SURFACE WATER MONITORING in the BIG SPRING BASIN 1986-1992: A Summary Review

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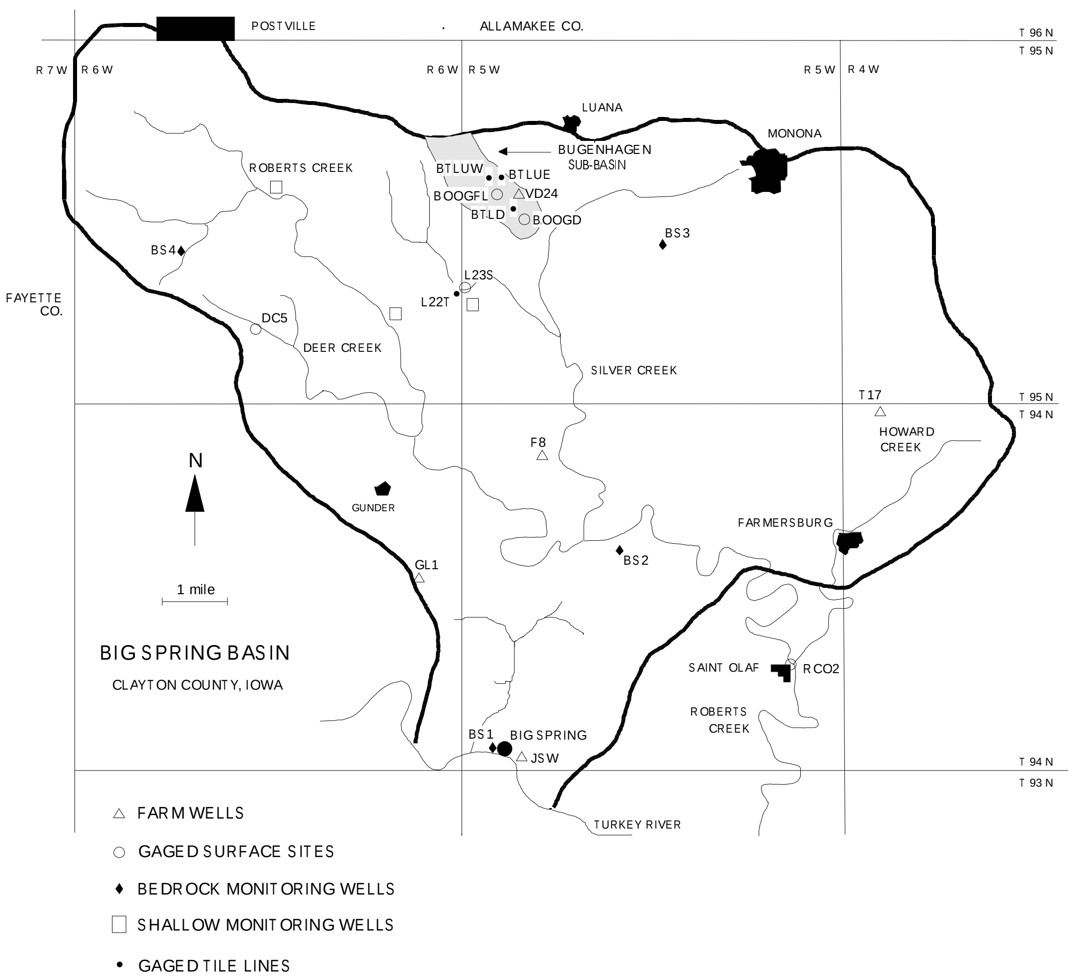

Iowa Department of Natural Resources
Larry J. Wilson, Director
January 1995

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A Report of The Big Spring Basin Demonstration Project

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SURFACE WATER MONITORING in the BIG SPRING BASIN 1986-1992: A Summary Review

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R.D. Rowden, R.D. Libra, G.R. Hallberg

ABSTRACT

The Big Spring basin is a 103 mi^2 groundwater basin in Clayton County, Iowa. Precipitation, surface water and 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 sub-basin surface-water sites BOOGD (1.15 mi^2), L23S (4.39 mi^2) and RC02 (70.7 mi^2) during water years (WYs) 1986 through 1992. During the monitoring period, precipitation has varied from 22.94 inches in WY 1988 to 47.27 inches in WY 1991. The driest consecutive two-year period in the state's history, WYs 1988 and 1989, preceded the wettest consecutive two-year period since monitoring began in 1981. Annual precipitation 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 precipitation total for WY 1992 was 35.74 inches. 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. During WY 1991, annual surface-water discharge totaled 1,020 acre feet (ac-ft) at BOOGD and 33,443 ac-ft at RC02. These were the highest annual discharges during WYs 1986-1992. The highest annual discharge from L23S, 3,980 ac-ft, occurred during WY 1992. The lowest annual surface-water discharges occurred in WY 1989, and were 57 ac-ft at BOOGD; 552 ac-ft at L23S; and 3,160 ac-ft at RC02.

The lowest annual flow-weighted (fw) mean nitrate-N concentrations and nitrate-N loads during WYs 1986-1992 occurred in WY 1989. Annual fw means and loads were 2.0 mg/L and 317 pounds at BOOGD; 2.0 mg/L and 2,998 pounds at L23S; and 2.0 mg/L and 17,393 pounds at RC02. During the WY 1982-1992 monitoring period at Big Spring, the lowest annual fw mean nitrate-N concentration and smallest nitrate-N load, 5.7 mg/L and 195,000 pounds, also occurred in WY 1989. The highest annual fw mean nitrate-N concentrations and greatest nitrate-N loads occurred during WY 1991. The fw mean and load from Big Spring for WY 1991 were 12.5 mg/L and 1,446,000 pounds. The fw mean and load from BOOGD were 16.0 mg/L and 44,336 pounds and from RC02 the mean and load were 11.3 mg/L and 1,032,119 pounds during WY 1991. At L23S, the highest annual fw mean nitrate-N concentration, 12.0 mg/L, occurred during WY 1991, but the greatest annual nitrate-N load, 123,530 pounds, was discharged during WY 1992. The annual fw mean nitrate-N concentrations and loads from the Turkey River were also lowest during WY 1989 and highest during WY 1991. Means and loads were 2.6 mg/L and 1.6 million pounds in WY 1989 and 9.9 mg/L and 29.6 million pounds in WY 1991.

Atrazine is the most consistently detected herbicide in Big Spring groundwater. It was

detected in 96% of the samples from Big Spring that were analyzed for pesticides during WYs 1982-1992. During WYs 1986-1992 atrazine was detected in 93% of the samples analyzed from BOOGD; 76% of the samples from L23S; and 94% of the samples from RC02. The highest annual fw mean atrazine concentrations and greatest atrazine loads generally occurred during WY 1991. The lowest means and loads were recorded during WYs 1987 and 1988. The annual fw mean atrazine concentrations and loads from Big Spring ranged from 0.13 µg/L and 9.2 pounds during WY 1988 to 1.17 µg/L and 135 pounds in WY 1991. At BOOGD fw means and loads varied from 0.17 µg/L and 0.1 pounds in WY 1987 to 3.32 µg/L and 9.2 pounds in WY 1991. At L23S the lowest fw mean, 0.12 µg/L, and smallest load, 0.4 pounds, occurred in WY 1987. The highest fw mean from L23S, 6.75 µg/L, occurred in WY 1989 and the greatest load, 22.5 pounds, occurred in WY 1991. At RC02, the lowest fw mean atrazine concentration, 0.24 µg/L, and smallest load, 6.7 pounds, were recorded in WY 1988, and the highest fw mean, 7.20 µg/L, and greatest load, 655 pounds, were registered in WY 1991. During WYs 1982-1992 the annual fw mean atrazine concentrations and loads from the Turkey River varied from 0.34 µg/L and 407 pounds in WY 1988, to 1.11 µg/L and 3,330 pounds in WY 1991. Alachlor, cyanazine, and metolachlor were also detected at most monitoring sites within the Big Spring basin and at the Turkey River during WYs 1986 through 1992.

Analysis of annual data from Big Spring and the Turkey River for WYs 1982-1992, and annual data from BOOGD, L23S and RC02 for WYs 1986-1992 indicates that while fw mean nitrate concentrations and loads generally parallel changes in discharge, fw mean atrazine concentrations and loads do not. Relatively high concentrations and loads of atrazine have occurred during years with low groundwater and surface-water discharge. During WYs 1988-1989 annual groundwater and surface-water discharge and annual fw mean nitrate concentrations and loads decreased to the lowest levels during the period of monitoring, while annual fw mean atrazine concentrations and loads increased significantly. The climatic variations and resulting hydrologic conditions exhibited in the Big Spring basin during WYs 1982-1992 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.

The similarity of seasonal trends and pronounced short- and long-term changes in nitrate and atrazine concentrations seen at monitoring sites throughout the Big Spring basin demonstrate the effectiveness of the nested monitoring network design. The pronounced short-term changes in nitrate and atrazine concentrations are responses to significant recharge events. The concentration changes at the larger watershed scales are not as great or immediate as changes at smaller scale monitoring sites, although they clearly occur. The nested design allows chemical responses to recharge events to be tracked through the hydrologic system, from the soil zone beneath individual fields to the basin water outlets. The design also allows integration and comparison of water-quality responses at different scales to assess effects of landuse and landscape-ecosystem processes. 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.

INTRODUCTION

The Big Spring basin is a 103 mi^2 groundwater basin located in Clayton County, northeast Iowa (Fig. 1). 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. As an outgrowth of research in the basin, a multi-agency group initiated the Big Spring Basin Demonstration Project (BSBDP) in 1986. This effort involves integrating public education, on-farm research, and demonstration projects that stress the environmental and economic benefits of prudent chemical management. The project involves various scales of monitoring to evaluate the environmental effects of farm management practices that improve efficiency and profitability, while reducing soil erosion, and chemical and nutrient contamination of surface and groundwater. Reviews of hydrologic and water-quality monitoring from Big Spring and the Turkey River for water years (WYs; October 1 through September 30) 1982 through 1991 have been presented by Hallberg and others (1983, 1984a, 1985, 1987, 1989), Libra and others (1986, 1987, 1991) and Rowden and others (1993). Analytical methods and landuse are reviewed in Hallberg and others (1989). 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 monitoring data for surface-water sites BOOGD, L23S and RC02

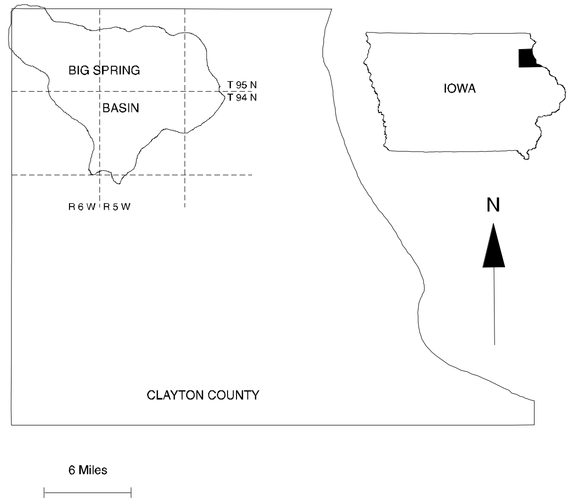


Figure 1. Map showing the location of the Big Spring basin.

during WYs 1986 through 1992 (Fig. 2). 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 other surface-water sites within the basin and sub-basins will be addressed in subsequent reports.

Geologic Setting and Landuse

The Big Spring basin is located within the Paleozoic Plateau Landform region (Prior, 1991; Hallberg et al., 1984b). Topographically, the basin varies from moderately rolling in the northern half of the area, to steeply sloping near the Turkey River Valley in the southern portion of the area (Fig. 2). Total relief in the basin is approximately 420 feet, with as much as 320 feet of relief occurring along the Turkey River Valley in the southwest corner of the basin (Hallberg et al., 1983). Bedrock units in the basin are comprised of Silurian and Ordovician strata and include the carbonate rocks of the Galena Group and the shales and silty-carbonate rocks of the Maquoketa Formation (Hallberg et al., 1983; Rowden and Libra, 1990). The bedrock is mantled by thin Quaternary deposits, but is frequently exposed along the small valleys in the basin. High on the landscape Pre-Illinoian till and glacial-

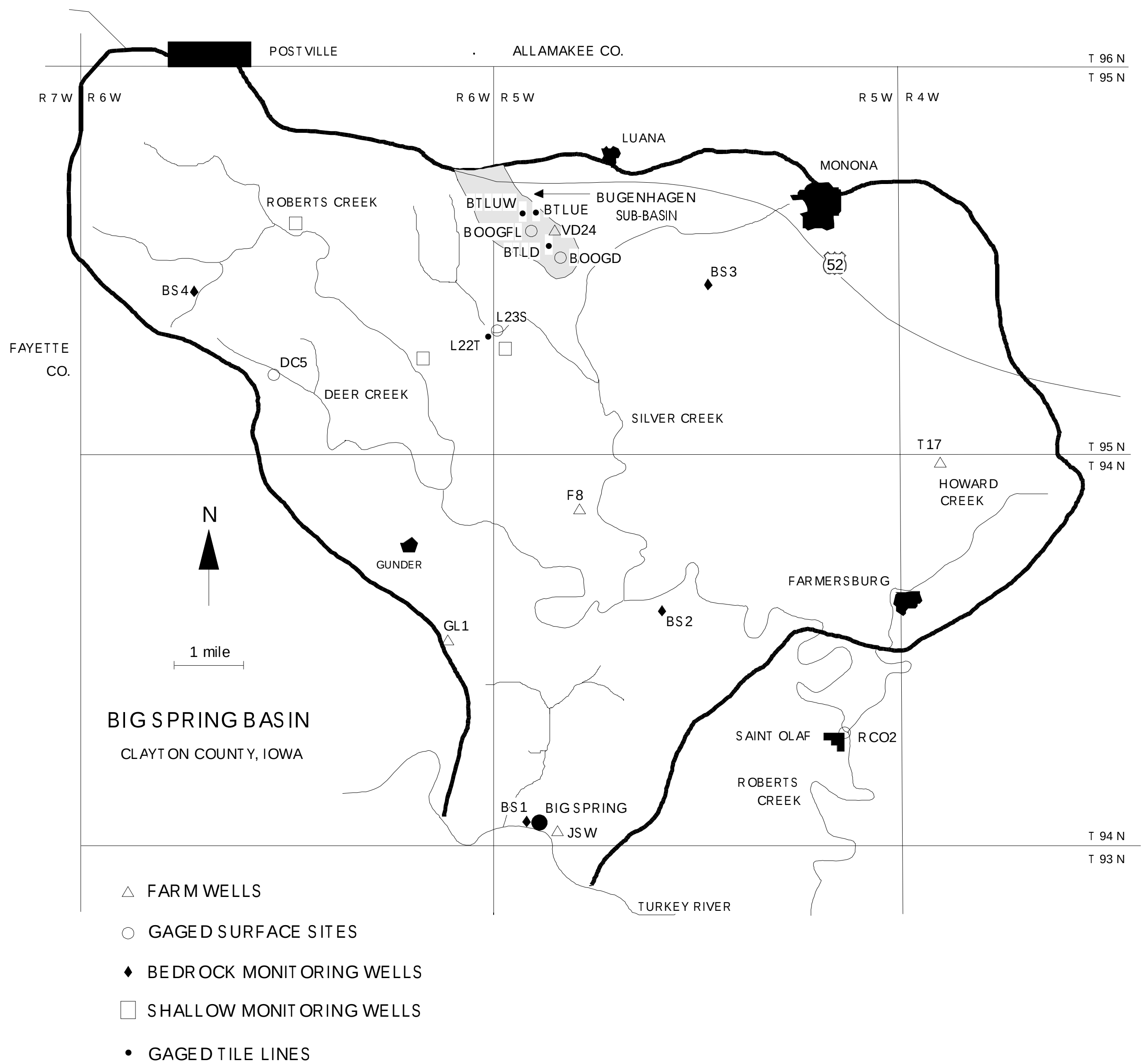


Figure 2. Map of the Big Spring basin showing the location of monitoring sites.

fluvial deposits are preserved. The uplands and hillslopes are draped by loess (wind-blown silt deposits), and loamy alluvial deposits occur in the stream valleys and drainageways.

The Galena aquifer is the main groundwater source in the basin. Where the Galena is at or near the surface, the basin exhibits a moderately developed karst landscape, as evidenced by sinkholes, occasional sinking streams, and springs. Big Spring, the main groundwater discharge point from the Galena aquifer, discharges in the valley of the Turkey River (Fig. 2).

The geographic extent of the groundwater basin was delineated through defining the water table/potentiometric surface of the Galena aquifer, dye traces, and locating and gaging gaining- and losing-stream reaches. Over 85% of the groundwater discharged from the basin flows through Big Spring. Surface water is discharged by various streams, but dominantly by Roberts Creek, which accounts for 65% of the basin's surface drainage area and about 75-80% of the surface-water flow leaving the basin.

Landuse within the basin is essentially all agricultural. There are no major urban or industrial areas, no landfills, commercial feedlots, or other major point sources to significantly affect groundwater quality. The only point sources within the basin are surface-water discharges from a creamery and a new sewage treatment plant. The effects of these discharges are monitored.

During most of the past decade, about 50% of the basin was in row crop, about 42% in cover crops, and about 5% of the basin is forest. The remainder of the basin is comprised of small urban areas, homesteads, quarries, and roads. Up until about 1986, 99% of the row crop acreage was in corn. Since then, there have been small increases in the amount of soybeans and sorghum grown in the area. The cover crops grown within the basin include haycrops, oats, and pasture, and occasionally small amounts of wheat. Landuse is interpreted from aerial photos, U.S. Department of Agriculture-Agricultural Stabilization and Conservation Service (USDA-ASCS) records, staff field notes, and landowner surveys.

Physiography and Groundwater in the Basin

The Big Spring basin includes most of the surface-drainage basin of Roberts Creek (Fig. 2). On the north and west, the groundwater-basin divide is nearly coincident with the surface-drainage divide, including the Roberts Creek system and a small unnamed creek which empties into the Turkey River near Big Spring (Fig. 2). On the east side of the basin, the groundwater divide cuts across the surface-drainage basins of Howard and Roberts creeks, and the basin of Bloody Run Creek, which lies to the east. Groundwater flows from the divide toward Big Spring, and discharges from the Galena aquifer through a narrow region to the Turkey River, with the major portion concentrated at Big Spring.

The relationship between the surface-water system and the groundwater system within the Big Spring basin is very complex. In their headwaters, most of the streams are recharged by shallow-groundwater flow from local seeps, or diffuse groundwater flow from the Maquoketa, Galena, and/or Quaternary deposits. In the central and eastern portions of the basin, the streams and their alluvial valleys are perched above the Galena potentiometric surface. Here streams lose surface water to the groundwater system through intermittent runoff into sinkholes, and as diffuse seepage in some perennial streams. As the streams leave the basin, in the St. Olaf area (Fig. 2), they receive discharge from the Galena aquifer, and again become gaining streams.

Most streams maintain perennial flows through portions of the basin that appear to be losing reaches. This is possible when sustained recharge, provided by shallow groundwater (including tile drainage) in the streams' headwaters, is greater than the rate of leakage into the groundwater system downstream. The upper portions of the alluvial deposits and large areas of the stream beds are relatively fine-textured, silty deposits, which provide relatively slow percolation, effectively retarding losses or leakage through the stream bed.

Much of the well-integrated, dendritic drainage network developed in the Big Spring basin is controlled by bedrock, especially the second order and larger valleys in the eastern two-thirds of the basin. Many valleys in this area appear to follow major joint trends. Several small blind valleys in this area disrupt the integrated drainage network and lead to the development of hollows which discharge entirely into sinkholes, entering the groundwater system of the Galena aquifer. However, infiltration rates through the soil and rock are relatively high in this area and runoff is infrequent. The majority of the sinkholes are filled with soil and quaternary deposits and as a consequence, the water that runs off into them must infiltrate through a mantle of silty to loamy sediment. The sinkhole basins occupy a total drainage area of 11.5 mi^2, or about 11% of the groundwater basin.

HYDROLOGIC AND WATER QUALITY MONITORING

The discharge of groundwater and surface-water in the study area is a function of recharge within the Big Spring 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 report will discuss the monitoring of precipitation, discharge, and water-quality at BOOGD, L23S and RC02, and some aspects of the discharge and water-quality record for Big Spring (BSP) and the Turkey River at Garber (TR01). 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 and other sites within the basin. All references to the Turkey River or Turkey River basin refer to the basin above Garber, Iowa. Discharge data for BOOGD, L23S, RC02, TR01, and BSP 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, 1984a; Libra et al., 1986, 1987, 1991; Rowden et al., 1993). These signatures can be tracked through the hydrologic system, from the soil zone beneath individual fields to the basin water outlets (Hallberg et al., 1984a; Libra et al., 1986, 1987, 1991; Littke and Hallberg, 1991; Rowden et al., 1993). Infiltration recharge is enriched in nitrate and other chemicals that are soluble and mobile in soil, relative to runoff recharge. Runoff recharge has lower concentrations of such compounds, but is enriched in herbicides and other chemicals with low solubility and soil mobility (e.g., greater adsorption). 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., 1984a). In general, low discharge periods are accompanied by lower contaminant concentrations, yielding small total contaminant loads. Concentrations are generally greater during periods of greater discharge, yielding larger loads, related to both the increased volume of water and greater concentrations.

Monitoring Site Descriptions

A network of over 50 sites in the Big Spring basin is routinely monitored for water quality. Precipitation, surface water, and groundwater from tile lines, shallow piezometers, bedrock wells and springs are included in the network (Fig. 2). The development of monitoring sites within the basin has been a cooperative effort. Staff from the USGS, Iowa City office, designed, constructed, and maintain the stream gaging stations (RC02, L23S, BOOGD, TR01, and BSP) and also cooperate in water-quality monitoring. Tile-monitoring installations (BTLUE, BTLUW, L22T, and BTLD) and a surface-water flume (BOOGFL) were designed and constructed under the direction of Dr. James Baker, Department of Agricultural Engineering, Iowa State University, Agriculture and Home Economics Experiment Station.

The basin monitoring network is designed in a nested fashion. The design 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., 1984a; Littke and Hallberg, 1991). Instrumentation at various sites adds significant detail to monitoring. The smallest sites instrumented are individual fields or landuse tracts (5 to 40 acres) with known management. From individual field sites, the nested monitoring design follows the natural hierarchy of the drainage system. Watersheds of increasing size are monitored, up to the main surface-water and groundwater outlets for the basin at RC02 and the Big Spring. The design allows integration and comparison of water-quality responses at different scales to assess effects 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 are clearly apparent 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 of all the individual parcels of land they contain.

Bugenhagen Sub-Basin

The Bugenhagen sub-basin includes approximately 1.7 mi^2 of the north-central Big Spring basin (Fig. 2). The sub-basin was selected early in the Big Spring Basin Demonstration Project to be a model area for implementation of improved farm management and soil conservation. The sub-basin generally has a small surface-water discharge, which drains towards a complex of soil-filled sinkholes on the margin of the Silver Creek floodplain. The uplands consist of loess, over remnants of glacial till and carbonate bedrock. The drainageways are filled with loamy alluvium that progressively thins, down drainage, over the bedrock. During low flow, surface water seeps into the alluvium of the stream-bed and the underlying bedrock before reaching the sinkholes. Intermittently, small openings or fractures in the bedrock swallow the discharge more directly. During higher flow conditions, discharge reaches the sinkhole complex located farther downstream. These sinkholes are large depressions filled with alluvium. They are not open directly into the bedrock, nor is bedrock exposed within the sinkholes. The water draining to the filled depressions infiltrates through the soil and into the groundwater system. During extreme runoff events the stream may overflow the sinks, beyond which there is no defined channel. Excess streamflow overflowing the sinkholes has been observed to spread out over the floodplain of Silver Creek and infiltrate into the alluvial soils.

The discharge from approximately 0.6 mi^2 of the upper half of the sub-basin is monitored by flow meters and automated water samplers housed in an instrument shed approximately 0.5 mi above the sinkhole complex. Both subsurface drainage from tile lines (BTLUE and BTLUW), and intermittent surface flow (BOOGFL) are monitored (Fig. 2). The tile lines have been sampled for water quality since 1981. They are installed in Otter and Worthen silt loams, poorly drained soils present in the gently sloping upland drainage basin. Otter soils occupy the drainageway and are flanked by Worthen soils at the base of the upland slopes (Kuehl, 1982).

Tile-outlet terraces were installed in the sub-basin beginning in 1987, as part of the implementation of soil conservation management practices. The addition of the tile outlets increased the drainage areas of BTLUW and BTLUE and caused the intermittent discharge through BOOGFL to essentially cease. BTLUE currently drains the eastern portion of the sub-basin north of the instrument shed, and the sub-basin area north of Highway 52/18. BTLUW drains the western part of the sub-basin, north of the equipment shed and south of the highway. The addition of the tile-outlet terraces changed the nature of the tile effluent. During dry periods BTLUE and BTLUW yield shallow groundwater. Following significant precipitation the tile intakes in the terraces direct surface runoff into the tiles, mixing it with the groundwater.

Sites BOOGD and BTLD are located approximately 0.25 mi downstream from BTLUE and BTLUW (Fig. 2). BOOGD monitors the intermittent surface-water discharge from 1.15 mi^2 of the sub-basin. The site is equipped with a standard USGS gaging station, with continuous discharge records beginning May 13, 1986 (Kalkhoff, 1989).

Site BTLD is located on the north bank of the sub-basin drainageway, immediately above BOOGD. The site monitors the discharge from a 5-inch tile line buried at a depth of approximately 3.5 feet in Otter silt loam. The drained field has been in pasture for over 30 years, and has had very little chemical application. This site provides a baseline for comparison with groundwater from fields more intensively cropped. There are no surface-water intakes connected to BTLD.

Silver Creek Sub-Basin

Site L23S monitors the surface water from a 4.39 mi^2 watershed of the west branch of Silver Creek (Fig. 2). The site is equipped with a standard USGS gaging station, with continuous discharge records since May 13, 1986.

L22T is 60 feet west of L23S, on the south bank of Silver Creek. The 5-inch tile is installed approximately 6 feet deep in alluvium mapped as Otter and Worthen soils. The field has been cropped to corn most of the years it has been monitored. L22T has flowed continuously since monitoring began. There are no surface intakes associated with the tile.

Deer Creek Sub-Basin

Deer Creek is a perennial tributary of Roberts Creek. It has been monitored at site DC05 since 1988 by the USGS (Fig. 2). At DC05, the creek has a 1.1 mi^2 drainage area. Tile lines, transects of shallow piezometers, and nested suction lysimeters are installed at this site. These are used to monitor groundwater movement and quality beneath an intensively cropped field, and to investigate interactions between the shallow groundwater and Deer Creek. Kahlkoff and Kuzniar (1991) provide further details on this site.

Roberts Creek

Site RC02 on Roberts Creek is located at St. Olaf, on the perimeter of the Big Spring basin (Fig. 2). Roberts Creek has a drainage area of 70.7 mi^2 above RC02. About 75-80% of the surface water exits the Big Spring basin here. The USGS maintains a standard gaging station at this location, with continuous discharge records available since March 25, 1986. Intermittent streamflow measurements have been made at Roberts Creek since the 1970's.

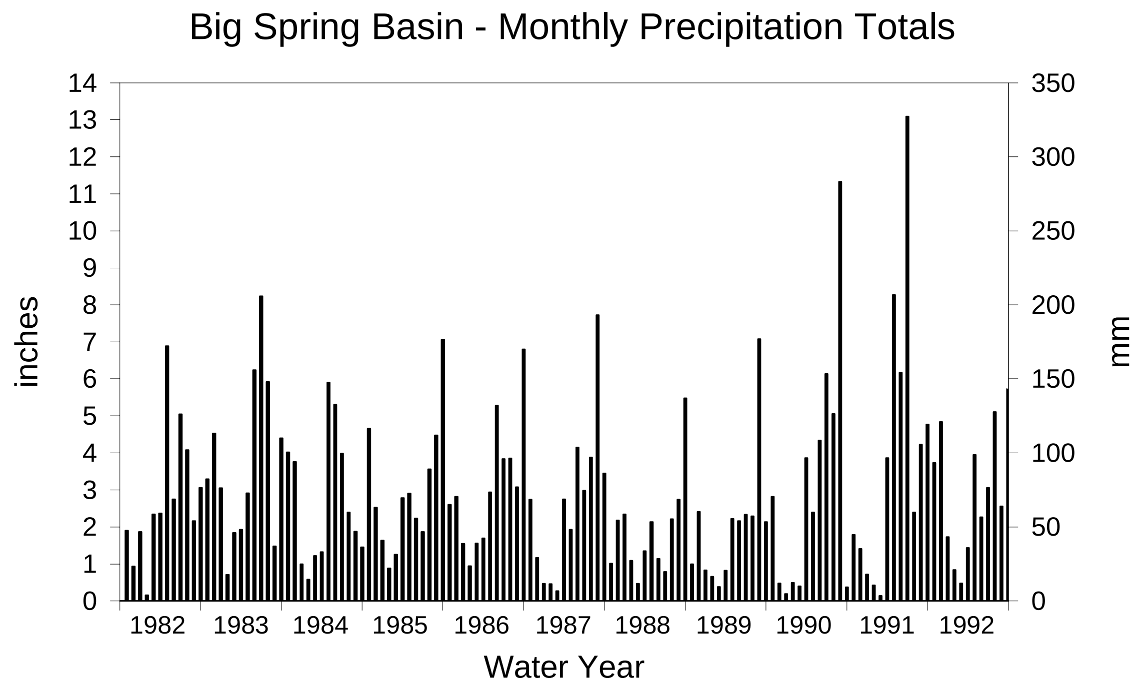
Precipitation

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, supplemented by observations within the 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 BOOGD and RC02. 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 1992 are shown in Figure 3. The eleven-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

A



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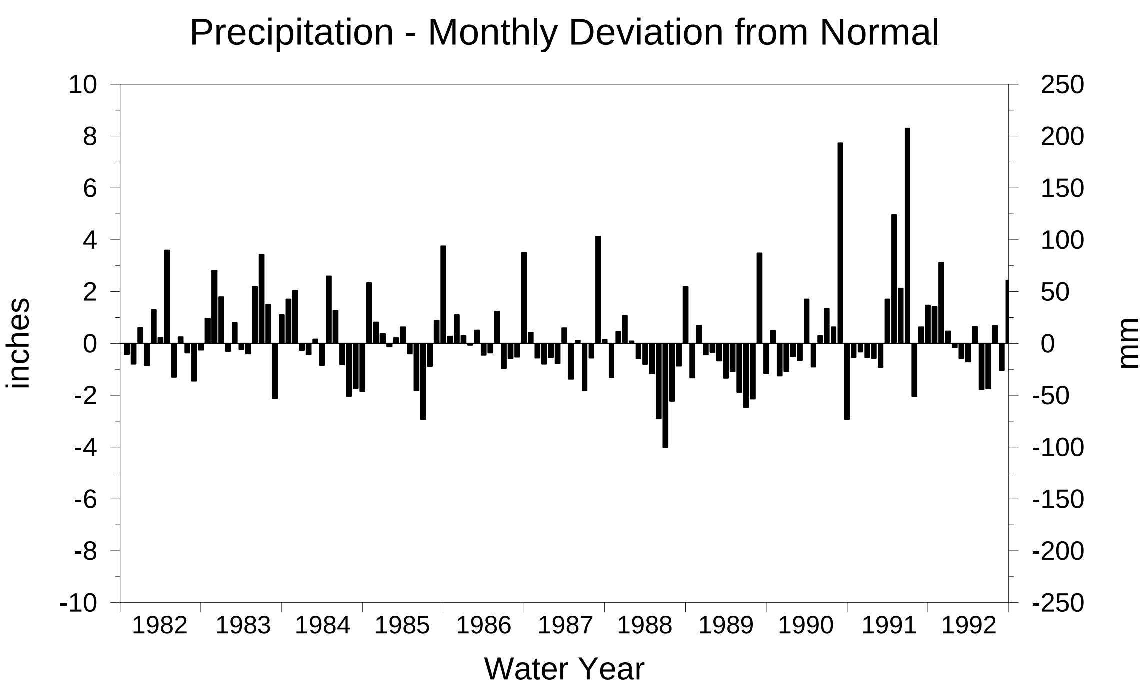

Figure 3. A) Monthly precipitation totals and B) departure from normal for the Big Spring basin, WYs 1982-1992 (Iowa Dept. of Ag. and Land Stewardship, State Climatology Office).

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, 1984a, 1989) have indicated that March through June are typically marked by low evapotranspiration and wet antecedent conditions, which are important for groundwater recharge. Precipitation during 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. Baseflow 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. 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 1982-1992 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

Table 1. Annual summary of water and chemical discharge for BOOGD for partial Water Year 1986; 05/13/86-09/30/86. (Discharge data from U.S. Geological Survey, Water Resources Division.)

DISCHARGE - Partial Water Year

Total	
acre-feet	67.0
millions cf	2.9
millions cm	0.08

Average	
cfs	0.24
cms	0.007
mg/d	0.2
gpm	108

PRECIPITATION AND DISCHARGE

	Partial Water Year
Precipitation	22.43 inches (569.7 mm)
Discharge	1.09 inches (27.7 mm)
Discharge as % of precipitation	4.9%

NITRATE DISCHARGE - Partial Water Year

Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	50.0	11.1
Mean of analyses	54.8	12.2

	NO_3-N output	**Total N output**
lbs - N	2,024	2,313
kg - N	918	1,049
lbs - N/acre	2.8	3.1

ATRAZINE DISCHARGE - Partial Water Year

Concentration - µg/L	
Flow-weighted mean	0.50
Mean of analyses	0.36

Total output	
lbs	0.09
g	41.3

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.

Precipitation during Water Year 1992 was about 2.8 inches above the long-term average. Rainfall was more evenly distributed than during WYs 1990 and 1991, with no large single rainfall or runoff events. Precipitation was above normal during October, November and September, and below normal during May, June, and August. The timing, intensity, and distribution of rainfall all affect the resultant surface runoff and recharge to the soil-groundwater system, and the concentrations of agricultural contaminants transported by surface- and groundwater.

Water Year 1986

Discharge Monitoring

Tables 1 through 3 and Figure 4 summarize the discharge, water quality and chemical-load data for surface-water sites BOOGD, L23S and RC02 for Water Year 1986. Continuous records of daily discharge data for site RC02 begin March 25, 1986 and for sites BOOGD and L23S, discharge data begin May 13, 1986. Since the discharge data from sites BOOGD, L23S and RC02 are incomplete, contaminant loading data in Tables 1 through 3 are computed for a partial water year.

Precipitation during the water year was 36.96 inches, about four inches above the long-term average. Precipitation from March 25 through September 30 was 25.79 inches, about 70% of the year's total. For the period May 13 through September 30, precipitation was 22.43 inches, or about 61% of the year's total. Precipitation was below normal during March, April, June, July, and August, above normal during May, and much higher than normal during September. Although the discharge hydrographs for RC02, L23S, and BOOGD are incomplete (Fig. 4), the discharge record from Big Spring for WY 1986 was dominated by a very

Table 2. Annual summary of water and chemical discharge for L23S for partial Water Year 1986; 05/13/86-09/30/86. (Discharge data from U.S. Geological Survey, Water Resources Division.)

