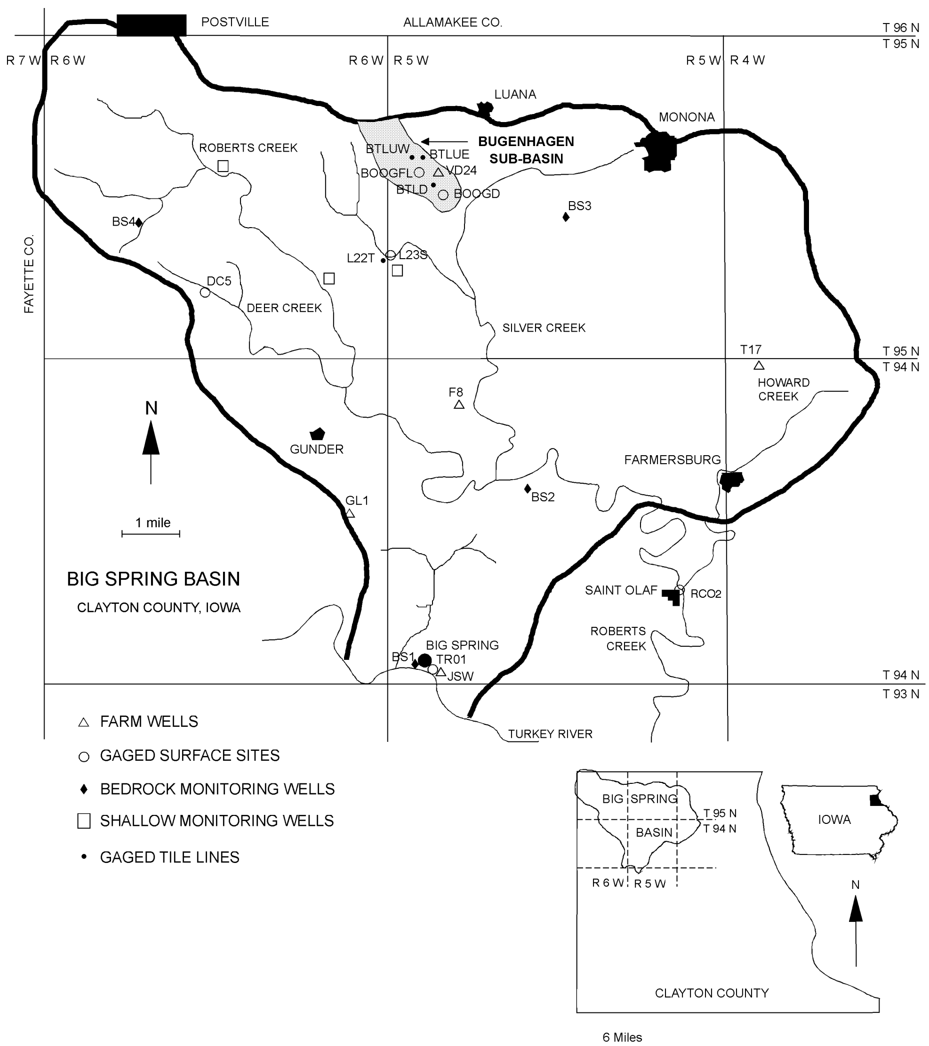
GROUNDWATER and SURFACE-WATER MONITORING in the BUGENHAGEN SUB-BASIN 1986 - 1995: A Summary Review

Geological Survey Bureau
Technical Information Series 41



Iowa Department of Natural Resources
Lyle W. Asell, Interim Director
June 2000

GROUNDWATER and SURFACE-WATER MONITORING in the BUGENHAGEN SUB-BASIN 1986 - 1995: A Summary Review

Geological Survey Bureau
Technical Information Series 41

A Report of The Big Spring Basin Demonstration Project

Prepared by

R.D. Rowden, R.D. Libra, H. Liu

Energy and Geological Resources Division
Geological Survey Bureau

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

June 2000

Iowa Department of Natural Resources
Lyle W. Asell, Interim Director

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GROUNDWATER AND SURFACE-WATER MONITORING in the BUGENHAGEN SUB-BASIN 1986-1995: A Summary Review

Iowa Department of Natural Resources, Geological Survey Bureau Technical Information Series 41, 2000, 150 p.

R.D. Rowden, R.D. Libra, H. Liu

ABSTRACT

The 1,105 acre Bugenhagen sub-basin is located in the north-central portion of the 103 mi^2 Big Spring 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 Big Spring basin since 1981. In 1986, as part of the Big Spring Demonstration Project, the Bugenhagen sub-basin was selected to be a "model" showcase for implementation of improved farm management and soil conservation using Best Management Practices. Landuse changes were tracked using farm surveys and aerial photographs that were digitized into a Geographic Information System. This report summarizes the results of monitoring at sub-basin tile-line sites BTLUE (250 acres), BTLUW (116 acres), BTLD (18 acres) and surface-water site BOOGD (736 acres) during water years (WYs) 1986-1995. During this period, precipitation has varied from 22.94 inches in WY 1988 to 47.28 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 WY 1981. Annual basin precipitation increased from 22.94 inches in WY 1988 and 24.32 inches in WY 1989 to 37.87 inches in WY 1990 and 47.28 inches in WY 1991. The precipitation total for WY 1992 was 35.74 inches. Water Year 1993 had the second-greatest annual precipitation total during WYs 1981-1995 at 46.47 inches, or 141% of the long-term average. The annual precipitation for WY 1994 was 30.42 inches, or 92% of normal, and precipitation for WY 1995 was 29.28 inches, or 89% of normal. The WY 1988 and 1989 totals were 70% and 74%, and the WY 1990 and 1991 totals were 115% and 143% of the long-term average precipitation of 32.97 inches. The increased precipitation during WYs 1990-1993 generated both runoff and infiltration recharge. During WY 1993, annual groundwater discharge totaled 372 acre feet (ac-ft) at BTLUE, 182 ac-ft at BTLUW, 38.5 ac-ft at BTLD, and 58,186 ac-ft at Big Spring. Monitoring at BOOGD ended in WY 1992 so discharge data for WY 1993 was not available. These were the greatest annual discharges for BTLUE and BTLUW during WYs 1987-1995, for BTLD during WYs 1987-1994, and for Big Spring during WYs 1982-1995. The greatest annual surface-water discharge for BOOGD during WYs 1986-1992, 1,020 ac-ft, occurred in WY 1991. The smallest annual discharges for BTLUE (10.5 ac-ft), BTLD (0 ac-ft), BOOGD 57 ac-ft), and Big Spring (12,672 ac-ft), occurred in WY 1989. The smallest annual discharge for BTLUW, 9.6 ac-ft, occurred in WY 1988.

Landuse changes significantly altered the sub-basin's hydrology. Prior to WY 1985 there were no tile intake terraces within the 418 acre upper sub-basin. Cumulatively, 34

acres, or 8.1% of the upper sub-basin were diverted into terraces in WY 1985; 113 acres, or 27.0% in WY 1986; 161 acres, or 38.5% in WY 1987; and 228 acres, or 54.6% of the upper sub-basin area drained into intake terraces and discharged through BTLUE and BTLUW in WY 1988.

Comparison of landuse changes within the sub-basin with annual fw mean NO_3-N and atrazine concentrations and loads from monitoring sites showed time lags. Corn acreage and total N applied within the upper and total sub-basins were greatest during WY 1990, at 339 and 680 acres, and 58,748 and 115,365 pounds (lbs), and smallest in WY 1987, at 137 and 389 acres, and 23,128 and 67,231 lbs. Within the lower sub-basin, the greatest amount of fertilizer, 60,760 lbs, was applied during WY 1989, the greatest corn acreage, 341 acres, was planted during WY 1990, and the smallest corn acreage and amount of nitrogen applied, 207 acres and 30,066 lbs occurred in WY 1993. Annual fw mean NO_3-N concentrations for BOOGD, BTLUE and BTLUW were greatest during WY 1991, at 16.0, 26.8 and 25.7 mg/L, and smallest during WY 1989, at 2.0, 3.9 and 3.5 mg/L. The greatest annual fw mean NO_3-N concentration for BTLD, 16.0 mg/L, also occurred in WY 1991, but the smallest, 9.8 mg/L, occurred in WY 1988. The greatest NO_3-N loads for BOOGD, BTLUE and BTLD, 44,336, 12,606 and 1,565 lbs, occurred during WY 1991, and the greatest load for BTLUW, 7,957 lbs, occurred in WY 1993. The smallest NO_3-N loads for BOOGD, BTLUE, BTLUW, and BTLD, 317, 111, 103, and 0 lbs occurred during WY 1989. At Big Spring, the greatest fw mean NO_3-N concentration, 12.5 mg/L, occurred in WY 1991, the greatest NO_3-N load, 1,796,013 lbs, occurred in WY 1993, and the smallest annual fw mean and load, 5.7 mg/L and 194,928 lbs, occurred in WY 1989.

The number of corn acres treated with atrazine and total pounds of atrazine applied within the upper sub-basin ranged from 160 acres in WY 1995 and 300 lbs in WY 1989 to 0 acres and 0 lbs in WYs 1991 and 1994. Within the lower sub-basin, the number of corn acres treated with atrazine and lbs of atrazine applied ranged from 220 acres and 433 lbs in WY 1987 to 32 acres and 32 lbs in WY 1988. For the total sub-basin, the number of corn acres treated with atrazine and lbs of atrazine applied ranged from 363 acres in WY 1995 and 697 lbs in WY 1987 to 55 acres and 61 lbs in WY 1988. At BOOGD, annual fw mean atrazine concentrations and loads ranged from 3.32 µg/L and 9.2 lbs in WY 1991 to 0.17 µg/L and 0.1 lbs in WY 1987. At BTLUE, fw mean atrazine concentrations ranged from 5.32 µg/L in WY 1989 to 0.17 µg/L in WYs 1994 and 1995, while atrazine loads ranged from 2.1 lbs in WY 1991 to 0.02 lbs in WY 1987. At BTLUW annual fw means ranged from 9.82 µg/L in WY 1990 to 0.12 µg/L in 1995, while loads ranged from 1.6 lbs in WY 1991 to 0.007 lbs in WYs 1988 and 1994. For BTLD, annual fw means ranged from 0.13 µg/L in WY 1994 to 0 µg/L in WY 1990, and annual loads ranged from 0.01 lbs in WY 1993 to 0 lbs in WYs 1989 and 1990. For Big Spring, the greatest annual fw mean atrazine concentration and load, 1.17 µg/L and 135 lbs, occurred in WY 1991, the smallest fw mean, 0.12 µg/L, occurred in WY 1995, and the smallest atrazine load, 9.2 lbs, occurred in WY 1988. Atrazine has been detected in 95% of the samples analyzed for pesticides from Big Spring during WYs 1982-1995. During WYs 1986-1995, atrazine was detected in 93% of the samples from BOOGD and BTLUE; 91% of the samples from BTLUW; and 25% of the samples from BTLD.

The annual data from the Bugenhagen sub-basin during WYs 1986-1995 supports observations from other sites within the Big Spring basin, showing that annual fw mean

NO_3-N concentrations and loads tend to parallel groundwater flux, as inferred by discharge, while annual fw mean atrazine concentrations and loads do not. Relatively great concentrations and loads of atrazine have occurred during some years with low groundwater discharge, and relatively small concentrations and loads have occurred during some years with high groundwater discharge. Annual climatic variations and resulting hydrologic conditions, along with variations in discharge, loading and fw means for NO_3-N and atrazine by factors ranging from two, to more than ten during the period of record complicate interpretation of changes in water quality and illustrate the need for detailed, long-term monitoring of nonpoint-source contamination. Climatic effects during the monitoring period make it difficult to ascertain relationships between landuse changes within the sub-basin and water quality responses at the monitoring sites. Incremental reductions in the application of nitrogen fertilizer and herbicides such as atrazine resulting from improved management practices may not result in pronounced short-term water-quality changes, but they will be detectable over time. Within both the Big Spring and Bugenhagen watersheds, 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- and groundwater systems. Therefore, before declines in fw mean NO_3-N and atrazine concentrations and loads can be attributed to improved agricultural management and source reduction, overall system variations must be considered.

INTRODUCTION

Since 1980, the Iowa Department of Natural Resources, Geological Survey Bureau (GSB), in conjunction with numerous state, federal, and local agencies, and university researchers, have been investigating the impact of agricultural chemicals, particularly nitrogen fertilizers and pesticides on groundwater and surface water within the 103 mi^2 Big Spring groundwater basin in Clayton County, northeast Iowa (Figure 1). Investigations by Hallberg and Hoyer (1982); Hallberg and others (1983, 1984a, 1985, 1986, 1989, 1993); Libra and others (1986, 1987, 1991, 1992); Seigley and others (1993); Rowden and others (1993a, 1993b, 1995a, 1995b, 1996, 1998); and Liu and others (1997) 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. The investigations have shown a long-term relationship between increases in nitrogen-fertilizer use and increasing nitrate concentrations in groundwater and surface water. The investigations have also demonstrated the persistence of atrazine and other pesticides in groundwater and surface water. As an outgrowth of research in the Big Spring basin, the multi-agency group involved, initiated the Big Spring Basin Demonstration Project (BSBDP) in 1986. This effort involved integrating public education, on-farm research, and demonstration projects that stressed the environmental and economic benefits of prudent chemical management. Full project funding through state oil-overcharge funds for the BSBDP ended during 1992. Since 1992, monitoring efforts and farm management implementation projects have been scaled back and refocused, and continued through the Northeast Iowa River Basin Demonstration Project (NEIDP). The projects involve various scales of monitoring to evaluate the environmental efficacy of farm management practices that improve efficiency and profitability, while reducing soil erosion, and chemical and nutrient contamination of surface water and groundwater. A significant portion of the BSBDP was focused on the Bugenhagen sub-basin, located in the north-central part of the Big Spring basin (Figure 2).

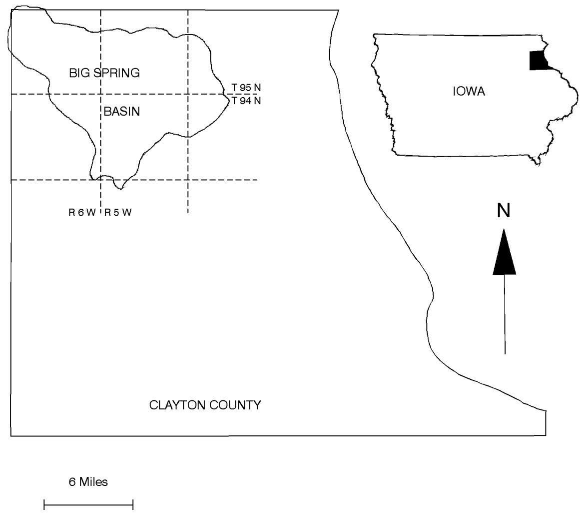


Figure 1. Map showing the location of the Big Spring basin.

The Bugenhagen sub-basin has been the site of routine water-quality monitoring of tile lines, surface water, and groundwater since 1981. In 1985 (for crop-year 1986), the 1,105 acre surface-watershed was selected to be a "model" showcase for the implementation of improved farm management and soil conservation practices (the Sub-Basin Demonstration Project). The project was designed to evaluate practical farm-owner experience with practices and allow agencies to integrate soil conservation techniques with improved fertilizer and pesticide management. The area was chosen for monitoring initially, and later for the Sub-Basin Demonstration Project because the watershed drains entirely to a series of sinkholes and generally maintains surface-water flow through groundwater discharge to the stream (Figure 3). Special cost-share funds were provided by the United States Department of Agriculture-Consolidated Farm Services Agency (USDA-CFSA) and the Iowa Department of Agriculture and Land Stewardship (IDALS) to work with land owners in the area. The USDA-Natural Resources Conservation Service (NRCS) provided technical as-

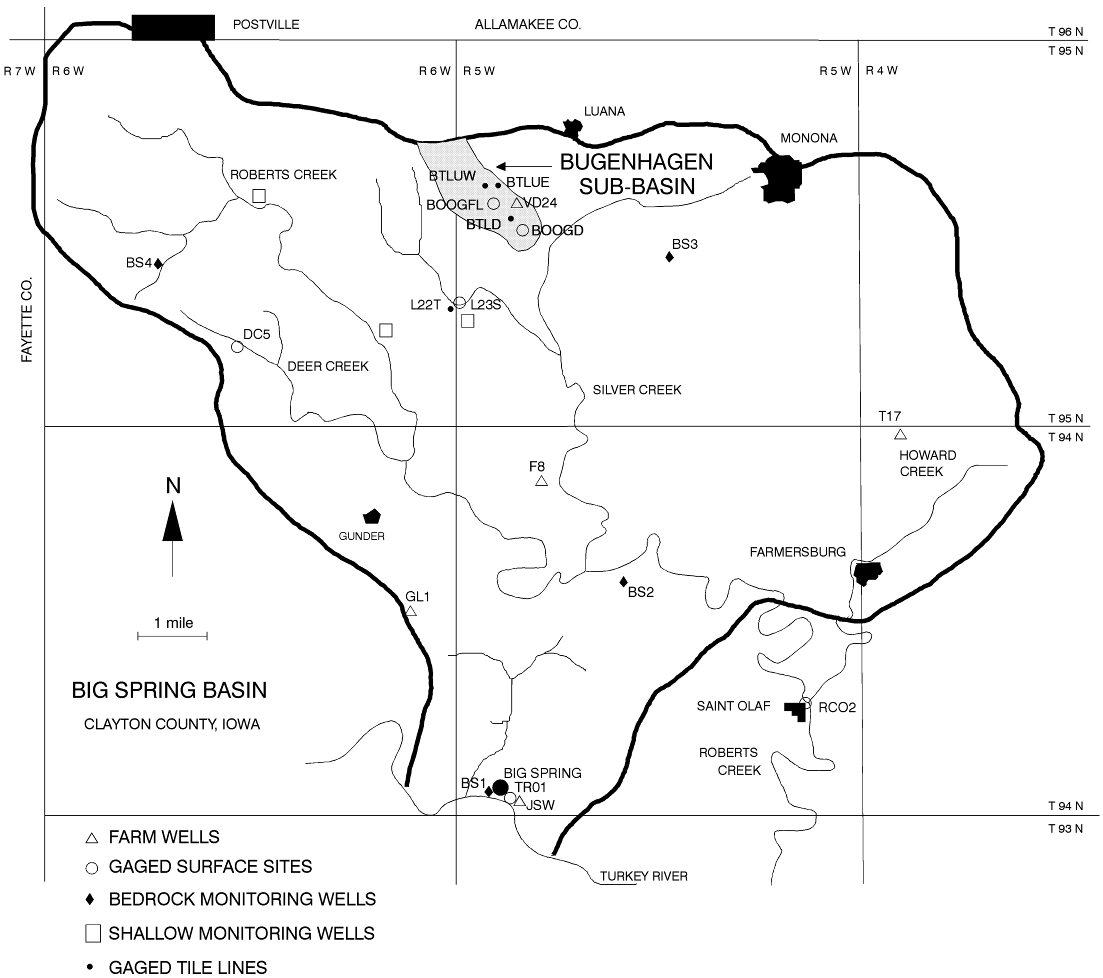


Figure 2. Map of the Big Spring basin showing the location of the Bugenhagen sub-basin and monitoring sites.

sistance in implementing the soil and water conservation practices, including crop rotations, used by the farmers. The Iowa State University Cooperative Extension Service (ISU-CES) provided special consultation and assistance to farmers in planning and applying improved nutrient and pesticide management. In 1986, 9 of 11 landowners controlling 89% of the cropped area in the sub-basin were enrolled in 7-year cooperative agreements to implement Best Management Practices (BMPs). In 1988, an additional landowner was enrolled in the project, to involve 98% of the sub-basin acreage.

Best Management Practices stress soil conservation, and fertilizer and pest management through one-on-one technical assistance. The principle goals of the sub-basin efforts were to implement and maintain integrated farm management practices that improve profitability and environmental efficacy. Monitoring equipment within the sub-basin was used to document changes in discharge and water quality related to the implementation of BMPs.

The hydrologic and water-quality monitoring of Big Spring and the Turkey River for water years (WYs; October 1 through September 30)

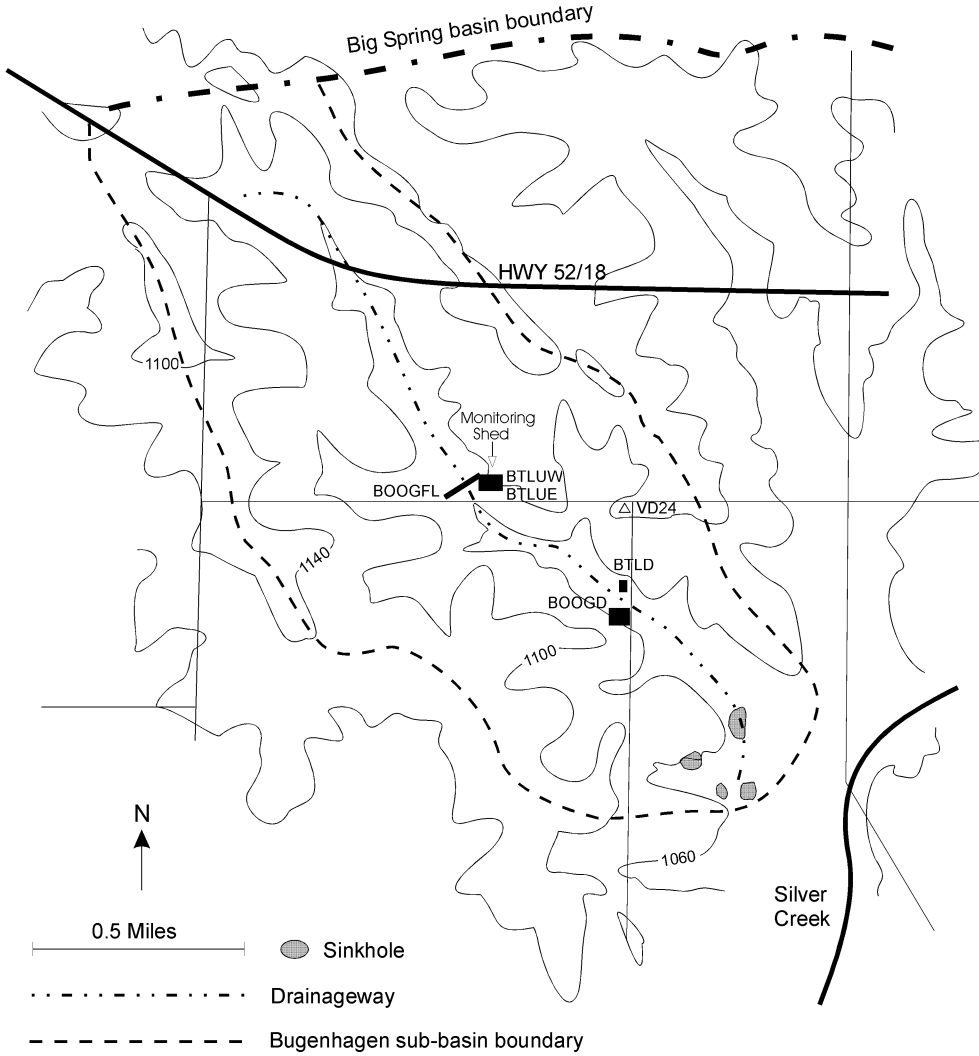


Figure 3. Topographic map of the Bugenhagen sub-basin showing monitoring site locations.

1982-1995 have been reviewed by Hallberg and others (1983, 1984a, 1989), Libra and others (1991), Rowden (1995), Rowden and others (1993a, 1995b), and Liu and others (1997). Data from several monitoring sites within the basin for WYs 1988-1991 are presented in Kalkhoff (1989), Kalkhoff and Kuzniar (1991, 1994), Kalkhoff and others (1992), Kalkhoff and Schaap (1996), Kolpin and Kalkhoff (1993) and Rowden and Libra (1990). Monitoring data from three surface water sub-basin sites, BOOGD, L23S and RC02, during WYs 1986-1992 are presented in Rowden and others (1995a), and monitoring data from tile-line site L22T and surface-water site L23S for WYs 1986-1995 are presented in Rowden and others (1998). 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 the landuse changes and hydrologic and water-quality data from monitoring sites within the Bugenhagen sub-basin for WYs 1986-1995. Analytical methods and landuse are reviewed in Hallberg and others (1989). The interpretation of data presented in this report requires analyses of data from the network of monitoring sites throughout the basin. The hydrologic and water-quality data from other tile lines, wells, and surface-water sites within the Big Spring basin and included sub-basins are addressed in subsequent reports.

Hydrogeologic Setting

The Big Spring basin is located within the Paleozoic Plateau Landform region in northeast Iowa (Prior, 1991; Hallberg et al., 1984b). The basin varies from moderately rolling in the northern one-half of the area, to steeply sloping near the Turkey River Valley in the southern portion of the area. Total relief in the basin is approximately 420 feet (128 m), with as much as 320 feet (98 m) of relief occurring along the Turkey River Valley in the southwest corner of the basin (Hallberg et al., 1983). The bedrock units in the basin are 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., 1984a; Rowden and Libra, 1990). The Galena Group forms the Galena aquifer, the main groundwater source in the basin. The bedrock is mantled by thin Quaternary deposits and is frequently exposed along small valleys in the basin. Pre-Illinoian till and glacial-fluvial deposits are preserved high on the landscape. The uplands and hillslopes are draped by loess (wind-blown silt deposits), and loamy alluvial deposits occur in the stream valleys and drainageways.

Where the Galena aquifer is at or near the surface, the basin exhibits a moderately developed karst landscape, as evidenced by sinkholes, occasional sinking streams, solutional openings in the rock, and the Big Spring. Big Spring issues from the Galena aquifer near the Turkey River.

The geographic extent of the Big Spring groundwater basin was delineated by mapping the potentiometric surface of the Galena aquifer, dye tracing, and gaging gaining- and losing-stream reaches (Hallberg et al., 1983). Over 85% of the groundwater discharged from the basin flows through Big Spring. Surface water is discharged from the basin by various streams, but dominantly by Roberts Creek, which accounts for 65% of the basin's surface area and 75-80% of the surface-water flow leaving the basin.

Landuse

Landuse within the Big Spring basin is essentially agricultural. Corn is the dominant crop, accounting for over 95% of the row-cropped area, with 50% grown as continuous corn. Typically 55% of the basin area is planted to corn, 35-40% to alfalfa, and 10% of the basin is in pasture. As of 1987, 43% of the basin was in row crop, 14% was strip cropped, 35% in cover crops, and 5% of the basin was forest. The remainder of the basin is comprised of small urban areas, quarries, and roads. Up until 1986, 99% of the row crop acreage was in corn. Since then, there have been small increases in soybeans and forage sorghum grown in the area. The cover crops grown within the basin include hay crops, oats, and pasture, and recently small amounts of other cereal grains. The basin includes approximately 200 farms with an average size of 330 acres. Over 80% of the farms in the basin have livestock operations, involving dairy cattle, beef cattle, or swine. While there are many sources of nitrogen in the basin, the greatest input is from fertilizer applied to corn.

There are no significant point sources impacting groundwater quality within the basin, making unambiguous study of the agricultural ecosystem possible. By monitoring the water quality and discharge of surface water and groundwater in the basin, the mass flux of nutrients and chemicals applied within the basin can be quantified. This allows assessment of chemical balances on a basin-wide scale.

With the thin mantle of glacial deposits and the local karst development, the Galena aquifer is highly responsive to recharge and consequently to changes in landuse practices as well. Throughout much of the basin, the aquifer's proximity to the land surface makes it susceptible to the rapid influx of contaminants borne by infiltration recharge. Infiltration recharge transports highly soluble ions, such as nitrate, from soils to the aquifer. In the few areas with open sinkholes, surface runoff can immediately recharge the aquifer, carrying characteristic contaminants such as suspended matter and sediment. The appearance of contaminants in Big Spring groundwater can be related to different recharge mechanisms since they are distinct in their transport time and chemical signatures. Monitoring groundwater and surface-water discharge, and water quality, allows estimation of the chemical loads delivered to the aquifer by infiltration and runoff recharge.

Monitoring Network Design

The Bugenhagen sub-basin is part of a network of over 50 sites within the Big Spring basin that has been routinely monitored for water quality since 1981. Precipitation, surface water, and groundwater from tiles, shallow piezometers, bedrock wells and springs have been included in the network. At key sites within the basin and sub-basin, instrumentation was used to continuously monitor discharge and initiate event-related sampling. The network was designed in a nested fashion, to allow detailed hydrologic and water-quality measurements at different scales. The design and implementation of the network is described in detail in Littke and Hallberg (1991).

The nested design follows the natural hierarchy of the drainage system. Watersheds of increasing size were instrumented and monitored, up to the main surface-water and groundwater outlets for the basin. At increasingly larger scales, changes in water quality require longer periods of time to become apparent. Within field plots, such as the Bugenhagen sub-basin, management practices can be altered at the beginning of any crop year, and resulting variations in water quality can be monitored immediately below the field. Within increasingly larger surface water and groundwater basins, changes in management are more gradual, and water quality is measured farther away, at the basin outlet. The water quality of these larger basins is an integration of the management practices on all the individual parcels of land they contain.

Monitoring Site Development

Instrumentation, which continuously monitored discharge and initiated event-related sampling, was used to supplement routine observations and samples collected by field personnel. The development of monitoring sites within the Big Spring basin was a cooperative effort. The U.S. Geological Survey, Water Resources Division (USGS-WRD), Iowa City office designed, constructed and maintained the stream gaging stations (BOOGD, L23S, RC02, and TR01) and also cooperated in water-quality monitoring. The tile monitoring sites (BTLD, BTLUE, BTLUW, and L22T) and the surface-water flume site (BOOGFL) were designed and constructed by Dr. James Baker, Department of Agricultural Engineering, Iowa State University, Agriculture and Home Economics Experiment Station.

WATER QUALITY AND AGRICULTURAL MANAGEMENT

Previous studies (Hallberg et al., 1983, 1984a) have indicated that appropriate chemical management must be combined with soil conservation measures to protect surface-water quality. Hallberg and others (1983, 1984a) also point out that concerns for soil conservation and surface-water quality must be balanced with the need to protect groundwater.

Agricultural management alternatives must address not only soil conservation, but also the need to reduce chemical losses through infiltration. In karst-carbonate aquifer regions there is the need to control soil loss and runoff, and to conserve the soil, as well as to reduce the loads of pesticides, sediment, and microbes that enter groundwater in the run-in component. Many standard approaches to control soil loss and runoff can enhance infiltration and the delivery of chemicals to groundwater in the infiltration recharge.

Effects and Evaluation of Land-Treatment Changes

The nitrate and pesticides in the surface and groundwater of the Big Spring basin are the result of recent and current agricultural practices. If present agricultural practices continue, the groundwater quality of the Galena aquifer may continue to deteriorate, and degradation of the Galena aquifer will eventually lead to degradation of deeper, alternative water sources. Improvement of water quality in the Big Spring basin and elsewhere will be possible only through altering agricultural practices.

Assessing how a variety of landuse practices affect water quality at a relatively large watershed scale is difficult at best. Difficulty in analysis comes from many practices being implemented simultaneously, climatic variability during the monitoring period, and the complex nature of the karst groundwater system. The Sub-Basin Demonstration Project attempted to evaluate the impacts of land-treatment practices on groundwater quality, as well as on soil erosion, runoff, and surface-water quality. In many cases only an estimate of the direction of change that a particular practice may impart is possible.

The brief narrative below summarizes the projected impacts of various management practices on the Big Spring karst-groundwater system, and is meant to serve as a point of discussion. The following review of various agricultural management practices and their projected impacts on the karst-groundwater system is more fully detailed in Hallberg and others (1983).

Structural Practices

1) Terrace construction reduces soil erosion and the delivery of sediment to sinkholes. Sediment is a significant problem in many surface waters and at Big Spring, and pesticides reach their greatest concentrations during periods of runoff and high turbidity. Peak loading of pesticides, turbidity, and bacteria during runoff is also a problem in various wells in the study area. Terraces reduce loading of sediment, pesticides, and bacteria, but are least effective during times of highest runoff, when contaminant delivery is greatest. Another problem associated with terraces is increased infiltration. Infiltrating water delivers high concentrations of nitrate as well as persistent but low concentrations of pesticides. Burwell and others (1976) data show that the water-yield from contoured watersheds occurred as 50% surface runoff and 50% subsurface flow, as compared with a water-yield of 94% by subsurface flow and 6% by runoff in a terraced area. An economic problem is also associated with terracing. Since it is necessary to recover the cost of construction, terracing often leads to increased corn acreage, reducing meadow rotations and increasing the amount of nitrogen fertilizer and other chemicals applied. The addition of tile outlets in the terraces diverts much of the subsurface flow and when the runoff component is added to the tile drainage, produces portions of runoff and subsurface flow similar to contouring. Even with the use of tile outlets, nitrate leaching is still enhanced, although the nitrate is discharged through the tile effluent, often to surface water instead of to depth, directly into groundwater.

2) Tiling is done to improve soil drainage in order to increase crop production acreage. Since it is associated with more intensive land utilization it adds to total fertilizer and chemical application. Tiling enhances the leaching of nitrate from the soil (Baker and Johnson, 1977, 1981: Harmon and Duncan, 1978). Tile effluent, which is high in nitrate and contains some pesticides, contributes to base flow in streams, which lose water to sinkholes and to groundwater in losing reaches. Tiles can function as "point discharges" entering the aquifer through sinkholes. Tile effluent can strongly affect groundwater quality during base flow periods, especially along fracture zones.

3) Detention structures can reduce peak flow into sinkholes during runoff. Correct location is critical because new sinkholes can open up behind the detention structure. As water is ponded, the increased head and infiltration leads to sinkhole formation. Where constructed in areas of local aquifer discharge or above shales, the structures could be beneficial.

4) Filling sinkholes is only feasible with small sites and is usually only a temporary solution, as the sinkholes will often reopen, or new sinkholes will develop nearby.

Land Management Systems

1) Strip cropping is an effective practice for reducing erosion and groundwater degradation. Strip cropping also reduces peak sediment and peak pesticide loading during runoff to sinkholes. It should also reduce nitrate infiltration by reducing the acreage on which chemicals are applied.

2) Increasing meadow rotations reduces corn acreage even more than strip cropping, thus reducing total nitrogen and pesticide application, further reducing groundwater degradation.

3) The influence of minimum tillage on runoff and infiltration is not clear. A study by Rice and Smith (1982) suggests that no till may increase nitrate losses through leaching and/or denitrification. Minimum tillage should have little effect on acreage treated with pesticides, although with minimum tillage, applications of insecticides and herbicides can be expected to increase. Since minimum tillage reduces soil erosion, it should reduce soil-attached chemicals, but will probably have little effect on water-soluble chemicals (Barisas et al., 1978; Hubbard et al. 1982).

4) The effect of buffer zones around sinkholes would be small, but could reduce sediment and pesticide loads entering sinkholes. Selection of grass species with high nitrogen uptake might further reduce nutrient loading.

Fertilization Management

Reducing the losses of nitrogen, particularly in the form of nitrate, can be accomplished by reducing application rates, by finding ways that crops will use nitrogen more efficiently (using new hybrids), or finding nitrogen-forms that are more stable.

1) Lower nitrogen-application rates will result in less nitrate buildup in soils and less leaching of nitrate, reducing nitrate concentrations recharging groundwater. The average fertilizer-nitrogen rate used on all corn rotations within the Big Spring basin was reduced from 174 lbs/acre in 1981 to 115 lbs/acre in 1993, resulting in a 34% reduction, with no decline in corn yields (Table 1). This decrease in nitrogen inputs should eventually result in a 30 to 50% reduction in nitrogen losses from the basin.

2) Multiple applications of nitrogen (versus one large application) during the growing season can reduce nitrogen losses by 20 to 40% (Arora and Juo, 1982; Baker and Austin, 1982) as well as improve crop yields even if the same amount of nitrogen is applied.

3) The effects of nitrogen stabilizers need further research, but could be of benefit.

4) Total nitrogen management considers all sources of nitrogen contributing to crop production before fertilizer application rates are established. Nitrogen production from crop rotations, organic material, and manure application must be estimated and added into the total nitrogen budget so that applied chemical-nitrogen can be reduced to help reduce nitrate leaching losses. Nitrate losses result from applying fertilizer in excess of what the crops will use over the growing season.

5) Improved nitrogen management must also include better management of manure and livestock wastes.

Pesticide Management

When compared with nitrogen losses, pesticide losses are low, but the possible health effects of these chemicals are of concern. The greatest concentrations of pesticides occur in runoff, and might be reduced by shallow incorporation of pesticides where appropriate (Baker, 1980). The use of less persistent pesticides could decrease total concentrations in groundwater, and integrated pest management could reduce insecticide use by as much as 50% according to some estimates.

Management Changes

The most important factor in making changes in agricultural management is the response of independent farm operators. The implementation of practices such as strip cropping, increased meadow rotations, reduced nitrogen application, multiple nitrogen applications, total nitrogen management, and integrated pest management requires the farm operator to make difficult deci-

Table 1. Fertilizer-nitrogen rates used for corn and continuous corn yields, from surveys and farm census inventories in the Big Spring basin.

BIG SPRING BASIN FERTILIZER-NITROGEN RATES

Rotation	All corn	1st-year corn after alfalfa	2nd-year corn after alfalfa	Continuous corn	Average Yield Continuous corn yields
Year	......................................lbs	N/Acre.......................................			Bushels/Acre
1981	174	123	160	178	128
1982	174	123	...	178	138
1984	158	115	155	169	130
1986	147	96	...	153	149
1987	149	84	121	157	141
1988	141	84	124	151	79*
1989	138	82	125	148	147
1990	123	66	121	145	145
1991	117	59	112	131	138
1992	117	...	...	128	165
1993	115	55	117	124	110**

* drought lowered yields in the basin and across Iowa
** frequent rains lowered yields in the basin and across Iowa

sions based on uncertain economic consequences. Since the individual farm operators and the residents of the Big Spring basin area are the ones affected by water quality problems they need to be informed about the quality of their water and how it is being adversely affected and informed as to how their groundwater quality can be improved.

BUGENHAGEN SUB-BASIN

In the western portion of the Big Spring basin, including the Bugenhagen sub-basin area, there is enough of a cap of glacial till, Maquoketa shales, and shaley dolomite that the water table occurs above the Galena aquifer. In this area, there is normally perennial groundwater discharge into the stream system. During normal climatic conditions, the tiles within the sub-basin and adjacent areas flow continuously enough to be useful for monitoring the effects of landuse and management at the top of the water table (top of the groundwater system). During WYs 1988 and 1989, which were the two driest consecutive years in Iowa's history, there were extended periods with very little groundwater or surface-water discharge. The very dry conditions limited discharge and water-quality monitoring during various periods of the project.

The 1,005 acre Bugenhagen sub-basin was selected early in the BSBDP to be a model area for implementation of improved farm management and soil conservation (Figure 3). From WY 1981 to WY 1986, much of the water-quality sampling within the sub-basin was done on an event basis, taking samples from the tile outlets and a few surface-water sites. In WY 1986, instrumentation that continuously monitored discharge and initiated event-related sampling was installed to supplement routine observations and samples collected by field personnel.

The sub-basin drains to 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, which crops out on the steeper slopes. The drainageways are filled with shallow alluvium that progressively thins, down drainage, over the bedrock. The soils in the sub-basin are mainly Otter and Worthen silt loams. Otter soils occupy the drainageway and are flanked by Worthen soils at the base of the upland slopes.

In the lower sub-basin during low flow, discharge seeps into the alluvium of the streambed and the underlying bedrock, before reaching the sinkholes. Intermittently, small openings or fractures in the bedrock swallow the discharge more directly. During higher flow, discharge reaches the sinkhole complex further downstream. These sinkholes are large depressions filled with alluvium. They are not open conduits into the underlying bedrock. The water draining to the sinkholes infiltrates through the soil and into the groundwater system. During extreme runoff, the stream may overflow the sinks, and spill out on to the floodplain of the east branch of Silver Creek. Beyond the sinkholes there is no defined channel and excess stream flow infiltrates into the soil.

Dye tracing established the connection between sinkholes in the Bugenhagen sub-basin and Big Spring (Hallberg et al., 1983, 1984a). Under high-flow conditions travel times from the sinks to Big Spring are approximately 24 hours, suggesting that a highly transmissive zone of conduit flow underlies, or at least connects part of the sub-basin to Big Spring. Monitoring of farm well VD24 (Figure 2) indicates that there is great spatial variability in the conduit zone. VD24 is 200 feet deep, cased to 100 feet, and is located 1,000 feet from the sub-basin drainageway (Figure 3). Under normal to wet climatic conditions water samples from the well contain 20 to 40 mg/L of nitrate (NO_3) and 20 to 30 units of tritium (3H). During high-flow conditions detectable concentrations of atrazine (>0.1 µg/L) occur.

Tritium is an isotope of hydrogen with a radioactive half-life of 12.3 years and an atmospheric residence time of 1.5 years. Prior to atmospheric contamination from testing of thermonuclear bombs, the natural tritium content of precipitation was 5 to 20 tritium units (T.U.). Groundwater recharged prior to 1953 should have tritium concentrations below 2 to 4 T.U.

During dry periods, the nitrate concentrations of VD24 decline to less than 5 mg/L, atrazine is not detectable, and tritium concentrations are less than 10 T.U. This suggests that during periods of limited recharge, groundwater that is over 20 years old and largely unaffected by agrichemicals can be pumped from within 1,000 feet of the conduit zone underlying the sub-basin. It is likely that during periods of limited recharge, similar groundwater discharges to the conduit zone and ultimately resurfaces at Big Spring. During periods of recharge, infiltrating water delivers high concentrations of nitrate to shallow groundwater, and this shallow groundwater transports the nitrate laterally to streams and downward into the Galena aquifer and Big Spring.

Within the sub-basin, landuse and cropping-patterns have changed significantly since water-quality monitoring began in 1981. Crop rotation sequences, changing ownership, changing farm programs (from PIK to CRP, etc.), and the special conservation BMP projects established in the sub-basin all imposed changes on the system. As part of the Sub-Basin Demonstration Project, tile-outlet terraces were developed and hooked into tile monitoring sites BTLUE and BTLUW, that drain the east and west sides of the sub-basin (Figure 4). The terraces reduced surface-water flow through BOOGFL, the surface-water outlet for the sub-basin, changed the nature of the tile effluent by allowing surface water influx, and changed the drainage area of the tile lines. Since 1981, the hydrology of the basin has been radically altered. Hence, the observations and monitoring in the basin are from a “real-world” agricultural setting, not a controlled experiment. These observations, along with more controlled, smaller scale experiments, may provide important perspectives of the inter-relationships of land management and water quality in a real operational farm setting.

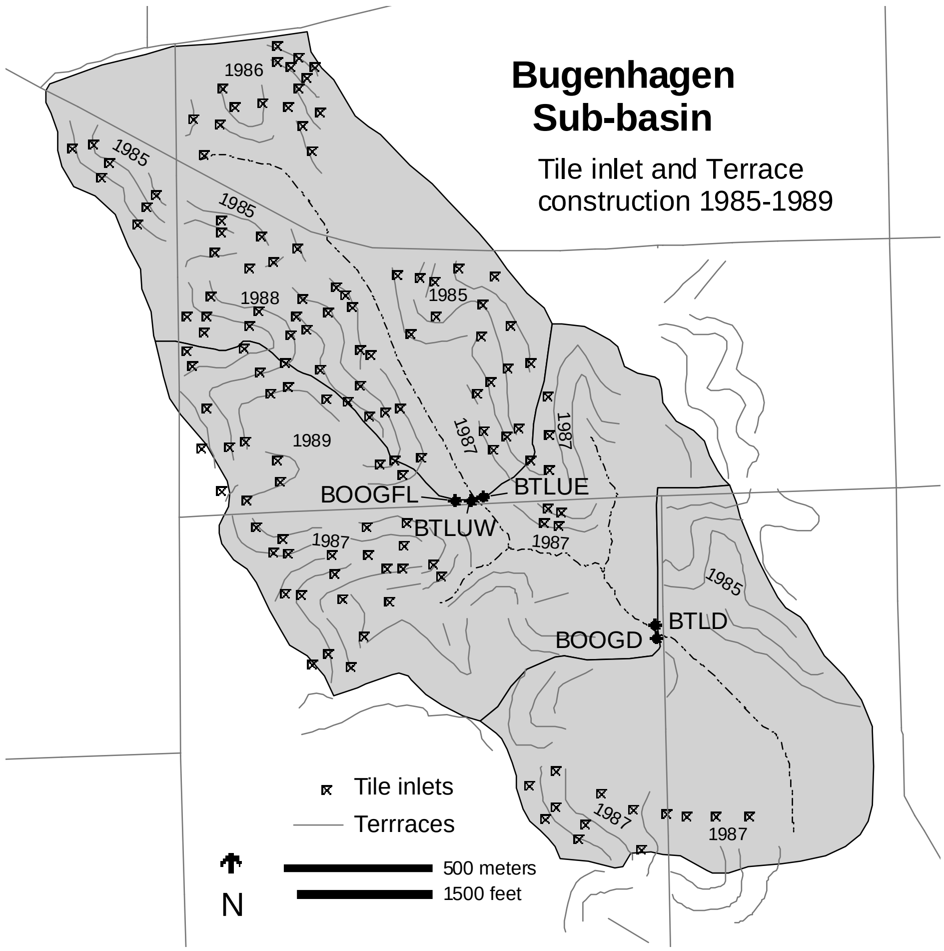


Figure 4. Map of the Bugenhagen sub-basin showing the location of streams, tile inlets, terraces, and monitoring sites. Also shown are dates of terrace construction and sub-basin boundaries.

Upper Bugenhagen Monitoring Sites

The sub-basin monitoring shed was located approximately 3/4 mile above the sinkhole complex (Figure 3). The instrumentation at this site was designed to monitor the discharge from the upper half of the sub-basin (approximately 418 acres). Subsurface drainage from tile-lines BTLUE and BTLUW, and surface-water discharge through BOOGFL were monitored continuously. The monitoring shed was an 8 by 12-foot corrugated metal structure, set on a foundation/sump, 7 feet in depth, made of 5/8-inch exterior plywood. Power for the instruments was supplied by a 12-volt lead-acid battery under a constant low-amp charge. This arrangement provided power for the equipment during periods of frequent sampling, and the battery functioned as a backup during power outages. A 250-watt infrared heat lamp and portable electric heater were used to offset extreme low temperatures and to decrease the humidity within the shed when needed.

BOOGFL

To measure intermittent surface-water flow, three HL-flumes were installed side by side in the main drainageway of the upper sub-basin. The flumes were set on 6 by 6-inch treated lumber posts. Flanges made of 5/8-inch treated plywood prevented flow from circumventing the flumes. Each flume was capable of measuring up to 117 cfs of discharge, and together the flumes had a maximum capacity of 351 cfs. To increase the precision of stage measurement, a flange directed surface water through the center flume during low flow (stages up to 1 foot). Mechanical float and tape stage recorders were used to record instantaneous stage through time in individual flumes. An ISCO flow meter measured stage in a stilling well in the center-flume, and an ISCO wastewater sampler was used to take flow-weighted samples from the center flume during runoff. Flow through the HL-flumes occurred only during intense rainfall or snowmelt, and following the installation of tile outlet terraces, discharge through the flumes essentially ceased.

BTLUE and BTLUW

Tile line sites BTLUE and BTLUW have been monitored for water quality since 1981. The tiles are installed at a depth of approximately 3.5 to 5 feet in Otter and Worthen silt loams, poorly drained soils in the gently sloping upland drainage basin. During the summer of 1986, BTLUW and BTLUE were routed into separate 1.5-foot H-flumes in the instrument-shed sump. The flumes were monitored by ISCO flow meters and sampled by ISCO wastewater samplers.

The original tile diameters of BTLUW and BTLUE were 5 and 6 inches, respectively. Both tiles had a surface inlet immediately down-drainage from a box culvert beneath Highway 52/18, but the intakes were plugged and not functional before 1981, and became plugged again during 1982. The culvert directed overland runoff and discharge from a tile drainage system north of the highway into the sub-basin drainageway. In May 1986 the tile drainage from the area in the sub-basin north of the highway was carried under the highway and allowed to discharge to the surface of the upper sub-basin. In September 1987 these tiles were connected into BTLUE. Monitoring of groundwater at BTLUE and BTLUW was discontinued at the end of WY 1995.

Lower Bugenhagen Monitoring Sites

The sites BOOGD and BTLD were located approximately 1/4 mile downstream from the instrument shed (Figure 3). BOOGD monitored the intermittent surface-water discharge from 736 acres of the sub-basin and BTLD monitored the groundwater discharge beneath an 18-acre area that had been in pasture for over 30 years.

BOOGD

BOOGD was a standard USGS gaging station, with continuous discharge records beginning May 1986 (Kalkhoff, 1989). The station was located on the south bank of the drainageway, just upstream of an elliptical, corrugated culvert-road crossing that the stream flows through. In May of 1988, a rain gage, and mini-monitor that measured water temperature, pH, and specific conductance were added. The data was stored on a multiple parameter data-logger and was downloaded weekly via telephone modem to computers at the USGS, WRD in Iowa City. Samples for sediment and nutrient analysis were taken by an ISCO water sampler that was activated by changes in stage. The sediment samples were supplemented with periodic and event-related sediment samples collected by local observers (sub-basin cooperators). Surface-water monitoring at BOOGD was discontinued at the end of WY 1992.

BTLD

Tile monitoring site BTLD was located on the north bank of the sub-basin drainageway, immediately upstream of site BOOGD. The 5-inch tile line, has no surface water intakes, and is buried at a depth of approximately 3.5 feet in Otter silt loam. The Otter series is a poorly drained, moderately permeable soil formed in silty alluvium in upland drainage basins. The drained field had been in pasture for over 30 years, with a variable cattle population and minimal chemical application. Since fertilizer application was minimal, and no herbicides or insecticides were applied in the pasture, the water quality of BTLD provided a baseline for comparison with the groundwater from tiles BTLUE and BTLUW that monitored more intensely cropped fields.

Monitoring at BTLD by the IDNR began in 1981. During the summer of 1986 the tile was routed into a box sump and through a 0.75 foot H-flume. Stage in the flume was measured by a mechanical clock-driven float and tape stage-recorder. Both Serco and ISCO water samplers have been used in time-sampling mode. A solar panel and 12 volt battery were later added to allow the use of ISCO sampling and flow-monitoring equipment as needed. The drainage area above BTLD is approximately 18 acres. With the small drainage area, the continuous cover, and the deep rooted forage plants, discharge through the tile was intermittent, particularly during the drought years 1988 and 1989. Monitoring of BTLD was discontinued at the end of WY 1994.

IMPLEMENTATION OF LANDUSE CHANGES IN THE SUB-BASIN

Erosion Control Practices

One of the goals of the sub-basin project was to reduce soil erosion on all cropland to less than "T", the tolerable soil loss considered as the maximum erosion that can take place on a given soil without degrading the soil's long-term productivity. The choice of BMPs implemented to achieve erosion control was made by the farmer owner/operator, working in conjunction with the Clayton County Soil and Water Conservation District. Conservation tillage, crop rotations, contouring, contour stripcropping, grassed waterways, and other management oriented soil conservation practices were encouraged. In areas other than where contour stripcropping was the major practice used, terracing was needed in conjunction with other management practices to control soil erosion to "T" or less.

As previously mentioned, cost sharing was used to encourage landowner/operators to participate in the sub-basin project, and to finish construction practices early in the 1985-1995 water monitoring phase of the study. Cost share rates were typically 75% agency share and 25% landowner share for construction of permanent soil conservation practices. Long-term contracts stipulated the BMPs selected to control erosion and to manage nutrients and pests to protect the soil and water resources in the sub-basin. The contracts outlined all requirements that farmers were to comply with for seven years. Seven farms covering 897 acres, or 89%, of the sub-basin were planned and approved during WY 1986 and an eighth farm was approved in WY 1988, increasing the coverage to 981 acres, or 98% of the sub-basin.

Terracing was the major practice selected to protect soil resources on 80% of the cropland within the sub-basin. The terrace system includes approximately 21.6 miles of terraces, 15.1 miles of tile lines, 250 tile inlets, and tile outlets within or contiguous with sub-basin fields (Figure 4). Contour stripcropping was used on 15% of the cropland acres, and the remaining 5% of the sub-basin cropland was bottomland with little sheet and rill erosion potential.

Conservation tillage was used for seedbed preparation on 88% of the crop acres within the sub-basin. A typical 30% corn residue left on the soil after planting, using fall chisel, spring soil finisher, and planting, reduces soil losses 60 to 70% compared to moldboard plowing. The 12% of fields, on which moldboard plows were used, used crop rotations with a high percent of perennial forage crop in the rotation, and either contour stripcropping and/or terraces to control erosion.

From 1987 through 1991, soil loss rates on surveyed cropland and permanent pasture were reduced by 64%, comparing before conservation treatment with after treatment Universal Soil Loss Equation computations. Annual soil losses in the sub-basin were reduced nearly 7,000 tons after treatment. This soil savings benefit will continue as long as the erosion control practices are maintained.

Tile System Changes

Tile-outlet terraces and stripcropping were implemented in the northeast portion of the sub-

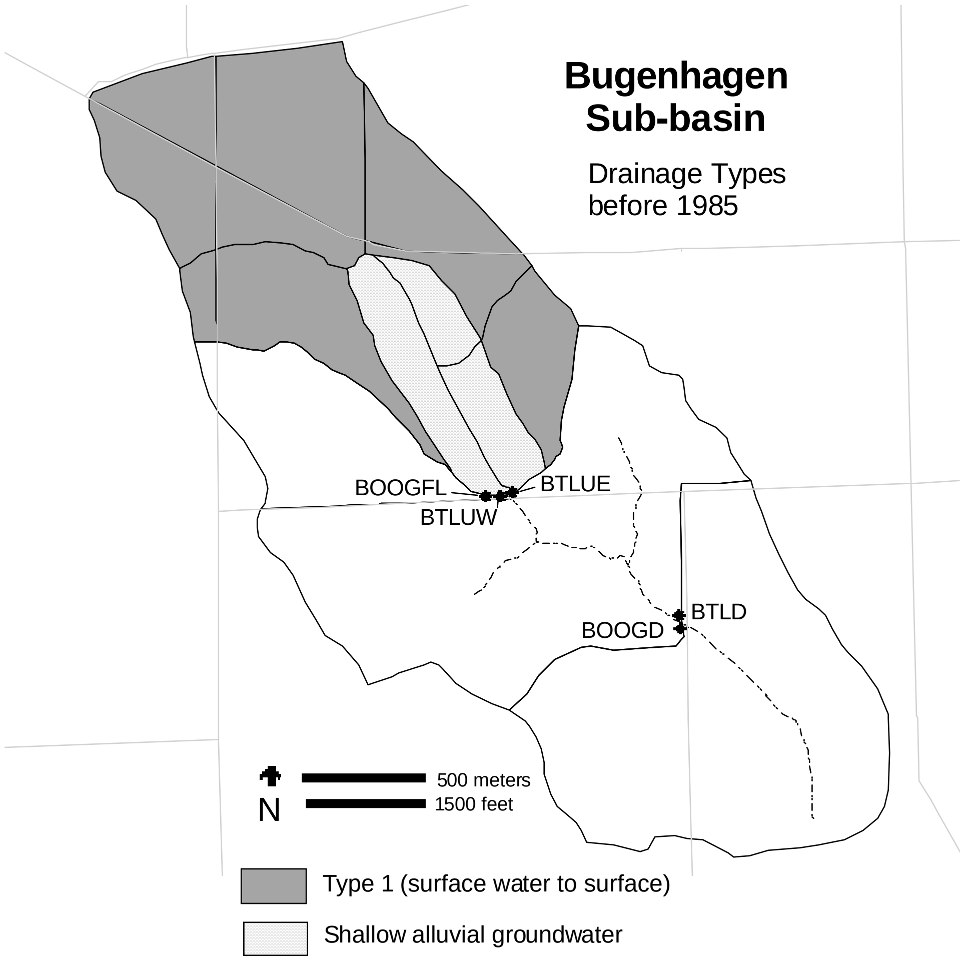


Figure 5. Map of the Bugenhagen sub-basin showing drainage types within the upper sub-basin prior to 1985.

basin as part of soil conservation BMPs beginning in June 1985 (Figure 4). In successive years, new tile outlets were connected to BTLUW and BTLUE, resulting in a progressive increase in the tile intake drainage areas (figures 5-7). To increase flow capacities, 10-inch diameter tile lines paralleling the existing tiles were added and retrofitted to the flumes. Prior to June 1985, there were no tile inlet terraces in the upper sub-basin. During June and July of WY 1985, 34 acres, or 8.1%, of the 418-acre area above the monitoring shed was diverted into tile intakes. At the beginning of WY 1986, in October, an additional 22 acres, or 5.3%, of area was diverted into intakes, and in June of 1986, an additional 57 acres, or 13.6%, of the area above the monitoring shed was diverted to intakes. In September of WY 1987, 48 acres, or 11.5%, of the area above the monitoring shed was routed into tile intakes, and at the beginning of WY 1988, in October, 67 acres, or 16%, of the 418 acres above the monitoring shed was diverted into tile intake terraces. Cumulatively, 34 acres, or 8.1%, of the 418-acre area above the monitoring shed drained into intakes in WY 1985; 113 acres, or 27.0%, in WY 1986; 161 acres, or 38.5%, in WY 1987; and 228 acres, or 54.6%, of the area above the monitoring shed were diverted into tile intake terraces in WY 1988. The last set of tile intake terraces drain 52 acres and were constructed in 1989 just below the lower west side of the upper sub-basin. These tiles discharge immediately below the monitoring shed.

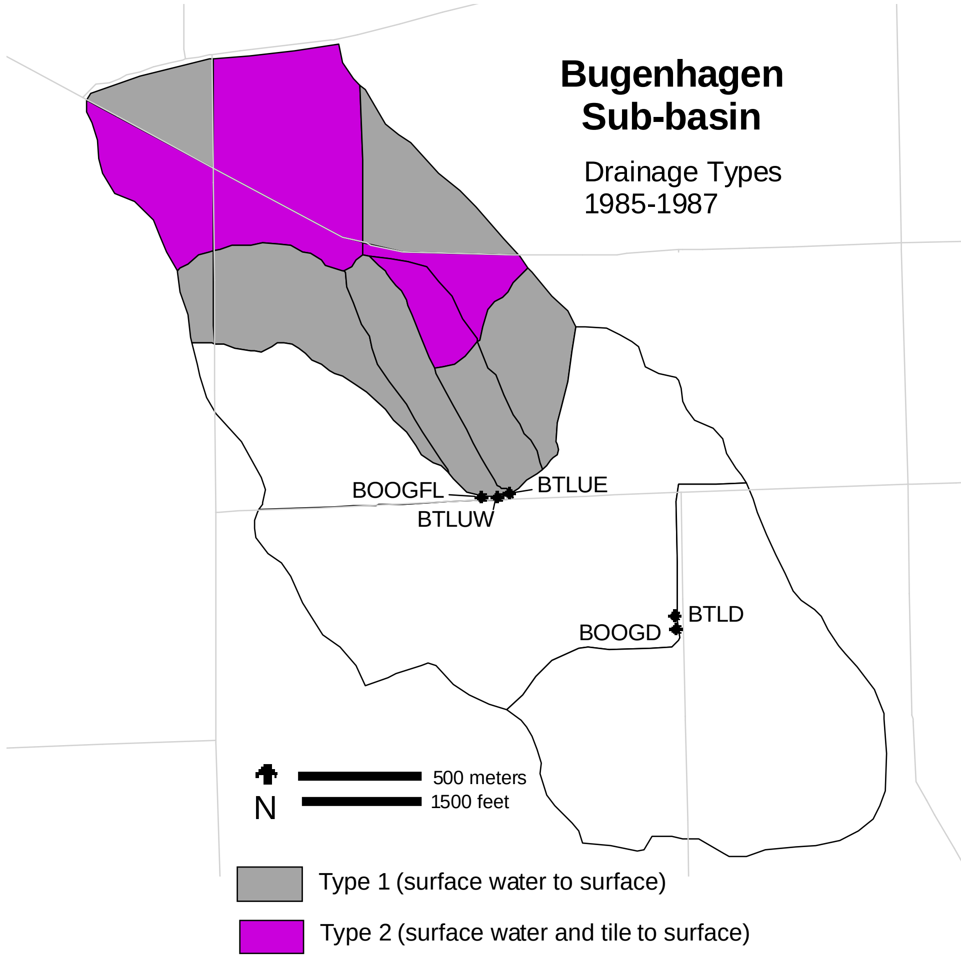


Figure 6. Map of the Bugenhagen sub-basin showing drainage types within the upper sub-basin during 1985-1987.

