mg/L as NO_3-N) in August (Fig. 4). The lack of recharge during the prevailing drought conditions explains some of the sharp decrease in nitrate concentrations. However, in-stream nitrate losses--from streambed denitrification and uptake by aquatic plants--(e.g.,

Table 5. Monthly summary of nitrate-N discharged in groundwater from the Big Spring basin to the Turkey River; Water Year 1988.

	1987 Oct	Nov	Dec	1988 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean NO_3 concentration, in mg/L;	47	41	42	44	46	42	46	46	41	39	37	34
as NO_3-N	10.4	9.1	9.3	9.7	10.3	9.3	10.2	10.3	9.2	8.6	8.2	7.7
Mean of NO_3 analyses, in mg/L;	47	41	42	44	45	41	46	47	41	39	36	34
as NO_3-N	10.3	9.1	9.4	9.7	9.9	9.1	10.2	10.4	9.2	8.6	8.0	7.5
Total monthly NO_3-N output, thousand lbs	64	50	56	63	74	86	67	62	50	41	34	25
Total monthly NO_3-N output, thousands kg	29	23	26	29	34	39	30	28	23	19	15	11

Bachmann et al., 1989; Isenhart and Crumpton, 1989) likely caused much of the decline. Monthly fw mean nitrate concentrations (Table 6) varied from 30 mg/L (6.5 mg/L as NO_3-N) in December to 5 mg/L (1.1 mg/L as NO_3-N) in the low-flow month of September. The greatest monthly nitrate-N discharge, 1,446 thousand pounds, occurred in March, and accounted for 24% of the total for WY 1988. In contrast, only 37 thousand pounds of nitrate-N were discharged in September, representing less than 1% of the total nitrate-N discharged.

Pesticide Monitoring

During WY 1988, sixty-seven samples from Big Spring were analyzed for pesticides. Fifty samples, or 75% of those collected, contained detectable atrazine. A total of 9.2 pounds of atrazine were discharged by basin groundwaters, at a fw mean concentration of 0.13 μg/L (Table 2). This was the lowest annual fw mean atrazine concentration and total load observed at Big Spring during the WY 1982 through 1988 period of record. Concentrations were relatively stable during the year, varying from non-detectable (<0.1 μg/L) to 0.42 μg/L (Fig.3). The highest concentrations of atrazine occurred in May and August. During November and April, atrazine concentrations were below detection limits for periods in excess of two weeks. Monthly fw mean concentrations were highest in May at 0.22 μg/L, and lowest in January at 0.09 μg/L (non-detections are assigned a value of 0.0 μg/L when fw means are calculated; this may result in a fw mean below the detection limit). Atrazine loads were highest in March, when the groundwater system discharged 1.7 pounds of atrazine, and lowest in August, when only 0.2 pounds were discharged (Table 7). Two samples, or about 3%, contained detectable amounts of cyanazine (Fig. 5). An August sample contained the highest concentration, 1.0 μg/L. Alachlor and metolachlor

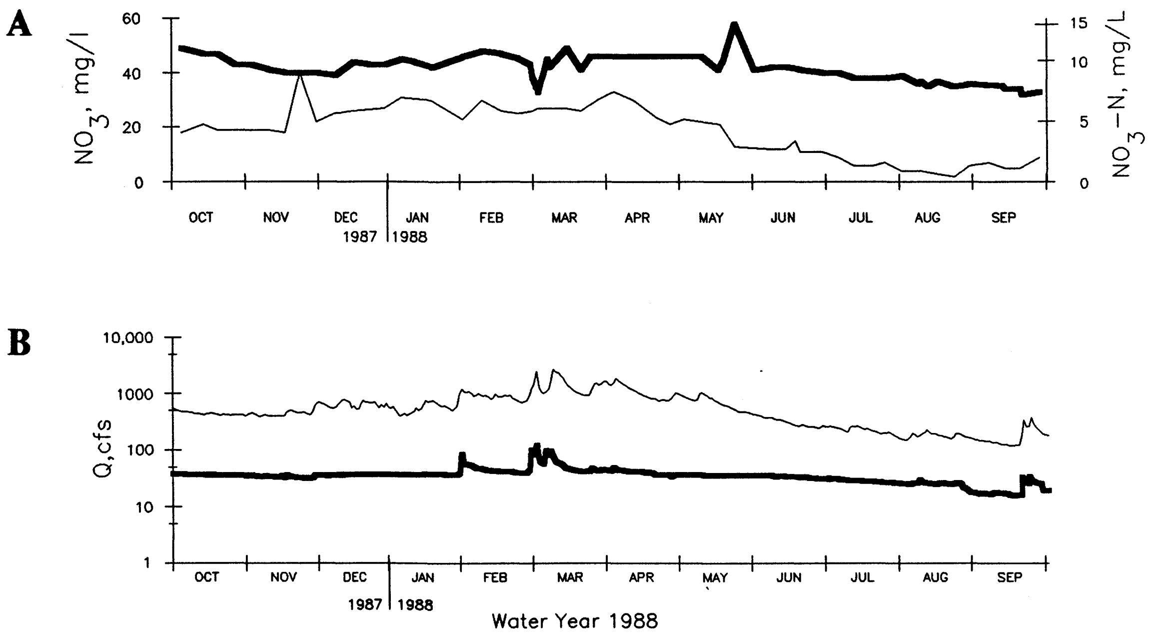

Figure 4. A) Nitrate concentrations and B) discharge hydrographs for Big Spring (bold lines) and the Turkey River (lighter lines) at Garber for WY 1988; (Turkey River discharge data from U.S.G.S., W.R.D., IA Dist.).

were not detected at Big Spring in WY 1988.

During WY 1988, 14 samples from the Turkey River were analyzed for pesticides. An estimated 407 pounds of atrazine were discharged, at a fw mean concentration of 0.34 μg/L (Table 3). Over half of the water-year total, 234 pounds, was discharged during May (Table 8). The lowest monthly atrazine discharge occurred in November, and was only 1.1 pounds. These months also showed the maximum and minimum monthly fw mean concentrations of 1.99 and 0.02 μg/L, respectively.

