Selected Nutrients in Stormwater Runoff From Davenport, Iowa, 1992

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
acre	4,047	square meter
gallon (gal)	3.785	liter
cubic foot (ft^3)	28.32	liter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
pound (lb)	0.4536	kilogram
degree Fahrenheit (°F)	°C = (°F-32)/1.8	degree Celsius (°C)

Abbreviated water quality units used in this report: Chemical concentrations are given in metric units. Chemical concentration is given in milligrams per liter (mg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million.

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

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By Bryan D. Schaap *and* Keith J. Lucey

Abstract

Flow-weighted composite samples of stormwater runoff from areas of different land use in Davenport, Iowa, were collected in the summer and fall of 1992 and analyzed for selected nutrients. Annual constituent loads were estimated for the area drained by the Davenport storm-sewer network. In all cases, the regression-equation estimate of mean annual load is less than the estimate obtained by using the method of the U.S. Environmental Protection Agency. The largest mean annual loads for total nitrite nitrogen, total nitrate nitrogen, total nitrite and nitrate nitrogen, total organic nitrogen, total ammonia and organic nitrogen, total nitrogen, and total phosphorus are associated with residential land, which covers 67.2 percent of the area drained.

Using concentration data from this study, it is estimated that an average storm-producing runoff during the 7-day, 10-year low-flow discharge of the Mississippi River would contribute about 4 percent of the total ammonia and organic nitrogen load in the river. Precipitation-chemistry data indicate that substantial parts of the nitrate nitrogen and ammonia nitrogen contained in the stormwater runoff could be from precipitation.

INTRODUCTION

Prior to the 1980's, urban stormwater runoff was considered to be an insignificant source of contamination of receiving waters. However, Nationwide Urban Runoff Program (NURP) studies conducted from 1978 to 1983 found that urban runoff could have detrimental effects on receiving waters (U.S. Environmental Protection Agency, 1983). The Water Quality Act of 1987 required the U.S. Environmental Protection Agency (USEPA) to regulate stormwater discharges under the National Pollutant Discharge Elimination System (NPDES) program, and guidelines for obtaining NPDES permits were established for areas with municipal separate storm-sewer systems serving populations greater than 100,000 (U.S. Environmental Protection Agency, 1992a, 1992b).

The U.S. Geological Survey (USGS), in cooperation with the City of Davenport, did a study to develop an improved understanding of urban runoff water-quality characteristics in relation to land use. Stormwater runoff samples were collected from drainage areas with specified types of land use—agricultural and vacant, residential, commercial, parks and wooded, and industrial. Runoff samples collected for the program were analyzed for major ions, nutrients, bacteria, biochemical oxygen demand, dissolved and suspended solids, metals, and organic constituents. Data from the sampling program can be used by policy makers to determine the effectiveness of stormwater-management practices and to develop future management programs to address water-quality concerns related to urban runoff.

The purpose of the report is to present data for selected nutrients in urban runoff from selected land uses. Annual constituent loads and event mean concentrations are estimated for the area drained by the storm-sewer network for total nitrite nitrogen, total nitrate nitrogen, total nitrite and nitrate nitrogen, total ammonia nitrogen, total organic nitrogen, total ammonia and organic nitrogen, total nitrogen, and total phosphorus. The effects of the stormwater runoff on total ammonia and organic nitrogen and total phosphorus concentrations in the Mississippi River, downstream of Davenport, are estimated. The possibility that much of the nitrate nitrogen and ammonia nitrogen found in the runoff samples is from precipitation is considered. The methods of data collection and load estimation also are documented in the report.

DESCRIPTION OF STUDY AREA

Location and Physical Characteristics

Davenport is in southeastern Iowa. It is the largest of the Quad Cities, which also include Bettendorf, Iowa, and Moline and Rock Island, Illinois. Davenport is the most populous city along the Mississippi River between St. Paul, Minnesota, and St. Louis, Missouri. Davenport and other areas of interest mentioned in the report are shown in figure 1. In 1980, Davenport had a population of 103,264 (U.S. Bureau of the Census, 1981). The population decreased to 95,754 in 1990 (U.S. Bureau of the Census, 1991), but it is expected to increase to 100,000 by 1997 (Bi-State Metropolitan Planning Commission, written commun., 1993).

Davenport is situated on the Southern Iowa Drift Plain, which is characterized by flat divides and wide alluvial lowlands (Karsten and Burkart, 1985). Within the city, land-surface elevations vary from 540 to 750 ft above sea level. The low-lying alluvium adjacent to the Mississippi River contrasts with the dissected bluffs and upland areas.

The bedrock in the Davenport area is composed primarily of Silurian and Devonian limestone and dolomite with isolated, Pennsylvanian erosional outliers consisting of one or more of the following rock units: shale, sandstone, siltstone, limestone, and coal (Anderson, 1983). The bedrock is covered with 0 to 400 ft of Pleistocene glacial deposits (Olcott, 1992).

Climate

Davenport has a temperate continental climate (Rudloff, 1981). Air movement is usually from the northwest from November to April and from the south for the remainder of the year (Soenksen and Eash, 1991). January is usually the coldest month, and July is usually the warmest month. July of 1992 was the coolest in 120 years of record with an average temperature of 68.7 °F, which is 5.6 °F below normal (National Oceanic and Atmospheric Administration, 1992b). The average temperature for January 1993 was 18.0 °F, which is the normal average temperature for January (National Oceanic and Atmospheric Administration, 1993).

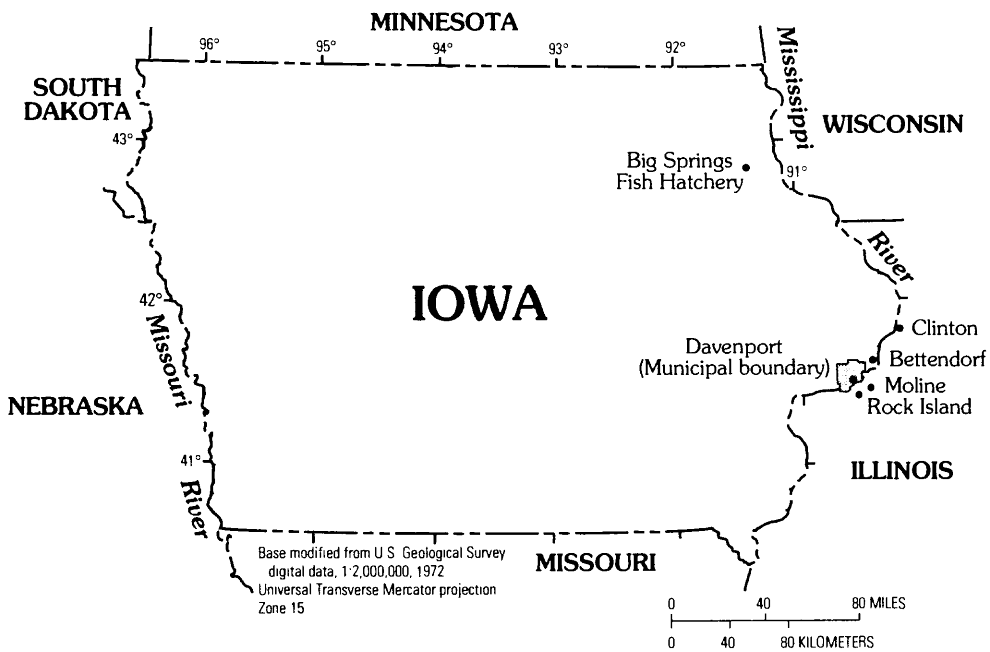

Figure 1. Location of study area.

Precipitation data collected by the National Oceanic and Atmospheric Administration (NOAA) at the airport in Moline, Illinois, which is located on the east bank of the Mississippi River immediately southeast of Davenport, was used to characterize monthly precipitation and storms (National Oceanic and Atmospheric Administration, 1969-89). Table 1 lists mean monthly and annual precipitation and snowfall based on data for the 20-year period, 1969-88. The mean annual precipitation is 39.10 in.; the months of July, May, August, and June receive large mean monthly precipitation, 4.65, 4.50, 4.37, and 4.34 in., respectively. Large mean monthly snowfall occurs in January (9.19 in.) and December (8.11 in.).

The computer program SYNOP, which was developed by the USEPA and the Federal Highway Administration, was used to examine precipitation data for 1969-88 and to characterize the average storm. By definition, a storm must produce at least 0.10 in. total precipitation and be preceded by at least 72 hours of less than 0.10 in. of total precipitation (U.S. Environmental Protection Agency, 1992b). Table 1 lists the mean monthly and annual number of storms, storm amount, storm duration, and storm intensity. An average of 33 storms occur each year; almost one-half of these storms occur in months that historically have no snowfall. The mean storm volume is 1.17 in., and the mean duration is 77.8 hours.

Land Use

Land use within the City of Davenport is summarized in table 2. The municipal boundary of Davenport encloses 63.75 mi^2. The predominant land use is agricultural or vacant, covering 31.18 mi^2 (48.9 percent). Residential land covers 17.27 mi^2 (27.1 percent), commercial land accounts for 3.71 mi^2 (5.8 percent), and parks and wooded areas cover 7.73 mi^2 (12.1 percent). The Davenport municipal boundary extends to mid-

Table 1. Precipitation and storm data, Moline, Illinois, 1969-88

[Storm analysis by computer program SYNOP; data from National Oceanic and Atmospheric Administration, 1969-89]

			Storm data			
Month	**Mean precipitation (inches)**	**Mean snowfall (inches)**	**Mean number of storms**	**Mean amount (inches)**	**Mean duration (hours)**	**Mean intensity (inches per hour)**
January	1.47	9.19	2.8	0.53	64.5	0.02
February	1.32	6.77	2.3	.58	72.5	.01
March	2.98	6.21	3.0	1.09	89.8	.02
April	3.72	2.19	2.8	1.27	80.0	.03
May	4.50	0	2.7	1.74	120.4	.04
June	4.34	0	2.6	1.48	74.4	.06
July	4.65	0	3.5	1.51	75.7	.08
August	4.37	0	2.9	1.28	57.6	.05
September	3.60	0	2.8	1.33	59.0	.05
October	3.12	.22	2.8	1.17	71.9	.04
November	2.58	3.67	2.8	.92	82.8	.02
December	2.45	8.11	2.3	.92	87.9	.02
Annual	[1]39.10	[1]36.36	[1]33.3	[2]1.17	[2]77.8	[2].04

[1]Annual total.

[2]Annual mean.