Figure 5 shows the drainage types and areas within the upper sub-basin prior to 1985, and Table 2 summarizes the drainage type, landuse and acreage in the upper sub-basin during 1980 and 1987. The upper sub-basin area that drains to the monitoring shed is approximately 366 acres and does not include the 52 acres of drainage that outlets below the monitoring shed. In 1980, approximately 295 acres, or 81%, of the drainage was surface water to surface (type 1), and 71 acres, or 19%, of the drainage was groundwater from the shallow alluvial system (type 0) into BTLUE and BTLUW. During 1980, 207 acres, or 70%, of the surface drainage area was in row crop, and 38 acres, or 53%, of the groundwater drainage was in row crop. From 1985 to 1987, the construction of tile intake terraces changed the nature of the type 0 drainage and decreased the upper sub-basin area of type 1 drainage to 212 acres, or 58% (Figure 6 and Table 2). The terraces at this time were not connected into BTLUE or BTLUW, and the tile effluent was discharged to the surface

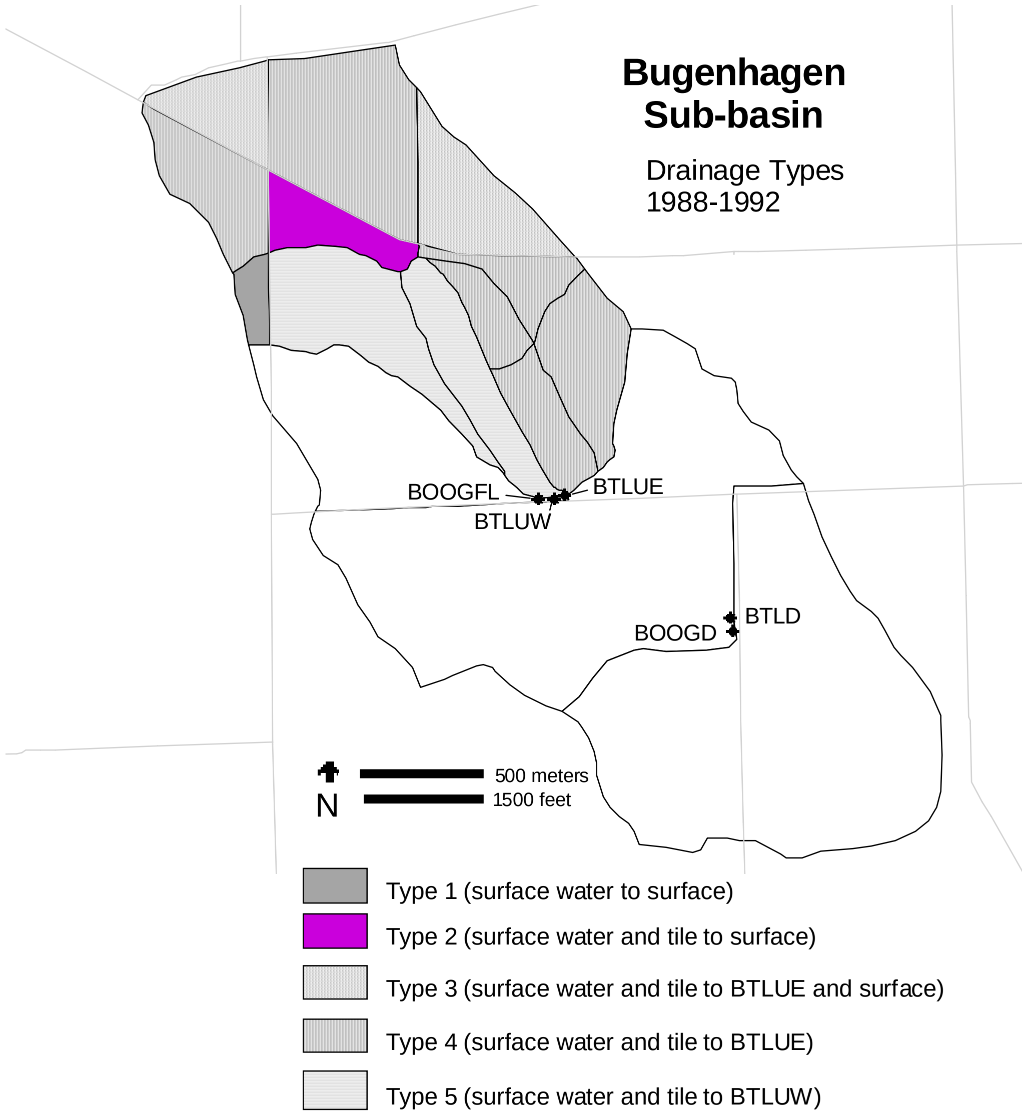


Figure 7. Map of the Bugenhagen sub-basin showing drainage types within the upper sub-basin during 1988-1992.

through tile outlets. This surface water and tile to surface type of drainage (type 2) accounted for 154 acres, or 42%, of the upper sub-basin. During 1987, approximately 39 acres, or 18%, of the surface drainage (type 1) was in corn, and 107 acres, or 69%, of the surface water and tile to surface drainage (type 2) was in corn.

In 1988, portions of terraces previously built were connected into BTLUE, and additional terraces were constructed on the west side of the sub-basin, with some of the tile lines discharging to the surface, and some of the tiles connected directly into BTLUW (figures 4 and 7). From 1988 to present, type 1 drainage to BTLUW accounts for 8 acres, or 2%, of the upper sub-basin; and type 2 drainage to BTLUW accounts for 21 acres, or 6%, of the upper sub-basin (Table 3). Surface water and tile to BTLUW drainage (type 5) has accounted for approximately 88 acres, or 24%, of the area above the monitoring shed since 1988. Surface water and tile to BTLUE and surface drainage (type 3; the area that is not tiled that

Table 2. Summary of landuse types and acreage within drainage types within the upper Bugenhagen sub-basin for 1980 and 1987.

UPPER BUGENHAGEN SUB-BASIN DRAINAGE TYPES AND LANDUSE 1980 and 1987

Drainage type and classification	Landuse type	Year 80	Drainage type and classification	Landuse type	Year 87
Shallow alluvial groundwater		Acres	Surface water to surface		Acres
			1	corn	38.99
0	corn	37.64	1	hay	161.12
0	hay	29.87	1	permanent pasture	9.84
0	permanent pasture	3.46	1	rotational pasture	0.18
0	farmstead	0.00	1	farmstead	2.08
	subtotal	70.97		subtotal	212.21
Surface water to surface			Surface water and tile to surface		
1	corn	207.39	2	corn	106.88
1	hay	59.78	2	hay	26.69
1	permanent pasture	23.88	2	permanent pasture	17.50
1	farmstead	4.27	2	farmstead	3.01
	subtotal	295.32		subtotal	154.08
Total acres to alluvial groundwater		70.97	Surface water to surface		212.21
Surface water to surface		295.32	Surface water and tile to surface		154.08
Total acres for upper sub-basin		366.29			366.29

drains to BTLUE) accounts for 61 acres, or 17%, of the upper sub-basin; and surface water and tile to BTLUE drainage (type 4) accounts for 189 acres, or 52%, of the upper sub-basin. The total area of drainage types 1, 2, and 5 draining to BTLUW is 116 acres, or 32%, of the upper sub-basin, and the total area of drainage types 3 and 4 draining to BTLUE is 250 acres, or 68%, of the upper sub-basin.

Cropping patterns within the various drainage areas continued to change from 1988 through 1995. In the type 1 drainage areas, corn accounted for 0.9 acre, or 12%, of the area in 1988; 7.6 acres, or 100%, of the area during 1989, 1990, 1994 and 1995; 1.3 acres, or 17%, of the area in 1991; 6.7 acres, or 88%, of the area in 1992; and 4.5 acres, or 59%, of the type 1 drainage area was in corn during 1993 (Table 3). In the type 2 drainage areas, corn accounted for approximately 16 acres, or 77%, of the area from 1988 through 1995. In the type 5 drainage areas, corn accounted for 13 acres, or 15%, of the area in 1988; 84 acres, or 95%, of the area from 1989-1992; 62 acres, or 71%, of the area in 1993 and 1994; and 49 acres, or 56%, of the type 5 drainage area in 1995.

Within the type 3 drainage areas, corn accounted for 1.4 acres, or 2%, of the area in 1988; 3.7 acres, or 6%, in 1989; 36 acres, or 59%, of the area during 1990 and 1991; 19 acres, or 31%, of the area in 1992; 7 acres, or 11%, of the area in 1993; and 33 acres, or 54%, of the type 3 area was in corn during 1994 and 1995. In the type 4 drainage areas, corn accounted for 120 acres, or 64%, of the area in 1988; 173 acres, or 92%, of the area in 1989 and 1990; 141 acres, or 75%, of the area in 1991; 152 acres, or 81%, of the area in 1992; 141 acres, or 74%, of the area in 1993; 169 acres, or 89%, of the area in 1994; and 89 acres, or 47%, of the type 4 area in 1995.

Table 3. Summary of landuse types and acreage within drainage types within the upper Bugenhagen sub-basin for 1988-1995.

UPPER BUGENHAGEN SUB-BASIN DRAINAGE TYPES AND LANDUSE 1988-1995									
Drainage type and classification	Landuse type	Year 88	89	90	91	92	93	94	95
Surface water to surface to BTLUW		Acres							
1	corn	0.92	7.65	7.65	1.33	6.72	4.51	7.64	7.64
1	beans	5.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	oats	0.00	0.00	0.00	6.32	0.00	0.00	0.00	0.00
1	hay	1.33	0.00	0.00	0.00	0.92	3.13	0.00	0.00
	subtotal	7.65	7.65	7.65	7.65	7.64	7.64	7.64	7.64
Surface water and tile to surface to BTLUW									
2	corn	15.94	15.94	15.94	15.94	15.94	15.94	15.94	15.94
2	permanent pasture	4.86	4.86	4.86	4.86	4.86	4.86	4.86	4.86
	subtotal	20.80	20.80	20.80	20.80	20.80	20.80	20.80	20.80
Surface water and tile to BTLUW									
5	corn	13.06	83.62	83.62	83.62	83.62	62.28	62.28	49.22
5	beans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.06
5	oats	0.00	0.00	0.00	0.00	0.00	21.34	0.00	0.00
5	hay	70.56	0.00	0.00	0.00	0.00	0.00	21.34	21.34
5	permanent pasture	3.39	3.39	3.39	3.39	3.39	3.39	3.39	3.39
5	farmstead	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
	subtotal	87.83	87.83	87.83	87.83	87.83	87.83	87.83	87.83
Total acres to BTLUW		116.28	116.28	116.28	116.28	116.27	116.27	116.27	116.27
Surface water and tile to BTLUE and surface									
3	corn	1.43	3.67	35.86	35.86	19.12	6.95	32.76	33.48
3	beans	17.69	0.00	0.00	0.00	17.70	17.70	0.00	0.00
3	oats	5.03	1.43	0.00	0.00	0.00	10.17	0.00	0.00
3	oats-set aside	0.00	17.69	0.00	0.00	0.00	0.00	4.62	0.00
3	hay	29.12	30.48	17.41	17.41	16.48	18.48	15.93	14.62
3	grass set aside	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.21
3	permanent pasture	6.45	6.45	6.45	6.45	6.45	6.45	6.45	6.45
3	farmstead	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26
	subtotal	60.98	60.98	60.98	60.98	61.01	61.01	61.02	61.02
Surface water and tile to BTLUE									
4	corn	120.04	173.00	173.00	141.21	152.20	140.71	169.13	88.98
4	beans	10.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	oats	0.00	0.00	0.00	31.31	0.50	0.94	0.63	80.33
4	hay	42.71	0.38	0.38	0.86	20.68	31.73	3.62	4.07
4	permanent pasture	12.64	12.64	12.64	12.64	12.63	12.63	12.63	12.63
4	farmstead	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01
	subtotal	189.03	189.03	189.03	189.03	189.02	189.02	189.02	189.02
Total acres to BTLUE		250.01	250.01	250.01	250.01	250.03	250.03	250.04	250.04
Total acres for upper sub-basin		366.29	366.29	366.29	366.29	366.30	366.30	366.31	366.31

Currently, BTLUE drains the eastern portion of the sub-basin, north of the monitoring shed, and the sub-basin area north of Highway 52/18 (Figure 3). BTLUW drains the western sub-basin, between the monitoring shed and Highway 52/18. Prior to the installation of the tile-outlet terraces BTLUE and BTLUW discharged groundwater. The addition of the tile-outlet terraces changed the nature of the water discharge. During dry periods the tiles yield shallow groundwater, but following significant precipitation, the tile-intakes in the terraces direct runoff into the tiles mixing surface water with groundwater.

Pest and Nutrient Management

Management practices applied and not cost shared included pest and nutrient management. Pest management practices were applied using ISU-CES guidelines and using pesticide label instructions. The Integrated Pest Management program (IPM) included field scouting for pest detection and to monitor crop conditions; economic threshold levels to determine need to treat; benefits of crop management and cultural practices to disrupt the pests environment; chemical and biological control of pests if cultural practices were not a practical alternative; and assistance with sprayer calibration.

The nutrient management program was enhanced by reducing erosion and runoff. As a consequence of keeping soil particles in place, compounds such as phosphorous (P) and potassium (K) that strongly attach to soil particles also remain in place. Nutrient credits from manure and legumes also reduced purchased fertilizer. Nutrient management practices included soil testing for nitrogen (N), P, K, pH and organic matter, with three year intervals for all tests other than N (N testing was experimental at the start of the project, but was used in 1990 and 1991 on a limited basis); setting realistic yield goals (YGs) from a weighted yield average using soil mapping units and historical field yield information; N recommendation rates for corn were reduced by reducing the N factor from 1.22 to 1.1 in the equation (YG x 1.1= lbs N needed to apply); and fertilizer and/or manure was not to be applied on snow covered, or frozen ground.

Cropping Pattern Changes

From 1987 through 1995, farm surveys were conducted by the ISU-CES to obtain information about landuse, and nutrient and pesticide application rates within the Bugenhagen sub-basin.

Within the 418-acre upper sub-basin, 32 acres are taken up by roads and 10 acres are taken up by buildings and lots, leaving 376 acres of cropland. Of this 376 acres of cropland, 294 acres were surveyed in 1987; 366 acres were surveyed in 1988-1993; 317 acres were surveyed in 1994; and 359 acres were surveyed in 1995. The middle and lower sub-basins include 587 acres, of which 15 acres are taken up by roads, 24 acres are taken up by buildings and lots, and 7 acres are wildlife areas or vegetated sinkholes. In addition, 37 acres were in permanent pasture during 1987-1992, and 29 acres were in permanent pasture during 1993-1995. This leaves 504 acres of cropland during 1987-1992 and 512 acres of cropland during 1993-1995. Within the middle and lower sub-basins, 496 acres were surveyed during 1987-1991; 457 acres were surveyed in 1992; 486 acres were surveyed during 1993-1994; and 499 acres were surveyed in 1995. The computations for nitrogen fertilizer use within the sub-basin are based on landuse acreage from the farm surveys, while the landuse statistics discussed previously, along with drainage types, and the landuse statistics discussed in the following paragraphs are based on landuse acreage from aerial photographs that were digitized into a Geographic Information System.

Figure 8 shows landuse within the Bugenhagen sub-basins in 1980, and figures 9-17 show landuse for 1987-1995. Table 4 summarizes the landuse statistics for 1980, and 1987-1995. In 1980, 245 acres, or 65%, of the 376 acre upper sub-basin was in corn; 90 acres, or 24%, was in alfalfa; and 27 acres, or 7%, of the upper sub-basin was in permanent pasture. The remaining 4 acres of the upper sub-basin was farmstead. During 1987-1995 the area in farmstead increased to approximately 5 acres, and the area in permanent pasture

Figure 8. Map of the Bugenhagen sub-basin showing landuse types during 1980. Also shown are the 1988-1992 drainage type boundaries in the upper sub-basin and the middle and lower sub-basin boundaries and roads.

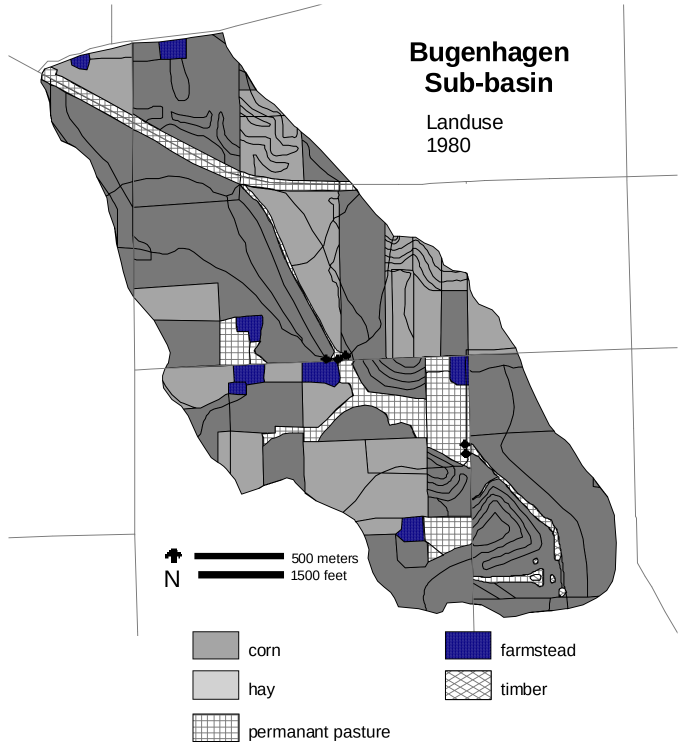
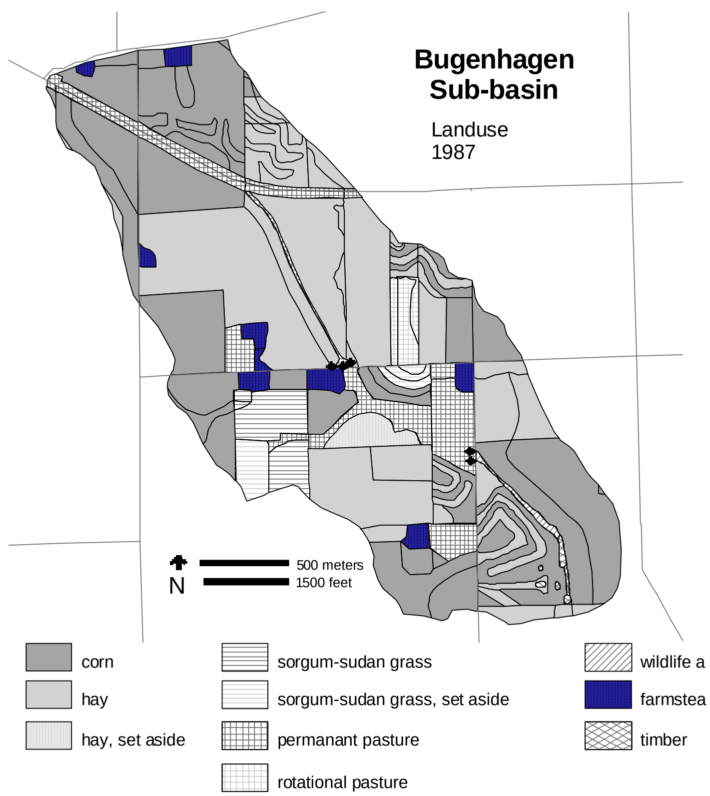


Figure 9. Map of the Bugenhagen sub-basin showing landuse types during 1987. Also shown are the roads.



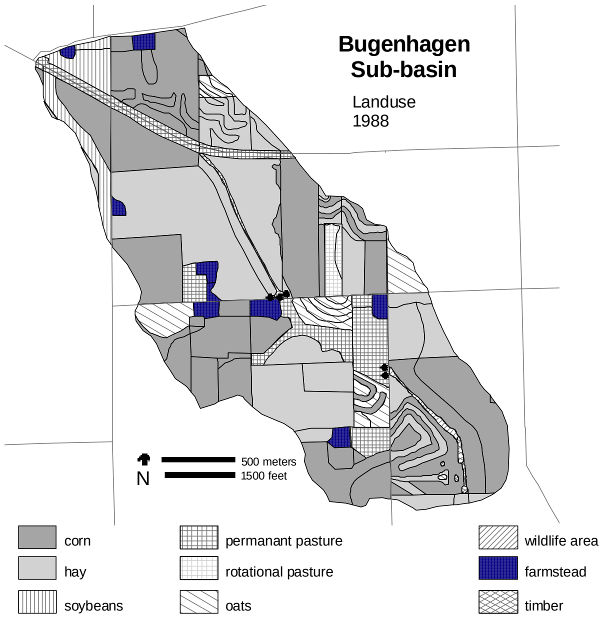


Figure 10. Map of the Bugenhagen sub-basin showing landuse types during 1988. Also shown are the roads.

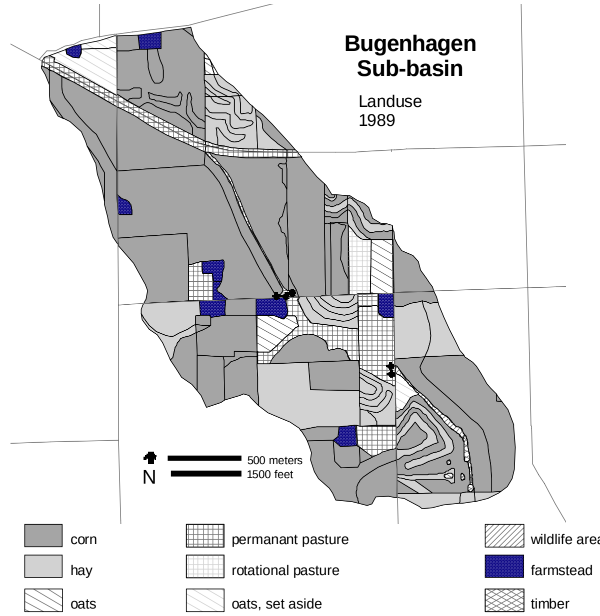


Figure 11. Map of the Bugenhagen sub-basin showing landuse types during 1989. Also shown are the roads.

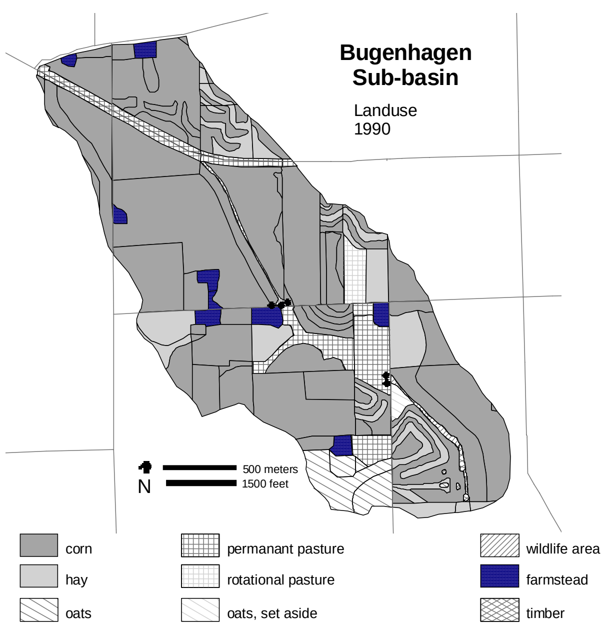


Figure 12. Map of the Bugenhagen sub-basin showing landuse types during 1990. Also shown are the roads.

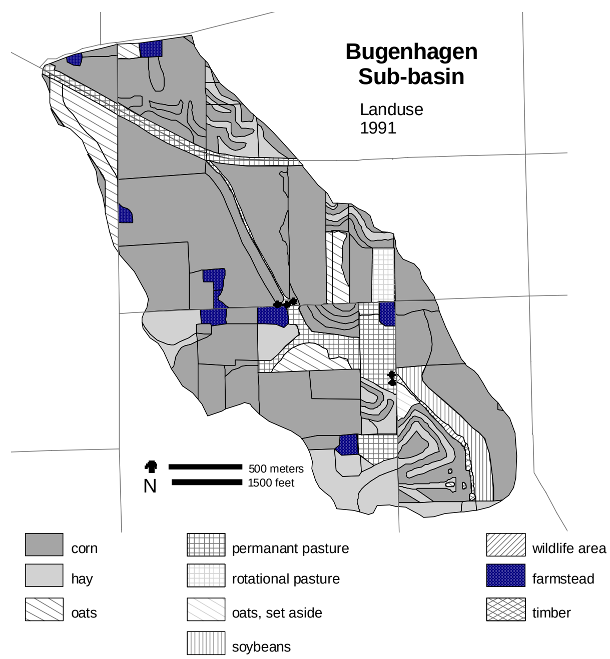


Figure 13. Map of the Bugenhagen sub-basin showing landuse types during 1991. Also shown are the roads.

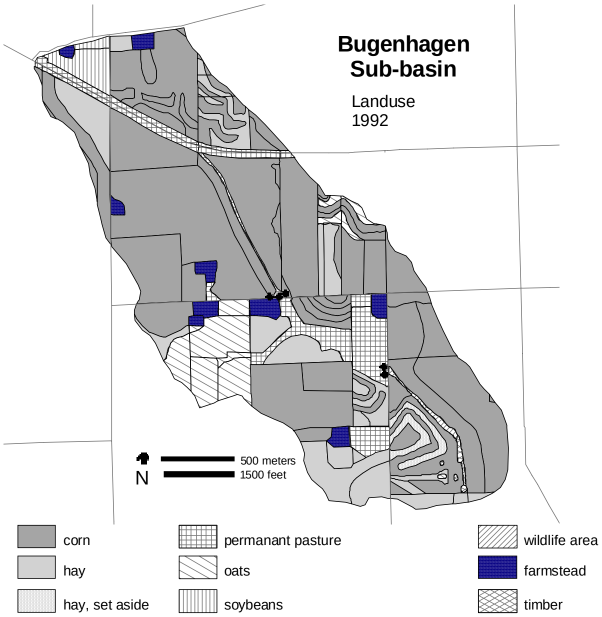


Figure 14. Map of the Bugenhagen sub-basin showing landuse types during 1992. Also shown are the roads.

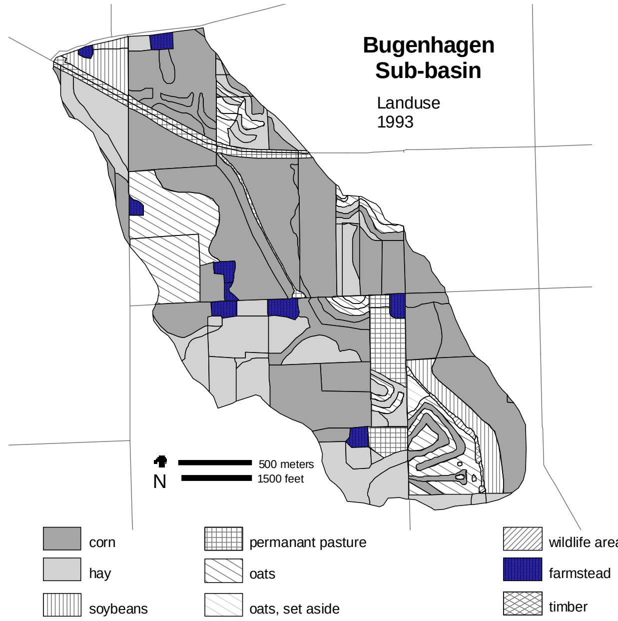


Figure 15. Map of the Bugenhagen sub-basin showing landuse types during 1993. Also shown are the roads.

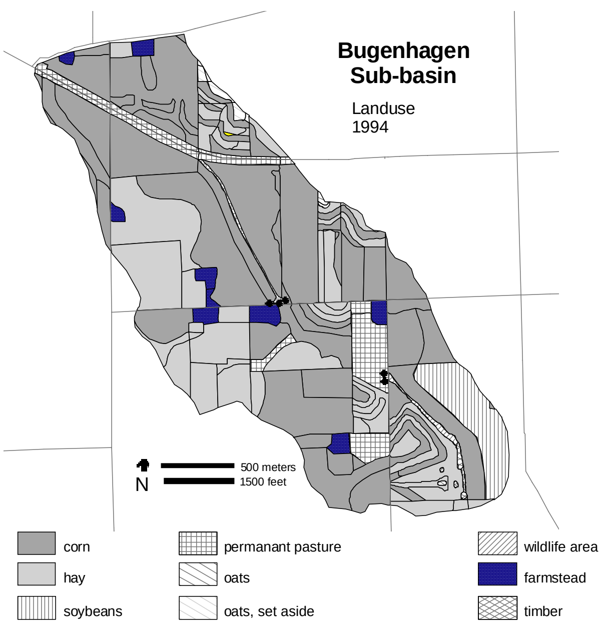


Figure 16. Map of the Bugenhagen sub-basin showing landuse types during 1994. Also shown are the roads.

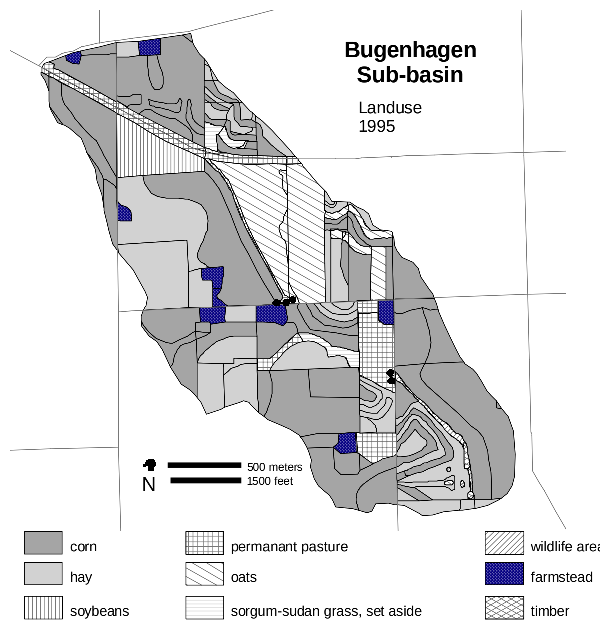


Figure 17. Map of the Bugenhagen sub-basin showing landuse types during 1995. Also shown are the roads.

remained at 27 acres. In 1987, corn accounted for 146 acres, or 40%, of the upper sub-basin; hay for 188 acres, or 51%; and rotating pasture accounted for 0.2 acres, or 0.05%, of the upper sub-basin. During 1988, corn acreage increased slightly to 151 acres, or 41%, of the upper sub-basin; the area in hay decreased to 144 acres, or 39%; and 34 acres, or 9%, of the upper sub-basin was planted to soybeans and 5 acres, or 1%, of the upper sub-basin was planted to oats. In 1989, the area of the upper sub-basin planted to corn increased to 284 acres, or 78%; the area in hay decreased to 31 acres, or 8%; the area in oats decreased to 1.4 acres, or 0.4%; and oats set-aside acreage increased to 18 acres, or 5%, of the upper sub-basin. Corn acreage increased to 316 acres, or 86%, of the upper sub-basin area in 1990, while the area in hay decreased to 18 acres, or 5%, of the upper sub-basin. In 1991, the area in corn was reduced to 278 acres, or 76%; the area in hay stayed essentially the same, and 38 acres, or 10%, of the upper sub-basin was planted to oats. In 1992 corn again accounted for 278 acres, or 76%, of the upper sub-basin; beans accounted for 18 acres, or 5%; hay accounted for 38 acres, or 10%; and oats accounted for 0.5 acre, or 0.1%, of the upper Bugenhagen sub-basin. In 1993, corn accounted for 230 acres, or 63%, of the upper sub-basin; hay for 53 acres, or 15%; oats for 32 acres, or 9%; and beans accounted for 18 acres, or 5%, of the upper sub-basin. During 1994, corn accounted for 288 acres, or 79%, of the upper sub-basin; the area in hay decreased to 41 acres, or 11%; the area planted to oats decreased to 0.6 acres, or 0.2%, of the upper sub-basin; the area in oats set-aside increased to 5 acres, or 1%, of the upper sub-basin; and no beans were planted. In 1995, corn acreage decreased to 195 acres, or 53%, of the upper sub-basin; the area planted to oats increased to 80 acres, or 22%, of the upper sub-basin; beans accounted for 13 acres, or 4%, of the upper sub-basin; hay accounted for 40 acres, or 11%, of the upper sub-basin; and 5 acres, or 1%, of the upper sub-basin were planted to sorghum and sudan grass set-aside.

As previously mentioned, the nutrients and pesticides used, and rates applied within the sub-basins were recorded through surveys to determine annual crop inputs. Crop yields at the end of the crop season indicated crop usage of nutrients. Groundwater and surface-water discharge were monitored, and sampled for various types of nitrogen and pesticides, and the water quality monitoring data were used to compute nutrient and pesticide losses from the sub-basins.

The most intensive water quality monitoring within the Bugenhagen sub-basin occurred within the water shed above the monitoring shed. The water quality monitoring from WY 1981-1992 was conducted as part of the Big Spring Basin Demonstration Project. Water quality monitoring within the sub-basin continued through WY 1995 as part of the Northeast Iowa Demonstration Project. Long-term water quality monitoring provides detailed observations of water quality changes resulting from improved soil conservation and nutrient and pesticide management, implemented as a total resource management program.

HYDROLOGIC AND WATER QUALITY MONITORING

Water-quality monitoring of tile lines, surface water, and groundwater began in the Bugenhagen sub-basin in 1981. Continuous discharge records for surface-water site BOOGD are available from May 1986 through September 1992. For tile-line site BTLD, discharge records are available from February 25, 1987 through September 1994, and for tile-line sites BTLUE and BTLUW, discharge was monitored from February 10, 1987 through September 1995. Both groundwater and surface-water discharge are a function of recharge within the sub-basin. Recharge is controlled by the amount, timing, and intensity of precipitation and snowmelt, along with antecedent conditions. The factors controlling recharge also influence the transport, concentration and loads of agriculturally related contaminants in groundwater and surface water. This section summarizes precipitation, discharge and water quality of the sites within the sub-basin for WYs 1982-1995.

Precipitation and Water Flux

Precipitation data for WYs 1982-1988 were calculated using data from the Elkader, Waukon, and Fayette weather stations, which form a triangle around the Big Spring basin. These data and daily minimum/maximum temperature data are supplied by the Iowa Department of Agriculture and Land Stewardship, State Climatology Office (IDALS, SCO). Precipitation has been recorded at the Big Spring Fish Hatchery since August 1984 as part of the National Atmospheric Deposition Program (NADP). At the hatchery, an automatic precipitation sampler collected rainfall that was analyzed weekly for major ions (including nutrients) by NADP laboratories (NADP, 1990). Beginning in WY 1985, data from the (NADP) station were also used to calculate basin precipitation. In the summer of 1988, tipping bucket rain gages were added to the USGS stream-gaging stations at BOOGD and RC02 (Figure 2). An additional rain gage was located at the monitoring shed in the upper Bugenhagen sub-basin. Basin precipitation for WYs 1989-1992 was based on data from the two USGS rain gages and data from the NADP station at the hatchery. Precipitation for WY 1993 was calculated with data from the Elkader, Fayette, and Waukon weather stations and the NADP station at the hatchery (Rowden et al., 1995b). In January 1991, IDALS began a weather station in Postville, which is much closer to the Big Spring basin than Waukon. Basin precipitation for WYs 1994 and 1995 were calculated based on data from the NADP station at the Big Spring hatchery and the IDALS stations in Elkader, Fayette and Postville. 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.

The timing, intensity, and distribution of rainfall all affect recharge to the soil-groundwater system. Monthly precipitation totals and departures from normal for the Big Spring basin during WYs 1982-1995 are shown in Figure 18. Mean annual precipitation and departure from normal during the fourteen-year period are shown in Table 5. The annual precipitation for WY 1982 was slightly above normal at 33.56 inches. During WY 1983, precipitation increased 33% to 44.53 inches. For WY 1984, annual precipitation was slightly below normal at 32.81 inches. The annual totals for WYs 1985, 1986, and 1987 were near normal at 35.84, 36.96 and 31.98 inches, although precipitation during June and July was below normal for all three water years. During WY 1985, precipitation was below normal from April through July, and, during WY 1986, precipitation was below normal from June through July. March and April of WYs 1986 and 1987 were also below normal for precipitation. During WYs 1984-1987, rainfall amounts were less than normal during the growing season, but greater than normal during the fall. Rainfall was above normal in October of WY 1985, and during WYs 1985-1987, rainfall was above average in either August or September.

Water years 1988 and 1989 were the two driest consecutive years in Iowa's recorded history with 22.94 and 24.32 inches of precipitation respectively. From a crop production standpoint, WY 1988 was considered a drought year. 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. Base-flow conditions prevailed for nearly 18 months, depleting groundwater storage in the Galena aquifer during WYs 1987 and 1988. Previous reports (Hallberg et al., 1983, 1984a, 1989) have indicated that March through June are typically marked by low evapotransporation and wet antecedent conditions, which are important for groundwater recharge. Precipitation during 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 month of WY 1988 was September, with 5.48 inches of precipitation, and the wettest month of WY 1989 was August, with 7.08 inches of precipitation. Less than 3 inches of precipitation occurred during any other month. June has typically been the wettest month in the Big Spring basin, with an

Table 4. Summary of landuse types and acreage within the upper (1), middle (2), and lower (3) Bugenhagen sub-basin for 1980 and 1987-1995.

BUGENHAGEN SUB-BASIN LANDUSE TYPES 1980 and 1987-1995

year	sub-basin	corn	beans	oats	oats set aside	hay	hay set aside	sorghum sudan grs.	sorghum sudan grs. set aside	permanant pasture	rotating pasture	wildlife area	farmstead	trees	sub-basin total acres
1980	1	245.03				89.65				27.34			4.27	0.00	366.29
	2	140.12				145.01				51.01			15.82	0.00	351.96
	3	208.27				23.56				15.79			3.36	1.89	252.87
	subtotals	593.42	0.00	0.00	0.00	258.22	0.00	0.00	0.00	94.14	0.00	0.00	23.45	1.89	971.12
1987	1	145.87				187.81	0.00	0.00	0.00	27.34	0.18	0.00	5.09	0.00	366.29
	2	113.89				94.92	12.88	30.90	16.77	51.01	14.75	0.00	16.84	0.00	351.96
	3	144.88				90.04	0.00	0.00	0.00	9.07	0.00	3.63	3.36	1.89	252.87
	subtotals	404.64	0.00	0.00	0.00	372.77	12.88	30.90	16.77	87.42	14.93	3.63	25.29	1.89	971.12
1988	1	151.39	33.72	5.03		143.72				27.34	0.00	0.00	5.09	0.00	366.29
	2	128.92	2.78	41.35		101.81				49.15	11.11	0.00	16.84	0.00	351.96
	3	140.82	0.00	9.34		84.76				9.07	0.00	3.63	3.36	1.89	252.87
	subtotals	421.13	36.50	55.72	0.00	330.29	0.00	0.00	0.00	85.56	11.11	3.63	25.29	1.89	971.12
1989	1	283.88		1.43	17.69	30.86				27.34	0.00	0.00	5.09	0.00	366.29
	2	189.80		20.18	0.00	64.49				49.15	11.50	0.00	16.84	0.00	351.96
	3	151.04		0.00	4.19	79.69				9.07	0.00	3.63	3.36	1.89	252.87
	subtotals	624.72	0.00	21.61	21.88	175.04	0.00	0.00	0.00	85.56	11.50	3.63	25.29	1.89	971.12
1990	1	316.07		0.00	0.00	17.79				27.34	0.00	0.00	5.09	0.00	366.29
	2	236.57		0.00	0.00	45.08				41.97	11.50	0.00	16.84	0.00	351.96
	3	148.49		36.59	4.19	45.65				9.07	0.00	3.63	3.36	1.89	252.87
	subtotals	701.13	0.00	36.59	4.19	108.52	0.00	0.00	0.00	78.38	11.50	3.63	25.29	1.89	971.12

Table 4. Continued.

BUGENHAGEN SUB-BASIN LANDUSE TYPES 1980 and 1987-1995															
year	sub-basin	corn	beans	oats	oats set aside	hay	hay set aside	sorghum sudan grs.	sorghum sudan grs. set aside	permanant pasture	rotating pasture	wildlife area	farmstead	trees	sub-basin total acres
1991	1	277.96	0.00	37.63	0.00	18.27				27.34	0.00	0.00	5.09	0.00	366.29
	2	221.10	0.00	27.76	0.00	33.73				41.97	10.56	0.00	16.84	0.00	351.96
	3	133.21	25.41	0.00	4.19	72.11				9.07	0.00	3.63	3.36	1.89	252.87
	subtotals	632.27	25.41	65.39	4.19	124.11	0.00	0.00	0.00	78.38	10.56	3.63	25.29	1.89	971.12
1992	1	277.60	17.70	0.50		38.08	0.00			27.33		0.00	5.09	0.00	366.30
	2	190.74	0.00	62.26		40.16	0.00			41.97		0.00	16.83	0.00	351.96
	3	162.81	0.00	0.00		59.25	12.86			9.07		3.63	3.36	1.89	252.87
	subtotals	631.15	17.70	62.76	0.00	137.49	12.86	0.00	0.00	78.37	0.00	3.63	25.28	1.89	971.13
1993	1	230.39	17.70	32.45	0.00	53.34				27.33		0.00	5.09	0.00	366.30
	2	145.27	0.00	64.38	0.00	101.89				23.55		0.00	16.87	0.00	351.96
	3	116.46	25.41	34.34	4.19	54.52				9.07		3.63	3.36	1.89	252.87
	subtotals	492.12	43.11	131.17	4.19	209.75	0.00	0.00	0.00	59.95	0.00	3.63	25.32	1.89	971.13
1994	1	287.75	0.00	0.63	4.62	40.89				27.33		0.00	5.09	0.00	366.31
	2	143.06	0.00	0.24	0.00	164.63				27.16		0.00	16.89	0.00	351.98
	3	137.21	44.30	0.00	0.00	53.41				9.07		3.63	3.36	1.89	252.87
	subtotals	568.02	44.30	0.87	4.62	258.93	0.00	0.00	0.00	63.56	0.00	3.63	25.34	1.89	971.16
1995	1	195.26	13.06	80.33		40.03			5.21	27.33		0.00	5.09	0.00	366.31
	2	150.24	0.00	20.41		132.00			5.27	27.16		0.00	16.88	0.00	351.96
	3	181.51	0.00	0.00		53.41			0.00	9.07		3.63	3.36	1.89	252.87
	subtotals	527.01	13.06	100.74	0.00	225.44	0.00	0.00	10.48	63.56	0.00	3.63	25.33	1.89	971.14

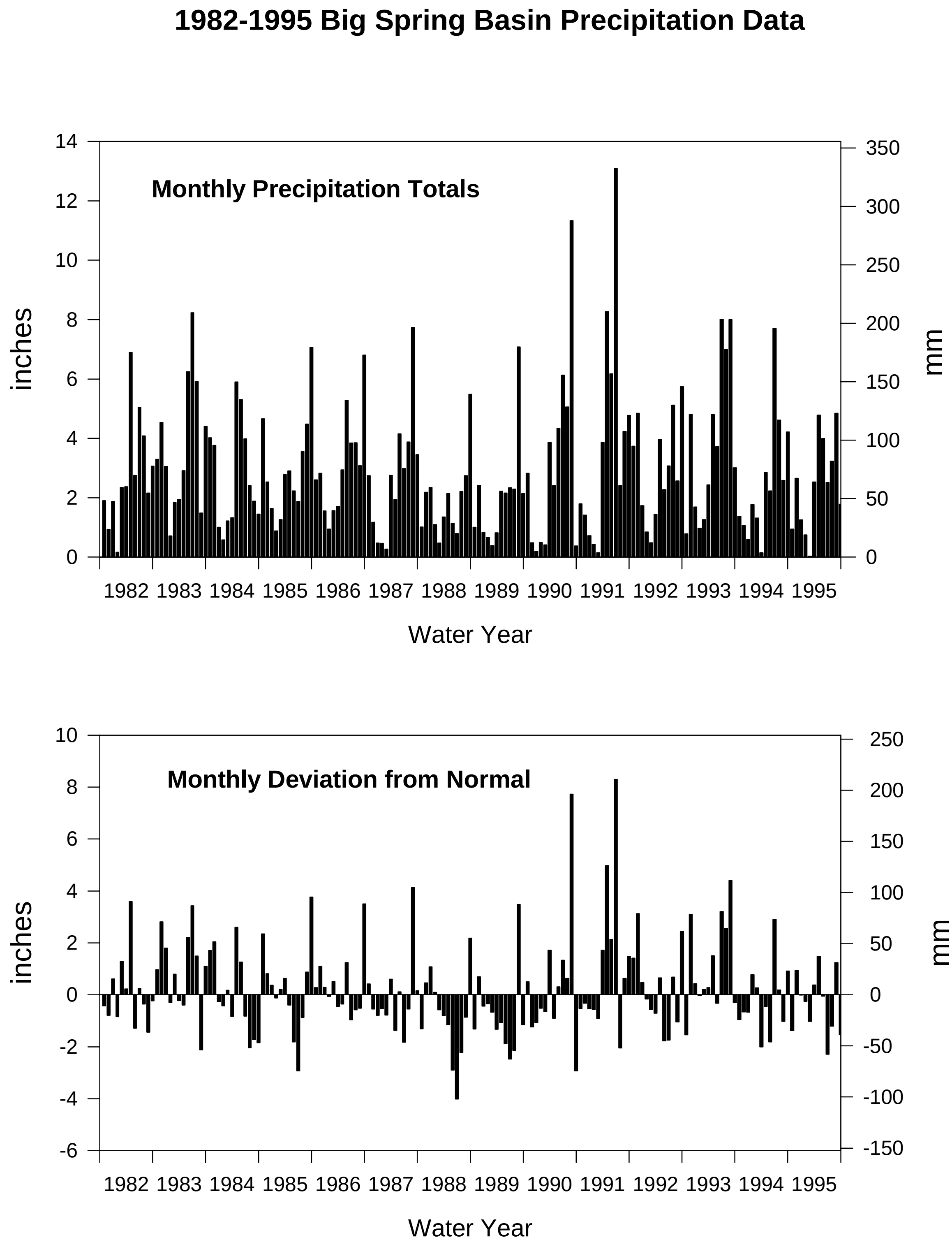


Figure 18. A) Monthly precipitation totals and B) departure from normal for the Big Spring basin, for WYs 1982-1995 (Iowa Dept. of Ag. and Land Stewardship, State Climatology Office).

average of 4.80 inches of precipitation for the 1951-1980 period. However, for WYs 1985-1989, either August, or September were the wettest months (Hallberg et al., 1989).

Precipitation patterns began changing during the spring of WY 1990. Precipitation for WY 1990 was 37.87 inches, or 4.9 inches above the long term average. Monthly precipitation was above normal during March, and from May through August. The wettest months were August and June, and the driest months were December and September. The two greatest single rainfalls of the water year occurred on August 24 and 25, with 1.82 and 1.74 inches of precipitation. The events caused extensive flooding throughout the Turkey River Valley.

Water Year 1991 had the greatest mean annual precipitation during the WY 1982-1995 period. Precipitation for the water year was 47.28 inches, or 143% of the long term average. Rainfall totals were slightly below normal from October through February, far below normal during July, and far above average from March through June. The greatest monthly precipitation, 13.09 inches, occurred in June, and was equal to 273% of the long-term average for June. The largest single rainfall (local reports of 11 to 13 inches) occurred on June 14, and caused extensive flooding throughout the Big Spring basin area.

The precipitation for WY 1992 was 35.74 inches, or 2.8 inches above the long term average. The precipitation during WY 1992 was more evenly distributed than in 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.

Water Year 1993 had the second-greatest annual precipitation during WYs 1982-1995. The mean annual precipitation of 46.47 inches was 141% of the long-term average. Rainfall was below normal during October, January, May and September, and well above normal in November, and from June through August. Approximately half of the annual precipitation occurred during the June through August period. October was the driest month of the water year, with 0.78 inches of precipitation, and June and August were the wettest months, with 8.01 and 8.00 inches of precipitation.

Water years 1994 and 1995 were relatively dry years with 30.42 inches, or 92% of normal, and 29.28 inches, or 89% of the long-term normal precipitation respectively. Water Year 1994 had the fourth-smallest annual precipitation total, and WY 1995 had the third-smallest annual precipitation total during WYs 1982-1995. The precipitation that occurred during WYs 1994 and 1995 was unevenly distributed. The wettest months of WY 1994 were January, February, June, and September, and the driest months were December, March, and May. The monthly precipitation for January and June, 1.77 and 7.70 inches, were 177 and 160% of normal, and the monthly precipitation for March, 0.14 inches, was 7 % of normal. During WY 1995, the wettest months were November, March, April, and August, and the driest months were February, June, and September. The monthly precipitation totals for November, April, and August, 2.65, 4.78, and 4.84 inches, were 154, 145,

Table 5. Mean annual precipitation, departure from normal, and percentage of normal; Big Spring basin for water years 1982-1995.

Water Year	Basin precipitation inches	Departure from normal inches	% of normal
1982	33.56	0.59	102
1983	44.53	11.56	135
1984	32.81	-0.16	100
1985	35.84	2.87	109
1986	36.96	3.99	112
1987	31.98	-0.99	97
1988	22.94	-10.03	70
1989	24.32	-8.65	74
1990	37.87	4.90	115
1991	47.28	14.31	143
1992	35.74	2.77	108
1993	46.47	13.50	141
1994	30.42	-2.55	92
1995	29.28	-3.69	89

and 134% of normal. The driest month of WY 1995, February, only had 0.03 inches of precipitation, or 3% of the monthly normal. As previously mentioned, the March through June period is important for groundwater recharge within the basin due to the typically low evapotranspiration and wet antecedent conditions. Precipitation totals were below normal during the March through June periods of WYs 1994 and 1995.

Previous reports (Rowden et al., 1995b, Liu et al., 1997) have shown that the annual groundwater discharge from Big Spring usually parallels basin precipitation. However, antecedent conditions, including the volume of groundwater in storage within the basin and groundwater levels and soil moisture conditions in the shallow groundwater system can cause time lags between changes in annual precipitation and changes in annual discharge as storage in the Galena aquifer is slowly depleted or replenished. Discharge rates at Big Spring reflect the effects of recharge to the Galena aquifer and to the shallow groundwater system within the Big Spring basin. The discharge rates at monitoring sites within the Bugenhagen sub-basin are affected by recharge and storage within the shallow groundwater system of the sub-basin. During WYs 1982-1995, basin precipitation has varied from 22.94 inches in WY 1988 to 47.28 inches in WY 1991 and groundwater discharge from Big Spring has ranged between 12,672 acre-feet during WY 1989 and 58,186 acre feet in WY 1993 (Rowden et al., 1995b). While annual precipitation totals during WYs 1992 and 1993 were similar to totals during WYs 1990 and 1991, the annual groundwater and surface-water discharges from most monitoring sites were much lower during WYs 1990 and 1991 than during WYs 1992 and 1993. The lower discharge rates during WYs 1990 and 1991 resulted in part, from decreases in groundwater in storage during WYs 1988 and 1989. Water years 1990 and 1991 were the two wettest consecutive years since monitoring began at Big Spring, but they followed the driest consecutive two-year period in the state's history.

Hydrology and Transport of Agricultural Contaminants

Previous reports (Hallberg et al., 1983, 1984a, 1985, Libra et al., 1986, 1987) have documented the relationship between recharge mechanisms and the concentrations of agricultural contaminants in Big Spring basin groundwater. The parallel responses in water quality changes over time between tile-line effluent and groundwater at Big Spring illustrate that tile line data can be used as an indication of the behavior of the shallow soil-groundwater system. The species and concentrations of nitrogen and pesticides in the tile-line discharge (for those without surface water influences) are indicative of the water quality routinely found in deeper groundwater.

The soil-tile line system is a direct small-scale analogy of a karst-groundwater system. Both systems have at least three flow components (Libra et al., 1984). The soil matrix (and aquifer matrix) is marked by microporosity and low interstitial hydraulic conductivity. The second component, the tile lines, are analogous to large conduits in a karst-carbonate aquifer flow system; they are a zone of very rapid groundwater movement which draws down the potentiometric surface and induces water flow towards and into them. Tile lines with tile-outlet terraces allow surface water through tile inlets into the flow system during runoff, much like a sinkhole. The third, and probably most dominant component of the flow system is intermediate between these end members and includes the zones of macropores with intermediate porosity's and conductivity's. The movement and quality of water transmitted through the tile will differ depending on the flow components that dominate at a given time and the type of recharge involved.

Infiltration and runoff recharge have unique chemical signatures (Hallberg et al., 1983, 1984a). 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). Infiltration recharge is enriched in nitrate and other chemicals that are mobile in soil, relative to runoff recharge; particularly runoff de-

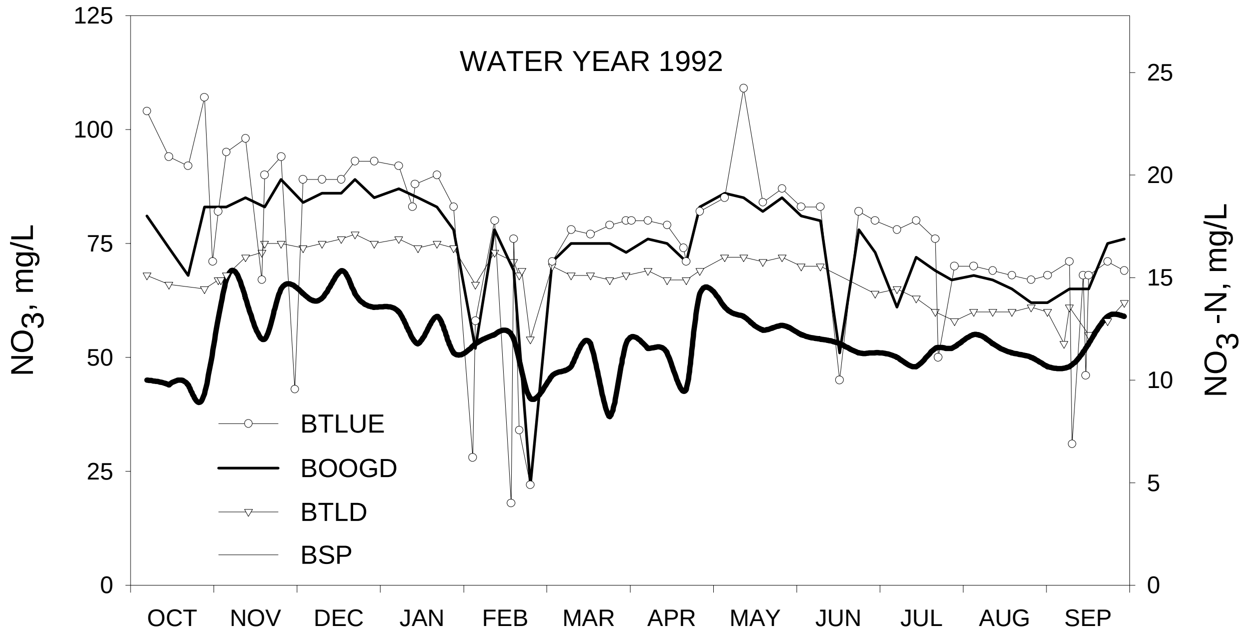


Figure 19. Graph of nitrate concentrations from monitoring sites BTLUE, BOOGD, BTLD, and Big Spring (BSP) during WY 1992.

rived from snowmelt. Runoff recharge has lower concentrations of such compounds, but is enriched in herbicides and other chemicals with low soil mobility. In tile systems with inlets, following significant precipitation or snowmelt, runoff recharge is intercepted by the tile inlets, and 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. During prolonged recession periods, nitrate and herbicide (particularly atrazine) concentrations usually show a slow, steady decline. This decline likely occurs as an increasing percentage of the discharge is from the less transmissive parts of the flow system. In general, low discharge periods are accompanied by low contaminant concentrations, yielding small total contaminant loads. Concentrations are generally higher during periods of higher discharge, yielding greater loads, related to both the increased volumes of water and greater concentrations.

Prior to the installation of tile-outlet terraces in the Bugenhagen sub-basin BTLD, BTLUE, and BTLUW all discharged groundwater. The installation of the tile-outlet terraces in the upper sub-basin changed the nature of the water flux and tile effluent of BTLUE and BTLUW. During dry periods the tiles yield shallow groundwater, but following significant precipitation, the tile intakes direct surface runoff into the tiles mixing it with the groundwater.

The nested monitoring network design used in the Big Spring basin allows water and chemical responses to recharge events to be tracked through the hydrologic system, from the soil zone beneath individual fields to the basin water outlets (Hallberg et al., 1984a). The design also allows integration and comparison of water quality responses at different scales to assess effects of landuse and landscape-ecosystem processes. Figure 19 compares nitrate concentrations from tile lines BTLD and BTLUE with nitrate concentrations from BOOGD, the surface water outlet for the sub-basin, and Big Spring (BSP), the basin's groundwater discharge point, during WY 1992

Similar seasonal trends, and pronounced short-term changes in nitrate concentrations, are seen at all four monitoring sites. The pronounced short-term changes in nitrate concentrations are responses to significant recharge. Figure 19 illustrates how a recharge response at the water table beneath row-cropped fields and permanent pasture is propagated through the hydrologic system. Figure 19 also shows that nitrate concentrations from BTLD fluctuate much less than nitrate concentrations from BTLUE, where surface water is intercepted by tile inlets during runoff. During WY 1992, nitrate concentrations from BTLD varied from 53 to 77 mg/L, and were typically 15 to 20 mg/L lower than nitrate concentrations from the more intensely fertilized fields of corn in the upper Bugenhagen sub-basin. Infiltrating recharge water from individual field sites delivers high concentrations of nitrate to shallow groundwater, and this shallow groundwater transports the nitrate laterally to streams and downward to the Galena aquifer and Big Spring. Although the discharge and chemical responses are not as great or immediate at the largest scales monitored, they clearly occur and the nested monitoring design allows responses to recharge events to be followed through the hydrologic system.

Tables 6-37 and figures 20-29 summarize the precipitation, and water-quality data for tile-line sites BTLD, BTLUE, and BTLUW and surface-water site BOOGD during WYs 1982-1995. Contaminant loading data are available for site BOOGD for WYs 1986-1992, for site BTLD for WYs 1987-1994, and for BTLUE, and BTLUW, loading data are available for WYs 1987-1995.

Water Year 1986

Discharge Monitoring

Table 6 summarizes the discharge, water quality and chemical-load data for surface-water site BOOGD and Figure 20 shows atrazine and nitrate concentrations for sites BTLUE, BTLUW, BOOGD, and BTLD, and mean daily discharge for site BOOGD for WY 1986. Continuous daily

Table 6. Summary of water and chemical discharge for BOOGD for partial WY 1986; 05/13/86-09/30/86. (Discharge data are from the U.S. Geological Survey, W.R.D., IA Dist.)

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	

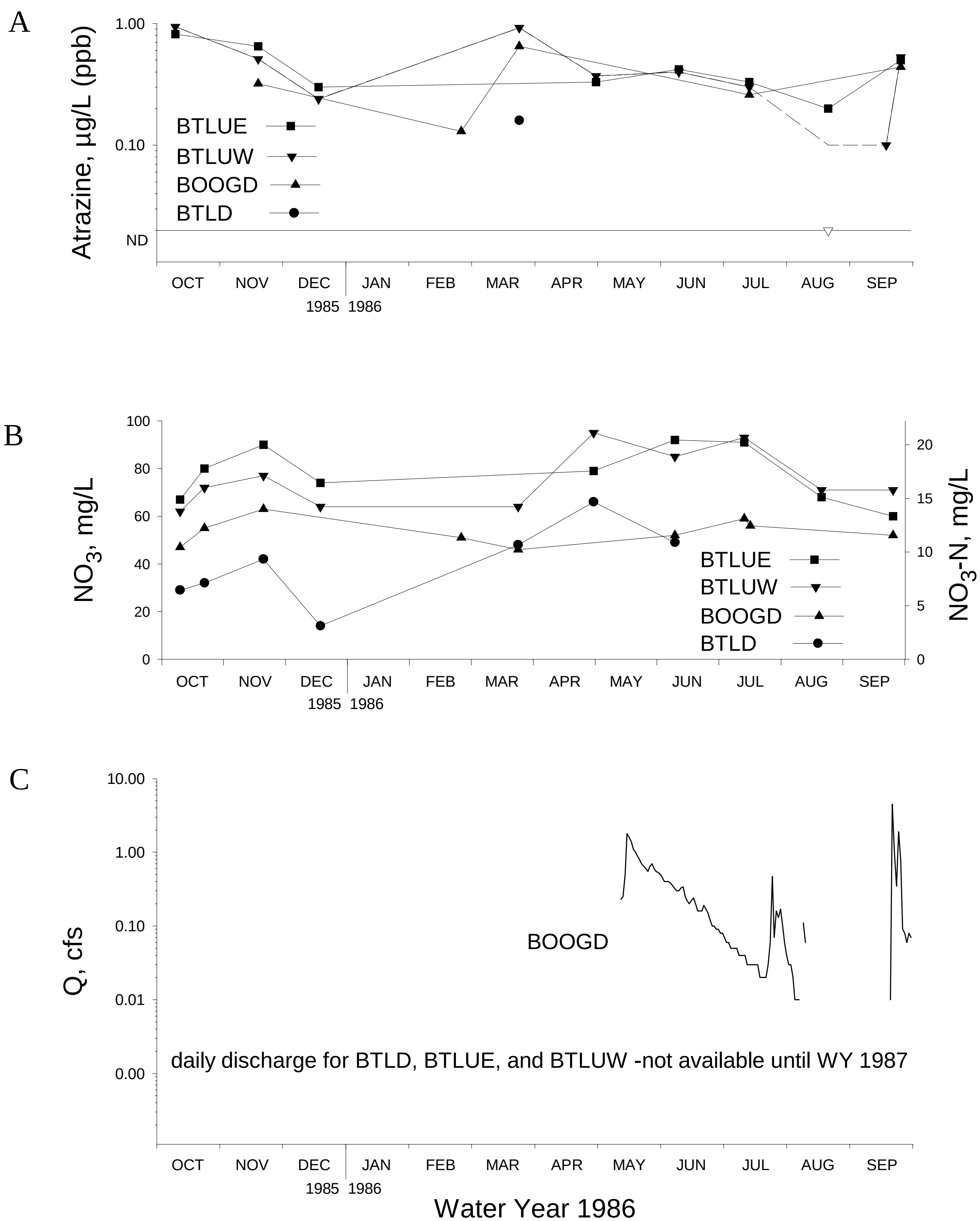


Figure 20. A) Atrazine and B) nitrate concentrations at BTLUE, BTLUW, BOOGD and BTLD, and C) surface-water discharge (Q) at BOOGD for WY 1986. (Discharge data for BOOGD are from the U.S. Geological Survey, W.R.D., IA Dist.)

discharge data for site BOOGD begins May 13, 1986, for sites BTLUE and BTLUW continuous discharge data begins February 10, 1987, and for BTLD discharge data begins February 25, 1987. Since the discharge data for these sites were incomplete, the data in tables 6 and 8-10 were computed for partial water years.