DISCHARGE - Partial Water Year		
Total		
acre-feet	398	
millions cf	17	
millions cm	0.49	
Average		
cfs	1.3	
cms	0.04	
mg/d	0.87	
gpm	601	
PRECIPITATION AND DISCHARGE		
	Partial Water Year	
Precipitation	22.43 inches (570mm)	
Discharge	1.70 inches (43.2mm)	
Discharge as % of precipitation	7.6%	
NITRATE DISCHARGE - Partial Water Year		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	36.1	8.0
Mean of analyses	27.9	6.2
	NO_3-N output	**Total N output**
lbs - N	8,687	10,355
kg - N	3,940	4,680
lbs - N/acre	3.1	3.7
ATRAZINE DISCHARGE - Partial Water Year		
Concentration - µg/L		
Flow-weighted mean	0.30	
Mean of analyses	0.11	
Total output		
lbs	0.33	
g	148	

Table 3. Annual summary of water and chemical discharge for RC02 for partial Water Year 1986; 03/25/86-09/30/86. (Discharge data from U.S. Geological Survey, Water Resources Division.)

DISCHARGE - Partial Water Year		
Total		
acre-feet	7,771	
millions cf	338	
millions cm	9.6	
Average		
cfs	20.3	
cms	0.6	
mg/d	13.1	
gpm	9,111	
PRECIPITATION AND DISCHARGE		
	Partial Water Year	
Precipitation	25.79 inches (655mm)	
Discharge	2.06 inches (52.3mm)	
Discharge as % of precipitation	8.0%	
NITRATE DISCHARGE - Partial Water Year		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	31.4	7.0
Mean of analyses	27.5	6.1
	NO_3-N output	**Total N output**
lbs - N	147,400	202,309
kg - N	66,848	91,770
lbs - N/acre	3.3	4.5
ATRAZINE DISCHARGE - Partial Water Year		
Concentration - µg/L		
Flow-weighted mean	1.00	
Mean of analyses	0.69	
Total output		
lbs	21.1	
kg	9.6	

large event that occurred in March, and accounted for 19% of the spring's annual discharge (Hallberg et al., 1989). In March, snowmelt accompanied by significant, intense rains generated the highest instantaneous discharge (in excess of 360 cubic feet per second [cfs]) observed at Big Spring during WYs 1984 through 1986 (Hallberg et al., 1989). Infiltration recharge associated with the event sustained relatively high discharge at Big Spring through April. Recharge during the remainder of the water year was relatively minor. All surface-water sites exhibited gradually declining flow rates, until late September. In September, intense rainfall events generated significant runoff-recharge and a small amount of infiltration recharge as evidenced by the rapid increase and decrease in discharge, followed by a sustained increase in discharge into the beginning of WY 1987.

The annual discharge from BOOGD from May 13 through September 30 was 67 acre feet (ac-ft), at an average daily discharge rate of 0.24 cfs (Table 1). The discharge was equivalent to 4.9% of the total precipitation during the period. Flow ceased at BOOGD from August 11 through September 19, except for August 14 when the mean daily discharge was 0.10 cfs. The annual discharge from L23S from May 13 through September 30 was 398 ac-ft, and the average daily discharge was 1.3 cfs (Table 2). Discharge equaled about 7.6% of the precipitation during the May 13 through September period. At site RC02, the annual discharge for the period March 25 through September 30 was 7,771 ac-ft (Table 3). Average daily discharge was 20.3 cfs, with the total discharge equaling about 8.0% of the precipitation during the period. At Big Spring the annual discharge was 30,290 ac-ft, or about 15% of the annual precipitation, at an average daily discharge rate of 42.0 cfs (Hallberg et al., 1989). The annual discharge from the Turkey River at Garber (TR01) was 920,600 ac-ft, or 28% of the annual precipitation, at an average discharge rate of 1,272 cfs (Hallberg et al., 1989). Discharge from TR01 was equivalent to 138% of the long-term (1951-1980) average.

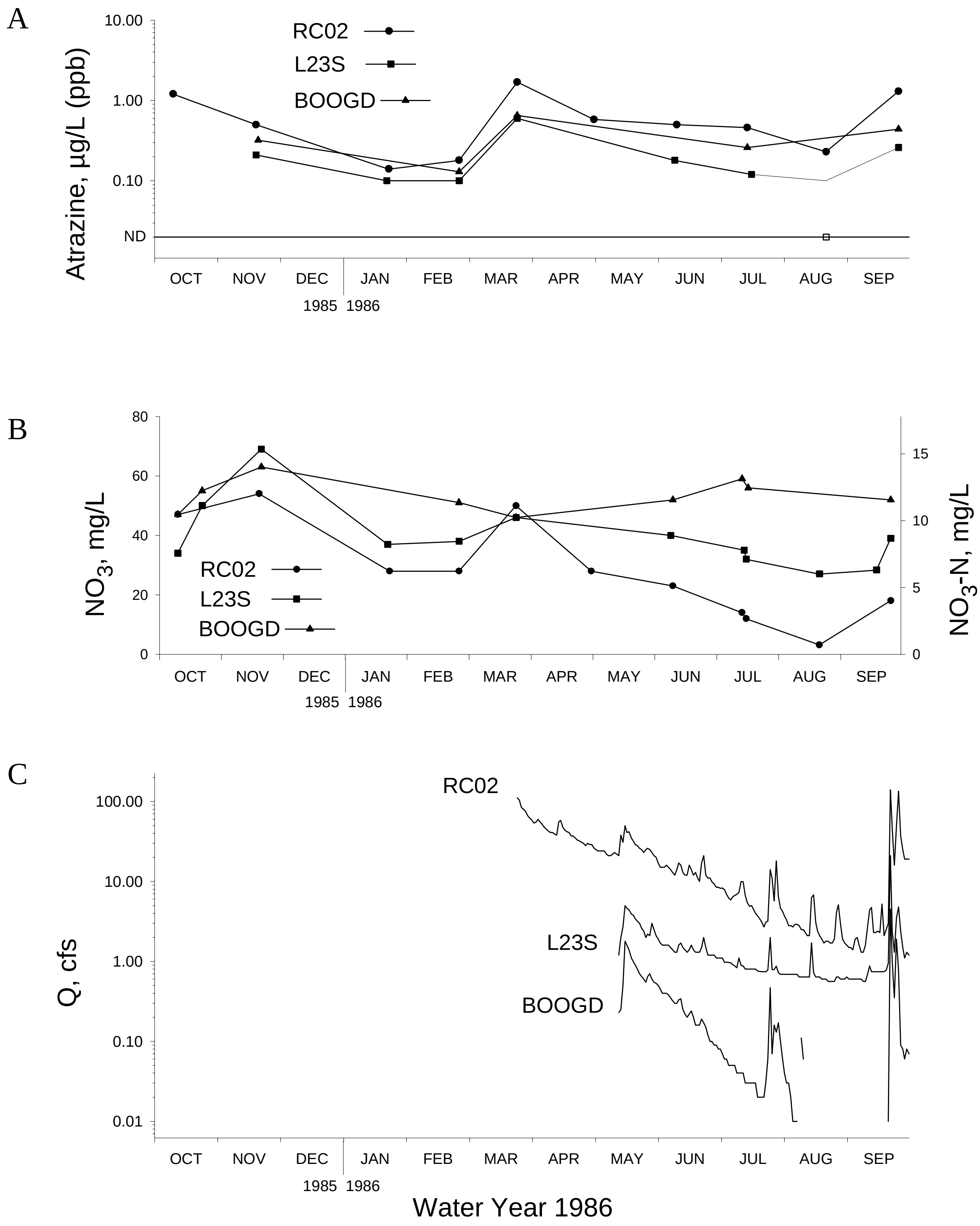

Figure 4. A) Atrazine and B) nitrate concentrations, and C) surface-water discharge (Q) at RC02, L23S, and BOOGD for WY 1986. (Discharge data are from the U.S. Geological Survey, W.R.D., IA Dist.).

Nitrate Monitoring

Tables 1 through 3 and Figure 4 summarize the nitrate analyses for BOOGD, L23S and RC02 during WY 1986 (Appendix A contains monthly nitrate data for sites BOOGD, L23S, and RC02 for WYs 1986 through 1992 in Tables 1a through 21a). During WY 1986, nitrate samples were generally taken at all sites on a monthly basis.

Table 1 summarizes the nitrate and nitrate-nitrogen monitoring at BOOGD from May 13 through September 30 of WY 1986. During the water year, nine samples were analyzed for nitrate, and five samples were analyzed for the full nitrogen series (N-series; nitrate- plus ammonia-, and organic-N). The detection limit for nitrate analyses is usually 1.0 mg/L, although the detection limit may be increased to 5.0 mg/L, depending on lab variations and quantity of water sampled. The detection limit for N-series analyses is usually 0.1 mg/L. The flow-weighted (fw) mean nitrate concentration (mean concentration per unit volume of discharge) for the water year was 50 mg/L (11.1 mg/L as NO_3-N). A total of 2,313 pounds of nitrogen (nitrate- plus organic-, and ammonia-nitrogen) were discharged by surface water from the sub-basin during the water year; of this total, 2,024 pounds, or 88%, was in the form of nitrate. Within the 1.15 mi^2 drainage area of BOOGD, the total nitrate-nitrogen output was equivalent to 2.8 lbs-N/acre and the total nitrogen output was 3.1 lbs-N/acre.

Near the beginning of WY 1986 nitrate concentrations at BOOGD were 47 mg/L (10.4 mg/L as NO_3-N; Fig. 4). Minor recharge resulted in a general rise in concentrations to 63 mg/L (14.0 mg/L as NO_3-N) in late November. Nitrate concentrations were 46 mg/L (10.2 mg/L as NO_3-N) in late March and 59 mg/L (13.1 mg/L as NO_3-N) in mid-July as discharge continued to recede. The general increase in nitrate concentrations at BOOGD from March to July was contrasted by a general decrease in nitrate concentrations at L23S and RC02 during the same period (Fig. 4). Nitrate concentrations at BOOGD were 52 mg/L (11.6 mg/L as NO_3-N) four days after a large runoff event in late September.

Monthly fw mean nitrate concentrations increased from 46.7 mg/L (10.4 mg/L as NO_3-N) in May, to 57 mg/L (12.7 mg/L as NO_3-N) in July, then decreased to 52 mg/L (11.6 mg/L as NO_3-N), during September (Table 1a). Discharge ceased at BOOGD from August 15 until September 20. During the last 19 days of May, 846 pounds of nitrate-nitrogen were discharged along with 29.9 ac-ft of water, accounting for 42% of the total nitrate-nitrogen and 45% of the total surface-water discharge for the five-month period. The lowest monthly nitrate-nitrogen discharge, 27 pounds, and the lowest monthly surface-water discharge, 0.8 ac-ft, occurred during August.

Tables 2 and 2a summarize the nitrate and nitrate-nitrogen monitoring at L23S from May 13 through September 30 of WY 1986. During the period, eleven samples were analyzed for nitrate, and four samples were analyzed for N-series. The fw mean nitrate concentration for the water year was 36.1 mg/L (8.0 mg/L as NO_3-N). A total of 10,355 pounds of nitrogen were discharged by surface water from the sub-basin during the water year; of this total, 8,687 pounds, or 84%, was in the form of nitrate. Within the 4.39 mi^2 drainage area of L23S, the total nitrate-nitrogen output was equivalent to 3.1 lbs-N/acre and the total nitrogen output was 3.7 lbs-N/acre.

Near the beginning of WY 1986, nitrate concentrations at L23S were 34 mg/L (7.6 mg/L as NO_3-N; Fig. 4). Concentrations increased to 69 mg/L (15.3 mg/L as NO_3-N) in late November, then declined to 37 mg/L (8.2 mg/L as NO_3-N) in late January following snowmelt. Nitrate concentrations increased to 46 mg/L (10.2 mg/L as NO_3-N) in late March. Following snowmelt and rainfall events in March, both discharge and nitrate concentrations generally declined through August. Rainfall in late September generated recharge, and nitrate concentrations increased to 39 mg/L (8.7 mg/L as NO_3-N), four days after peak discharge occurred.

Table 2a summarizes the nitrate data from L23S for the last five months of WY 1986. The highest monthly fw mean nitrate concentration, 42.8 mg/L (9.5 mg/L as NO_3-N), occurred during May, and the lowest monthly fw mean, 28.2 mg/L (6.3 mg/L as NO_3-N), occurred during August as discharge continued to recede. May also had the highest monthly nitrate-nitrogen discharge, 2,878 pounds, and the highest monthly surface-water discharge, 111 ac-ft, accounting for about 33% of the total nitrate-nitrogen output and about 28% of the total surface-water discharge during the five-month period.

Tables 3 and 3a summarize the nitrate and nitrate-nitrogen monitoring at RC02 from March 25 through September 30 of WY 1986. During the water year, ten samples were analyzed for nitrate, and eight samples were analyzed for N-series. The fw mean nitrate concentration for the water year was 31.4 mg/L (7.0 mg/L as NO_3-N). A total of 202,309 pounds of nitrogen were discharged by surface water from Roberts Creek during the water year; of this total, 147,400 pounds, or 73%, was in the form of nitrate. Within the 70.7 mi^2 drainage area of RC02, the total nitrate-nitrogen output was equivalent to 3.3 lbs-N/acre and the total nitrogen output was 4.5 lbs-N/acre.

Nitrate concentrations increased from 47 mg/L (10.4 mg/L as NO_3-N; Fig. 4) in early October to 54 mg/L (12.0 mg/L as NO_3-N) in November. In January and February nitrate concentrations were 28 mg/L (6.2 mg/L as NO_3-N). In March, nitrate concentrations rose to 50 mg/L (11.1 mg/L as NO_3-N). During the remainder of the water year, both discharge and nitrogen concentrations gradually declined until rainfall events in September generated recharge. Nitrate concentrations increased from <5 mg/L (0.7 mg/L as NO_3-N) in late August to 18 mg/L (4.0 mg/L as NO_3-N) in late September.

Table 3a summarizes the nitrate data for the last seven months of WY 1986 (March is computed using the last seven days of the month). The highest monthly fw mean, 50 mg/L (11.1 mg/L as NO_3-N), occurred in March following significant recharge events. The lowest fw mean, 5.2 mg/L (1.2 mg/L as NO_3-N), occurred during August as discharge continued to recede. August also had the lowest monthly output of nitrate-nitrogen, 536 pounds, and the lowest monthly surface-water discharge, 171 ac-ft. During April, 59,349 pounds of nitrate-nitrogen were discharged along with 2,522 ac-ft of surface water, accounting for about 40% of the nitrate-nitrogen and about 32% of the surface-water discharged during the last seven months of WY 1986.

At Big Spring, the fw mean nitrate concentration for the water year was 43.0 mg/L (9.7 mg/L as NO_3-N; Hallberg et al., 1989). A total of 839,790 pounds of nitrogen were discharged, and of this total, 790,454 pounds, or 94%, was in the form of nitrate. Within the 103 mi^2 drainage area of Big Spring, the total nitrogen output was equivalent to 12.7 lbs-N/acre and the total nitrate-nitrogen output was 12.0 lbs-N/acre. The highest monthly fw mean, 49 mg/L (10.9 mg/L as NO_3-N), occurred in April, and the greatest monthly nitrate-nitrogen discharge, 165,000 pounds, occurred in March accounting for 21% of the annual total.

The fw mean nitrate concentration for the Turkey River during WY 1986 was 28.0 mg/L (6.2 mg/L as NO_3-N; Hallberg et al., 1989). A total of 14,306,000 pounds of nitrogen were discharged during the water year. Within the 1,545 mi^2 drainage area of TR01, the total nitrogen output was equivalent to 14.5 lbs-N/acre. The greatest monthly nitrate-nitrogen discharge, 3,800,00 pounds, occurred in March, and accounted for 27% of the annual discharge.

Pesticide Monitoring

Tables 1 through 3 and Figure 4 summarize the results of pesticide monitoring at BOOGD, L23S and RC02 during WY 1986 (Tables 22 and 23 summarize the maximum concentrations and percentage of pesticides detected in samples on an annual basis, and Appendix B contains the monthly atrazine data for sites BOOGD, L23S, and RC02 for WYs 1986 through 1992 in Tables 1b through 21b). Samples for pesticide analyses were generally taken at all sites on a monthly basis during the water year.

Five samples from BOOGD were analyzed for pesticides during WY 1986. Atrazine was the only pesticide detected during the water year. *All* samples collected contained detectable levels of atrazine (the detection limit for pesticides is usually 0.10 μg/L, although the detection limit may be increased to 0.20 μg/L, depending on the quantity or turbidity of water sampled). During the five-month period a total of 0.09 pounds of atrazine were discharged, at a fw mean concentration of 0.50 µg/L.

Atrazine concentrations were 0.32 µg/L in November and decreased to 0.13 µg/L in late February (Fig. 4). Snowmelt and rainfall events in March generated runoff, and atrazine concentrations increased to 0.65 µg/L, the maximum concentration detected during the water year. Following March, both discharge and atrazine concentrations declined through mid-July. Atrazine concentrations were 0.26 µg/L in mid-July, and 0.44 µg/L in late September, following a significant recharge event.

Monthly fw mean atrazine concentrations for BOOGD decreased from 0.62 µg/L in May to 0.26 µg/L in July, then increased to 0.44 µg/L in September (Table 1b). August had the lowest monthly atrazine output, 0.39 grams, and lowest monthly surface-water discharge, 0.83 ac-ft, during the water year. May had the highest monthly atrazine output, 23 grams, and the highest discharge, 30 ac-ft, which accounted for 56% of the atrazine output and 45% of the surface-water discharge during the five-month period.

During the water year, eight samples from L23S were analyzed for pesticides. Seven samples, or 88% of the samples collected contained detectable levels of atrazine. The total output of atrazine at L23S was 0.33 pounds, at a fw mean concentration of 0.30 µg/L (Table 2).

Atrazine concentrations declined from 0.21 µg/L in November to 0.10 µg/L in January and late February (Fig. 4). Atrazine concentrations increased to 0.60 µg/L following runoff events in March. Concentrations reached non-detectable levels in late August as discharge continued to recede. Rainfall events in September generated runoff and atrazine concentrations increased to 0.26 µg/L.

Table 2b summarizes the atrazine data from L23S for the last five months of WY 1986. Monthly fw mean atrazine concentrations decreased from 0.36 µg/L in May to 0.10 µg/L in August, then increased to 0.53 µg/L during September. The lowest monthly atrazine output, 5.1 grams, occurred during August, and the highest monthly output, 69 grams, occurred during September. September accounted for 47% of the atrazine output during the five-month period.

Other pesticides detected at L23S during the water year include alachlor in three, or 38% of the samples collected, and metolachlor in one, or 13% of the samples collected. The highest concentration of pesticides detected during the water year included atrazine at 0.60 µg/L; metolachlor at 0.60 µg/L; and alachlor at 0.31 µg/L. The maximum concentration detected for atrazine occurred in March, and for metolachlor and alachlor, maximum detections occurred in June. Metolachlor was detected during June only, and alachlor was detected in March, June, and September. Atrazine and alachlor were detected in samples collected several weeks, and in some cases months, prior to chemical applications for the 1986 growing season.

Table 3 summarizes the atrazine data for RC02 for WY 1986. During the water year, 10 samples were analyzed for pesticides. All samples collected contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration was 1.00 µg/L and the annual atrazine discharge was about 21 pounds.

Atrazine concentrations at RC02 showed the same seasonal trends as sites BOOGD and L23S, although concentrations were generally higher. Concentrations decreased from 1.20 µg/L in mid-October to 0.14 µg/L in January. Atrazine concentrations increased to 1.70 µg/L in late March, then decreased to 0.29 µg/L in August. Near the end of the water year atrazine concentrations were 1.30 µg/L.

Table 3b presents the atrazine data for the last seven months of WY 1986 on a monthly basis. Monthly fw mean atrazine concentrations decreased from 1.70 µg/L in March to 0.30 µg/L in August, then increased to 1.29 µg/L in September. The greatest monthly atrazine output, 3,535 grams, occurred during April, and the lowest monthly output, 63 grams, occurred during August. April accounted for about 37% of the total atrazine output during the seven-month period.

Other pesticides detected at RC02 during the water year include alachlor in two, or 20% of the samples collected, and cyanazine in one, or 10% of the samples collected. The highest concentration of pesticides detected during the water year included atrazine at 1.70 µg/L; alachlor at 0.31 µg/L; and cyanazine at 0.14 µg/L. The maximum concentration detected for atrazine occurred in March, and maximum detections for alachlor and cyanazine occurred in September. Alachlor was detected in May and September, and cyanazine was detected during September only.

At Big Spring, about 29 pounds of atrazine were discharged during WY 1986, at a fw mean concentration of 0.35 µg/L (Hallberg et al., 1989). The largest monthly atrazine discharge, 6.9 pounds, occurred in March and accounted for 24% of the annual discharge.

The annual fw mean atrazine concentration for the Turkey River was 0.60 µg/L and the annual atrazine discharge was 1,407 pounds (Hallberg et al., 1989). The largest monthly atrazine discharge from TR01, 189 pounds, occurred in September and accounted for 10% of the annual discharge.

Water Year 1987

Discharge Monitoring

Tables 4 through 6 and Figure 5 summarize the discharge, water-quality and chemical-load data for surface-water sites BOOGD, L23S and RC02 during WY 1987. In Figure 5, note the decrease in scale on the nitrate plot and the increase in scale on the discharge plot relative to WY 1986.

Although the annual precipitation of 31.98 inches was only about an inch below normal, the temporal distribution of precipitation along with antecedent conditions led to limited groundwater recharge during WY 1987. From WYs 1984 through 1987 precipitation during the March through June months was below normal, having a cumulative effect on groundwater and surface-water recharge within the Big Spring basin. During WY 1987, precipitation totals were below normal during the growing season and greater than normal during the fall. About 7.7 inches, or 24% of the annual precipitation occurred during August, with the remainder of the water year being more than 5.0 inches or, about 16% below normal.

Table 4. Annual summary of water and chemical discharge for BOOGD for Water Year 1987. (Discharge data from U.S. Geological Survey, Water Resources Division.)

DISCHARGE		
Total		
acre-feet	219	
millions cf	9.5	
millions cm	0.27	
Average		
cfs	0.30	
cms	0.008	
mg/d	0.2	
gpm	135	
PRECIPITATION AND DISCHARGE		
Precipitation	31.98 inches (812mm)	
Discharge	3.57 inches (90.7mm)	
Discharge as % of precipitation	11%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	42.1	9.4
Mean of analyses	38.9	8.6
	NO_3-N output	**Total N output**
lbs - N	5,591	6,747
kg - N	2,535	3,059
lbs - N/acre	7.6	9.2
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	0.17	
Mean of analyses	0.31	
Total output		
lbs	0.10	
g	46.2	

Table 5. Annual summary of water and chemical discharge for L23S for Water Year 1987. (Discharge data from U.S. Geological Survey, Water Resources Division.)

DISCHARGE

Total

acre-feet	1,220
millions cf	53
millions cm	1.5

Average

cfs	1.7
cms	0.05
mg/d	1.1
gpm	763

PRECIPITATION AND DISCHARGE

Precipitation	31.98 inches (812mm)
Discharge	5.21 inches (132mm)
Discharge as % of precipitation	16%

NITRATE DISCHARGE

Concentration - mg/L	As NO_3	As NO_3-N
Flow-weighted mean	38.3	8.5
Mean of analyses	37.7	8.4

	NO_3-N output	Total N output
lbs - N	27,177	38,303
kg - N	12,779	17,370
lbs - N/acre	9.7	13.6

ATRAZINE DISCHARGE

Concentration - µg/L

Flow-weighted mean	0.12
Mean of analyses	0.02

Total output

lbs	0.40
kg	0.18

The annual discharge for BOOGD during WY 1987 was 219 ac-ft, at an average daily discharge rate of 0.30 cfs (Table 4). Discharge during the water year was equivalent to 11% of the annual precipitation. Discharge at BOOGD ceased November 26, and was intermittent until February 6. The mean daily discharge for BOOGD on days with discharge during this period was approximately 0.01 cfs. Discharge occurred on December 2, 6-9, 17, 25-28, and on January 4, 6, and 14-15. BOOGD was dry on February 14, and 17-18 and July 10. The discharge for L23S during the water year was 1,220 ac-ft, at an average daily rate of 1.7 cfs (Table 5). The discharge was equivalent to 16% of the annual precipitation. At RC02, the annual discharge was 12,220 ac-ft and the average daily rate equaled 16.9 cfs (Table 6). During WY 1987, the discharge from RC02 was equivalent to 10% of the precipitation. At Big Spring the annual discharge was 25,554 ac-ft, or about 14% of the annual precipitation, at an average daily discharge rate of 35.4 cfs (Hallberg et al., 1989). Total discharge from the Turkey River at Garber (TR01) was 700,100 ac-ft, at an average discharge rate of 967 cfs (Hallberg et al., 1989). Annual discharge from TR01 was equivalent to 27% of the annual precipitation and 106% of the long-term average.

The hydrographs for WY 1987 show a minor recharge event in October, followed by generally receding discharge until mid-February (Fig. 5). Snowmelt and rainfall events in February, early March and late April generated runoff and minor recharge, sustaining increased discharge at RC02 and L23S. At BOOGD, discharge receded to near previous levels by early April. From April through June, general recession at all sites was punctuated by minor runoff and infiltration recharge events. In August and late September, intense rainfall events generated the largest runoff events of the water year, with the exception of spring runoff at BOOGD.

Nitrate Monitoring

Tables 4 through 6 and Figure 5 summarize the nitrate analyses from BOOGD, L23S and RC02 during WY 1987. Beginning in May 1987, the sampling interval for nitrate, N-series, and pesticides was increased from monthly to weekly, increasing the resolution of monitoring data.

During the water year, twenty-five samples from BOOGD were analyzed for nitrate, and sixteen samples were analyzed for N-series. The annual fw mean nitrate concentration was 42.1 mg/L (9.4 mg/L as NO_3-N; Table 4). A total of 6,747 pounds of nitrogen were discharged by surface water from the sub-basin during the water year; of this total, 5,591 pounds, or 83%, was in the form of nitrate. Within the drainage area of BOOGD, the total nitrate-nitrogen output was equivalent to 7.6 lbs-N/acre and the total nitrogen output was 9.2 lbs-N/acre.

Near the beginning of WY 1987 nitrate concentrations at BOOGD were 54 mg/L (12.0 as NO_3-N; Fig. 5). Concentrations declined to 41 mg/L (9.1 as NO_3-N) following minor runoff recharge from snowmelt in February. Nitrate concentrations were 43 mg/L (9.6 as NO_3-N) near the end of March, as discharge continued to recede. Rainfall events in April generated minor runoff and nitrate concentrations decreased to 35 mg/L (7.8 as NO_3-N), one day before the maximum daily discharge for the month occurred on April 22. Six days later, nitrate concentrations increased to 57 mg/L (12.7 as NO_3-N), as the percentage of groundwater baseflow constituting the discharge increased. Nitrate concentrations remained near 45 mg/L (10.0 as NO_3-N) throughout May as discharge generally receded. From May through mid-June both discharge and nitrate concentrations generally declined. Precipitation events during the remainder of the water year caused significant fluctuations in both discharge and nitrate concentrations. Small rainfall events had little effect on the overall volume of surface-water discharge, but probably affected the proportion of infiltration- versus runoff-recharge comprising the surface water. These fluctuations in recharge component caused significant variations in nitrate concentrations (from 19 mg/L on June 17, to 51 mg/L on June 21, to 17 mg/L in mid-July). Nitrate concentrations increased to 47 mg/L (10.4 as NO_3-N) on July 27, three days after the maximum daily discharge for the month occurred. The lowest nitrate concentration sampled during the water year, 3 mg/L (0.7 as NO_3-N),

Table 6. Annual summary of water and chemical discharge for RC02 for Water Year 1987. (Discharge data from U.S. Geological Survey, Water Resources Division.)

DISCHARGE		
Total		
acre-feet	12,220	
millions cf	532	
millions cm	15	
Average		
cfs	16.9	
cms	0.48	
mg/d	10.9	
gpm	7,585	
PRECIPITATION AND DISCHARGE		
Precipitation	31.98 inches (812mm)	
Discharge	3.24 inches (82.3mm)	
Discharge as % of precipitation	10%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	32.1	7.1
Mean of analyses	27.7	6.2
	NO_3-N output	**Total N output**
lbs - N	236,057	277,391
kg - N	107,075	125,821
lbs - N/acre	5.2	6.1
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	0.68	
Mean of analyses	0.41	
Total output		
lbs	22.5	
kg	10.2	

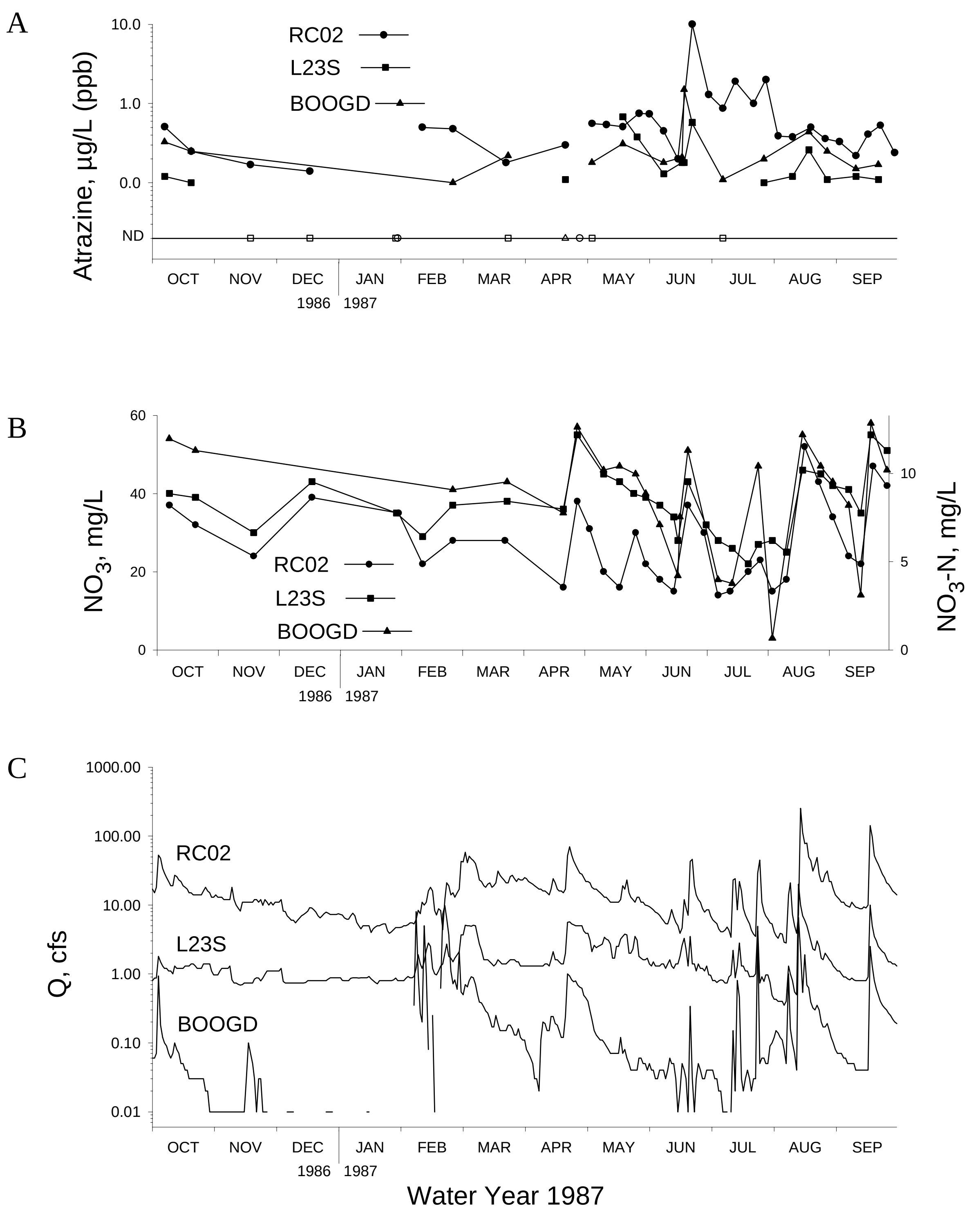

Figure 5. A) Atrazine and B) nitrate concentrations, and C) surface-water discharge (Q) at RC02, L23S, and BOOGD for WY 1987 (note the decrease in scale on the nitrate plot and the increase in scale on the discharge plot relative to WY 1986). (Discharge data are from the U.S. Geological Survey, W.R.D., IA Dist.)

occurred in early August. Nitrate concentrations increased to 55 mg/L (12.2 as NO_3-N), five days after peak daily discharge occurred in mid-August, then declined to 14 mg/L (3.1 as NO_3-N) just prior to peak daily discharge in September. Five days later, nitrate concentrations increased to 58 mg/L (12.9 as NO_3-N), then declined to 46 mg/L (10.2 as NO_3-N) at the end of the water year.

Table 4a summarizes the nitrate data for BOOGD during WY 1987 on a monthly basis. Monthly fw mean nitrate concentrations varied from 53.1 mg/L (11.8 as NO_3-N) in October to 30.6 mg/L (6.8 as NO_3-N) in September. Variations in monthly surface-water discharge resulted in large variations in monthly nitrate-nitrogen outputs. Monthly nitrate-nitrogen output and monthly surface-water discharge varied from 2.0 pounds and 0.1 ac-ft in January to 2,432 pounds and 98 ac-ft in February. February accounted for about 43% of the annual nitrate-nitrogen output and about 45% of the annual surface-water discharge.

During WY 1987, thirty-two samples from L23S were analyzed for nitrate, and twenty-one samples were analyzed for N-series. The annual fw mean nitrate concentration for L23S was 38.3 mg/L (8.5 mg/L as NO_3-N; Table 5). The total nitrate-nitrogen output for the water year was 27,177 pounds, which is equivalent to 9.7 lbs-N/acre and the total nitrogen output (including organic- and ammonia-nitrogen) was 38,303 pounds, which is equivalent to 13.6 lbs-N/acre within the L23S drainage area.

From the beginning of the water year through the first week of February, surface-water discharge at L23S remained relatively constant. Nitrate concentrations decreased from 40 mg/L (8.9 as NO_3-N) in October to 30 mg/L (6.7 as NO_3-N) in November, then increased to 43 mg/L (9.6 as NO_3-N) in December before declining to 29 mg/L (6.4 as NO_3-N) in mid-February. Snowmelt in late February generated minor recharge and nitrate concentrations increased to 37 mg/L (8.2 as NO_3-N). From late February until mid-April, nitrate concentrations generally increased. The highest nitrate concentration reported from L23S during the water year, 55 mg/L (12.2 as NO_3-N), was sampled in late April, five days after the maximum daily discharge for the month occurred. From April through July, minor recharge events had little effect on receding discharge and nitrate concentrations generally declined. Rainfall events in August and September, generated both runoff and infiltration recharge, which were followed by increases in nitrate concentrations in the first post-event samples. Concentrations then decreased in the weeks following, as discharge continued to recede from the events.

Table 5a summarizes the nitrate data for L23S during WY 1987 on a monthly basis. Flow-weighted mean nitrate concentrations varied from 45.5 mg/L (10.1 as NO_3-N) in May to 25.2 mg/L (5.6 as NO_3-N) in July. Although monthly fw mean concentrations were relatively constant, variations in monthly surface-water discharge caused large variations in total monthly nitrate-nitrogen output. Monthly nitrate-nitrogen output varied from 1,054 pounds in November to 4,471 pounds in May. The nitrate-nitrogen output during May was equivalent to about 16% of the annual total and the nitrate-nitrogen output during November was equivalent to about 4% of the annual total.