Table 2. Land use within the municipal boundary and the area drained by the Davenport municipal storm-sewer network

[From the City of Davenport (Kenneth Oestreich, Community and Economic Development, written commun., 1991) and the Bi-State Metropolitan Planning Commission (1984); mi^2, square mile]

Land use	Area within municipal boundary			Area drained by storm-sewer network		
	(mi^2)	(acres)	(percent)	(mi^2)	(acres)	(percent)
Agricultural and vacant	31.18	19,955	48.9	1.63	1,043	9.1
Residential	17.27	11,053	27.1	12.02	7,693	67.2
Parks and wooded	7.73	4,947	12.1	1.66	1,062	9.3
Commercial	3.71	2,375	5.8	2.07	1,325	11.6
Mississippi River	2.00	1,280	3.2	0	0	0
Industrial	1.86	1,190	2.9	.51	327	2.8
Total	63.75	40,800	100.0	17.89	11,450	100.0

channel of the Mississippi River, so the Mississippi River accounts for 2.00 mi^2 (3.2 percent). Industrial land comprises 1.86 mi^2 (2.9 percent). Nearly two-thirds (64.2 percent) of the municipal area is undeveloped. This includes agricultural land, vacant areas, parks, wooded areas, and the Mississippi River.

The storm-sewer network of the City of Davenport drains 17.89 mi^2 (table 2). The area drained by the Davenport storm-sewer network is shown in figure 2. Agricultural and vacant land accounts for 1.63 mi^2 (9.1 percent) of the area. The predominant land use is residential, which comprises 12.02 mi^2 (67.2 percent). Commercial land accounts for 2.07 mi^2 (11.6 percent), and parks and wooded areas amount to 1.66 mi^2 (9.3 percent). Of the five land-use categories, industrial land use covers the smallest area, 0.51 mi^2 (2.8 percent).

METHODS OF INVESTIGATION

Stormwater runoff samples were collected from five sites each representative of a specific land use. Regulatory requirements for the municipal NPDES permit (U.S. Environmental Protection Agency, 1992b) require that samples be collected from three separate storm events at each site and that sampled events at an individual site should occur at least 1 month apart. Each sampled storm is required to have rainfall of at least 0.1 in., and there cannot have been a storm event of greater than 0.1 in. for at least 72 hours prior to the sampled event.

Site Selection and Land Characteristics

The areal distribution of land use was related to drainage-basin area and location to assist in selecting representative sampling sites. Land-use information was supplied by the City of Davenport (Kenneth Oestreich, Community and Economic Development, written commun., 1991) and the Bi-State Metropolitan Planning Commission (1984). The City of Davenport also supplied information about the municipal storm-sewer network. The land-use and storm-sewer information was digitized to create geographic information system (GIS) map coverages. Geographic data are stored on computer and can be manipulated, analyzed, and displayed using locational information and feature attributes. These coverages and those created from six 7.5-minute USGS quadrangle maps were used to determine land-use areas for Davenport (table 2), for the area drained by the storm-sewer network (table 2), and for the drainage areas of the sampling sites (table 3).

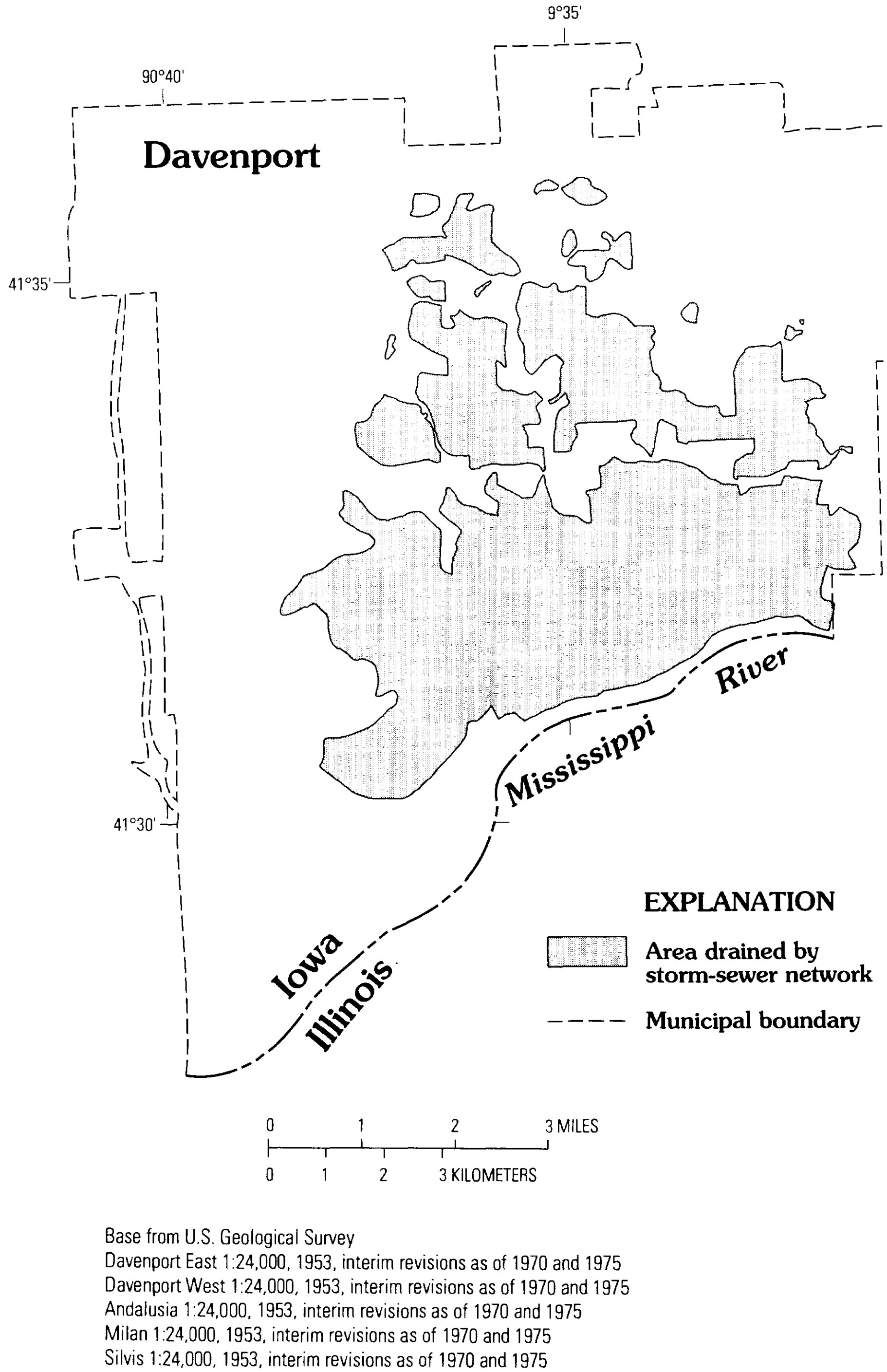

Figure 2. Area drained by storm-sewer network.

Five sampling sites were selected to characterize the quality of stormwater runoff from each of five major land-use categories—agricultural and vacant, residential, commercial, parks and wooded, and industrial. The sites and their drainage basins are shown in figure 3. Throughout the rest of the report, site numbers will be used to refer to specific sampling sites. Table 3 lists the site number, USGS station number, and the land use in the drainage basin for each sampling site. Sites were selected on the basis of uniformity of land use in the drainage basin, hydraulic factors allowing an adequate stage-discharge rating to be established, maximization of catchment size while maintaining reasonable uniformity of land use, accessibility, and the safety of those collecting the samples.

Table 3. Land use in sampling-site drainage basins

[Land-use data from the City of Davenport (Kenneth Oestreich, Community and Economic Development, written commun., 1991) and the Bi-State Metropolitan Planning Commission (1984); mi^2, square mile]

Sampling site (fig. 3)	USGS station number	Land use in drainage basin	Drainage area (mi^2)	Drainage area (acres)	Percent of drainage area
1	05422590	Agricultural and vacant	2.406	1,539.8	90.3
		Industrial	.212	135.7	8.0
		Residential	.026	16.6	1.0
		Commercial	.019	12.2	.7
		Total	2.663	1,704.3	100.0
2	05422586	Residential	.480	307.2	92.1
		Agricultural and vacant	.036	23.0	6.9
		Parks and wooded	.005	3.2	1.0
		Total	.521	333.4	100.0
3	05422584	Commercial	.023	14.7	95.8
		Residential	.001	.7	4.2
		Total	.024	15.4	100.0
4	05422640	Residential	.440	281.6	50.1
		Parks and wooded	.215	137.6	24.5
		Agricultural and vacant	.163	104.3	18.5
		Commercial	.061	39.0	6.9
		Total	.879	562.5	100.0
5	05422650	Industrial	.132	84.5	60.8
		Commercial	.047	30.1	21.7
		Residential	.038	24.3	17.5
		Total	.217	138.9	100.0

Runoff sampled at site 1 is assumed to be representative of runoff from agricultural and vacant land within the city limits. Site 1 is located in the open channel of Pheasant Creek in the northeastern part of Davenport. During the study period, there was always flow in Pheasant Creek, and care was taken to sample storm runoff, not base flow, and still comply with the sampling guidelines. The drainage area associated with the site is 2.663 mi^2, with agriculture and vacant land comprising 2.406 mi^2 (90.3 percent) of the total. This is the largest drainage area for any of the sampling sites. All other sites have drainage areas less than 1 mi^2. The larger drainage area for agricultural land use tends to minimize effects caused by runoff from individual agricultural practices or crop types and provides a runoff sample containing constituents from a variety of agricultural activities. Industrial land use associated with one manufacturing facility comprises 8.0 percent of the land use in the drainage basin of site 1. At that facility, all manufacturing materials are stored inside, and water used in the manufacturing process is trucked offsite for treatment and disposal.

