CHARACTERIZATION OF URBAN RUNOFF FROM GRANGE HALL CREEK AT NORTHGLENN, ADAMS COUNTY, COLORADO

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Quality and quantity of urban runoff in upper Grange Hall Creek basin was studied during 1978-79. For selected storms a median of 54.5 percent of rainfall resulted in runoff in the urbanized upper subbasin and 24 percent in the entire basin; runoff volumes increased almost linearly with rainfall. Peak flows from thunderstorms also increased with rainfall but responses were two-phase linear. No simple relationships were observed between rainfall and runoff. In dry-weather flow, specific-conductance values in the creek ranged from 500 to 3,930 micromhos per centimeter and in the unnamed southern tributary ranged from 430 to 2,500. Specific conductances tended to be greater in winter and less in summer. Storm runoff decreased specific conductance, except during snowmelt runoff when streets were sanded with up to 7-percent salt. Lead, manganese, cadmium, chromium, and copper concentrations exceeded Colorado water-quality standards. During storm runoff, major ion concentrations usually decreased with increased flow; conversely, loads increased with increased flow, and there was evidence of a first-flush of loads in runoff from longer storms. Loads directly proportional to runoff volume per acre per inch of runoff were about equal for upstream and downstream subbasins, but unit loads from the upstream subbasin were two to four times greater due to greater unit runoff of rainfall.

Increased urbanization will increase storm runoff as a consequence of increasing impermeable area. Constituent loads will be expected to increase in dry-weather flow due to a combination of factors, such as increased input and decreased removal.

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CITY OF NORTHGLENN

Lakewood, Colorado
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METRIC CONVERSION TABLE

Multiply inch-pound unit	*By*	*To obtain metric unit*
acre	0.4047	hectare
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.40	millimeter
inch per hour (in./hr)	25.40	millimeter per hour
mile (mi)	1.609	kilometer
pound (avoirdupois)	0.4536	kilogram
pound per second	0.4536	kilogram per second
pound per acre per inch	44.13	kilogram per hectare per meter
square mile (mi^2)	2.590	square kilometer

GLOSSARY

Terms defined in the GLOSSARY are underscored when first used in the report.

antecedent dry days.--The number of days without significant precipitation preceding a storm.

base flow.--The streamflow that occurs without direct contribution from precipitation. Flow during a storm is composed of base flow and storm runoff.

basin.--See drainage basin.

daily mean streamflow.--The average streamflow for a given day.

drainage basin.--The entire tract of land drained by a river or stream and its tributaries.

drainage subbasin.--A part of a drainage basin that may be treated as a unit based on drainage characteristics.

dry-weather flow.--The flow in a stream during a period without rainfall or snowmelt runoff. Dry-weather flow consists of base flow and urban runoff, such as that from lawn watering.

effective impervious area.--Impervious area connected to drainage conveying runoff away from the area, such as roofs that drain onto driveways, streets, sidewalks, and paved parking lots.

fecal-coliform bacteria.--Bacteria that are present in the intestine or feces of warmblooded animals. They are often used as indicators of the sanitary quality of the water.

first-flush.--Initial storm runoff containing a high portion of the total constituent load.

impervious area.--Not permitting percolation (or infiltration) of water, such as streets, sidewalks, roofs, and paved parking lots.

instantaneous load.--The load at a point in the stream at a given instant in time. Determined by taking the product of the instantaneous flow and the constituent concentration.

instantaneous streamflow.--The total flow at a cross section of the stream at a given instant in time.

land use.--The physical characteristics of the land surface and the human activities associated with the land surface.

load.--The amount of a constituent carried from a drainage basin or subbasin during a given time period or in the runoff from a given storm.

major ions.--Chemical ions usually present in natural water at concentrations greater than 1 milligram per liter.

mean daily streamflow.--The average daily streamflow for a specified period or set of days.

mean annual precipitation--The long-term average of the annual precipitation at a given location.

mean annual snowfall--The long-term average of the annual snowfall at a given location.

mean monthly precipitation.--The long-term average precipitation for a particular month.

monthly precipitation.--The total precipitation for a given month.

noneffective impervious area.--Impervious but draining to a pervious area, such as roofs that drain onto lawns.

nutrients.--Elements or compounds such as nitrogen, carbon, and phosphorus that are required for growth of living organisms.

one-hundred-year flood (100-year flood).--A flood of flow magnitude equaled or exceeded, on the average, only once in 100 years.

pervious area.--Allowing percolation (or infiltration) of water, such as lawns and fields of porous material.

pesticides.--Chemical compounds used to control undesirable plants and animals. Major categories of pesticides include insecticides, miticides, fungicides, herbicides, and rodenticides. Insecticides and herbicides, which control insects and plants, respectively, are the two categories reported.

polychlorinated byphenyls (PCB's).--Industrial chemicals that are mixtures of chlorinated byphenyl compounds having various percentages of chlorine. These compounds are similar in structure to organochlorine insecticides.

rainfall runoff.--Streamflow coming directly from surface runoff of rainfall.

sediment.--Solid material that originates mostly from disintegrated rocks and is transported by, suspended in, or deposited from water; includes chemical and biochemical precipitates and decomposed organic material, such as humus (complex molecules formed by partial decomposition of plant or animal matter). The quantity, characteristics, and cause of the occurrence of sediment in streams are influenced by environmental factors. Some major factors are degree of slope, length of slope, soil characteristics, land usage, and quantity and intensity of precipitation.

snowmelt runoff.--Streamflow coming directly from surface runoff of melted snow.

storm runoff.--Rainfall or snowmelt runoff.

subbasin.--See drainage subbasin.

suspended sediment.--The sediment that at any given time is maintained in suspension by the upward components of turbulent currents or that exists in suspension as a colloid. A colloid is a particle that is not dissolved (too large to pass through a semipermeable membrane), but will not settle out of solution.

ten-year flood (10-year flood).--A flood of flow magnitude equaled or exceeded, on the average, only once in 10 years.

trace elements.--Elements usually present in natural water at concentrations less than 1 milligram per liter.

urban runoff.--Dry-weather flow or storm runoff or both from an urban drainage basin.

water year.--A 12-month period arbitrarily beginning October 1 and ending the following September 30. The year designation is the same as the calendar year in which it ends. Thus, the year ended September 30, 1978, is the 1978 water year.

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By Dennis C. Hall and A. C. Duncan

ABSTRACT

The quality and quantity of urban runoff in the upper Grange Hall Creek basin in Northglenn was studied during the 1978-79 water years. Precipitation at Northglenn was below average during the first year and above average during the second year of this study. Streamflow volume from the basin was about 1,190 acre-feet in 1978 and 1,510 acre-feet in 1979. Mean daily flows were about 1.65 cubic feet per second in 1978 and 2.09 cubic feet per second in 1979. Dry-weather flow generally ranged from 0.1 to 1.0 cubic feet per second.

From December 8, 1977, through September 30, 1979, in Grange Hall Creek there were 104 storm-runoff peaks--50 from snowmelt and 54 from rainfall. Peak flows were 339 cubic feet per second in water year 1978 and 876 cubic feet per second in water year 1979. The peak flow in 1979 was approximately a 10-year flood.

A median of 54.5 percent of rainfall for selected storms resulted in runoff in the urbanized upper subbasin and 24 percent in the entire upper Grange Hall Creek basin. Runoff volumes increased almost linearly with the rainfall of a storm. Peak flows for runoff from thunderstorms also increased with rainfall, but the responses, especially those for the basin, were two-phase linear. No simple relationships were observed between rainfall and runoff regardless of antecedent conditions.

Specific-conductance values in dry-weather flow in Grange Hall Creek ranged from 500 to 3,930 micromhos per centimeter and in the unnamed southern tributary ranged from 430 to 2,500. Specific conductances tended to be greater in the winter months and less in the summer months. Storm runoff decreased the specific conductance, except during snowmelt runoff when the streets were sanded with large quantities containing up to 7-percent salt.

Lead, manganese, cadmium, chromium, and copper occurred at concentrations exceeding Colorado water-quality standards for agricultural water. At the exit to the basin, lead exceeded the standard in none of the dry-weather flow samples, in 47 percent of snowmelt-runoff samples, and in 74 percent of rainfall-runoff samples. Manganese exceeded the standard in 39 percent of dry-weather flow samples, in 95 percent of snowmelt-runoff samples, and in 90 percent of rainfall-runoff samples. In addition, cadmium exceeded the standard in 5 percent, chromium in 2 percent, and copper in 5 percent of rainfall-runoff samples.

During storm runoff major ion concentrations usually decreased with increased flow, and conversely loads increased with increased flow. There was evidence of a first-flush of constituent loads in runoff from longer-duration rainstorms. Loads of water-quality constituents were directly proportional to runoff volume. Loads per acre per inch of runoff were about equal for the upstream subbasin and the downstream subbasin, but unit loads were two to four times greater from the upstream subbasin--the increase due to greater unit runoff of rainfall.

Increased urbanization, especially along the unnamed southern tributary, will increase storm runoff as a consequence of increasing the impermeable area of the basin. Increased water-quality constituent loads will also be expected to increase in dry-weather flow due to a combination of factors, such as increased constituent input into the system and decreased removal in reservoirs and open space.

