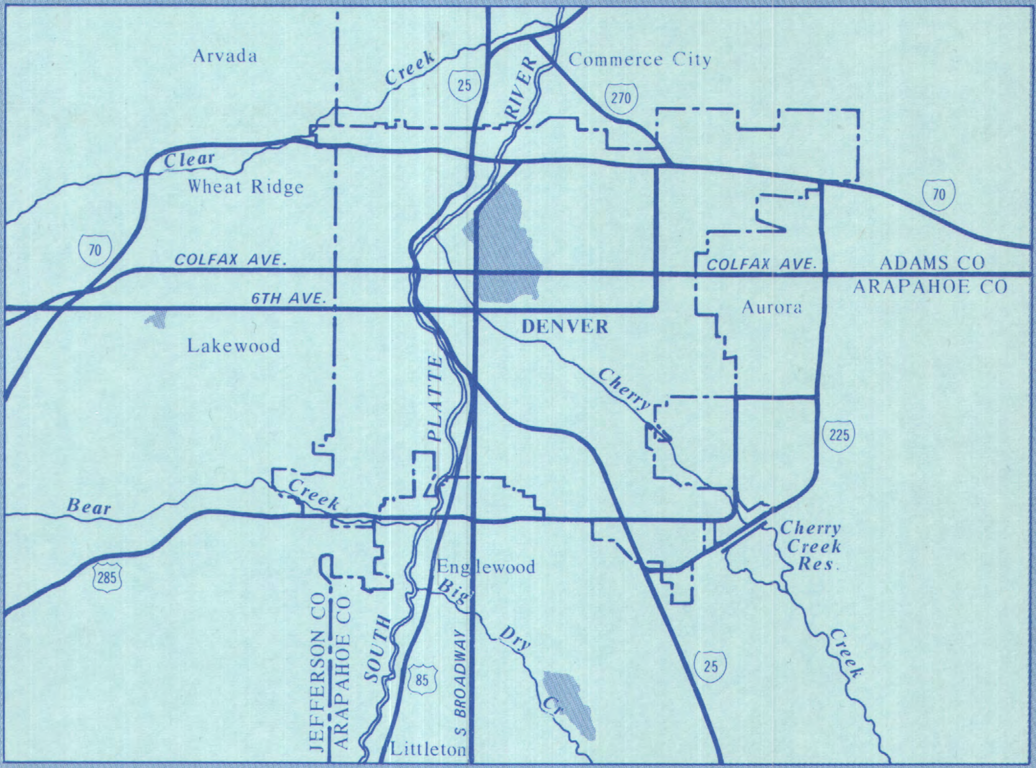
c. 1

QUANTITY AND QUALITY OF URBAN RUNOFF FROM THREE LOCALITIES IN THE DENVER METROPOLITAN AREA, COLORADO

U. S. GEOLOGICAL SURVEY



Water-Resources Investigations 79-64

d in cooperation with the
Board of Water Commissioners,
Regional Council of Governments,
rainage and Flood Control District

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.

4. Title and Subtitle
QUANTITY AND QUALITY OF URBAN RUNOFF FROM THREE LOCALITIES IN THE DENVER METROPOLITAN AREA, COLORADO

5. Report Date May 1979

6.

7. Author(s)
Sherman R. Ellis and William M. Alley

8. Performing Organization Rept. No. USGS/WRI 79-64

9. Performing Organization Name and Address
U.S. Geological Survey, Water Resources Division
Denver Federal Center, Box 25046, Mail Stop 415
Lakewood, CO 80225

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. Sponsoring Organization Name and Address
U.S. Geological Survey, Water Resources Division
Denver Federal Center, Box 25046, Mail Stop 415
Lakewood, CO 80225

13. Type of Report & Period Covered Final

15. Supplementary Notes

16. Abstracts Considerable variation in constituent concentrations was shown in urban runoff data for 1975-77 from three metropolitan Denver drainage basins. Constituent concentrations, greatest during initial rainfall runoff, generally peaked midday of snowmelt runoff, corresponding with maximum melting and runoff. Instantaneous loads of constituents were largely a function of discharge. Days since last street sweeping or antecedent precipitation had no apparent effect; snowmelt-runoff loads apparently increased with number of days snow had been on the ground. Urban storm runoff may significantly contribute total ammonia nitrogen, total nonfiltrable residue, total copper, total iron, total lead, and total zinc; and snowmelt runoff may significantly contribute sodium and chloride, to local receiving waters. Data from two basins were used for calibration and verification of U.S. Environmental Protection Agency's Storm Water Management Model II for rainfall-runoff modeling of flow and total nitrogen. The model assumption that land-surface loads of total nitrogen are directly proportional to number of days prior to storm during which accumulated rainfall was less than 1.0 inch was not substantiated.

17. Key Words and Document Analysis. 17a. Descriptors

Urban runoff, Rainfall runoff, Water quality, Storm-water management, Colorado

17b. Identifiers/Open-Ended Terms

Arapahoe County, Denver County, Jefferson County

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
No restriction on distribution	UNCLASSIFIED	66
	20. Security Class (This Page) UNCLASSIFIED	22. Price

QUANTITY AND QUALITY OF URBAN RUNOFF FROM THREE LOCALITIES IN THE DENVER METROPOLITAN AREA, COLORADO

By Sherman R. Ellis and William M. Alley

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 79-64

Prepared in cooperation with the
Denver Board of Water Commissioners, the
Denver Regional Council of Governments, and the
Urban Drainage and Flood Control District

May 1979

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

H. William Menard, Director

For additional information write to:

District Chief
U.S. Geological Survey
Box 25046, Mail Stop 415
Denver Federal Center
Lakewood, CO 80225

CONTENTS

ILLUSTRATIONS

CONTENTS

CONTENTS

TABLES

GLOSSARY

dry-weather flow.--That flow from an urban drainage basin that contains no storm water but rather results from base flow, lawn watering, dumping of wastes into the storm-sewer system, and other similar causes.

impervious areas, effective.--Impervious areas which are connected and do not drain to pervious areas. Streets, roofs which drain onto driveways, and paved parking lots are examples of effective impervious areas.

impervious areas, noneffective.--Impervious areas which drain to pervious areas, such as roofs which drain onto lawns.

rainfall runoff.--That part of a rainstorm that appears at the outlet from a drainage basin.

receiving water.--"Natural" body of water which receives runoff from one or more drainage basins; this includes a stream, river, estuary, bay, lake, or other body of water.

snowmelt runoff.--Water from melting snow that appears at the outlet of a drainage basin.

storm runoff.--This term is used when referring to both rainfall runoff and snowmelt runoff.

urban runoff.--Runoff from an urban drainage basin. The term may relate to either dry-weather flow or storm runoff or both.

METRIC CONVERSION FACTORS

Multiply inch-pound unit	*By*	*To obtain metric unit*
inch (in.)	25.40	millimeter
inch per hour (in./h)	25.40	millimeter per hour
foot (ft)	0.3048	meter
acre	0.4047	hectare
gallon	3.785	liter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
pound (avoirdupois)	0.4536	kilogram
pound per acre	1.121	kilogram per hectare
pound per acre per inch	44.13	kilogram per hectare per meter
pound per day per foot	1.488	kilogram per day per meter
pound per second	0.4536	kilogram per second

QUANTITY AND QUALITY OF URBAN RUNOFF FROM THREE LOCALITIES IN THE DENVER METROPOLITAN AREA, COLORADO

By Sherman R. Ellis and William M. Alley

ABSTRACT

Urban-runoff data were collected from 1975 to 1977 on three drainage basins in the Denver metropolitan area. Constituent concentrations in the urban runoff varied considerably. However, constituent concentrations in rainfall runoff generally were greatest during the initial parts of the runoff periods and then decreased with time. In snowmelt runoff, constituent concentrations generally peaked during the middle of the day corresponding with periods of maximum melting and runoff. Instantaneous loads of constituents were largely a function of discharge for both rainfall and snowmelt runoff. A first flush, defined as a disproportionately large part of the total storm-runoff load in the initial part of the storm runoff, was rare.

Antecedent precipitation or the number of days since the last street sweeping had no apparent effect on rainfall-runoff quality. However, snowmelt-runoff loads apparently increased with the number of days snow had been on the ground. In addition, several instances were documented in which land-use activities, such as building construction or application of fertilizers and pesticides, had a discernible effect on the quality of storm runoff.

Urban storm runoff may be a significant contributor of total ammonia nitrogen, total nonfiltrable residue, total copper, total iron, total lead, and total zinc to local receiving waters. During the winter months, snowmelt runoff may be a significant contributor of sodium and chloride to local receiving waters.

Data from two of the basins were used for calibration and verification of the U.S. Environmental Protection Agency's Storm Water Management Model II for rainfall-runoff modeling of flow and total nitrogen. Using values for the accumulation and washoff parameters as suggested in the user's manual for the model and basin-characteristic parameters as determined from the model calibration for flow, the errors in simulated rainfall-runoff loads of total nitrogen ranged from +67 to +1,000 percent. The model assumption that land-surface loads of total nitrogen are directly proportional to the number of days prior to the storm during which the accumulated rainfall was less than 1.0 inch was not substantiated. Based on the results of this study, caution should be used when applying the Storm Water Management Model II or other similar models to assist in making water-quality-management decisions, particularly in the absence of local data for model calibration and verification.

INTRODUCTION

The effects of urban runoff on water quality are of concern in most metropolitan areas in the United States. This concern has been largely a result of the areawide planning requirements of Section 208 of Public Law 92-500, 1972 Amendments to the Federal Water Pollution Control Act.

The urban-runoff-quality process is complex and not well understood. The data base needed to understand urban-runoff quality in the Denver metropolitan area was practically nonexistent. There was a particular lack of synchronized precipitation, runoff, and water-quality data.

In response to the above considerations, during 1975 the U.S. Geological Survey entered into separate but coordinated cooperative agreements with several local governmental entities--the Denver Board of Water Commissioners, the Denver Regional Council of Governments, and the Urban Drainage and Flood Control District--to investigate the quantity and quality of urban runoff. Three drainage basins in the Denver metropolitan area (fig. 1) were instrumented. Data collected during the investigation have been published by Ellis (1978).

The purposes of this report are:

1. To improve knowledge of the types and concentrations of dissolved and suspended material in urban runoff in the Denver metropolitan area.
2. To improve knowledge of the impact of urban runoff on the quality of local receiving waters.
3. To report the results of calibration and verification of the U.S. Environmental Protection Agency's Storm Water Management Model II (Huber and others, 1975).

DESCRIPTIONS OF THE DRAINAGE BASINS

Selected basin data for the three monitoring sites are shown in table 1. The drainage basin located in Littleton, Colo. (the Littleton site), has an area of 606 acres, of which approximately 75 percent is single-family dwellings and 25 percent is parks and open space (fig. 2). About 15 percent of the basin is covered by effective impervious surfaces and 10 percent by noneffective impervious surfaces. Street gutters and open ditches are the predominant drainage types for flow conveyance.

The drainage basin located in Lakewood, Colo. (the Lakewood site), has an area of 76.7 acres, of which approximately 50 percent is undeveloped land, 30 percent is multifamily dwellings, and 20 percent is commercial development (fig. 3). Approximately 30 percent of the basin is covered by effective impervious surfaces and 10 percent by noneffective impervious surfaces. Street gutters convey storm runoff to a storm sewer crossing the basin.

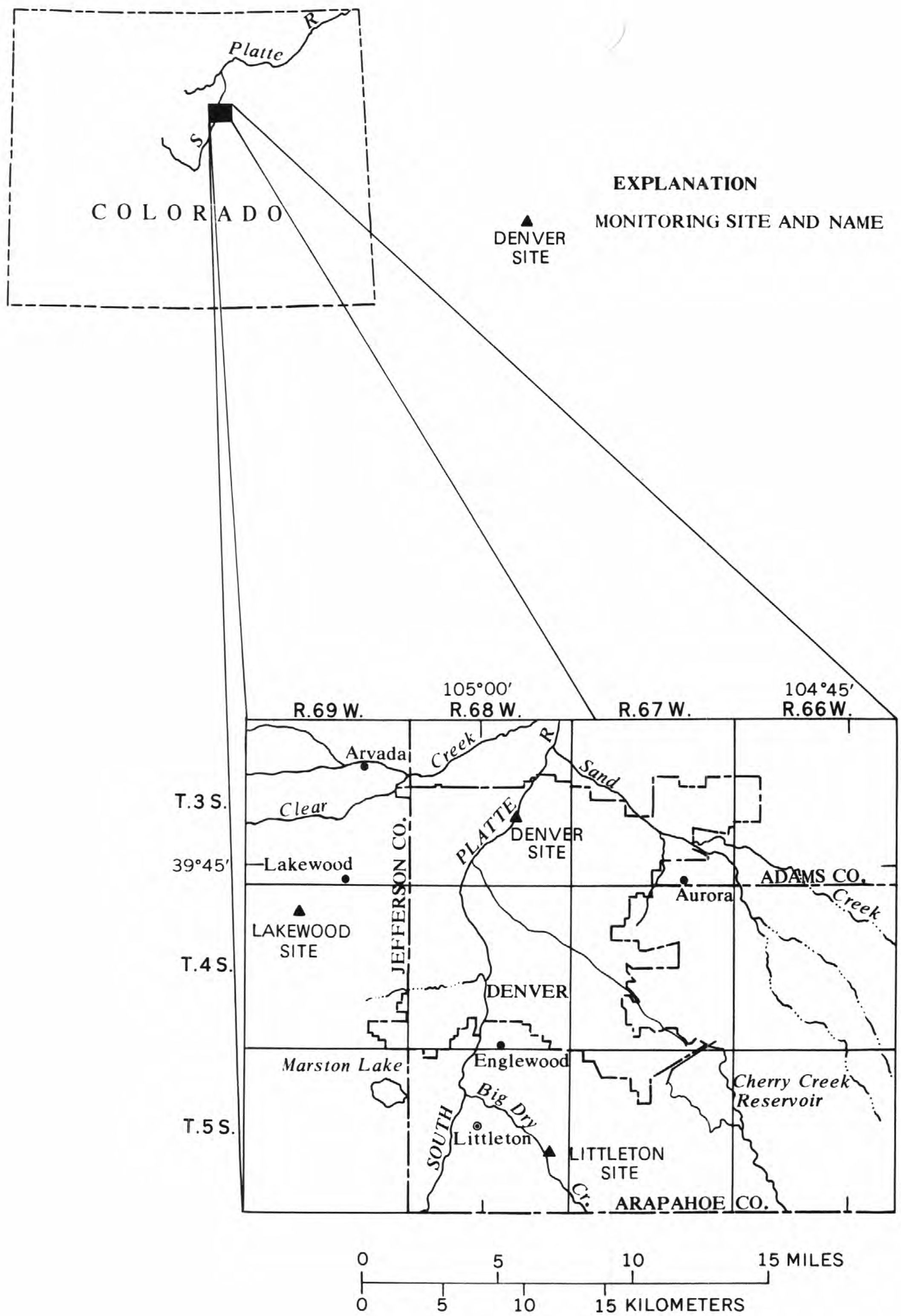


Figure 1.--Location of urban-runoff monitoring sites.

Table 1.--*Selected basin data for monitoring sites*

U.S. Geological Survey downstream order number	Name of monitoring site	Latitude-longitude location	Drainage area (acres)	Predominant land use	Percentage of area covered by	
					Effective impervious surfaces	Noneffective impervious surfaces
		LITTLETON SITE				
06712100	Big Dry Creek tributary at Littleton.	39°35'46", 104°57'06".	606	Single-family residential.	15	10
		LAKEWOOD SITE				
06711635	North Avenue Storm Drain at Denver Federal Center, at Lakewood.	39°43'21", 105°07'47".	76.7	Undeveloped land and multifamily residential.	30	10
		DENVER SITE				
06714100	Thirty-sixth Street Storm Sewer at Denver.	39°46'23", 104°58'45".	2,246	High-density residential and commercial.	40	25

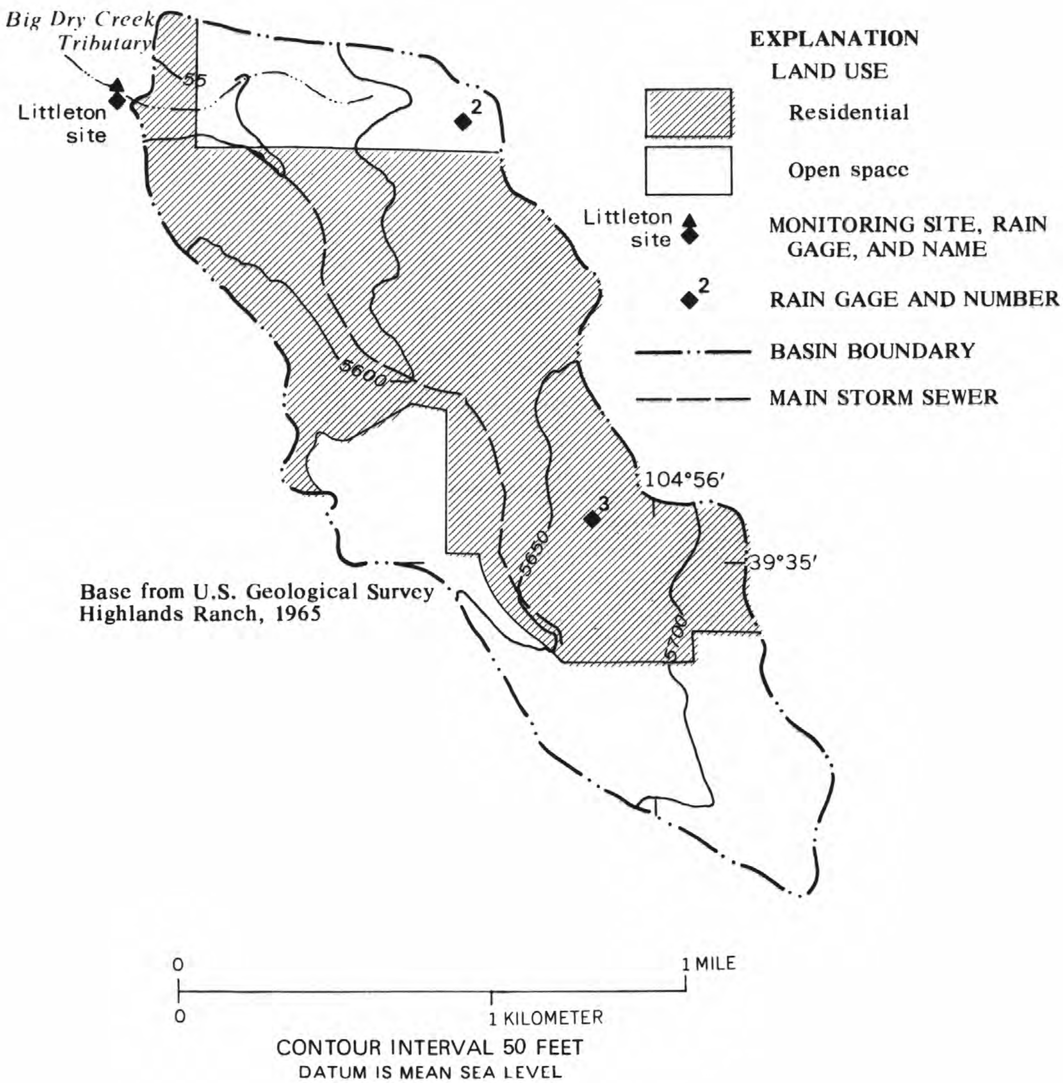


Figure 2.--The Littleton drainage basin.

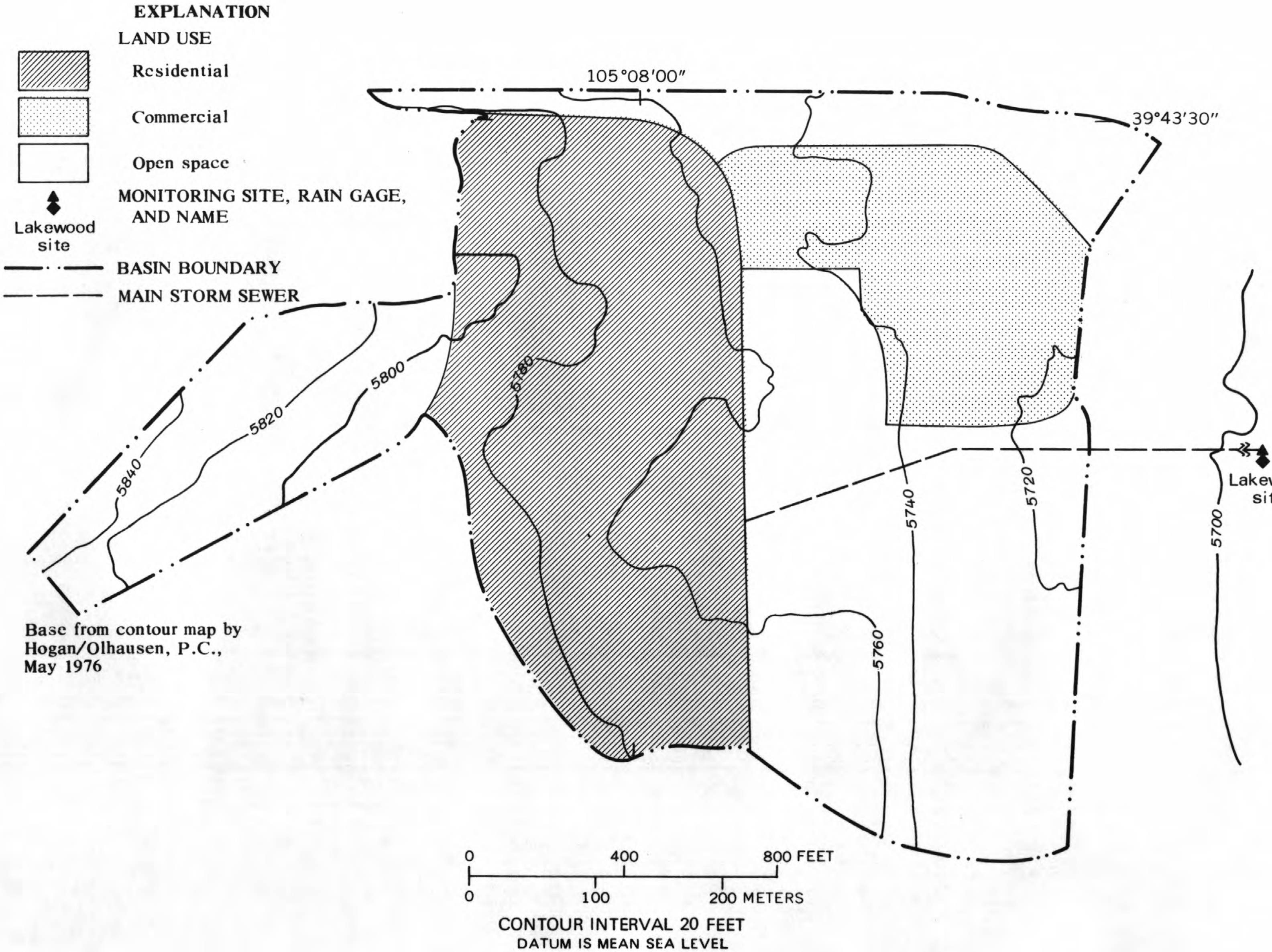


Figure 3.--The Lakewood drainage basin.