Site 2 runoff samples are considered representative of runoff from residential land. Site 2 is located in north-central Davenport in an open channel upstream of a 72-in. inside-diameter concrete

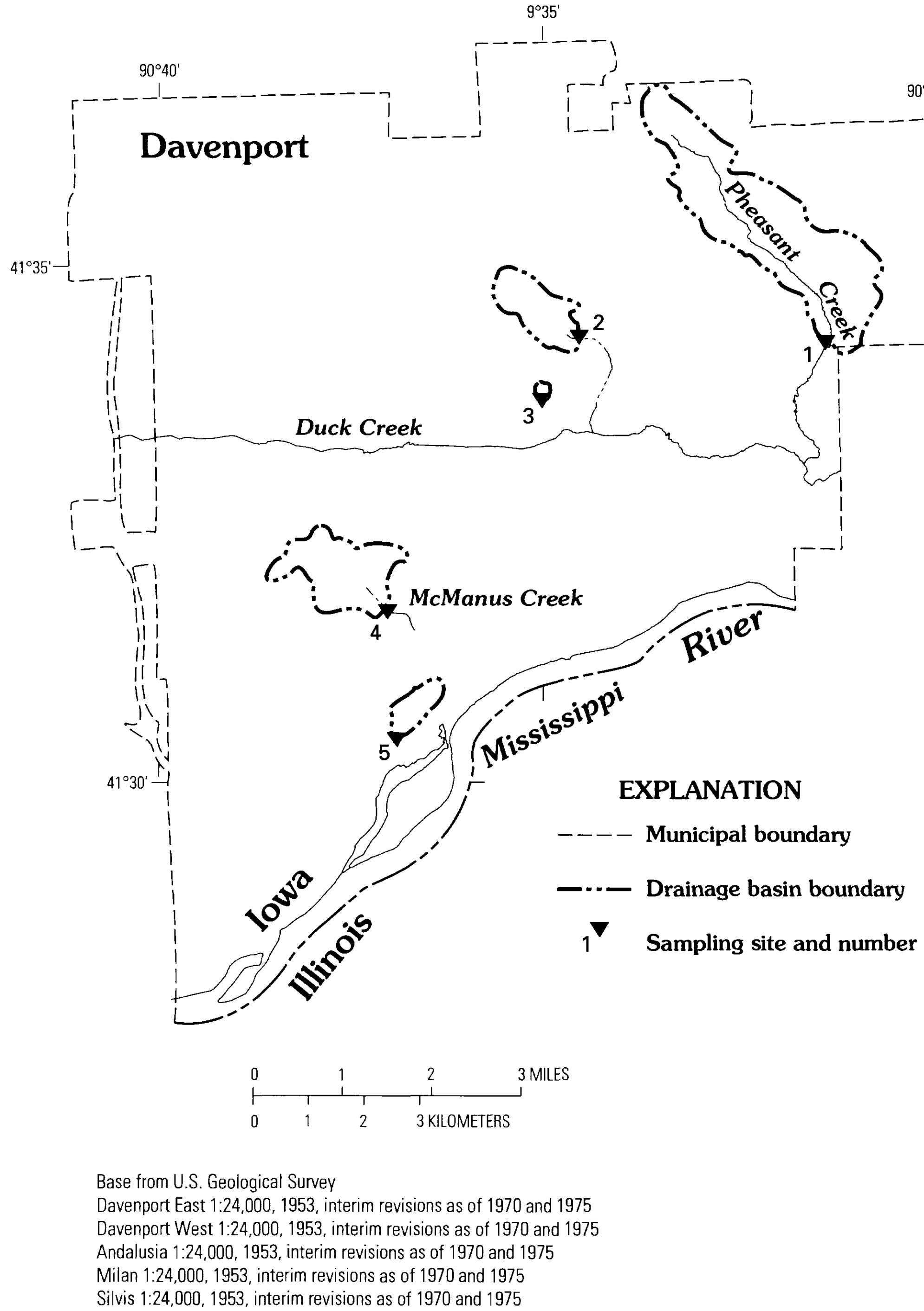

Figure 3. Stormwater runoff sampling sites and their drainage basins.

culvert. The majority of the 0.521 mi^2 drainage basin is low- and moderate-density residential areas (0.480 mi^2, or 92.1 percent). The remainder of the basin is agricultural and vacant land (6.9 percent) and parks and wooded areas (1.0 percent). Runoff from residential areas south of Duck Creek in the older areas of Davenport typically drains to large collector systems with outfalls either along the Mississippi River or Duck Creek. Sampling sites in these areas would be subject to the effects of backwater, which would affect the ability to obtain an accurate stage-discharge rating and could significantly affect constituent-load calculations.

Site 3 runoff comes from a commercial area in central Davenport. The drainage area, 0.024 mi^2, consists of 0.023 mi^2 (95.8 percent) of commercial land and 0.001 mi^2 (4.2 percent) of residential land. The commercial land is mostly parking areas associated with small retail and service establishments. The sampling site was located in an open channel immediately below two concrete outfalls, 24-in. and 36-in. inside diameters.

Site 4 runoff samples are considered to characterize parks and wooded areas. The site is located in the open channel of McManus Creek, immediately downstream of a 72-in. inside-diameter concrete outfall in southwest Davenport. The drainage basin is 0.879 mi^2, with only 0.215 mi^2 (24.5 percent) of the basin classified as parks and wooded areas. However, the residential land (50.1 percent) is sparsely populated, with much of it used for single-family homes with large wooded lots, and the commercial land (6.9 percent) is composed largely of the Mississippi Valley Fair Grounds. Agricultural and vacant land account for 18.5 percent of the basin. Site 4 has a drainage basin less than 1 mi^2, it is easily and safely accessible, and the stage-discharge rating was relatively easy to develop. It was the best site available using the stated criteria.

Site 5 is located in southwest Davenport in an open channel upstream of two 48-in. diameter culverts. Although the 0.217-mi^2 drainage basin consists of only 0.132 mi^2 of industrial land (60.8 percent), intensive industrial activity has occurred in this area along the Mississippi River for several decades. Present and previous industrial activities include battery manufacturing, locomotive works, foundries, scrapyards, and a railroad shipping terminal. Alternative industrial sites in Davenport are associated with light industrial activity. Samples are considered representative of industrial land use.

Drainage area, percentage of imperviousness, and runoff-coefficient values are needed for load-estimation procedures. Percentage of imperviousness and runoff-coefficient values were related to land use. Percentage of imperviousness, the percentage of the land surface that is impervious to water, is a variable in the regional regression equations developed by Driver and Tasker (1990) (table 4). Runoff coefficient, the fraction of precipitation that becomes runoff, is a variable in the simple method from the guidance manual for the preparation of part 2 of the NPDES permit applications (U.S. Environmental Protection Agency, 1992b). Percentage of imperviousness is related to the runoff coefficient (U.S. Environmental Protection Agency, 1992b) by equation 1:

$$Rv = 0.05 + (0.009 \times IA) \ , \qquad (1)$$

where Rv = runoff coefficient, and

IA = percentage of imperviousness.

A list of the percentage of imperviousness and runoff-coefficient values used in load-estimate calculations are presented in table 5. Values of percentage of imperviousness for the various land uses are provided by the USEPA (1992b).

Table 4. Regression equations used to determine nutrient loads in storm runoff

[From Driver and Tasker (1990). Range of percentage error is a measure of the relative accuracy of the equation based on the standard error of the estimate: TKN, annual total ammonia and organic nitrogen load;TRN, total storm rainfall, in inches; DA, drainage area, in square miles; IA, impervious area, in percent; TN, annual total nitrogen load, in pounds; TP, annual total phosphorus load, in pounds]

Three-variable storm-runoff load equations	Standard error of estimate (log)	Range of percentage error
$TKN = 3.89 \times TRN^{0.944} \times DA^{0.765} \times (IA+1)^{0.556} \times 1.524$	0.381	-58 to +140
$TN = 4.04 \times TRN^{0.936} \times DA^{0.937} \times (IA+1)^{0.692} \times 1.373$	.353	-56 to +125
$TP = 0.697 \times TRN^{1.008} \times DA^{0.628} \times (IA+1)^{0.469} \times 1.790$	.411	-61 to +158

Table 5. Percentage of imperviousness and runoff-coefficient values

Land use	Percentage of imperviousness[1]	Runoff coefficient[2]
Agricultural and vacant	15	0.18
Residential	24	.27
Commercial	75	.72
Parks and wooded	15	.18
Industrial	55	.54

[1]From U.S. Environmental Protection Agency (1992b, p. 5-16).
[2]Calculated using equation 1.

Site Instrumentation

At each of the sampling sites, data loggers recorded rainfall in 0.01-in. increments every 5 minutes by a tipping-bucket rain gage. At sampling sites 1, 3, and 5, rain gages were mounted on the tops of the instrument shelters. At sites 2 and 4, they were installed on towers to prevent interference from nearby trees. This information was used to document the sampled storm characteristics and the preceding 72-hour dry period.

Water levels associated with the stage in the stream or drainage ditch at the sites were measured in a stilling well connected to the channel by polyvinyl chloride pipe and recorded at 5-minute intervals by the data logger. With manual discharge measurements taken periodically during and between storm events, a stage-discharge relation was developed for each site. This information then allowed flow to be determined at a site for a given stream stage.

Sample Collection and Processing

All equipment used for sample collection and processing was washed in succession with soapy tapwater, tapwater, deionized water, and methanol. Items were air dried and covered with aluminum foil until they were needed.

Automatic samplers were installed at two of the sampling sites. After runoff samples were collected at these two sites, the samplers were moved to two sites where samples had not been collected in nearly 30 days. Polytetrafluoroethylene tubing, through which water was pumped from the channel to the sampler, remained at each site. Each time a sampler was moved, it was washed in succession with soapy tapwater, tapwater, deionized water, and methanol. The automatic sampler then was connected to the next site-dedicated tubing, and water from the channel was pumped through the tubing and the sampler. The automatic sampler was programmed to begin collecting three 0.7-gal samples at 15-minute intervals when water levels in the channel increased to a programmed height. When the specified height was reached, the sampler performed one rinse cycle before collecting samples.

Discrete samples for flow-weighted compositing were collected at about 15-minute intervals either by the automatic sampler or manually. If runoff from the storm continued for more than 3 hours, samples were collected only during the initial 3 hours of runoff; otherwise, runoff from the entire storm was sampled. By collecting the first three 15-minute discrete samples when activated, the automatic sampler gave sampling crews approximately 1 hour from the beginning of runoff to arrive at the site and begin manual sampling and to collect the remaining discrete samples.

Flow in the channel was considered to be well mixed, and cross sections were only a few feet wide, so samples were collected near the middle of the channel. The intakes for the automatic samplers were installed in the middle of the channels. Manually collected samples were obtained by lowering a 1-gal glass bottle into the centroid of flow. Field values of specific conductance, pH, and water temperature were recorded at the time each sample was collected.

