Quantity and Quality of Runoff from Selected Guttered and Unguttered Roadways in Northeastern Ramsey County, Minnesota

By Gregory B. Mitton and Gregory A. Payne

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Contents

Illustrations

Tables

Conversion Factors and Abbreviated Water-Quality Units

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.4	millimeter
foot (ft)	.3048	meter
mile (mi)	1.609	kilometer
square (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	.02832	cubic meter per second
cubic foot (ft^3)	.02832	cubic meter
foot squared (ft^2)	.09290	meter squared
gallon (gal)	.003785	cubic meter
gallon per minute (gal/min)	.06308	liter per second
million gallons per day (Mgal/d)	.04381	cubic meter per second
pound (lb)	453.6	gram

Chemical concentrations are given in metric units. Chemical concentrations of substances in water are given in milligrams per liter (mg/L) or micrograms per liter (µg/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. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million.

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Abstract

Five roadway sections in northeastern Ramsey County, Minnesota were monitored during 1993-95, to evaluate water quality and loading of constituents from roadway runoff. Two snowmelt-runoff and five rainfall-runoff events were monitored per year at each site. Additional samples of rainfall were analyzed to determine if rainfall was a direct source of constituent loading to roadway runoff. Roadway-runoff samples were analyzed for selected physical properties, dissolved solids, nutrients, dissolved ions, selected metals, and semi-volatile compounds.

Concentrations of dissolved ions such as sodium, chloride, and metals such as aluminum, chromium, lead, and zinc were detected at much greater levels for snowmelt-runoff samples than rainfall-runoff samples. Analysis of chemical samples from rainfall indicate that rainfall was not a direct source for most constituents. Dissolved nitrate and dissolved ammonia in rainfall, however, can contribute up to one-half the amounts detected in roadway runoff.

Concentrations of total phosphorus and fecal *Streptococcus* bacteria were greater at unguttered sites than at guttered sites. Concentrations of dissolved solids, and some metals were greater at guttered sites than at unguttered sites. This suggests that the vegetated road ditches associated with unguttered sites may filter out heavier particles such as metals and solids, while contributing additional organic matter. Concentrations of aluminum, copper, lead, and zinc exceeded chronic condition standard limits established by the Minnesota Pollution Control Agency for metropolitan storm water from 96 percent, 52 percent, 9 percent, and 20 percent of the samples collected, respectively. Chemical loadings of specific constituents, such as suspended solids, from an individual rainfall-runoff event accounted for greater than 90 percent of the cumulative loadings of that constituent for all monitored events at site 4, for the entire study period.

Length of latent period was statistically compared to constituent concentration levels of total phosphorus, dissolved sulfate, and total zinc and there was a correlation. Constituent loads were not associated with latent period. No correlation was found between traffic volumes—which ranged from 1,888 to 7,172 vehicles per day—and constituent concentrations or loads for this study.

Introduction

Water quality of runoff from metropolitan areas is a growing concern for Federal, State and local governments. Since 1972, major point-source dischargers of contaminants, such as factories and sewage treatment facilities, are required to have a National Pollutant Discharge Elimination System (NPDES) permit. In 1987, the U.S. Environmental Protection Agency, under a directive of Congress, established additional NPDES requirements for stormwater discharge monitoring that extend to large metropolitan areas. Since 1992, stormwater discharge permits are required for municipalities that have populations greater than 100,000. Consideration is presently being given to require stormwater discharge permits for municipalities with populations less than 100,000, and to require monitoring of selected land-use types within a metropolitan area.

Urban-runoff studies in the United States have examined the effects of land use on the quality of rainfall runoff. The 1987 changes to the NPDES program resulted in the establishment of monitoring programs in several metropolitan areas in the United States. There also has been a growing interest in nonpoint-source runoff within metropolitan areas. One area of particular concern to State and local planners and engineers is the potential effect that runoff from municipal roadways could have on receiving waters. This concern, and the possibility that further amendments to the NPDES program may focus on selected land-use types, led to this three-year study. The U.S. Geological Survey (USGS), in cooperation with the Minnesota Department of Transportation, and the Minnesota Local Road Research Board, implemented the study to examine rainfall- and snowmelt-runoff at five municipal roadways in Ramsey County, Minnesota. Sampling protocols used in this study were tailored after NPDES guidelines. This study, however, was performed independent of the U.S. Environmental Protection Agency's NPDES program.

The objectives of this study were to compare rainfall-runoff and snowmelt-runoff water quality; determine rainfall-runoff event loading of dissolved solids, nutrients, dissolved ions, selected metals, and semi-volatile organic compounds; and describe effects of traffic patterns and latent periods on runoff quality from selected guttered and unguttered roadways.

Purpose and Scope

This report describes the quantity and quality of runoff from selected municipal roadway sections in northeastern Ramsey County. The data were collected from five roadways that were guttered or unguttered, and include rainfall- and snowmelt-runoff events monitored during 1993-95. The report includes a description of:

1. Rainfall-runoff and snowmelt-runoff water quality.
2. Constituent loadings from rainfall-runoff events.
3. Effects of traffic patterns and latent periods on runoff quality.

Description of Study Area

All five sites are located in northeastern Ramsey County (fig. 1) within the Minneapolis-St. Paul metropolitan area. Municipalities included in the study area were Little Canada, Maplewood, Vadnais Heights, and White Bear Township. This area has gently rolling topography with scattered lakes and wetlands. Land use is primarily residential with limited industrial and commercial development. All sites are located in a 28 mi^2 area and are within the Mississippi River Basin. Receiving waters include Lake Vadnais, Kohlman Lake, Mississippi River (by way of storm sewers), and some wetlands. Average annual precipitation is approximately 30 inches, of which about two-thirds is rainfall (Kuehnast and others, 1975). More recent precipitation data collected from communities near the study area suggest that the figure of 30 inches is still reasonable (James Zandlo, State Climatologist, Minnesota Department of Natural Resources, oral commun., 1996).

Description of Sites

For purposes of this study the five sampling sites were classified by: (1) road design and maintenance, and (2) the Minnesota Department of Transportation (Mn/DOT) municipal state aid road designations. The road designs were either guttered or unguttered. A guttered design is a road section bounded on one side by the road crown (typically the centerline) and on the other side by curbing, while an unguttered design is a road section bounded on one side by the road crown and on the other side by the topographic high of a definable road ditch. Unguttered (uncurbed) road sections usually receive less frequent surface cleaning and might be expected to accumulate more deposits from vehicles over time than curbed road sections. Three road designation categories, which were based on Mn/DOT designations, were also included in this study: (1) county roads, which are major arteries owned and maintained by respective counties, (2) municipal state-aid roads, which are secondary arteries maintained by municipalities using State financial aid, and (3)

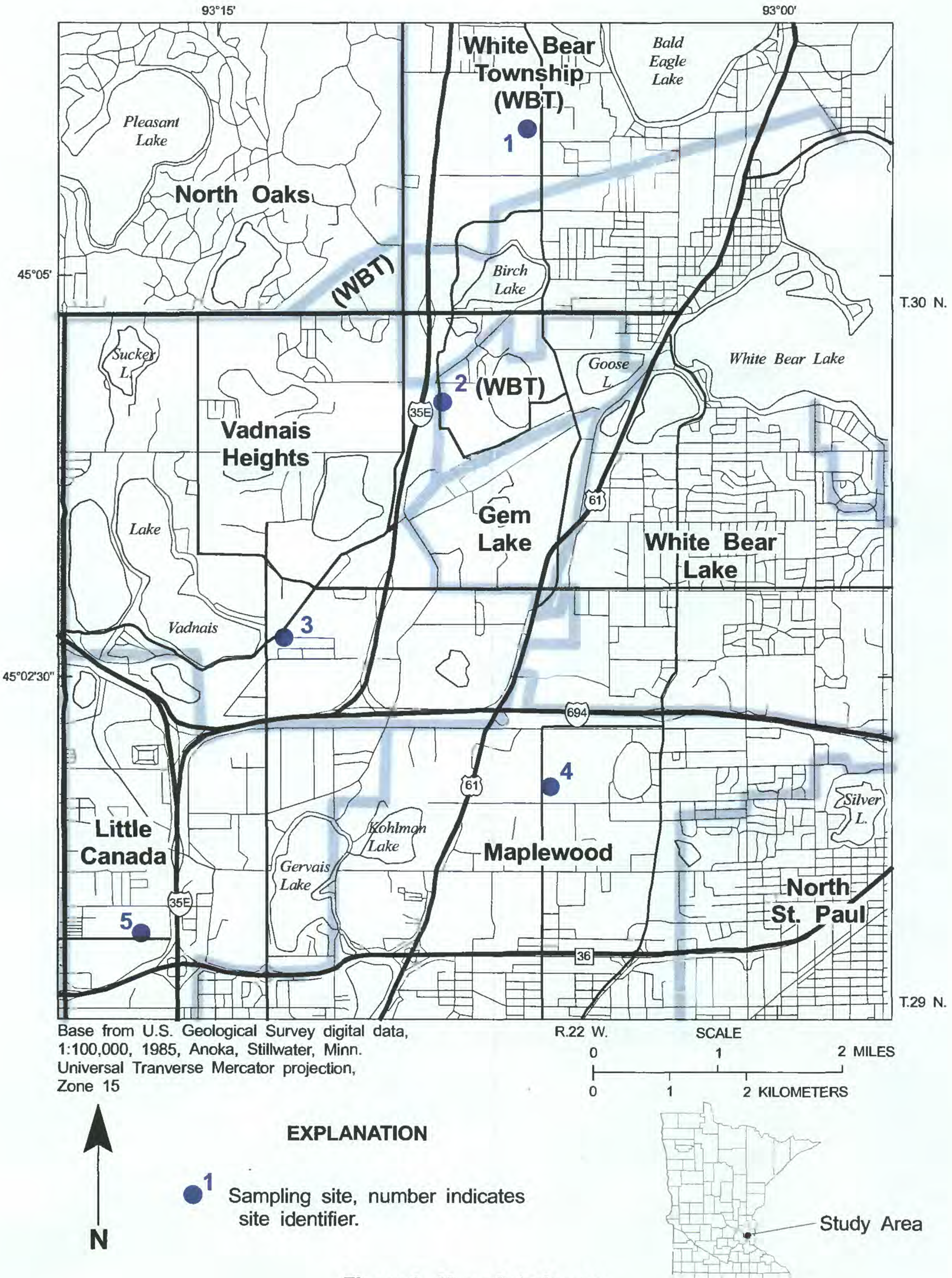


Figure 1. Map of study area.

Table 1.—Sampling site characteristics

[--, not applicable]

Catchment basin (site) identification number	Site name	Minnesota Department of Transportation roadway classification	Common roadway classification	Primary catchment basin size, in square feet	Primary plus secondary catchment basin size, in square feet	Average traffic count, in vehicles per day
1	Otter Lake Road	County - unguttered	Primary - arterial	54,180	156,600	6,686
2	White Bear Parkway	Residential - guttered	Secondary - arterial	20,330	30,750	3,982
3	Centerville Road	County - guttered	Primary - arterial	33,540	--	7,172
4	Hazelwood Street	Municipal state-aid - unguttered	Secondary - arterial	37,280	83,880	5,129
5	County Road B2	Municipal state-aid - guttered	Secondary - arterial	21,820	51,900	1,888

residential roads, which are owned and maintained by municipalities. Using definitions familiar to municipal engineers and planners, the five sites would be classified as either primary arterial or secondary arterial roads (table 1). The five selected sites included; county unguttered, residential guttered, county guttered, municipal state-aid unguttered, and municipal state-aid guttered. A sixth site, residential unguttered, was included in the original study plans but a suitable site was not found.

Physical characteristics of each site, including roadway classification, location, catchment basin size, and average daily traffic volume are described in table 1. Additional site diagrams (figs 2a-2e) include a schematic diagram based on field surveys of each site. Each diagram depicts the sampling point, primary catchment basin, and secondary catchment basin. Instrumentation for a typical site is illustrated in figure 3.

For all sites, a primary catchment basin would be defined on two sides by the road crown and curbing (or topographic high of road ditch) while the ends would be limited on the uphill side by a hilltop or other topographic break, or at an interception point (e.g. sewer drop box) for runoff farther upgradient; and on the downhill side by the sampling point. The secondary basin size includes additional drainage area that could contribute runoff during rainfall events of great intensity (e.g., one inch per hour) or long duration (e.g., over 12 hours). For example, a road with an uneven crown, such as site 2, may have caused additional runoff to enter the catchment basin during heavy rainfalls. At another site, site 5, the uphill extent of the catchment, which normally is a point where a sewer drop box intercepts runoff from farther uphill, could become extended when the drop box became plugged or when rainfall was intense enough to cause the drop box to be overrun. Site 1 included a holding pond which intercepted runoff from a portion of the secondary basin. Following extended periods of rain, however, the holding pond could overflow causing the secondary basin to be part of the effective catchment basin. These extended basins were determined on the basis of field surveys and from field observations during rainfall. It would be difficult to determine the effective catchment basin size for each runoff event without on-site field observations of flow patterns within each basin throughout each runoff event. Catchment basin sizes and rainfall-runoff coefficients listed in this report are given as minimum (primary catchment basin) and maximum (primary + secondary catchment basin) values (tables 1 and 4).

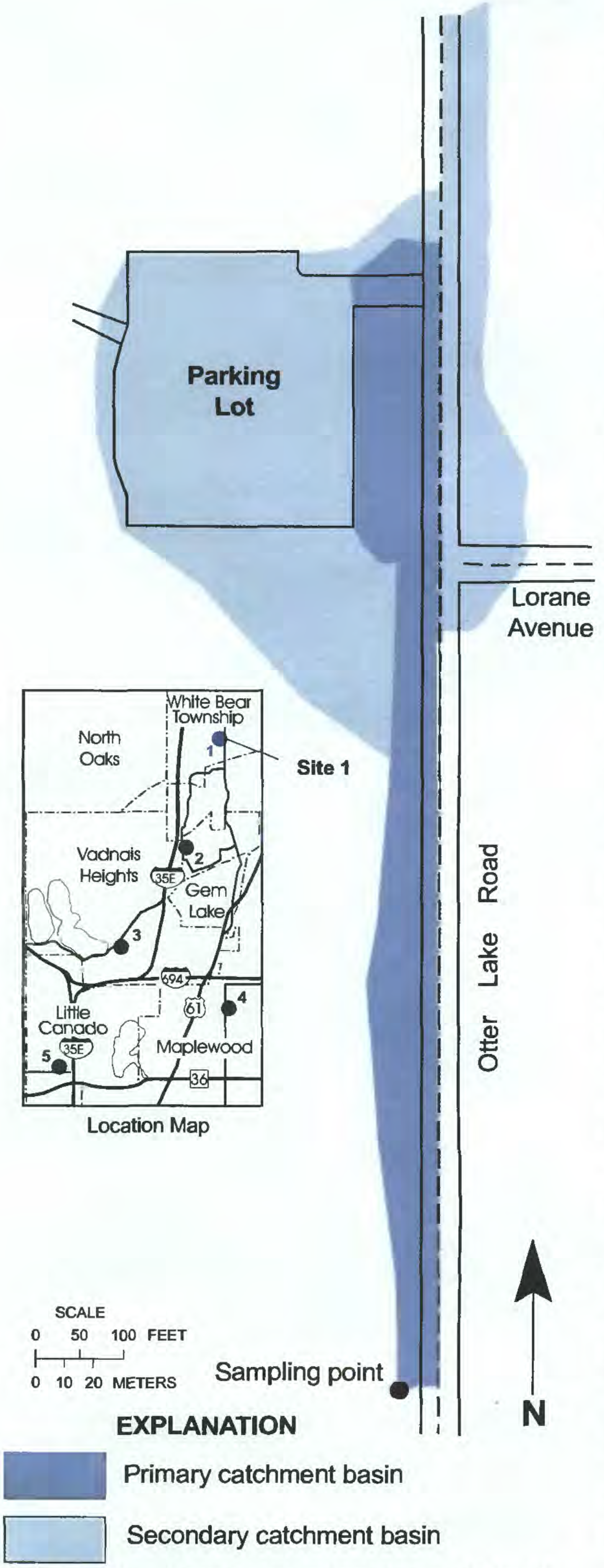


Figure 2a. County-unguttered road (Site 1) at Otter Lake Road in White Bear Lake Township, Minnesota.

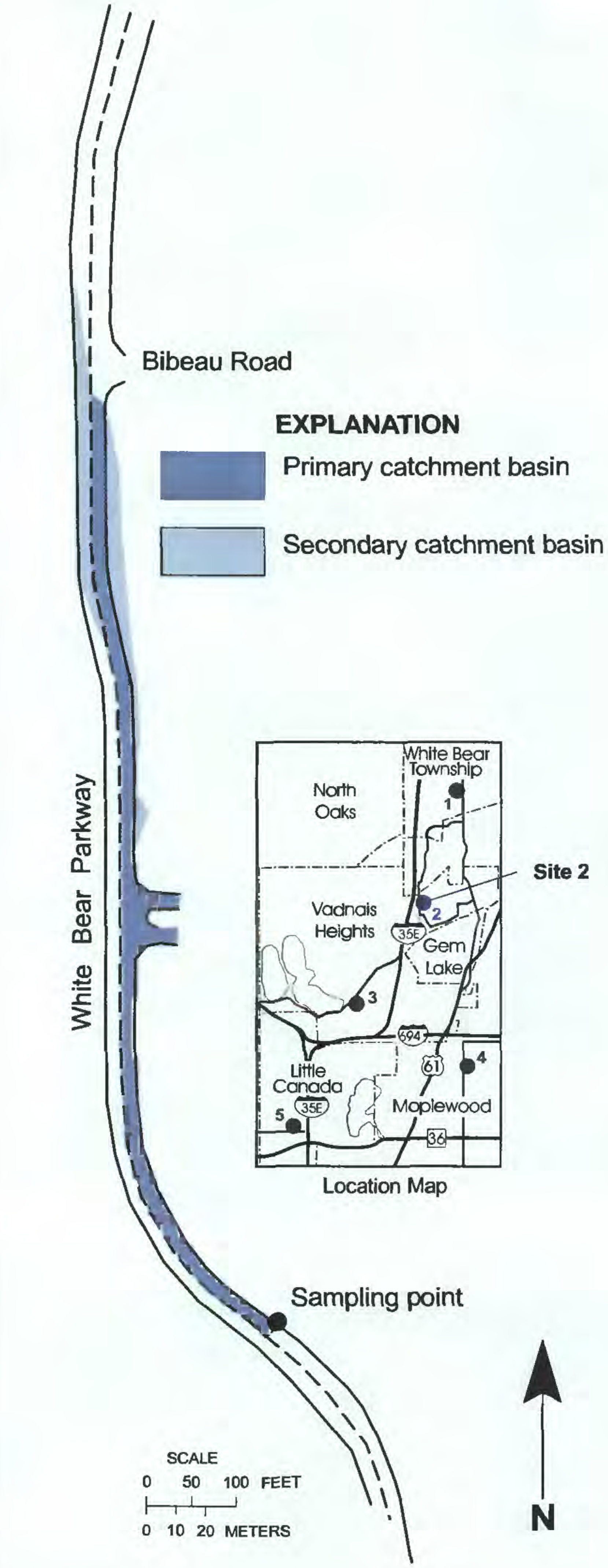


Figure 2b. Residential-guttered road (Site 2) at White Bear Parkway in White Bear Lake Township, Minnesota.

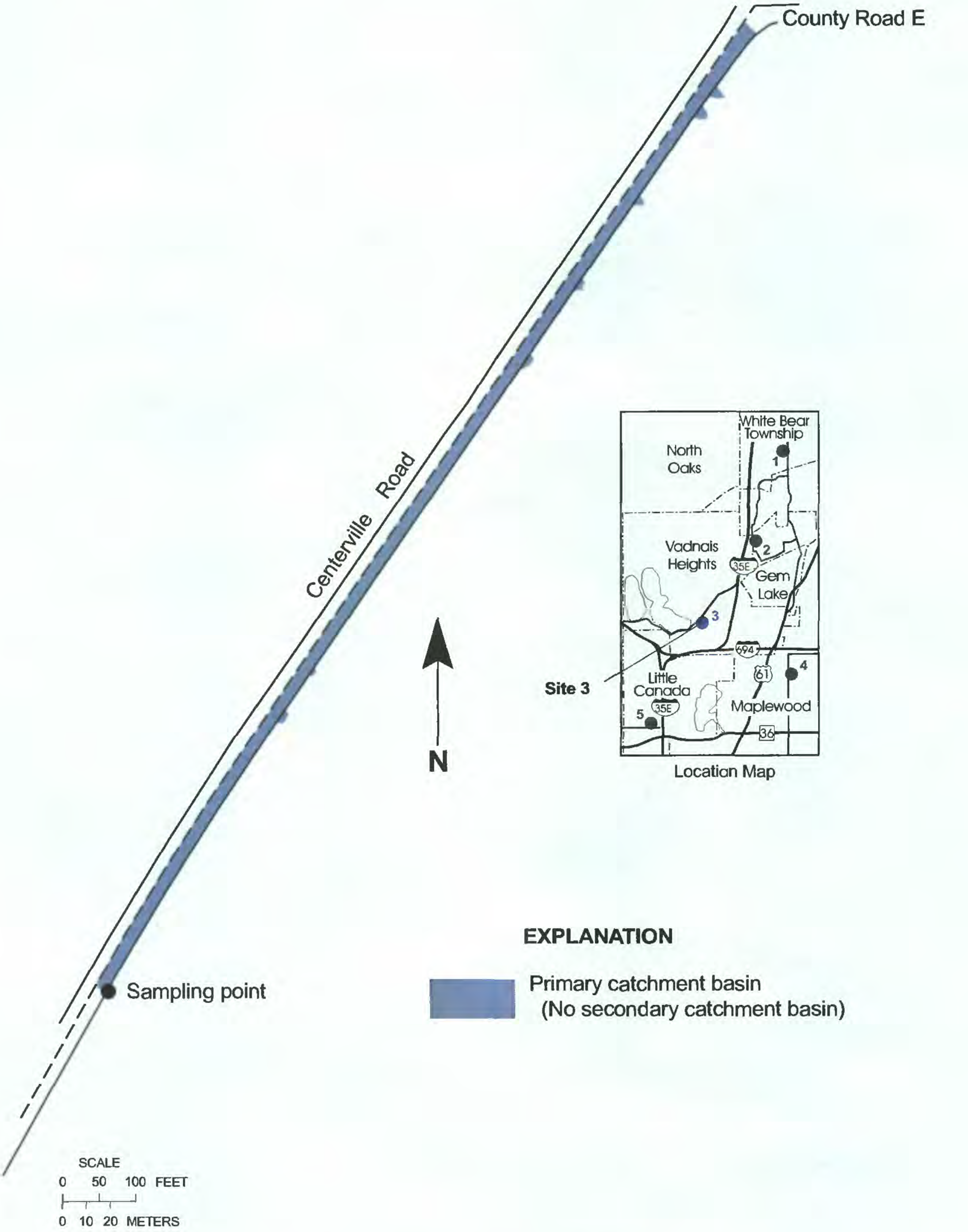


Figure 2c. County-guttered road (Site 3) at Centerville Road in Vadnais Heights, Minnesota.

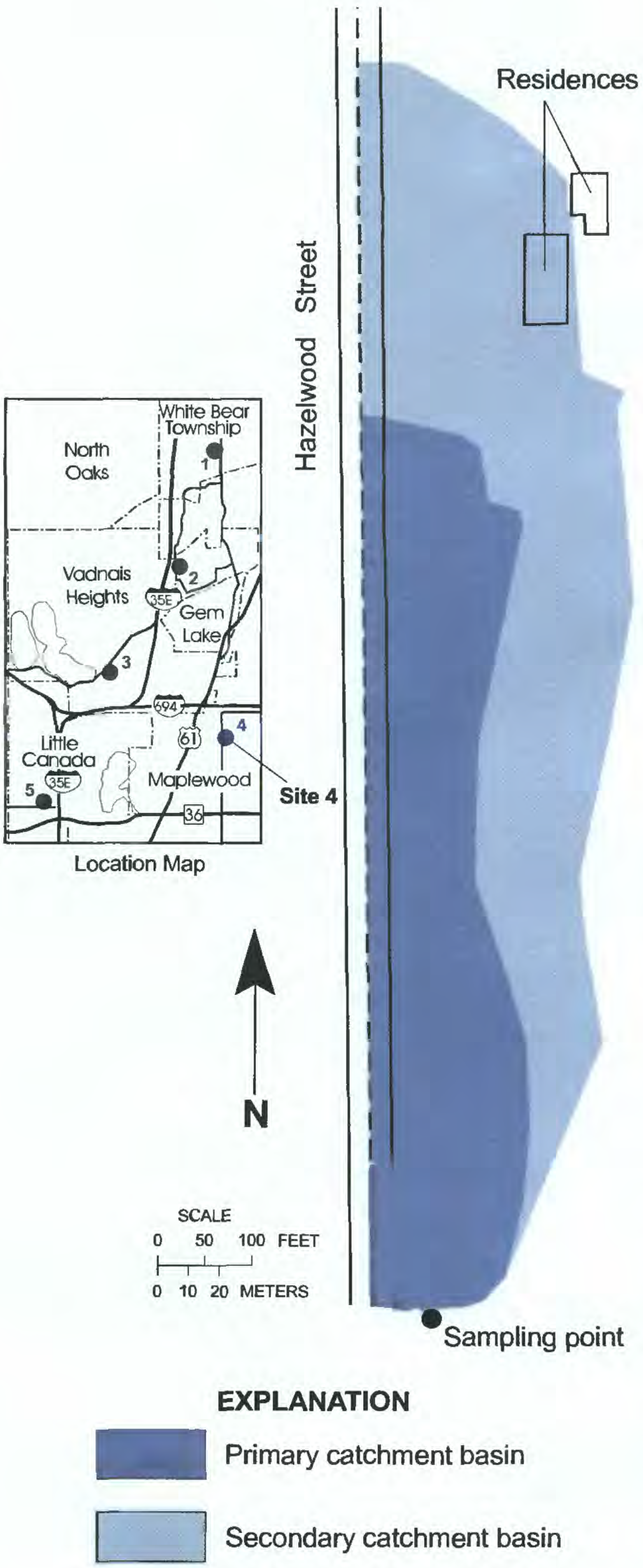


Figure 2d. Municipal-unguttered road (Site 4) at Hazelwood Street in Maplewood, Minnesota.

Acknowlegments

The author acknowledges the assistance of members of a technical-advisory panel that developed a general objective and approach for this study in addition to assisting with site selections, equipment needs, and gathering traffic information. Panel members include Ron Cassellius (Minnesota Department of Transportation), Jim Gates (City of Bloomington), James Grube (Hennepin County), Terry Noonan, (Ramsey County), Judy Sventek (Metropolitan Council), and Kenneth Moxness (Minnesota Department of Transportation). Sampling and recording equipment was provided by Minnesota Department of Transportation.

Methods of Investigation

Site Selection

Monitoring sites were located along roadway sections where runoff was limited to the roadway section with minimal influence from adjacent lands. Wind drift from nearby areas with potential contamination, and runoff from lawns, driveways, and intersecting streets that drained towards the roadway section were cause for eliminating a potential site. Sufficient slope was needed at the roadway sections to generate runoff and prevent ponding. County, municipal, and residential designations, as well as traffic counts, were derived from 1989 municipality traffic maps furnished by Mn/DOT. The designations ‘county’, ‘municipal’, and ‘residential’ used by Mn/DOT (and in this report) are based on road maintenance funding and ownerships in place at the time of the study. Traffic counts were later updated using data provided by Ramsey County. The sites were located within a 30-minute drive of each other and of the U.S. Geological Survey (USGS) District office to allow for rapid response to runoff events (NPDES guidelines suggest grab sampling begin within 30 minutes after the onset of runoff). Because of the site selection criteria used, these sites may not be characteristic of other roadway sections with the same designations.

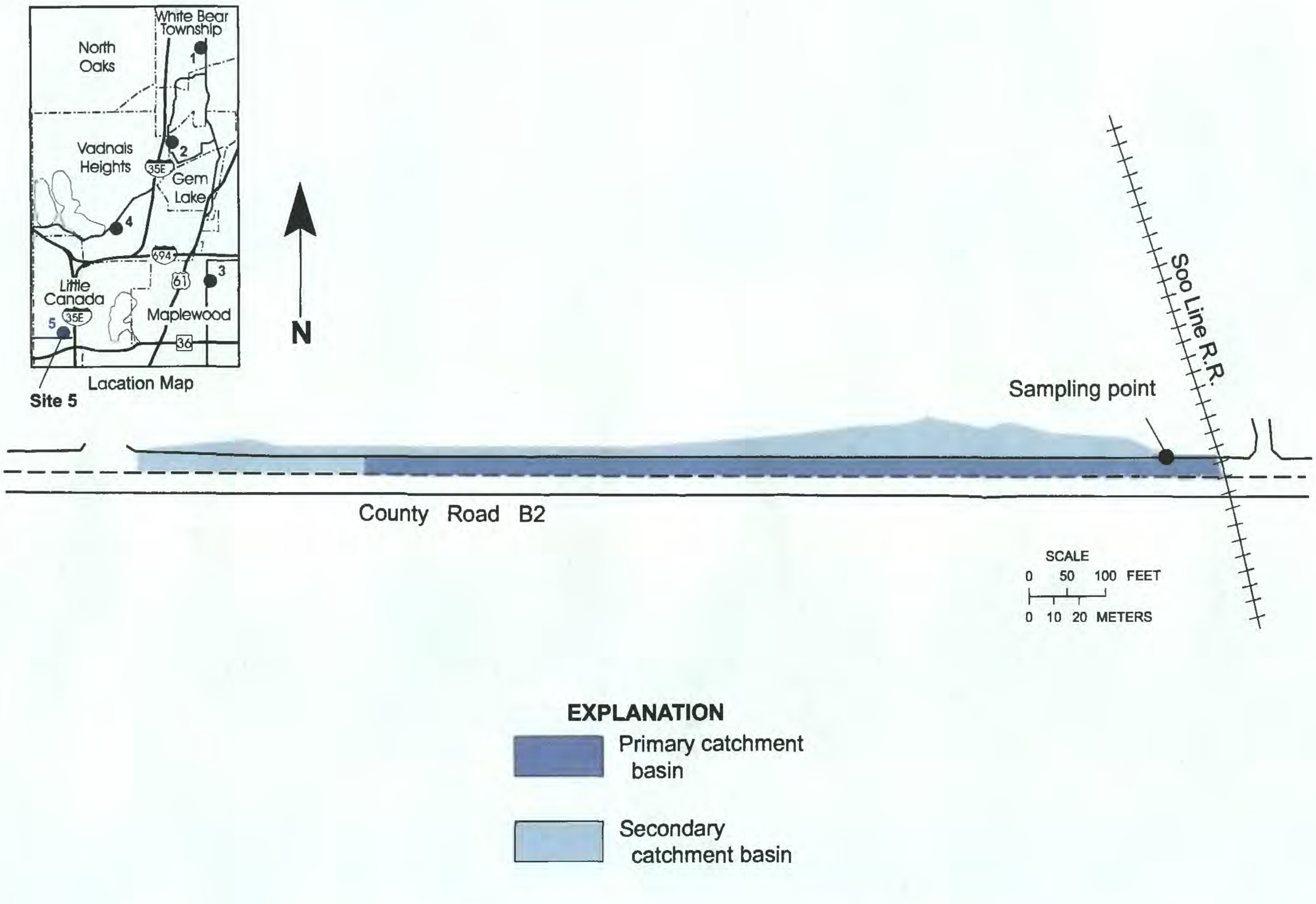


Figure 2e. Municipal-guttered road (Site 5) at County Road B2 in Little Canada, Minnesota.