The drainage basin located in Denver, Colo. (the Denver site), has an area of 2,246 acres, of which approximately 37 percent is multifamily dwellings, 37 percent is mixed single-family and multifamily dwellings, 20 percent is commercial development, and 6 percent is parks (fig. 4). Approximately 40 percent of the basin is covered by effective impervious surfaces and 25 percent by noneffective impervious surfaces. The basin is underlain by a complex storm-sewer system that conveys the runoff to an outfall at the South Platte River.

INSTRUMENTATION AND DATA COLLECTION

Data were collected from May 1975 through July 1977. Samples of rainfall runoff for water-quality analysis were collected manually from May 1975 through January 1976. Generally, only one sample was collected per storm. The parameter values determined in these samples were used as the basis for selection of parameters to be included in subsequent detailed sampling of runoff periods using automatic equipment.

Automatic water-quality-sampling and storm-runoff monitors were installed at each site during February 1976. The automatic monitor and its operation are described by Smoot, Davidian, and Billings (1974).

Three tipping-bucket rain gages were installed in both the Littleton and Denver basins, and one tipping-bucket rain gage was installed in the Lakewood basin. Precipitation data were not collected during the winter months.

Flows were determined and samples were collected at the outlets of the drainage basins using the automatic equipment. Gage height-discharge relationships used for the Lakewood and Denver sites were theoretical ratings derived for v-notch weirs. The gage height-discharge relationship used for the Littleton site was computed using the step-backwater approach (Shearman, 1976).

Samples for water-quality analysis were collected at intervals ranging from 2 to 60 minutes, depending upon basin size, experience gained during the sampling program, and whether rainfall or snowmelt runoff was expected. These intervals were occasionally changed during runoff periods. All samples were analyzed at the U.S. Geological Survey regional laboratories.

Problems occurred during the laboratory analysis of five of the water-quality constituents: BOD_5 (biochemical oxygen demand, 5-day); suspended organic carbon, and total-coliform, fecal-coliform, and fecal-streptococcus bacteria. Trace metals commonly were of sufficient concentration to interfere with the BOD_5 analyses. For example, at times concentrations of iron exceeded 10 mg/L (milligrams per liter) and at times concentrations of lead and zinc exceeded 1.0 mg/L. The determination of suspended organic carbon was hampered due to difficulty in obtaining a representative subsample of 20 mL (milliliters) from a 2-liter bottle containing concentrations of sediment that, at times, exceeded 6,000 mg/L. Also, the concentration of suspended organic carbon commonly exceeded the preset maximum-detection limit of

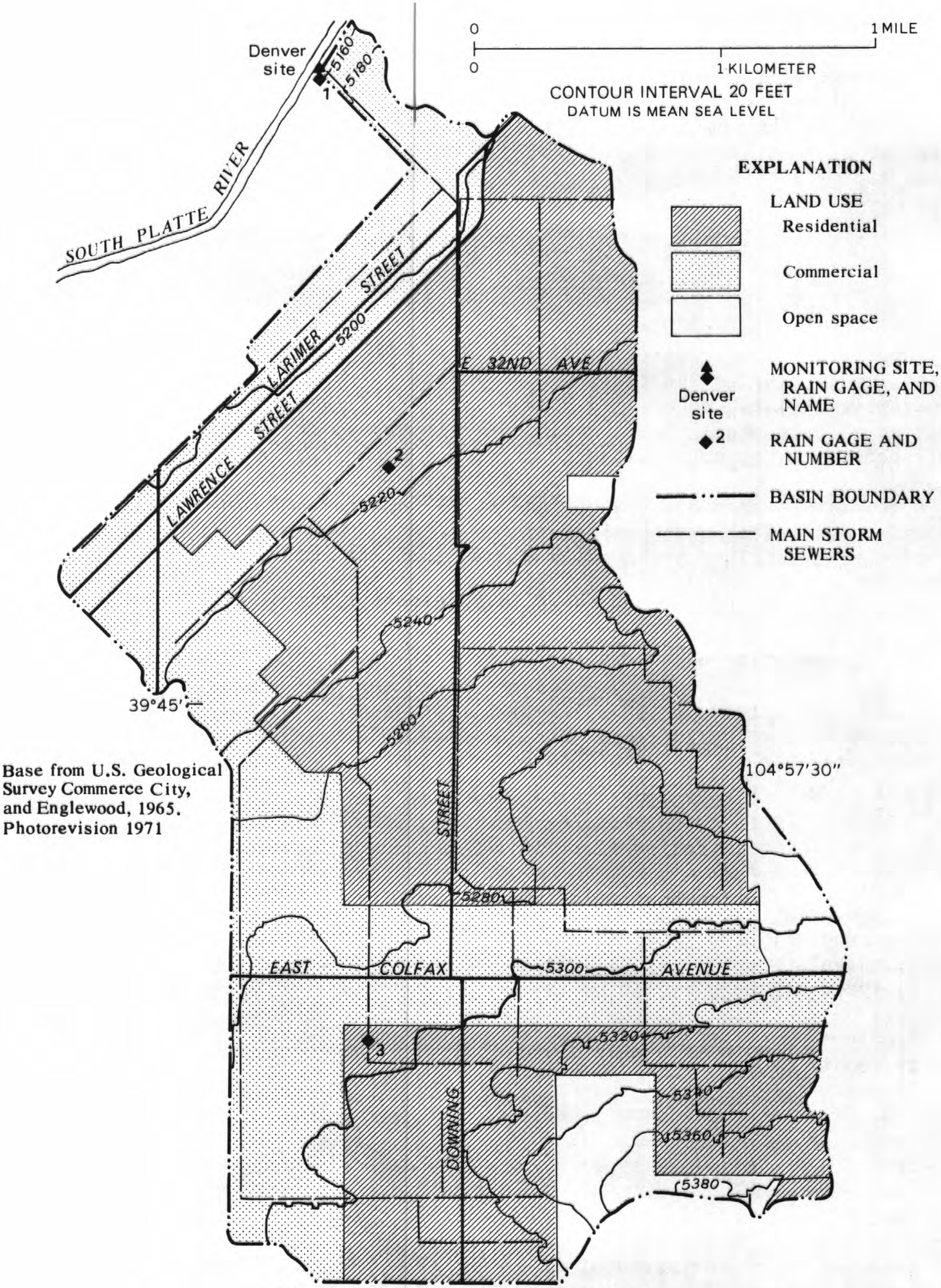


Figure 4.--The Denver drainage basin.

the analytical equipment used in the laboratory, resulting in almost useless values of greater than 25 mg/L reported for many of the samples. The problems involving total- and fecal-coliform and fecal-streptococci analyses included coliform plate samples from the Denver site usually covered with a fungus ranging in color from white to purple. The three sites usually had ratios of nonideal colonies to ideal colonies that were, at times, greater than 5, resulting in a count of fewer total-coliform than fecal-coliform bacteria. Sediment concentrations at the Lakewood site usually were sufficiently large to cover the plate if a sample size of more than 1 mL was used, resulting in sample plates with no visible colonies.

As a result of the above-mentioned problems, data for BOD_5, total- and fecal-coliform, and fecal-streptococci bacteria were not included in the interpretive analyses of this report. Complications with suspended organic carbon data, along with the lack of meaningful BOD_5 and coliform-bacteria data, make determination of the extent of organic contamination of storm runoff from the three sites difficult.

PRECIPITATION AND RUNOFF

Average annual precipitation in the Denver metropolitan area is approximately 15 in. (Hansen and others, 1978). About three-fourths of the precipitation occurs as rainfall, generally during April through October, and the remainder as snowfall during November through March. During the data-collection period, monthly precipitation was generally less than average.

Summaries of the rainfall and runoff data for measured rainfall-runoff periods are shown in tables 2 through 4. Storm rainfalls measured at three rain gages within the 606-acre Littleton basin and at three rain gages within the 2,246-acre Denver basin show that differences of greater than 50 percent were not uncommon in measured storm rainfall between two gages in the same basin. No data for snowfall depth or water content were collected; therefore, no comparisons could be made between snowfall and runoff.

The percentage of rainfall to leave a basin as runoff for a given storm is a function of rainfall characteristics (depth, duration, intensity, and distribution), impervious area, and antecedent moisture conditions, as well as many other factors. Rainfall runoff from the three basins was generally between 15 and 30 percent of rainfall (see tables 2-4).

Table 2.--*Rainfall-runoff data for the Littleton site*

Date	Rainfall, in inches[1]			Weighted average rainfall[2] (in.)	Runoff volume (in.)	Runoff as percent of rainfall	Peak discharges (ft^3/s)
	Rain gage 1	Rain gage 2	Rain gage 3				
May 30, 1976--	0.30	0.31	0.18	0.24	0.053	22	63
July 25, 1976--	.14	.28	.23	.24	.052	22	69
Sept. 7, 1976--	.47	.48	.63	.56	.070	12	52
Apr. 15, 1977--	.75	.80	.72	.75	.17	23	33
Apr. 19, 1977--	.56	.53	.47	.50	.078	16	14
June 11, 1977--	.39	.44	----	[3].43	.12	28	96

[1]See figure 2 for location of rain gages.

[2]Unless otherwise specified, rain gage 1 was assigned a weight of 84, rain gage 2 a weight of 212, and rain gage 3 a weight of 310.

[3]For the storm of June 11, 1977, rain gage 1 was assigned a weight of 155 and rain gage 2 a weight of 451.

Table 3.--*Rainfall-runoff data for the Lakewood site*

Date	Rainfall (in.)	Runoff volume (in.)	Runoff as percent of rainfall	Peak discharge (ft^3/s)
Apr. 11, 1977------------	0.16	0.036	22	3.4
Apr. 12, 1977------------	.26	.079	30	3.5
Apr. 15, 1977------------	.50	.16	32	4.3
Apr. 19-20, 1977---------	.74	.25	34	3.3
May 20, 1977------------	.05	.0092	18	1.3
May 20, 1977------------	.07	.018	26	3.4

Table 4.--*Rainfall-runoff data for the Denver site*

Date	Rainfall, in inches[1]			Weighted average rainfall[2] (in.)	Runoff volume (in.)	Runoff as percent of rainfall	Peak discharges (ft^3/s)
	Rain gage 1	Rain gage 2	Rain gage 3				
Apr. 29-30, 1976--	0.20	0.21	0.19	0.20	0.050	25	[3]70
May 24, 1976-----	.01	.02	.01	.014	.0024	17	4.6
May 25, 1976-----	.04	.06	.11	.085	.015	18	43
Aug. 2, 1976-----	.15	.17	.18	.17	.034	20	[3]58
Aug. 24, 1976-----	.10	.12	.05	.083	.017	20	42
Oct. 6, 1976-----	.17	.23	.24	.23	.071	31	163
May 20, 1977-----	.02	.09	.08	.081	.025	31	99
May 28, 1977-----	.09	.10	.12	.11	.020	18	52
June 5-6, 1977-----	.24	.31	.25	.28	.065	23	55
June 6, 1977-----	.11	.10	.17	.14	.018	13	15
June 19, 1977-----	.17	.19	.18	.18	.039	22	53
July 5, 1977-----	.52	.38	.46	.43	.11	26	183

[1]See figure 4 for location of rain gages.
[2]Rain gage 1 was assigned a weight of 120, rain gage 2 a weight of 972, and rain gage 3 a weight of 1,154.
[3]Estimated.

URBAN-RUNOFF QUALITY

Urban-runoff quality is discussed under three categories: rainfall-runoff quality, snowmelt-runoff quality, and dry-weather-flow quality.

Rainfall-Runoff Quality

Constituents and Properties

Mean, median, minimum, and maximum values of selected water-quality constituents and properties in rainfall runoff are presented in table 5 for the three monitoring sites. In general, median values were less than mean values.

Constituent concentrations varied considerably, both within and between storms. In general, rainfall runoff from the Denver site had the largest constituent concentrations, whereas rainfall runoff from the Littleton site had the smallest constituent concentrations. There were several exceptions

Table 5.--*Summary of water-quality constituents and*

Water-quality constituent or property	Number of samples	Mean	Median	Minimum	Maximum
		LITTLETON SITE			
Temperature (°C)	13	12	10	1.0	22
Specific conductance (μmho/cm)	119	140	120	50	320
pH (units)	112	--------	7.5	6.5	9.0
Dissolved calcium (mg/L)	117	15	13	3.5	42
Dissolved magnesium (mg/L)	30	1.7	1.7	.7	3.6
Dissolved potassium (mg/L)	30	3.7	3.7	2.4	5.5
Dissolved sodium (mg/L)	117	7.7	7.0	1.8	24
Dissolved chloride (mg/L)	118	6.7	4.6	1.6	26
Dissolved sulfate (mg/L)	118	18	12	2.5	65
Sodium-adsorption ratio	30	.5	.4	.2	1.1
Total nitrite plus nitrate as N (mg/L)	118	.87	.79	.14	2.0
Total ammonia nitrogen as N (mg/L)	118	.44	.42	.03	1.2
Total Kjeldahl nitrogen as N (mg/L)	118	1.9	1.7	.20	9.5
Dissolved phosphorus as P (mg/L)	115	.26	.24	.07	.81
Total orthophosphate as P (mg/L)	117	.24	.21	.04	.69
Dissolved organic carbon as C (mg/L)	72	12	11	2.4	37
Suspended organic carbon as C (mg/L)	57	([1])	([1])	.2	>25
Dissolved solids (mg/L)	117	90	75	22	220
Total nonfiltrable residue (mg/L)	117	240	130	24	1,340
Volatile nonfiltrable residue (mg/L)	117	61	42	0	268
Total arsenic (μg/L)	26	6	6	2	12
Total copper (μg/L)	27	30	20	<10	90
Total iron (μg/L)	20	8,200	6,350	2,400	24,000
Total lead (μg/L)	27	360	300	100	1,200
Total zinc (μg/L)	27	180	130	60	650

[1]Mean or median could not be calculated because many data were reported as greater than a given value.

to these generalizations, and the differences in the mean and range of constituent concentrations between the basins of different land use were often less than might be expected, based on published data (American Public Works Association, 1969; AVCO Economic Systems Corporation, 1970; and Shubinski and Nelson, 1975). However, several significant differences between the constituent concentrations at the three sites are evident from the data in table 5. The maximum dissolved-phosphorus concentration of 12 mg/L and maximum total-orthophosphate concentration of 13 mg/L for the Denver site were more than 10 times the maximum concentrations of these parameters at the other two sites. The mean concentration of total nonfiltrable residue (1,160 mg/L) and the mean concentration of volatile nonfiltrable residue (170 mg/L) for the Lakewood site were 3 to 9 times the mean concentrations of these constituents *properties in rainfall runoff at the three sites*

Number of samples	Mean	Median	Minimum	Maximum	Number of samples	Mean	Median	Minimum	Maximum
		LAKEWOOD SITE					DENVER SITE		
11	17	21	1.5	23	13	14	15.5	5.0	22
82	150	140	75	470	102	180	110	<50	700
75	---------	8.3	6.5	8.9	94	------	7.5	6.3	8.5
82	13	9.7	6.2	60	102	14	8.7	4.3	49
22	1.1	1.0	.7	2.1	---	------	------	------	-----
22	1.4	1.2	1.0	2.7	1	2.0	2.0	2.0	2.0
82	11	10	4.1	32	102	15	6.8	2.5	79
82	7.2	5.9	2.7	25	102	15	7.0	1.4	120
82	15	9.8	5.4	66	102	23	13	4.3	120
22	1.0	1.0	.7	1.5	1	.4	.4	.4	.4
111	.78	.63	.15	2.8	100	.61	.56	.01	2.1
111	.74	.35	.01	8.1	100	.70	.56	.00	2.4
111	3.0	2.1	.09	17	100	3.6	2.9	.21	17
75	.20	.16	.00	1.1	96	.65	.35	.00	12
111	.33	.26	.00	1.2	100	.42	.15	.08	13
54	16	15	5.1	84	70	22	18	.8	53
52	(1)	9.9	.3	>25	51	(1)	(1)	.2	>25
82	100	77	50	455	95	140	78	28	454
82	1,170	650	72	6,600	94	130	80	10	908
82	170	120	15	808	94	52	37	8	442
40	15	15	6	30	---	------	------	------	-----
41	54	60	20	120	---	------	------	------	-----
19	38,000	39,000	20,000	62,000	---	------	------	------	-----
41	410	400	100	1,000	---	------	------	------	-----
41	400	370	150	1,100	---	------	------	------	-----

at the other two sites. Finally, the mean total-iron concentration of 37,000 µg/L (micrograms per liter) for the Lakewood site was more than 1.5 times the *maximum* total iron concentration at the Littleton site.

The larger concentrations of total nonfiltrable residue and volatile nonfiltrable residue at the Lakewood site probably were due to the construction of two buildings in the commercial part of the drainage basin during the data-collection period and the larger total-iron concentrations may be the result of the larger nonfiltrable residue concentrations at this site. The reasons for the anomalously large maximum concentrations of dissolved phosphorus and total orthophosphate at the Denver site are unknown.

In addition to the construction activity within the Lakewood basin, the application of fertilizers and pesticides to lawns apparently had a measurable effect on the quality of rainfall runoff. On September 14, 1976, maximum concentrations of total ammonia nitrogen (8.1 mg/L), dissolved phosphorus (1.1 mg/L), and total orthophosphate (1.2 mg/L) were determined in rainfall runoff from the Lakewood site. Almost the entire lawn area of the Lakewood basin is associated with an apartment complex. When contacted, the owners of this apartment complex reported that they had applied fertilizer to the entire lawn area the day before the rainfall runoff.

The third instance demonstrating the effects of land-use activities on rainfall-runoff quality was apparent from the results of three rainfall-runoff samples which were analyzed for total polychlorinated biphenyl (PCB) and pesticides, as shown in table 6. Analysis of the pesticide sample collected at the Littleton site on September 7, 1976, indicated large concentrations of total chlordane (1.7 μg/L), total diazion (0.78 μg/L), total malathion (3.5 μg/L), total 2,4-D (7.5 μg/L), and total silvex (3.2 μg/L). Interviews with homeowners in the basin indicated that fertilizers and pesticides had been applied to many lawns on September 4-6 (Labor Day weekend). Unfortunately, no samples were analyzed for nutrients in the rainfall runoff of September 7. A second pesticide sample, collected on September 25, 1976, showed much smaller concentrations.

The mean, median, minimum, and maximum concentrations of five trace elements--arsenic, copper, iron, lead, and zinc--are shown in table 5. However, rainfall runoff from the Littleton and Denver sites initially was analyzed for 13 trace elements. Results for two samples analyzed for both the dissolved and total (particulate plus dissolved) phases of the 13 trace elements, shown in table 7, indicate that the particulate phase was much more prevalent than the dissolved phase. Subsequent samples were analyzed for total trace elements. Due to economic constraints, subsequent analyses were restricted to five trace elements--arsenic, copper, iron, lead, and zinc--chosen because of existing water-quality standards and local interest. Although not selected in this study, chromium and, to a lesser extent, cadmium or manganese also might have been justifiably included in subsequent analyses based on the data in table 7. The trace-elements data have been discussed in more detail in a paper by Alley and Ellis (1978).

Trends, Correlations, and Regressions

Although constituent concentrations varied considerably, some trends and correlations were found. Some of the trends of the water-quality constituents in rainfall runoff are illustrated by figures 5-7. The constituent concentrations generally were largest during the initial parts of the rainfall runoff and then decreased with time. An exception is shown in figure 5 when at 1845 hours a second peak in total nitrogen and total Kjeldahl nitrogen concentrations occurred. Occasionally, as shown in figure 6, instantaneous loads of constituents were largest during the initial parts of the rainfall runoff. However, instantaneous loads of constituents were largely a function of discharge. A first flush, defined as a disproportionately large part of the total storm-runoff load in the initial part of the runoff, was rare at all three sites.

Table 6.--*Concentrations of PCB and pesticides in rainfall runoff at the Littleton and Lakewood sites*

[ND, not detected]

Water-quality constituent	Concentrations, in micrograms per liter		
	LITTLETON SITE		LAKEWOOD SITE
	Sept. 7, 1976	Sept. 25, 1976	Sept. 14, 1976
	Discharge= 15 ft^3/s	Discharge= 20 ft^3/s	Discharge= 3.4 ft^3/s
Total PCB-------------------	ND	ND	ND
Total aldrin----------------	ND	ND	ND
Total chlordane-------------	1.7	0.1	0.1
Total DDD-------------------	ND	ND	ND
Total DDE-------------------	.02	ND	ND
Total DDT-------------------	ND	ND	ND
Total diazinon--------------	.78	.24	.08
Total dieldrin--------------	ND	ND	.01
Total endrin----------------	ND	ND	ND
Total ethion----------------	ND	ND	ND
Total heptachlor------------	.25	ND	ND
Total heptachlor epoxide----	.04	ND	ND
Total lindane---------------	.05	.01	.04
Total malathion-------------	3.5	.13	ND
Total methyl parathion------	ND	ND	ND
Total methyl trithion-------	ND	ND	ND
Total parathion-------------	ND	ND	ND
Total toxaphene-------------	ND	ND	ND
Total trithion--------------	ND	ND	ND
Total 2,4-D-----------------	7.5	.40	.04
Total 2,4,5-T---------------	ND	.04	ND
Total silvex----------------	3.2	.14	ND

Linear and log-linear correlations were determined for selected constituent concentrations with discharge, elapsed time from start of storm, and cumulative rainfall-runoff volume. In general, the log-linear correlation coefficients, shown in table 8, were larger than the linear correlation coefficients.