Water Year 1989

Discharge Monitoring

Groundwater discharge from the Big Spring basin was 12,672 ac-ft, at an average rate of 18 cfs. Discharge was equivalent to about 9% of precipitation (Table 9). Discharge and the equivalent percentage of precipitation discharged in WY 1989 were the lowest recorded for the WY 1982 through 1989 period of record at Big Spring.

Discharge from the Turkey River basin was 220,700 ac-ft, at an average rate of 305 cfs (Table 10). Discharge accounted for 11% of precipitation, and was only 32% of the long-term (1951-1980) average. Discharge records for the Turkey River are available for all but seven years since WY 1914, and are continuous since WY 1933. WY 1989 had the fourth lowest discharge for the period of record.

Discharge at Big Spring followed a declining trend during WY 1989, as drought conditions continued (Fig. 6). Between October and July discharge decreased from about 20 cfs to just over 10 cfs. This long recession was broken by intermittent snow-melt recharge from January through March, when the highest discharge of the water year, over 200 cfs, occurred. Rainfalls generated minor runoff and infiltration recharge in November, April, August and September. Significant rainfall occurred during August and September (Fig. 6), but dry antecedent conditions limited recharge, and maximum discharges remained below 40 cfs.

The greatest monthly discharge was in March, 1,906 ac-ft, at an average rate of 31 cfs, and was produced largely by snow melt (Table 11). The lowest monthly discharge occurred in July when only 735 ac-ft was discharged, at an average rate of 12 cfs. This was the lowest monthly discharge measured at Big Spring during the WY 1982

Table 6. Monthly summary of nitrate-N discharge for the Turkey River at Garber; Water Year 1988.

	1987 Oct	Nov	Dec	1988 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean NO_3 concentration, in mg/L;	19	24	25	29	25	27	28	20	12	7	4	6
as NO_3-N;	4.3	5.3	5.5	6.5	5.6	5.9	6.2	4.4	2.7	1.6	0.9	1.3
Mean of NO_3 analyses, in mg/L;	19	25	26	30	26	26	27	20	12	7	5	7
as NO_3-N;	4.3	5.5	5.8	6.7	5.8	5.8	6.0	4.4	2.7	1.6	1.0	1.4
Total monthly NO_3 output, thousands lbs;	318	380	594	651	790	1446	1099	519	138	59	27	37
Total monthly NO_3 output, thousands kg;	144	172	269	295	358	656	498	235	62	27	12	17

through WY 1989 period of record. The previous lowest monthly discharge on record was 1,206 ac-ft in September of WY 1988. During WY 1989, only March and January exceeded that amount. March and July also registered the highest and lowest monthly discharges, respectively, for the Turkey River. March discharge was 70,790 ac-ft, at an average rate of 1,151 cfs, and accounted for almost one-third of the total discharge for WY 1989. Only 8,190 ac-ft were discharged during July, at an average rate of 133 cfs.

Nitrate Monitoring

During WY 1989, 166 samples of Big Spring groundwater were analyzed for nitrate; 70 of these were also analyzed for ammonia-and organic-N. A total of 242 thousand pounds of nitrogen was discharged with groundwater (Table 9). Of this total, 195 thousand pounds, or 80%, was in the form of nitrate, at a fw mean concentration of 25 mg/L (5.7 mg/L as NO_3-N). Both the fw mean nitrate concentration and the total nitrate-N output were the lowest documented during the WY 1982 through WY 1989 period of record at Big Spring.

In general, nitrate concentrations declined slowly, falling from about 35 mg/L to 25 mg/L (7.8 mg/L to 5.5 mg/L as NO_3-N), a trend similar to that displayed by the discharge record (Fig. 7). This general trend was broken only by snow-melt dilution of nitrate concentrations during the January through March period. Concentrations varied by less than 2 mg/L (0.5 mg/L as NO_3-N) during other minor recharge periods.

The highest monthly fw mean nitrate concentrations occurred in October, November, and December, varying from 31 to 33 mg/L (7.0 to 7.2 mg/L as NO_3-N; Table 12). The lowest monthly fw concentration was 18 mg/L (4.0 mg/L as NO_3-N) in February. Monthly nitrate-N loads varied from a low of 10 thousand pounds in February to a high of 24 thousand pounds in March. The maximum monthly nitrate-N load in WY 1989 was less than the minimum monthly load in WY 1988.

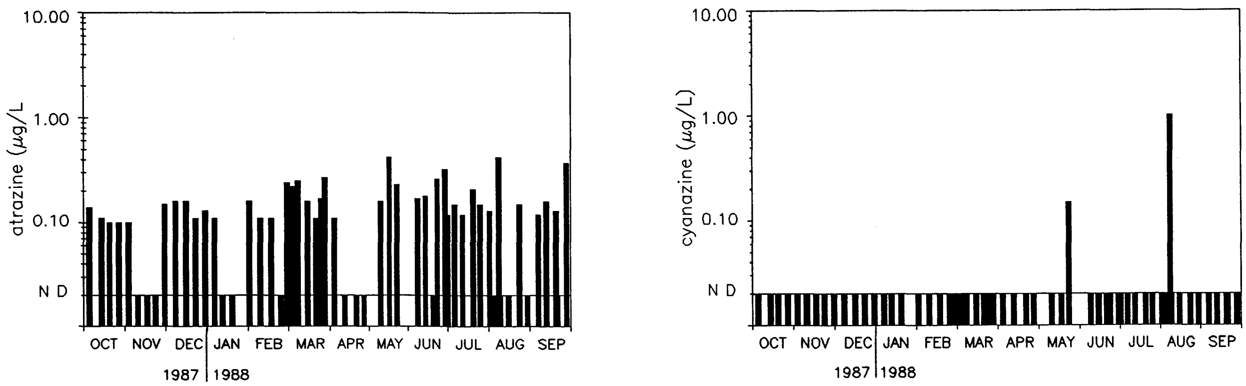

Figure 5. Bar graphs of pesticide concentrations at Big Spring for WY 1988. ND represents not detected.