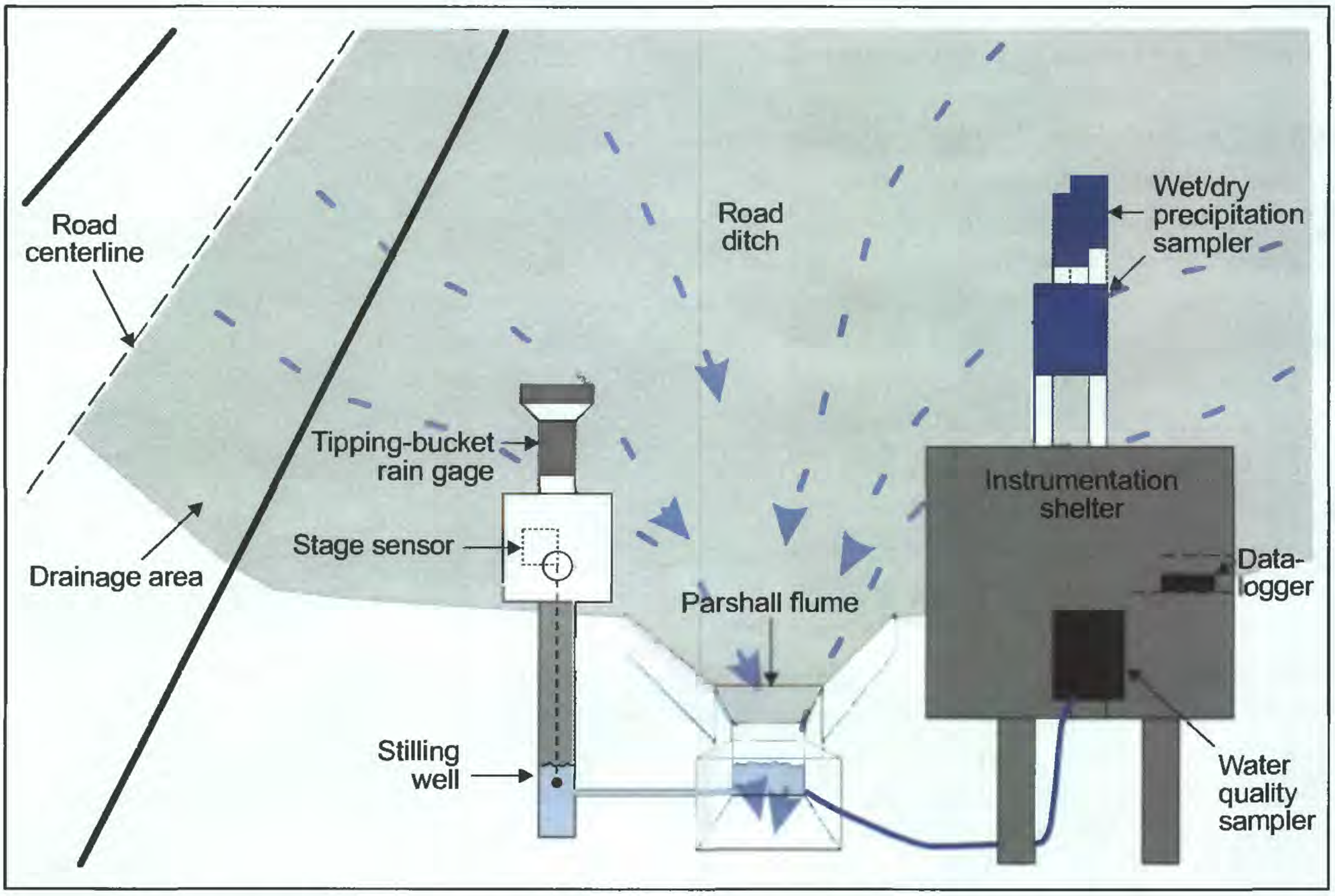


Figure 3. Schematic diagram of instrumentation at a monitoring site.

Runoff Measurements

Parshall flumes with either 3-inch or 6-inch throat sizes were used to measure runoff flow rates. Flumes with 3-inch throats were used to measure flows ranging from 0.03 to 0.89 ft^3/s, and flumes with 6-inch throats were used to measure flows ranging from 0.05 to 2.06 ft^3/s. Flume sizes were based on (1) catchment basin size, and (2) a maximum rainfall intensity of 1 inch per hour. Flow rates factored with time intervals produced total flow amounts for each event. Catchment basin areas, particularly those portions most likely to contribute runoff during a rainfall event, were initially estimated using a tape rule. These areas may have included pervious substrate that could absorb some of the precipitation. For purposes of estimating flume sizes, it was assumed that a primary catchment basin (figs. 2a-e) was the main contributor of runoff for each precipitation event. Published frequency data on rainfall intensities are usually related to storm durations, such as 30-minute, 1-hour, 2-hour, and so on. In the study area, rainfall events lasting 1 hour with a rate of about 1 inch of rain per hour would occur about once a year (Huff and Angel, 1992). A 30-minute rainfall event producing about one-half inch of rain would occur, on average, once every 2-3 months. Assuming all rainfall events lasted 30-minutes or longer, the flume sizes selected for this study would theoretically accommodate all but about two or three events per year. These two or three rainfall events could have enough intensity to produce runoff that would exceed the measuring capacity of the flumes selected. The frequency of occurrence of a rainfall event of a given intensity decreases exponentially with time. For example a rainfall event of about 1 inch of rain per hour and lasting 2 hours would occur once every 7 to 8 years, which suggests that using larger flumes to handle potentially larger runoff volumes would not be practical for this study.

Stage-discharge relations (Kilpatrick and Schneider,

1983) were used to determine flows from recorded stage. The lower threshold at which the flumes can accurately measure flow (±5 percent) is a stage (height) of 0.10 ft in the flume. This stage threshold also was the minimum stage at which the recorders could monitor flow through the flumes. Below a stage of 0.05 ft the flow measurements derived using a flume become unreliable. Between stages of 0.05 and 0.10 ft estimates of flow were obtained using observed stages in the flumes at preselected time intervals. Flow rates and runoff volumes determined between stages of 0.05 and 0.10 ft were calculated using predetermined stage-flow relations for the flumes, although there is a decrease in accuracy of the discharges. Flow rates and volumes determined from stages between 0.05 and 0.10 ft were assumed to have accuracies within ±25 percent. For stages at or above 0.10 ft dataloggers recorded the stage of water in the flume at predetermined intervals during runoff events and calculated runoff volumes for these intervals over the entire event. A shaft encoder, activated by a float-counterweight device, housed in a stilling well with a hydraulic connection to the flume, was the mechanism for transferring water stages in the flume to the datalogger. Field observations of stages were used to verify the accuracy of recorded stages, and at times, were used to replace missing or questionable recorded data. For runoff events where the stage did not exceed the 0.05 ft threshold (which included most snowmelt-runoff events), flow-rate estimates were made using a tape measure to determine cross-section dimensions and a stopwatch timing floating debris to measure velocities.

The float mechanism and water connection could not be maintained during below-freezing temperature conditions. Flow estimates of snowmelt runoff, therefore, were only made by field personnel when conditions allowed. Snowmelt-runoff sampling was done primarily to determine concentration levels for selected constituents.

Catchment basin drainage areas were determined by transit-traverse surveys. Site three was delimited for a primary drainage area and was determined to have no secondary drainage area. The other sites were delimited for both primary and secondary (potentially additional) drainage areas.

Rainfall Measurements

Rainfall amounts were monitored at two sites during each rainfall-runoff sampling event using tipping-bucket rain gages. Tipping-bucket tripping events were recorded with a datalogger in 0.1- or 0.01-inch increments. Wedge-type bulk precipitation gages were later installed at all five sites to verify accuracy of tipping-bucket gages, and to check for rainfall variability over the study area. Rainfall amounts during an event were used in conjunction with total runoff volumes and catchment basin drainage area sizes to obtain an estimate of rainfall-runoff coefficients and runoff per-unit-area values for rainfall-runoff events at each catchment basin.

Water-Quality Sampling and Analysis

Sampling procedures were not directly governed by the U.S. Environmental Protection Agency's NPDES program, but were based in part on the NPDES guidelines (U.S. Environmental Protection Agency, 1991) for monitoring urban runoff from municipalities with populations of 100,000 or greater. The guidelines require that sampled runoff events be preceded by a latent period of at least 72 hours with no rainfall greater than 0.10 inches. For this study it was also implied that the latent period would have no runoff occurring at any monitored site. A minimum of 0.10 in. of rainfall per event was also required to initiate sampling. These guidelines were also used in part to establish which constituents and field parameters to sample (table 2). Grab samples (usually collected at the upstream end of the flume) and field parameters were obtained within 30 minutes of the onset of runoff, or as soon thereafter as possible. These samples were used for analysis of selected constituents where minimal contact with other equipment was desired and where holding time was kept to a minimum. Remaining samples were collected using an automatic sampler that held 28 1-liter bottles. These samples were collected using flow-weighting methods based on discharge data determined from the dataloggers, and were later composited for laboratory analysis. These flow-composited samples were collected based on even increments of flow that were measured and recorded by stage sensors and dataloggers. Programs within the dataloggers compiled flow incrementally and activated automatic samplers

Table 2.—Chemical constituents analyzed, minimum reporting limits, and Minnesota Pollution Control Agency (MPCA) aquatic life standard limits.

[mg/L, milligrams per liter; °Celsius, degree Celsius; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter; NA, not applicable]

Constituent[1]	Minimum reporting limit	MPCA standard limit (2B-Chronic)[2]
Physical properties and additional constituents		
Water temperature (°Celsius)	NA	
Specific conductance, field, in µS/cm	1	
Dissolved oxygen, mg/L	.1	
pH, field, standard units	.1	
Biological oxygen demand (mg/L)	NA	
Chemical oxygen demand (mg/L)	10	
Coliform, fecal (colonies/100 mL)	NA	
Streptococcus, fecal (colonies/100 mL)	NA	
Alkalinity as $CaCO_3$ (mg/L)	1	
Carbonate as CO_3 (mg/L)	1	
Bicarbonate as HCO_3 (mg/L)	1	
Methlyene blue active substances (MBAS) (mg/L)	.01	
Solids, residue, 105°Celsius, total (mg/L)	1	
Solids, residue, 105°Celsius, suspended (mg/L)	1	
Oil and grease, total (mg/L)	1	
Nutrients		
Nitrogen NH_3-N dissolved (mg/L)	.01	
Nitrogen, dissolved NO_2 as N (mg/L)	.01	
Nitrogen NH_3+organic N-N dissolved (mg/L)	.2	
Nitrogen, dissolved NO_2+NO_3-N (mg/L)	.05	
Phosphorus, total (mg/L)	.01	
Phosphorus, dissolved (mg/L)	.01	
Major ions and metals		
Cyanide, total (mg/L)	.01	5.2
Calcium, dissolved (mg/L)	.02	
Magnesium, dissolved (mg/L)	.01	
Sodium, dissolved (mg/L)	.1	
Potassium, dissolved (mg/L)	.1	
Chloride, dissolved (mg/L)	.1	
Sulfate, dissolved (mg/L)	.1	
Flouride, dissolved (mg/L)	.1	
Silica, dissolved (mg/L)	.01	
Aluminum, total	10	125
Arsenic, dissolved	1	
Barium, dissolved	2	
Beryllium, dissolved	.5	
Cadmium, dissolved	1	
Cadmium, total	10	1.95
Chromium, dissolved	5	

Table 2.—Chemical constituents analyzed, minimum reporting limits, and Minnesota Pollution Control Agency (MPCA) aquatic life standard limits—continued.

Constituent[1]	Minimum reporting limit	MPCA standard limit (2B-Chronic)[2]
Major ions and metals—continued.		
Chromium, total	1	11
Cobalt, dissolved	3	
Copper, dissolved	10	
Copper, total	10	15.1
Iron, dissolved	3	
Lead, dissolved	10	
Lead, total	100	7.7
Lithium, dissolved	4	
Manganese, dissolved	1	
Mercury, dissolved	2	.1
Molybdenum, dissolved	10	
Nickel, dissolved	10	
Silver, dissolved	1	
Strontium, dissolved	.5	
Vanadium, dissolved	6	
Zinc, dissolved	3	
Zinc, total	10	191
Semi-volatile organic compounds		
Chloro-methylphenol, total	30	
2,4-Dichlorophenol, total	5	
2,4-Dimethylphenol, total	5	
2,4-Dinitrophenol, total	20	
4-Nitrophenol, total	30	
Phenol, total	5	123
Acenaphthylene, total	5	
Benzidine, total	40	
Benzo(b)fluoranthe, total	10	
Benzo(a)pyrene, total	10	
Butyl benzyl phthalate, total	5	
2-Chlorethyl ether, total	5	
4-Bromophenyl phenylether, total	5	
4-Chlorophenyl phenylether, total	5	
Dibenzanthracene, total	10	
1,2-Dichlorobenzene, total	5	
1,4-Dichlorobenzene, total	5	
Diethyl phthalate, total	5	2.1
2,4-Dinitrotoluene, total	5	
Di-n-octylphthalate, total	10	30
Fluorene, total	5	
Hexachlorobenzene, total	5	.00022

Table 2.—Chemical constituents analyzed, minimum reporting limits, and Minnesota Pollution Control Agency (MPCA) aquatic life standard limits—continued.

Constituent[1]	Minimum reporting limit	MPCA standard limit (2B-Chronic)[2]
Semi-volatile organic compounds—continued.		
Hexachlorocyclopentadiene, total	5	
Indeno(1,2,3)pyrene, total	10	
Naphthalene, total	5	
Nitrosodimethlyamine, total	5	
N-nitrosodi-n-propylamine, total	5	
Pyrene, total	5	
1 2-Diphenylhydrazine	5	
2-Chlorophenol, total	5	
2,4,6-Trichlorophenol, total	20	2
Dinitromethylphenol, total	30	
2-Nitrophenol, total	5	
Pentachlorophenol, total	30	5.7
Acenaphthene, total	5	12
Anthracene, total	5	.029
Benzo(a)anthracene, total	10	
Benzo(k)fluoranthene, total	10	
Benzo(g,h,i)perylene, total	10	
2-Chlorethoxy methane, total	5	
2-Chloroisopropyl ether, total	5	
2-Chloronaphthalene, total	5	
Chrysene, total	10	
Di-n-butyl phthalate, total	5	
1,3-Dichlorobenzene, total	5	
3,3-Dichlorobenzid, total	20	
Dimethyl phthalate, total	5	
2,6-Dinitrotoluene, total	5	
2-Ethlyhexyl phthalate, total	5	
Fluoranthene, total	5	4.6
Hexachlorobutadiene, total	5	
Hexachloroethane, total	5	
Isophorone, total	5	
Nitrobenzene, total	5	
N-nitrosodiphenylamine, total	5	
Phenanthrene, total	5	2.1
1,2,4-Trichlorobenzene, total	5	

[1] in micrograms per liter (µg/L) unless otherwise noted.

[2] Minnesota Pollution Control Agency, Chapter 7050, class 2B-'chronic' standards for metropolitan storm water, applied to aquatic life (Minnesota Pollution Control Agency, 1994, written commun.).

when a pre-assigned flow threshold was reached. The pre-assigned flow threshold was initially based on expected runoff flow rates from rainfall events of 0.5 inch per hour intensity and lasting one-half hour. Flow thresholds were sometimes adjusted later based on runoff volumes experienced from previous events. Manual time-composited samples were collected by field personnel when conditions prevented use of automated sampling equipment. Compositing is done by combining equal volumes from each flow-composited (or time-composited) sample into one common container. All samples were collected and processed based on USGS protocols (Horowitz and others, 1994). Chemical loadings for each rainfall-runoff event were computed for constituents collected from flow-weighted (or time-composited) samples.

Composite samples were flow-weighted or time-composited for each event. Time-composited samples were collected when flow-weighting was not possible—usually when flow levels were below the designed thresholds for automatic sampling. Under these conditions flow was typically stable producing flat hydrographs. Discharges varied no more than ±25 percent and only occasionally varied more than ±50 percent, so samples composited at even-time intervals approximated flow-composited sampling. However, inherent inaccuracies in determining flow at low stages would make flow compositing difficult. Total runoff volumes and constituent loadings for these events were small when compared to runoff volumes and constituent loadings from events that used flow compositing.

Snowmelt-runoff samples were collected by dipping sample bottles directly into runoff. No determinations of total runoff volume were made, although instantaneous flow estimates were made for some sites or events. Equipment operating limitations precluded collection of composited water-quality samples, or obtaining accurate estimates or runoff volumes. Snowmelt-runoff loads were therefore not determined. A snowmelt-runoff event was defined as any event producing snowmelt runoff, and separated from other events by a period of no runoff lasting more than one day.

Wetfall/dryfall precipitation collectors were installed at two sites to collect rainfall samples. Wetfall samples were analyzed for nutrients, dissolved ions, and selected metals to determine if rainfall was a direct source of constituents found in roadway runoff. Dryfall was considered a part of the accumulation process to roadway surfaces (which included deposition from vehicles) between rainfall-runoff events, therefore, dryfall samples were not collected.

Laboratory analytical methods and procedures were based on USGS protocols (Fishman and Friedman, 1985). Determinations of water temperature, conductivity, dissolved oxygen, and pH were made in the field using a portable, multi-parameter instrument. Analysis of 5-day biochemical oxygen demand (BOD), fecal coliform, fecal *Streptococcus* bacteria, and alkalinity was performed in the USGS laboratory in Mounds View, Minnesota. All other analyses were performed in the USGS National Water Quality Laboratory (NWQL) in Arvada, Colorado, and included chemical oxygen demand, detergents, dissolved and suspended solids, oil-and-grease, nutrients, dissolved ions, selected metals, and semi-volatiles (including acidic, basic and neutral methylene chloride extractable compounds or poly-nuclear aromatic hydrocarbons (PAH's). Samples collected for later laboratory analysis were filtered, chilled, or chemically treated when necessary before transport. Chemical loads for selected constituents were computed for each rainfall-runoff event by multiplying constituent concentrations by total runoff volume.

Quality Assurance

Quality assurance for sampling consisted of several elements that were designed to assure quality at all stages of data gathering from field sampling through laboratory analysis. Procedures were selected to assure that samples were not compromised by possible contamination from equipment, field handling, and processing. Laboratory analytical performance and field sampling techniques were assessed by submission of duplicate samples from the field in conjunction with on-going quality-assurance procedures that are part of the operating protocols within the USGS NWQL. Personnel involved in water-quality sampling and analysis receive annual testing and training to insure reliable performance. Results of quality-assurance sampling are described at the end of this report (Supplemental Information section).

Runoff measurements

Flumes used in this study were precalibrated by the manufacturer. Similar flumes have been verified by USGS personnel using several standard discharge-measurement methods. On-site readings of water stages in the flume by field personnel were used to verify automated readings.

Rainfall measurements

Tipping-bucket rain gages were calibrated at the beginning of each rainfall-runoff sampling season using volumetric techniques. Wedge-type bulk precipitation collectors were initially installed at the two sites with tipping-bucket gages, to verify accuracy. Bulk gages were installed at the three remaining sites after the first year of sampling to determine variability of rainfall from site to site.

Runoff and precipitation sampling

Sampling equipment that contacted environmental samples (runoff and precipitation) was cleaned before and after field use. Equipment and bottles were cleaned by scrubbing in a Liquinox solution. After scrubbing, equipment and bottles were rinsed with hot tap water followed by a rinse using a five-percent hydrochloric acid solution, followed by three rinses using deionized water.

Cleaned equipment was tested with blank water at the beginning of each sampling season. Blank water (deionized organic-free water) was passed through the sampling equipment and then submitted to the laboratory where it was analyzed for each of the constituents that were determined for runoff samples. Separate blank analyses were run on the automatic-sampler bottles, automatic-sampler pump/tube assemblies, peristaltic pumps, and wetfall/dryfall precipitation collection buckets. At the beginning of the study, Parshall flumes at two of the sites were also tested with blank water.

Quality control for determining precision of sampling, processing, and laboratory analysis was undertaken by collecting a duplicate sample at site 2 (White Bear Parkway) for every sampled rainfall-runoff event at site 2 during the study. In the first year of study, duplicate samples also were collected at site 1 (Otter Lake Road), site 3 (Centerville Road) and site 5 (County Road B2) during some of the runoff events. Duplicates were collected for all constituents that were analyzed at the USGS NWQL. Duplicate samples were collected by pumping runoff water and alternating outflow from the pump between regular and quality-assurance sample-collection bottles. Duplicate sampling was not done for analyses that were performed in the Mounds View laboratory (BOD, bacteria, and alkalinity).

Concentration levels for selected constituents from rainfall samples also were compared with data from two precipitation monitoring sites in Minnesota that are part of the National Atmospheric Deposition Program (NADP) (NADP—National Trends Network, Annual Data Summary—Natural Resources Ecology Laboratory, Colorado State University, Ft. Collins, CO, electronic communication, 1996). For comparative purposes, roadway-runoff precipitation data from only 1994 was used. Data from the two roadway study sites were combined and averaged for this comparison (table 3). Comparisons were possible for four constituents—dissolved calcium, dissolved magnesium, dissolved nitrate, and dissolved ammonia.

The water quality of precipitation from the NADP sites compare with concentration levels in rainfall samples from this study. Mean concentration levels of selected constituents (table 3) from this study were generally within the range of levels of constituent concentrations from the two NAPD sites (although mean concentrations of dissolved nitrate and dissolved ammonia were lower), which suggests that the water quality of rainfall samples collected during this study is representative of precipitation in the region.

Quantity of Roadway Runoff

Storm-runoff flow volumes were measured or estimated during each rainfall-runoff event. These volumes were determined based on data collected automatically by recorders, with additional data obtained by field personnel. Baseflow conditions were

Table 3.—Comparison of roadway study samples and National Atmospheric Deposition Program (NADP) precipitation analyses.

[mg/L, milligrams per liter; Max, maximum,; Min, minimum]

Rainfall data source	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Nitrate, dissolved (mg/L)	Ammonia, dissolved (mg/L)
Roadway study—rainfall data (1994)	Max = 0.96 Min = 0.08	Max =0.13 Min = 0.03	Max =0.28* Min = 0.19	Max = 0.27 Min = 0.08
	Mean = 0.36	Mean = 0.07	Mean = 0.23*	Mean = 0.20
NADP—Lamberton	Max = 3.07 Min =0.06	Max = 0.34 Min = 0.01	Max = 8.00 Min =0.56	Max = 3.40 Min = 0.02
	Mean = 0.50	Mean = 0.07	Mean = 1.97	Mean = 0.86
NADP—Camp Ripley	Max = 1.50 Min = 0.03	Max = 0.26 Min = 0.00	Max = 4.10 Min = 0.26	Max = 1.90 Min = 0.04
	Mean = 0.25	Mean = 0.04	Mean = 1.38	Mean = 0.53
Roadway study—roadway-runoff, all sites, 1994			Mean = 0.53*	Mean = 0.40
			*Used $(NO_2+NO_3)-NO_2$	

not a factor when determining runoff volumes, due to the absence of any flow between events. The catchment basins included in this study were generally less than one acre in area. Road surfaces were nearly impervious, particularly for guttered roadway basins, which were completely paved. These paved surfaces contributed to rapid response times from the beginning of precipitation to the onset of runoff at the sampling sites. In a few cases, particularly with the larger, more pervious catchment basins, runoff continued beyond the water-quality monitoring period, either due to delayed runoff response time in part of the secondary drainage area, or because of an extended precipitation event that lasted up to 18 hours. In these instances, the water-quality monitoring and sampling efforts generally ended after the first two hours of runoff, although flow monitoring continued throughout the event.

Hydrographs from selected runoff events show considerable variation both in shape and extent. Rainfall intensity, amount, and duration often varied from event to event, and from site to site for the same event. Selected rainfall-runoff hydrographs (figs. 4a-d) from events in the first year (1993) of sampling show variations in runoff with respect to response time (interval between beginning of rain and beginning of runoff), duration of runoff, and variations in stage throughout the events. The event of June 16-17 at site 1 (fig. 4a) depicts a situation where rainfall and runoff continued well beyond the water-quality monitoring period. The additional rainfall and runoff were included in the rainfall and runoff totals for the event, but represented a minor contribution. It is important to note that a runoff event at one site may cease hours before another site owing to differences in runoff characteristics that can cause a shorter recession period.

Guttered Roadways

Guttered-roadway sites have primary catchment basins that are paved and have rapid response time, rapid ascension, and rapid recession periods. Pavement that was hot and dry was observed to respond more slowly to precipitation than saturated, cool pavement—particularly for low intensity rainfall events. Evaporation from, and absorption into the pavement were factors that could have delayed response time. While pavement is fairly impervious to water, it will absorb some moisture, particularly if it is older, more weathered pavement. Response times (from beginning of rainfall to start of runoff at sampling site) for guttered-roadway basins averaged 42 minutes and ranged from 2 to 175 minutes.

Some rainfall events had multiple storm surges producing more than one rise on the hydrograph (figs. 4a,c). Other events with low intensity rainfalls (< 0.10 inches per hour) lasted as long as several hours and produced discharges that were too low to be accurately measured with the automated equipment (fig. 4d). In the latter cases, streamflow data were collected manually by field personnel.

Unguttered Roadways

Factors (such as pavement-moisture content or evaporation) that influenced hydrograph trends for guttered roadways also were evident for unguttered roadways. Response time, however, was about three times longer for unguttered roadways than for guttered roadways. The response time ranged from 15 to 325 minutes and averaged 133 minutes for the unguttered sites. The recession periods were as long as ten hours (fig. 4a). The type and extent of ground cover in these catchment basins contributed to longer recession periods. Greater than 50 percent of the surface area of the primary catchment basin for unguttered roadway sites was unpaved, consisting of grass-covered road ditches and, at some sites, adjacent, undeveloped, land areas. Pervious, unsaturated soils at these sites may have absorbed more moisture before reaching saturation, resulting in slower response times on the rising side of the hydrograph (fig. 4b). The recession periods at unguttered sites often continued during intermittent pauses in precipitation when runoff ceased at guttered sites. Additional precipitation occurring after these breaks would be included in the event total, providing runoff had not ceased. The total precipitation and total runoff monitored at unguttered sites for any event was, therefore, often greater than for guttered sites.

Catchment Yields

During the study period, 31 rainfall events were monitored. Typically, two to three sites were sampled per event. Total rainfall, total runoff, runoff per-unit-area (primary and primary+secondary catchment basins), and rainfall-runoff coefficients were determined from these events (table 4). Runoff per-unit-area and rainfall-runoff coefficient data are presented for both primary and primary+secondary drainage areas. Because it could not be determined whether the secondary drainage area contributed to the total runoff for any given event, two sets of runoff yield data were calculated for each event, which show a maximum and minimum potential rainfall-runoff coefficient.

The rainfall-runoff coefficient is the percentage of rainfall that ran off. The formula used to determine rainfall-runoff coefficient is described below:

$$Rc = Ra/P,$$

where Rc = rainfall runoff coefficient;
P = total rainfall (inches); and

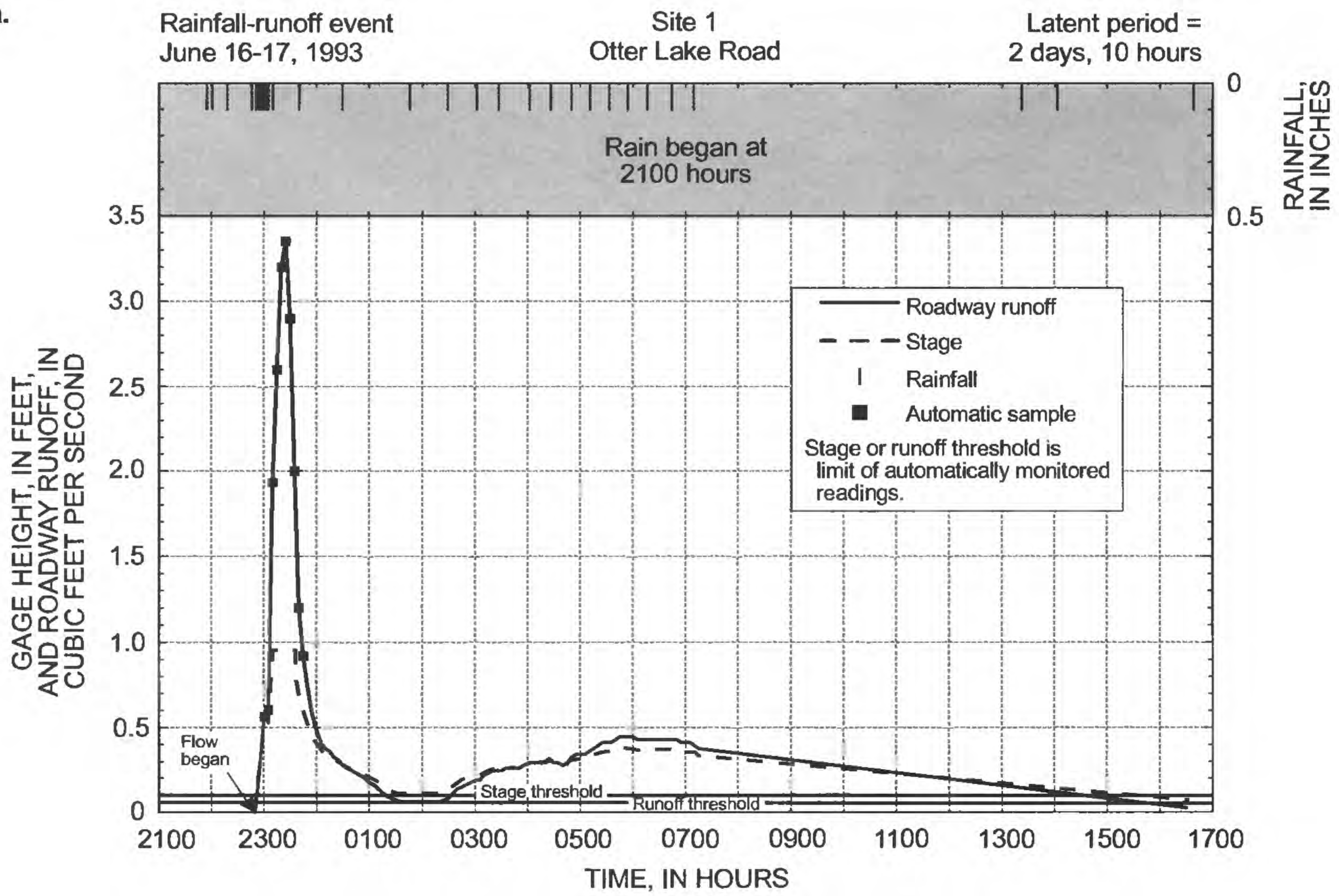
$$Ra = r/DA,$$

where Ra = runoff per square ft;
r = total runoff (cubic ft)/12; and
DA = drainage area (square ft)

For guttered sites, the total measured runoff volume (for all monitored rainfall-runoff events) was 15,280 ft^3. Using total rainfall amounts from table 4, this results in a rainfall-runoff coefficient of 0.53 for the primary catchment basin or 0.22 for the combined primary+secondary catchment basin. If it is assumed that all runoff originated from the primary drainage area, then 53 percent of the rainfall ran off directly past the monitoring site while the remaining 47 percent was absorbed into the substrate, ponded, diverted in transport, or evaporated.

For the unguttered sites, the total measured runoff was 33,080 ft^3. Using total rainfall amounts from table 4, this results in a rainfall-runoff coefficient of 0.37 for the primary catchment basin or 0.14 for the combined primary+secondary catchment basin.

The impact of one large rainfall on receiving waters compared to several smaller events is evident when observing the runoff volumes from unguttered roadway sites. Of the 14-15 events monitored per unguttered site for the study period, 60-68 percent of total runoff volumes occurred from one rainfall event on June 16, 1993. For guttered sites, one major event also produced a significant portion of the total runoff volume. About 20 percent of the total runoff volume at guttered sites a.



b.