The discrete samples collected at 15-minute intervals from runoff were used to obtain a flow-weighted composite sample. Using the stage-discharge relation at each site, the ratio of flow at the time each discrete sample was collected to the sum of the flows at the times each sample was collected was determined. Next, the appropriate volume of each discrete sample was calculated to prepare a composite sample volume of 3 gal. The calculated volume from each discrete sample was poured into a glass bottle as it sat on a magnetic stir plate in a laboratory. A polytetrafluoroethylene-covered stir bar continuously mixed the composite sample from the beginning of the compositing process until the final subsample had been withdrawn. Subsamples were withdrawn with a peristaltic pump, preserved with mercuric chloride, and submitted for analysis.

Sample Analysis

The samples collected for this study were analyzed by the USGS's National Water-Quality Laboratory (NWQL) in Arvada, Colorado. The methods used to analyze the samples are described in table 6 (Fishman and Friedman, 1989; Patton and Truitt, 1992). Samples were not analyzed directly for total nitrate nitrogen, total organic nitrogen, and total nitrogen. These concentrations were determined by calculation. The total nitrate nitrogen concentration was determined by subtracting the total nitrite nitrogen concentration from the total nitrite and nitrate nitrogen concentration. The total organic nitrogen concentration was determined by subtracting the total ammonia nitrogen concentration from the total ammonia and organic nitrogen concentration. The total nitrogen concentration was the sum of the total nitrite and nitrate nitrogen concentration and the total ammonia and organic nitrogen concentration.

An investigation of the methods used to determine total nitrite nitrogen, total nitrite and nitrate nitrogen, and total ammonia nitrogen concentrations showed that the methods determined only dissolved concentrations (U.S. Geological Survey, Office of Water Quality, Technical Memorandum 93.04, December 2, 1992). This occurred because the nitrogen on the particulates in the unfiltered samples was not detected; the methods did not include a digestion procedure to remove the nitrogen species from the particulates because this would alter the nitrogen species (C.J. Patton, NWQL, oral commun., 1993). Because nitrite, nitrate, and ammonia ions are

Table 6. Laboratory methods used for analysis of stormwater runoff samples

[WATSTORE, Water Data Storage and Retrieval System of the U.S. Geological Survey; mg/L, milligrams per liter; N, nitrogen; P, phosphorus]

Constituent	Unit	Method[1]	WATSTORE parameter code (see table 7)
Nitrogen, nitrite, total	mg/L as N	Colorimetric, diazotization, automated	00615
Nitrogen, nitrate, total	mg/L as N	Computed (00630 - 00615)	00620
Nitrogen, nitrite and nitrate, total	mg/L as N	Colorimetric, cadmium reduction-diazotization, automated	00630
Nitrogen, ammonia, total	mg/L as N	Colorimetric, salicylate-hypochlorite, automated	00610
Nitrogen, organic, total	mg/L as N	Computed (00625 - 00610)	00605
Nitrogen, ammonia and organic, total	mg/L as N	Colorimetric, salicylate-hypochlorite, automated	00625
Nitrogen, total	mg/L as N	Computed (00630 + 00625)	00600
Phosphorus, total	mg/L as P	Colorimetric, phosphomolybdate, automated	00665

[1]From Fishman and Friedman (1989) and Patton and Truitt (1992).

extremely soluble and very little nitrogen is removed by filtering (C.J. Patton, NWQL, oral commun., 1993), the reported total concentration would be very close to the actual total concentration. Throughout this report, the concentrations for the stormwater runoff samples are considered to be for total nitrite nitrogen, total nitrite and nitrate nitrogen, and total ammonia nitrogen.

Five-digit Water Data Storage and Retrieval System (WATSTORE) parameter codes, which are used to store and retrieve values in and from the USGS computerized data base, are supplied for each constituent. The parameter codes conform to those used by the USEPA's data base, STORET, for storage and retrieval of constituent data for United States waterways.

Quality Assurance

Field and laboratory quality-assurance samples are important to assess the validity of analytical results. For this study, replicate samples to assess precision of analytical results and equipment blanks to determine possible sources of contamination were submitted by field personnel. Accuracy of analytical results was evaluated by analyses of known standards.

Precision is the measure of the variability of individual sample measurements and was calculated as the percentage difference in replicate measurements using equation 2, as follows:

$$P = \frac{|A-B|}{0.5\,(A+B)} \times 100 \,, \qquad (2)$$

where P = precision of the measurement pair, in percent;
A = concentration of the field sample; and
B = concentration of the field-sample replicate.

NWQL precision was tested by submitting two sets of subsamples from the same composite sample. For example, a set of discrete samples collected at site 1 on August 25, 1992, was used to produce one composite sample. From this composite, two complete sets of subsamples, the field samples and the field-sample replicates, were submitted to NWQL. This procedure was repeated for samples collected at site 2 on October 31, 1992. The results for the two sets of field samples and field-sample replicates are summarized in table 7 and indicate small variability.

Accuracy is the measure of system bias or the difference between the true concentration of the sample and the measured concentration of the sample. Accuracy was calculated using equation 3, as follows:

$$A = \frac{RV}{MPV} \times 100 \,, \qquad (3)$$

where A = accuracy of the determination, in percent;
RV = measured concentration in the sample; and
MPV = most probable value of the concentration of the sample.

NWQL accuracy is continually monitored by analyses of internal standards and by participation in the USGS interlaboratory evaluation program. The program provides a measure of analytical accuracy as selected organic constituents in natural matrix reference materials are analyzed by several laboratories every 6 months. The median value determined from the results from all participating laboratories becomes the most probable value (MPV) for the constituent and is compared to individual laboratory results. Nonparametric statistical methods are used in the analysis of the analytical results from the labora-tories; FSIG (f-pseudosigma) is the equivalent of the standard deviation in traditional statistics. Refer to Long and Farrar (1993) for a more detailed discussion of statistical techniques used in the interlaboratory evaluation program.

The data for the reference samples distributed in October 1992 are summarized in table 8 for those constituent analyses performed on the stormwater samples. Accuracy was nearly 100 percent for the analytical methods of interest. An accuracy of 76 percent was calculated for one reference sample having a small concentration of total ammonia and organic nitrogen.

Possible sample contamination from cleaning techniques and compositing procedures was investigated when a set of equipment blanks from each of the automatic samplers and two sets of composite blanks from the equipment used in the compositing procedure were submitted to NWQL

Table 7. Results of quality-assurance analyses for field samples and field-sample replicates collected at sampling sites 1 and 2, 1992

[WATSTORE, Water Data Storage and Retrieval System of the U.S. Geological Survey; A, concentration in field sample; B, concentration in field-sample replicate; mg/L, milligrams per liter; N, nitrogen; P, phosphorus]

WATSTORE parameter code	Constituent	Units	A	B	Precision (percent)
	Samples collected on August 25, 1992, at sampling site 1				
00615	Nitrogen, nitrite, total	mg/L as N	0.050	0.050	0
00620	Nitrogen, nitrate, total	mg/L as N	6.85	6.85	0
00630	Nitrogen, nitrite plus nitrate, total	mg/L as N	6.90	6.90	0
00610	Nitrogen, ammonia, total	mg/L as N	.030	.030	0
00605	Nitrogen, organic, total	mg/L as N	.67	.57	16.1
00625	Nitrogen, ammonia and organic, total	mg/L as N	.70	.60	15.4
00600	Nitrogen, total	mg/L as N	7.6	7.5	1.32
00665	Phosphorus, total	mg/L as P	.140	.140	0
	Samples collected on October 31, 1992, at sampling site 2				
00615	Nitrogen, nitrite, total	mg/L as N	.070	.080	13.3
00620	Nitrogen, nitrate, total	mg/L as N	.760	.740	2.66
00630	Nitrogen, nitrite plus nitrate, total	mg/L as N	.830	.820	1.21
00610	Nitrogen, ammonia, total	mg/L as N	.410	.400	2.47
00605	Nitrogen, organic, total	mg/L as N	1.5	1.5	0
00625	Nitrogen, ammonia and organic, total	mg/L as N	1.9	1.9	0
00600	Nitrogen, total	mg/L as N	2.7	2.7	0
00665	Phosphorus, total	mg/L as P	.990	.980	1.02

for analysis. The results are listed in table 9. In three of the four blanks, small concentrations of total ammonia nitrogen were reported, and in two of the four blanks, small concentrations of total phosphorus were reported.

The results from the quality-assurance samples indicate good precision and accuracy for the analytical methods at the NWQL. Equipment blanks indicate possible sample contamination of ammonia and phosphorus from the automatic samplers and compositing procedure, but the small concentrations are at or near the minimum reporting level for the methods.

DESCRIPTION OF SAMPLED STORMS AND PRECIPITATION

Storms were sampled and precipitation recorded at the five stormwater-runoff sampling sites during July through November 1992. The monthly precipitation totals from the five sites (fig. 3) and from the Moline NOAA station are given in table 10. The monthly rainfall recorded at the sampling sites is similar to that recorded at the Moline NOAA station. In 1992, July, September, and November were wetter than normal, and August and October were drier than normal.

Table 8. Results of U.S. Geological Survey interlaboratory testing program for reference samples distributed in October 1992

[WATSTORE, Water Data Storage and Retrieval System of the U.S. Geological Survey. RV, reported value; MPV, most probable value; FSIG, f-pseudosigma; mg/L, milligrams per liter; N, nitrogen; P, phosphorus; for more information see Long and Farrar, 1993]

WATSTORE parameter code	Constituent	Units	RV	MPV	FSIG	Accuracy (percent)
00630	Nitrogen, nitrite plus nitrate, total	mg/L as N	0.182	0.182	0.023	100
			.853	.857	.099	99.5
00610	Nitrogen, ammonia, total	mg/L as N	.119	.113	.019	105
			.876	.876	.121	100
00625	Nitrogen, ammonia and organic, total	mg/L as N	.187	.246	.129	76.0
			1.06	1.10	.22	96
00665	Phosphorus, total	mg/L as P	.107	.110	.013	97.3
			.217	.220	.021	98
			1.23	1.19	.07	103

Table 9. Results of analysis of equipment blanks submitted for sampling sites 1, 3, and 4, 1992

[All values are concentrations, in milligrams per liter as N (nitrogen) or P (phosphorus). NO_2+NO_3, nitrite plus nitrate; number in parentheses is U.S. Geological Survey Water Data Storage and Retrieval System parameter code. <, less than method minimum reporting level; --, data not available]