Precipitation during the water year was 36.96 inches, approximately four inches above the long-term average. The precipitation from May 13 through September 30 was 22.43 inches, or 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 hydrograph for BOOGD is incomplete (Fig. 20), the discharge record from Big Spring for WY 1986 was dominated by a very 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 greatest instantaneous discharge (in excess of 360 cubic feet per second [cfs]) observed at Big Spring during WYs 1984-1986 (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. Most monitoring sites in the Big Spring basin exhibited gradually declining flow rates, until late September. In September, intense rainfalls generated significant runoff-recharge and a small amount of infiltration recharge as evidenced by the rapid increase and decrease in discharge at BOOGD.

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 6). 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. At Big Spring the annual discharge was 30,290 ac-ft, or 15% of the annual precipitation, at an average daily discharge rate of 42.0 cfs (Hallberg et al., 1989).

Nitrate Monitoring

Table 6 summarizes annual data for BOOGD and Figure 20 summarizes the nitrate analyses for BOOGD, BTLUE, BTLUW, and BTLD during WY 1986. During WY 1986, nitrate samples were taken at all sites on a monthly basis.

Table 6 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 BOOGD for the water year was 50.0 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 the nitrate concentration at BOOGD was 47 mg/L (10.4 mg/L as NO_3-N; Fig. 20). Minor recharge resulted in a general rise in concentrations to 63 mg/L (14.0 mg/L as NO_3-N) in late November. The nitrate concentration was 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 nitrate concentration at BOOGD was 52 mg/L (11.6 mg/L as NO_3-N) four days after significant runoff in late September.

The monthly fw mean nitrate concentration increased from 46.7 mg/L (10.4 mg/L as NO_3-N) in May, to 57.0 mg/L (12.7 mg/L as NO_3-N) in July, then decreased to 52.0 mg/L (11.6 mg/L as NO_3-N), in September. 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 smallest monthly nitrate-nitrogen discharge, 27 pounds, and the smallest monthly surface-water discharge, 0.8 ac-ft, occurred during August.

At BTLUE, nine samples were analyzed for nitrate, and six samples were analyzed for N-series during the water year. Near the beginning of the water year, the nitrate concentration at BTLUE was 67 mg/L (14.9 mg/L as NO_3-N; Fig. 20). The concentration increased to 90 mg/L (20.0 mg/L as NO_3-N) in late November, then declined to 74 mg/L (16.4 mg/L as NO_3-N) in mid-December. The nitrate concentration peaked at 92 mg/L (20.4 mg/L as NO_3-N) in June, then generally declined through September.

At BTLUW, ten samples were analyzed for nitrate, and seven samples were analyzed for N-series during WY 1986. Nitrate concentrations showed trends similar to BTLUE, with concentrations being lower during the first half of the year, and slightly higher during the last three months of the water year. At BTLUW, concentrations decreased slightly from April to May, as concentrations at BTLUE increased slightly.

Seven samples from BTLD were analyzed for nitrate, and five samples were analyzed for N-series during WY 1986. Nitrate concentrations from BTLD remained lower than concentrations at BTLUE and BTLUW, and were usually lower than concentrations from BOOGD during the water year. The smallest concentration recorded during the water year, 14 mg/L (3.1 mg/L as NO_3-N), occurred in December, and the greatest concentration recorded, 66 mg/L (14.7 mg/L as NO_3-N), occurred during May.

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 greatest monthly fw mean, 49.0 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.

Pesticide Monitoring

Table 6 summarizes annual data for BOOGD and Figure 20 summarizes the results of pesticide monitoring at BOOGD, BTLUE, BTLUW, and BTLD during WY 1986. Samples for pesticide analyses were 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 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 41.3 grams of atrazine were discharged, at a fw mean concentration of 0.50 µg/L.

The atrazine concentration was 0.32 µg/L in November and decreased to 0.13 µg/L in late February (Fig. 20). Snowmelt and rainfall in March generated runoff, and the atrazine concentration 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. The atrazine concentration was 0.26 µg/L in mid-July and 0.44 µg/L in late September, following significant recharge.

The monthly fw mean atrazine concentration 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. August had the smallest monthly atrazine output, 0.39 grams, and smallest monthly surface-water discharge, 0.83 ac-ft, during the water year. May had the greatest monthly atrazine output, 23 grams, and the greatest 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

BTLUE were analyzed for pesticides. All of the samples collected contained detectable levels of atrazine. The atrazine concentration declined from 0.82 µg/L in October to 0.30 µg/L in December (Fig. 20). The concentration increased from 0.33 µg/L in May to 0.42 µg/L in June, then decreased to 0.20 µg/L in August. Near the end of the water year the atrazine concentration was 0.50 µg/L. Atrazine was the only pesticide detected at BTLUE during the water year.

At BTLUW, nine samples were analyzed for pesticides during the water year. Eight of the samples collected contained detectable levels of atrazine. Atrazine concentrations declined from 0.94 µg/L in October to 0.24 µg/L in December (Fig. 20). Concentrations increased to 0.92 µg/L in March, then generally decreased to non-detectable levels (<0.10 µg/L) in August. The atrazine concentration increased to 0.10 µg/L in mid-September, then near the end of the water year the atrazine concentration increased to 0.53 µg/L. Atrazine was the only pesticide detected at BTLUW during the water year.

At BTLD, only one sample was analyzed for pesticides during WY 1986. The atrazine concentration of this sample, taken on March 25, was 0.16 µg/L. No other pesticides were detected in this sample.

At Big Spring, 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.

Water Year 1987

Discharge Monitoring

Tables 7-10 and Figure 21 summarize the discharge, water-quality and chemical-load data for surface-water site BOOGD and tile-line sites BTLUE, BTLUW and BTLD during WY 1987. Continuous daily discharge data for sites BTLUE and BTLUW begins February 10, 1987, and for BTLD discharge data begins February 25, 1987. Since the discharge data for these sites are incom-

Table 7. Annual summary of water and chemical discharge for BOOGD for WY 1987. (Discharge data are from the U.S. Geological Survey, W.R.D., IA Dist.)

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 (812 mm)	
Discharge	3.57 inches (90.7 mm)	
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	

plete, the data in tables 8-10 are computed for partial water years. In Figure 21, note the increase in scale on the atrazine plot relative to WY 1986.

The annual precipitation during WY 1987 was 31.98 inches. The precipitation from February 10 through September 30 was 26.90 inches, and the precipitation from February 25 through September 30 was 26.87 inches. These totals equaled 84% of the annual total. Although the annual basin precipitation for WY 1987 was only an inch below normal, the distribution of precipitation along with antecedent conditions led to limited groundwater recharge during the water year. From WY 1984-1987 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 and Bugenhagen subbasin. During WY 1987, precipitation totals were below normal during most of the growing season and greater than normal during the fall. Approximately 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, 16%, below normal.

The annual discharge for BOOGD during WY 1987 was 219 ac-ft, at an average daily discharge rate of 0.30 cfs (Table 7). 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 BTLUE during the partial water year was 26.5 ac-ft, at an average daily rate of 0.037 cfs (Table 8). This discharge was equivalent to 5% of the precipitation during February 10 through September 30. At BTLUW, the annual discharge was 33.6 ac-ft and the average daily rate equaled 0.046 cfs (Table 9). During the partial WY 1987, the discharge from BTLUW was equivalent to 13% of the precipitation. The discharge for BTLD during the water year was 5.6 ac-ft, at an average daily rate of 0.008 cfs

Table 8. Summary of water and chemical discharge for BTLUE for partial WY 1987; 02/10/87-09/30/87.

DISCHARGE - Partial Water Year		
Total		
acre-feet	26.5	
millions cf	1.15	
millions cm	0.033	
Average		
cfs	0.037	
cms	0.001	
mg/d	0.024	
gpm	16.6	
PRECIPITATION AND DISCHARGE		
	Partial Water Year	
Precipitation	26.90 inches (683.3 mm)	
Discharge	1.27 inches (32.3 mm)	
Discharge as % of precipitation	5%	
NITRATE DISCHARGE - Partial Water Year		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	72.0	16.0
Mean of analyses	71.1	15.8
	NO_3-N output	**Total N output**
lbs - N	1,152	1,175
kg - N	523	533
lbs - N/acre	4.6	4.7
ATRAZINE DISCHARGE - Partial Water Year		
Concentration - µg/L		
Flow-weighted mean	0.34	
Mean of analyses	0.49	
Total output		
lbs	0.024	
g	11.0	

Table 9. Summary of water and chemical discharge for BTLUW for partial WY 1987; 02/10/87-09/30/87.

DISCHARGE - Partial Water Year	
Total	
acre-feet	33.6
millions cf	1.46
millions cm	0.041
Average	
cfs	0.046
cms	0.001
mg/d	0.030
gpm	20.6

PRECIPITATION AND DISCHARGE	
Partial Water Year	
Precipitation	26.90 inches (683.3 mm)
Discharge	3.48 inches (88.4 mm)
Discharge as % of precipitation	13%

NITRATE DISCHARGE - Partial Water Year		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	63.9	14.2
Mean of analyses	57.4	12.8
	NO_3-N output	**Total N output**
lbs - N	1,296	1,354
kg - N	588	614
lbs - N/acre	11.2	11.6

ATRAZINE DISCHARGE - Partial Water Year	
Concentration - µg/L	
Flow-weighted mean	0.35
Mean of analyses	0.82
Total output	
lbs	0.032
g	14.5

(Table 10). This discharge was equivalent to 14% of the precipitation that occurred from February 25 through September 30. At Big Spring the annual discharge was 25,554 ac-ft, or 14% of the annual precipitation, at an average daily discharge rate of 35.4 cfs (Hallberg et al., 1989).

The hydrograph for BOOGD for WY 1987 shows minor recharge in early October, followed by generally receding discharge through the end of the month. Discharge remained near 0.01 cfs through mid-November, then increased to 0.10 cfs on November 17 following minor recharge (Fig. 21). BOOGD went dry on November 27 and remained dry during most of December and January. Discharge resumed at BOOGD on February 6. Snowmelt and rainfall in February, early March and late April provided runoff and minor recharge, generating discharge at BTLUE, BTLUW and BTLD. 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. In August and late September, intense rainfall generated significant runoff within both the Bugenhagen sub-basin and the Big Spring basin.

The mean daily discharge from tile line BTLUE ranged from 0.31 cfs on March 4 to 0 cfs on September 13-16. At site BTLUW, the greatest mean daily discharge during the water year, 0.55 cfs, also occurred on March 4, and the only day with no discharge from BTLUW occurred on September 16. The greatest mean daily discharge recorded at BTLD during the water year, 0.064 cfs, occurred on February 25. Discharge ceased at BTLD from May 20-23, and from May 28 through August 15, and again from September 7-16.

Nitrate Monitoring

Tables 7-10 and Figure 21 summarize the nitrate analyses from BOOGD, BTLUE, BTLUW and BTLD 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 7). 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 the nitrate concentration at BOOGD was 54 mg/L (12.0 mg/L as NO_3-N; Fig. 21). The concentration declined to 41 mg/L (9.1 mg/L as NO_3-N) following minor runoff recharge from snowmelt in February. The nitrate concentration was 43 mg/L (9.6 mg/L as NO_3-N) near the end of March, as discharge continued to recede. Rainfall in April generated minor runoff and the nitrate concentration decreased to 35 mg/L (7.8 mg/L as NO_3-N), one day before the maximum daily discharge for the month occurred on April 22. Six days later, the nitrate concentration increased to 57 mg/L (12.7 mg/L as NO_3-N), as the percentage of groundwater baseflow constituting the discharge increased. Nitrate concentrations remained near 45 mg/L (10.0 mg/L as NO_3-N) throughout May as discharge receded. From May through mid-June, both discharge and nitrate concentrations generally declined. Precipitation during the remainder of the water year caused significant fluctuations in both discharge and nitrate concentrations. Minor rainfall 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). The nitrate concentration increased to 47 mg/L (10.4 mg/L as NO_3-N) on July 27, three days after the maximum daily discharge for the month occurred. The smallest nitrate concentration sampled during the water year, 3 mg/L (0.7 mg/L as NO_3-N), occurred in early August. The

Table 10. Summary of water and chemical discharge for BTLD for partial WY 1987; 02/25/87-09/30/87.

DISCHARGE - Partial Water Year		
Total		
acre-feet	5.6	
millions cf	0.24	
millions cm	0.007	
Average		
cfs	0.008	
cms	0.0002	
mg/d	0.005	
gpm	3.6	

PRECIPITATION AND DISCHARGE		
	Partial Water Year	
Precipitation	26.87	inches (682.5 mm)
Discharge	3.73	inches (94.7 mm)
Discharge as % of precipitation	14%	

NITRATE DISCHARGE - Partial Water Year		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	47.0	10.5
Mean of analyses	45.2	10.0
	NO_3-N output	**Total N output**
lbs - N	159	168
kg - N	72.1	76.2
lbs-N/acre	8.8	9.3

ATRAZINE DISCHARGE - Partial Water Year	
Concentration - µg/L	
Flow-weighted mean	0.01
Mean of analyses	0.04
Total output	
lbs	0.0002
g	0.094

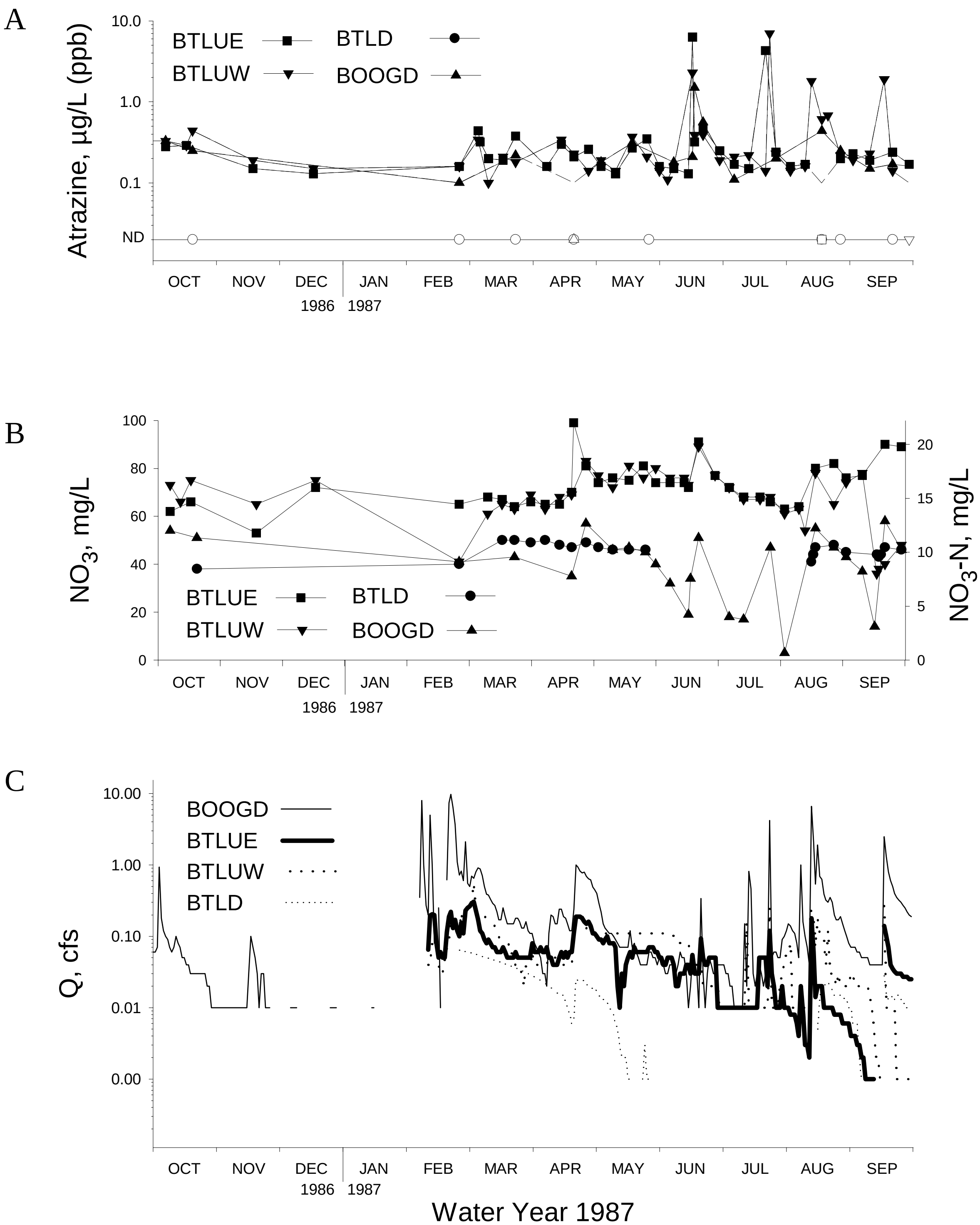


Figure 21. A) Atrazine and B) nitrate concentrations, and C) groundwater and surface-water discharge (Q) at BTLUE, BTLUW, BOOGD and BTLD for WY 1987 (note the increase in scale on the atrazine plot relative to WY 1986). (Discharge data for BOOGD are from the U.S. Geological Survey, W.R.D., IA Dist.)

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

Monthly fw mean nitrate concentrations from BOOGD varied from 53.1 mg/L (11.8 mg/L as NO_3-N) in October to 30.6 mg/L (6.8 mg/L 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 43% of the annual nitrate-nitrogen output and 45% of the annual surface-water discharge.

During WY 1987, forty-four samples from BTLUE were analyzed for nitrate, and thirty-seven samples were analyzed for N-series. The annual fw mean nitrate concentration for BTLUE was 72.0 mg/L (16.0 mg/L as NO_3-N; Table 8). The nitrate-nitrogen output for the water year was 1,152 pounds, which is equivalent to 4.6 lbs-N/acre and the total nitrogen output (including organic- and ammonia-nitrogen) was 1,175 pounds, which is equivalent to 4.7 lbs-N/acre within the 250 acre drainage area of BTLUE.

From the beginning of the water year the nitrate concentration at BTLUE increased from 62 mg/L (13.8 mg/L as NO_3-N) on October 7 to 66 mg/L (14.6 mg/L as NO_3-N) on October 17, then decreased to 53 mg/L (11.8 mg/L as NO_3-N) in mid-November before increasing to 72 mg/L (16.0 mg/L as NO_3-N) in mid-December. Snowmelt in late February generated minor recharge and the nitrate concentration decreased to 65 mg/L (14.4 mg/L as NO_3-N) as discharge was receding. From late February, nitrate concentrations remained relatively steady until April 22 when the concentration increased to 99 mg/L (22.0 mg/L as NO_3-N) during a discharge event. This was the greatest nitrate concentration reported from BTLUE during the water year. From late April, nitrate concentrations remained around 75 mg/L (16.7 mg/L as NO_3-N) until June 22 when the concentration increased to 91 mg/L (20.2 mg/L as NO_3-N) following an event on June 21. From late June, nitrate concentrations generally declined through mid-July. The smallest concentration sampled during the water year, 21 mg/L (4.7 mg/L as NO_3-N), occurred on July 14 at 21:45. This sample does not appear on the nitrate plot since it was part of a multiple sampling, and only the greatest concentrations of multiple daily samplings are plotted. Rainfall in August and September generated both runoff and infiltration recharge, which were followed by increases in nitrate concentrations in the first post-event samples. The nitrate concentration was 90 mg/L (20.0 mg/L as NO_3-N) near the end of the water year.

Monthly fw mean nitrate concentrations for BTLUE varied from 65.0 mg/L (14.4 mg/L as NO_3-N) in February to 89.4 mg/L (19.9 mg/L as NO_3-N) in September. Monthly nitrate-nitrogen output varied from 247 pounds in March to 49.4 pounds in August. The nitrate-nitrogen output during March was equivalent to 21% of the annual total and the nitrate-nitrogen output during August was equivalent to 4% of the annual total. The monthly groundwater discharge for March equaled 23% of the annual total and the groundwater discharge for August equaled 4% of the annual total.

Fifty-one samples from BTLUW were analyzed for nitrate, and forty-eight samples were analyzed for N-series during the water year. The annual fw mean nitrate concentration was 63.9 mg/L (14.2 mg/L as NO_3-N; Table 9). The total nitrate-nitrogen output for the water year was 1,296 pounds and the total nitrogen output was 1,354 pounds. Within the 116-acre drainage area of BTLUW, the nitrate-nitrogen output was equivalent to 11.2 lbs-N/acre and the total nitrogen output was equivalent to 11.6 lbs-N/acre.

The discharge and nitrate plots for BTLUW show the same general trends as the plots for BTLUE, although nitrate concentrations at BTLUW were lower during February and September (Fig. 21). This difference may result from BTLUW having a larger component of surface water in the tile effluent from runoff during these periods. The greatest nitrate concentration from BTLUW during the water year, 89 mg/L (19.8 mg/L as NO_3-N), occurred on June 22 and the smallest concentration sampled during the water year, 8 mg/L (1.8 mg/L as NO_3-N), occurred during peak discharge of an event that occurred on September 17.

Monthly fw mean nitrate concentrations for BTLUW varied from 41.8 mg/L (9.3 mg/L as NO_3-N) in February to 78.2 mg/L (17.4 mg/L as NO_3-N) in June. Monthly nitrate-nitrogen discharge varied from 313.8 pounds in May to 29.9 pounds in September. The nitrate-nitrogen discharge during May was equivalent to 27% of the annual total and the nitrate-nitrogen discharge during September was equivalent to 3% of the annual total. The monthly groundwater discharge for March equaled 25% of the annual total and the groundwater discharge for September equaled 3% of the annual total.

At BTLD, twenty-eight samples were analyzed for nitrate, and fifteen samples were analyzed for N-series during the water year. The annual fw mean nitrate concentration was 47.0 mg/L (10.5 mg/L as NO_3-N; Table 10). The total nitrate-nitrogen output for the water year was 159 pounds and the total nitrogen output was 168 pounds. Within the 18-acre drainage area of BTLD, the nitrate-nitrogen output was equivalent to 8.8 lbs-N/acre and the total nitrogen output was equivalent to 9.3 lbs-N/acre.

Nitrate concentrations from BTLD were more stable, and much lower than concentrations from BTLUE and BTLUW. The smallest concentration from BTLD, 38 mg/L (8.4 mg/L as NO_3-N), was sampled on October 20, and the greatest concentration sampled, 50 mg/L (11.1 mg/L as NO_3-N), occurred on March 18, March 24, and April 8. The more stable and lower nitrate concentrations from BTLD are to be expected. Since BTLD has no surface inlets to allow direct surface-water runoff to enter the tile line, the composition of the tile effluent does not change as quickly as the effluent from BTLUE and BTLUW, which do have surface tile inlets. The lower nitrate concentrations are the result of the much lower nitrogen fertilizer rates applied to the pasture that BTLD drains, relative to the application rates used on the corn crops above BTLUE and BTLUW.

Monthly fw mean nitrate concentrations from BTLD varied from 40.0 mg/L (8.9 mg/L as NO_3-N) in February to 48.6 mg/L (10.8 mg/L as NO_3-N) in April. Although monthly fw mean concentrations were relatively constant, variations in monthly groundwater discharge caused large variations in monthly nitrate-nitrogen output. Monthly nitrate-nitrogen output varied from 78.8 pounds in March to 9.0 pounds in May. March accounted for 50% of the annual nitrate-nitrogen output and 49% of the annual groundwater discharge, while May accounted for 6% of the annual nitrate-nitrogen output and 6% of the annual groundwater total.

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.

Pesticide Monitoring

Tables 7-10 and Figure 21 summarize the results of pesticide monitoring at BOOGD, BTLUE, BTLUW and BTLD 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 46.2 grams 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. The atrazine concentration decreased from 0.33 μg/L on October 7 to 0.25 μg/L on October 20 (Fig. 21). Concentrations increased from 0.10 μg/L in late February to 0.22 μg/L in late March. The atrazine concentration was below detection limits on April 21, before increasing to 0.31 μg/L in May. The greatest atrazine concentration reported during the water year, 1.50 μg/L, was sampled on June 18, the day with the greatest rainfall during the month. The next greatest concentration reported, 0.44 μg/L, occurred in mid-August following rainfall. Atrazine concentrations remained <0.20 μg/L in September.

Monthly fw mean atrazine concentrations from BOOGD decreased from 0.31 μg/L in October to 0.10 μg/L in January and February. The smallest monthly fw mean, 0.08 μg/L, occurred in April, and the greatest fw mean atrazine concentration, 0.42 μg/L, occurred in June. The smallest monthly atrazine output, 0.01 grams, and surface-water discharge, 0.1 ac-ft, occurred during January, and the greatest monthly atrazine output, 16 grams, and second-greatest surface-water discharge, 35 ac-ft, occurred during August, and accounted for 35% of the annual atrazine output and 16% of the annual surface-water discharge.

Other pesticides detected at BOOGD during the water year include cyanazine in two, or 12%, of the samples collected, and alachlor in one, or 6%, of the samples collected. The greatest concentrations 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.

Forty samples from BTLUE were analyzed for pesticides during WY 1987. Thirty-nine, or 98%, of the samples contained detectable levels of atrazine (>0.10 μg/L). The annual fw mean atrazine concentration was 0.34 μg/L and the annual atrazine discharge was 11.0 grams. Atrazine concentrations at BTLUE declined from 0.29 μg/L in mid-October to 0.13 μg/L in mid-December (Fig. 21). From December to mid-June, concentrations ranged from 0.44 μg/L to 0.13 μg/L. The greatest atrazine concentration recorded at BTLUE during the water year, 6.30 μg/L, occurred on June 17 during minor runoff. The atrazine concentration decreased to 0.32 μg/L on the following morning, then increased to 0.48 μg/L on June 22, following a larger recharge event on June 21. Concentrations declined to 0.15 μg/L in mid-July, then increased to 4.30 μg/L on July 22 during minor recharge. Atrazine concentrations decreased to non-detectable levels (>0.40 μg/L) on August 18, then ranged from 0.24 μg/L to 0.17 μg/L during the remainder of the water year.

Monthly fw mean atrazine concentrations from BTLUE varied from 0.18 μg/L in February to 1.26 μg/L in July. March had the greatest monthly atrazine output, 2.69 grams, and the greatest groundwater discharge, 6.24 ac-ft, which accounted for 24% of the annual atrazine output and 24% of the annual discharge.

Other pesticides detected at BTLUE during the water year include cyanazine in four, or 10%, of the samples collected, and alachlor in two, or 5%, of the samples collected. The maximum concentrations of pesticides detected during the water year include atrazine at 6.30 μg/L, cyanazine at 3.70 μg/L, and alachlor at 3.40 μg/L. All maximum concentrations occurred on June 17. Cyanazine was detected during June and July, and alachlor was detected only during June. Atrazine was not detected in one sample collected in August.

During WY 1987, fifty-four samples from BTLUW were analyzed for pesticides. Fifty-two, or 96%, of the samples contained detectable levels of atrazine (>0.10 μg/L). The annual fw mean atrazine concentration was 0.35 μg/L and the annual atrazine output was 14.5 grams. Atrazine concentrations at BTLUW showed trends similar to concentrations sampled at BTLUE. The greatest atrazine concentration sampled at BTLUW during the water year, 7.00 μg/L, occurred on July 24 during runoff, and the smallest concentration sampled, <0.10 μg/L, occurred on September 29. The next-smallest concentration sampled, <0.50 μg/L, occurred on August 13.

Monthly fw mean atrazine concentrations from

BTLUW ranged from 0.17 μg/L in February to 1.36 μg/L in August, and remained below 0.25 μg/L from March through May. The smallest monthly atrazine output, 0.79 grams, occurred in February, accounting for 5% of the annual total and the greatest monthly atrazine output, 3.26 grams, occurred in August and accounted for 22% of the annual output.

Other pesticides detected at BTLUW during the water year include cyanazine in fifteen, or 28%, of the samples collected and alachlor in four, or 7%, of the samples collected. The greatest concentrations of pesticides detected during the water year included atrazine at 7.00 μg/L, alachlor at 2.10 μg/L, and cyanazine at 1.40 μg/L. The maximum detection for atrazine occurred on July 24, and the maximum detections for cyanazine and alachlor occurred on June 17. Alachlor was detected during June and July, and cyanazine was detected in May, June, July, August, and September.

Eight samples from BTLD were analyzed for pesticides during WY 1987. None of the samples contained detectable levels (>0.10 μg/L) of any pesticides. During the water year a total of 0.094 grams of atrazine were discharged, at a fw mean concentration of 0.01 μg/L. As previously discussed, discharge ceased at BTLD from May 20 through May 23, and from May 28 through August 15, and again from September 7 through September 16. These are periods when pesticides are generally detected at most sites throughout the Big Spring Basin.

August was the only month at BTLD with a fw mean atrazine concentration above the 0.10 μg/L detection limit. The monthly fw mean for August was 0.15 μg/L, and the monthly atrazine output was 0.09 grams. August accounted for the entire annual atrazine output and 9% of the annual surface-water discharge.

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 and October. The monthly fw mean atrazine concentration for October, 0.34 μg/L, was the second greatest during the water year.

Water Year 1988

Discharge Monitoring

Tables 11-14 and Figure 22 summarize the discharge, water quality and chemical-load data for surface-water site BOOGD and tile-line sites BTLUE, BTLUW and BTLD during WY 1988. In Figure 22, note the increase in scale on the nitrate 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 conditions that began in WY 1987 continued through WY 1988, severely limiting surface-water runoff and groundwater recharge within the Bugenhagen sub-basin.

The hydrographs reflect the lack of significant recharge from snowmelt and rainfall during WY 1988 (Fig. 22). 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 minor precipitation, generated runoff, but streams and tile lines returned to baseflow conditions within a few days. The most significant recharge during the water year occurred in early March and was associated with snowmelt rather than rainfall. 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 runoff in April, discharge continued to recede. Discharge ceased at BTLD and BTLUW in May, at BOOGD in late June and at BTLUE in early July. Discharge at other monitoring sites within the Big Spring basin continued to decline until late September. The most intense rainfall during the water year oc-

Table 11. Annual summary of water and chemical discharge for BOOGD for WY 1988. (Discharge data are from the U.S. Geological Survey, W.R.D., IA Dist.)

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 (583 mm)	
Discharge	2.82 inches (71.6 mm)	
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	

curred in late September, but the associated run-off- and infiltration-recharge were too limited to generate discharge at any of the monitoring sites within the Bugenhagen sub-basin.

The mean daily discharge from tile line BTLUE ranged from 1.17 cfs on April 3 to 0 cfs on July 8. No discharge occurred at BTLUE from July 8-10, July 14 through September 21, and from September 23 through January 29. At site BTLUW, the greatest mean daily discharge during the water year, 0.40 cfs, occurred on March 8. Periods with no groundwater discharge from BTLUW include October 15 through December 12, December 16 through January 26, February 7-25, and May 20 through January 29. The greatest mean daily discharge recorded at BTLD during the water year, 0.084 cfs, occurred on April 3. Discharge ceased at BTLD from October 3 through January 31, on February 24, and from May 23 through the entire 1989 WY to August 24 of WY 1990.

The annual surface-water discharge from BOOGD during the water year was 173 ac-ft and the average daily discharge was 0.24 cfs (Table 11). The annual discharge was equivalent to 12% of the annual precipitation. At BTLUE, the annual discharge for WY 1988 was 78.0 ac-ft, at an average daily discharge of 0.108 cfs (Table 12). The annual discharge from BTLUE was equal to 16% of the annual precipitation. The annual discharge for BTLUW was 9.6 ac-ft and the average daily discharge was 0.013 cfs (Table 13). The annual discharge for BTLUW was equivalent to 4% of the annual precipitation. At BTLD, the annual discharge for WY 1988 was 7.7 ac-ft, at an average daily discharge of 0.011 cfs (Table 14). The annual discharge from BTLD was equivalent to 22% of the annual precipitation. At Big Spring the annual discharge for WY 1988 was 26,008 ac-ft, or 20.5% of the annual precipitation, at an average daily discharge rate of 35.8 cfs (Libra et al., 1991).

Nitrate Monitoring

Tables 11-14 and Figure 22 summarize the nitrate analyses from BOOGD, BTLUE, BTLUW and BTLD for WY 1988.

Table 12. Annual summary of water and chemical discharge for BTLUE for WY 1988.

DISCHARGE		
Total		
acre-feet	78.0	
millions cf	3.4	
millions cm	0.096	
Average		
cfs	0.108	
cms	0.003	
mg/d	0.070	
gpm	48.5	
PRECIPITATION AND DISCHARGE		
Precipitation	22.94 inches (582.6 mm)	
Discharge	3.74 inches (94.0 mm)	
Discharge as % of precipitation	16%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	78.8	17.5
Mean of analyses	66.4	14.7
	NO_3-N output	**Total N output**
lbs - N	3,714	3,888
kg - N	1,684	1,763
lbs - N/acre	14.9	15.6
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	0.57	
Mean of analyses	0.32	
Total output		
lbs	0.12	
g	54.7	

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 42.0 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.

The nitrate concentration 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. 22). The concentration 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.

A number of samples were taken at BOOGD during snowmelt on February 29 and March 1. As previously mentioned, runoff recharge, from snowmelt, usually 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 peak discharge from runoff, relatively low nitrate and high herbicide concentrations occur. This is typically followed by higher nitrate and lower herbicide concentrations as the associated infiltration recharge moves through the system as the discharge recedes. The nitrate concentration decreased to 12 mg/L (2.7 mg/L as NO_3-N) on February 29 at 16:45 and by 22:30, the concentration had increased to 21 mg/L (4.7 mg/L as NO_3-N). On March 1, the concentration decreased 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, the concentration had increased to 17 mg/L (3.8 mg/L as NO_3-N), and by March 3, the concentration was 42 mg/L (9.3 mg/L as NO_3-N) as discharge continued to recede. The nitrate concentration 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. The concentration 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 generated short-term infiltration recharge. During the remainder of the water year discharge 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.

The greatest monthly fw mean nitrate concentration from BOOGD, 64.3 mg/L (14.3 mg/L as NO_3-N), occurred during April and the smallest 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-nitrogen output. Monthly nitrate-nitrogen output varied from 8.4 pounds in January to 1,858 pounds in March. March accounted for 42% of the annual nitrate-nitrogen output, and 54% of the annual surface-water discharge.

During the water year, ninety-eight samples from BTLUE were analyzed for nitrate, and fifty-six samples were analyzed for N-series. The annual fw mean nitrate concentration was 78.8 mg/L (17.5 mg/L as NO_3-N; Table 12). The annual nitrate-nitrogen output was 3,714 pounds, and the annual total nitrogen output (nitrate- plus organic-and ammonia-nitrogen) was 3,888 pounds. Within the drainage area of BTLUE, these outputs were equivalent to 14.9 lbs-N/acre of nitrate-nitrogen and 15.6 lbs-N/acre of total nitrogen.

Nitrate concentrations at BTLUE were significantly greater than concentrations from other monitoring sites within the sub-basin, but showed trends similar to site BOOGD. Concentrations at BTLUE decreased from the beginning of the water year through mid-November, peaked at 110 mg/L (24.4 mg/L as NO_3-N) on November 28, declined in early December, then increased through

Table 13. Annual summary of water and chemical discharge for BTLUW for WY 1988.

DISCHARGE		
Total		
acre-feet	9.6	
millions cf	0.42	
millions cm	0.012	
Average		
cfs	0.013	
cms	0.0004	
mg/d	0.008	
gpm	5.8	
PRECIPITATION AND DISCHARGE		
Precipitation	22.94 inches (582.7 mm)	
Discharge	0.99 inches (25.1 mm)	
Discharge as % of precipitation	4%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	27.8	6.2
Mean of analyses	28.5	6.3
	NO_3-N output	**Total N output**
lbs - N	162	199
kg - N	73.3	90.2
lbs - N/acre	1.4	1.7
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	0.26	
Mean of analyses	0.19	
Total output		
lbs	0.007	
g	3.03	

Table 14. Annual summary of water and chemical discharge for BTLD for WY 1988.

DISCHARGE		
Total		
acre-feet	7.7	
millions cf	0.33	
millions cm	0.01	
Average		
cfs	0.011	
cms	0.0003	
mg/d	0.007	
gpm	4.9	
PRECIPITATION AND DISCHARGE		
Precipitation	22.94 inches (582.7 mm)	
Discharge	5.13 inches (130.3 mm)	
Discharge as % of precipitation	22%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	44.0	9.8
Mean of analyses	40.6	9.0
	NO_3-N output	**Total N output**
lbs - N	204	233
kg - N	92.5	102
lbs-n/acre	11.3	12.9
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	0.03	
Mean of analyses	0.07	
Total output		
lbs	0.001	
g	0.23	

most of January. Concentrations increased to 100 mg/L (22.2 mg/L as NO_3-N) in early February, then decreased through February. The nitrate concentration was diluted to 5 mg/L (1.1 mg/L as NO_3-N) during peak discharge from runoff on March 3. This was the lowest concentration recorded at BTLUE during the water year. Nitrate concentrations generally increased from March through mid-April, and then generally decreased from May through mid-July.

Samples taken at BTLUE during runoff in late February and early March showed the same responses as samples taken at BOOGD. Nitrate concentrations decreased during peak discharge, then increased as discharge receded. The concentration increased from 17 mg/L (3.8 mg/L as NO_3-N) on February 29 at 14:00 to 33 mg/L (7.3 mg/L as NO_3-N) at 21:10 as discharge declined from 1.65 cfs to 1.37 cfs. The concentration then increased to 43 mg/L (9.6 mg/L as NO_3-N) on March 1 at 10:45, before decreasing to 5 mg/L (1.1 mg/L as NO_3-N) at 21:00, as discharge increased from 0.63 cfs to 1.52 cfs. The nitrate concentration increased to 55 mg/L (12.2 mg/L as NO_3-N) on March 3 as mean daily discharge decreased from 1.05 cfs on March 1 to 0.57 cfs on March 3.

Monthly fw mean nitrate concentrations from BTLUE varied from 101.6 mg/L (22.6 mg/L as NO_3-N) in January to 40.0 mg/L (8.9 mg/L as NO_3-N) in September. No groundwater discharge occurred during August, and the only day in September with discharge was September 22. Monthly fw mean nitrate concentrations remained above 80 mg/L from October through January, and remained above 90 mg/L from April through June. Large variations in monthly groundwater discharge led to wide variations in monthly nitrogen output. The greatest monthly nitrogen output, 1,230 pounds, occurred in April and the smallest monthly output, 0 pounds, occurred in August. Monthly discharge varied from 23.7 ac-ft, or 30% of the annual discharge in March to 0 ac-ft in August.

Fifty samples from BTLUW were analyzed for nitrate, and twenty-four samples were analyzed for N-series during WY 1988. The annual fw mean nitrate concentration was 27.8 mg/L (6.2

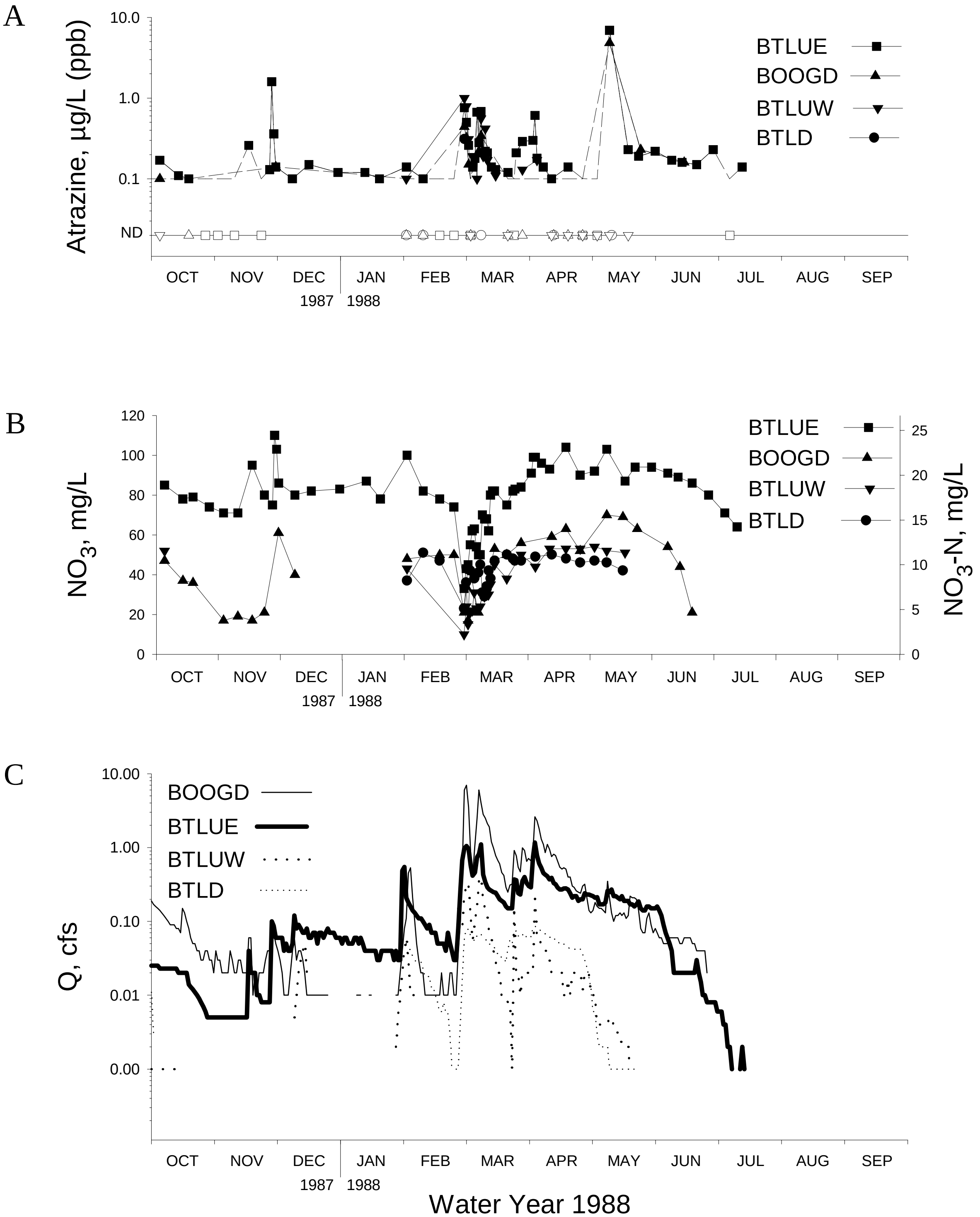


Figure 22. A) Atrazine and B) nitrate concentrations, and C) groundwater and surface-water discharge (Q) at BTLUE, BTLUW, BOOGD and BTLD for WY 1988 (note the increase in scale on the nitrate plot relative to WY 1987). (Discharge data for BOOGD are from the U.S. Geological Survey, W.R.D., IA Dist.)

mg/L as NO_3-N; Table 13). The annual nitrate-nitrogen output for WY 1988, 162 pounds, was equivalent to 1.4 lbs-N/acre within the drainage area of BTLUW. The total nitrogen output (including organic- and ammonia-nitrogen) was 199 pounds, or 1.7 lbs-N/acre within the drainage area of BTLUW.

Nitrate concentrations from BTLUW remained relatively low during the water year, and showed less fluctuation than concentrations from BOOGD and BTLUE. The lowest nitrate concentration recorded during the water year, 4 mg/L (0.89 mg/L as NO_3-N), occurred during peak discharge from runoff on March 6. The greatest concentration recorded at BTLUW during the water year, 54 mg/L (12.0 mg/L as NO_3-N) occurred May 3 as discharge continued to recede from early April.

Monthly fw mean nitrate concentrations from BTLUW remained below 45 mg/L (10.0 mg/L as NO_3-N) except during October and May. The greatest monthly fw mean, 52.8 mg/L (11.7 mg/L as NO_3-N) occurred in May, and the smallest, 14.7 mg/L (3.3 mg/L as NO_3-N) occurred in February. Large variations in monthly discharge led to large variations in monthly nitrate-nitrogen discharge. Monthly nitrate-nitrogen output varied from 0.9 pounds in October, a month with the second-greatest monthly fw mean at BTLUW during the water year, to 80.3 pounds in March, a month with the second-smallest monthly fw mean during the water year. October accounted for 0.6% of the annual nitrate-nitrogen output and 0.3% of the annual groundwater discharge, while March accounted for 50% of the annual nitrate-nitrogen output and 59% of the annual groundwater discharge.

During the WY 1988, thirty-four samples from BTLD were analyzed for nitrate, and eighteen samples were analyzed for N-series. The annual fw mean nitrate concentration was 44.0 mg/L (9.8 mg/L as NO_3-N; Table 14). The annual nitrate-nitrogen output was 204 pounds, and the annual total nitrogen output (nitrate- plus organic- and ammonia-nitrogen) was 233 pounds. Within the drainage area of BTLD, these outputs were equivalent to 11.3 lbs-N/acre of nitrate-nitrogen and 12.9 lbs-N/acre of total nitrogen.

Like BTLUW, nitrate concentrations from BTLD remained relatively low during the water year, and showed less fluctuation than concentrations from BOOGD and BTLUE. The greatest nitrate concentration recorded at BTLD during the water year, 51 mg/L (11.3 mg/L as NO_3-N) occurred on February 9 as groundwater discharge continued to recede from runoff on February 1. The smallest nitrate concentration recorded at BTLD during the water year, 21 mg/L (4.7 mg/L as NO_3-N), occurred as groundwater discharge was increasing during runoff on February 29.

Monthly fw mean nitrate concentrations from BTLD remained below 50 mg/L (11.1 mg/L as NO_3-N) during the water year. The greatest monthly fw mean, 48.5 mg/L (10.8 mg/L as NO_3-N) occurred in April, and the smallest monthly fw mean, 38.8 mg/L (8.6 mg/L as NO_3-N) occurred in February. As was the case at BTLUW, large variations in monthly discharge led to large variations in monthly nitrate-nitrogen discharge. Monthly nitrate-nitrogen output varied from 0.8 pounds in October, a month with the second-greatest monthly fw mean nitrate concentration at BTLD during the water year, to 91.6 pounds in April, a month with the greatest monthly fw mean, and the second-greatest monthly groundwater discharge during the water year. October accounted for 0.4% of the annual nitrate-nitrogen output and 0.4% of the annual groundwater discharge, while April accounted for 45% of the annual nitrate-nitrogen output and 40% of the annual groundwater 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.

Pesticide Monitoring

Tables 11-14 and Figure 22 summarize the results of pesticide monitoring at sites BOOGD, BTLUE, BTLUW and BTLD 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 54.8 grams.

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 the atrazine concentration increased to 0.44 µg/L. During the event, the concentration decreased to 0.14 µg/L on March 1 at 12:00 then increased to 0.32 µg/L by 17:50. The atrazine concentration decreased to non-detectable levels (<0.10 µg/L) 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, the concentration 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 minor runoff on April 5 when concentrations increased to 0.27 µg/L. The atrazine concentration increased to 4.8 µg/L during the second week in May, following 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.

Monthly fw mean atrazine concentrations from BOOGD 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 greatest 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, seventy-seven samples from BTLUE were analyzed for pesticides. Sixty-six, or 86%, of the samples contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration was 0.57 µg/L and the total atrazine output was 54.7 grams.

The atrazine plot for BTLUE shows trends similar to the atrazine plot from BOOGD (Fig. 22). The lack of significant recharge during the first half of the water year was reflected by low atrazine concentrations, especially during the first five months of the water year. Atrazine concentrations were below the detection limit (<0.10 µg/L) in most samples collected from late October through November. The concentration increased to 1.60 µg/L on November 28 during runoff. As discharge receded through most of December and January, atrazine concentrations remained between 0.15 µg/L and 0.10 µg/L. Concentrations declined to non-detectable levels in mid-February, then increased to 0.76 µg/L on February 29 during snowmelt. During March and April, atrazine concentrations generally increased and decreased along with discharge. The greatest atrazine concentration reported from BTLUE during WY 1988, 6.90 µg/L, was sampled on May 9, following precipitation on May 8. During the remainder of the water year, atrazine concentrations remained below 0.24 µg/L as discharge receded, and then ceased at BTLUE in mid-July. The only day with discharge at BTLUE during the rest of the water year was September 22, with an average daily discharge of 0.07 cfs.

Monthly fw mean atrazine concentrations and loads at BTLUE varied from 2.57 µg/L and 36.6 grams in May to non-detectable levels and 0 grams in September. May accounted for 67% of the annual atrazine output and 15% of the annual groundwater discharge, while September did not account for any of the annual atrazine output and accounted for less than 0.2% of the annual groundwater discharge.

Other pesticides detected at BTLUE during the water year include cyanazine in four, or 5%, of the samples, alachlor in four, or 5%, dyfonate in one, or 1%, and metolachlor in one, or 1%, of the samples. The greatest concentrations of pesticides detected at BTLUE during the water year included atrazine at 6.90 µg/L, alachlor at 5.50 µg/L, cyanazine at 0.32 µg/L, dyfonate at 0.10µg/L, and metolachlor at 0.15 µg/L. The maximum detections for atrazine and alachlor occurred on May 9, for cyanazine on February 29, for dyfonate on April 4, and for metolachlor the maximum detection occurred on November 28. Alachlor was detected during November, December, February, and May, cyanazine was detected twice on November 28 and twice on May 29, dyfonate was detected only in April, and metolachlor was detected only in November.

During WY 1988, thirty-eight samples from BTLUW were analyzed for pesticides. Twenty-seven, or 71%, of the samples contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration was 0.26 µg/L and the total atrazine output was 3.0 grams.

Atrazine concentrations at BTLUW were generally lower than concentrations from BOOGD and BTLUE, and less variable. Concentrations increased from non-detectable levels in early October to the greatest concentration recorded at BTLUW during the water year, 1.00 µg/L, during snowmelt on February 29. As was the case with other monitoring sites in the sub-basin, during March, atrazine concentrations fluctuated along with groundwater discharge. Concentrations declined from 0.17 µg/L on April 4 to non-detectable levels on May 11, and remained below the 0.10 µg/L detection limit until discharge ceased on May 20. BTLUW remained dry until January 30, 1989.

The only months at BTLUW with atrazine discharge were February, March, and April. Monthly fw mean atrazine concentrations for BTLUW varied from 0.36 µg/L in February to 0.13 µg/L in April. Monthly atrazine output varied from 2.14 grams in March to 0.30 grams in April. March accounted for 71% of the annual atrazine output and 59% of the annual groundwater discharge, and April accounted for 10% of the annual atrazine output and 20% of the groundwater discharge during the water year.

Atrazine was the only pesticide detected at BTLUW during the water year. It was detected during all months with groundwater discharge, except for October and May.

During WY 1988, seven samples from BTLD were analyzed for pesticides. Two, or 29%, of the samples collected contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration for BTLD was 0.03 µg/L and the total atrazine output was 0.23 grams (Table 14).

Atrazine concentrations at BTLD remained below the 0.10 µg/L detection limit in all samples, except for two collected during snowmelt on February 29. Concentrations increased from non-detectable levels on February 9, to 0.17 µg/L at 16:20 on February 29, then increased to 0.31 µg/L at 21:45. During this time, groundwater discharge increased from 0.023 cfs on February 9, to 0.067 cfs on February 29 at 16:20, then peaked at 0.24 cfs at 17:00, and then receded to 0.074 cfs at 22:45. On March 8, the atrazine concentration at BTLD was below the 0.10 µg/L detection limit and the mean daily discharge was 0.065 cfs. Discharge ceased on May 23, and BTLD remained dry through WY 1989, and most of WY 1990, until August 25.

The only months at BTLD with atrazine discharge were February and March. The monthly flow-weighted mean atrazine concentration and monthly atrazine load for February were 0.03 µg/L and 0.04 grams, and for March, the monthly flow-weighted mean atrazine concentration and monthly atrazine load were 0.05 µg/L and 0.19 grams. February accounted for 17% of the annual atrazine output and 13% of the annual groundwater discharge, and March accounted for 83% of the annual atrazine output and 44% of the groundwater discharge during the water year. Atrazine was the only pesticide detected at BTLD during the water year.

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 was the smallest annual fw mean atrazine concentration and load observed at Big Spring during WYs 1982-1994 (Liu et al., 1997). 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.

Water Year 1989

Discharge Monitoring

Tables 15-17 and Figure 23 summarize the discharge, water quality and chemical-load data for BOOGD, BTLUE and BTLUW for WY 1989. BTLD is not included since it was dry during the water year. In Figure 23, note the large increase in scale on the atrazine plot and the large 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. Statewide, average precipitation was more than 18 inches below normal. Precipitation in the Big Spring area was approximately 10 inches below normal during WY 1988 and 8.7 inches below normal during WY 1989.

The hydrographs reflect the continuation of the drought conditions that prevailed during WY 1988 (Fig. 23). BTLUW remained dry from May 20, 1988 through January 29, 1989, BOOGD was dry from June 28, 1988 through March 8, 1989, and BTLUE remained dry from July 14, 1988 through January 29, 1989, except for some discharge on September 22, 1988.

Rainfall occurred throughout WY 1989, gener-

Table 15. Annual summary of water and chemical discharge for BOOGD for WY 1989. (Discharge data are from the U.S. Geological Survey, W.R.D., IA Dist.).

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 (618 mm)	
Discharge	0.93 inches (23.7 mm)	
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	

ating minor runoff, but the intensity and accumulation of rainfall were too low to generate significant groundwater recharge. Precipitation was 1.6 inches above normal during November and August, 1.3 inches below normal in March, 2.4 inches below normal in June, and 3.0 inches below normal in July. Almost 2 inches of precipitation fell November 18th, but recharge was minimal and all monitoring sites within the Bugenhagen sub-basin remained dry. The most significant runoff during the water year occurred in late January, early February and mid-March and was associated with snowmelt rather than rainfall. The amount of recharge associated with these events was limited and any discharge that was initiated, ceased within a few days. The events that occurred from March 10 through March 15 accounted for 75% of the annual discharge at BOOGD, 72% of the annual total at BTLUE, and 56% of the annual discharge from BTLUW. During the remainder of the water year, very little discharge occurred. Intense rainfall in July, August and September generated minor runoff, but the associated infiltration recharge was very limited.

Site BOOGD went dry during the last week in June 1988 and remained dry throughout most of WY 1989 except during periods in March, July, August, and September. The longest period of continuous daily discharge was nine days surrounding snowmelt 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 15). The annual discharge was equivalent to 4% of the precipitation for the water year. At site BTLUE, the annual discharge for WY 1989 was 10.5 ac-ft, at an average daily discharge of 0.014 cfs (Table 16). The annual discharge from BTLUE was equivalent to 2% of the precipitation during the water year. The annual discharge from BTLUW was 10.9 ac-ft, at an average daily discharge rate of 0.015 cfs (Table 17). The annual discharge from BTLUW equaled 5% of the annual precipitation during the water year. The annual surface-water discharge and the equivalent percentage of precipitation discharged from BOOGD during WY 1989 were the lowest recorded during WYs 1986-1995. The

Table 16. Annual summary of water and chemical discharge for BTLUE for WY 1989.

DISCHARGE		
Total		
acre-feet	10.5	
millions cf	0.46	
millions cm	0.013	
Average		
cfs	0.014	
cms	0.0004	
mg/d	0.009	
gpm	6.3	
PRECIPITATION AND DISCHARGE		
Precipitation	24.32 inches (617.7 mm)	
Discharge	0.50 inches (12.8 mm)	
Discharge as % of precipitation	2%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	17.5	3.9
Mean of analyses	17.7	3.9
	NO_3-N output	**Total N output**
lbs - N	111	360
kg - N	50.3	163
lbs - N/acre	0.4	1.4
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	5.32	
Mean of analyses	5.93	
Total output		
lbs	0.15	
g	68.7	

annual groundwater discharge and equivalent percentage of precipitation discharged from BTLUE during WY 1989 were the lowest recorded during WYs 1987-1995. At site BTLUW, the lowest annual groundwater discharge and equivalent percentage of precipitation discharged were recorded during WY 1988, rather than WY 1989.

The 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. The annual discharge and percent of precipitation discharged from Big Spring during WY 1989 were the lowest recorded during WYs 1982-1995 (Liu et al., 1997).

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 small annual fw mean nitrate-nitrogen concentrations and loads, and large annual fw mean atrazine concentrations and loads at most monitoring sites. Some bias was probably also introduced into the computation of the annual fw mean nitrate-nitrogen and atrazine concentrations and loads, since most of the groundwater and surface-water discharge, and the samples of the discharge were event related.

Nitrate Monitoring

Tables 15-17 and Figure 23 summarize the nitrate analyses from BOOGD, BTLUE and BTLUW for WY 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 nitrate-nitrogen and 1.9 lbs-N/acre for total nitrogen. The

Table 17. Annual summary of water and chemical discharge for BTLUW for WY 1989.

DISCHARGE		
Total		
acre-feet	10.9	
millions cf	0.47	
millions cm	0.013	
Average		
cfs	0.015	
cms	0.0004	
mg/d	0.010	
gpm	6.7	
PRECIPITATION AND DISCHARGE		
Precipitation	24.32 inches (617.7 mm)	
Discharge	1.13 inches (28.7 mm)	
Discharge as % of precipitation	5%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	15.7	3.5
Mean of analyses	21.6	4.8
	NO_3-N output	**Total N output**
lbs - N	103	332
kg - N	46.7	151
lbs - N/acre	0.9	2.9
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	8.72	
Mean of analyses	12.42	
Total output		
lbs	0.26	
g	117	

annual fw mean nitrate-nitrogen concentration and load for WY 1989 were the smallest recorded at BOOGD during WYs 1986-1992.

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 runoff events of the water year. The nitrate concentration was 16 mg/L (3.6 mg/L as NO_3-N), three days after the first and largest event (Fig. 23).

The monthly fw mean nitrate concentration for BOOGD during March was 10.9 mg/L (2.4 mg/L as NO_3-N) and the total monthly nitrate-nitrogen output was 317 pounds. March accounted for all of the annual nitrate-nitrogen output and 84% of the annual surface-water discharge at BOOGD.

During WY 1989, twenty samples from BTLUE were analyzed for nitrate, and twelve samples were analyzed for N-series. The annual fw mean nitrate concentration was 17.5 mg/L (3.9 mg/L as NO_3-N). The annual nitrate-nitrogen output for the water year was 111 pounds, and the annual total nitrogen output (nitrate- plus organic- and ammonia-nitrogen) was 360 pounds. Within the drainage area of BTLUE, the annual nitrate-nitrogen output was equivalent to 0.4 lbs-N/acre and the annual nitrogen output was equal to 1.4 lbs-N/acre. The annual fw mean nitrate-nitrogen concentration and load for WY 1989 were the smallest recorded at BTLUE during WYs 1987-1995.