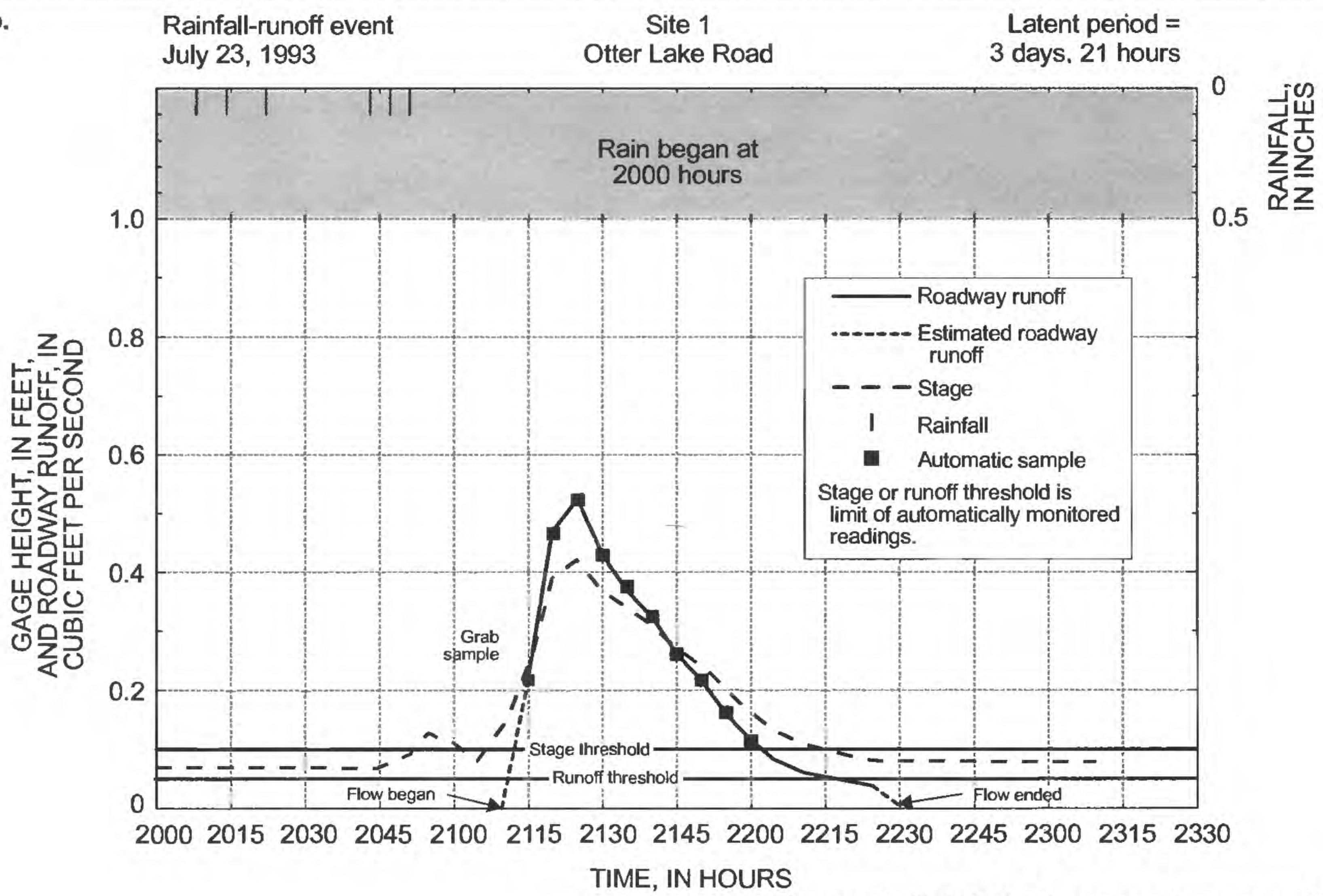
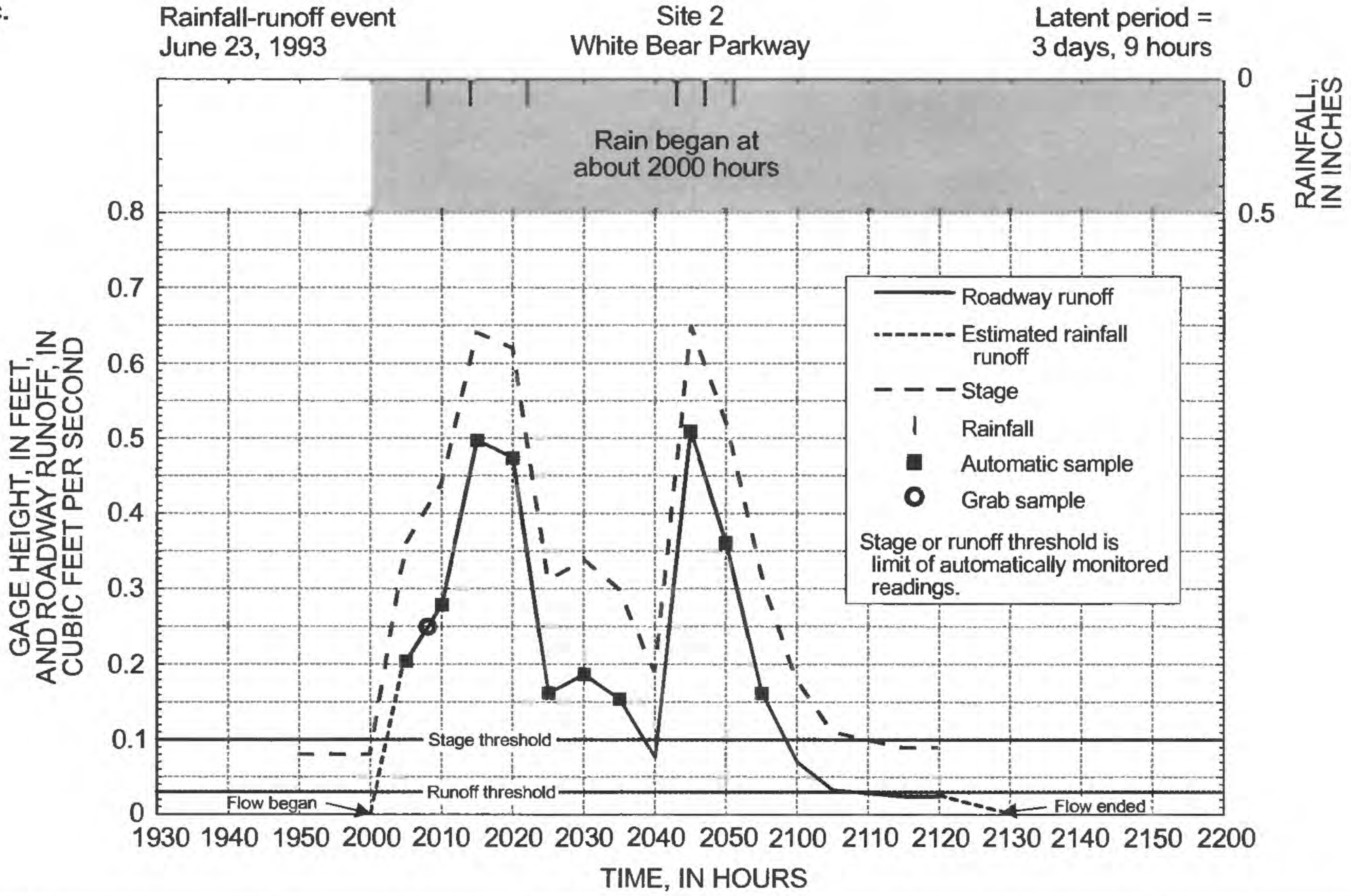
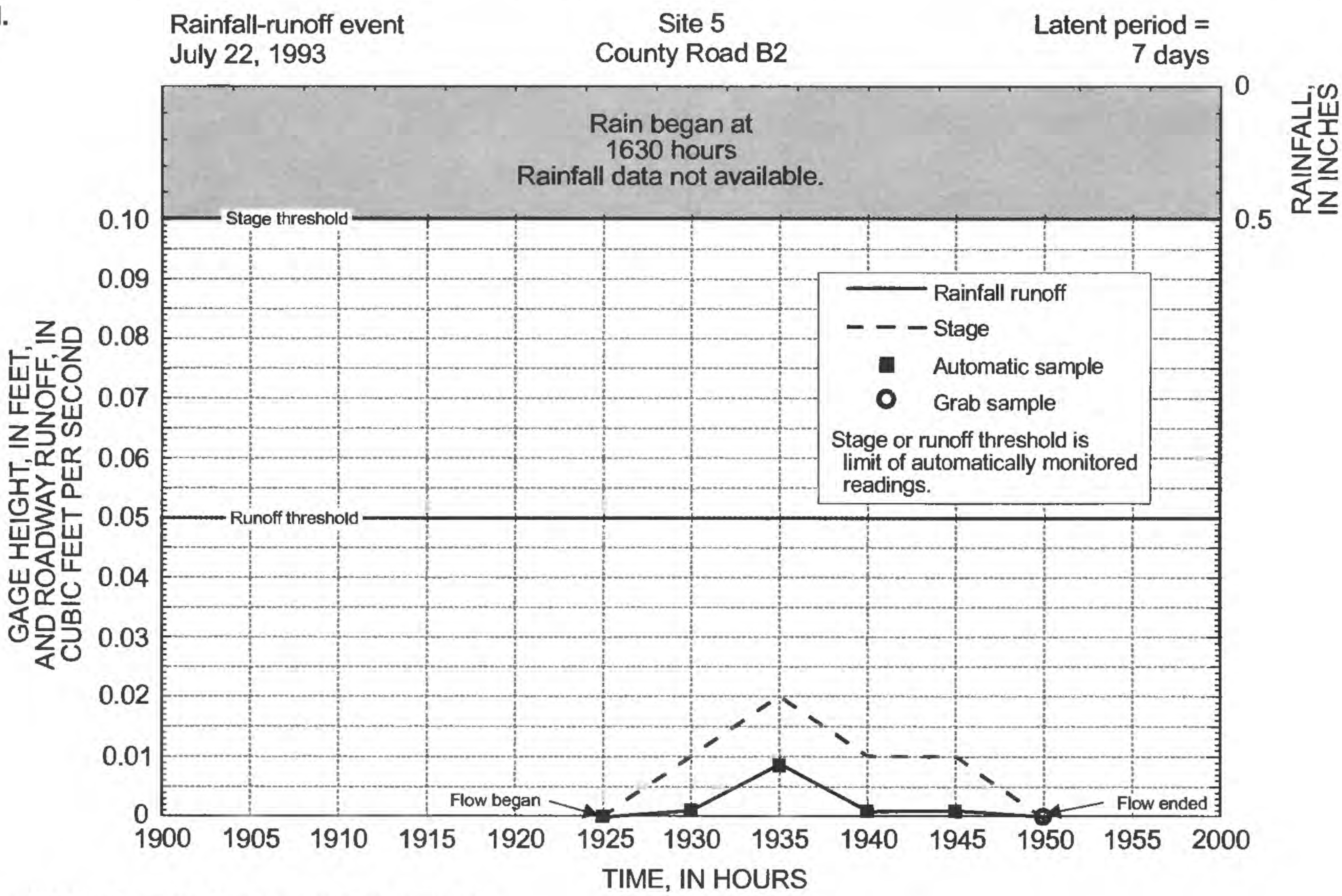


Figure 4. Rainfall, stage, roadway runoff, events for (a) Site 1, Otter Lake Road, (b) Site 1, and (d) Site 5,

c.



d.



and latent periods for rainfall-runoff
Otter Lake Road, (c) Site 2, White Bear Parkway,
County Road B2.

came from just one event. It should be noted that determinations of rainfall-runoff coefficients require precise knowledge of the contributing catchment basin in effect for each rainfall event, rainfall totals collected over the extent of each catchment basin, and accurate flow data collected over the entire range of flows encountered.

Rainfall-runoff coefficients (and constituent yields) presented in this report are based on a limited amount of data. Two of the five sites, sites 1 and 4 (both unguttered sites), were equipped with tipping-bucket rain gages; however, even at these sites rainfall totals may have varied from the sampling point to the upper extremes of the catchment basin. In addition, rainfall data collected at these two sites was used for runoff-coefficient computations at other sites for some of the first rainfall-runoff events until additional bulk-type collectors could be installed at the other sites. Intermittant rains leading up to a rainfall-runoff event were added to the rainfall totals used in this report based on subjective evidence as to whether they contributed to the measured runoff. Determining when to start or stop including rainfall to be used in the total for a runoff event could, by itself, explain the wide range in rainfall-runoff coefficients listed in table 4. The extent of the catchment basin was not easily determined. As mentioned earlier in this report, the catchment basin area that contributed runoff during a specific event may have varied depending on factors including rainfall intensity and degree of soil saturation. All of these circumstances contributed to some variability of calculated rainfall-runoff coefficients for individual events.

Rainfall and Snowmelt-Runoff Quality

Rainfall Quality

Precipitation in the Minneapolis-St. Paul metropolitan area averages about 30 inches per year (Kuehnast and others, 1975), of which approximately 20 inches per year represents the rainfall-runoff sampling period (May through October). The rainfall monitored during this study for the sampling period averaged 4.51 inches per year (1993 through 1995). Monitored rainfall from all sampled rainfall-runoff events therefore was about one-fourth of the average rainfall for the sampling period May through October.

Nineteen rainfall samples were collected from May 1993 to August 1995. Sites 1 and 4 were equipped with wetfall/dryfall collectors to collect rainfall samples for analysis of specific conductance, pH, and up to 27 constituents including nutrients, dissolved ions, and selected metals (table 5). The number of constituents for which analyses were done was dependent on available sample water from the wetfall/dryfall collector. Analysis of rainfall samples was used to determine which of the constituents detected in roadway-runoff samples may have originated directly from rainfall. One-half of the constituents were found to be at or below detection limits while some constituents, such as ammonia+organic, were found at levels approaching those found in roadway runoff—particularly for events from June through September 1994 (table 5).

Dissolved nitrate and dissolved ammonia concentrations in rainfall samples were about one-half of levels from roadway runoff (table 3). Dissolved sulfate was not analyzed in rainfall samples from the study, but NADP results (0.94 mg/L) can be compared with roadway runoff results (4.84 mg/L). These values suggest that rainfall was not a direct source for most constituents found in roadway runoff, but for a few constituents, such as dissolved nitrate and dissolved ammonia, it may account for as much as one-half of the concentrations found in roadway runoff.

Snowmelt-Runoff Quality

Snowmelt-runoff samples were collected two to three times per year at all sites. A total of 31 snowmelt-runoff samplings representing 10 separate events were collected. Estimates of snowmelt-runoff flow rates were obtained at the time of sampling. Snowmelt-runoff constituent loadings were not determined because conditions prevented the collection of incremental flow data. A snowmelt-runoff event was defined as a period of runoff (generally lasting 4-6 hours) followed by a period of cooler weather that interrupted runoff for

Table 4.—Rainfall and rainfall-runoff characteristics

[N.A., not available; e, estimated; --, not determined; some totals are not exact because of rounding.]

Station name	Site ID	Event date (mm-dd-yy)	Event beginning time	Latent period (hours)	Total rainfall (inches)	Total runoff (cubic feet)	Primary catchment basin runoff/square foot (inches)	Primary + secondary catchment basin runoff/square foot (inches)	Primary catchment basin rainfall-runoff coefficient	Primary + secondary catchment basin rainfall-runoff coefficient
					Guttered sites					
WHITE BEAR	2	05-08-93	1835	168	0.62	343	0.20	0.13	0.33	0.22
PARKWAY	2	06-16-93	0515	54	.30	440	.26	.17	.87	.57
surveyed pri-	2	06-23-93	2008	81	.60	964	.57	.38	.90	.63
mary drainage:	2	06-29-93	1849	114	.54	384	.23	.15	.42	.28
20,330 sq. ft.	2	07-31-93	1035	130	.20	714	.42	.28	2.11	1.39
primary + sec-	2	10-05-93	1700	184	.22	127	.07	.05	.34	.23
ondary drain-	2	10-15-93	1450	158	.13	118	.07	.05	.54	.35
age:	2	06-17-94	1310	108	.15	107	.06	.04	.42	.28
30,750 sq. ft.	2	08-23-94	0955	300	.10	87	.05	.03	.51	.34
	2	06-25-95	1050	384	.46	599	.35	.23	.77	.51
	2	08-04-95	0945	96	.26	401	.24	.16	.91	.60
	2	08-11-95	0900	114	.68	612	.36	.24	.53	.35
	2	09-15-95	0930	390	.18	219	.13	.09	.72	.47
	2	10-05-95	2030	73	.39	398	.23	.16	.60	.40
Average (A), Total (T), or Flow-weighted average (W)				168 (A)	4.83 (T)	5,513 (T)	3.24 (T)	2.15 (T)	.67 (W)	.45 (W)
CENTER-	3	05-08-93	1810	168	.50	185	.07	--	.13	--
VILLE ROAD	3	06-16-93	0525	54	.50	444	.16	--	.32	--
surveyed pri-	3	06-23-93	2035	81	.50	759	.27	--	.54	--
mary drainage:	3	06-29-93	1830	108	.30	351	.13	--	.42	--
33,540 sq. ft.	3	07-31-93	1100	130	.30	494	.18	--	.59	--
	3	10-15-93	1520	168	.10	72	.03	--	.26	--
	3	08-09-94	1510	384	.20	198	.07	--	.35	--
	3	05-08-95	1110	288	.16	150	.05	--	.34	--
	3	06-25-95	1112	384	.74	184	.07	--	.09	--
	3	07-25-95	1945	94	.41	31	.01	--	.03	--
	3	08-04-95	0945	96	.17	267	.10	--	.56	--
	3	08-11-95	0805	114	.70	953	.34	--	.49	--
	3	08-19-95	0032	125	.48	587	.21	--	.44	--
Average (A), Total (T), or Flow-weighted average (W)				169 (A)	5.06 (T)	4,675 (T)	1.67 (T)		.33 (W)	
COUNTY RD.	5	05-08-93	1950	168	e.3	N.A.	--	--	--	--
B2	5	06-16-93	0445	52	.56	1,080	.59	.25	1.06	.45
surveyed pri-	5	06-23-93	1950	81	.50	690	.38	.16	.76	.32
mary drainage:	5	06-29-93	1810	131	.30	550	.30	.13	1.01	.42
21,820 sq. ft.	5	07-22-93	1930	168	.10	14.4	.01	.00	.08	.03
primary + sec-	5	07-31-93	1020	130	.80	764	.42	.18	.53	.22
ondary drain-	5	10-20-93	1520	112	e.23	N.A.	--	--	--	--
age:	5	08-09-94	1510	384	.27	95	.05	.02	.19	.08
51,900 sq. ft.	5	05-08-95	1000	288	.19	132	.07	.03	.38	.16
	5	08-04-95	1030	96	.24	68.1	.04	.02	.16	.07
	5	08-11-95	0812	114	.58	578	.32	.13	.55	.23
	5	08-19-95	0022	125	.66	687	.38	.16	.57	.24
	5	09-15-95	1000	390	.11	62.8	.03	.01	.31	.13
	5	09-29-95	1410	324	.12	86.3	.05	.02	.40	.17
	5	10-05-95	2030	73	.49	285	.16	.07	.32	.13
Average (A), Total (T), or Flow-weighted average (W)				176 (A)	4.92 (T)	5,093 (T)	2.80 (T)	1.18 (T)	.57 (W)	.24 (W)

Table 4.—Precipitation and runoff characteristics—continued

Station name	Site ID	Event date (mm-dd-yy)	Time	Antecedent period (hours)	Total rainfall (inches)	Total runoff (cubic feet)	Primary catchment basin runoff/square foot (inches)	Primary + secondary catchment basin runoff/square foot (inches)	Primary catchment basin rainfall-runoff coefficient	Primary + secondary catchment basin rainfall-runoff coefficient
					Unguttered sites					
OTTER LAKE	1	05-08-93	2110	168	e0.52	N.A.	--	--	--	--
ROAD	1	06-16-93	2300	58	2.6	18,200	4.03	1.39	1.55	0.54
surveyed primary	1	06-23-93	2115	93	0.7	1030	.23	.08	.33	.11
drainage:	1	07-01-93	0930	168	--	--	--	--	--	--
54,180 sq. ft.	1	08-18-93	0745	72	e1.22	N.A.	--	--	--	--
primary + second-	1	08-30-93	0810	72	1.2	3,570	.79	.27	.66	.23
ary drainage:	1	10-08-93	1100	288	.45	12.2	0	0	0	0
156,600 sq. ft.	1	06-07-94	1355	944	.39	'est .4'	--	--	--	--
	1	07-21-94	1125	327	.85	477	.11	.04	.12	.04
	1	10-03-94	0830	264	1.30	144	.03	.01	.02	.01
	1	10-06-94	1915	72	1.16	851	.19	.07	.16	.06
	1	06-25-95	1155	480	1.35	1,650	.37	.13	.27	.09
	1	08-11-95	0840	114	.70	14.1	0	0	0	0
	1	10-05-95	2155	74	.70	223	.05	.02	.07	.02
	1	10-23-95	1205	1,080	1.05	462	.10	.04	.10	.03
Average (A), Total (T), or Flow-weighted average (W)				330 (A)	12.45 (T)	26,633.3 (T)	5.90 (T)	2.04 (T)	.47 (W)	.16 (W)
HAZELWOOD	4	05-08-93	2020	168	.3	291	.09	.04	.31	.14
STREET	4	06-16-93	2150	57	1.9	3670	1.18	.53	.62	.28
surveyed primary	4	06-23-93	2046	81	.48	385	.12	.06	.26	.11
drainage:	4	06-29-93	1930	131	.40	9.3	0	0	.01	0
37,280 sq. ft.	4	07-31-93	1425	432	.80	401	.13	.06	.16	.07
primary + second-	4	09-19-93	1845	144	.60	24.3	.01	0	.01	.01
ary drainage:	4	10-20-93	1635	112	.40	9.0	0	0		0
83,880 sq. ft.	4	09-21-94	2230	182	.43	70.5	.02	.01	.05	.02
	4	10-06-94	1920	72	.93	815	.26	.12	.28	.13
	4	08-04-95	1555	504	.24	43.5	.01	.01	.06	.03
	4	08-11-95	0837	114	1.08	328.0	.11	.05	.10	.04
	4	09-29-95	1825	960	.71	43.2	.01	.01	.02	.01
	4	10-05-95	2100	74	.74	270.0	.09	.04	.12	.05
	4	10-23-95	1010	384	.35	88.6	.03	.01	.08	.04
Average (A), Total (T), or Flow-weighted average (W)				244 (A)	9.36 (T)	6,448.4 (T)	2.08 (T)	.92 (T)	.22 (W)	.10 (W)
GUTTERED SITES										
Average (A), Total (T), or Flow-weighted average (W)				171 (A)	14.81 (T)	15,280 (T)	7.73 (T)	3.33 (T)	.53 (W)	.22 (W)
UNGUTTERED SITES										
Average (A), Total (T), or Flow-weighted average (W)				283 (A)	21.81 (T)	33,080 (T)	7.97 (T)	2.96 (T)	.37 (W)	.14 (W)

Table 5.—Rainfall water quality.

[µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; --, not determined; Some totals are not exact because of rounding.]

Site	Date (mm-dd-yy)	Rainfall event start time	Rainfall, total (inches)	Specific conductance (µS/cm at 25°C)	Specific conductance, lab (µS/cm at 25°C)	pH, field (standard units)	pH, lab (standard units)	Nitrite, dissolved, mg/L as N	Ammonia + organic, total, mg/L as N	Phosphorus, total, mg/L as P	Calcium, dissolved, mg/L as Ca	Magnesium, dissolved, mg/L as Mg	Sodium, dissolved, mg/L as Na
1	05-08-93	2110	0.52	--	9	--	5.9	--	0.7	0.02	--	--	--
1	06-16-93	2300	2.6	19	8	7.0	7.1	0.01	.4	.01	0.31	0.03	<0.20
1	06-23-93	2115	.7	32	29	5.8	6.5	.01	1.1	.04	1.80	.29	<.20
1	07-01-93	930	.85	21	--	4.4	--	.01	.5	.08	--	--	--
1	07-21-94	1125	.85	50	5	6.1	4.9	--	--	--	.24	.07	<.20
1	08-09-94	1510	1.25	--	7	5.4	5.1	.01	.2	.01	.11	.03	<.20
1	08-23-94	1900	1.10	7	10	5.8	6.4	.01	.5	.01	.48	.09	<.20
1	10-03-94	830	1.30	--	11	--	4.5	--	--	--	.08	.02	<.20
1	06-25-95	1200	1.35	36	20	4.9	7.5	--	--	--	.20	.06	<.20
1	08-19-95	32	.50	--	10	--	7.5	--	--	--	.55	.07	<.20
1	10-05-95	2155	.70	50	4	7.0	7.5	.01	.2	.01	.05	<.01	<.20
4	05-08-93	2020	.3	--	17	--	5.6	--	1.0	.03	--	--	--
4	06-16-93	2150	1.9	16	9	6.9	6.0	<.01	.5	.01	.28	.04	<.20
4	06-23-93	2046	.48	54	24	4.4	5.5	<.01	1.3	.07	1.20	.21	<.20
4	06-29-93	1930	.4	--	--	--	--	<.01	.8	.15	--	--	--
4	09-19-93	1845	.60	20	22	5.0	7.5	<.01	.4	.04	.18	.05	<.20
4	08-09-94	1510	1.25	--	7	5.6	5.2	.01	.2	<.01	.28	.05	<.20
4	09-21-94	2230	.43	--	--	--	--	.02	.9	.76	--	--	--
4	10-06-94	1920	.93	27	21	6.3	5.8	--	--	--	.96	.13	<.20
4	10-05-95	2100	.74	--	4	--	7.2	.01	.2	.03	.21	.05	<.20
	Maximum:		2.6	54	29	7.0	7.5	.02	1.3	.76	1.80	.29	<.20
	Minimum:		.30	7	4	4.4	4.5	.01	.2	.01	.05	<.01	
	Mean:			30	13	5.7	6.2	.01	.6	.09	.46	<.08	

Table 5—Rainfall water quality—continued.

Site	Date (mm-dd-yy)	Aluminum, total, µg/L as Al	Barium, dissolved, µg/L as Ba	Beryllium, dissolved, µg/L as Be	Cadmium, dissolved, µg/L as Cd	Cadmium, total, µg/L as Cd	Chromium, dissolved, µg/L as Cr	Chromium, total, µg/L as Cr	Cobalt, dissolved, µg/L as Co	Copper, total, µg/L as Cu	Iron, dissolved, µg/L as Fe	Lead, dissolved, µg/L as Pb	Lead, total, µg/L as Pb
1	05-08-93	--	--	--	--	20	--	<10	--	10	--	--	<100
1	06-16-93	--	<2.0	<0.50	1.0	--	<5.0	--	<3.0	--	4.0	<10	--
1	06-23-93	100	<2.0	<.50	<1.0	<10	<5.0	<10	<3.0	<10	5.0	<10	<100
1	07-21-94	<10	<2.0	<.50	<1.0	<10	<5.0	<10	<3.0	<10	3.0	<10	<100
1	08-09-94	10	<2.0	<.50	<1.0	<10	<5.0	<10	<3.0	<10	<3.0	<10	<100
1	08-23-94	30	<2.0	<.50	<1.0	<10	<5.0	<10	<3.0	<10	13.0	<10	<100
1	10-03-94	<10	<2.0	<.50	<1.0	<10	<5.0	<1	<3.0	<10	8.0	<10	<100
1	06-25-95	40	<2.0	<.50	2.00	<10	<5.0	<1	<3.0	<10	26.0	<10	<100
1	08-19-95	40	<2.0	<.50	<1.0	<10	<5.0	<1	<3.0	10	20.0	20	<100
1	10-05-95	<10	<2.0	<.50	2.00	<10	<1.0	--	<3.0	--	<3.0	<10	<100
4	05-08-93	--	--	--	--	<10	--	<10	--	<10	--	--	<100
4	06-16-93	--	<2.0	<.50	<1.0	--	<5.0	--	<3.0	--	<3.0	<10	--
4	06-23-93	110	<2.0	<.50	1.0	<10	<5.0	<10	<3.0	<10	8.0	<10	<100
4	09-19-93	10	<2.0	<.50	<1.0	<10	<5.0	50	<3.0	20	4.0	<10	<100
4	08-09-94	10	<2.0	<.50	<1.0	<10	<5.0	20	<3.0	<10	3.0	<10	<100
4	10-06-94	60	<2.0	<.50	<1.0	<10	<5.0	<1	<3.0	<10	22.0	<10	<100
4	10-05-95	10	<2.0	<.50	3.0	<10	<1.0	--	<3.0	--	7.0	20	<100
	Maximum:	110	<2.0	<.50	3.0	20	<5.0	50	<3.0	20	26.0	20	<100
	Minimum:	<10	--	--	<1.0	<10	<1.0	<1	--	<10	<3.0	<10	--

Table 5.—Rainfall water quality—continued.

Site	Date (mm-dd-yy)	Lithium, dissolved, µg/L as L	Manganese, dissolved, µg/L as as Mn	Mercury, dissolved, µg/L as Hg	Molybdenum, dissolved, µg/L as Mo	Nickel, dissolved, µg/L as Ni	Silver, dissolved, µg/L as Ag	Strontium, dissolved, µg/L as Sr	Vanadium, dissolved, µg/L as V	Zinc, total, µg/L as Zn
1	05-08-93	--	--	0.20	--	--	--	--	--	30
1	06-16-93	<4.0	3.0	--	<10	<10	2.0	0.70	<6.0	--
1	06-23-93	<4.0	8.0	<.10	<10	<10	<1.0	1.00	<6.0	20
1	07-21-94	<4.0	2.0	<.10	<10	<10	<1.0	.50	<6.0	20
1	08-09-94	<4.0	1.0	<.10	<10	<10	<1.0	<.5	<6.0	<10
1	08-23-94	<4.0	5.0	<.10	<10	<10	<1.0	1.0	<6.0	<10
1	10-03-94	<4.0	1.0	<.10	<10	<10	<1.0	<.5	<6.0	<10
1	06-25-95	4.0	3.0	<.10	<10	<10	<1.0	.6	<6.0	<10
1	08-19-95	7.0	4.0	<.10	<10	<10	1.0	2.0	<6.0	<10
1	10-05-95	<4.0	<1.0	<.10	10	<10	<1.0	<.5	<6.0	<10
4	05-08-93	--	--	<.10	--	--		--	--	30
4	06-16-93	<4.0	3.0	--	<10	<10	<1.0	<.50	<6.0	--
4	06-23-93	<4.0	7.0	<.10	<10	<10	<1.0	1.00	<6.0	50
4	09-19-93	<4.0	2.0	<.10	10	<10	1.0	.60	<6.0	<10
4	08-09-94	<4.0	2.0	<.10	<10	<10	<1.0	<.50	<6.0	<10
4	10-06-94	<4.0	5.0	<.10	<10	<10	<1.0	2.00	<6.0	<10
4	10-05-95	<4.0	3.0	<.10	<10	<10	<1.0	<.50	<6.0	<10
	Maximum:	7.0	8.0	.20	10	<10	2.0	2.0	<6.0	50
	Minimum:	<4.0	<1.0	<.10	<10	--	<1.0	<.5	--	<10

several hours or for several days. When runoff was continuous for more than 24 hours, sampling in some instances extended into the second day with samples being time-composited over the event.

Median concentrations for selected constituents determined from snowmelt-runoff analyses were compared between guttered and unguttered sites by averaging the median concentrations within the guttered or unguttered groups. Median concentrations of total suspended solids, dissolved chloride, dissolved sulfate, and total chromium ranged from two to seven times greater at guttered sites (figure 5). Median concentrations of the other constituents examined, (total phosphorus and total zinc) were not markedly different between guttered and unguttered sites. Data from all snowmelt-runoff sampling are listed in table 6, in the Supplemental Information section.

Additional comparisons of snowmelt-quality data were made between each of the study years. The data from selected constituents for all sites were combined into one data set per year. Median concentration values of total suspended solids, dissolved chloride, and total zinc for 1993 were one-half to one-third lower than for 1994 or 1995 (figure 5). Snowmelt-quality data also were compared with data for snowmelt runoff from interstate highways in the Minneapolis-St. Paul metropolitan area (Howard, J.E., 1981, Moxness, K.L., 1987, Moxness, K.L., 1988). Median concentrations of total suspended solids and dissolved chloride, were as much as 10 times higher from the study sites than from interstate highways.

Variability of constituent concentrations from snowmelt runoff may be related to total snowfall or ice conditions. Elevated sodium and chloride concentrations, and to a lesser extent, concentrations of dissolved ions and metals, such as dissolved sulfate, aluminum, chromium, and zinc, reflect the application of sand and salt each winter to reduce ice buildup on road surfaces. The higher levels of dissolved ions and metals found in snowmelt runoff suggests that other processes such as corrosion of metals by road salts may affect the quality of roadway runoff.

Mean concentrations of dissolved chloride and dissolved sodium were approximately 1,000 times higher for snowmelt runoff (table 6, Supplemental Information section) than for rainfall runoff (table 7, Supplemental Information section). Mean concentrations of dissolved aluminum, dissolved chromium, dissolved lead and dissolved zinc, were two to four times higher for snowmelt runoff.

Rainfall-Runoff Quality, Loads, and Yields

Rainfall-runoff samples were collected from May 1993 through October 1995. Seventy-one samples were collected, representing 31 separate storm events. Constituents analyzed are shown in table 2. Sampling and analysis for semi-volatile organic compounds was performed one or two times per year. For all semi-volatile organic compounds sampled, constituent concentration levels were below detection limits. Results for the remaining constituents are described below. Concentrations and loads for all detected constituents are listed in table 7, in the Supplemental Information section.