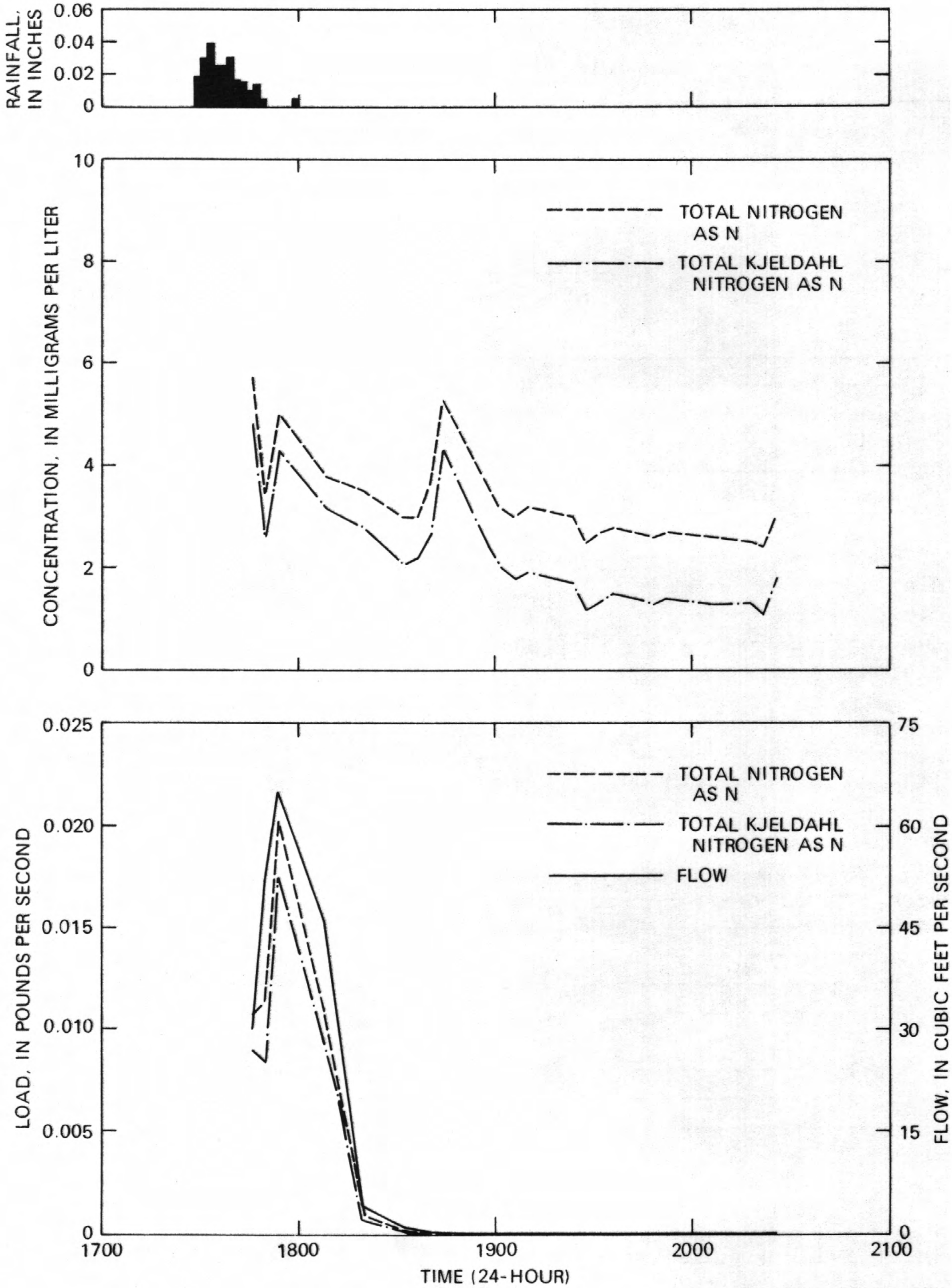


Figure 5.--Rainfall, concentrations and loads of total Kjeldahl nitrogen and total nitrogen, and flow from Littleton site for rainfall runoff of July 25, 1976.

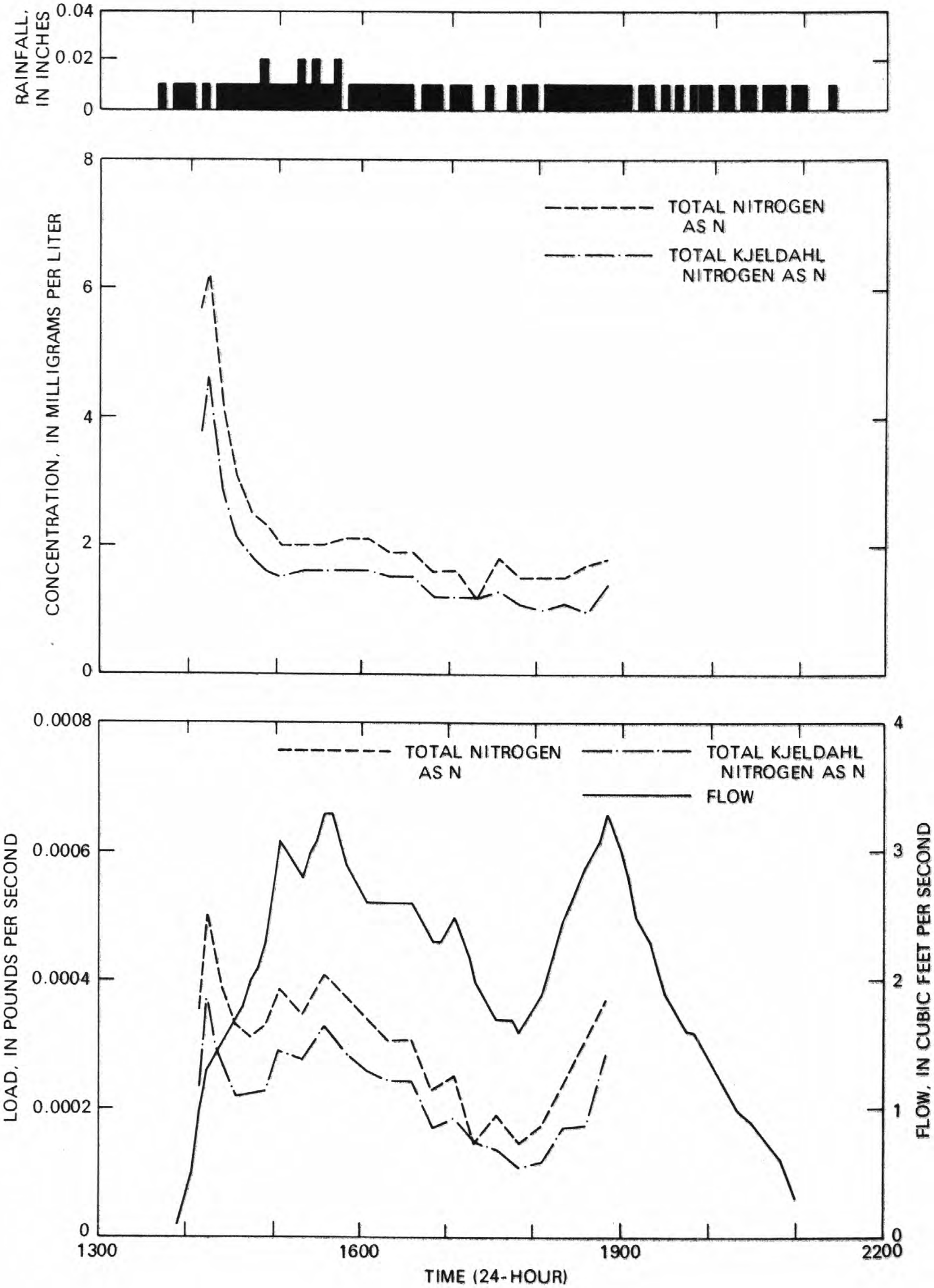


Figure 6.--Rainfall, concentrations and loads of total Kjeldahl nitrogen and total nitrogen, and flow from Lakewood site for rainfall runoff of April 19, 1977.

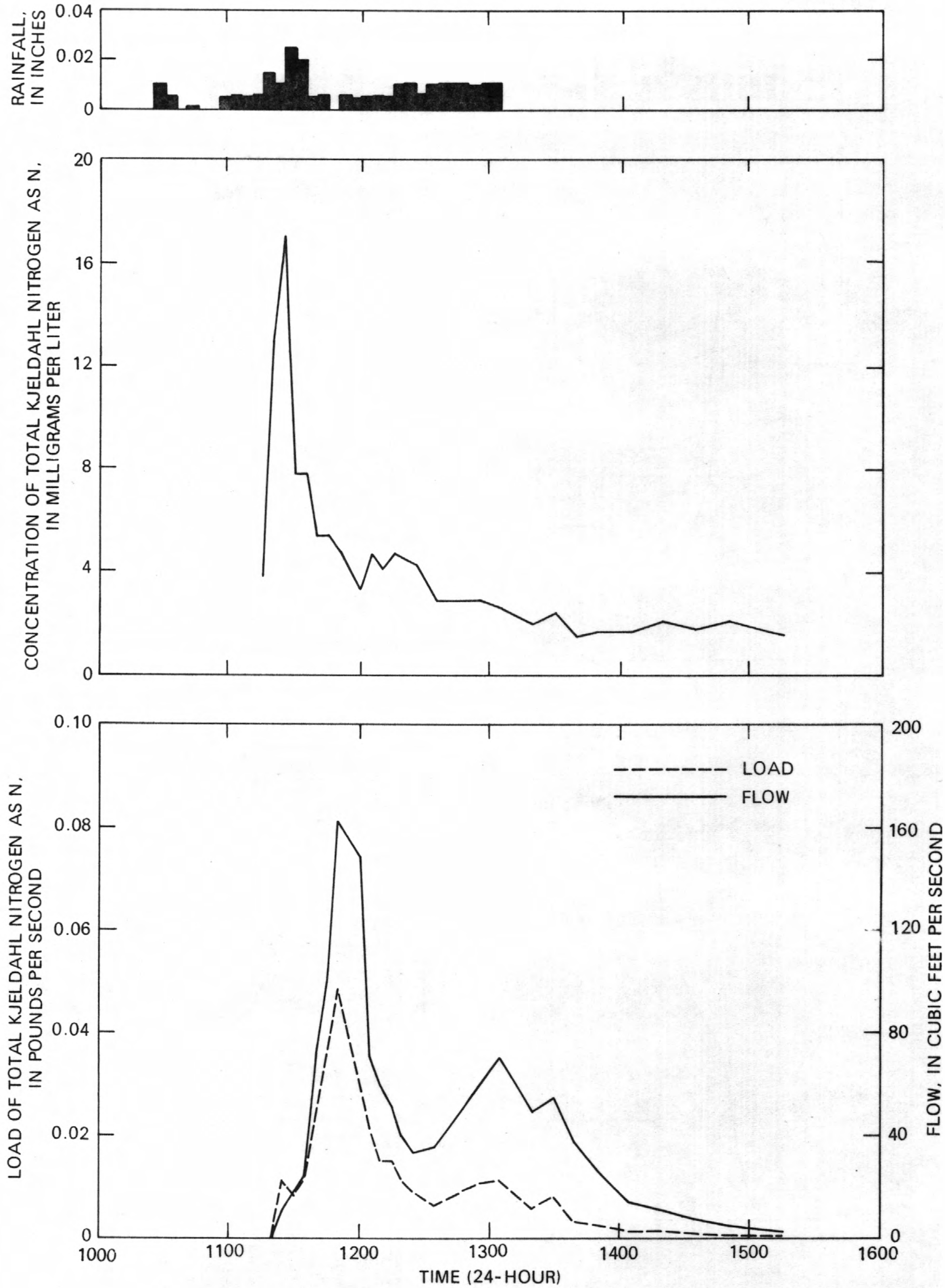


Figure 7.--Rainfall, concentrations and loads of total Kjeldahl nitrogen, and flow from Denver site for rainfall runoff of October 6, 1976.

Table 7.--*Concentrations of dissolved and total trace elements in initial samples*

[ND, not detected]

Trace element	Concentrations, in micrograms per liter			
	LITTLETON SITE		DENVER SITE	
	July 19, 1976 Discharge=10 ft^3/s		October 6, 1976 Discharge=18 ft^3/s	
	Dissolved	Total	Dissolved	Total
Antimony------------------------	ND	ND	ND	3
Arsenic-------------------------	9	------	20	50
Cadmium-------------------------	1	10	1	<10
Chromium------------------------	10	70	80	340
Copper--------------------------	4	90	---	280
Iron----------------------------	190	24,000	500	12,000
Lead----------------------------	16	1,200	42	<100
Lithium-------------------------	10	30	ND	10
Manganese-----------------------	170	810	160	400
Mercury-------------------------	ND	ND	ND	.2
Nickel--------------------------	---	------	6	<50
Selenium------------------------	1	------	---	--------
Zinc----------------------------	40	650	290	1,200

In general, the best correlation coefficients were obtained using either elapsed time from start of rainfall or cumulative rainfall-runoff volume as the independent variable. Most of these correlation coefficients demonstrate a negative correlation between constituent concentrations and the elapsed time from start of storm or cumulative rainfall-runoff volume. About the same number of negative correlation coefficients as positive correlation coefficients were obtained between constituent concentrations and discharge.

Regression equations are shown in table 9 for each of the constituents listed in table 8. Independent variables used in these equations are discharge (Q) and either elapsed time from start of storm (CT) or cumulative rainfall-runoff volume (CV), whichever resulted in the smaller standard error.

Good correlations (correlation coefficients of 0.88 to 0.98) were found between concentrations of dissolved solids and specific conductance at each of the three sites. The results are shown on figure 8.

Table 8.--*Correlations of constituent concentrations with discharge, elapsed time from start of storm, and cumulative rainfall-runoff volume*

[Linear correlation equations are: Dependent variable=a+b (independent variable), where a and b are regression parameters. Log-linear correlation equations are: Dependent variable=k (independent variable^n), where k and n are regression parameters; a log transformation will convert this equation to linear form]

Variables, correlated as shown	Correlation coefficient (r)					
	LITTLETON SITE		LAKEWOOD SITE		DENVER SITE	
	Linear	Log-linear	Linear	Log-linear	Linear	Log-linear
WITH DISCHARGE:						
Total nitrite plus nitrate------	-0.52	-0.27	-0.36	-0.30	-0.53	-0.46
Total Kjeldahl nitrogen---------	.11	.10	-.11	-.07	-.08	-.25
Dissolved phosphorus------------	-.11	-.10	-----	-----	-.18	-.51
Total orthophosphate------------	-.14	.09	.30	.37	-.11	-.47
Dissolved organic carbon--------	-.26	-.31	-----	-----	.29	.03
Total nonfiltrable residue------	-.59	.73	-----	-----	.30	.54
Volatile nonfiltrable residue---	-.60	.75	-----	-----	.26	.58
Total arsenic-------------------	.50	.42	.00	-.03	-----	-----
Total copper--------------------	.70	.59	.17	.20	-----	-----
Total lead----------------------	.65	.58	-.05	-.06	-----	-----
Total zinc----------------------	.51	.44	-.03	-.04	-----	-----
WITH ELAPSED TIME FROM START OF STORM:						
Total nitrite plus nitrate------	-0.08	0.03	-0.29	-0.52	0.43	0.31
Total Kjeldahl nitrogen---------	-.34	-.40	-.72	-.74	-.28	-.18
Dissolved phosphorus------------	-.20	-.11	-.38	-.56	-.12	-.02
Total orthophosphate------------	-.09	-.08	-.38	-.30	-.15	-.09
Dissolved organic carbon--------	-.52	-.54	-.52	-.54	-.54	-.53
Total nonfiltrable residue------	-.59	-.78	-.35	-.52	-.45	-.58
Volatile nonfiltrable residue---	-.60	-.58	-.36	-.48	-.40	-.53
Total arsenic-------------------	-.59	-.57	-.75	-.62	-----	-----
Total copper--------------------	-.51	-.54	-.79	-.73	-----	-----
Total lead----------------------	-.72	-.80	-.79	-.81	-----	-----
Total zinc----------------------	-.61	-.66	-.73	-.77	-----	-----
WITH CUMULATIVE RAINFALL-RUNOFF VOLUMES:						
Total nitrite plus nitrate------	-0.37	-0.23	-0.33	-0.60	-0.25	-0.07
Total Kjeldahl nitrogen---------	-.64	-.73	-.73	-.91	-.48	-.62
Dissolved phosphorus------------	.23	.47	-----	-----	-.27	-.62
Total orthophosphate------------	.80	.52	-.38	-.13	-.19	-.61
Dissolved organic carbon--------	-.60	-.70	-----	-----	-.35	-.42
Total nonfiltrable residue------	-.44	-.18	-----	-----	-.26	-.14
Volatile nonfiltrable residue---	-.07	-.06	-----	-----	-.21	-.04
Total arsenic-------------------	-.45	-.23	-.78	-.78	-----	-----
Total copper--------------------	-.19	.07	-.79	-.85	-----	-----
Total iron----------------------	-.47	-.33	-.80	-.92	-----	-----
Total lead----------------------	-.44	-.28	-.74	-.92	-----	-----

Table 9.--*Regression equations for constituent concentrations, in milligrams per liter*

Constituent	Equation[1]	Coefficient of determination (r^2)	Standard error of estimate (percent)
	LITTLETON SITE		
Total nitrite plus nitrate as N--	$0.781\ Q^{-0.131}CV^{-0.144}$	0.13	85
Total Kjeldahl nitrogren as N----	$0.685\ Q^{0.028}CV^{-0.292}$	.54	36
Dissolved phosphorus as P--------	$0.878\ Q^{-0.051}CV^{0.296}$	.24	80
Total orthophosphate as P--------	$0.435\ Q^{0.028}CV^{0.197}$	.29	42
Dissolved organic carbon as C----	$7.20\ Q^{-0.057}CV^{-0.229}$	.56	44
Total nonfiltrable residue-------	$4{,}830\ Q^{0.213}CT^{-0.803}$	.67	50
Volatile nonfiltrable residue----	$14.30\ Q^{0.400}CT^{0.184}$	.57	56
Total arsenic--------------------	$0.0469Q^{0.030}CT^{-0.540}$	.33	38
Total copper---------------------	$0.0904Q^{0.135}CT^{-0.376}$	.40	41
Total lead-----------------------	$19.7\ Q^{0.061}CT^{-1.045}$	.65	38
Total zinc-----------------------	$3.34\ Q^{0.021}CT^{-0.752}$	.44	40
	LAKEWOOD SITE		
Total nitrite plus nitrate as N--	$0.312\ Q^{-0.236}CV^{-0.198}$	0.47	31
Total Kjeldahl nitrogen as N-----	$0.707\ Q^{-0.078}CV^{-0.301}$	.84	17
Total orthophosphate as P--------	$0.734\ Q^{0.364}CT^{-0.249}$	.11	64
Total arsenic--------------------	$0.00418Q^{0.032}CV^{-0.320}$	.61	32
Total copper---------------------	$0.0132Q^{0.251}CV^{-0.324}$	.80	20
Total lead-----------------------	$0.0835Q^{0.016}CV^{-0.414}$	.85	21
Total zinc-----------------------	$0.0842Q^{0.032}CV^{-0.397}$	.85	20
	DENVER SITE		
Total nitrite plus nitrate as N--	$0.139\ Q^{-0.342}CT^{0.370}$	0.22	204
Total Kjeldahl nitrogen as N-----	$1.08\ Q^{0.024}CV^{-0.209}$	.39	45
Dissolved phosphorus as P--------	$0.200\ Q^{-0.140}CV^{-0.244}$	.40	71
Total orthophosphate as P--------	$0.088\ Q^{-0.110}CV^{-0.254}$	.41	75
Dissolved organic carbon as C----	$3{,}670\ Q^{-0.103}CT^{-1.00}$	.29	66
Total nonfiltrable residue-------	$835\ Q^{0.165}CT^{-0.553}$	.41	62
Volatile nonfiltrable residue----	$187\ Q^{0.177}CT^{-0.420}$	.42	57

[1]Q is instantaneous discharge, in cubic feet per second; CT is elapsed time from start of storm, in minutes; and CV is cumulative rainfall-runoff volume, in inches.

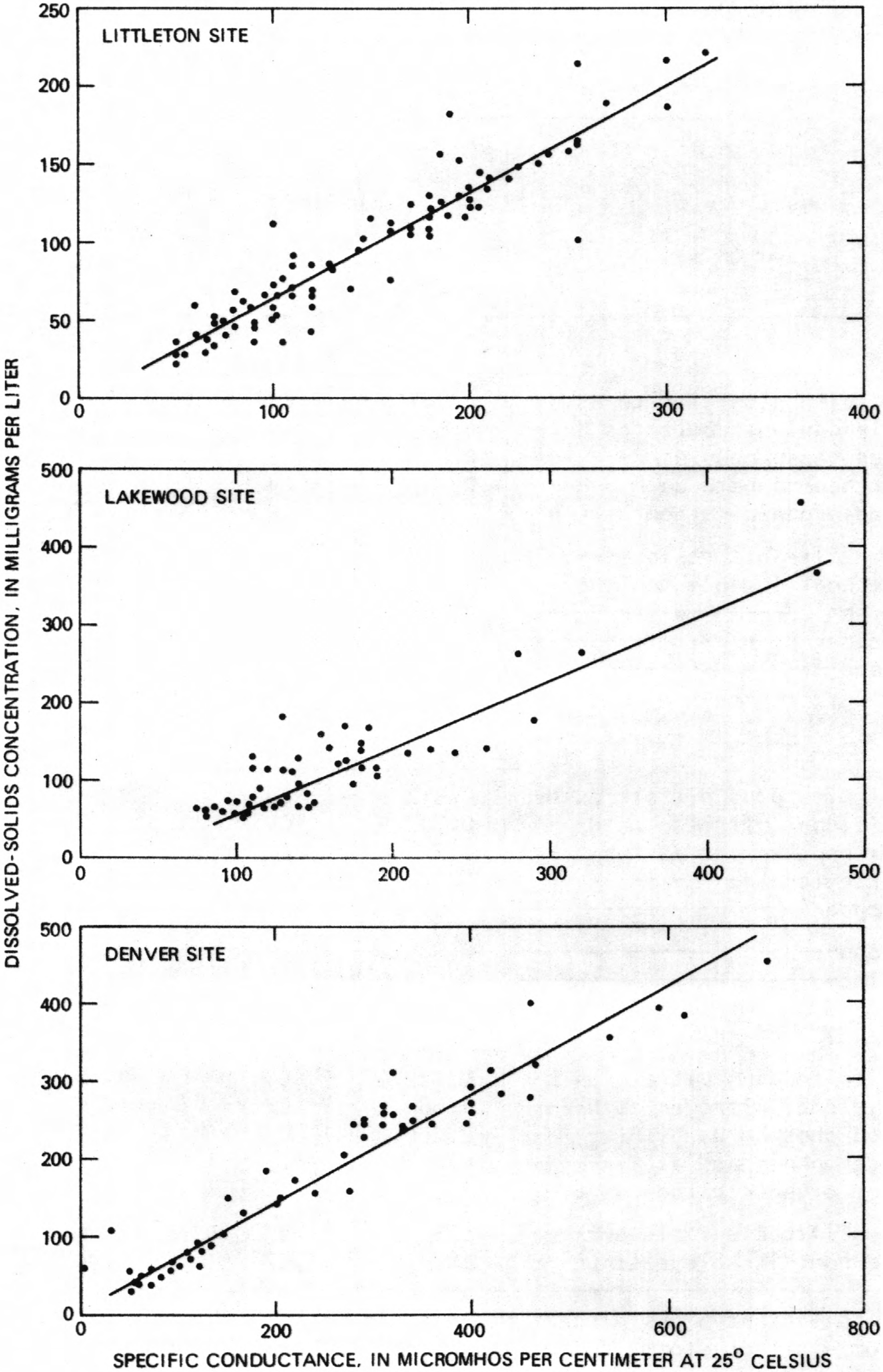


Figure 8.--Relation between dissolved-solids concentration and specific conductance in rainfall runoff at the three sites.