Table 7. Monthly summary of atrazine discharged in groundwater from the Big Spring basin to the Turkey River; Water Year 1988.

	1987 Oct	Nov	Dec	1988 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean atrazine concentration, in *u*g/L	0.12	0.06	0.14	0.09	0.13	0.19	0.07	0.22	0.16	0.15	0.06	0.11
Mean of atrazine analyses, in *u*g/L	0.11	0.05	0.15	0.04	0.14	0.20	0.03	0.27	0.17	0.15	0.08	0.17
Total monthly atrazine output, lbs	0.7	0.3	0.9	0.6	0.9	1.7	0.5	1.4	0.9	0.7	0.2	0.4
Total monthly atrazine output, grams	329	138	397	271	417	782	206	616	399	325	107	164

Table 8. Monthly summary of atrazine discharge for the Turkey River at Garber; Water Year 1988.

	1987 Oct	Nov	Dec	1988 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean atrazine concentration, in *u*g/L	0.17	0.02	0.18	0.16	0.13	0.24	0.11	1.99	0.20	0.21	0.25	0.05
Mean of atrazine analyses, in *u*g/L	0.13	*	0.19	0.16	0.07	0.23	0.10	4.40	0.20	0.23	0.28	*
Total monthly atrazine output, lbs	12.9	1.1	19.3	16.3	18.5	57.8	19.7	234.5	10.3	7.9	7.5	1.3
Total monthly atrazine output, kg	5.9	0.5	8.8	7.4	8.4	26.2	8.9	106.4	4.7	3.6	3.4	0.6

* All samples below detection limit.

Table 9. Annual summary of groundwater and chemical discharge from the Big Spring basin to the Turkey River for Water Year 1989.

DISCHARGE		
Total		
acre-feet	12,672	
millions cf	552	
millions cm	16	
Average		
cfs	17.6	
cms	0.5	
mg/d	11.3	
gpm	7899	
PRECIPITATION AND DISCHARGE		
Precipitation	24.32 inches (617.7mm)	
Discharge	2.3 inches (58.42mm)	
Discharge as % of precipitation	9%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	25	5.7
Mean of analyses	26	5.7
	NO_3-N output	**Total N output**
lbs - N	194,928	242,245
kg - N	88,403	109,863
ATRAZINE DISCHARGE		
Concentration - ug/L		
Flow-weighted mean	0.61	
Mean of analyses	0.70	
Total output		
lbs	21.2	
kg	9.6	

Table 10. Annual summary of water and chemical discharge for the Turkey River at Garber for Water Year 1989. (Discharge data from the U.S. Geological Survey, Water Resources Division).

DISCHARGE		
Total		
acre-feet	220,700	
millions cf	9,614	
millions cm	272	
Average		
cfs	305	
cms	8.6	
mg/d	197	
gpm	136,884	
PRECIPITATION AND DISCHARGE		
Precipitation	24.85 inches (631.2mm)	
Discharge	2.68 inches (68.1mm)	
Discharge as % of precipitation	11%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	11.9	2.6
Mean of analyses	11.7	2.6
	NO_3-N output	**Total N output**
lbs - N	1,580,050	3,853,485
kg - N	716,577	1,747,612
ATRAZINE DISCHARGE		
Concentration - ug/L		
Flow-weighted mean	0.95	
Mean of analyses	0.95	
Total output		
lbs	571.3	
kg	259.1	