Thirty-two samples from RC02 were analyzed for nitrate, and thirty samples were analyzed for N-series during the water year. The annual fw mean nitrate concentration was 32.1 mg/L (7.1 mg/L as NO_3-N; Table 6). The total nitrate-nitrogen output for the water year was 236,057 pounds and the total nitrogen output was 277,391 pounds. Within the drainage area of RC02, the total nitrate-nitrogen output was equivalent to 5.2 lbs-N/acre and the total nitrogen output was equivalent to 6.1 lbs-N/acre.

The discharge and nitrate plots for RC02 showed the same general trends as the plots from L23S, although nitrate concentrations at RC02 were generally lower. Concentrations decreased from 37 mg/L (8.2 as NO_3-N) in October to 24 mg/L (5.3 as NO_3-N) in November, then increased to 39 mg/L (8.7 as NO_3-N) in mid-December. Nitrate concentrations decreased to 22 mg/L (4.9 as NO_3-N) in mid-February, then increased to 28 mg/L (6.2 as NO_3-N) about two weeks later. Concentrations decreased from 28 mg/L (6.2 as NO_3-N) in March, to 16 mg/L (3.6 as NO_3-N) in April. Throughout the remainder of the water year, nitrate concentrations remained out-of-phase with fluctuations in surface-water discharge. Peaks in nitrate concentrations generally followed peaks in surface-water discharge. The concentrations of soluble chemicals such as nitrate tend to decrease during peak surface-water discharge and increase shortly after the peak, as discharge recedes and the percentage of shallow-groundwater baseflow (and direct tile drainage) constituting the discharge increases.

Previous monitoring of both surface water and groundwater in the Big Spring basin has shown that during peak discharge events, much of the discharge is composed of runoff, containing low concentrations of nitrate-nitrogen (Hallberg et al., 1983, 1984a, 1985, 1987, 1989). Following peak discharge, as the percentage of infiltration recharge comprising the discharge increases, the nitrate-nitrogen concentration generally increases, then again decreases. Conversely, pesticides and products associated with soils (sediment) and runoff, such as organic-nitrogen and ammonium-nitrogen, and insoluble products such as potassium, phosphate and iron increase during peak runoff and decrease during baseflow dominated periods. During prolonged recession periods, both nitrate and pesticide concentrations generally show a slow, steady decline.

Table 6a summarizes the nitrate data for RC02 during WY 1987 on a monthly basis. The lowest monthly fw mean nitrate concentration, 18 mg/L (4.0 as NO_3-N), occurred in July and the highest monthly fw mean, 46.8 mg/L (10.4 as NO_3-N), occurred during August. These months also had the lowest and highest monthly nitrate-nitrogen outputs, 6,346 pounds in July, and 57,529 pounds in August. About 24% of the annual nitrate-nitrogen discharge, and about 17% of the annual surface-water discharge occurred during August.

At Big Spring, the annual fw mean nitrate concentration for WY 1987 was 41.0 mg/L (9.1 mg/L as NO_3-N; Hallberg et al., 1989). A total of 649,413 pounds of nitrogen were discharged, and of this total, 628,614 pounds, or 97%, was in the form of nitrate. Within the 103 mi^2 drainage area of Big Spring, the total nitrogen output was equivalent to 9.9 lbs-N/acre and the total nitrate-nitrogen output was 9.5 lbs-N/acre. The relatively constant discharge and nitrate concentrations during the water year resulted in fairly constant monthly nitrate-nitrogen loads. Flow-weighted mean monthly nitrate concentrations varied from 34.0 mg/L (7.6 mg/L as NO_3-N) in February to 46 mg/L (10.2 mg/L as NO_3-N) in September. Monthly nitrate-nitrogen discharge varied from 38,000 pounds in February to 64,000 pounds in May.

A total of 11,100,000 pounds of nitrate-nitrogen were discharged by the Turkey River at a fw mean concentration 26.0 mg/L (5.8 mg/L as NO_3-N) during the water year (Hallberg et al., 1989). Within the 1,545 mi^2 drainage area of TR01, the total nitrate-nitrogen output was equivalent to 11.2 lbs-N/acre. Monthly fw mean nitrate concentrations varied from 31.0 mg/L (6.9 mg/L as NO_3-N) in March to 14.0 mg/L (3.1 mg/L as NO_3-N) in July. The greatest monthly nitrate-nitrogen discharge, 2,500,000 pounds, occurred in October, accounting for 23% of the annual discharge. The smallest monthly discharge, 249,000 pounds, occurred during July.

Pesticide Monitoring

Tables 4 through 6 and Figure 5 summarize the results of pesticide monitoring at BOOGD, L23S and RC02 during WY 1987.

Seventeen samples from BOOGD were analyzed for pesticides during WY 1987. Sixteen samples, or 94%, contained detectable levels of atrazine (>0.10 µg/L). During the water year a total of 0.10 pounds of atrazine were discharged, at a fw mean concentration of 0.17 µg/L. As previously discussed, surface-water discharge at BOOGD was intermittent from November 26 through February 6. Atrazine concentrations were relatively constant during October, decreasing from 0.33 µg/L on October 7 to 0.25 µg/L on October 20 (Fig. 5). Concentrations increased from 0.10 µg/L in late February to 0.22 µg/L in late March. Atrazine concentrations were below detection limits on April 21, before increasing to 0.31 µg/L in May. The highest atrazine concentration reported during the water year, 1.50 µg/L, was sampled June 18, the day with the greatest rainfall accumulation during the month. The next highest concentration reported, 0.44 µg/L, occurred in mid-August following a number of rainfall events. Atrazine concentrations remained <0.20 µg/L in September.

Table 4b summarizes the atrazine data for BOOGD during Water Year 1987 on a monthly basis. Monthly fw mean atrazine concentrations decreased from 0.31 µg/L in October to 0.10 µg/L in January and February. The lowest monthly fw mean, 0.08 µg/L, occurred in April, and the highest fw mean, 0.42 µg/L, occurred in June. The lowest monthly atrazine output, 0.01 grams, and surface-water discharge, 0.1 ac-ft, occurred during January, and the highest monthly atrazine output, 16 grams, and second-highest surface-water discharge, 35 ac-ft, occurred during August. August accounted for about 35% of the annual atrazine output and about 16% of the annual surface-water discharge.

Other pesticides detected at BOOGD during the water year include cyanazine in 2, or 12% of the samples collected, and alachlor in 1, or 6% of the samples collected. The highest concentration of pesticides detected during the water year included atrazine at 1.50 µg/L; alachlor at 0.83 µg/L; and cyanazine at 0.61 µg/L. The maximum concentration detected for atrazine, and all detections for cyanazine and alachlor, occurred in June. Atrazine was not detected in one sample collected at BOOGD in April.

During WY 1987, twenty-one samples from L23S were analyzed for pesticides. Fifteen, or 71% of the samples collected contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration was 0.12 µg/L and the annual atrazine discharge was 0.4 pounds. Atrazine concentrations at L23S declined from 0.12 µg/L in early October to non-detectable levels in mid-November (Fig. 5). Atrazine concentrations were below detection limits in samples collected during November, December, January, and March. The highest atrazine concentration during the water year, 0.68 µg/L, occurred May 19, the day with the largest daily rainfall accumulation during the month. The next highest concentration, 0.58 µg/L, occurred in June following a series of rainfall events. Atrazine concentrations decreased to non-detectable levels in early July, then increased to 0.26 µg/L in mid-August five days after the largest discharge event of the water year which occurred August 20. During the remainder of the water year atrazine concentrations remained near 0.1 µg/L.

Table 5b summarizes the atrazine data for L23S during WY 1987 on a monthly basis. Monthly fw mean atrazine concentrations varied from non-detectable levels in December, January and March to 0.35 µg/L in May. May also had the highest monthly atrazine output, 70 grams, and the second-highest surface-water discharge, 163 ac-ft, which accounted for 39% of the annual atrazine output and 13% of the annual discharge.

Other pesticides detected at L23S during the water year include cyanazine in four, or 19% of the samples collected, and alachlor in one, or 5% of the samples collected. The maximum concentration of pesticides detected during the water year includes atrazine at 0.68 µg/L; cyanazine at 0.19 µg/L; and alachlor at 0.12 µg/L. All maximum concentrations were detected during May. Cyanazine was detected during May and June, and alachlor was detected only during May. Atrazine was not detected in samples collected in November, December, January, and March.

During the water year, thirty-three samples from RC02 were analyzed for pesticides. Thirty, or 91% of the samples collected contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration was 0.68 µg/L and the total atrazine output during WY 1987 was 22.5 pounds. Atrazine concentrations at RC02 were generally higher than concentrations sampled at sites BOOGD and L23S. Concentrations declined from 0.51 µg/L in early October to non-detectable levels in late January. In February, snowmelt generated runoff, and atrazine concentrations increased to 0.50 µg/L. Concentrations decreased from 0.48 µg/L in late February to 0.18 µg/L in late March. Precipitation events in April generated runoff, and atrazine concentrations increased to 0.30 µg/L, then decreased to non-detectable levels as discharge receded. Discharge continued to recede from late April through mid-June, and atrazine concentrations remained between 0.50 µg/L and 0.70 µg/L through mid-May, then decreased from 0.75 µg/L in late May to 0.20 µg/L in mid-June. The highest atrazine concentration recorded during the water year, 10.00 µg/L, and the largest daily discharge recorded during June, occurred June 22. The next two highest atrazine concentrations reported, 2.00 µg/L and 1.90 µg/L, occurred in July. Atrazine concentrations remained below 0.53 µg/L during the remainder of the water year.

Table 6b shows the atrazine data for RC02 during WY 1987 on a monthly basis. Monthly fw mean atrazine concentrations decreased from 0.40 µg/L in October to 0.06 µg/L in January, then remained below 0.60 µg/L through May. The highest monthly fw mean atrazine concentrations occurred in June (5.60 µg/L) and July (1.72 µg/L). From July, fw mean atrazine concentrations decreased to 0.39 µg/L in September. The lowest monthly atrazine output, 24 grams, occurred during January and the highest monthly atrazine output, 4,283 grams, occurred during June and accounted for about 42% of the annual output.

Other pesticides detected at RC02 during the water year include cyanazine in eleven, or 34% of the samples collected; alachlor in eight, or 25%; and metolachlor in two, or 6% of the samples collected. The highest concentration of pesticides detected during the water year included atrazine at 10.00 µg/L; alachlor at 4.80 µg/L; cyanazine at 3.00 µg/L; and metolachlor at 0.72 µg/L. All maximum detections occurred June 22. Alachlor was detected during October, February, May, June, July, and September; cyanazine was detected in May, June, July, and September; and metolachlor was detected during February and June.

At Big Spring, 17.6 pounds of atrazine were discharged during the water year, at a fw mean concentration of 0.25 µg/L (Hallberg et al., 1989). As was the case with discharge and nitrate concentrations, atrazine concentrations were relatively stable, leading to fairly constant monthly means and loads. Monthly fw means and loads varied from 0.16 µg/L and 0.8 pounds in January to 0.38 µg/L and 2.2 pounds in August. The monthly atrazine discharge during October was also 2.2 pounds and the monthly fw mean, 0.34 µg/L, was the second highest during the water year.

The annual fw mean atrazine concentration for

Table 7. Annual summary of water and chemical discharge for BOOGD for Water Year 1988. (Discharge data from U.S. Geological Survey, Water Resources Division.)

DISCHARGE		
Total		
acre-feet	173	
millions cf	7.6	
millions cm	0.20	
Average		
cfs	0.24	
cms	0.007	
mg/d	0.2	
gpm	108	
PRECIPITATION AND DISCHARGE		
Precipitation	22.94 inches (583mm)	
Discharge	2.82 inches (71.6mm)	
Discharge as % of precipitation	12%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	42.0	9.3
Mean of analyses	41.9	9.3
	NO_3-N output	**Total N output**
lbs - N	4,387	4,982
kg - N	1,990	2,259
lbs - N/acre	6.0	6.8
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	0.26	
Mean of analyses	0.34	
Total output		
lbs	0.12	
g	54.8	

the Turkey River was 0.47 µg/L and the annual atrazine discharge was 891 pounds (Hallberg et al., 1989). The largest monthly atrazine discharge from TR01, 312 pounds, occurred in October and accounted for 35% of the annual discharge. The smallest monthly atrazine discharge, 23 pounds, occurred in January. Monthly fw mean atrazine concentrations varied from 1.16 µg/L in June to 0.23 µg/L in February.

Water Year 1988

Discharge Monitoring

Tables 7 through 9 and Figure 6 summarize the discharge, water quality and chemical-load data for surface-water sites BOOGD, L23S and RC02 during WY 1988. In Figure 6, note the increase in scale on the nitrate plot and the decrease in scale on the discharge plot relative to WY 1987.

Precipitation during WY 1988 was 22.94 inches, or 10.03 inches below normal for the Big Spring basin. During the March through June period, months important for groundwater recharge, precipitation was 8.87 inches below normal. The extremely dry antecedent conditions that began in WY 1987 continued through WY 1988, severely limiting surface-water runoff and groundwater recharge within the Big Spring basin.

The discharge hydrographs reflect the lack of significant recharge from snowmelt and rainfall during the 1988 Water Year (Fig. 6). From October through January, a number of precipitation events occurred, but intensity and amounts of rainfall were too low to generate significant recharge. Snowmelt in early February, combined with a series of minor precipitation events, generated runoff, but streams returned to baseflow conditions within a few days. The most significant recharge events of the water year occurred in early March and were associated with snowmelt rather than rainfall events. Precipitation in late March and early April generated runoff and minor infiltration recharge that sustained increased discharge temporarily, but in a matter of days discharge receded. Following a minor runoff event in May, discharge continued to generally decline until late September.

Table 8. Annual summary of water and chemical discharge for L23S for Water Year 1988. (Discharge data from U.S. Geological Survey, Water Resources Division.)

DISCHARGE		
Total		
acre-feet	1,150	
millions cf	50	
millions cm	1.4	
Average		
cfs	1.6	
cms	0.04	
mg/d	1.0	
gpm	709	
PRECIPITATION AND DISCHARGE		
Precipitation	22.94 inches (583mm)	
Discharge	4.91 inches (125mm)	
Discharge as % of precipitation	21%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	43.0	9.6
Mean of analyses	37.6	8.4
	NO_3-N output	**Total N output**
lbs - N	29,885	35,891
kg - N	13,553	16,277
lbs - N/acre	10.6	12.8
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	0.24	
Mean of analyses	0.35	
Total output		
lbs	0.76	
kg	0.34	

Table 9. Annual summary of water and chemical discharge for RC02 for Water Year 1988. (Discharge data from U.S. Geological Survey, Water Resources Division.)

DISCHARGE		
Total		
acre-feet	10,193	
millions cf	443	
millions cm	13	
Average		
cfs	14.1	
cms	0.40	
mg/d	9.1	
gpm	6,319	
PRECIPITATION AND DISCHARGE		
Precipitation	22.94 inches (583mm)	
Discharge	2.70 inches (68.6mm)	
Discharge as % of precipitation	12%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	31.0	6.9
Mean of analyses	21.7	4.8
	NO_3-N output	**Total N output**
lbs - N	190,829	234,704
kg - N	86,544	106,442
lbs - N/acre	4.2	5.2
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	0.24	
Mean of analyses	0.27	
Total output		
lbs	6.7	
kg	3.0	

The most intense rainfall events of the water year occurred in late September, but the associated runoff- and infiltration-recharge were limited.

The surface-water discharge from site BOOGD during the water year was 173 ac-ft and the average daily discharge was 0.24 cfs (Table 7). The annual discharge was equivalent to 12% of the annual precipitation. At site L23S, the annual discharge for WY 1988 was 1,150 ac-ft, at an average daily discharge of 1.6 cfs (Table 8). The annual discharge was equal to 21% of the annual precipitation. The annual discharge for site RC02 was 10,193 ac-ft and the average daily discharge was 14.1 cfs (Table 9). The annual discharge for RC02 was equivalent to 12% of the annual precipitation. At Big Spring the annual discharge for WY 1988 was 26,008 ac-ft, or about 20.5% of the annual precipitation, at an average daily discharge rate of 35.8 cfs (Libra et al., 1991). Total discharge from the Turkey River at Garber (TR01) was 436,100 ac-ft, at an average discharge rate of 601 cfs (Libra et al., 1991). Annual discharge from TR01 was equivalent to 23% of the annual precipitation and about 65% of the long-term annual discharge average.

Nitrate Monitoring

Tables 7 through 9 and Figure 6 summarize the nitrate analyses from BOOGD, L23S and RC02 for Water Year 1988.

During the water year, thirty-one samples from BOOGD were analyzed for nitrate, and twenty-five samples were analyzed for N-series. The annual fw mean nitrate concentration was 42 mg/L (9.3 mg/L as NO_3-N). The total nitrate-nitrogen output during the water year was 4,387 pounds, and the total nitrogen output (nitrate- plus organic- and ammonia-nitrogen) was 4,982 pounds. Within the drainage area of BOOGD, the total nitrate-nitrogen output was equivalent to 6.0 lbs-N/acre and the total nitrogen output was 6.8 lbs-N/acre.

Nitrate concentrations declined from 47 mg/L (10.4 mg/L as NO_3-N) in October to 17 mg/L (3.8 mg/L as NO_3-N) in early November, then increased to 61 mg/L (13.6 mg/L as NO_3-N) following precipitation in late November (Fig. 6). Con-

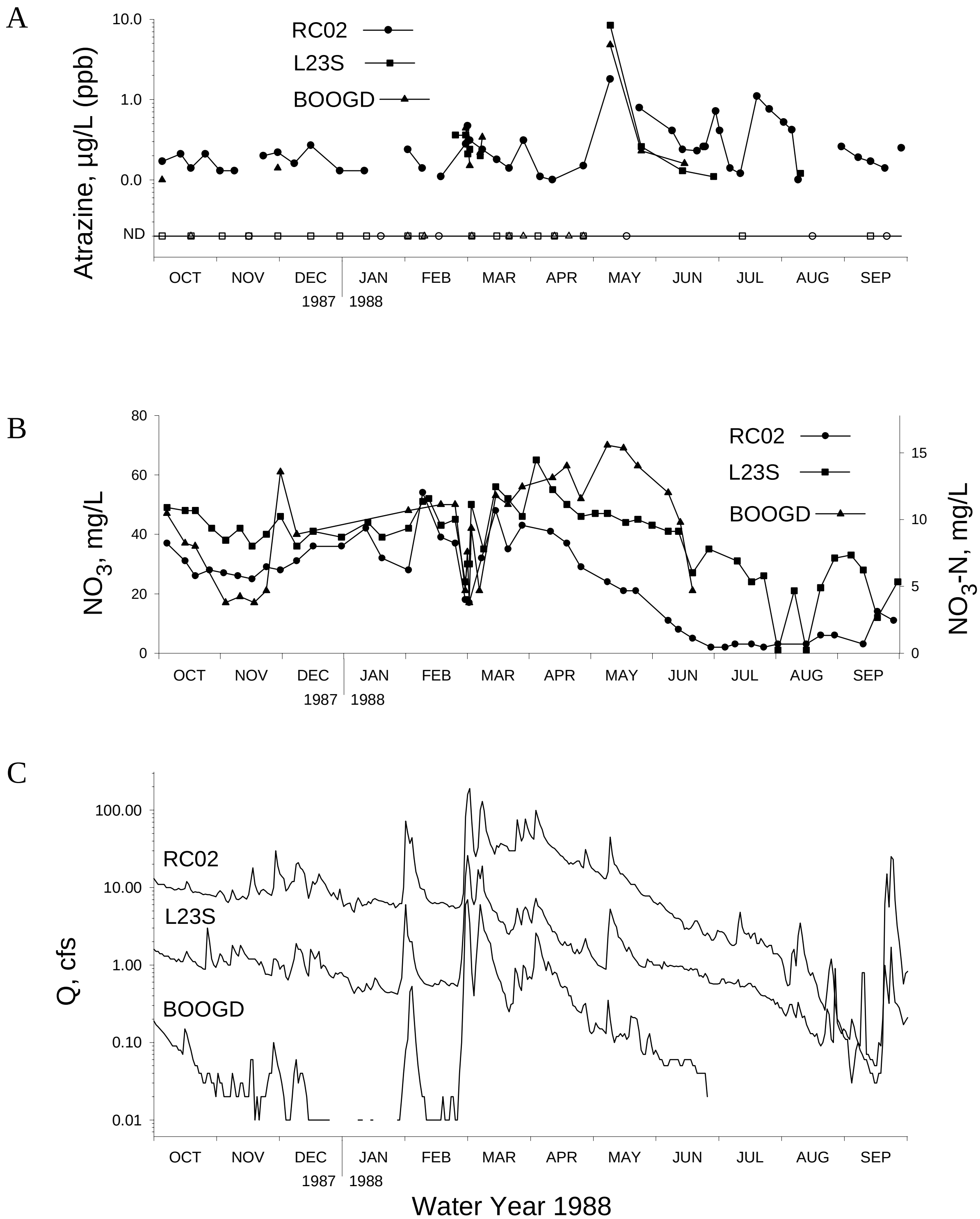

Figure 6. A) Atrazine and B) nitrate concentrations, and C) surface-water discharge (Q) at RC02, L23S, and BOOGD for WY 1988 (note the increase in scale on the nitrate plot and the decrease in scale on the discharge plot relative to WY 1987). (Discharge data are from the U.S. Geological Survey, W.R.D., IA Dist.)

centrations declined to 40 mg/L (8.9 mg/L as NO_3-N) in early December. BOOGD went dry December 26, and remained dry through most of January. Snowmelt in late January and precipitation in early February generated enough recharge to sustain discharge through February. Nitrate levels remained around 50 mg/L (11.1 mg/L as NO_3-N) throughout most of February.

Multiple samples were taken at BOOGD during the snowmelt generated runoff events on February 29 and March 1. As previously mentioned, runoff recharge, particularly snowmelt, generally has lower concentrations of nitrate and other chemicals that are mobile in the soil and is enriched in herbicides and other chemicals with low soil mobility. During a runoff event, relatively low nitrate and high herbicide concentrations occur during peak discharge. This is typically followed by higher nitrate and lower herbicide concentrations as the associated infiltration recharge moves through the system as the discharge recedes. Nitrate concentrations decreased to 12 mg/L (2.7 mg/L as NO_3-N) on February 29 at 16:45 and by 22:30, concentrations were 21 mg/L (4.7 mg/L as NO_3-N). On March 1, nitrate concentrations went from 34 mg/L (7.6 mg/L as NO_3-N) at 12:00 to 9 mg/L (2.0 mg/L as NO_3-N) at 17:50. On March 2, nitrate concentrations had increased to 17 mg/L (3.8 mg/L as NO_3-N), and by March 3, concentrations were 42 mg/L (9.3 mg/L as NO_3-N) as discharge continued to recede. Nitrate concentrations declined to 21 mg/L (4.7 mg/L as NO_3-N) four days later, as dilution occurred from a second influx of surface runoff. Concentrations increased to 50 mg/L (11.1 mg/L as NO_3-N) as discharge receded from March 7 to March 21. Both nitrate concentrations and discharge generally increased from March 21 to April 3 as minor precipitation events generated short-term infiltration recharge. During the remainder of the water year discharge generally receded and finally ceased during the last week in June and BOOGD remained dry through the remainder of the water year. Nitrate concentrations reached 70 mg/L (15.5 mg/L as NO_3-N) in mid-May, then declined through June, as discharge receded.

Table 7a summarizes the nitrate data for BOOGD during WY 1988 on a monthly basis. The highest monthly fw mean nitrate concentration, 64.3 mg/L (14.3 mg/L as NO_3-N), occurred during April and the lowest monthly fw mean nitrate concentration, 22.7 mg/L (5.0 mg/L as NO_3-N), occurred during February. Large variations in surface-water discharge and nitrate concentrations caused significant variations in monthly nitrate output. Monthly nitrate output varied from 8.4 pounds in January to 1,858 pounds in March. March accounted for about 42% of the annual nitrate output, and about 54% of the annual surface-water discharge.

During the water year, fifty-three samples from L23S were analyzed for nitrate, and twenty-eight samples were analyzed for N-series. The annual fw mean nitrate concentration was 43 mg/L (9.6 mg/L as NO_3-N; Table 8). The annual nitrate-nitrogen output was 29,885 pounds, and the annual nitrogen output (nitrate- plus organic-and ammonia-nitrogen) was 35,891 pounds. Within the drainage area of L23S, these outputs were equivalent to 10.6 lbs-N/acre of nitrate-nitrogen and 12.8 lbs-N/acre of total nitrogen.

From the beginning of the water year through most of February, nitrate concentrations at L23S were relatively constant, fluctuating between 49 mg/L (10.9 mg/L as NO_3-N) in early October to 36 mg/L (8.0 mg/L as NO_3-N) in November and December and 52 mg/L (11.6 mg/L as NO_3-N) in mid-February (Fig. 6). Samples taken at L23S during the runoff events in late February and early March showed the same response as samples taken at BOOGD. Nitrate concentrations decreased during peak discharge, then increased as discharge receded. Concentrations increased from 13 mg/L (2.9 mg/L as NO_3-N) on February 29 at 15:45 to 24 mg/L (5.3 mg/L as NO_3-N) at 23:10, then increased to 30 mg/L on March 1 at 13:30, before decreasing to 14 mg/L (3.1 mg/L as NO_3-N) at 18:10. Nitrate concentrations increased to 50 mg/L (11.1 mg/L as NO_3-N) on March 3 as mean daily discharge decreased from 26 cfs on March 1 to 7.4 cfs on March 3. The maximum nitrate concentration sampled during the water year, 65 mg/L (14.4 mg/L as NO_3-N), occurred in early April following minor recharge events in late March. From April, nitrate concentrations generally declined, reaching non-detectable concentrations (<1.0 mg/L) twice in August. The majority of rainfall events that occurred in August and September had little impact on discharge, but caused nitrate concentrations to fluctuate between less than 1 mg/L (0.2 mg/L as NO_3-N) in early August and 33 mg/L (7.3 mg/L as NO_3-N) in early September. Nitrate concentrations were 24 mg/L (5.3 mg/L as NO_3-N) near the end of the water year.

Table 8a summarizes the nitrate data at L23S for WY 1988 on a monthly basis. Monthly fw mean nitrate concentrations varied from 58.5 mg/L (13.0 mg/L as NO_3-N) in April to 13.9 mg/L (3.1 mg/L as NO_3-N) in August. Variations in monthly fw nitrate concentrations and in monthly discharge were characterized by wide variations in monthly nitrogen output. The highest monthly nitrogen output, 10,759 pounds, occurred in March and the lowest monthly output, 107 pounds, occurred in August. Monthly discharge varied from 433 ac-ft, or about 38% of the annual discharge in March to 11 ac-ft, or about 1% of the annual discharge in August.

Forty-nine samples from RC02 were analyzed for nitrate, and sixty samples were analyzed for N-series during WY 1988. The annual fw mean nitrate concentration was 31 mg/L (6.9 mg/L as NO_3-N). The total nitrate-nitrogen output for WY 1988 was 190,829 pounds, which is equivalent to 4.2 lbs-N/acre within the drainage area of RC02. The total nitrogen output (including organic- and ammonia-nitrogen) was 234,704 pounds, which is equivalent to 5.2 lbs-N/acre within the drainage area of RC02.

Nitrate concentrations from RC02 showed the same seasonal trends as concentrations from BOOGD and L23S, although concentrations fluctuated less and were generally lower, especially as discharge receded from March through April. Throughout Water Year 1988 most precipitation events were minor and had limited effect on recharge within the basin. Nitrate concentrations decreased from 37 mg/L (8.2 mg/L as NO_3-N) in early October to 25 mg/L (5.6 mg/L as NO_3-N) in mid-November, then increased to 42 mg/L (9.3 mg/L as NO_3-N) in January. Nitrate concentrations decreased to 28 mg/L (6.2 mg/L as NO_3-N) during a snowmelt event in early February, then increased to 54 mg/L (12.0 mg/L as NO_3-N) a week later as discharge receded. Concentrations declined to 17 mg/L (3.8 mg/L as NO_3-N) during peak runoff from snowmelt in late February and early March. Nitrate concentrations increased to 48 mg/L (10.7 mg/L as NO_3-N) in mid-March, as the mean daily discharge decreased from 190 cfs on March 2 to 35 cfs on March 15. From late March through mid-September, both discharge and nitrate concentrations generally declined. From June until mid-September nitrate concentrations fluctuated between 2 mg/L (0.4 mg/L as NO_3-N) and 6 mg/L (1.3 mg/L as NO_3-N). During September, nitrate concentrations increased to 14 mg/L (3.1 mg/L as NO_3-N) just prior to the most intense rainfall events of the water year.

Table 9a summarizes the nitrate data at RC02 for WY 1988 on a monthly basis. Monthly fw mean nitrate concentrations remained below 35 mg/L (7.8 mg/L as NO_3-N) except during April. The highest monthly fw mean, 37.5 mg/L (8.3 mg/L as NO_3-N) occurred in April, and the lowest, 2.6 mg/L (0.6 mg/L as NO_3-N) in July. Monthly nitrate output varied from 68,144 pounds in March to 112 pounds in August. March accounted for about 36% of the annual nitrate output and about 34% of the annual surface-water discharge.

At Big Spring, the annual fw mean nitrate concentration for the water year was 43 mg/L (9.5 mg/L as NO_3-N; Libra et al., 1991). A total of 700,617 pounds of nitrogen were discharged, and of this total, 672,023 pounds, or 96%, was in the form of nitrate. Within the 103 mi^2 drainage area of Big Spring, the total nitrogen output was equivalent to 10.6 lbs-N/acre and the total nitrate-nitrogen output was 10.2 lbs-N/acre. Monthly fw mean nitrate concentrations varied from 47 mg/L (10.4 mg/L as NO_3-N) in October to 34 mg/L (7.7 mg/L as NO_3-N) in September. Monthly nitrate-nitrogen loads and groundwater discharge varied from 86,000 pounds and 3,383 ac-ft in March, to 25,000 pounds and 1,206 ac-ft in September. March accounted for 13% of the nitrate-nitrogen, and 13% of the groundwater discharged during WY 1988.

A total of 6,248,173 pounds of nitrate-nitrogen were discharged by the Turkey River at a fw mean concentration 23 mg/L (5.1 mg/L as NO_3-N) during the water year (Libra et al., 1991). Of this total, 6,052,690 pounds, or 97% was in the form of nitrate. Within the 1,545 mi^2 drainage area of TR01, the total nitrogen output was equivalent to 6.3 lbs-N/acre and the total nitrate-nitrogen output was equivalent to 6.1 lbs-N/acre. Monthly fw mean nitrate concentrations varied from 29 mg/L (6.5 mg/L as NO_3-N) in January to 4 mg/L (0.9 mg/L as NO_3-N) in August. The greatest monthly nitrate-nitrogen discharge, 1,446,000 pounds, and surface-water discharge, 90,400 ac-ft, occurred in March, accounting for 24% of the annual nitrate-nitrogen discharge and 21% of the annual surface-water discharge. The smallest monthly nitrate-nitrogen load, 27,000 pounds, occurred in August, and accounted for 0.4% of the annual nitrate-nitrogen discharge. The smallest monthly surface-water discharge, 10,740 ac-ft, occurred in September, and represented about 2.5% of the annual surface-water discharge.

Pesticide Monitoring

Tables 7 through 9 and Figure 6 summarize the results of pesticide monitoring at sites BOOGD, L23S and RC02 during WY 1988.

Twenty-four samples from BOOGD were analyzed for pesticides during WY 1988. Fourteen samples contained detectable levels of atrazine (>0.10 µg/L). The fw mean atrazine concentration for WY 1988 was 0.26 µg/L and the total atrazine output was 0.12 pounds.

From the beginning of the water year until the end of February, atrazine concentrations fluctuated between non-detectable levels and 0.14 µg/L. BOOGD went dry in late December and remained dry through most of January. In late February and early March, snowmelt generated runoff and atrazine concentrations increased to 0.44 µg/L. During the event, concentrations decreased to 0.14 µg/L on March 1 at 12:00, then increased to 0.32 µg/L by 17:50. Atrazine concentrations decreased to non-detectable levels (<0.10) by March 3, as discharge continued to recede from 7.0 cfs on March 1 to 0.8 cfs on March 3. During the next runoff event, concentrations increased from 0.22 µg/L on March 7 at 16:45 to 0.34 µg/L on March 8 at 11:30, then decreased to <0.10 µg/L at 14:05 before increasing again to 0.34 µg/L at 16:55. From late March through April, atrazine concentrations remained below the detection limit, except during a small event on April 5 when concentrations increased to 0.27 µg/L. Atrazine concentrations increased to 4.8 µg/L during the second week in May, following minor runoff from precipitation. During the remainder of the water year, atrazine concentrations declined as discharge receded. Discharge ceased on June 28, and BOOGD remained dry during the remainder of the water year.

Table 7b summarizes the atrazine data for BOOGD during WY 1988 on a monthly basis. Monthly fw mean atrazine concentrations remained below 0.20 µg/L most of the water year. Concentrations ranged from 0.02 µg/L in April to 2.42 µg/L in May. Monthly atrazine output varied from 0.1 grams in December to 26 grams in May. The relatively high atrazine output during May was more a function of the timing of chemical application than event related. While May accounted for 47% of the annual atrazine output, only 5% of the annual surface-water total was discharged during May.

The only other pesticide detected at BOOGD during the water year was alachlor in two, or 8% of the samples collected. The highest concentration of pesticides detected during the water year included atrazine at 4.80 µg/L and alachlor at 3.90 µg/L. The maximum concentration detected for both atrazine and alachlor occurred in May. The only other detection of alachlor, 0.13 µg/L, occurred in late November.

During WY 1988, thirty samples from L23S were analyzed for pesticides. Twelve, or 40% of the samples collected contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration was 0.24 µg/L and the total atrazine output was 0.76 pounds.

The atrazine plot for L23S is very similar to the atrazine plot from BOOGD (Fig. 6). The lack of significant recharge during most of the water year was reflected by low atrazine concentrations, especially during the first seven months of the water year. Atrazine concentrations were below the detection limit (<0.10 µg/L) in samples collected from October through most of February. Concentrations increased to 0.36 µg/L in late February following snowmelt. As discharge receded, atrazine concentrations remained between 0.24 µg/L and non-detectable levels through April. The highest atrazine concentration reported during WY 1988, 8.4 µg/L, was sampled May 9, following a precipitation event. As discharge continued to recede, atrazine concentrations declined to non-detectable levels in mid-July. Concentrations increased to 0.12 µg/L following rainfall events in August, then decreased to non-detectable levels prior to the intense rainfall events that occurred near the end of the water year.

Table 8b summarizes the atrazine data for L23S during WY 1988 on a monthly basis. Monthly fw mean atrazine concentrations varied from non-detectable levels during much of the water year to 1.96 µg/L in May. The greatest monthly atrazine output, 246 grams, occurred during May and accounted for about 72% of the annual atrazine output.

Other pesticides detected at L23S during the water year include cyanazine in two, or 7% of the samples collected; alachlor in two, or 7%; and metolachlor in one, or 3% of the samples collected. The highest concentration of pesticides detected during the water year included atrazine at 8.40 µg/L; alachlor at 4.50 µg/L; cyanazine at 1.90 µg/L; and metolachlor at 0.20 µg/L. All maximum detections occurred May 9. Alachlor was detected during May and August; cyanazine was detected twice in May; and metolachlor was detected only in May.