The loads of selected water-quality constituents for rainfall-runoff periods are shown in table 10. Loads, expressed as pounds per acre per inch of unoff for each water-quality constituent, were generally of the same order of magnitude for each of the rainfall-runoff periods. Rainfall-runoff loads were largely a function of runoff volume as illustrated on figure 9, while no effects of street sweeping or antecedent precipitation were evident. For example, although the runoff of April 19, 1977, at the Lakewood site was preceded by more than 1 in. of rainfall in the week prior to the storm, it resulted in constituent loads similar to those of the other sampled runoff periods (with the exception of the anomalously small load of dissolved phosphorus).

Snowmelt-Runoff Quality

Constituents and Properties

Mean, median, minimum, and maximum values of selected water-quality constituents and properties in snowmelt runoff are presented in table 11 for the three study sites. As in rainfall runoff, the constituent concentrations in snowmelt runoff varied considerably.

In general, snowmelt runoff from the Denver site tended to have the largest constituent concentrations, whereas snowmelt runoff from the Littleton site tended to have the smallest constituent concentrations. There were many exceptions to this generalization. Several large differences between the constituent concentrations at the three sites are evident, as shown in table 11. Snowmelt runoff at the Denver site had mean concentrations of total ammonia nitrogen (0.75 mg/L), dissolved phosphorus (0.62 mg/L), and total orthophosphate (0.31 mg/L), which were 3 to 15 times the mean concentrations of the same constituents in snowmelt runoff at the Littleton and Lakewood sites. Snowmelt runoff at the Lakewood site had mean concentrations of total nonfiltrable residue (1,120 mg/L) and volatile nonfiltrable residue (217 mg/L), which were 3 to 7 times the mean concentrations of the same constituents at the Littleton and Denver sites. As in rainfall runoff, the larger concentrations of total nonfiltrable residue in snowmelt runoff at the Lakewood site were probably due to the construction activity in the basin.

Several differences were noted among the values of constituents and properties in rainfall runoff and in snowmelt runoff. Mean sodium-absorption ratio and the mean concentrations of dissolved sodium and dissolved chloride were 12 to 47 times greater in the snowmelt runoff than in the rainfall runoff at each site. Mean specific conductance and the mean concentration of dissolved solids were 4 to 8 times greater in the snowmelt runoff than in the rainfall runoff at each site. The mean concentrations of dissolved calcium, magnesium, potassium, and sulfate were 1.2 to 3.5 times greater in the snowmelt runoff than in the rainfall runoff at each site. The higher concentrations in snowmelt runoff are probably attributable to snow-removal practices, such as street sanding and salting. The mean concentrations of the nitrogen and phosphorus species, dissolved organic carbon, total nonfiltrable residue, and volatile nonfiltrable residue were about the same in snowmelt runoff as in rainfall runoff at each site.

Table 10.--*Loads of water-quality constituents for rainfall-runoff periods*

Date	Rainfall (in.)	Runoff volume[1] (in.)	Percentage of total runoff from first to last sample	Seven-day antecedent precipitation (in.)	Number of days since last street sweeping	Number of samples	Load[1] (pounds per acre per inch of runoff) Total nitrite plus nitrate as N	Total Kjeldahl nitrogen as N	Total nitrogen as N	Dissolved phosphorus as P	Total orthophosphate as P	Dissolved organic carbon as C	Total nonfiltrable residue	Volatile nonfiltrable residue
						LITTLETON SITE, 606 ACRES								
July 25, 1976----	0.24	0.042	81	0.06	66	23	0.15	0.81	0.97	0.059	0.045	---	190	34
May 30, 1976----	.24	.039	74	.02	10	[2]15	.19	.73	.92	.071	.038	2.0	120	18
June 11, 1977----	.43	.11	96	.00	>10	[3]24	.14	.39	.53	.051	.064	2.8	110	36
						LAKEWOOD SITE, 76.7 ACRES								
July 19, 1976----	0.19	0.031	[4]58	0.00	46	[5]24	0.14	0.49	0.63	0.050	0.060	4.3	180	29
Apr. 12, 1977----	.26	.072	91	.44	5	29	.10	.51	.61	-----	.099	---	---	--
Apr. 19, 1977----	.74	.14	[4]42	1.05	12	22	.12	.34	.45	.0057	.051	1.9	110	20
						DENVER SITE, 2,246 ACRES								
Apr. 29-30, 1976--	0.20	0.049	98	0.44	---	21	0.12	0.84	0.96	0.057	0.029	2.3	---	--
Aug. 2, 1976----	.17	.034	98	.92	---	18	.13	.42	.55	.053	.029	---	20	10
Oct. 6, 1976----	.23	.071	99	.00	---	[6]26	.041	.80	.84	.13	.079	6.3	42	16

[1]Runoff volumes and loads are based on runoff volume occurring between first and last samples collected for the runoff period.
[2]Thirteen samples for dissolved phosphorus and for dissolved organic carbon.
[3]Twenty-three samples for dissolved phosphorus and for total orthophosphate.
[4]The runoff was sampled during the middle part of the runoff period.
[5]Seventeen samples for dissolved organic carbon.
[6]Nineteen samples for dissolved organic carbon.

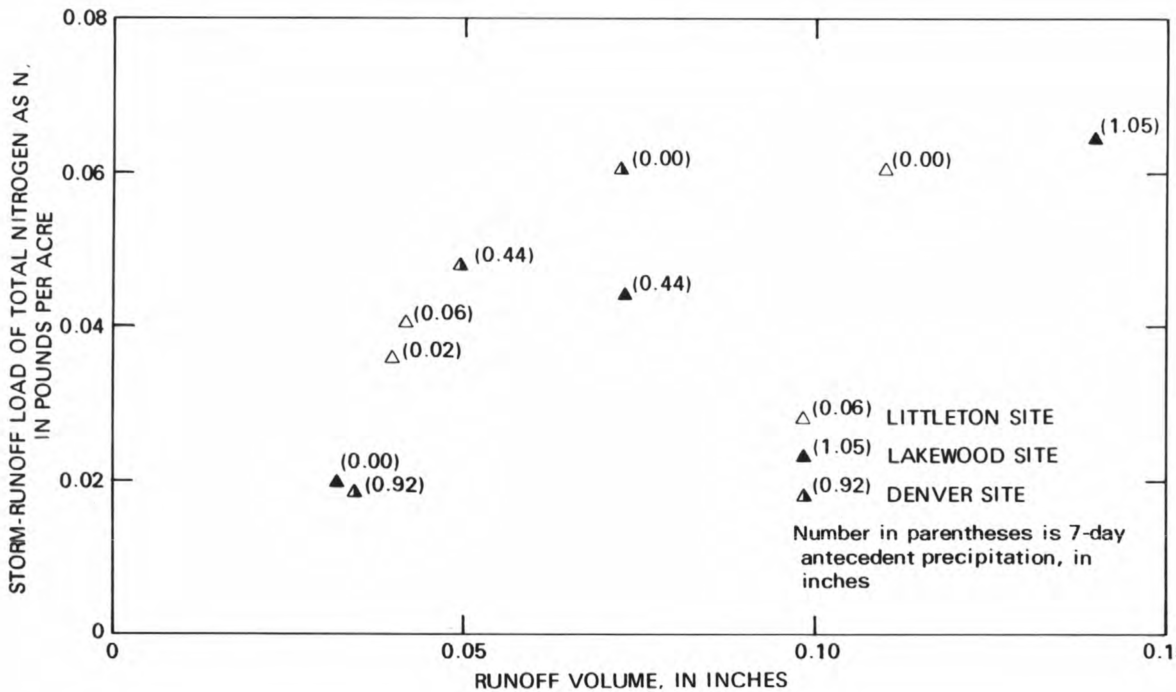


Figure 9.--Relation between rainfall-runoff load of total nitrogen and runoff volume.

Water-quality constituent or property	Number of samples	Mean	Median	Minimum	Maximum
		LITTLETON SITE			
Specific conductance (μmho/cm)	9	600	480	80	2,150
pH (units)	9	------	7.6	7.1	8.3
Dissolved calcium (mg/L)	9	24	9.1	6.5	140
Dissolved magnesium (mg/L)	-	------	------	------	--------
Dissolved potassium (mg/L)	-	------	------	------	--------
Dissolved sodium (mg/L)	9	91	82	7.3	280
Dissolved chloride (mg/L)	9	150	130	6.3	440
Dissolved sulfate (mg/L)	9	42	13	5.2	280
Sodium-adsorption ratio	-	------	------	------	--------
Total nitrite plus nitrate as N (mg/L)	9	.88	.78	.34	3.4
Total ammonia nitrogen as N (mg/L)	9	.05	.04	.00	.09
Total Kjeldahl nitrogen as N (mg/L)	9	1.8	1.5	1.1	3.1
Dissolved phosphorus as P (mg/L)	9	.05	.04	.03	.07
Total orthophosphate as P (mg/L)	9	.10	.11	.01	.13
Dissolved organic carbon as C (mg/L)	4	9.9	8.0	7.3	15
Suspended organic carbon as C (mg/L)	1	>10	>10	>10	>10
Dissolved solids (mg/L)	9	350	293	43	1,340
Total nonfiltrable residue (mg/L)	9	210	163	69	428
Volatile nonfiltrable residue (mg/L)	9	48	46	18	106
Total arsenic (μg/L)	-	------	------	------	--------
Total copper (μg/L)	-	------	------	------	--------
Total iron (μg/L)	-	------	------	------	--------
Total lead (μg/L)	-	------	------	------	--------
Total zinc (μg/L)	-	------	------	------	--------

[1]Mean or median could not be calculated because many data were reported as greater than a given value.

Trends and Correlations

Although constituent concentrations varied considerably, some trends and correlations were found. Constituent concentrations generally peaked during the middle of the day, corresponding with periods of maximum melting and runoff, as shown on figure 10. Occasionally, constituent concentrations were largest during the initial parts of the snowmelt runoff. Usually, instantaneous loads of constituents were largely a function of discharge.

At all three sites, correlation coefficients of 0.99 were found between dissolved-solids concentrations and specific conductance. The results are shown on figure 11.

properties in snowmelt runoff at the three sites

Number of samples	Mean	Median	Minimum	Maximum	Number of samples	Mean	Median	Minimum	Maximum
		LAKEWOOD SITE					DENVER SITE		
20	1,260	1,230	360	2,140	65	1,490	360	110	8,000
20	--------	7.4	7.0	8.7	65	--------	7.6	6.8	8.4
20	17	15	8.7	27	65	25	18	5.6	67
13	2.2	2.0	1.7	3.4	17	3.9	3.9	2.8	5.7
13	2.8	2.6	2.2	4.1	17	7.0	7.1	5.4	8.1
20	220	205	61	380	65	270	54	14	1,900
20	340	320	79	610	65	460	77	16	3,300
20	18	19	8.3	27	65	32	30	9.2	73
13	15	15	11	20	17	15	14	7.5	25
20	.55	.51	.33	1.1	65	.88	.81	.03	2.2
20	.20	.04	.00	2.3	65	.75	.53	.00	1.8
20	3.2	3.2	2.0	4.5	65	3.2	3.5	.97	5.6
20	.07	.08	.01	.12	65	.62	.55	.09	2.1
20	.07	.07	.00	.19	65	.31	.22	.01	.99
13	23	25	9.7	33	55	25	21	11	50
13	([1])	([1])	6.2	>25	46	([1])	([1])	1.5	>25
20	660	622	227	1,120	65	856	231	79	5,480
20	1,120	1,010	618	2,360	65	178	88	20	1,100
20	217	215	114	310	65	67	39	10	297
--	--------	--------	------	--------	11	13	12	6	19
--	--------	--------	------	--------	11	100	90	50	210
--	--------	--------	------	--------	11	6,500	8,000	2,900	8,800
--	--------	--------	------	--------	11	700	800	200	1,000
--	--------	--------	------	--------	11	610	630	450	720

The loads of selected water-quality constituents for snowmelt-runoff periods at the Denver site are shown in table 12. Data were insufficient to determine loads for runoff periods at the Littleton and Lakewood sites. Of particular interest are the much larger loads of total nonfiltrable residue, dissolved sodium, and dissolved chloride in pounds per acre per inch of runoff for the runoff periods of March 6, 1976, and February 14, 1977. Snow had been on the ground for 4 days prior to March 6, 1976, when a warming trend caused it to melt and run off. Apparently, several applications of sand and salt were made in an attempt to clear the streets of snow and ice during the 4 days.

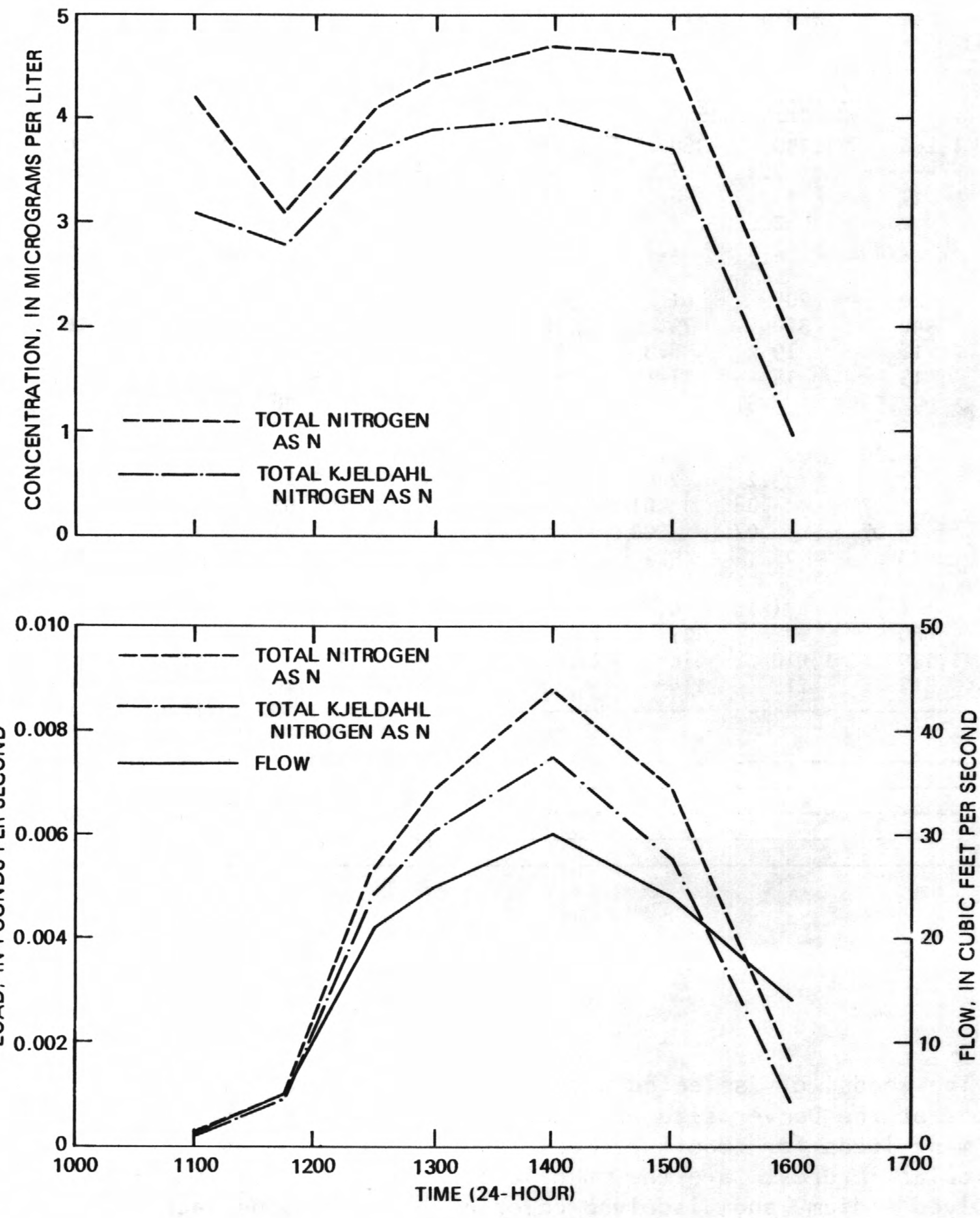


Figure 10.--Concentrations and loads of total Kjeldahl nitrogen and total nitrogen, and flow from Denver site for snowmelt runoff of March 6, 1976.

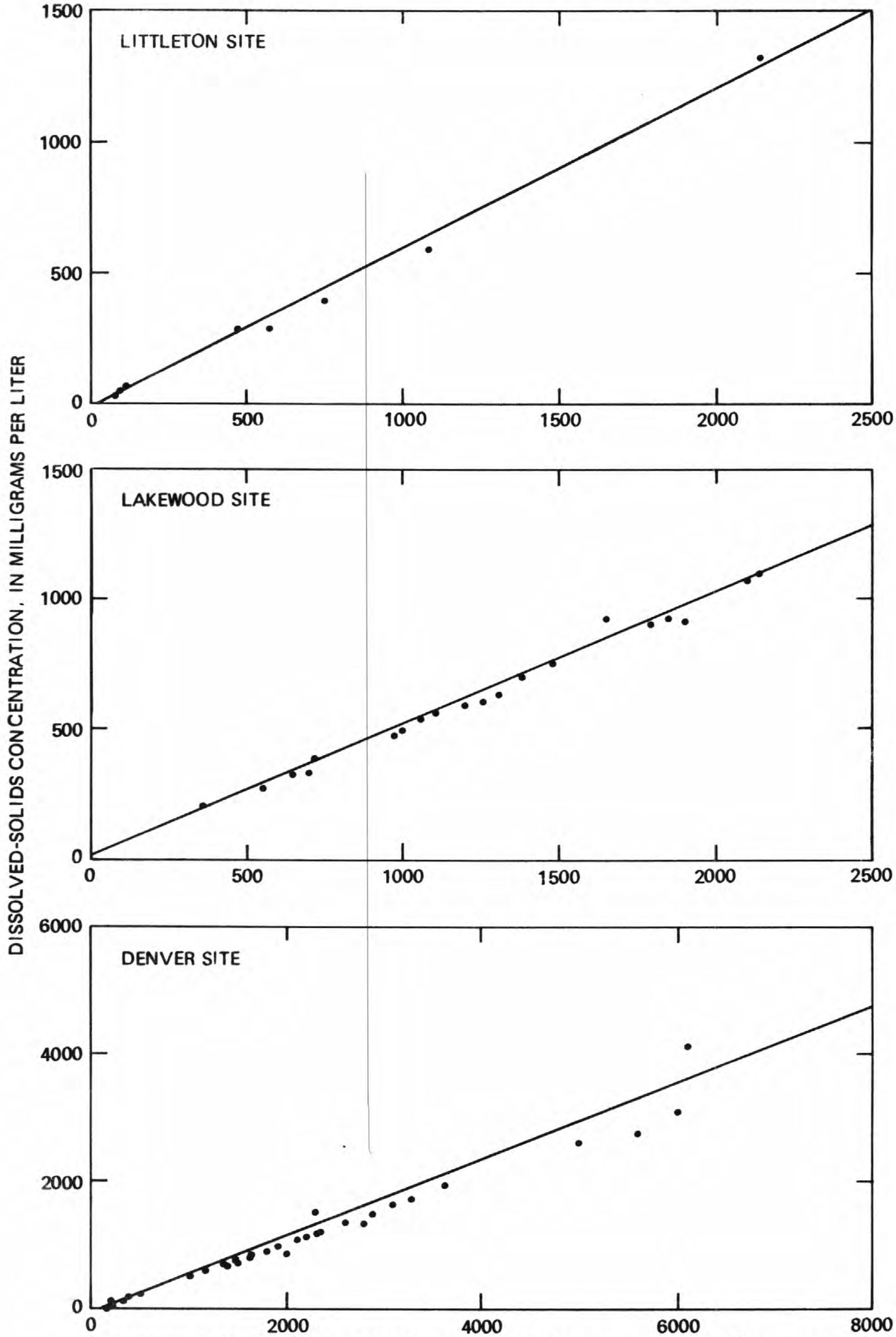


Figure 11.--Relation between dissolved-solids concentration and specific conductance in snowmelt runoff at the three sites.

Table 12.--*Loads of water-quality constituents for snowmelt-runoff periods at the Denver site*

Date	Snow-melt volume[1] (in.)	Number of samples	Load[1] (pounds per acre per inch of runoff)											
			Total nitrite plus nitrate as N	Total Kjel-dahl nitro-gen as N	Total nitro-gen as N	Dis-solved phos-phorus as P	Total ortho-phos-phate as P	Dis-solved organic carbon as C	Total nonfil-trable residue	Volatile nonfil-trable residue	Dis-solved calcium	Dis-solved sodium	Dis-solved chloride
Mar. 6, 1976--	0.043	7	0.15	0.81	0.96	0.049	0.046	---	71	14	5.6	77	130
Mar. 26, 1976--	.0094	12	.25	.78	1.0	.16	.061	4.5	13	6.1	3.3	4.1	4.0
Mar. 29, 1976--	.014	[2]13	.17	.54	.71	.11	.051	4.1	14	6.4	2.7	7.4	10
Feb. 14, 1977--	.011	[3]17	.27	1.0	1.3	.16	.087	9.3	57	28	10	100	170

[1]Snowmelt volumes and loads are based on snowmelt volume occurring between first and last samples collected for the runoff period.