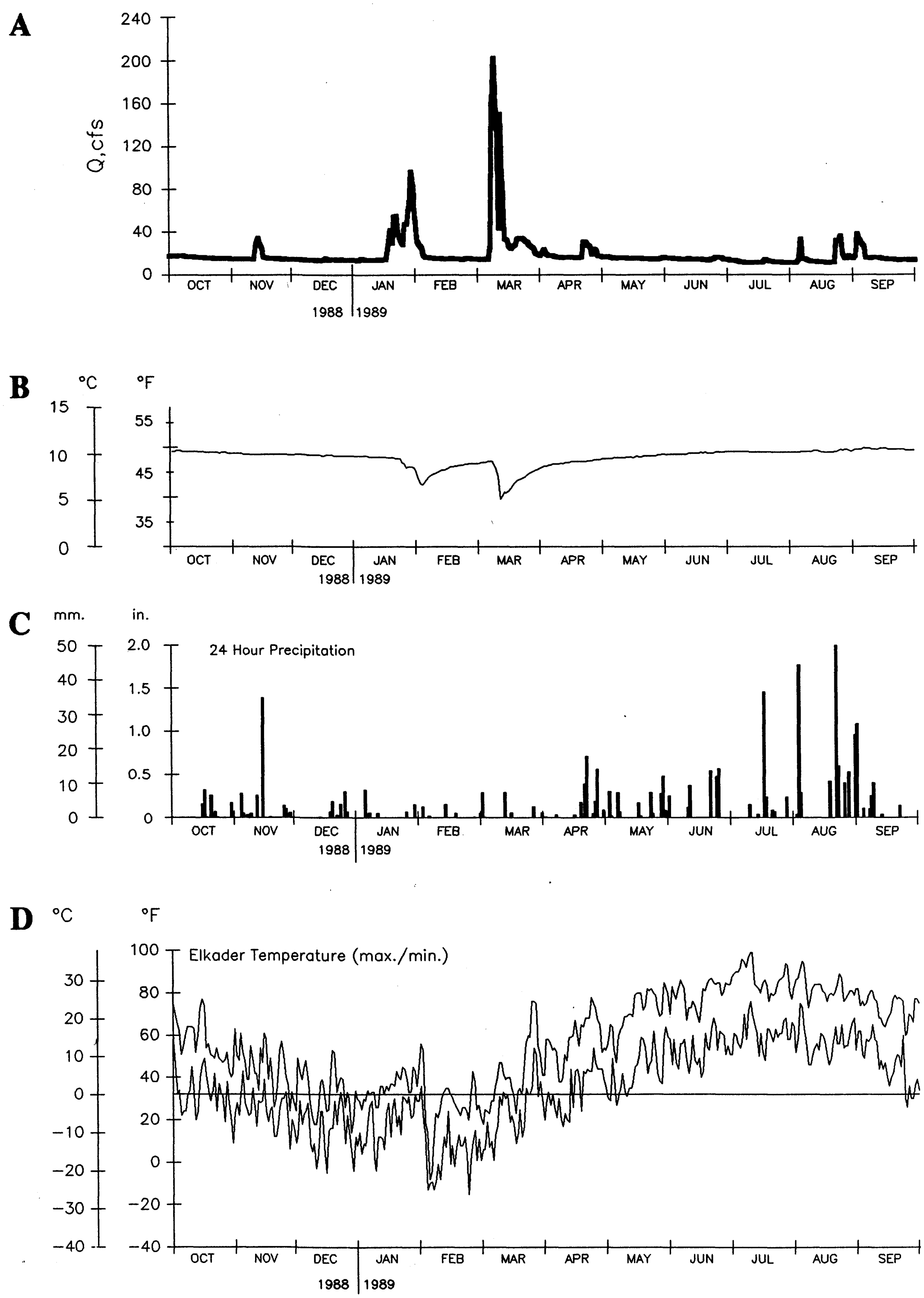

Figure 6. A) Groundwater discharge, B) groundwater temperature, and C) daily precipitation for the Big Spring basin, and D) maximum-minimum temperatures for Elkader, IA (Iowa Dept. of Ag. and Land Stewardship, State Climatology Office), for WY 1989.

Table 11. Monthly summary of groundwater discharge from the Big Spring basin for Water Year 1989.

	1988 Oct	Nov	Dec	1989 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
TOTAL MONTHLY DISCHARGE												
Acre-feet	1024	975	860	1417	961	1906	1132	954	869	735	895	944
Cubic feet (millions)	45	42	37	62	42	83	49	42	38	32	39	41
Gallons (millions)	334	318	280	462	313	621	369	311	283	240	292	308
Cubic meters (millions)	1.3	1.2	1.1	1.7	1.2	2.4	1.4	1.2	1.1	0.9	1.1	1.2
AVERAGE DISCHARGE												
cfs	17	16	14	23	17	31	19	16	15	12	15	16
cms	0.5	0.5	0.4	0.7	0.5	0.9	0.5	0.4	0.4	0.3	0.4	0.5
mg/d	11	11	9	15	11	20	12	10	9	8	9	11
MAXIMUM												
cfs	20	34	15	96	53	202	30	17	16	14	36	38
cms	0.6	1.0	0.4	2.7	1.5	5.7	0.8	0.5	0.5	0.4	1.0	1.1
MINIMUM												
cfs	15	15	13	14	15	14	16	14	13	11	11	14
cms	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.4	0.4	0.3	0.3	0.4

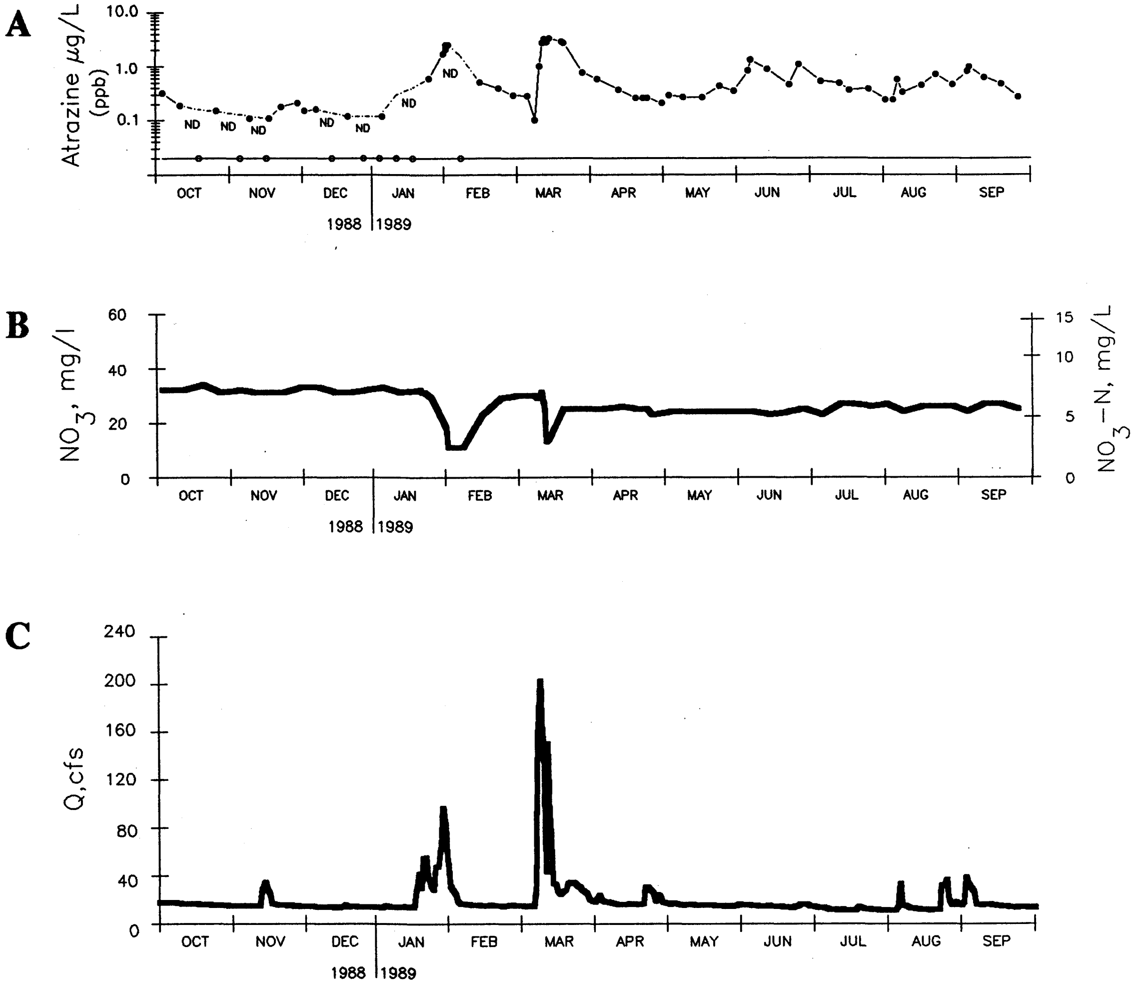

Figure 7. A) Atrazine and B) nitrate concentrations, and C) groundwater discharge at Big Spring for WY 1989.