INTRODUCTION

The City of Northglenn (fig. 1) and the Farmers Reservoir and Irrigation Company (FRICO) have developed a progressive water-sharing plan: The Northglenn and FRICO Land and Water Resources Management Plan. This plan, described in detail by the City of Northglenn (1977) and Sheaffer and Roland, Inc. (1977), provides for FRICO water from Standley Lake Reservoir to be used as a municipal water supply by Northglenn. Treated wastewater and urban runoff from Grange Hall Creek will be routed to FRICO for irrigation use. Stonehocker Reservoir has been proposed to collect and store urban runoff in Grange Hall Creek at a site about 0.75 mi downstream from the study area (fig. 2).

Beginning in 1977, the U.S. Geological Survey, in cooperation with the City of Northglenn, conducted a 2-year study of the quantity and quality of urban runoff from the upper Grange Hall Creek basin in Northglenn. Hydrologic data collected during this study have been published previously (Hall and Duncan, 1980).

Purpose

The purpose of the study was to (1) determine quantity and quality of urban runoff from the upper Grange Hall Creek drainage basin in Northglenn; (2) identify constituents exceeding water-quality standards for agricultural waters; (3) compare differences in quality between dry-weather flow, snowmelt runoff and rainfall runoff; (4) determine rainfall-runoff relationships; (5) investigate relationships between constituent concentrations, specific conductance, and streamflow; and (6) suggest, where appropriate, alternatives of urban-runoff management.

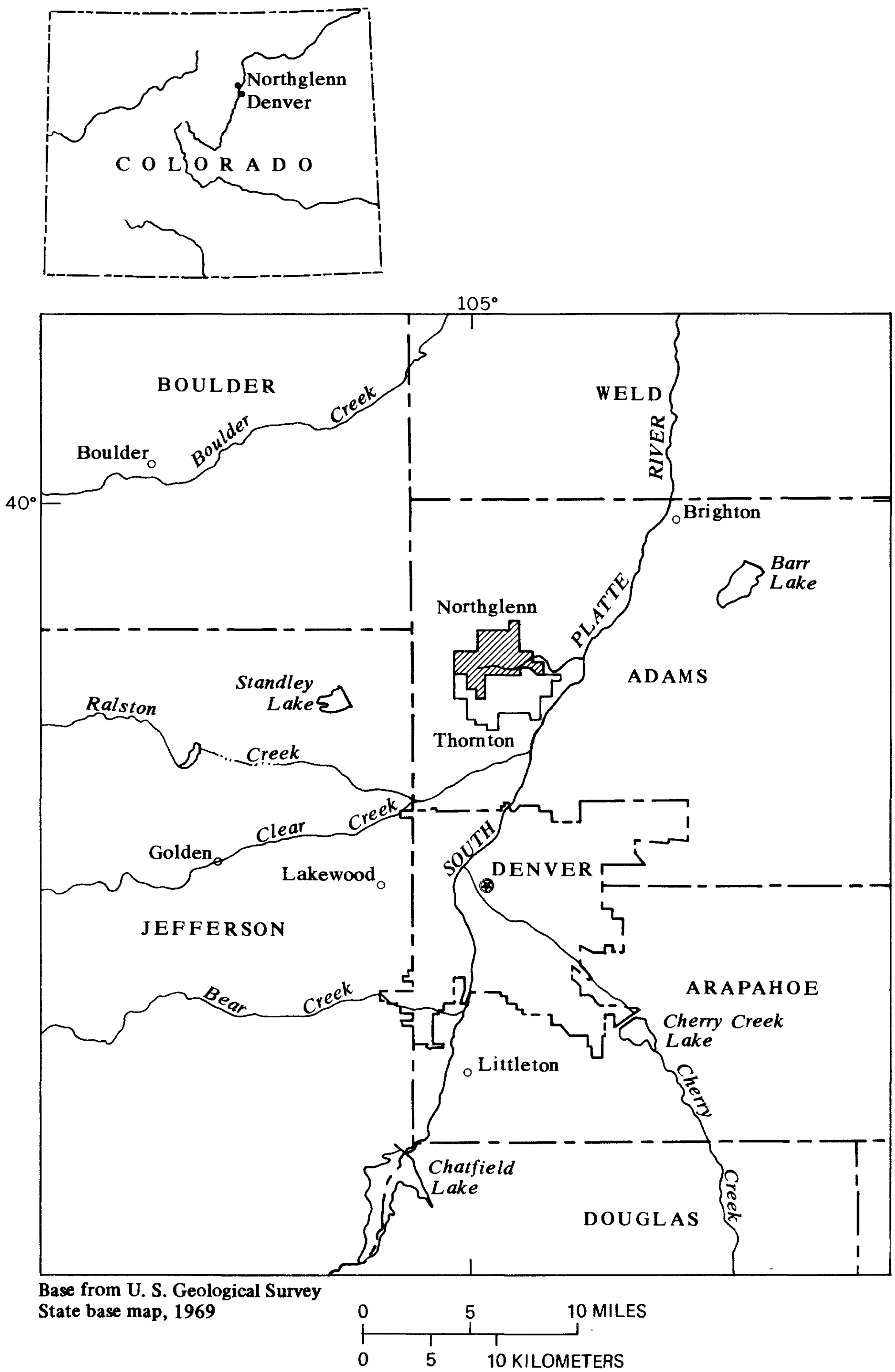


Figure 1.--Location of Northglenn.

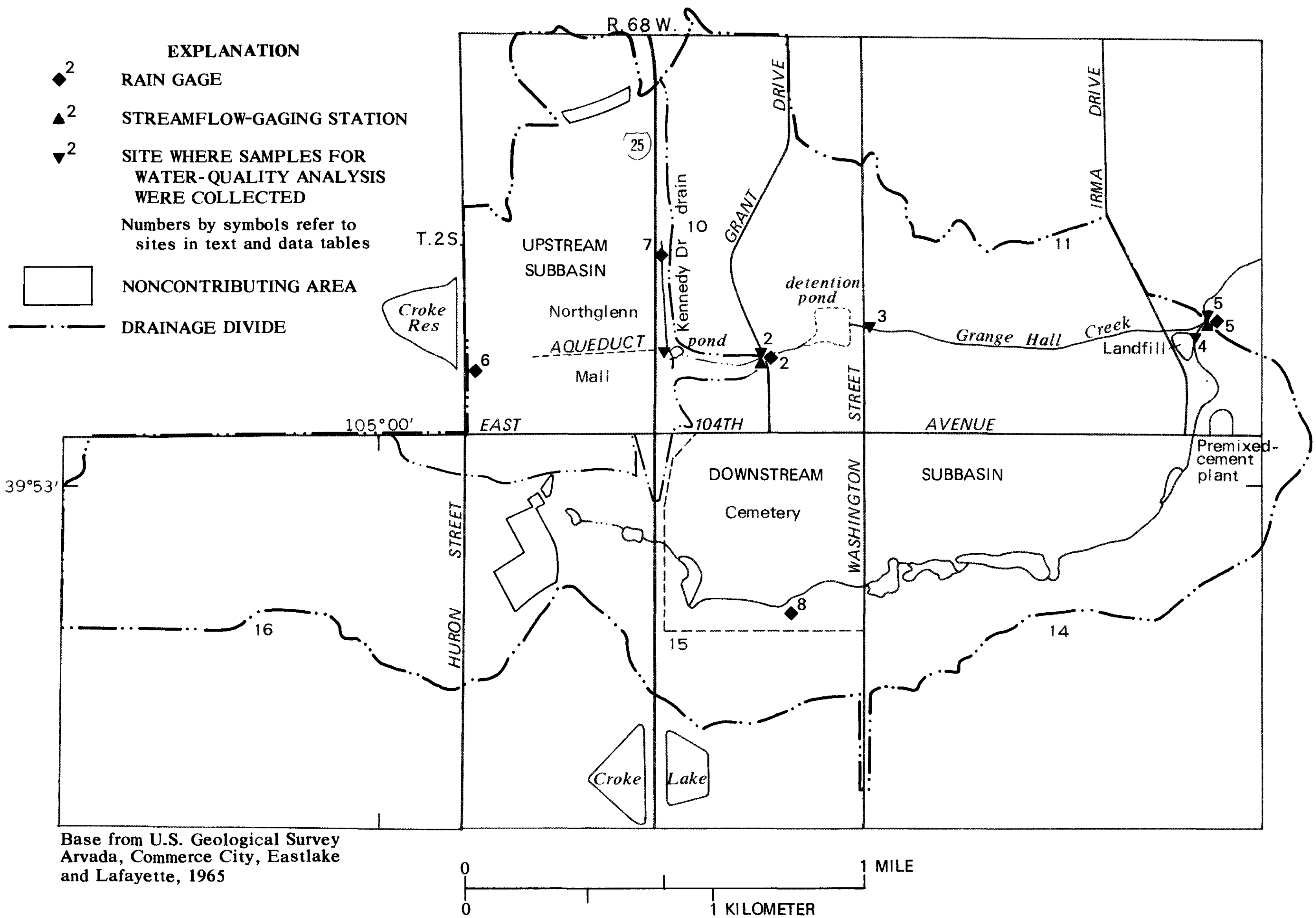


Figure 2. -- Drainage boundaries and location of monitoring sites in upper Grange Hall Creek basin.

Approach

Land-use areas were determined from aerial photographs (mid to late 1970's). Percentages of impervious area and effective impervious area for each land use were estimated using relationships determined by Alley and Veenhuis (1979, p. 13-17).