[2]Twelve samples for dissolved organic carbon.

[3]Fifteen samples for dissolved organic carbon.

Dry-Weather Flow

Dry-weather flow was common at the Denver site but rare at the other two sites. From January 8 through February 6, 1977, dry-weather flow at the Denver site was monitored at 15-minute intervals for discharge and specific conductance. Twice-a-week site visits and a thorough preventative-maintenance program were required to obtain these data. Specific conductance during this time was variable, ranging from 176 to 15,100 μmhos/cm (micromhos per centimeter at 25°C). The average specific conductance was 705 μmhos/cm, with a standard deviation of 934 μmhos/cm. The variability of dry-weather flow and specific conductance, illustrated on figure 12, is perhaps a result of the random dumping of wastes into the storm-sewer system. For example, in a federally sponsored study asking people who change their own automobile oil what they do with the waste, 11.4 percent of the respondents reported that they disposed of it in a storm sewer (Water Information Center, Inc., 1976).

During the late spring and early summer of 1977, a period of water rationing, the discharge of dry-weather flow from the Denver site often increased from about midnight to 3 or 4 o'clock in the morning. This was probably the result of illegal lawn watering.

COMPARISON WITH WATER-QUALITY STANDARDS

Urban storm runoff seldom has a particular use, but, rather, affects the water quality of local receiving waters, which usually has a direct beneficial use. Colorado water-quality standards for drinking water, water supply, aquatic life, and agriculture are shown in table 13. A comparison of the quality of urban storm runoff with these water-quality standards can provide some indication of the potential for adverse impact of this runoff on the beneficial uses of local receiving waters. If all or most of the samples of urban storm runoff did not exceed a particular water-quality standard, assuming the samples collected are representative of the Denver metropolitan area, then urban storm runoff likely will not be a problem with regard to that particular water-quality constituent or property and that particular beneficial use. On the other hand, if many or all samples exceeded a particular water-quality standard, then urban storm runoff may be a problem with reference to that particular water-quality constituent or property and that particular beneficial use. The extent of the problem, if any, would be a complex interrelationship of such factors as the constituent loads in the receiving waters and in the storm runoff, reactions among constituents, and the assimilative capacity of the receiving waters.

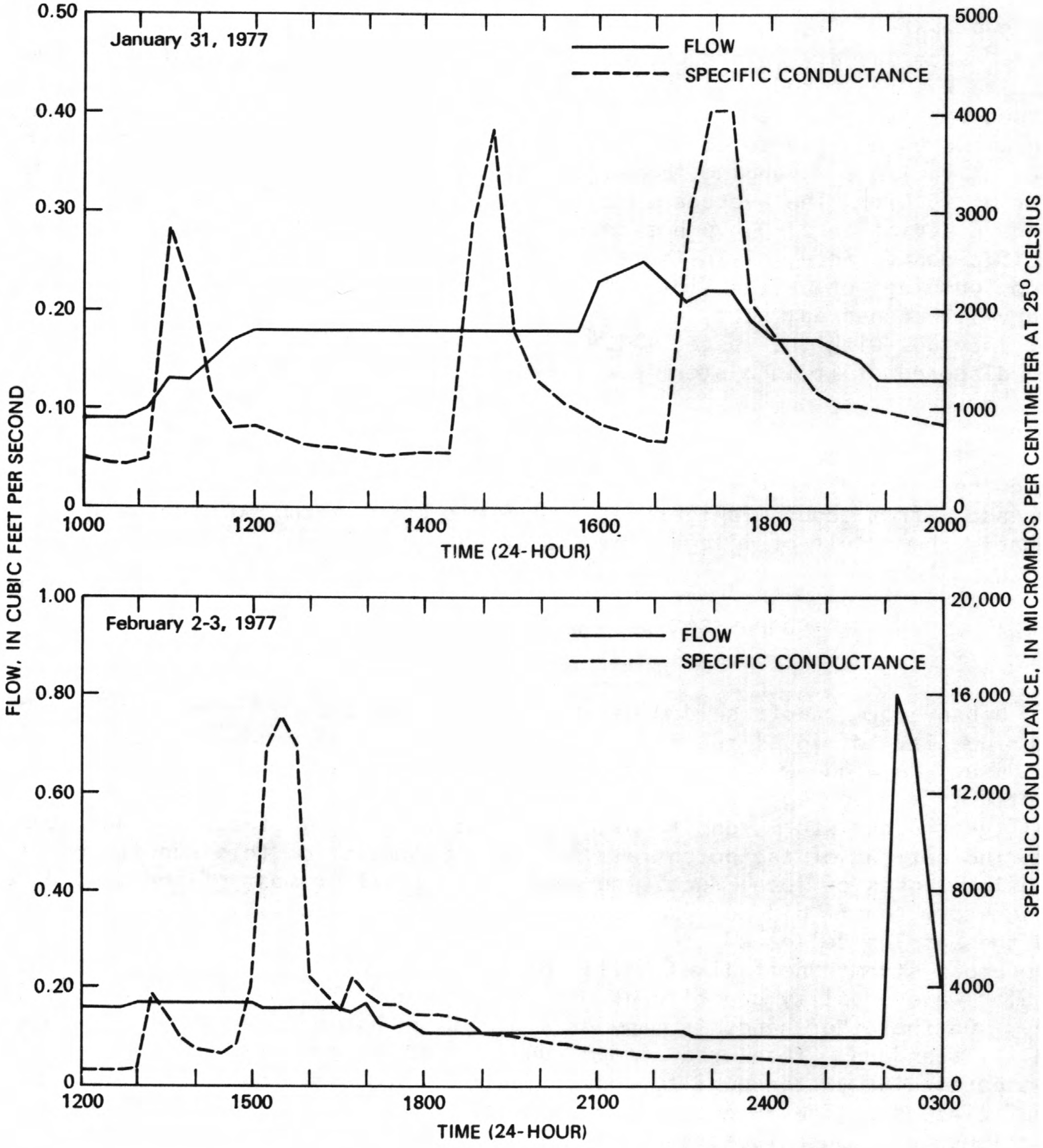


Figure 12.--Time plots showing the variability of specific conductance and discharge of dry-weather flow at the Denver site.

Table 13.--*Water-quality standards for water use in Colorado*

[Value given is the maximum allowed, unless otherwise specified]

Water-quality constituent or property	National (U.S. Environmental Protection Agency, 1975, 1977) and proposed Colorado (Colorado Department of Health, 1977a) drinking-water regulations	Proposed Colorado water-quality standards (Colorado Department of Health, 1977b)		
		Water supply[1]	Aquatic life[2]	Agriculture[3]
pH (units)---------------	[4]$6.5 \le pH \le 8.5$	[5]$5.0 \le pH \le 9.0$	$6.5 \le pH \le 9.0$	-----
Magnesium (mg/L)---------	-----------	125	----------	-----
Chloride (mg/L)----------	[4]250	250	----------	-----
Sulfate (mg/L)-----------	[4]250	250	----------	-----
Nitrate as N (mg/L)------	[6]10	10	----------	[7]100
Ammonia nitrogen as N (mg/L).	-----------	[8].5	[9].02	-----
Dissolved solids (mg/L)--	[4]500	-----------	----------	-----
Arsenic (μg/L)-----------	[6]50	50	50	100
Copper (μg/L)------------	[4]1,000	1,000	10	200
Iron (μg/L)--------------	[4]300	[10]300	1,000	-----
Lead (μg/L)--------------	[6]50	50	4	100
Zinc (μg/L)--------------	[4]5,000	5,000	50	2,000

[1]Includes uncontaminated ground water and ground and surface water requiring disinfection or standard treatment (raw water).

[2]Includes cold-water biota (inhabitants, including trout, of waters where temperatures do not normally exceed 20°C) and warm-water biota (inhabitants of waters where temperatures normally exceed 20°C). Trace-element standards apply to waters having total hardness from 0 to 100 mg/L as $CaCO_3$; standards for waters of greater hardness may be equal or greater. Total trace-element concentrations are given, unless otherwise specified.

[3]Includes irrigation and stock watering.

[4]Secondary maximum contaminant level. These "* * * are not federally enforceable and are intended as guidelines for the States * * *" (U.S. Environmental Protection Agency, 1977).

[5]Applies only to ground and surface water requiring disinfection or standard treatment (raw water).

[6]Interim primary maximum contaminant level. Applies to all systems providing piped water for human consumption, "* * * if such system has at least fifteen service connections or regularly serves at least twenty-five individuals." (U.S. Environmental Protection Agency, 1975). Proposed primary drinking-water regulations (Colorado Department of Health, 1977a).

[7]Includes nitrite as N.

[8]Recommended standard because of effect on chlorination.

[9]Nonionized. Applies only to cold-water biota; standard for warm-water biota is 0.10 mg/L.

[10]Refers to soluble form.

Only two of the samples of rainfall runoff and none of the samples of snowmelt runoff had pH values that were outside the range of values specified as water-quality standards in table 13. In general, concentrations of dissolved magnesium, dissolved sulfate, total nitrate, and total arsenic in both rainfall runoff and snowmelt runoff were much less than the water-quality standards for magnesium, sulfate, nitrate, and arsenic. Concentrations of dissolved chloride and dissolved solids exceeded the water-quality standards for chloride and dissolved solids in approximately one-half the samples of snowmelt runoff but in none of the samples of rainfall runoff. Most of the samples of both rainfall runoff and snowmelt runoff contained concentrations of total ammonia nitrogen exceeding the aquatic-life standard, while approximately 30 percent of the samples of rainfall runoff and 40 percent of the samples of snowmelt runoff had concentrations of total ammonia nitrogen that exceeded the water-supply standard. Almost all of the samples of both rainfall runoff and snowmelt runoff had concentrations of total copper, total iron, total lead, and total zinc that exceeded the standards for aquatic life. Finally, almost all of the samples of rainfall runoff and snowmelt runoff had concentrations of total iron and total lead that exceeded both the drinking-water and agriculture standards. Because copper, iron, lead, and zinc in urban storm runoff are mainly in the particulate phase, they probably concentrate in the bottom sediments of local receiving-water bodies as the suspended particles settle out. During anaerobic or low-pH conditions, these trace elements might become dissolved in the receiving waters.

COMPARISON WITH SECONDARY-WASTEWATER TREATMENT-PLANT EFFLUENT

A useful comparison can be made between constituent concentrations and loads in storm runoff and in secondary-wastewater treatment-plant effluent originating from the same area, as shown in table 14. Loads are not included for snowmelt runoff because snowmelt-runoff volumes usually could not be determined. The rainfall-runoff loads shown are based on the average loads of the water-quality constituents for each of the three basins in pounds per inch of rainfall and the measured rainfall during April 1976 through September 1976 in each of the three basins.

Two types of comparisons can be made using the data in table 14. A comparison of average concentrations of constituents in storm runoff with average concentrations in secondary-wastewater treatment-plant effluent provides an indication of the relative magnitudes of constituent loads on an "equivalent-volume" basis. A comparison of the constituent loads from rainfall runoff and from secondary-wastewater treatment-plant effluent during April through September 1976 provides a comparison on a "long-term" basis. Neither comparison accounts for the fact that constituent loads from storm runoff are not evenly distributed in time but rather occur only during the periods of storm runoff, thus causing "shock" loading effects on receiving waters. Based on the data in table 14, on an "equivalent-volume" basis, storm runoff contained larger concentrations of total nonfiltrable residue, total lead, and total zinc; about the same amount of total copper; and less total Kjeldahl nitrogen and total orthophosphate than did effluent.

Table 14.--*Comparison of storm runoff with secondary-wastewater treatment-plant effluent*

Water-quality constituent	Average concentration (mg/L)						
	Rainfall runoff			Snowmelt runoff			Effluent[1]
	Littleton site	Lakewood site	Denver site	Littleton site	Lakewood site	Denver site	
Total Kjeldahl nitrogen as N.	1.9	3.0	3.6	1.8	3.2	3.2	21
Total orthophosphate as P.	.24	.33	.42	.10	.07	.31	4.5
Total nonfiltrable residue.	240	1,160	130	210	1,120	178	30
Total copper-----------	.03	.05	------	------	--------	.10	.04
Total lead-------------	.36	.41	------	------	--------	.70	.02
Total zinc-------------	.18	.40	------	------	--------	.61	.14

Water-quality constituent	Load during April through September 1976[2] (pounds)					
	Littleton site		Lakewood site		Denver site	
	Rainfall runoff	Effluent	Rainfall runoff	Effluent	Rainfall runoff	Effluent
Total Kjeldahl nitrogen as N.	530	15,000	91	1,800	2,900	180,000
Total orthophosphate as P.	43	3,200	14	400	200	40,000
Total nonfiltrable residue.	120,000	21,000	31,000	2,700	140,000	270,000
Total copper-----------	4.0	28	2.3	3.5	-------	-------
Total lead-------------	39	14	18	1.8	-------	-------
Total zinc-------------	20	98	17	12	-------	-------

[1]Ray McNeil, written commun., 1977.
[2]Based on an estimated wastewater flow of 60 gallons per capita per day.

When compared to secondary-wastewater treatment-plant effluent on a "long-term" basis, rainfall runoff in the Denver metropolitan area may be a significant contributor of total nonfiltrable residue and total lead to local receiving waters. The effects of this total nonfiltrable residue may include interference with sunlight penetration, reduction of daytime dissolved oxygen, increase of turbidity, and siltation of fish-spawning beds. The total lead will probably concentrate in the bottom sediments of local receiving waters. During anaerobic or low-pH conditions of receiving waters, this lead might become dissolved in the stream or lake.

COMPARISON WITH THE WATER QUALITY OF LOCAL STREAMS

During 1976 and 1977, the Colorado Department of Health collected samples from selected stream sites approximately twice a month. The location of five of these stream-quality sites is shown on figure 13. Although these samples were collected without regard to either streamflow or storm-runoff conditions, the results can be used to provide a general comparison of the water quality of storm runoff with the water quality of local streams.

Of the water-quality constituents shown in tables 5 and 11, samples from the five stream sites were analyzed for specific conductance, pH, sodium, chloride, sulfate, total nitrite plus nitrate, total ammonia nitrogen, total Kjeldahl nitrogen, total nonfiltrable residue, and five trace metals--arsenic, copper, iron, lead, and zinc. Specific conductance, sodium, chloride, and total ammonia nitrogen were selected for the comparison between the quality of storm runoff and the quality of the five local stream sites. The other water-quality constituents were associated more with the stream sediments than with the water column or were considered of lesser importance, based on the comparisons with the water-quality standards and with secondary-wastewater treatment-plant effluent.

Graphic comparisons of water-quality data from local streams with water-quality data from rainfall runoff and snowmelt runoff are shown in figures 14 and 15. The average concentrations of total ammonia nitrogen in storm runoff from the three urban sites generally were slightly larger than the average concentrations in samples from three of the five stream sites and much less than those in samples from the other two stream sites. Mean specific conductance and mean concentrations of dissolved sodium and dissolved chloride in samples of rainfall runoff were generally less than the minimum specific conductance and minimum concentrations of total sodium and total chloride in samples from each of the five stream sites. On the other hand, many samples of snowmelt runoff had specific conductance and concentrations of dissolved sodium and dissolved chloride larger than the mean specific conductance and mean concentrations of total sodium and total chloride in each of the five stream sites. Based on the above results, storm runoff may be a significant contributor of total ammonia nitrogen to local receiving waters. In addition, during the winter months, snowmelt runoff may be a significant contributor of sodium and chloride to local receiving waters.

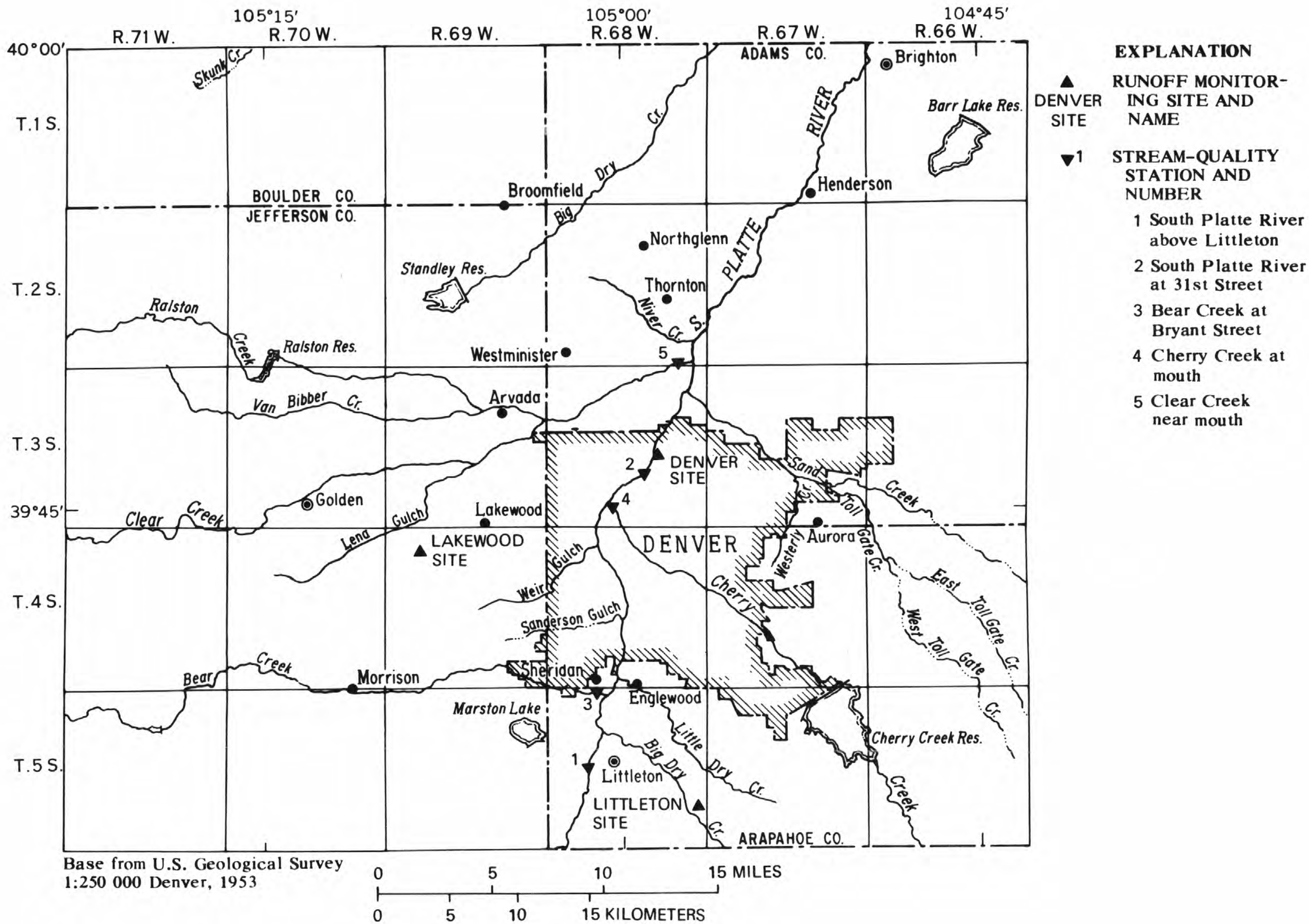


Figure 13.--Location of stream-quality stations.

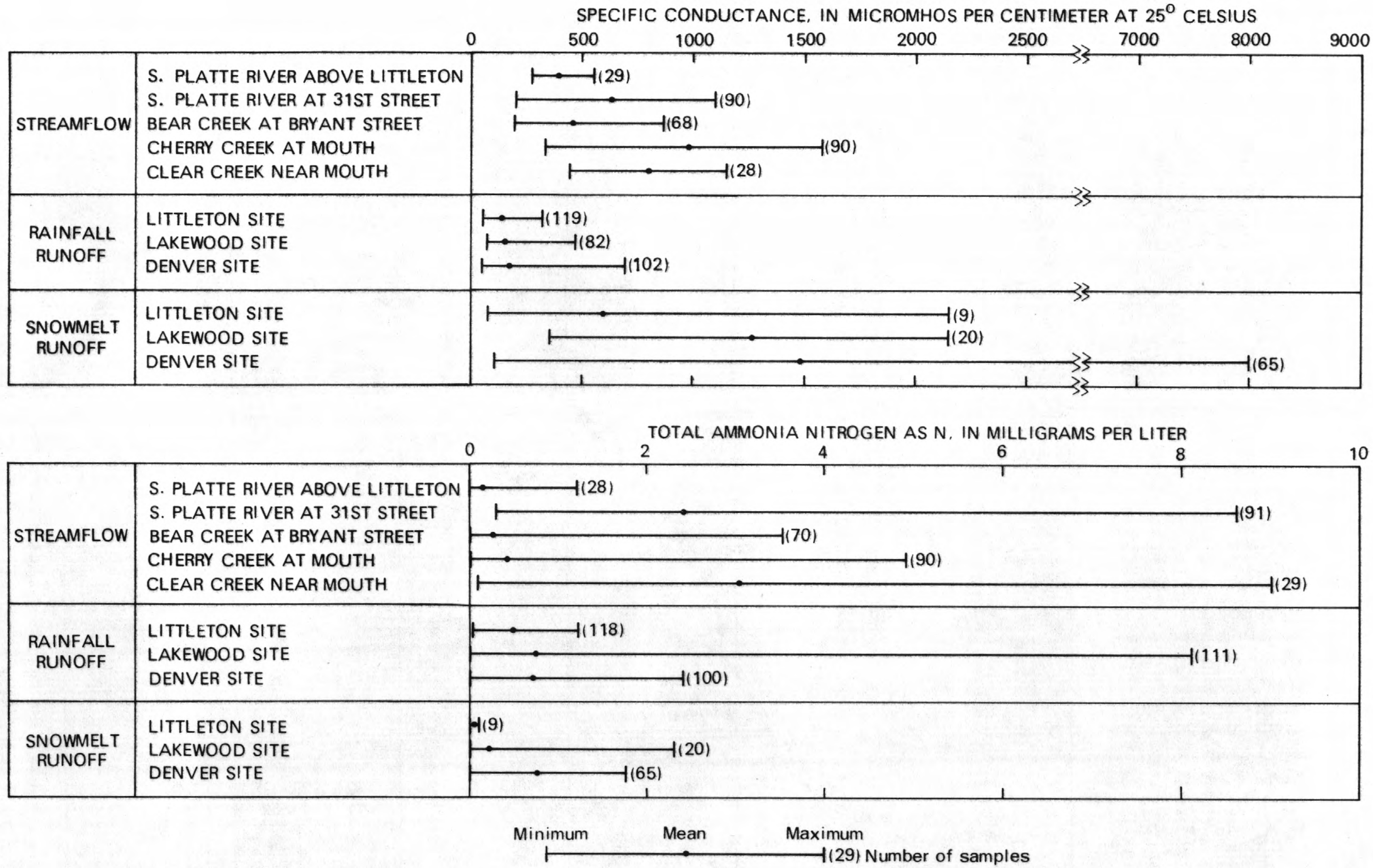


Figure 14.--Comparison of specific conductance and concentrations of total ammonia nitrogen in storm runoff with the specific conductance and concentrations of total ammonia nitrogen in local streams.