During runoff in late January, the nitrate concentration increased from 9 mg/L (2.0 mg/L as NO_3-N) on January 30 at 16:35 to 19 mg/L (4.2 mg/L as NO_3-N) on January 31 at 17:20. Discharge receded from 0.90 cfs on January 30 at 16:30 to 0.02 cfs at 20:00. On January 31, discharge increased from 0.02 cfs at 04:00 to 0.68 cfs at 14:00, then declined to 0.14 cfs at 18:15, and flow ceased by 22:00. BTLUE remained dry from February 1 through February 22, from February 24 through March 1, and from March 3 through March 8. The nitrate concentration increased from 7 mg/L (1.6 mg/L as NO_3-N) on March 10 at 14:00 to 26 mg/L (5.8 mg/L as NO_3-N) on March 13 at 14:15, then peaked at 38 mg/L (8.4 mg/L as NO_3-N) on March 14 at 10:50. Discharge increased from 0 cfs on March 10 at 08:00 to 1.56 cfs at 16:15, then receded to 0.08 cfs on March 11 at 08:00 before peaking at 1.64 cfs at 14:30. Discharge declined to 0.26 cfs on March 12 at 08:30, then increased to 1.14 cfs at 12:45, before declining again to 0.01 cfs on March 13 at 10:00. Discharge increased to 0.72 cfs at 15:45, declined to 0.04 cfs on March 14 at 09:15, then peaked at 1.70 cfs at 10:30. Discharge ceased at BTLUE during the evening of March 16, and BTLUE remained dry through March 19. During the remainder of the water year, BTLUE was dry from March 30 through August 27, August 29 and 30, and from September 2 through February 4. The smallest nitrate concentration sampled at BTLUE during the water year, 2 mg/L (0.4 mg/L as NO_3-N), occurred two hours after peak discharge from snowmelt on March 23. The nitrate concentration increased to 6 mg/L (1.3 mg/L as NO_3-N) on March 24, then to 15 mg/L (3.3 mg/L as NO_3-N) on March 26 as discharge receded. Nitrate concentrations remained below 10 mg/L (2.2 mg/L as NO_3-N) in the samples taken during the remainder of the year.

Monthly fw mean nitrate-nitrogen concentrations and loads for BTLUE were computed for the months of January, February, March, August, and September. Monthly fw mean concentrations varied from 18.9 mg/L (4.2 mg/L as NO_3-N) in March to 5 mg/L (1.1 mg/L as NO_3-N) in September. Great variations in monthly groundwater discharge led to great variations in monthly nitrate-nitrogen output. February had the second-greatest monthly fw mean nitrate concentration, 18 mg/L (4.0 mg/L as NO_3-N), but the smallest nitrate-nitrogen output, 0.05 pounds, and the smallest computed monthly groundwater discharge at 0.005 ac-ft. March had the greatest monthly nitrate-nitrogen output, 98.3 pounds, and the greatest monthly groundwater discharge, 8.63 ac-ft. March accounted for 82% of the annual groundwater discharge and 89% of the annual nitrate-nitrogen output, while February accounted for 0.05% of the annual groundwater discharge and 0.05% of the annual nitrate-nitrogen discharge.

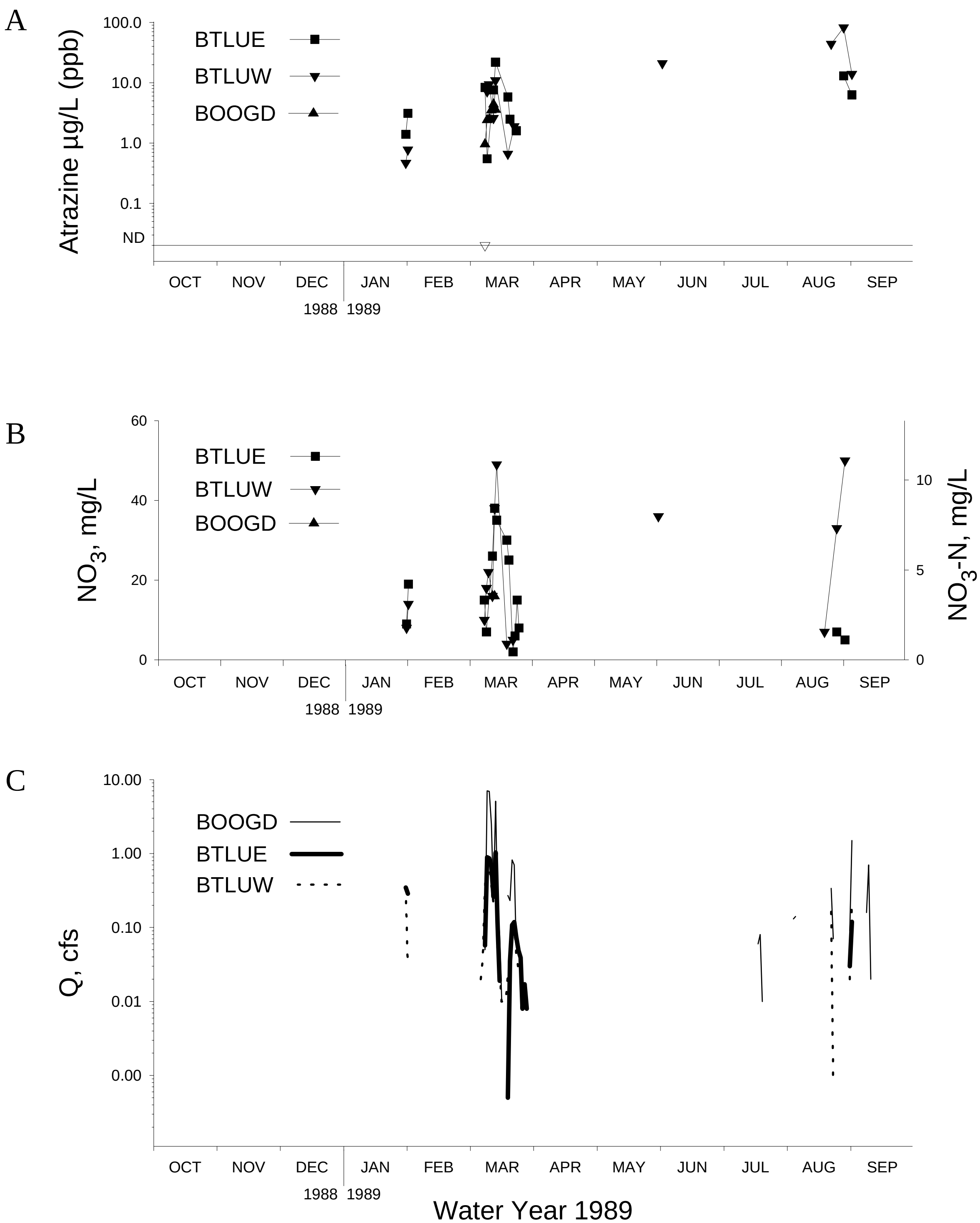


Figure 23. A) Atrazine and B) nitrate concentrations, and C) groundwater and surface-water discharge (Q) at BTLUE, BTLUW and BOOGD for WY 1989 (note the increase in scale on the atrazine plot and the decrease in scale on the nitrate plot relative to WY 1988). (Discharge data for BOOGD are from the U.S. Geological Survey, W.R.D., IA Dist.)

At BTLUW, twenty-eight samples were analyzed for nitrate, and thirteen samples were analyzed for N-series during WY 1989. The annual fw mean nitrate concentration was 15.7 mg/L (3.5 mg/L as NO_3-N). The annual nitrate-nitrogen output for the water year was 103 pounds and the annual total nitrogen output (nitrate- plus organic-, and ammonia-nitrogen) was 332 pounds. Within the drainage area of BTLUW, these outputs were equivalent to 0.9 lbs-N/acre for nitrate-nitrogen and 2.9 lbs-N/acre for total nitrogen. The annual fw mean nitrate-nitrogen concentration and load for WY 1989 were the lowest recorded at BTLUW during WYs 1987-1995.

As with BTLUE, the nitrate samples taken at BTLUW during the water year were all event related. During runoff in late January, the nitrate concentration at BTLUW increased from 8 mg/L (1.8 mg/L as NO_3-N) on January 30 at 16:40 to 14 mg/L (3.1 mg/L as NO_3-N) on January 31 at 17:30. Groundwater discharge receded from 0.90 cfs on January 30 at 16:15 to 0.02 cfs at 21:00, then on January 31, discharge increased from 0 cfs at 09:45 to 1.06 cfs at 12:45, then declined to 0.02 cfs at 20:45, and flow ceased by 23:30. BTLUW remained dry from February 1 through March 6. The nitrate concentration decreased from 10 mg/L (2.2 mg/L as NO_3-N) at 13:15 to 8 mg/L (1.8 mg/L as NO_3-N) at 16:10 on March 9, as discharge increased from 0.06 cfs at 12:00 to 0.84 cfs at 18:30, then decreased to 0.08 cfs at 21:45. The nitrate concentration decreased from 18 mg/L (4.0 mg/L as NO_3-N) on March 10 at 11:30 to 14 mg/L (3.1 mg/L as NO_3-N) at 14:10, then decreased to 12 mg/L (2.7 mg/L as NO_3-N) at 16:30 and 22:00. Groundwater discharge at BTLUW increased from 0 cfs on March 10 at the beginning of the day to 1.24 cfs at 12:00, then decreased to 1.20 cfs, then increased again to 1.24 cfs at 18:00, before receding to 0.06 cfs on March 11 at 08:30. The nitrate concentration increased to 22 mg/L (4.9 mg/L as NO_3-N) on March 11 at 10:30, then decreased to 16 mg/L (3.6 mg/L as NO_3-N) at 13:30 as discharge increased from 0.06 cfs at 08:30 to 1.56 cfs at 14:15, then decreased to 0.36 cfs at 24:00. The nitrate concentration for BTLUW was again 16 mg/L (3.6 mg/L as NO_3-N) at 14:10 on March 13, as groundwater discharge increased from 0.01 cfs at 04:00 to 0.57 cfs at 16:15. On March 14, the nitrate concentration increased from 20 mg/L (4.4 mg/L as NO_3-N) at 10:55, to 31 mg/L (6.9 mg/L as NO_3-N) at 13:00, then increased to 32 mg/L (7.1 mg/L as NO_3-N) at 15:00, and 34 mg/L (7.6 mg/L as NO_3-N) at 17:00. The nitrate concentration then decreased slightly to 33 mg/L (7.3 mg/L as NO_3-N) at 19:00 before increasing to 38 mg/L (8.4 mg/L as NO_3-N) at 21:30. During March 14, groundwater discharge increased from 0.04 cfs at 07:30 to 1.61 cfs at 11:30 then declined to 0.01 cfs at 12:00 on March 15. As discharge declined at BTLUW, the nitrate concentration increased to 49 mg/L (10.9 mg/L as NO_3-N) at 01:00 on March 15. Discharge declined from March 15-19, then on March 20, discharge increased from 0.01 cfs to 0.04 cfs at 15:40, and the nitrate concentration declined to 4 mg/L (0.9 mg/L as NO_3-N), which was the smallest concentration recorded at BTLUW during the water year.

Discharge receded to 0 cfs on March 21 at 19:30, then resumed again at 11:45 the next day. On March 23, the nitrate concentration was 5 mg/L (1.1 mg/L as NO_3-N) at 14:00 as discharge peaked at 0.30 cfs. Following this, discharge generally receded, increasing during the warmest part of the days and decreasing in the evenings. Discharge ceased during March 29 and BTLUW remained dry until June 2 when the nitrate concentration was 36 mg/L (8.0 mg/L as NO_3-N). Discharge ceased again, and BTLUW remained dry from June 3-21 and from June 23 through August 21. On August 22, the nitrate concentration was 7 mg/L (1.6 mg/L as NO_3-N) during a minor event. Discharge ceased during August 23, resumed during August 26, then ceased again, and BTLUW was dry on August 27. On August 28, the nitrate concentration decreased from 17 mg/L (3.8 mg/L as NO_3-N) at 03:40 to 10 mg/L (2.2 mg/L as NO_3-N) at 04:05, then increased again to 33 mg/L (7.3 mg/L as NO_3-N) at 04:35. Discharge ceased on August 28, and BTLUW remained dry until 23:30 on August 31. On September 1, the nitrate concentration increased from 14 mg/L (3.1 mg/L as NO_3-N) at 03:00 to 42 mg/L (9.3 mg/L as

NO_3-N) at 06:00, then increased to 50 mg/L (11.1 mg/L as NO_3-N) at 08:00, which was the greatest nitrate concentration recorded at BTLUW during the water year. Discharge ceased later during the day on September 1 and BTLUW remained dry until February 5, 1990. For most of the discharge events during the water year, nitrate concentrations generally decreased during peak discharge, and later increased as the discharge receded.

Monthly fw mean nitrate-nitrogen concentrations and loads for BTLUW were computed for January, March, May, June, August, and September. Monthly fw mean concentrations varied from 36.0 mg/L (8.0 mg/L as NO_3-N) in May and June to 7.2 mg/L (1.6 mg/L as NO_3-N) in January. Variations in monthly groundwater discharge led to variations in monthly nitrate-nitrogen output. March had the greatest monthly nitrate-nitrogen output, 79.7 pounds, and the greatest monthly groundwater discharge, 7.95 ac-ft, which accounted for 77% of the annual nitrate-nitrogen output and 73% of the annual groundwater discharge. January had the smallest monthly nitrate-nitrogen output, 0.86 pounds, and the smallest computed monthly groundwater discharge, 0.04 ac-ft, which accounted for 0.8% of the annual nitrate-nitrogen discharge and 0.4% of the annual groundwater 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-nitrogen concentration and load were the smallest recorded during WYs 1982-1995 (Liu et al., 1995). 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.

Pesticide Monitoring

Tables 15-17 and Figure 23 summarize the results of pesticide monitoring at sites BOOGD, BTLUE and BTLUW during WY 1989.

Nine samples from BOOGD were analyzed for pesticides during WY 1989. One sample was collected on January 30, and the rest of 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 for BOOGD was 2.31 µg/L and the annual output was 163 grams.

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. In March, snowmelt generated the two largest runoff events during the water year. The atrazine concentration 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. The atrazine concentration was 2.50 µg/L, and the mean daily discharge was 6.9 cfs the following day. On March 12, the atrazine concentration had increased to 3.50 µg/L, and daily discharge had decreased to 2.5 cfs. The mean daily discharge decreased to 0.24 cfs, and the atrazine concentration increased to 4.40 µg/L, three days after peak runoff. The following day, as a second influx of runoff occurred, the atrazine concentration was 3.60 µg/L and the mean daily discharge was 5.1 cfs.

During March, the total monthly atrazine output for BOOGD 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 greatest concentrations 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, thirteen samples from BTLUE were analyzed for pesticides. All of the samples contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration for BTLUE was 5.32 µg/L and the annual atrazine output was 68.7 grams. The fw mean atrazine concentration for BTLUE during WY 1989 was the greatest recorded during WYs 1987-1995, and was probably, in part, due to bias introduced by sampling only during runoff events.

BTLUE was dry from September 23 until snowmelt initiated discharge on January 30. The atrazine concentration increased from 1.40 µg/L on January 30 to 3.10 µg/L on January 31 during the two separate events. Discharge ceased late on the evening of January 31 and BTLUE remained dry through February 22. Some groundwater discharge occurred on February 23, and then BTLUE was dry again from February 24 through March 1. On March 2 discharge resumed briefly, then BTLUE was dry again through March 8. On March 9, the atrazine concentration was 8.40 µg/L at 16:00, as discharge increased from 0.02 cfs at 14:30 to 0.14 at 18:00, then decreased to 0.02 cfs at 22:45. On March 10 the atrazine concentration increased from 0.17 µg/L at 14:30 to 0.55 µg/L at 17:00, as discharge increased from 0 cfs at 08:00 to 1.56 cfs at 16:15, then decreased to 1.0 cfs at 23:30. Discharge remained relatively high during the following two days, and on March 13 the atrazine concentration was 7.60 µg/L at 14:00, as the discharge increased from 0.01 cfs at 10:00 to 0.72 at 15:45, then receded to 0.14 cfs at 24:00. The greatest atrazine concentration recorded at BTLUE during the water year, 22.00 µg/L, occurred at 10:50 on March 14, just after the discharge peaked at 1.70 cfs at 10:30. The atrazine concentration decreased to 4.70 µg/L at 20:00, as discharge receded to 1.23 cfs. Groundwater discharge continued to recede through March 15, then increased slightly, then ceased on March 16. BTLUE remained dry until March 20, when the atrazine concentration was 5.80 µg/L during very low-flow conditions. The following day, the atrazine concentration was 2.50 µg/L and the discharge was 0.03 cfs at 14:15, prior to discharge peaking at 0.14 cfs at 15:30. During the next two days, discharge increased during the warmest part of the day and decreased in the evenings. On March 24 the atrazine concentration was 1.60 µg/L at 16:00 as discharge was receding. Discharge receded during the following few days, and ceased on March 29. BTLUE remained dry until August 28 when the atrazine concentration was 13.00 µg/L at 04:00, following peak discharge at 03:25. Discharge ceased later that morning, and BTLUE remained dry until late on August 31. The atrazine concentration was 6.30 µg/L at 03:00, thirty minutes after discharge peaked. Discharge ceased during the afternoon of August 31, and BTLUE remained dry until February 5, 1990.

Monthly fw mean atrazine concentrations were computed for the months January, February, March, August, and September. Monthly fw mean atrazine concentrations varied from 2.17 µg/L in January to 11.84 µg/L in August. As with monthly nitrate-nitrogen loads, great variations in discharge led to great variations in monthly atrazine loads. The smallest computed monthly atrazine load, 0.04 grams, was discharged during February, the month with the third-greatest fw mean, 6.00 µg/L, but the smallest computed monthly groundwater discharge, 0.005 ac-ft. The largest monthly atrazine load, 58.5 grams, was discharged during March, the month with the second-smallest fw mean atrazine concentration, but the greatest monthly groundwater discharge, 8.63 ac-ft. February accounted for 0.06% of the annual atrazine output and 0.05% of the annual groundwater discharge, while March accounted for 85% of the annual atrazine output and 82% of the annual groundwater discharge.

Other pesticides detected at BTLUE during the water year include cyanazine in six, or 46%, of the samples, alachlor in three, or 23%, and metolachlor in one, or 12%, of the samples collected. The greatest concentrations of pesticides detected during the water year included atrazine at 22.00 µg/L, alachlor at 0.28 µg/L, cyanazine at

0.31 µg/L, and metolachlor at 0.10 µg/L. The maximum detection for alachlor occurred January 30, all other maximum detections occurred on March 14. Cyanazine was detected during March and September, alachlor was detected in January and March, and metolachlor was detected in March only.

Nineteen samples from BTLUW were analyzed for pesticides during WY 1989. Eighteen, or 95%, of the samples, contained detectable levels of atrazine (>0.10 µg/L). The fw mean atrazine concentration for BTLUW was 8.72 µg/L and the total atrazine output during the water year was 117 grams.

BTLUW was dry from May 20 through January 29. The atrazine concentration was 0.47 µg/L at 16:40 on January 30, thirty minutes after discharge peaked. The atrazine concentration was 0.78 µg/L at 17:30, as discharge was receding from another runoff event the following day. Discharge ceased later that evening and BTLUW remained dry until March 7. A sample taken on March 9 was the only sample from BTLUW during the water year that did not contain detectable atrazine. This sample was taken within an hour following peak discharge. On March 10, the atrazine concentration decreased from 7.20 µg/L at 14:10 to 5.10 µg/L at 17:00 as the discharge slowly receded. On March 11, the atrazine concentration was 9.40 µg/L at 13:00, prior to discharge peaking at 1.56 cfs at 14:15. Following another event on March 12, the atrazine concentration was 2.60 µg/L on March 13 at 14:10 as discharge increased from 0.01 cfs at 04:00 to 0.57 cfs at 16:15. On March 14 the atrazine concentration increased from 1.50 µg/L at 10:55 to 8.80 µg/L at 13:00, then increased to 11.00 µg/L at 17:00. The discharge increased from 0.04 cfs at 07:30 to 1.61 cfs at 11:30 then receded through March 19. On March 20, the atrazine concentration was 0.66 µg/L at 15:40, as discharge increased from 0.01 cfs at 12:00 to 0.04 cfs at 15:30. Discharge remained relatively steady on March 21, then increased through the afternoon of March 23. The atrazine concentration was 1.90 µg/L during peak discharge at 14:00. Discharge declined through March 25, increased slightly on March 26, then continued to decline until ceasing on March 29. BTLUW remained dry through May 28, resumed discharge briefly on May 29, then flow ceased again until June 2, when the atrazine concentration was 21.00 µg/L at 16:30. Discharge ceased later that evening, and the tile line remained dry through June 21. Discharge resumed temporarily on June 22, then ceased and BTLUW remained dry until August 22, when the atrazine concentration was 44.00 µg/L during runoff. Discharge ceased again on August 23, and BTLUW remained dry until August 26. Discharge ceased again during August 26, then resumed on August 28, and the atrazine concentration decreased from 83.00 µg/L at 03:40, which was the greatest atrazine concentration recorded at BTLUW during the water year, to 6.70 µg/L at 04:35, as the discharge receded. Discharge ceased later that evening and the tile remained dry until late on August 31. On September 1, the atrazine concentration decreased from 13.00 µg/L at 03:00 to 4.80 at 08:00 as discharge receded. Discharge ceased following the event, and the tile remained dry through February 4, 1990.

Monthly fw mean atrazine concentrations were computed for the months January, March, May, June, August, and September. Monthly fw mean atrazine concentrations varied from 0.64 µg/L in January to 44.95 µg/L in August. The high atrazine concentration of the sample taken on August 28, along with the limited number of samples taken during the month generated a relatively high monthly fw mean atrazine concentration and load for August. The smallest computed monthly atrazine load, 1.0 gram, was discharged during January, the month with the second-greatest monthly groundwater discharge, 1.28 ac-ft. The largest monthly atrazine load, 64.6 grams, was discharged during August, the month with the third-greatest monthly groundwater discharge, 1.17 ac-ft. January accounted for 0.9% of the annual atrazine output and 12% of the annual groundwater discharge, while August accounted for 55% of the annual atrazine output and 11% of the annual groundwater discharge. March had the second-lowest monthly fw mean atrazine concentration, 4.37 µg/L, but, by far, the greatest monthly groundwater discharge, 7.59 ac-ft, which generated the second greatest monthly atrazine load of 42.86 grams. March accounted for 37% of the annual atrazine output and 73% of the annual groundwater discharge.

Other pesticides detected at BTLUW during WY 1989 include alachlor in eight, or 42%, of the samples, cyanazine in seven, or 39%, metolachlor in one, or 5%, butylate in one, or 5%, and metribuzin in one, or 5%, of the samples collected. The greatest concentrations of pesticides detected during the water year included atrazine at 83.00 µg/L, alachlor at 23.00 µg/L, metribuzin at 13.00 µg/L, cyanazine at 1.74 µg/L, butylate at 0.80 µg/L, and metolachlor at 0.15 µg/L. The maximum detections of alachlor and cyanazine occurred on June 2, for atrazine on August 28, for butylate on September 1, for metolachlor on March 14, and for metribuzin the maximum occurred on August 22. Alachlor was detected during January, March, June, and August, Cyanazine was detected during March, June, August, and September, butylate was detected only in September, metolachlor was detected only during March, and Metribuzin was detected only during August.

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.

Water Year 1990

Discharge Monitoring

Tables 18-21 and Figure 24 summarize the discharge, water quality and chemical-load data for monitoring sites BOOGD, BTLUE, BTLUW, and BTLD during WY 1990. In Figure 24, note the large 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 approximately five inches above the long-term average for northeast Iowa.

Table 18. Annual summary of water and chemical discharge for BOOGD for WY 1990. (Discharge data are from the U.S. Geological Survey, W.R.D., IA Dist.).

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	

Table 19. Annual summary of water and chemical discharge for BTLUE for WY 1990.

DISCHARGE		
Total		
acre-feet	53.7	
millions cf	2.34	
millions cm	0.07	
Average		
cfs	0.074	
cms	0.002	
mg/d	0.048	
gpm	33.2	
PRECIPITATION AND DISCHARGE		
Precipitation	37.87 inches (961.9 mm)	
Discharge	2.58 inches (65.5 mm)	
Discharge as % of precipitation	7%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	117.0	26.0
Mean of analyses	109.2	24.3
	NO_3-N output	**Total N output**
lbs - N	3,797	4,039
kg - N	1,722	1,832
lbs - N/acre	15.2	16.2
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	3.36	
Mean of analyses	3.50	
Total output		
lbs	0.49	
g	223	

The greatest monthly accumulation of rainfall occurred during August. The largest single rainfall occurred on August 25, following two days of widespread rainfall, and caused extensive flooding throughout the Turkey River Valley.

The hydrographs reflect the continuation of antecedent drought conditions that prevailed during WYs 1988 and 1989. Extremely low-flow conditions persisted during the first four months of the water year throughout the Big Spring basin. BTLUE and BTLUW remained dry from September 2, 1989 through February 4, 1990, BOOGD was dry from September 11, 1989 through January 15, 1990, except for some limited discharge on October 5, 16, and 30, 1989, and BTLD remained dry from May 23, 1988 through August 24, 1990. Snowmelt in February and March, and precipitation in March generated runoff, but very little infiltration recharge, and any groundwater and surface-water discharge initiated, ceased within a matter of days. Rainfall 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. 24). Discharge ceased again in mid-March and BOOGD remained dry until June, except during three days in May. In June, precipitation generated enough recharge to initiate baseflow, which was sustained through July. Additional rainfall in June, July, and August generated enough recharge to sustain discharge throughout the remainder of the water year. The annual surface-water discharge from BOOGD for WY 1990 was 173 ac-ft, at an average daily discharge rate of 0.24 cfs (Table 18). The annual surface-water discharge was equivalent to 7% of the annual precipitation during the water year.

As mentioned earlier, BTLUE was dry until snowmelt initiated discharge on February 5. Dis-

Table 20. Annual summary of water and chemical discharge for BTLUW for WY 1990.

DISCHARGE		
Total		
acre-feet	13.9	
millions cf	0.61	
millions cm	0.017	
Average		
cfs	0.019	
cms	0.001	
mg/d	0.012	
gpm	8.5	
PRECIPITATION AND DISCHARGE		
Precipitation	37.87 inches (961.9 mm)	
Discharge	1.44 inches (36.6 mm)	
Discharge as % of precipitation	4%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	47.0	10.4
Mean of analyses	44.6	9.9
	NO_3-N output	**Total N output**
lbs - N	395	712
kg - N	179	323
lbs - N/acre	3.4	6.1
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	9.82	
Mean of analyses	7.54	
Total output		
lbs	0.37	
g	169	

charge ceased on February 13, and BTLUE remained dry through February 27. Discharge occurred from February 28 through March 2, then ceased again until March 8. Discharge occurred through March 17, then ceased through April 7, then was initiated briefly on April 8, before ceasing again through April 18. BTLUE had discharge from April 19-23, then went dry again from April 24 through May 18. During the remainder of the water year, enough recharge occurred to sustain discharge through September. The annual groundwater discharge from BTLUE during the water year was 53.7 ac-ft and the average daily discharge was 0.074 cfs (Table 19). The annual discharge was equivalent to 7% of the precipitation during the water year.

BTLUW was dry during much of WY 1990. The first period of discharge during the water year was initiated by snowmelt and lasted from February 5-9. The tile was dry on February 10 and 11, had limited discharge on February 12, and then was dry again until February 28. Snowmelt generated discharge from February 28 through March 2. During the remainder of the month, discharge occurred from March 8-15, then flow ceased until May 19. Discharge ceased late on May 19, and BTLUW remained dry through June 1. Following limited discharge on June 2, the tile went dry again and remained dry until June 12. During the remainder of June, discharge occurred on June 12-13, June 15-17, and June 21-25. In July discharge occurred only during July 19 and 27. During the remainder of the water year discharge from BTLUW occurred August 18-19 and from August 24 through September 11. The nineteen-day period following August 24 was the longest period of continuous discharge from BTLUW during the water year. The annual discharge from BTLUW was 13.9 ac-ft at an average daily discharge rate of 0.019 cfs (Table 20). This discharge was equivalent to 4% of the annual precipitation during WY 1990.

As mentioned before, BTLD remained dry through WY 1989 and most of WY 1990 until August 25. Once discharge began on August 25, discharge was continuous through September 26. The annual groundwater discharge from BTLD during the water year was 1.2 ac-ft and the average daily discharge was 0.002 cfs (Table 21). The annual discharge was equivalent to 2% of the precipitation during the water year.

At Big Spring the annual discharge during WY 1990 was 17,476 ac-ft, or 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 percentage of precipitation discharged during WYs 1982-1995 (Liu et al., 1995).

Although the annual precipitation was approximately 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 Big Spring basin during the water year. A large percentage of 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 18-21 and Figure 24 summarize the nitrate analyses from BOOGD, BTLUE, BTLUW, and BTLD 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 annual nitrate-nitrogen output for the water year was 5,103 pounds, and the annual 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 nitrate-nitrogen and 16.6 lbs-N/acre for total nitrogen.

As previously mentioned, BOOGD was essentially dry during the first four months of WY 1990 and from mid-March through mid-June (Fig. 24). The nitrate concentration was 8 mg/L (1.8 mg/L as NO_3-N) on January 16 as discharge began after being dry since October 30. The concentration was 51 mg/L (11.3 mg/L as NO_3-N) in mid-March following a series of minor rainfalls. Precipitation in June generated recharge,

Table 21. Annual summary of water and chemical discharge for BTLD for WY 1990.

DISCHARGE		
Total		
acre-feet	1.2	
millions cf	0.05	
millions cm	0.002	
Average		
cfs	0.002	
cms	0.0001	
mg/d	0.001	
gpm	0.90	
PRECIPITATION AND DISCHARGE		
Precipitation	37.87 inches (961.9 mm)	
Discharge	0.80 inches (20.3 mm)	
Discharge as % of precipitation	2%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	66.2	14.7
Mean of analyses	64.5	14.3
	NO_3-N output	**Total N output**
lbs - N	49.7	50.6
kg - N	22.6	23.0
lbs-N/acre	2.8	2.8
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	0.00	
Mean of analyses	0.00	
Total output		
lbs	0.00	
g	0.00	

and continuous discharge began on June 13. The nitrate concentration increased from 4 mg/L (0.9 mg/L as NO_3-N) on June 15 to 133 mg/L (29.6 mg/L as NO_3-N) on June 26. The nitrate concentration decreased to 65 mg/L (14.4 mg/L as NO_3-N) in mid-July during minor runoff. From July, the nitrate concentration increased to 95 mg/L (21.1 mg/L as NO_3-N) in early August, two days after runoff. The concentration 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 declined.

The greatest monthly fw mean nitrate concentration for BOOGD during the water year, 99.0 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 greatest monthly nitrate-nitrogen output of 4,542 pounds, and the greatest monthly surface-water discharge, 110 ac-ft, which accounted for 89% of the annual nitrate-nitrogen output and 64% of the annual surface-water discharge at BOOGD.

Seventy-nine samples from BTLUE were analyzed for nitrate, and forty-nine samples were analyzed for N-series during WY 1990. The annual fw mean nitrate concentration was 117.0 mg/L (26.0 mg/L as NO_3-N). The annual nitrate-nitrogen output for the water year was 3,797 pounds, which is equivalent to 15.2 lbs-N/acre and the annual total nitrogen output (nitrate- plus organic- and ammonia-nitrogen) was 4,039 pounds or 16.2 lbs-N/acre within the drainage area of BTLUE.

Nitrate concentrations from BTLUE followed the same general trends as concentrations from BOOGD. Concentrations fluctuated between 7 mg/L (1.6 mg/L as NO_3-N) and 13 mg/L (2.9 mg/L as NO_3-N) from February 5-8 (Fig. 24). Snowmelt in early March generated runoff, and nitrate concentrations decreased to the lowest concentration recorded during the water year, 4 mg/L (0.9 mg/L as NO_3-N), during peak discharge on March 1. Discharge ceased late on March 2, then resumed March 8, and the nitrate concentration increased to 24 mg/L (5.3 mg/L as NO_3-N) as discharge declined. Precipitation in mid-March generated runoff and minor infiltration recharge and the nitrate concentration increased from 79 mg/L (17.6 mg/L as NO_3-N) on March 11 to 129 mg/L (28.7 mg/L as NO_3-N) on March 13. The concentration increased further to 147 mg/L (23.7 mg/L as NO_3-N) on March 14, as discharge receded. Following the events in mid-March, discharge ceased from March 17 until April 8, then ceased again from April 9-18. Discharge resumed from April 19-23, then ceased again until May 19. On May 20, the nitrate concentration was 209 mg/L (46.4 mg/L as NO_3-N) as discharge was receding from an event that occurred on May 19. Discharge and nitrate concentrations remained steady through May 22, then nitrate concentrations declined along with discharge to 157 mg/L (34.9 mg/L as NO_3-N) on May 30. Concentrations decreased to 112 mg/L (24.8 mg/L as NO_3-N) during an event on June 2, then increased to 144 mg/L (32.0 mg/L as NO_3-N) on June 7 as discharge continued to recede through June 11. The nitrate concentration decreased to 97 mg/L (21.6 mg/L as NO_3-N) during an event on June 12, then increased to 126 mg/L (28.0 mg/L as NO_3-N) at 01:00 on June 13 as discharge receded. The concentration declined to 33 mg/L (7.3 mg/L as NO_3-N) at 09:45 after discharge peaked at 1.40 cfs at 09:20, then increased to 180 mg/L (40.0 mg/L as NO_3-N) at 21:30 as discharge declined from this event. The nitrate concentration was 171 mg/L (38.0 mg/L as NO_3-N) on June 14, as discharge continued to decline. On June 15, the concentration was diluted to 96 mg/L (21.3 mg/L as NO_3-N) during minor runoff, then on the following day the concentration increased to 190 mg/L (42.2 mg/L as NO_3-N) as discharge receded. On June 17, the concentration decreased to 140 mg/L (31.1 mg/L as NO_3-N) at 05:30, as discharge increased, then increased to 219 mg/L (48.7 mg/L as NO_3-N) at 21:00 as discharge receded. Nitrate concentrations remained near 200 mg/L (44.4 mg/L as NO_3-N) as discharge continued to recede through June 21. The greatest nitrate concentration recorded at BTLUE during the water year, 231 mg/L (51.3 mg/L as NO_3-N), occurred on June 22 at 20:00, following peak

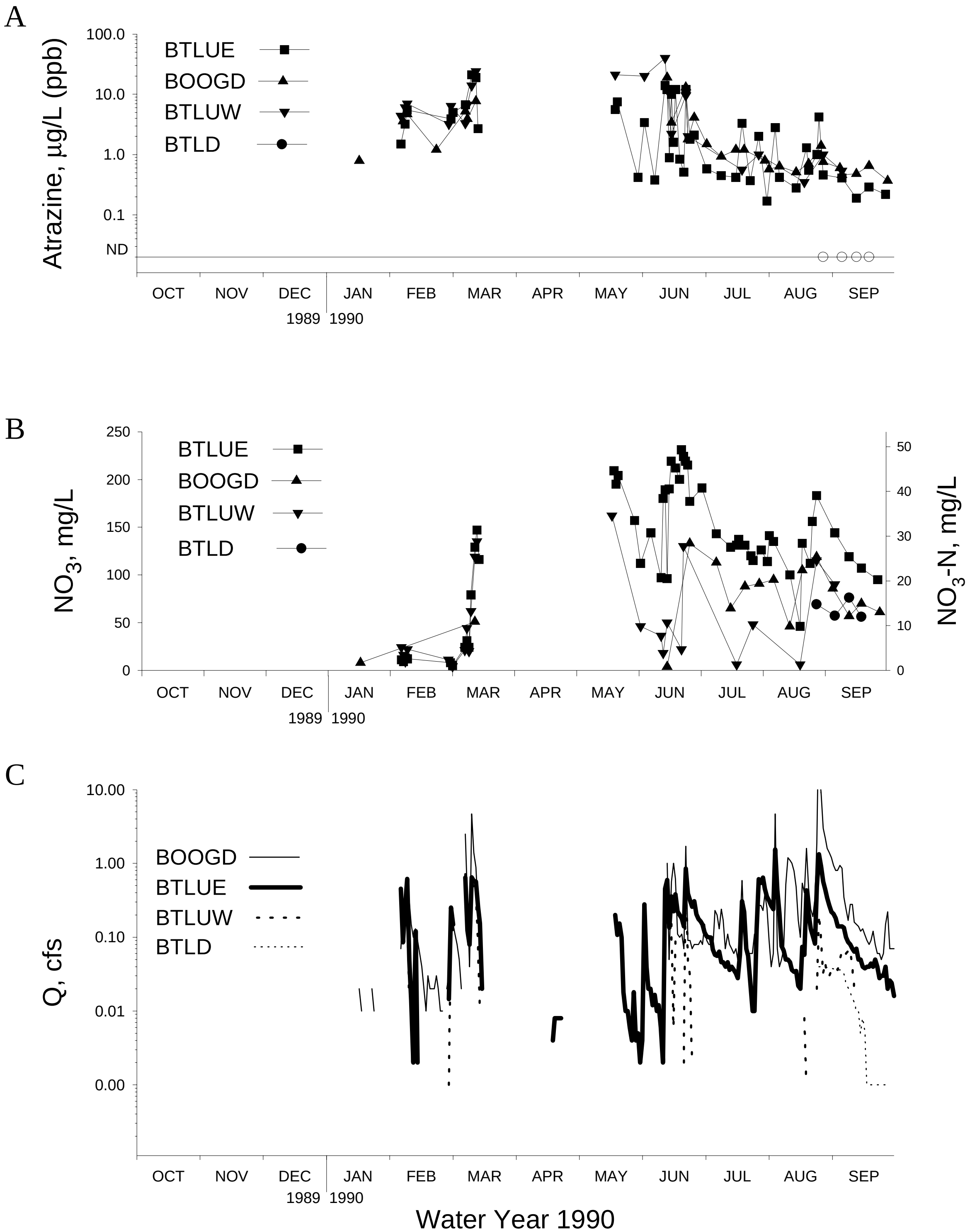


Figure 24. A) Atrazine and B) nitrate concentrations, and C) groundwater and surface-water discharge (Q) at BTLUE, BTLUW, BOOGD and BTLD for WY 1990 (note the large increase in scale on the nitrate plot relative to WY 1989). (Discharge data for BOOGD are from the U.S. Geological Survey, W.R.D., IA Dist.)

discharge of 1.48 cfs at 08:15. Following this, discharge receded through July 17, and nitrate concentrations generally declined, and were diluted to 46 mg/L (10.2 mg/L as NO_3-N) during runoff on August 19. The nitrate concentration increased to 133 mg/L (29.6 mg/L as NO_3-N) on August 20 and discharge receded through August 23. After the last major precipitation during the water year, mean daily discharge increased to 1.33 cfs on August 25, then discharge receded through September. The nitrate concentration decreased to 50 mg/L (11.1 mg/L as NO_3-N) an hour after peak discharge on August 25, then increased to 156 mg/L (34.7 mg/L as NO_3-N) at 21:30 as discharge receded. The nitrate concentration increased to 183 mg/L (40.7 mg/L as NO_3-N) on August 27, then decreased along with discharge during the remainder of the water year.

Monthly fw mean nitrate concentrations and nitrate-nitrogen loads for BTLUE were computed for the months of February through September. Monthly fw mean concentrations varied from 10.1 mg/L (2.2 mg/L as NO_3-N) in February to 186 mg/L (41.3 mg/L as NO_3-N) in May. February and March were the only months during the water year with fw mean nitrate concentrations below 100 mg/L (22.2 mg/L as NO_3-N). April had the third-lowest monthly fw mean nitrate concentration, 100 mg/L (22.2 mg/L as NO_3-N), the smallest nitrate-nitrogen output, 5.0 pounds, and the smallest computed monthly groundwater discharge at 0.083 ac-ft. August had the greatest monthly nitrate-nitrogen output, 1,286 pounds, and the greatest monthly groundwater discharge, 18.02 ac-ft. August accounted for 34% of the annual groundwater discharge and 34% of the annual nitrate-nitrogen output, while April accounted for 0.15% of the annual groundwater discharge and 0.13% of the annual nitrate-nitrogen discharge.

At BTLUW, thirty-nine samples were analyzed for nitrate, and twenty samples were analyzed for N-series during the water year. The annual fw mean nitrate concentration was 47.0 mg/L (10.4 mg/L as NO_3-N). The annual nitrate-nitrogen output for the water year was 395 pounds, and if organic- and ammonia-nitrogen are considered, the annual total nitrogen output was 712 pounds. Within the drainage area of BTLUW, the total nitrate-nitrogen output was equivalent to 3.4 lbs-N/acre, and total nitrogen output was equal to 6.1 lbs-N/acre.

Nitrate concentrations from BTLUW followed the same trends as concentrations from BTLUE and BOOGD, although concentrations were usually lower. As at other sites, concentrations increased significantly in early March and mid-May, declined in mid-June, mid-July and mid-August, then increased in late August before declining in September. Unlike BTLUE and BOOGD, the greatest nitrate concentration recorded at BTLUW during the water year, 162 mg/L (36.0 mg/L as NO_3-N), occurred following runoff on May 19, rather than in mid to late June. The smallest concentration recorded at BTLUW during the water year, 4 mg/L (0.9 mg/L as NO_3-N), occurred during runoff on March 2.

Monthly fw mean nitrate concentrations and nitrate-nitrogen loads for BTLUW were computed for the months of February and March, and May through September. Monthly fw mean concentrations varied from 13.0 mg/L (2.9 mg/L as NO_3-N) in February to 157.3 mg/L (35.0 mg/L as NO_3-N) in May. August was the only other month at BTLUW during the water year with a fw mean nitrate concentration greater than 100 mg/L (22.2 mg/L as NO_3-N). March had the greatest monthly nitrate-nitrogen output, 167.7 pounds, and the greatest monthly groundwater discharge, 5.94 ac-ft, accounting for 42% of the annual nitrate-nitrogen output and 43% of the annual groundwater discharge. July had the smallest monthly nitrate-nitrogen output, 1.53 pounds, and the smallest computed monthly groundwater discharge, 0.13 ac-ft, accounting for 0.39% of the annual nitrate-nitrogen discharge and 0.94% of the annual groundwater discharge.

Since BTLD remained dry until August 25, not many water quality samples were taken during WY 1990. Four samples were analyzed for nitrate, and four samples were analyzed for N-series during the water year. The annual fw mean nitrate concentration for BTLD for WY 1990 was 66.2 mg/L (14.7 mg/L as NO_3-N; Table 21). The annual nitrate-nitrogen output was 49.7 pounds, and the total nitrogen output (nitrate- plus organic- and ammonia-nitrogen) was 50.6 pounds. Within the drainage area of BTLD, these outputs were equivalent to 2.8 lbs-N/acre of nitrate-nitrogen and 2.8 lbs-N/acre of total nitrogen.

Discharge receded from 0.04 cfs on August 25 to 0.001 cfs on September 26, then flow ceased, and BTLD remained dry until March 12, 1991. Nitrate concentrations were relatively low during the sampling period, and showed less fluctuation than concentrations from BOOGD, BTLUE and BTLUW. The nitrate concentration decreased from 69 mg/L (15.3 mg/L as NO_3-N) on August 27 to 57 mg/L (12.7 mg/L as NO_3-N) on September 9. The greatest nitrate concentration recorded at BTLD during the water year, 76 mg/L (16.9 mg/L as NO_3-N), occurred on September 12, and the smallest nitrate concentration recorded, 56 mg/L (12.4 mg/L as NO_3-N), occurred on September 18.

The monthly fw mean nitrate concentration, nitrate-nitrogen load, and groundwater discharge for BTLD for August were 69.0 mg/L (15.3 mg/L as NO_3-N), 22.6 pounds, and 0.54 ac-ft. For September, the fw mean nitrate concentration, nitrate-nitrogen load, and groundwater discharge were 64.0 mg/L (14.2 mg/L as NO_3-N), 27.1 pounds, and 0.70 ac-ft. August accounted for 45% of the annual nitrate-nitrogen output and 45% of the annual groundwater discharge, while September accounted for 55% of the annual nitrate-nitrogen output and 55% of the annual groundwater discharge for BTLD during WY 1990.

The annual fw mean nitrate concentration for Big Spring for WY 1990 was 37 mg/L (8.2 mg/L as NO_3-N; Rowden, et al., 1993a). 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 18.5 mg/L (4.1 mg/L as NO_3-N) in February to 50.9 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 smallest and smallest groundwater discharge, respectively. The nitrate-nitrogen discharges during these two months were the smallest monthly nitrate-nitrogen loads recorded at Big Spring during WYs 1982-1995 (Liu, et al., 1997).

Pesticide Monitoring

Tables 18-21 and Figure 24 summarize the results of pesticide monitoring at sites BOOGD, BTLUE, BTLUW, and BTLD 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 653 grams.

Due to discontinuous daily discharge, pesticide samples were not taken at BOOGD until January 16, when the atrazine concentration was 0.79 µg/L (Fig. 24). In February, the atrazine concentration increased to 4.70 µg/L following runoff from minor precipitation and snowmelt. The concentration declined to 1.20 µg/L in late February as discharge receded. In March, precipitation generated runoff and the atrazine concentration 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, 23, and 31 and on June 2. The greatest atrazine concentration reported from BOOGD, 19.0 µg/L, was sampled June 13, the day that continuous daily discharge resumed. During the remainder of the water year, recharge from precipitation sustained discharge and atrazine concentrations generally declined.

Monthly fw mean atrazine concentrations for BOOGD 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 56% of the annual atrazine discharge and 64% of the annual surface-water discharge.

Other pesticides detected at BOOGD during WY 1990 include cyanazine in fourteen, or 45%, of the samples, and metolachlor and alachlor in seven, or 23%, of the samples collected. The greatest concentrations 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.

Sixty-one samples from BTLUE were analyzed for pesticides during WY 1990. All of the samples collected contained detectable levels of atrazine (>0.10 µg/L). The annual atrazine discharge from BTLUE was 223 grams, at an annual fw mean concentration of 3.36 µg/L.

BTLUE was dry from September 2 until February 5, when the atrazine concentration increased from 1.10 µg/L at 15:15 to 1.50 µg/L at 18:15, as discharge decreased from 0.90 cfs at 16:15 to 0.02 cfs at 23:30. The atrazine concentration increased from 3.20 µg/L on February 7 to 5.50 µg/L on February 8 as discharge increased. Discharge ceased on February 13 and BTLUE remained dry until February 28. The atrazine concentration increased from 3.30 µg/L on March 1 to 5.00 µg/L on March 2, prior to discharge ceasing again late on March 2. Discharge resumed on March 8, and the atrazine concentration increased from 1.80 µg/L at 08:30 to 4.70 µg/L at 16:45. The concentration increased further to 6.70 µg/L at 19:35, as discharge increased from 0.51 cfs at 08:30 to 0.94 cfs at 09:00, then decreased to 0.25 cfs at 22:00. The greatest atrazine concentration recorded at BTLUE during the water year, 21.00 µg/L, occurred during peak discharge from runoff on March 11. During runoff on March 13, the concentration increased from 7.10 µg/L at 14:00 to 19.00 µg/L at 19:00 as discharge increased from 0.097 cfs to 1.30 cfs. The concentration was 2.70 µg/L during another, smaller event on March 14. Discharge ceased again on March 16, and BTLUE remained dry through May 18, except for some minor discharge on April 8 and April 19-23. On May 19, the atrazine concentration decreased from 5.60 µg/L at 14:10 to 3.40 µg/L at 20:00 as discharge receded from a minor event. The concentration was 7.50 µg/L the following day as discharge continued to recede. After minor runoff on May 21, discharge generally receded through May 31, and the atrazine concentration decreased to 0.42 µg/L on May 30. The concentration declined from 3.40 µg/L on June 2 to 0.38 µg/L on June 7 as discharge receded through June 11. The atrazine concentration increased to 14.00 µg/L during an event on June 12, and decreased from 12.00 µg/L at 09:45 to 1.00 µg/L at 21:30 as discharge receded during another event on June 13. The atrazine concentration declined to 0.89 µg/L on June 14 as discharge continued to recede, then increased to 10.00 µg/L during minor runoff on the following day. The concentration declined, along with discharge, to 1.60 µg/L on June 16. During an event on June 17, the concentration increased from 1.00 µg/L at 05:30 to 12.00 µg/L at 21:00, then decreased to 0.84 µg/L on June 19 and 0.51 µg/L on June 21, as discharge receded. On June 22, the atrazine concentration decreased from 12.00 µg/L at 08:30 to 2.90 µg/L at 20:00 as discharge receded. The shape of the hydrograph indicates that some infiltration recharge was associated with this event, since discharge did not return to baseflow as quickly as in previous events (Fig. 24). The generally lower atrazine concentrations following this event also suggest that an increased proportion of the tile effluent was being supplied by infiltration recharge. The concentration was 1.80 µg/L on June 24, then increased slightly, along with discharge, to 2.10 µg/L on June 26, before declining to 0.42 µg/L on July 16. During the remainder of the water year, atrazine concentrations remained below 5.00 µg/L. In July and August, concentrations generally increased and decreased along with discharge. The atrazine concentration increased to 4.20 µg/L during the last major event of the water year on August 25, then concentrations declined, along with discharge, through the end of the water year.

Monthly fw mean atrazine concentrations for BTLUE were calculated for the months February through September. Monthly fw mean atrazine concentrations varied from 10.97 µg/L in March, to 0.30 µg/L in September. March had the greatest monthly atrazine output, 90.3 grams, and the fourth-greatest monthly groundwater discharge, 6.67 ac-ft, accounting for 40% of the annual atrazine output and 12% of the annual groundwater discharge. April had the smallest monthly atrazine output, 0.31 grams, and the smallest monthly groundwater discharge, 0.083 ac-ft, accounting for 0.14% of the annual atrazine output and 0.15% of the annual groundwater discharge.

Other pesticides detected at BTLUE during the water year include cyanazine in twenty-seven, or 44%, of the samples, alachlor in twenty, or 33%, and metolachlor in three, or 5%, of the samples collected. The greatest concentrations of pesticides detected during the water year included cyanazine at 46.00 µg/L, alachlor at 41.00 µg/L, atrazine at 21.00 µg/L, and metolachlor at 2.20 µg/L. The maximum concentration for atrazine occurred on March 11, the maximum for cyanazine occurred on June 2, and the maximum concentrations for alachlor and metolachlor occurred on June 12. Cyanazine was detected during May, June, July and August, alachlor was detected in March, May and June, and metolachlor was detected only in June.

Thirty samples from BTLUW 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 for BTLUW was 9.82 µg/L, and the annual atrazine output was 169 grams.

The atrazine plot for BTLUW shows seasonal variations in concentrations similar to the changes in atrazine concentrations from BTLUE (Fig. 24), although concentrations from BTLUW were generally greater in March and May, and showed less fluctuation from June through September. Like BTLUE, BTLUW was dry from the beginning of the water year until February 2. On February 5, the concentration increased from 1.90 µg/L at 15:45 to 4.40 µg/L at 19:00 as discharge receded from 1.52 cfs to 0.93 cfs. The concentration increased from 4.50 µg/L to 6.10 µg/L on February 7, and from 6.20 µg/L to 7.00 µg/L on February 8, as daily discharge increased. Discharge ceased at BTLUW late on February 12, and the tile remained dry until February 28, when the atrazine concentration was 3.20 µg/L during very low-flow conditions. On March 1, the concentration decreased from 5.80 µg/L at 15:20 to 5.60 µg/L at 15:50, then increased to 6.40 µg/L at 18:20, as discharge increased from 0.34 cfs to 0.38 cfs, then decreased to 0.23 cfs. Discharge ceased during the evening of March 2 and BTLUW remained dry until March 8.

The responses of atrazine concentrations to recharge during the events discussed above appear to be different than the responses of atrazine seen at BTLUE during the same events. At BTLUE, atrazine concentrations generally increased and decreased along with discharge. At BTLUW, during these events, the increase in atrazine concentrations followed slightly behind the peaks in discharge. This may be due to sampling bias, or it may be due to different proportions of runoff versus infiltration recharge occurring during peak discharge at the two tile lines due to structural differences in the tile-line systems. Differences in soil conditions and pesticide application areas between the two sites may also be a contributing factor.

Discharge at BTLUW resumed on March 8, and the atrazine concentration increased from 2.70 µg/L at 08:15 to 3.30 µg/L at 13:45. The concentration increased to 6.70 µg/L at 02:00 on March 9, as discharge increased from 0.30 cfs at 08:15 to 1.06 cfs at 09:00, then decreased to 0.81 cfs at 13:45 and 0.25 cfs at 02:00. The atrazine concentration increased to 14.00 µg/L as discharge increased on March 11. On March 13, the atrazine concentration increased from 9.80 µg/L at 13:50 to 24.00 µg/L at 19:00 after discharge peaked at 0.88 cfs at 17:45. Discharge ceased on March 15, and BTLUW remained dry until May 19, when the atrazine concentration was 21.00 µg/L. Flow ceased again later that evening and the tile was dry until June 2, when the atrazine concentration was 20.00 µg/L. Flow ceased again that evening, and BTLUW remained dry through June 11. The greatest atrazine concentration recorded at BTLUW during the water year, 40.00 µg/L, occurred during runoff on June 12. The atrazine concentration decreased to 12.00 µg/L as discharge receded from another event on June 13, and decreased to 2.20 µg/L during another event on June 15. BTLUW went dry on June 17, and remained dry until June 21. The atrazine concentration decreased, along with discharge, from 9.60 µg/L on June 22 to 2.00 µg/L on June 23. Discharge ceased again on June 25, and the tile line remained dry until July 19 when the concentration decreased from 0.56 µg/L at 14:50 to 0.40 µg/L at 16:15 following peak discharge at 15:00. Discharge ceased later that evening, and BTLUW was dry again until July 27, when the atrazine concentration was 1.00 µg/L during a very brief period of discharge. The atrazine concentration was 0.35 µg/L as discharge resumed on August 18. Flow ceased on August 19, and BTLUW remained dry until August 24. On August 27, the atrazine concentration was 1.00 µg/L during very low-flow conditions. Discharge remained steady through September 4, increased slightly from September 5-9, then receded through September 11. BTLUW was dry from September 12 through the remainder of the water year. The atrazine concentration of the last sample taken during the water year was 0.54 µg/L on September 5.

Monthly fw mean atrazine concentrations for BTLUW were calculated for the months February and March, and May through September. Monthly fw mean atrazine concentrations varied from 20.76 µg/L in May to 0.60 µg/L in September. The greatest monthly atrazine output, 88 grams, and the greatest monthly groundwater discharge, 5.94 ac-ft, occurred during March and accounted for 52% of the annual atrazine output and 43% of the annual groundwater discharge from BTLUW. The smallest monthly atrazine output, 0.10 grams, and the smallest computed monthly groundwater discharge, 0.13 ac-ft, occurred during July and accounted for 0.06% of the annual atrazine output and 0.94% of the annual groundwater discharge.

Other pesticides detected at BTLUW during WY 1990 include cyanazine in twenty-two, or 73%, of the samples, alachlor in fifteen, or 50%, and metolachlor in five, or 17%, of the samples collected. The greatest concentrations of pesticides detected at BTLUW during the water year include alachlor at 84.00 µg/L, cyanazine at 62.00 µg/L, atrazine at 40.00 µg/L, and metolachlor at 2.80 µg/L.

The maximum detections of alachlor, metolachlor and cyanazine occurred June 2 and the maximum detection for atrazine occurred June 12. Alachlor was detected during February, March, May, and June, cyanazine was detected during February, March, May, June, July, and August, and metolachlor was detected during June only.

As previously mentioned, BTLD remained dry from May 23, 1988 until August 25, 1990. Four samples from BTLD were analyzed for pesticides during late August and September of WY 1990. None of the samples contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration for BTLD was 0 µg/L, and the annual atrazine output was 0 grams (Table 21).

Groundwater discharge receded from 0.04 cfs on August 25 to 0.001 cfs on September 26, then flow ceased, and BTLD remained dry until March 12, 1991. No pesticides were detected in the samples taken on August 27 and September 5, 12 and 18

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

Water Year 1991

Discharge Monitoring

Tables 22-25 and Figure 25 summarize the discharge, water quality and chemical-load data for BOOGD, BTLUE, BTLUW and BTLD during WY 1991. In Figure 25 note the decrease in scale on the nitrate plot and the large increase in scale on the discharge plot relative to WY 1990.

Precipitation during the water year was 47.28 inches, or 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 the largest single rainfall (local reports of 11 to 13 inches near Monona, Iowa) occurred on June 14, causing extensive flooding throughout the Big Spring area. The annual precipitation during WY 1991 was the greatest recorded within the Big Spring basin during WYs 1982-1995 (Liu et al., 1997).

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 22). The annual discharge from BOOGD was equivalent to 35% of the annual precipitation. At site BTLUE, the annual discharge for the water year was 173 ac-ft, at an average daily discharge of 0.24 cfs (Table 23). The annual discharge was equal to 18% of the annual precipitation. The annual discharge for site BTLUW was 85.3 ac-ft and the average daily discharge was 0.118 cfs (Table 24). The annual discharge for BTLUW was equivalent to 19% of the annual precipitation. The annual discharge for site BTLD during the water year was 36.1 ac-ft, at an average daily discharge of 0.050 cfs (Table 25). The annual discharge from BTLD was equal to 51% of the annual precipitation. The annual surface-water discharge from BOOGD during WY 1991 was the greatest recorded at BOOGD during WYs 1986-1992. At Big Spring, the annual groundwater discharge was 42,481 ac-ft, or 16% of the annual precipitation, at an average flow rate of 59

Table 22. Annual summary of water and chemical discharge for BOOGD for WY 1991. (Discharge data are from the U.S. Geological Survey, W.R.D., IA Dist.).

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 23. Annual summary of water and chemical discharge for BTLUE for WY 1991.

DISCHARGE		
Total		
acre-feet	173	
millions cf	7.51	
millions cm	0.21	
Average		
cfs	0.24	
cms	0.007	
mg/d	0.16	
gpm	107	
PRECIPITATION AND DISCHARGE		
Precipitation	47.28 inches (1,201 mm)	
Discharge	8.30 inches (210.8 mm)	
Discharge as % of precipitation	18%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	120.8	26.8
Mean of analyses	107.1	23.8
	NO_3-N output	**Total N output**
lbs - N	12,606	13,467
kg - N	5,717	6,107
lbs - N/acre	50.4	53.9
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	4.36	
Mean of analyses	6.48	
Total output		
lbs	2.1	
g	929	

cfs (Rowden et al., 1993a).

During the first two months of the water year, discharge from BOOGD and BTLUE continued to recede from the last major runoff event in WY 1990 (Fig. 25). 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 BTLUE remained relatively steady from late October through mid-November, ranging from 0.038 cfs on October 8 to 0.002 cfs on November 17. Flow ceased on November 17, and BTLUE remained dry through February 26. Site BTLUW remained dry from the beginning of the water year until November 6, then had very minimal discharge through November 11, and was dry again through March 12. Discharge resumed on March 13, and BTLUW maintained flow through July 21, then was dry again through August 7, and from August 9 through September 8. Discharge ceased on September 10, then resumed on September 12 and continued through September 26. Site BTLUW remained dry from September 27 through the end of the water year. BTLD was dry from September 27 of WY 1990 through March 11, and from August 19 through September 11.

Snowmelt and small amounts of 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. Discharge at all sites peaked in mid-June following intense rainfall, and then receded through August. Precipitation in mid-September generated minor runoff, followed by receding discharge during the remainder of the water year. The peak daily discharges recorded on June 15 were the greatest observed at Big Spring during WYs 1982-1992, at BOOGD during WYs 1986-1992, at BTLD during WYs 1987-1994, and at BTLUE and BTLUW during WYs 1987-1995. The sustained increase in mean daily discharge during the latter half of the water year indicates a net increase in overall storage in the Big Spring basin's hydrologic system.

Table 24. Annual summary of water and chemical discharge for BTLUW for WY 1991.

DISCHARGE		
Total		
acre-feet	85.3	
millions cf	3.72	
millions cm	0.105	
Average		
cfs	0.118	
cms	0.003	
mg/d	0.076	
gpm	53.0	

PRECIPITATION AND DISCHARGE	
Precipitation	47.28 inches (1,201 mm)
Discharge	8.82 inches (224.0 mm)
Discharge as % of precipitation	19%

NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	115.6	25.7
Mean of analyses	105.8	23.5
	NO_3-N output	**Total N output**
lbs - N	5,959	6,653
kg - N	2,702	3,017
lbs - N/acre	51.4	57.4

ATRAZINE DISCHARGE	
Concentration - µg/L	
Flow-weighted mean	6.90
Mean of analyses	4.76
Total output	
lbs	1.60
g	726

Nitrate Monitoring

Tables 22-25 and Figure 25 summarize the nitrate analyses from BOOGD, BTLUE, BTLUW and BTLD during WY 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 nitrate-nitrogen and 68.7 lbs-N/acre for total nitrogen. The annual fw mean nitrate-nitrogen concentration and load for WY 1991 were the greatest recorded from BOOGD during WYs 1986-1992.

As previously mentioned, BOOGD was essentially dry from November through February (Fig. 25). During October, the nitrate concentration 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). The concentration increased to 64 mg/L (14.2 mg/L as NO_3-N) following minor runoff in mid-March. From late March, a general increase in both nitrate concentrations and discharge occurred at BOOGD, and at most other sites in the basin. Nitrate concentrations remained above 100 mg/L (22.5 mg/L as NO_3-N) until early July, decreasing to 99 mg/L (22.0 mg/L as NO_3-N) in early April and 86 mg/L (19.1 mg/L as NO_3-N) in late April. The concentration peaked at 182 mg/L (40.4 mg/L as NO_3-N) on July 23, as discharge receded. The smallest 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. The concentration 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.