Quality

Grab samples were collected to determine concentrations of BOD, chemical oxygen demand (COD), bacteria, dissolved mercury, and oil+grease. These samples were collected as soon after the onset of runoff as possible. Whereas this study did not include an examination for any elevated concentrations resulting from the first flush of roadway runoff, it should be noted that constituents are often found in higher concentrations during the onset (or first flush) of roadway runoff than later in the runoff event. Grab samples were usually collected within a few minutes following the onset of runoff. If a first-flush effect is assumed at all sites, then constituent concentrations from grab samples would be at or near the highest concentration levels occurring during the rainfall-runoff event. A constituent load calculated from these first-flush concentration values would likewise be higher than a load derived from a flow-adjusted mean concentration for the runoff event. However, because time-discrete samples were not collected for each runoff event to characterize a first-flush effect, the constituent concentration levels found in grab samples cannot be assumed to be characteristic of either first-flush or post-first-flush runoff. Two sets of time-discrete samples collected in 1993 were inconclusive in showing a first-flush effect.

Means of concentrations for selected constituents listed in table 7, in the Supplemental Information section, were averaged using flow-weighted methods with the formula:

$$\Sigma X_c = [\Sigma(A_c \times A_q)+(B_c \times B_q)...+(Z_c \times Z)_q]/\Sigma(A_q+B_q..+Z_q),$$

where X_c = flow-weighted mean concentration;
A_c = constituent concentration for sample event A; and
A_q = total runoff for sample event A

Median concentrations of suspended solids, total chromium and total zinc were generally greater at guttered sites. Median total phosphorus concentrations and fecal *Streptococcus* bacteria levels were greater at unguttered sites, and median dissolved sulfate concentrations were similar at guttered and unguttered sites (figure 6). The vegetated road ditches associated with unguttered sites may act to trap heavier particles such as metals and suspended-solids, while contributing additional materials such as nutrients and coliform bacteria that may come from decaying plant and animal matter.

The median concentrations of suspended solids, total phosphorus, total chromium, and total zinc were compared with median concentrations from Minneapolis - St. Paul metropolitan interstate highways (Howard, J.E., 1981, Moxness, K.L., 1987, Moxness, K.L., 1988). Median concentrations for total phosphorus, suspended solids, and total chromium were similar, whereas median concentrations of total zinc were lower at the study sites than at the highway sites.

Four constituent concentrations exceeded chronic condition standard limits established by the Minnesota Pollution Control Agency (Minnesota Pollution Control Standards, 1994) for 'metropolitan storm water' for chronic conditions during some rainfall-runoff events. While 'metropolitan storm water' limits to not necessarily apply to roadway runoff, they do provide a base of reference. Total aluminum exceeded the MPCA standard limit of 125 µg/L for all but three (96 percent) of the 69 rainfall-runoff event samplings. Data from table 7, in the Supplemental Information section, was used for the following comparisons. Total aluminum concentrations that exceed this limit ranged from 160 to 150,000 µg/L with a median concentration of 1,200 µg/L. Total copper exceeded the MPCA standard limit of 15.1 µg/L for 36 of 69 (52 percent) rainfall-runoff events. Total copper concentrations that exceeded the MPCA standard limit ranged from 20 to 850 µg/L with a median concentration of 30 µg/L. Total lead concentrations exceeded the MPCA standard limit of 7.7 µg/L for at least 6 of 69 (9 percent) rainfall-runoff event samplings. All other samples were less than the detection limit of 100 µg/L. Total lead concentrations that exceeded this limit ranged from 100 to 800 µg/L with a median concentration of 100 µg/L. The minimum reporting limit for total lead was 100 µg/L. Total zinc concentrations exceeded the standard limit of 191 µg/L for 14 of 69 (20 percent) rainfall-runoff event samplings. Total zinc concentrations exceeding this limit ranged from 200 to 2,900 µg/L with a median concentration of 280 µg/L.

Loads and Yields

Constituent loads for each event were determined by the formula below and are expressed in grams or kilograms (table 7, Supplemental Information section).

For example:

$$Load_c = (A_q \times 28.32 \times A_c) / 1,000$$

where $Load_c$ = constituent load in grams;
A_q = total event runoff (cubic feet);
A_c = constituent concentration (mg/L);
and where 28.32 is a cubic-foot to liter conversion factor and 1,000 is a milligrams to grams conversion.

One particularly intense rainfall event resulting in large rainfall and runoff totals can account for greater than one-half of the monitored runoff volumes and constituent loads for a year, or even for several years. For example, for the unguttered sites (sites 1 and 4) for the study period, from 57 to 68 percent of runoff

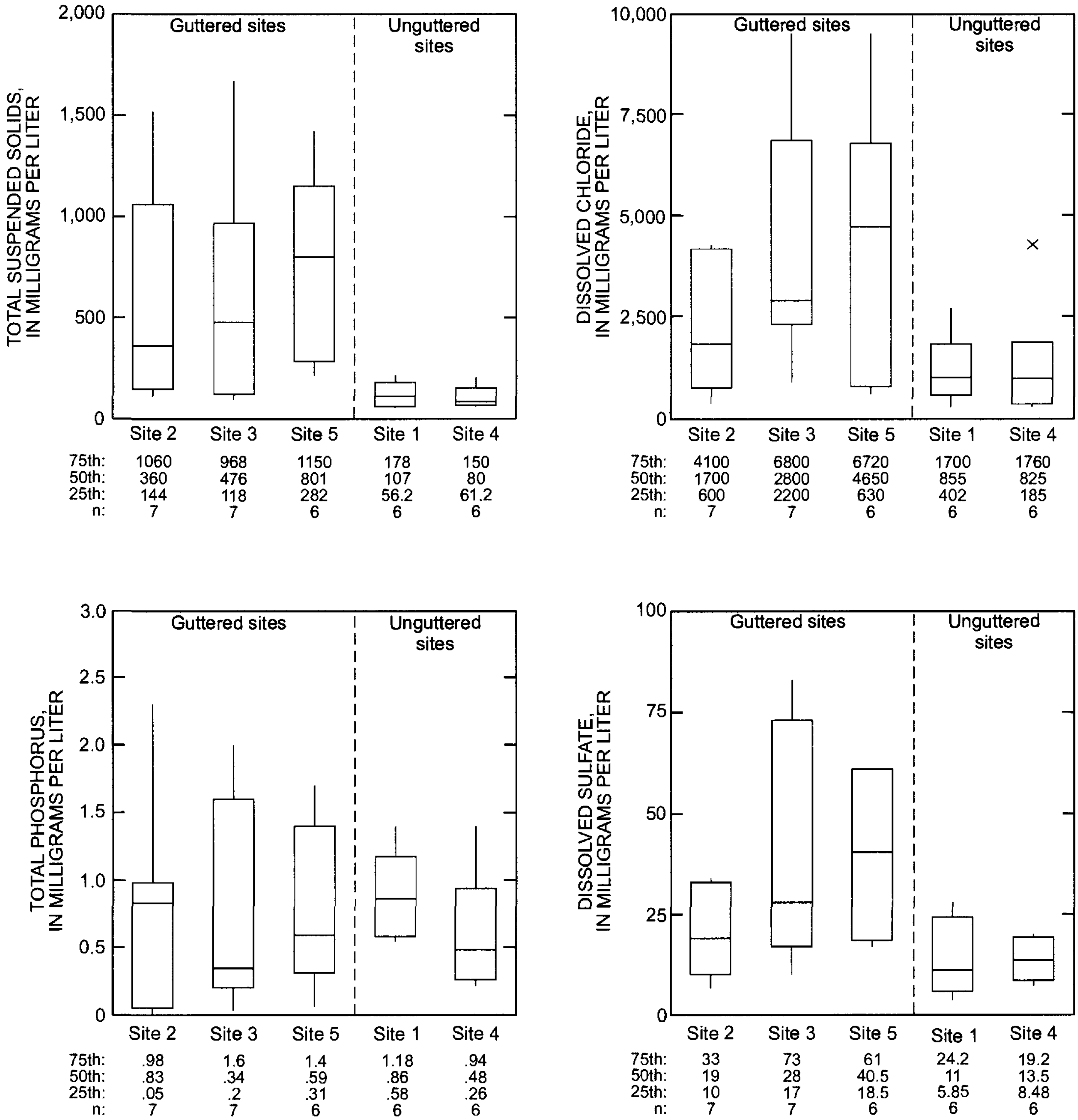
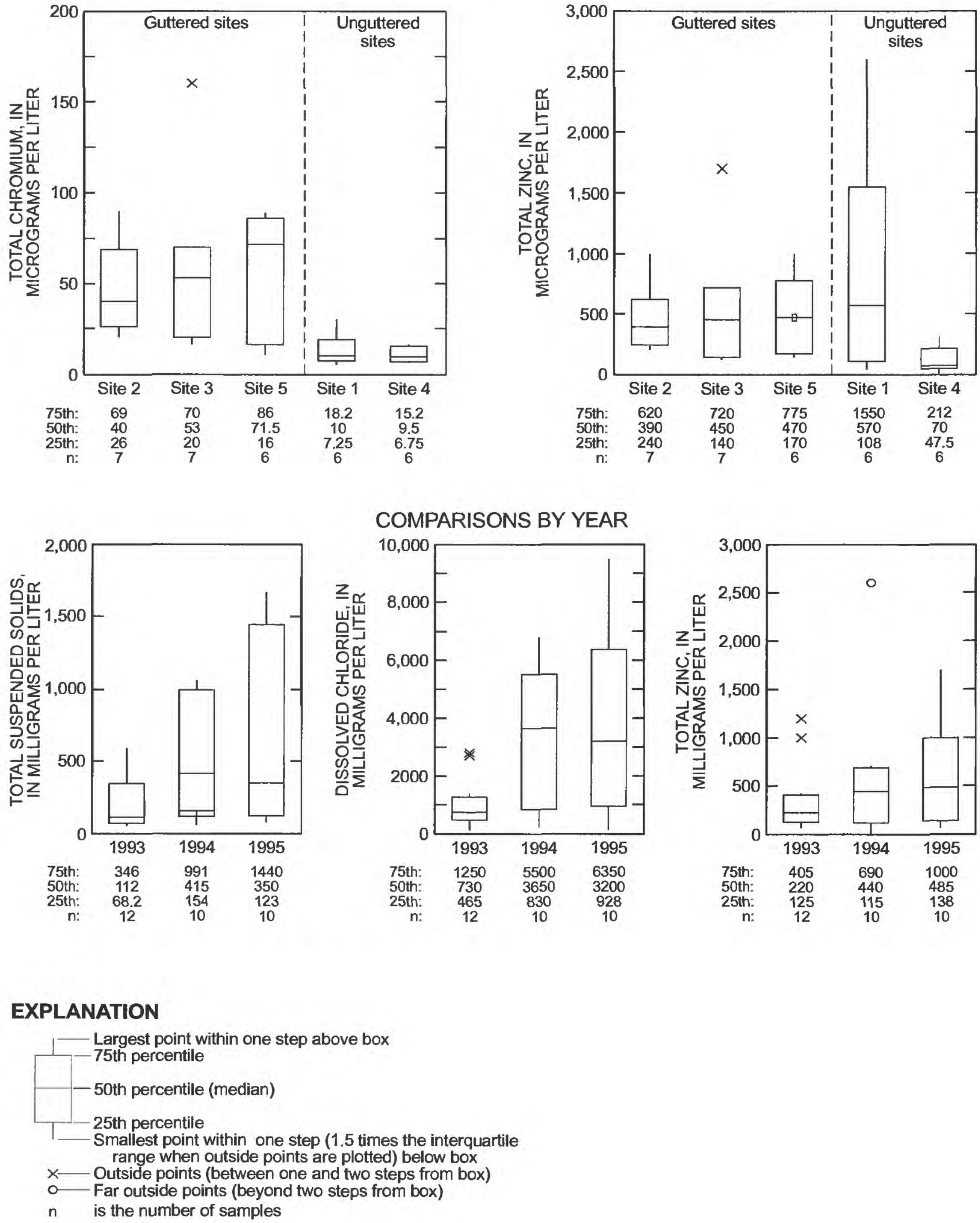


Figure 5. Chemical constituents at guttered and unguttered sites during snowmelt-



runoff events and yearly variations during the study period (1993-95).

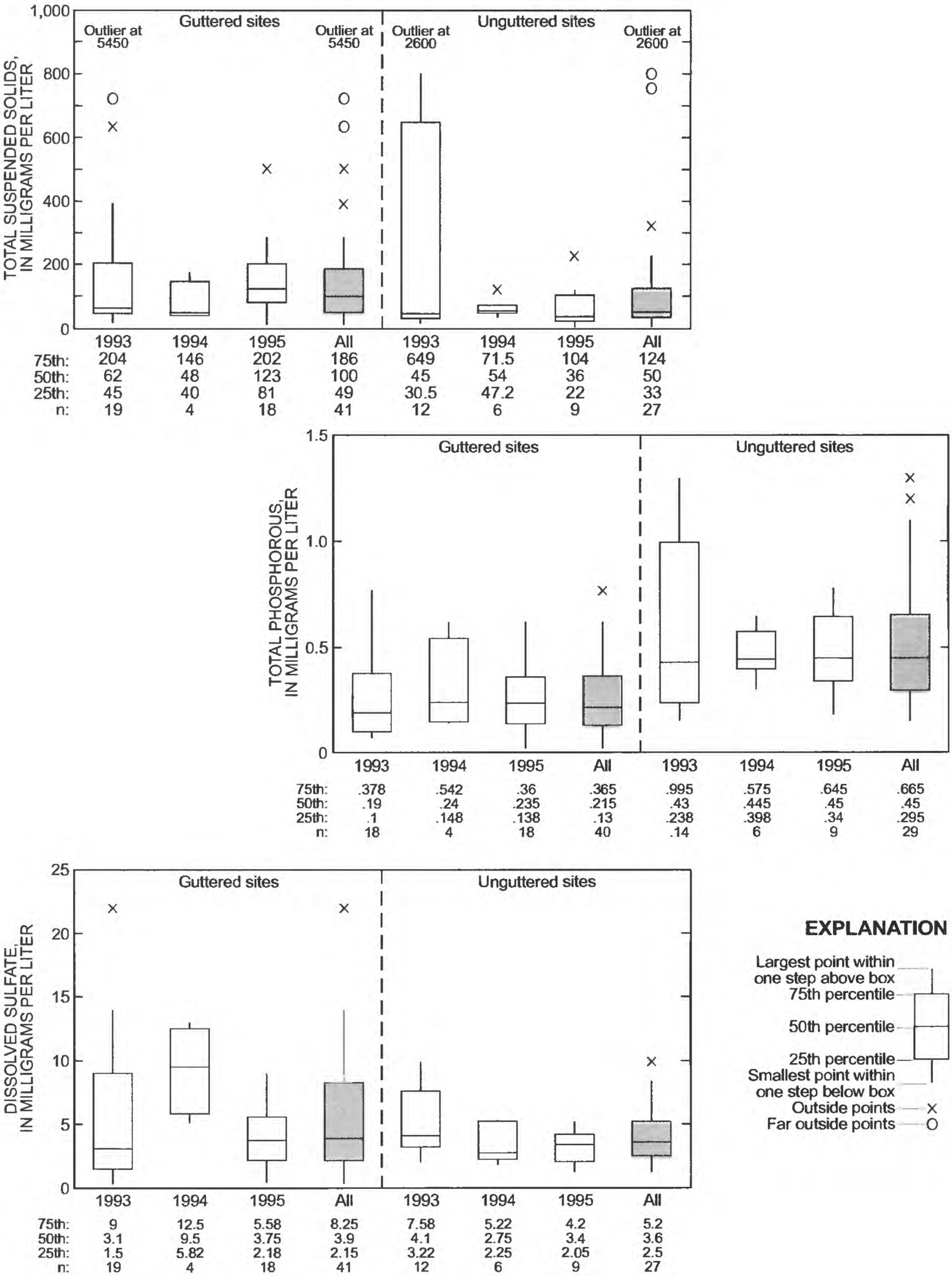
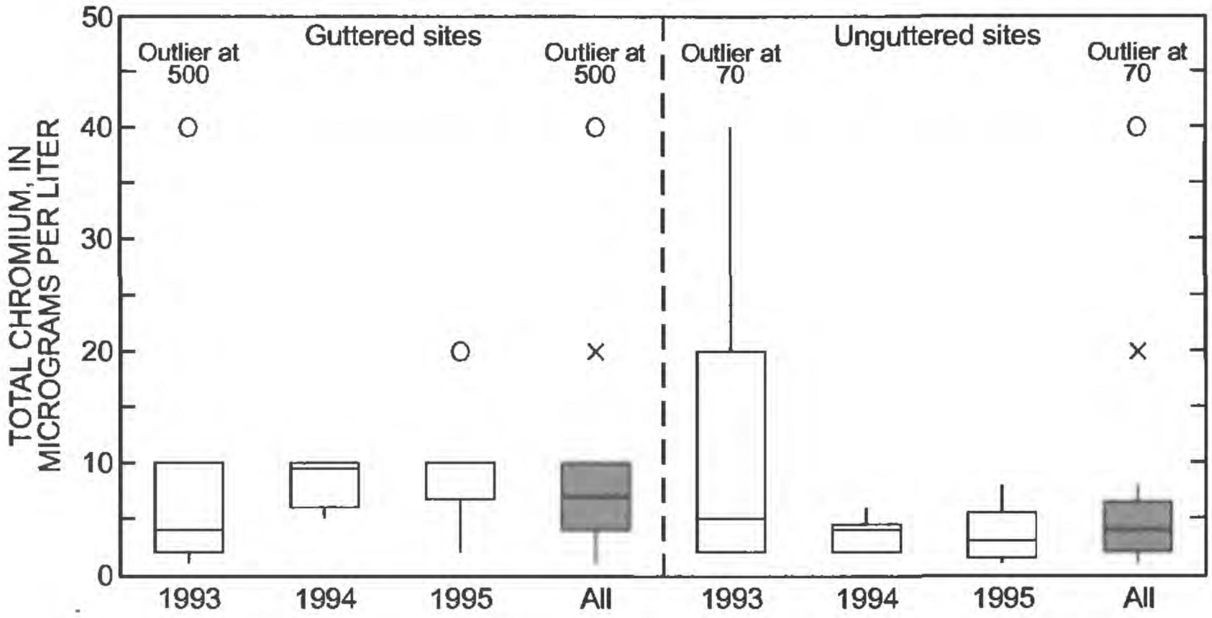
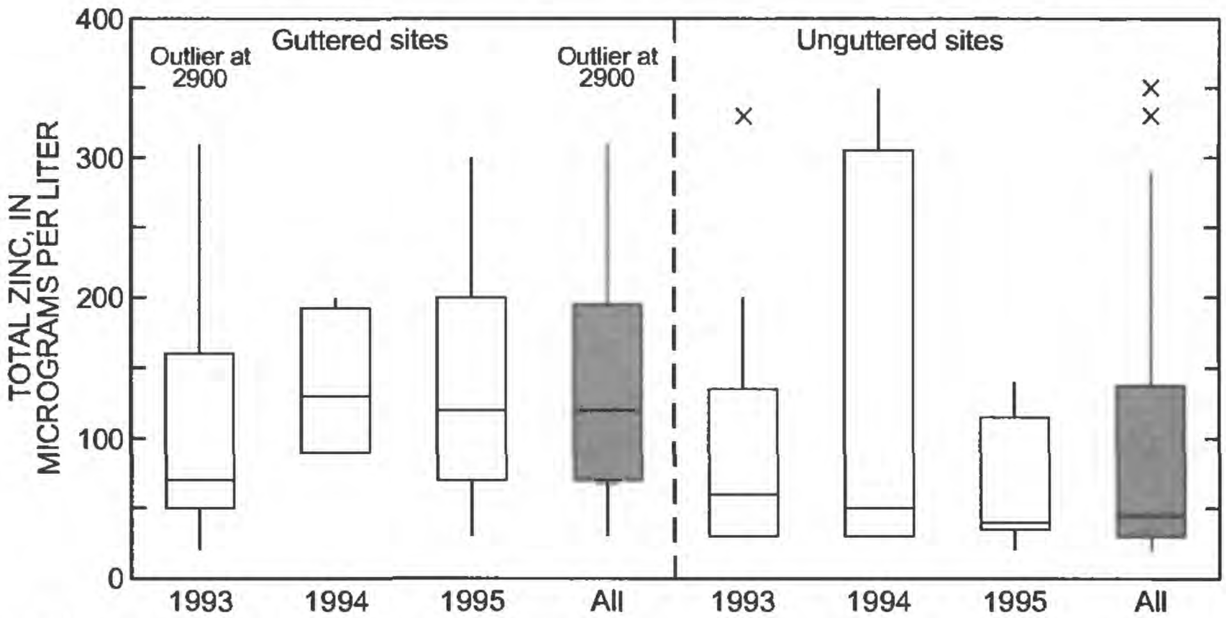


Figure 6. Quality of rainfall-runoff for selected



	1993	1994	1995	All	1993	1994	1995	All
75th:	10	10	10	10	20	4.5	5.5	6.5
50th:	4	9.5	10	7	5	4	3	4
25th:	2	6	6.75	4	2	2	1.65	2
n:	19	4	18	41	11	6	9	26



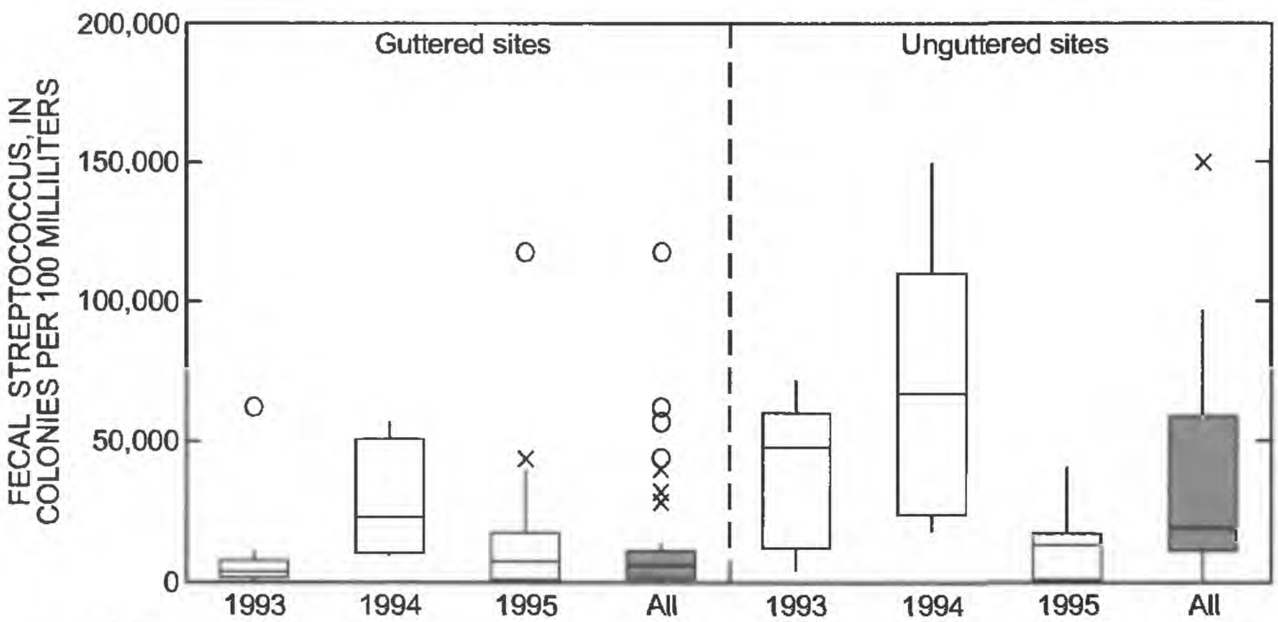
	1993	1994	1995	All	1993	1994	1995	All
75th:	160	192	200	195	135	305	115	138
50th:	70	130	120	120	60	50	40	45
25th:	50	90	70	70	30	30	30	355
n:	19	4	17	37	13	6	9	28

One step - 1.5 times the interquartile range when outside points are plotted

Outside points - between one and two steps from box

Far outside points - beyond two steps from box

n is the number of samples



	1993	1994	1995	All	1993	1994	1995	All
75th:	7450	50750	17600	11000	60250	110300	17250	59000
50th:	3600	23000	7100	5800	48000	67000	13200	19200
25th:	1400	10100	582	1200	12250	24000	700	11000
n:	17	4	18	39	12	6	9	27

constituents at guttered and unguttered sites (1993-95).

volumes from all rainfall events sampled occurred from just one event—June 16, 1993. Seventy-eight percent of the total suspended solids loads monitored at site 1 for the study period, came from just the June 16th rainfall event, while for site 4 this amount was 92 percent. Total phosphorus and total zinc loads were 42 percent and 82 percent of the monitored portion of the study period total, respectively, for site 1, and, 36 percent and 78 percent, respectively, for site 4, for the same rainfall event.

Total runoff and constituent loads for the study period from guttered sites were not dominated by runoff and loads from single rainfall events as was observed for unguttered sites. For example, the maximum total loads achieved from any single monitored runoff event accounted for between 21 and 37 percent of the total loads for the study period. These lower percentages may be explained in part by shorter response time and recession periods at guttered sites than at unguttered sites (see Quantity of roadway runoff—Unguttered roadways).

Yields were computed from flow-weighted or time-composited samples. Because constituent loads for any given rainfall event were often small (less than one gram). Yields listed in table 7, in the Supplemental Information section, were only calculated from the total constituent loads and total precipitation for the events sampled for the study period. In addition, since the contributing drainage area for any rainfall-runoff event could not be determined, yields presented in table 7, in the Supplemental Information section, are based on only the primary drainage area, which is the minimal area that would have contributed runoff for all rainfall events.

These yields were derived from the following formula:

$$Y_c = [L_c/P] * K$$

where Y_c = Yield of constituent in grams per inch of rain per acre;

L_c = constituent load (grams);

P = total rainfall (inches); and

K = 43,560 sq. ft. per acre /study site primary drainage area (sq. ft.)

While water-quality monitoring was performed for only the first 1-2 hours of runoff, the majority of runoff occurred during the monitored portion. Hydrographs developed from runoff events that extended beyond the water-quality sampling period included only a minor amount of additional rainfall and runoff. These additional amounts were included in the rainfall and runoff totals for the event, even though sampling had ceased. Constituent concentrations determined from the water-quality sampled portion of the event were assumed to be representative of the entire event and were applied to the runoff total to determine a runoff load for the entire event.

Latent Periods and Traffic Volume

Latent Periods

The length of the latent period (elapsed time between runoff events) was identified as a factor that could affect water quality at the study sites. It was hypothesized that long periods with no runoff could result in an accumulation of more material on roadways. Runoff that occurred after long latent periods could, therefore, result in transport of a greater amount of accumulated material, thereby affecting concentrations, loads, and yields.

The length of the latent period was plotted with corresponding concentrations of selected constituents. Constituents were selected for plotting only when a substantial portion of the analyses for a constituent were reported as having concentrations greater than or equal to the minimum reporting limits. Constituents were selected so major categories such as suspended solids, nutrients, major ions, and metals were represented. Plots for a representative constituent from each of the major categories are shown in figure 7.

Concentrations of constituents generally did not tend to increase when the latent period increased (fig 7a). The plots show that most constituents at most of the sites reached relatively high concentrations when latent periods were as short as 50-100 hours.

Nonparametric-correlation measures (Kendall's tau and Spearman's rho) were computed to determine whether, and to what extent, a relation exists between the length of the latent period and concentrations of total suspended solids, total phosphorus, dissolved sulfate, total chromium, and total zinc. Whereas, Spearman correlation coefficients are discussed here, Kendall results were similar. Correlations were considered significant when the p value was <0.05. When data from all sites were combined in the correlations, total phosphorus (correlation coefficient=0.32, p=0.0062), dissolved sulfate (correlation coefficient=0.25, p=0.0344), and total zinc (correlation coefficient=0.32, p=0.0065) were associated with length of the latent period. For guttered roadway sites, concentrations of dissolved sulfate (correlation coefficient=0.35, p=0.0239), total chromium (correlation coefficient=0.33, p=0.0360), and total zinc (correlation coefficient=0.48, p=0.0016) were associated with length of the latent period. For unguttered roadway sites, only total phosphorus concentration (correlation coefficient=0.42, p=0.0216) was associated with the length of the latent period.

A weak correlation between constituent concentrations and length of latent period may be explained because: 1) each concentration represents a flow-weighted (or time-weighted) average concentration for each runoff event, and 2) the amount of accumulated material is finite. The amount of rainfall during each event could, therefore, strongly influence total runoff event constituent concentrations by providing varying volumes of runoff water that would result in varying concentrations owing to dilution.

Total loads for each runoff event would not be affected by dilution however, and loads therefore might be expected to increase as more material accumulated on roadway surfaces during long latent periods. Constituent loads were plotted with latent period (fig 7b). Loads did not show a tendency to increase with increasing latent periods. Maximum loads for some constituents often occurred after relatively short latent periods. Loads for runoff events that followed long latent periods were among the lowest measured for some constituents at some of the sites. Constituent loads were not positively correlated with length of the latent period for any of the site groupings (all, guttered, or unguttered). These results for loads were unexpected and call into question two assumptions underlying the working hypothesis. It was assumed that during a runoff event, all accumulated material was removed. It was also assumed that during latent periods (between runoff events), material accumulated continuously, reaching a maximum at the end of the latent period.

The first assumption, that all accumulated material is removed during each runoff event, may not hold true for all events. Events of lesser magnitude may not produce sufficient water volume and energy to completely mobilize and transport all accumulated material from the roadway surfaces. Material that is mobilized might not necessarily be transported to the mouth of the catchment if the catchment surfaces are not totally impervious. Cracks in paved portions of a catchment basin can absorb a certain amount of the flow, especially when rainfall amounts or intensities are low. This is substantiated by the primary catchment basin rainfall-runoff coefficients (table 4). Even for guttered sites, which are entirely paved, many of these coefficients are substantially less that 1.00. The average rainfall-runoff coefficient for site 3, for example, was 0.33.

The second assumption, that material accumulates on the roadway surfaces throughout a latent period until it is washed off during rainfall, also may not be true. It is possible that material is removed from the roadway surfaces by processes other than rainfall runoff. Deposited material, for example, may be blown from roadway surfaces by both atmospheric and vehicle-generated wind gusts. Thus the amount of material present on the roadway surface at the onset of a rainfall event may be controlled by traffic volume, speed, and type (for example, large trucks versus cars) as well as by the length of the latent period.