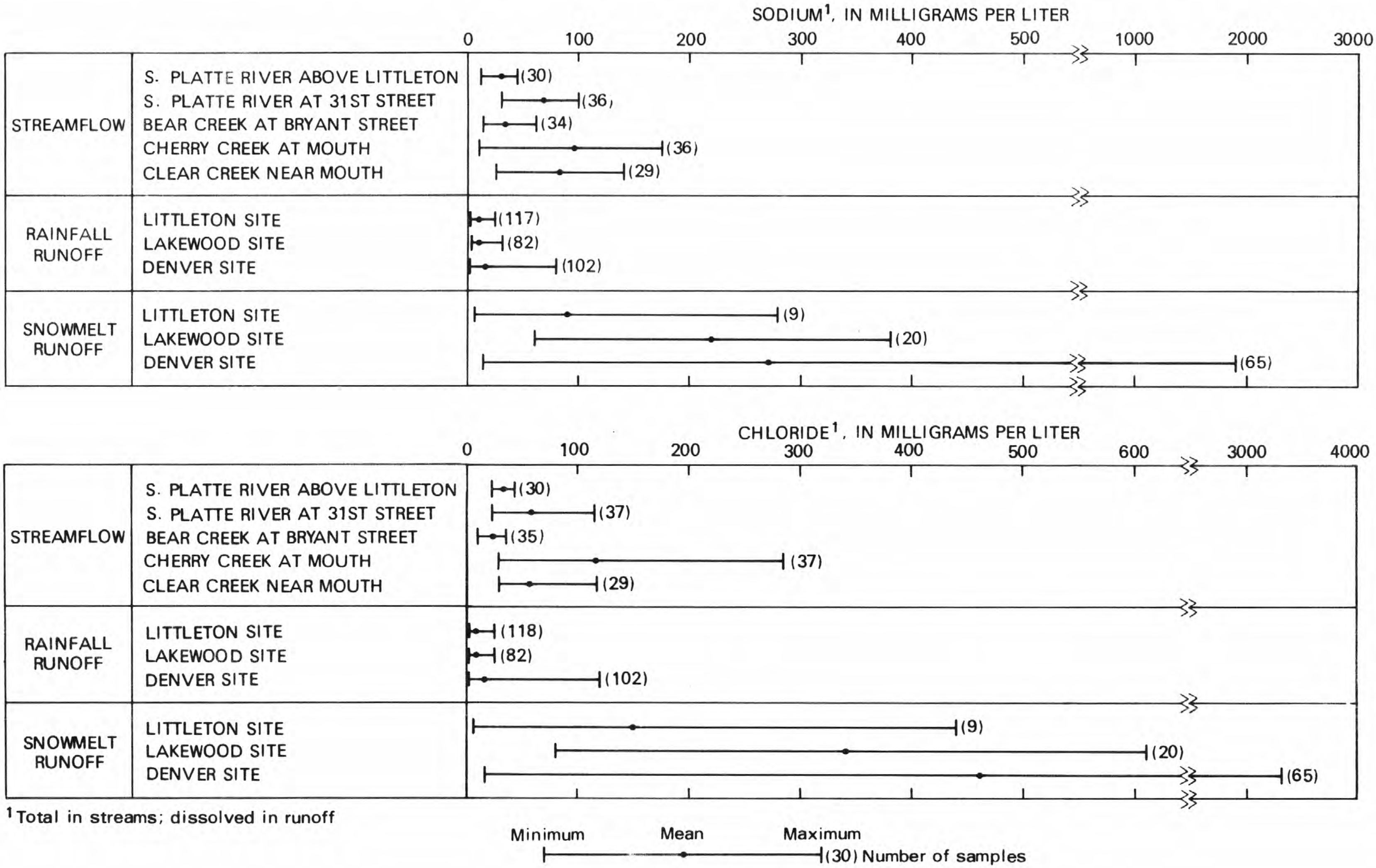


Figure 15.—Comparison of concentrations of sodium and chloride in storm runoff with the concentrations in local streams.

CALIBRATION AND VERIFICATION OF THE STORM WATER MANAGEMENT MODEL II

The U.S. Environmental Protection Agency's Storm Water Management Model II (Huber and others, 1975) is a computer model for the simulation of storm and combined sewerage systems. Data from the Littleton and Lakewood basins were used in the model for calibration and verification purposes. Both flow and total nitrogen were modeled for rainfall-runoff events. Watershed descriptors used by the model are "homogeneous" subbasins and a gutter and pipe network. These are delineated for the Littleton and Lakewood basins on figures 16 and 17.

Flow

During this study, six periods of rainfall runoff were gaged at each site so that runoff volumes and peak flows could be determined. Three of these six periods of rainfall runoff were selected for model calibration and three for model verification. Runoff periods selected for flow calibration were those during which sufficient samples were collected to provide meaningful estimates of total nitrogen loads. Thus, the runoff periods used for total nitrogen calibration were those used in flow calibration rather than those used in flow verification.

Prior to calibrating the model, a literature review was made to obtain an improved understanding of model-output sensitivity to changes in the input parameters. Three studies have included sensitivity analysis of the model (Graham and others, 1974; Huber and others, 1975; and Proctor and Redfern Limited and James F. MacLaren Limited, 1976). During each of these studies, all model parameters except one were held constant. The model parameter being tested was then varied through a range of values greater and lesser than the accepted mean value. All studies concluded that model output was most sensitive to the amount of effective impervious area. Sensitivity of the other model parameters was somewhat variable depending upon basin characteristics and the range of parameter values used. In general, runoff volumes were most sensitive to the amount of effective impervious area and infiltration rates. Peak flows were most sensitive to the amount of effective impervious area, infiltration rates, and subbasin widths. Additional sensitivity analyses made by the authors showed both runoff volumes and peak flows also to be sensitive to changes of ±5 percent in basin area.

The initial simulations for model calibration were made using the basin-characteristics parameters as reported by Ellis (1978) and values for the infiltration and retention-storage parameters as suggested in the user's manual (Huber and others, 1975). The model parameters were then varied during trial-and-error calibration, guided by a knowledge of model sensitivity, experience gained in previous simulations, and the ranges within which model parameters realistically may be adjusted.

For all initial simulations, the model underestimated runoff volumes and peak flows. Model calibration was then performed as follows: During the first stage of calibration, the maximum infiltration rate was changed from

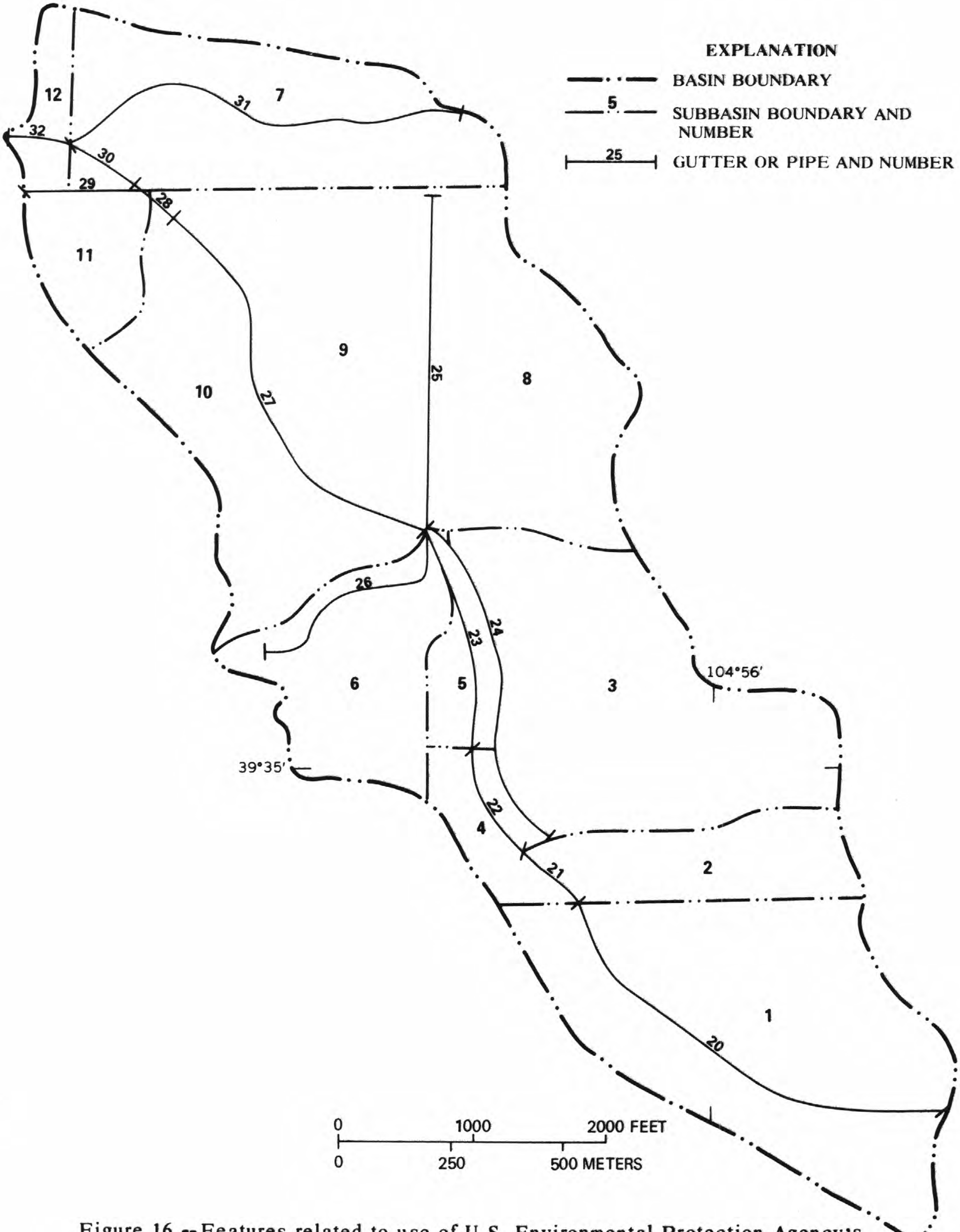


Figure 16.--Features related to use of U.S. Environmental Protection Agency's Storm Water Management Model II for the Littleton basin.

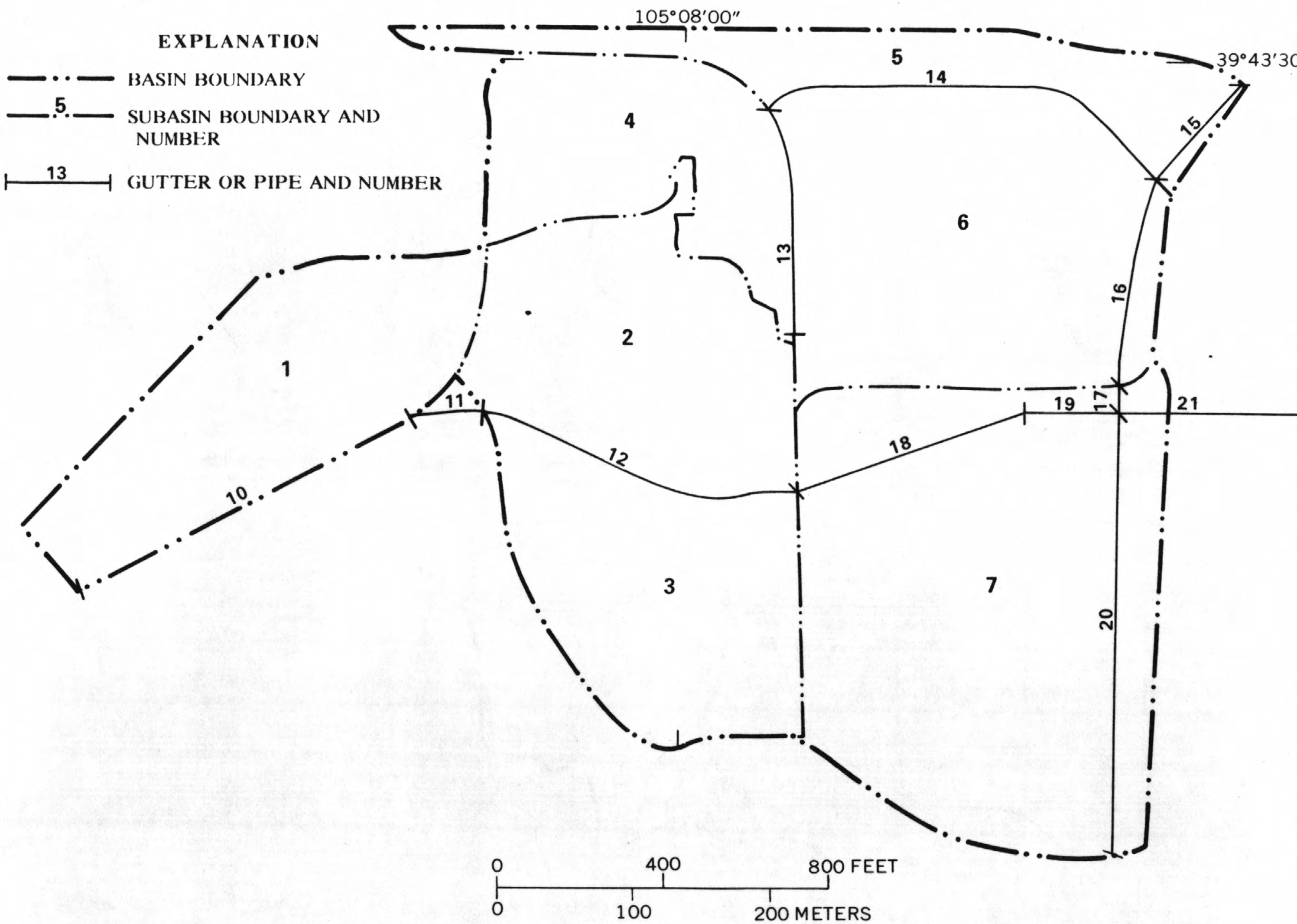


Figure 17.--Features related to use of U.S. Environmental Protection Agency's Storm Water Management Model II for the Lakewood basin.

3.0 to 0.5 in./h and the minimum infiltration rate was changed from 0.5 to 0.2 in./h. These values were more consistent with the soil characteristics of the basins (Larsen and Brown, 1971). Effective impervious areas for each subbasin were then multiplied by a factor as large as 1.5. This accounted for any errors made in determining effective impervious areas as well as the impact of noneffective impervious areas. If the average ratio of simulated runoff volume to measured runoff volume could not attain 1.0 using this strategy, then all subbasin areas were multiplied by a factor as large as 1.05 until this ratio was 1.0. A "best" fit was then obtained in the timing of hydrograph peaks and troughs by multiplying all subbasin widths by a factor as large as 1.25. Upon completion of this step, the impervious-area multiplication factor was reduced, if necessary, to achieve an average ratio of simulated runoff volume to measured runoff volume of 1.0, and the model was then considered calibrated.

Littleton Site

Runoff periods of May 30 and July 25 in 1976 and June 11, 1977, were selected for model calibration. Runoff volumes for initial (uncalibrated) simulations averaged 63 percent of the measured runoff volumes and the peak flows averaged 42 percent of the measured peak flows.

Model calibration was then performed. The final calibrated model had a maximum infiltration rate of 0.5 in./h and a minimum infiltration rate of 0.2 in./h. In addition, all subbasin areas were multiplied by 1.05, effective impervious areas for each subbasin were multiplied by 1.48, and all subbasin widths were multiplied by 1.25. The results for the calibrated model are shown in figure 18. The simulated peak flows averaged 79 percent of the measured peak flows.

Verification simulations were made for runoff periods of September 7, 1976, and April 15 and April 19 in 1977, using the model parameters determined during model calibration. The results of model verification are shown in table 15 and figure 19. The timing of hydrograph peaks and troughs was

Table 15.--*Measured and simulated runoff volumes and peak flows at the Littleton site, model verification*

Date	Measured runoff volume (in.)	Simulated runoff volume (in.)	Percent error	Measured peak flow (ft^3/s)	Simulated peak flow (ft^3/s)	Percent error
Sept. 7, 1976--	0.07	0.14	100	52	77	48
April 15, 1977--	.17	.20	18	33	30	-9
April 19, 1977--	.08	.13	62	14	18	29

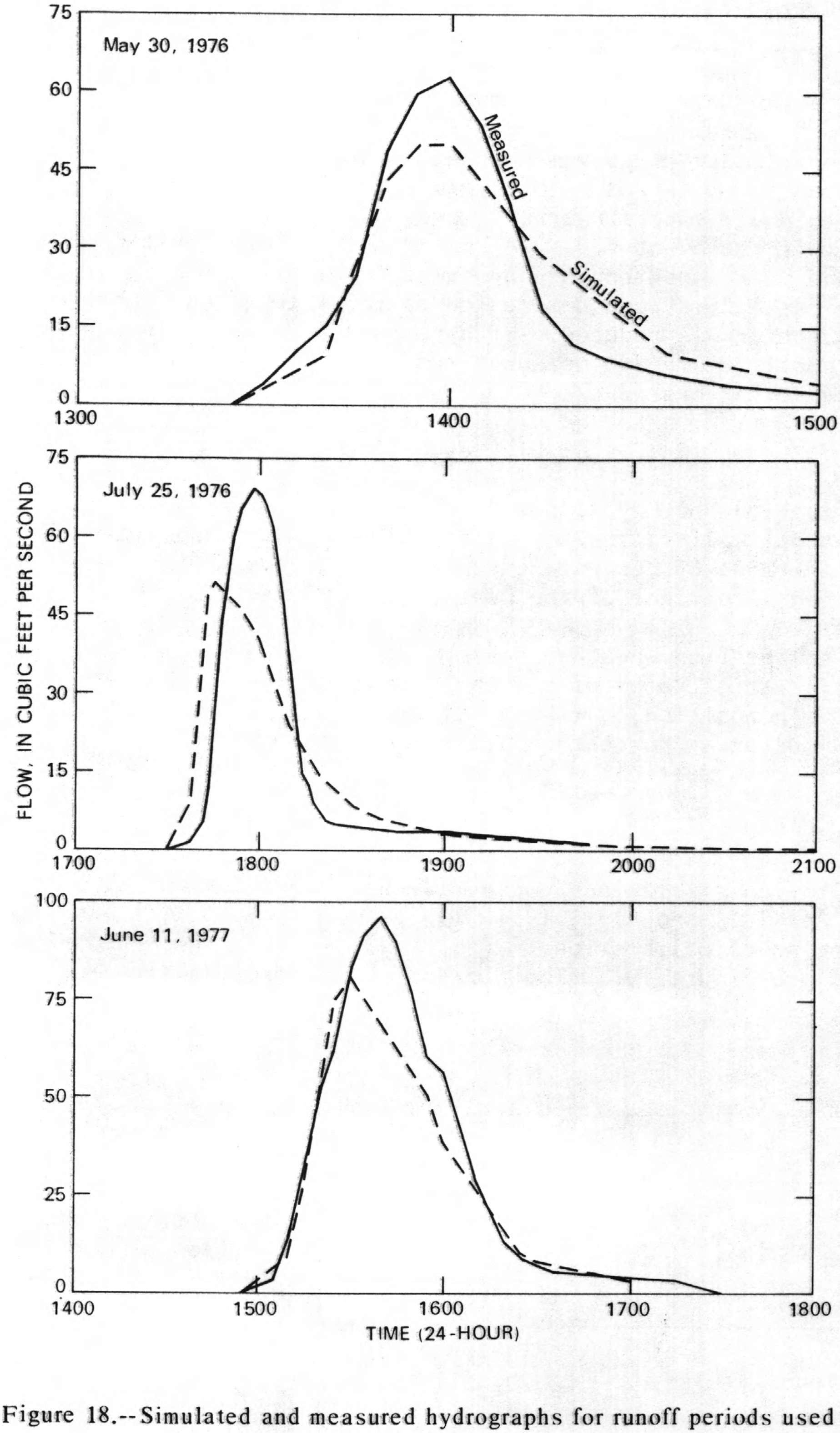


Figure 18.--Simulated and measured hydrographs for runoff periods used in model calibration for the Littleton site.