The greatest monthly fw mean nitrate concentration from BOOGD, 108 mg/L (24.0 mg/L as NO_3-N), occurred during May, and the smallest monthly fw mean, 25 mg/L (5.6 mg/L as NO_3-N) occurred during November. June had the greatest monthly nitrate-nitrogen output, 14,366 pounds,

Table 25. Annual summary of water and chemical discharge for BTLD for WY 1991.

DISCHARGE		
Total		
acre-feet	36.1	
millions cf	1.57	
millions cm	0.044	
Average		
cfs	0.050	
cms	0.001	
mg/d	0.032	
gpm	22.4	
PRECIPITATION AND DISCHARGE		
Precipitation	47.28 inches (1,201 mm)	
Discharge	24.07 inches (611.4 mm)	
Discharge as % of precipitation	51%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	71.8	15.9
Mean of analyses	64.0	14.2
	NO_3-N output	**Total N output**
lbs - N	1,565	1,593
kg - N	710	723
lbs-N/acre	86.9	88.5
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	0.04	
Mean of analyses	0.09	
Total output		
lbs	0.004	
g	1.86	

and the greatest monthly surface-water discharge, 466 ac-ft, which accounted for 32% of the annual nitrate-nitrogen output and 46% of the annual surface-water discharge at BOOGD.

During WY 1991, fifty-seven samples from BTLUE were analyzed for nitrate, and fifty-six samples were analyzed for N-series. The annual fw mean nitrate concentration for BTLUE was 120.8 mg/L (26.8 mg/L as NO_3-N). The annual nitrate-nitrogen output for the water year was 12,606 pounds, which is equivalent to 50.4 lbs-N/acre and the total nitrogen output was 13,467 pounds, or 53.9 lbs-N/acre within the BTLUE drainage area. The annual fw mean nitrate-nitrogen concentration and load from BTLUE for WY 1991 were the greatest recorded at BTLUE during WYs 1987-1995.

Nitrate concentrations from BTLUE showed trends similar to concentrations from BOOGD during the water year, although concentrations were usually greater than concentrations from BOOGD and BTLUW. Nitrate concentrations were relatively steady at BTLUE during the first two months of the water year. Concentrations ranged from 90 mg/L (20.0 mg/L as NO_3-N) on October 1 to 81 mg/L (18.0 mg/L as NO_3-N) on November 13. Flow ceased on November 17, and BTLUE remained dry through February 26. The nitrate concentration increased from 116 mg/L (25.8 mg/L as NO_3-N) on March 5 to 128 mg/L (28.4 mg/L as NO_3-N) on March 6 as discharge receded from a minor event. The greatest nitrate concentration sampled at BTLUE during the water year, 148 mg/L (32.9 mg/L as NO_3-N), occurred on March 25 as discharge receded from an event that occurred on March 22. The smallest concentration sampled at BTLUE during the water year, 49 mg/L (10.9 mg/L as NO_3-N), occurred on April 29 during peak discharge from runoff. The concentration increased to 144 mg/L (32.0 mg/L as NO_3-N) on May 6 following a minor event on May 5. On June 15, the nitrate concentration increased to 148 mg/L (32.9 mg/L as NO_3-N), matching the previous peak concentration, 2 hours after the greatest discharge peak recorded during the water year at BTLUE. Two days later the nitrate concentration decreased to

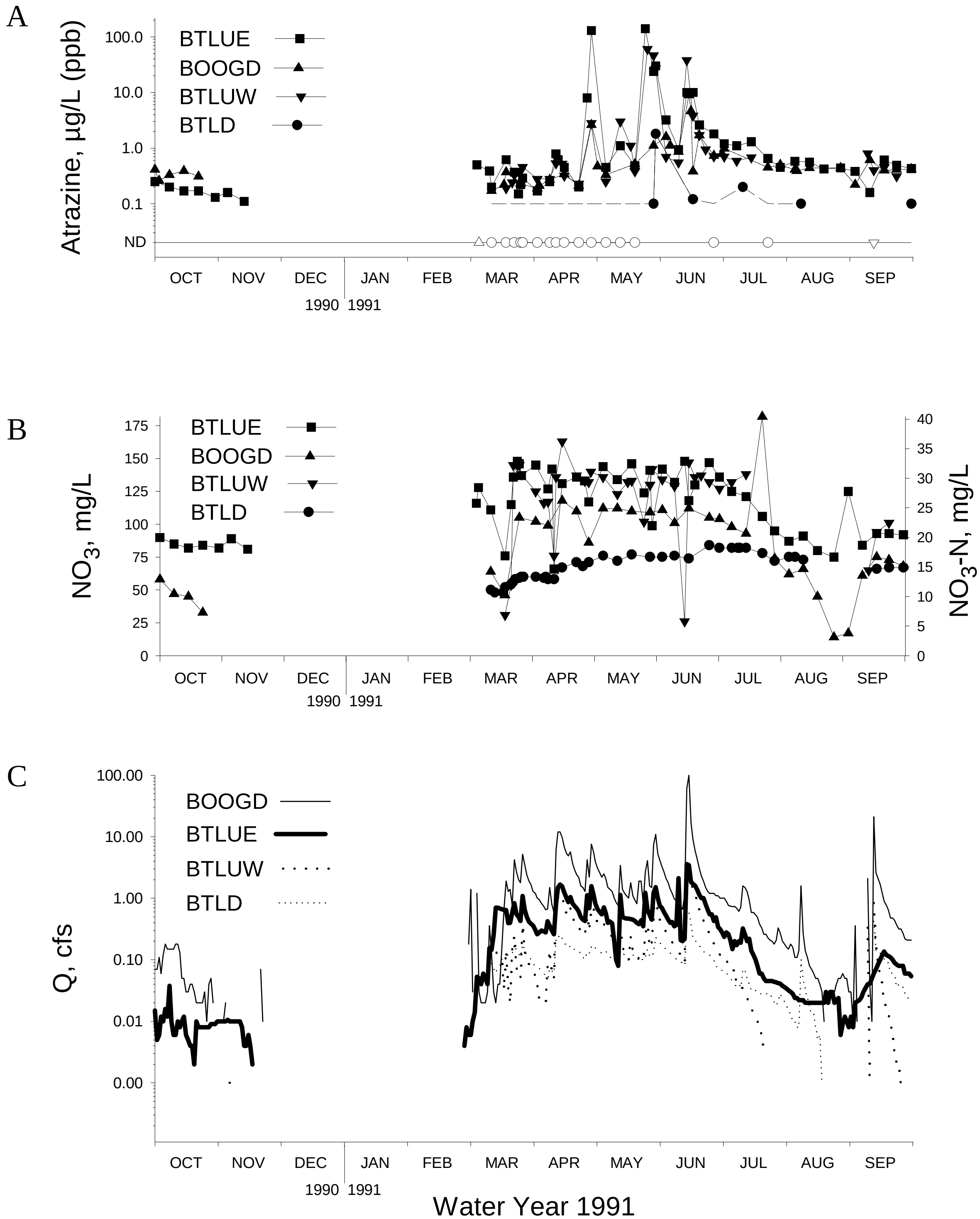


Figure 25. A) Atrazine and B) nitrate concentrations, and C) groundwater and surface-water discharge (Q) at BTLUE, BTLUW, BOOGD and BTLD for WY 1991 (note the decrease in scale on the nitrate plot and the increase in scale on the discharge plot relative to WY 1990). (Discharge data for BOOGD are from the U.S. Geological Survey, W.R.D., IA Dist.)

118 mg/L (26.2 mg/L as NO_3-N) as discharge receded. During the remainder of June and July, nitrate concentrations ranged from 147 mg/L (32.7 mg/L as NO_3-N) on June 27 to 95 mg/L (21.1 mg/L as NO_3-N) on July 29. From June, discharge continued to recede through August, and the nitrate concentration declined to 75 mg/L (16.7 mg/L as NO_3-N) on August 27. The concentration increased to 125 mg/L (27.8 mg/L as NO_3-N) during a minor event on September 3, then decreased to 84 mg/L (18.7 mg/L as NO_3-N) one week later as discharge increased. Groundwater discharge continued to increase through September 17, then decreased through the end of the year. Nitrate concentrations remained near 93 mg/L (20.7 mg/L as NO_3-N) during the last three weeks of the water year.

Monthly fw mean nitrate concentrations for BTLUE were computed for all months during the water year except December and January. Monthly fw mean concentrations remained over 100 mg/L (22.2 mg/L as NO_3-N) from February through July. The smallest monthly fw mean nitrate concentration from BTLUE during the water year, 85.5 mg/L (19.0 mg/L as NO_3-N), occurred during both October and November. The greatest monthly fw mean, 127.0 mg/L (28.2 mg/L as NO_3-N), occurred during July, when an increased percentage of discharge was probably being supplied by infiltration recharge. The smallest monthly nitrate-nitrogen load, 1.7 pounds, and the smallest computed monthly groundwater discharge, 0.024 ac-ft, occurred during February, and the greatest monthly nitrate-nitrogen load, 4,241 pounds, and greatest monthly groundwater discharge, 55.8 ac-ft, occurred during June. February accounted for 0.01% of both the annual nitrate-nitrogen and the annual groundwater discharge from BTLUE. June accounted for 34% of the annual nitrate-nitrogen discharge and 32% of the annual groundwater discharge.

At BTLUW, forty-seven samples were analyzed for nitrate, and thirty-eight samples were analyzed for N-series during the water year. The annual fw mean nitrate concentration was 115.6 mg/L (25.7 mg/L as NO_3-N). The annual nitrate-nitrogen output for the water year was 5,959 pounds, and if organic- and ammonia-nitrogen are considered, the total nitrogen output was 6,653 pounds. Within the drainage area of BTLUW, the annual nitrate-nitrogen output was equivalent to 51.4 lbs-N/acre, and total nitrogen output was equal to 57.4 lbs-N/acre. The annual fw mean nitrate concentration for WY 1991 was the greatest recorded at BTLUW during WYs 1987-1995. The annual nitrate-nitrogen discharge during WY 1991 was the second greatest recorded at BTLUW during WYs 1987-1995.

Nitrate concentrations from BTLUW showed seasonal trends similar to concentrations from BOOGD and BTLUE, with concentrations being generally smaller than concentrations from BTLUE, and generally greater than concentrations from BOOGD. BTLUW was dry from September 12 through November 5, and again from November 12 through March 12. The nitrate concentration increased from 31 mg/L (6.9 mg/L as NO_3-N) on March 19, to 145 mg/L (32.2 mg/L as NO_3-N) on March 23, 25 and 26 following a series of runoff events. The greatest nitrate concentration recorded at BTLUW during the water year, 163 mg/L (36.2 mg/L as NO_3-N), occurred on April 16, as discharge receded from an event on April 14. From late April to mid-June nitrate concentrations remained above 100 mg/L (22.2 mg/L as NO_3-N), except during events when concentrations were temporarily diluted by the influx of surface runoff. The smallest nitrate concentration sampled at BTLUW during the water year, 26 mg/L (5.8 mg/L as NO_3-N), occurred on June 15, at 14:15, 10 hours after the greatest discharge peak recorded at BTLUW during the water year. Two days later, the nitrate concentration increased to 147 mg/L (32.7 mg/L as NO_3-N) as discharge continued to recede. Groundwater discharge receded from mid-June until ceasing on July 21. Nitrate concentrations declined from mid-June to 127 mg/L (28.2 mg/L as NO_3-N) on July 2, then increased to 138 mg/L (30.7 mg/L as NO_3-N) on July 15. BTLUW remained dry from July 22 through August 7, then was dry again from August 9 through September 8, and was also dry on September 11. The nitrate concentration increased from 65 mg/L (14.4 mg/L as NO_3-N) on

September 13 to 94 mg/L (20.9 mg/L as NO_3-N) on September 17, and increased to 101 mg/L (22.4 mg/L as NO_3-N) on September 23, as discharge receded. Flow ceased at BTLUW on September 26 and the tile remained dry through October 31.

Monthly fw mean nitrate concentrations for BTLUW were computed for November and March through September. Monthly fw mean concentrations remained over 100 mg/L (22.2 mg/L as NO_3-N) from April through July. The smallest monthly fw mean nitrate concentration from BTLUW during the water year, 30.0 mg/L (6.7 mg/L as NO_3-N), occurred in November and the greatest monthly fw mean, 133.2 mg/L (29.6 mg/L as NO_3-N), occurred during April, when an increased percentage of discharge was probably being supplied by infiltration recharge. The smallest monthly nitrate-nitrogen load, 0.2 pounds, and the smallest computed monthly groundwater discharge, 0.012 ac-ft, occurred during November, and the greatest monthly nitrate-nitrogen load, 2,253 pounds, and greatest monthly groundwater discharge, 35.0 ac-ft, occurred during June. November accounted for less than 0.003% of the annual nitrate-nitrogen output and 0.01% of the annual groundwater discharge from BTLUW. June accounted for 38% of the annual nitrate-nitrogen output and 41% of the annual groundwater discharge.

During the water year, forty-five samples from BTLD were analyzed for nitrate, and twenty-eight samples were analyzed for N-series. The annual fw mean nitrate concentration for BTLD was 71.8 mg/L (15.9 mg/L as NO_3-N), the annual nitrate-nitrogen output was 1,565 pounds, and the total nitrogen output was 1,593 pounds. Within the drainage area of BTLD these outputs were equivalent to 86.9 lbs-N/acre for nitrate-nitrogen and 88.5 lbs-N/acre for total nitrogen. The fw mean nitrate-nitrogen concentration and load for WY 1991 were the greatest recorded at BTLD during WYs 1987-1994.

BTLD was dry from September 27, 1990 through March 11, 1991, then was dry again from August 19 through September 11. The nitrate concentration increased from 48 mg/L (10.7 mg/L as NO_3-N) on March 14 to 84 mg/L (18.7 mg/L as NO_3-N) on June 27. From late June, concentrations decreased to 73 mg/L (16.2 mg/L as NO_3-N) on August 12, a week before discharge ceased. After discharge resumed, the nitrate concentration increased from 66 mg/L (14.7 mg/L as NO_3-N) on September 17 to 67 mg/L (14.9 mg/L as NO_3-N) on September 23 and 30.

Monthly fw mean nitrate concentrations for BTLD were computed for the months of March through September. Monthly fw mean concentrations remained over 60 mg/L (13.3 mg/L as NO_3-N) from April through September. The smallest monthly fw mean nitrate concentration from BTLD during the water year, 54.4 mg/L (12.1 mg/L as NO_3-N), occurred during March and the greatest monthly fw mean, 82.7 mg/L (18.4 mg/L as NO_3-N), occurred in June. The greatest monthly nitrate-nitrogen load, 488 pounds, and the greatest monthly groundwater discharge from BTLD during the water year, 9.8 ac-ft, occurred during June. The smallest monthly nitrate-nitrogen load, 31.2 pounds, and smallest computed monthly discharge, 0.70 ac-ft, occurred during August. June accounted for 31% of the annual nitrate-nitrogen output and 27% the annual groundwater discharge from BTLD, while August accounted for 2% of both the annual nitrate-nitrogen output and the annual groundwater discharge.

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., 1993a). 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 for WY 1991 was the greatest recorded at Big Spring during WYs 1982-1995 (Liu et al., 1997). The annual nitrate-nitrogen output for WY 1991 was the second greatest recorded at Big Spring during WYs 1982-1995 (Liu et al., 1997).

The greatest monthly fw mean nitrate concentrations recorded at Big Spring during WYs 1982-1995 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 mg/L as NO_3-N). The greatest monthly fw mean nitrate concentrations previously recorded were 54 mg/L (12.0 mg/L as NO_3-N) in April, and 56 mg/L (12.4 mg/L as NO_3-N) in July of WY 1983. The smallest monthly fw mean nitrate concentration during the water year, 30.0 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 smallest groundwater discharge, to 326,000 pounds in June, the month with the greatest groundwater discharge. The monthly nitrate-nitrogen discharges during April and June of WY 1991 were the greatest monthly discharges recorded at Big Spring during WYs 1982-1995 (Liu et al., 1997).

Pesticide Monitoring

Tables 22-25 and Figure 25 summarize the results of pesticide monitoring at sites BOOGD, BTLUE, BTLUW and BTLD during WY 1991.

Forty-five samples from BOOGD were analyzed for pesticides during WY 1991. Forty-four, or 98%, of the samples contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration, 3.32 µg/L, and the annual atrazine output, 4.2 kilograms, were the greatest recorded at BOOGD during WYs 1986-1992.

Due to discontinuous daily discharge, pesticide samples were not taken at BOOGD from the end of October through early March. On March 6, the atrazine concentration was below the 0.10 µg/L detection limit (Fig. 25). 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. The concentration increased to 2.60 µg/L in late April during runoff, then decreased to 0.33 µg/L in May, as discharge receded. The atrazine concentration peaked at 9.00 µg/L on June 15 during the largest runoff event recorded at BOOGD during WYs 1986-1992. 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 the atrazine concentration was 0.61 µg/L the following day. Concentrations decreased slightly during the remainder of the water year.

Monthly fw mean atrazine concentrations from BOOGD 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, 3.5 kilograms, also occurred during June and accounted for 84% of the annual atrazine discharge.

Other pesticides detected at BOOGD during WY 1991 include cyanazine in eleven, or 24%, of the samples, alachlor in nine, or 20%, and metolachlor in two, or 4%, of the samples collected. The greatest concentrations 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, fifty-five samples from BTLUE were analyzed for pesticides. Fifty-four, or 98%, of the samples contained detectable levels of atrazine (>0.10 µg/L). The annual atrazine discharge from BTLUE was 929 grams, and the annual fw mean concentration was 4.36 µg/L. The annual atrazine discharge for WY 1991 was the greatest recorded at BTLUE during WYs 1986-1995. The annual fw mean atrazine concentration for WY 1991 was the second greatest recorded at BTLUE during WYs 1986-1995.

Atrazine concentrations from BTLUE showed seasonal trends similar to concentrations from BOOGD, although concentrations from BTLUE were usually greater. Atrazine concentrations generally decreased from 0.25 µg/L at the beginning of the water year to 0.11 µg/L on November 13, prior to discharge ceasing on November 17. Discharge resumed on February 27, and concentrations increased from 0.20 µg/L at 11:45 to 0.50 µg/L at 18:15 during minor runoff on March 5. From March through May, a number of runoff events generated fluctuations in atrazine concentrations. From mid-March through mid-April concentrations ranged from 0.15 µg/L on March 25 to 0.79 on April 12. The atrazine concentration increased from 2.40 µg/L at 13:50 to 130.00 µg/L at 14:30 during runoff on April 29. On May 6, concentrations were 0.45 µg/L as discharge continued to recede. The greatest atrazine concentration recorded at BTLUE during the water year, 140.00 µg/L, occurred during runoff on May 25. During an event on May 29, the atrazine concentration increased from 1.40 µg/L at 10:55 to 24.00 at 18:30, then decreased to 0.80 at 21:45. The only sample from BTLUE during the water year that did not contain detectable atrazine (>0.10 µg/L) was taken at 01:30 during an event on May 30. Four hours later, the atrazine concentration had increased to 30.00 µg/L. Since the non-detection was part of a multiple sampling during an event, it is not shown on Figure 25. The atrazine concentration was 3.20 µg/L on June 4, as groundwater discharge declined through June 9. The greatest runoff of the water year occurred June 14-15, and atrazine concentrations were 10.00 µg/L on June 14 and June 17. Following the event, both discharge and atrazine concentrations generally declined through August. Groundwater discharge increased through September 17, then receded during the remainder of the water year. The atrazine concentration decreased from 0.38 µg/L on September 3 to 0.16 µg/L on September 10, then increased to 0.61 µg/L on September 17 before declining to 0.43 µg/L on September 30.

Monthly fw mean atrazine concentrations and loads for BTLUE were computed for every month during the water year except December and January. Monthly fw mean atrazine concentrations varied from 0.11 µg/L in October to 6.93 µg/L in May. February had the smallest monthly atrazine discharge, 0.01 grams, accounting for 0.001% of the annual atrazine discharge. The monthly atrazine discharge for June, 383 grams, accounted for 41% of the annual atrazine output and was the greatest monthly atrazine discharge from BTLUE during WYs 1987-1995.

Other pesticides detected at BTLUE during the water year include alachlor in fifteen, or 27%, of the samples, cyanazine in twelve, or 22%, pendimethalin in 3, or 8%, and terbufos in one, or 3%, of the samples collected. The greatest concentrations of pesticides detected during the water year include atrazine and alachlor at 140.00 µg/L, cyanazine at 70.00 µg/L, terbufos at 3.40 µg/L, and pendimethalin at 0.63 µg/L. The maximum detections for cyanazine and terbufos occurred on April 29, maximums for atrazine and alachlor occurred on May 25, and for pendimethalin the maximum occurred on May 29. Alachlor was detected during November, April, May, and June, cyanazine was detected in April, May and June, pendimethalin was detected in May and June, and terbufos was detected only once in April.

Forty samples from BTLUW were analyzed for pesticides during WY 1991. Thirty-nine, or 98%, of the samples contained detectable levels of atrazine (>0.10 µg/L). The annual atrazine discharge for WY 1991, 726 grams, was the greatest annual discharge recorded at BTLUW during WYs 1987-1995. The annual fw mean atrazine concentration for WY 1991, 6.90 µg/L, was the third greatest recorded at BTLUW during WYs 1987-1995.

The atrazine plot for BTLUW shows seasonal variations in concentrations similar to the changes in concentrations at sites BOOGD and BTLUE during the last seven months of the water year (Fig. 25). As with BOOGD and BTLUE, atrazine concentrations at BTLUW were relatively low in March, increased during events in April, May, and June, then generally decreased along with discharge during the remainder of the water year. The greatest atrazine concentration recorded at BTLUW during WY 1991, 60.00 µg/L, occurred during minor runoff on May 26. Concentrations fluctuated along with discharge through the remainder of May and June, then declined as discharge receded. Flow ceased at BTLUW from July 22 through August 7, from August 9 through September 8, and on September 11. The only sample during the water year that did not contain detectable atrazine (>0.10 µg/L) was collected on September 13, as discharge receded from an event that occurred on September 12. Flow ceased September 26, and BTLUW remained dry through October 31.

Monthly fw mean atrazine concentrations and loads for BTLUW were calculated for the months of November, and March through September. Monthly fw mean atrazine concentrations and loads varied from 13.12 µg/L and 566 grams in June to 0.10 µg/L and 0.001 grams in November. The greatest monthly groundwater discharge, 35.0 ac-ft, occurred during June and the smallest computed monthly groundwater discharge, 0.01 ac-ft, occurred in November. The great differences among monthly fw mean atrazine concentrations and monthly groundwater discharges led to very great differences in monthly atrazine discharge. November accounted for 0.0001% of both the annual atrazine discharge and annual groundwater discharge, and June accounted for 78% of the annual atrazine discharge and 41% of the annual groundwater discharge.

Other pesticides detected at BTLUW during WY 1991 include alachlor in eighteen, or 45%, of the samples, cyanazine in eleven, or 31%, metolachlor in two, or 6%, and pendimethalin in two, or 6%, of the samples collected. The greatest concentrations of pesticides detected during the water year include alachlor at 100.00 µg/L, atrazine at 60.00 µg/L, cyanazine at 9.90 µg/L, pendimethalin at 0.44 µg/L, and metolachlor at 0.20 µg/L. The maximum detections for alachlor and atrazine occurred on May 26, the maximum for metolachlor occurred on May 29, the maximum for pendimethalin occurred on May 30, and the maximum for cyanazine occurred on June 14. Alachlor was detected during April, May, June and September, cyanazine was detected in April, May and June, and metolachlor and pendimethalin were detected in May and June.

During WY 1991, twenty-five samples from BTLD were analyzed for pesticides. Six, or 24%, of the samples contained detectable levels of atrazine (>0.10 µg/L). The annual atrazine discharge from BTLD was 1.86 grams, and the annual fw mean concentration was 0.04 µg/L. No pesticides other than atrazine were detected at BTLD during WY 1991.

BTLD was dry from September 27 through March 11. Atrazine concentrations from BTLD remained below the 0.10 µg/L detection limit from March 12 through May 20. During an event on May 29, the concentration increased from non-detectable levels at 13:05 to 0.10 µg/L at 24:00. The concentration peaked at 1.80 µg/L on the following morning at 08:00 as groundwater discharge continued to increase from the event. Discharge receded through June 13, then peaked on June 15. The atrazine concentration decreased from 0.12 µg/L on June 17 to non-detectable levels on June 27 as discharge continued to recede. The atrazine concentration increased to 0.20 µg/L during a minor event on July 11, then returned below the 0.10 µg/L detection limit on July 23 as discharge receded through August 7. The atrazine concentration was 0.10 µg/L at 16:00 on August 8 after discharge peaked at 08:00 that morning. Flow ceased on August 18 and BTLD remained dry through September 11. Discharge receded from mid-September through the remainder of the water year. On September 30, the atrazine concentration was 0.10 µg/L.

Monthly fw mean atrazine concentrations and loads for BTLD were computed for the months of March, and May through September. Monthly fw mean atrazine concentrations varied from 0.0001 µg/L in March to 0.16 µg/L in September. March had the smallest computed monthly atrazine discharge, 0 grams, and June had the greatest monthly atrazine discharge, 0.75 grams, accounting for 40% of the annual atrazine discharge. June also had the greatest monthly groundwater discharge at, 9.8 ac-ft, or 27% of annual groundwater discharge.

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., 1993a). The annual fw mean atrazine concentration and load for WY 1991 were the greatest recorded at Big Spring during WYs 1982-1995 (Liu et al., 1997). Monthly fw mean concentrations varied from 3.32 µg/L in June to 0.16 µg/L in February. The greatest monthly atrazine load occurred during June, when 76.0 pounds of atrazine were discharged, and the smallest monthly atrazine load, 0.4 pounds, occurred in February. The atrazine discharge during June accounted for 56% of the annual total. The monthly fw means and loads registered during May and June of WY 1991 exceeded all monthly fw means and loads from Big Spring during WYs 1982-1995.

At many monitoring sites within the Big Spring basin, the greatest atrazine concentrations of WY 1991 occurred during the runoff events that peaked on June 15. At most sites within the Bugenhagen sub-basin the automated sampling equipment was inundated, so water quality samples were not taken at or very near peak discharge. As a result the maximum concentrations of pesticides detected during the water year were probably lower than they would have been if samples had been taken on June 15. This in turn leads to the computation of lower monthly atrazine loads for June, and lower annual atrazine discharge than what may have occurred during WY 1991.

Water Year 1992

Discharge Monitoring

Tables 26-29 and Figure 26 summarize the discharge, water quality and chemical-load data for BOOGD, BTLUE, BTLUW and BTLD during WY 1992. In Figure 26, 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 1982-1995. Precipitation during the water year was 35.74 inches, or approximately 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 late in WY 1991, led to sustained increases in discharge at all monitoring sites during November and December. Discharge generally receded from December through most of February, as minor snowmelt and precipitation generated limited runoff. Snowmelt and precipitation later in February generated enough recharge to sustain discharge for a few weeks, and then discharge receded through most of April. The sec-

Table 26. Annual summary of water and chemical discharge for BOOGD for WY 1992. (Discharge data are from the U.S. Geological Survey, W.R.D., IA Dist.).

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	35.74 inches (907.8 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	

ond greatest runoff event during the water year occurred in mid-April, followed by general recession through mid-June. Precipitation in July 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 BOOGD during WY 1992 was 825 ac-ft and the average daily discharge was 1.0 cfs (Table 26). The annual discharge from BOOGD was equivalent to 38% of the annual precipitation. At BTLUE, the annual discharge during WY 1992 was 245 ac-ft, and the average daily discharge was 0.34 cfs (Table 27). This was the greatest discharge recorded at BTLUE during WYs 1987-1992. The annual discharge from BTLUE was equal to 33% of the annual precipitation. For site BTLUW, the annual discharge rate was 98.8 ac-ft and the average daily discharge rate was 0.14 cfs (Table 28). This was also the greatest annual discharge recorded at BTLUW during WYs 1987-1992. The annual discharge for BTLUW was equivalent to 29% of the annual precipitation during WY 1992. The groundwater discharge for site BTLD during WY 1992 was 34.7 ac-ft and the average daily discharge was 0.048 cfs (Table 29). The annual discharge from BTLD was equivalent to 65% of the annual precipitation during the water year.

At Big Spring the annual discharge during WY 1992 was 37,278 ac-ft, or 19% of the annual precipitation, and the average daily discharge rate was 51.4 cfs (Rowden et al., 1995b).

The increase in annual groundwater discharge from WY 1991 to WY 1992 at BTLUE and BTLUW, in spite of the significant decrease in precipitation during this period suggests that an increase in the amount of groundwater stored in the sub-basin's shallow hydrologic system occurred during WY 1991, and that some of this groundwater was discharged during WY 1992.

Table 27. Annual summary of water and chemical discharge for BTLUE for WY 1992.

DISCHARGE		
Total		
acre-feet	245	
millions cf	10.7	
millions cm	0.30	
Average		
cfs	0.34	
cms	0.01	
mg/d	0.22	
gpm	152	
PRECIPITATION AND DISCHARGE		
Precipitation	35.74 inches (907.8 mm)	
Discharge	11.76 inches (298.7 mm)	
Discharge as % of precipitation	33%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	73.5	16.3
Mean of analyses	71.5	15.9
	NO_3-N output	**Total N output**
lbs - N	10,874	11,636
kg - N	4,932	5,277
lbs - N/acre	43.5	46.5
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	0.47	
Mean of analyses	0.51	
Total output		
lbs	0.31	
g	142	

Nitrate Monitoring

Tables 26-29 and Figure 26 summarize the nitrate analyses from BOOGD, BTLUE, BTLUW and BTLD during WY 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 annual nitrate-nitrogen output for the water year was 35,646 pounds, and the annual total nitrogen output (nitrate- plus organic-, and ammonia-nitrogen) was 37,957 pounds (Table 26). Within the drainage area of BOOGD these outputs were equivalent to 48.4 lbs-N/acre for 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 higher nitrate concentrations at all sites throughout the water year. The nitrate concentration at BOOGD increased from 68 mg/L (15.1 mg/L as NO_3-N) in October to 89 mg/L (19.8 mg/L as NO_3-N) in late November as discharge increased. Nitrate concentrations remained above 78 mg/L (17.3 mg/L as NO_3-N) from November through January. The nitrate concentration was 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. 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 decreased to 51 mg/L (11.3 mg/L as NO_3-N) during minor runoff in mid-June, then increased to 78 mg/L (17.3 mg/L as NO_3-N) the following week. The nitrate concentration decreased to 61 mg/L (13.6 mg/L as NO_3-N) during runoff 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 mg/L (16.9 mg/L as NO_3-N) in late September as discharge receded from events earlier in the month.

Monthly fw mean nitrate concentrations for BOOGD were consistently high during the water

Table 28. Annual summary of water and chemical discharge for BTLUW for WY 1992.

DISCHARGE		
Total		
acre-feet	98.8	
millions cf	4.3	
millions cm	0.12	
Average		
cfs	0.14	
cms	0.004	
mg/d	0.09	
gpm	61.0	
PRECIPITATION AND DISCHARGE		
Precipitation	35.74 inches (907.8 mm)	
Discharge	10.22 inches (259.6 mm)	
Discharge as % of precipitation	29%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	80.9	18.0
Mean of analyses	78.6	17.5
	NO_3-N output	**Total N output**
lbs - N	4,833	5,045
kg - N	2,192	2,288
lbs - N/acre	41.7	43.5
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	0.61	
Mean of analyses	0.54	
Total output		
lbs	0.16	
g	73.9	

Table 29. Annual summary of water and chemical discharge for BTLD for WY 1992.

DISCHARGE

Total

acre-feet	34.7
millions cf	1.51
millions cm	0.043

Average

cfs	0.048
cms	0.001
mg/d	0.031
gpm	21.5

PRECIPITATION AND DISCHARGE

Precipitation	35.74 inches (907.8 mm)
Discharge	23.13 inches (587.5 mm)
Discharge as % of precipitation	65%

NITRATE DISCHARGE

Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	68.9	15.3
Mean of analyses	67.5	15.0

	NO_3-N output	**Total N output**
lbs - N	1,447	1,475
kg - N	656	669
lbs-N/acre	80.4	81.9

ATRAZINE DISCHARGE

Concentration - µg/L

Flow-weighted mean	0.01
Mean of analyses	0.02

Total output

lbs	0.001
g	0.49

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 greatest monthly fw mean, 84.3 mg/L (18.7 mg/L as NO_3-N), occurred during May. December had the greatest monthly nitrate-nitrogen output, 6,752 pounds, and the second-greatest monthly surface-water discharge, 136 ac-ft, accounting for 19% of the annual nitrate-nitrogen output and 16% of the annual surface-water discharge at BOOGD.

During WY 1992, seventy-one samples from BTLUE were analyzed for nitrate, and sixty-five samples were analyzed for N-series. The annual fw mean nitrate concentration was 73.5 mg/L (16.3 mg/L as NO_3-N). The annual nitrate-nitrogen output for the water year was 10,874 pounds, or 43.5 lbs-N/acre, and the total nitrogen output (nitrate- plus organic- and ammonia-nitrogen) was 11,636 pounds, or 46.5 lbs-N/acre, within the BTLUE drainage area.

The nitrate plot for BTLUE shows the same general trends as concentrations from BOOGD during the water year, although concentrations from BTLUE were usually slightly greater than concentrations from BOOGD. Nitrate concentrations were relatively steady during the water year, except when diluted by surface-water influx into the tiles during runoff. The smallest concentration sampled at BTLUE during the water year, 12 mg/L (2.7 mg/L as NO_3-N), occurred on February 3 during snowmelt, and the greatest concentration sampled during the water year, 109 mg/L (24.2 mg/L as NO_3-N), occurred on May 12 as discharge was receding from runoff in late April. Nitrate concentrations generally declined from May through the remainder of the water year, and were temporarily diluted during events in June and September.

Monthly fw mean nitrate concentrations from BTLUE remained above 60 mg/L (13.3 mg/L as NO_3-N) during all months except February. The greatest monthly fw mean nitrate concentration, 91.1 mg/L (20.2 mg/L as NO_3-N), occurred during October, and the smallest monthly fw mean, 37.7 mg/L (8.4 mg/L as NO_3-N) occurred during February, when an increased percentage of dis-

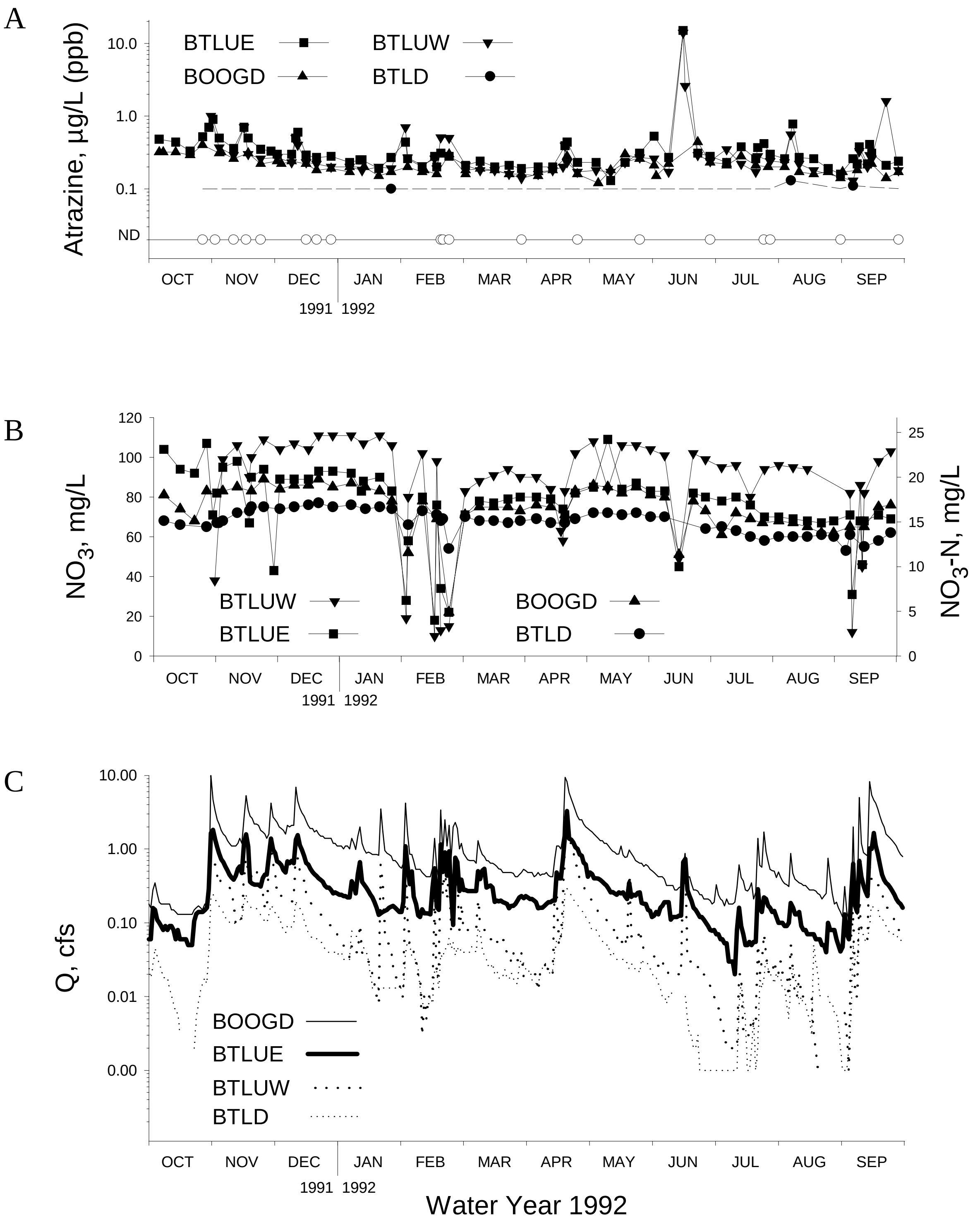


Figure 26. A) Atrazine and B) nitrate concentrations, and C) groundwater and surface-water discharge (Q) at BTLUE, BTLUW, BOOGD and BTLD for WY 1992 (note the decrease in scale on the atrazine, nitrate and discharge plots relative to WY 1991). (Discharge data for BOOGD are from the U.S. Geological Survey, W.R.D., IA Dist.)

charge was being supplied by runoff recharge from snowmelt. October had the greatest monthly nitrate-nitrogen output, 2,153 pounds, accounting for 20% of the annual total, and the greatest monthly groundwater discharge, 43.4 ac-ft, accounting for 18% of the annual discharge.

At BTLUW, sixty-three samples were analyzed for nitrate, and sixty-one samples were analyzed for N-series during WY 1992. The annual fw mean nitrate concentration for BTLUW was 80.9 mg/L (18.0 mg/L as NO_3-N). The annual nitrate-nitrogen output for the water year was 4,833 pounds, and if organic- and ammonia-nitrogen are considered, the annual total nitrogen output was 5,045 pounds. Within the drainage area of BTLUW, the nitrate-nitrogen output was equivalent to 41.7 lbs-N/acre, and total nitrogen output was equal to 43.5 lbs-N/acre.

Site BTLUW was dry from September 27 through October 31, and also on June 1, and from August 21 through September 1. Nitrate concentrations from BTLUW showed trends similar to concentrations from BOOGD and BTLUE, although concentrations from BTLUW were usually greater and fluctuated more than concentrations from other sites. The greatest nitrate concentration from BTLUW during the water year, 111 mg/L (24.7 mg/L as NO_3-N), was recorded on December 22 and 29, and January 7 and 21, as discharge receded from runoff that occurred on December 12 and 13. The smallest nitrate concentration recorded during the water year, 7 mg/L (1.6 mg/L as NO_3-N), occurred during snowmelt on February 3. During the event, the nitrate concentration increased from 7 mg/L (1.6 mg/L as NO_3-N) at 16:45 to 8 mg/L (1.8 mg/L as NO_3-N) at 19:15, then to 19 mg/L (4.2 mg/L as NO_3-N) at 23:00 as groundwater discharge decreased from 1.26 cfs, to 0.89 cfs, then to 0.51 cfs. As with sites BOOGD and BTLUE, nitrate concentrations remained generally high during the water year except during periods of dilution from runoff.

Monthly fw mean nitrate concentrations were computed for every month of the water year except October. Monthly fw mean nitrate concentrations remained above 80 mg/L (17.8 mg/L as NO_3-N) for all months except February, June and September. The greatest monthly fw nitrate concentration, 103 mg/L (22.8 mg/L as NO_3-N), occurred during December, and the smallest monthly fw mean, 24.6 mg/L (5.5 mg/L as NO_3-N), occurred in February. The greatest monthly nitrate-nitrogen output, 1,313 pounds, occurred during November, the month with the fourth-smallest monthly fw mean concentration during the water year, 91 mg/L (20.2 mg/L as NO_3-N). November also had the greatest groundwater discharge, 24.0 ac-ft, and accounted for 27% of the annual nitrate-nitrogen discharge and 24% of the annual groundwater discharge. The smallest monthly nitrate-nitrogen output, 34 pounds, occurred during August, the month with the third-smallest monthly fw mean nitrate concentration during the water year, 95 mg/L (21.1 mg/L as NO_3-N). August also had the smallest monthly groundwater discharge, 0.59 ac-ft, and accounted for 0.7% of the annual nitrate-nitrogen discharge and 0.6% of the annual groundwater discharge.

At BTLD, fifty-six samples were analyzed for nitrate, and eighteen samples were analyzed for N-series during WY 1992. The annual fw mean nitrate concentration for BTLD was 68.9 mg/L (15.3 mg/L as NO_3-N). The annual nitrate-nitrogen output for the water year was 1,447 pounds, and if organic- and ammonia-nitrogen are considered, the annual total nitrogen output was 1,475 pounds. Within the drainage area of BTLD, the nitrate-nitrogen output was equivalent to 80.4 lbs-N/acre, and total nitrogen output was equal to 81.9 lbs-N/acre.

BTLD was dry from October 18-23, from June 12-13, and from August 22-24. Nitrate concentrations from BTLD showed trends similar to concentrations from BOOGD, BTLUE and BTLUW, although concentrations from BTLD were significantly lower and fluctuated much less than concentrations from other sites, especially during runoff. This is to be expected since BTLD has no intakes to allow direct access of runoff, which usually has lower concentrations of nitrate, into the tile line. As with BTLUW, the greatest nitrate concentration recorded at BTLD during the water year, 77 mg/L (17.1 mg/L as NO_3-N), occurred on December 22 as discharge receded from runoff on December 12 and 13. The smallest nitrate concentration recorded during the water year, 53 mg/L (11.8 mg/L as NO_3-N), occurred during an event on September 6. As with the other monitoring sites in the sub-basin, nitrate concentrations remained relatively high during the water year except during periods of dilution associated with runoff.

Monthly fw mean nitrate concentrations for BTLD were computed for every month of the water year. Monthly fw mean nitrate concentrations remained at or above 60 mg/L (13.3 mg/L as NO_3-N) for all months during WY 1992 except September. The greatest monthly fw mean nitrate concentration, 75.2 mg/L (16.7 mg/L as NO_3-N), occurred during January, and the smallest monthly fw mean, 57.4 mg/L (12.8 mg/L as NO_3-N), occurred in September. The greatest monthly nitrate-nitrogen output, 679 pounds, and the greatest monthly groundwater discharge, 8.8 ac-ft, occurred during November, and the smallest monthly nitrate-nitrogen output, 13.8 pounds, and the smallest monthly groundwater discharge, 0.33 ac-ft, occurred during June. November accounted for 47% of the annual nitrate-nitrogen discharge and 25% of the annual groundwater discharge. June accounted for 1% of the annual nitrate-nitrogen discharge and 1% of the annual groundwater discharge.

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., 1995b. 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 for WY 1992 was the second greatest, and the annual nitrate-nitrogen output was the third greatest recorded at Big Spring during WYs 1982-1995 (Liu et al., 1997).

At Big Spring, the greatest monthly fw mean nitrate concentration and nitrate-nitrogen load, 63.0 mg/L (14.1 mg/L as NO_3-N) and 179,000 pounds, occurred during December, and the smallest monthly fw mean and load, 44.0 mg/L (9.8 mg/L as NO_3-N) and 51,000 pounds, occurred in October.

Pesticide Monitoring

Tables 26-29 and Figure 26 summarize the results of pesticide monitoring at sites BOOGD, BTLUE, BTLUW and BTLD for WY 1992.

Sixty-two samples from BOOGD were analyzed for pesticides during WY 1992. Sixty-one, or 98%, of the samples contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration for BOOGD was 0.33 µg/L and the annual atrazine output was 333 grams (Table 26). Atrazine was the only pesticide detected at BOOGD during the water year.

Atrazine concentrations were relatively stable at BOOGD during the water year. The concentration decreased from 0.40 µg/L in late October to 0.15 µg/L near the end of January (Fig. 26). The concentration increased to 0.30 µg/L during runoff in late February, then remained below 0.20 µg/L until April. The concentration 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 greatest atrazine concentration sampled at BOOGD during the water year, 0.44 µg/L, occurred in mid-June during 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.

The smallest monthly fw mean atrazine concentration from BOOGD during WY 1992, 0.16 µg/L, occurred in August, and the largest monthly mean, 0.53 µg/L, occurred during September. The second greatest monthly fw mean atrazine concentration during the water year, 0.47 µg/L, occurred during November and July. October and August had the smallest monthly atrazine outputs, 4.0 grams, and smallest monthly surface-water discharges, 11 ac-ft during October, and 21 ac-ft during August. November had the greatest monthly atrazine output, 83.1 grams, and the greatest surface-water discharge, 144 ac-ft, accounting for 25% of the annual atrazine output and 17% of the surface-water discharge during the water year.

At BTLUE, seventy-nine samples were analyzed for pesticides during WY 1992. All samples contained detectable levels of atrazine (>0.10 µg/L). The annual atrazine discharge from BTLUE was 142 grams, at a fw mean concentration of 0.47 µg/L (Table 27).

Atrazine concentrations from BTLUE showed trends similar to concentrations from BOOGD, although levels were generally greater at BTLUE. Atrazine concentrations generally declined from 0.90 µg/L in early November to 0.19 µg/L on January 21. From late January through May, atrazine concentrations remained below 0.50 µg/L. Concentrations remained below 1.00 µg/L during the entire water year, except in one sample taken during runoff on June 16 when the atrazine concentration was 15.00 µg/L. Following this, concentrations ranged between 0.23 µg/L and 0.42 µg/L until August 8 when concentrations increased to 0.78 µg/L as discharge receded from a minor event on August 7. During the remainder of the water year, atrazine concentrations ranged from 0.16 µg/L on August 31 to 0.41 µg/L on September 14.

Monthly fw mean atrazine concentrations from BTLUE varied from 0.21 µg/L in March, to 3.37 µg/L during June. June also had the greatest atrazine discharge, 44.4 grams, but a relatively small groundwater discharge, 10.7 ac-ft, and accounted for 31% of the annual atrazine output and 4% of the annual groundwater discharge. August had the smallest atrazine discharge, 2.0 grams, accounting for 1% of the annual atrazine discharge, and the smallest groundwater discharge, 5.3 ac-ft, accounting for 2% of the annual groundwater discharge.

Other pesticides detected at BTLUE during WY 1992 include alachlor in seven, or 10%, of the samples and terbufos in one, or 2%, of the samples collected. The greatest concentrations of pesticides detected during the water year included atrazine at 15.00 µg/L, alachlor at 14.00 µg/L, and terbufos at 0.18 µg/L. All maximum detections occurred on June 16. Alachlor was also detected during October, November and December.

Seventy-one samples from BTLUW were analyzed for pesticides during WY 1992. All of the samples contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration for BTLUW was 0.61 µg/L and the annual atrazine output was 73.9 grams (Table 28).

The atrazine plot for BTLUW shows trends similar to BTLUE, generally declining through January, then remaining relatively steady during the water year, except during significant runoff events (Fig. 26). Like BTLUE, the greatest concentration recorded at BTLUW during the water year, 14.00 µg/L, occurred on June 16. One significant difference between the atrazine plots for BTLUE and BTLUW was the much greater atrazine concentration sampled at BTLUW on September 22. The atrazine concentration for BTLUW was 1.60 µg/L, while the atrazine concentration for BTLUE was 0.21 µg/L in samples taken five minutes apart. The reason for this significant difference in concentrations remains unclear, but may be related to differing amounts of runoff versus infiltration recharge constituting the two different tile effluents at approximately the same time.

Monthly fw mean atrazine concentrations from BTLUW were computed for the months November through September. Concentrations varied from 0.19 µg/L in March to 6.72 µg/L in June. The greatest monthly atrazine output, 31.6 grams, occurred during June, the month with the third-smallest groundwater discharge, 3.81 ac-ft. June accounted for 43% of the annual atrazine discharge and 4% of the annual groundwater discharge from BTLUW. The smallest monthly atrazine discharge, 0.2 grams, and smallest monthly groundwater discharge, 0.59 ac-ft, occurred during August and accounted for 0.3% of the annual atrazine output, and 0.6% of the annual discharge.

Other pesticides detected at BTLUW during WY 1992 include alachlor in nine, or 14%, of the samples, cyanazine in five, or 9%, and terbufos in one, or 2%, of the samples collected. The greatest concentrations of pesticides detected during the water year included alachlor at 15.00 µg/L, atrazine at 14.00 µg/L, cyanazine at 5.50 µg/L, and terbufos at 0.26 µg/L. All maximum detections occurred on June 16. Alachlor was detected during November, December, June, July, and September, and cyanazine was detected during June, July and September.

Twenty-four samples from BTLD were analyzed for pesticides during WY 1992. Three, or 13%, of the samples contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration for BTLD was 0.01 µg/L and the annual atrazine output was 0.49 grams (Table 29). Atrazine was the only pesticide detected at BTLD during WY 1992.

The first atrazine detection at BTLD during the water year, 0.10 µg/L, occurred on January 27 during low-flow conditions. The two other atrazine detections at BTLD during the water year, 0.13 µg/L, on August 7 and, 0.11 µg/L, on September 6, were both associated with minor discharge events.

December through February, and August and September were the only months during the water year at BTLD with atrazine discharge, and February, August and September were the only months with monthly fw mean atrazine concentrations greater than 0 µg/L. Monthly fw mean atrazine concentrations and atrazine loads varied from 0 µg/L and 0 grams during most months, to 0.08 µg/L and 0.43 grams in September. September accounted for 88% of the annual atrazine discharge, but only 12% of the annual groundwater discharge from BTLD.

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., 1995b). This was the forth-smallest annual fw mean atrazine concentration observed at Big Spring during WYs 1982-1995 (Liu et al., 1997). 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.

Water Year 1993

Discharge Monitoring

Tables 30-32 and Figure 27 summarize the

Table 30. Annual summary of water and chemical discharge for BTLUE for WY 1993.

DISCHARGE		
Total		
acre-feet	372	
millions cf	16.2	
millions cm	0.46	
Average		
cfs	0.52	
cms	0.02	
mg/d	0.33	
gpm	231	
PRECIPITATION AND DISCHARGE		
Precipitation	46.47 inches (1,180 mm)	
Discharge	17.84 inches (453.1 mm)	
Discharge as % of precipitation	38%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	54.4	12.1
Mean of analyses	61.7	13.7
	NO_3-N output	**Total N output**
lbs - N	12,229	13,281
kg - N	5,546	6,023
lbs - N/acre	48.9	53.1
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	0.37	
Mean of analyses	0.50	
Total output		
lbs	0.37	
g	168	

Table 31. Annual summary of water and chemical discharge for BTLUW for WY 1993.

DISCHARGE		
Total		
acre-feet	182	
millions cf	7.9	
millions cm	0.22	
Average		
cfs	0.25	
cms	0.007	
mg/d	0.16	
gpm	113	
PRECIPITATION AND DISCHARGE		
Precipitation	46.47 inches (1,180 mm)	
Discharge	18.81 inches (477.8 mm)	
Discharge as % of precipitation	40%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	72.4	16.1
Mean of analyses	80.9	18.0
	NO_3-N output	**Total N output**
lbs - N	7,957	8,608
kg - N	3,609	3,904
lbs - N/acre	68.6	74.2
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	0.27	
Mean of analyses	0.19	
Total output		
lbs	0.14	
g	61.2	

discharge, climatic, water quality and chemical loading data for BTLUE, BTLUW and BTLD for WY 1993. Monitoring of BOOGD was discontinued at the end of WY 1992.

Water Year 1993 had the second-greatest annual precipitation during WYs 1982-1995. The mean annual precipitation was 46.47 inches or 141% of the long-term average. Rainfall totals were below normal during October, January, May, and September, and well above normal in November, and from June through August. Approximately half of the annual precipitation occurred during the June through August period. October was the driest month of the water year, with 0.78 inches of precipitation, and June and August were the wettest months, with 8.01 and 8.00 inches of precipitation, respectively.

Discharge at most monitoring sites in the subbasin decreased from the beginning of the water year through most of October, then increased in early November, and increased further in late November (Fig. 27). From late November, discharge generally receded at the sites through late February. Snowmelt in late February and precipitation in March and April generated significant increases in discharge at all sites. Discharge receded at all sites during May, then increased along with precipitation in June and the first half of July before receding again into early August. Discharge increased again during August, then receded through the remainder of the water year.

Discharge from BTLUE was continuous during the entire water year. The annual discharge for BTLUE for WY 1993 was 372 ac-ft, and the average daily discharge was 0.52 cfs (Table 30). The annual discharge from BTLUE was equal to 38% of the annual precipitation. BTLUW was dry from October 20-31, from November 16-19, and from January 19 through March 2. The annual discharge from BTLUW was 182 ac-ft, the average daily discharge rate was 0.25 cfs, and the annual discharge was equivalent to 40% of the annual precipitation (Table 31). At BTLD, discharge was continuous throughout the water year, except during February 19-24. The groundwater discharge from BTLD during the water year was 38.5 ac-ft and the average daily discharge was

0.053 cfs (Table 32). The annual discharge from BTLD was equivalent to 55% of the annual precipitation during the water year. The annual discharges recorded at the sub-basin monitoring sites during WY 1993 were the greatest recorded during WYs 1987-1995. The discharge as a percentage of precipitation from BTLUE and BTLUW during WY 1993 were also the greatest recorded during WYs 1987-1995, while the discharge as a percentage of precipitation for BTLD was the second-greatest recorded during WYs 1987-1995, following WY 1992.

The annual groundwater discharge from Big Spring during WY 1993 was 58,186 ac-ft, at an average daily discharge rate of 80.4 cfs (Rowden et al., 1995b). Groundwater discharge was equivalent to 23% of precipitation during the water year. The annual discharge and discharge as a percent of precipitation for Big Spring for WY 1993 were the greatest recorded during WYs 1982-1995 (Liu et al., 1997).

The sustained, general increase in mean daily discharge at most monitoring sites within the Big Spring basin during the latter half of WY 1993 indicates a net increase in overall storage in the basin's hydrologic system.

Nitrate Monitoring

Tables 30-32 and Figure 27 summarize the nitrate analyses from BTLUE, BTLUW and BTLD during WY 1993.

During WY 1993, fifty-five samples from BTLUE were analyzed for nitrate, and sixty-three samples were analyzed for N-series. The annual fw mean nitrate concentration for BTLUE was 54.4 mg/L (12.1 mg/L as NO_3-N). The annual nitrate-nitrogen output for the water year was 12,229 pounds, or 48.9 lbs-N/acre, and the annual total nitrogen output (nitrate- plus organic- and ammonia-nitrogen) was 13,281 pounds, or 53.1 lbs-N/acre, within the BTLUE drainage area. The annual nitrate-nitrogen discharge from BTLUE during WY 1993 was the second-greatest annual discharge recorded at BTLUE during WYs 1987-1995.

The nitrate plot for BTLUE shows concentra-

Table 32. Annual summary of water and chemical discharge for BTLD for WY 1993.

DISCHARGE		
Total		
acre-feet	38.5	
millions cf	1.67	
millions cm	0.047	
Average		
cfs	0.053	
cms	0.002	
mg/d	0.034	
gpm	23.8	
PRECIPITATION AND DISCHARGE		
Precipitation	46.47 inches (1,180 mm)	
Discharge	25.67 inches (652.0 mm)	
Discharge as % of precipitation	55%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	56.6	12.6
Mean of analyses	60.2	13.4
	NO_3-N output	**Total N output**
lbs - N	1,316	1,354
kg - N	597	614
lbs-N/acre	73.1	75.2
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	0.09	
Mean of analyses	0.07	
Total output		
lbs	0.01	
g	4.35	

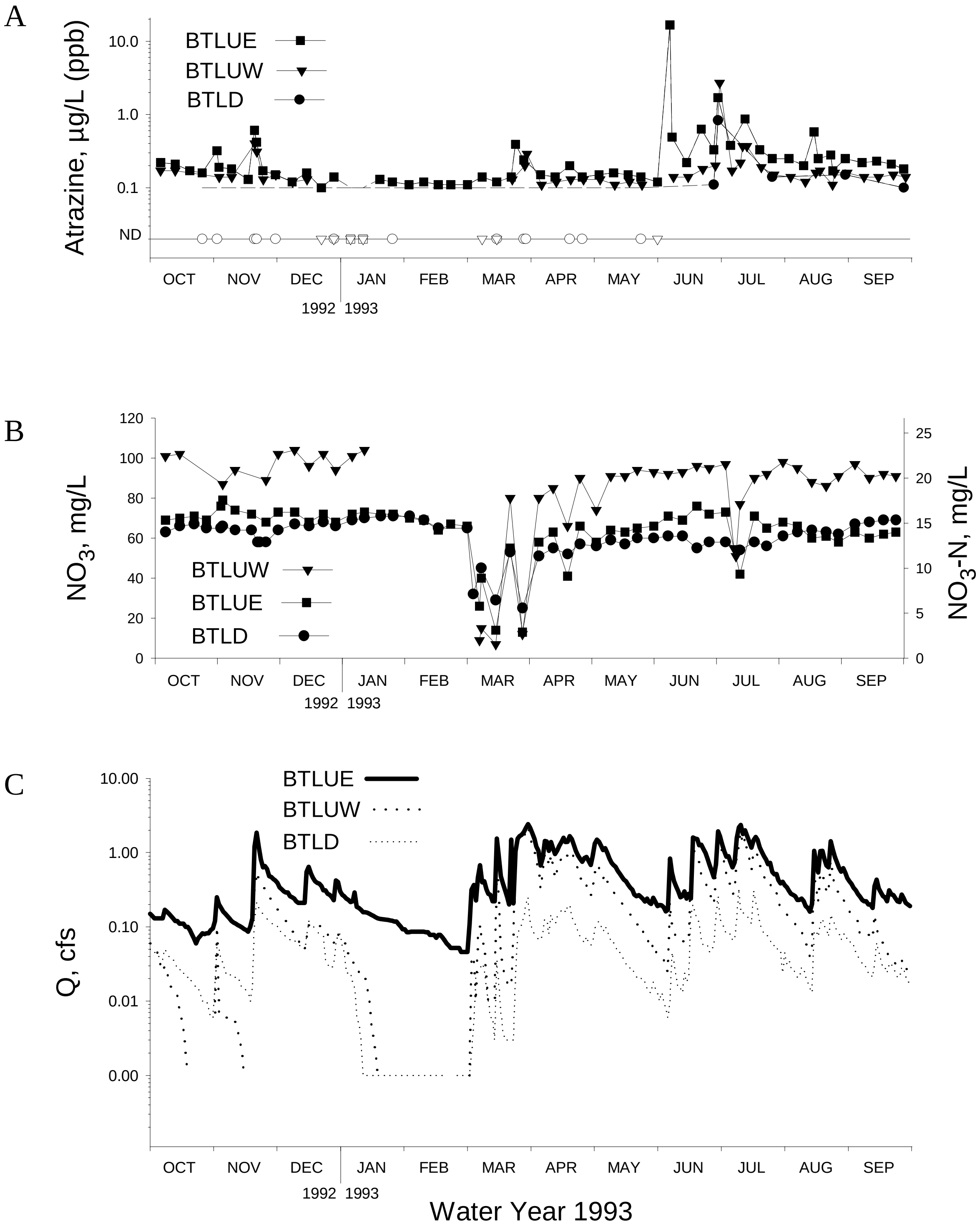


Figure 27. A) Atrazine and B) nitrate concentrations, and C) groundwater discharge (Q) at BTLUE, BTLUW and BTLD for WY 1993.

tions remaining relatively steady from the beginning of the water year through February. The greatest nitrate concentration recorded at BTLUE during the water year, 79 mg/L (17.6 mg/L as NO_3-N), occurred on November 3, as discharge was receding from a minor event that occurred on November 2. Nitrate concentrations were diluted during runoff from snowmelt in March, and declined to the smallest concentration recorded at BTLUE during the water year, 13 mg/L (2.9 mg/L as NO_3-N), on March 29. Precipitation in late March and April generated significant infiltration recharge, and the nitrate concentration increased to 76 mg/L (16.9 mg/L as NO_3-N) on June 22. The nitrate concentration decreased to 42 mg/L (9.3 mg/L as NO_3-N) during runoff on July 13, then increased to 71 mg/L (15.8 mg/L as NO_3-N) on July 20 before generally decreasing through August. During September, nitrate concentrations remained relatively steady and were 63 mg/L (14.0 mg/L as NO_3-N) near the end of the water year.