During WY 1988, fifty-seven samples from RC02 were analyzed for pesticides. Fifty-one, or 89% of the samples collected contained detectable levels of atrazine (>0.10 µg/L).The annual fw mean atrazine concentration was 0.24 µg/L and the total atrazine output was 6.7 pounds.

The atrazine plot for RC02 is similar to plots for BOOGD and L23S, although concentrations at RC02 were generally higher, and more variable. From October through February, atrazine concentrations fluctuated between 0.11 µg/L and 0.28 µg/L, declining to non-detectable levels during periods in November, January and February. In early March, concentrations increased to 0.47 µg/L following runoff from snowmelt. Concentrations then declined, until additional precipitation generated runoff and concentrations increased to 0.31 µg/L near the end of the month. Atrazine concentrations increased to 1.80 µg/L during a runoff event in early May, then declined to non-detectable levels, before increasing again to 0.79 µg/L later in the month. Throughout the remainder of the water year, minor rainfall events had little effect on the quantity of receding discharge, but apparently did effect the proportion of runoff versus infiltration recharge composing the surface water. Atrazine concentrations increased to 0.72 µg/L in June and 1.10 µg/L in July during days that the mean daily discharge continued to decline. Atrazine concentrations decreased to non-detectable levels in mid-August, then increased to 0.26 µg/L at the end of August. Concentrations were 0.25 µg/L near the end of September following precipitation events.

Table 9b summarizes the atrazine data for WY 1988 at RC02 on a monthly basis. Flow-weighted mean atrazine concentrations varied from 0.13 µg/L in January and September to 0.54 µg/L in July. Monthly atrazine output varied from 1,251 grams in March to 12 grams in August. March accounted for 42% of the annual atrazine output and 34% of the annual surface-water discharge, and August accounted for 0.4% of the annual atrazine output and 0.5% of the surface-water discharge during the water year.

Other pesticides detected at RC02 during WY 1988 include cyanazine in nine, or 16% of the samples collected; alachlor in three, or 5%; and metolachlor in one, or 2% of the samples collected. The highest concentration of pesticides detected during the water year included atrazine at 1.80 µg/L; alachlor at 1.90 µg/L; cyanazine at 1.00 µg/L; and metolachlor at 0.20 µg/L. All maximum detections occurred May 9. Cyanazine was detected during December, May, June, July, and August; alachlor was detected in March, May, and August; and metolachlor was detected during May only.

At Big Spring, 9.2 pounds of atrazine were discharged during the water year, at a fw mean concentration of 0.13 µg/L (Libra et al., 1991). This

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

DISCHARGE		
Total		
acre-feet	57	
millions cf	2.5	
millions cm	0.07	
Average		
cfs	0.08	
cms	0.002	
mg/d	0.05	
gpm	35.9	
PRECIPITATION AND DISCHARGE		
Precipitation	24.32 inches (618mm)	
Discharge	0.93 inches (23.7mm)	
Discharge as % of precipitation	4%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	9.1	2.0
Mean of analyses	10.0	2.2
	NO_3-N output	**Total N output**
lbs - N	317	1,398
kg - N	144	643
lbs - N/acre	0.4	1.9
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	2.31	
Mean of analyses	2.47	
Total output		
lbs	0.36	
g	163	

was the lowest annual fw mean atrazine concentration and load observed at Big Spring during the WY 1982-1992 period of record. Monthly fw mean atrazine concentrations varied from 0.22 µg/L in May to 0.06 µg/L in November and August. The monthly atrazine discharge was greatest in March, at 1.7 pounds, and smallest in August, at 0.2 pounds.

The annual fw mean atrazine concentration for the Turkey River, was 0.34 µg/L and the annual atrazine discharge totaled 407 pounds (Libra et al., 1991). The largest monthly atrazine discharge, 234 pounds, and highest monthly fw mean atrazine concentration, 1.99 µg/L, occurred in May and accounted for 57% of the annual atrazine discharge. The smallest monthly atrazine discharge, 1.1 pounds, and the lowest monthly fw mean, 0.02 µg/L, occurred in November.

Water Year 1989

Discharge Monitoring

Tables 10 through 12 and Figure 7 summarize the discharge, water quality and chemical-load data for surface-water sites BOOGD, L23S and RC02 for Water Year 1989. In Figure 7, note the increase in scale on the atrazine and discharge plots and the decrease in scale on the nitrate plot relative to WY 1988.

As previously mentioned, WYs 1988 and 1989 were the two driest consecutive years in Iowa's recorded history. State-wide, average precipitation was more than 18 inches below normal. Precipitation in the Big Spring area was about 10 inches below normal during WY 1988 and about 8.7 inches below normal during WY 1989.

The discharge hydrographs reflect the continuation of drought conditions that prevailed during the 1988 Water Year (Fig. 7). Rainfall events occurred throughout the water year, generating a number of minor runoff events, but intensity and accumulation of rainfall were too low to generate significant groundwater recharge. Precipitation was about 1.6 inches above normal during November and August, about 1.3 inches below normal in March, about 2.4 inches below normal in June, and about 3.0 inches below normal in July. Almost 2

Table 11. Annual summary of water and chemical discharge for L23S for Water Year 1989. (Discharge data from U.S. Geological Survey, Water Resources Division.)

DISCHARGE		
Total		
acre-feet	552	
millions cf	24	
millions cm	0.68	
Average		
cfs	0.76	
cms	0.02	
mg/d	0.49	
gpm	341	
PRECIPITATION AND DISCHARGE		
Precipitation	24.32 inches (617mm)	
Discharge	2.36 inches (59.9mm)	
Discharge as % of precipitation	10%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	9.0	2.0
Mean of analyses	23.0	5.1
	NO_3-N output	**Total N output**
lbs - N	2,998	19,813
kg - N	1,360	8,988
lbs-N/acre	1.1	7.1
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	6.75	
Mean of analyses	5.43	
Total output		
lbs	10.1	
kg	4.6	

inches of precipitation fell November 18th, but recharge was minimal and discharge returned to baseflow conditions within two days. The most significant runoff events of the water year occurred in late January, early February and mid-March and were associated with snowmelt rather than rainfall events. The amount of recharge associated with these events was limited and discharge returned to pre-event levels within five days of the events in February and within about four weeks of the events in March. The events during the period from March 10 through March 15 accounted for 75% of the annual discharge at BOOGD, 55% of the annual total at L23S, and 48% of the annual discharge from RC02. During the remainder of the water year, generally declining discharge was punctuated occasionally by minor recharge events. Intense rainfall events in August and September generated small runoff events, but the associated infiltration recharge was limited.

Site BOOGD went dry during the last week in June, 1988 and remained dry throughout most of the water year except during periods in March, July, August, and September. The longest period of continuous daily discharge was nine days surrounding snowmelt runoff events in mid-March. The annual surface-water discharge from BOOGD was 57.0 ac-ft and the average daily discharge rate was 0.08 cfs (Table 10). The annual discharge was equivalent to 4% of the precipitation for the water year. At site L23S, the annual discharge for WY 1989 was 552 ac-ft, at an average daily discharge of 0.76 cfs (Table 11). The annual discharge from L23S was equivalent to 10% of the precipitation during the water year. The annual surface-water discharge from RC02 was 3,160 ac-ft, at an average daily discharge rate of 4.4 cfs (Table 12). The annual discharge from RC02 equaled 3% of the annual precipitation during the water year. The discharge and the equivalent percentage of precipitation discharged during WY 1989 were the lowest recorded at all surface-water sites during WYs 1986-1989.

Annual groundwater discharge from Big Spring was 12,672 ac-ft at an average rate of 17.6 cfs (Libra et al., 1991). The discharge was equivalent to 9% of the precipitation during the water year.

Table 12. Annual summary of water and chemical discharge for RC02 for Water Year 1989. (Discharge data from U.S. Geological Survey, Water Resources Division.)

DISCHARGE		
Total		
acre-feet	3,160	
millions cf	138	
millions cm	3.9	
Average		
cfs	4.4	
cms	0.12	
mg/d	2.8	
gpm	1,957	
PRECIPITATION AND DISCHARGE		
Precipitation	24.32 inches (617mm)	
Discharge	0.84 inches (21.3mm)	
Discharge as % of precipitation	3%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	9.1	2.0
Mean of analyses	7.3	1.6
	NO_3-N output	**Total N output**
lbs - N	17,393	69,838
kg - N	7,888	31,673
lbs - N/acre	0.4	1.5
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	1.98	
Mean of analyses	0.95	
Total output		
lbs	17.1	
kg	7.8	

The annual discharge and percent of precipitation discharged from Big Spring during WY 1989 were the lowest recorded during the WY 1982-1989 period of record.

Surface-water discharge from the Turkey River was 220,700 ac-ft, or 11% of the annual precipitation, at an average rate of 305 cfs (Libra et al., 1991). The annual discharge was only 32% of the long-term (1951-1980) average. Discharge records from the Turkey River at Garber are available since WY 1914 for all but seven years, and are continuous since WY 1933. The discharge from TR01 during WY 1989 was the fourth lowest during this entire period of record.

The prolonged recession period, along with the large proportion of annual surface-water discharge that was composed of snowmelt with very low nitrate concentrations and relatively high atrazine concentrations, led to low annual fw mean nitrate concentrations and loads, and high annual fw mean atrazine concentrations and loads.

Nitrate Monitoring

Tables 10 through 12 and Figure 7 summarize the nitrate analyses from BOOGD, L23S and RC02 for Water Year 1989.

During the water year, three samples from BOOGD were analyzed for nitrate, and nine samples were analyzed for N-series. Two samples were taken at the end of January, and the rest of the samples were taken during March 9 through 14. The annual fw mean nitrate concentration was 9.1 mg/L (2.0 mg/L as NO_3-N). The total nitrate-nitrogen output for the water year was 317 pounds, and the total nitrogen output (nitrate-plus organic- and ammonia-nitrogen) was 1,398 pounds. Within the drainage area of BOOGD, these outputs were equivalent to 0.4 lbs-N/acre for total nitrate-nitrogen and 1.9 lbs-N/acre for total nitrogen.

As previously mentioned, BOOGD was dry during much of WY 1989. March was the only month that had adequate data to allow computation of monthly nitrate-nitrogen and atrazine discharge data. Snowmelt in March generated the two largest discharge events of the water year. Nitrate concentrations were 16 mg/L (3.6 mg/L as NO_3-

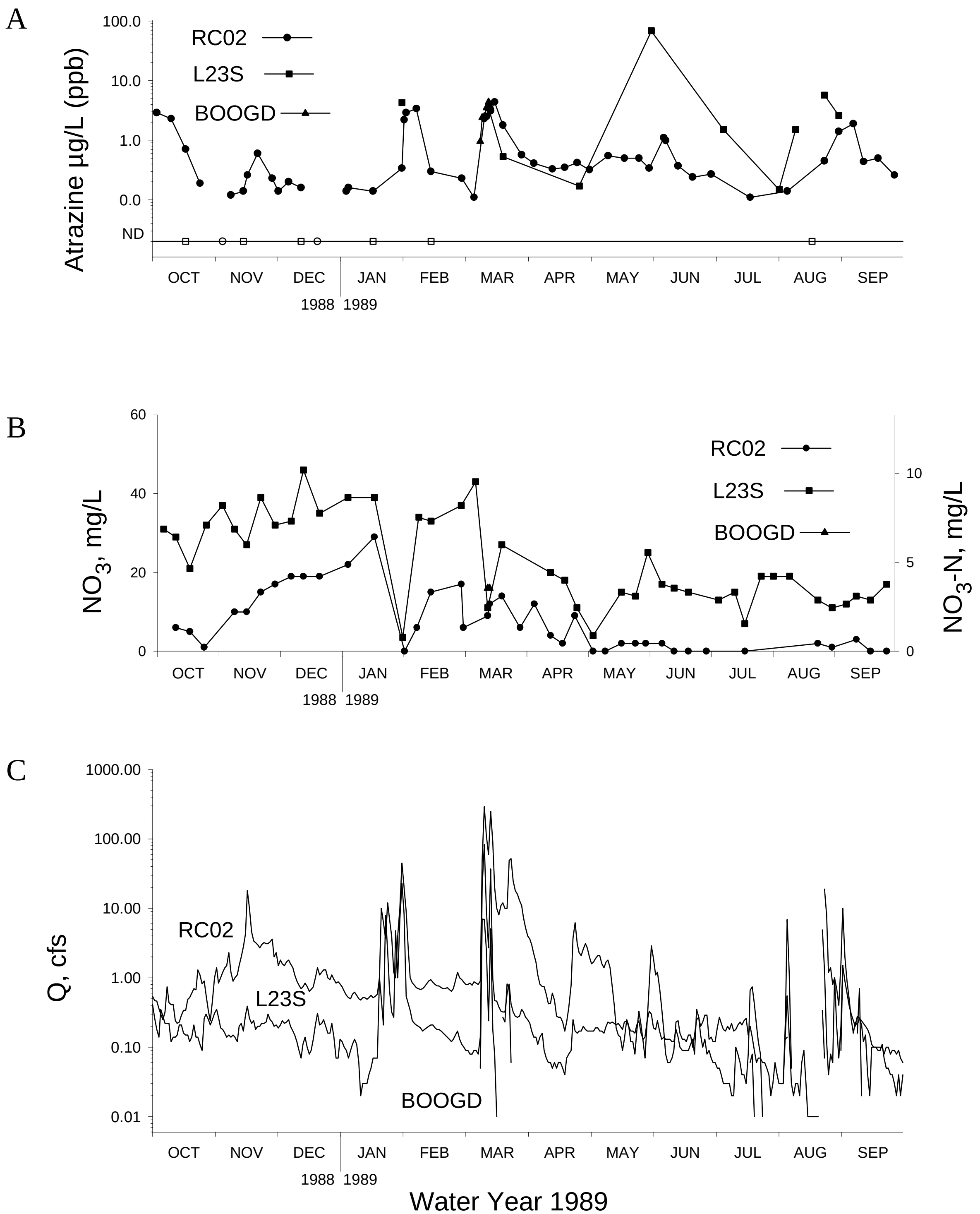

Figure 7. A) Atrazine and B) nitrate concentrations, and C) surface-water discharge Q) at RC02, L23S, and BOOGD for WY 1989 (note the increase in scale on the atrazine and discharge plots and the decrease in scale on the nitrate plot relative to WY 1988). (Discharge data are from the U.S. Geological Survey, W.R.D., IA Dist.)

N), three days after the first and largest runoff event (Fig. 7).

Table 10a summarizes the nitrate data for BOOGD during WY 1989 on a monthly basis. The monthly fw mean nitrate concentration during March was 10.9 mg/L (2.4 mg/L as NO_3-N) and the total monthly nitrate output was 317 pounds. March accounted for about 84% of the annual surface-water discharge at BOOGD.

During WY 1989, fifty-three samples from L23S were analyzed for nitrate, and twenty-eight samples were analyzed for N-series. The annual fw mean nitrate concentration was 9 mg/L (2.0 mg/L as NO_3-N). The total nitrate-nitrogen output for the water year was 2,998 pounds, and the total nitrogen output (nitrate- plus organic- and ammonia-nitrogen) was 19,813 pounds. Within the drainage area of L23S, the total nitrate-nitrogen output was equivalent to 1.1 lbs-N/acre and the total nitrogen output was equal to 7.1 lbs-N/acre.

From the beginning of the water year through mid-January, nitrate concentrations generally increased, fluctuating between 21 mg/L (4.7 mg/L as NO_3-N) in mid-October and 46 mg/L (10.2 mg/L as NO_3-N) in mid-December (Fig. 7). Nitrate concentrations decreased to 3.5 mg/L (0.8 mg/L as NO_3-N) in late January during peak runoff from snowmelt. From January, nitrate concentrations increased to 43 mg/L (9.6 mg/L as NO_3-N) on March 7, just prior to another snowmelt event. Two days after the runoff event nitrate concentrations had declined to 11 mg/L (2.4 mg/L as NO_3-N). As discharge continued to recede in March, nitrate concentrations increased to 27 mg/L (6.0 mg/L as NO_3-N). Concentrations decreased to 4 mg/L (0.9 mg/L as NO_3-N) following precipitation events in late April and early May. Nitrate concentrations increased to 25 mg/L (5.6 mg/L as NO_3-N) at the end of May. During the remainder of the water year, nitrate concentrations were relatively steady, fluctuating between 7 mg/L (1.6 mg/L as NO_3-N) in mid-July during a precipitation event and 19 mg/L (4.2 mg/L as NO_3-N) in late July and early August during extremely low flow conditions.

Table 11a summarizes the nitrate data for L23S during WY 1989 on a monthly basis. Monthly fw mean nitrate concentrations remained under 40 mg/L (8.9 mg/L as NO_3-N), varying from 36.9 mg/L (8.2 mg/L as NO_3-N) in December to 3 mg/L (0.7 mg/L as NO_3-N) in March. Variations in monthly fw mean nitrate concentrations were buffered by variations in total monthly discharge during much of the water year. January and March had the greatest monthly discharges during the water year, at 116 ac-ft and 319 ac-ft, and relatively low monthly fw mean nitrate concentrations, at 12.9 mg/L (2.9 mg/L as NO_3-N) and 3 mg/L (0.7 mg/L as NO_3-N). March accounted for about 58% of the annual surface-water discharge and about 19% of the annual nitrate-nitrogen output. The largest monthly nitrate-nitrogen output, 907 pounds, occurred during January, and accounted for about 30% of the annual nitrate-nitrogen discharge.

At RC02, forty-one samples were analyzed for nitrate, and fifty-eight samples were analyzed for N-series during WY 1989. Eleven samples analyzed for nitrate were below the detection limit (<1.0 mg/L). The annual fw mean nitrate concentration was 9.1 mg/L (2.0 mg/L as NO_3-N). The total nitrate-nitrogen output for the water year was 17,393 pounds and the total nitrogen output (nitrate-plus organic-, and ammonia-nitrogen) was 69,838 pounds. Within the drainage area of RC02, these outputs were equivalent to 0.4 lbs-N/acre for total nitrate-nitrogen and 1.5 lbs-N/acre for total nitrogen.

Nitrate concentrations at RC02 followed the same seasonal trends seen at L23S, although concentrations were generally much lower (Fig. 7). Nitrate concentrations increased from 1 mg/L (0.2 mg/L as NO_3-N) in late October to 29 mg/L (6.4 mg/L as NO_3-N) in mid-January. Nitrate concentrations were below detection limits (<1.0 mg/L) in late January following runoff from snowmelt. Concentrations increased to 17 mg/L (3.8 mg/L as NO_3-N) in late February as discharge remained relatively constant. From February through April, nitrate concentrations generally declined, fluctuating between 17 mg/L (3.8 mg/L as NO_3-N) and 2 mg/L (0.4 mg/L as NO_3-N). During the remainder of the water year, nitrate concentrations fluctuated between non-detectable levels and 3 mg/L (0.7 mg/L as NO_3-N).

Table 12a summarizes the nitrate data at RC02 for Water Year 1989 on a monthly basis. Monthly fw mean nitrate concentrations remained below 20 mg/L (4.4 mg/L as NO_3-N) during the water year. Monthly means varied from 19 mg/L (4.2 mg/L as NO_3-N) in December to less than detectable levels in July. The largest monthly nitrate-nitrogen output, 13,533 pounds, occurred in March and accounted for about 78% of the annual output. March also had the largest monthly surface-water discharge, 2,250 ac-ft, which accounted for about 71% of the annual discharge.

The annual fw mean nitrate concentration for Big Spring during WY 1989 was 25 mg/L (5.7 mg/L as NO_3-N; Libra et al., 1991). A total of 242,245 pounds of nitrogen were discharged, and of this total, 194,928 pounds, or 80%, was in the form of nitrate. Within the 103 mi^2 drainage area of Big Spring, the total nitrogen output was equivalent to 3.7 lbs-N/acre and the total nitrate-nitrogen output was 3.0 lbs-N/acre. The annual fw mean nitrate concentration and total nitrate-nitrogen output were the lowest recorded during WYs 1982-1992. Flow-weighted mean monthly nitrate concentrations varied from 33 mg/L (7.2 mg/L as NO_3-N) in October to 18 mg/L (4.0 mg/L as NO_3-N) in February. Monthly nitrate-nitrogen discharge varied from 10,000 pounds in February to 24,000 pounds in March. The greatest monthly nitrate-nitrogen discharge during WY 1989 was less than the smallest monthly discharge (25,000 pounds in September) in WY 1988.

A total of 3,853,485 pounds of nitrogen were discharged by the Turkey River in WY 1989 (Libra et al., 1991). Of this total, 1,580,050 pounds, or 41%, was discharged in the form of nitrate at a fw mean concentration of 11.9 mg/L (2.6 mg/L as NO_3-N). Within the 1,545 mi^2 drainage area of TR01, the total nitrogen output was equivalent to 3.9 lbs-N/acre, and the total nitrate-nitrogen output equaled 1.6 lbs-N/acre. Nitrate concentrations from the Turkey River were more variable than concentrations from Big Spring during the water year. Monthly fw mean nitrate concentrations varied from 19 mg/L (4.2 mg/L as NO_3-N) in December to 5 mg/L (1.2 mg/L as NO_3-N) in July. The greatest monthly nitrate-nitrogen discharge, 398,000 pounds, occurred in March, accounting for 25% of the annual discharge, and the smallest monthly discharge, 26,000 pounds, occurred during July.

Pesticide Monitoring

Tables 10 through 12 and Figure 7 summarize the results of pesticide monitoring at sites BOOGD, L23S and RC02 during WY 1989.

Eight samples from BOOGD were analyzed for pesticides during WY 1989. The samples were collected from March 9 through March 14. All samples contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration was 2.31 µg/L and the annual output was 0.36 pounds.

At BOOGD, March was the only month during WY 1989 that had adequate data to compute monthly atrazine discharge data. BOOGD had been dry from the last week in June, 1988 until the second week in March, 1989. Snowmelt in March generated the two largest runoff events during the water year. Atrazine concentrations increased from 0.96 µg/L on March 9 to 2.4 µg/L on March 10, as the mean daily discharge increased from 0.05 cfs to 7.0 cfs. Atrazine concentrations were 2.50 µg/L, and the mean daily discharge was 6.9 cfs the following day. On March 12, atrazine concentrations had increased to 3.50 µg/L, while daily discharge had decreased to 2.5 cfs. The mean daily discharge decreased to 0.24 cfs, and atrazine concentrations increased to 4.40 µg/L, three days after peak runoff. The following day, as a second influx of runoff occurred, atrazine concentrations were 3.60 µg/L, and the mean daily discharge was 5.1 cfs.

Table 10b summarizes the atrazine data for BOOGD during Water Year 1989 on a monthly basis. During March the total monthly atrazine output was 163 grams and the monthly fw mean atrazine concentration was 2.76 µg/L. March accounted for 84% of the surface-water discharge, and all of the atrazine discharge during the water year.

Other pesticides detected at BOOGD during the water year include cyanazine in six, or 67% of the samples collected; metolachlor in six, or 67%;

and alachlor in one, or 11% of the samples collected. The highest concentration of pesticides detected during the water year included atrazine at 4.40 µg/L; metolachlor at 0.71 µg/L; cyanazine at 0.28 µg/L; and alachlor at 0.14 µg/L. The maximum detection for alachlor occurred on March 12; for atrazine the maximum detection was on March 13; and for cyanazine and metolachlor the maximum occurred on March 14.

During WY 1989, sixteen samples from L23S were analyzed for pesticides. Ten, or 63% of the samples collected contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration for L23S was 6.75 µg/L and the annual atrazine output was 10.1 pounds. The fw mean atrazine concentration for L23S during WY 1989 was the highest recorded during the period of record, and was probably, in part, due to a very high concentration sampled on May 31.

At L23S, atrazine concentrations were below detectable limits from the beginning of the water year through most of January (Fig. 7). In late January, concentrations increased to 4.30 µg/L during runoff from snowmelt, then decreased to less than detectable concentrations by mid-February. Atrazine concentrations increased to 3.50 µg/L in March, two days after peak runoff following snowmelt. Near the end of April, atrazine concentrations had declined to 0.17 µg/L. In May, atrazine concentrations increased to 68.00 µg/L following minor precipitation events. This was the highest atrazine concentration sampled at the surface-water sites during WY 1989. Atrazine concentrations decreased to 1.50 µg/L in July, then to 0.15 µg/L in early August as discharge continued to recede. Following minor rainfall events in August, concentrations increased to 1.50 µg/L, then decreased to non-detectable levels about a week later. L23S went dry on August 21, then rainfall events generated runoff on August 22 and atrazine concentrations increased to 5.70 µg/L on August 23. Near the end of the month, atrazine concentrations were 2.60 µg/L following a series of minor precipitation events.

Table 11b summarizes the atrazine data for site L23S during WY 1989. Monthly fw mean atrazine concentrations varied from non-detectable levels early in the water year to 9.84 µg/L in March. March accounted for about 3,875 grams or about 84% of the annual atrazine output and about 58% of the annual surface-water discharge.

Other pesticides detected at L23S during the water year include cyanazine in seven, or 44% of the samples collected; alachlor in two, or 13%; metolachlor in two, or 13%; and metribuzin in one, or 6% of the samples collected. The highest concentration of pesticides detected during the water year included atrazine at 68.00 µg/L; alachlor at 38.00 µg/L; cyanazine at 22.00 µg/L; metolachlor at 4.20 µg/L; and metribuzin at 0.13 µg/L. All maximum detections occurred May 31. Cyanazine was detected during March, April, May, July, and August; alachlor was detected in May and August; metolachlor was detected in May and July; and metribuzin was detected during May only.

Fifty-nine samples from RC02 were analyzed for pesticides during WY 1989. Fifty-six, or 95% of the samples collected, contained detectable levels of atrazine (>0.10 µg/L). The fw mean atrazine concentration was 1.98 µg/L and the total atrazine output during the water year was 17.1 pounds.

Atrazine concentrations declined from 2.90 µg/L in early October to non-detectable levels in early November. Rainfall in mid-November generated runoff and concentrations increased to 0.60 µg/L. Atrazine concentrations declined to non-detectable levels near the end of December. Snowmelt in late January generated runoff and concentrations increased to 3.40 µg/L in early February. Atrazine concentrations declined to 0.11 µg/L in early March, then increased to 4.40 µg/L in mid-March following the two largest runoff events of WY 1989. From March through the end of May, minor rainfall events caused small fluctuations in the generally declining atrazine concentrations. Concentrations increased to 1.10 µg/L in early June following minor rainfall events, then decreased to 0.11 µg/L in mid-July. RC02 went dry during the last week of July and was dry from August 8 to August 22. Atrazine concentrations increased from 0.14 µg/L in early August to 1.90 µg/L in early September following a number of rainfall events. During the remainder of the water year atrazine concentrations decreased as discharge generally receded.

Table 12b summarizes the atrazine data for RC02 during Water Year 1989. Monthly fw mean atrazine concentrations varied from 2.52 µg/L in March to 0.06 µg/L in July. The largest monthly atrazine output, 7,015 grams, occurred during March and accounted for about 90% of the annual atrazine output. March also accounted for about 71% of the annual surface-water discharge.

Other pesticides detected at RC02 during WY 1989 include cyanazine in twenty-four, or 41% of the samples collected; alachlor in sixteen, or 27%; and metolachlor in fifteen, or 25% of the samples collected. The highest concentration of pesticides detected during the water year included atrazine at 4.40 µg/L; metolachlor at 0.83 µg/L; cyanazine at 0.74 µg/L; and alachlor at 0.69 µg/L. The maximum detections of cyanazine and alachlor occurred October 10, and for atrazine and metolachlor, maximum detections occurred March 16. Cyanazine was detected during all months except November and April; alachlor was detected in October, January, February, March, May, and August; and metolachlor was detected during October, January, February, March, May, June, August, and September.

During WY 1989, 21.2 pounds of atrazine were discharged from Big Spring, at a fw mean concentration of 0.61 µg/L (Libra et al., 1991). Monthly fw mean atrazine concentrations and loads varied from 1.68 µg/L and 8.7 pounds in March, to 0.08 µg/L and 0.2 pounds in December.

The annual fw mean atrazine concentration for the Turkey River was 0.95 µg/L and the annual atrazine discharge totaled 571 pounds (Libra et al., 1991). The highest monthly fw mean atrazine concentration, 1.88 µg/L, occurred during May, and the lowest fw mean, 0.04 µg/L, occurred in December. The largest monthly atrazine discharge, 246 pounds, occurred in March, accounting for 43% of the annual discharge, and the smallest monthly discharge, 1.2 pounds, occurred during December.

Table 13. Annual summary of water and chemical discharge for BOOGD for Water Year 1990. (Discharge data from U.S. Geological Survey, Water Resources Division.)

DISCHARGE		
Total		
acre-feet	173	
millions cf	7.5	
millions cm	0.20	
Average		
cfs	0.24	
cms	0.007	
mg/d	0.16	
gpm	108	
PRECIPITATION AND DISCHARGE		
Precipitation	37.87 inches (969.9 mm)	
Discharge	2.82 inches (71.6 mm)	
Discharge as % of precipitation	7%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	48.9	10.9
Mean of analyses	74.5	16.6
	NO_3-N output	**Total N output**
lbs - N	5,103	12,211
kg - N	2,315	5,538
lbs - N/acre	6.9	16.6
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	3.07	
Mean of analyses	2.77	
Total output		
lbs	1.4	
g	653	

Water Year 1990

Discharge Monitoring

Tables 13 through 15 and Figure 8 summarize the discharge, water quality and chemical-load data for surface-water sites BOOGD, L23S and RC02 during Water Year 1990. In Figure 8, note the increase in scale on the nitrate plot relative to WY 1989.

Water Year 1990 followed the two driest consecutive years in Iowa's recorded history. In the Big Spring area, precipitation during the water year was 37.87 inches, or about five inches above the long-term average for northeast Iowa. The greatest monthly accumulation of rainfall occurred during August and the largest single rainfall event occurred August 25, following two days of widespread rainfall, causing extensive flooding throughout the Turkey River valley.

The discharge hydrographs reflect the continuation of drought conditions that prevailed during WYs 1988 and 1989. Extremely low-flow conditions persisted during the first four months of the water year. Precipitation events in March generated runoff, but very little infiltration recharge, and surface-water discharge quickly returned to base levels. Rainfall events in May, June and July generated minor runoff and provided enough infiltration recharge to sustain discharge between events.

The overall increase in precipitation during the later part of the water year caused large increases in both runoff and infiltration recharge, which in turn caused large increases in discharge and the output of both nitrogen and pesticides.

From the beginning of the water year until early February, BOOGD remained dry except during three days in October and four days in January (Fig. 8). Discharge ceased again in mid-March, and BOOGD remained dry until June, except during three days in May. Precipitation in June generated enough recharge to initiate baseflow, which was sustained through July. Additional rainfall events in June, July, and August generated enough recharge to sustain discharge throughout the remainder of the water year. The annual surface-water dis-

Table 14. Annual summary of water and chemical discharge for L23S for Water Year 1990. (Discharge data from U.S. Geological Survey, Water Resources Division.)

DISCHARGE		
Total		
acre-feet	982	
millions cf	43	
millions cm	1.2	
Average		
cfs	1.4	
cms	0.04	
mg/d	0.88	
gpm	610	
PRECIPITATION AND DISCHARGE		
Precipitation	37.87 inches (962mm)	
Discharge	4.19 inches (106mm)	
Discharge as % of precipitation	11%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	25.4	5.6
Mean of analyses	34.9	7.8
	NO_3-N output	**Total N output**
lbs - N	15,034	65,047
kg - N	6,818	29,500
lbs-N/acre	5.4	23.2
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	6.52	
Mean of analyses	1.14	
Total output		
lbs	17.4	
kg	7.9	

charge from BOOGD for WY 1990 was 173 ac-ft, at an average daily discharge rate of 0.24 cfs (Table 13). The annual surface-water discharge was equivalent to 7% of the annual precipitation during the water year. The annual discharge from L23S during the water year was 982 ac-ft and the average daily discharge was 1.4 cfs (Table 14). The annual discharge from L23S was equivalent to 11% of the precipitation during the water year. For site RC02, the annual surface-water discharge was 6,030 ac-ft at an average daily discharge rate of 8.3 cfs (Table 15). The annual surface-water discharge from RC02 was equivalent to 4% of the annual precipitation during WY 1990.

At Big Spring the annual discharge during WY 1990 was 17,476 ac-ft, or about 8% of the annual precipitation, and the average daily discharge rate was 24.1 cfs (Rowden, et al., 1993). This is the second-lowest annual discharge, and the lowest percent of precipitation discharged during WYs 1982-1992. The annual surface-water discharge from the Turkey River was 631,900 ac-ft, at an average discharge rate of 873 cfs (Rowden, et al., 1993). Annual discharge from TR01 was equivalent to 20% of the annual precipitation and about 93% of the long-term discharge average.

Although the annual precipitation was about five inches above the long-term average, the amount of runoff, annual discharge and discharge as a percent of precipitation were relatively low throughout the basin during the water year. A large percentage of the precipitation likely replenished soil moisture and infiltrated the less transmissive parts of the basin's hydrologic system that had been depleted during WYs 1988 and 1989.

Nitrate Monitoring

Tables 13 through 15 and Figure 8 summarize the nitrate analyses from BOOGD, L23S and RC02 during Water Year 1990.

During the water year, sixteen samples from BOOGD were analyzed for nitrate, and thirty-one samples were analyzed for N-series. The annual fw mean nitrate concentration was 48.9 mg/L (10.9 mg/L as NO_3-N). The total nitrate-nitrogen output for the water year was 5,103 pounds, and the total

Table 15. Annual summary of water and chemical discharge for RC02 for Water Year 1990. (Discharge data from U.S. Geological Survey, Water Resources Division.)