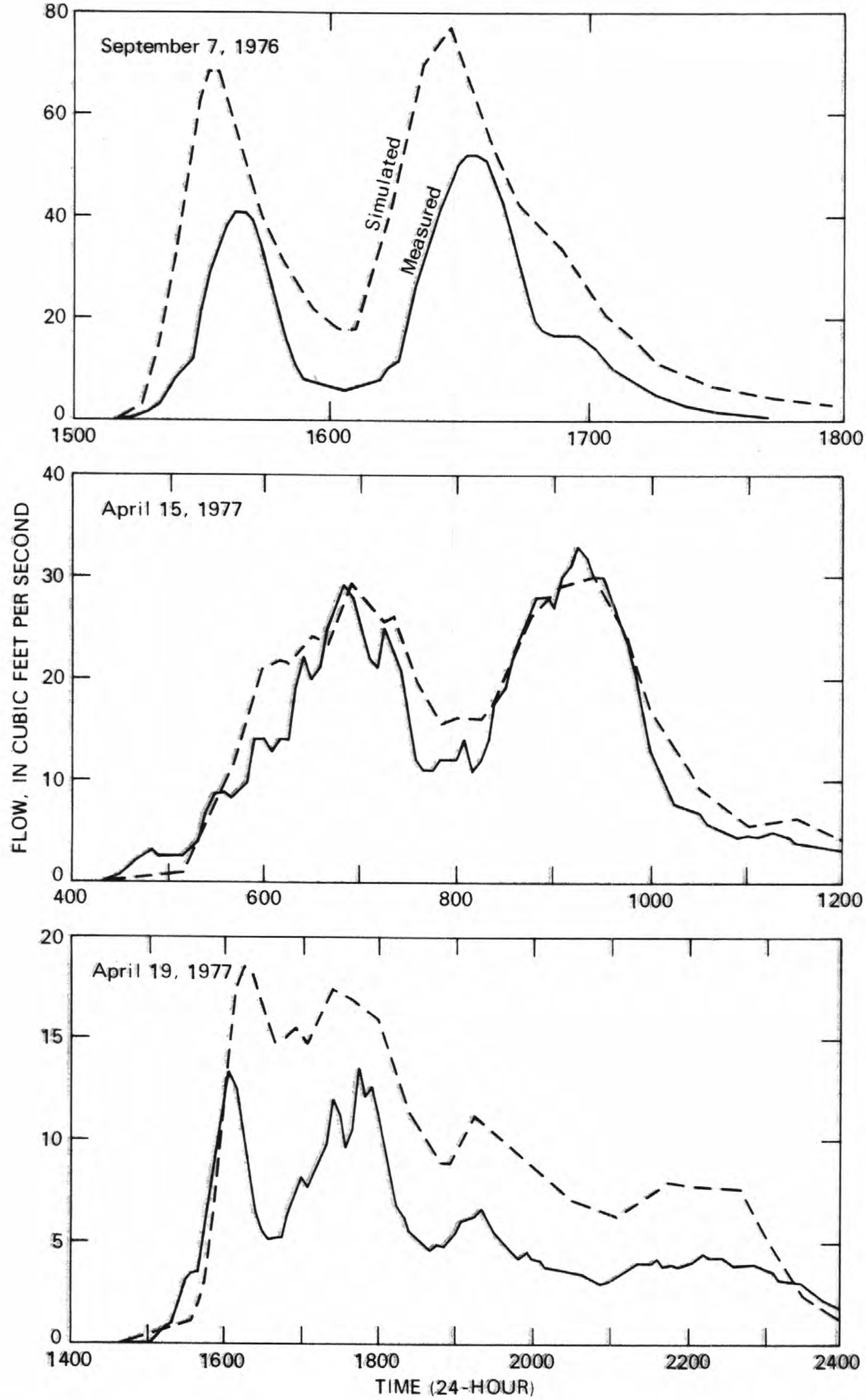


Figure 19.--Simulated and measured hydrographs for runoff periods used in model verification for the Littleton site.

similar for the measured and simulated hydrographs. However, the simulated runoff volumes and peak flows were significantly larger than the measured runoff volumes and peak flows for the runoff periods of September 7, 1976, and April 19, 1977. The measured and simulated hydrographs of April 15, 1977, were similar.

Lakewood Site

Runoff periods of April 12, April 19-20, and May 20 in 1977 were selected for model calibration. Runoff volumes for initial (uncalibrated) simulations averaged 86 percent of the measured runoff volumes for April 12 and April 19-20. The simulated runoff volume for May 20 was about 40 percent of the measured runoff volume. The runoff of May 20, which was the result of only 0.07 in. of measured rainfall, was deleted from the calibration process because of its anomalously large measured runoff volume and peak flow, which were perhaps caused by unmeasured rainfall in the upper reaches of the basin.

Model calibration was then performed. The final calibrated model had a maximum infiltration rate of 0.5 in./h and a minimum infiltration rate of 0.2 in./h. In addition, impervious areas for each subbasin were multiplied by 1.10. The results for the calibrated model are shown on figure 20. The results for the runoff of May 20 are included on figure 20, even though this runoff period was eliminated from the calibration process.

Verification simulations were then made for runoff periods of April 11, April 15, and May 20 in 1977 (a different runoff period than used for model calibration), using the model parameters determined during model calibration, as shown in table 16 and figure 21. The measured and simulated hydrographs of April 11 and April 15 were similar. The simulated runoff volume and peak flow of May 20 were significantly smaller than the measured runoff volume and peak flow, perhaps caused by unmeasured rainfall in the upper reaches of the basin.

Table 16.--*Measured and simulated runoff volumes and peak flows at the Lakewood site, model verification*

Date	Measured runoff volume (in.)	Simulated runoff volume (in.)	Percent error	Measured peak flow (ft^3/s)	Simulated peak flow (ft^3/s)	Percent error
1977						
April 11-------	0.036	0.043	19	3.4	3.6	6
April 15-------	.16	.16	0	4.3	4.7	9
May 20---------	.0092	.0039	-58	1.3	.38	-71

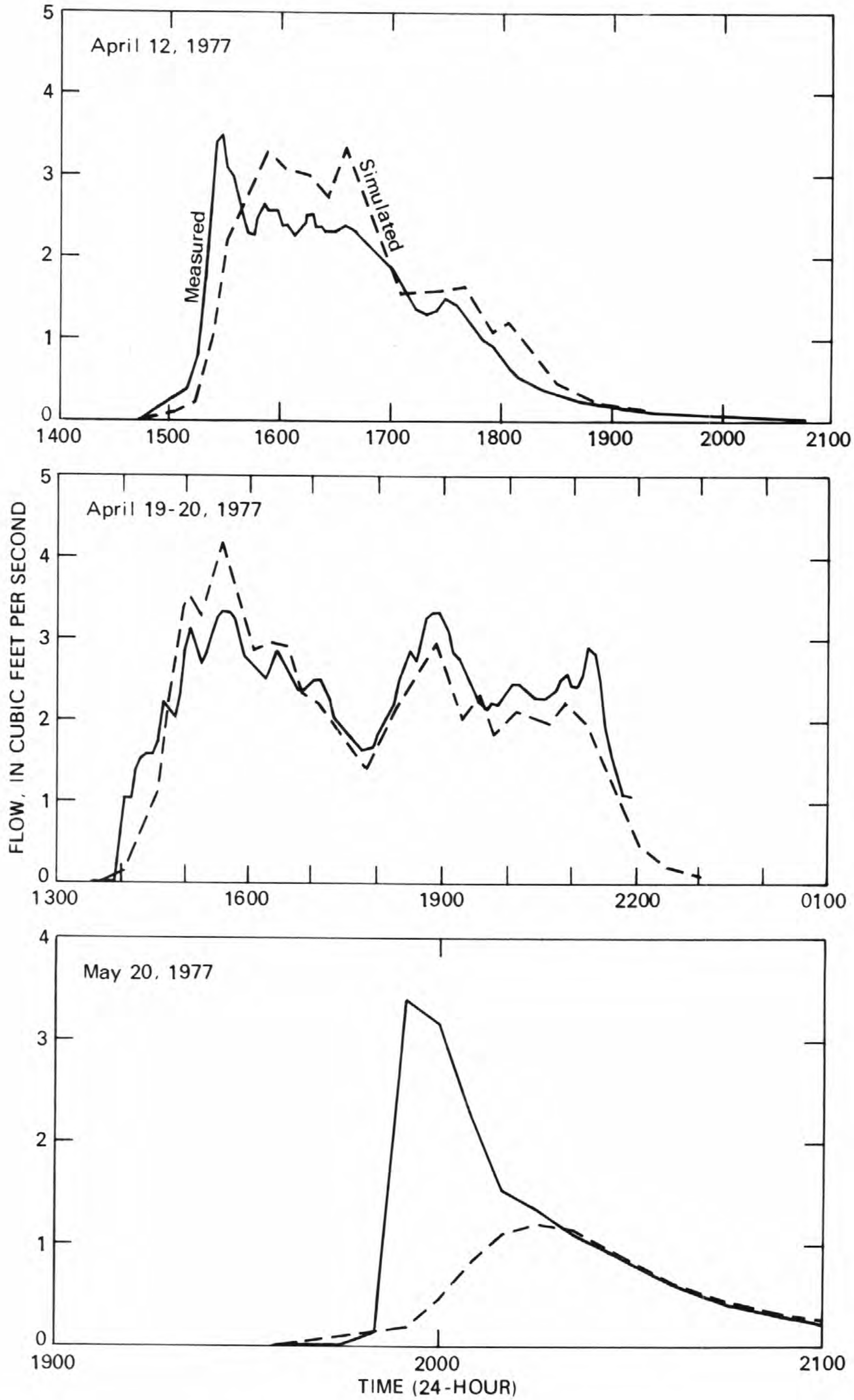


Figure 20.--Simulated and measured hydrographs for runoff periods used in model calibration for the Lakewood site.

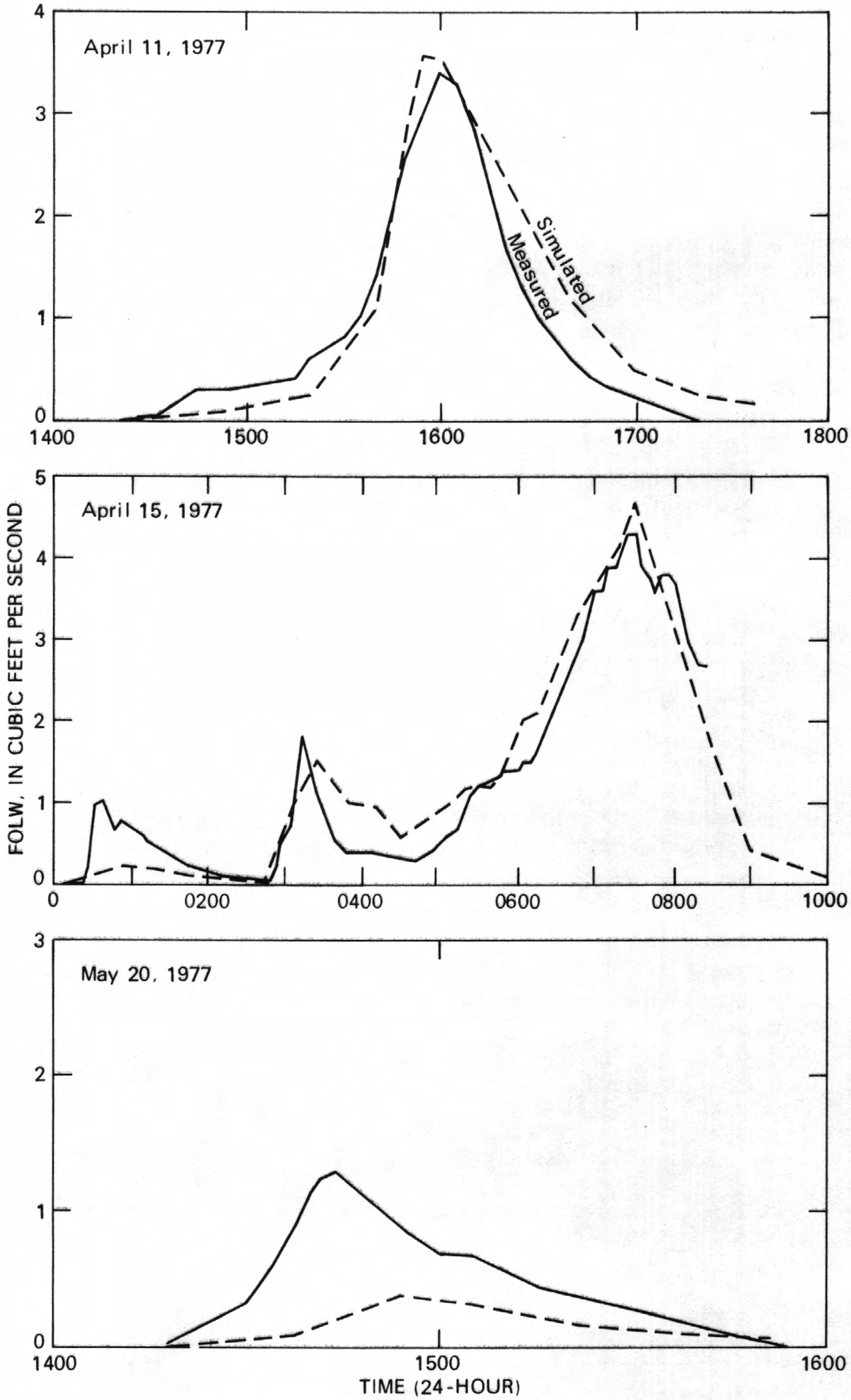


Figure 21.--Simulated and measured hydrographs for runoff periods used in model verification for the Lakewood site.

Total Nitrogen

The mathematical algorithms for rainfall-runoff quality of the U.S. Environmental Protection Agency's Storm Water Management Model II are the relationships most widely used in urban storm-runoff-quality models. The model will simulate settleable solids, suspended solids, coliform bacteria, biochemical oxygen demand, chemical oxygen demand, total nitrogen, and total phosphate. Of these constituents, only total nitrogen was determined in samples of rainfall runoff.

There are two main components of the rainfall-runoff-quality algorithms in the model: Constituent accumulation and constituent washoff. Constituent accumulation is estimated as a function of land use, the number of days prior to the storm during which the accumulated rainfall is less than 1.0 in., and street-cleaning frequency and efficiency. The constituent load on the ground surface (land-surface load) at the start of a storm is modeled as:

$$LLOAD = QFACT \times DFACT \times DRYDAYS \times GLEN \times 453.6, \qquad (1)$$

where

LLOAD = land-surface load, in milligrams;
QFACT = milligram of constituent per gram of "dust and dirt";
DFACT = "dust and dirt" loading rate for each land use, in pounds per day per foot of curb;
DRYDAYS = number of days prior to the storm during which the accumulated rainfall is less than 1.0 in. (modified to account for street sweeping); and
GLEN = curb length, in feet.
453.6 = conversion factor (grams per pound).

The parameter values for total nitrogen accumulation suggested in the user's manual for the model (Huber and others, 1975) are shown in table 17.

Table 17.--*Recommended values for total nitrogen accumulation parameters*

[From Huber and others, 1975]

Land use	DFACT "Dust and dirt" accumulation (pounds per day per 100 feet of curb)	QFACT Milligrams of total nitrogen as N per gram of "dust and dirt"
Single-family residential---	0.7	0.48
Multifamily residential-----	2.3	.61
Commercial------------------	3.3	.41
Industrial------------------	4.6	.43
Parks and open space--------	1.5	.05

Washoff of constituents is modeled using an exponential decay equation:

$$\underline{POFF} = PO[1-\underline{e}^{(-\underline{B}x\underline{R}x\Delta\underline{t})}], \qquad (2)$$

where

$\underline{POFF}$ = amount of constituent removed from land surface during a time step, in milligrams;
$\underline{PO}$ = amount of constituent on land surface at beginning of time step, in milligrams;
$\underline{B}$ = decay coefficient;
$\underline{R}$ = runoff rate, in inches per hour; and
$\Delta\underline{t}$ = time step, in hours.

The primary assumption for use of this equation is that the amount of constituent washed off during each time step is proportional to the amount remaining on the land surface at the start of the time step. The rate of washoff is controlled by the runoff rate for each time step and an exponent, $\underline{B}$, which is set at a constant value of 4.6, assuming that a uniform rainfall of 0.5 in./h would wash off 90 percent of the constituent in 1 hour. For total nitrogen, the model assumes that 4.5 percent of the suspended-solids concentration and 1.0 percent of the settleable-solids concentration simulated by the model should be added to the nitrogen concentration computed from the constituent-washoff equation (equation 2).

Littleton Site

The same runoff periods used in the flow calibration, May 30 and July 25 in 1976 and June 11, 1977, were used for the total nitrogen calibration. The initial simulations were made using values for the accumulation and washoff parameters as suggested in the user's manual (Huber and others, 1975), and values for the infiltration and basin-characteristic parameters as determined from the model calibration for flow.

Comparisons of initial simulations with measured runoff loads of total nitrogen are shown in table 18. Simulation errors ranged from +140 to +1,000 percent. The extent of this overprediction increases with the value of the model parameter, DRYDAYS. This is because the model model assumes that land-surface loads of total nitrogen are directly proportional to the number of days prior to the storm during which the accumulated rainfall was less than 1.0 in. This assumption is inconsistent with the data from the Littleton basin which showed no discernible effect of antecedent precipitation on rainfall-runoff loads.

A second simulation was made in which a model option was selected so that no part of the suspended-solids or settleable-solids concentration was added to the total nitrogen concentration. The results, shown in table 18, varied from -90 to -66 percent error. The error differences between simulations 1 and 2 indicate that the model simulations of total nitrogen are very sensitive to these model assumptions.

Table 18.--*Measured and simulated runoff loads of total nitrogen from the Littleton basin*

Date	DRYDAYS[1]	Measured load (pounds)	Simulation 1[2] Simulated load (pounds)	Simulation 1[2] Percent error	Simulation 2[3] Simulated load (pounds)	Simulation 2[3] Percent error
May 30, 1976---	31	30	72	140	3.1	-90
July 25, 1976---	56	30	240	700	7.3	-76
June 11, 1977--	57	38	420	1,000	13	-66

[1]DRYDAYS is a model parameter set at the number of days prior to the storm during which the accumulated rainfall is less than 1.0 in.

[2]Model constituent-accumulation and constituent-washoff parameters were set at those values suggested by model documentation (Huber and others, 1975).

[3]Same as simulation 1 except no part of the suspended-solids or settleable-solids concentrations was added to the total nitrogen concentration.

Most computer models which simulate the quality of rainfall runoff from urban areas contain similar algorithms to those used in the Storm Water Management Model II. Likewise, many of these models have a similar set of recommended values for the model parameters used in the runoff-quality algorithms. These models have been widely used as a source of input for making management decisions. The large simulation errors obtained for the Littleton site suggest that caution should be used when applying these models to assist in making water-quality-management decisions, particularly in the absence of local data for model calibration and verification.

A model option to specify the land-surface load in pounds per acre at the beginning of runoff for each subbasin was then used in place of the constituent-accumulation equation. The land-surface loads for each of the three runoff periods were adjusted until the ratio of simulated to measured runoff load was 1.0. Because of the lack of any other data, the land-surface loads were allocated between land uses in the same proportions as the values of DFACT x QFACT from table 17. The results of the "calibrated" model for each runoff period are shown in table 19. No apparent relationship of basin-average land-surface load with number of days since last street sweeping is displayed by these results. In addition, the rainfall that occurred before the runoff of May 30, 1976 (0.17 in. on May 20 and 0.28 in. on May 21), did not appear to have noticeably affected the land-surface load at the beginning of storm runoff on May 30. The results of the three calibration simulations are shown on figure 22. These indicate that the simulated and measured rates of decreasing total nitrogen concentrations with elapsed time from the start of a storm are similar, resulting in some confidence in the constituent-washoff equation (equation 2).

Table 19.--*Basin-average land-surface loads of total nitrogen at the beginning of runoff based on model calibration for the Littleton basin*

Date	Daily rainfall for previous 10 days[1] (inches)										Number of days since last street sweeping	Basin-average land-surface load of total nitrogen as N at beginning of runoff as determined from model calibration (pounds per acre)
	10	9	8	7	6	5	4	3	2	1		
May 30, 1976--	0.17	0.28	0	0	0.02	0	0	0	0	0	10	0.16
July 25, 1976--	0	0	0	0	.06	0	0	0	0	0	66	.17
June 11, 1977--	0	0	0	0	0	0	0	0	0	0	>10	.12

[1]Refers to number of days prior to date of runoff.

Three additional runoff periods were sampled for total nitrogen, but an insufficient number of samples was collected to provide meaningful estimates of total nitrogen loads. However, these runoff periods could be used for model verification for total nitrogen concentrations. Basin-average land-surface load of total nitrogen was assumed to be equal to the average of the basin-average land-surface loads shown in table 19. The results of the three verification simulations are shown in figure 23.

Lakewood Site

The runoff periods of July 19, 1976, and April 12 and April 19-20 in 1977, were used for model calibration. Again, the initial simulations for model calibration were made, using values for the accumulation and washoff parameters as suggested in the user's manual (Huber and others, 1975), and values for the infiltration and basin-characteristic parameters as determined from the model calibration for flow.

Comparisons of simulated with measured runoff loads of total nitrogen for the initial simulations are shown in table 20. Simulation errors ranged from +67 to +940 percent. The extent of this overprediction again increases with the value of the model parameter, DRYDAYS. This is because the model assumes that land-surface loads of total nitrogen are directly proportional to the number of days prior to the storm during which the accumulated rainfall was less than 1.0 in. This assumption is inconsistent with the rainfall-runoff-load data from the Lakewood basin which showed no discernible effect from antecedent precipitation.

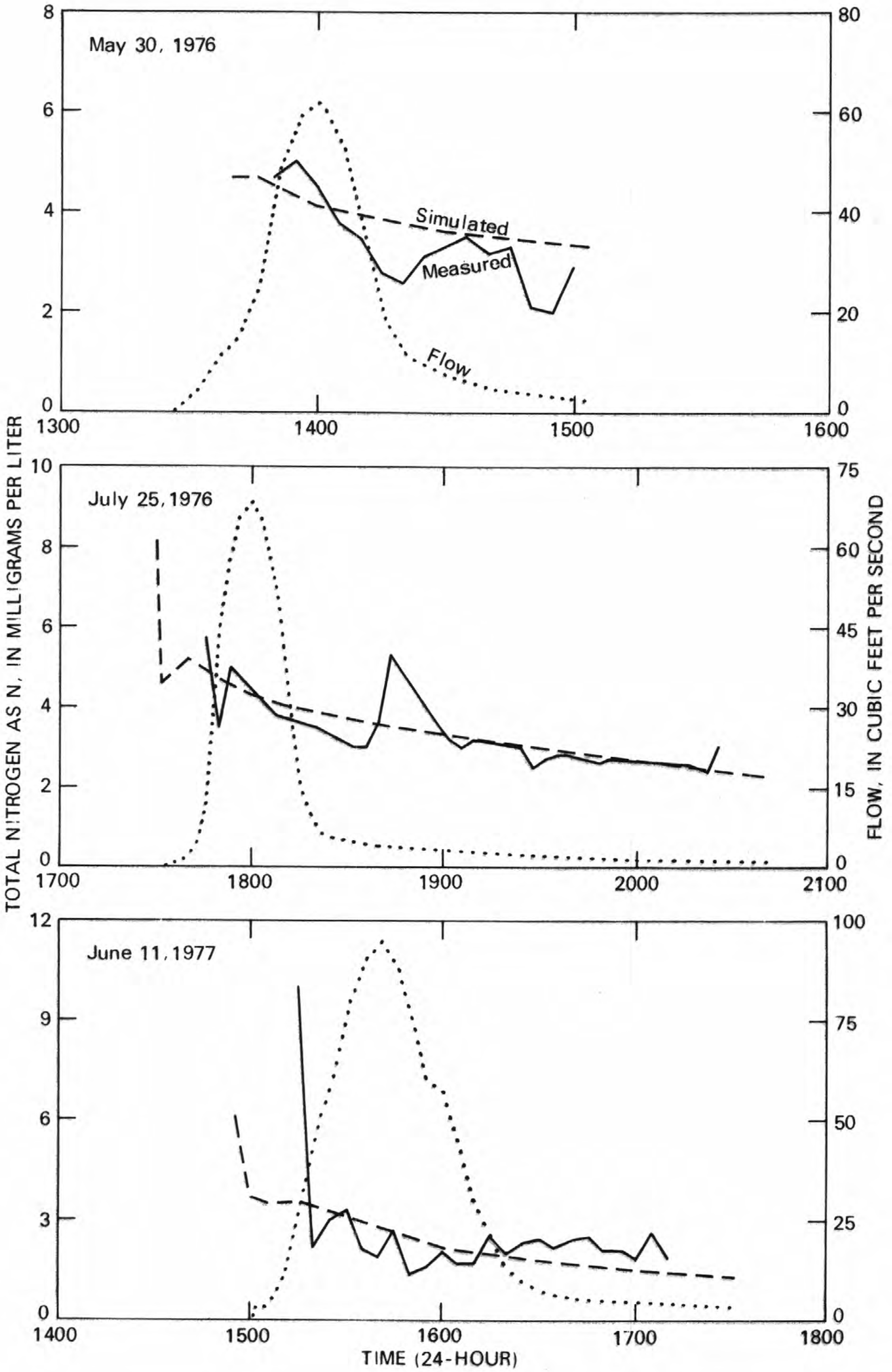


Figure 22.--Simulated and measured concentrations of total nitrogen with time for runoff periods used in model calibration for the Littleton site.