Traffic Volume

Traffic volume was identified as a factor that could affect water quality of roadway runoff. Material worn from tires or brake linings, as well as fluids leaking from vehicles, could accumulate on roadway surfaces, thereby adding to the amount of material available for

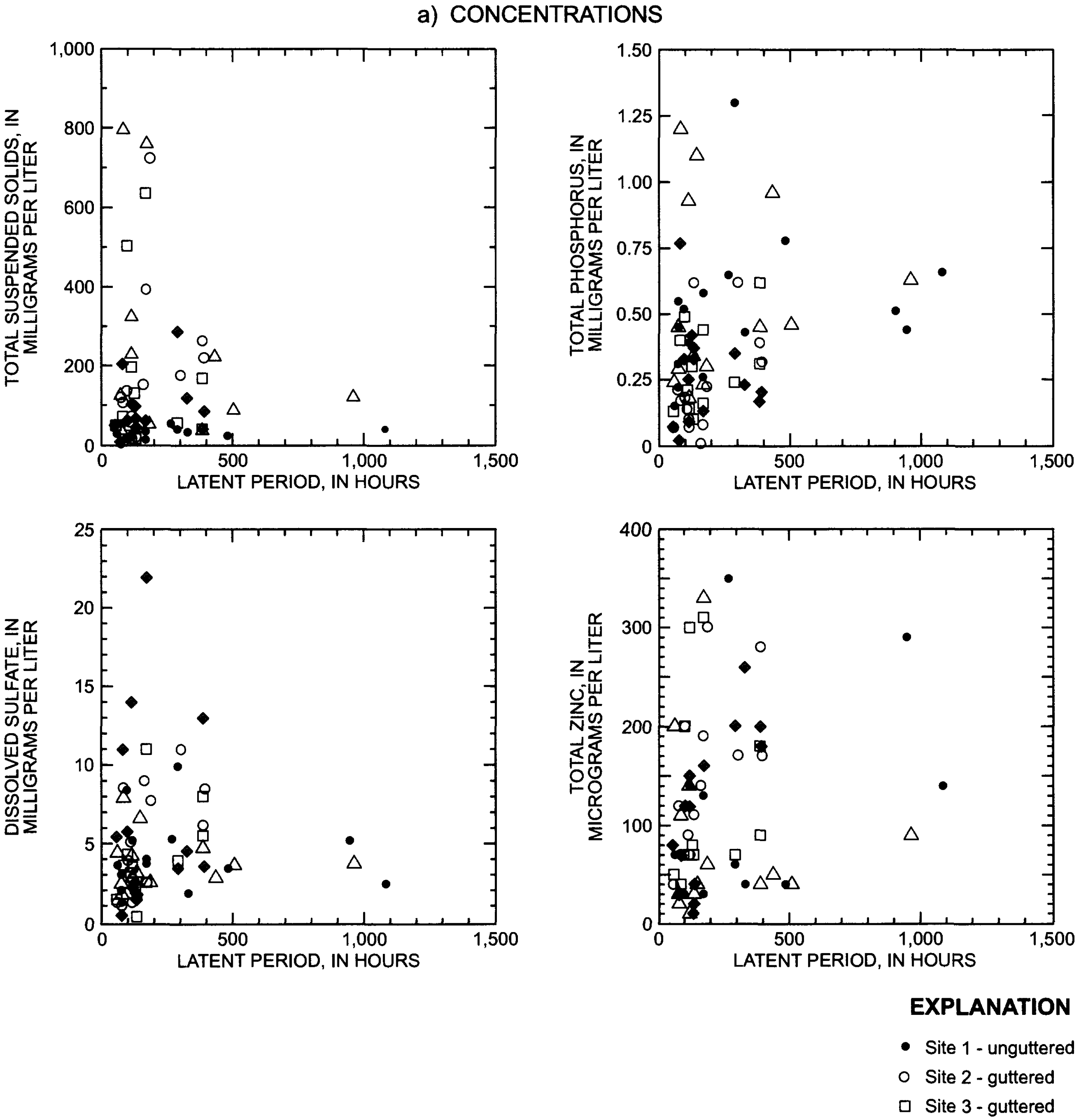
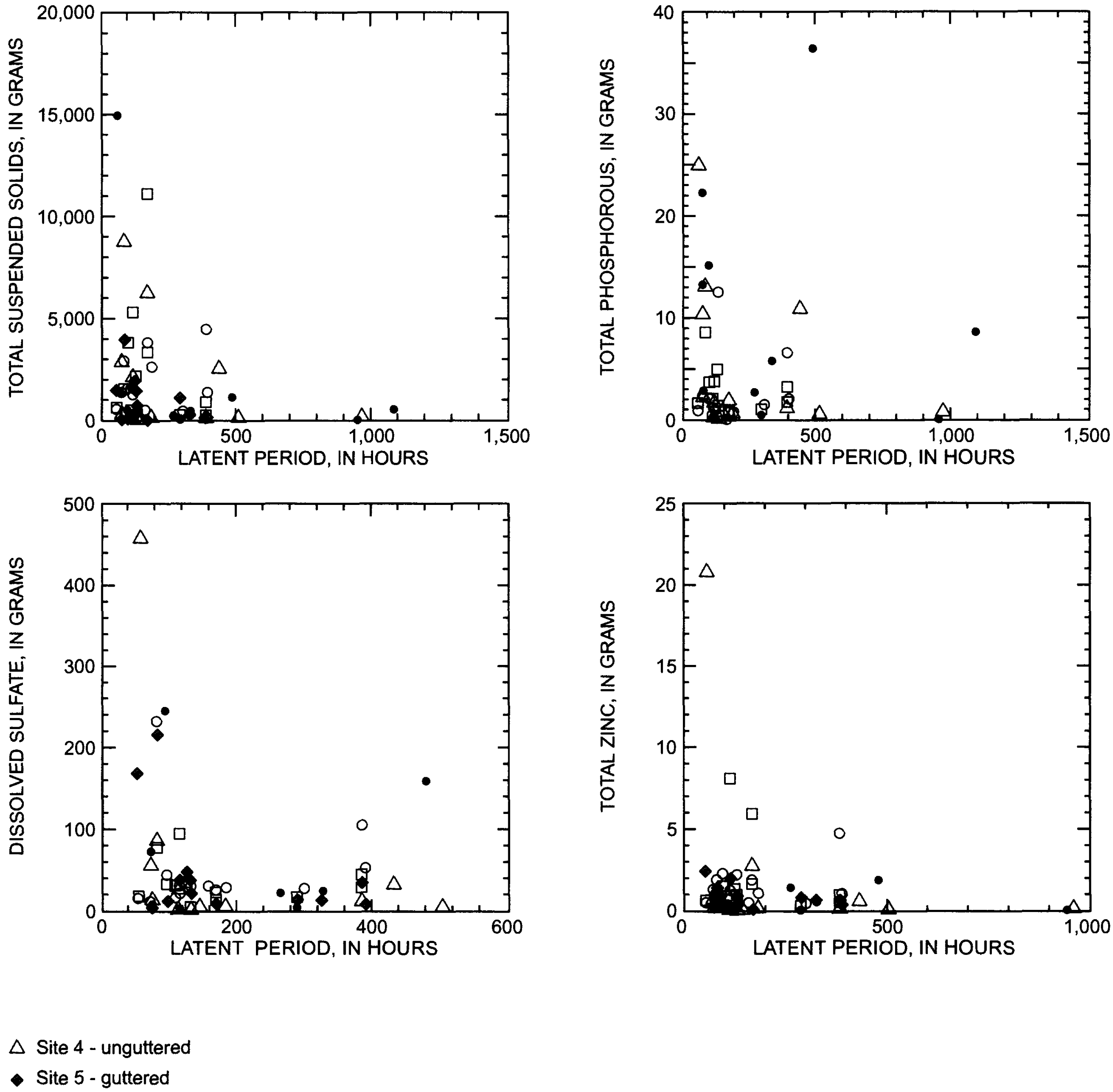


Figure 7. Comparison of selected chemical constituent a) concentrations,

transport during runoff events. Mud, oil, and grease, furthermore, could be washed from vehicle undercarriages when vehicles are driven on wet roadway surfaces during rainfall events.

Traffic-volume data, based on biennial traffic surveys, were provided for each site. Traffic counts, expressed as average number of vehicles per day were plotted with constituent concentrations, loads, and yields. A nonparametric test (Kruskal-Wallis), based on ranked data, was performed to determine if concentrations, loads, and yields of selected constituents differed by site. Constituent concentrations, loads, and yields were considered to be significantly different if the chi-square approximation of the Kruskal-Wallis test indicated that the probability of a greater chi square was less than or equal to 0.05.

b) LOADS



and b) loads to length of latent period before sampled runoff event.

Average traffic volume for all sites ranged from 1,888 vehicles per day (site 5) to 7,122 vehicles per day (site 3). Both sites 3 and 5 are guttered roadways. A third guttered-roadway site (site 2) had traffic volume of 3,982 vehicles per day. The guttered-roadway sites provided an opportunity to compare water quality at sites representing a wide range of traffic volumes at the study sites. There was no significant difference in the distribution of total rainfall amounts, runoff volumes, and inches of runoff between the guttered roadway sites. Concentrations, loads, and yields of total suspended solids, total phosphorus, dissolved sulfate, total chromium, and total zinc did not differ between the guttered-roadway sites (fig. 8).

Average traffic volume at unguttered roadways were

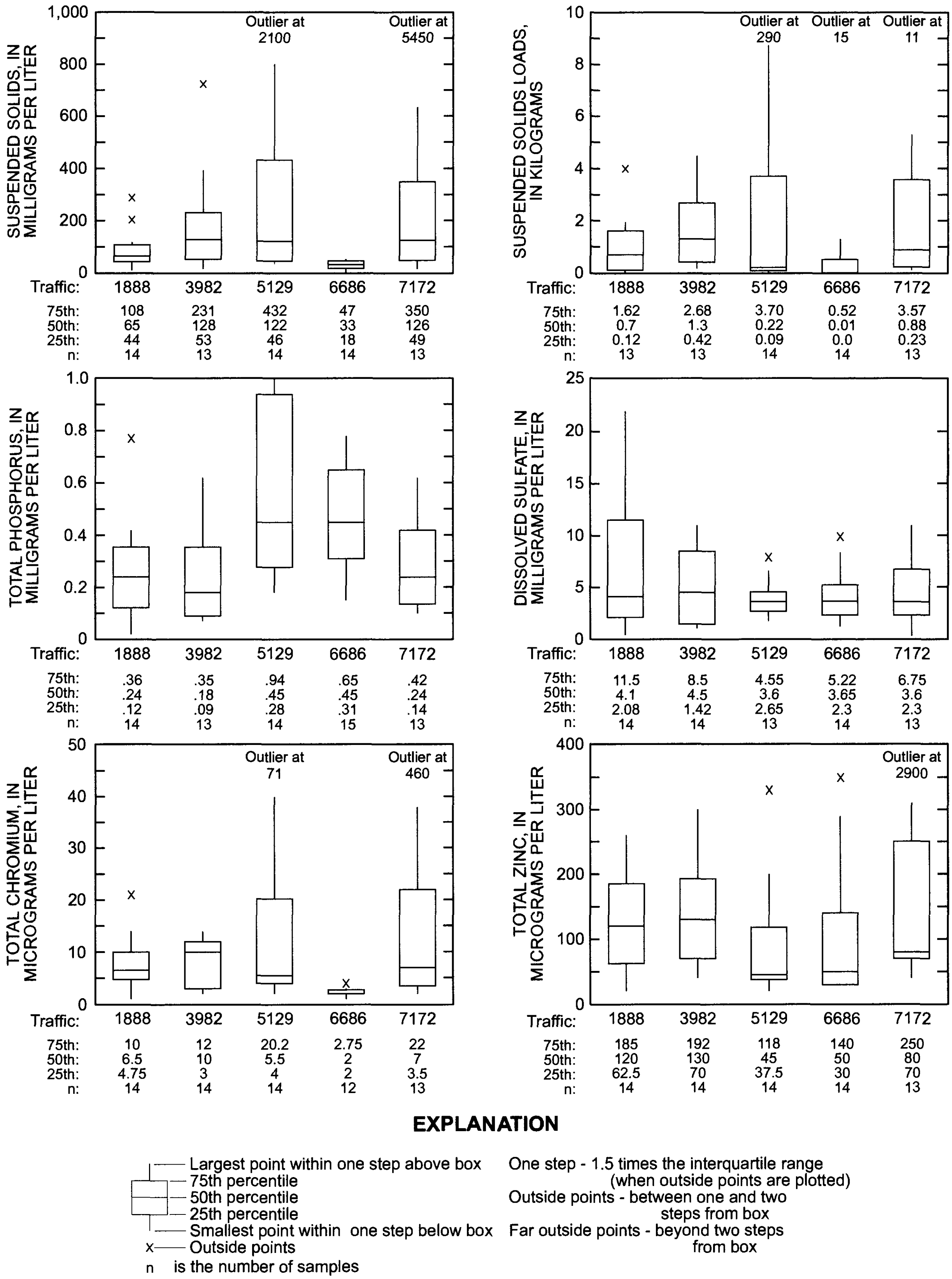


Figure 8. Concentrations and loads of selected chemical constituents and traffic volume counts in vehicles per day.

5,129 vehicles per day (site 4) and 6,686 vehicles per day (site 1) (table 1). No differences were found between unguttered sites with respect to loads and yields of total suspended solids, total phosphorus, dissolved sulfate, total chromium, and total zinc. Differences were indicated between the unguttered sites (site 1 and 4) with respect to concentrations of total suspended solids and total chromium. However, concentrations of these constituents were lower at the site that had the higher traffic volume (site 1). There was a significant difference in total rainfall amounts between site 1 and site 4 (table 4). Constituent concentrations were negatively correlated with total rainfall. The difference in concentrations of total suspended solids and total chromium may be associated with higher total rainfall amounts at site 1.

Summary

Five roadway sections located in northeastern Ramsey County, Minnesota were monitored during 1993-95 to evaluate water quality and loading of constituents from roadway runoff. Water-quality samples were collected from 31 snowmelt-runoff events representing 10 separate snowmelt periods, and 71 rainfall-runoff events representing 31 separate rainfall events. Rainfall samples were collected from 19 rainfall events to determine contribution of rainfall directly to runoff water quality. Additional data collected included total rainfall, total runoff volume, and physical parameters including pH and specific conductance.

Runoff volumes were determined for rainfall-runoff events. On-site equipment collected rainfall data, and monitored flow rates for all but low- intensity runoff events. Runoff from guttered sites, which have catchment basins that were predominantly paved, responded in one-third the time to the onset of rainfall than did unguttered sites. The unguttered sites, which had greater unpaved surface areas, also had longer recession periods. These longer recession periods at unguttered sites resulted in more total rainfall (from recurring rains) and total runoff. Rainfall-runoff coefficients for primary drainage areas averaged 0.53 for guttered sites and 0.37 for unguttered sites. Total runoff from one major rainfall event accounted for at least 50 percent of all runoff from monitored events at unguttered sites and about 20 percent of all monitored runoff at guttered sites.

Wetfall rainfall samples were collected at two sites. Chemical analysis suggests that rainfall was not a direct source of most constituents; for some constituents, such as dissolved nitrate and dissolved ammonia, rainfall can contribute up to one-half of the amounts present in runoff. Mean concentrations for sodium and chloride were approximately 1,000 times greater for snowmelt-runoff samples than for rainfall-runoff samples while mean concentrations of metals such as aluminum, chromium, lead, and zinc were two to four times greater in snowmelt runoff than in rainfall runoff.

Snowmelt runoff was sampled two or three times per year. Median concentrations of total suspended solids, dissolved chloride, dissolved sulfate, and total chromium were two to seven times greater at guttered sites than at unguttered sites while total phosphorus and total zinc median concentrations were not noticeably different. Year to year variations in median concentrations of these same constituents may reflect variations in winter severity and road salt applications. Elevated levels of sodium and chloride, and to a lesser extent, other dissolved ions and metals, in snowmelt runoff suggest not only the application of road salts, but also the corrosive effect of these salts on metals from vehicles. Median concentrations of total suspended solids and dissolved chloride were as much as 10 times greater in runoff from the study sites than from interstate roadway runoff.

Flow- or time-composited rainfall-runoff samples were collected from 31 separate rainfall events. Concentrations of total suspended solids, total chromium, and total zinc were greater at guttered sites while concentrations of total phosphorus and fecal *Streptococcus* bacteria were greater at unguttered sites. This suggests that vegetated road ditches associated with unguttered sites may trap out heavier particles such as metals and suspended solids, while contributing additional organic matter including nutrients and coliform bacteria. Concentrations of metals such as aluminum, copper, lead, and zinc exceeded chronic condition standard limits established by the Minnesota Pollution Control Agency for metropolitan storm water for some runoff events. These limits were exceeded 96 percent, 52 percent, 9 percent and 20 percent of the time, respectively. Semi-volatile compounds were not detected in any of the samples.

Rainfall-runoff loads and yields were computed for most flow- or time-composited samples. For some constituents, such as total suspended solids, as much as 92 percent of the computed loads at one site (site 4) for the entire study occurred in just one rainfall event. The dominating effect of one event was more apparent at unguttered sites. However, even for guttered sites, the percentage of loadings of any constituent from the largest runoff event was between 21 percent and 37 percent of the total loads computed for the study period.

The length of the latent period (elapsed time between runoff events) was identified as a factor that could affect water quality at the study sites. Plots of concentrations of selected constituents with latent period show that concentration levels did not tend to increase when the latent period increased. Nonparametric-correlation measures were used to compare concentration levels with length of latent period. When data for all sites were examined collectively, only total phosphorus, dissolved sulfate, and total zinc concentrations showed a correlation with latent period. Constituent loads for the same constituents did not correlate with latent periods.

Traffic volume also was identified as a factor that could affect water quality of roadway runoff. However, a statistical analysis, using nonparametric methods, showed no significant differences in constituent concentrations, loads, or yields, based on traffic volume.

Site selection criteria such as being within 30 minutes of the U.S. Geological Survey District office, location away from influences such as intersecting streets, driveways, or sloped lawns, limited the sites selected to narrowly-defined characteristics, and to a limited region within the Minneapolis-St. Paul metropolitan area. Because of these limitations, results from this study may not be applicable to other roadways of similar design and classification.

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Supplemental Information

Equipment Blanks

Blank water was passed through sampling equipment used in this study and later analyzed in the same manner as regular samples. The results were also compared with analytical results for regular rainfall-runoff and precipitation samples. To relate results from equipment blanks to results from regular runoff samples, constituents can be categorized based on the potential for contamination from equipment that may have been in contact with that sample. Results are referenced to minimum reporting limits (MRL), which are listed in table 2.

The following constituents were below MRL in blank water passed through equipment that was used in sampling for that constituent: dissolved ammonia, dissolved nitrite, dissolved ammonia+organic, dissolved nitrite plus nitrate nitrogen, total aluminum, dissolved arsenic, dissolved beryllium, dissolved cobalt, dissolved fluoride, dissolved magnesium, dissolved mercury, dissolved sodium, dissolved barium, dissolved manganese, dissolved molybdenum, dissolved strontium, and dissolved vanadium.

Several constituents were detected at levels at or near the MRL in blank water passed through equipment that was used in sampling for same constituent. This range of concentration levels is expressed as [MRL - to - constituent concentration level]. For example: for phosphorus concentrations reported from roadway runoff, values between the MRL and 0.01 mg/L could in part be affected by contact with sampling equipment. Constituent concentrations, within the specified ranges, could in part be affected by sampling equipment or methods. The constituents detected at or near the MRL were: dissolved solids [MRL to 4 mg/L], total phosphorus and dissolved phosphorus [MRL to 0.01 mg/L], dissolved calcium [MRL to 0.07 mg/L], dissolved silica [MRL to 0.05 mg/L], dissolved cadmium [MRL to 2.0 μg/L], dissolved chromium [MRL to 15.0 μg/L], dissolved copper [MRL], total copper [MRL to 20.0 μg/L], dissolved iron [MRL to 11.0 μg/L], dissolved lead [MRL to 30 μg/L], dissolved lithium [MRL to 5.0 μg/L], dissolved silver [MRL to 3.0 μg/L], and dissolved zinc [MRL to 14.0 μg/L].

Results of equipment-blank testing suggest that ambient conditions or other factors not directly associated with the sampling procedures, may contribute to presence of constituents at concentration levels at or near the MRL. Several of the constituents mentioned in the previous paragraph were found in regular runoff samples at similar concentrations, suggesting a low-level pervasive presence in the environment.

Results for constituents commonly found in the environment (such as silica) and detected at low levels from blank-testing of flumes, were not included in this discussion. Flumes were tested under field conditions rather than in a controlled environment (which is necessary for low-level determination of constituents common in the environment). At sites 3 and 4, grab and time-composited samples were collected below the flumes which introduced the flume as a potential source of contamination. Five metals; cadmium, copper, iron, lead, and zinc, were detected in blank-water passed through flumes. A comparison of concentrations of these metals in blank water tests with concentrations in runoff samples at all five sites indicates that flumes were not a source of contamination.

Duplicate Samples

The performance of field personnel and the USGS - National Water Quality Lab (NWQL) with respect to ability to replicate results was evaluated on the basis of 16 sets of duplicate samples. Duplicate samples were collected for constituents to be analyzed at the USGS-NWQL. These samples were collected at the same time as the regular samples for selected rainfall-runoff events. A sign test as described in Helsel and Hirsch (1992) was applied to paired analytical results. The test was performed on paired results for each constituent that was reported above the MRL in a sufficient number of pairs to provide an adequate sample size. Results for 25 constituents were tested, including all of the nutrients, solids, detergents, major ions, and most of the metals. Results of the sign test showed that there was no significant difference in analytical results between the regular and duplicate sample sets.

NWQL Performance

Quality control tests and procedures are performed regularly at the USGS NWQL, to ensure that accurate and reliable analytical procedures are maintained. The tests include analysis of duplicate, replicate, spiked, and blank samples that are provided from either internal or external sources. Results of these tests are available upon request.

Table 6.—Snowmelt-runoff quality.

[ft^3/sec, cubic feet per second; µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; colonies/100 mL, colonies per 100 milliliters; e, estimated; >, greater than; <, less than; --, not determined; Some totals are not exact because of rounding.]

	Site ID	Date (mm-dd-yy)	Sampling time	Discharge (ft^3/sec)	Specific conductance (µS/cm at 25°C)	pH, field (standard units)	BOD 5-day at 20 (mg/L)	COD, high level (mg/L)	Fecal coliform (colonies/100 mL)	Fecal streptococci (colonies/100 mL)
					Guttered sites					
WHITE BEAR PARKWAY	2	02-01-93	1502	--	2,230	9.7	>3	340	e52	280
	2	02-14-94	1250	e0.003	9,960	7.0	10	510	e0	e100
	2	03-02-93	1555	e.009	979	8.5	>15	250	e208	e1540
	2	04-01-93	1330	e.02	3,150	8.3	4	130	e4	e20
	2	02-28-94	1545	e.002	12,300	7.9	14	420	0	e60
	2	01-17-95	1110	e.0079	5,240	7.8	--	250	136	980
	2	02-17-95	1250	e.01	17,400	7.9	31	970	e20	e32
			Maximum =		17,400	9.7	31	970	e208	1540
			Minimum =		979	7.0	4	130	0	20
			Mean =		7,320	8.2	≥15	422	e62	e449
CENTERVILLE ROAD	3	02-01-93	1540	e.005	9,680	9.1	>6	410	e0	56
	3	03-02-93	1400	e.02	2,830	8.2	>15	--	e10	e320
	3	04-01-93	1230	e.005	10,700	8.2	10	88	e4	e8
	3	02-16-94	1350	e.0064	2,410	7.5	37	910	e0	e0
	3	03-01-94	1430	e.00057	17,400	7.9	22	1100	e0	e800
	3	01-17-95	1210	e.0372	6,640	7.9	13	230	e170	880
	3	02-18-95	1340	e.027	21,700	8.7	28	1300	e18	e71
			Maximum =		21,700	9.1	≥37	1300	e170	880
			Minimum =		2,410	7.5	10	88	e0	e0
			Mean =		10,200	8.2	>21	726	e34	347
COUNTY ROAD B-2	5	02-01-93	1345	e.01	2,430	7.9	>8	270	e10	>470
	5	03-02-93	1235	e.02	1,530	8.3	>14	220	e12	e1100
	5	02-14-94	1145	e.0022	15,900	>7.4	34	1000	e0	e0
	5	02-28-94	1345	e.002	12,300	8.2	12	480	e8	e30
	5	01-31-95	1210	e.0059	14,500	8.0	>29	1100	e67	730
	5	02-17-95	1300	e.075	21,700	8.1	30	550	e28	390
			Maximum =		21,700	≥8.3	34	1100	e67	≥1100
			Minimum =		1,530	>7.4	8	220	e0	0
			Mean =		11,400	≥8.0	21	603	e21	>453
					Unguttered sites					
OTTER LAKE ROAD	1	02-02-93	1545	<.002	4,820	7.7	>7	130	e0	e2700
	1	03-02-93	1530	e.04	2,990	6.8	>14	170	e4	e1000
	1	02-17-94	1625	e.00055	6,750	7.8	18	200	e6	630
	1	03-02-94	1310	--	1,860	7.9	16	110	e4	460
	1	03-11-95	1150	e.0034	3,180	8.3	9	62	e0	240
	1	03-12-95	1140	--	3,450	8.0	--	79	--	--
			Maximum =		6,750	8.3	≥18	200	e6	2700
			Minimum =		1,860	6.8	>7	62	e0	240
			Mean =		3,840	7.8	>13	125	e3	1006
HAZELWOOD STREET	4	02-02-93	1430	e.005	2,550	7.5	6	83	e2	52
	4	03-02-93	1415	e.05	408	8.0	12	110	e0	e60
	4	02-17-94	1515	e.00114	3,360	7.7	--	160	e0	e340
	4	03-01-94	1545	e.006	1,150	8.5	17	98	e4	720
	4	02-17-95	1415	e.016	12,600	7.9	30	360	e5	e62
	4	03-10-95	1435	e.0027	3,940	8.4	26	130	e4	350
			Maximum =		12,600	8.5	30	360	5	720
			Minimum =		408	7.5	6	83	0	--
			Mean =		4,000	8.0	18	157	3	226
					All sites					
			Maximum =		21,700	9.7	≥37	1300	e208	2700
			Minimum =		408	6.8	>3	62	0	0
			Mean =		7,230	7.9	≥17	394	e25	451

Table 6.—Snowmelt-runoff quality—continued.

	Site ID	Date (mm-dd-yy)	Time	Alkalinity (mg/L as $CaCO_3$)	Carbonate (mg/L as CO_3)	Bicarbonate (mg/L as HCO_3)	Detergents (MBAS) (mg/L)	Solids, total (mg/L)	Solids, dissolved (mg/L)	Solids, suspended (mg/L)	Oil and grease (mg/L)	Ammonia, dissolved (mg/L as N)
						Guttered sites						
WHITE BEAR PARKWAY	2	02-01-93	1502	64	0	78	1.4	1,170	--	105	--	.81
	2	03-02-93	1555	67	0	79	.79	738	--	144	3	.95
	2	04-01-93	1330	25	0	30	.59	920	--	360	2	.54
	2	02-14-94	1250	27	0	33	1.4	6,160	--	620	5	1.40
	2	02-28-94	1545	35	0	43	1.8	8,050	--	1060	2	1.20
	2	01-17-95	1110	--	--	--	.86	--	2810	330	6	1.20
	2	02-17-95	1250	37	0	45	1.7	--	7050	1520	3	2.40
			Maximum =	67	--	79	1.8	8,050	7050	1520	6	2.40
			Minimum =	25	--	30	.59	738	2810	144	2	.54
			Mean =	42	--	51	1.2	3,410	4930	591	4	1.21
CENTERVIL-LEROAD	3	02-01-93	1540	45	0	55	.92	5,630	--	88		1.20
	3	03-02-93	1400	62	0	76	1.0	1,980	--	476	3	4.20
	3	04-01-93	1230	26	0	32	.44	840	--	118	1	.74
	3	02-16-94	1350	64	0	78	.10	12,700	--	968	2	1.80
	3	03-01-94	1430	60	0	73	.02	10,800	--	870	1	1.50
	3	01-17-95	1210	44	0	54	.43		3870	370	8	1.00
	3	02-18-95	1340	68	0	83	.93		15800	1670	5	1.90
			Maximum =	68		83	1.0	12,700	15800	1670	8	4.20
			Minimum =	26		32	.02	840	3870	118	1	.74
			Mean =	53		64	.54	6,390	9835	651	3	1.76
COUNTY ROAD B-2	5	02-01-93	1345	66	0	81	0.54	1,590	--	592	--	0.78
	5	03-02-93	1235	102	0	123	.68	1,230	--	306	2	1.50
	5	02-14-94	1145	45	0	55	1.0	11,000	--	1060	19	<.01
	5	02-28-94	1345	47	0	57	.65	7,210	--	210	6	.86
	5	01-31-95	1210	67	0	82	1.1	--	9050	1010	10	1.00
	5	02-17-95	1300	50	0	61	1.7	--	15200	1420	7	3.00
			Maximum =	102	--	123	1.7	11,000	15200	1420	19	3.00
			Minimum =	45	--	55	.54	1,230	9050	210	2	.01
			Mean =	63	--	77	.95	5,258	12125	766	9	1.19
						Unguttered sites						
OTTER LAKE ROAD	1	02-02-93	1545	117	0	143	.34	2,630	--	51	--	2.20
	1	03-02-93	1530	67	0	82	.64	776	--	58	1	3.60
	1	02-17-94	1625	61	0	74	.22	4,760	--	166	1	1.60
	1	03-02-94	1310	40	0	49	.24	1,070	--	118	1	1.30
	1	03-11-95	1150	26	0	32	.29	--	1660	212	1	1.10
	1	03-12-95	1140	38	0	46	.07	--	272	96	2	1.40
			Maximum =	117	0	143	.64	4,760	1660	212	2	3.60
			Minimum =	26	0	32	.07	776	272	51	1	1.10
			Mean =	58	0	71	.30	2,309	966	117	1	1.87
HAZELWOOD STREET	4	02-02-93	1430	54	0	66	.37	1,440	--	63	--	.59
	4	03-02-93	1415	305	0	372	.34	296	--	84	1	.52
	4	02-17-94	1515	58	0	71	.13	1,870	--	202	1	3.00
	4	03-01-94	1545	57	0	70	.12	551	--	56	1	1.90
	4	02-17-95	1415	41	0	50	.65	--	6850	132	1	2.30
	4	03-10-95	1435	42	0	51	.16	--	1660	76	1	.99
			Maximum =	305	--	372	.65	1,870	6850	202	1	3.00
			Minimum =	41	--	50	.12	296	1660	56	1	.52
			Mean =	93	--	113	.30	1,039	4255	102	1	1.55
						All sites						
			Maximum =	305	--	372	1.8	12,700	15800	1670	19	4.20
			Minimum =	25	--	30	.02	551	272	51	1	.01
			Mean =	62	--	75	.68	3,791	6422	457	4	1.52

Table 6.—Snowmelt-runoff quality—continued

	Site ID	Date (mm-dd-yy)	Time	Nitrite, dissolved (mg/L as N)	Ammonia, organic, total (mg/L as N)	Nitrogen, $NO_2 + NO_3$, dissolved (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, dissolved (mg/L as P)	Cyanide, total (mg/L as Cn)	Calcium, dissolved (mg/L as Ca)
					Guttered sites					
WHITE BEAR PARKWAY	2	02-01-93	1502	0.15	3.2	0.90	0.97	0.19	0.02	17
	2	03-02-93	1555	.02	3.2	.33	.98	.62	<.01	--
	2	04-01-93	1330	.03	.6	.25	.03	.02	<.01	24
	2	02-14-94	1250	.21	5.3	1.20	.83	.09	.03	47
	2	02-28-94	1545	.22	2.1	.97	.05	.04	.02	83
	2	01-17-95	1110	.08	2.0	1.20	.16	.05	.04	22
	2	02-17-95	1250	.24	7.5	2.30	2.30	.14	.08	66
			Maximum =	.24	7.5	2.30	2.30	.62	.08	83
			Minimum =	.02	.6	.25	.03	.02	<.01	22
			Mean =	.13	3.5	1.04	.73	.16	≤.03	48
CENTERVILLE ROAD	3	02-01-93	1540	.06	2.6	.57	.24	.11	.01	26
	3	03-02-93	1400	.12	17.0	.29	2.00	1.20	.04	--
	3	04-01-93	1230	.05	.9	.22	.03	.03	.01	39
	3	02-16-94	1350	.41	10.0	1.20	1.60	.32	.04	59
	3	03-01-94	1430	.50	2.8	1.20	.20	.20	<.01	89
	3	01-17-95	1210	.11	2.8	1.40	.50	.05	.06	22
	3	02-18-95	1340	.35	3.8	1.70	.34	.07	.02	55
			Maximum =	.50	17.0	1.70	2.00	1.20	.06	89
			Minimum =	.05	.9	.22	.03	.03	.01	22
			Mean =	.26	6.2	1.00	.78	.31	.03	53
COUNTY ROAD B-2	5	02-01-93	1345	.11	2.3	.48	.70	.26	.03	15
	5	03-02-93	1235	.12	4.9	.37	1.30	.84	.02	--
	5	02-14-94	1145	<.01	3.3	.05	.48	.04	.08	34
	5	02-28-94	1345	.22	2.0	1.10	.06	.05	.01	48
	5	01-31-95	1210	.50	3.1	1.30	.39	.11	.12	53
	5	02-17-95	1300	.23	7.5	2.20	1.70	.25	.11	82
			Maximum =	.50	7.5	2.20	1.70	.84	.12	82
			Minimum =	.01	2.0	.05	.06	.04	.01	15
			Mean =	.20	3.9	.92	.77	.26	.06	46
					Unguttered sites					
OTTER LAKE ROAD	1	02-02-93	1545	.16	4.5	1.00	.62	.48	.01	54
	1	03-02-93	1530	.09	7.7	.59	1.40	1.20	.02	--
	1	02-17-94	1625	.16	4.9	1.20	1.10	.57	.02	59
	1	03-02-94	1310	.07	2.7	.39	.59	.43	.01	18
	1	03-11-95	1150	.05	2.7	.94	.54	.41	.01	12
	1	03-12-95	1140	.02	4.6	.34	1.10	.78	<.01	4
			Maximum =	.16	7.7	1.20	1.40	1.20	.02	59
			Minimum =	.02	2.7	.34	.54	.41	.01	4
			Mean =	.09	4.5	.74	.89	.65	.01	29
HAZELWOOD STREET	4	02-02-93	1430	.15	1.6	1.10	.21	.10	.02	37
	4	03-02-93	1415	.07	1.6	.57	.27	.18	<.01	--
	4	02-17-94	1515	.19	5.6	1.30	1.40	1.20	.02	56
	4	03-01-94	1545	.14	4.3	.52	.78	.58	.01	22
	4	02-17-95	1415	.20	4.6	2.10	.40	.24	.02	68
	4	03-10-95	1435	.06	2.9	1.50	.56	.35	<.01	28
			Maximum =	.20	5.6	2.10	1.40	1.20	.02	68
			Minimum =	.06	1.6	.52	.21	.10	.01	22
			Mean =	.14	3.4	1.18	.60	.44	.02	42
					All sites					
			Maximum =	.50	17.0	2.30	2.30	1.20	.12	89
			Minimum =	.01	.6	.05	.03	.02	<.01	4
			Mean =	.16	4.2	.96	.74	.35	≤.03	42