Table 12. Monthly summary of nitrate-N discharged in groundwater from the Big Spring basin to the Turkey River; Water Year 1989.

	1988 Oct	Nov	Dec	1989 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean NO_3 concentration, in mg/L;	33	31	32	26	18	21	25	24	24	25	26	25
as NO_3-N;	7.2	7.0	7.1	5.8	4.0	4.6	5.5	5.3	5.3	5.6	5.7	5.5
Mean of NO_3 analyses, in mg/L;	32	32	32	28	18	22	25	24	24	26	26	26
as NO_3-N;	7.2	7.0	7.1	6.3	3.9	4.9	5.5	5.3	5.4	5.7	5.7	5.7
Total monthly NO_3-N output, thousand lbs;	20	18	17	23	10	24	17	14	13	11	14	14
Total monthly NO_3-N output, thousands kg;	9	8	8	10	5	11	8	6	6	5	6	6

During WY 1989, 55 water samples from the Turkey River were analyzed for nitrate-N; 12 of these were also analyzed for ammonia-and organic-N. A total of 1,580 thousand pounds of nitrate-N were discharged by the Turkey River, at a fw mean concentration of 11.9 mg/L (2.6 mg/L as NO_3-N; Table 10). Nitrate concentrations were more variable for the Turkey River than at Big Spring, ranging from about 1 mg/L to 25 mg/L (0.2 mg/L to 5 mg/L as NO_3-N; Fig. 8). Low concentrations were prevalent during the summer months under low-flow conditions. These likely resulted from a lack of significant nitrate inputs caused by the drought, and from in-stream nitrogen losses (Bachmann et al., 1989; Isenhart and Crumpton, 1989). Higher concentrations, similar to those at Big Spring, occurred following minor runoff events in April, August, and September. On a monthly basis, fw-mean concentrations varied between 19 mg/L in December and 5 mg/L in July (3.2 mg/L and 1.2 mg/L as NO_3-N; Table 13). During March, 398 thousand pounds of nitrate-N were discharged, while only 26 thousand pounds were discharged in July.

Pesticide Monitoring

During WY 1989, 77 samples of Big Spring groundwater were analyzed for pesticides. Atrazine was detected in 68 samples, or 88% of those collected; cyanazine, in 24, or 31%; alachlor, in 14, or 18%; and metolachlor in 4, or 5%. The highest atrazine concentration was 3.3 μg/L, in March; cyanazine, 3.0 μg/L, in August; alachlor, 0.22 μg/l, in March; and metolachlor, 0.21 μg/L, in March (Fig. 9). All of these herbicides were detected in samples collected several weeks prior to chemical applications for the 1989 growing season.

Prior to the snow-melt period beginning in January, atrazine concentrations varied between $<$0.1 μg/L and 0.5 μg/L (Fig.7). During high-discharge snow-melt events in the January through March period, concentrations increased and exceeded 3 μg/L. Concentrations varied between 0.1 and 1.0 μg/L during the remainder of the year, with most of the higher concentrations occurring after minor rainfall events and infiltration recharge periods in June and July, and combined runoff and infiltration recharge periods in August and September (Fig. 7).

A total of 21.2 pounds of atrazine was discharged in Big Spring groundwater at a fw mean concentration of 0.61 μg/L (Table 9). March showed the highest fw mean concentrations, 1.85 μg/L, while the lowest, 0.09 μg/L, occurred in December (Table 14). Loads varied from 8.7 pounds in March to 0.2 pounds in December.

Twelve samples from the Turkey River were analyzed for pesticides. An estimated 571 pounds of atrazine were discharged at a fw mean concentration of 0.95 μg/L (Table 10). The highest monthly fw mean concentration occurred in May, at 1.88 μg/L, while the lowest occurred during December, at 0.04 μg/L (Table 15). Over 40% of the atrazine output for WY 1989 occurred in March, when over 245 pounds were discharged. In contrast, December's output was only about one pound.

DISCUSSION

Monitoring during WYs 1988 and 1989 showed the effects of drought on the basin's hydrologic system, and on the transport of contaminants within the system. Discharge hydrographs and nitrate and atrazine concentration plots for WYs 1988 and 1989 show that discharge declined very slowly, even after months with essentially no recharge. Daily discharges did not fall below 20 cfs until August of WY 1988 (Figs. 2 and 6). Minimum discharges of 11-12 cfs did not occur until almost a year later, in July of 1989. This sustained discharge is provided by relatively slow-moving groundwater of the less transmissive parts of the basin's hydrologic system (see Hallberg et al., 1989). Nitrate concentrations declined with discharge, from about 50 mg/L to 35 mg/L during WY 1988, to less than 25 mg/L in July of WY 1989. The decrease in nitrate concentrations across this period may be the result of several factors. A dominant part of the discharge at Big Spring is relatively recent, nitrate-rich recharge water (Hallberg et al., 1983, 1984). Recharge from this source was minimal during the drought, and an increasingly larger proportion of the discharge was provided by relatively older water from the less transmissive parts of the groundwater system. Some of this older 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). In addition, or as an alternative, denitrification may occur within some