Monthly fw mean nitrate concentrations from BTLUE remained at or above 60 mg/L (13.3 mg/L as NO_3-N) during all months of WY 1993 except March, April and June. The greatest monthly fw mean nitrate concentration, 71.7 mg/L (15.9 mg/L as NO_3-N), occurred during November, and the smallest monthly fw mean, 26.0 mg/L (5.8 mg/L as NO_3-N) occurred during March, when an increased percentage of discharge was being supplied by runoff recharge from snowmelt. July had the greatest monthly nitrate-nitrogen discharge, 2,499 pounds, accounting for 20% of the annual total, and the second-greatest monthly groundwater discharge, 68.9 ac-ft, accounting for 19% of the annual discharge. February had the smallest monthly nitrate-nitrogen discharge, 164 pounds, and the smallest monthly groundwater discharge, 4.0 ac-ft, accounting for 1% of the annual nitrate-nitrogen discharge and 1% of the annual groundwater discharge.

At BTLUW, forty-eight samples were analyzed for nitrate, and fifty-one samples were analyzed for N-series during WY 1993. The annual fw mean nitrate concentration for BTLUW was 72.4 mg/L (16.1 mg/L as NO_3-N). The annual nitrate-nitrogen output for the water year was 7,957 pounds, and if organic- and ammonia-nitrogen are considered, the annual total nitrogen output was 8,608 pounds. Within the drainage area of BTLUW, the nitrate-nitrogen output was equivalent to 68.6 lbs-N/acre, and total nitrogen output was equal to 74.2 lbs-N/acre. The annual nitrate-nitrogen discharge from BTLUW during WY 1993 was the greatest annual discharge recorded at BTLUW during WYs 1987-1995.

Nitrate concentrations from BTLUW showed trends similar to concentrations from BTLUE and BTLD, although concentrations from BTLUW were usually greater and fluctuated more than concentrations from other sites. The greatest nitrate concentration recorded at BTLUW during the water year, 104 mg/L (23.1 mg/L as NO_3-N), occurred on December 8 and January 11, as discharge generally declined from runoff that occurred on November 21 and December 29. The smallest nitrate concentration recorded during the water year, 7 mg/L (1.6 mg/L as NO_3-N), occurred during snowmelt on March 16. As with sites BTLUE and BTLD, nitrate concentrations remained relatively high during the water year except during periods of dilution from runoff.

Monthly fw mean nitrate concentrations were computed for BTLUW for every month of the water year except February. Monthly fw mean nitrate concentrations remained at or above 80 mg/L (17.8 mg/L as NO_3-N) during all months except March and April. The greatest monthly fw nitrate concentration at BTLUW during the water year, 100.5 mg/L (22.3 mg/L as NO_3-N), occurred during October, and the smallest monthly fw mean, 16.6 mg/L (3.7 mg/L as NO_3-N), occurred in March. The greatest monthly nitrate-nitrogen discharge, 2,087 pounds, and greatest monthly groundwater discharge, 43.1 ac-ft, occurred during July, and accounted for 26% of the annual nitrate-nitrogen discharge and 24% of the annual groundwater discharge. The smallest monthly nitrate-nitrogen output, 55 pounds, and smallest monthly groundwater discharge, 0.91 ac-ft, occurred during October, the month with the greatest monthly fw mean nitrate concentration during the water year. October accounted for

0.7% of the annual nitrate-nitrogen discharge and 0.5% of the annual groundwater discharge.

At BTLD, fifty-six samples were analyzed for nitrate, and fourteen samples were analyzed for N-series during WY 1993. The annual fw mean nitrate concentration for BTLD was 56.6 mg/L (12.6 mg/L as NO_3-N). The annual nitrate-nitrogen output for the water year was 1,316 pounds, and if organic- and ammonia-nitrogen are considered, the annual total nitrogen output was 1,354 pounds. Within the drainage area of BTLD, the nitrate-nitrogen output was equivalent to 73.1 lbs-N/acre, and total nitrogen output was equal to 75.2 lbs-N/acre.

Nitrate concentrations from BTLD showed trends similar to concentrations from BTLUE and BTLUW, although concentrations from BTLD were significantly lower and fluctuated much less than concentrations from other sites, especially during runoff periods. The greatest nitrate concentration recorded at BTLD during the water year, 71 mg/L (15.8 mg/L as NO_3-N), occurred on January 19 and 25, and February 2, during low-flow conditions. As with BTLUW, the smallest nitrate concentration recorded during the water year, 29 mg/L (6.4 mg/L as NO_3-N), occurred during snowmelt on March 16. Like other monitoring sites in the sub-basin, nitrate concentrations remained relatively high during the water year except during periods of dilution associated with runoff.

Monthly fw mean nitrate concentrations for BTLD were computed for every month of WY 1993. Monthly fw mean nitrate concentrations remained at or above 60 mg/L (13.3 mg/L as NO_3-N) from October through February and from August through September. The greatest monthly fw mean nitrate concentration, 68.9 mg/L (15.3 mg/L as NO_3-N), the smallest monthly nitrate-nitrogen discharge, 3.2 pounds, and the smallest monthly groundwater discharge, 0.08 ac-ft, occurred during February. The smallest monthly fw mean nitrate concentration, 28.8 mg/L (6.4 mg/L as NO_3-N), occurred during March, and the greatest monthly nitrate-nitrogen discharge, 224 pounds, and the greatest monthly groundwater discharge, 6.9 ac-ft, occurred during July. February accounted for 0.2% of the annual nitrate-nitrogen discharge and 0.2% of the annual groundwater discharge, while July accounted for 17% of the annual nitrate-nitrogen discharge and 18% of the annual groundwater discharge.

The annual fw mean nitrate concentration for Big Spring during WY 1993 was 51.1 mg/L (11.4 mg/L as NO_3-N; Rowden et al., 1995b). A total of 1,916,838 pounds of nitrogen were discharged, and of this total, 1,796,013 pounds, or 94%, was in the form of nitrate. Within the 103 mi^2 drainage area of Big Spring, the annual total nitrogen output was equivalent to 29.1 lbs-N/acre and the annual nitrate-nitrogen output was 27.2 lbs-N/acre. The annual fw mean nitrate concentration for Big Spring for WY 1993 was the second greatest, and the annual nitrate-nitrogen output was the greatest recorded at Big Spring during WYs 1982-1995 (Liu et al., 1997).

At Big Spring, monthly fw mean nitrate concentrations exceeded the 45 mg/L (10 mg/L as NO_3-N) drinking water standard for nitrate during all months except March. The greatest monthly fw mean nitrate concentration during WY 1993, 61.5 mg/L (13.7 mg/L as NO_3-N), occurred in December and the smallest monthly fw mean, 27.7 mg/L (6.2 mg/L as NO_3-N), occurred in March. Monthly nitrate-nitrogen discharge varied from 67,000 pounds in October, the month with the smallest groundwater discharge, to 288,000 pounds in July, the month with the greatest groundwater discharge. July accounted for 16% of the annual nitrate-nitrogen load and 14.5% of the annual discharge. The monthly nitrate-nitrogen discharge for July was the second greatest recorded during WYs 1983-1995 at Big Spring (Liu et al., 1997). The greatest monthly nitrate-nitrogen discharge recorded at Big Spring was 326,000 pounds in June of WY 1991 (Rowden et al., 1993a).

Pesticide Monitoring

Tables 30-32 and Figure 27 summarize the results of pesticide monitoring at sites BTLUE, BTLUW and BTLD for WY 1993. Beginning in January 1993, the pesticide samples collected for the Big Spring Demonstration Project have been analyzed for the atrazine metabolites, desethylatrazine and desisopropylatrazine.

Sixty-one samples from BTLUE were analyzed for pesticides during WY 1993. Fifty-nine samples, or 97%, contained detectable levels of atrazine (>0.10 µg/L). The annual atrazine discharge from BTLUE was 168 grams, at a fw mean concentration of 0.37 µg/L (Table 30).

The atrazine concentration at BTLUE declined from 0.22 µg/L at the beginning of the water year to 0.16 µg/L on October 26. The concentration increased to 0.32 µg/L during a minor event on November 2, then declined, along with discharge, to 0.13 µg/L on November 17. The atrazine concentration increased to 0.61 µg/L during another event on November 20, then declined, to below the 0.10 µg/L detection limit on January 5 and January 11. From mid-January through May, atrazine concentrations remained below 0.20 µg/L, except during discharge events in March and April. The greatest atrazine concentration sampled at BTLUE during the water year, 16.72 µg/L, occurred during runoff on June 7. During precipitation events in June through mid-July, atrazine concentrations fluctuated with discharge, ranging between 0.22 µg/L on June 15 and 1.70 µg/L on June 30. From mid-July, concentrations declined, along with discharge, reaching 0.20 µg/L on August 10. Concentrations increased to 0.58 µg/L during an event on August 15, then remained below 0.30 µg/L during the remainder of the water year.

Monthly fw mean atrazine concentrations from BTLUE varied from 0.07 µg/L in January, to 1.03 µg/L during June. July had the greatest monthly atrazine discharge, 56.3 grams, and the second-greatest monthly groundwater discharge, 68.9 ac-ft, accounting for 34% of the annual atrazine output and 19% of the annual groundwater discharge. February had the smallest atrazine discharge, 0.56 grams, accounting for 0.3% of the annual atrazine discharge, and the smallest groundwater discharge, 4.0 ac-ft, accounting for 1% of the annual groundwater discharge.

Other pesticides detected at BTLUE during WY 1993 include desethylatrazine in twenty-three samples, or 56%, alachlor in seven, or 13%, desisopropylatrazine in one, or 2%, and cyanazine in one, or 2%, of the samples collected. The greatest concentrations of pesticides detected during the water year included atrazine at 16.72 µg/L, alachlor at 2.00 µg/L, desethylatrazine at 0.92 µg/L, desisopropylatrazine at 0.23 µg/L, and cyanazine at 0.14 µg/L. The maximum concentration for atrazine occurred on June 7, the maximums for alachlor and cyanazine occurred on June 30, and the maximum concentrations for desethylatrazine and desisopropylatrazine occurred on July 13. Desethylatrazine was also detected during January, February, March, May, June, July, August, and September, and alachlor was also detected during March, June, and July.

Fifty-three samples from BTLUW were analyzed for pesticides during WY 1993. Forty-six, or 87%, of the samples contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration for BTLUW was 0.27 µg/L and the annual atrazine output was 61.2 grams (Table 31).

The atrazine plot for BTLUW shows trends similar to BTLUE, declining from the beginning of the water year through December, except during events in November. Concentrations decreased below the 0.10 µg/L detection limit on December 22, and remained below detectable levels in samples taken through March 16. The atrazine concentration increased to 0.29 µg/L on March 30, following a series of runoff events that began on March 24. Following March, concentrations remained below 0.14 µg/L through May, and were below the 0.10 µg/L detection limit on June 1. During June, atrazine concentrations generally increased, reaching the greatest concentration recorded at BTLUW during the water year, 2.70 µg/L, during an event on June 30. Concentrations fluctuated along with discharge during July, ranging from 0.17 µg/L on July 6 to 0.37 µg/L on July 11 and July 13. During the remainder of the water year, atrazine concentrations ranged from 0.19 µg/L on July 20 to 0.12 µg/L on August 10.

Monthly fw mean atrazine concentrations for BTLUW were computed for all months during the water year, except February. Monthly atrazine concentrations and loads varied from 0 µg/L and 0 grams in January to 0.61 µg/L in June, and 23.1 grams in July. July had the second-greatest monthly groundwater discharge, and accounted for 38% of the annual atrazine discharge and 24% of the annual groundwater discharge from BTLUW.

Other pesticides detected at BTLUW during WY 1993 include desethylatrazine in twenty-three samples, or 61%, and alachlor in five, or 10%, of the samples collected. The greatest concentrations of pesticides detected during the water year included alachlor at 4.70 µg/L, atrazine at 2.70 µg/L, and desethylatrazine at 0.45 µg/L. The maximum detections for alachlor and atrazine occurred on June 30, and for desethylatrazine, the maximum concentration occurred on July 13. Desethylatrazine was detected during March, May, June, July, August, and September, and alachlor was detected during March, June and July.

Nineteen samples from BTLD were analyzed for pesticides during WY 1993. Five, or 26%, of the samples contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration for BTLD was 0.09 µg/L and the annual atrazine discharge was 4.35 grams (Table 32).

BTLD had continuous groundwater discharge during the water year, except from February 19-24. Atrazine concentrations were below the 0.10 µg/L detection limit in samples taken from October 26 through May 24. The first atrazine detection at BTLD during the water year, 0.11 µg/L, occurred on June 28 as discharge was receding from an event that occurred on June 18. Like BTLUW, the greatest atrazine concentration recorded at BTLD during the water year, 0.83 µg/L, occurred during an event on June 30. Following this, atrazine concentrations ranged from 0.15 µg/L on August 30 to 0.10 µg/L on September 27.

July through September were the only months during the water year at BTLD with atrazine discharge, and March, and July through September were the only months with monthly fw mean atrazine concentrations greater than 0 µg/L. Monthly fw mean atrazine concentrations and loads varied from 0 µg/L and 0 grams during most months, to 0.26 µg/L during both June and July, and 2.21 grams in July. July accounted for 51% of the annual atrazine discharge and 18% of the annual groundwater discharge from BTLD.

Other pesticides detected at BTLD during WY 1993 include desethylatrazine in three samples, or 30%, desisopropylatrazine in one, or 10%, and alachlor and cyanazine in one, or 8%, of the samples collected. The greatest concentrations of pesticides detected during the water year include atrazine at 0.83 µg/L, desethylatrazine at 0.16 µg/L, cyanazine at 0.14 µg/L, and alachlor and desisopropylatrazine at 0.13 µg/L. The maximum concentrations of atrazine, alachlor and cyanazine occurred on June 30, and the maximum concentrations for desethylatrazine and desisopropylatrazine occurred on August 30. Desethylatrazine was detected during July, August, and September, alachlor and cyanazine were detected only during June, and desisopropylatrazine was detected only during August.

At Big Spring, 42 pounds of atrazine were discharged during WY 1993, at a fw mean concentration of 0.27 µg/L (Rowden et al., 1995b). This was the fifth-smallest annual fw mean atrazine concentration, and the fourth-greatest annual atrazine discharge observed at Big Spring during WYs 1982-1995 (Liu et al., 1997). Monthly fw mean atrazine concentrations varied from 0.07 µg/L in January to 0.69 µg/L in June. The greatest monthly atrazine load occurred during July, when 12.9 pounds of atrazine were discharged, and the smallest monthly atrazine discharge, 0.6 pounds, occurred in January. Atrazine discharge during July accounted for 31% of the annual total at Big Spring.

Water Year 1994

Discharge Monitoring

Tables 33-35 and Figure 28 summarize the discharge, climatic, water quality and chemical loading data for BTLUE, BTLUW and BTLD for WY 1994. Note the decrease in scale on the atrazine and nitrate plots for WY 1994 relative to WY 1993.

The annual precipitation for WY 1994, 30.42

inches, was 2.55 inches below normal, or 92% of the long-term average. The annual precipitation total for WY 1994 was the fourth smallest recorded in the Big Spring basin during WYs 1982-1995 (Liu et al., 1997). Monthly precipitation totals for January, February, June, and September were much greater than normal. The monthly precipitation for June, 7.70 inches, was 2.90 inches above normal, or 160% of the long-term average precipitation. The driest month of WY 1994 was March, with 0.14 inches of precipitation. From 1951-1980, June has typically been the wettest month in the Big Spring basin.

During WY 1994, discharge at BTLUE was relatively steady during October, increased during November, and then generally decreased through mid-February (Fig. 28). At BTLUW, discharge decreased, then increased slightly in early October, then receded, and ceased on October 31. At BTLD, groundwater discharge decreased, then increased in early October, then receded, and ceased on December 9. Snowmelt in February and early March and precipitation in April generated significant runoff, followed by rapidly receding discharge at most sites. Discharge increased along with precipitation in June and mid-July before generally receding again into early August. Discharge increased again during August, then receded through most of September. Precipitation on September 25 generated runoff, and then discharge quickly receded during the remaining days of the water year.

Discharge from BTLUE was continuous during the entire water year. The annual discharge for BTLUE for WY 1994 was 76.4 ac-ft, and the average daily discharge was 0.11 cfs (Table 33). The annual discharge from BTLUE was equal to 12% of the annual precipitation.

Site BTLUW was dry from November 1 through February 17, February 28 through March 3, April 5-13, April 24-25, April 28 through May 16, May 18 through June 6, June 8-12, August 5-18, August 20 through September 24, and September 27 through November 26. The annual discharge from BTLUW was 18.7 ac-ft, the average daily discharge rate was 0.03 cfs, and the annual discharge was equivalent to 6% of the annual

Table 33. Annual summary of water and chemical discharge for BTLUE for WY 1994.

DISCHARGE		
Total		
acre-feet	76.4	
millions cf	3.3	
millions cm	0.09	
Average		
cfs	0.11	
cms	0.003	
mg/d	0.07	
gpm	47.6	
PRECIPITATION AND DISCHARGE		
Precipitation	30.42 inches (772.7 mm)	
Discharge	3.67 inches (93.2 mm)	
Discharge as % of precipitation	12%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	55.9	12.4
Mean of analyses	69.7	15.5
	NO_3-N output	**Total N output**
lbs - N	2,583	2,666
kg - N	1,172	1,209
lbs - N/acre	10.3	10.7
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	0.17	
Mean of analyses	0.12	
Total output		
lbs	0.04	
g	16.2	

Table 34. Annual summary of water and chemical discharge for BTLUW for WY 1994.

DISCHARGE		
Total		
acre-feet	18.7	
millions cf	0.81	
millions cm	0.02	
Average		
cfs	0.03	
cms	0.001	
mg/d	0.02	
gpm	11.7	
PRECIPITATION AND DISCHARGE		
Precipitation	30.42 inches (772.7 mm)	
Discharge	1.93 inches (49.0 mm)	
Discharge as % of precipitation	6%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	40.8	9.1
Mean of analyses	73.0	16.2
	NO_3-N output	**Total N output**
lbs - N	462	499
kg - N	209	226
lbs - N/acre	4.0	4.3
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	0.14	
Mean of analyses	0.09	
Total output		
lbs	0.007	
g	3.2	

precipitation (Table 34).

Site BTLD was dry from December 10 through February 17, from May 11 through June 12, and from August 5 through the end of the water year. The groundwater discharge for site BTLD during the water year was 9.2 ac-ft and the average daily discharge was 0.013 cfs (Table 35). The annual discharge from BTLD was equivalent to 20% of the annual precipitation during the water year.

The annual groundwater discharge for Big Spring for WY 1994 was 31,266 ac-ft, at an average daily discharge rate of 43.2 cfs (Liu et al., 1997). The annual discharge was equivalent to 18.7% of the annual precipitation during the water year.

Nitrate Monitoring

Tables 33-35 and Figure 28 summarize the nitrate analyses from BTLUE, BTLUW and BTLD during WY 1994. Due to sampling changes discussed below, the nitrate plots for BTLUE and BTLUW are based on nitrate concentrations from N-series analyses, rather than concentrations from nitrate samples. The nitrate plot for BTLD is based on concentrations from nitrate samples as in previous water years.

In previous water years, samples for both nitrate and full nitrogen series (N-series; nitrate-plus ammonia- and organic-nitrogen) analyses were collected weekly from the monitoring sites within the Bugenhagen sub-basin. During WY 1994, the sampling schedule was changed due to budget constraints, and weekly nitrate sampling was dropped at BTLUE and BTLUW, and weekly full nitrogen series sampling was replaced by weekly partial nitrogen series (partial N-series; nitrate-plus ammonia-nitrogen) sampling. The last full N-series samples from BTLUE and BTLUW were collected on February 19. At BTLD weekly nitrate sampling continued, but weekly collection of full N-series samples was discontinued, and replaced with monthly partial N-series sampling. As a result of the sampling changes, the estimates used to calculate annual fw mean nitrate concentrations and nitrate-nitrogen loads for BTLUE and

Table 35. Annual summary of water and chemical discharge for BTLD for WY 1994.

DISCHARGE		
Total		
acre-feet	9.2	
millions cf	0.40	
millions cm	0.011	
Average		
cfs	0.013	
cms	0.0004	
mg/d	0.008	
gpm	5.8	

PRECIPITATION AND DISCHARGE	
Precipitation	30.42 inches (772.7 mm)
Discharge	6.13 inches (155.7 mm)
Discharge as % of precipitation	20%

NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	60.3	13.4
Mean of analyses	61.7	13.7
	NO_3-N output	**Total N output**
lbs - N	334	338
kg - N	151	153
lbs-N/acre	18.6	18.8

ATRAZINE DISCHARGE	
Concentration - µg/L	
Flow-weighted mean	0.13
Mean of analyses	0.11
Total output	
lbs	0.003
g	1.50

BTLUW were based on the nitrate-nitrogen concentrations from N-series analyses, rather than concentrations from the analyses of nitrate samples.

Previously, the annual total nitrogen outputs for monitoring sites were calculated by adding the total nitrate-nitrogen output to the total ammonia- and organic-nitrogen outputs. Since the replacement of full N-series analysis with partial N-series analysis, the total nitrogen outputs from the monitoring sites for WY 1994 were calculated by adding the total nitrate-nitrogen output to total ammonia-nitrogen outputs, without the organic-nitrogen component previously used. During the early part of the water year when full N-series samples were taken, the total nitrogen outputs were calculated as in previous water years. As a result of the sampling changes, the total nitrogen loads for monitoring sites for WY 1994 will be somewhat smaller than if they had been calculated using full N-series analyses.

During WY 1994, seven samples from BTLUE were analyzed for nitrate, nine samples were analyzed for full N-series, and forty-five samples were analyzed for partial N-series. The annual fw mean nitrate concentration for BTLUE was 55.9 mg/L (12.4 mg/L as NO_3-N). The annual nitrate-nitrogen output for the water year was 2,583 pounds, or 10.3 lbs-N/acre, and the annual total nitrogen output (nitrate- plus organic- and ammonia-nitrogen) was 2,666 pounds, or 10.7 lbs-N/acre, within the BTLUE drainage area. The annual fw mean nitrate-nitrogen concentration and load from BTLUE during WY 1994 were the third smallest annual fw mean and load recorded at BTLUE during WYs 1987-1995.

The nitrate plot for BTLUE shows concentrations remaining relatively steady from the beginning of WY 1994 through mid-February. Concentrations declined from 81 mg/L (18.0 mg/L as NO_3-N) on October 25, to 63 mg/L (14.0 mg/L as NO_3-N) on November 2, 9, 16, and 23. The greatest nitrate concentration from BTLUE during the water year, 86 mg/L (19.0 mg/L as NO_3-N), was recorded on January 11 as discharge was generally receding from minor events that occurred in late December. Following this, the nitrate concentration declined to 68 mg/L (15.1

mg/L as NO_3-N) on January 18, then remained near 72 mg/L (16.0 mg/L as NO_3-N) through mid-February. Nitrate concentrations were diluted by snowmelt during the remainder of February and March, and ranged between 40 mg/L (8.9 mg/L as NO_3-N) and 54 mg/L (12.0 mg/L as NO_3-N) through the end of March. The concentration increased from 59 mg/L (13.1 mg/L as NO_3-N) on April 5 to 77 mg/L (17.1 mg/L as NO_3-N) on June 14, as discharge increased later in April, then declined through May, and increased again in early June. The smallest nitrate concentration at BTLUE during WY 1994, 12 mg/L (2.7 mg/L as NO_3-N), was recorded on July 5 as discharge was receding from an event that occurred on June 23. The nitrate concentration was 63 mg/L (14.0 mg/L as NO_3-N) on July 12 and July 19 as discharge continued to recede, then during significant runoff on July 20, the concentration was diluted to 32 mg/L (7.2 mg/L as NO_3-N). The concentration returned to 63 mg/L (14.0 mg/L as NO_3-N) on July 25 and remained relatively steady through August 9 as discharge receded. The concentration increased to 72 mg/L (16.0 mg/L as NO_3-N) on August 16 as discharge receded from a minor event that occurred on August 10. The concentration declined to 59 mg/L (13.0 mg/L as NO_3-N) in late August and early September as discharge receded. The concentration increased to 72 mg/L (16.0 mg/L as NO_3-N) on September 27 as discharge receded from the last runoff event of the water year, which occurred on September 25.

Monthly fw mean nitrate concentrations from BTLUE remained above 60 mg/L (13.3 mg/L as NO_3-N) during all months of WY 1994 except February, March, April and June. The greatest monthly fw mean nitrate concentration, 74.1 mg/L (16.5 mg/L as NO_3-N), occurred during January, and the smallest monthly fw mean, 42.3 mg/L (9.4 mg/L as NO_3-N) occurred during July, when a large proportion of discharge was supplied by runoff recharge. June had the greatest monthly nitrate-nitrogen discharge, 413 pounds, accounting for 16% of the annual total, and the second-greatest monthly groundwater discharge, 11.0 ac-ft, accounting for 14% of the annual discharge. January had the smallest monthly nitrate-nitrogen discharge, 33 pounds, and the smallest monthly groundwater discharge, 0.74 ac-ft, and accounted for 1% of the annual nitrate-nitrogen discharge and 1% of the annual groundwater discharge.

During WY 1994, four samples from BTLUW were analyzed for nitrate, four samples were analyzed for full N-series, and sixteen samples were analyzed for partial N-series. The annual fw mean nitrate concentration for BTLUW was 40.8 mg/L (9.1 mg/L as NO_3-N). The annual nitrate-nitrogen output for the water year was 462 pounds, and if organic- and ammonia-nitrogen are considered, the annual total nitrogen output was 499 pounds. Within the drainage area of BTLUW, the nitrate-nitrogen output was equivalent to 4.0 lbs-N/acre, and the total nitrogen output was equal to 4.3 lbs-N/acre.

BTLUW was dry during much of WY 1994, but nitrate concentrations showed trends similar to concentrations from BTLUE during periods with discharge. Like BTLUE, concentrations declined in late October, and were diluted in late February, early March, and June. The greatest nitrate concentration recorded at BTLUW during the water year, 99 mg/L (22.0 mg/L as NO_3-N), occurred on October 5 and 19, as discharge slowly receded from September of WY 1993. The concentration declined to 81 mg/L (18.0 mg/L as NO_3-N) on October 25, prior to discharge ceasing on October 31. The nitrate concentration increased from 12 mg/L (2.7 mg/L as NO_3-N) during runoff on February 19, to 50 mg/L (11.1 mg/L as NO_3-N) two days later as discharge rapidly receded. Concentrations declined slightly in early March, then increased to 77 mg/L (17.0 mg/L as NO_3-N) on March 28 as discharge generally declined. Discharge ceased on April 4, then resumed on April 14, and the nitrate concentration was 68 mg/L (15.0 mg/L as NO_3-N) on April 19 as discharge receded and then ceased on April 23. The nitrate concentration declined from 63 mg/L (14.0 mg/L as NO_3-N) on June 21 to 14 mg/L (3.1 mg/L as NO_3-N) on July 5 as discharge receded from June 23. The concentration increased to 77 mg/L (17.0 mg/L as NO_3-N) on July 12 then decreased to 72 mg/L (16.0 mg/L as NO_3-N) on July 19, as discharge receded from a small event that occurred

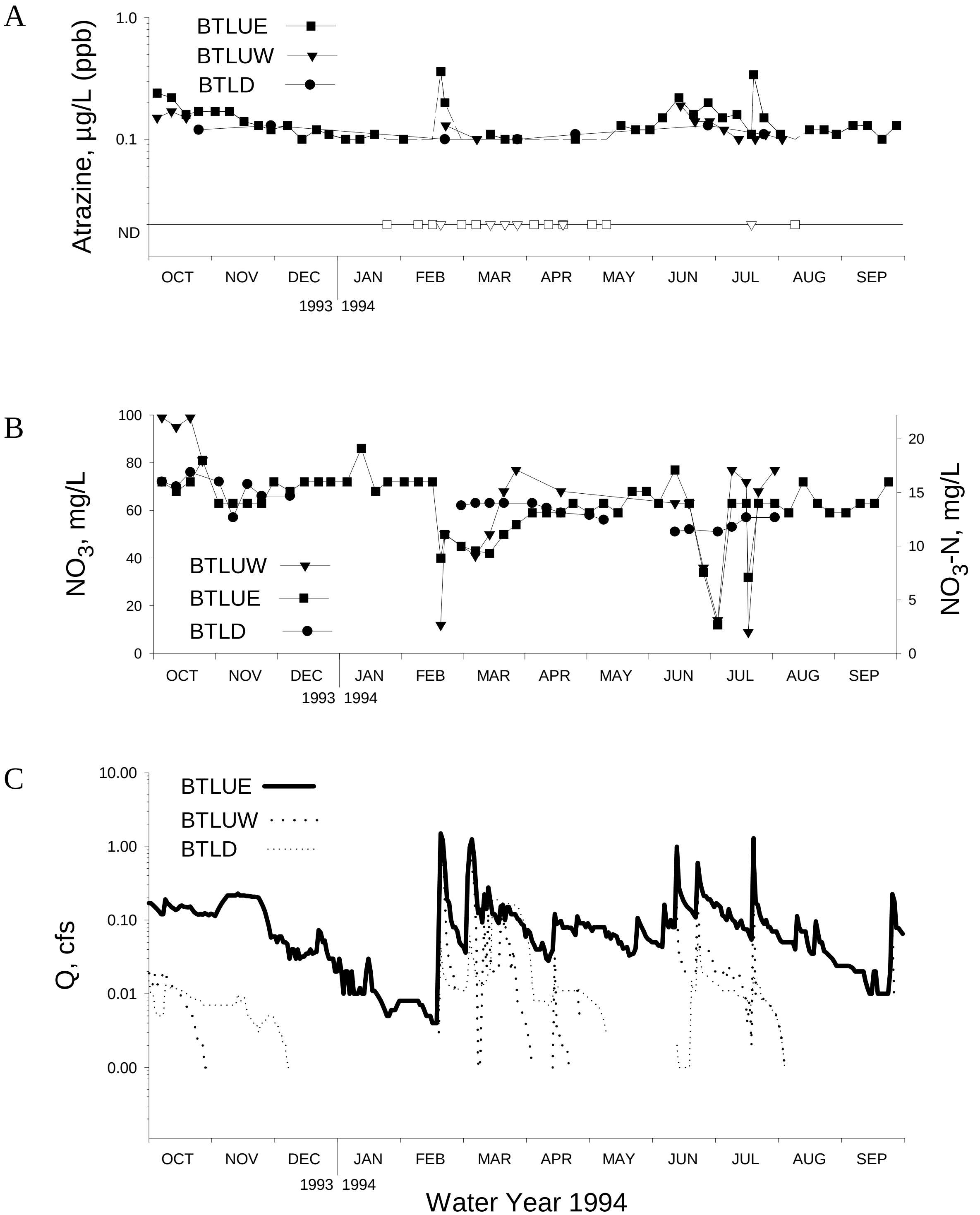


Figure 28. A) Atrazine and B) nitrate concentrations, and C) groundwater discharge (Q) at BTLUE, BTLUW and BTLD for WY 1994 (note the decrease in scale on the atrazine and nitrate plots relative to WY 1993).

on July 8. The smallest nitrate concentration recorded at BTLUW during the water year, 9 mg/L (2.0 mg/L as NO_3-N), occurred during runoff on July 20. Following this, the concentration increased to 77 mg/L (17.0 mg/L as NO_3-N) on August 2, prior to discharge ceasing on August 4.

Monthly fw mean nitrate concentrations were computed for BTLUW for every month of the water year except November, December, and January. The greatest monthly fw nitrate concentration at BTLUW during the water year, 88.8 mg/L (19.7 mg/L as NO_3-N), occurred during October, and the smallest monthly fw mean, 27.7 mg/L (6.2 mg/L as NO_3-N), occurred in February. The greatest monthly nitrate-nitrogen discharge, 137 pounds, and greatest monthly groundwater discharge, 5.8 ac-ft, occurred during March, and accounted for 30% of the annual nitrate-nitrogen discharge and 31% of the annual groundwater discharge. The smallest monthly nitrate-nitrogen output, 5.1 pounds, and smallest computed monthly groundwater discharge, 0.14 ac-ft, occurred during August and accounted for 1% of the annual nitrate-nitrogen discharge and 0.8% of the annual groundwater discharge.

At BTLD, twenty-three samples were analyzed for nitrate, and seven samples were analyzed for N-series during WY 1994. The annual fw mean nitrate concentration for BTLD was 60.3 mg/L (13.4 mg/L as NO_3-N). The annual nitrate-nitrogen discharge for the water year was 334 pounds, and if organic- and ammonia-nitrogen are considered, the annual total nitrogen output was 338 pounds. Within the drainage area of BTLD, the nitrate-nitrogen output was equivalent to 18.6 lbs-N/acre, and the total nitrogen output was equal to 18.8 lbs-N/acre.

Nitrate concentrations from BTLD showed much less variation than concentrations from BTLUE and BTLUW during the water year. The greatest nitrate concentration recorded at BTLD during the water year, 76 mg/L (16.9 mg/L as NO_3-N), occurred on October 19 as discharge was receding from a minor event that occurred on October 9. The nitrate concentration declined to 57 mg/L (12.7 mg/L as NO_3-N) on November 11 as discharge continued to recede from October. Minor recharge occurred on November 13 and the nitrate concentration increased to 71 mg/L (15.8 mg/L as NO_3-N) on November 16. The concentration decreased to 66 mg/L (14.7 mg/L as NO_3-N) on November 23 and remained at 66 mg/L (14.7 mg/L as NO_3-N) on December 7, as discharge declined and then ceased on December 9. After discharge resumed on February 18, nitrate concentrations were 63 mg/L (14.0 mg/L as NO_3-N) in samples taken from March 8 through April 5, as discharge receded through March 13, then increased during an event on March 19 and receded again through April 13. From April 5, concentrations declined to 56 mg/L (12.4 mg/L as NO_3-N) on May 10 as discharge slowly receded from a minor event that occurred on April 15. Discharge ceased on May 10, then resumed on June 13. The smallest nitrate concentration recorded at BTLD during the water year, 51 mg/L (11.3 mg/L as NO_3-N), occurred on June 14 and July 15 during receding periods. From mid-July, the nitrate concentration increased to 57 mg/L (12.7 mg/L as NO_3-N) on August 2, prior to flow ceasing on August 4.

Monthly fw mean nitrate concentrations for BTLD were computed for every month of WY 1994, except January and September. The greatest monthly fw mean nitrate concentration from BTLD during WY 1994, 73.0 mg/L (16.2 mg/L as NO_3-N), occurred in October, and the smallest monthly fw mean nitrate concentration, 51.8 mg/L (11.5 mg/L as NO_3-N), occurred in June. The smallest monthly nitrate-nitrogen discharge, 1.7 pounds, and the second-smallest monthly groundwater discharge, for months with discharge, 0.04 ac-ft, occurred in December, accounting for 0.5% of the annual nitrate-nitrogen discharge, and 0.4% of the annual groundwater discharge. The greatest monthly nitrate-nitrogen discharge, 209 pounds, and the greatest monthly groundwater discharge, 5.8 ac-ft, occurred during March and accounted for 63% of the annual nitrate-nitrogen discharge and 63% of the annual groundwater discharge from BTLD during WY 1994.

The annual fw mean nitrate concentration for Big Spring during WY 1994 was 47.0 mg/L (10.4 mg/L as NO_3-N; Liu et al., 1997). A total of

911,133 pounds of nitrogen were discharged, and of this total, 888,518 pounds, or 98%, was in the form of nitrate. Within the 103 mi^2 drainage area of Big Spring, the annual total nitrogen output was equivalent to 13.8 lbs-N/acre and the annual nitrate-nitrogen output was 13.5 lbs-N/acre. Water Year 1994 had the fourth-greatest annual fw mean nitrate concentration, and the fifth-greatest annual nitrate-nitrogen discharge during WYs 1982-1995 (Liu et al., 1997).

At Big Spring, monthly fw mean nitrate concentrations exceeded the 45 mg/L (10 mg/L as NO_3-N) drinking water standard for nitrate during all months except February, March and September (Liu et al., 1997). The greatest monthly fw mean nitrate concentration during WY 1994, 55.1 mg/L (12.3 as NO_3-N), occurred during October and the smallest monthly fw mean, 35.4 mg/L (7.9 as NO_3-N), occurred in February. Monthly nitrate-nitrogen discharge varied from 117,400 pounds in October, the month with the second-greatest monthly groundwater discharge, to 37,000 pounds in September, the month with the smallest groundwater discharge. October accounted for 13% of the annual nitrate-nitrogen load and 11% of the annual discharge.

Pesticide Monitoring

Tables 33-35 and Figure 28 summarize the results of pesticide monitoring at sites BTLUE, BTLUW and BTLD for WY 1994.

Fifty-four samples from BTLUE were analyzed for pesticides during WY 1994. Forty-three, or 80%, of the samples contained detectable levels of atrazine (>0.10 µg/L). This is the second-smallest annual percentage of detections of atrazine from BTLUE during WYs 1987-1995. The annual fw mean atrazine concentration for WY 1994, 0.17 µg/L, was the smallest annual fw mean atrazine concentration recorded at BTLUE during WYs 1987-1995 (Table 33). The annual atrazine discharge for WY 1994, 16.2 grams, was the second-smallest annual atrazine load recorded at BTLUE during WYs 1987-1995.

Atrazine concentrations at BTLUE declined from 0.24 µg/L at the beginning of the water year to 0.10 µg/L on December 14. Concentrations ranged from 0.12 µg/L on December 21 to 0.10 µg/L on January 4 and January 11. Concentrations increased to 0.11 µg/L on January 18, then declined to below the 0.10 µg/L detection limit on January 24. The atrazine concentration increased to 0.10 µg/L on February 1, then was below the 0.10 µg/L detection limit on February 8 and February 15. The greatest concentration recorded at BTLUE during the water year, 0.36 µg/L, occurred on February 19 during the first major runoff of WY 1994. Following the event, the atrazine concentration declined to 0.20 µg/L on February 21, and was below the 0.10 µg/L detection limit on March 1 as discharge continued to recede. The atrazine concentration was below detectable levels on March 8, following runoff on March 6. From mid-March through May 10, concentrations ranged between 0.11 µg/L and non-detectable levels. Atrazine concentrations increased, along with runoff from mid-May to mid-June. Concentrations increased from 0.12 µg/L on May 24 to 0.22 µg/L on June 14, then decreased to 0.11 µg/L on July 19. The atrazine concentration increased to 0.34 µg/L during runoff on July 20, then decreased, along with discharge, to non-detectable levels on August 9. During the remainder of the water year, atrazine concentrations ranged from 0.13 µg/L to 0.10 µg/L.

Monthly fw mean atrazine concentrations and atrazine loads from BTLUE varied from 0.26 µg/L and 2.6 grams in February, to 0.03 µg/L in April and 0.08 grams in January. February had the fifth-greatest monthly groundwater discharge, 8.3 ac-ft, accounting for 11% of the annual groundwater discharge, and accounted for 16% of the annual atrazine discharge. January had the smallest monthly groundwater discharge, 0.74 ac-ft, accounting for 1% of the annual total, and accounted for 0.5% of the annual atrazine discharge.

Other pesticides detected at BTLUE during WY 1994 include desethylatrazine in fifty-one samples, or 98%, metolachlor in three, or 6%, and alachlor in two, or 4%, of the samples collected. The greatest concentrations of pesticides detected during the water year include metolachlor at 0.71 µg/L, desethylatrazine at 0.45 µg/L, atrazine at

0.36 µg/L, and alachlor at 0.16 µg/L. The maximum concentration for desethylatrazine occurred on October 10, the maximum for atrazine occurred on February 19, and the maximum concentrations for alachlor and metolachlor occurred on June 14. Desethylatrazine was detected during every month of WY 1994, while metolachlor and alachlor were detected only during June.

Nineteen samples from BTLUW were analyzed for pesticides during WY 1994. Thirteen, or 68%, of the samples contained detectable levels of atrazine (>0.10 µg/L). Like BTLUE, the percentage of atrazine detections during WY 1994 was the second smallest recorded at BTLUW during WYs 1987-1995. The annual fw mean atrazine concentration for WY 1994, 0.14 µg/L, was the second-smallest annual fw mean recorded at BTLUW during WYs 1987-1995 (Table 34). The annual atrazine output for WY 1994, 3.2 grams, was the smallest annual atrazine discharge recorded at BTLUW during WYs 1987-1995.

As previously mentioned, BTLUW was dry during much of WY 1994. The atrazine plot for BTLUW shows some similarity to the plot for BTLUE during periods with discharge. The atrazine concentration increased from 0.15 µg/L on October 5, to 0.17 µg/L on October 12, then decreased back to 0.15 µg/L on October 19, as discharge declined from a minor event that occurred on October 9. Discharge ceased on October 31 and BTLUW remained dry through February 17. The concentration increased from non-detectable levels on February 19 to 0.13 µg/L on February 21 as discharge receded from an event that occurred on February 19. The atrazine concentration declined from 0.10 µg/L on March 8 to non-detectable levels on March 15, and remained below the 0.10 µg/L detection limit in samples taken through April 19. The greatest atrazine concentration from BTLUW during WY 1994, 0.19 µg/L, was recorded on June 14 as discharge receded from runoff that occurred on June 13. Following this, the atrazine concentration declined from 0.14 µg/L on June 21 to non-detectable levels on July 19. The concentration increased to 0.10 µg/L during runoff on July 20, then increased to 0.11 µg/L on July 25, and decreased back to 0.10 µg/L on August 2, as discharge receded from the event.

Monthly fw mean atrazine concentrations for BTLUW were computed for all months during the water year, except November through January. Monthly atrazine concentrations and loads varied from 0.04 µg/L and 0.01 grams in April to 0.30 µg/L and 1.5 grams in May. April accounted for 0.3% of the annual atrazine discharge and 0.8% of the annual groundwater discharge and May accounted for 47% of the annual atrazine discharge and 21% of the annual groundwater discharge from BTLUW.

Other pesticides detected at BTLUW during WY 1994 include desethylatrazine in seventeen samples, or 100%, metolachlor in three, or 18%, and alachlor in one, or 6%, of the samples collected. The greatest concentrations of pesticides detected during the water year include metolachlor at 0.68 µg/L, alachlor at 0.47 µg/L, desethylatrazine at 0.37 µg/L, and atrazine at 0.19 µg/L. The maximum concentration for desethylatrazine occurred on October 10, and for metolachlor, alachlor and atrazine, the maximum concentrations occurred on June 14. Desethylatrazine was detected during all months with groundwater discharge, while metolachlor and alachlor were detected during June only.

Seven samples from BTLD were analyzed for pesticides during WY 1994. All of the samples contained detectable levels of atrazine (>0.10 µg/L). The annual fw mean atrazine concentration for WY 1994 was 0.13 µg/L and the annual atrazine discharge was 1.50 grams (Table 35). The annual fw mean atrazine concentration and percentage of atrazine detections during WY 1994 were the greatest recorded at BTLD during WYs 1987-1994.

BTLD was dry from December 10 through February 17, from May 11 through June 12 and from August 5 through the end of the water year. Atrazine concentrations showed little variation in monthly samples taken during the water year. The atrazine concentration increased from 0.12 µg/L on October 25 to 0.13 µg/L on November 29 as discharge declined. Concentrations were 0.10 µg/L in samples taken on February 21 and March

28. On April 25, the atrazine concentration was 0.11 µg/L, and on June 28, the atrazine concentration was 0.13 µg/L, matching the previous high for the water year, recorded on November 29. The concentration of the last pesticide sample of the water year, taken on July 25, was 0.11 µg/L.

Monthly fw mean atrazine concentrations for BTLD were computed for all months during the water year except January and September. Monthly fw mean atrazine concentrations varied from 0.14 µg/L in March to 0.10 µg/L in April. Monthly atrazine and groundwater discharge varied from 1.0 grams and 5.8 ac-ft in March to 0.002 grams and 0.02 ac-ft in August. March accounted for 67% of the annual atrazine discharge and 63% of the annual groundwater discharge from BTLD.

Other pesticides detected at BTLD during WY 1994 include desethylatrazine in seven samples, or 100%, and desisopropylatrazine in two, or 29%, of the samples collected. The greatest concentrations of pesticides detected during the water year include atrazine at 0.13 µg/L, and desethylatrazine and desisopropylatrazine at 0.18 µg/L. The maximum concentrations of atrazine, desethylatrazine and desisopropylatrazine all occurred on November 29. Desisopropylatrazine was detected in monthly samples in October and November.

At Big Spring, 17.8 pounds of atrazine were discharged during WY 1994, at a fw mean concentration of 0.21 µg/L (Liu et al., 1997). This was the third-smallest annual fw mean atrazine concentration, and the fourth-smallest annual atrazine discharge observed at Big Spring during WYs 1982-1995 (Liu et al., 1997).

Monthly fw mean atrazine concentrations and loads varied from 0.04 µg/L and 0.25 pounds in April to 0.62 µg/L and 5.3 pounds in July (Liu et al., 1997). Atrazine discharge during April accounted for 1.4% of the annual total, and atrazine discharge during July accounted for 30% of the annual atrazine discharge from Big Spring.

Water Year 1995

Discharge Monitoring

Tables 36 and 37 and Figure 29 summarize the discharge, climatic, water quality, and chemical loading data for monitoring sites BTLUE and BTLUW for WY 1995. Groundwater monitoring at site BTLD was discontinued at the end of WY 1994. Note the increase in scale on the atrazine and nitrate plots for WY 1995 relative to WY 1994.

The annual precipitation for WY 1995, 29.28 inches, was 3.69 inches below normal, or 89% of the long-term average for the Big Spring basin. The annual precipitation for WY 1995 was the third smallest recorded in the basin during WYs 1982-1995 (Liu et al., 1997). Monthly precipitation totals for November, March, April and August were much greater than normal. The wettest month of WY 1995 was April, with 4.78 inches of precipitation, which was 145% of the long-term average for the month. The driest month of the water year was February, with 0.03 inches of precipitation. The monthly precipitation for June, which has typically been the wettest month in the basin, was 2.51 inches, or 52% of the long-term monthly average.

Groundwater discharge at BTLUE was relatively steady from October through mid-February. Discharge generally decreased from late October through late November, then increased due to greater than normal precipitation during November, and then generally receded through mid-February (Fig. 29). Precipitation in March and April generated runoff and infiltration recharge, and discharge increased through mid-April. From April, discharge generally declined through most of May. Following runoff in May, discharge again generally declined through late July. During the remainder of the water year, receding discharge was punctuated by a number of minor runoff events.

Groundwater discharge from BTLUE was continuous during the entire water year. The annual discharge for BTLUE for WY 1995 was 97.5 ac-ft, and the average daily discharge was 0.14 cfs (Table 36). The annual discharge from BTLUE was equal to 16% of the annual precipitation.

Site BTLUW was dry from the beginning of the water year through November 26, November 28 through February 17, February 24, February 26 through March 9, March 16-19, July 9-22, July 25-26, August 5, August 11-27, September 1-5, and September 9 through the end of the water year. The annual discharge from BTLUW was 29.1 ac-ft, the average daily discharge rate was 0.04 cfs, and the annual discharge was equivalent to 10% of the annual precipitation (Table 37).

The annual groundwater discharge for Big Spring for WY 1995 was 30,013 ac-ft, at an average daily discharge rate of 41.5 cubic feet per second (Liu et al., 1997). The annual discharge was equivalent to 18.7% of the annual precipitation during the water year.

Nitrate Monitoring

Tables 36 and 37 and Figure 29 summarize the nitrate analyses from BTLUE and BTLUW during WY 1995.

Due to sampling changes discussed below, the nitrate plots for BTLUE and BTLUW for WY 1995 were based on concentrations from nitrate samples, as were the plots for WYs 1986-1993, rather than nitrate concentrations from N-series analyses, as was the plot for WY 1994.

In WY 1995, weekly sampling of partial N-series at BTLUE and BTLUW was discontinued, and replaced with weekly nitrate sampling. As a result of the sampling changes, loads for ammonia-nitrogen and/or organic-nitrogen could not be calculated, and in turn, annual total nitrogen discharge could not be calculated.

During the water year, fifty-three samples from BTLUE were analyzed for nitrate. The annual fw mean nitrate concentration for BTLUE was 73.2 mg/L (16.3 mg/L as NO_3-N; Fig. 36). The annual nitrate-nitrogen output for the water year was 4,315 pounds, or 17.3 lbs-N/acre, within the drainage area of BTLUE. The annual fw mean nitrate concentration for WY 1995 was the fifth greatest, and the nitrate-nitrogen discharge the fourth greatest recorded at BTLUE during WYs 1987-1995.

Table 36. Annual summary of water and chemical discharge for BTLUE for WY 1995.

DISCHARGE		
Total		
acre-feet	97.5	
millions cf	4.2	
millions cm	0.12	
Average		
cfs	0.14	
cms	0.004	
mg/d	0.09	
gpm	60.6	
PRECIPITATION AND DISCHARGE		
Precipitation	29.28 inches (717.4 mm)	
Discharge	4.68 inches (118.9 mm)	
Discharge as % of precipitation	16%	
NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	73.2	16.3
Mean of analyses	69.4	15.4
	NO_3-N output	**Total N output**
lbs - N	4,315	n/a
kg - N	1,957	n/a
lbs - N/acre	17.3	n/a
ATRAZINE DISCHARGE		
Concentration - µg/L		
Flow-weighted mean	0.17	
Mean of analyses	0.15	
Total output		
lbs	0.05	
g	20.9	

The nitrate plot for BTLUE for WY 1995 shows trends similar to the discharge plot for BTLUE. Nitrate concentrations remained relatively steady from the beginning of WY 1995 through early-March. Concentrations ranged from 72 mg/L (16.0 mg/L as NO_3-N) on November 28 to 61 mg/L (13.5 mg/L as NO_3-N) in samples taken from February 21 through March 7. The smallest nitrate concentration from BTLUE during the water year, 18 mg/L (4.0 mg/L as NO_3-N), occurred on March 11, during runoff. Following this, the nitrate concentration increased to 68 mg/L (15.6 mg/L as NO_3-N) on March 14 as discharge quickly receded. The concentration increased to 79 mg/L (17.6 mg/L as NO_3-N) on March 21, following runoff on March 20. Nitrate concentrations were diluted by runoff during the remainder of March and early April, and were 65 mg/L (14.4 mg/L as NO_3-N) on March 27, and 63 mg/L (14.0 mg/L as NO_3-N) on April 4. The concentration increased to 87 mg/L (19.3 mg/L as NO_3-N) on April 11 as discharge increased and then peaked on April 12. The concentration was diluted to 44 mg/L (9.8 mg/L as NO_3-N) during an event on April 18, then increased to 87 mg/L (19.3 mg/L as NO_3-N) on April 24 as discharge receded. Concentrations remained relatively constant through most of May, then increased to the greatest concentration recorded at BTLUE during the water year, 110 mg/L (24.4 mg/L as NO_3-N), on May 30 as discharge receded from an event that occurred on May 28. During the remainder of the water year, nitrate concentrations generally declined as groundwater discharge receded. The nitrate concentration of the last sample of the water year was 65 mg/L (14.4 mg/L as NO_3-N).

Monthly fw mean nitrate concentrations from BTLUE remained at or above 60 mg/L (13.3 mg/L as NO_3-N) during all months of WY 1995 except for February. The greatest monthly fw mean nitrate concentration, 88.8 mg/L (19.7 mg/L as NO_3-N), occurred during June, and the smallest monthly fw mean, 58.4 mg/L (13.0 mg/L as NO_3-N) occurred during February. April had the greatest monthly nitrate-nitrogen discharge, 1,317 pounds, which accounted for 31% of the annual total, and the greatest monthly groundwater dis-

Table 37. Annual summary of water and chemical discharge for BTLUW for WY 1995.

DISCHARGE		
Total		
acre-feet	29.1	
millions cf	1.3	
millions cm	0.04	
Average		
cfs	0.04	
cms	0.001	
mg/d	0.03	
gpm	18.0	

PRECIPITATION AND DISCHARGE	
Precipitation	29.28 inches (717.4 mm)
Discharge	3.01 inches (76.5 mm)
Discharge as % of precipitation	10%

NITRATE DISCHARGE		
Concentration - mg/L	**As NO_3**	**As NO_3-N**
Flow-weighted mean	80.9	18.0
Mean of analyses	80.2	17.8
	NO_3-N output	**Total N output**
lbs - N	1,425	n/a
kg - N	646	n/a
lbs - N/acre	12.3	n/a

ATRAZINE DISCHARGE	
Concentration - µg/L	
Flow-weighted mean	0.12
Mean of analyses	0.15
Total output	
lbs	0.01
g	4.34

charge, 32.7 ac-ft, which accounted for 34% of the annual discharge. September had the smallest monthly nitrate-nitrogen discharge, 42 pounds, and the smallest monthly groundwater discharge, 1.1 ac-ft, and accounted for 1% of the annual nitrate-nitrogen discharge and 1% of the annual groundwater discharge.

During WY 1995, twenty samples from BTLUW were analyzed for nitrate. The annual fw mean nitrate concentration for BTLUW was 80.9 mg/L (18.0 mg/L as NO_3-N; Table 37). The annual nitrate-nitrogen output for the water year was 1,425 pounds, or 12.3 lbs-N/acre within the drainage area of BTLUW.

Site BTLUW was dry during much of the water year, but showed trends similar to concentrations from BTLUE during periods with discharge. Like BTLUE, nitrate concentrations at BTLUW were diluted in late March and early April, increased later in April, remained relatively steady through most of May, peaked at the end of May, and then generally decreased during the rest of the water year. The smallest nitrate concentration from BTLUW during the water year, 50 mg/L (11.1 mg/L as NO_3-N), was recorded on April 11 and April 18. Like BTLUE, the greatest nitrate concentration recorded at BTLUW during the water year, 105 mg/L (23.3 mg/L as NO_3-N), occurred on May 30, as discharge receded from runoff that occurred on May 28. From late May, the nitrate concentration declined to 57 mg/L (12.7 mg/L as NO_3-N) on August 29.

Monthly fw mean nitrate concentrations were computed for BTLUW for every month of the water year except October, December, and January. Monthly fw mean nitrate concentrations from BTLUW remained above 65 mg/L (14.4 mg/L as NO_3-N) during all months except September. The greatest monthly fw nitrate concentration at BTLUW during the water year, 95.9 mg/L (21.3 mg/L as NO_3-N), occurred during June, and the smallest monthly fw mean, 58.6 mg/L (13.0 mg/L as NO_3-N), occurred in September. The greatest monthly nitrate-nitrogen discharge, 516 pounds, and greatest monthly groundwater discharge, 12.8 ac-ft, occurred during April, and accounted for 36% of the annual nitrate-nitrogen discharge and 44% of the annual groundwater discharge. The smallest monthly nitrate-nitrogen output, 0.96 pounds, and smallest computed monthly groundwater discharge, 0.02 ac-ft, occurred during November and accounted for 0.07% of the annual nitrate-nitrogen discharge and 0.07% of the annual groundwater discharge.

The annual fw mean nitrate concentration for Big Spring for WY 1995 was 45.3 mg/L (10.1 mg/L as NO_3-N; Liu et al., 1997). A total of 826,212 pounds of nitrogen (excluding organic-nitrogen) were discharged, and of this total, 822,569 pounds, or 99.6%, was in the form of nitrate. Within the 103 mi^2 drainage area of Big Spring, the annual total nitrogen and annual nitrate-nitrogen outputs were both equivalent to 12.5 lbs-N/acre. Water Year 1995 had the sixth-greatest annual fw mean nitrate concentration, and the eighth-greatest annual nitrate-nitrogen discharge during WYs 1982-1995 (Liu et al., 1997).

At Big Spring, monthly fw mean nitrate concentrations exceeded the 45 mg/L (10 mg/L as NO_3-N) drinking water standard for nitrate from April through July (Liu et al., 1997). The greatest monthly fw mean nitrate concentration during WY 1995, 51.8 mg/L (11.5 as NO_3-N), occurred during May and the smallest monthly fw mean, 33.0 mg/L (7.3 as NO_3-N), occurred in March. Monthly nitrate-nitrogen discharge varied from 159,000 pounds in May, the month with the greatest monthly groundwater discharge, to 38,000 pounds in October, the month with the smallest groundwater discharge. May accounted for 19% of the annual nitrate-nitrogen load and 17% of the annual groundwater discharge.

Pesticide Monitoring

Tables 36 and 37 and Figure 29 summarize the results of pesticide monitoring at sites BTLUE and BTLUW for WY 1995. During WY 1995, pesticide samples from BTLUE and BTLUW were taken on a monthly, rather than weekly basis.

Twelve samples from BTLUE were analyzed for pesticides during the water year. Six, or 50%, of the samples contained detectable levels of atra-

A
B
C

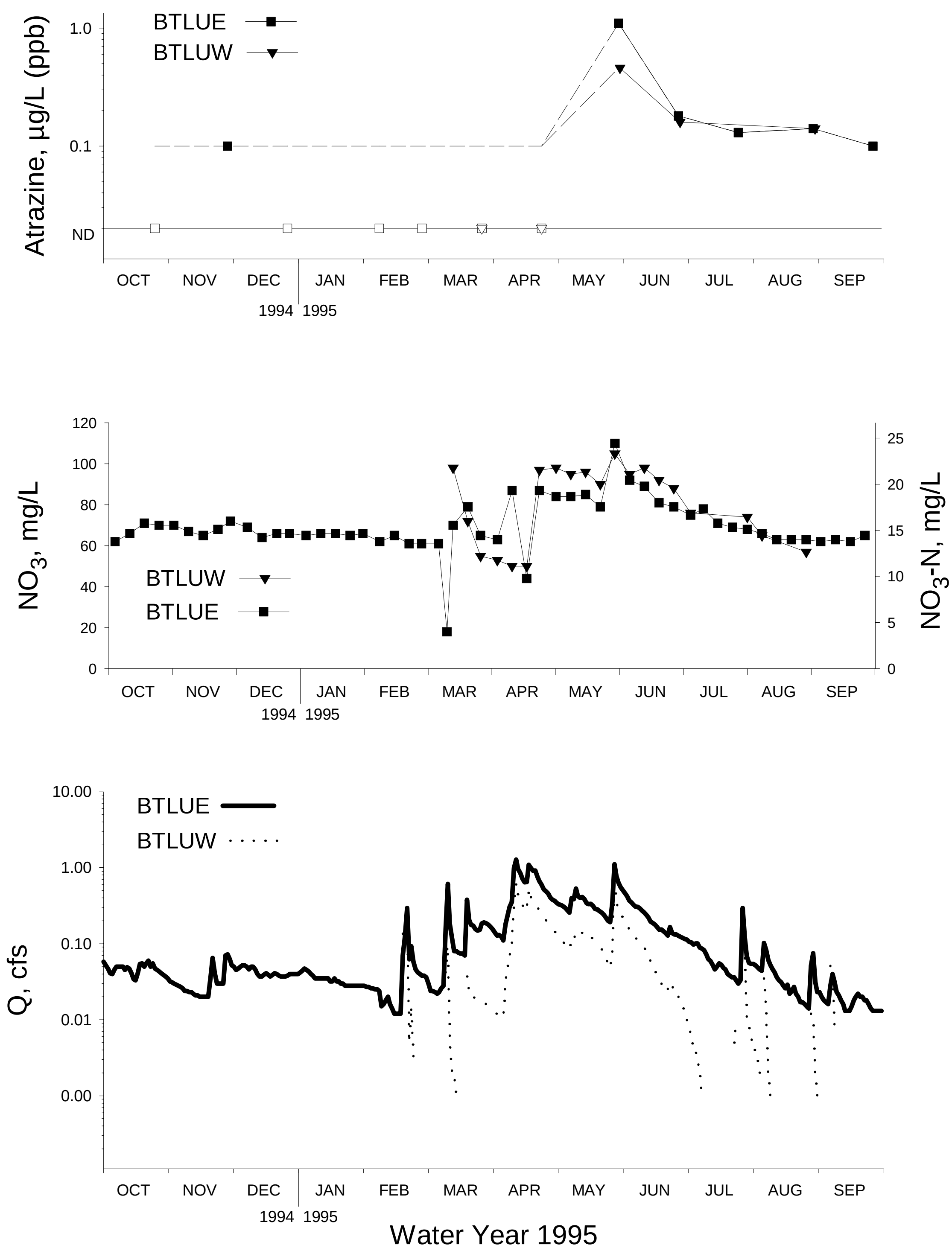


Figure 29. A) Atrazine and B) nitrate concentrations, and C) groundwater discharge (Q) at BTLUE and BTLUW for WY 1995 (note the increase in scale on the nitrate plot relative to WY 1994).

zine (>0.10 µg/L). This was the smallest annual percentage of detections of atrazine from BTLUE during WYs 1987-1995, and may be due, in part, to the lower sampling frequency and lack of event sampling. The annual fw mean atrazine concentration for BTLUE during WY 1995, 0.17 µg/L, equaled the annual fw mean atrazine concentration for WY 1994, which was the smallest annual fw mean atrazine concentration recorded at BTLUE during WYs 1987-1994 (Table 36). The annual atrazine discharge for WY 1995, 20.9 grams, was the third-smallest annual atrazine load recorded at BTLUE during WYs 1987-1995.