	Site ID	Date (mm-dd-yy)	Time	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as Fl)	Silica, dissolved (mg/L as SiO_2)
				Guttered sites						
WHITE BEAR PARKWAY	2	02-01-93	1502	3.3	400	8.4	600	19	<.10	3
	2	03-02-93	1555	--	--	--	200	10	.10	3
	2	04-01-93	1330	1.8	540	1.9	810	6.6	.20	2
	2	02-14-94	1250	4.7	2,000	5.1	3,300	33	.20	1
	2	02-28-94	1545	9.0	2,300	7.6	4,100	32	.10	2
	2	01-17-95	1110	2.6	1,100	3.3	1,700	12	.10	1
	2	02-17-95	1250	9.7	2,800	12.0	4,200	34	.20	2
			Maximum =	9.7	2,800	12.0	4,200	34	.20	3
			Minimum =	1.8	540	1.9	200	6.6	<.10	1
			Mean =	5.6	1,748	6.0	2,385	21	≤.15	2
CENTERVILLE ROAD	3	02-01-93	1540	1.7	2,100	4.2	2,800	48	.40	2
	3	03-02-93	1400	--	--	--	730	17	.20	2
	3	04-01-93	1230	2.5	1,700	1.9	2,700	10	.40	1
	3	02-16-94	1350	5.6	4,400	6.2	6,800	83	.30	3
	3	03-01-94	1430	8.5	3,100	8.0	5,400	73	.20	3
	3	01-17-95	1210	1.7	1,500	2.7	2,200	22	.20	1
	3	02-18-95	1340	4.5	6,300	7.3	9,500	28	.30	2
			Maximum =	8.5	6,300	8.0	9,500	83	.40	3
			Minimum =	1.7	1,500	1.9	730	10	.20	1
			Mean =	4.6	3,400	5.2	4,555	39	.27	2
COUNTY ROAD B-2	5	02-01-93	1345	1.8	480	3.8	700	17	<.10	3
	5	03-02-93	1235	--	--	--	420	19	<.10	5
	5	02-14-94	1145	2.7	3,600	4.0	5,800	61	.20	1
	5	02-28-94	1345	4.0	2,500	4.3	4,000	55	.20	1
	5	01-31-95	1210	4.7	3,500	6.8	5,300	61	.20	3
	5	02-17-95	1300	6.9	5,900	12.0	9,500	26	.10	2
			Maximum =	6.9	5,900	12.0	9,500	61	.20	5
			Minimum =	1.8	480	3.8	420	17	<.10	1
			Mean =	4.0	3,196	6.2	4,287	40	≤.15	3
				Unguttered sites						
OTTER LAKE ROAD	1	02-02-93	1545	9.5	890	17.0	1,400	23	.10	10
	1	03-02-93	1530	--	--	--	780	11	.20	2
	1	02-17-94	1625	8.3	1,700	11.0	2,600	28	<.10	4
	1	03-02-94	1310	2.0	310	4.1	500	11	<.10	3
	1	03-11-95	1150	1.6	600	4.1	930	6.6	<.10	2
	1	03-12-95	1140	1.0	81	5.3	110	3.6	<.10	2
			Maximum =	9.5	1,700	17.0	2,600	28	.20	10
			Minimum =	1.0	81	4.1	110	3.6	<.10	2
			Mean =	4.5	716	8.3	1,053	14	≤.12	4
HAZELWOOD STREET	4	02-02-93	1430	4.1	430	5.0	730	18	<.10	4
	4	03-02-93	1415	--	--	--	110	7.2	<.10	1
	4	02-17-94	1515	8.9	540	20.0	940	19	<.10	4
	4	03-01-94	1545	3.3	130	7.2	210	8.9	<.10	6
	4	02-17-95	1415	6.2	2,600	29.0	4,200	20	.20	2
	4	03-10-95	1435	3.6	560	13.0	920	9.0	<.10	3
			Maximum =	8.9	2,600	29.0	4,200	20	.20	6
			Minimum =	3.3	130	5.0	110	7.2	<.10	1
			Mean =	5.2	852	14.8	1,185	14	≤.12	3
				All sites						
			Maximum =	9.7	6,300	29.0	9,500	83	.40	10
			Minimum =	1.0	81	1.9	110	3.6	<.10	1
			Mean =	4.6	1,928	8.0	2,631	26	≤.17	3

Table 6.—Snowmelt-runoff quality—continued.

	Site ID	Date (mm-dd-yy)	Time	Aluminum, total (µg/L as Al)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Beryllium, dissolved (µg/L as Be)	Cadmium, dissolved (µg/L as Cd)	Cadmium, total (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Chromium, total (µg/L as Cr)
					Guttered sites						
WHITE BEAR PARKWAY	2	02-01-93	1502	9,200	<1	44	<2	<3.0	<10	<20	35
	2	03-02-93	1555	6,300	--	--	--	--	<10	--	20
	2	04-01-93	1330	11,000	<1	100	<10	1.0	20	4	40
	2	02-14-94	1250	16,000	<1	300	<10	<2.0	30	4	55
	2	02-28-94	1545	16,000	<1	300	<10	<2.0	30	4	55
	2	01-17-95	1110	8,300	<1	86	<2	<3.0	<10	31	69
	2	02-17-95	1250	24,000	2	400	<10	2.0	40	5	90
			Maximum =	24,000	2	400	<10	3.0	40	30	90
			Minimum =	6,300	<1	47	<2	1.0	10	4	20
			Mean =	11,983	≤1	187	<7	2.2	20	13	50
CENTERVILLE ROAD	3	02-01-93	1540	1,900	1	68	<2	1.0	20	12	20
	3	03-02-93	1400	7,900	--	--	--	--	10	--	70
	3	04-01-93	1230	1,900	<1	100	3	<1.0	20	<30	16
	3	02-16-94	1350	12,000	1	200	10	1.0	50	5	48
	3	03-01-94	1430	11,000	1	300	<10	<2.0	30	4	53
	3	01-17-95	1210	6,200	<1	<100	<10	<5.0	10	23	56
	3	02-18-95	1340	24,000	<1	200	<10	3.0	50	5	160
			Maximum =	24,000	1	300	10	5.0	50	30	160
			Minimum =	1,900	<1	<100	3	1.0	10	4	16
			Mean =	10,500	≤1	≤180	<9	2.4	28	13	67
COUNTY ROAD B-2	5	02-01-93	1345	5,900	<1	22	<2	3.0	<10	<20	63
	5	03-02-93	1235	4,300	--	--	--	--	<10	--	10
	5	02-14-94	1145	13,000	<1	100	10	1.0	40	<4	80
	5	02-28-94	1345	2,600	<1	200	<10	<2.0	20	5	18
	5	01-31-95	1210	14,000	<1	100	<10	<1.0	10	4	89
	5	02-17-95	1300	13,000	<1	400	<10	2.0	50	7	85
			Maximum =	14,000	<1	400	10	3.0	50	20	89
			Minimum =	2,600	<1	22	<2	1.0	10	4	10
			Mean =	8,800	<1	164	≤8	1.8	23	8	58
					Unguttered sites						
OTTER LAKE ROAD	1	02-02-93	1545	800	2	67	<2	<3.0	10	<20	15
	1	03-02-93	1530	1,200	--	--	--	--	10	--	30
	1	02-17-94	1625	1,800	3	100	<10	<1.0	20	3	11
	1	03-02-94	1310	2,000	1	31	<1	<1.0	<10	<5	8
	1	03-11-95	1150	2,200	<1	28	<2	8.0	<10	<20	9
	1	03-12-95	1140	1,600	<1	10	<1	2.0	<10	<5	5
			Maximum =	2,200	3	100	<10	8.0	20	<20	30
			Minimum =	800	<1	10	<1	<1.0	<10	3	5
			Mean =	1,600	<2	47	<3	≤3.0	≤12	≤11	13
HAZELWOOD STREET	4	02-02-93	1430	1,800	<1	54	<2	<3.0	10	<15	15
	4	03-02-93	1415	1,700	--	--	--	--	<10	--	10
	4	02-17-94	1515	2,600	2	92	<2	<3.0	<10	<15	9
	4	03-01-94	1545	2,100	1	26	<1	<1.0	<10	5	6
	4	02-17-95	1415	2,500	<1	200	<10	1.0	20	6	16
	4	03-10-95	1435	1,300	1	50	<2	<3.0	10	<15	7
			Maximum =	2,600	2	200	<10	3.0	20	20	16
			Minimum =	1,300	<1	26	<1	1.0	10	5	6
			Mean =	2,000	≤1	84	<3	2.2	12	14	11
					All sites						
			Maximum =	24,000	3	400	10	8.0	50	<30	160
			Minimum =	800	<1	10	<1	<1.0	0	≤3	≤5
			Mean =	6,888	≤1	≤127	≤6	≤2.3	≤18	≤12	≤39

Table 6.—Snowmelt-runoff quality—continued.

	Site ID	Date (mm-dd-yy)	Time	Cobalt, dissolved (µg/L as Co)	Copper, dissolved (µg/L as Cu)	Copper, total (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Lead, total (µg/L as Pb)	Lithium, dissolved (µg/L as Li)
					Guttered sites					
WHITE BEAR PARKWAY	2	02-01-93	1502	<9	<30	90	280	<30	100	<12
	2	03-02-93	1555	--	--	70	--	--	<100	--
	2	04-01-93	1330	<9	<30	40	57	<30	100	<12
	2	02-14-94	1250	1	15	120	80	<1.0	100	<10
	2	02-28-94	1545	1	14	160	50	<10	200	<10
	2	01-17-95	1110	9	<30	80	17	70	100	<12
	2	02-17-95	1250	2	39	330	90	<2.0	700	<10
			Maximum =	9	39	330	90	70	700	<12
			Minimum =	1	≤14	40	17	<1.0	<100	<10
			Mean =	<5	≤21	130	59	≤23	≤220	<11
CENTERVILLE ROAD	3	02-01-93	1540	3	24	50	56	1.0	200	<12
	3	03-02-93	1400	--	--	140	--	--	300	--
	3	04-01-93	1230	1	6	30	57	1.0	100	<20
	3	02-16-94	1350	3	23	160	100	2.0	200	<10
	3	03-01-94	1430	3	15	130	50	10	300	<10
	3	01-17-95	1210	2	16	90	10	5.0	100	<10
	3	02-18-95	1340	8	40	560	40	<4.0	700	<10
			Maximum =	8	40	560	100	10	700	<20
			Minimum =	1	6	30	10	1.0	100	<10
			Mean =	3	20	180	51	≤4.0	280	<12
COUNTY ROAD B-2	5	02-01-93	1345	<9	<30	90	320	<30	200	<12
	5	03-02-93	1235	--	--	90	--	--	200	--
	5	02-14-94	1145	1	20	280	60	<1.0	300	10
	5	02-28-94	1345	3	22	80	40	<10	100	<10
	5	01-31-95	1210	1	86	410	50	<1.0	300	<10
	5	02-17-95	1300	4	78	380	130	<4.0	500	<10
			Maximum =	<9	86	410	320	<30	500	<12
			Minimum =	1	≤20	80	40	<1.0	100	<10
			Mean =	≤4	≤47	220	120	≤9.0	270	<10
					Unguttered sites					
OTTER LAKE ROAD	1	02-02-93	1545	<9	<30	20	62	<30	100	<12
	1	03-02-93	1530	--	--	40	--	--	100	--
	1	02-17-94	1625	<1	12	50	50	<1.0	<100	<10
	1	03-02-94	1310	<3	20	50	73	<10	<100	<4
	1	03-11-95	1150	<9	<30	50	58	<30	100	<12
	1	03-12-95	1140	6	<10	40	400	<10	<100	<4
			Maximum =	<9	30	50	400	<30	100	<12
			Minimum =	<1	10	20	50	<1.0	100	<4
			Mean =	<6	20	40	129	≤16	100	<8
HAZELWOOD STREET	4	02-02-93	1430	<9	<30	30	61	<30	100	<12
	4	03-02-93	1415	--	--	20	--	--	<100	--
	4	02-17-94	1515	<9	<30	20	38	<30	<100	<12
	4	03-01-94	1545	<3	10	20	270	<10	<100	<4
	4	02-17-95	1415	2	25	140	60	<2.0	200	<10
	4	03-10-95	1435	<9	<30	30	44	<30	<100	<12
			Maximum =	<9	30	140	270	<30	200	<12
			Minimum =	2	10	20	38	<2.0	<100	<4
			Mean =	<6	25	43	95	<20	≤120	<10
					All sites					
			Maximum =	9	86	560	400	70	700	<20
			Minimum =	<1	<6	20	10	<1.0	<100	<4
			Mean =	≤5	27	122	96	≤15	≤190	<10

Table 6.—Snowmelt-runoff quality—continued.

	Site ID	Date (mm-dd-yy)	Time	Mercury, dissolved (µg/L as Hg)	Molybdenum, dissolved (µg/L as Mo)	Nickel, dissolved (µg/L as N)	Silver, dissolved (µg/L as Ag)	Strontium, dissolved (µg/L as Sr)	Vanadium, dissolved (µg/L as V)	Zinc, dissolved (µg/L as Zn)	Zinc, total (µg/L as Zn)
					Guttered sites						
WHITE BEAR PARKWAY	2	02-01-93	1502	0.1	<30	<30	3	50	<18	30	360
	2	03-02-93	1555	.1	--	--	--	--	--	--	240
	2	04-01-93	1330	.1	<30	<30	<3	39	<18	11	200
	2	02-14-94	1250	.1	<1	5	<1	220	51	120	430
	2	02-28-94	1545	.1	<1	5	<1	300	59	30	620
	2	01-17-95	1110	.4	<30	<30	<3	46	<18	34	390
	2	02-17-95	1250	.2	2	8	<4	190	84	30	1000
			Maximum =	.4	<30	<30	<4	300	84	120	1000
			Minimum =	.1	<1	5	1	39	<18	11	200
			Mean =	.2	--	≤16	2	159	≤46	45	480
CENTERVILLE ROAD	3	02-01-93	1540	.1	<1	4	<1	58	40	14	120
	3	03-02-93	1400	.1	--	--	--	--	--	--	420
	3	04-01-93	1230	.1	2	2	<1	69	43	33	140
	3	02-16-94	1350	.1	3	3	<1	160	110	120	450
	3	03-01-94	1430	.1	2	5	<1	180	82	80	720
	3	01-17-95	1210	.3	2	3	<5	50	48	40	580
	3	02-18-95	1340	.3	4	10	<10	160	200	50	1700
			Maximum =	.3	4	10	10	180	200	120	1700
			Minimum =	.1	<2	2	1	50	43	33	140
			Mean =	.2	--	4	3	124	97	65	668
COUNTY ROAD B-2	5	02-01-93	1345	0.1	<30	<30	<3	28	<18	<9	260
	5	03-02-93	1235	.1	--	--	--	--	--	--	180
	5	02-14-94	1145	.1	1	7	<2	230	87	40	680
	5	02-28-94	1345	.1	1	7	<1	140	57	20	140
	5	01-31-95	1210	.1	3	7	<1	140	85	70	1000
	5	02-17-95	1300	.3	3	10	<10	180	200	30	700
			Maximum =	.3	<30	<30	10	230	200	70	1000
			Minimum =	.1	<1	7	1.0	28	<18	<9	140
			Mean =	.1	--	≤12	3.4	144	≤89	≤34	490
					Unguttered sites						
OTTER LAKE ROAD	1	02-02-93	1545	.1	30	<30	<3	86	<18	1200	1200
	1	03-02-93	1530	.1	--	--	--	--	--	--	1000
	1	02-17-94	1625	.1	<1	2	<1	100	43	1200	2600
	1	03-02-94	1310	.1	<10	<10	<1	25	<6	12	40
	1	03-11-95	1150	<.1	30	<30	<3	15	<18	36	130
	1	03-12-95	1140	<.1	10	<10	<1	8	<6	30	140
			Maximum =	.1	30	<30	3.0	100	43	1200	2600
			Minimum =	.1	1	2.0	1.0	8	<6	12	40
			Mean =	.1	<20	≤16	1.8	47	≤18	496	850
HAZELWOOD STREET	4	02-02-93	1430	.1	<30	<30	<3	64	<18	30	80
	4	03-02-93	1415	.1	--	--	--	--	--	--	60
	4	02-17-94	1515	.1	<30	<30	<3	86	<18	150	310
	4	03-01-94	1545	.1	10	<10	<1	32	<6	7	10
	4	02-17-95	1415	.2	2	4	<4	150	81	40	180
	4	03-10-95	1435	.1	<30	30	<3	45	<18	14	60
			Maximum =	.2	<30	<30	4.0	150	81	150	310
			Minimum =	.1	2	4	1.0	32	<6	7	10
			Mean =	.1	--	≤20	2.8	75	≤28	48	120
					All sites						
			Maximum =	.4	30	<30	10	300	200	1200	2600
			Minimum =	.1	<1	2	1.0	8	<6	7	10
			Mean =	.1	--	≤10	2.7	106	≤54	≤129	500

Table 7.—Summary of rainfall-runoff quality data.

[°C, degrees Celsius; µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; gms, grams; kgms, kilograms; µg/L, micrograms per liter; colonies/100 mL, colonies per 100 milliliters; --, not determined; k, nonideal count; >, greater than; <, less than; Some totals are not exact because of rounding.]

Site ID	Date (mm-dd-yy)	Time	Water temperature (°C)	Specific conductance (µS/cm at 25 °C)	Oxygen, dissolved (mg/L)	pH, field (standard units)	BOD (mg/L)	COD (mg/L)	Fecal coliform (colonies/100 mL)	Fecal streptococci (colonies/100 mL)	Alkalinity (mg/L as $CaCO_3$)
Guttered sites											
2	05-08-93	1835	20.0	54	8.3	7.8	1.4	130	84	k1,200	18
2	06-16-93	0515	--	35	--	6.4	--	36	--	--	--
2	06-23-93	2008	23.0	58	7.3	7.1	16	140	k8	88	7
2	06-29-93	1849	23.0	41	7.0	7.0	11	72	240	k9,700	9
2	07-31-93	1035	21.5	38	--	8.0	<5.6	91	k1,400	3,600	5
2	10-05-93	1700	14.0	81	9.7	7.3	29	230	560	2,800	36
2	10-15-93	1450	13.0	84	8.2	8.0	23	150	700	1,000	18
2	06-17-94	1310	25.5	91	7.8	8.0	--	110	k22,000	k57,000	--
2	08-23-94	0955	19.5	141	7.1	8.2	--	280	k2,000	k32,000	19
2	06-25-95	1050	22.0	66	7.5	7.6	28	110	k590	k44,000	18
2	08-04-95	0945	22.5	58	--	8.0	19	270	k35	k670	12
2	08-11-95	0900	22.5	54	18.7	6.6	2.6	23	k9	42	6
2	09-15-95	0930	15.5	160	11.0	8.1	53	350	4,300	k118,000	87
2	10-05-95	2030	11.5	28	12.2	8.2	19	100	400	8,100	6
	Total =	--	--	--	--	--	--	--	--	--	--
	Yield =	--	--	--	--	--	--	--	--	--	--
3	05-08-93	1810	19.5	90	9.0	7.8	7.9	58	k460	k2,000	17
3	06-16-93	0525	--	40	--	6.5	--	32	--	--	--
3	06-23-93	2035	22.5	50	8.0	6.6	8.0	41	k3,800	k3,800	4
3	06-29-93	1830	22.0	85	8.5	7.6	>14	250	k300	k7,900	17
3	07-31-93	1100	21.5	57	8.7	8.5	<5.7	31	3,800	k11,000	9
3	10-15-93	1520	11.5	139	10.1	8.1	32	270	k10,000	k62,000	69
3	08-09-94	1510	19.5	174	7.9	7.8	--	330	e9,800	8,800	30
3	05-08-95	1110	13.5	111	9.8	7.9	16	190	68	1,500	26
3	06-25-95	1112	22.0	89	7.9	6.8	28	260	k590	6,100	18
3	07-25-95	1945	25.5	200	6.2	8.0	28	380	k4,600	k600	40
3	08-04-95	0945	22.5	82	7.4	7.4	37	280	k1,100	k14,000	12
3	08-11-95	0805	22.5	39	9.8	7.9	13	200	--	5,800	10
3	08-19-95	0032	24.0	25	7.1	8.0	17	55	430	10,400	7
	Total =	--	--	--	--	--	--	--	--	--	--
	Yield =	--	--	--	--	--	--	--	--	--	--
5	05-08-93	1950	19.0	53	8.9	7.7	5.5	63	k300	k1,600	15
5	06-16-93	0445	--	69	--	7.4	--	76	--	--	--
5	06-23-93	1950	26.0	180	--	7.1	>14	330	1,000	k7,000	13
5	06-29-93	1810	24.5	112	7.4	6.7	>13	410	840	4,600	13
5	07-22-93	1930	23.0	185	7.4	7.6	21	350	k170	4,800	23
5	07-31-93	1020	21.5	22	8.8	7.3	<6.6	35	k800	1,100	9
5	10-20-93	1520	12.5	94	9.5	7.3	28	130	740	1,600	19
5	08-09-94	1510	20.0	180	7.0	7.0	--	400	k1,300	14,000	21
5	05-08-95	1000	14.5	59	9.6	8.4	17	170	2,400	k140	14
5	08-04-95	1030	22.0	50	9.1	7.6	21	330	k18	k530	16
5	08-11-95	0812	23.5	95	7.3	7.5	23	200	k6	k15	15
5	08-19-95	0022	24.0	35	9.1	7.8	19	120	450	8,300	7
5	09-15-95	1000	16.0	111	7.5	8.1	34	320	2,900	k40,000	21
5	09-29-95	1410	19.5	60	9.2	8.1	24	220	k45	k28,400	20
5	10-05-95	2030	12.0	99		7.9	14	65	480	9,900	9
	Total =	--	--	--	--	--	--	--	--	--	--
	Yield =	--	--	--	--	--	--	--	--	--	--
Summary of guttered sites	Maximum =	--	--	200	19	9	53	410	k22,000	k118,000	87
	Minimum =	--	--	22	6	6	1	23	k6	k15	4
	Flow-weighted mean =			86	9	8	19	187	2,158	14,348	19
	Total =	--	--	--	--	--	--	--	--	--	--
	Yield =	--	--	--	--	--	--	--	--	--	--

Yield = grams (or kilograms) per inch of rain per acre based on primary drainage area.

Table 7.—Summary of rainfall-runoff quality data—continued.

Site ID	Date (mm-dd-yy)	Time	Water temperature (°C)	Specific conductance (µS/cm at 25 °C)	Oxygen, dissolved (mg/L)	pH, field (standard units)	BOD (mg/L)	COD (mg/L)	Fecal coliform (colonies/100 mL)	Fecal streptococci (colonies/10 0 mL)	Alkalinity (mg/L as $CaCO_3$)
Unguttered sites											
1	05-08-93	2110	16.5	67	--	7.7	8.6	77	k800	k16,000	64
1	06-16-93	2300	--	61	--	8.2	--	--	--	--	--
1	06-23-93	2115	21.5	108	5.0	6.9	--	--	k9,400	k49,000	36
1	07-01-93	0930	18.0	393	8.4	7.9	6.0	66	k1,500	k47,000	117
1	08-18-93	0745	21.5	83	5.7	7.5	6.9	42	k11,000	k72,000	32
1	08-30-93	0810	21.0	81	6.6	7.6	3.8		3,200	k64,000	43
1	10-08-93	1100	9.0	164	8.9	7.6	9.1	77	k2,600	k61,000	66
1	06-07-94	1355	19.0	241	8.9	7.9		100	k150	k97,000	--
1	07-21-94	1125	20.0	64	7.6	7.4		44	k2,800	k150,000	--
1	10-03-94	0830	10.5	150	8.7	7.7	6.7	82	7,200	75,000	75
1	10-06-94	1915	17.0	52	10.0	6.5	7.5	100	5,800	k59,000	17
1	06-25-95	1155	19.5	98	7.8	7.2	14	70	510	k41,000	17
1	08-11-95	0840	21.0	117	9.2	7.2	6.9	54	k137	k520	34
1	10-05-95	2155	11.0	75	12.4	7.6	8.8	36	k1,860	k13,200	32
1	10-23-95	1205	5.5	71	14.4	7.8	10	85	k1,900	k13,300	18
	Total =	--	--	--	--	--	--	--	--	--	--
	Yield =	--	--	--	--	--	--	--	--	--	--
4	05-08-93	2020	17.5	77	7.9	8.2	4.4	84	410	k3,900	25
4	06-16-93	2150	--	81	--	8.3	--	300	--	--	--
4	06-23-93	2046	22.0	53	--	8.2	6.4	130	k5,000	k19,000	22
4	06-29-93	1930	19.5	62	7.7	8.0	7.1	44	810	k11,000	24
4	07-31-93	1425	23.0	114	8.0	7.9	<7.7	56	k19,000	k52,000	43
4	09-19-93	1845	13.0	79	10.9	7.9	5.9	37	k53,000	k58,000	35
4	10-20-93	1635	9.5	90	10.8	7.7	6.0	130	780	k9,600	51
4	09-21-94	2230	17.5	79	--	7.2	6.3	41	8,100	k26,000	30
4	10-06-94	1920	17.0	56	8.1	7.7	7.3	46	6,800	18,000	13
4	08-04-95	1555	30.0	81	7.0	8.3	4.6	61	k190	k250	28
4	08-11-95	0837	23.0	60	6.7	8.9	9.1	77	--	k880	21
4	09-29-95	1825	19.5	102	9.0	8.0	5.4	33	82	k19,200	27
4	10-05-95	2100	10.5	75			6.9	43	410	k15,300	18
4	10-23-95	1010	5.5	70	14.5	7.8	12	57	k1,700	6,400	11
	Total =	--	--	--	--	--	--	--	--	--	--
	Yield =	--	--	--	--	--	--	--	--	--	--
Summary of unguttered sites	Maximum =		--	393	14.50	8.90	14.00	300	k53,000	k150,000	117
	Minimum =		--	52	5.00	6.50	3.80	33	82	k250	11
	Flow-weighted mean =		--	104	8.92	7.68	7.78	63	5,590	38,986	37
	Total=	--	--	--	--	--	--	--	--	--	--
	Yield =	--	--	--	--	--	--	--	--	--	--
Summary of all sites	Maximum =		--	393	18.70	8.90	52.60	410	53,000	k150,000	117
	Minimum =		--	22	5.00	6.40	1.40	[illegible]	k6.00	k15.00	4
	Flow-weighted mean =		--	91	8.80	7.65	14.06	140	3,440	23,207	26
	Total=	--	--	--	--	--	--	--	--	--	--
	Yield =	--	--	--	--	--	--	--	--	--	--

Table 7.—Summary of rainfall-runoff quality data—continued.

Site ID	Date	Carbonate (mg/L as CO_3)	Bicarbonate, (mg/L as HCO_3)	Detergents (MBAS) (mg/L)	Detergents (MBAS) load (gm)	Solids, residue, total (mg/L)	Solids, residue, dissolved (mg/L)	Solids, residue, suspended (mg/L)	Solids, residue, suspended, load (kgms)	Oil and grease, total (mg/L)
Guttered sites										
2	05-08-93	0	22	.35	3.4	578	--	394	3.83	1
2	06-16-93	--	--	.21	2.6	74.0	--	45.0	.561	<1
2	06-23-93	0	9	.16	4.4	164	--	107	2.92	1
2	06-29-93	0	11	.41	4.5	46.0	--	16.0	.174	1
2	07-31-93	--	6	.31	6.3	52.0	--	20.0	.404	<1
2	10-05-93	0	44	.38	1.4	1,080	--	724	2.60	4
2	10-15-93	0	22	.09	.30	118	--	152	.508	4
2	06-17-94	--	--	.62	1.9	--	75.0	56.0	.170	2
2	08-23-94	0	23	1.2	3.0	--	116	176	.434	<1
2	06-25-95	0	22	.49	8.3	--	62.0	264	4.48	<1
2	08-04-95	0	15	.50	5.7	--	62.0	136	1.54	<1
2	08-11-95	0	8	.11	1.9	--	20.0	72.0	1.25	<1
2	09-15-95	0	106	1.0	6.2	--	142	220	1.36	<1
2	10-05-95	0	7	.09	1.0	--	16.0	120	1.35	<1
	Total =	--	--	--	51	--	--	--	21.6	--
	Yield =	--	--	--	23	--	--	--	9.98	--
3	05-08-93	0	21	.23	1.2	775	--	636	3.33	3
3	06-16-93	--	--	.17	2.1	111	--	49.0	.616	<1
3	06-23-93	0	5	.07	1.5	58.0	--	71.0	1.53	<1
3	06-29-93	0	21	.39	3.9	87.0	--	49.0	.487	<1
3	07-31-93	0	11	.28	3.9	42.0	--	16.0	.224	<1
3	10-15-93	0	84	--	--	33,800	122	5,440	11.1	--
3	08-09-94	0	37	1.4	7.9	--	114	40.0	.224	<1
3	05-08-95	0	32	.41	1.7	--	66.0	56.0	.238	9
3	06-25-95	0	22	.58	3.0	--	76.0	168	.875	6
3	07-25-95	0	49	1.6	1.4	--	146	126	.111	2
3	08-04-95	0	15	.42	3.2	--	70.0	504	3.81	<1
3	08-11-95	0	12	.15	4.0	--	50.0	196	5.29	3
3	08-19-95	0	9	.16	2.7	--	26.0	130	2.16	3
	Total =	--	--	--	37	--	--	--	30.0	--
	Yield =	--	--	--	12	--	--	--	9.58	--
5	05-08-93	0	18	--	--	--	--	--	--	2
5	06-16-93	--	--	.48	15	166	--	50.0	1.53	2
5	06-23-93	0	16	.22	4.3	982	--	204	3.99	2
5	06-29-93	0	16	.29	4.5	80.0	--	45.0	.701	2
5	07-22-93	0	28	3.9	1.6	254	--	62.0	.025	4
5	07-31-93	--	11	.29	6.3	185	--	66.0	1.43	1
5	10-20-93	0	23	.66	--	110	--	26.0	--	1
5	08-09-94	0	26	2.0	5.4	--	173	40.0	.108	<1
5	05-08-95	0	17	.53	2.0	--	62.0	288	1.08	4
5	08-04-95	0	20	1.2	2.3	--	102	64.0	.123	3
5	08-11-95	0	18	.19	3.1	--	32.0	104	1.70	2
5	08-19-95	0	9	.12	2.3	--	14.0	100	1.95	5
5	09-15-95	0	26	.96	1.7	--	62.0	84.0	.149	7
5	09-29-95	0	24	.83	2.0	--	52.0	118	.288	2
5	10-05-95	0	11	.09	.73	--	1.0	11.0	.089	4
	Total =	--	--	--	51	--	--	--	13.2	--
	Yield =	--	--	--	19	--	--	--	4.8	--
Summary of guttered sites	Maximum =	0	106	3.9	15	--	--	5,440	11.1	9
	Minimum =	0	5	.07	.73	--	--	11.0	.025	<1
	Flow-weighted mean =	0	23	.59	--	--	--	150	--	--
	Total =	--	--	--	140	--	--	--	64.7	--
	Yield =	--	--	--	17	--	--	--	8.07	--

Yield = grams (or kilograms) per inch of rain per acre.