Sampling-site number (fig. 3)	Blank type	Date	Nitrogen, nitrite, total (as N) (00615)	Nitrogen, nitrate, total (as N) (00620)	Nitrogen, NO_2+NO_3, total (as N) (00630)	Nitrogen, ammonia, total (as N) (00605)	Nitrogen, organic, total (as N) (00605)	Nitrogen, ammonia and organic, total (as N) (00600)	Nitrogen, total (as N) (00600)	Phosphorus, total (as P) (00665)
1	Composite	07-13-92	<0.010	--	<0.050	0.010	--	<0.20	--	<0.010
	Composite	09-30-92	<.010	--	<.050	<.010	--	<0.20	--	.010
3	Sampler	07-16-92	<.010	--	<.050	.020	--	<.20	--	<.010
4	Sampler	09-30-92	<.010	--	<.050	.010	--	<.20	--	.010

The stream at site 1 had flow throughout the sampling period. At site 2 there was little or no flow in the channel except during or immediately following rainfall. At site 3, unless it was raining or it had just finished raining, there was no flow in the channel. During periods of no flow, there was no water in the channel except for a small amount that might last for a few days in pools just downstream from the outfalls. At site 4, discharge not associated with storms was minimal, and samples were collected only after stormwater runoff had an opportunity to dilute and displace the water in the

Table 10. Monthly precipitation at Davenport, Iowa, sampling sites and at Moline, Illinois, weather station during July through Novermber 1992

Location (fig. 3)	Precipitation (inches)				
	July	August	September	October	November
Davenport sampling sites					
1	12.71	1.59	5.84	1.35	6.20
2	12.12	1.41	7.34	1.73	5.39
3	11.52	1.43	6.86	1.68	5.54
4	10.05	1.28	5.75	1.56	5.41
5	[1]--	1.22	5.04	1.28	5.20
Moline[2] weather station	11.76	1.70	4.80	1.49	6.77

[1]Precipitation gage not installed until July 22, 1992.
[2]National Oceanic and Atmospheric Administration, 1992a.

pool just downstream from the outfall by monitoring change in water color and stage. At site 5, all discharge was associated with storms, but during the usual state of no flow there was water pooled in the channel. Discrete samples were not collected until storm-runoff discharge had greatly diluted or displaced the pooled water as evidenced by the change in specific conductance, pH, and color.

Fifteen sets of stormwater runoff samples were collected from July through November 1992. The date and duration of the storm sampled, an estimate of the amount of rainfall that generated the sampled discharge, peak rainfall intensity from the beginning of the storm until the last sample was collected, and the elapsed time between the storm sampled and the end of the previous storm are listed in table 11. Rainfall from the beginning of the sampled storms to the time the last discrete samples were collected ranged from 0.09 to 0.48 in. For comparison, total rainfall from the beginning of the sampled storms to the end of the sampled storms ranged from 0.09 to 2.10 in. (table 11).

Runoff produced from rainfall on July 2, 1992, was sampled at sites 2 and 3. Discrete samples were collected manually for 3 hours at site 2. At site 3, the stream stage returned to a no-flow level after 2 hours, so discrete samples were collected only during the first 2 hours of runoff. Rainfall producing runoff at sites 2 and 3 during sampling was 0.13 and 0.15 in., respectively. More than 160 hours had passed since the last storm greater than 0.10 in. of rain fell at both sites (table 11).

On July 11, 1992, runoff from a 0.34-in. rain was sampled at site 1. Discrete samples were collected for 3 hours; the initial three discrete samples were collected by automatic sampler. It had been 98.4 hours since the last storm with greater than 0.10 in. of rain (table 11).

Runoff produced from rainfall on July 22, 1992, was sampled at sites 4 and 5. At site 4, after the automatic sampler collected the initial three discrete samples, discrete samples were collected manually for the remainder of the 3-hour period. At site 5, flow ceased after 2 hours. Rainfall producing runoff at sites 4 and 5 was 0.19 and 0.30 in., respectively. More than 160 hours had passed since the last storm with greater than 0.10 in. of rain (table 11).

Runoff from a 0.09-in. rain on August 10, 1992, was sampled at site 3. Discrete samples were collected manually for 2 hours. After 2 hours, the recorded stage was near its pre-storm level, and no flow was observed. There were 67.7 hours since the last storm of greater than 0.10 in. of rain (table 11). The 15.4-acre drainage basin for this commercial site is predominately a parking area, so the 0.09-in. rain produced an adequate volume of representative runoff; the 67.7 hours since the previous storm should have allowed the accumula-

Table 11. Characteristics of storms sampled in 1992

[RS, total rainfall from the beginning of the storm until the last sample was collected; IS, peak intensity of rainfall from the beginning of the storm until the last sample was collected; Total, total rainfall for the entire storm; Elapsed time, time between the storm sampled and the previous storm of greater than 0.10 inch; in., inch; in/5 min, inch per 5 minutes]

Sampling-site number (fig. 3)	Date	Date and time (24-hour) storm began	Date and time (24-hour) storm ended	Rainfall			Elapsed time (hours)
				RS (in.)	IS (in/5 min)	Total (in.)	
1	07-11-92	07-11 at 1755	07-11 at 1820	0.34	0.14	0.34	98.4
	08-25-92	08-25 at 1940	08-26 at 1725	.40	.06	.82	164.8
	10-31-92	10-31 at 1610	11-01 at 1700	.37	.02	1.64	279.6
2	07-02-92	07-02 at 0825	07-02 at 1650	.13	.08	1.05	[1]161.6
	08-25-92	08-25 at 1935	08-26 at 1820	.48	.11	.77	313.2
	10-31-92	10-31 at 1615	11-01 at 1655	.29	.02	1.29	275.8
3	07-02-92	07-02 at 0825	07-02 at 1700	.15	.08	1.08	161.6
	08-10-92	08-10 at 1115	08-10 at 1125	.09	.05	.09	67.7
	10-08-92	10-08 at 0500	10-08 at 0845	.26	.05	.26	274.9
4	07-22-92	07-22 at 2030	07-22 at 2140	.19	.11	.19	162.4
	10-08-92	10-08 at 0850	10-08 at 0940	.20	.07	.20	[2]278.6
	11-19-92	11-19 at 0730	11-21 at 0040	.22	.01	2.10	164.3
5	07-22-92	07-22 at 2025	07-22 at 2130	.30	.19	.30	[3]162.3
	10-08-92	10-08 at 0845	10-08 at 1015	.20	.09	.20	[4]278.3
	11-19-92	11-19 at 0635	11-21 at 0115	.20	.01	2.06	161.5

[1]Elapsed time from site 3 rain gage was used because site 2 rain gage was partially obstructed.
[2]Rainfall of 0.11 in. from 0455 to 0610 on October 8, 1992, did not produce significant runoff.
[3]Elapsed time from site 4 rain gage because site 5 rain gage was not installed until July 22, 1992.
[4]Rainfall of 0.11 in. from 0455 to 0610 on October 8, 1992, did not produce significant runoff.

tion of nutrients on exposed surfaces in the drainage basin, which was the intent of the 72-hour regulatory requirement.

Runoff from rainfall on August 25, 1992, was sampled at sites 1 and 2. Discrete samples were collected manually for 3 hours at site 1. At site 2, the automatic sampler collected the initial three discrete samples, and the remaining discrete samples for the 3-hour runoff period were collected manually. Rainfall producing runoff at sites 1 and 2 was 0.40 and 0.48 in., respectively. There were 164.8 and 313.2 hours, respectively, at sites 1 and 2 since the last storm of greater than 0.10 in. of rain (table 11).

Runoff from rainfall on October 8, 1992, was sampled at sites 3, 4, and 5. At site 3, discrete samples were collected for a total of 3 hours, with the automatic sampler collecting the initial three samples at 15-minute intervals (fig. 4). At site 4, manual discrete sampling continued for 2.5 hours. At site 5, discrete sampling was discontinued after 2 hours when flow ceased. Rainfall producing runoff at sites 3, 4, and 5 was 0.26, 0.20, and 0.20 in., respectively. More than 270 hours had passed at the three sites since the last storm producing any significant runoff. There was 0.11 in. of low-intensity rain at sites 4 and 5 approximately 4 hours prior to the sampled storm on October 8; nonetheless, runoff was insignificant (table 11).

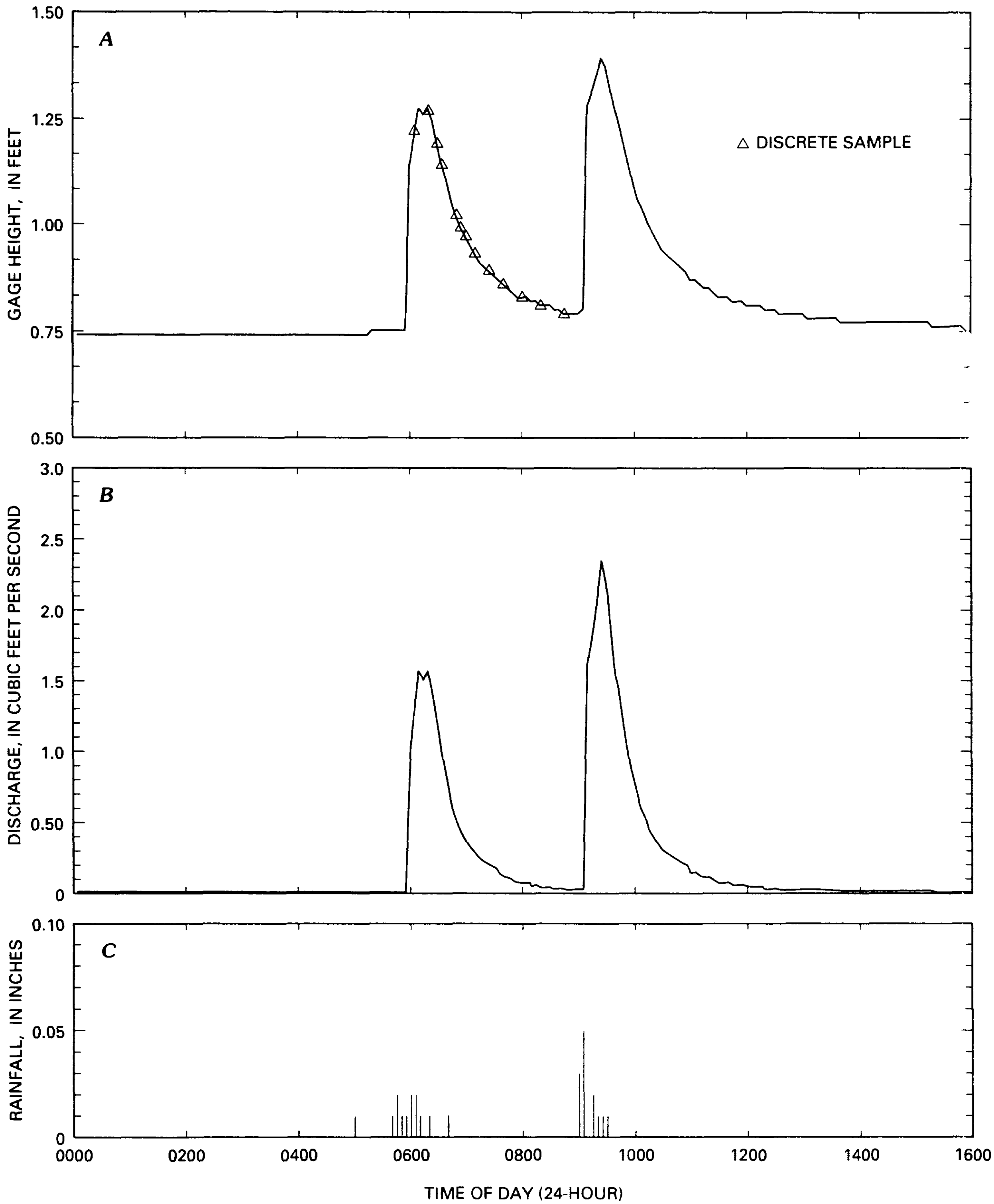

Figure 4. (*A*) Gage height, (*B*) discharge, and (*C*) rainfall for storm sampled on October 8, 1992, at site 3.