Atrazine concentrations from BTLUE were below the 0.10 µg/L detection limit in all samples taken from October through April, except on November 28, when the atrazine concentration was 0.10 µg/L. The greatest atrazine concentration recorded at BTLUE during the water year, 1.10 µg/L, occurred on May 30, as discharge was receding from a large event that occurred on May 28. During the remainder of the water year, atrazine concentrations generally declined as discharge receded. The atrazine concentration of the last sample of the water year, taken on September 26, was 0.10 µg/L.

Monthly fw mean atrazine concentrations and loads for BTLUE were computed for all months of the water year except January. Monthly fw mean atrazine concentrations and loads from BTLUE varied from 0.33 µg/L and 9.5 grams in May, to 0.04 µg/L in December and 0.12 grams in November. May had the second-greatest monthly groundwater discharge, 23.3 ac-ft, accounting for 24% of the annual total, and accounted for 45% of the annual atrazine discharge. November had the second-smallest monthly groundwater discharge, 1.9 ac-ft, accounting for 2% of the annual discharge, and accounted for 0.6% of the annual atrazine load.

Other pesticides detected at BTLUE during the water year include desethylatrazine in twelve, or 100%, and acetochlor in one, or 8%, of the samples collected. The greatest concentrations of pesticides detected during the water year include acetochlor at 1.30 µg/L, atrazine at 1.10 µg/L, and desethylatrazine at 0.31 µg/L. All maximum concentrations occurred on May 30. Desethylatrazine was detected in all months, except January, in which no pesticide samples were taken.

Five samples from BTLUW were analyzed for pesticides during WY 1995. Three, or 60%, of the samples contained detectable levels of atrazine (>0.10 µg/L). Like BTLUE, the percentage of atrazine detections for BTLUW during WY 1995 was the smallest recorded at BTLUW during WYs 1987-1995. The annual fw mean atrazine concentration for the water year, 0.12 µg/L, was the smallest annual fw mean recorded at BTLUW during WYs 1987-1995 (Table 37). The annual atrazine discharge for WY 1995, 4.34 grams, was the second-smallest annual atrazine discharge recorded at BTLUW during WYs 1987-1995.

As previously mentioned, BTLUW was dry during the first four months of WY 1995. The atrazine plot for BTLUW shows some similarity to the plot for BTLUE during periods with discharge. Atrazine concentrations were below the 0.10 µg/L detection limit in samples taken in March and April. Like BTLUE, the greatest atrazine concentration recorded at BTLUW during the water year, 0.46 µg/L, occurred on May 30 as discharge receded from an event that occurred on May 28. On June 27, the atrazine concentration was 0.16 µg/L and on August 29 the atrazine concentration was 0.14 µg/L.

Monthly fw mean atrazine concentrations for BTLUW for WY 1995 were computed for the months February through September. Monthly atrazine concentrations varied from 0.02 µg/L in March to 0.20 µg/L in June. Monthly atrazine loads from BTLUW varied from 0.02 grams in March to 1.44 grams in April. March accounted for 0.5% of the annual atrazine discharge and 2.6% of the annual groundwater discharge and April accounted for 33% of the annual atrazine discharge and 44% of the annual groundwater discharge from BTLUW.

Other pesticides detected at BTLUW during the water year include desethylatrazine in four, or 80%, and acetochlor in one, or 20%, of the samples collected. The greatest concentrations of pesticides detected during the water year include acetochlor at 0.56 µg/L, atrazine at 0.46 µg/L, and desethylatrazine at 0.21 µg/L. The maximum concentrations for acetochlor and atrazine occurred on May 30, and the maximum concentration for desethylatrazine occurred on June 27. Desethylatrazine was detected in April, May, June and August, while acetochlor was detected only in May.

At Big Spring, 9.8 pounds of atrazine were discharged during WY 1995, at a fw mean concentration of 0.12 µg/L (Liu et al., 1997). This was the smallest annual fw mean atrazine concentration, and the second-smallest annual atrazine discharge observed at Big Spring during WYs 1982-1995.

Monthly fw mean atrazine concentrations remained below 0.20 µg/L during all months except June, and were below 0.10 µg/L in November, and from January through April (Liu et al., 1997). Monthly fw mean atrazine concentrations varied from 0.04 µg/L during January and April to 0.22 µg/L in June. Monthly atrazine discharge from Big Spring varied from 0.17 pounds in January to 2.6 pounds in May, with all months except May and June having monthly atrazine loads of less than one pound. Atrazine discharge during January accounted for 0.4% of the annual total, and atrazine discharge during May accounted for 27% of the annual atrazine discharge from Big Spring.

DISCUSSION

Relating water quality changes to changes in landuse and management within a watershed over time requires consideration of many factors. 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 the Bugenhagen sub-basin 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 landuse changes within the sub-basin include changes in cropping patterns over time, and changes caused by constructing tile-intake terraces and connecting additional tile outlets to BTLUE and BTLUW, resulting in a progressive increase in the tile intake drainage areas (figures 4-17 and tables 2-4).

Climatic variability during the monitoring period and the resulting hydrologic conditions complicate the interpretation of changes in water quality within the sub-basin. The two driest consecutive years in the state's history, WYs 1988 and 1989, preceded the two wettest consecutive years since monitoring began in the sub-basin. Precipitation patterns changed significantly from WYs 1988 and 1989 to WYs 1990 and 1991. Annual precipitation increased from being 30% below normal during WYs 1988 and 1989 to 115% of normal in WY 1990 and 143% of normal in WY 1991. The increased precipitation generated both runoff and infiltration recharge. Water years 1985-1989 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. Annual precipitation during WY 1992 was approximately 2.8 inches above normal, and more evenly distributed than during WYs 1990 and 1991. Greater than normal annual precipitation continued during WYs 1992 and 1993 with annual precipitation totals of 108% and 141% of normal respectively. Water Year 1992 had a very dry growing season, and WY 1993 had a wet growing season. Water Year 1993 had the second-greatest annual precipitation during WYs 1982-1995, and was characterized by episodes of major flooding across the upper Midwest. Annual precipitation decreased to 92% of normal in WY 1994, and continued to decrease to 89% of normal during WY 1995. Water Year 1994 had a dry growing season until June, and the WY 1995 growing season was relatively wet until June.

The addition of tile-outlet terraces within the sub-basin changed the nature of the tile effluent of BTLUE and BTLUW. During dry periods the tiles yield shallow groundwater, but following sig-

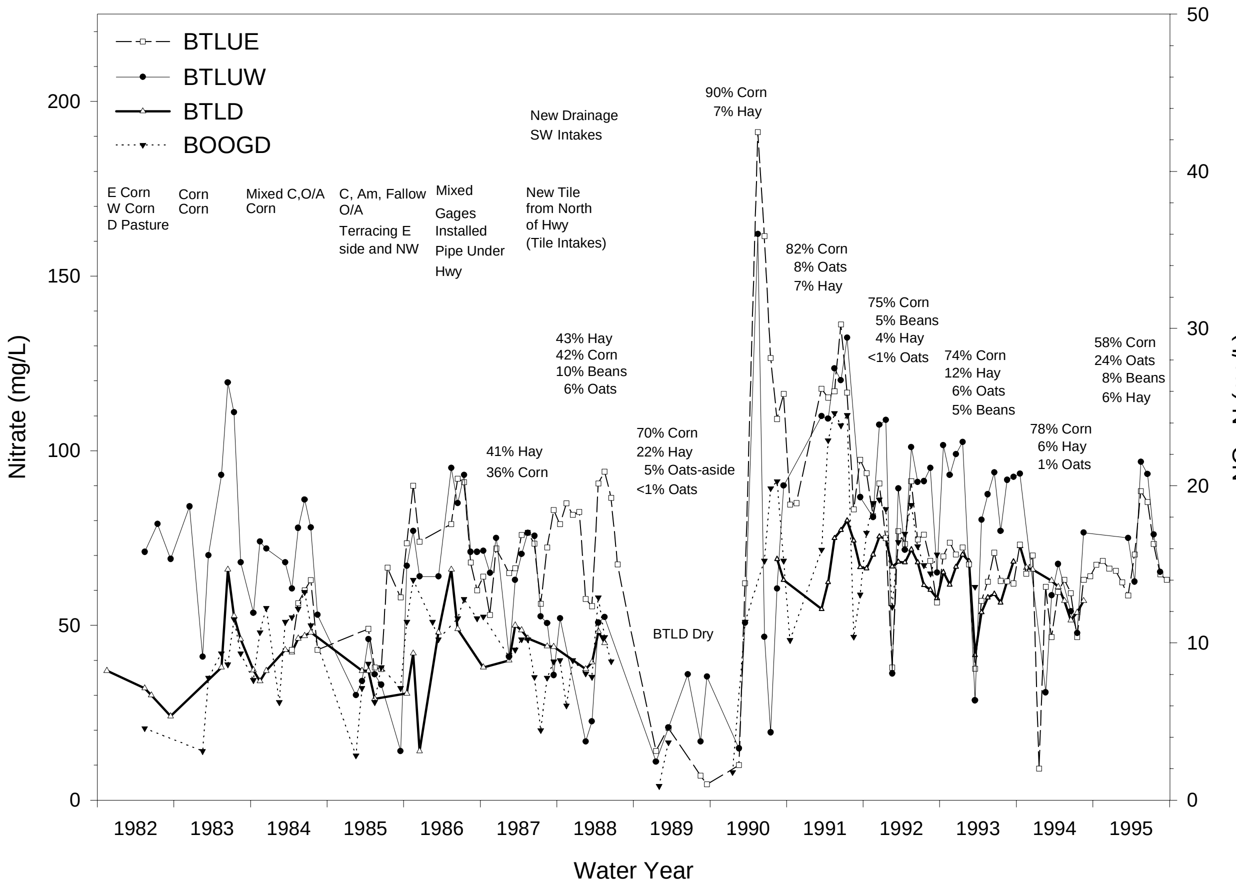


Figure 30. Monthly mean nitrate concentrations from sites BTLUE, BTLUW, BTLD, and BOOGD for WYs 1982-1995. Changes in landuse and cropping-patterns are shown near top of graph.

nificant precipitation or snowmelt, the tile-intakes in the terraces direct runoff into the tiles, mixing surface water with groundwater. As runoff recharge enters the tile lines, relatively low nitrate and high herbicide concentrations occur during peak discharge periods. This is typically followed by higher nitrate concentrations and lower herbicide concentrations as the associated infiltration recharge moves through the tile system.

Figures 30 and 31 show monthly mean nitrate and atrazine concentrations from monitoring sites BTLUE, BTLUW, BTLD, and BOOGD for WYs 1982-1995. Monthly mean concentrations were used to remove some of the sampling bias and to make monitoring results more comparable. Figure 30 also shows changes in terrace and tile-line configurations and annual percentages of various crops within the upper sub-basin, based on farm surveys. On Figure 31, mean monthly atrazine concentrations of <0.10 µg/L are shown as non-detections (ND) even if some samples taken during the month were above detectable concentrations. Since these data are from monitoring actual farm operations, where a number of best management practices were implemented simultaneously, interpretation is not as straightforward as with data from controlled, experimental farm operations.

During WYs 1982-1983, landuse on the east and west sides of the upper sub-basin was similar. Landuse and cropping patterns began changing in 1984. Generally, the side of the watershed with

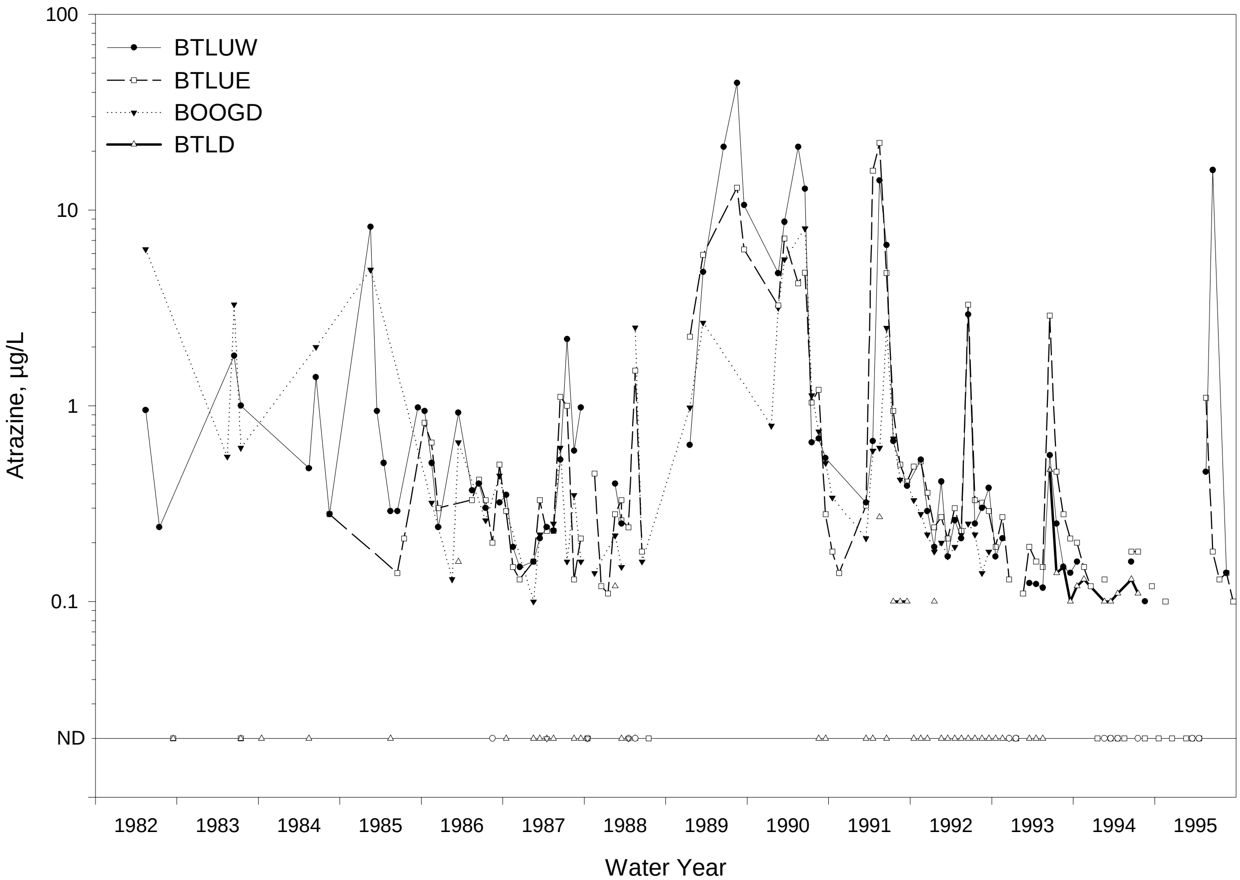


Figure 31. Monthly mean atrazine concentrations from sites BTLUE, BTLUW, BTLD, and BOOGD for WYs 1982-1995.

the most fertilized corn exhibited the greatest average nitrate concentrations and the greatest peak concentrations (George Hallberg, personal communication). As tile-outlet structures were connected into the tiles, the water quality of the two tiles has become more variable due to the increase in drainage area and surface runoff that is diverted into the tiles during significant precipitation or snowmelt. During a period that the area north of highway 18-52 was almost entirely in corn, nitrate concentrations from the tiles on the north side of the highway averaged 17 mg/L greater than the concentrations from the composite drainage from BTLUE (George Hallberg, personal communication).

As mentioned before, the tile BTLD drains a field that had been in pasture for over 30 years. The pasture has been fertilized (top-dressed) at varying rates depending on the condition of the pasture, and manure was occasionally surface spread as well. Application rates of 60 lbs-N/acre were used in WYs 1983, 1986, and 1987. During WY 1988, 75 lbs-N/acre were applied, and in WYs 1989 and 1990, application rates were 46 lbs-N/acre. No fertilizer was applied to the pasture during WYs 1982, 1984, 1985, 1991, 1993, 1994 and 1995. During WY 1992, 80 lbs-N/acre were applied. Nitrate concentrations usually fluctuated between 30 and 65 mg/L; typically 10 to 35 mg/L lower than the tile effluent from BTLUE and BTLUW. Peak nitrate concentrations often occurred at BTLD during the first significant recharge following fertilizer application in the spring. Atrazine concentrations were typically below detectable levels, with detections (>0.1 µg/L) generally occurring during peak discharge following significant precipitation. Since fertilizer application was minimal, and no herbicides or insecticides were applied in the pasture, the water quality of BTLD provides a baseline for comparison with the groundwater from tiles BTLUE and BTLUW.

In the early years of the project, as either side of the sub-basin were put into an alfalfa meadow rotation, the concentrations of the tile effluent declined, although they did not decline to the 'background' concentrations of BTLD. Figure 30 shows monthly nitrate concentrations from BTLUE and BTLUW generally declining through the drought during WYs 1988 and 1989, while Figure 31 shows monthly atrazine concentrations generally increasing. Figure 31 also shows very few atrazine detections and much lower atrazine concentrations at BTLD during the 14-year monitoring period.

According to farm surveys, corn acreage in the upper sub-basin increased from 137 acres in WY 1987, which was the lowest corn acreage during the monitoring period, to 160 acres in WY 1988, and 262 acres in WY 1989 (Table 38). The greatest corn acreage in the upper sub-basin during WYs 1987-1995, 339 acres, occurred in WY 1990. Corn acreage in the upper sub-basin decreased to 307 acres in WY 1991, then 281 acres in WY 1992, and 280 acres in 1993. During WY 1994, 292 acres were planted to corn in the upper sub-basin, and in WY 1995; 217 acres were in corn. The total nitrogen (from all sources) applied within the upper sub-basin increased from the low for the monitoring period of 23,128 pounds in WY 1987, to 27,683 pounds in WY 1988, and increased again to 46,822 pounds in WY 1989. The greatest amount of nitrogen within the upper sub-basin during the period, 58,748 pounds, was applied in WY 1990. Pounds of applied nitrogen within the upper sub-basin decreased from 52,023 in WY 1991 to 48,360 in 1992, then decreased to 44,729 in WY 1993. In WY 1994 the amount of nitrogen applied within the upper sub-basin increased to 50,943 pounds, then decreased to 33,466 pounds in WY 1995. Corn yields in the upper sub-basin ranged from 88 bu/acre during WY 1988, to 177 bu/acre in WY 1991.

In the lower sub-basin, corn acreage decreased from 252 acres in WY 1987 to 237 acres in WY 1988, then increased to 323 acres in WY 1989. Like the upper sub-basin, the greatest corn acreage in the lower sub-basin, 341 acres, occurred in WY 1990. Corn acreage in the lower sub-basin declined to 317 acres in 1991, then to 296 acres in WY 1992, and then declined to the lowest corn acreage during the monitoring period, 207 acres, in WY 1993. Corn acreage in the lower sub-basin increased to 247 acres in WY 1994, and 314 acres in WY 1995. Total nitrogen applied within the lower sub-basin decreased from 44,103 pounds in WY 1987 to 40,086 pounds in WY 1988, then increased to the high for the monitoring period of 60,760 pounds in WY 1989. During WY 1990, 56,617 pounds of nitrogen were applied in the lower sub-basin and in WY 1991, 51,309 pounds of nitrogen were applied. Pounds of applied nitrogen within the lower sub-basin increased to 54,544 in WY 1992, then decreased to the low for the monitoring period of 30,066 in WY 1993. In WY 1994 the amount of nitrogen applied within the lower sub-basin increased to 45,812 pounds, then increased further to 49,675 pounds in WY 1995. Within the lower sub-basin, corn yields ranged from 81 bu/acre during WY 1988, to 169 bu/acre in WY 1989.

In spite of large increases in the number of acres of fertilized corn and pounds of nitrogen applied in both the upper and lower sub-basins from WY 1988 to 1989, annual fw mean nitrate-nitrogen concentrations and loads from BTLUE, BTLUW and BOOGD declined significantly (Figure 32). From WY 1988 to WY 1989, the annual groundwater discharge at BTLUE declined from 78.0 ac-ft to a record low of 10.5 ac-ft, while the annual discharge from BTLUW increased slightly from a record low of 9.6 ac-ft to 10.9 ac-ft. At BOOGD, surface-water discharge declined from 173 ac-ft to a record low of 57 ac-ft. During the same period, annual fw mean nitrate-nitrogen concentrations and loads decreased from 17.5 mg/L and 3,714 pounds, to 3.9 mg/L and 111 pounds at

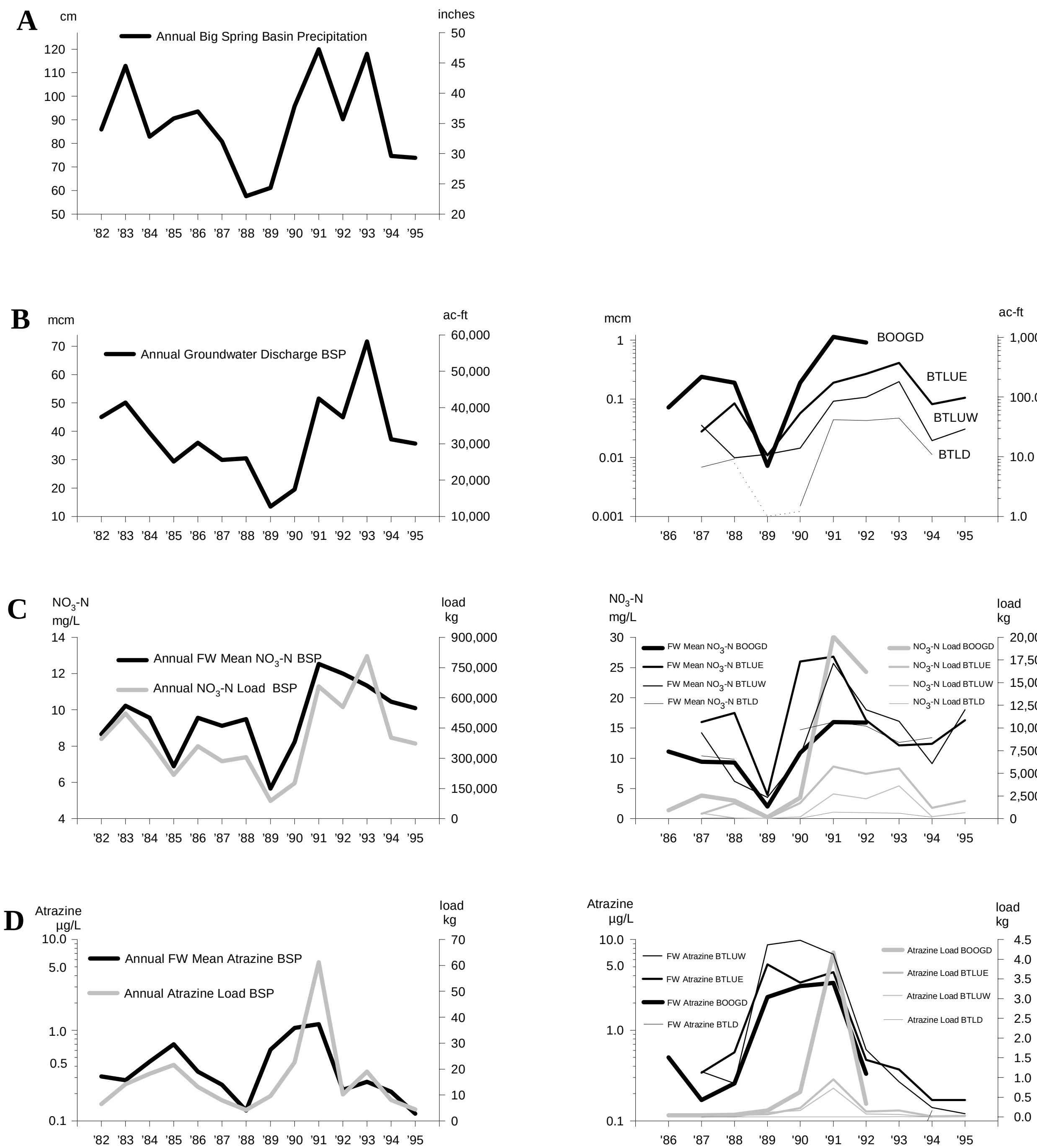


Figure 32. Summary of annual A) basin precipitation, B) groundwater discharge, C) flow-weighted mean NO_3-N concentrations and NO_3-N loads, and D) flow-weighted mean atrazine concentrations and atrazine loads for Big Spring and sites BOOGD, BTLUE, BTLUW, and BTLD.

BTLUE; decreased from 6.2 mg/L and 162 pounds, to 3.5 mg/L and 103 pounds at BTLUW; and decreased from 9.3 mg/L and 4,387 pounds, to 2.0 mg/L and 317 pounds at BOOGD (Table 38). At Big Spring, the annual groundwater discharge declined from 26,008 ac-ft to a record low of 12,672 ac-ft, and the fw mean nitrate-nitrogen concentration and load decreased from 9.5 mg/L and 672,023 pounds to record lows of 5.7 mg/L and 194,928 pounds from WY 1988 to WY 1989 (Libra et al., 1991). During the same period, the annual fw mean atrazine concentrations and loads increased at all four sub-basin monitoring sites.

Atrazine use within the upper sub-basin decreased from 264 pounds on 133 acres during WY 1987, to 29 pounds on 23 acres in WY 1988 (Table 39). During WY 1989, atrazine use within the upper sub-basin increased to 300 pounds on 137 acres. This was the greatest mass of atrazine used in the upper sub-basin during WYs 1987-1995. In WY 1990, 40 acres of corn were treated with 60 pounds of atrazine, and during WY 1991, no atrazine was used within the upper sub-basin. From WY 1992 to WY 1993, atrazine use in the upper sub-basin increased from 1 pound on 2 acres to 6 pounds on 11 acres. During WY 1994, no atrazine was used within the upper sub-basin, and in WY 1995, 160 pounds of atrazine were applied to 160 acres of corn. This was the greatest number of corn acres treated with atrazine within the upper sub-basin during WYs 1987-1995. The combined annual atrazine loads from BTLUE and BTLUW as a percentage of the amount of atrazine applied in the upper sub-basin varied from 0.02% in WY 1987 to >>100% during WYs 1991 and 1994. Since discharge monitoring at BTLUE and BTLUW did not begin until February 25, 1987, the annual atrazine and nitrate-nitrogen loads for WY 1987 are probably somewhat reduced, although data from BOOGD and other sites near the basin show declining trends in discharge and atrazine and nitrate concentrations from the beginning of the water year through mid-February, so the reductions may be minor.

Within the lower sub-basin, 433 pounds of atrazine were applied to 220 acres of corn during WY 1987. This was the greatest mass of atrazine used, and the greatest corn acreage treated with atrazine within the lower sub-basin during WYs 1987-1995. In WY 1988, 32 pounds of atrazine were applied to 32 acres of corn. This was the smallest mass of atrazine used, and the smallest corn acreage treated within the lower sub-basin during WYs 1987-1995. From WY 1989 to WY 1990, atrazine use in the lower sub-basin decreased from 308 pounds on 139 acres to 72 pounds on 50 acres. In WY 1991, 133 pounds of atrazine were used on 89 acres, and during WY 1992, 84 pounds of atrazine were applied to 129 acres of corn within the lower sub-basin. From WY 1993 to WY 1994, atrazine use in the lower sub-basin decreased from 120 pounds on 83 acres to 116 pounds on 77 acres, and in WY 1995, 229 pounds of atrazine were applied to 203 acres of corn.

Within the total sub-basin, the greatest mass of atrazine, 697 pounds, was applied during WY 1987, while the greatest number of corn acres, 363 acres, were treated with atrazine during WY 1995. The greatest atrazine application rates, in pounds per acre, for both the upper and lower sub-basins during WYs 1987-1995 occurred in WY 1989. The annual atrazine load from BOOGD as a percentage of the amount of atrazine applied in the total sub-basin varied from 0.01% in WY 1987 to 6.9% during WY 1991.

In spite of the significant decreases in the number of corn acres treated, and pounds of atrazine applied within the upper sub-basin from WY 1987 to WY 1988, the annual fw mean atrazine concentrations and loads from BTLUE and BOOGD increased from WY 1987 to WY 1988. At BTLUE, the annual fw mean atrazine concentration and load increased from 0.34 µg/L, and a record low of 0.024 pounds, to 0.57 µg/L and 0.12 pounds (Table 39). At BOOGD, the annual fw mean atrazine concentration and load increased from record lows of 0.17 µg/L and 0.10 pounds in WY 1987 to 0.26 µg/L and 0.12 pounds in WY 1988. During the same period, the fw mean atrazine concentration and annual atrazine load from BTLUW decreased from 0.35 µg/L and 0.032 pounds to 0.26 µg/L and a record low of 0.007 pounds. At Big Spring, the annual fw mean

Table 38. Corn acres, pounds of nitrogen applied, fertilizer-nitrogen rates, and corn yields within the Bugenhagen sub-basin. Also shown are nitrate-nitrogen loads and flow-weighted mean nitrate-nitrogen concentrations for sites BTLUE, BTLUW, and BOOGD. Maximums are shown in bold and minimums are shown in italics. Sub-basin summaries of corn acres, applied nitrogen, corn yields, nitrogen loads, nitrogen needs, nitrogen loads as a percentage of nitrogen applied, and nitrogen deficits are also shown.

SUB-BASIN FERTILIZER-NITROGEN RATES, NO_3-N LOADS, AND FW MEAN NO_3-N CONCENTRATIONS

Water Year	Sub Basin	Fertilized Corn Acres	Applied Nitrogen Total lbs	Applied Nitrogen lbs/Acre	Yield Corn bu/acre	BTLUE NO_3-N Load lbs	BTLUE FW Mean NO_3-N mg/L	BTLUW NO_3-N Load lbs	BTLUW FW Mean NO_3-N mg/L	BOOGD NO_3-N Load lbs	BOOGD FW Mean NO_3-N mg/L
1987*	Upper	*137*	*23,128*	169	167	1,152	16.0	1,296	14.2		
	Lower	252	44,103	175	160						
	Total	*389*	*67,231*	173	163					5,591	9.4
1988	Upper	160	27,683	173	*88*	3,714	17.5	162	6.2		
	Lower	237	40,086	169	*81*						
	Total	397	67,769	171	*84*					4,387	9.3
1989	Upper	262	46,822	**179**	167	*111*	*3.9*	*103*	*3.5*		
	Lower	323	**60,760**	**188**	**169**						
	Total	585	107,582	**184**	168					*317*	*2.0*
1990	Upper	**339**	**58,748**	173	165	3,797	26.0	395	10.4		
	Lower	**341**	56,617	166	162						
	Total	**680**	**115,365**	170	164					5,103	10.9
1991	Upper	307	52,032	168	**177**	**12,606**	**26.8**	5,959	**25.7**		
	Lower	317	51,309	163	164						
	Total	624	103,341	166	**173**					**44,336**	**16.0**
1992	Upper	281	48,360	172	157	10,874	16.3	4,833	18.0		
	Lower	296	54,544	184	144						
	Total	577	102,904	178	153					35,646	15.9
1993	Upper	280	44,729	160	96	12,229	12.1	**7,957**	16.1		
	Lower	*207*	*30,066*	*145*	95						
	Total	487	74,795	*154*	96					n/a	n/a
1994	Upper	292	50,943	174	155	2,583	12.4	462	9.1		
	Lower	247	45,812	185	166						
	Total	539	96,755	180	159					n/a	n/a
1995	Upper	217	33,466	*155*	144	4,315	16.3	1,425	18.0		
	Lower	314	49,675	158	142						
	Total	531	83,141	157	143					n/a	n/a

SUB-BASIN SUMMARIES WYs 1987-1992 and 1987-1995

Water Year	Sub Basin	Fertilized Corn Acres	Applied Nitrogen Total lbs	Applied Nitrogen lbs/Acre	Yield Corn bu/acre
1987-1992	Upper	1,486	256,773	172	154
	Lower	1,766	307,419	174	147
	Total	3,252	564,192	174	151
1987-1995	Upper	2,275	385,911	169	146
	Lower	2,534	432,972	171	143
	Total	4,809	818,883	170	145

NITROGEN DEFICITS

Water Year	Sub Basin	Sub-basin NO_3-N Load lbs	Pounds of N Needed	% of N needed Applied	Load as % of N Applied	Total Nitrogen Deficit
1987-1992	Upper	45,002	278,283	92.3%	17.5%	-66,512
	Lower	50,378	315,996	97.3%	16.4%	-58,955
	Total	95,380	598,422	94.3%	16.9%	-129,610
1987-1995	Upper	73,973	405,840	95.1%	19.2%	-93,902
	Lower	n/a	440,708	98.2%	n/a	n/a
	Total	73,973**	849,408	96.4%	n/a	n/a

*Partial water year for BTLUE and BTLUW **Loads for BOOGD were not computed after WY 1992 atrazine concentration and load decreased from 0.25 µg/L and 17.6 pounds in WY 1987 to 0.13 µg/L and 9.2 pounds in WY 1988 (Hallberg et al., 1989 and Libra et al., 1991). The annual fw mean atrazine concentration from Big Spring for WY 1988 was the second-lowest recorded, and the annual atrazine load, was the lowest recorded, during WYs 1982-1995 (Liu et al., 1997).

Previous reports (Hallberg et al., 1983, 1984a, 1985, 1987, 1989; Libra et al., 1986, 1987, 1991; Rowden et al., 1993a, 1993b, 1995a, 1995b; and Liu et al., 1997) have shown that increases and decreases in groundwater flux, as inferred by annual groundwater discharge at Big Spring, have been accompanied by increases and decreases in annual fw mean nitrate-nitrogen concentrations and loads. Annual fw mean atrazine concentrations and loads from Big Spring have shown no consistent relationship to annual discharge, although atrazine concentrations generally increase with increasing runoff on a short-term basis. Similar seasonal trends and short- and long-term changes in nitrate-nitrogen and atrazine concentrations and loads are apparent at other monitoring sites within the Big Spring basin (Rowden et al., 1995a, 1998) and at the monitoring sites within the Bugenhagen sub-basin.

At most monitoring sites, during prolonged recession periods, nitrate and herbicide (particularly atrazine) concentrations usually show a slow, steady decline. This decline likely occurs as an increasing percentage of the discharge is from the less transmissive parts of the flow system. Denitrification within some of the less transmissive parts of the hydrologic system may also be responsible for lower nitrate concentrations, particularly under low flow conditions. In general, low discharge periods are accompanied by low contaminant concentrations, yielding small total contaminant loads. Concentrations are generally higher during periods of higher discharge, yielding greater loads, related to both the increased volumes of water and greater concentrations. Within both the Big Spring basin and the Bugenhagen sub-basin, the dry conditions during WYs 1988 and 1989 led to decreased groundwater flux through the soil, and decreased leaching of nitrate, resulting in lower nitrate-nitrogen concentrations and loads. Within the sub-basin, decreases in annual nitrate-nitrogen concentrations and loads occurred in spite of the increase in nitrate available for transport due to increases in corn acreage and increased nitrogen application. The increases in fw mean atrazine concentrations and loads at BTLUE and BOOGD from WY 1987 to WY 1988, in spite of significant decreases in the number of corn acres treated with atrazine and the mass of atrazine applied, may be related to variations in the location of atrazine applications, variations in the timing and intensity of precipitation, and changes in the relative proportion of infiltration- versus runoff recharge composing the tile effluent and surface-water discharge. Variations in atrazine concentrations and loads are probably also related to pesticide degradation rates, which are related to soil moisture conditions.

During WY 1987, 7.7 inches, or 24%, of the annual precipitation fell in August. Also, in WY 1987 there was little snowpack in the spring. These conditions led to very limited runoff during WY 1987. In WY 1988 the largest discharge events were in February and March, and were related to snowmelt, and in WY 1989, most of the discharge occurred in March and was also associated with snowmelt. These conditions probably led to a greater proportion of runoff, versus infiltration recharge for WYs 1988 and 1989 relative to WY 1987, which in turn would have lead to greater annual fw mean atrazine concentrations. During WY 1989, most of the samples from the sub-basin were collected during runoff events. This sampling bias probably also contributed to greater annual fw mean atrazine concentrations, and smaller annual fw mean nitrate concentrations.

Monitoring during WYs 1990 and 1991 showed the effects of significant increases in precipitation and resultant recharge on the hydrologic systems within both the Big Spring basin and the Bugenhagen sub-basin, and on the transport of contaminants within the systems, following the drought conditions of WYs 1988 and 1989. Figures 30 and 31 show significant increases in monthly nitrate and atrazine concentrations at all

Table 39. Corn acres, pounds of atrazine applied, and atrazine rates used for corn within the Bugenhagen sub-basin. Also shown are atrazine loads and flow-weighted mean atrazine concentrations for sites BTLUE, BTLUW, and BOOGD, and atrazine loads as a percentage of atrazine applied, for the upper and total sub-basins. Maximums are shown in bold and minimums are shown in italics.

SUB-BASIN ATRAZINE RATES, ATRAZINE LOADS, AND FW MEAN ATRAZINE CONCENTRATIONS

Water Year	Sub Basin	Treated Corn Acres	Applied Atrazine Total lbs	Applied Atrazine lbs/Acre	BTLUE Atrazine Load lbs	BTLUE FW Mean µg/L	BTLUW Atrazine Load lbs	BTLUW FW Mean µg/L	BOOGD Atrazine Load lbs	BOOGD FW Mean µg/L	Load as % of Atrazine Applied
1987*	Upper	133	264	1.98	*0.024*	0.34	0.032	0.35			*0.02%*
	Lower	**220**	**433**	1.97							
	Total	353	**697**	1.97					*0.10*	*0.17*	*0.01%*
1988	Upper	23	29	1.25	0.120	0.57	*0.007*	0.26			0.44%
	Lower	*32*	*32*	1.00							
	Total	*55*	*61*	1.10					0.12	0.26	0.20%
1989	Upper	137	**300**	**2.19**	0.150	**5.32**	0.260	8.72			0.14%
	Lower	139	308	**2.20**							
	Total	276	608	**2.20**					0.36	2.31	0.06%
1990	Upper	40	60	1.50	0.490	3.36	0.370	**9.82**			1.43%
	Lower	50	72	1.44							
	Total	90	132	1.47					1.40	3.07	1.06%
1991	Upper	*0*	*0*	*0.00*	**2.100**	4.36	**1.600**	6.90			**>>100%**
	Lower	89	133	1.50							
	Total	89	133	1.50					**9.20**	**3.32**	**6.92%**
1992	Upper	2	1	0.50	0.310	0.47	0.160	0.61			47.0%
	Lower	129	84	0.65							
	Total	131	85	*0.65*					0.73	0.33	0.86%
1993	Upper	11	6	0.50	0.370	0.37	0.140	0.27			9.27%
	Lower	83	120	1.45							
	Total	94	126	1.33					n/a	n/a	n/a
1994	Upper	*0*	*0*	*0.00*	0.040	*0.17*	*0.007*	0.14			**>>100%**
	Lower	*77*	116	1.50							
	Total	77	116	1.50					n/a	n/a	n/a
1995	Upper	**160**	160	1.00	0.050	*0.17*	0.010	*0.12*			0.04%
	Lower	203	229	1.13							
	Total	**363**	389	1.07					n/a	n/a	n/a
SUB-BASIN SUMMARIES WYs 1987-1992 and 1987-1995											
1987-1992	Upper	335	654	1.24	3.2	2.40	2.4	4.44			0.86%
	Lower	659	1,062	1.46							
	Total	994	1,716	1.48					11.2	1.52	0.98%
1987-1995	Upper	506	820	0.99	3.7	1.68	2.6	3.02			0.77%
	Lower	1,022	1,527	1.43							
	Total	1,528	2,346	1.42					n/a	n/a	n/a

*Partial water year for BTLUE and BTLUW

sub-basin monitoring sites.

Annual precipitation increased from being 30% below the long term average in WYs 1988 and 1989 to 115% of the long term average in WY 1990 and 143% of the long term average in WY 1991. Annual groundwater discharge, annual fw mean nitrate-nitrogen concentrations and loads, and annual atrazine loads increased significantly at all sites within the sub-basin from WY 1989 through WY 1991 (Fig. 32). At BTLUE, annual groundwater discharge increased from 53.7 ac-ft in WY 1990 to 173 ac-ft in WY 1991, while the annual fw mean nitrate-nitrogen concentration increased from 26.0 mg/L to a record high of 26.8 mg/L, and the nitrate-nitrogen load increased from 3,797 pounds to a record high of 12,606 pounds. At BTLUW, groundwater discharge increased from 13.9 ac-ft in WY 1990 to 85.3 ac-ft in WY 1991, the annual fw mean nitrate-nitrogen concentration increased from 10.4 mg/L to a record high of 25.7 mg/L, and the nitrate-nitrogen load increased from 395 pounds to 5,959 pounds. At BTLD, the annual groundwater discharge increased from 1.2 ac-ft in WY 1990 to 36.1 ac-ft in WY 1991, while the annual fw mean nitrate-nitrogen concentration increased from 14.7 mg/L to a record high of 15.9 mg/L, and the nitrate-nitrogen load increased from 49.7 pounds to a record high of 1,565 pounds. The annual surface-water discharge at BOOGD increased from 173 ac-ft in WY 1990 to a record high of 1,020 ac-ft in WY 1991, the annual fw mean nitrate-nitrogen concentration increased from 10.9 mg/L to a record high of 16.0 mg/L, and the nitrate-nitrogen load increased from 5,103 pounds to a record high of 44,336 pounds. At Big Spring, the annual groundwater discharge increased from 17,476 ac-ft in WY 1990 to 42,481 ac-ft in WY 1991, while the annual fw mean nitrate-nitrogen concentration increased from 8.2 mg/L to a record high of 12.5 mg/L, and the nitrate-nitrogen load increased from 388,479 pounds to 1,445,506 pounds. The annual fw mean nitrate-nitrogen concentrations from Big Spring and the sub-basin monitoring sites during WY 1991 were the greatest recorded during the periods of monitoring for all sites. The annual nitrate-nitrogen loads recorded at BOOGD, BTLUE, and BTLD during WY 1991 were also the greatest recorded during the monitoring periods for these sites. At BTLUW, the greatest nitrate-nitrogen load recorded during the WY 1987-1995 period was discharged during WY 1993.

The year-to-year changes in annual fw mean atrazine concentrations for the sub-basin monitoring sites from WY 1989-1991 were more variable from site-to-site than the changes seen in annual fw mean nitrate concentrations. At BTLUE, the annual fw mean atrazine concentration decreased from a record high of 5.32 µg/L in WY 1989 to 3.36 µg/L in WY 1990, then increased to 4.36 µg/L in WY 1991. The annual fw mean atrazine concentration for BTLUW increased from 8.72 µg/L in WY 1989 to a record high of 9.82 µg/L in WY 1990, then decreased to 6.90 µg/L in WY 1991. At BTLD, which was dry during WY 1989, the annual fw mean atrazine concentration remained below the 0.10 µg/L detection limit during WYs 1990 and 1991, and at BOOGD, the annual fw atrazine concentration increased from 2.31 µg/L in WY 1989 to 3.07 µg/L in WY 1990, then increased to a record high of 3.32 µg/L in WY 1991. The annual fw mean atrazine concentration for Big Spring increased from 0.61 µg/L in WY 1989 to 1.06 µg/L in WY 1990, then increased to a record high of 1.17 µg/L in WY 1991.

Annual atrazine loads increased to record levels at Big Spring, and all Bugenhagen sub-basin sites except BTLD in WY 1991. The annual atrazine load for Big Spring increased from 21.2 pounds in WY 1989, to 50.0 pounds in WY 1990, then increased further to 135.0 pounds in WY 1991. At BTLUE, the annual atrazine load increased from 0.15 pounds in WY 1989 to 0.49 pounds in WY 1990, then increased again to 2.1 pounds in WY 1991. The annual atrazine load for BTLUW increased from 0.26 pounds in WY 1989 to 0.37 pounds in WY 1990, then increased again to 1.6 pounds in WY 1991. At BOOGD, the annual atrazine load increased from 0.36 pounds in WY 1989 to 1.40 pounds in WY 1990, then increased further to 9.2 pounds in WY 1991, and at BTLD, the annual atrazine load increased from 0 pounds in WY 1990 to 0.004 pounds in WY 1991.

As mentioned before, the greatest nitrogen fertilizer application rates, for both the upper and lower sub-basin, and the greatest mass of nitrogen applied in the lower sub-basin occurred in WY 1989 (Table 38). From WY 1988 to 1989, the number of fertilized corn acres in the upper sub-basin increased 64%, while the amount of applied nitrogen increased 69%. Within the lower sub-basin the number of fertilized corn acres increased 36%, while the amount of applied nitrogen increased 52%. In spite of these significant increases, the annual fw mean nitrate-nitrogen concentrations and loads for WY 1989 at BTLUE, BTLUW and BOOGD all decreased to the lowest levels recorded. The greatest number of fertilized corn acres in the upper and lower sub-basin, and the greatest mass of nitrogen applied in the upper and total sub-basins occurred in WY 1990. From WY 1990 to WY 1991, fertilized corn acreage in the upper sub-basin decreased by 9.4%, while the amount of nitrogen applied decreased by 11.4%. For the total sub-basin, the fertilized corn acreage decreased by 8.2%, while the amount of nitrogen applied decreased by 10.4%.

The greatest atrazine application rates, for both the upper and lower sub-basins occurred in WY 1989 (Table 39). Within the upper sub-basin, the greatest mass of atrazine was applied during WY 1989, while the greatest number of corn acres were treated with atrazine during WY 1995. Within the lower sub-basin, the greatest number of corn acres were treated with the greatest mass of atrazine during WY 1987. The greatest mass of atrazine applied within the total sub-basin also occurred in WY 1987. From WY 1990 to WY 1991, the area within the upper sub-basin treated with atrazine decreased from 40 to 0 acres and the mass of atrazine applied deceased from 60 to 0 pounds. During the same period within the lower sub-basin, the area treated with atrazine increased from 50 to 88.5 acres, or 77%, and the mass of atrazine applied increased from 72 to 133 pounds, or 85%.

In spite of decreases in the number of corn acres treated with nitrogen, and decreases in the mass of nitrogen applied within the sub-basin from WY 1990 to WY 1991, the annual fw mean nitrate-nitrogen concentrations and loads for BTLUE, BTLD and BOOGD increased to record levels in WY 1991. At the same time, the annual fw mean atrazine concentration for BTLUE increased by 30%, the fw mean atrazine concentration for BTLUW decreased by 30%, and the annual atrazine loads from BTLUE and BTLUW increased to record levels, even though no atrazine was used in the upper sub-basin during WY 1991. At BOOGD, the annual atrazine load increased by 8.1%, while the annual fw mean atrazine concentration increased by 566%. As mentioned earlier, the fw mean atrazine concentration from BTLD remained below detectable concentrations, while the annual atrazine load increased from 0 in WY 1990 to 0.004 pounds in WY 1991.

The increases in nitrate-nitrogen concentrations and loads at the sub-basin monitoring sites in spite of reductions in corn acreage and the amount of nitrogen fertilizer used in the sub-basin during WYs 1990 and 1991 probably resulted from several factors. The below normal precipitation and resultant lack of significant recharge during WYs 1988 and 1989 would have led to less leaching, leaving a greater than normal mass of nitrate in storage in the soil system available for transport during WYs 1990 and 1991. In addition, at BOOGD and Big Spring, the affects of denitrification and nitrogen uptake by aquatic vegetation were probably less pronounced under the relatively higher-flow conditions of WYs 1990 and 1991. Decreased crop uptake of nitrogen related to decreased yields during the drought, particularly in WY 1988, also may have contributed to increased nitrate storage.

The increases in atrazine concentrations and loads during WYs 1990 and 1991 were 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 surface water and groundwater during WYs 1990 and 1991.

The increases in atrazine loading during WYs 1990 and 1991 can also be partially attributed to very large runoff events in March of WY 1990 and June of WY 1991. At BTLUE, March accounted for 12% of the annual groundwater discharge and 41% of the annual atrazine load. At BTLUW, March accounted for 43% of the annual groundwater discharge and 52% of the annual atrazine load, and at BOOGD, March accounted for 12% of the annual surface-water discharge and 31% of the annual atrazine load. At Big Spring, March accounted for 13% of the annual groundwater discharge and 28% of the annual atrazine load during WY 1990 (Rowden et al., 1993a). During WY 1991, June accounted for 32% of the annual groundwater discharge and 41% of the annual atrazine load at BTLUE; 41% of the annual groundwater discharge and 78% of the annual atrazine load at BTLUW; and 46% of the annual surface-water discharge and 84% of the annual atrazine load at BOOGD. At Big Spring, June accounted for 20% of the annual discharge and 56% of the annual atrazine load during WY 1991 (Rowden et al., 1993a).

From WY 1991 to WY 1992, annual basin precipitation decreased from 143% of normal to 108% of normal. Precipitation during WY 1992 was more evenly distributed than during WYs 1990 and 1991. Annual discharge decreased from 1,020 to 825 ac-ft at BOOGD, and from 36.1 to 34.7 ac-ft at BTLD. At BTLUE, annual discharge increased from 173 to 245 ac-ft and at BTLUW annual discharge increased from 85.3 to 98.8 ac-ft. Monthly mean nitrate and atrazine concentrations decreased significantly at all sub-basin monitoring sites from WY 1991 to WY 1992 (figures 30 and 31). During the same period, annual fw mean nitrate-nitrogen concentrations and loads decreased at all sites, and annual fw mean atrazine concentrations and loads decreased by a factor of ten at all sites except BTLD (Figure 32).

At BTLUE, from WY 1991 to WY 1992, groundwater discharge increased 42%, the fw mean nitrate-nitrogen concentration decreased 39%, the nitrate-nitrogen load decreased 14%, the fw mean atrazine concentration decreased 89%, and the atrazine load decreased 85%. At BTLUW, groundwater discharge increased 16%, the fw mean nitrate-nitrogen concentration decreased 30%, the nitrate-nitrogen load decreased 19%, the fw mean atrazine concentration decreased 91%, and the atrazine load decreased 90%. At BTLD, groundwater discharge decreased 4%, the fw mean nitrate-nitrogen concentration decreased 4%, the nitrate-nitrogen load decreased 8%, the fw mean atrazine concentration remained below detectable levels, and the atrazine load decreased 75%. At BOOGD, surface-water discharge decreased 19%, the fw mean nitrate-nitrogen concentration decreased 0.3%, the nitrate-nitrogen load decreased 20%, the fw mean atrazine concentration decreased 90%, and the atrazine load decreased 92%. At Big Spring, relative to WY 1991, WY 1992 had 14% less groundwater discharge, a 4% lower fw mean nitrate-nitrogen concentration, a 19% reduction in nitrate-nitrogen load, a 445% lower fw mean atrazine concentration and a 500% reduction in atrazine load (Rowden et al., 1995b). As in previous years, the changes in annual fw mean nitrate-nitrogen concentrations and loads were more proportional to the changes in annual groundwater and surface-water discharge than were changes in fw mean atrazine concentrations and loads.

The increases in annual groundwater discharge from WY 1991 to WY 1992 at BTLUE and BTLUW, in spite of the significant decrease in precipitation during the period suggests that an increase in the amount of groundwater stored in the sub-basin's shallow hydrologic system occurred during WY 1991, and that some of this groundwater was discharged during WY 1992.

The decreases in annual fw mean nitrate concentrations during WY 1992 may be related to decreased groundwater flux during the early growing season. Water Year 1991 had a wet spring and a dry fall, while WY 1992 had a relatively dry spring and a wet fall. Decreased groundwater flux during the period when nitrogen fertilizer is usually applied and the increased flux during the period after crop uptake of nitrogen may have contributed to lower annual fw nitrate concentrations. 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 also related to decreases in the proportion of runoff, contributing to the annual groundwater and surface-water discharges 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 and 1991 may also have enhanced pesticide degradation processes, leaving a lower than normal mass of herbicide available for transport during WY 1992.

During WY 1993, annual basin precipitation increased to 141% of normal, and the resultant recharge led to the greatest annual groundwater discharges recorded at BTLUE, BTLUW, BTLD and at Big Spring during their respective periods of monitoring. Annual fw mean nitrate concentrations decreased at all sub-basin sites and at Big Spring during WY 1993, while annual nitrate-nitrogen loads increased slightly at BTLUE, decreased slightly at BTLD, and increased to record levels at Big Spring and BTLUW. Annual fw mean atrazine concentrations decreased at BTLUE and BTLUW, remained below the 0.10 µg/L detection limit at BTLD, and increased slightly at Big Spring in WY 1993. Annual atrazine loads increased slightly at BTLUE, BTLD and Big Spring, and decreased slightly at BTLUW.

At BTLUE, from WY 1992 to WY 1993, groundwater discharge increased from 245 to 372 ac-ft, the fw mean nitrate-nitrogen concentration decreased from 16.3 to 12.1 mg/L, the nitrate-nitrogen load increased from 10,874 to 12,229 pounds, the fw mean atrazine concentration decreased from 0.47 to 0.37 µg/L, and the atrazine load increased from 0.31 to 0.37 pounds. At BTLUW, groundwater discharge increased from 98.8 to 182 ac-ft, the fw mean nitrate-nitrogen concentration decreased from 18.0 to 16.1 mg/L, the nitrate-nitrogen load increased from 4,833 to 7,957 pounds, the fw mean atrazine concentration decreased from 0.61 to 0.27 µg/L, and the atrazine load decreased from 0.16 to 0.14 pounds. At BTLD, groundwater discharge increased from 34.7 to 38.5 ac-ft, the fw mean nitrate-nitrogen concentration decreased from 15.3 to 12.6 mg/L, the nitrate-nitrogen load decreased from 1,447 to 1,316 pounds, the fw mean atrazine concentration remained below detectable levels, and the atrazine load increased from 0.001 to 0.01 pounds. At Big Spring, the annual groundwater discharge increased from 37,278 to 58,186 ac-ft, the annual fw mean nitrate-nitrogen concentration decreased from 12.0 to 11.4 mg/L, the annual nitrate-nitrogen load increased from 1,220,099 to 1,796,013 pounds, the fw mean atrazine concentration increased from 0.22 to 0.27 µg/L, and the annual atrazine load increased from 22.5 to 42.0 pounds from WY 1992 to WY 1993 (Rowden et al., 1995b).

The corn acreage and mass of applied nitrogen within the upper sub-basin decreased from 281 acres and 48,360 pounds in WY 1992 to 280 acres and 44,729 pounds in WY 1993. Within the lower sub-basin, the corn acreage and mass of applied nitrogen decreased from 296 acres and 54,544 pounds in WY 1992 to 207 acres and 30,066 pounds in WY 1993. The corn acreage and mass of nitrogen applied in the lower sub-basin in WY 1993 were the lowest recorded during WYs 1987-1995. The corn acreage treated with atrazine and mass of atrazine applied within the upper sub-basin increased from 2 acres and 1 pound in WY 1992 to 11 acres and 5.5 pounds in WY 1993. For the lower sub-basin, the corn acreage treated with atrazine decreased from 129 to 83 acres, and the mass of atrazine applied increased from 83.5 to 120 pounds from WY 1992 to WY 1993. The corn yields in the upper and lower sub-basins for WY 1993, 96 and 95 bu/acre, were the second-lowest yields during WYs 1987-1995. The low yields resulted from the much wetter than normal conditions.

Water Year 1993 was the first year of monitoring at Big Spring that the annual fw mean nitrate concentration decreased as the annual groundwater discharge increased. As discussed earlier, fw mean nitrate concentrations also decreased at the sub-basin monitoring sites during

WY 1993, but these sites have had previous years when annual fw mean nitrate concentrations decreased as annual groundwater discharge increased. The decreases in annual nitrate concentrations, as annual groundwater discharges increased, may be related to several factors. A number of large runoff events occurred during the latter half of WY 1993. Nitrate concentrations typically decrease during runoff and increase as the discharge is receding. If a greater than normal proportion of the annual discharge was composed of runoff, this could reduce the annual fw mean nitrate concentration. In addition, the greater than normal precipitation during WY 1991, and the significant infiltration recharge during the first half of WY 1992, would have led to increased leaching, possibly leaving a smaller than normal mass of nitrate in storage in the soil system available for transport to the hydrologic system during WY 1993. It is also possible, at least for Big Spring, that the gradual reductions in nitrogen fertilizer applied within the basin during the project are beginning to affect changes in the water quality of the basin.

Annual precipitation decreased from 141% of normal in WY 1993 to 92% of normal in WY 1994 and 89% of normal in WY 1995. Annual groundwater discharge decreased at all sub-basin sites during WY 1994, but then increased at BTLUE and BTLUW during WY 1995. The annual groundwater discharge from Big Spring decreased from WY 1993 through WY 1995.

At BTLUE, the annual groundwater discharge decreased from 372 ac-ft in WY 1993 to 76.4 ac-ft in WY 1994, then increased to 97.5 ac-ft in WY 1995. The annual fw mean nitrate-nitrogen concentration increased from 12.1 mg/L in WY 1993 to 12.4 mg/L in WY 1994, then increased to 16.3 mg/L in WY 1995, while the nitrate-nitrogen load decreased from 12,229 pounds to 2,583 pounds, then increased to 4,315 pounds. The fw mean atrazine concentration decreased from 0.37 µg/L in WY 1993 to 0.17 µg/L in both WYs 1994 and 1995. The annual atrazine load decreased from 0.37 pounds in WY 1993 to 0.04 pounds in WY 1994, then increased to 0.05 pounds in WY 1995. The annual fw mean atrazine concentration for WY 1994 was the second lowest recorded at BTLUE during WYs 1987-1995. The fw mean atrazine concentration for the partial WY 1987, 0.024 µg/L, was the lowest annual mean recorded at BTLUE during WYs 1987-1995.

At BTLUW, groundwater discharge decreased from 182 ac-ft in WY 1993 to 18.7 ac-ft in WY 1994, then increased to 29.1 ac-ft in WY 1995. The fw mean nitrate-nitrogen concentration decreased from 16.1 mg/L to 9.1 mg/L, then increased to 18.0 mg/L. The nitrate-nitrogen load decreased from 7,957 pounds in WY 1993, which was the greatest annual load recorded at BTLUW during WYs 1987-1995, to 462 pounds in WY 1994, then increased to 1,425 pounds in WY 1995. The fw mean atrazine concentration decreased from 0.27 µg/L to 0.14 µg/L, then decreased to 0.12 µg/L in WY 1995. The atrazine load decreased from 0.14 pounds in WY 1993 to 0.007 pounds in WY 1994, then increased to 0.01 pounds in WY 1995. The annual atrazine load for 1994 and the annual fw mean atrazine concentration for WY 1995 were the lowest recorded at BTLUW during WYs 1987-1995.

At BTLD, groundwater discharge decreased from 38.5 ac-ft in WY 1993 to 9.2 ac-ft in WY 1994. During the same period, the fw mean nitrate-nitrogen concentration increased from 12.6 to 13.4 mg/L, the nitrate-nitrogen load decreased from 1,316 to 334 pounds, the fw mean atrazine concentration increased from 0.09 to 0.13 µg/L, and the atrazine load decreased from 0.01 to 0.003 pounds. Water Year 1994 was the first year of monitoring at BTLD with an annual fw mean atrazine concentration greater than the 0.10 µg/L detection limit.

At Big Spring, the annual groundwater discharge decreased from 58,186 ac-ft in WY 1993 to 31,266 ac-ft in WY 1994, then decreased further to 30,013 ac-ft in WY 1995 (Liu et al., 1997). The annual fw mean nitrate-nitrogen concentration decreased from 11.4 mg/L to 10.4 mg/L and in WY 1995 decreased to 10.1 mg/L. The annual nitrate-nitrogen load decreased from 1,796,013 pounds in WY 1993 to 888,518 pounds in WY 1994, and 822,569 pounds in WY 1995. The fw mean atrazine concentration decreased from 0.27

to 0.21 µg/L, then declined to 0.12 µg/L in WY 1995, which was the lowest fw mean atrazine concentration recorded at Big Spring during WYs 1982-1995. The annual atrazine load decreased from 42.0 pounds in WY 1993 to 17.8 pounds in WY 1994, then declined to 9.8 pounds in WY 1995. The atrazine load for Big Spring for WY 1995 was the second smallest recorded during WYs 1982-1995. The smallest annual atrazine load from Big Spring, 9.2 pounds, was discharged during WY 1988 (Libra et al., 1991).

Annual groundwater and surface-water discharges during WYs 1994 and 1995 were relatively high, given the amount of precipitation that occurred during the period. The discharges were probably sustained by groundwater discharge from storage that accumulated during WYs 1990-1993. The increases in annual groundwater discharges at BTLUE and BTLUW during WY 1995, as annual precipitation decreased, were probably also related to the timing and intensity of precipitation, as well as soil moisture conditions and evapotranspiration rates of crops grown in the sub-basin. Water Year 1994 had a dry growing season until June, and the WY 1995 growing season was relatively wet until June. Much of the precipitation that fell in June and July, after crops were up in WY 1994 was probably utilized by the crops, rather than infiltrating into the tiles, or running off into the tile intake terraces. Evapotranspiration rates are also greater during this part of the growing season. Much of the precipitation during WY 1995 occurred from February through May. During some of this period, the ground may have been frozen, leading to increased runoff into intakes, and there was probably less uptake of soil moisture from crops and lower evapotranspiration rates, leading to more infiltration into the tiles.