DISCHARGE		
Total		
acre-feet	6,030	
millions cf	263	
millions cm	7.4	
Average		
cfs	8.3	
cms	0.24	
mg/d	5.4	
gpm	3,743	
PRECIPITATION AND DISCHARGE		
Precipitation	37.87 inches (962mm)	
Discharge	1.60 inches (40.6mm)	
Discharge as % of precipitation	4%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	29.5	6.6
Mean of analyses	17.8	4.0
	NO_3-N output	**Total N output**
lbs - N	110,979	232,583
kg - N	50,330	105,480
lbs - N/acre	2.5	5.1
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	2.89	
Mean of analyses	2.30	
Total output		
lbs	48.8	
kg	22.1	

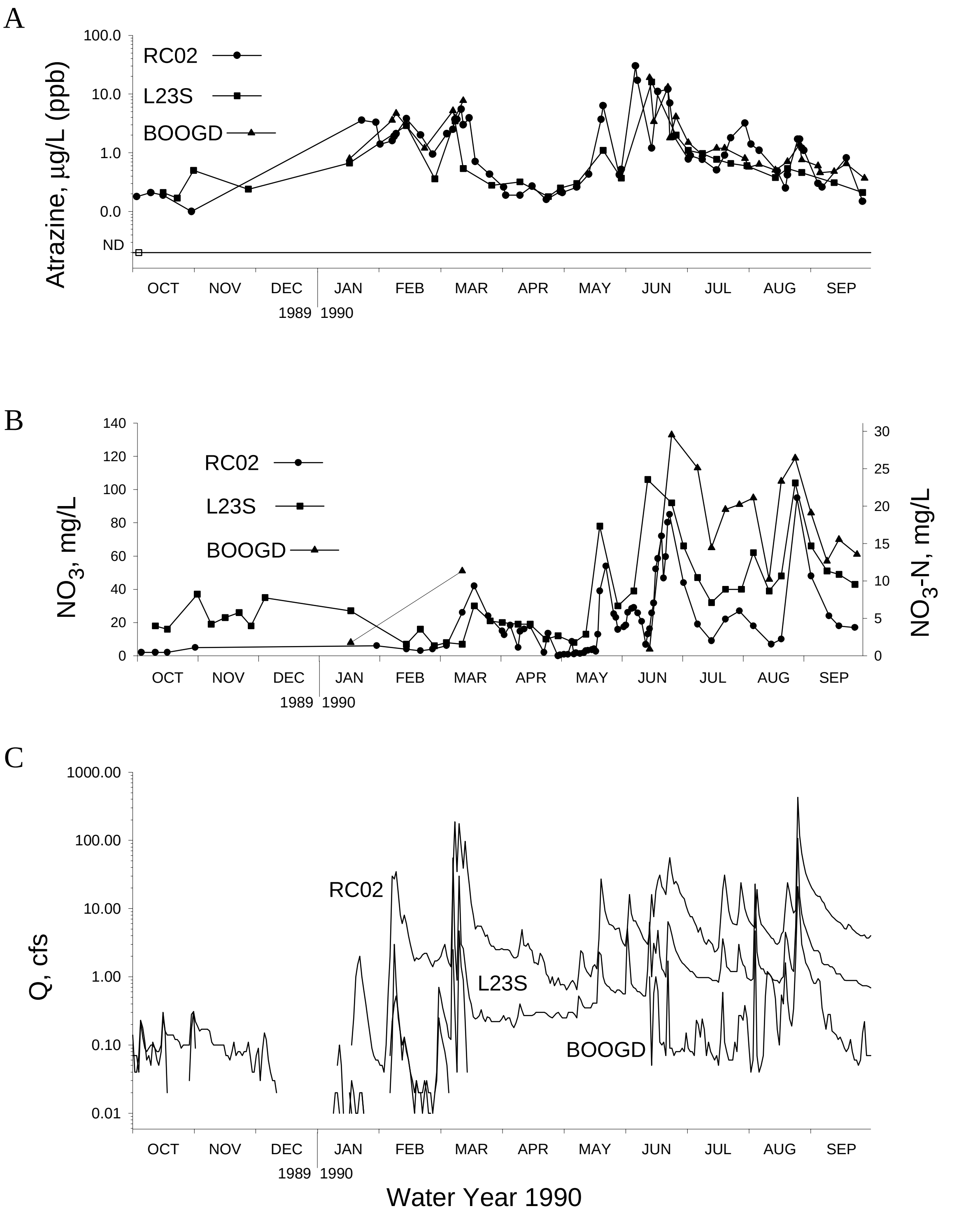

Figure 8. A) Atrazine and B) nitrate concentrations, and C) surface-water discharge (Q) at RC02, L23S, and BOOGD for WY 1990 (note the increase in scale on the nitrate plot relative to WY 1989). (Discharge data are from the U.S. Geological Survey, W.R.D., IA Dist.)

nitrogen output (nitrate- plus organic- and ammonia-nitrogen) was 12,211 pounds. Within the drainage area of BOOGD these outputs were equivalent to 6.9 lbs-N/acre for total nitrate-nitrogen and 16.6 lbs-N/acre for total nitrogen.

As previously mentioned, BOOGD was essentially dry during the first four months of Water Year 1990 and from mid-March through mid-June (Fig. 8). Nitrate concentrations were 8 mg/L (1.8 mg/L as NO_3-N) on January 16 as discharge began after being dry since October 30. Nitrate concentrations were 51 mg/L (11.3 mg/L as NO_3-N) in mid-March following a series of minor precipitation events. Precipitation events in June generated recharge, and continuous discharge began June 13. Nitrate concentrations increased from 4 mg/L (0.9 mg/L as NO_3-N) June 15 to 133 mg/L (29.6 mg/L as NO_3-N) June 26. Nitrate concentrations decreased to 65 mg/L (14.4 mg/L as NO_3-N) in mid-July during a minor runoff event. From July, nitrate concentrations increased to 95 mg/L (21.1 mg/L as NO_3-N) in early August, two days after a runoff event. Concentrations decreased to 46 mg/L (10.2 mg/L as NO_3-N) in mid-August then increased to 119 mg/L (26.4 mg/L as NO_3-N) two days after peak daily discharge occurred on August 25. During the remainder of the water year both discharge and nitrate concentrations generally declined.

Table 13a summarizes the monthly nitrate data for BOOGD during WY 1990. The highest monthly fw mean nitrate concentration, 99 mg/L (22.0 mg/L as NO_3-N), occurred during July, the first month of the water year at BOOGD with continuous daily discharge. August had the highest monthly nitrate output of 4,542 pounds, and the highest monthly surface-water discharge, 110 ac-ft, which accounted for about 89% of the annual nitrate-nitrogen output and about 64% of the annual surface-water discharge at BOOGD.

During WY 1990, forty-six samples from L23S were analyzed for nitrate, and thirty-one samples were analyzed for N-series. The annual fw mean nitrate concentration was 25.4 mg/L (5.6 mg/L as NO_3-N). The total nitrate-nitrogen output for the water year was 15,034 pounds, which is equivalent to 5.4 lbs-N/acre and the total nitrogen output (nitrate- plus organic- and ammonia-nitrogen) was 65,047 pounds or 23.2 lbs-N/acre within the L23S drainage area.

Nitrate concentrations from L23S followed the same general trends as concentrations from BOOGD and RC02. During the first five months of the water year concentrations fluctuated between 37 mg/L (8.2 mg/L as NO_3-N) in late October and 6 mg/L (1.3 mg/L as NO_3-N) in late February (Fig. 8). Precipitation events in mid-March generated runoff, and minor infiltration recharge, and nitrate concentrations increased from 7 mg/L (1.6 mg/L as NO_3-N) to 30 mg/L (6.7 mg/L as NO_3-N). Following the events in March, discharge remained relatively steady and nitrate concentrations declined to 8 mg/L (1.8 mg/L as NO_3-N) in early May. Later in May nitrate concentrations increased to 78 mg/L (17.3 mg/L as NO_3-N) following minor precipitation events. The highest nitrate concentration sampled from L23S during the water year, 106 mg/L (23.6 mg/L as NO_3-N), was sampled in mid-June, one day after a runoff event. Increases in precipitation during the latter part of WY 1990 led to increased infiltration recharge and elevated nitrate concentrations from June through September. During August, nitrate concentrations increased to 104 mg/L (23.1 mg/L as NO_3-N), two days after the largest runoff event of the water year. Concentrations then decreased, along with discharge, throughout the remainder of the water year.

Table 14a summarizes the nitrate data from L23S during WY 1990 on a monthly basis. The lowest fw mean nitrate concentration, 3.5 mg/L (0.8 mg/L as NO_3-N), occurred during March when runoff, derived from snowmelt, constituted a large percentage of discharge. The highest monthly fw mean, 57 mg/L (12.7 mg/L as NO_3-N), occurred during June, when an increased percentage of discharge was being supplied by infiltration recharge. About 40% of the annual nitrate nitrogen, or 6,033 pounds, was discharged during August. August also had the highest monthly surface-water discharge, which accounted for about 42% of the annual total.

At RC02, forty samples were analyzed for nitrate, and eighty-one samples were analyzed for N-series during the water year. The annual fw mean nitrate concentration was 29.5 mg/L (6.6 mg/L as NO_3-N). The total nitrate-nitrogen output for the water year was 110,979 pounds, and if organic- and ammonia-nitrogen are considered, the total nitrogen output was 232,583 pounds. Within the drainage area of RC02, the total nitrate-nitrogen output was equivalent to 2.5 lbs-N/acre, and total nitrogen output was equal to 5.1 lbs-N/acre.

Nitrate concentrations from RC02 followed the same trends as concentrations from BOOGD and L23S, although concentrations were generally lower. During the first five months of the water year, nitrate concentrations at RC02 remained under 6 mg/L (1.3 mg/L as NO_3-N) (Fig. 8). In March, nitrate concentrations increased to 42 mg/L (9.3 mg/L as NO_3-N) following a series of precipitation events. Concentrations then generally declined to below detection limits (<1.0 mg/L) in late April. Nitrate concentrations peaked in May (39 mg/L; 8.7 mg/L as NO_3-N), June (85 mg/L; 18.9 mg/L as NO_3-N) and August (95 mg/L; 21.1 mg/L as NO_3-N), approximately two to three days after peak discharge events. From late August, both discharge and nitrate concentrations generally declined.

Monthly nitrate data for RC02 during WY 1990 is summarized in Table 15a. During the first five months of the water year, monthly fw mean nitrate concentrations ranged from 2.5 mg/L (0.6 mg/L as NO_3-N) in October to 8.4 mg/L (1.9 mg/L as NO_3-N) in January. No discharge occurred at RC02 during December. The highest monthly fw nitrate concentration, 51.5 mg/L (11.5 mg/L as NO_3-N), occurred during June. The largest monthly nitrate output, 40,206 pounds, occurred during August and accounted for about 36% of the annual nitrate-nitrogen output. August also had the highest monthly surface-water discharge, 1,820 ac-ft, which accounted for about 30% of the annual discharge at RC02.

The annual fw mean nitrate concentration for Big Spring during WY 1990 was 37 mg/L (8.2 mg/L as NO_3-N; Rowden, et al., 1993). A total of 420,294 pounds of nitrogen were discharged, and of this total, 388,479 pounds, or 92%, was in the form of nitrate. Within the 103 mi^2 drainage area of Big Spring, the total nitrogen output was equivalent to 6.4 lbs-N/acre, and the total nitrate-nitrogen output was 5.9 lbs-N/acre. Monthly fw mean nitrate concentrations varied from 19 mg/L (4.1 mg/L as NO_3-N) in February to 51 mg/L (11.3 mg/L as NO_3-N) in July. Monthly fw means remained below 30 mg/L (6.7 mg/L as NO_3-N) from October through April and above the 45 mg/L (10.0 mg/L as NO_3-N) drinking water standard from June through September. The greatest monthly nitrate-nitrogen load and groundwater discharge, 70,000 pounds and 2,542 ac-ft, occurred in August. The smallest monthly nitrate-nitrogen load, 11,000 pounds, occurred during November and December, months with the second lowest and lowest groundwater discharge, respectively. The nitrate-nitrogen discharge from Big Spring during these two months was the lowest recorded during WYs 1982-1992.

A total of 16,724,530 pounds of nitrogen were discharged by the Turkey River in WY 1990 (Rowden, et al., 1993). Of this total, 11,649,897 pounds, or 70%, was discharged in the form of nitrate at a fw mean concentration of 30.5 mg/L (6.8 mg/L as NO_3-N). Within the 1,545 mi^2 drainage area of TR01, the total nitrogen output was equivalent to 16.9 lbs-N/acre, and the total nitrate-nitrogen output equaled 11.8 lbs-N/acre. 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. 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-nitrogen discharge, 3,578,000 pounds, or 31% of the annual discharge, occurred in August, the month with the highest surface-water discharge. The smallest monthly nitrate-nitrogen discharge, 66,000 pounds, occurred during October, and represented less than 0.6% of the annual discharge.

Pesticide Monitoring

Tables 13 through 15 and Figure 8 summarize the results of pesticide monitoring at sites BOOGD, L23S and RC02 during water year 1990.

Thirty-one samples from BOOGD were analyzed for pesticides during WY 1990. All samples contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration was 3.07 µg/L, and the annual atrazine output was 1.4 pounds.

Due to discontinuous daily discharge, pesticide samples were not taken at BOOGD until January 16, when atrazine concentrations were 0.79 µg/L (Fig. 8). In February, atrazine concentrations increased to 4.70 µg/L following runoff from minor precipitation and snowmelt. Concentrations declined to 1.20 µg/L in late February as discharge receded. In March, precipitation events generated runoff and atrazine concentrations reached 7.70 µg/L, three days before discharge ceased. No discharge occurred during April, and from May 1 through June 12, discharge occurred only on May 18, May 23, May 31 and June 2. The highest atrazine concentration reported from BOOGD, 19.00 µg/L, was sampled June 13, the day that continuous daily discharge resumed. During the remainder of the water year, recharge from numerous precipitation events sustained discharge and atrazine concentrations generally declined.

Table 13b summarizes the atrazine data from BOOGD during WY 1990 on a monthly basis. Monthly fw mean atrazine concentrations varied from 9.06 µg/L in June to 0.54 µg/L in September. The greatest monthly atrazine output, 365 grams, and the greatest monthly surface-water discharge, 110 ac-ft, occurred during August and accounted for about 56% of the annual atrazine discharge and about 64% of the annual discharge.

Other pesticides detected at BOOGD during WY 1990 include cyanazine in fourteen, or 45% of the samples collected; metolachlor in seven, or 23%; and alachlor in seven, or 23% of the samples collected. The highest concentration of pesticides detected during the water year included atrazine at 19.00 µg/L; alachlor at 8.60 µg/L; cyanazine at 7.20 µg/L; and metolachlor at 3.80 µg/L. The maximum detections for atrazine and alachlor occurred June 13, and for cyanazine and metolachlor, the maximum detections occurred June 22. Cyanazine was detected during February, March, June, and July, and metolachlor and alachlor were detected during February and June.

During WY 1990, thirty-one samples from L23S were analyzed for pesticides. Twenty-eight, or 94% of the samples collected contained detectable levels of atrazine (>0.10 µg/L). The annual atrazine output from L23S was 17.4 pounds, at an annual fw mean concentration of 6.52 µg/L.

Atrazine concentrations at L23S increased from non-detectable levels in early October to 2.90 µg/L in mid-February, then declined to 0.36 µg/L in late February. Concentrations increased to 3.50 µg/L following runoff in March, then generally declined to 0.18 µg/L in late April. In May, atrazine concentrations increased to 1.10 µg/L following minor precipitation events, then declined to 0.37 µg/L near the end of the month. The highest atrazine concentration reported from L23S, 16.0 µg/L, was sampled June 14, one day after a runoff event. During the remainder of the water year, atrazine concentrations generally declined.

Table 14b summarizes the monthly atrazine data for L23S during WY 1990. Monthly fw mean atrazine concentrations varied from 0.14 µg/L in October, to 9.14 µg/L in August. August had the highest monthly atrazine output, 4,664 grams, and the highest monthly surface-water discharge, 413 ac-ft, which accounted for about 59% of the annual atrazine output and about 42% of the surface-water discharge.

Other pesticides detected at L23S during the water year include cyanazine in four, or 13% of the samples collected; alachlor in four, or 13%; and metolachlor in three, or 10% of the samples collected. The highest concentration of pesticides detected during the water year included atrazine at 16.00 µg/L; metolachlor at 1.90 µg/L; alachlor at 1.40 µg/L; and cyanazine at 0.57 µg/L. All maximum detections occurred June 14. Cyanazine was detected during February, May, and June; alachlor was detected in November, May and June; and metolachlor was detected in April and June.

Seventy-six samples from RC02 were analyzed for pesticides during WY 1990. All of the samples collected contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration was 2.89 µg/L, and the annual atrazine output was 48.8 pounds.

The atrazine plot for RC02 shows seasonal variations in concentrations similar to the changes in atrazine concentrations at sites BOOGD and L23S (Fig. 8). As previously mentioned, the first four months of the water year were extremely dry. Discharge ceased from October 19 to October 28. Atrazine concentrations were about 0.20 µg/L from early to mid-October and 0.10 µg/L on October 31. From November 2 until January 17, discharge occurred only on November 27, and January 10 through January 13. No discharge occurred during December. Atrazine concentrations decreased from 3.60 µg/L to 1.40 µg/L during late January, then increased to 3.80 µg/L in mid-February following snowmelt. Precipitation events in March generated runoff and atrazine concentrations increased to 5.50 µg/L, then generally declined, along with discharge, to 0.16 µg/L in April. Atrazine concentrations increased to 6.30 µg/L following runoff from rainfall events in May, then decreased to 0.42 µg/L in late May. Atrazine concentrations peaked at 30.00 µg/L in early June, then decreased to 1.20 µg/L as discharge receded. Precipitation events in mid-June generated both infiltration and runoff recharge, and atrazine concentrations increased to 12.00 µg/L. During the remainder of the water year, atrazine concentrations at RC02 generally declined, fluctuating between 12.00 µg/L in June and 0.15 µg/L in late September.

Table 15b summarizes the monthly atrazine data for RC02 during Water Year 1990. Monthly fw mean atrazine concentrations varied from 0.20 µg/L in October to 6.01 µg/L in June. The greatest monthly atrazine output, 8,830 grams, occurred during March and accounted for about 40% of the annual output. August had the highest monthly surface-water discharge, 1,820 ac-ft, which accounted for about 30% of the annual discharge.

Other pesticides detected at RC02 during WY 1990 include cyanazine in forty-one, or 54% of the samples collected; alachlor in thirty-four, or 45%; metolachlor in twenty-seven, or 36%; butylate in one, or 1%; and trifluralin in one, or 1% of the samples collected. The highest concentration of pesticides detected during the water year included atrazine at 30.00 µg/L; cyanazine at 8.50 µg/L; alachlor at 8.20 µg/L; metolachlor at 7.40 µg/L;

Table 16. Annual summary of water and chemical discharge for BOOGD for Water Year 1991. (Discharge data from U.S. Geological Survey, Water Resources Division.)

DISCHARGE		
Total		
acre-feet	1,020	
millions cf	44	
millions cm	1.3	
Average		
cfs	1.4	
cms	0.04	
mg/d	0.91	
gpm	633	
PRECIPITATION AND DISCHARGE		
Precipitation	47.28 inches (1,201 mm)	
Discharge	16.65 inches (422.9 mm)	
Discharge as % of precipitation	35%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	71.8	16.0
Mean of analyses	82.9	18.4
	NO_3-N output	**Total N output**
lbs - N	44,336	50,588
kg - N	20,107	22,943
lbs - N/acre	60.2	68.7
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	3.32	
Mean of analyses	0.83	
Total output		
lbs	9.2	
kg	4.2	

Table 17. Annual summary of water and chemical discharge for L23S for Water Year 1991. (Discharge data from U.S. Geological Survey, Water Resources Division.)

DISCHARGE		
Total		
acre-feet	3,594	
millions cf	156	
millions cm	4.4	
Average		
cfs	4.9	
cms	0.14	
mg/d	3.2	
gpm	2,230	
PRECIPITATION AND DISCHARGE		
Precipitation	47.27 inches (1,201mm)	
Discharge	15.36 inches (390mm)	
Discharge as % of precipitation	32%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	53.9	12.0
Mean of analyses	55.1	12.3
	NO_3-N output	**Total N output**
lbs - N	117,164	174,304
kg - N	53,136	79,050
lbs - N/acre	41.7	62.0
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	2.30	
Mean of analyses	0.24	
Total output		
lbs	22.5	
kg	10.2	

butylate at 1.30 µg/L; and trifluralin at 0.10 µg/L. The maximum detections of atrazine, alachlor and metolachlor occurred June 6, and maximum detections for cyanazine and alachlor occurred June 22. Cyanazine and alachlor were detected during all months except October, November, December, and April; metolachlor was detected in all months except October, November, December, April, and September; trifluralin was detected in February; and butylate was detected in September.

During the water year, 50.0 pounds of atrazine were discharged from Big Spring, at a fw mean concentration of 1.06 µg/L (Rowden et al., 1993). This was the highest annual fw mean atrazine concentration and annual load observed at Big Spring during WYs 1982-1990. Monthly fw mean atrazine concentrations and loads varied from 2.38 µg/L and 14.9 pounds in June, to 0.16 µg/L and 0.3 pounds in December.

The annual fw mean atrazine concentration for the Turkey River was 1.90 µg/L and the annual atrazine discharge totaled 3,259 pounds (Rowden et al., 1993). The highest monthly fw mean atrazine concentration, 4.88 µg/L, occurred in June, and the lowest fw mean, 0.14 µg/L, occurred in December. The greatest monthly atrazine discharge, 1,236 pounds, occurred in August, accounting for 38% of the annual discharge, and the smallest monthly discharge, 2.4 pounds, occurred during December.

Water Year 1991

Discharge Monitoring

Tables 16 through 18 and Figure 9 summarize the discharge, water quality and chemical-load data for surface-water sites BOOGD, L23S and RC02 during Water Year 1991 (note the increase in scale on the discharge plot relative to WY 1990 in Figure 9).

Precipitation during the water year was 47.27 inches, or about 143% of the long-term average for the basin area. Precipitation was slightly below normal from October through February, far below normal in July, and far above normal from March through June. The greatest monthly accumulation of rainfall (13.09 inches) occurred during June and

Table 18. Annual summary of water and chemical discharge for RC02 for Water Year 1991. (Discharge data from U.S. Geological Survey, Water Resources Division.)

DISCHARGE		
Total		
acre-feet	33,443	
millions cf	1,457	
millions cm	41	
Average		
cfs	46.2	
cms	1.3	
mg/d	29.9	
gpm	20,735	

PRECIPITATION AND DISCHARGE	
Precipitation	47.27 inches (1,201mm)
Discharge	8.87 inches (225mm)
Discharge as % of precipitation	19%

NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	51.0	11.3
Mean of analyses	36.3	8.1
	NO_3-N output	**Total N output**
lbs - N	1,032,119	1,536,742
kg - N	468,081	696,935
lbs - N/acre	22.8	34.0

ATRAZINE DISCHARGE	
Concentration - µg/L	
Flow-weighted mean	7.20
Mean of analyses	1.08
Total output	
lbs	655
kg	297

the largest single rainfall event (local reports of 11 to 13 inches near Monona, Iowa) occurred on June 14, causing extensive flooding throughout the Big Spring area.

The surface-water discharge from site BOOGD during WY 1991 was 1,020 ac-ft and the average daily discharge was 1.4 cfs (Table 16). The annual discharge from BOOGD was equivalent to 35% of the annual precipitation. At site L23S, the annual discharge for the water year was 3,594 ac-ft, at an average daily discharge of 4.9 cfs (Table 17). The annual discharge was equal to 32% of the annual precipitation. The annual discharge for site RC02 was 33,443 ac-ft and the average daily discharge was 46.2 cfs (Table 18). The annual discharge for RC02 was equivalent to 19% of the annual precipitation.

At Big Spring, the annual groundwater discharge was 42,481 ac-ft, or about 16% of the annual precipitation, at an average flow rate of 59 cfs (Rowden et al., 1993). The annual discharge from the Turkey River was 1,103,000 ac-ft, at an average rate of 1,524 cfs (Rowden et al., 1993). The discharge accounted for about 28% of the precipitation, and was 160% of the long-term discharge average. The greatest instantaneous discharge recorded during WYs 1914-1992 at Garber, 49,900 cfs, occurred on June 15, 1991. The annual precipitation, and groundwater and surface-water discharge from sites BSP, TR01, BOOGD, L23S and RC02 during WY 1991 were the highest recorded during WYs 1982-1991.

During the first four months of the water year, discharge at all surface-water sites continued to recede from the last major runoff event in WY 1990 (Fig. 9). Discharge at BOOGD ceased on October 30, and during November, discharge occurred only on November 3, 4, 8, 17, 21, and 22. BOOGD remained dry from November 23 until March 1. Discharge at L23S remained relatively steady from October through February, ranging from 0.88 cfs in early October to 0.22 cfs in early December. At RC02, discharge decreased from 7.6 cfs in October to 0.01 cfs at the end of January. Flow essentially ceased at RC02 during the first two days in February, then very slowly increased through the end of the month. Snowmelt and small amounts of

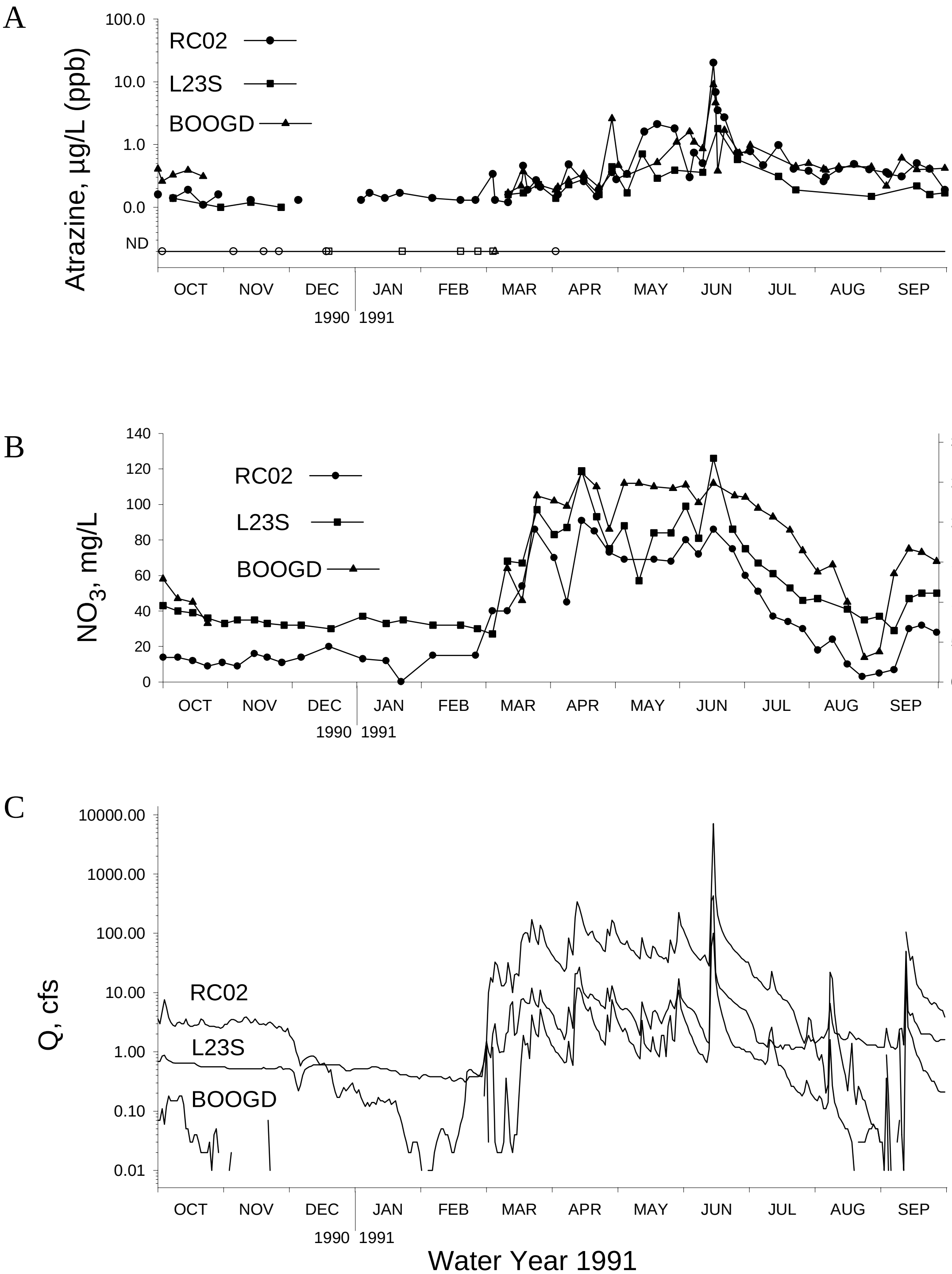

Figure 9. A) Atrazine and B) nitrate concentrations, and C) surface-water discharge (Q) at RC02, L23S, and BOOGD for WY 1991 (note the increase in scale on the discharge plot relative to WY 1990). (Discharge data are from the U.S. Geological Survey, W.R.D., IA Dist.)

rainfall in late February and March generated minor runoff and infiltration recharge, and discharge at all sites increased significantly. Above average rainfall during April, May, and June generated significant runoff and infiltration recharge. Mean daily discharge at all sites peaked in mid-June following intense rains, and then generally receded through August. Precipitation events in mid-September generated minor runoff, followed by generally receding discharge during the remainder of the water year. The peak daily discharges recorded in mid-June were the highest observed at the surface-water sites during WYs 1986-1992 and at Big Spring during WYs 1982-1992. 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.

Nitrate Monitoring

Tables 16 through 18 and Figure 9 summarize the nitrate analyses from BOOGD, L23S and RC02 during Water Year 1991.

During the water year, thirty-four samples from BOOGD were analyzed for nitrate, and forty-five samples were analyzed for N-series. The annual fw mean nitrate concentration was 71.8 mg/L (16.0 mg/L as NO_3-N). The total nitrate-nitrogen output for the water year was 44,336 pounds, and the total nitrogen output was 50,588 pounds. Within the drainage area of BOOGD these outputs were equivalent to 60.2 lbs-N/acre for total nitrate-nitrogen and 68.7 lbs-N/acre for total nitrogen. The annual fw mean nitrate concentration and annual nitrate-nitrogen output for WY 1991 were the highest recorded during WYs 1986-1991.

As previously mentioned, BOOGD was essentially dry from November through February (Fig. 9). During October, nitrate concentrations decreased from 58 mg/L (12.9 mg/L as NO_3-N) to 33 mg/L (7.3 mg/L as NO_3-N). Concentrations increased to 64 mg/L (14.2 mg/L as NO_3-N) following a minor runoff event in mid-March. From March, a general increase in both nitrate concentrations and discharge occurred at BOOGD (and most other sites in the basin). Nitrate concentrations remained above 86 mg/L (19.1 mg/L as NO_3-N) until late July. Concentrations peaked at 182 mg/L (40.4 mg/L as NO_3-N) on July 23, as discharge receded. The lowest nitrate concentration sampled during the water year, 14 mg/L (3.1 mg/L as NO_3-N) occurred in late August during very low-flow conditions. Concentrations increased to 75 mg/L (16.7 mg/L as NO_3-N) in mid-September following minor recharge, then declined during the remainder of the water year.

Table 16a summarizes the monthly nitrate data for BOOGD during WY 1991. The highest monthly fw mean nitrate concentration, 108 mg/L (24.0 mg/L as NO_3-N), occurred during May, and the lowest monthly fw mean, 25 mg/L (5.6 mg/L as NO_3-N) occurred during November. June had the highest monthly nitrate output of 14,366 pounds, and the highest monthly surface-water discharge, 466 ac-ft, which accounted for about 32% of the annual nitrate-nitrogen output and about 46% of the annual surface-water discharge at BOOGD.

During WY 1991, forty-eight samples from L23S were analyzed for nitrate, and thirty samples were analyzed for N-series. The annual fw mean nitrate concentration was 53.9 mg/L (12.0 mg/L as NO_3-N). The total nitrate-nitrogen output for the water year was 117,164 pounds, which is equivalent to 41.7 lbs-N/acre and the total nitrogen output was 174,304 pounds, or 62.0 lbs-N/acre within the L23S drainage area. The annual fw mean nitrate concentration and total nitrogen output for WY 1991 were the highest recorded during WYs 1986-1991.

Nitrate concentrations from L23S followed the same general trends as concentrations from BOOGD and RC02 during the water year, generally being lower than concentrations from BOOGD and higher than concentrations from RC02. The lowest concentration sampled during the water year, 27 mg/L (6.0 mg/L as NO_3-N), occurred in March during a minor runoff event, and the highest concentration, 126 mg/L (28.0 mg/L as NO_3-N), occurred June 17, two days after the largest runoff event during the period of record.

Table 17a summarizes the nitrate data from L23S during WY 1991 on a monthly basis. The lowest monthly fw mean nitrate concentration, 31.1 mg/L (6.9 mg/L as NO_3-N), occurred during December, and the highest monthly fw mean, 81 mg/L (18.0 mg/L as NO_3-N), occurred during April, when an increased percentage of discharge was being supplied by infiltration recharge. About 44% of the annual nitrate nitrogen, or 51,157 pounds, were discharged during June. June also had the highest monthly surface-water discharge, 1,920 ac-ft, which accounted for about 53% of the annual total.

At RC02, forty-six samples were analyzed for nitrate, and seventy-five samples were analyzed for N-series during the water year. The annual fw mean nitrate concentration was 51 mg/L (11.3 mg/L as NO_3-N). The total nitrate-nitrogen output for the water year was 1,032,119 pounds, and if organic- and ammonia-nitrogen are considered, the total nitrogen output was 1,536,742 pounds. Within the drainage area of RC02, the total nitrate-nitrogen output was equivalent to 22.8 lbs-N/acre, and total nitrogen output was equal to 34.0 lbs-N/acre. The annual fw mean nitrate concentration and annual nitrate-nitrogen output for WY 1991 were the highest recorded during WYs 1986-1991.

Nitrate concentrations from RC02 followed the same seasonal trends as concentrations from BOOGD and L23S, although concentrations were generally lower. During the first five months of the water year, nitrate concentrations at RC02 remained under 20 mg/L (4.4 mg/L as NO_3-N), declining to non-detectable levels (<1.0 mg/L) in late January (Fig. 9). Concentrations increased to 91 mg/L (20.2 mg/L as NO_3-N) in mid-April following a series of precipitation events. Concentrations then generally declined to 3 mg/L (0.7 mg/L as NO_3-N) in late August as discharge continued to recede. Concentrations increased to 32 mg/L (7.1 mg/L as NO_3-N) in late September following the last runoff event of the water year.

Monthly nitrate data for RC02 during WY 1991 is summarized in Table 18a. During the first five months of the water year, monthly fw mean nitrate concentrations remained below 20 mg/L (4.4 mg/L as NO_3-N). The highest monthly fw nitrate concentration, 64.9 mg/L (14.4 mg/L as NO_3-N), occurred during May. The largest monthly nitrate output, 521,009 pounds, occurred during June and accounted for about 50% of the annual nitrate-nitrogen output. June also had the highest monthly surface-water discharge, 18,650 ac-ft, which accounted for about 56% of the annual discharge at RC02.

The annual fw mean nitrate concentration for Big Spring during WY 1991 was 56.4 mg/L (12.5 mg/L as NO_3-N; Rowden et al., 1993). A total of 1,561,450 pounds of nitrogen were discharged, and of this total, 1,445,506 pounds, or 93%, was in the form of nitrate. Within the 103 mi^2 drainage area of Big Spring, the total nitrogen output was equivalent to 23.7 lbs-N/acre and the total nitrate-nitrogen output was 21.9 lbs-N/acre. The annual fw mean nitrate concentration and total nitrate-nitrogen output were the highest recorded during the WY 1982-1992 period of record.

The highest monthly fw mean nitrate concentrations from Big Spring during WYs 1982-1991 occurred 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 were 54 mg/L in April, and 56 mg/L in July of WY 1983. The lowest monthly fw mean nitrate concentration during the water year, 30 mg/L (6.7 mg/L as NO_3-N), occurred in January and February. Monthly nitrate-nitrogen 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-nitrogen discharges during April, May, June, and July were the highest recorded during WYs 1982-1991.

A total of 34,244,926 pounds of nitrogen were discharged by the Turkey River during WY 1991 (Rowden et al., 1993). Of this total, 29,591,638 pounds, or 86% was discharged in the form of nitrate, at a fw mean concentration of 44.4 mg/L (9.9 mg/L as NO_3-N). Within the 1,545 mi^2 drainage area of TR01, the total nitrogen output was equivalent to 34.6 lbs-N/acre, and the total nitrate-nitrogen output equaled 29.9 lbs-N/acre. Monthly fw mean nitrate concentrations varied from 22 mg/L (5.0 mg/L as NO_3-N) in January to 49 mg/L (10.9 mg/L as NO_3-N) in March. Monthly nitrate-nitrogen discharge varied from 198,000 pounds in January to about 7,369,000 pounds in

April, which accounted for about 25% of the annual total for WY 1991. The monthly nitrate-nitrogen 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

Tables 16 through 18 and Figure 9 summarize the results of pesticide monitoring at sites BOOGD, L23S and RC02 during water year 1991.