Runoff from rainfall on October 31, 1992, was sampled at sites 1 and 2. Discrete samples were collected manually for 3 hours at both sites. Rainfall producing runoff at sites 1 and 2 was 0.37 and 0.29 in., respectively. There were more than 270 hours since the last storm of greater than 0.10 in. of rain (table 11).

Runoff from rainfall on November 19, 1992, was sampled at sites 4 and 5. Discrete samples were collected manually for 3 hours at both sites. Rainfall producing runoff at sites 4 and 5 was 0.22 and 0.20 in., respectively. More than 160 hours had passed at sites 4 and 5 since the last storm of greater than 0.10 in. of rain (table 11).

SELECTED NUTRIENTS IN STORM RUNOFF

In the following section, the quantitative analytical data for each sampled storm are presented. Results from two methods to estimate mean annual loads for the area drained by the Davenport storm-sewer network are compared. Estimated event mean concentrations (EMC's) for cumulative annual discharges are calculated and presented. A calculation assessing the effects of total ammonia and organic nitrogen in urban runoff on the Mississippi River is shown, and an estimate of the proportion of ammonia nitrogen and nitrate nitrogen contained in urban runoff that is derived from precipitation is made.

Concentrations During Sampled Storms

Quantitative data for the nitrogen species and phosphorus are presented in table 12 for each storm sampled at each sampling site. Concentrations of total nitrate nitrogen and total nitrite and nitrate nitrogen were consistently larger in samples from site 1 (agricultural site). The largest concentrations of total ammonia nitrogen, total organic nitrogen, total ammonia and organic nitrogen, and total nitrogen detected occurred in a sample from site 5 (industrial site).

Estimated Nutrient Loads

Regional regression equations in table 4 (Driver and Tasker, 1990) were used to estimate annual loads of total ammonia and organic nitrogen, total nitrogen, and total phosphorus for the area drained by the Davenport storm-sewer network. A simple method described by the U.S. Environmental Protection Agency (1992b) was used to estimate annual loads of total nitrite nitrogen, total nitrate nitrogen, total nitrite and nitrate nitrogen, total ammonia nitrogen, total organic nitrogen, total ammonia and organic nitrogen, total nitrogen, and total phosphorus for the same area. Both methods utilize information regarding precipitation, drainage area, and land use (in the form of percentage of imperviousness or runoff coefficient).

Regression Equation Method

Driver and Tasker (1990) developed several sets of regional linear regression equations from extensive urban storm-runoff data collected during the NURP studies (U.S. Environmental Protection Agency, 1983). The three-variable storm-runoff load equations (table 4) were used to predict the loads for each of the storms sampled at each of the sites. For comparison, a field-estimated load also was determined for each of the storms at each of the sites by multiplying the total stormwater runoff volume by the concentration of the respective composite sample. Table 13 lists the date and time discharge began and ended, the stormwater runoff volume during sampling and for the entire storm, and the field-estimated loads and the regression-determined loads for total ammonia and organic nitrogen, total nitrogen, and total phosphorus associated with each of the composite samples collected.

Field-estimated storm loads for total nitrogen generally are larger than the regression-determined loads. However, similar results are obtained when comparing relative estimated loads from selected land uses calculated by the same method. For example, the largest total nitrogen loads generally occur at site 1 (agricultural site), and the smallest total phosphorus loads generally occur at site 3 (commercial) using either method (table 13).

The regression equations were developed using a different definition of a storm than that used by the USEPA for the NPDES program (U.S. Environmental Protection Agency, 1992b). For the regression equations, a storm must have

Table 12. Results of analysis of stormwater runoff samples from Davenport, Iowa, for nitrogen species and total phosphorus, 1992

[All values are concentrations, in milligrams per liter as N (nitrogen) or P (phosphorus). NO_2+NO_3, nitrite and nitrate; number in parentheses is the U.S. Geological Survey Water Data Storage and Retreival System parameter code]

Sampling-site number (fig. 3)	Date	Nitrogen, nitrite, total (as N) (00615)	Nitrogen, nitrate, total (as N) (00620)	Nitrogen, NO_2+NO_3, total (as N) (00630)	Nitrogen, ammonia, total (as N) (00610)	Nitrogen, organic, total (as N) (00605)	Nitrogen, ammonia and organic, total (as N) (00625)	Nitrogen, total (as N) (00600)	Phosphorus, total (as P) (00665)
1	07-11-92	0.060	4.74	4.80	0.080	2.4	2.5	7.3	1.00
	08-25-92	.050	6.85	6.90	.030	.67	.70	7.6	.140
	08-25-92	.050	6.85	6.90	.030	.57	.60	7.5	.140
	10-31-92	.090	6.61	6.70	.110	.49	.60	7.3	.130
2	07-02-92	.100	1.30	1.40	.430	2.9	3.3	4.7	.380
	08-25-92	.050	.620	.670	.100	.80	.90	1.6	.220
	10-31-92	.070	.760	.830	.410	1.5	1.9	2.7	.990
	10-31-92	.080	.740	.820	.400	1.5	1.9	2.7	.980
3	07-02-92	.130	1.47	1.60	.730	2.0	2.7	4.3	.680
	08-10-92	.040	.760	.800	.350	1.2	1.5	2.3	.240
	10-08-92	.070	1.23	1.30	.800	1.6	2.4	3.7	.370
4	07-22-92	.040	1.06	1.10	.180	1.3	1.5	2.6	.590
	10-08-92	.110	1.09	1.20	.560	1.5	2.1	3.3	.800
	11-19-92	.080	1.52	1.60	.160	.64	.80	2.4	.230
5	07-22-92	.040	.460	.500	.270	1.7	2.0	2.5	.450
	10-08-92	.100	.550	.650	23.0	19	42	43	.040
	11-19-92	.140	.860	1.00	.900	4.6	5.5	6.5	.520

total rainfall of least 0.05 in. separated by consecutive 6 hours with no precipitation (Driver and Tasker, 1990). The precipitation data again were analyzed using SYNOP. Using this definition of a storm, there were 1,572 storms with a mean volume of 0.49 in. at Moline NOAA station from 1969-88.

A two-step process (Gary D. Tasker, U.S. Geological Survey, written commun., 1993) was used to estimate mean annual loads and their root mean-square errors. First, a regression of the natural log of the observed loads versus the natural log of the loads predicted by the regression equations for each of the sampled storms was performed in a model-adjustment procedure described by Hoos and Sisolak (1993). Then, information from the statistical analysis of the long-term storm data and of the model-adjustment procedure was used to estimate mean annual loads and their root mean-square errors for each of the five land-use categories by a method described in Gilroy and others (1990) for estimating total loads

Table 13. Runoff duration, volume, and loads associated with stormwater samples collected in 1992

[ft^3, cubic feet; TKN, total ammonia and organic nitrogen; TN, total nitrogen; TP, total phosphorus]

Sampling-site number (fig. 3)	Date and time (24-hour) discharge began	Date and time (24-hour) discharge ended	Stormwater runoff volume (ft^3)		Field-estimated load (pounds)			Regression-determined load (pounds)		
			During sampling	Total	TKN	TN	TP	TKN	TN	TP
1	07-11-92 at 1800	07-11-92 at 2305	38,500	53,300	8.32	24.3	3.33	21.2	34.5	2.86
	08-25-92 at 2005	08-28-92 at 0100	28,400	490,000	19.9	233	4.28	48.6	78.6	6.94
	10-31-92 at 1635	11-01-92 at 2340	12,600	697,000	26.1	318	5.66	93.5	150	13.9
2	07-02-92 at 0835	07-03-92 at 0100	9,970	319,000	65.7	93.6	7.57	22.6	29.2	3.94
	08-25-92 at 2005	08-26-92 at 2400	56,600	100,000	5.62	9.99	1.37	16.8	21.9	2.88
	10-31-92 at 1705	11-01-92 at 2305	27,100	446,000	52.9	75.2	27.4	27.4	35.4	4.85
3	07-02-92 at 0830	07-03-92 at 0025	784	66,600	11.2	17.9	2.83	4.08	3.62	.988
	08-10-92 at 1125	08-10-92 at 1350	1,230	2,570	.241	.369	.039	.391	.354	.081
	10-08-92 at 0600	10-08-92 at 1515	4,350	11,500	1.72	2.66	.266	1.06	.956	.235
4	07-22-92 at 2035	07-23-92 at 0240	83,700	87,600	8.20	14.2	3.23	5.23	7.08	.792
	10-08-92 at 0855	10-08-92 at 1630	17,300	29,100	3.82	6.00	1.45	5.49	7.42	.834
	11-19-92 at 0750	11-21-92 at 1205	19,500	838,000	41.9	126	12.0	50.6	67.1	8.92
5	07-22-92 at 2120	07-23-92 at 0410	6,100	12,300	1.54	1.92	.346	5.54	6.96	.938
	10-08-92 at 0955	10-08-92 at 1540	4,400	6,640	17.4	17.8	.017	3.78	4.76	.623
	11-19-92 at 1020	11-22-92 at 1210	5,770	266,000	91.4	108	8.64	34.2	42.3	6.54

when periodic measurements are available. The computer program (Gary D. Tasker, U.S. Geological Survey, written commun., 1993) used for the second step of the process is listed in Appendix 1.