Data collection consisted of monitoring rainfall, streamflow, and water quality at several selected sites within the upper Grange Hall Creek drainage basin (fig. 2). Rainfall was measured at one to five sites; however, no attempt was made to measure snowfall depth or water content. Streamflow was determined at two sites on Grange Hall Creek: Grange Hall Creek at Grant Park, at Northglenn (site 2) and Grange Hall Creek at Northglenn (site 5). Water-quality samples were collected and analyzed from four sites on Grange Hall Creek and one site on an unnamed southern tributary; most samples were collected from the two major sites on Grange Hall Creek where streamflow and rainfall were also determined. Dry-weather flow was frequently sampled: bimonthly for 16 months, including weekly for 2 months during that period, and less frequently than bimonthly for the final 7 months of the study. One to 10 samples of snowmelt or rainfall runoff were collected at each site for selected storms. Water-quality samples were analyzed for various combinations of the following constituents and properties: specific conductance, temperature, fecal-coliform bacteria (membrane-filter method), suspended sediment, and sediment-size distribution, major ions, nutrients, trace elements, pesticides, and polychlorinated biphenyls (PCB's). All determinations except for sediment were made on single grab samples. Samples for major ions, nutrients, and trace elements were collected by automatic samplers or manually. Fecal-coliform bacteria samples were usually collected manually or infrequently by automatic samplers. Pesticides and PCB's were collected manually. Sediment samples were collected occasionally by dip sampling, but more often were collected by the equal-transit-rate method (Guy and Norman, 1970, p. 30-33).

In this report the data are briefly interpreted. For related literature the reader is referred to Engineering Consultants, Inc. (1974); Ellis (1978); Alley and Ellis (1978); Ellis and Alley (1979); and Smullen and Plant (1979).

DESCRIPTION OF DRAINAGE BASIN AND SUBBASINS

Grange Hall Creek, an easterly flowing tributary of the South Platte River, drains about 80 percent of the City of Northglenn and a small part of the City of Thornton. The terrain is flat and part is highly urbanized; part is undeveloped. The area of the upper Grange Hall Creek drainage basin is about 1,950 acres or 3.05 mi^2. The drainage basin was divided into two subbasins (fig. 2) on the basis of urban development. The larger subbasin (about 1,600 acres or 2.51 mi^2) is referred to as the downstream subbasin and the smaller subbasin (about 350 acres or 0.54 mi^2) is referred to as the upstream subbasin. During July 1979 sewer construction along 104th Avenue west of Interstate Highway 25 altered both the total area of upper Grange Hall Creek basin and the areas of the subbasins. The total drainage area was increased by 12.6 acres, the area of the downstream subbasin was increased by 22.2 acres, and the area of the upstream subbasin was decreased by 9.6 acres. Noncontributing areas that drain into irrigation canals occur in both subbasins--19 acres in the downstream subbasin and 3.2 acres in the upstream subbasin (fig. 2).

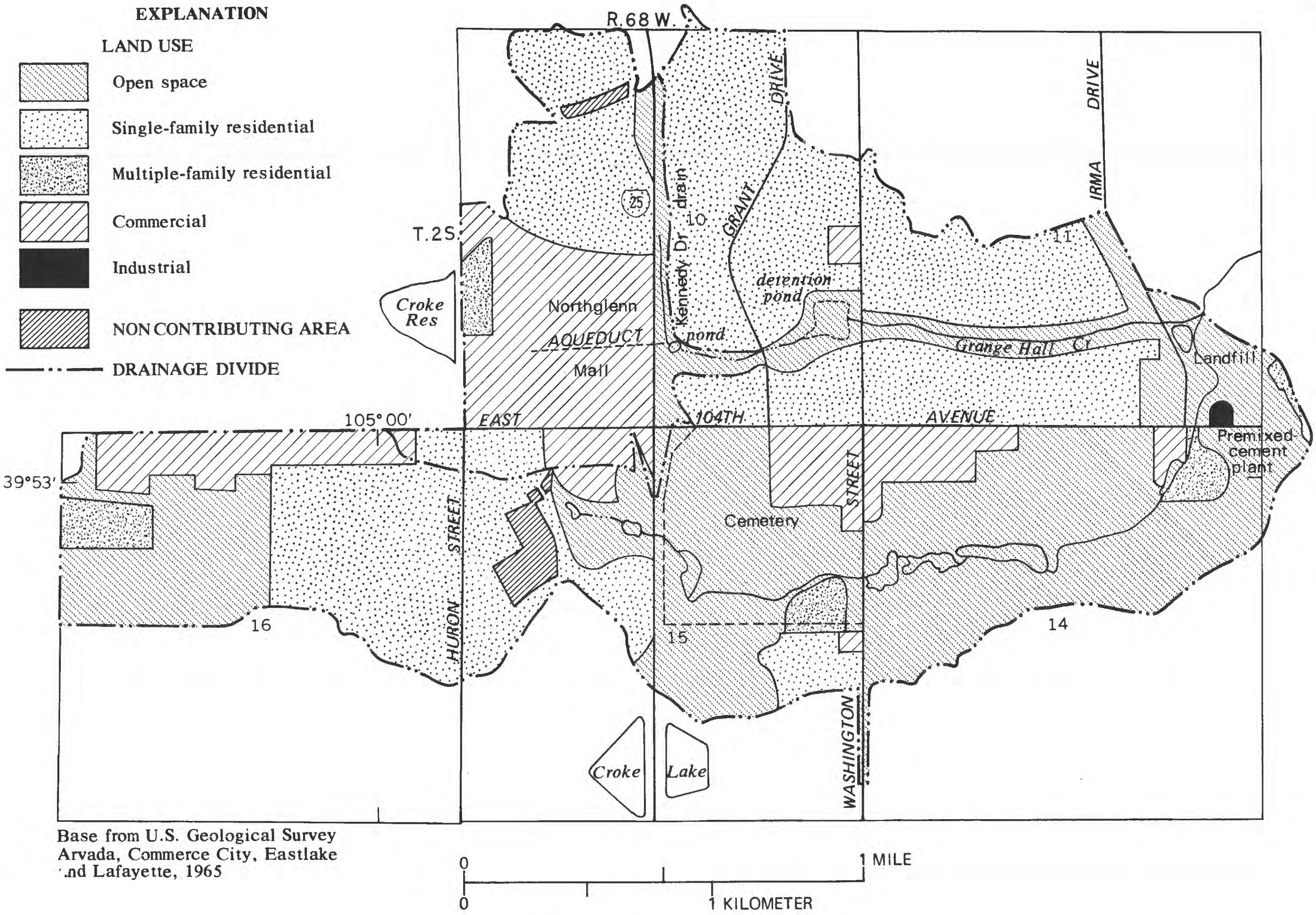
Croke Reservoir, a municipal water-storage facility, is located adjacent to the upstream boundary of the upper Grange Hall Creek drainage basin. Ordinarily there is leakage but no overflow from the reservoir into the Grange Hall Creek drainage basin. However, during floods somewhat greater than a 10-year flood, Croke Reservoir overflows into the upper Grange Hall Creek drainage basin (Engineering Consultants, Inc., 1974). The estimated overflow during a 100-year flood would be 50 ft^3/s. Croke Reservoir overflowed only once (August 10, 1979) during the study period (Walid Hajj, City of Thornton, Water Resources Engineer, oral commun., 1980).

About 66 percent of upper Grange Hall Creek basin is pervious, and about 34 percent is impervious (24-percent effective impervious area and 10-percent noneffective impervious area). Land use consists of about 49-percent single-family residential, 2-percent multifamily residential, 14-percent commercial, and 35-percent undeveloped open space (fig. 3). Other than Northglenn Mall, the largest business or industry in the basin is a premixed-cement plant. This plant and a cemetery, which is considered undeveloped space, are located in the downstream basin.

Of the downstream subbasin about 73 percent is pervious and about 27 percent is impervious (18-percent effective impervious area and 9-percent noneffective impervious area). Land use consists of about 50-percent single-family residential, 2-percent multifamily residential, 6-percent commercial, 42-percent undeveloped open space, and less than 1-percent light industrial. There are eight reservoirs in this subbasin (fig. 2); seven reservoirs are located along the unnamed southern tributary of Grange Hall Creek and one--a large flood-detention reservoir, usually dry--is located on Grange Hall Creek immediately upstream from Washington Street. Part of the unnamed southern tributary drains land in the City of Thornton.

About 66 percent of the upstream subbasin is impervious (55-percent effective impervious area and 11-percent noneffective impervious area) and about 34 percent is pervious. Land use consists of about 42-percent single-family residential, 2-percent multifamily residential, 53-percent commercial (principally Northglenn Mall), and 3-percent undeveloped open space (fig. 3). The only reservoir in the upstream subbasin is a small pond on Grange Hall Creek downstream from Northglenn Mall (fig. 2).

During the data-collection period, activities in the basin affecting water quality included sanding of streets during snowstorms, street sweeping, and construction. The City of Northglenn occasionally applies sand containing as much as 7-percent salt (Jack Debelle, City of Northglenn, Department of Public Works, oral commun., 1977) to streets during snowstorms, sweeps major streets weekly, and



Base from U.S. Geological Survey
Arvada, Commerce City, Eastlake
and Lafayette, 1965

Figure 3.--Generalized land-use areas.

sweeps residential streets at least once a month. During the study, street sweepings were placed in a landfill near the confluence of Grange Hall Creek and the unnamed southern tributary (fig. 2). Construction during the study included residential dwellings, commercial building, street and sewer improvements along 104th Avenue, and installation of a culvert on Grange Hall Creek at Grant Drive. Activities of this type are frequent in an urban environment, and, therefore, will continue to affect water quality in the basin in future years.