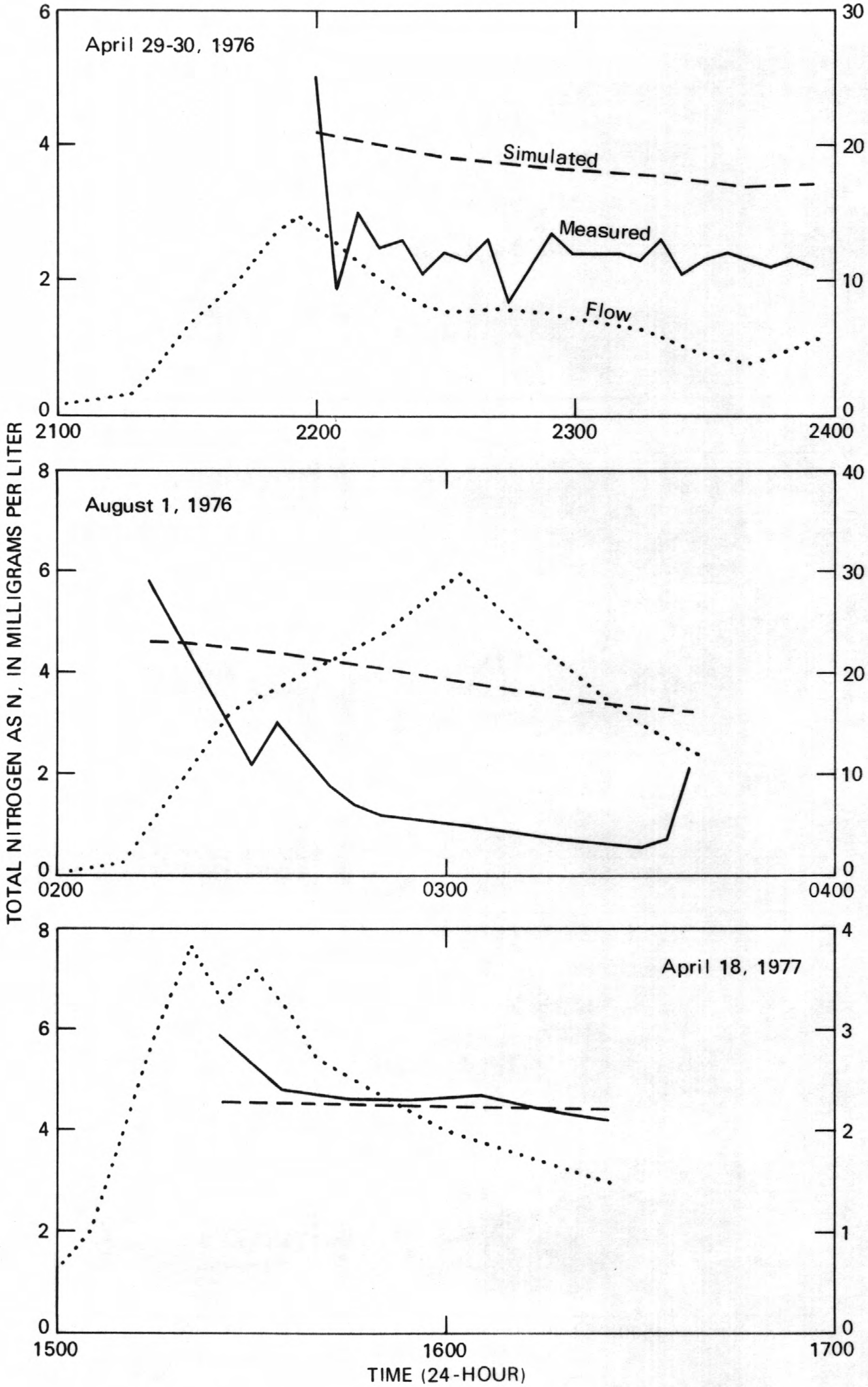


Figure 23.--Simulated and measured concentrations of total nitrogen with time for runoff periods used in model verification for the Littleton site.

Table 20.--*Measured and simulated runoff loads of total nitrogen from the Lakewood basin*

Date	DRYDAYS[1]	Measured load (pounds)	Simulation 1[2]		Simulation 2[3]	
			Simulated load (pounds)	Percent error	Simulated load (pounds)	Percent error
July 19, 1976-----	32	2.6	27	940	1.8	-31
Apr. 12, 1977-----	33	3.7	33	790	2.6	-30
Apr. 19-20, 1977--	7	12	20	67	1.1	-90

[1]DRYDAYS is a model parameter set at the number of days prior to the storm during which the accumulated rainfall is less than 1.0 in.

[2]Model constituent-accumulation and constituent-washoff parameters were set at those values suggested by model documentation (Huber and others, 1975).

[3]Same as simulation 1 except no part of the suspended-solids or settleable-solids concentrations was added to the total nitrogen concentration.

A second simulation was made in which a model option was selected so that no part of the suspended-solids or settleable-solids concentration was added to the total nitrogen concentration. The results, shown in table 20, varied from -30 to -90 percent error. The error differences between simulations 1 and 2 again indicate that the model simulations of total nitrogen concentrations are very sensitive to these model assumptions. Again, the large simulation errors suggest that caution should be used when applying the Storm Water Management Model II or other similar models to assist in making water-quality-management decisions, particularly in the absence of local data for model calibration and verification.

The model option to specify the land-surface loads in pounds per acre prior to runoff for each subbasin was again used in place of the constituent-accumulation equation. The land-surface loads for each of the three runoff periods were adjusted as previously described for the Littleton basin, and the results are shown in table 21. No apparent relationship of initial basin-average land-surface load of total nitrogen with antecedent precipitation or number of days since last street sweeping is displayed by these results. The initial basin-average land-surface loads of total nitrogen are similar for the Littleton (table 19) and Lakewood (table 21) sites. The results of the three calibration simulations are shown in figure 24.

Three additional runoff periods were sampled for total nitrogen, but an insufficient number of samples was collected to provide meaningful estimates of constituent loads. However, these runoff periods could be used for model verification of simulated total nitrogen concentrations. Basin-average land-surface load of total nitrogen was assumed to be equal to the average of the basin-average land-surface loads shown in table 21. The results of the three verification simulations are shown in figure 25.

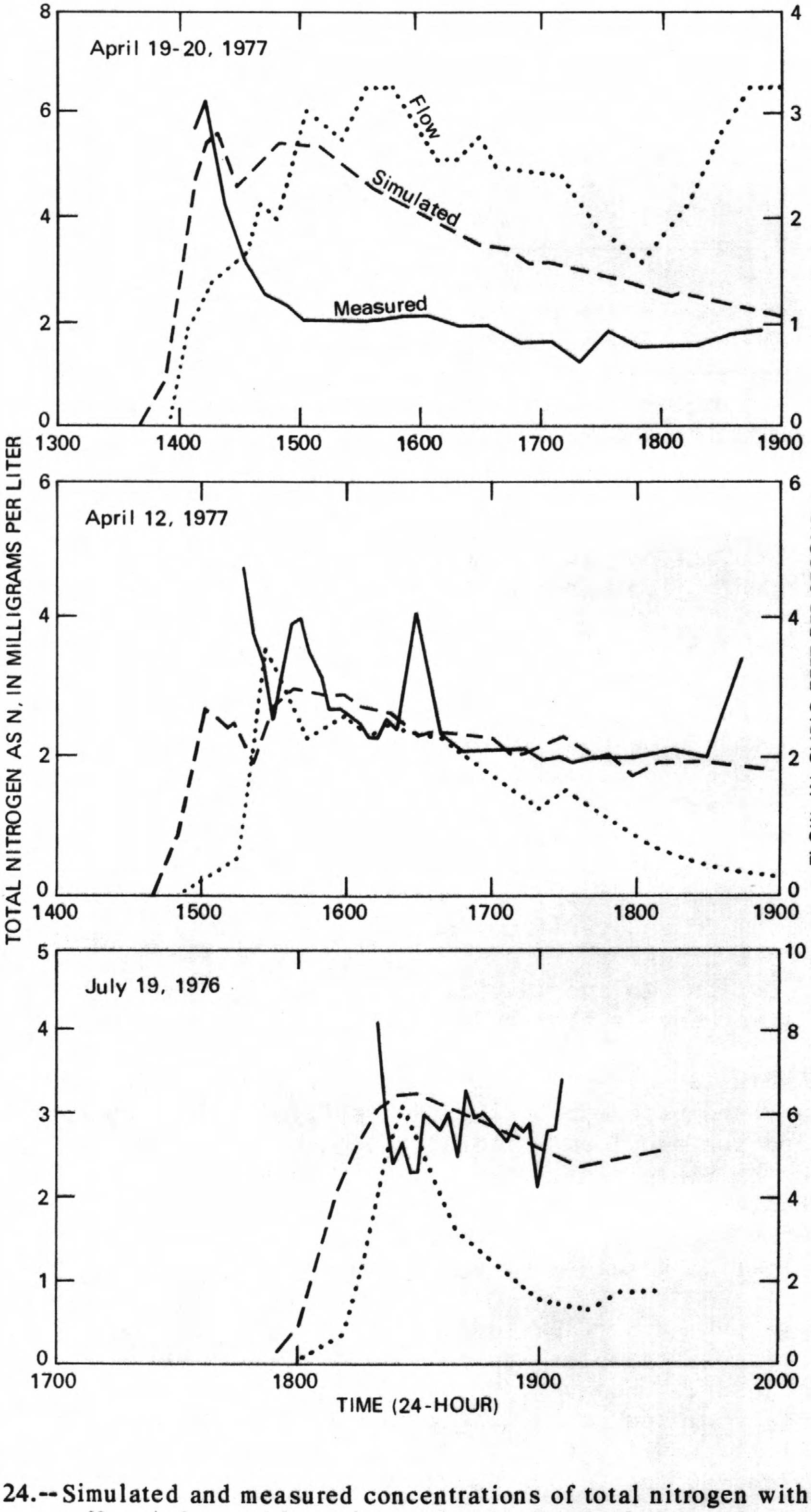


Figure 24.--Simulated and measured concentrations of total nitrogen with time for runoff periods used in model calibration for the Lakewood site.

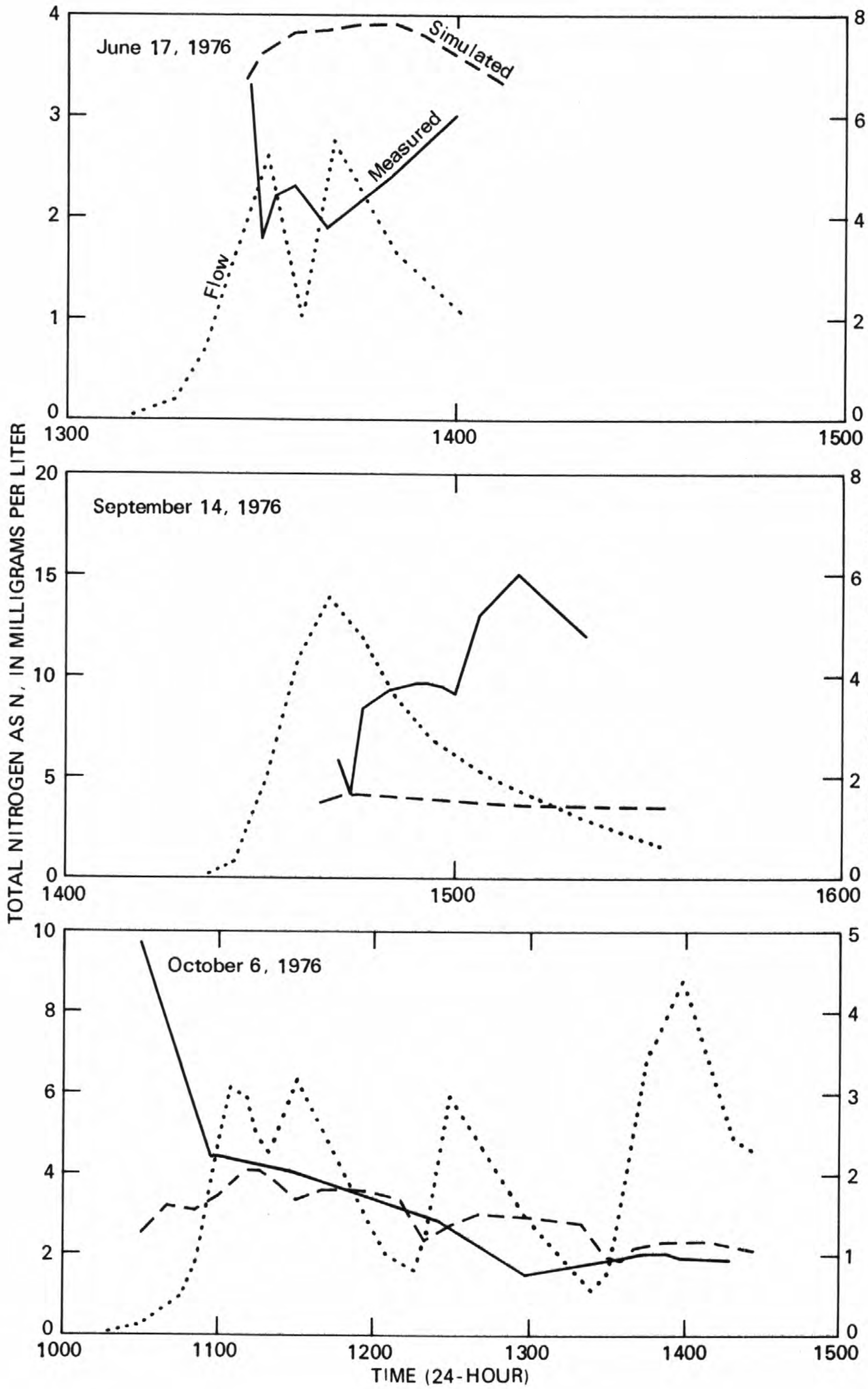


Figure 25.--Simulated and measured concentrations of total nitrogen with time for runoff periods used in model verification for the Lakewood site.

Table 21.--*Basin-average land-surface loads of total nitrogen at the beginning of runoff based on model calibration for the Lakewood basin*

Date	Daily rainfall for previous 10 days[1] (inches)										Number of days since last street sweeping	Basin-average land-surface load of total nitrogen as N at beginning of runoff as determined from model calibration (pounds per acre)
	10	9	8	7	6	5	4	3	2	1		
July 19, 1976-----	0	0	0	0	0	0	0	0	0	0	46	0.11
Apr. 12, 1977-----	0	0	0	0	0	0	0	0	.16	.28	5	.11
Apr. 19-20, 1977--	0	.16	.28	.29	.02	.49	.21	0	.01	.03	12	.21

[1]Refers to number of days prior to date of runoff.

The 7-day antecedent precipitation for the runoff period of September 14, 1976, was 0.45 in., of which 0.26 in. occurred on September 13. The 7-day antecedent precipitation for the runoff period of June 17, 1976, was 0.00 in.; for October 6, 1976, it was 0.001 in. The number of days since the last street sweeping was greater than 12 for all three runoff periods. Having used the same initial land-surface loads of total nitrogen for each of the verification simulations, one might expect that simulated total nitrogen concentrations in runoff from the storm of September 14 might have been larger than those measured, as this was the only one of the three verification storms which had appreciable antecedent precipitation. However, it was also the only one of the three verification simulations which resulted in large underestimates of total nitrogen concentrations, suggesting that antecedent precipitation did not have a discernible effect on the measured total nitrogen concentrations.

SUMMARY AND CONCLUSIONS

Constituent concentrations in storm runoff varied considerably. In general, storm runoff from the Denver site tended to have the largest constituent concentrations, whereas storm runoff from the Littleton site tended to have the smallest constituent concentrations. In rainfall runoff, constituent concentrations were generally largest during the initial parts of the periods of runoff and then decreased with time. In snowmelt runoff, constituent concentrations generally peaked during the middle of the day, corresponding with periods of maximum melting and runoff. Instantaneous loads of constituents were largely a function of discharge for both rainfall runoff and snowmelt runoff. A first flush, defined as a disproportionately high part of the total storm-runoff load in the initial part of the runoff, was rare.

Antecedent precipitation or the number of days since the last street sweeping showed no discernible effects on the quality of rainfall runoff. However, snowmelt-runoff loads apparently increase with the number of days snow has been lying on the ground. In addition, several instances were documented in which land-use activities, such as building construction or application of fertilizers and pesticides, had a discernible effect on the quality of storm runoff.

The water quality of storm runoff was compared with water-quality standards, secondary-wastewater treatment-plant effluent, and the water quality of local streams. Based on these comparisons, storm runoff may be a significant contributor of total ammonia nitrogen, total nonfiltrable residue, total copper, total iron, total lead, and total zinc to local receiving waters. In addition, during the winter months, snowmelt runoff may be a significant contributor of sodium and chloride to local receiving waters.

Data from the Littleton and Lakewood basins were used for calibration and verification of the U.S. Environmental Protection Agency's Storm Water Management Model II for modeling of flow and total nitrogen. Using values for the accumulation and washoff parameters as suggested in the user's manual (Huber and others, 1975) and parameters as determined from the model calibration for flow, errors in simulated storm-runoff loads of total nitrogen ranged from +140 to +1,000 percent at the Littleton site and from +67 to +940 percent at the Lakewood site. The extent of overprediction increased with the value of the model parameter, DRYDAYS. The model assumption that land-surface loads of total nitrogen are directly proportional to the number of days prior to the storm during which the accumulated rainfall was less than 1.0 in. was not substantiated. The results indicate that the model simulations of total nitrogen are very sensitive to the poorly defined model parameters specifying the part of the suspended-solids and settleable-solids concentrations added to the total nitrogen concentration. Based on the results of this study, caution should be used when applying the Storm Water Management Model II or other similar models to assist in making water-quality-management decisions, particularly in the absence of local data for model calibration and verification.

REFERENCES

Alley, W. M., and Ellis, S. R., 1978, Trace elements in runoff from rainfall and snowmelt at several localities in the Denver, Colorado, metropolitan area, *in* International Symposium on Urban Storm Water Management, July 24-27, 1978, Proceedings: University of Kentucky, Lexington, p. 193-198.

American Public Works Association, 1969, Water pollution aspects of urban runoff: U.S. Department of the Interior, Federal Water Pollution Control Administration, Water Pollution Control Research Service, WP-20-15, 272 p.

AVCO Economic Systems Corporation, 1970, Storm water pollution from urban land activity: U.S. Department of Interior, Federal Water Quality Administration, Program no. 11034FKL, Contract no. 14-12-187, 325 p.

Colorado Department of Health, 1977a, Primary drinking water regulations: Denver, proposed July 19, 1977; corrected after August 31, 1977, hearing; 59 p.

_____1977b, Proposed water quality standards for Colorado: Denver, draft no. 9, November 17, 1977, 51 p.

Ellis, S. R., 1978, Hydrologic data for urban storm runoff from three localities in the Denver metropolitan area, Colorado: U.S. Geological Survey Open-File Report 78-410, 135 p.

Graham, P. H., Costello, L. S., and Mallon, H. J., 1974, Estimation of imperviousness and specific curb length for forecasting storm-water quality and quantity: Water Pollution Control Federation Journal, v. 46, no. 4, p. 717-725.

Hansen, W. R., Chronic, John, and Matelock, John, 1978, Climatography of the Front Range Urban Corridor and vicinity, Colorado: U.S. Geological Survey Professional Paper 1019, 59 p.

Huber, W. L., Heaney, J. P., Medina, M. A., Peltz, W. A., Sheikh, Hasan, and Smith, G. F., 1975, Storm water management model user's manual, Version II: Cincinnati, Ohio, U.S. Environmental Protection Agency, National Environmental Research Center, EPA-67012-75-017, 350 p.

Larsen, L. S., and Brown, J. B., 1971, Soil survey of Arapahoe County, Colorado: U.S. Soil Conservation Service, 78 p., 63 maps.

Proctor and Redfern Limited and James F. MacLaren Limited, 1976, Storm Water Management Model Study, Volume 1: Toronto, Ontario, Canada, Ontario Ministry of the Environment, Research Report No. 47, 295 p.

Shearman, J. O., 1976, Computer applications for step-backwater and flooding analysis: U.S. Geological Survey Open-File Report 76-499, 103 p.

Shubinski, R. P., and Nelson, S. N., 1975, Effects of urbanization on water quality: American Society of Civil Engineers, Urban Water Resources Research Program, Technical Memorandum no. 26, 34 p.

Smoot, G. F., Davidian, Jacob, and Billings, R. H., 1974, Urban storm rainfall-runoff-quality instrumentation, *in* Paris Symposium on Flash Floods, September 1974, Proceedings: IAHS-AISH Publication 112, p. 44-47.

U.S. Environmental Protection Agency, 1975, National interim primary drinking water regulations: Federal Register, v. 40, no. 248, p. 59566-59588.

_____1977, National secondary drinking water regulations--Proposed regulations: Federal Register, v. 42, no. 62, p. 17144-17146.

Water Information Center, 1976, Watergrams: Ground Water Newsletter, v. 6, no. 17, p. 6.

☆U.S. GOVERNMENT PRINTING OFFICE:1979—680-415 / 501

QUANTITY AND QUALITY OF URBAN RUNOFF FROM THREE LOCALITIES IN THE DENVER METROPOLITAN AREA, COLORADO