The estimated mean annual loads and their root mean-square errors are listed in table 14. The estimated annual load from the area drained by the storm-sewer network was determined by adding the estimated mean annual loads for each of the five types of land use. The largest annual total nitrogen and total phosphorus loads result from residential land use, which covers 67.2 percent (table 2) of the area drained.

U.S. Environmental Protection Agency Method

Annual constituent loads also were estimated using equation 4, a method reported by the U.S. Environmental Protection Agency (1992b):

$$L = \left[\frac{P \times CF \times Rv}{12}\right] EMC \times A \times 2.72 \quad , \qquad (4)$$

where L = annual constituent load, in pounds;
P = mean precipitation, in inches per year;
CF = correction factor that adjusts for storms where no runoff occurs;
Rv = runoff coefficient for the drainage area;
EMC = event mean concentration of constituent, in milligrams per liter; and
A = drainage area, in acres.

The USEPA (1992b) reports that 0.9 often is used for the correction factor (CF). The event mean concentration (EMC) is the theoretical concentration that would be found in any sample of stormwater runoff if the constituent load were distributed evenly throughout time and space. Because the sampling program for this study did not allow a definitive determination of the EMC, a range of values was used for the purpose of estimating loads.

For each land-use type, three different site-specific EMC's were used to estimate the minimum, maximum, and mean annual load. Sample concentrations for a constituent from individual sites were considered to be representative of all storm-related discharge from the corresponding land-use type. For example, sample concentration values from site 3, the commercial site, were considered to be representative of all stormwater runoff from all commercial land in Davenport. The minimum, maximum, and mean concentrations of the three storms sampled at each site (table 12) were used as the EMC's to estimate the minimum, maximum, and mean annual loads, respectively, for the appropriate land-use type (table 14). If a concentration was reported as less than or greater than a value, it was set equal to that value for the EMC calculations.

Following is an example of how EMC values for total phosphorus in runoff from commercial land were determined:

[mg/L, milligrams per liter]

Sampling-site number (fig. 3)	Date	Total phosphorus concentration from table 12 (mg/L as P)
3	07-02-92	0.680
	08-10-92	.240
	10-08-92	.370

Minimum EMC = 0.240 mg/L;
Maximum EMC = 0.680 mg/L; and
Mean EMC = (0.680 mg/L + 0.240 mg/L + 0.370 mg/L)/3 = 0.430 mg/L.

An example calculation using the USEPA method to estimate the mean annual load of total phosphorus in runoff from commercial land drained by the Davenport storm-sewer network (U.S. Environmental Protection Agency, 1992b) is demonstrated using equation 5, as follows:

$$L = \left[\frac{P \times CF \times Rv}{12}\right] EMC \times A \times 2.72 , \qquad (5)$$

where L = annual constituent load, in pounds (3,272) (table 14);
P = mean precipitation, in inches per year (39.10) (table 1);
CF = correction factor that adjusts for storms where no runoff occurs (0.9);

Table 14. Estimated annual nitrogen species and total phosphorus loads for area drained by Davenport storm-sewer network

[RMSE, root mean-square error, in percent; --, no regression equation for this parameter; EPA minimum, maximum, and mean loads are calculated using a method reported in U.S. Environmental Protection Agency (1992b)]

Load-estimate method	Nitrogen, nitrite, total (pounds)	Nitrogen, nitrate, total (pounds)	Nitrogen, nitrite and nitrate, total (pounds)	Nitrogen, ammonia, total (pounds)	Nitrogen, organic, total (pounds)	Nitrogen, ammonia and organic, total (pounds)	Nitrogen, total (pounds)	Phosphorus, total (pounds)
Agricultural and vacant								
Regression equation/ RMSE	--	--	--	--	--	1,482 / 35	4,127 / 31	319 / 59
EPA minimum	75	7,084	7,174	45	732	897	10,911	194
EPA maximum	135	10,238	10,313	164	3,587	3,737	11,359	1,495
EPA mean	100	9,072	9,162	109	1,794	1,794	11,060	628
Residential								
Regression equation/RMSE	--	--	--	--	--	6,922 / 57	38,930 / 56	1,732 / 90
EPA minimum	829	10,275	11,103	1,657	13,258	14,915	26,515	3,646
EPA maximum	1,657	21,544	23,201	7,126	48,059	54,688	77,889	16,324
EPA mean	1,243	14,749	15,909	5,171	28,173	33,144	49,716	8,750
Commercial								
Regression equation/RMSE	--	--	--	--	--	3,683 / 46	15,760 / 44	882 / 74
EPA minimum	304	5,783	6,088	2,663	9,131	11,414	17,502	1,826
EPA maximum	989	11,186	12,175	6,088	15,219	20,546	32,721	5,174
EPA mean	609	8,751	9,360	4,771	12,175	16,741	25,872	3,272
Parks and wooded								
Regression equation/RMSE	--	--	--	--	--	1,500 / 35	4,200 / 31	323 / 59
EPA minimum	61	1,618	1,679	244	977	1,221	3,663	351
EPA maximum	168	2,320	2,442	855	2,289	3,205	5,036	1,221
EPA mean	118	1,862	1,984	458	1,679	2,289	4,273	824
Industrial								
Regression equation/RMSE	--	--	--	--	--	1,254 / 34	3,285 / 30	270 / 58
EPA minimum	56	648	704	380	2,394	2,817	3,521	56
EPA maximum	197	1,211	1,408	32,395	26,761	59,156	60,564	732
EPA mean	131	877	1,014	11,409	11,268	22,536	23,944	475
Total								
Regression equation	--	--	--	--	--	14,841	66,302	3,526
EPA minimum	1,325	25,408	26,748	4,990	26,493	31,264	62,112	6,074
EPA maximum	3,146	46,499	49,539	46,628	95,916	141,331	187,570	24,946
EPA mean	2,200	35,312	37,429	21,917	55,088	76,504	114,866	13,948

Rv = runoff coefficient for the drainage area (0.72) (table 5);

EMC = event mean concentration of constituent, in milligrams per liter (0.430); and

A = drainage area of commercial land, in acres (1,325) (table 2).

The mean loads by land-use type were summed together to determine the mean estimated annual load for the entire area served by the Davenport storm-sewer network. The same procedure was used to estimate the minimum, maximum, and mean annual loads (table 14) for the other constituents.

Table 14 summarizes the results of the annual loads estimated using the regression-equation method and the USEPA method. Constituent loads for the five land-use types and total constituents loads for the entire area drained by the storm-sewer network are provided. The largest mean annual load of total ammonia nitrogen occurs from industrial land, which covers 2.8 percent of the area drained, whereas the largest mean annual loads for all other constituents are associated with residential land, which covers 67.2 percent of the area drained (table 2). Commercial land, which covers 11.6 percent of the area drained (table 2), produces the second largest mean annual loads for total nitrite nitrogen, total nitrite and nitrate nitrogen, total organic nitrogen, total nitrogen, and total phosphorus. For example, the mean annual load of total nitrogen by the USEPA method from residential land is 49,716 lb; from commercial land, 25,872 lb; from industrial land, 23,944 lb; and from agricultural land, 11,060 lb.

In all cases, the regression equation estimate is less than the estimate of mean annual load based on the USEPA method. This might be explained by site-specific differences between the local drainage basin and those sampled in the NURP studies (U.S. Environmental Protection Agency, 1983), the fact that stormwater runoff from industrial drainage basins was not sampled in the NURP studies, and differences in sampling protocols between the NURP studies and the study described in this report. Runoff from the beginning of the storm to the end of the storm was sampled in the NURP studies, whereas only the first 3 hours of runoff were sampled for the NPDES permit procedure. The NURP studies found that the majority of chemical constituents are transported early in the runoff period (U.S Environmental Protection Agency, 1983), so larger calculated loads could be expected from the NPDES data for certain constituents.

Event Mean Concentrations of Cumulative Discharges

EMC's of the annual cumulative discharges from the Davenport storm-sewer network were calculated by rewriting equation 5 to solve for the EMC and using the estimated mean annual load, drainage area, and weighted-average runoff coefficient for the area drained by the storm-sewer network. The weighted-average runoff coefficient can be calculated using equation 6 (U.S. Environmental Protection Agency, 1992b), as follows:

$$Rv_i = \frac{(\Sigma A_i Rv)}{\Sigma A_i} , \qquad (6)$$

where Rv_i = weighted-average runoff coefficient;

A_i = catchment area for specific land-use type, in acres (table 2); and

Rv = catchment runoff coefficient for a specific land-use type (table 5).

The estimated minimum, maximum, and mean EMC's of the cumulative discharges from the Davenport storm-sewer network were determined from the estimated minimum, maximum, and mean annual constituent loads calculated using the USEPA method. An example of how the total phosphorus maximum EMC for storm runoff was determined using equation 7 follows:

$$EMC = L \times \left[\frac{12}{P \times CF \times Rv_i}\right] \times \frac{1}{A \times 2.72} , \qquad (7)$$

where EMC = event mean concentration of constituent, in milligrams per liter (0.874) (table 15);

L = annual maximum constituent load, in pounds (24,946) (table 14);

P = mean precipitation, in inches per year (39.10) (table 1);

Table 15. Estimated event mean concentrations for cumulative stormwater discharges from the Davenport storm-sewer network

[All values are concentrations, in milligrams per liter as N (nitrogen) or P (phosphorus)]

	Nitrogen, nitrite, total (as N)	Nitrogen, nitrate, total (as N)	Nitrogen, nitrite and nitrate, total (as N)	Nitrogen, ammonia, total (as N)	Nitrogen, organic, total (as N)	Nitrogen, ammonia and organic, total (as N)	Nitrogen, total (as N)	Phosphorus, total (as P)
Minimum	0.046	0.890	0.937	0.175	0.93	1.1	2.2	0.213
Maximum	.110	1.63	1.74	1.63	3.4	5.0	6.6	.874
Mean	.077	1.24	1.31	.768	1.9	2.7	4.0	.489

CF = correction factor that adjusts for storms where no runoff occurs (0.9);

Rv_i = weighted-average runoff coefficient for the area served by the Davenport storm-sewer network (0.31246); and

A = area drained by the Davenport storm-sewer network, in acres (11,450) (table 2).

Table 15 summarizes the range of estimated EMC's for cumulative stormwater runoff from the area drained by the Davenport storm-sewer network.