Forty-five samples from BOOGD were analyzed for pesticides during WY 1991. Forty-four, or 98% of the samples collected contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration, 3.32 µg/L, and the annual atrazine output, 9.2 pounds, were the greatest recorded at BOOGD during WYs 1986-1991.

Due to discontinuous daily discharge, pesticide samples were not taken at BOOGD from the end of October until March 6, when atrazine concentrations were below the detection limit (Fig. 9). During October, atrazine concentrations varied between 0.41 µg/L and 0.26 µg/L. Atrazine concentrations generally increased from March through mid-April, as discharge increased following precipitation events. Concentrations increased to 2.60 µg/L in late April during a runoff event, then decreased to 0.33 µg/L in May, as discharge continued to recede. Atrazine concentrations peaked at 9.00 µg/L on June 15 during the largest runoff event recorded during the period of record at BOOGD. Throughout the remainder of the water year both discharge and atrazine concentrations generally declined until flow ceased on September 5. Discharge resumed on September 9 and atrazine concentrations were 0.61 µg/L the following day. Concentrations decreased slightly during the remainder of the water year.

Table 16b summarizes the atrazine data from BOOGD during WY 1991 on a monthly basis. Monthly fw mean atrazine concentrations varied from 0.32 µg/L in October to 6.07 µg/L in June. The greatest monthly atrazine output during the period of monitoring, 3,497 grams, also occurred during June and accounted for about 84% of the annual atrazine discharge.

Other pesticides detected at BOOGD during WY 1991 include cyanazine in eleven, or 24% of the samples collected; alachlor in nine, or 20%; and metolachlor in two, or 4% of the samples collected. The highest concentration of pesticides detected during the water year included atrazine at 9.00 µg/L; cyanazine at 2.60 µg/L; alachlor at 2.50 µg/L; and metolachlor at 0.20 µg/L. The maximum detections for atrazine, cyanazine, and metolachlor occurred June 15, and for alachlor the maximum detection occurred April 29. Cyanazine and alachlor were detected during April, May, and June, and metolachlor was detected during June only.

During WY 1991, thirty samples from L23S were analyzed for pesticides. Twenty-five, or 83% of the samples collected contained detectable levels of atrazine (>0.10 µg/L). The annual atrazine output from L23S was 22.5 pounds, at an annual fw mean concentration of 2.30 µg/L. The annual atrazine output for the water year was the highest recorded at L23S during WYs 1986-1991.

Atrazine concentrations from L23S showed the same seasonal trends as concentrations from BOOGD, although they were generally lower. From the beginning of the water year, concentrations decreased from 0.14 µg/L to 0.10 µg/L at the end of October. In November concentrations increased to 0.12 µg/L, then declined to non-detectable levels in mid-December. Atrazine concentrations remained below the detection limit until mid-March. From March through May, a number of runoff events led to a general increase in atrazine concentrations. Atrazine concentrations increased to 0.71 µg/L during an event in mid-May, then declined to 0.29 µg/L a week later as discharge receded. The highest atrazine concentration from L23S, 1.80 µg/L, was sampled two days after the major runoff even that occurred June 15. During the remainder of the water year, concentrations generally declined to about 0.20 µg/L in September.

At BOOGD, RC02 and Big Spring, the highest atrazine concentrations of the water year occurred during the runoff event in mid-June. Site L23S was not sampled during the event, so the maximum concentration for the water year was much lower than the maximums from other sites in the basin.

Estimates of atrazine concentrations during the event were based on concentrations from other sites, and as a result, the annual fw mean atrazine concentration for L23S exceeded the maximum concentration detected during the year.

Table 17b summarizes the monthly atrazine data for L23S during WY 1991. Monthly fw mean atrazine concentrations varied from 0.06 µg/L in December to 3.91 µg/L in June. June had the highest monthly atrazine output, 9,279 grams, and the highest monthly surface-water discharge, 1,920 ac-ft, during the period of record. This accounted for about 91% of the annual atrazine output and about 53% of the annual surface-water discharge.

Other pesticides detected at L23S during the water year include cyanazine in four, or 13% of the samples collected; alachlor in four, or 13%; and metolachlor in two, or 7% of the samples collected. The highest concentration of pesticides detected during the water year included atrazine at 1.80 µg/L; cyanazine at 0.74 µg/L; metolachlor at 0.56 µg/L; and alachlor at 0.32 µg/L. The maximum detections for atrazine, metolachlor, and alachlor occurred June 17, and for cyanazine the maximum detection occurred April 9. Alachlor was detected during January, May, and June; cyanazine was detected in April, May and June; and metolachlor was detected in May and June.

Seventy samples from RC02 were analyzed for pesticides during WY 1991. Sixty-four, or 91% of the samples collected contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration, 7.20 µg/L, and the annual atrazine output, 655 pounds, were the highest recorded at RC02 during WYs 1986-1991.

The atrazine plot for RC02 shows seasonal variations in concentrations similar to the changes in atrazine concentrations at sites BOOGD and L23S (Fig. 9). Concentrations remained below 0.20 µg/L during the first five months of the water year, declining to non-detectable levels in October, November, and December. Concentrations increased to 0.34 µg/L in early March following recharge from snowmelt and precipitation. During the remainder of the water year, atrazine concentrations generally followed discharge, increasing during runoff periods and decreasing as discharge receded. Atrazine concentrations reached 20.00 µg/L during the major runoff event in mid-June, then generally decreased, fluctuating between 0.98 µg/L in mid-July and 0.19 µg/L in late September.

Table 18b summarizes the monthly atrazine data for RC02 during Water Year 1991. Monthly fw mean atrazine concentrations varied from 0.06 µg/L in November to 12.00 µg/L in June. The greatest monthly atrazine output, 276,180 grams, and greatest monthly surface-water discharge, 18,650 ac-ft, occurred during June and accounted for about 93% of the annual atrazine output, and about 56% of the annual discharge.

Other pesticides detected at RC02 during WY 1991 include alachlor in sixteen, or 23% of the samples collected; cyanazine in twelve, or 17%; and metolachlor in eleven, or 16% of the samples collected. The highest concentration of pesticides detected during the water year included atrazine at 20.00 µg/L; alachlor at 8.80 µg/L; metolachlor at 6.70 µg/L; and cyanazine at 3.00 µg/L. All maximum detections occurred June 15. Alachlor was detected during December, March, April, May, and June; cyanazine was detected in May, June, and July; and metolachlor was detected in May and June.

At Big Spring, 135 pounds of atrazine were discharged during the water year at a fw mean concentration of 1.17 µg/L (Rowden et al., 1993). Monthly fw mean concentrations varied from 3.32 µg/L in June to 0.16 µg/L in February. The highest monthly atrazine loads 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 fw means and loads from Big Spring during WYs 1982-1992.

The atrazine discharge from the Turkey River during the water year was 3,325 pounds, at a fw mean concentration of 1.11 µg/L (Rowden et al., 1993). 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

Table 19. Annual summary of water and chemical discharge for BOOGD for Water Year 1992. (Discharge data from U.S. Geological Survey, Water Resources Division.)

DISCHARGE		
Total		
acre-feet	825	
millions cf	36	
millions cm	1.0	
Average		
cfs	1.0	
cms	0.03	
mg/d	0.65	
gpm	449	
PRECIPITATION AND DISCHARGE		
Precipitation	35.75 inches (908.1 mm)	
Discharge	13.45 inches (341.6 mm)	
Discharge as % of precipitation	38%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	71.6	15.9
Mean of analyses	74.6	16.6
	NO_3-N output	**Total N output**
lbs - N	35,646	37,957
kg - N	16,166	17,214
lbs - N/acre	48.4	51.6
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	0.33	
Mean of analyses	0.21	
Total output		
lbs	0.73	
g	333	

pounds. Over 63% of the annual atrazine output occurred during June.

The annual fw mean atrazine concentrations and loads observed at Big Spring and the Turkey River at Garber during WY 1991 exceeded all previous annual fw means and loads registered during WYs 1986 through 1992.

Water Year 1992

Discharge Monitoring

Tables 19 through 21 and Figure 10 summarize the discharge, water quality and chemical-load data for surface-water sites BOOGD, L23S and RC02 during Water Year 1992. In Figure 10, note the decrease in scale on the atrazine, nitrate and discharge plots relative to WY 1991.

Water Year 1992 followed the wettest year during WYs 1982-1992. Precipitation during the water year was 35.75 inches, or about 2.8 inches above the long-term average. Rainfall was more evenly distributed than during WYs 1990 and 1991, with no large single rainfall or runoff events. Precipitation was above average during October, November and September, and below average during May, June, and August.

Above average precipitation during October and November, combined with the recharge that occurred during WY 1991, led to sustained increases in discharge at all surface-water sites during November and December. Discharge generally receded from December through most of February, with minor snowmelt and precipitation generating small runoff events. Snowmelt and precipitation later in February generated enough recharge to sustain discharge for a few weeks, then discharge continued to recede through most of April. The second largest runoff event of the water year occurred in mid-April, followed by general recession through mid-June. During July, a number of precipitation events led to small increases in discharge, followed by generally receding discharge through August. Above average precipitation during September led to increases in discharge early in the month, followed by general recession during the remainder of the water year.

The surface-water discharge from site BOOGD during the water year was 825 ac-ft and the average daily discharge was 1.0 cfs (Table 19). The annual discharge from BOOGD was equivalent to 38% of the annual precipitation. At L23S, the annual discharge during WY 1992 was 3,980 ac-ft, and the average daily discharge was 5.5 cfs (Table 20). These were the highest discharge rates recorded during WYs 1986-1992. The annual discharge from L23S was equal to 48% of the annual precipitation. For site RC02, the annual discharge rate was 27,890 ac-ft and the average daily discharge was 38.4 cfs (Table 21). The annual discharge for RC02 was equivalent to 21% of the annual precipitation.

At Big Spring the annual discharge during WY 1992 was 37,278 ac-ft, or about 19% of the annual precipitation, and the average daily discharge rate was 51.5 cfs (Rowden et al., in production). The annual surface-water discharge from the Turkey River was 1,101,000 ac-ft, at an average discharge rate of 1,517 cfs (Rowden et al., in production). Annual discharge from TR01 was equivalent to 37% of the annual precipitation and about 162% of the long-term discharge average.

Nitrate Monitoring

Tables 19 through 21 and Figure 10 summarize the nitrate analyses from BOOGD, L23S and RC02 during Water Year 1992.

During the water year, fifty-two samples from BOOGD were analyzed for nitrate, and sixty-three samples were analyzed for N-series. The annual fw mean nitrate concentration was 71.6 mg/L (15.9 mg/L as NO_3-N). The total nitrate-nitrogen output for the water year was 35,646 pounds, and the total nitrogen output (nitrate- plus organic-, and ammonia-N) was 37,957 pounds. Within the drainage area of BOOGD these outputs were equivalent to 48.4 lbs-N/acre for total nitrate-nitrogen and 51.6 lbs-N/acre for total nitrogen.

The overall increase in infiltration recharge to surface-water sites during WY 1992, led to generally high nitrate concentrations at all sites throughout the water year. Nitrate concentrations at BOOGD increased from 68 mg/L (15.1 mg/L as

Table 20. Annual summary of water and chemical discharge for L23S for Water Year 1992. (Discharge data from U.S. Geological Survey, Water Resources Division.)

DISCHARGE		
Total		
acre-feet	3,980	
millions cf	173	
millions cm	4.9	
Average		
cfs	5.5	
cms	0.16	
mg/d	3.5	
gpm	2,459	
PRECIPITATION AND DISCHARGE		
Precipitation	35.75 inches (908mm)	
Discharge	17.00 inches (432mm)	
Discharge as % of precipitation	48%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	51.5	11.4
Mean of analyses	52.5	11.7
	NO_3-N output	**Total N output**
lbs - N	123,530	143,301
kg - N	56,023	64,990
lbs - N/acre	44.0	51.0
ATRAZINE DISCHARGE		
Concentration - μg/L		
Flow-weighted mean	0.26	
Mean of analyses	0.20	
Total output		
lbs	2.9	
kg	1.3	

Table 21. Annual summary of water and chemical discharge for RC02 for Water Year 1992. (Discharge data from U.S. Geological Survey, Water Resources Division.)

DISCHARGE

Total

acre-feet	27,890
millions cf	1,215
millions cm	34

Average

cfs	38.4
cms	1.1
mg/d	24.8
gpm	17,234

PRECIPITATION AND DISCHARGE

Precipitation	35.75 inches (908 mm)
Discharge	7.40 inches (188 mm)
Discharge as % of precipitation	21%

NITRATE DISCHARGE

Concentration - mg/L	As NO_3	As NO_3-N
Flow-weighted mean	38.1	8.5
Mean of analyses	37.1	8.2

NO_3-N output		Total N output
lbs - N	643,061	770,744
kg - N	291,638	349,544
lbs - N/acre	14.2	17.0

ATRAZINE DISCHARGE

Concentration - µg/L

Flow-weighted mean	0.36
Mean of analyses	0.46

Total output

lbs	27.2
kg	12.3

NO_3-N) in October to 89 mg/L (19.8 mg/L as NO_3-N) in late November as discharge generally increased. Nitrate concentrations remained above 78 mg/L (17.3 mg/L as NO_3-N) from November through January. Nitrate concentrations were diluted to 52 mg/L (11.6 mg/L as NO_3-N) in early February, and 22 mg/L (4.9 mg/L as NO_3-N) later in the month during snowmelt events. Nitrate concentrations remained above 70 mg/L (15.6 mg/L as NO_3-N) during March and April, and above 80 mg/L (17.8 mg/L as NO_3-N) during May. Concentrations dropped to 51 mg/L (11.3 mg/L as NO_3-N) during a minor runoff event in mid-June, then increased to 78 mg\L (17.3 mg/L as NO_3-N) the following week. Nitrate concentrations dropped to 61 mg/L (13.6 mg/L as NO_3-N) during a precipitation event in July, then increased to 72 mg/L (16.0 mg/L as NO_3-N) one week later. During the remainder of the water year, concentrations declined to 62 mg/L (13.8 mg/L as NO_3-N) in late August, then increased to 76 (16.9 mg/L as NO_3-N) in late September as discharge receded from events earlier in the month.

Table 19a summarizes the monthly nitrate data for BOOGD during WY 1992. Monthly fw mean nitrate concentrations were consistently high during the water year. Monthly fw means were above 60 mg/L (13.3 mg/L as NO_3-N), except during February when the fw mean was 41.7 mg/L (9.3 mg/L as NO_3-N). The highest monthly fw mean, 84.3 mg/L (18.7 mg/L as NO_3-N), occurred during May. December had the highest monthly nitrate output, 6,752 pounds, and the second-highest monthly surface-water discharge, 136 ac-ft, which accounted for about 19% of the annual nitrate-nitrogen output and about 16% of the annual surface-water discharge at BOOGD.

During WY 1992, fifty-one samples from L23S were analyzed for nitrate, and twenty samples were analyzed for N-series. The annual fw mean nitrate concentration was 51.5 mg/L (11.4 mg/L as NO_3-N). The total nitrate-nitrogen output for the water year was 123,530 pounds, which is equivalent to 44.0 lbs-N/acre, and the total nitrogen output (nitrate- plus organic- and ammonia-nitrogen) was 143,301 pounds, or 51.0 lbs-N/acre, within the L23S drainage area. The annual nitrate-nitrogen

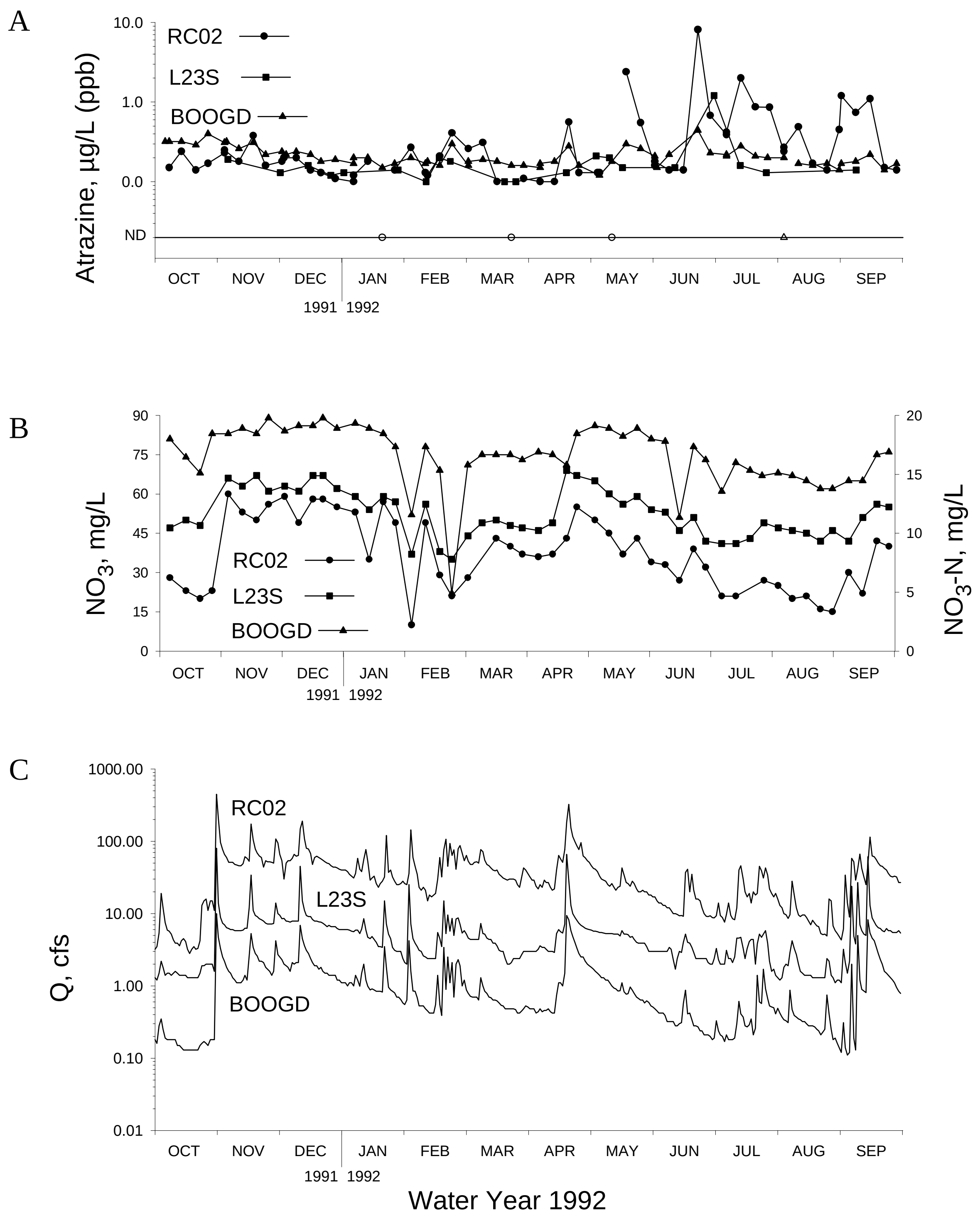

Figure 10. A) Atrazine and B) nitrate concentrations, and C) surface-water discharge (Q) at RC02, L23S, and BOOGD for WY 1992 (note the decrease in scale on the atrazine, nitrate and discharge plots relative to WY 1991). (Discharge data are from the U.S. Geological Survey, W.R.D., IA Dist.)

discharge during WY 1992 was the greatest recorded at L23S during WYs 1986-1992.

The nitrate plot for L23S shows the same general trends as concentrations from BOOGD during the water year, although concentrations from L23S were generally lower than concentrations from BOOGD and did not tend to drop as greatly during runoff events. Nitrate concentrations increased from 47 mg/L (10.4 mg/L as NO_3-N) in early October to 67 mg/L (14.9 mg/L as NO_3-N) in November following infiltration recharge from precipitation events. Concentrations remained relatively steady through December, then generally declined during January and February. The lowest concentration sampled during the water year, 35 mg/L (7.8 mg/L as NO_3-N) occurred in February during snowmelt, and the highest concentration, 69 mg/L (15.3 mg/L as NO_3-N), occurred in April following a runoff event. Nitrate concentrations generally declined from April through mid-June, then increased temporarily following minor discharge events later in June, July and August. Concentrations increased slightly in September following runoff events.

Table 20a summarizes the nitrate data from L23S during WY 1992 on a monthly basis. The highest monthly fw mean nitrate concentration, 61.7 mg/L (13.7 mg/L as NO_3-N), occurred during December, and the lowest monthly fw mean, 37.9 mg/L (8.4 mg/L as NO_3-N) occurred during February, when an increased percentage of discharge was being supplied by runoff recharge from snowmelt. December had the highest monthly nitrate-nitrogen output, 21,418 pounds, which accounted for about 17% of the annual total, and the second-highest monthly discharge, 574 ac-ft, which accounted for about 14% of the annual discharge.

At RC02, fifty samples were analyzed for nitrate, and sixty-four samples were analyzed for N-series during the water year. The annual fw mean nitrate concentration was 38.1 mg/L (8.5 mg/L as NO_3-N). The total nitrate-nitrogen output for the water year was 643,061 pounds, and if organic- and ammonia-nitrogen are considered, the total nitrogen output was 770,744 pounds. Within the drainage area of RC02, the total nitrate-nitrogen output was equivalent to 14.2 lbs-N/acre, and total nitrogen output was equal to 17.0 lbs-N/acre.

Nitrate concentrations from RC02 followed the same seasonal trends as concentrations from BOOGD and L23S, although concentrations were generally lower. The highest nitrate concentration recorded during the water year, 60 mg/L (13.3 mg/L as NO_3-N), occurred November 5, four days after the largest discharge event of the water year. The lowest nitrate concentration recorded during the water year, 10 mg/L (2.2 mg/L as NO_3-N), occurred during snowmelt in early February. As with sites BOOGD and L23S, nitrate concentrations generally increased from late February through April, then generally decreased through August. Nitrate concentrations increased in September following runoff events.

Monthly nitrate data for RC02 during WY 1992 is summarized in Table 21a. Monthly fw mean nitrate concentrations remained below 50 mg/L (11.1 mg/L as NO_3-N) during the water year. The highest monthly fw nitrate concentration, 49.1 mg/L (10.9 mg/L as NO_3-N), occurred during December, and the lowest monthly fw mean, 21 mg/L (4.7 mg/L as NO_3-N), occurred in August. The largest monthly nitrate-nitrogen output, 120,127 pounds, occurred during November and accounted for about 19% of the annual total. November also had the greatest monthly surface-water discharge, 4,910 ac-ft, which accounted for about 18% of the annual discharge at RC02.

The annual fw mean nitrate concentration for Big Spring during WY 1992 was 54.2 mg/L (12.0 mg/L as NO_3-N; Rowden et al., in production). A total of 1,257,410 pounds of nitrogen were discharged, and of this total, 1,220,099 pounds, or 97%, was in the form of nitrate. Within the 103 mi^2 drainage area of Big Spring, the total nitrogen output was equivalent to 19.1 lbs-N/acre and the total nitrate-nitrogen output was 18.5 lbs-N/acre. The annual fw mean nitrate concentration and total nitrate-nitrogen output were the second highest recorded during the WY 1982-1992 period of record.

The highest monthly fw mean nitrate concentration and load, 63.0 mg/L (14.1 mg/L as NO_3-N) and 179,000 pounds, occurred during December, and the lowest monthly fw mean and load, 44.0 mg/

L (9.8 mg/L as NO_3-N) and 51,000 pounds, occurred in October.

A total of 29,644,014 pounds of nitrogen were discharged by the Turkey River during WY 1992 (Rowden et al., in production). Of this total, 27,244,063 pounds, or 92% was discharged in the form of nitrate at a fw mean concentration of 41.0 mg/L (9.1 mg/L as NO_3-N). Within the 1,545 mi^2 drainage area of TR01, the total nitrogen output was equivalent to 30.0 lbs-N/acre, and the total nitrate-nitrogen output equaled 27.6 lbs-N/acre. Monthly fw mean nitrate concentrations and loads varied from 33.0 mg/L (7.3 mg/L as NO_3-N) and 745,000 pounds in October to 50.0 mg/L (11.1 mg/L as NO_3-N) and 5,913,000 pounds in December. The monthly nitrate-nitrogen discharge remained above 1 million pounds during all months except October and August.

Pesticide Monitoring

Tables 19 through 21 and Figure 10 summarize the results of pesticide monitoring at sites BOOGD, L23S and RC02 during Water Year 1992.

Sixty-two samples from BOOGD were analyzed for pesticides during WY 1992. Atrazine was the only pesticide detected during the water year. Sixty-one, or 98% of the samples collected contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration was 0.33 µg/L and the annual atrazine output was 0.73 pounds (Table 19).

Atrazine concentrations were relatively stable at BOOGD during the water year. Concentrations generally decreased from 0.40 µg/L in late October to 0.15 µg/L near the end of January (Fig. 10). Concentrations increased to 0.30 µg/L during a runoff event in late February, then remained below 0.20 µg/L until April. Concentrations increased to 0.28 µg/L during a large event in mid-April, then declined to 0.12 µg/L as discharge continued to recede in early May. The highest atrazine concentration sampled at BOOGD during the water year, 0.44 µg/L, occurred in mid-June during relatively low-flow conditions. During the remainder of the water year atrazine concentrations remained below 0.30 µg/L, reaching non-detectable concentrations (<0.10 µg/L) in early August.

Table 19b summarizes the atrazine data from BOOGD during WY 1992 on a monthly basis. The lowest monthly fw mean atrazine concentration, 0.16 µg/L, occurred in August, and the highest monthly mean, 0.53 µg/L, occurred during September. The second highest monthly fw mean atrazine concentration during the water year, 0.47 µg/L, occurred during November and July. October and August had the lowest monthly atrazine outputs, 4 grams, and lowest monthly surface-water discharges, 11 ac-ft during October, and 21 ac-ft during August. November had the highest monthly atrazine output, 83 grams, and the highest discharge, 144 ac-ft, which accounted for 25% of the annual atrazine output and 17% of the surface-water discharge during the water year.

At L23S, twenty samples were analyzed for pesticides during WY 1992. All samples analyzed contained detectable levels of atrazine (>0.10 µg/L). The annual atrazine output from L23S was 2.9 pounds, at a fw mean concentration of 0.26 µg/L (Table 20).

Atrazine concentrations from L23S showed trends similar to concentrations from BOOGD, although levels were generally much lower. Atrazine concentrations generally declined from 0.19 µg/L in October to 0.10 µg/L in early February. Atrazine concentrations increased to 0.20 µg/L during runoff events later in February, then decreased as discharge receded through March. Following the large runoff event in April, discharge remained relatively steady through May, and atrazine concentrations increased to 0.21 µg/L. From May through June, both discharge and atrazine concentrations decreased. Atrazine concentrations reached 1.20 µg/L during a runoff event in mid-July, then declined during the remainder of the year.

Table 20b summarizes the monthly atrazine data for L23S during WY 1992. Monthly fw mean atrazine concentrations varied from 0.63 µg/L in November, to 0.14 µg/L during January, March and August. November had the highest monthly atrazine output, 515 grams, and the highest monthly surface-water discharge, 662 ac-ft, which accounted for about 40% of the annual atrazine output and about 17% of the surface-water discharge.

Other pesticides detected at L23S during the water year include cyanazine in two, or 10% of the samples collected; alachlor in two, or 10%; and metolachlor in one, or 5% of the samples collected. The highest concentration of pesticides detected during the water year included atrazine at 1.20 µg/L; metolachlor at 0.50 µg/L; cyanazine at 0.28 µg/L; and alachlor at 0.13 µg/L. All maximum detections occurred July 14. Cyanazine and alachlor were also detected during May.

Sixty-two samples from RC02 were analyzed for pesticides during WY 1992. Fifty-nine, or 95% of the samples collected contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration was 0.36 µg/L and the annual atrazine output was 27.2 pounds.

The atrazine plot for RC02 shows much greater variation in concentrations than the plots for sites BOOGD and L23S (Fig. 10). Concentrations dropped below detection limits during low-discharge periods in January, March and May, and exceeded 1.00 µg/L during a number of discharge events from May through September.

Table 21b summarizes the monthly atrazine data for RC02 during WY 1992. Monthly fw mean atrazine concentrations varied from 0.11 µg/L in January to 1.57 µg/L in June. The lowest monthly atrazine output, 97 grams, occurred during October, and greatest monthly output, 2,126 grams, and greatest monthly surface-water discharge, 4,910 ac-ft, occurred during November and accounted for about 17% of the annual atrazine output, and about 18% of the annual discharge.

Other pesticides detected at RC02 during WY 1992 include alachlor in thirteen, or 21%; cyanazine in eleven, or 18%; and metolachlor in ten, or 16% of the samples collected. The highest concentration of pesticides detected during the water year included atrazine at 8.10 µg/L; metolachlor at 4.80 µg/L; cyanazine at 4.40 µg/L; and alachlor at 3.40 µg/L. All maximum detections occurred June 23. Metolachlor, cyanazine and alachlor were all detected during the last six months of the water year.

During WY 1992, 22.5 pounds of atrazine were discharged from Big Spring , at a fw mean concentration of 0.22 µg/L (Rowden et al., in production). This was the third lowest annual fw mean atrazine concentration observed at Big Spring during WYs 1982-1992. Monthly fw mean atrazine concentrations varied from 0.30 µg/L during November and July, to 0.16 µg/L in March. The greatest monthly atrazine discharge, 3.8 pounds, occurred in November and the smallest monthly atrazine discharge, 1.1 pounds, occurred during October and August.

The annual fw mean atrazine concentration for the Turkey River, was 0.25 µg/L and the annual atrazine discharge totaled 739 pounds (Rowden et al., in production). The highest monthly fw mean atrazine concentration, 0.51 µg/L, occurred in July, and the lowest fw mean, 0.17 µg/L, occurred in March. The greatest monthly atrazine discharge, 113.9 pounds, occurred in November, accounting for 15% of the annual discharge, and the smallest monthly discharge, 27 pounds, occurred during August.

DISCUSSION

Relating watershed-scale water quality to differences in landuse and management between watersheds, or within a watershed over time, requires consideration of many complex processes. The timing, intensity, and distribution of rainfall, along with antecedent conditions, all affect the resultant runoff and recharge to the surface-water and soil-groundwater systems, and the concentrations of agricultural contaminants transported by these systems. Other factors that complicate the analysis of water-quality changes within watersheds include landuse changes, changes in input rates of fertilizers and pesticides, mineralization of organic material into nitrogen, in-stream biological processing, losing stream effects, subsequent storage, or carry-over effects, and system time lags, particularly at the watershed scale.

The mineralization of organic matter, either naturally occurring or later added to soils, is a source of nitrogen which is part of the nitrogen cycle that is poorly understood, but should be considered when trying to assess nitrogen balances on a watershed scale. As organic matter is transformed into nitrogen in the soil, the amount of fertilizer nitrogen needed by crops decreases. Rates of mineralization vary with climate-dependent factors such as temperature, soil moisture, and groundwater flux through the soil.

Significant, but gradual improvements in nitrogen management have been made within the Big Spring basin through the Big Spring Basin Demonstration Project. From 1981 to 1991, the average rates of fertilizer used on all corn within the basin have been reduced from 174 lbs/acre to 117 lbs/acre, reducing nitrogen loading by 30 to 50% with no yield loss. Since these changes in nitrogen management have been gradual and incremental, the resulting changes in water quality within the basin will also be gradual. It will take time to accurately define these changes, even under ideal circumstances. The assessment of water-quality improvements within the basin has been complicated by the climatic aberrations during recent years. In spite of the decreases in nitrogen loading that occurred within the basin during WYs 1981 through 1992, annual fw mean nitrate concentrations increased to record levels during WYs 1991 and 1992. From late WY 1987 through early WY 1990 conditions were abnormally dry, and from late WY 1990 through WY 1992 conditions were abnormally wet. The drought conditions probably allowed the accumulation of residual nitrate-nitrogen in the soil-water system, which was later mobilized by the excessive precipitation and resulting recharge.

The watersheds of Roberts Creek (70.7 mi^2), Bloody Run (37.6 mi^2), and Sny Magill (35.6 mi^2) are contiguous and share a similar hydrologic framework which allows comparison of surface-water data to understand the relationships between landuse, management practices, and water quality (Seigley et al., 1993). Comparison of these watersheds provides insights on nitrogen cycling in the groundwater and surface-water systems as it relates to landuse differences, in-stream biological processing, seasonal variations, and the size of the watersheds sampled. The watersheds differ in landuse and this difference affects nitrogen loading within the watersheds. Within all three watersheds there are no significant urban or industrial nitrogen sources, and the watersheds are dominated by agricultural activity. Corn accounts for over 95% of the row-cropped areas in these watersheds, with about 50% grown as continuous corn, and the remainder grown in rotation with alfalfa and oats. Over 80% of the farms in the watersheds have livestock, involving dairy or beef cattle, and/or swine, so manure is utilized as a nutrient source. Although there are many sources of nitrogen within these watersheds, the greatest nitrogen input is from fertilizer applied to corn. Therefore, the proportion of land area in corn production within these watersheds directly affects the nitrate concentrations and nitrogen loads in the surface water and groundwater. Comparison of the water quality of the streams within these watersheds is instructive. During WY 1991, 53% of the Roberts Creek watershed was in row-crop and the stream had an annual mean nitrate concentration of 36 mg/L (8 mg/L as NO_3-N). In comparison, Bloody Run watershed had 39% of its area in corn with an annual mean of 18 mg/L (4 mg/L as NO_3-N), and Sny Magill had 26% of the watershed in row-crop production and an annual mean nitrate concentration of 9 mg/L (2 mg/L as NO_3-N). The comparison of annual nitrogen loading within these watersheds is complicated by variations in fertilizer-application rates and changes in the land area used for corn production.

In the Roberts Creek, Sny Magill, and Bloody Run watersheds, nitrate-nitrogen concentrations tend to decline downstream (Seigley et al., 1993). Within Roberts Creek watershed, landuse and loading factors show little change downstream and there are no significant changes in landuse sources that might dilute nitrate-nitrogen. In the central and eastern portion of the Big Spring basin, Roberts Creek loses water through its bed to groundwater. Without other influences nitrate-nitrogen should remain constant. The downstream decline in nitrate-nitrogen can be related to in-stream biological processing (Crumpton and Isenhart, 1987; Isenhart and Crumpton, 1989; Bachmann et al., 1990). Studies suggest that the depletion of nitrate in these stream systems is facilitated by bacterial denitrification in the anaerobic stream-sediment interface and algal assimilation of nitrate and ammonium (Isenhart et al., 1989). Data from Roberts Creek indicate that the rate and mass of in-stream nitrate removal reaches a maximum during summer low flow, high temperature periods when groundwater inputs are at a minimum. The seasonal variations are related to seasonal discharge patterns that affect residence time of the water and NO_3-N, as well as temperature.

In-stream processing contributes to significant variability of nitrate concentrations in surface water. During cool seasons nitrate concentrations from RC02 tend to parallel concentrations at Big Spring. During warm seasons, concentrations at RC02 tend to be much lower than the integrated groundwater concentrations from Big Spring because of the in-stream processing. Similar trends occur at BOOGD and L23S, but at watershed scales much greater than Roberts Creek, an equilibrium pattern appears to be reached. In similar monitoring from the Turkey River, little downstream difference in nitrate concentrations has been apparent, although similar seasonal trends in concentrations occur (Hallberg et al., 1983, 1984a, 1985, 1987, 1989; Libra et al., 1986, 1987, 1991; Rowden et al., 1993). The spatial and temporal variability of nitrate concentrations in surface water must be considered when comparing surface-water data from different monitoring sites and in defining the scale of watershed comparisons that are feasible.