PRECIPITATION

Long-term mean annual precipitation at both Denver and Northglenn is about 13 in. (Hansen and others, 1978); however, for the period 1931-70 the mean annual precipitation at Denver was 15.5 in. (U.S. Weather Service, 1977-79). Estimated from records at nearby stations, the minimum historical annual precipitation has been about 6 in., and the maximum annual historical rainfall is estimated to have been about 23 in. (Hansen and others, 1978). About one-third of this precipitation falls as snow. The mean annual snowfall at Denver is 55 in. and at Northglenn is about 50 in.; the 30-year average November-through-April precipitation (mostly snowfall) at Denver is 5.6 in. (U.S. Weather Bureau, 1967; U.S. Weather Service, 1977-79). The 30-year average May-through-October precipitation (mostly rainfall) at Denver is 9.9 in., although the 11-year May-through-October average beginning in 1969 at gage 7 in Northglenn was only 8.60 in.

Rainfall at site 7 for 1978, 8.18 in., was below the 11-year average, and for 1979, 11.65 in., was above the 11-year average. At Denver, precipitation for the 1978 water year, 10.03 in., was below average (average is 15.51 in.) and for the 1979 water year, 21.18 in., was considerably above average. Precipitation patterns at Northglenn appear to be similar to those at Denver and were, therefore, assumed to be below average for water year 1978 and above average for 1979. This is consistent with the monthly precipitation and mean monthly precipitation data plotted in figure 4.

The maximum 5-minute rainfall observed during the study was 0.38 in. (gage 5, August 9, 1979). Rainfall in excess of 0.25 in. was observed for 5-minute periods during several storms, but was generally on the order of 0.008 to 0.016 in. Some notable rates of accumulation of rainfall were 0.77 in. in 40 minutes (gage 7, May 17, 1978); 1.43 in. in 12 hours (gage 2, August 9-10, 1979); and 2.09 in. in 24 hours (gage 7, June 7-8, 1979). Estimated precipitation depths for selected durations and return frequencies at Northglenn are given in table 1.

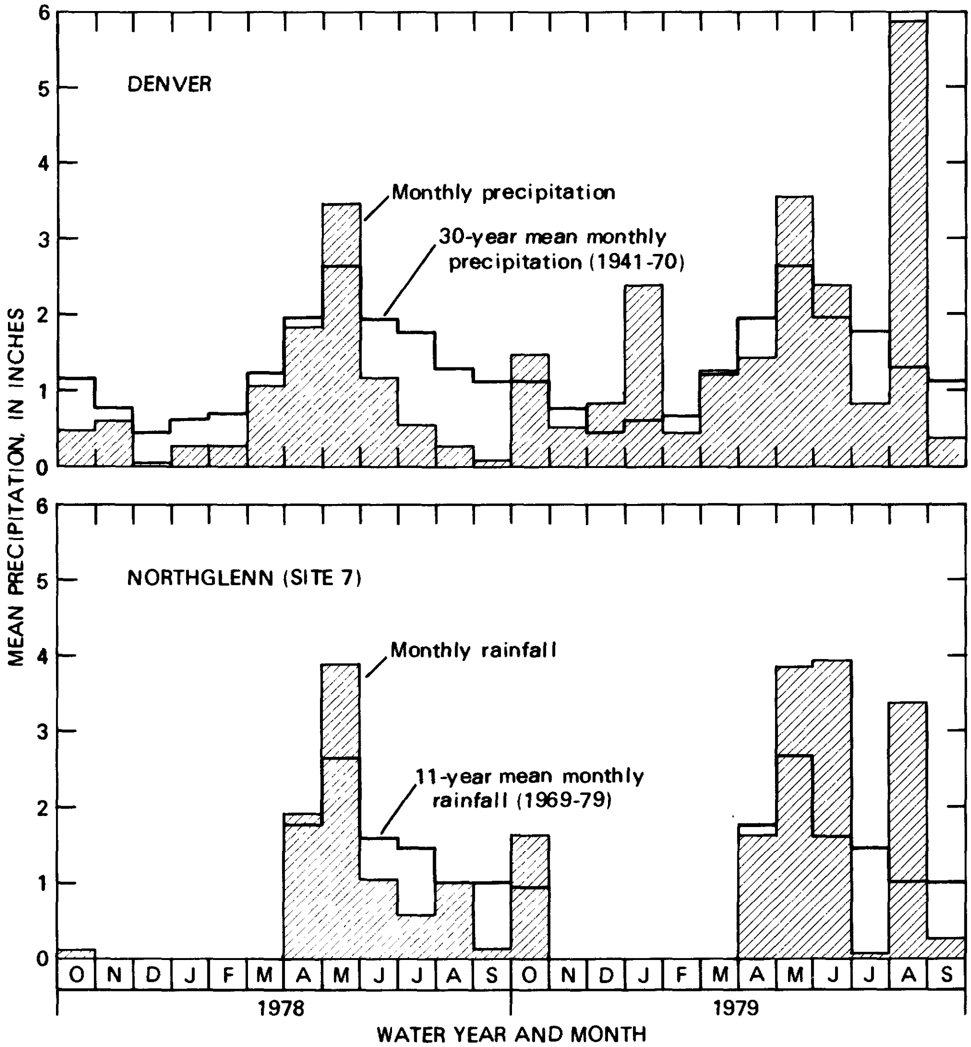


Figure 4.--Monthly and mean monthly precipitation at Denver, and monthly and mean monthly rainfall at Northglenn, water years 1978 and 1979. (Denver data from U.S. Weather Service, 1977, 1978, and 1979.)

Table 1.--*Precipitation depths for selected durations and return frequencies at Northglenn*

Return frequency	Precipitation depth, in inches, for indicated duration[1]			
	5-minute	1-hour	6-hour	24-hour
2-year--------	0.29	1.0	1.5	2.1
10-year--------	.49	1.7	2.4	3.3
100-year--------	.75	2.6	3.7	5.2

[1]Estimated from data and equations given by Miller and others (1973).

The rainfall intensities observed at Northglenn during the study are far from the maximum intensities recorded along the Front Range Urban Corridor of Colorado that includes Denver and Northglenn (Hansen and others, 1978). The maximum recorded 24-hour rainfall at Denver was 6.5 in. on May 22, 1876, and again on August 11, 1936. On May 30, 1935, at Elbert the 24-hour rainfall was 24 in. Maximum reported intensities were 12 in. in 4 hours near Castle Rock, June 16, 1965; 14 in. in 4 hours near Larkspur, June 16, 1965; and 7 in. in 0.5 hour at Missouri Canyon, near Masonville, September 10, 1938.

For use in rainfall-runoff calculations later in the report, data from rain gage 7 were used when available, because they were considered to be more reliable and consistent than data from the other sites. Fortunately, this rain gage was centrally located. Ideally, rainfall averaged throughout the rain-gage network in the drainage area would have been preferable had the data been more adequate.

QUANTITY OF URBAN RUNOFF

The daily mean streamflows for sites 2 and 5 for December 1977 through September 1979 are shown in figures 5 and 6 and a summary of the streamflows is given in table 2. Of the urban runoff from upper Grange Hall Creek basin during the study, 22 percent came from the upstream subbasin and 78 percent came from the downstream subbasin, which includes the unnamed southern tributary. The relative drainage areas are about the same as the relative flow contributions--the upstream subbasin comprising 18 percent and the downstream subbasin 82 percent of the total basin area.

Caution should be used in comparing flows from the two subbasins, especially during dry weather, because of the effects of reservoirs in the downstream subbasin. Artificial regulation of discharges from the reservoirs can significantly alter flow patterns.