Table 7.—Summary of rainfall-runoff quality data—continued.

Site ID	Date	Carbonate (mg/L as CO_3)	Bicarbonate, (mg/L as HCO_3)	Detergents (MBAS) (mg/L)	Detergents (MBAS) load (gm)	Solids, residue, total (mg/L)	Solids, residue, dissolved (mg/L)	Solids, residue, suspended (mg/L)	Solids, residue, suspended, load (kgms)	Oil and grease, total (mg/L)
Unguttered sites										
1	05-08-93	0	78	0.14	--	182	--	35	--	<1
1	06-16-93	--	--	.09	46	82	--	29	14.9	<1
1	06-23-93	0	44	.12	3.5	541	--	17	.496	<1
1	07-01-93	0	143	.09	--	177	--	14	--	<1
1	08-18-93	0	39	1.0	--	74	--	<1	--	<1
1	08-30-93	0	53	--	--	--	--	--	--	--
1	10-08-93	0	81	.08	.028	286	--	40	.014	<1
1	06-07-94	--	--	.08	.00091	--	192	54	.00061	<1
1	07-21-94	--	--	.10	1.4	--	56	33	.446	<1
1	10-03-94	0	92	.05	.20	--	114	54	.220	<1
1	10-06-94	0	21	.06	1.4	--	53	54	1.30	<1
1	06-25-95	0	21	.06	2.8	--	70	24	1.12	<1
1	08-11-95	0	42	.04	.016	--	94	20	.0080	<1
1	10-05-95	0	39	.03	.19	--	56	2	.013	<1
1	10-23-95	0	22	.04	.52	--	28	40	.523	<1
	Total =	--	--	--	56	--	--	--	19.1	--
	Yield =	--	--	--	3.2	--	--	--	1.1	--
4	05-08-93	0	30	.06	.49	1470	--	757	6.24	<1
4	06-16-93	--	--	.04	4.2	1800	--	2,600	270	<1
4	06-23-93	0	27	.06	.65	907	--	802	8.74	2
4	06-29-93	0	29	.16	.042	77	--	36	.00948	<1
4	07-31-93	--	52	.07	.79	60	--	222	2.52	<1
4	09-19-93	0	43	.09	.062	85	--	50	.0344	<1
4	10-20-93	0	62	.03	.0076	516	--	324	.0826	<1
4	09-21-94	0	37	.05	.10	--	62	52	.104	<1
4	10-06-94	0	15	<.02	--	--	32	124	2.86	<1
4	08-04-95	0	34	.08	.10	--	78	87	.107	<1
4	08-11-95	0	26	.03	.28	--	60	228	2.12	<1
4	09-29-95	0	33	<.02	--	--	56	120	.147	<1
4	10-05-95	0	22	<.02	--	--	38	36	.275	<1
4	10-23-95	0	13	.09	.23	--	38	36	.0903	<1
	Total =	--	--	--	7.6	--	--	--	294	--
	Yield =	--	--	--	.94	--	--	--	37	--
Summary of unguttered sites	Maximum =	0	143	1.0	46	--	--	2,600	270	2
	Minimum =	0	13	<.02	--	--	--	<1	--	<1
	Flow-weighted mean =	0	45	≤.11	--	--	--	69.0	--	--
	Total=	--	--	--	63	--	--	--	313	--
	Yield =	--	--	--	2.1	--	--	--	10	--
Summary of all sites	Maximum =	0	143	3.9	46	--	--	5,440	270	9
	Minimum =	0	5	<.02	--	--	--	<1	--	<1
	Flow-weighted mean =	0	31	--	--	--	--	276	--	--
	Total=	--	--	--	203	--	--	--	377	--
	Yield =	--	--	--	6.2	--	--	--	12	--

Table 7.—Summary of rainfall-runoff quality data—continued.

Site ID	Date	Ammonia, dissolved (mg/L as N)	Ammonia, dissolved, load (gms)	Nitrite, dissolved (mg/L as N)	Nitrite, dissolved, load (gms)	Ammonia + organic (mg/L as N)	Ammonia + organic, load (gms)	NO_2 + NO_3, dissolved (mg/L as N)	NO_2 + NO_3, dissolved, load (gms)	Phosphorous, total (mg/L as P)
Guttered sites										
2	05-08-93	0.28	2.7	0.01	0.10	0.8	7.8	0.30	2.91	0.08
2	06-16-93	.25	3.1	.01	.12	.5	6.2	.19	2.37	.07
2	06-23-93	1.5	41	.02	.55	2.3	63	1.0	27.3	.17
2	06-29-93	.32	3.5	.01	.11	1.0	11	.25	2.72	.10
2	07-31-93	.40	8.1	.01	.20	.9	18	.31	6.27	.62
2	10-05-93	1.2	4.3	.02	.07	2.7	9.7	.81	2.91	.22
2	10-15-93	1.1	3.7	.08	.27	3.2	11	.58	1.94	<.01
2	06-17-94	.47	1.4	.07	.21	1.5	4.5	1.0	3.03	.14
2	08-23-94	.73	1.8	.07	.17	4.6	11	1.8	4.43	.62
2	06-25-95	1.0	17	.04	.68	2.9	49	1.1	18.7	.39
2	08-04-95	.55	6.3	.03	.34	1.2	14	.63	7.15	.18
2	08-11-95	.33	5.7	.01	.17	.4	6.9	.38	6.59	.07
2	09-15-95	.74	4.6	.06	.37	2.0	12	1.0	6.20	.32
2	10-05-95	.17	1.9	.01	.11	.9	10	.18	2.03	.21
	Total =	--	105	--	3.48	--	230	--	94.5	--
	Yield =	--	48.6	--	1.61	--	110	--	43.7	--
3	05-08-93	.27	1.4	.03	.16	1.0	5.2	.31	1.62	.16
3	06-16-93	.20	2.5	.01	.13	.5	6.3	.35	4.40	.13
3	06-23-93	.89	19.1	.01	.21	1.0	21	.42	9.03	.40
3	06-29-93	.38	3.8	.03	.30	1.4	14	.47	4.67	.21
3	07-31-93	.49	6.9	.02	.28	1.0	14	.48	6.72	.10
3	10-15-93	.27	.55	.28	.57	2.5	5.1	.79	1.61	.44
3	08-09-94	.69	3.9	.06	.34	2.3	13	.70	3.93	.31
3	05-08-95	.77	3.3	.05	.21	2.0	8.5	.73	3.10	.24
3	06-25-95	2.8	15	.08	.42	5.2	27	.93	4.85	.62
3	07-25-95	.73	.64	.17	.15	2.6	2.3	1.20	1.05	.13
3	08-04-95	.36	2.7	.04	.30	2.4	18	1.00	7.56	.49
3	08-11-95	.53	14	.05	1.35	1.3	35	.74	20.0	.14
3	08-19-95	.31	5.2	.02	.33	1.5	25	.38	6.32	.30
	Total =	--	78.8	--	4.75	--	200	--	74.8	--
	Yield =	--	25.2	--	1.52	--	64	--	23.9	--
5	05-08-93	--	--	--	--	--	--	--	--	--
5	06-16-93	.35	11	.03	.92	.9	28	.34	10.4	.07
5	06-23-93	2.1	41	.07	1.37	3.1	61	1.20	23.4	.77
5	06-29-93	.36	5.6	.02	.31	.6	9.3	.24	3.74	.37
5	07-22-93	2.2	.90	.17	.07	4.4	1.8	2.20	.90	.13
5	07-31-93	.40	8.6	.02	.43	1.5	32	.28	6.06	.33
5	10-20-93	2.3	--	.07		4.0	--	1.20	--	.25
5	08-09-94	1.4	3.8	.05	.13	3.2	8.6	1.20	3.23	.17
5	05-08-95	.79	3.0	.03	.11	2.5	9.3	.52	1.94	.35
5	08-04-95	.85	1.6	.04	.08	4.0	7.7	.68	1.31	.33
5	08-11-95	.52	8.5	.02	.33	.9	15	.65	10.6	.09
5	08-19-95	.33	6.4	<.01	--	.8	16	.38	7.39	.42
5	09-15-95	1.3	2.3	.03	.05	2.4	4.3	.54	.96	.20
5	09-29-95	.70	1.7	.04	.10	1.3	3.2	.46	1.12	.23
5	10-05-95	.16	1.3	<.01	--	.3	2.4	.09	.73	.02
	Total =	--	95.5	--	3.90	--	200	--	71.9	--
	Yield =	--	35.0	--	1.43	--	73	--	26.3	--
Summary of guttered sites	Maximum =	2.8	41.0	.28	1.37	5.2	63	2.2	27.3	.77
	Minimum =	.16	.551	<.01	.05	.3	1.8	.09	.726	<.01
	Flow-weighted mean =	.62	--	.03	--	1.4	--	.56	--	.26
	Total =	--	279	--	12.1	--	630	--	241	--
	Yield =	--	34.8	--	1.51	--	79	--	30.1	--

Yield = grams (or kilograms) per inch of rain per acre based on primary drainage area.

Table 7.—Summary of rainfall-runoff quality data—continued.

Site ID	Date	Ammonia, dissolved (mg/L as N)	Ammonia, dissolved, load (gms)	Nitrite, dissolved (mg/L as N)	Nitrite, dissolved, load (gms)	Ammonia + organic (mg/L as N)	Ammonia + organic, load (gms)	$NO_2 + NO_3$, dissolved (mg/L as N)	$NO_2 + NO_3$, dissolved, load (gms)	Phosphorous, total (mg/L as P)
Unguttered sites										
1	05-08-93	0.39	--	0.08	--	2.9	--	1.20	--	0.58
1	06-16-93	.30	155	.02	10.3	1.0	520	.53	273	.15
1	06-23-93	.63	18.4	.05	1.46	1.6	47	.81	23.6	.52
1	07-01-93	.16	--	.01	--	2.3	--	.08	--	.26
1	08-18-93	.04	--	.01	--	1.3	--	.17	--	.31
1	08-30-93	.04	4.04	<.01	--	.7	71	.08	7.89	.22
1	10-08-93	.14	.05	.02	.01	2.0	.7	1.20	.41	1.30
1	06-07-94	.11	.0012	.03	.0003	2.4	.03	.20	.00	.44
1	07-21-94	.05	.68	.02	.27	1.6	22	.13	1.76	.43
1	10-03-94	.04	.16	.01	.04	1.7	6.9	.14	.57	.65
1	10-06-94	.10	2.41	.01	.24	1.3	31	.26	6.27	.55
1	06-25-95	.34	15.9	.05	2.34	1.7	79	.58	27.1	.78
1	08-11-95	.03	.01	.02	.01	1.5	.6	.22	.09	.39
1	10-05-95	.03	.19	<.01		.7	4.4	.07	.44	.45
1	10-23-95	.06	.79	.01	.13	1.2	16	.17	2.22	.66
	Total =	--	197	--	14.8	--	800	--	344	--
	Yield =	--	11	--	.84	--	45	--	19	--
4	05-08-93	--	--	--	--	1.0	8.2	--	--	.23
4	06-16-93	.08	8.31	.02	2.08	.9	94	.46	47.8	.24
4	06-23-93	.39	4.25	.03	.33	.9	9.8	.85	9.27	1.20
4	06-29-93	.19	.05	.02	.01	.8	.2	.30	.08	.34
4	07-31-93	.19	2.16	.02	.23	2.6	30	.53	6.02	.96
4	09-19-93	1.20	.83	.02	.01	.4	.3	.35	.24	1.10
4	10-20-93	.11	.03	.02	.01	2.2	.6	.33	.08	.93
4	09-21-94	.17	.34	<.01	--	<.2	--	.21	.42	.30
4	10-06-94	.23	5.31	.01	.23	1.2	28	.20	4.62	.45
4	08-04-95	.06	.07	.02	.02	.9	1.1	.67	.83	.46
4	08-11-95	.17	1.58	.02	.19	.4	3.7	.60	5.57	.18
4	09-29-95	.45	.55	.04	.05	1.1	1.3	.78	.95	.63
4	10-05-95	.04	.31	.01	.08	.4	3.1	.14	1.07	.29
4	10-23-95	.17	.43	.03	.08	.9	2.3	.59	1.48	.45
	Total =	--	24.2	--	3.30	--	180	--	78.4	--
	Yield =	--	3.02	--	.41	--	22	--	9.79	--
Summary of unguttered sites	Maximum =	1.20	155	.08	10.3	2.9	520	1.20	273	1.30
	Minimum =	.03	.0012	<.01	--	<.2	.03	.07	.002	.15
	Flow-weighted mean =	.21	--	.02	--	1.3	--	.41	--	.53
	Total=	--	221	--	18.1	--	980	--	422	--
	Yield =	--	7	--	.59	--	32	--	14	--
Summary of all sites	Maximum =	2.80	155	.28	10	5.2	520	2.20	273	1.30
	Minimum =	.03	.0012	<.01		<.2	.027	.07	.00227	<.01
	Flow-weighted mean =	.36	--	.02	--	1.2	--	.48	--	.27
	Total =	--	501	--	30	--	1600	--	663	--
	Yield =	--	15	--	.92	--	49	--	20	--

Table 7.—Summary of rainfall-runoff quality data—continued.

Site ID	Date	Phosphorous, load (gms)	Phosphorous, dissolved (mg/L as P)	Phosphorous, dissolved load (gms)	Cyanide, total (mg/L as Cn)	Calcium, dissolved (mg/L as Ca)	Calcium, dissolved, load (kgms)	Magnesium, dissolved (mg/L as Mg)	Magnesium, dissolved, load (gms)	Sodium, dissolved (mg/L as Na)
Guttered sites										
2	05-08-93	0.78	0.04	0.39	<0.01	4.5	0.044	0.7	6.3	4.2
2	06-16-93	.87	.08	1.00	<.01	2.4	.030	.4	4.5	2.1
2	06-23-93	4.64	.04	1.09	<.01	5.4	.15	.9	23	1.6
2	06-29-93	1.09	.78	8.48	<.01	4.0	.043	.6	6.6	2.3
2	07-31-93	12.5	.14	2.83	<.01	2.7	.055	.4	8.9	1.4
2	10-05-93	.79	.10	.36	<.01	4.1	.015	.8	2.8	2.7
2	10-15-93	--	.01	.03	<.01	8.4	.028	1.5	5.0	4.9
2	06-17-94	.42	.02	.06	<.01	8.1	.025	1.5	4.5	8.2
2	08-23-94	1.53	.25	.62	<.01	13	.032	4.4	11	10
2	06-25-95	6.62	.12	2.04	<.01	7.1	.12	1.5	25	3.1
2	08-04-95	2.04	.13	1.48	<.01	6.2	.070	1.4	16	2.5
2	08-11-95	1.21	.04	.69	<.01	3.4	.059	.7	13	1.4
2	09-15-95	1.98	.23	1.43	<.01	17	.11	5.0	31	6.7
2	10-05-95	2.37	.07	.79	<.01	3.5	.039	.5	5.6	1.8
	Total =	36.9	--	21.3	--	--	.81	--	160	--
	Yield =	17.1	--	9.84	--	--	.38	--	74	--
3	05-08-93	.84	.12	.63	<.01	7.7	.040	.5	2.6	4.2
3	06-16-93	1.63	.11	1.38	<.01	3.0	.038	.4	4.9	2.4
3	06-23-93	8.60	.09	1.93	<.01	3.4	.073	.5	10	.8
3	06-29-93	2.09	.11	1.09	<.01	5.6	.056	.8	7.8	3.3
3	07-31-93	1.40	.10	1.40	<.01	3.1	.043	.5	6.4	2.0
3	10-15-93	.90	.09	.18	<.01	21	.043	4.8	9.8	8.1
3	08-09-94	1.74	.22	1.23	<.01	9.6	.054	1.3	7.3	8.2
3	05-08-95	1.02	.19	.81	<.01	6.2	.026	.5	2.0	8.9
3	06-25-95	3.23	.24	1.25	<.01	7.5	.039	.8	4.1	4.9
3	07-25-95	.11	.11	.10	<.01	18	.016	2.0	1.8	7.5
3	08-04-95	3.71	.08	.60	<.01	8.6	.065	1.5	11	1.7
3	08-11-95	3.78	.14	3.78	<.01	6.6	.18	.8	21	2.2
3	08-19-95	4.99	.10	1.66	<.01	3.9	.065	.6	9.1	1.8
	Total =	34.0	--	16.1	--	--	.74	--	98	--
	Yield =	11	--	5.13	--	--	.24	--	31	--
5	05-08-93	--	--	--	--	--	--	--	--	--
5	06-16-93	2.14	.05	1.53	<.01	8.7	.27	.7	23	2.4
5	06-23-93	15.0	.27	5.28	<.01	7.9	.15	.7	13	.7
5	06-29-93	5.76	.04	.62	<.01	3.7	.058	.4	6.9	.8
5	07-22-93	.05	.14	.06	<.01	23	.0094	2.5	1.0	6.7
5	07-31-93	7.14	.03	.65	<.01	3.4	.074	.6	12	.8
5	10-20-93	--	.17	--	<.01	11	--	1.3	--	3.1
5	08-09-94	.46	.14	.38	<.01	16	.043	2.0	5.4	6.8
5	05-08-95	1.31	.07	.26	<.01	8.0	.030	.4	1.5	4.1
5	08-04-95	.64	.10	.19	<.01	8.8	.017	.9	1.8	3.7
5	08-11-95	1.47	.06	.98	<.01	4.7	.077	.6	10	1.1
5	08-19-95	8.17	.44	8.56	<.01	3.5	.068	.5	10	.9
5	09-15-95	.36	.12	.21	<.01	6.1	--	.6	--	1.9
5	09-29-95	.56	.06	.15	<.01	13	.032	1.2	2.9	3.1
5	10-05-95	.16	.03	.24	<.01	1.9	.015	.2	1.5	.5
	Total =	43.3	--	19.1	--	--	.85	--	90	--
	Yield =	15.8	--	7.00	--	--	.31	--	33	--
Summary of guttered sites	Maximum =	15.0	.78	8.6	<.01	23	.27	5.0	31	10
	Minimum =	--	.01	.03	--	1.9	.0094	.2	1.0	.5
	Flow-weighted mean =	--	.13	--	--	5.6	--	.8	--	2.3
	Total =	114	--	56.4	--	--	2.4	--	350	--
	Yield =	14.2	--	7.04	--	--	.30	--	44	--

Yield = grams (or kilograms) per inch of rain per acre based on primary drainage area.

Table 7.—Summary of rainfall-runoff quality data—continued.

Site ID	Date	Phosphorous, load (gms)	Phosphorous, dissolved (mg/L as P)	Phosphorous, dissolved load (gms)	Cyanide, total (mg/L as Cn)	Calcium, dissolved (mg/L as Ca)	Calcium, dissolved, load (kgms)	Magnesium, dissolved (mg/L as Mg)	Magnesium, dissolved, load (gms)	Sodium, dissolved (mg/L as Na)
Unguttered sites										
1	05-08-93	--	0.44	--	<.01	8.3	--	1.8	--	26
1	06-16-93	77.3	.09	46.4	<.01	4.2	2.2	1.0	520	4.9
1	06-23-93	15.2	.37	10.8	<.01	8.4	.25	1.9	55	6.1
1	07-01-93	--	.21	--	<.01	28	--	6.5	--	13
1	08-18-93	--	.27	--	<.01	8.9	--	2.3	--	3.2
1	08-30-93	22.2	.19	19.2	--	9.0	.91	2.3	230	3.1
1	10-08-93	.45	1.10	.38	<.01	17	.0059	4.8	1.7	7.5
1	06-07-94	0	.21	0	<.01	14	.00016	2.9	.03	36
1	07-21-94	5.81	.32	4.32	<.01	4.7	.063	1.2	16	7.0
1	10-03-94	2.65	.46	1.88	<.01	14	.057	3.5	14	14
1	10-06-94	13.3	.38	9.16	<.01	5.0	.12	1.3	31	5.9
1	06-25-95	36.4	.73	34.1	<.01	4.9	.23	1.2	56	7.3
1	08-11-95	.16	.31	.12	<.01	9.8	.0039	2.6	1.0	7.4
1	10-05-95	2.84	.46	2.91	<.01	7.5	.047	2.0	13	3.9
1	10-23-95	8.64	.59	7.72	<.01	5.3	.069	1.4	18	2.8
	Total =	185	--	137	--	--	3.9	--	960	--
	Yield =	10	--	7.76	--	--	.22	--	54	--
4	05-08-93	1.90	--		<.01					
4	06-16-93	24.9	.11	11.4	<.01	8.3	.86	.8	81	6.4
4	06-23-93	13.1	1.00	10.9	<.01	11	.12	1.0	11	4.3
4	06-29-93	.09	.23	.06	<.01	6.5	.002	.7	0.2	6.9
4	07-31-93	10.9	.91	10.3	<.01	7.1	.081	1.0	11	4.4
4	09-19-93	.76	.97	.67	<.01	13	.0089	2.0	1.4	4.8
4	10-20-93	.24	.34	.09	<.01	10	.0025	1.4	.4	11
4	09-21-94	.60	.29	.58	<.01	7.2	.014	1.1	2.2	5.7
4	10-06-94	10.4	.28	6.46	<.01	4.9	.11	.8	18	1.9
4	08-04-95	.57	.33	.41	<.01	4.5	.0055	.5	.7	14
4	08-11-95	1.67	.17	1.58	<.01	5.1	.047	.5	4.4	11
4	09-29-95	.77	.56	.69	<.01	6.2	.0076	.9	1.1	10
4	10-05-95	2.22	.27	2.06	<.01	4.5	.034	.6	4.6	5.5
4	10-23-95	1.13	.38	.95	<.01	5.3	.013	.7	1.7	7.7
	Total =	69.3	--	46.2	--	--	1.3	--	140	--
	Yield =	8.64	--	5.77	--	--	.16	--	17	--
Summary of unguttered sites	Maximum =	77	1.10	46	<.01	28	2.2	6.5	520	36
	Minimum =	.005	.09	.002	--	4.2	.00016	.5	.03	2
	Flow-weighted mean =	--	.42	--	--	8.6	--	1.8	--	9
	Total=	254	--	183	--	--	5.2	--	1,100	--
	Yield =	8.25	--	5.95	--	--	.17	--	36	--
Summary of all sites	Maximum =	77	1.10	46	.01	28	2	6.5	520	36
	Minimum =	--	.01	.0024	0	1.9	.00016	.2	.033	.5
	Flow-weighted mean =	--	.17	--	.01	5.6	--	1.1	--	4.2
	Total=	368		240	--	--	8	--	1,500	--
	Yield =	11		7.31	--	--	.23	--	46	--

Table 7.—Summary of rainfall-runoff quality data—continued.

Site ID	Date	Sodium, dissolved, load, kgms	Potassium, dissolved (mg/L as K)	Potassium, dissolved, load, gms	Chloride, dissolved (mg/L as C)l	Chloride, dissolved, load, gms	Sulfate, dissolved (mg/L as SO)	Suflate, dissolved, load, gms	Fluoride, dissolved (mg/L as F)
Guttered sites									
2	05-08-93	0.041	0.7	6.8	6.2	60	2.5	24	<0.10
2	06-16-93	.026	1.3	16	1.1	14	1.2	15	.10
2	06-23-93	.044	1.7	46	1.4	38	8.5	230	<.10
2	06-29-93	.025	.8	8.7	2.1	23	2.7	29	<.10
2	07-31-93	.028	.9	18	1.6	32	1.5	30	<.10
2	10-05-93	.010	1.3	4.7	2.3	8.3	7.7	28	.20
2	10-15-93	.016	2.1	7.0	3.6	12	9.0	30	.20
2	06-17-94	.025	2.5	7.6	5.8	18	5.1	15	.10
2	08-23-94	.025	3.2	7.9	6.4	16	11	27	.50
2	06-25-95	.053	1.5	25	2.1	36	6.2	100	<.10
2	08-04-95	.028	1.7	19	2.3	26	3.9	44	<.10
2	08-11-95	.024	.7	12	0.8	14	1.2	21	<.10
2	09-15-95	.042	3.3	20	6.1	38	8.5	53	.20
2	10-05-95	.020	.6	6.8	1.1	12	1.0	11	<.10
	Total =	.41	--	210	--	350	--	660	--
	Yield =	.19	--	97	--	160	--	300	--
3	05-08-93	.022	.7	3.7	3.6	19	2.5	13	<.10
3	06-16-93	.030	<.1	--	2.5	31	1.4	18	<.10
3	06-23-93	.017	.3	6.4	1.1	24	3.6	77	<.10
3	06-29-93	.033	.6	6.0	3.5	35	3.1	31	<.10
3	07-31-93	.028	.4	5.6	5.0	70	.3	4.2	<.10
3	10-15-93	.017	2.2	4.5	8.7	18	11	22	.40
3	08-09-94	.046	1.4	7.9	5.6	31	8.0	45	.20
3	05-08-95	.038	1.0	4.2	4.7	20	3.9	17	.10
3	06-25-95	.026	1.7	8.9	6.1	32	5.5	29	<.10
3	07-25-95	.0066	1.5	1.3	3.9	3.4	9.0	7.9	.20
3	08-04-95	.013	.9	6.8	1.6	12	4.3	33	<.10
3	08-11-95	.059	1.1	30	2.3	62	3.5	94	<.10
3	08-19-95	.030	.9	15	2.2	37	2.1	35	<.10
	Total =	.36	--	100	--	390	--	420	--
	Yield =	.12	--	32	--	120	--	130	--
5	05-08-93	--	--	--	--	--	--	--	--
5	06-16-93	.073	.5	15	3.3	100	5.5	170	<.10
5	06-23-93	.014	.5	9.8	1.5	29	11	220	<.10
5	06-29-93	.012	.2	3.1	1.4	22	1.4	22	<.10
5	07-22-93	.0027	1.1	0.45	7.3	3.0	22	9.0	.40
5	07-31-93	.017	1.6	35	1.3	28	1.7	37	<.10
5	10-20-93	--	.8	--	3.3	--	14	--	.30
5	08-09-94	.018	1.2	3.2	6.2	17	13	35	.10
5	05-08-95	.015	.5	1.9	2.3	8.6	3.5	13	.10
5	08-04-95	.0071	1.1	2.1	4.0	7.7	5.8	11	.10
5	08-11-95	.018	.6	9.8	2.1	34	2.2	36	<.10
5	08-19-95	.018	4.3	84	2.4	47	2.4	47	<.10
5	09-15-95	--	.6	--	1.4	2.5	3.6	6.4	<.10
5	09-29-95	.0076	.6	1.5	2.3	5.6	4.6	11	.10
5	10-05-95	.0040	<.1		0.3	2.4	0.4	3.2	<.10
	Total =	.21	--	170	--	310	--	610	--
	Yield =	.08	--	62	--	110	--	220	--
Summary of guttered sites	Maximum =	.073	4.3	84	8.7	100	22	230	.50
	Minimum =	.0027	<.1	.45	.3	2.4	.3	3.2	<.10
	Flow-weighted mean =	--	1.1	--	2.4	--	3.9	--	--
	Total =	1.0	--	480	--	1000	--	1700	--
	Yield =	.12	--	60	--	120	--	210	--

Yield = grams (or kilograms) per inch of rain per acre based on primary drainage area.

Table 7.—Summary of rainfall-runoff quality data—continued.

Site ID	Date	Sodium, dissolved, load, kgms	Potassium, dissolved (mg/L as K)	Potassium, dissolved, load, gms	Chloride, dissolved (mg/L as C)l	Chloride, dissolved, load, gms	Sulfate, dissolved (mg/L as SO)	Suflate, dissolved, load, gms	Fluoride, dissolved (mg/L as F)
Unguttered sites									
1	05-08-93	--	3.2	--	3.2	--	4.0	--	<0.10
1	06-16-93	2.5	<.1	--	1.0	520	3.6	1,900	.10
1	06-23-93	.18	5.0	150	2.8	82	8.4	240	<.10
1	07-01-93	--	5.4	--	3.6	--	3.7	--	.10
1	08-18-93	--	3.8	--	1.4	--	2.0	--	.10
1	08-30-93	.31	3.0	300	--	--	--	--	--
1	10-08-93	.0026	13	4.5	5.5	1.9	9.9	3.4	.20
1	06-07-94	.00041	7.4	.08	13	.1	5.2	.1	<.10
1	07-21-94	.095	4.0	54	1.5	20	1.8	24	<.10
1	10-03-94	.057	5.7	23	3.5	14	5.3	22	<.10
1	10-06-94	.14	3.7	89	2.4	58	3.0	72	<.10
1	06-25-95	.34	5.5	260	2.5	120	3.4	160	<.10
1	08-11-95	.0030	5.9	2.4	3.9	1.6	5.2	2.1	.30
1	10-05-95	.025	3.8	24	1.6	10	1.2	7.6	<.10
1	10-23-95	.037	4.1	54	2.2	29	2.4	31	<.10
	Total =	3.7	--	960	--	860	--	2,500	--
	Yield =	.21	--	54	--	49	--	140	--
4	05-08-93	--	--	--	--	--	--		--
4	06-16-93	.67	<.1	--	2.4	250	4.4	460	<.10
4	06-23-93	.047	2.5	27	2.8	31	7.9	86	<.10
4	06-29-93	.0018	1.9	.50	2.0	.5	3.1	.8	<.10
4	07-31-93	.050	8.5	97	2.1	24	2.8	32	<.10
4	09-19-93	.0033	5.3	3.6	2.1	1.4	6.6	4.5	.10
4	10-20-93	.0028	3.0	.76	2.8	.7	4.2	1.1	.10
4	09-21-94	.011	4.9	9.8	2.7	5.4	2.5	5.0	<.10
4	10-06-94	.044	2.9	67	1.0	23	2.4	55	<.10
4	08-04-95	.017	3.0	3.7	3.6	4.4	3.6	4.4	<.10
4	08-11-95	.10	1.6	15	2.3	21	2.8	26	<.10
4	09-29-95	.012	4.5	5.5	2.8	3.4	3.7	4.5	<.10
4	10-05-95	.042	1.6	12	1.0	7.6	1.7	13	<.10
4	10-23-95	.019	2.5	6.3	2.6	6.5	4.7	12	<.10
	Total =	1.0	--	250	--	380	--	700	--
	Yield =	.13	--	31	--	47	--	87	--
Summary of unguttered sites	Maximum =	2.5	13	300	13	520	9.9	1,900	.30
	Minimum =	.00041	<.1	.08	1.0	.1	1.2	.1	.10
	Flow-weighted mean =	--	4.4	--	2.9	--	3.9	--	--
	Total=	4.7	--	1,200	--	1,200	--	3,200	--
	Yield =	.15	--	39	--	39	--	100	--
Summary of all sites	Maximum =	3	13	300	13	520	22	1,900	.50
	Minimum =	.00041	.1	.08	.30	.1	.3	.1	<.10
	Flow-weighted mean =	--	1.3	--	1.7	--	3.5	--	--
	Total=	6	--	1,680	--	2,200	--	4,900	--
	Yield =	.17	--	51	--	67	--	150	--

Table 7.—Summary of rainfall-runoff quality data—continued.