A weak but statistically significant relationship was found between some water-quality properties in Roberts Creek and the underlying geology during baseflow conditions (Kalkhoff, 1993). Roberts Creek gains water in areas of the basin having a greater proportion of shale bedrock and alluvial material and loses water in areas with a greater percentage of carbonate bedrock. In areas underlain by shale, groundwater infiltration is impeded and the water will move laterally into streams. Where unconsolidated material is underlain by karstic carbonates, infiltration is not impeded and water moves more directly into the carbonate aquifer rather than into the streams. In gaining streams the water is representative of shallow groundwater in the Big Spring basin which usually has a pH near 7.0, is less than 20 degrees C and has nitrate-nitrogen concentrations > 3 mg/L (Kalkhoff and Kuzniar, 1991; Kalkhoff et al., 1992). In losing streams, during baseflow, the water commonly has a greater pH, is warmer, and contains lower concentrations of nitrogen. Photosynthetic activity by algae and aquatic vegetation remove CO_2, increasing pH, and biological assimilation and denitrification remove nitrogen (Hill, 1981). The water temperature increases in losing streams due to the lack of relatively cool groundwater input.

There was no significant relationship between atrazine concentrations and geology in the Big Spring basin (Kalkhoff, 1993), and therefore no significant relationship between atrazine concentrations and gaining or loosing stream reaches. This infers that in-stream biological processes may have a more limited effect on atrazine concentrations. The application of atrazine to crops within the basin is likely not as uniform as the application of nitrogen, hence the variation in atrazine concentrations are probably more related to where atrazine is applied than to the geology of the watershed.

The Big Spring basin hydrologic system receives both infiltration and runoff recharge, which have unique chemical signatures (Hallberg et al., 1983, 1984a). 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. As runoff recharge moves through a stream, 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. The surface-water monitoring sites generally show declines during extended recession periods. Low discharge periods often 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 contaminant concentrations.

Monitoring during WYs 1986 through 1992 showed the effects of significant variations in precipitation and resultant recharge on the surface-water sites within the Big Spring basin. The change in precipitation patterns from WYs 1988 and 1989 to WYs 1990 and 1991 was dramatic. Annual precipitation increased from 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. Precipitation during WY 1992 was about 2.8 inches above the long-term average. Rainfall was more evenly distributed during WY 1992, with no large single rainfall or runoff events. 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. Precipitation during WY 1992 was above average during October, November and September, and below average during May, June, and August.

Water years 1988 and 1989 were the two driest consecutive years in Iowa's recorded history. From a crop production standpoint, WY 1988 was considered a drought year, however, from a hydrologic standpoint the drought began much earlier. 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, recharge of any kind was limited after snowmelt in March of WY 1986. Baseflow conditions prevailed for nearly 18 months, depleting groundwater storage during WYs 1987 and 1988.

Previous reports (Hallberg et al., 1983, 1984a, 1989) have indicated that March through June are typically marked by low evapotranspiration and wet antecedent conditions, which are important for groundwater recharge. Precipitation 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 small rainfalls; no daily rainfall exceeded one inch. The wettest months of WY 1988 and WY 1989 were September (5.48 inches) and August (7.08 inches), respectively. Less than 3 inches of precipitation occurred during any other month. June has typically been 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). The climatic variations during the period of monitoring were probably the greatest factor affecting nitrate and atrazine concentrations and loads in the surface-water sites within the Big Spring basin.

The discharge hydrographs and nitrate and atrazine concentration plots for WYs 1986 through 1992 are shown on Figures 4 through 10. Although the discharge hydrographs for RC02, L23S, and BOOGD for WY 1986 are incomplete, the discharge record from Big Spring was dominated by a very large snowmelt event that occurred in March, and accounted for 19% of the spring's annual discharge (Hallberg et al., 1989). Infiltration recharge associated with the event sustained relatively high discharge at Big Spring through April. Recharge during the remainder of the water year was relatively minor. All surface-water sites exhibited declining discharge, until late September. In September, intense rainfall events generated significant runoff and minor infiltration recharge as evidenced by the rapid increase and decrease in discharge. This was followed by a sustained increase in discharge into the beginning of WY 1987. During WY 1986, nitrate concentrations at all sites increased through November and decreased through February. Concentrations at L23S and RC02 increased in March, then declined through August. At BOOGD, concentrations increased from March to July, then decreased in September. At L23S and RC02, nitrate concentrations increased following precipitation near the end of the water year. Atrazine concentrations and the frequency and magnitude of detections of other herbicides remained relatively low, decreasing through February, increasing in March and then decreasing through August. Atrazine concentrations increased during runoff in late September.

Although precipitation during WY 1987 was only about an inch below normal, the temporal distribution of precipitation and antecedent conditions led to limited groundwater recharge during the water year. Precipitation totals were below normal during the growing season and greater than normal during the fall. About 7.7 inches, or 24% of the annual precipitation occurred during August, with the remainder of the water year being more than 5.0 inches, or about 16%, below normal. Following a minor recharge event in October, discharge declined until mid-February. Minor snowmelt and rainfall recharge occurred in March and April, followed by generally receding discharge through June. The largest runoff events of the water year occurred in August and September. Atrazine concentrations remained relatively low during the first half of WY 1987. Concentrations remained below detection limits (<0.10 µg/L) at L23S from November through March and remained below 0.60 µg/L at RC02 from October through May. Nitrate concentrations at L23S and RC02 declined from October through November, increased in December, then generally decreased through mid-February. During the latter part of the water year, a number of minor runoff events caused large fluctuations in both atrazine and nitrate concentrations.

Precipitation during WY 1988 was about 10 inches below normal, and during the March through June period, months important for groundwater recharge, precipitation was 8.87 inches below normal. The dry conditions that began in WY 1987 continued through WY 1988, severely limiting groundwater recharge within the Big Spring basin. From October through January, a number of precipitation events occurred, but intensity and amounts of rainfall were too low to generate significant recharge. Snowmelt in early February, combined with a series of minor precipitation events, generated runoff, but streams returned to baseflow conditions within days. The most significant recharge events occurred in early March and were associated with snowmelt rather than rainfall events. Precipitation in late March and early April generated runoff and minor infiltration recharge, but in a matter of days discharge began to recede. Following a minor runoff event in May, discharge continued to decline, in general, until late September. The most intense rainfall events of the water year occurred in late September, but the associated runoff and infiltration recharge were limited. Atrazine concentrations remained below 0.50 µg/L at all surface-water sites during the first seven months of the water year. Atrazine concentrations increased at all sites during runoff events in May, and again at RC02 in June and July, but remained low at L23S during the remainder of the water year. Nitrate concentrations generally increased from November through February. In late February and early March, concentrations were temporarily diluted during runoff from snowmelt. During the remainder of the water year both discharge and nitrate concentrations generally declined.

The discharge hydrograph for WY 1989 reflects the continuation of drought conditions that prevailed during WY 1988. Site BOOGD was dry except during runoff periods, and the annual discharges from L23S and RC02 were the lowest recorded since monitoring began. Precipitation during the water year was about nine inches below normal. Rainfall events occurred throughout the period, but intensity and accumulation were too low to generate significant recharge. The timing of rainfall events also limited groundwater recharge. Precipitation was above normal during November and August and below normal during March, June and July. Almost two inches of precipitation fell November 18th, but recharge was minimal and discharge returned to baseflow conditions within a few days. The most significant runoff events of the water year occurred in late January, early February and mid-March and were associated with snowmelt rather than rainfall events. The amount of recharge associated with these events was limited and discharge returned to pre-event levels within days of the events in February and within weeks of the events in March. During the remainder of the water year a number of minor runoff events occurred, but discharge continued to generally decline. Intense rainfall in August and September generated runoff, but the associated infiltration recharge was limited. Atrazine concentrations exceeded 2.00 µg/L during a number of runoff events throughout the water year, and remained above 0.20 µg/L at RC02 from mid-March through mid-July. Nitrate concentrations generally increased from late October to mid-January before being diluted by snowmelt-generated runoff at the end of January. During February, nitrate concentrations increased as discharge receded. From mid-March through the end of the water year, nitrate concentrations remained below 30 mg/L (6.7 mg/L as NO_3-N) at L23S, and below 15 mg/L (3.3 mg/L as NO_3-N) at RC02. The snowmelt events in mid-March accounted for a large percentage of annual discharges, and had a significant effect on annual fw mean nitrate and atrazine concentrations and loads. The continued lack of significant infiltration recharge, combined with a large influx of runoff recharge with low nitrate concentrations and relatively high atrazine concentrations contributed to low annual fw mean nitrate concentrations and loads, and relatively high annual fw mean atrazine concentrations and loads.

Water Year 1990 followed the two driest consecutive years in Iowa's recorded history. In the Big Spring area, precipitation during the water year was about five inches above the long-term average for northeast Iowa. The greatest monthly accumulation of rainfall occurred during August, and the largest single rainfall event occurred August 25, causing extensive flooding throughout the Turkey River valley. The discharge hydrographs for WY 1990 reflect the continuation of drought conditions that prevailed during WYs 1988 and 1989. Extremely low-flow conditions persisted during the first four months of the water year. Precipitation events in March generated runoff, but very little infiltration recharge, and surface-water discharge quickly returned to base levels. Rainfall events in May, June and July generated minor runoff and provided enough infiltration recharge to sustain discharge between events. The overall increase in precipitation during the later part of WY 1990 caused large increases in both runoff and infiltration recharge, which in turn caused large increases in discharge and the output of both nitrogen and pesticides. Atrazine concentrations followed the same general trends as discharge during the water year, generally increasing in March, then decreasing through April. Atrazine concentrations peaked in June, then generally decreased through September. Nitrate concentrations remained relatively low through April. During the last five months of the water year, nitrate concentrations showed large increases immediately following peak discharges. On August 27, nitrate concentrations varied from 95 mg/L (21.1 mg/L as NO_3-N) at RC02 to 119 mg/L (26.4 mg/L as NO_3-N) at BOOGD two days after the largest event of the water year.

During WY 1991 precipitation was about 14.3 inches or 43% above the long-term average for northeast Iowa. Rainfall was slightly below normal from October through February, far below normal in July, and far above normal from March through June. The greatest monthly accumulation of rainfall (13.09 inches) occurred during June and the largest single rainfall event (local reports of 11 to 13 inches near Monona, Iowa) occurred on June 14, causing extensive flooding throughout the Big Spring area. During the first four months of the water year, discharge at all surface-water sites receded to the lowest levels during the WY 1986-1991 period of record. At BOOGD, discharge ceased near the end of October, and was intermittent during six days in November. BOOGD remained dry from November 23 until March 1. Discharge at L23S remained relatively stable through February, ranging from 0.88 cfs in early October to 0.22 cfs in early December. At RC02, discharge decreased from 7.6 cfs in October to 0.01 cfs at the end of January. Flow ceased at RC02 during the first two days in February, then very slowly increased through the end of the month. Snowmelt and rainfall in late February and March generated minor runoff and infiltration recharge, and discharge at all sites increased significantly. Rainfall events in April, May and June generated additional runoff and infiltration recharge, sustaining increased discharge at all sites. Discharges peaked in mid-June, then generally receded through August. Precipitation events in mid-September generated minor runoff, followed by generally receding discharge during the remainder of the water year. Atrazine concentrations during WY 1991 followed the same general trends as discharge. Concentrations remained below 0.40 µg/L at all surface-water sites from October through February. Atrazine concentrations peaked in June, ranging from 20.00 µg/L at RC02 on June 15 to 1.80 µg/L at L23S on June 17. Concentrations then generally decreased through September. Nitrate concentrations stayed relatively low through February, remaining below 45 mg/L (10.0 mg/L as NO_3-N) at L23S and below 20 mg/L (4.4 mg/L as NO_3-N) at RC02. Nitrate concentrations increased significantly from March through June as infiltration recharge occurred. During the remainder of the water year nitrate concentrations generally decreased through August and increased following precipitation in September.

Water Year 1992 followed the two wettest consecutive years during WYs 1982-1992. Annual precipitation was about 2.8 inches above the long-term average. Rainfall was more evenly distributed throughout the year than during WYs 1990 and 1991, with no large single rainfall or runoff events. Precipitation was above average during October, November and September, and below average during May, June, and August. Precipitation during October and November led to sustained increases in discharge at all surface-water sites during November and December. Discharge generally receded from December through most of February, with minor snowmelt and precipitation generating small runoff events. Snowmelt and precipitation later in February generated enough recharge to sustain discharge for a few weeks, then discharge continued to recede through most of April. The second largest runoff event of the water year occurred in mid-April, followed by general recession through mid-June. During July, a number of precipitation events led to small increases in discharge, followed by generally receding discharge through August. Above average precipitation during September led to increases in discharge, followed by general recession during the remainder of the water year. Atrazine concentrations remained relatively stable at all sites during the first half of the water year. Concentrations remained below 0.25 μg/L at L23S the entire year except during an event in mid-July, and at BOOGD atrazine concentrations remained below 0.40 μg/L except during events in October and June. At RC02, concentrations remained below 0.40 μg/L until late February. During the latter half of the water year, the highest atrazine concentrations occurred at RC02, exceeding 2.00 μg/L during runoff events in May, June, and July.

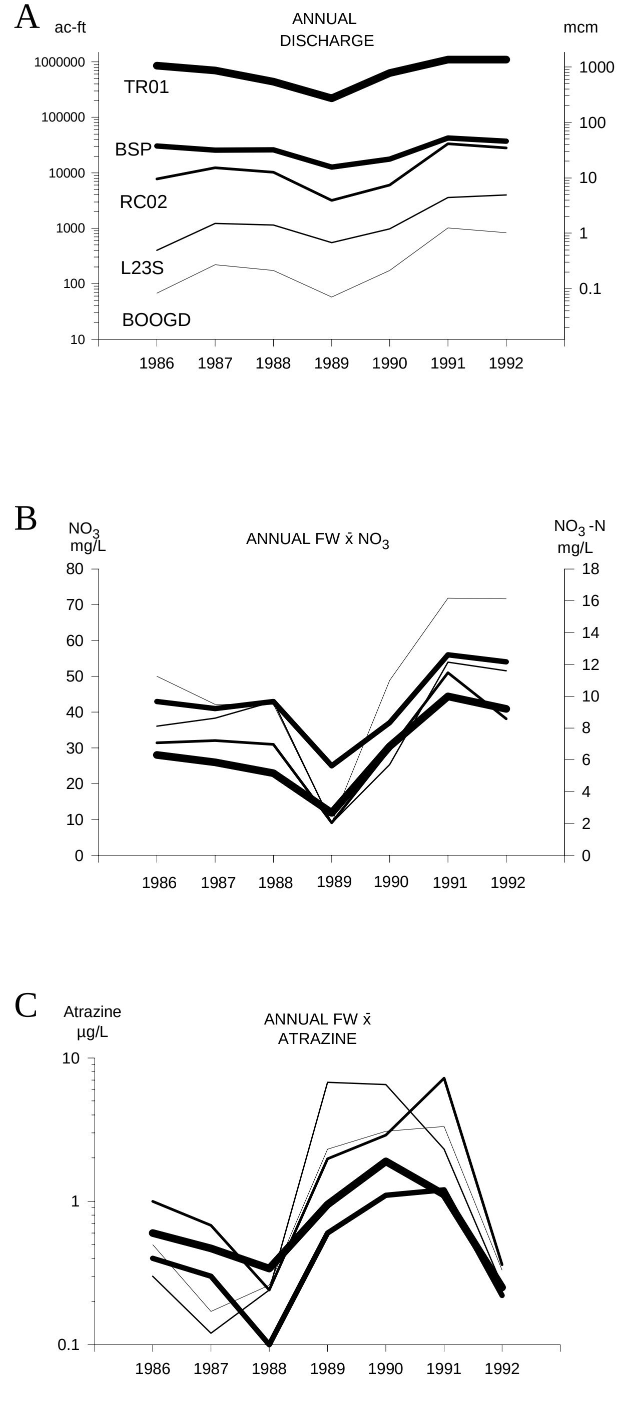

Figure 11. Summary of annual A) discharge (Q), and B) flow-weighted mean NO_3 and C) atrazine concentrations from TR01, BSP, RC02, L23S, and BOOGD.

Previous reports (Hallberg et al., 1983, 1984a, 1985, 1987, 1989; Libra et al., 1986, 1987, 1991; Rowden et al., 1993) have shown that increases and decreases in annual discharge at Big Spring (BSP) and the Turkey River at Garber, Iowa (TR01) have been accompanied by increases and decreases in annual fw mean nitrate concentrations and nitrate loads (Fig. 11). Annual fw mean atrazine concentrations and loads have shown no consistent relationship to annual groundwater discharge, although atrazine concentrations tend to increase with increasing runoff on a short-term basis. Similar seasonal trends and short- and long-term changes in nitrate and atrazine concentrations occur at the surface-water monitoring sites within the Big Spring basin. From WY 1988 to WY 1989, annual surface water and groundwater discharge and annual fw nitrate concentrations and loads declined to the lowest values recorded during the period of monitoring while annual fw mean atrazine concentrations increased significantly. From WY 1989 to WY 1991, surface water and groundwater discharge and annual fw mean nitrate concentrations and loads all increased to the highest values recorded during the period of record. Annual atrazine concentrations and loads also increased at most monitoring sites from WY 1989 to WY 1990. From WY 1990 to WY 1991 the fw mean atrazine concentration increased significantly at RC02, decreased significantly at L23S, and increased slightly at BOOGD while concentrations showed minor increases at Big Spring and minor decreases at TR01. During the same period, the annual atrazine loads increased to record levels at most monitoring sites throughout the basin. From WY 1991 to WY 1992, the annual surface water, and groundwater discharge and annual fw mean nitrate concentrations from most monitoring sites showed minor decreases while annual fw mean atrazine concentrations and loads decreased significantly.

Comparison of the annual data from WY 1988 through WY 1992 from Big Spring and Roberts Creek shows general relationships between annual discharge and annual fw mean nitrate and atrazine concentrations and loads. At Big Spring, relative to WY 1988, WY 1989 had 6% more precipitation, 51% less groundwater discharge, a 42% lower fw mean nitrate concentration, a 71% smaller nitrate load, a 369% higher fw mean atrazine concentration and a 130% greater atrazine load. At RC02, surface-water discharge decreased 69%, fw mean nitrate decreased 71%, the nitrate load decreased 91%, fw mean atrazine concentration increased 725%, and the atrazine load increased 155%. Relative to WY 1988, WY 1990 had 65% more precipitation, and Big Spring had a 33% decrease in groundwater discharge, a 14% lower fw mean nitrate concentration, a 42% smaller nitrate load, a 715% higher fw mean atrazine concentration and a 443% greater atrazine load. At RC02 surface-water discharge decreased 41%, fw mean nitrate decreased 5%, the nitrate load decreased 42%, fw mean atrazine concentration increased 1,104%, and the atrazine load increased 628%. While the changes in discharge and fw mean nitrate and atrazine concentrations and loads from RC02 are generally greater, they are proportional to the changes at Big Spring.

The increases in atrazine loading during WYs 1990 and 1991 can be partially attributed to very large runoff events in March and August of WY 1990 and June of WY 1991. At Big Spring monthly discharge during August of WY 1990 accounted for 20% of the annual groundwater discharge and 56% of the annual atrazine load. At RC02, 26% of the annual discharge and 40% of the annual atrazine load occurred in March. During WY 1991, June accounted for 20% of the annual discharge and 56% of the annual atrazine load at Big Spring, and 56% of the annual discharge and 93% of the annual atrazine load at RC02.

During WY 1992, annual precipitation was about 32% lower than during WY 1991 and rainfall was more evenly distributed with no large runoff events. At Big Spring, relative to WY 1991, WY 1992 had 14% less groundwater discharge, a 4% lower fw mean nitrate concentration, a 19% reduction in nitrate load, a 445% lower fw mean atrazine concentration and a 500% reduction in atrazine load. At RC02, surface-water discharge decreased 20%, fw mean nitrate decreased 34%, the nitrate load decreased 61%, fw mean atrazine concentration decreased 1,700%, and the atrazine load decreased 2,300%.

The increases in nitrate concentrations and loads during WYs 1990 and 1991 may be the result of several factors. The effects 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 resulting 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. Decreased crop uptake of nitrogen related to decreased yields during the drought also contributed to increased nitrate storage during the drought.

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.

The small decreases in annual nitrate concentrations and loads during WY 1992 are probably related to the minor decreases in groundwater and surface-water discharge during the period. The increased infiltration and leaching of nitrogen during WY 1991 may also have left a smaller than normal mass of nitrate in storage in the soil system available for transport during WY 1992. The large decreases in annual atrazine concentrations and loads during WY 1992 are probably related to decreases in the proportion of runoff, contributing to the annual groundwater and surface-water discharge during the water year. The increased runoff during WYs 1990 and 1991 probably removed a greater than normal mass of herbicide, leaving less available for mobilization and transport during WY 1992. The cumulative increase in soil moisture during WYs 1990 through 1992 may also have enhanced pesticide degradation processes, leaving a lower than normal mass of herbicide available for transport in WY 1992.

Farm surveys and inventories conducted in the study area during the past decade have indicated that overall, nitrogen and atrazine loading within the basin have been decreasing. It is possible that the gradual reductions in nitrogen fertilizer and pesticides applied within the basin are beginning to affect changes in the water quality of the Big Spring basin. It required five years of data collection and analysis to establish the water-quality significance of input changes from the Payment-In-Kind set-aside program in 1983, when the basin area used in corn production was reduced by about 33% relative to 1982 (Hallberg et al., 1993). It will likely take additional years of monitoring and analysis to fully ascertain the changes in water quality caused by smaller magnitude landuse changes and gradual improvements in nitrogen and pesticide management within the basin.

During WYs 1986-1992, annual fw mean nitrate concentrations were generally higher at the smaller BOOGD and L23S watersheds, and lower at the larger RC02 and TR01 watersheds (Fig. 11). The annual nitrate concentrations from Big Spring (BSP) were generally higher than the concentrations from the surface-water sites, except for BOOGD. Annual fw mean atrazine concentrations were more variable, but generally lower at Big Spring and TR01. The general decrease in nitrate concentrations at increasingly larger watershed scales is probably related in part to in-stream denitrification and nitrogen uptake by aquatic vegetation. In addition, in the smaller streams, the influence of nitrate-rich tile effluent may be more pronounced, constituting a larger percentage of the total surface-water discharge. The variability of annual atrazine concentrations is probably related to variations in the concentrations of atrazine applied and in the percentage of area within each subbasin where atrazine is used. The relatively high concentrations of atrazine that persist year-round at many sites within the basin suggest that in-stream biological processing is not as effective on atrazine as it is on nitrate.

The data from WYs 1986 through 1992 show a relationship between groundwater and surface-water discharge, and fw mean nitrate concentrations and loads, and a lack of any clear relationship between annual discharge, and annual fw mean atrazine concentrations and loads when runoff inputs are minimal. The data also show time lags between increases in precipitation and increases in groundwater and surface-water discharge, as storage within the Big Spring basin is slowly replenished. The parallel responses in water-quality changes over time of the various scale watersheds within the basin and the groundwater at Big Spring illustrate that hydrologic and chemical responses to recharge events can be tracked from the smaller scale monitoring sites through the larger groundwater and surface-water systems. The water quality of these watersheds, and ultimately at Big Spring, is an integration of the management practices of all the individual parcels of land they contain. Water-quality improvements caused by changes in agricultural practices will require longer periods of time to become apparent at increasingly larger watershed scales.

OVERVIEW OF MONITORING RESULTS FOR WYs 1986 THROUGH 1992

Figure 11 and Tables 22 through 27 summarize the results of hydrologic and water-quality monitoring at BOOGD, L23S and RC02 for WYs 1986 through 1992. Data for partial WY 1986 begin March 25, 1986 for RC02, and May 13, 1986 for sites BOOGD and L23S. During the period, annual precipitation varied from 22.9 inches in WY 1988 to 47.3 inches during WY 1991. Annual surface- and groundwater discharge was lowest during WY 1989 (57 ac-ft at BOOGD; 552 ac-ft at L23S; 3,160 ac-ft at RC02; and 12,700 ac-ft at Big Spring), and highest during WY 1991 (1,020 ac-ft at BOOGD; 33,443 ac-ft at RC02; and 42,500 ac-ft at Big Spring). The greatest surface-water discharge from L23S, 3,980 ac-ft, occurred in WY 1992. Surface-water discharge from the Turkey River at Garber ranged from 220,700 ac-ft in WY 1989 to 1,103,000 ac-ft during WY 1991. The lowest annual fw mean nitrate concentrations and smallest nitrate-N loads from most sites occurred during WY 1989 and the highest annual fw means and greatest loads occurred in WY 1991. Annual fw mean nitrate concentrations ranged from 9.1 to 72 mg/L (2.0 to 16.0 mg/L as NO_3-N) at BOOGD; 9.0 to 54 mg/L (2.0 to 12.0 mg/L as NO_3-N) at L23S; 9.1 to 51 mg/L (2.0 to 11.3 mg/L as NO_3-N) at RC02; and 25 to 56 mg/L (5.6 to 12.4 mg/L as NO_3-N) at Big Spring from WY 1989 to WY 1991. Annual nitrate-N loads from WY 1989 to WY 1991 varied between 317 and 44,336 pounds at BOOGD; 17,393 and 1,032,119 pounds at RC02; and 195,000 and 1,446,000 pounds at Big Spring. At L23S annual nitrate-N loads ranged from 2,998 pounds in WY 1989 to 123,530 pounds in WY 1992. The annual fw mean nitrate concentrations and loads from the Turkey River were lowest during WY 1989 (12 mg/L and 1.6 million pounds) and highest in WY 1991 (44 mg/L and 29.6 million pounds). The lowest annual fw mean atrazine concentrations, and smallest annual atrazine loads from BOOGD (0.17 µg/L and 0.10 pounds) and L23S (0.12 µg/L and 0.40 pounds) occurred during WY 1987. At RC02, the lowest fw mean atrazine concentration, 0.24 µg/L, and smallest atrazine load, 6.7 pounds, occurred in WY 1988. The highest fw mean atrazine concentrations and greatest atrazine loads from BOOGD (3.32 µg/L and 9.2 pounds) and RC02 (7.20 µg/L and 655 pounds) occurred in WY 1991. At L23S, the highest fw mean atrazine concentration, 6.75 µg/L, occurred during WY 1989, and the greatest annual atrazine load, 22.5 pounds, occurred in WY 1991. At Big Spring, annual fw mean atrazine concentrations and loads ranged from 0.13 µg/L and 9.2 pounds during WY 1988 to 1.17 µg/L and 135 pounds during 1991. The lowest annual fw mean atrazine concentration and load from the Turkey River, 0.34 µg/L and 407 pounds, also occurred in WY 1988. The highest annual fw mean concentration from the Turkey River, 1.90 µg/L, occurred during WY 1990, and the greatest annual atrazine load, 3,325 pounds, occurred in WY 1991. At Big Spring, maximum atrazine concentrations analyzed varied from 0.40 µg/L in WY 1988 to 16.00 µg/L in WY 1991. At BOOGD maximum atrazine concentrations varied from 19.00 µg/L in WY 1990 to 0.40 µg/L in WY 1992; at L23S maximum atrazine concentrations varied from 0.60 µg/L in WY 1986 to 68.00

µg/L in WY 1989; and at RC02 maximum atrazine concentrations varied from 1.70 µg/L in WY 1986 to 30.00 µg/L in WY 1990. The extreme variability of these annual parameters over short periods 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; Rowden et al., 1993), 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. At Big Spring, annual groundwater discharge and fw mean nitrate concentrations decreased from WY 1983 to WY 1985 and from WY 1988 to WY 1989, while annual fw mean atrazine concentrations and loads increased from WY 1982 to WY 1985 and from WY 1988 to WY 1991. At BOOGD, L23S, and RC02, annual surface-water discharge and fw mean nitrate concentrations decreased to the lowest values recorded in WY 1989, as fw mean atrazine concentrations increased significantly. At L23S, the highest annual fw mean atrazine concentration, 6.75 µg/L, and the third greatest atrazine load, 10.1 pounds, occurred during WY 1989, a year with the lowest annual surface-water discharge (552 ac-ft) during the period of monitoring. 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. 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. The large decrease in fw mean atrazine concentrations and loads during WY 1992 may be related in part to the lack of large runoff events during the year and the great losses that occurred during WYs 1990 and 1991, leaving a smaller than normal mass of herbicide available for mobilization and transport.

SUMMARY

WYs 1986 through 1992 were characterized by extreme climatic variability. The driest consecutive two-year period in the state's history, WYs 1988 and 1989, preceded the two wettest consecutive years during the WY 1982-1992 period of monitoring within the Big Spring basin. The change in distribution patterns of precipitation from WYs 1988 and 1989 to WYs 1990 and 1991 was also a significant factor. 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. Precipitation during WY 1992 was about 2.8 inches above average and more evenly distributed than during WYs 1990 and 1991, with no large single rainfall or runoff events. The increased precipitation generated both runoff and infiltration recharge, and discharge rates generally increased across the period as a net increase in overall storage within the basin's hydrologic system occurred.

Analysis of annual surface-water data for WYs 1986 through 1992 supports observations from Big Spring indicating that fw mean nitrate concentrations and loads generally parallel discharge, and fw mean atrazine concentrations and loads do not. Relatively high concentrations and loads of atrazine have occurred during years with low groundwater and surface-water discharge. The variable climatic and hydrologic conditions exhibited in the Big Spring basin during the monitoring period complicate the interpretation of changes in water quality and illustrate the need for detailed, long-term monitoring of nonpoint-source contamination.

The similarity of seasonal trends and pronounced short- and long-term changes in nitrate and atrazine concentrations seen at monitoring sites throughout the Big Spring basin demonstrates the effectiveness of the nested monitoring network used in the basin. The pronounced short-term changes in nitrate and atrazine concentrations are responses to significant recharge events. The concentration changes at the larger watershed scales are not as great or immediate as changes at smaller scale monitoring sites, although they clearly occur. The monitoring network allows tracking of water and chemical responses to recharge events as they are propagated through the hydrologic system from the soil profile beneath individual fields to the basin water outlets (Hallberg et al., 1984a). This allows the integration and comparison of various watershed scales to assess the effects of different landuse and landscape-ecosystem processes. Within larger scale watersheds, such as Big Spring, many landuse and management practices are integrated, and water-quality responses are dampened and complicated by climatic variations, storage effects, and biochemical processing in both surface-water and groundwater systems. The nested monitoring network affords detailed observation of these watershed systems at a variety of scales. Responses to changes in management practices can be tracked at these various scales, and a detailed record of the chemical flux through the basin can be established. The gradual reductions in nitrogen fertilizer and in the use of herbicides such as atrazine resulting from improved management practices may not result in pronounced water-quality changes in the short-term, but they will be detectable over time. Policy makers and planners must be aware of the time lags involved at these larger watershed scales and make appropriate commitments to long-term support of monitoring and implementation projects. Ongoing analysis of monitoring data from streams, springs, tile lines and wells, over time, will provide a better understanding of water-quality improvements resulting from changes in agricultural practices.

Table 22. Summary of annual maximum concentrations for pesticides in surface water at BOOGD, L23S and RC02.

Pesticide common chemical name	Water Year 86	87	88	89	90	91	92	% detections (total record)
	maximum concentration, µg/L							
BOOGD								
Herbicides								
atrazine	0.7	1.5	4.8	4.4	19.0	9.0	0.4	93%
alachlor	nd	0.8	3.9	0.1	8.6	2.5	nd	10%
cyanazine	nd	0.6	nd	0.3	7.2	2.6	nd	17%
metolachlor	nd	nd	nd	0.7	3.8	0.2	nd	8%
metribuzin	nd	nd	nd	nd	nd	nd	nd	nd
L23S								
Herbicides								
atrazine	0.6	0.7	8.4	68.0	16.0	1.8	1.2	76%
alachlor	0.3	0.1	4.5	38.0	1.4	0.3	0.1	12%
cyanazine	nd	0.2	1.9	22.0	0.6	0.7	0.3	15%
metolachlor	0.6	nd	0.2	4.2	1.9	0.6	0.5	6%
metribuzin	nd	nd	nd	0.1	nd	nd	nd	1%
RC02								
Herbicides								
atrazine	1.7	10.0	1.8	4.4	30.0	20.0	8.1	94%
alachlor	0.3	4.8	1.9	0.7	8.2	8.8	3.4	25%
cyanazine	0.1	3.0	1.0	0.7	8.5	3.0	4.4	30%
metolachlor	nd	0.7	0.2	0.8	7.4	6.7	4.8	18%
metribuzin	nd	nd	nd	nd	nd	nd	nd	nd

nd- not detected

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

Table 23. Summary of annual % of detections for pesticides in surface water at BOOGD, L23S and RC02.

Pesticide common chemical name	86	87	88	89	90	91	92	% detections (total record)
	Water Year							
	% detections							
BOOGD								
Herbicides								
atrazine	100%	94%	58%	100%	100%	98%	98%	93%
alachlor	nd	6%	8%	11%	23%	20%	nd	10%
cyanazine	nd	12%	nd	67%	45%	24%	nd	17%
metolachlor	nd	nd	nd	67%	23%	4%	nd	8%
metribuzin	nd	nd	nd	nd	nd	nd	nd	nd
L23S								
Herbicides								
atrazine	88%	71%	40%	63%	94%	83%	100%	76%
alachlor	38%	5%	7%	13%	13%	13%	10%	12%
cyanazine	nd	19%	7%	44%	13%	13%	10%	15%
metolachlor	13%	nd	3%	13%	10%	7%	5%	6%
metribuzin	nd	nd	nd	6%	nd	nd	nd	1%
RC02								
Herbicides								
atrazine	100%	91%	89%	95%	100%	91%	95%	94%
alachlor	20%	25%	5%	27%	45%	23%	21%	25%
cyanazine	10%	34%	16%	41%	54%	17%	18%	30%
metolachlor	nd	6%	2%	25%	36%	16%	16%	18%
metribuzin	nd	nd	nd	nd	nd	nd	nd	nd

nd- not detected

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

Table 24. Water year summary data for surface-water discharge from BOOGD.

	Water Year						
	86*	87	88	89	90	91	92
Precipitation:							
water inches	22.4	32.0	22.9	24.3	37.9	47.3	35.8
Surface-water discharge (Q):							
mean Q, cfs	0.2	0.3	0.2	0.1	0.2	1.4	1.0
total Q, inches	1.1	3.6	2.8	0.9	2.8	16.7	13.5
acre-feet	67	219	173	57	173	1,020	825
Nitrogen discharged with surface water:							
flow-wtd mean concentration, mg/L							
as nitrate (NO3)	50	42	42	9.1	49	72	72
as nitrate-N (NO3-N)	11.1	9.4	9.3	2.0	10.9	16.0	15.9
ammonia-N	0.1	0.1	0.1	0.5	1.5	0.1	0.1
organic-N	0.3	0.3	0.2	1.1	1.9	0.4	0.2
nitrogen load:							
(nitrate-N + nitrite-N)							
lbs-N	2,024	5,591	4,387	317	5,103	44,336	35,646
lbs-N/acre	2.8	7.6	6.0	0.4	6.9	60.2	48.4
(for sub-basin area)							
Atrazine discharged with surface water:							
flow-wtd mean concentration,							
atrazine, µg/L	0.5	0.2	0.3	2.3	3.1	3.3	0.3
atrazine load:							
lbs - atrazine	0.1	0.1	0.1	0.4	1.4	9.2	0.7

* Partial water year

Table 25. Water year summary data for surface-water discharge from L23S.