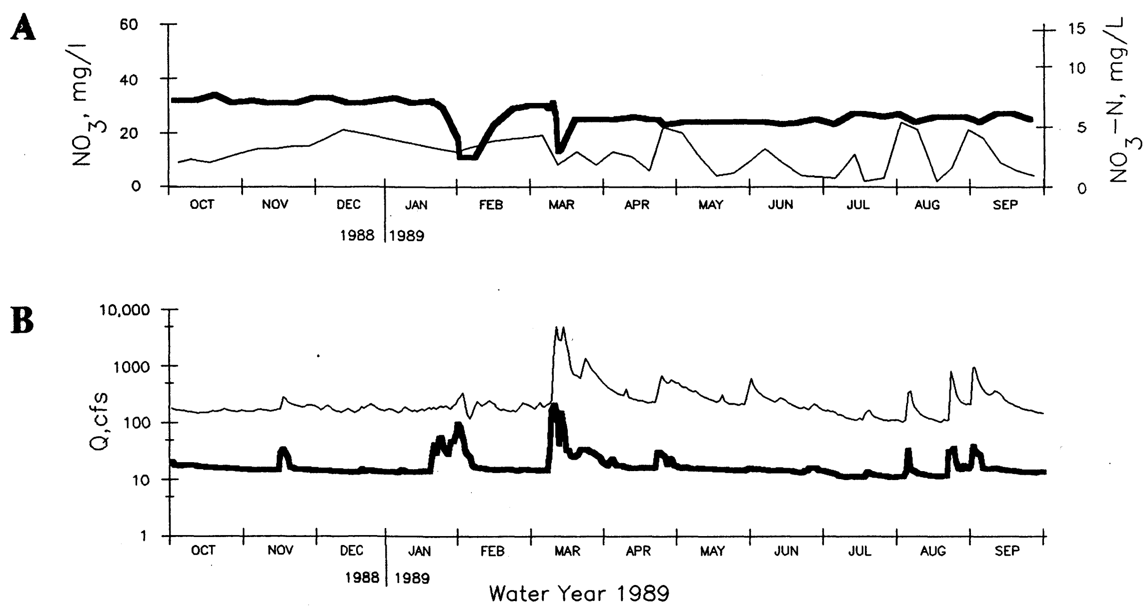

Figure 8. A) Nitrate concentrations and B) discharge hydrographs for Big Spring (bold lines) and the Turkey River (lighter lines) at Garber for WY 1989; (Turkey River discharge data from U.S.G.S., W.R.D., IA Dist.).

of the less transmissive parts of the system, resulting in lower nitrate concentrations. Leakage of surface water from streams to groundwater occurs within the basin, and this may also have affected nitrate concentrations at Big Spring. Denitrification and nitrogen uptake by aquatic vegetation are significant in-stream processes within the basin, particularly under low-flow and high-temperature conditions, generating low nitrate concentrations in the streams (Crumpton and Isenhart, 1987; Isenhart and Crumpton, 1989). If leakage from streams supplied an increasingly large part of the basin's discharge under very low flow conditions, this water source may have contributed to the decline in nitrate concentrations during warm-weather periods. Future reports will utilize monitoring data from streams, tile lines, and wells to evaluate the possibilities discussed above.

While groundwater discharge and nitrate concentrations gradually declined to the lowest values recorded during the period of record at Big Spring, atrazine and other herbicides concentrations followed a different trend. Hallberg et al. (1989) noted that atrazine concentrations and the frequency of detections of other herbicides declined during WYs 1986 and 1987. These trends continued in WY 1988 (Figs. 3 and 5) and early WY 1989 (Figs. 7 and 9). Atrazine concentrations fell below detection limits numerous times beginning in November 1987 when discharge from Big Spring was still about 35 cfs, and nitrate concentrations exceeded 40 mg/L. Atrazine concentrations stayed relatively low, occasionally below detection limits, until early WY 1989, when concentrations began increasing. While some of the increase was coincident with snow-melt runoff recharge in February and March 1989, concentrations remained relatively high through the summer of WY 1989. Detections of other herbicides, particularly cyanazine (Fig. 9) also increased. As discussed, the summer of WY 1989 produced the lowest discharge rates, and the lowest baseflow nitrate concentration, for WYs 1988-89. The cause of the increase in atrazine concentrations and herbicide detections, under conditions that result in low flows and low nitrate concentrations, is unclear. Hallberg et al. (1989) note that nitrate concentrations related closely to average water flux through the Big Spring system on an annual basis for WYs 1982 through 1987. However, atrazine concentrations were "out of phase" with these parameters, possibly as a result of a general retardation of atrazine transport through the hydrologic system by adsorption or degradation processes. The data from WY 1989 may be further indicating a retardation of atrazine transport.

Table 13. Monthly summary of nitrate-N discharge for the Turkey River at Garber; Water Year 1989.

	1988 Oct	Nov	Dec	1989 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean NO_3 concentration,												
in mg/L;	10	14	19	17	16	9	15	12	9	5	14	13
as NO_3-N;	2.2	3.2	4.2	3.7	3.5	2.1	3.3	2.6	2.0	1.2	3.2	2.9
Mean NO_3 analyses,												
in mg/L;	9	14	20	13	17	12	13	10	9	5	15	9
as NO_3-N;	2.1	3.2	4.3	2.9	3.8	2.7	2.9	2.2	2.0	1.1	3.3	2.1
Total monthly NO_3 output, thousands lbs;	59	98	125	114	105	398	193	133	83	26	108	141
Total monthly NO_3 output, thousands kg;	27	45	57	52	48	180	88	60	37	12	49	64

However, the prevailing drought conditions were likely a factor. Pesticide degradation rates vary with environmental factors, including soil moisture conditions. Low soil moisture may inhibit hydrolysis and microbial activity, which are important degradation processes (USEPA, 1986). Dry conditions in WY 1988 may have left a larger than normal mass of herbicide available for mobilization and transport to the groundwater.

OVERVIEW OF MONITORING RESULTS FOR WYs 1982 THROUGH 1989

During the WY 1982 through WY 1989 period of record at Big Spring, precipitation has varied from 23 inches (WY 1988) to 44.5 inches (WY 1983) and groundwater discharge ranged between 12,600 ac-ft (WY 1989) and 41,400 ac-ft (WY 1983). The highest annual fw mean nitrate concentration, 46 mg/L, and the greatest nitrate-N load, 1,150 thousand pounds occurred in WY 1983. The lowest values, 25 mg/L nitrate and 195 thousand pounds of nitrate-N, occurred in WY 1989. WY 1985 registered an atrazine load of almost 50 pounds, at a fw mean concentration of 0.7 μg/L. In contrast, only nine pounds of atrazine were discharged during WY 1988, at a fw mean concentration of 0.13 μg/L. Maximum atrazine concentrations varied from 0.4 μg/L in WY 1988 to 10.0 μg/L in WY 1984 (Table 16). Annual variations in these parameters, by factors ranging from two to six, underscore the need for long-term monitoring of nonpoint-source contamination.