EFFECT OF DAVENPORT STORMWATER RUNOFF ON THE MISSISSIPPI RIVER

In an effort to understand the effect of Davenport stormwater runoff on the Mississippi River, an estimate can be made of the effect on the river concentrations of ammonia and organic nitrogen in runoff from an average storm:

(1) A uniform 1.17 in. rainfall, which is the annual mean amount for storms in this area (table 1), on the 11,450 acres drained by the storm-sewer network with a weighted-average runoff coefficient of 0.31246 would produce about 15,200,000 ft^3 of runoff.

(2) The average storm lasts 77.8 hours (table 1). If the average time it takes the first of the rain as runoff to reach the Mississippi River is the same as the average time it takes the last of the rain as runoff to reach the Mississippi River, the average discharge from Davenport as a result of the storm is about 54 ft^3/s.

(3) The Davenport Water Pollution Control Plant has an NPDES permit from the State of Iowa, which lists the 7-day, 10-year low-flow discharge of the Mississippi River at Davenport as 13,820 ft^3/s (James Resnick, Superintendent of Davenport Water Pollution Control Plant, written commun., 1993). This refers to the lowest average discharge of the river over a 7-day period that can be expected to occur once every 10 years.

(4) By combining these flows, the average low-flow discharge of the Mississippi River at Davenport during an average storm would be about 13,874 ft^3/s.

(5) Storm runoff from the area drained by the Davenport storm-sewer system would contribute about 0.4 percent of the Mississippi River's discharge under the conditions specified. An analysis using the maximum total ammonia and organic nitrogen EMC for runoff from an average storm and the minimum concentration in the Mississippi River from an agricultural-chemical transport study provides information on the most adverse effect that stormwater runoff from Davenport might have on constituent concentrations and loads in the Mississippi River. From June 4, 1991, to July 27, 1992, 60 sets of Mississippi River samples were collected about 40 mi northeast of Davenport at Clinton, Iowa (D.A. Goolsby, U.S. Geological Survey, written commun.,

1993). Reported concentrations for total ammonia and organic nitrogen ranged from 0.50 to 2.1 mg/L. The minimum concentration of 0.50 mg/L was reported for samples collected three different days, on April 6, 24, and 28, 1992, when daily mean discharges were 97,400, 124,000, and 143,000 ft^3/s, respectively. The maximum concentration of 2.1 mg/L was reported for samples collected on June 17, 1991, when the daily mean discharge was 135,000 ft^3/s. For comparison, the annual daily mean discharge at the Clinton, Iowa, sampling site for 1873-1992 was 48,000 ft^3/s (Gorman and others, 1993).

(6) For the area drained by the storm-sewer network, the minimum and maximum estimated EMC's for total ammonia and organic nitrogen in Davenport stormwater runoff were 1.1 and 5.0 mg/L, respectively (table 15).

(7) If 54 ft^3 of Davenport runoff with a total ammonia and organic nitrogen concentration of 5.0 mg/L were mixed instantaneously with 13,820 ft^3 of Mississippi River water with a concentration of 0.50 mg/L, the combined 13,874 ft^3 of water would have an average concentration of about 0.52 mg/L.

In this example, the total ammonia and organic nitrogen concentration of the stormwater runoff was 10 times the concentration of the Mississippi River before being theoretically mixed. Therefore, because the stormwater would have contributed about 0.4 percent of the discharge, it would have contributed about 4 percent of the constituent load of the Mississippi River during the 77.8 hours that stormwater runoff would have entered the river. Because the stormwater runoff was estimated to contribute about 4 percent of the total ammonia and organic nitrogen in the Mississippi River under these conditions, it would seem unlikely that Davenport stormwater runoff from an average storm would greatly increase constituent concentrations in the Mississippi River during periods of greater discharge.

EFFECT OF PRECIPITATION CHEMISTRY ON STORMWATER RUNOFF

Nitrogen in rainfall could be a source of some of the nitrogen detected in the 1992 Davenport urban stormwater runoff samples. The Big Springs Fish Hatchery, located about 120 mi to the north of Davenport, is the closest precipitation-chemistry data-collection station to Davenport and is part of the National Atmospheric Deposition Program/ National Trends Network (NADP/NTN) (fig. 1). Precipitation collected during 1992 at the Big Springs Fish Hatchery had mean annual precipitation-weighted concentrations of 1.62 mg/L of the dissolved nitrate ion and 0.60 mg/L of the dissolved ammonium ion (National Atmospheric Deposition Program, 1993). This converts to 0.366 mg/L of dissolved nitrate as nitrogen and 0.467 mg/L of dissolved ammonia as N. The mean EMC's for stormwater runoff are 1.24 mg/L of nitrate nitrogen as N and 0.768 mg/L of ammonia nitrogen as N (table 15). On the basis of these data, substantial parts of the nitrate nitrogen and of the ammonia nitrogen detected in the runoff samples could be from precipitation.

SUMMARY AND CONCLUSIONS

The USGS, in cooperation with the City of Davenport, Iowa, conducted an urban stormwater runoff study during the summer and fall of 1992. Five open-channel sampling sites were selected to characterize the water quality of storm runoff from the following land-use types: agricultural and vacant, residential, commercial, parks and wooded, and industrial. Three sets of stormwater runoff samples were collected at each of the sampling sites. Flow-weighted composite samples from the first 3 hours of runoff were analyzed for selected nutrients.

Annual constituent loads were estimated for the area drained by the Davenport storm-sewer network. In all cases, the regression equation (Driver and Tasker, 1990) estimate of mean annual load is less than the USEPA method (U.S. Environmental Protection Agency, 1992b) estimate. This might be explained by the fact that stormwater runoff from industrial drainage basins was not sampled in the NURP studies and there were differences in sampling protocols between the NURP studies and the study described in this report. Runoff from the beginning of the storm to the end of the storm was sampled in the NURP studies, whereas only the first 3 hours of runoff were sampled for the NPDES permit procedure. The NURP studies found that the majority of chemical constituents are trans-ported early in the runoff period so larger calcula-ted loads could be expected from the NPDES data for certain constituents. The largest mean annual load of total ammonia nitrogen occurs from indus-trial land, which covers 2.8 percent of the area drained, whereas the largest mean annual loads for total nitrite nitrogen, total nitrate nitrogen, total nitrite and nitrate nitrogen, total organic nitrogen, total ammonia and organic nitrogen, total nitrogen, and total phosphorus are associated with residential land, which covers 67.2 percent of the area drained. Commercial land, which covers 11.6 percent of the area drained, produces the second largest mean annual loads for total nitrite nitrogen, total nitrite and nitrate nitrogen, total organic nitrogen, total nitrogen, and total phosphorus.

An estimate was made that suggested that total ammonia and organic nitrogen in stormwater runoff from the City of Davenport's storm sewers would have a minimal effect on constituent concentrations in the Mississippi River. The estimate was made assuming an average storm produced runoff with the maximum EMC at a time when the Mississippi River had a 7-day, 10-year low-flow discharge and a small concentration of total ammonia and organic nitrogen. Because the stormwater runoff was estimated to contribute about 4 percent of the total ammonia and organic nitrogen in the Mississippi River under these conditions, it would seem unlikely that Davenport stormwater runoff from an average storm would greatly increase constituent concentrations in the Mississippi River during periods of greater discharge. Precipitation-chemistry data collected at the NADP/NTN Big Springs Fish Hatchery site in 1992 indicate that substantial parts of the nitrate nitrogen and ammonia nitrogen contained in the stormwater runoff from the area drained by the Davenport storm-sewer network could be from precipitation.

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APPENDIX

APPENDIX 1. PROGRAM (FORTRAN) TO COMPUTE MEAN ANNUAL LOAD FROM ADJUSTED REGRESSION EQUATION (GARY D. TASKER, U.S. GEOLOGICAL SURVEY, WRITTEN COMMUN., DECEMBER 20, 1993)

```
c
c Program to compute mean annual load from adjusted regression equation
c
      real da,ia rmu,rsd, nstorms, nyears,lda,lia,c0,c1,c2,c3,mux,sdx,
     + b0,b1,sdb1,se,ltot,mal,m,mm2,mse,rmse,phi,lambda,xbar
      print *, ' ENTER drainage area and percent impervious area'
      print *, ' for site for which estimate is to be made.'
      read (*,*) da, ia
      print *, ' ENTER regression coefficients, B0, B1, B2, and B3'
      print *, ' from Table 3 in Driver and Tasker (1990)'
      read (*,*)c0, c1, c2, c3
      print *, ' ENTER number of storms, number of years of record,'
      print *, ' mean of natural (base e) logs of storm rain and std.'
      print *, ' dev. of natural logs of storms in rainfall record.'
      read (*,*) nstorms, nyears, rmu, rsd
c
c Compute mux, estimate of the long term mean of the natural log of the
c the predicted value, and sdx, standard deviation of the natural log
c of the predicted value
c
      lda=log(da)
      lia=log(ia+1.0)
      c0=log(c0)
      mux=c0+rmu*c1+lda*c2+lia*c3
      sdx=c1*rsd
c
c Enter local equation info
c
      print *, ' ENTER intercept, slope, std. dev of slope, std.'
      print *, ' dev. of residuals from local regression of log of'
      print *, ' observed load vs. log of load predicted from equation'
      print *, ' in Table 3 of Driver and Tasker (1990), number of'
      print *, ' observations in local regression, and mean of'
      print *, ' natural log of the predicted values.'
      read (*,*) b0, b1, sdb1, se, m, xbar
c
c Compute mean annual load from Gilroy and others (1990), page 2075,
c equation A2.
c
      ltot=nstorms*exp((se**2)/2.0+b0+b1*mux+(b1**2*sdx**2)/2.0)
      mal=ltot/nyears
c
c Compute RMSE from Gilroy and others (1990), page 2077
c
      mm2=m-2.0
      phi=sdx**2*sdb1**2/2.0
      lambda=(b1+(mux-xbar)/(sdx**2))**2/(sdb1**2)
      mse=(1.-se**2/mm2)**mm2*(1.-2.*se**2/mm2)**(-mm2/2.0)
```

```
      mse=mse*(1.-2.*phi)*(1.-4.*phi)**(-.5)
      mse=mse*exp(se**2/m+4.*phi**2*lambda/((1.-4.*phi)*(1.-2*phi)))
      rmse=100.*(sqrt(mse-1.))
      write (*,1000)mal, rmse
1000 format (' Mean annual load = ',g13.4,/,' Standard error, in %=',
     +f10.1)
      stop
      end
```


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