The hydrologic conditions during WY 1994 were similar to WY 1992 in that both years followed very wet years. The large decreases in annual nitrate-nitrogen loads from WY 1993 to WY 1994 were probably related to decreased groundwater flux during the period. The increased infiltration and leaching of nitrogen during WY 1993 probably also left a smaller than normal mass of nitrate in storage in the soil system available for transport during WY 1994.

The decreases in annual atrazine concentrations and loads during WYs 1994 and 1995 are probably related to decreases in the proportion of runoff, contributing to the annual groundwater discharge during the water years. The increased runoff during WY 1993 may also have removed a greater than normal mass of herbicide, leaving less available for mobilization and transport during WYs 1994 and 1995. The cumulative increase in soil moisture during WYs 1990-1993 may have enhanced pesticide degradation processes, leaving a lower than normal mass of herbicide available for transport in WYs 1994 and 1995.

The increases in fw mean nitrate-nitrogen concentrations and loads at BTLUE and BTLUW during WY 1995 were probably in part, related to increased groundwater flux relative to WY 1994 and probably also related to the timing and intensity of precipitation within in the sub-basin. Precipitation during March, April and May of WY 1994 was 49% of normal, while the precipitation during these three months in WY 1995 was 121% of normal. In WY 1994, large snowmelt events in February and March, and runoff in June and July diluted nitrate concentrations. Monthly fw mean nitrate concentrations for BTLUE were below 50 mg/L during March and April, and remained below 60 mg/L in May (Figure 30). During WY 1995, the monthly fw mean nitrate concentrations for BTLUE for March, April and May were 60 mg/L, 67 mg/L and 83 mg/L. During the three-month period in WY 1994, 641 pounds of nitrate-nitrogen were discharged along with 21.4 ac-ft of groundwater, accounting for 28% of the annual nitrate-nitrogen discharge, and 25% of the annual groundwater discharge. During the same period in WY 1995, 2,784 pounds of nitrate-nitrogen were discharged along with 64.1 ac-ft of groundwater, accounting for 65% of the annual nitrate-nitrogen discharge, and 66% of the annual groundwater discharge.

Comparison of annual changes in corn acreage and nitrogen and atrazine applications within the sub-basin with annual fw mean nitrate-nitrogen and atrazine concentrations and loads from monitoring sites shows time lags involved between the implementation of landuse changes and water quality responses. Corn acreage and total applied nitrogen within the upper and total sub-basins were smallest during WY 1987 and smallest in the lower sub-basin in WY 1993 (Table 38). The greatest corn acreage in the upper and lower sub-basins occurred in WY 1990. The greatest mass of nitrogen was applied within the upper and total sub-basins in WY 1990, and in the lower sub-basin the greatest mass was applied in WY 1989. Annual fw mean nitrate-nitrogen concentrations and loads for all sub-basin monitoring sites were smallest in WY 1989, the year with the greatest mass of nitrogen applied within the lower sub-basin, and greatest nitrogen application rates used in both the upper and lower sub-basins. The annual nitrate-nitrogen concentration for BTLUW and the annual nitrate-nitrogen concentrations and loads for BTLUE and BOOGD were greatest in WY 1991, one year following the year with the greatest fertilized corn acreage and mass of nitrogen applied in both the upper and total sub-basins. The greatest annual nitrate-nitrogen load from BTLUW occurred during WY 1993, in spite of decreases in corn acreage and in the mass of nitrogen applied within the upper sub-basin from WY 1990-1993. During WYs 1987-1995, a total of 385,911 pounds of nitrogen, or 95.1% of that needed by crops, were applied to 2,275 acres of corn within the upper sub-basin. The combined nitrate-nitrogen discharge from BTLUE and BTLUW, 73,973 pounds equaled 19.2% of the nitrogen applied during the period. Within the entire sub-basin, a total of 818,883 pounds of nitrogen, or 96.4% of that needed by crops, were applied to 4,809 acres of corn during WYs 1987-1995. Since surface-water discharge monitoring ended at BOOGD after WY 1992, loads for nitrate-nitrogen and atrazine were not computed for BOOGD during WYs 1993-1995. This significantly reduces the total sub-basin loads for WYs 1993-1995, and does not allow the computation of nitrate-nitrogen and atrazine loads for the lower and total sub-basins for the WY 1987-1995 period. Within the entire sub-basin during WYs 1987-1992, a total of 564,192 pounds of nitrogen, or 94.3% of that needed, were applied to 3,252 acres of corn. The nitrate-nitrogen discharge from BOOGD, 95,380 pounds, equaled 16.9% of the nitrogen applied during the WY 1987-1992 period.

The greatest number of corn acres treated with atrazine and mass of atrazine applied within the lower sub-basin occurred in WY 1987 (Table 39). In the upper sub-basin, the greatest mass of atrazine was applied in WY 1989, while the greatest corn acreage was treated with atrazine in WY 1995. Within the total sub-basin, the greatest mass of atrazine was applied in WY 1987, while the greatest corn acreage was treated with atrazine in WY 1995. The smallest corn acreage treated with atrazine, and mass of atrazine applied within the lower and total sub-basins occurred in WY 1988. Within the upper sub-basin, the smallest corn acreage treated with atrazine and mass of atrazine applied, occurred during WYs 1991 and 1994, when no atrazine was used. During WYs 1987-1995, a total of 820 pounds of atrazine were applied to 506 acres of corn within the upper sub-basin. The combined atrazine discharge from BTLUE and BTLUW, 6.3 pounds equaled 0.77% of the atrazine applied during the period. During WYs 1987-1992, a total of 654 pounds of atrazine were applied to 335 acres of corn within the upper sub-basin. The combined atrazine discharge from BTLUE and BTLUW, 5.6 pounds equaled 0.86% of the atrazine applied during this period. Within the entire sub-basin, during WYs 1987-1992, a total of 1,716 pounds of atrazine were applied to 994 acres of corn. The combined atrazine discharge from BTLUE, BTLUW and BOOGD, 16.8 pounds equaled 0.98% of the atrazine applied during the WY 1987-1992 period.

The in-stream degradation of atrazine by biotic and/or abiotic processing is likely a significant factor affecting atrazine concentrations and loads within the Big Spring basin. Since January 1993, the pesticide samples collected for the Big Spring Project have been analyzed for the atrazine metabolites desethylatrazine and deisopropylatrazine (Rowden et al., 1995b). A large number of detections (>0.10 µg/L) of desethylatrazine, along with the absence of detections of desisopropylatrazine during WYs 1993-1995 at monitoring sites within the Big Spring basin and the Bugenhagen sub-basin, support research that has shown desethylatrazine to be the more stable initial biotic degradation product (Adams and Thurman, 1991; Geller, 1980). Pesticide analyses from Big Spring and the Turkey River show similar atrazine and desethylatrazine concentrations, generally increasing and decreasing simultaneously. As with atrazine, desethylatrazine concentrations generally increase during runoff periods and decrease during prolonged recession periods. Both desethylatrazine and desisopropylatrazine have been detected in monitoring sites along Roberts and Silver creeks, and in tile line monitoring sites within the basin and sub-basin. Preliminary data show desethylatrazine being detected more often than desisopropylatrazine, and usually at higher concentrations at most monitoring sites. Near the basin's surface water outlet on Roberts Creek, atrazine typically showed the greatest concentrations, followed by desethylatrazine, then desisopropylatrazine concentrations. At tile line monitoring sites, desethylatrazine often showed the greatest concentrations, followed by atrazine, then desisopropylatrazine concentrations. Most detections of desisopropylatrazine occurred during June through August, which may support the inference that the amount of sunlight is an important factor in atrazine degradation.

The landuse changes based on farm surveys previously discussed, divided the sub-basin into a 418 acre area above the monitoring shed (upper sub-basin) and a 587 acre area below the monitoring shed (lower sub-basin). The landuse changes discussed below, are based on landuse acreage from aerial photographs that were digitized into a Geographic Information System (GIS). The GIS coverage is divided into a 366 acre area above the monitoring shed (sub-basin 1), a 352 acre area between the monitoring shed and BOOGD (sub-basin 2), and a 252 acre area below BOOGD (sub-basin 3). The GIS coverages can then be further divided into basins above individual monitoring sites. The nitrogen fertilizer application rates, pounds of fertilizer applied within the sub-basins, and corn yields are based on landuse information from farm surveys.

Table 40 shows corn acres, pounds of nitrogen applied per acre and the total pounds of nitrogen applied from all sources within the drainage areas above BTLUE (116 acres), BTLUW (250 acres), BTLD (18 acres), sub-basin 2 (352 acres), and BOOGD (718 acres), versus pounds of nitrogen needed, based on actual crop removal (maintenance rate), and percent of nitrogen applied versus nitrogen needed. The area above BTLD was in permanent pasture during the entire monitoring period, so no corn was grown above BTLD. The table also shows average annual corn yields, annual nitrate-nitrogen discharge, in pounds, from the monitoring sites, the discharge as a percentage of nitrogen applied, and the amount of nitrogen remaining or deficient (nitrogen deficit) after subtracting the nitrogen removed by crops and the nitrogen discharged by monitoring sites, from the nitrogen applied. Corn acreages for BOOGD are a combination of acreages for BTLUE, BTLUW, and sub-basin 2. The acreages above BTLD and below BOOGD (sub-basin 3) were not used. The nitrate-nitrogen loads used for the area above BOOGD are the nitrate-nitrogen discharge from BOOGD, without the addition of loads from BTLUE and BTLUW. Nitrate-nitrogen loads for BOOGD were not computed after WY 1992, so loads as a percentage of nitrogen applied and nitrogen deficits for BOOGD during WYs 1993-1995 and for the WY 1988-1995 period could not be computed. As a result, the summary of annual nitrate-nitrogen loads, loads as a percentage of nitrogen applied, and nitrogen deficits for the area above BOOGD were computed for the WY 1988-1992 period, rather than for the WY 1988-1995 period.

Excess nitrogen may result from over application of nitrogen, mineralization from various sources within the sub-basin, the accumulation of nitrogen from previous applications, and nitrogen that is brought into the sub-basin by precipitation. Water years 1988, 1992 and 1993 were the only years during the monitoring period that excess nitrogen was applied within the sub-basin. The over application of nitrogen in WYs 1988 and 1993 may have resulted from decreased crop uptake due to poor yields caused by drought conditions in WY 1988 and very wet conditions in

Table 40. Summary of corn acres, pounds of nitrogen (N) applied per acre, pounds of N applied, yield in bushels per acre, pounds of N needed by crops, percentage of N needed that was applied, annual nitrate-N load, annual load as a percentage of N applied, and the N deficit for sites BTLUE, BTLUW and BOOGD. Also shown are acres of permanent pasture, pounds of N applied per acre, annual nitrate-N load, and load as a percentage of N applied for site BTLD, and corn acres, pounds of N applied per acre, pounds of N applied, yield in bushels per acre, pounds of N needed, and percentage of N needed that was applied within sub-basin 2.

SUB-BASIN FERTILIZER-NITROGEN RATES, NITROGEN NEEDED BY CROPS, AND NO_3-N LOADS

	Year								
	88	89	90	91	92	93	94	95	88-95
BTLUE									
corn acres	121	177	209	177	171	148	202	122	1,327
lbs N/acre	173	179	173	168	172	160	174	155	170
lbs N applied	21,014	31,624	36,133	29,746	29,467	23,626	35,129	18,981	225,720
yield bu/acre	88	167	165	177	157	96	155	144	148
lbs N needed	13,041	35,995	42,044	38,234	32,815	17,294	38,177	21,514	239,113
% of N needed applied	161%	88%	86%	78%	90%	137%	92%	88%	94%
annual nitrate-N load	3,714	111	3,797	12,606	10,874	12,229	2,583	4,315	50,229
load as % of N applied	17.7%	0.4%	10.5%	42.4%	36.9%	51.8%	7.4%	22.7%	22.3%
nitrogen deficit	4,259	-4,482	-9,708	-21,094	-14,222	-5,897	-5,632	-6,847	-63,622
BTLUW									
corn acres	30	107	107	101	106	83	86	73	693
lbs N/acre	173	179	173	168	172	160	174	155	170
lbs N applied	5,176	19,191	18,547	16,950	18,280	13,237	14,940	11,284	117,604
yield bu/acre	88	167	165	177	157	96	155	144	151
lbs N needed	3,212	21,843	21,581	21,786	20,357	9,689	16,236	12,790	127,495
% of N needed applied	161%	88%	86%	78%	90%	137%	92%	88%	92%
annual nitrate-N load	162	103	395	5,959	4,833	7,957	462	1,425	21,296
load as % of N applied	3.1%	0.5%	2.1%	35.2%	26.4%	60.1%	3.1%	12.6%	18.1%
nitrogen deficit	1,802	-2,755	-3,429	-10,796	-6,910	-4,410	-1,758	-2,931	-31,187
BTLD									
acres perm. pasture	18	18	18	18	18	18	18	18	144
lbs N/acre	75	46	46	0	80	0	0	0	31
lbs N applied	1,350	828	828	0	1,440	0	0	0	4,446
annual nitrate-N load	204	0	50	1,565	1,447	1,316	334	n/a	4,916
load as % of N applied	15.1%	0.0%	6.0%	>>100%	100.5%	>>100%	>>100%	n/a	111%
sub-basin 2									
corn acres	129	190	237	221	191	145	143	150	1,406
lbs N/acre	169	188	166	163	184	145	185	158	170
lbs N applied	21,787	35,682	39,271	36,039	35,096	21,064	26,466	23,738	239,144
yield bu/acre	81	169	162	164	144	95	166	142	145
lbs N needed	12,740	39,133	46,756	44,238	33,509	16,837	28,973	26,028	248,212
% of N needed applied	171%	91%	84%	81%	105%	125%	91%	91%	96%
BOOGD (BTLUE + BTLUW + sub-basin 2)									
corn acres	280	474	553	499	468	376	431	346	3,426
lbs N/acre	171	184	170	166	178	154	180	157	170
lbs N applied	47,978	86,497	93,951	82,735	82,843	57,927	76,535	54,003	582,468
yield bu/acre	84	168	164	173	150	96	160	143	147
lbs N needed	28,993	96,971	110,381	104,258	86,681	43,820	83,386	60,331	614,820
% of N needed applied	165%	89%	85%	79%	96%	132%	92%	90%	95%
annual nitrate-N load	4,387	317	5,103	44,336	35,646	n/a	n/a	n/a	89,789*
load as % of N applied	9.1%	0.4%	5.4%	53.6%	43.0%	n/a	n/a	n/a	21.0%*
nitrogen deficit	14,598	-10,791	-21,533	-65,859	-39,484	n/a	n/a	n/a	-123,069*

* Loads for BOOGD were not computed after WY 1992; values computed are for WYs 1988-1992

WY 1993. Water Year 1988 was the only year during the monitoring period that the amount of nitrogen applied exceeded the amount of nitrogen removed by crops plus the nitrogen discharged by monitoring sites. For the WY 1988-1995 period, nitrogen application rates for corn within the area above BOOGD equaled 95% of the recommended application rates, with all sources of nitrogen accounted for. For the WY 1988-1992 period, nitrogen application rates for corn within the area above BOOGD equaled 103% of the recommended application rates. The nitrogen discharged along with surface water from BOOGD equaled 21% of the nitrogen applied within the sub-basin during WYs 1988-1992. Nitrogen discharges as a percentage of nitrogen applied, were smallest during the drought conditions of WYs 1988 and 1989 and greatest during the wet conditions of WYs 1991-1993. The nitrogen discharges as a percentage of nitrogen applied were also small in WY 1994, probably due to increased leaching of nitrogen during WYs 1991-1993. For BTLUE and BTLUW, the annual loads as a percent of nitrogen applied varied from 0.4 and 0.5% in WY 1989 to 51.8 and 60.1% in WY 1993. For BTLD and BOOGD, the annual loads as a percent of discharge varied from 0 and 0.4% in WY 1989 to >>100 and 53.6% in WY 1991. For BTLD, the annual loads as a percent of discharge were also >>100 % in WYs 1993 and 1994. The greatest annual nitrogen deficits all occurred during WY 1991, at 21,094 pounds for BTLUE, 10,796 pounds for BTLUW and 65,859 pounds for BOOGD. The nitrogen deficits for BTLUE and BTLUW during the WY 1988-1995 period were 63,622 and 31,187 pounds, or 255 lbs/acre distributed over the 250 acre BTLUE sub-basin and 269 lbs/acre distributed over the 116 acre BTLUW sub-basin. The nitrogen deficits for the BTLUE and BTLUW during the WY 1988-1992 period were 45,247 and 22,088 pounds, or 181 and 190 lbs/acre distributed over the BTLUE and BTLUW sub-basins. Using the GIS corn acreages to compute the amount of nitrogen needed by crops, then adding the annual nitrate-nitrogen discharge from BOOGD and subtracting this total from the amount of nitrogen applied within sub-basins 1 and 2, the total nitrogen deficit during WYs 1988-1992 was 123,069 pounds, or 171 lbs/acre distributed over the 718 acre area comprising sub-basins 1 and 2.

Using the corn acreages from landuse surveys to compute the amount of nitrogen used by crops, then adding the annual nitrate-nitrogen discharge from BTLUE, BTLUW and BOOGD, then subtracting this total from the amount of nitrogen applied within 418 acre upper sub-basin and the 587 acre lower sub-basin, the total nitrogen deficit during WYs 1987-1992 was 129,610 pounds (Table 38). This total is equivalent to 129 lbs/acre distributed over the entire 1,005 acre sub-basin. The nitrogen deficits for the upper and lower sub-basins during the WY 1987-1992 period were 66,512 and 58,955 pounds, or 159 lbs/acre distributed over the upper sub-basin and 100 lbs/acre distributed over the lower sub-basin. The nitrogen deficit for the upper sub-basin during the WY 1987-1995 period was 93,902 pounds, or 225 lbs/acre distributed over the upper sub-basin. The differences in the nitrogen deficits computed using GIS corn acreages versus the deficits computed using farm survey corn acreages are due mainly to differences in annual corn acreages, monitoring periods, and sub-basin areas used.

As previously mentioned, groundwater and surface-water flux and resulting discharge at most sites within the sub-basin decreased from WY 1988 through WY 1989, then increased significantly through WY 1991 and peaked in WY 1993. Flow-weighted mean nitrate-nitrogen concentrations and loads were generally smallest in WY 1989 and greatest in WY 1991. Annual fw mean atrazine concentrations were more variable, with BTLUE peaking in WY 1989, BTLUW peaking in WY 1990, BOOGD peaking in WY 1991, and BTLD peaking in WY 1994. The smallest annual fw atrazine concentration for BTLUE occurred during both WYs 1994 and 1995, for BTLUW, the smallest fw mean was in WY 1995 and for BOOGD, the smallest fw mean was in WY 1987. At BTLD, the annual fw mean atrazine concentration remained below the 0.10 μg/L detection limit during WYs 1987-1993. Annual atrazine loads for all sub-basin sites, except BTLD, were greatest in WY 1991. The greatest atrazine load from BTLD was discharged in WY 1993. The smallest annual atrazine loads for BTLUE and BOOGD occurred in WY 1987, the smallest for BTLUW was in WY 1988 and again in WY 1994, and the smallest annual atrazine loads from BTLD were during WYs 1989 and 1990 when no atrazine was discharged.

As has been the case with monitoring sites throughout the Big Spring basin, annual fw mean nitrate-nitrogen concentrations and loads from the sub-basin sites show a more clear relationship to annual groundwater and surface-water discharge than do the annual fw atrazine means and loads. The effects of annual changes in groundwater and surface-water flux overshadow any clear relationship between annual changes in corn acreage and nitrogen fertilizer and atrazine use, and annual changes in water quality within the sub-basin. The climatic effects on the transport of nitrate-nitrogen and atrazine within the sub-basin, and the resulting annual fw mean concentrations and loads were probably compounded by having two very dry years precede two very wet years.

The decreased groundwater flux during WYs 1988 and 1989 would probably have led to decreased annual fw mean nitrate-nitrogen concentrations and loads, and the increased flux during WYs 1990, 1991 and 1993 would probably have led to increased fw means and loads, even if nitrogen application and landuse within the sub-basin had remained constant during the monitoring period. The increased proportion of surface-water runoff during WY 1991 would probably have led to increases in annual atrazine loads even if atrazine application and landuse within the sub-basin had remained unchanged. The extremes in climatic variability make it difficult to ascertain and quantify relationships between landuse changes within the sub-basin and the water quality responses at the monitoring sites.

The parallel responses in water quality changes over time between tile-line effluent within the Bugenhagen sub-basin and groundwater at Big Spring illustrate that tile line effluent can be useful as an indication of the behavior of the shallow soil-groundwater system. The species and concentrations of nitrate-nitrogen and pesticides in tile-line discharge, especially in tiles without surface water influences, are indicative of the water quality routinely found in deeper groundwater.

The nested monitoring design used within the Big Spring basin allows tracking of water and chemical responses to recharge events through the hydrologic system, from the soil and water beneath individual fields to the basin water outlets (Hallberg et al., 1984a). This allows integration and comparison of various monitoring scales to assess the affects of landuse and landscape-ecosystem processes. Similar seasonal trends, and pronounced short- and long-term changes in nitrate concentrations, are seen at monitoring sites within both the Bugenhagen sub-basin and the Big Spring basin. The pronounced short-term changes in nitrate concentrations are responses to significant recharge events. The recharge responses at the water table beneath the row-cropped fields of the sub-basin are propagated through the basin's hydrologic system. Infiltrating recharge water within the sub-basin delivers high nitrate concentrations to shallow groundwater, and this shallow groundwater transports the nitrate laterally to streams and downward to the Galena aquifer and Big Spring. The concentration changes are not as great or as immediate at the largest scales monitored, however they are clearly apparent, and the nested monitoring design allows these recharge responses to be followed back to their source.

The monitoring data from the Bugenhagen sub-basin demonstrate that climatic effects, residual factors and time lags must be considered when trying to document improvements in water quality associated with improved management practices at various watershed scales.

OVERVIEW OF MONITORING RESULTS FOR WYs 1986-1995

Within the Bugenhagen sub-basin, landuse and cropping-patterns have continuously changed since water-quality monitoring began in 1981. Crop rotation sequences, changing ownership, changing farm programs, (from PIK to CRP, etc.), and the special conservation BMP projects established in the sub-basin all imposed changes on the hydro-

Table 41. 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	35.7
Surface-water discharge (Q):							
mean Q, cfs	0.24	0.30	0.24	0.08	0.24	1.40	1.00
total Q, inches	1.1	3.6	2.8	0.9	2.8	16.7	13.5
acre-feet	67.0	219	173	57.0	173	1,020	825
Nitrogen discharged with surface-water: flow-wtd mean concentration, mg/L							
as nitrate (NO_3)	50	42	42	9.1	49	72	72
as nitrate-N (NO_3-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 (for sub-basin area)	2.8	7.6	6.0	0.4	6.9	60.2	48.4
Atrazine discharged with surface water: flow-wtd mean concentration,							
atrazine, µg/L	0.50	0.17	0.26	2.31	3.07	3.32	0.33
atrazine load;							
lbs - atrazine	0.09	0.10	0.12	0.36	1.40	9.20	0.73

* Partial water year

logic system. As part of the sub-basin demonstration project, tile-outlet terraces were developed and connected into BTLUE and BTLUW. The terraces reduced surface-water flow, changed the nature of the tile effluent by allowing surface water influx, and changed the drainage area of the tile lines. Since 1981, the hydrology of the basin has been radically altered. Hence, observations and monitoring results from the basin are from a "real-world" setting, not a controlled experiment. These observations, in conjunction with more controlled experiments, may provide important perspectives on the relationships between land management and groundwater and surface-water quality in actual operational farm settings, at larger watershed scales.

During WYs 1982-1995 precipitation in the Big Spring basin varied from 22.9 inches in WY

Table 42. Water year summary data for groundwater discharge from BTLUE.

	Water Year								
	87*	88	89	90	91	92	93	94	95
Precipitation:									
water inches	26.9	22.9	24.3	37.9	47.3	35.7	46.5	30.4	29.3
Groundwater discharge (Q):									
mean Q, cfs	0.037	0.108	0.014	0.074	0.240	0.340	0.520	0.110	0.140
total Q, inches	1.3	3.7	0.5	2.6	8.3	11.8	17.8	3.7	4.7
acre-feet	26.5	78.0	10.5	53.7	173	245	372	76.4	97.5
Nitrogen discharged with groundwater: flow-wtd mean concentration, mg/L									
as nitrate (NO_3)	72	79	18	117	121	74	54	56	73
as nitrate-N (NO_3-N)	16.0	17.5	3.9	26.0	26.8	16.3	12.1	12.4	16.3
ammonia-N	0.1	0.1	1.7	0.4	0.2	0.3	0.2	0.2	**
organic-N	0.2	0.7	7.0	1.3	1.6	0.8	0.9	0.2	**
nitrogen load: (nitrate-N + nitrite-N)									
lbs-N	1,152	3,714	111	3,797	12,606	10,874	12,229	2,583	4,315
lbs-N/acre (for sub-basin area)	4.6	14.9	0.4	15.2	50.4	43.5	48.9	10.3	17.3
Atrazine discharged with groundwater: flow-wtd mean concentration,									
atrazine, µg/L	0.34	0.57	5.32	3.36	4.36	0.47	0.37	0.17	0.17
atrazine load;									
lbs - atrazine	0.024	0.120	0.150	0.491	2.100	0.310	0.370	0.040	0.050

* Partial water year

** In WY 1995, N-series samples were not collected from BTLUE.

1988 to 47.3 inches in WY 1991 (tables 41-44). The smallest annual surface-water discharge at BOOGD, 57.0 ac-ft, and groundwater discharges at BTLUE and BTLD, 10.5 and 0 ac-ft, occurred in WY 1989. BTLD went dry in May 1988 and remained dry until late August 1990. For BTLUW, the smallest annual groundwater discharge was 9.6 ac-ft, during WY 1988. The greatest surface-water discharge for BOOGD was 1,020 ac-ft, during WY 1991. The greatest groundwater discharges from BTLUE, BTLUW, and BTLD were 372, 182, and 38.5 ac-ft, during WY 1993.

The greatest annual fw mean NO_3-N concentrations from the sub-basin monitoring sites occurred in WY 1991 and the smallest annual fw mean NO_3-N concentrations and loads occurred

Table 43. Water year summary data for groundwater discharge from BTLUW.

	Water Year								
	87*	88	89	90	91	92	93	94	95
Precipitation:									
water inches	26.9	22.9	24.3	37.9	47.3	35.7	46.5	30.4	29.3
Groundwater discharge (Q):									
mean Q, cfs	0.046	0.013	0.015	0.019	0.118	0.140	0.250	0.030	0.040
total Q, inches	3.5	1.0	1.1	1.4	8.8	10.2	18.8	1.9	3.0
acre-feet	33.6	9.6	10.9	13.9	85.3	98.8	182	18.7	29.1
Nitrogen discharged with groundwater:									
flow-wtd mean concentration, mg/L									
as nitrate (NO_3)	64	28	16	47	116	81	72	41	81
as nitrate-N (NO_3-N)	14.2	6.2	3.5	10.4	25.7	18.0	16.1	9.1	18.0
ammonia-N	0.1	0.3	1.7	1.8	0.1	0.2	0.2	0.4	**
organic-N	0.5	1.1	6.0	6.5	2.8	0.6	1.1	0.3	**
nitrogen load:									
(nitrate-N + nitrite-N)									
lbs-N	1,269	162	103	395	5,959	4,833	7,957	462	1,425
lbs-N/acre	11.2	1.4	0.9	3.4	51.4	41.7	68.6	4.0	12.3
(for sub-basin area)									
Atrazine discharged with groundwater:									
flow-wtd mean concentration,									
atrazine, µg/L	0.35	0.26	8.72	9.82	6.90	0.61	0.27	0.14	0.12
atrazine load;									
lbs - atrazine	0.032	0.007	0.260	0.370	1.600	0.160	0.140	0.007	0.010

* Partial water year

** In WY 1995, N-series samples were not collected from BTLUW.

during WY 1989. Annual NO_3-N concentrations ranged from 2.0 to 16.0 mg/L at BOOGD, 3.9 to 26.8 mg/L at BTLUE, 3.5 to 25.7 mg/L at BTLUW, and 9.8 to 15.9 mg/L at BTLD. During WY 1989, the annual NO_3-N loads from BOOGD, BTLUE, BTLUW, and BTLD were 317, 111, 103, and 0 pounds. The greatest annual NO_3-N loads at BOOGD, BTLUE, and BTLD, 44,336, 12,606, and 1,565 pounds, all occurred in WY 1991. The greatest annual NO_3-N load from BTLUW was 7,957 pounds, in WY 1993.

Extremes in annual fw mean atrazine concentrations and loads were more variable among sites than extremes in annual fw mean nitrate-nitrogen concentrations and loads. Annual fw mean atrazine concentrations were generally lower

Table 44. Water year summary data for groundwater discharge from BTLD.

	Water Year							
	87*	88	89	90	91	92	93	94
Precipitation:								
water inches	26.9	22.9	24.3	37.9	47.3	35.7	46.5	30.4
Groundwater discharge (Q):								
mean Q, cfs	0.008	0.011	**	0.002	0.050	0.048	0.053	0.013
total Q, inches	3.7	5.1	**	0.8	24.1	23.1	25.7	6.1
acre-feet	5.6	7.7	**	1.2	36.1	34.7	38.5	9.2
Nitrogen discharged with groundwater:								
flow-wtd mean concentration, mg/L								
as nitrate (NO_3)	47	44	**	66	72	69	57	60
as nitrate-N (NO_3-N)	10.5	9.8	**	14.7	15.9	15.3	12.6	13.4
ammonia-N	0.1	0.1	**	<0.1	<0.1	<0.1	0.1	0.2
organic-N	0.6	0.8	**	0.2	0.3	0.3	0.3	<0.1
nitrogen load:								
(nitrate-N + nitrite-N)								
lbs-N	159	204	**	50	1,565	1,447	1,316	334
lbs-N/acre	8.8	11.3	**	2.8	86.9	80.4	73.1	18.6
(for sub-basin area)								
Atrazine discharged with groundwater:								
flow-wtd mean concentration,								
atrazine, µg/L	0.01	0.03	**	<0.01	0.04	0.01	0.09	0.13
atrazine load;								
lbs - atrazine	0.0002	0.001	**	0.000	0.004	0.001	0.010	0.003

* Partial water year
** BTLD was dry during WY 1989.

during WYs 1987, 1988, 1994 and 1995 and generally higher during WYs 1989, 1990 and 1991. At BOOGD, annual fw mean atrazine concentrations varied from 3.32 µg/L, in WY 1991 to 0.17 µg/L in WY 1987. For BTLUE annual fw mean atrazine concentrations varied from 5.32 µg/L, in WY 1989 to 0.17 µg/L, in both WYs 1994 and 1995. At BTLUW, the greatest annual fw mean atrazine concentration, 9.82 µg/L, occurred in WY 1990 and the smallest fw mean, 0.12 µg/L, occurred in WY 1995. Annual fw mean atrazine concentrations for BTLD varied from 0.13 µg/L, in WY 1994 to 0 µg/L in WY 1990. The greatest annual atrazine loads for BOOGD, BTLUE, and BTLUW, 9.2, 2.1, and 1.6 pounds, all occurred in WY 1991, and the greatest atrazine load from

BTLD, 0.01 pounds, occurred in WY 1993. The smallest annual atrazine load for complete water years at BOOGD, 0.10 pounds, occurred in WY 1987 and smallest annual atrazine load for complete water years at BTLUE, 0.04 pounds, occurred in WY 1994. The smallest atrazine load from BTLUW, 0.007 pounds occurred in WYs 1988 and 1994, and the smallest load from BTLD, 0 pounds, occurred in WY 1990.

Figure 32 shows annual basin precipitation, annual groundwater and surface-water discharge, annual fw mean nitrate-nitrogen concentrations and loads, and annual fw mean atrazine concentrations and loads for Big Spring for WYs 1982-1995, for BOOGD for WYs 1986-1992, for BTLUE and BTLUW for WYs 1987-1995, and for BTLD during WYs 1987-1994. At Big Spring, annual groundwater discharge and annual fw mean nitrate-nitrogen concentrations and loads declined from WY 1983-1985, and from WY 1988-1989, and increased from WY 1985-1986, and from WY 1989-1991. During WY 1992, the annual discharge, and fw mean nitrate-nitrogen concentration and load decreased, and from WY 1992-1993 the annual groundwater discharge and nitrate-nitrogen load increased to record highs, while the annual fw mean nitrate-nitrogen concentration decreased. From WY 1993-1995, the annual groundwater discharge, and annual fw mean nitrate-nitrogen concentration and load all decreased. Annual fw mean atrazine concentrations and loads from Big Spring increased from WY 1982-1985, decreased from WY 1985-1988, increased from WY 1988-1991, decreased from WY 1991-1992, then increased again in WY 1993 before decreasing through WY 1995.

At the Bugenhagen sub-basin monitoring sites, annual fw mean nitrate-nitrogen concentrations and loads generally decreased along with annual discharge during WYs 1988 and 1989, and increased as annual groundwater and surface-water discharge increased from WY 1989 to WY 1991. From WY 1991 to WY 1992 annual discharge at BTLUE and BTLUW increased slightly and annual discharge at BTLD and BOOGD decreased slightly, while annual fw mean nitrate concentrations decreased at all sites. During WY 1993, annual fw mean nitrate concentrations decreased, as groundwater discharge increased to record levels at BTLUE, BTLUW and BTLD. The nitrate-nitrogen load at BTLUE increased, and the load at BTLUW increased to record levels in WY 1993, while the load for BTLD decreased slightly. From WY 1993-1994, annual groundwater discharges and nitrate-nitrogen loads decreased at all sites, while annual nitrate concentrations increased slightly at BTLUE and BTLD and decreased significantly at BTLUW. During WY 1995 annual groundwater discharges and annual fw mean nitrate-nitrogen concentrations and loads from BTLUE and BTLUW all increased.

From WY 1988 to WY 1989 annual fw mean atrazine concentrations and loads increased significantly at all sites except BTLD as annual discharges decreased. During WYs 1989-1991, annual fw mean atrazine concentrations remained relatively steady, while atrazine loads increased to record levels at all sites except BTLD. From WY 1991 to WY 1992, fw mean atrazine concentrations and loads decreased significantly, as discharge increased at BTLUE and BTLUW, and decreased at BOOGD and BTLD. In WY 1993 annual groundwater discharges increased at BTLUE, BTLUW and BTLD, and annual fw mean atrazine concentrations decreased at BTLUE and BTLUW. The fw mean atrazine concentration increased, and the annual atrazine load increased to record levels at BTLD during WY 1993. The atrazine load for BTLUE increased slightly and the load for BTLUW decreased slightly in WY 1993. In WY 1994, the annual groundwater discharge decreased at all sub-basin sites. The annual fw mean atrazine concentration for BTLUE declined, and the atrazine load declined to a record low. At BTLUW the fw mean atrazine concentration decreased, and the atrazine load decreased to a record low, and at BTLD the fw mean atrazine concentration increased to a record high as the atrazine load decreased. From WY 1994 to WY 1995, annual groundwater discharges increased, the annual fw mean atrazine concentration remained at the record low at BTLUE and decreased to a record low at BTLUW, and annual atrazine loads increased slightly at both sites.

Tables 45 and 46 summarize the annual percentage of detections and maximum concentrations for pesticides for BOOGD, BTLUE, BTLUW, and BTLD for WYs 1986-1995. The greatest percentage of atrazine detections for the WY 1986-1995 period of record, 93%, occurred at BOOGD and BTLUE, followed by 91% at BTLUW, and 25% at BTLD. At Big Spring, the percentage of atrazine detections for WYs 1982-1995 was 95% (Liu et al., 1997). Atrazine was detected in all samples collected from BOOGD and BTLUE during WYs 1986, 1989 and 1990. At BTLUE atrazine was also detected in all samples taken during WY 1992. Atrazine was detected in all samples collected at BTLUW during WYs 1990 and 1992, and all samples collected at BTLD during WYs 1986 and 1994. Atrazine was detected in all samples collected at Big Spring during WYs 1982-1985, 1987, and WYs 1990-1992 (Liu et al., 1997). The lowest annual percentage of atrazine detections at BOOGD, 58%, occurred in WY 1988. The lowest percentage of atrazine detections at BTLUE, 50%, and at BTLUW, 60%, occurred during WY 1995. At BTLD, no atrazine was detected in samples collected during WYs 1987 and 1990. At Big Spring the lowest annual percentage of atrazine detections, 75%, occurred in WYs 1988 and 1995 (Liu et al., 1997). At BOOGD maximum atrazine concentrations varied from 19.0 µg/L in WY 1990 to 0.4 µg/L in WY 1992. At BTLUE and BTLUW, maximum atrazine concentrations varied from 140.0 and 60.0 µg/L in WY 1991 to 0.4 and 0.2 µg/L in WY 1994. At BTLD maximum atrazine concentrations ranged from 1.8 µg/L in WY 1991 to 0.1 µg/L in WY 1994. At Big Spring maximum atrazine concentrations varied from 0.40 µg/L in WY 1988 to 16.00 µg/L in WY 1991 (Liu et al., 1997).

Comparison of annual discharge, nitrate, and atrazine data from the Bugenhagen sub-basin and the Big Spring basin shows the same general trends during the monitoring period. Annual fw mean nitrate-nitrogen concentrations and loads have tended to parallel changes in groundwater flux, as inferred by changes in groundwater discharge, and annual fw mean atrazine concentrations and loads, as well as the frequency and magnitude of other pesticides have not. Some of the greatest annual fw mean atrazine concentrations have occurred during years with some of the smallest annual discharges and some relatively small fw mean atrazine concentrations have occurred during years with the greatest annual discharges. At BTLUE, the greatest annual fw mean atrazine concentration, 5.32 µg/L, and the smallest annual discharge, 10.5 ac-ft, occurred during WY 1989. At BTLUW, the greatest annual fw mean atrazine concentration, 9.82 µg/L, occurred during WY 1990, a year which had the third-smallest annual discharge, 13.9 ac-ft, during the period of record. In WY 1993, as groundwater discharges increased to record levels at BTLUE and BTLUW, fw mean atrazine concentrations decreased. It is unclear why annual fw mean atrazine concentrations tend to be out of phase with discharge. Retardation of atrazine transport by adsorption and degradation processes, and annual changes in the mass of atrazine present on the land surface are likely important factors. While the mass of atrazine present on the land surface is largely a function of the amount applied, environmental factors likely affect chemical and microbial degradation processes, in turn affecting the amount of atrazine available for transport.

Within the sub-basin, the method of transport of a contaminant (runoff into an intake versus infiltration) into the tile lines probably has a large influence on the concentration and type of the contaminant in the tile effluent. During periods when runoff is intercepted by the tile inlets, 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 tile system. The proportion of runoff- versus infiltration recharge composing the discharge, as well as soil moisture conditions and the timing and magnitude of runoff events during a water year also influence annual concentrations and loads of contaminants.

SUMMARY

The period of monitoring within the Bugenhagen

Table 45. Summary of annual % of detections for pesticides in surface water at BOOGD and groundwater at BTLUE, BTLUW and BTLD.

Pesticide common chemical name	Water Year 86	87	88	89	90	91	92	93	94	95	% detections (total record)
	% detections										
BOOGD											
Herbicides											
atrazine	100%	94%	58%	100%	100%	98%	98%	na	na	na	93%
acetochlor	na	na	na	na	na	na	na	na	na	na	na
alachlor	nd	6%	8%	11%	23%	20%	nd	na	na	na	10%
cyanazine	nd	12%	nd	67%	45%	24%	nd	na	na	na	17%
metolachlor	nd	nd	nd	67%	23%	4%	nd	na	na	na	8%
metribuzin	nd	nd	nd	nd	nd	nd	nd	na	na	na	nd
BTLUE											
Herbicides											
atrazine	100%	98%	86%	100%	100%	98%	100%	97%	80%	50%	93%
acetochlor	na	na	na	na	na	na	na	na	nd	8%	6%
alachlor	nd	5%	5%	23%	33%	27%	10%	13%	4%	nd	13%
cyanazine	nd	10%	5%	46%	44%	22%	nd	2%	nd	nd	12%
metolachlor	nd	nd	1%	8%	5%	nd	nd	nd	6%	nd	2%
metribuzin	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
BTLUW											
Herbicides											
atrazine	90%	96%	71%	95%	100%	98%	100%	87%	68%	60%	91%
acetochlor	na	na	na	na	na	na	na	na	na	20%	20%
alachlor	nd	7%	nd	42%	50%	45%	14%	10%	6%	nd	19%
cyanazine	nd	28%	nd	39%	73%	31%	9%	nd	nd	nd	19%
metolachlor	nd	nd	nd	5%	17%	6%	nd	nd	18%	nd	4%
metribuzin	nd	nd	nd	5%	nd	nd	nd	nd	nd	nd	0%
BTLD											
Herbicides											
atrazine	100%	nd	29%	dry	nd	24%	13%	26%	100%	na	25%
acetochlor	na	na	na	dry	na	na	na	na	na	na	na
alachlor	nd	nd	nd	dry	nd	nd	nd	8%	nd	na	1%
cyanazine	nd	nd	nd	dry	nd	nd	nd	8%	nd	na	1%
metolachlor	nd	nd	nd	dry	nd	nd	nd	nd	nd	na	nd
metribuzin	nd	nd	nd	dry	nd	nd	nd	nd	nd	na	nd

nd- not detected
na- not analyzed

The following compounds were not detected:
carbofuran, chlorpyrifos, diazinon, dimethoate, ethoprop, malathion, parathion, phorate, propachlor, thimet, and trifuralin.

Table 46. Summary of annual maximum concentrations for pesticides in surface water at BOOGD and groundwater at BTLUE, BTLUW and BTLD.

	Water Year										
	86	87	88	89	90	91	92	93	94	95	
Pesticide common chemical name	maximum concentration, µg/L										% detections (total record)
BOOGD											
Herbicides											
atrazine	0.7	1.5	4.8	4.4	19.0	9.0	0.4	na	na	na	93%
acetochlor	na	na	na	na	na	na	na	na	na	na	na
alachlor	nd	0.8	3.9	0.1	8.6	2.5	nd	na	na	na	10%
cyanazine	nd	0.6	nd	0.3	7.2	2.6	nd	na	na	na	17%
metolachlor	nd	nd	nd	0.7	3.8	0.2	nd	na	na	na	8%
metribuzin	nd	nd	nd	nd	nd	nd	nd	na	na	na	nd
BTLUE											
Herbicides											
atrazine	0.8	6.3	6.9	22.0	21.0	140.0	15.0	16.7	0.4	nd	93%
acetochlor	na	na	na	na	na	na	na	na	nd	1.3	6%
alachlor	nd	3.4	5.5	0.3	41.0	140.0	14.0	2.0	0.2	nd	13%
cyanazine	nd	3.7	0.3	0.3	46.0	70.0	nd	0.1	nd	nd	12%
metolachlor	nd	nd	0.2	0.1	2.2	nd	nd	nd	0.7	nd	2%
metribuzin	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
BTLUW											
Herbicides											
atrazine	0.9	7.0	1.0	83.0	40.0	60.0	14.0	2.7	0.2	0.5	91%
acetochlor	na	na	na	na	na	na	na	na	na	0.6	20%
alachlor	nd	2.1	nd	23.0	84.0	100.0	15.0	4.7	0.5	nd	19%
cyanazine	nd	1.4	nd	1.7	62.0	9.9	5.5	nd	nd	nd	19%
metolachlor	nd	nd	nd	0.2	2.8	0.2	nd	nd	0.7	nd	4%
metribuzin	nd	nd	nd	13.0	nd	nd	nd	nd	nd	nd	0%
BTLD											
Herbicides											
atrazine	0.2	nd	0.3	dry	nd	1.8	1.3	0.8	0.1	na	25%
acetochlor	na	na	na	dry	na	na	na	na	na	na	na
alachlor	nd	nd	nd	dry	nd	nd	nd	0.1	nd	na	1%
cyanazine	nd	nd	nd	dry	nd	nd	nd	0.1	nd	na	1%
metolachlor	nd	nd	nd	dry	nd	nd	nd	nd	nd	na	nd
metribuzin	nd	nd	nd	dry	nd	nd	nd	nd	nd	na	nd

nd- not detected
na- not analyzed

The following compounds were not detected:
carbofuran, chlorpyrifos, diazinon, dimethoate, ethoprop, malathion, parathion, phorate, propachlor, thimet, and trifuralin.

sub-basin was characterized by extremes in climatic variability and the implementation of a number of landuse changes that significantly altered the basin's hydrology. The two driest consecutive years in the state's history, WYs 1988 and 1989, preceded the two wettest consecutive years since the project's inception. Precipitation patterns changed significantly from WYs 1988 and 1989 to WYs 1991 and 1992. The increased precipitation generated both runoff and infiltration recharge. Discharge rates generally decreased during WYs 1988 and 1989, then increased significantly at all sites from WY 1989 to WY 1991. During WY 1992, annual basin precipitation decreased and annual discharges increased slightly at BTLUE and BTLUW and decreased slightly at BTLD and BOOGD. In WY 1993, the second-greatest annual precipitation during the period of record occurred, and annual discharges increased to record levels at BTLUE, BTLUW and BTLD. In WY 1994, basin precipitation decreased and annual groundwater discharges decreased at all sub-basin sites. During WY 1995, annual basin precipitation decreased slightly and annual groundwater discharges at BTLUE and BTLUW increased slightly.

Prior to WY 1985 there were no tile intake terraces within the upper sub-basin. Cumulatively, 34 acres, or 8.1%, of the 418 acre area above the monitoring shed were diverted into terraces in WY 1985, 113 acres, or 27.0%, in WY 1986, 161 acres, or 38.5%, in WY 1987, and 228 acres, or 54.6%, of area above the monitoring shed drained into tile intake terraces and discharged through BTLUE and BTLUW in WY 1988. The addition of the tile-outlet terraces changed the nature of the tile effluent from BTLUE and BTLUW by allowing direct runoff into the tiles mixing surface water with groundwater.

Comparison of annual changes in corn acreage and nitrogen and atrazine applied within the sub-basin with annual fw mean nitrate-nitrogen and atrazine concentrations and loads from monitoring sites showed time lags involved between the implementation of landuse changes and water quality responses. Annual changes in groundwater and surface-water flux tended to obscure any clear relationship between annual changes in corn acreage and nitrogen fertilizer and atrazine use, and annual changes in water quality within the sub-basin.

Corn acreage and nitrogen use within the upper and total sub-basins were greatest during WY 1990 and smallest in WY 1987. Within the lower sub-basin, the greatest fertilizer use occurred during WY 1989, the greatest corn acreage was planted during WY 1990, and the smallest corn acreage and nitrogen use occurred in WY 1993. Annual fw mean nitrate concentrations for BOOGD, BTLUE and BTLUW were greatest during WY 1991 and smallest during WY 1989. The greatest annual fw mean nitrate concentration for BTLD occurred in WY 1991 and the smallest occurred in WY 1988. The greatest nitrate-nitrogen loads for BOOGD, BTLUE, and BTLD occurred during WY 1991, and the greatest load for BTLUW occurred in WY 1993. The smallest nitrate-nitrogen loads for all sub-basin sites occurred during WY 1989. At Big Spring, the greatest fw mean nitrate concentration occurred in WY 1991, the greatest nitrate-nitrogen load occurred in WY 1993, and the smallest annual fw mean and load occurred in WY 1989.

Within the lower sub-basin, the number of corn acres treated with atrazine and total pounds of atrazine applied were greatest in WY 1987 and smallest in WY 1988. In the upper sub-basin, the greatest mass of atrazine was applied during WY 1989, while the greatest number of corn acres were treated with atrazine in WY 1995. The smallest atrazine use within the upper sub-basin occurred during WYs 1991 and 1994, when no atrazine was used. At BOOGD, the annual fw mean atrazine concentration and load were greatest in WY 1991 and smallest in WY 1987. At BTLUE, the greatest fw mean atrazine concentration occurred in WY 1989 and the smallest occurred in WYs 1994 and 1995. The atrazine load for BTLUE was greatest in WY 1991 and smallest in WY 1987. At BTLUW the greatest annual fw mean occurred in WY 1990 and the smallest occurred in WY 1995. The atrazine load for BTLUW was greatest in WY 1991 and smallest in WYs 1988 and 1994. For BTLD, the greatest annual fw mean occurred in WY 1994 and the smallest occurred in WY 1990. The greatest annual atrazine load from BTLD was discharged in WY 1993 and the smallest was discharged in WY 1990. Site BTLD was dry during WY 1989.

The annual data from the Bugenhagen sub-basin during WYs 1986-1995 supports observations from other monitoring sites within the Big Spring basin, showing that annual fw mean nitrate-nitrogen concentrations and loads tend to parallel groundwater flux, while annual fw mean atrazine concentrations and loads do not. Climatic variations and resulting hydrologic conditions during the monitoring period make it difficult to document relationships between landuse changes within the sub-basin and water quality responses at the monitoring sites. The incremental changes in nitrogen fertilizer and in the use of herbicides such as atrazine resulting from improved management practices may not result in pronounced short-term water-quality changes, but should generate detectable changes over time. Within larger scale watersheds, 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- and groundwater systems. 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 projects.

ACKNOWLEDGEMENTS

The Big Spring Basin Demonstration Project of the Iowa Department of Natural Resources (IDNR) has been supported in part through the Groundwater Protection Act and the Petroleum Violation Escrow accounts, and other sponsoring agencies: the U.S. Department of Agriculture, Natural Resources Conservation Service, the U.S. Environmental Protection Agency (USEPA), Region VII, Kansas City, Nonpoint Source Programs, the Iowa State University Extension (ISUE), and the University of Iowa Hygienic Laboratory (UHL).

The Bugenhagen Sub-Basin Demonstration Project was supported through special cost share funds provided by the U.S. Department of Agriculture-Farm Service Agency (USDA-FSA), the USDA Natural Resources Conservation Service (NRCS) and the Iowa Department of Agriculture and Land Stewardship (IDALS). The USDA-NRCS provided technical assistance in implementing the soil and water conservation practices, including crop rotations, used by the farmers. Thanks to Dave Gibney, District Conservationist, USDA-NRCS, Clayton County, and Frank Phippen, formerly with the USDA-FSA, Clayton County. The ISUE provided special consultation and assistance to farmers in planning and applying improved nutrient and pesticide management. Thanks to Jim Hosch from the Clayton County Extension Service (CCES) and Rodger Koster, now retired from the CCES. Thanks also to John Rodecap and Charles Wittman who were with the Northeast Iowa Demonstration Project (NEIDP) until it ended and Kathie Bentley, Kevin Kuhn and Nick Rolling, who left the NEIDP.

The development of monitoring sites within the Big Spring basin and the Bugenhagen sub-basin has been a cooperative effort. The USGS, Water Resources Division designed, constructed and maintained the stream gaging stations and also cooperated in water-quality monitoring. The tile monitoring sites and the surface-water flume site were designed and constructed by Dr. James Baker, Department of Agricultural Engineering, Iowa State University, Agriculture and Home Economics Experiment Station. Other cooperating agencies include the departments of Agronomy and Botany, ISU, the UHL, the Institute of Agricultural Medicine and Occupational Health, the departments of Geology and Preventive Medicine, the University of Iowa, and the Department of Biology, University of Northern Iowa.

Individuals that were instrumental in maintaining the coordination of inter-agency activities include: Dr. George Hallberg, the Cadmus Group; Dr. Gerald Miller, ISUE; Julie Elfving, USEPA; Rick Kelly, Nancy Hall, and Lynn Hudachek, UHL; Dan Lindquist and James Gulliford, Division of Soil Conservation, IDALS; Lyle Asell and Ubbo Agena, IDNR; Roger Link, USDA-NRCS; and the Clayton County Soil and Water Conservation District.

Many of the Geological Survey Bureau staff were involved with the Big Spring Demonstration Project (BSDP) at one time or another. Much of the background information contained in this report is a result of their combined efforts. Dr. George Hallberg was responsible for the establishment, and design of the BSDP. John Littke made significant contributions to the monitoring network design and made improvements at many of the monitoring sites. John Schmidt developed and maintains the Big Spring database. Jim Giglierano developed the geographic information system coverages associated with the project. Thanks to Pat Lohmann for formatting this report. Thanks also go to the Hydrologic and Environmental Studies Section staff that have assisted with fieldwork over the years.

Many thanks to Jerry Spykerman who recently retired and his staff at the IDNR Big Spring Hatchery for allowing us the use of their facilities over the years.

The farmers and families living in the Big Spring study area have been the most important cooperators involved in the demonstration projects. They were often the key workers in many of the demonstrations, and hopefully will be the main benefactors of the research. The level of support, hospitality, and enthusiasm provided by the local residents remains unparalleled. Many thanks to the families that allowed us to install and access monitoring sites on their property.

REFERENCES

Adams, C.D. and Thurman, E.M., 1991, Formation and transport of deethylatrazine in the soil and vadose zone: Journal of Environmental Quality, v. 20, no. 3, p. 540-547.

Arora, Yagesh, and Juo, A.S.R., 1982, Leaching of fertilizer ions in a kaolinitic ultisol in the high rainfall tropics: leaching of nitrate in field plots under cropping and bare fallows: *Soil Sci. Soc. Am. Jour.*, v.46, p. 1212-1218.

Baker, J.L., 1980, Agricultural areas as nonpoint sources of pollution; *In* Overcash, M. R. and Davidson, J.M., eds: *Environmental Impacts of Nonpoint Source Pollution*, Ann Arbor Science Publishers, Inc., Ann Arbor, MI, p. 275-310.

Baker, J.L. and Austin, T. A., 1982, Impact of agri-cultural drainage wells on groundwater quality: U.S. Env. Prot. Agency, contract Rept., EPA Rept. No. G007228010, 126 p.

Baker, J.L. and Johnson, H. P., 1977, Impact of sub-surface drainage on water quality: *Proc. Third Nat'l. Drainage Symp.*, Am. Soc. Ag. Eng., St. Joseph, MO.

Baker, J.L., and Johnson, H.P., 1981, Nitrate-nitrogen in tile drainage as affected by fertilization: Jour. Environ. Qual., v. 10, p. 519-522.

Barisas, S. G., Baker, J. L, Johnson, H. P., and Laflen, J. M., 1978, Effect of tillage systems on runoff losses of nutrients, a rainfall simulation study: *Trans. Am. Soc. Ag. Eng.*, V. 21, p. 893-897.

Burwell, R. E., Schuman, G. E., Saxton, K. E., and Heinemann, H.E., 1976, Nitrogen in subsurface drainage from agricultural watersheds: *Jour. Environ. Qual.*, v. 5, p. 325-329.

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

Geller, A., 1980, Studies on the degradation of atrazine by bacterial communities enriched from various biotypes: Archives of Environmental Contamination and Toxicology, v. 9, no. 3, p. 289-305.

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

Hallberg, G.R. and Hoyer, B.E., 1982, Sinkholes, hydrogeology, and groundwater quality in northeast Iowa: Iowa Geological Survey, Open-File Report 82-3, 120 p.

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

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

Hallberg, G.R., Prior, J.C., and Bettis, E.A., III, 1984b, Geologic overview of the Paleozoic Plateau Region of northeastern Iowa: Proceedings Iowa Academy of Science, v. 91, p. 3-11.

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

Hallberg, G.R., Baker, J.L., and Randall, G.W., 1986, Utility of tile-line effluent studies to evaluate the impact of agricultural practices on groundwater, *in* Agricultural Impacts on Ground Water: Worthington, Ohio, National Water Well Association, p. 298-326.

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

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

Hallberg, G.R., Libra, R.D., Zhi-jun Liu, Rowden, R.D., and Rex, K.D., 1993, Watershed-scale water-quality response to changes in landuse and nitrogen management: Proceedings, Agricultural Research to Protect Water Quality, Soil and Water Conservation Society, Ankeny, IA, p. 80-84.

Harmon, L., and Duncan, E. R., 1978, A technical assessment of nonpoint pollution in Iowa: Contract Report 77-001 to the Iowa Dept. Soil Conserv., College of Agric., Iowa State Univ., 427 p.

Hubbard, R. K., Erickson, A. E., Ellis, B. G., and Walcott, A. R., 1982, Movement of diffuse source pollutants in small agricultural watersheds of the Great Lakes basin: *Jour. Environ. Qual.*, v. 11, p. 117-123.

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

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

Kalkhoff, S.J., and Kuzniar, R.L., 1994, Hydrologic data for the Big Spring Basin, Clayton County, Iowa, Water Year 1991: U.S. Geological Survey Open-File Report 94-56, 87 p.

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

Kalkhoff, S.J., and Schaap, B.D., 1996, Agricultural chemicals in ground and surface water in a small watershed in Claton County, Iowa, 1988-91: U.S. Geological Survey Water-Resources Investigation Report 95-4158, 38 p.

Kolpin, D.W., and Kalkhoff, S.J., 1993, Atrazine degradation in a small stream in Iowa: Environmental Science and Technology, v. 27, no. 1, p. 134-139.

Libra, R.D., Hallberg, G.R., Ressmeyer, G.R., and Hoyer, B.E., 1984, Groundwater quality and hydrogeology of Devonian-Carbonate aquifers in Floyd and Mitchell Counties, Iowa: Iowa Geological Survey, Open File Report 84-2, 106 p.

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

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

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

Libra, R.D., Hallberg, G.R., Rowden, R.D., Bettis, E.A., III, Kalkhoff, S.J., and Baker, D.G., 1992, Environmental geology of the Big Spring groundwater basin, northeast Iowa: Iowa Department of Natural Resources, Geological Survey Bureau, Guidebook Series no. 15, 51 p.

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

Liu, H., Rowden, R.D., and Libra, R.D., 1997, Groundwater monitoring in the Big Spring basin 1994-1995: a summary review: Iowa Department of Natural Resources, Geological Survey Bureau, Technical Information Series 37, 45 p.

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

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

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

Prior, J.C., 1991, Landforms of Iowa: University of Iowa Press, Iowa City, IA, 153 p.

Rice, C. W., and Smith, M. S., 1982, Denitrification in no-till and plowed soils: *Soil Sci. Soc. Am. Jour.*, v. 46, p. 1168-1173.

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

Rowden, R.D., Libra, R.D., Hallberg, G.R., and Nations, B.K., 1993a, Groundwater monitoring in the Big Spring basin 1990-1991: a summary review: Iowa Department of Natural Resources, Geological Survey Bureau, Technical Information Series 27, 36 p.

Rowden, R.D., Hallberg, G.R. and Libra, R.D., 1993b, Temporal trends in groundwater quality of the Big Spring basin 1982-1992: Proceedings, 38th Annual Midwest Ground Water Conference, Abstracts of Papers, October 6-8, 1993 Champaign, IL, p. 23.

Rowden, R.D., 1995, Temporal trends in groundwater quality of the Big Spring basin 1982-1994: Proceedings, 40th Annual Midwest Ground Water Conference, Abstracts of Papers, October 16-18, 1995, Columbia, MO, p. 50.

Rowden, R.D., Libra, R.D., and Hallberg, G.R., 1995a, Surface water monitoring in the Big Spring basin 1986-1992: a summary review: Iowa Department of Natural Resources, Geological Survey Bureau, Technical Information Series 33, 109 p.

Rowden, R.D., Libra, R.D., Hallberg, G.R., and Nations, B.K., 1995b, Groundwater monitoring in the Big Spring basin 1992-1993: a summary review: Iowa Department of Natural Resources, Geological Survey Bureau, Technical Information Series 34, 43 p.

Rowden, R.D., and Libra, R.D., 1996, Groundwater quality and agriculture: results from the Big Spring basin: Proceedings, Agriculture and Environment; Building Local Partnerships, January 16-18, 1996 Ames, IA, p. 5-39 to 5-50.

Rowden, R.D., Libra, R.D., and Liu, H., 1998, Shallow groundwater and surface water monitoring of the Silver Creek sub-basin within the Big Spring basin 1986-1995: a summary review: Iowa Department of Natural Resources, Geological Survey Bureau, Technical Information Series 38, 94 p.

Seigley, L.S., Hallberg, G.R., Rowden, R.D., Libra, R.D., Giglierano, J.D., Quade, D.J., and Mann, K. 1993, Agricultural landuse and nitrate cycling in surface water in northeast Iowa: Proceedings, Agricultural Research to Protect Water Quality, Soil and Water Conservation Society, Ankeny, IA, p. 85-88.

U.S. Environmental Protection Agency, 1986, Pesticides in Groundwater: Background Document: U.S.E.P.A., Office of Pesticide Programs, Washington, D.C.

Iowa Department of Natural Resources
Energy and Geological Resources Division
Geological Survey Bureau
109 Trowbridge Hall
Iowa City, Iowa 52242-1319
(319) 335-1575