Annual fw mean nitrate concentrations increase with increasing groundwater discharge (Fig. 10 and Table 17; Libra et al., 1986; Hallberg et al., 1989). Annual fw mean atrazine concentrations, and the frequency and magnitude of detections of other herbicides, do not increase with discharge. Rather, the highest fw mean atrazine concentrations occur during years with the lowest total groundwater discharge. The reasons for this difference are unclear. Retardation of atrazine transport to and through the groundwater system, by adsorption and

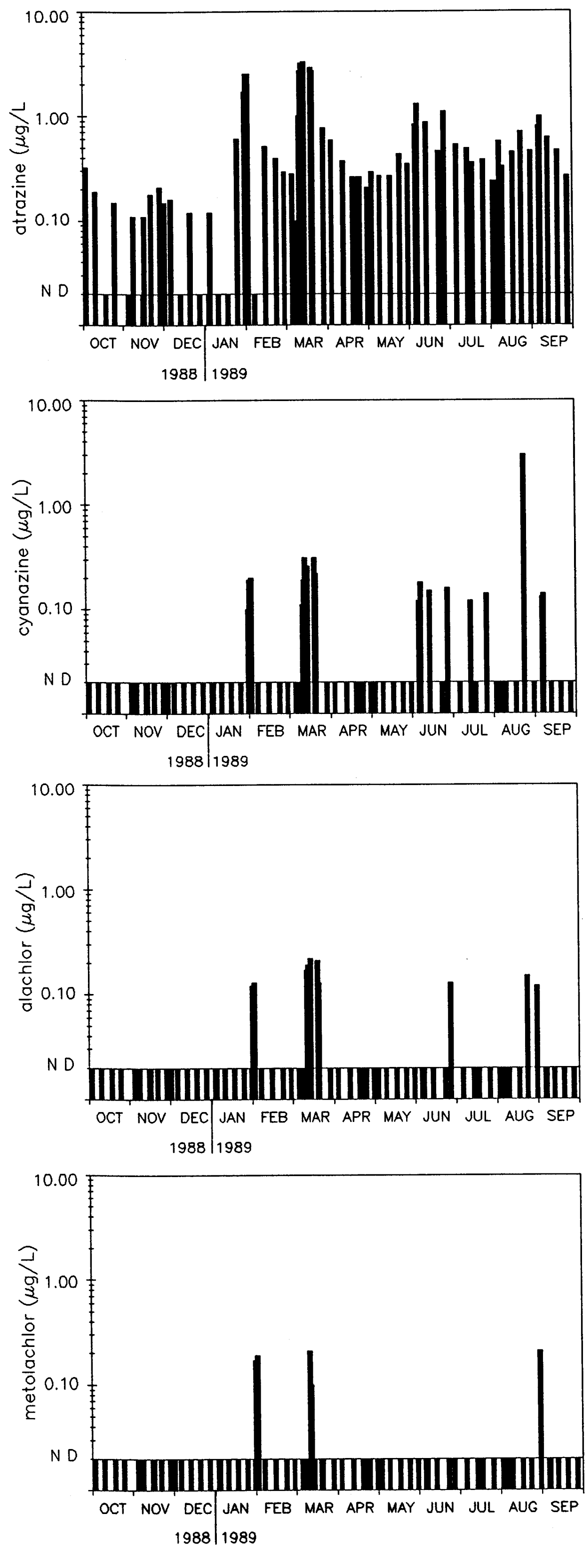

Figure 9. Bar graphs of pesticide concentrations at Big Spring for WY 1989. ND represents not detected.

Table 14. Monthly summary of atrazine discharged in groundwater from the Big Spring basin to the Turkey River; Water Year 1989.

	1988 Oct	Nov	Dec	1989 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean atrazine concentration, in *u*g/L	0.17	0.12	0.08	0.69	0.49	1.68	0.43	0.30	0.81	0.45	0.42	0.62
Mean of atrazine analyses, in *u*g/L	0.17	0.10	0.09	1.04	0.97	1.85	0.35	0.30	0.91	0.46	0.43	0.63
Total monthly atrazine output, lbs	0.5	0.3	0.2	2.7	1.3	8.7	1.3	0.8	1.9	0.9	1.0	1.6
Total monthly atrazine output, grams	218	139	90	1202	581	3959	595	353	865	411	468	722

Table 15. Monthly summary of atrazine discharge for the Turkey River at Garber; Water Year 1989.

	1988 Oct	Nov	Dec	1989 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean atrazine concentration, in *u*g/L	0.06	0.15	0.04	0.30	0.49	1.28	0.76	1.88	1.70	0.62	0.68	0.90
Mean of atrazine analyses, in *u*g/L	0.13	0.15	*	1.30	0.23	1.00	1.50	4.60	**	0.72	0.41	**
Total monthly atrazine output, lbs	1.6	4.8	1.2	9.2	14.6	245.7	44.6	97.3	71.2	13.9	23.3	44.0
Total monthly atrazine output, kg	0.7	2.2	0.5	4.2	6.6	111.4	20.2	44.1	32.3	6.3	10.6	19.9

* All samples below detection limit, ** Not sampled.

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

	Water Year								
	'82	'83	'84	'85	'86	'87	'88	'89	
Pesticide common chemical name	maximum concentration, ug/L								% detections
Herbicides									
atrazine	2.5	5.1	10.0	6.1	1.4	0.7	0.4	3.3	98%
alachlor	0.2	0.6	4.0	5.0	0.7	0.2	na	0.2	15%
cyanazine	0.7	1.2	1.7	4.6	0.1	0.2	1.0	3.0	15%
metolachlor	nd	0.6	4.5	4.6	0.6	nd	nd	0.2	5%
metribuzin	nd	nd	nd	3.6	nd	nd	nd	nd	<1%
2,4-D	na	na	na	0.2	nd	na	na	na	<1%
Insecticides									
fonofos	nd	0.1	0.3	0.4	nd	nd	na	na	<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.