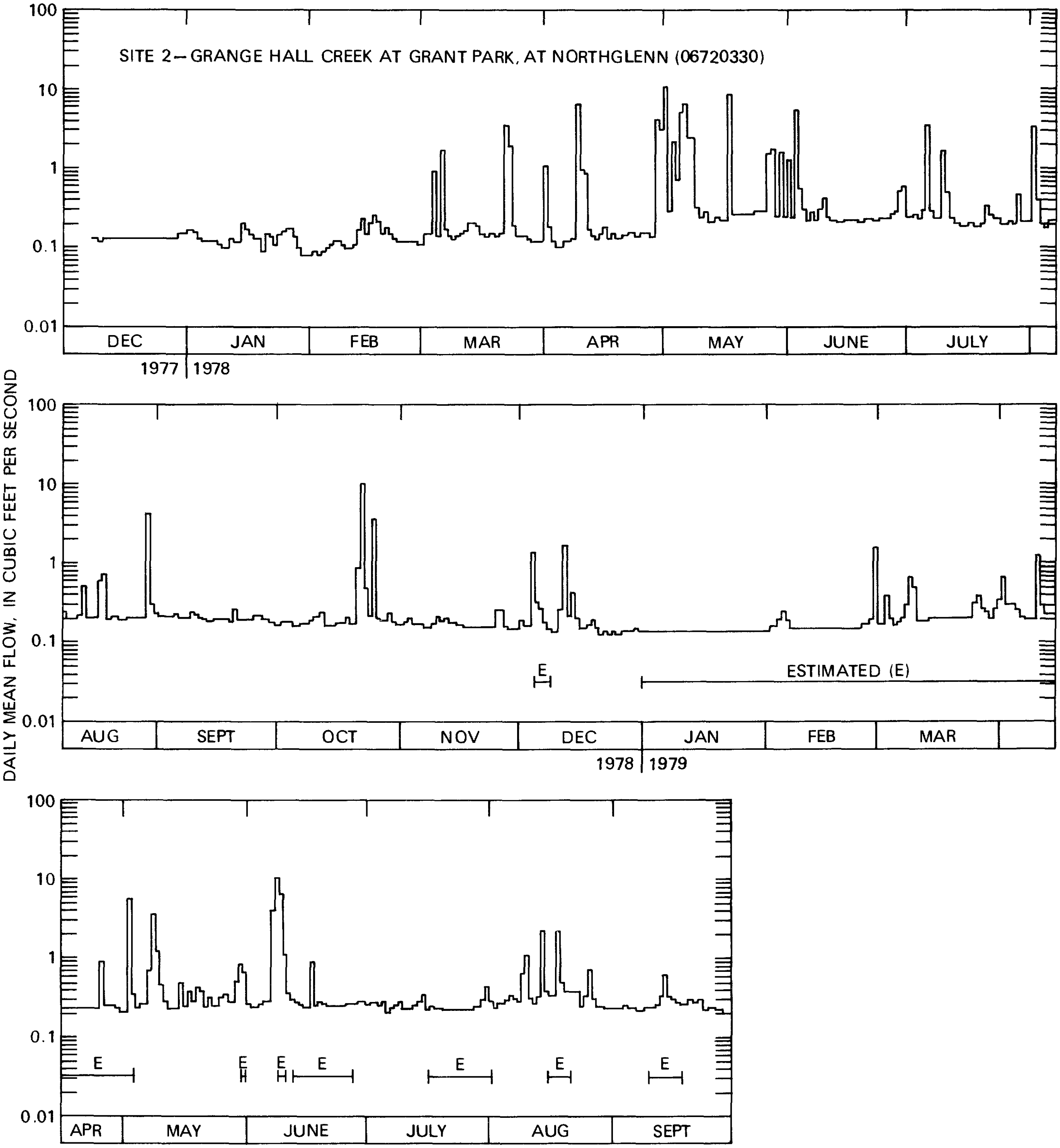


Figure 5.--Streamflow in Grange Hall Creek at site 2, December 1977 through September 1979.

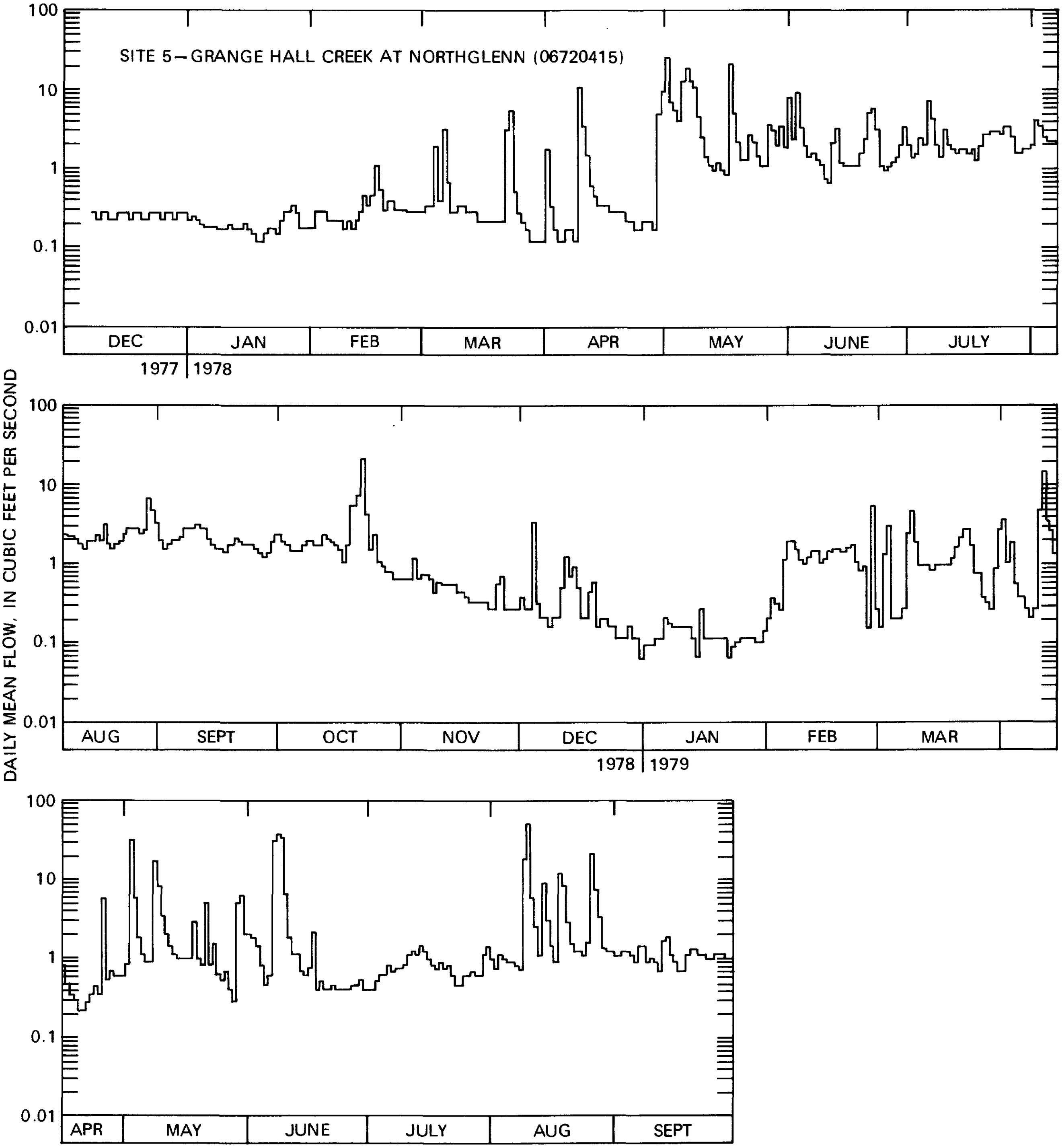


Figure 6.--Streamflow in Grange Hall Creek at site 5, December 1977 through September 1979.

Table 2.--*Summary of streamflow data from Grange Hall Creek, 1978 and 1979 water years*

Site No.	Water year	Annual flow (acre-ft)	Daily flows, in cubic feet per second		
			Mean	Minimum	Maximum
2	[1]1978	297	0.41	0.08	11
2	1979	295	.41	.13	13
5	[1]1978	1,190	1.65	.12	26
5	1979	1,510	2.09	.17	65

[1]Flows were estimated for the period October 1 through December 7, 1978, before the streamflow gages were put into operation.

Quantity of Dry-Weather Flow

Grange Hall Creek flows year round, sustained mostly by ground-water seepage and by leakage from Croke Reservoir and the smaller reservoirs in the downstream subbasin. Dry-weather flow at site 2 was generally between 0.1 to 0.3 ft^3/s and at site 5 was generally between 0.1 to 1.0 ft^3/s. Flows were less during the colder months and greater during the warmer months when lawns are watered. The unnamed southern tributary was ungaged, but field observation indicated that during the summer months the dry-weather flow from the tributary contributed a greater proportion of the flow (often more than one-half the flow) than during the remainder of the year.

Quantity of Storm Runoff

During spring and fall periods, many storms begin as rain and end as snow; the reverse also may occur. For purposes of this report, most storms occurring during November through April are considered to be snowstorms and those occurring during May through October are considered to be rainstorms.

From December 8, 1977, through September 30, 1979, there were 104 storm-runoff peaks in Grange Hall Creek; 50 resulted from snowmelt runoff and 54 from rainfall runoff. The distribution of peak flows at site 5 is given in table 3.

Table 3.--*Distribution of peak flows during storm runoff at site 5, December 8, 1977, through September 30, 1979*

Peak flows[1] (ft^3/s)	Number of peak flows: Water year 1978: Snowmelt runoff	Water year 1978: Rainfall runoff	Water year 1979: Snowmelt runoff	Water year 1979: Rainfall runoff
Less than 5.0	8	3	6	4
5.0 to 9.9	2	7	6	4
10 to 49	11	12	15	9
50 to 99	2	3	0	4
100 to 199	0	0	0	4
200 to 399	0	1	0	1
400 to 799	0	0	0	1
800 or more	0	0	0	1

[1]Corrections were made for base flow.

Quantity of Snowmelt Runoff

There were 23 runoff peaks from snowmelt for December 8, 1977, through May 8, 1978, and 27 runoff peaks from snowmelt for November 1, 1978, through April 30, 1979 (table 3). Runoff from snowmelt is generally gradual and the peak flows, therefore, are not large, except for wet storms during the autumn or spring. For the 2 years of the study, peak flows from snowmelt runoff at site 5 were greater than 50 ft^3/s only twice, and 44 percent of the peak flows were below 10 ft^3/s. Peak flows usually occurred in the afternoon or late afternoon--the warmest part of the day.