	Water Year						
	86*	87	88	89	90	91	92
Precipitation:							
water inches	22.4	32.0	22.9	24.3	37.9	47.3	35.8
Surface-water discharge (Q):							
mean Q, cfs	1.3	1.7	1.6	0.8	1.4	4.9	5.5
total Q, inches	1.7	5.2	4.9	2.4	4.2	15.4	17.0
acre-feet	398	1,220	1,150	552	982	3,594	3,980
Nitrogen discharged with surface water:							
flow-wtd mean concentration, mg/L							
as nitrate (NO3)	36	38	43	9.0	25	54	52
as nitrate-N (NO3-N)	8.0	8.5	9.6	2.0	5.6	12.0	11.4
ammonia-N	0.1	0.1	0.1	2.4	1.2	0.1	0.1
organic-N	0.2	0.5	0.3	0.1	2.9	1.3	0.3
nitrogen load:							
(nitrate-N + nitrite-N)							
lbs-N	8,687	27,177	29,885	2,998	15,034	117,164	123,530
lbs-N/acre	3.1	9.7	10.6	1.1	5.4	41.7	44.0
(for sub-basin area)							
Atrazine discharged with surface water:							
flow-wtd mean concentration,							
atrazine, µg/L	0.3	0.1	0.2	6.8	6.5	2.3	0.3
atrazine load:							
lbs - atrazine	0.3	0.4	0.8	10.1	17.4	22.5	2.9

* Partial water year

Table 26. Water year summary data for surface-water discharge from RC02.

	Water Year						
	86*	87	88	89	90	91	92
Precipitation:							
water inches	25.8	32.0	22.9	24.3	37.9	47.3	35.8
Surface-water discharge (Q):							
mean Q, cfs	20.3	16.9	14.1	4.4	8.3	46.2	38.4
total Q, inches	2.1	3.2	2.7	0.8	1.6	8.9	7.4
acre-feet	7,771	12,220	10,193	3,160	6,030	33,443	27,890
Nitrogen discharged with surface water:							
flow-wtd mean concentration, mg/L							
as nitrate (NO3)	31	32	31	9.1	30	51	38
as nitrate-N (NO3-N)	7.0	7.1	6.9	2.0	6.6	11.3	8.5
ammonia-N	0.1	0.1	0.1	0.3	0.4	0.1	0.1
organic-N	0.5	0.2	0.3	1.1	1.2	1.1	0.3
nitrogen load:							
(nitrate-N + nitrite-N)							
lbs-N	147,400	236,057	190,829	17,393	110,979	1,032,119	643,061
lbs-N/acre	3.3	5.2	4.2	0.4	2.5	22.8	14.2
(for sub-basin area)							
Atrazine discharged with surface water:							
flow-wtd mean concentration,							
atrazine, µg/L	1.0	0.7	0.2	2.0	2.9	7.2	0.4
atrazine load:							
lbs - atrazine	21.1	22.5	6.7	17.1	48.8	655	27.2

* Partial water year

Table 27. Water year summary data for surface-water discharge from BOOGD, L23S, RC02, and TR01, and groundwater discharge from Big Spring.

	Water Year						
	86*	87	88	89	90	91	92
				Discharge (in.)			
BOOGD	1.1	3.6	2.8	0.9	2.8	16.7	13.5
L23S	1.7	5.2	4.9	2.4	4.2	15.4	17.0
RC02	2.1	3.2	2.7	0.8	1.6	8.9	7.4
TR01	11.2	8.5	5.3	2.7	7.7	13.4	13.4
BSP	5.5	4.6	4.7	2.3	3.2	7.7	6.8
				Flow weighted mean NO3 concentration (mg/L)			
BOOGD	50	42	42	9	49	72	72
L23S	36	38	43	9	25	54	52
RC02	31	32	31	9	30	51	38
TR01	28	26	23	12	31	44	41
BSP	43	41	43	25	37	56	54
				NO3-N load (lbs/acre)			
BOOGD	2.8	7.6	6.0	0.4	6.9	60.2	48.4
L23S	3.1	9.7	10.6	1.1	5.4	41.7	44.0
RC02	3.3	5.2	4.2	0.4	2.5	22.8	14.2
TR01	14.5	11.2	6.1	1.6	11.8	29.9	27.6
BSP	12.0	9.5	10.2	3.0	5.9	21.9	18.5
				Flow weighted mean atrazine concentration (µg/L)			
BOOGD	0.5	0.2	0.3	2.3	3.1	3.3	0.3
L23S	0.3	0.1	0.2	6.8	6.5	2.3	0.3
RC02	1.0	0.7	0.2	2.0	2.9	7.2	0.4
TR01	0.6	0.5	0.3	1.0	1.9	1.1	0.3
BSP	0.4	0.3	0.1	0.6	1.1	1.2	0.2
				Atrazine load (lbs)			
BOOGD	0.1	0.1	0.1	0.4	1.4	9.2	0.7
L23S	0.3	0.4	0.8	10.1	17.4	22.5	2.9
RC02	21.1	22.5	6.7	17.1	48.8	655	27.2
TR01	1,407	891	407	571	3,259	3,325	739
BSP	29.0	17.6	9.2	21.2	50.0	135	22.5

*Partial water year except for sites TR01 and BSP

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APPENDIX A.

Monthly summaries of nitrate-N discharge for BOOGD, L23S and RCO2 for WYs 1986 through 1992

Table 1a. Monthly summary of nitrate-N discharge for Unnamed Creek (BOOGD); partial Water Year 1986.

	1985 Oct	Nov	Dec	1986 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean NO_3 concentration, in mg/L;								46.7	52.3	57.0	53.3	52.0
as NO_3-N								10.4	11.6	12.7	11.8	11.6
Mean of NO_3 analyses, in mg/L;								*	52.0	57.5	*	52.0
as NO_3-N								*	11.6	12.8	*	11.6
Total monthly NO_3-N output, lbs								846	469	146	27	537
Total monthly NO_3-N output, kg								384	213	66	12	243

* Not sampled

Table 2a. Monthly summary of nitrate-N discharge for Silver Creek (L23S); partial Water Year 1986.

	1985 Oct	Nov	Dec	1986 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean NO_3 concentration, in mg/L;								42.8	38.8	33.5	28.2	31.2
as NO_3-N								9.5	8.6	7.5	6.3	6.9
Mean of NO_3 analyses, in mg/L;								*	40.0	33.5	27.0	39.0
as NO_3-N								*	8.9	7.4	6.0	8.7
Total monthly NO_3-N output, hundreds lbs								29	20	11	7.0	20
Total monthly NO_3-N output, hundreds kg								13	9.1	5.0	3.2	9.1

* Not sampled

Table 3a. Monthly summary of nitrate-N discharge for Roberts Creek (RC02); partial Water Year 1986.

	1985 Oct	Nov	Dec	1986 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean NO_3 concentration, in mg/L;						50.0	38.9	27.2	22.2	13.1	5.2	17.9
as NO_3-N						11.1	8.7	6.0	4.9	2.9	1.2	4.0
Mean of NO_3 analyses, in mg/L;						50.0	*	28.0	23.0	13.0	*	18.0
as NO_3-N						11.1	*	6.2	5.1	2.9	*	4.0
Total monthly NO_3-N output, hundreds lbs						349	593	274	107	32	5.4	114
Total monthly NO_3-N output, hundreds kg						158	269	124	48	15	2.4	52

* Not sampled

Table 4a. Monthly summary of nitrate-N discharge for Unnamed Creek (BOOGD); Water Year 1987.

	1986 Oct	Nov	Dec	1987 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean NO_3 concentration, in mg/L;	53.1	45.0	45.0	40.5	41.0	41.9	44.6	50.4	42.8	40.1	48.2	30.6
as NO_3-N	11.8	10.0	10.0	9.0	9.1	9.3	9.9	11.2	9.5	8.9	10.7	6.8
Mean of NO_3 analyses, in mg/L;	52.5	*	*	*	41.0	43.0	46.0	46.0	35.2	27.3	29.0	39.6
as NO_3-N	11.7	*	*	*	9.1	9.6	10.2	10.2	7.8	6.1	6.4	8.8
Total monthly NO_3-N output, lbs	171	29	5.4	2.0	2,432	532	515	205	70	295	999	337
Total monthly NO_3-N output, kg	78	13	2.4	0.9	1,103	241	234	93	32	134	453	153

* Not sampled

Table 5a. Monthly summary of nitrate-N discharge for Silver Creek (L23S); Water Year 1987.

	1986 Oct	Nov	Dec	1987 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean NO_3 concentration, in mg/L;	39.6	31.5	38.7	36.5	32.4	36.5	43.7	45.5	36.5	25.2	36.5	43.2
as NO_3-N	8.8	7.0	8.6	8.1	7.2	8.1	9.7	10.1	8.1	5.6	8.1	9.6
Mean of NO_3 analyses, in mg/L;	39.5	30.0	43.0	35.0	33.0	38.0	45.5	43.7	36.2	27.0	36.0	44.8
as NO_3-N	8.8	6.7	9.6	7.8	7.3	8.4	10.1	9.7	8.0	6.0	8.0	10.0
Total monthly NO_3-N output, hundreds lbs	18	11	12	11	17	33	41	45	20	11	37	27
Total monthly NO_3-N output, hundreds kg	8.2	4.8	5.4	5.1	7.5	15	19	20	9.2	4.9	17	12

Table 6a. Monthly summary of nitrate-N discharge for Roberts Creek (RC02); Water Year 1987.

	1986 Oct	Nov	Dec	1987 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean NO_3 concentration, in mg/L;	35.1	25.7	36.9	36.9	25.7	27.9	27.9	23.4	29.3	18.0	46.8	33.3
as NO_3-N	7.8	5.7	8.2	8.2	5.7	6.2	6.2	5.2	6.5	4.0	10.4	7.4
Mean of NO_3 analyses, in mg/L;	34.5	24.0	39.0	35.0	25.0	28.0	27.0	24.3	24.4	18.0	32.0	33.8
as NO_3-N	7.7	5.3	8.7	7.8	5.6	6.2	6.0	5.4	5.4	4.0	7.1	7.5
Total monthly NO_3-N output, hundreds lbs	269	106	106	73	93	301	256	125	110	64	575	286
Total monthly NO_3-N output, hundreds kg	122	48	48	33	42	136	116	57	50	29	261	130

Table 7a. Monthly summary of nitrate-N discharge for Unnamed Creek (BOOGD); 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;	41.2	30.6	43.2	33.4	22.7	33.1	64.3	50.4	38.1	**	**	**
as NO_3-N	9.2	6.8	9.6	7.4	5.0	7.4	14.3	11.2	8.5	**	**	**
Mean of NO_3 analyses, in mg/L;	40.0	27.0	40.0	*	38.7	35.3	63.0	46.7	39.7	**	**	**
as NO_3-N	8.9	6.0	8.9	*	8.6	7.8	14.0	10.4	8.8	**	**	**
Total monthly NO_3-N output, lbs	133	34	27	8.4	227	1,858	1,689	264	60	**	**	**
Total monthly NO_3-N output, kg	60	15	12	3.8	103	842	766	119	27	**	**	**

* Not sampled; ** No discharge

Table 8a. Monthly summary of nitrate-N discharge for Silver Creek (L23S); 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;	47.2	38.8	40.3	40.2	39.0	41.1	58.5	46.0	37.0	26.7	13.9	19.6
as NO_3-N	10.5	8.6	9.0	8.9	8.7	9.1	13.0	10.2	8.2	5.9	3.1	4.4
Mean of NO_3 analyses, in mg/L;	46.8	40.4	38.7	41.5	38.6	40.5	54.0	45.2	36.0	27.0	15.4	24.3
as NO_3-N	10.4	9.0	8.6	9.3	8.6	9.0	12.0	10.0	8.0	6.0	3.4	5.4
Total monthly NO_3-N output, hundreds lbs	23	17	16	11	18	108	60	28	11	4.9	1.1	1.7
Total monthly NO_3-N output, hundreds kg	10	7.7	7.0	5.1	8.3	49	27	13	5.1	2.2	0.5	0.8

Table 9a. Monthly summary of nitrate-N discharge for Roberts Creek (RC02); 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;	31.0	26.3	32.6	32.8	34.2	32.3	37.5	23.4	8.5	2.6	3.5	12.5
as NO_3-N	6.9	5.9	7.2	7.3	7.6	7.2	8.3	5.2	1.9	0.6	0.8	2.8
Mean of NO_3 analyses, in mg/L;	24.4	27.0	34.3	37.0	35.2	30.0	35.7	22.0	6.5	2.6	4.5	8.3
as NO_3-N	6.8	5.9	7.6	8.2	7.8	6.7	7.9	4.9	1.4	0.6	1.0	1.8
Total monthly NO_3-N output, hundreds lbs	109	93	143	104	170	681	460	120	11	2.1	1.1	14
Total monthly NO_3-N output, hundreds kg	50	42	65	47	77	309	208	55	5.1	1.0	0.5	6.2

Table 10a. Monthly summary of nitrate-N discharge for Unnamed Creek (BOOGD); 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;	**	**	**	**	**	10.9	**	**	**	*	*	*
as NO_3-N	**	**	**	**	**	2.4	**	**	**	*	*	*
Mean of NO_3 analyses, in mg/L;	**	**	**	**	**	16.0	**	**	**	*	*	*
as NO_3-N	**	**	**	**	**	3.6	**	**	**	*	*	*
Total monthly NO_3-N output, lbs	**	**	**	**	**	317	**	**	**	*	*	*
Total monthly NO_3-N output, kg	**	**	**	**	**	144	**	**	**	*	*	*

* Not sampled; **No discharge

Table 11a. Monthly summary of nitrate-N discharge for Silver Creek (L23S); 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;	31.5	36.1	36.9	12.9	32.5	3.0	16.9	13.8	15.3	13.5	10.9	11.7
as NO_3-N	7.0	8.0	8.2	2.9	7.2	0.7	3.7	3.1	3.4	3.0	2.4	2.6
Mean of NO_3 analyses, in mg/L;	28.3	33.2	38.0	21.0	34.7	27.0	16.3	14.5	16.0	13.5	16.6	14.0
as NO_3-N	6.3	7.4	8.4	4.7	7.7	6.0	3.6	3.2	3.6	3.0	3.7	3.1
Total monthly NO_3-N output, hundreds lbs	2.4	2.8	2.3	9.1	2.2	5.7	0.7	1.0	0.9	0.7	1.2	1.0
Total monthly NO_3-N output, hundreds kg	1.1	1.3	1.0	4.1	1.0	2.6	0.3	0.5	0.4	0.3	0.6	0.5

Table 12a. Monthly summary of nitrate-N discharge for Roberts Creek (RC02); 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;	4.3	11.2	19.0	4.6	10.7	9.9	7.1	0.5	0.4	*	2.3	0.6
as NO_3-N	1.0	2.5	4.2	1.0	2.4	2.2	1.6	0.1	0.1	*	0.5	0.1
Mean of NO_3 analyses, in mg/L;	4.0	13.0	19.0	17.0	12.7	10.3	6.8	1.5	0.5	*	1.0	0.8
as NO_3-N	0.9	2.9	4.2	3.8	2.8	2.3	1.5	0.3	0.1	*	0.2	0.2
Total monthly NO_3-N output, hundreds lbs	0.8	13	8.0	7.4	4.2	135	4.2	0.2	0.04	*	1.2	0.1
Total monthly NO_3-N output, hundreds kg	0.4	5.7	3.6	3.4	1.9	61	1.9	0.07	0.02	*	0.5	0.06

* All samples below detection limits

Table 13a. Monthly summary of nitrate-N discharge for Unnamed Creek (BOOGD); 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;	5.0	**	**	8.0	8.3	17.0	**	60.4	46.9	99.0	68.4	79.8
as NO_3-N	1.1	**	**	1.8	1.9	3.8	**	13.4	10.4	22.0	15.2	17.7
Mean of NO_3 analyses, in mg/L;	*	**	**	8.0	*	51.0	**	*	68.5	81.3	73.0	68.5
as NO_3-N	*	**	**	1.8	*	11.3	**	*	15.2	18.1	16.2	15.2
Total monthly NO_3-N output, lbs	0.2	**	**	0.6	23	220	**	2.2	337	549	4,542	734
Total monthly NO_3-N output, kg	0.1	**	**	0.3	11	100	**	1.0	153	249	2,060	333

* Not sampled; ** No discharge

Table 14a. Monthly summary of nitrate-N discharge for Silver Creek (L23S); 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;	18.6	23.1	34.6	27.5	5.2	3.5	16.5	27.0	57.0	40.0	24.1	54.6
as NO_3-N	4.1	5.1	7.7	6.1	1.2	0.8	3.7	6.0	12.7	8.9	5.4	12.1
Mean of NO_3 analyses, in mg/L;	23.5	21.5	37.0	24.7	9.7	16.5	15.0	32.3	77.5	45.0	63.3	52.3
as NO_3-N	5.2	4.8	8.2	5.5	2.1	3.7	3.3	7.2	17.2	10.0	14.1	11.6
Total monthly NO_3-N output, hundreds lbs	0.9	0.9	0.3	0.06	0.3	4.3	1.6	5.9	45	20	60	25
Total monthly NO_3-N output, hundreds kg	0.4	0.4	0.1	0.03	0.1	1.9	0.7	2.7	20	9.0	27	11

Table 15a. Monthly summary of nitrate-N discharge for Roberts Creek (RC02); 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;	2.5	4.1	*	8.4	7.2	17.2	10.8	24.6	51.5	23.2	36.8	36.1
as NO_3-N	0.6	0.9	*	1.9	1.6	3.9	2.4	5.5	11.5	5.2	8.2	8.0
Mean NO_3 analyses, in mg/L;	2.6	2.5	*	10.5	3.7	24.5	6.0	16.5	42.3	24.2	26.0	26.8
as NO_3-N	0.6	0.6	*	2.3	0.8	5.4	1.3	3.7	9.4	5.4	5.8	6.0
Total monthly NO_3 output, hundreds lbs	0.07	0.005	*	0.8	15	188	7.8	37	285	72	402	102
Total monthly NO_3 output, hundreds kg	0.03	0.002	*	0.4	6.7	85	3.5	17	129	33	182	46

* No discharge

Table 16a. Monthly summary of nitrate-N discharge for Unnamed Creek (BOOGD); 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;	46.8	25.0	*	*	*	78.2	91.4	108	50.9	103	58.1	56.2
as NO_3-N	10.4	5.6	*	*	*	17.4	20.3	24.0	11.3	22.8	12.9	12.5
Mean of NO_3 analyses, in mg/L;	45.8	**	*	*	*	65.3	103	111	107	110	46.8	58.8
as NO_3-N	10.2	**	*	*	*	14.5	22.9	24.6	23.8	24.5	10.4	13.1
Total monthly NO_3-N output, lbs	123	15	*	*	*	3,298	11,857	9,617	14,366	2,300	276	2,481
Total monthly NO_3-N output, kg	56.0	6.8	*	*	*	1,495	5,377	4,361	6,515	1,043	125	1,125

* No discharge; ** Not sampled

Table 17a. Monthly summary of nitrate-N discharge for Silver Creek (L23S); 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;	39.4	33.8	31.1	35.0	32.3	75.1	81.0	77.5	44.0	66.1	43.6	31.7
as NO_3-N	8.8	7.5	6.9	7.8	7.2	16.7	18.0	17.2	9.8	14.7	9.7	7.0
Mean of NO_3 analyses, in mg/L;	38.2	33.8	31.0	35.0	31.3	65.0	91.4	78.3	98.0	60.4	41.0	42.6
as NO_3-N	8.5	7.5	6.9	7.8	7.0	14.4	20.3	17.4	21.8	13.4	9.1	9.5
Total monthly NO_3-N output, hundreds lbs	9.3	6.4	6.0	6.1	4.0	127	238	151	512	40	30	41
Total monthly NO_3-N output, hundreds kg	4.2	2.9	2.7	2.8	1.8	58	108	69	232	18	14	19

Table 18a. Monthly summary of nitrate-N discharge for Roberts Creek (RC02); 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;	12.4	12.0	13.4	10.7	15.0	56.6	62.1	64.9	46.2	50.5	14.9	18.3
as NO_3-N	2.8	2.7	3.0	2.4	3.3	12.6	13.8	14.4	10.3	11.2	3.3	4.1
Mean of NO_3 analyses, in mg/L;	12.0	12.5	17.0	8.3	15.0	55.0	72.8	68.7	78.3	42.4	13.8	20.4
as NO_3-N	2.7	2.8	3.8	1.8	3.3	12.2	16.2	15.3	17.4	9.4	3.1	4.5
Total monthly NO_3-N output, hundreds lbs	15	13	3.2	0.43	0.79	1,087	2,166	1,537	5,210	196	10	81
Total monthly NO_3-N output, hundreds kg	6.8	6.0	1.4	0.19	0.36	493	982	697	2,363	89	4.7	37

Table 19a. Monthly summary of nitrate-N discharge for Unnamed Creek (BOOGD); Water Year 1992.

	1991 Oct	Nov	Dec	1992 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean NO_3 concentration, in mg/L;	78.0	70.7	82.3	82.2	41.7	71.6	74.7	84.3	72.4	63.6	66.0	63.0
as NO_3-N	17.3	15.7	18.3	18.3	9.3	15.9	16.6	18.7	16.1	14.1	14.7	14.0
Mean of NO_3 analyses, in mg/L;	76.5	85.0	86.0	83.3	55.3	73.8	76.3	84.5	72.6	67.3	64.8	70.3
as NO_3-N	17.0	18.9	19.1	18.5	12.3	16.4	17.0	18.8	16.1	15.0	14.4	15.6
Total monthly NO_3-N output, lbs	496	6,166	6,752	3,371	1,700	1,750	5,316	3,199	910	1,025	820	4,141
Total monthly NO_3-N output, kg	225	2,796	3,062	1,529	771	794	2,411	1,451	413	465	372	1,878

Table 20a. Monthly summary of nitrate-N discharge for Silver Creek (L23S); Water Year 1992.

	1991 Oct	Nov	Dec	1992 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean NO_3 concentration, in mg/L;	48.0	53.1	61.7	57.7	37.9	46.1	53.0	61.5	50.8	42.3	45.8	43.6
as NO_3-N	10.7	11.8	13.7	12.8	8.4	10.2	11.8	13.7	11.3	9.4	10.2	9.7
Mean of NO_3 analyses, in mg/L;	48.3	64.3	64.0	57.3	41.5	47.6	57.8	60.0	49.2	43.5	45.2	51.0
as NO_3-N	10.7	14.3	14.2	12.7	9.2	10.6	12.8	13.3	10.9	9.7	10.0	11.3
Total monthly NO_3-N output, hundreds lbs	28	213	214	112	74	64	153	112	53	51	29	133
Total monthly NO_3-N output, hundreds kg	13	97	97	51	34	29	70	51	24	23	13	60

Table 21a. Monthly summary of nitrate-N discharge for Roberts Creek (RC02); Water Year 1992.

	1991 Oct	Nov	Dec	1992 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean NO_3 concentration, in mg/L;	23.4	40.4	49.1	44.9	27.3	34.1	41.8	46.4	32.2	21.8	21.0	30.6
as NO_3-N	5.2	9.0	10.9	10.0	6.1	7.6	9.3	10.3	7.2	4.8	4.7	6.8
Mean of NO_3 analyses, in mg/L;	23.5	54.8	55.8	48.5	27.3	37.0	42.8	43.8	33.0	23.0	19.4	33.5
as NO_3-N	5.2	12.2	12.4	10.8	6.1	8.2	9.5	9.7	7.3	5.1	4.3	7.4
Total monthly NO_3-N output, hundreds lbs	61	1,201	1,201	649	460	539	987	485	176	165	76	430
Total monthly NO_3-N output, hundreds kg	28	545	545	294	209	245	448	220	80	75	34	195

APPENDIX B.

Monthly summaries of atrazine discharge for BOOGD, L23S and RCO2 for WYs 1986 through 1992

Table 1b. Monthly summary of atrazine discharge for Unnamed Creek (BOOGD); partial Water Year 1986.

	1985 Oct	Nov	Dec	1986 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean atrazine concentration, in µg/L								0.62	0.39	0.26	0.38	0.44
Mean of atrazine analyses, in µg/L								*	*	0.26	*	0.44
Total monthly atrazine output, grams								23	7.2	1.4	0.39	9.3

* Not sampled

Table 2b. Monthly summary of atrazine discharge for Silver Creek (L23S); partial Water Year 1986.

	1985 Oct	Nov	Dec	1986 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean atrazine concentration, in µg/L								0.36	0.17	0.12	0.10	0.53
Mean of atrazine analyses, in µg/L								*	0.18	0.12	**	0.26
Total monthly atrazine output, grams								49	18	8.1	5.1	69

* Not sampled; ** All samples below detection limits

Table 3b. Monthly summary of atrazine discharge for Roberts Creek (RC02); partial Water Year 1986.

	1985 Oct	Nov	Dec	1986 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean atrazine concentration, in µg/L						1.70	1.14	0.57	0.50	0.46	0.30	1.29
Mean of atrazine analyses, in µg/L						1.70	*	0.58	0.50	0.46	0.29	1.30
Total monthly atrazine output, grams						2,420	3,535	1,165	486	230	63	1,682

* Not sampled

Table 4b. Monthly summary of atrazine discharge for Unnamed Creek (BOOGD); Water Year 1987.

	1986 Oct	Nov	Dec	1987 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean atrazine concentration, in µg/L	0.31	0.20	0.21	0.10	0.10	0.14	0.08	0.21	0.42	0.18	0.39	0.17
Mean of atrazine analyses, in µg/L	0.29	*	*	*	0.10	0.22	*	0.31	0.61	0.16	0.35	0.16
Total monthly atrazine output, grams	2.0	0.3	0.05	0.01	12	3.7	2.0	1.8	1.4	2.7	16	3.8

* Not sampled

Table 5b. Monthly summary of atrazine discharge for Silver Creek (L23S); Water Year 1987.

	1986 Oct	Nov	Dec	1987 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean atrazine concentration, in µg/L	0.11	0.03	**	**	*	**	0.06	0.35	0.26	0.06	0.17	0.11
Mean of atrazine analyses, in µg/L	0.11	**	**	**	*	**	0.01	0.08	0.15	0.01	0.16	0.12
Total monthly atrazine output, grams	10	1.9	**	**	*	**	12	70	30	5.4	36	14

* Not sampled; ** All samples below detection limits

Table 6b. Monthly summary of atrazine discharge for Roberts Creek (RC02); Water Year 1987.

	1986 Oct	Nov	Dec	1987 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean atrazine concentration, in µg/L	0.40	0.19	0.14	0.06	0.46	0.33	0.15	0.57	5.60	1.72	0.46	0.39
Mean of atrazine analyses, in µg/L	0.38	0.17	0.14	*	0.16	0.18	0.03	0.58	2.54	1.59	0.41	0.35
Total monthly atrazine output, grams	631	157	84	24	333	733	279	615	4,283	1,234	1,153	689

* Not sampled

Table 7b. Monthly summary of atrazine discharge for Unnamed Creek (BOOGD); Water Year 1988.

	1987 Oct	Nov	Dec	1988 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean atrazine concentration, in µg/L	0.05	0.12	0.09	*	0.32	0.18	0.02	2.42	0.14	**	**	**
Mean of atrazine analyses, in µg/L	0.05	0.14	*	*	0.22	0.15	***	2.52	0.16	**	**	**
Total monthly atrazine output, grams	0.4	0.3	0.1	*	6.5	20	1.1	26	0.5	**	**	**

* Not sampled; ** No discharge; *** All samples below detection limits

Table 8b. Monthly summary of atrazine discharge for Silver Creek (L23S); Water Year 1988.

	1987 Oct	Nov	Dec	1988 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean atrazine concentration, in µg/L	*	*	*	*	0.15	0.13	*	1.96	0.17	0.04	0.11	*
Mean of atrazine analyses, in µg/L	*	*	*	*	0.14	0.13	*	4.33	0.12	*	0.12	*
Total monthly atrazine output, grams	*	*	*	*	14	69	*	246	10	1.3	1.7	*

* All samples below detection limits

Table 9b. Monthly summary of atrazine discharge for Roberts Creek (RC02); Water Year 1988.

	1987 Oct	Nov	Dec	1988 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean atrazine concentration, in µg/L	0.18	0.14	0.21	0.13	0.19	0.29	0.14	0.49	0.34	0.54	0.18	0.13
Mean of atrazine analyses, in µg/L	0.15	0.14	0.19	*	0.15	0.28	0.12	0.86	0.33	0.51	0.24	0.15
Total monthly atrazine output, grams	132	97	187	81	196	1,251	360	513	92	90	12	28

* All samples below detection limits

Table 10b. Monthly summary of atrazine discharge for Unnamed Creek (BOOGD); Water Year 1989.

	1988 Oct	Nov	Dec	1989 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean atrazine concentration, in µg/L	**	**	**	**	**	2.76	**	**	**	*	*	*
Mean of atrazine analyses, in µg/L	**	**	**	**	**	2.66	**	**	**	*	*	*
Total monthly atrazine output, grams	**	**	**	**	**	163	**	**	**	*	*	*

* Not sampled; ** No discharge

Table 11b. Monthly summary of atrazine discharge for Silver Creek (L23S); Water Year 1989.

	1988 Oct	Nov	Dec	1989 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean atrazine concentration, in µg/L	*	*	*	3.25	0.18	9.84	0.06	1.64	3.87	0.85	5.95	2.42
Mean of atrazine analyses, in µg/L	*	*	*	2.87	*	2.02	0.17	68.00	**	1.50	1.99	**
Total monthly atrazine output, grams	*	*	*	465	2.5	3,875	0.6	25	46	9.1	135	42

* All samples below detection limits; ** Not sampled

Table 12b. Monthly summary of atrazine discharge for Roberts Creek (RC02); Water Year 1989.

	1988 Oct	Nov	Dec	1989 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean atrazine concentration, in µg/L	1.06	0.35	0.13	0.62	1.74	2.52	0.42	0.53	1.19	0.06	0.43	2.45
Mean of atrazine analyses, in µg/L	1.52	0.22	0.13	0.60	2.20	2.29	0.38	0.44	0.59	0.19	0.59	0.62
Total monthly atrazine output, grams	42	79	11	203	138	7,015	51	35	26	0.5	45	96

Table 13b. Monthly summary of atrazine discharge for Unnamed Creek (BOOGD); 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	*	**	**	0.79	3.32	7.58	**	1.34	9.06	1.09	2.69	0.54
Mean of atrazine analyses, in µg/L	*	**	**	0.79	3.17	5.60	**	*	8.05	1.10	0.72	0.51
Total monthly atrazine output, grams	*	**	**	0.1	19	200	**	0.1	133	12	365	10

*Not sampled; ** No discharge

Table 14b. Monthly summary of atrazine discharge for Silver Creek (L23S); 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	0.14	0.31	*	0.69	3.42	7.53	0.25	1.11	7.27	0.87	9.14	0.30
Mean of atrazine analyses, in µg/L	0.22	0.24	*	0.22	1.63	1.44	0.23	0.51	9.00	0.82	0.46	0.26
Total monthly atrazine output, grams	1.3	2.4	*	0.3	42	1,905	4.9	49	1,157	87	4,664	27

* Not sampled

Table 15b. Monthly summary of atrazine discharge for Roberts Creek (RC02); 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	0.20	0.21	*	3.67	2.36	4.02	0.22	3.24	6.01	1.64	1.40	0.46
Mean of atrazine analyses, in µg/L	0.17	0.20	*	2.82	2.06	2.47	0.21	1.69	10.3	1.27	1.00	0.38
Total monthly atrazine output, grams	1.2	0.1	*	71	987	8,830	33	1,038	6,778	1,038	3,128	263

* No discharge

Table 16b. Monthly summary of atrazine discharge for Unnamed Creek (BOOGD); 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	0.32	2.08	*	*	*	0.69	1.17	1.08	6.07	0.87	0.47	0.84
Mean of atrazine analyses, in µg/L	0.34	**	*	*	*	0.20	0.64	0.61	2.50	0.68	0.42	0.40
Total monthly atrazine output, grams	1.7	2.6	*	*	*	59	310	195	3,497	40	4.6	76

* No discharge; ** Not sampled

Table 17b. Monthly summary of atrazine discharge for Silver Creek (L23S); 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	0.12	0.07	0.06	*	*	0.23	0.35	0.43	3.91	0.34	0.19	1.48
Mean of atrazine analyses, in µg/L	0.12	0.11	**	*	*	0.14	0.18	0.39	0.91	0.25	0.15	0.18
Total monthly atrazine output, grams	5.9	2.6	2.2	*	*	78	210	170	9,279	42	27	397

* Not sampled; ** All samples below detection limits

Table 18b. Monthly summary of atrazine discharge for Roberts Creek (RC02); 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	0.14	0.06	0.16	0.15	0.13	0.26	0.86	2.48	12.0	0.68	0.68	0.99
Mean of atrazine analyses, in µg/L	0.13	0.03	0.17	0.16	0.13	0.26	0.23	1.20	5.16	0.62	0.37	0.35
Total monthly atrazine output, grams	36	14	7.7	1.2	1.4	1,032	6,130	12,004	276,180	537	95	891

Table 19b. Monthly summary of atrazine discharge for Unnamed Creek (BOOGD); Water Year 1992.

	1991 Oct	Nov	Dec	1992 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean atrazine concentration, in µg/L	0.33	0.47	0.23	0.19	0.38	0.18	0.26	0.19	0.29	0.47	0.16	0.53
Mean of atrazine analyses, in µg/L	0.33	0.28	0.22	0.17	0.20	0.17	0.19	0.22	0.25	0.22	0.14	0.18
Total monthly atrazine output, grams	4	83	39	16	31	9	38	15	8	15	4	71

Table 20b. Monthly summary of atrazine discharge for Silver Creek (L23S); Water Year 1992.

	1991 Oct	Nov	Dec	1992 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean atrazine concentration, in µg/L	0.19	0.63	0.16	0.14	0.17	0.14	0.26	0.19	0.15	0.33	0.14	0.21
Mean of atrazine analyses, in µg/L	0.19	0.13	0.14	0.14	0.16	0.10	0.13	0.19	0.15	0.68	0.13	0.14
Total monthly atrazine output, grams	22	515	112	55	70	40	151	70	32	80	19	131

Table 21a. Monthly summary of nitrate-N discharge for Roberts Creek (RC02); Water Year 1992.

	1991 Oct	Nov	Dec	1992 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flow-weighted mean NO_3 concentration, in mg/L;	23.4	40.4	49.1	44.9	27.3	34.1	41.8	46.4	32.2	21.8	21.0	30.6
as NO_3-N	5.2	9.0	10.9	10.0	6.1	7.6	9.3	10.3	7.2	4.8	4.7	6.8
Mean of NO_3 analyses, in mg/L;	23.5	54.8	55.8	48.5	27.3	37.0	42.8	43.8	33.0	23.0	19.4	33.5
as NO_3-N	5.2	12.2	12.4	10.8	6.1	8.2	9.5	9.7	7.3	5.1	4.3	7.4
Total monthly NO_3-N output, hundreds lbs	61	1,201	1,201	649	460	539	987	485	176	165	76	430
Total monthly NO_3-N output, hundreds kg	28	545	545	294	209	245	448	220	80	75	34	195