Site ID	Date	Fluoride, dissolved, load (gms)	Silica, dissolved (mg/L as SiO_3)	Silica, dissolved, load (gms)	Aluminum, total (µg/L as Al)	Aluminum, total, load (gms)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Barium, dissolved, load (gms)	Beryllium, dissolved, (µg/L as Be)
Guttered sites										
2	05-08-93	--	1.0	9.7	5,400	52	<1	6	0.06	<0.5
2	06-16-93	1.2	.63	7.9	590	7.4	<1	2	.02	<.5
2	06-23-93	--	.92	25	1,200	33	<1	10	.30	<.5
2	06-29-93	--	.86	9.4	310	3.4	<1	5	.05	<.5
2	07-31-93	--	.71	14	410	8.3	60	4	.08	<.5
2	10-05-93	.72	.63	2.3	4,700	17	1	5	.02	<.5
2	10-15-93	.67	1.8	6.0	4,600	15	1	10	.03	<.5
2	06-17-94	.30	2.9	8.8	1,700	5.2	<1	10	.04	<.5
2	08-23-94	1.2	3.2	7.9	3,900	9.6	1	20	.04	<.5
2	06-25-95	--	1.3	22	3,900	66	<1	10	.2	<.5
2	08-04-95	--	1.4	16	1,700	19	<1	10	.1	<.5
2	08-11-95	--	1.3	23	2,300	40	<1	5	.09	<.5
2	09-15-95	1.2	3.8	24	4,600	29	2	20	.1	<.5
2	10-05-95	--	.78	8.8	4,100	46	<1	4	.05	<.5
	Total =	5.4	--	180	--	350	--	--	1	--
	Yield =	2.5	--	83	--	162	--	--	.6	--
3	05-08-93	--	.75	3.9	5,900	31	<1	6	.03	<.5
3	06-16-93	--	.37	4.7	550	6.9	<1	3	.04	<.5
3	06-23-93	--	.30	6.4	370	8.0	<1	3	.06	<.5
3	06-29-93	--	.59	5.9	590	5.9	<1	7	.07	<.5
3	07-31-93	--	.35	4.9	170	2.4	<1	4	.06	<.5
3	10-15-93	.82	6.7	14	150,000	310	1	20	.05	<.5
3	08-09-94	1.1	1.6	9.0	1,100	6.2	<1	10	.06	<.5
3	05-08-95	.42	1.2	5.1	860	3.7	<1	6	.03	<.5
3	06-25-95	--	.68	3.5	2,000	10	<1	10	.06	<.5
3	07-25-95	.18	2.8	2.5	2,100	1.8	<1	20	.02	<.5
3	08-04-95	--	.96	7.3	5,300	40	<1	10	.08	<.5
3	08-11-95	--	.90	24	9,700	260	<1	6	.2	<.5
3	08-19-95	--	.64	11	2,100	35	<1	5	.08	<.5
	Total =	2.5	--	100	--	720	--	--	.8	--
	Yield =	.81	--	32	--	230	--	--	.3	--
5	05-08-93	--	--	--	--	--	--	--	--	--
5	06-16-93	--	1.1	34	1,500	46	<1	6	.2	<.5
5	06-23-93	--	.74	14	1,300	25	<1	7	.1	<.5
5	06-29-93	--	.33	5.1	120	1.9	<1	4	.06	<.5
5	07-22-93	.16	1.3	.53	740	.3	<1	30	.01	<.5
5	07-31-93	--	.47	10	570	12	<1	4	.09	<.5
5	10-20-93	--	1.0	--	<10	--	1	20	--	<.5
5	08-09-94	.27	.93	2.5	680	1.8	<1	20	.05	<.5
5	05-08-95	.37	1.1	4.1	2,700	10	1	7	.03	<.5
5	08-04-95	.19	1.2	2.3	750	1.4	<1	10	.02	<.5
5	08-11-95	--	.71	12	1,200	20	<1	5	.08	<.5
5	08-19-95	--	.35	6.8	1,000	19	<1	5	.1	<.5
5	09-15-95	--	.83	1.5	830	1.5	<1	8	.01	<.5
5	09-29-95	.24	1.6	3.9	1,900	4.6	<1	20	.05	<.5
5	10-05-95	--	.21	1.7	290	2.3	<1	3	.02	<.5
	Total =	1.2	--	98	--	150	--	--	.8	--
	Yield =	.5	--	36	--	55	--	--	.3	--
Summary of guttered sites	Maximum =	1.2	6.7	34	150,000	310	60	30	.30	<.5
	Minimum =	.16	.21	.53	<10	.30	<1	2	.01	--
	Flow-weighted mean =	--	.89	--	2,800	--	--	6	--	--
	Total =	9.2	--	380	--	1,200	--	--	3	--
	Yield =	1.1	--	47	--	150	--	--	.4	--

Yield = grams (or kilograms) per inch of rain per acre based on primary drainage area.

Table 7.—Summary of rainfall-runoff quality data—continued.

Site ID	Date	Fluoride, dissolved, load (gms)	Silica, dissolved (mg/L as SiO_3)	Silica, dissolved, load (gms)	Aluminum, total (µg/L as Al)	Aluminum, total, load (gms)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Barium, dissolved, load (gms)	Beryllium, dissolved, (µg/L as Be)
Unguttered sites										
1	05-08-93	--	5.6	--	450	--	1	10	--	<0.5
1	06-16-93	52	1.7	880	430	220	<1	6	3	<.5
1	06-23-93	--	2.5	73	160	4.7	<1	10	.4	<.5
1	07-01-93	--	6.9	--	80	--	3	40	--	<.5
1	08-18-93	--	2.8	--	210	--	<1	10	--	<.5
1	08-30-93	--	2.7	270	--	--	<1	10	1	<.5
1	10-08-93	.07	4.5	1.6	610	.21	2	20	.01	<.5
1	06-07-94	--	7.3	.08	2,100	.02	1	20	.0002	<.5
1	07-21-94	--	3.4	46	640	8.6	<1	9	.1	<.5
1	10-03-94	--	4.7	19	1,300	5.3	1	20	.07	<.5
1	10-06-94	--	3.0	72	900	22	<1	7	.2	<.5
1	06-25-95	--	2.1	98	290	14	<1	9	.4	<.5
1	08-11-95	.12	7.2	2.9	620	.25	3	20	.01	<.5
1	10-05-95	--	4.0	25	340	2.1	<1	10	.07	<.5
1	10-23-95	--	2.0	26	970	13	1	8	.1	<.5
	Total =	52	--	1500	--	290	--	--	6	--
	Yield =	2.9	--	85	--	16.4	--	--	.3	--
4	05-08-93	--	--	--	13,000	110			--	
4	06-16-93	--	2.5	260	16,000	1,700	2	6	.6	<.5
4	06-23-93	--	2.6	28	10,000	110	1	6	.07	<.5
4	06-29-93	--	3.4	.90	1,100	.29	1	7	.002	<.5
4	07-31-93	--	3.6	41	3,800	43	2	10	.1	<.5
4	09-19-93	.07	6.0	4.1	900	.62	1	10	.01	<.5
4	10-20-93	.03	5.0	1.3	550	.14	2	10	.003	<.5
4	09-21-94	--	4.2	8.4	1,300	2.6	2	8	.02	<.5
4	10-06-94	--	2.3	53	2,500	58	<1	6	.1	<.5
4	08-04-95	--	5.6	6.9	2,000	2.5	2	4	.005	<.5
4	08-11-95	--	4.3	40	3,800	35	2	3	.03	<.5
4	09-29-95	--	4.0	4.9	2,200	2.7	1	7	.01	<.5
4	10-05-95	--	2.3	18	1,500	11	<1	3	.02	<.5
4	10-23-95	--	2.1	5.3	930	2.3	1	6	.02	<.5
	Total =	.09	--	470	--	2,040	--	--	1	--
	Yield =	.01	--	59	--	255	--	--	.1	--
Summary of unguttered sites	Maximum =	52	7.3	880	16,000	1,700	3	40	3	<.5
	Minimum =	--	1.7	.08	80	.02	<1	3	.0002	--
	Flow-weighted mean =	--	4.0	--	1,200	--	--	11	--	--
	Total=	52	--	2,000	--	2,300	--	--	7	--
	Yield =	1.7	--	65	--	74.7	--	--	.2	--
Summary of all sites	Maximum =	52	7.3	880	150,000	1,700	60	40	3	<.5
	Minimum =	--	.21	.08	<10	--	<1	2	.0002	--
	Flow-weighted mean =	--	1.7	--	2,600	--	--	7	--	--
	Total=	61	--	2400	--	3,500	--	--	10	--
	Yield =	1.9	--	73	--	107	--	--	.3	--

Table 7.—Summary of rainfall-runoff quality data—continued.

Site ID	Date	Cadmium, dissolved (µg/L as Cd)	Cadmium, total (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Chromium, total (µg/L as Cr)	Chromium, total, load (gms)	Cobalt, dissolved (µg/L as Co)	Copper, dissolved (µg/L as Cu)	Copper, total (µg/L as Cu)	Copper, total, load (gms)
Guttered sites										
2	05-08-93	<1.0	<10	<5	10	0.1	<3	<10	40	0.4
2	06-16-93	<1.0	<10	<5	2	.02	<3	<10	<10	--
2	06-23-93	1.0	<10	<5	3	.08	<3	<10	<10	--
2	06-29-93	1.0	<10	<5	2	.02	<3	<10	<10	--
2	07-31-93	<1.0	<10	<5	3	.06	<3	<10	<10	--
2	10-05-93	2.0	<10	<5	9	.03	<3	<10	20	.1
2	10-15-93	<1.0	<10	<5	10	.03	<3	<10	20	.1
2	06-17-94	<1.0	<10	8	10	.04	<3	<10	20	.1
2	08-23-94	<1.0	<10	5	10	.03	<3	20	40	.1
2	06-25-95	4.0	<10	<5	10	.2	<3	<10	20	.3
2	08-04-95	<1.0	<10	<5	7	.07	<3	10	20	.2
2	08-11-95	<1.0	<10	6	10	.2	<3	<10	10	.2
2	09-15-95	<1.0	<10	<5	10	.07	<3	<10	30	.2
2	10-05-95	<1.0	<10	<5	10	.1	<3	<10	20	.2
	Total =	--	--	--	--	1	--	--	--	1.8
	Yield =	--	--	--	--	.5	--	--	--	.8
3	05-08-93	<1.0	<10	<5	40	.2	<3	<10	70	.4
3	06-16-93	<1.0	<10	<5	3	.04	<3	<10	<10	--
3	06-23-93	<1.0	<10	<5	2	.04	<3	<10	<10	--
3	06-29-93	1.0	<10	<5	4	.04	<3	<10	<10	--
3	07-31-93	<1.0	<10	<5	2	.03	<3	<10	<10	--
3	10-15-93	<1.0	30	<5	500	.9	<3	20	850	1.7
3	08-09-94	<1.0	<10	<5	5	.03	<3	10	30	.2
3	05-08-95	<1.0	<10	5	7	.03	<3	10	30	.1
3	06-25-95	5.0	<10	<5	10	.05	<3	10	30	.2
3	07-25-95	1.0	<10	<5	7	.01	<3	10	20	.02
3	08-04-95	<1.0	<10	6	20	.1	<3	<10	60	.5
3	08-11-95	<1.0	<10	<5	20	.7	4	<10	60	1.6
3	08-19-95	<1.0	<10	<5	5	.08	<3	<10	20	.3
	Total =	--	--	--	--	2	--	--	--	5.0
	Yield =	--	--	--	--	.6	--	--	--	1.6
5	05-08-93	--	--	--	--	--	--	--	--	--
5	06-16-93	<1.0	<10	<5	10	.3	<3	<10	20	.6
5	06-23-93	<1.0	<10	<5	6	.1	<3	<10	20	.4
5	06-29-93	<1.0	<10	<5	1	.02	<3	<10	<10	--
5	07-22-93	<1.0	<10	5	9	.004	<3	30	40	.02
5	07-31-93	<1.0	<10	<5	5	.1	<3	<10	10	.2
5	10-20-93	<1.0	<10	<5	4	--	<3	30	30	--
5	08-09-94	<1.0	<10	5	9	.02	4	30	50	.1
5	05-08-95	<1.0	<10	<5	20	.08	<3	10	60	.2
5	08-04-95	<1.0	<10	8	7	.01	<3	20	30	.1
5	08-11-95	<1.0	<10	<5	10	.2	5	<10	30	.5
5	08-19-95	2.0	<10	<5	6	.1	<3	<10	30	.6
5	09-15-95	<1.0	<10	<5	6	.01	<3	10	20	.04
5	09-29-95	<1.0	<10	5	10	.03	<3	10	70	.2
5	10-05-95	<1.0	<10	<5	2	.02	<3	<10	10	.1
	Total =	--	--	--	--	1	--	--	--	3.0
	Yield =	--	--	--	--	.4	--	--	--	1.1
Summary of guttered sites	Maximum =	5.0	30	8	500	.9	5	30	850	1.7
	Minimum =	<1.0	<10	<5	1	.004	<3	<10	<10	.02
	Flow-weighted mean =	--	--	--	10	--	--	--	--	--
	Total =	--	--	--	--	4	--	--	--	10
	Yield =	--	--	--	--	.5	--	--	--	1.2

Yield = grams (or kilograms) per inch of rain per acre based on primary drainage area.

Table 7.—Summary of rainfall-runoff quality data—continued.

Site ID	Date	Cadmium, dissolved (µg/L as Cd)	Cadmium, total (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Chromium, total (µg/L as Cr)	Chromium, total, load (gms)	Cobalt, dissolved (µg/L as Co)	Copper, dissolved (µg/L as Cu)	Copper, total (µg/L as Cu)	Copper, total, load (gms)
Unguttered sites										
1	05-08-93	<1.0	<10	<5	2	--	<3	<10	<10	--
1	06-16-93	<1.0	<10	<5	2	1	<3	<10	<10	--
1	06-23-93	<1.0	<10	<5	2	.06	<3	<10	<10	-
1	07-01-93	<1.0	<10	<5	<1	--	<3	<10	<10	--
1	08-18-93	<1.0	<10	<5	<1	--	<3	<10	<10	--
1	08-30-93	<1.0	--	<5		--	<3	<10	--	0.0
1	10-08-93	<1.0	<10	<5	2	.001	<3	<10	10	0
1	06-07-94	<1.0	<10	<5	6	.0001	<3	10	20	0
1	07-21-94	<1.0	<10	<5	2	.03	<3	<10	<10	--
1	10-03-94	<1.0	<10	<5	4	.02	<3	<10	<10	--
1	10-06-94	<1.0	<10	<5	2	.05	<3	<10	<10	--
1	06-25-95	2.0	<10	<5	1	.05	<3	10	10	.5
1	08-11-95	2.0	<10	<5	2	.001	7	<10	10	0
1	10-05-95	<1.0	<10	<5	1	.01	<3	<10	<10	--
1	10-23-95	<1.0	<10	<5	3	.03	<3	<10	10	.1
	Total =	--	--	--	--	1	--	--	--	.6
	Yield =	--	--	--	--	.07	--	--	--	.03
4	05-08-93	--	10	--	70	.6	--	--	110	.9
4	06-16-93	<1.0	<10	<5	40	4	<3	<10	80	8.3
4	06-23-93	<1.0	<10	<5	20	.2	<3	<10	30	.3
4	06-29-93	<1.0	<10	<5	2	.001	<3	<10	<10	--
4	07-31-93	<1.0	<10	<5	8	.09	<3	<10	10	.1
4	09-19-93	<1.0	<10	<5	5	.003	<3	<10	<10	--
4	10-20-93	<1.0	<10	<5	20	.01	<3	<10	50	0
4	09-21-94	<1.0	<10	<5	4	.01	3	<10	<10	--
4	10-06-94	<1.0	<10	<5	4	.09	<3	<10	<10	--
4	08-04-95	<1.0	<10	<5	6	.01	<3	<10	10	0
4	08-11-95	2.0	<10	<5	8	.08	<3	<10	20	.2
4	09-29-95	<1.0	<10	<5	5	.01	<3	<10	20	0
4	10-05-95	<1.0	<10	<5	4	.03	<3	<10	<10	--
4	10-23-95	<1.0	<10	<5	3	.01	<3	<10	<10	--
	Total =	--	--	--	--	5	--	--	--	9.9
	Yield =	--	--	--	--	.7	--	--	--	1.2
Summary of unguttered sites	Maximum =	2.0	10	<5	70	4	7	10	110	8.3
	Minimum =	<1.0	<10	--	1	.0001	<3	<10	<10	--
	Flow-weighted mean =	--	--	--	4	--	--	--	--	--
	Total=	--	--	--	--	7	--	--	--	11
	Yield =	--	--	--	--	.2	--	--	--	.34
Summary of all sites	Maximum =	5.0	30	8	500	4	7	30	850	8
	Minimum =	<1.0	<10	<5	<1	.0001	<3	<10	<10	0
	Flow-weighted mean =	--	--	--	8	--	--	--	--	--
	Total=	--	--	--	--	10	--	--	--	--
	Yield =	--	--	--	--	.3	--	--	--	--

Table 7.—Summary of rainfall-runoff quality data—continued.

Site ID	Date	Iron, dissolved (µg/L as Fe)	Iron, dissolved, load (gms)	Lead, dissolved (µg/L as Pb)	Lead, total (µg/L as Pb)	Lithium, dissolved (µg/L as Li)	Manganese, dissolved (µg/L as Mn)	Manganese, dissolved, load (gms)	Mercury, dissolved (µg/L as Hg)	Molybdenum, dissolved (µg/L as Mo)
Guttered sites										
2	05-08-93	41	0.40	<10	<100	<4	13	0.13	<0.1	<10
2	06-16-93	40	.50	<10	<100	<4	28	.35	<.1	<10
2	06-23-93	86	2.4	<10	<100	<4	54	1.5	<.1	<10
2	06-29-93	29	.32	<10	<100	<4	26	.28	<.1	<10
2	07-31-93	34	.69	<10	<100	<4	29	.59	<.1	<10
2	10-05-93	52	.19	<10	<100	<4	37	.13	<.1	<10
2	10-15-93	67	.22	<10	<100	<4	64	.21	<.1	<10
2	06-17-94	98	.30	<10	<100	<4	20	.061	<.1	<10
2	08-23-94	44	.11	20	<100	<4	30	.074	<.1	<10
2	06-25-95	46	.78	20	<100	4	36	.61	<.1	20
2	08-04-95	43	.49	<10	<100	<4	27	.31	<.1	10
2	08-11-95	110	1.9	20	<100	<4	13	.23	<.1	<10
2	09-15-95	27	.17	<10	<100	<4	54	.33	<.1	<10
2	10-05-95	57	.64	<10	<100	<4	10	.11	<.1	<10
	Total =	--	9.0	--	--	--	--	4.9	--	--
	Yield =	--	4.2	--	--	--	--	2.3	--	--
3	05-08-93	23	.12	<10	200	<4	17	.09	<.1	<10
3	06-16-93	53	.67	<10	<100	<4	27	.34	<.1	<10
3	06-23-93	14	.30	<10	<100	<4	27	.58	<.1	<10
3	06-29-93	31	.31	<10	<100	<4	52	.52	<.1	<10
3	07-31-93	26	.36	<10	<100	<4	39	.55	<.1	<10
3	10-15-93	70	.14	<10	800	<4	8	.016	<.1	<10
3	08-09-94	110	.62	<10	<100	<4	110	.62	<.1	<10
3	05-08-95	90	.38	<10	<100	<4	42	.18	.3	<10
3	06-25-95	98	.51	20	<100	<4	110	.57	<.1	<10
3	07-25-95	52	.05	<10	<100	<4	98	.086	<.1	<10
3	08-04-95	52	.39	<10	<100	<4	32	.24	<.1	<10
3	08-11-95	14	.38	<10	<100	<4	16	.43	<.1	20
3	08-19-95	49	.81	<10	<100	<4	22	.37	<.1	<10
	Total =	--	5.0	--	--	--	--	4.6	--	--
	Yield =	--	1.6	--	--	--	--	1.5	--	--
5	05-08-93	--	--	--	--	--	--	--	<.1	--
5	06-16-93	32	1.0	<10	<100	<4	42	1.3	<.1	<10
5	06-23-93	13	.25	<10	<100	<4	45	.88	<.1	<10
5	06-29-93	65	1.0	<10	<100	<4	32	.50	<.1	<10
5	07-22-93	97	.04	<10	<100	4	350	.14	<.1	<10
5	07-31-93	31	.67	<10	<100	<4	33	.71	<.1	<10
5	10-20-93	53	--	10	100	<4	65	--	<.1	<10
5	08-09-94	100	.27	<10	<100	6	230	.62	<.1	<10
5	05-08-95	120	.45	<10	<100	<4	52	.19	<.1	<10
5	08-04-95	97	.19	<10	<100	<4	76	.15	<.1	10
5	08-11-95	61	1.0	<10	<100	<4	33	.54	<.1	<10
5	08-19-95	25	.49	20	<100	<4	14	.27	<.1	<10
5	09-15-95	110	.20	<10	<100	<4	60	.11	<.1	<10
5	09-29-95	45	.11	<10	<100	<4	40	.10	<.1	<10
5	10-05-95	14	.11	<10	<100	<4	7	.06	<.1	<10
	Total =	--	5.8	--	--	--	--	5.6	--	--
	Yield =	--	2.1	--	--	--	--	2.0	--	--
Summary of guttered sites	Maximum =	120	2.3	20	800	6	350	1.5	.3	20
	Minimum =	13	.04	<10	<100	<4	7	.016	<.1	<10
	Flow-weighted mean =	46	--	--	--	--	35	--	--	--
	Total =	--	20	--	--	--	--	15	--	--
	Yield =	--	2.5	--	--	--	--	1.9	--	--

Yield = grams (or kilograms) per inch of rain per acre based on primary drainage area.

Table 7.—Summary of rainfall-runoff quality data—continued.

Site ID	Date	Iron, dissolved (µg/L as Fe)	Iron, dissolved, load (gms)	Lead, dissolved (µg/L as Pb)	Lead, total (µg/L as Pb)	Lithium, dissolved (µg/L as Li)	Manganese, dissolved (µg/L as Mn)	Manganese, dissolved, load (gms)	Mercury, dissolved (µg/L as Hg)	Molybdenum, dissolved (µg/L as Mo)
Unguttered sites										
1	05-08-93	280	--	<10	<100	<4	5	--	<0.1	<10
1	06-16-93	75	39	<10	<100	<4	1	0.52	<.1	<10
1	06-23-93	98	2.9	<10	<100	<4	2	.058	<.1	<10
1	07-01-93	65	--	<10	<100	<4	2	--	<.1	<10
1	08-18-93	71	--	<10	<100	<4	1	--	<.1	<10
1	08-30-93	47	4.8	<10	--	<4	2	.20	--	10
1	10-08-93	63	.02	<10	<100	<4	4	.0014	<.1	<10
1	06-07-94	88	.001	<10	<100	<4	<1	--	<.1	<10
1	07-21-94	360	4.9	<10	<100	<4	2	.027	<.1	<10
1	10-03-94	39	.16	<10	<100	<4	<1	--	<.1	<10
1	10-06-94	100	2.4	<10	<100	<4	1	.024	<.1	<10
1	06-25-95	92	4.3	<10	<100	4	11	.51	<.1	20
1	08-11-95	310	.12	40	<100	<4	5	.0020	<.1	10
1	10-05-95	130	.82	<10	<100	<4	2	.013	<.1	<10
1	10-23-95	27	.35	<10	<100	<4	1	.013	<.1	<10
	Total =	--	59	--	--	--	--	1.4	--	--
	Yield =	--	3.4	--	--	--	--	.08	--	--
4	05-08-93	--	--	--	100	--	--	--	<.1	
4	06-16-93	35	3.6	<10	100	<4	2	.21	--	<10
4	06-23-93	25	.27	<10	<100	<4	1	.011	<.1	<10
4	06-29-93	72	.02	<10	<100	<4	2	.0005	<.1	<10
4	07-31-93	64	.73	<10	<100	<4	3	.03	<.1	<10
4	09-19-93	99	.07	<10	<100	<4	9	.0062	<.1	<10
4	10-20-93	220	.06	<10	100	4	16	.0041	<.1	<10
4	09-21-94	15	.03	10	<100	<4	<1	--	<.1	20
4	10-06-94	79	1.8	10	<100	<4	2	.046	<.1	<10
4	08-04-95	62	.08	40	<100	<4	2	.0025	<.1	<10
4	08-11-95	10	.09	<10	<100	<4	1	--	<.1	20
4	09-29-95	30	.04	<10	<100	<4	4	.0049	<.1	<10
4	10-05-95	20	.15	<10	<100	<4	<1	--	<.1	<10
4	10-23-95	35	.09	20	<100	<4	5	.013	<.1	<10
	Total =	--	7.1	--	--	--	--	.33	--	--
	Yield =	--	.88	--	--	--	--	.04	--	--
Summary of unguttered sites	Maximum =	360	39	40	100	4	16	.5	<.1	20
	Minimum =	10	.001	<10	<100	<4	<1	--	--	<10
	Flow weighted mean =	98	--	--	--	--	--	--	--	--
	Total=	--	66	--	--	--	--	1.7	--	--
	Yield =	--	2.2	--	--	--	--	.06	--	--
Summary of all sites	Maximum =	360	39	40	800	6	350	1	0.3	20
	Minimum =	10	.001	<10	<100	<4	<1	--	<.1	<10
	Flow-weighted mean =	63	--	--	--	--	12	.26	--	--
	Total=	--	86	--	--	--	--	17	--	--
	Yield =	--	2.6	--	--	--	--	.51	--	--

Table 7.—Summary of rainfall-runoff quality data—continued.

Site ID	Date	Nickel, dissolved (µg/L as Ni)	Silver, dissolved (µg/L as Ag)	Strontium, dissolved (µg/L as Sr)	Strontium, dissolved, load (gms)	Vanadium, dissolved (µg/L as V)	Zinc, dissolved (µg/L as Zn)	Zinc, dissolved, load (gms)	Zinc, total (µg/L as Zn)	Zinc, total, load (gms)
Guttered sites										
2	05-08-93	<10	2	7	0.07	6	13	0.13	190	1.8
2	06-16-93	<10	<1	4	.05	6	20	.25	40	.5
2	06-23-93	<10	1	10	.27	6	33	.90	70	1.9
2	06-29-93	<10	<1	7	.08	6	47	.51	70	.8
2	07-31-93	<10	<1	13	.26	<6	54	1.1	1,10	2.2
2	10-05-93	<10	<1	8	.03	<6	20	.072	300	1.1
2	10-15-93	<10	<1	18	.06	<6	7	.023	140	.5
2	06-17-94	<10	<1	20	.06	<6	21	.064	90	.3
2	08-23-94	<10	<1	32	.08	<6	18	.044	170	.4
2	06-25-95	<10	<1	14	.24	<6	39	.66	280	4.7
2	08-04-95	<10	<1	13	.15	<6	74	.84	200	2.3
2	08-11-95	<10	<1	6	.10	<6	12	.21	70	1.2
2	09-15-95	<10	<1	32	.20	<6	6	.037	170	1.1
2	10-05-95	<10	<1	5	.06	<6	8	.090	120	1.4
	Total =	--	--	--	1.7	--	--	4.9	--	20
	Yield =	--	--	--	.79	--	--	2.3	--	9.3
3	05-08-93	<10	<1	9	.05	<6	17	.089	310	1.6
3	06-16-93	<10	2	4	.05	<6	23	.29	50	.6
3	06-23-93	<10	<1	4	.09	<6	19	.41	40	.9
3	06-29-93	<10	<1	6	.06	<6	34	.34	70	.7
3	07-31-93	<10	<1	4	.06	<6	40	.56	70	1.0
3	10-15-93	<10	<1	32	.07	<6	<3	--	2,900	5.9
3	08-09-94	<10	<1	12	.07	<6	37	.21	90	.5
3	05-08-95	<10	<1	9	.04	<6	22	.093	70	.3
3	06-25-95	<10	1	11	.06	<6	37	.19	180	.9
3	07-25-95	<10	<1	29	.03	<6	30	.026	70	.1
3	08-04-95	<10	<1	11	.08	<6	17	.13	200	1.5
3	08-11-95	<10	1	9	.24	<6	5	.13	300	8.1
3	08-19-95	<10	<1	6	.10	<6	8	.13	80	1.3
	Total =	--	--	--	.98	--	--	2.6	--	23
	Yield =	--	--	--	.31	--	--	.83	--	7.5
5	05-08-93	--	--	--						
5	06-16-93	<10	1	11	.34	<6	17	.52	80	2.4
5	06-23-93	<10	<1	9	.18	<6	20	.39	70	1.4
5	06-29-93	<10	<1	4	.06	<6	19	.30	20	.3
5	07-22-93	10	<1	24	.01	<6	85	.035	160	.1
5	07-31-93	<10	<1	4	.09	<6	8	.17	40	.9
5	10-20-93	<10	<1	12	--	<6	82	--	150	--
5	08-09-94	<10	<1	19	.05	<6	150	.40	200	.5
5	05-08-95	<10	<1	11	.04	<6	14	.052	200	.7
5	08-04-95	<10	3	11	.02	<6	52	.10	120	.2
5	08-11-95	<10	<1	5	.08	<6	26	.43	120	2.0
5	08-19-95	<10	1	4	.08	<6	12	.23	70	1.4
5	09-15-95	<10	<1	6	.01	<6	66	.12	180	.3
5	09-29-95	<10	<1	18	.04	<6	120	.29	260	.6
5	10-05-95	<10	<1	2	.02	<6	13	.10	30	.2
	Total =	--	--	--	1.0	--	--	3.1	--	11
	Yield =	--	--	--	.4	--	--	1.2	--	4.1
Summary of guttered sites	Maximum =	10	3	32	.3	<6	150	1.1	2,900	8.1
	Minimum =	<10	<1	2	.01	--	<3	.023	20	.1
	Flow-weighted mean =	--	--	8	--	--	25	--	130	--
	Total =	--	--	--	3.7	--	--	11	--	55
	Yield =	--	--	--	.46	--	--	1.3	--	6.8

Yield = grams (or kilograms) per inch of rain per acre based on primary drainage area.

Table 7.—Summary of rainfall-runoff quality data—continued.

Site ID	Date	Nickel, dissolved (µg/L as Ni)	Silver, dissolved (µg/L as Ag)	Strontium, dissolved (µg/L as Sr)	Strontium, dissolved, load (gms)	Vanadium, dissolved (µg/L as V)	Zinc, dissolved (µg/L as Zn)	Zinc, dissolved, load (gms)	Zinc, total (µg/L as Zn)	Zinc, total, load (gms)
Unguttered sites										
1	05-08-93	<10	<1	12	--	<6	21	--	30	--
1	06-16-93	<10	2	6	3.1	<6	31	16	70	36
1	06-23-93	<10	<1	13	.38	<6	24	.70	30	.88
1	07-01-93	<10	<1	41	--	<6	68	--	130	--
1	08-18-93	<10	<1	14	--	<6	6	--	30	--
1	08-30-93	<10	<1	13	1.3	<6	5	.51	--	--
1	10-08-93	<10	<1	22	.01	<6	17	.0059	60	.021
1	06-07-94	<10	<1	21	.0002	<6	140	.0016	290	.0033
1	07-21-94	<10	<1	5	.07	<6	20	.27	40	.54
1	10-03-94	<10	<1	20	.08	<6	83	.34	350	1.4
1	10-06-94	<10	2	7	.17	<6	9	.22	30	.72
1	06-25-95	<10	<1	7	.33	<6	28	1.3	40	1.9
1	08-11-95	20	<1	17	.01	<6	97	.039	140	.06
1	10-05-95	<10	<1	11	.07	<6	19	.12	30	.19
1	10-23-95	<10	<1	8	.10	<6	30	.39	140	1.8
	Total =	--	--	--	5.6	--	--	20	--	44
	Yield =	--	--	--	.32	--	--	1.1	--	2.5
4	05-08-93	--	--	--	--	--	--	--	330	2.7
4	06-16-93	<10	2	12	1.2	<6	110	11	200	21
4	06-23-93	<10	<1	15	.16	<6	<3	--	110	1.2
4	06-29-93	<10	<1	9	.002	<6	<3	--	30	.0079
4	07-31-93	<10	<1	13	.148	<6	18	.20	50	.57
4	09-19-93	<10	<1	17	.01	<6	9	.0062	40	.028
4	10-20-93	<10	<1	14	.004	<6	9	.0023	140	.036
4	09-21-94	<10	<1	10	.02	<6	14	.028	60	.12
4	10-06-94	<10	3	15	.35	<6	4	.092	30	.69
4	08-04-95	<10	<1	6	.01	<6	5	.0062	40	.049
4	08-11-95	<10	<1	6	.06	<6	<3	--	40	.37
4	09-29-95	<10	<1	8	.01	<6	34	.042	90	.11
4	10-05-95	<10	<1	5	.04	<6	3	.023	20	.15
4	10-23-95	<10	1	7	.02	<6	13	.033	40	.10
	Total =	--	--	--	2.1	--	--	12	--	27
	Yield =	--	--	--	.26	--	--	1.5	--	3.4
Summary of unguttered sites	Maximum =	20	3	41	3.1	<6	140	16	350	36
	Minimum =	<10	<1	5	.0002	--	<3	.0016	20	.0033
	Flow-weighted mean =	--	--	13	--	--	27	--	80	--
	Total=	--	--	--	7.7	--	--	32	--	71
	Yield =	--	--	--	.25	--	--	1.0	--	2.3
Summary of all sites	Maximum =	20	3	41	3	<6	150	16	2,900	36
	Minimum =	<10	<1	2	.0002	--	<3	.0016	20	.0033
	Flow-weighted mean =	--	--	8.3	--	--	31	--	90	--
	Total=	--	--	--	11	--	--	42	--	120
	Yield =	--	--	--	.35	--	--	1.3	--	3.7