Quantity of Rainfall Runoff

There were 26 runoff peaks from rainfall from May 1, 1978, through September 30, 1978, and 28 runoff peaks from rainfall from October 1, 1978, through September 30, 1979 (table 3). Annual peak flows at site 5 were 339 ft^3/s on May 17, 1978, and 876 ft^3/s on August 19, 1979. Peak discharge for the 10-year flood was estimated to be 670 ft^3/s at site 2 and 870 ft^3/s at site 5, while the 100-year flood was estimated to be 770 ft^3/s at site 2 and 1,450 ft^3/s at site 5 (Engineering Consultants, Inc., 1974). After future development of the open space along the unnamed southern tributary upstream from site 5, the peak flows for the 10-year and the 100-year floods are expected to increase to 1,060 ft^3/s and 1,630 ft^3/s (Engineering Consultants, Inc., 1974). Although during the study the maximum runoff at site 2, 366 ft^3/s, was considerably less than a 10-year flood, the maximum runoff at site 5, 876 ft^3/s, was approximately a 10-year flood. The differences are probably due to unequal rainfall distribution or possibly to inaccuracies in predicted flood frequencies.

Rainfall-runoff data for selected storms are given in table 4. Runoff as percent of rainfall at site 2 for 12 storms ranged from 45 to 94 percent with a mean of 60 percent and a median of 54.5 percent. Runoff as percent of rainfall at site 5 for 17 storms ranged from 14 to 96 percent with a mean of 30 percent and a median of 24 percent. The medians are better indicators of the central tendencies because they are less influenced by the extreme values, which in many cases probably result from using unrepresentative rainfall data for storms of unequal rainfall distribution. Runoff volume increases approximately linearly with rainfall (fig. 7), but at site 5 runoff volumes seem to respond to a lesser degree for storms of less than 0.35 in. of rainfall. Peak flows during rainfall runoff for storms of short duration (thunderstorms) may be predicted using the graphical relationships (determined by visual inspection) in figure 8. Such a prediction would be only approximate because there is considerable scatter in the data. These rainfall-runoff relationships are biphasic, evidently dependent on the drainage characteristics of the two subbasins involved. No discernible relationships for either subbasin were observed between rainfall and percentage runoff or antecedent dry days and percentage runoff.

Table 4.--*Rainfall-runoff data for selected storms*

[s=snowfall included]

Date	Rainfall at site 7 unless otherwise indicated (inches)	Storm runoff (inches)	Runoff as percent of rainfall	Peak flow (cubic feet per second)	Antecedent dry days
		SITE 2			
Apr. 1, 1978	s0.15	0.075	50	36	9.3
Apr. 29-30, 1978	.57 (site 5)	.27	47	61	18.4
Apr. 30, 1978	.33 (site 2)	.20	61	21	.3
May 5-6, 1978	s.48	.45	94	22	.1
May 17, 1978	.70	.36	80	366	8.8
Aug. 29-30, 1978	.39	.28	72	95	12.0
May 1-2, 1979	s1.35	1.04	77	27	6.9
June 7-8, 1979	2.09	1.22	58	50	7.4
Aug. 9, 1979	.39	.20	51	81	53.4
Aug. 10, 1979	.70	.28	40	195	.3
Aug. 14, 1979	.58	.26	45	19	3.9
Aug. 26, 1979	.63	.31	49	121	6.8
		SITE 5			
Apr. 1, 1978	s0.15	0.024	16	19	9.3
Apr. 29-30, 1978	.57 (site 5)	.10	18	59	18.4
Apr. 30, 1978	.33 (site 2)	.070	21	29	.3
May 17, 1978	.70	.32	46	339	8.8
May 30, 1978	.15	.022	15	26	2.0
June 1, 1978	.31	.048	15	30	1.2
July 10, 1978	.21	.030	14	34	3.8
Aug. 2, 1978	.21	.036	17	39	23.0
Aug. 29-30, 1978	.39	.095	24	54	12.0
May 1-3, 1979	s1.56	.44	28	79	6.9
May 8, 1979	s.43	.16	37	58	.2
May 20, 1979	.32	.051	16	39	2.5
June 7-9, 1979	3.67	1.94	53	140	7.4
Aug. 9, 1979	.73 (site 2)	.21	29	467	53.4
Aug. 10, 1979	.70	.67	96	876	.3
Aug. 14, 1979	.58	.14	24	39	3.9
Aug. 26, 1979	.71 (site 2)	.33	46	274	6.8

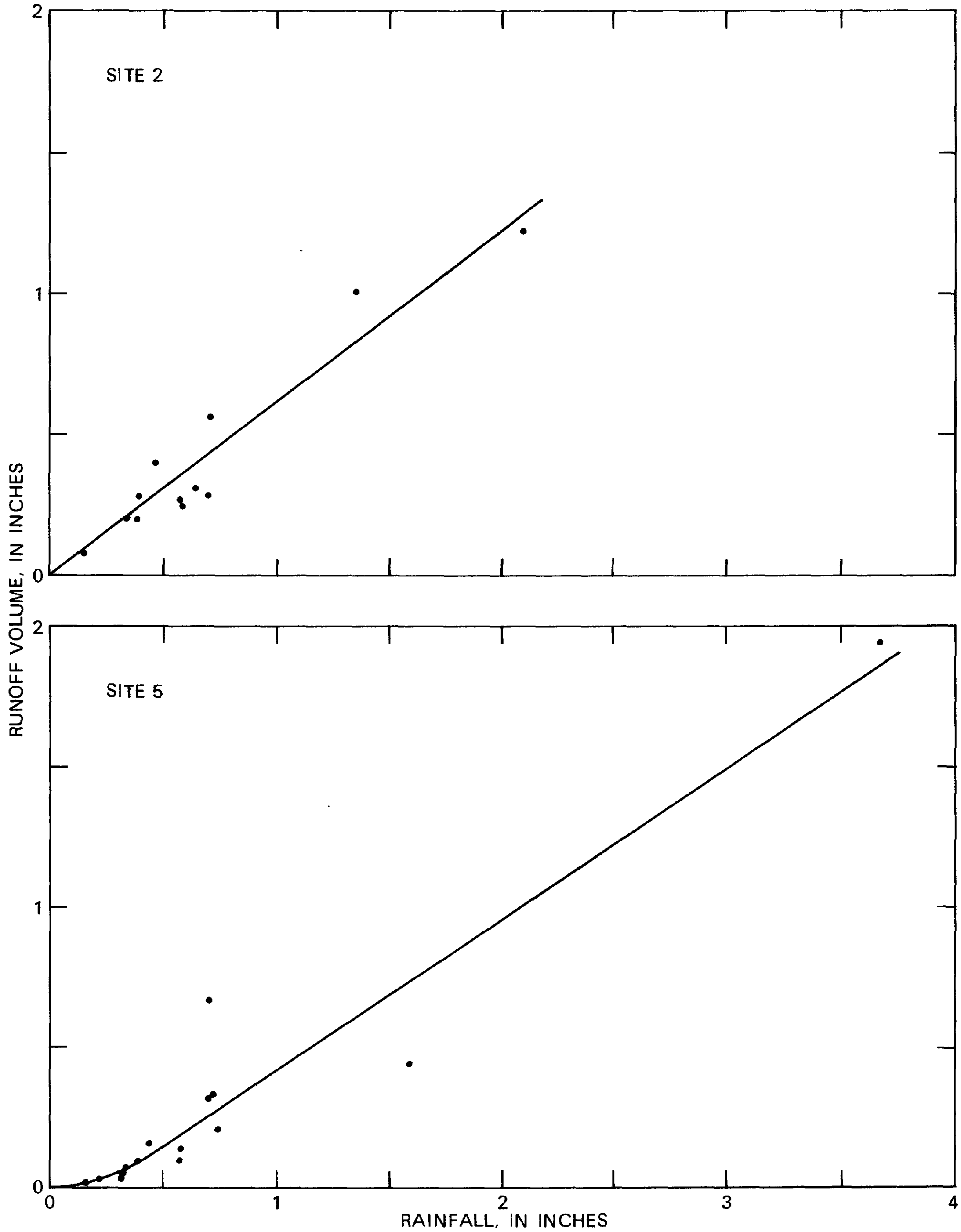


Figure 7.--Relationship between rainfall and runoff volume.