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
Precipitation:								
water inches	34.0	44.5	32.8	35.8	36.7	32.0	22.9	24.3
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
total Q, inches	6.8	7.5	5.9	4.6	5.5	4.6	4.7	2.3
acre-feet, 1,000s	37.4	41.4	32.7	25.1	30.3	25.5	26.0	12.7
Nitrogen discharged with groundwater: flow-wtd mean concentration, mg/L								
as nitrate (NO_3)	39	46	43	31	43	41	43	25
as nitrate-N (NO_3-N)	8.8	10.3	9.7	7.0	9.7	9.1	9.6	5.7
ammonia-N *	*	*	*	*	0.1	0.1	0.1	0.6
organic-N *	*	*	*	*	0.5	0.2	0.3	0.8
nitrogen load; (nitrate-N + nitrite-N)								
1,000s lbs - N	873.0	1,150.0	843.4	476.8	796.8	636.1	672.0	194.9
lbs-N/acre (for total basin area)	13.2	17.4	12.8	7.2	12.1	9.6	10.2	3.0
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
atrazine load;								
lbs - atrazine	14.2	31.2	40.0	47.6	29.0	17.6	9.2	21.2

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

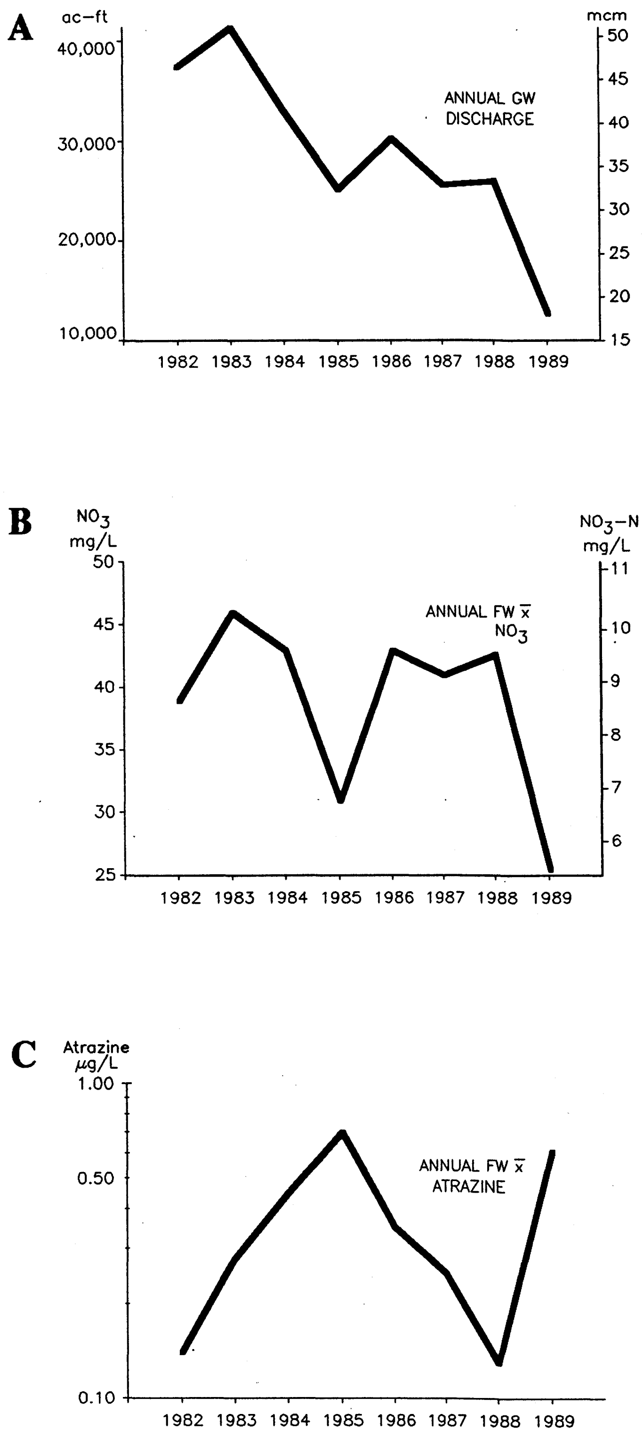

Figure 10. Summary of annual A) groundwater discharge, and B) flow-weighted mean NO_3 and C) atrazine concentrations from Big Spring groundwater.

degradation processes, and annual changes in the mass of atrazine present on the land surface, are likely important factors. While the mass of atrazine is largely a function of the amount applied in a given year, environmental factors may significantly affect chemical and microbial degradation processes, leaving variable percentages of the amount applied available for transport.

SUMMARY

WYs 1988 and 1989 were marked by extreme drought. Apart from several major snow-melt periods, recharge was limited and discharge was largely supplied by groundwater released from storage within the less transmissive parts of the hydrologic system. The resulting gradual decline in discharge was matched by a similar decrease in nitrate concentrations. Groundwater discharge declined from about 40 to just over 10 cfs, while nitrate concentrations dropped from 50 to 25 mg/L. During WY 1988 and early WY 1989, atrazine concentrations and the frequency of detections of other herbicides also followed a decreasing trend that had started in WY 1986. However, midway through WY 1989, atrazine concentrations and herbicide detections showed significant increases, although low discharge and low nitrate concentrations continued.

Analysis of annual data for WYs 1982 through 1989 show parallel trends for groundwater discharge and fw mean nitrate concentrations. Atrazine concentrations and detections of other herbicides do not show the same trends. Maxima occur during years of lower total groundwater discharge. Precipitation, discharge, and contaminant loads and concentrations have varied by factors of two to six during the eight years of record. This underscores the importance of long-term monitoring records for the understanding of nonpoint-source contamination.

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