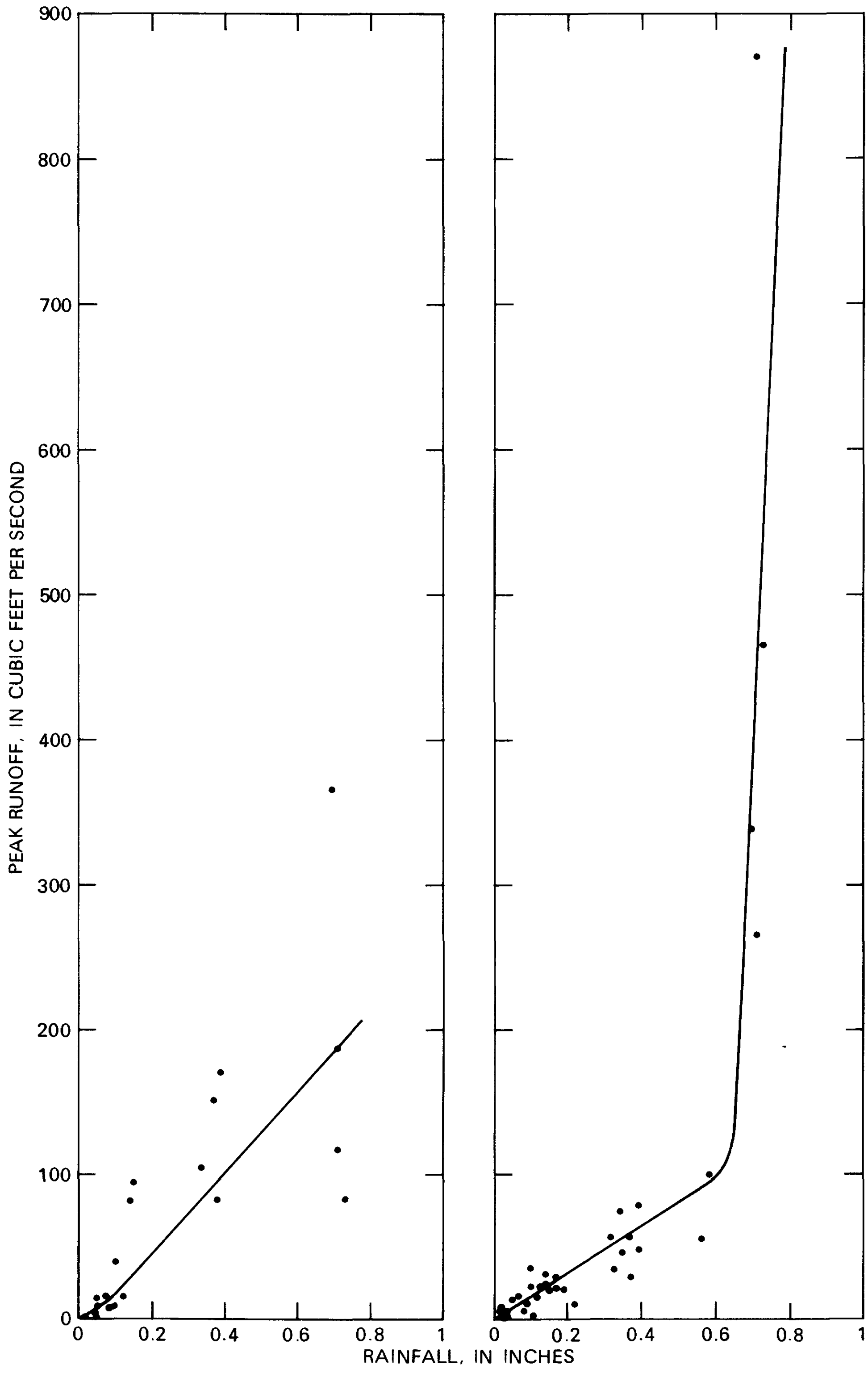


Figure 8.--Relationship between thunderstorm rainfall and peak runoff.

QUALITY OF URBAN RUNOFF

Urban-runoff quality is discussed under two categories: Dry-weather flow and storm runoff. Storm runoff consists of either snowmelt runoff or rainfall runoff.

Quality of Dry-Weather Flow

Water-quality samples were collected and analyzed from sites 1, 2, 3, and 5 along Grange Hall Creek and site 4 on the unnamed southern tributary to Grange Hall Creek. Samples were collected bimonthly or more frequently for the first 16 months of the study. Results of analysis of these samples indicated little difference in the chemical quality of water along Grange Hall Creek with the exception of site 5. Therefore, collection at sites 1 and 3 was discontinued and data from these sites will not be discussed in this report. The sampling frequency at sites 2 and 5 was increased to weekly for a 2-month period during the summer of 1978 and less frequently during 1979. Sampling was continued at site 4 along the unnamed southern tributary, but on an infrequent basis.

Minimum, median, mean, and maximum values of the analyzed constituents from samples collected at sites 2, 4, and 5 are presented in table 5. Median concentrations of most of the constituents at the farthest downstream site (site 5) are less than those at the upstream site (site 2). This is due to the inflow of water from the unnamed southern tributary which enters Grange Hall Creek above site 5. Water in this unnamed tributary contains lesser constituent concentrations (exceptions to this are iron and manganese) than water in Grange Hall Creek because it drains an area of less urbanization and also there are seven reservoirs along this southern tributary that may act as sediment traps. Both iron and manganese have greater concentrations at site 5 than at site 2. This also can be attributed to inflow of the unnamed southern tributary which also has greater concentrations of these two metals than flow at site 2.

Water-quality standards for agricultural water in Colorado, along with the number of samples exceeding the standards, are presented in table 6. Of the samples collected at sites 2, 4, and 5 during dry-weather flow, only three of the constituents--lead, manganese, and fecal-coliform bacteria--had concentrations exceeding the standards. During dry-weather flow, lead concentrations exceeded the standard in only 1 of 46 total samples (2 percent), and manganese concentrations exceeded the standard in 9 of 40 samples (22 percent). In general, constituent values in table 5 show that the dry-weather flow is of suitable quality for agricultural use.

Samples for analysis of pesticides were collected only twice at site 2 and five times at site 5 during dry-weather flow. Although no standards for agricultural water have currently (1980) been established in Colorado for pesticides, significant concentrations of total diazinon (0.78 µg/L), total malathion (0.16 µg/L), total 2,4-D (12 µg/L), total 2,4,5-T (1.5 µg/L), and total silvex (1.1 µg/L) were found in these seven samples.

Table 5.--*Summary of the concentrations of chemical constituents and values of the physical* *November 1977 through*

[ft^3/s=cubic feet per second; umho/cm=micromho per centimeter at 25°Celsius; °C=degrees Celsius; SAR=sodium adsorption ratio; T/d=ton per day;

Constituent or physical characteristic	Number of samples	Minimum	Median	Mean	Maximum
	Site 2				
Streamflow (ft^3/s)--------------------------	16	0.08	0.20	0.20	0.38
Specific conductance (μmho/cm)---------------	19	1,650	2,180	2,280	2,940
pH[1] (units)----------------------------------	18	7.0	8.1	7.8	8.4
Temperature (°C)------------------------------	19	.0	15.8	14.9	21.5
Fecal-coliform bacteria[2] (colonies/100 mL)---	9	100	250	1,800	9,300
Hardness (mg/L as $CaCO_3$)---------------------	18	660	830	870	1,100
Calcium, dissolved (mg/L)--------------------	18	180	230	240	350
Magnesium, dissolved (mg/L)------------------	18	39	66	67	90
Sodium, dissolved (mg/L)---------------------	18	180	220	250	420
Sodium-adsorption ratio (SAR)----------------	18	3.0	3	4	6
Chloride, dissolved (mg/L)-------------------	18	53	74	83	150
Fluoride, dissolved (mg/L)-------------------	12	.5	1.1	1.0	1.4
Solids, residue at 105°C, suspended (mg/L)---	18	0	13	17	60
Solids, volatile, suspended (mg/L)-----------	18	0	9	11	32
Oxygen demand, chemical (mg/L)---------------	18	23	47	50	83
Nitrate, dissolved as N (mg/L)---------------	17	1.9	3.0	3.1	4.5
Nitrite, dissolved as N (mg/L)---------------	17	.04	.08	.13	.14
Ammonia, total as N (mg/L)-------------------	17	.00	.01	.03	.13
Organic nitrogen, total as N (mg/L)----------	17	.71	1.2	1.2	2.5
Kjeldahl nitrogen, total as N (mg/L)---------	17	.72	1.2	1.3	2.3
Nitrogen, total as N (mg/L)------------------	17	2.7	4.4	4.4	6.4
Phosphorus, dissolved as P (mg/L)------------	18	.02	.11	8.7	120
Orthophosphorus, total as P (mg/L)-----------	17	.01	.05	.07	.23
Organic carbon, total as C (mg/L)------------	12	17	16	18	42
Organic carbon, dissolved as C (mg/L)--------	14	6.6	12	16	41
Organic carbon, suspended as C (mg/L)--------	12	.4	.8	.8	1.3
Oil and grease (mg/L)------------------------	12	0	0	0	0
Arsenic, total (μg/L)------------------------	14	1	2	2	5
Beryllium, total recoverable (μg/L)----------	12	0	0	2	10
Boron, total recoverable (μg/L)--------------	15	390	500	500	630
Cadmium, total recoverable[2] (μg/L)-----------	18	0	1	2	10
Chromium, total recoverable (μg/L)-----------	16	0	10	8	20
Copper, total recoverable[2] (μg/L)------------	17	5	8	10	15
Iron, total recoverable (μg/L)---------------	17	70	130	150	350
Lead, total recoverable[2] (μg/L)--------------	18	3	15	39	380
Manganese, total recoverable (μg/L)----------	16	20	70	83	340
Nickel, total recoverable[2] (μg/L)------------	12	0	6	10	50
Selenium, total (μg/L)-----------------------	11	4	6	7	10
Selenium, dissolved (μg/L)-------------------	--	--------	--------	--------	--------
Zinc, total recoverable (μg/L)---------------	17	20	40	60	170

[1]Mean pH values were calculated as hydrogen ion activities.
[2]Less than qualifications were ignored for these calculations.

characteristics of water in streams in the Grange Hall Creek basin during dry-weather flow, September 1979

colonies/100 mL=colonies per 100 milliliters; $CaCO_3$=calcium carbonate; mg/L=milligram per liter; mm=millimeter; µg/L=microgram per liter]

Number of samples	Minimum	Median	Mean	Maximum	Number of samples	Minimum	Median	Mean	Maximum
		Site 4					Site 5		
--	------	------	--------	--------	18	0.12	1.1	1.2	3.1
9	430	834	1,190	2,420	20	610	1,370	1,680	3,390
9	6.5	8.3	7.3	9.0	19	6.8	8.25	7.8	8.4
9	2.0	8.8	10.2	19.5	20	.0	16	14.2	23
1	------	500	500	--------	14	56	400	2,000	8,400
9	140	270	320	710	19	210	410	540	1,100
9	41	78	101	240	19	59	120	155	350
9	10	14	17	27	19	14	27.5	36	73
9	44	101	158	340	19	60	145	192	430
9	1.6	2.7	3.6	5.6	19	1.8	3.2	3.4	5.8
9	16	32	52	150	19	20	44	63	160
1	------	1.1	--------	--------	13	.3	.8	.7	1.1
9	9	21	29.7	91	19	5	24.5	32	67
9	2	10	11.9	22	19	0	12	14	31
4	19	24	26	32	18	10	32	34	52
8	.00	.32	.94	2.4	18	.00	.73	1.2	3.8
8	.01	.04	.09	.25	18	.01	.05	.06	.15
8	.01	.01	.20	1.2	18	.00	.03	.08	.63
8	.54	.76	.95	1.7	18	.52	.75	.80	1.1
8	.61	.77	1.1	2.2	18	.58	.80	.88	1.7
8	.75	1.4	1.6	2.7	18	.73	1.6	2.0	5.4
9	.01	.04	.09	.48	19	.02	.07	36	59
8	.00	.01	.02	.08	18	.01	.03	.12	1.5
3	7.2	7.4	14	28	17	6.0	9.0	9.9	18
3	6.1	6.5	13	27	17	5.2	8.0	9.0	17
3	.8	.9	1.0	1.1	15	.4	.7	.8	1.4
2	0	0	0	0	14	0	0	0	0
6	1	1	2	4	14	1	2	3	5
1	------	0	0	--------	13	0	0	0	5
4	110	160	210	400	16	160	250	302	630
9	0	0	1	10	19	0	1	1	10
4	0	0	5	10	18	0	5	7	20
9	4	6	7	11	17	4	8	10	38
9	180	550	790	2,300	17	190	650	790	2,300
9	3	10	20	100	19	4	12	18	100
6	60	100	180	520	18	120	160	240	630
1	------	0	0	--------	13	0	6	13	60
1	------	0	0	--------	11	0	2	2	4
--	------	------	--------	--------	1	------	18	18	--------
8	20	20	20	30	16	10	30	40	80

Table 6.--*Numbers of dry-weather-flow samples exceeding Colorado water-quality standards for agricultural water*

Constituent[1]	Water-quality standard[2] (milligrams per liter unless otherwise indicated)	Site 2		Site 4		Site 5	
		Number of samples	Number exceeding standard	Number of samples	Number exceeding standard	Number of samples	Number exceeding standard
Nitrate (as nitrogen)--	100	17	0	8	0	18	0
Nitrite (as nitrogen)--	10	17	0	8	0	18	0
Beryllium--------------	.1	12	0	1	0	13	0
Boron------------------	.75	15	0	4	0	16	0
Cadmium----------------	.01	18	0	9	0	19	0
Chromium[3]--------------	.1	16	0	4	0	18	0
Copper-----------------	.2	17	0	9	0	17	0
Lead-------------------	.1	18	1	9	0	19	0
Manganese--------------	.2	16	1	6	1	18	7
Nickel-----------------	.2	12	0	1	0	13	0
Selenium---------------	.02	11	0	1	0	12	0
Zinc-------------------	2	17	0	8	0	16	0

[1]All constituents are total recoverable except nitrate and nitrite, and 1 of 24 selenium analyses are dissolved.

[2]Colorado Department of Health, 1979.

[3]Neither trivalent nor hexivalent chromium may exceed the standard of 0.1 milligram per liter. Analyses here are for all chromium species.

Suspended-sediment concentrations were not determined in dry-weather flow; however, suspended-solids concentrations, which were measured, are representative of suspended-sediment concentrations. These ranged from 0 to 91 mg/L.

The specific-conductance values at sites 2, 4, and 5 for dry-weather flow from October 1977 through July 1979 are presented in figure 9. There is seasonal variation in specific conductance at all three sites, trending toward greater values during winter and lesser values during summer. The greater specific-conductance values during the colder months are probably due to salt used for deicing the streets. The decline in specific-conductance values in the spring and summer can be attributed to increased precipitation and lawn watering during this period. The rapid decrease in specific-conductance values at site 5 during the spring months of 1978 and 1979 can be attributed to water with lower specific conductance entering Grange Hall Creek from the unnamed southern tributary which has a greater relative flow at this time of the year.

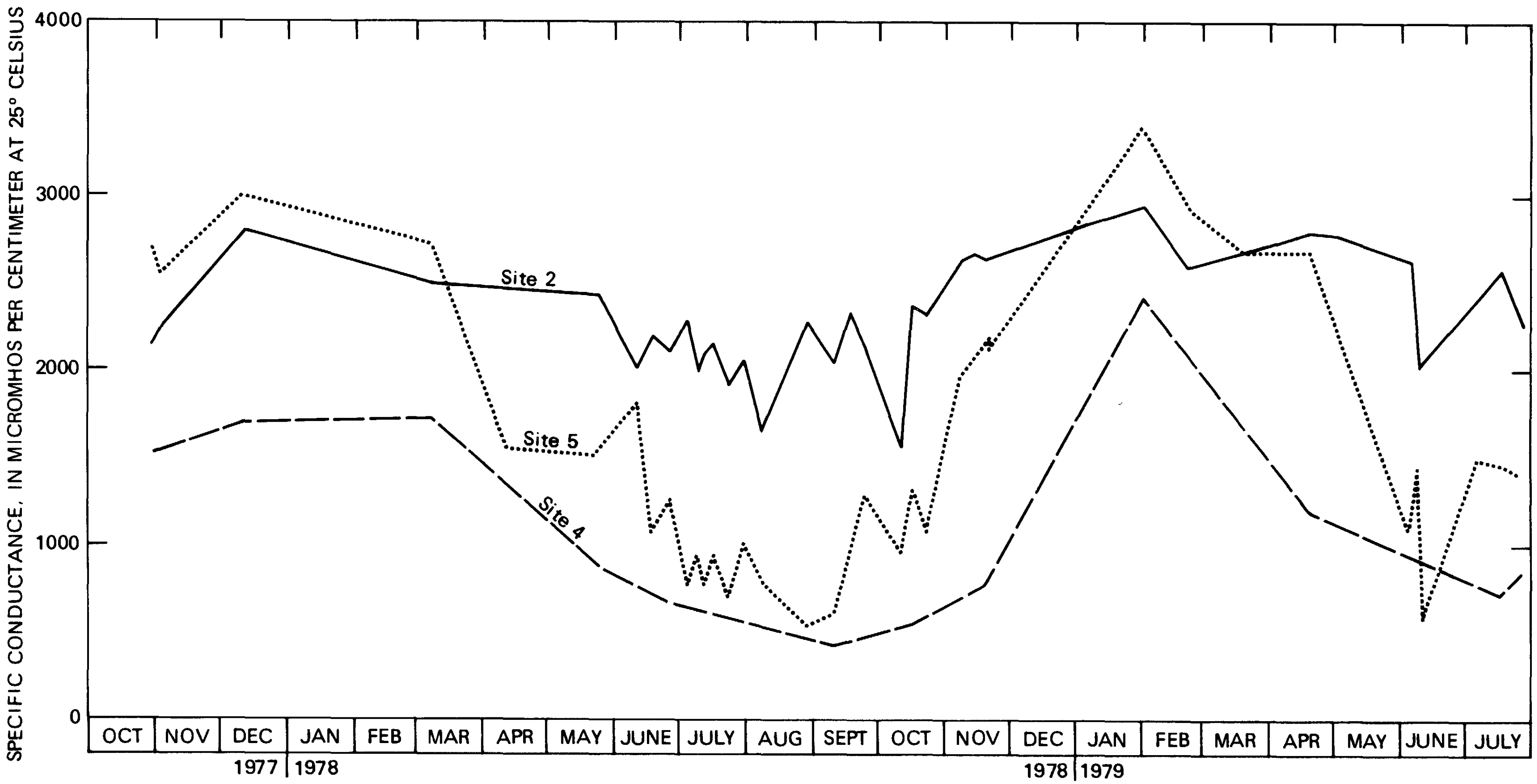


Figure 9.--Specific-conductance values of dry-weather flow at sites 2, 4, and 5, October 1977 through July 1979.

Quality of Storm Runoff

Quality of Snowmelt Runoff

There were 50 snowmelt peak flows during the study. Of these 50 peak flows, 5 were sampled for selected water-quality properties and constituents. Minimum, median, mean, and maximum values of these selected properties and constituents are presented in table 7 for the two monitoring sites along Grange Hall Creek and one site on the unnamed southern tributary.

The values of sampled properties and constituents varied considerably during snowmelt-runoff events. Snowmelt runoff at site 2 generally had the greatest constituent concentrations of major ions, while the concentrations of the nutrients and trace elements were often about the same at the three sites or occasionally greater at site 5. Many property and constituent values were greater in snowmelt runoff than in dry-weather flow. The increase in the major ions can be attributed to the sanding and salting of the streets for control of snow and ice. Trace-element concentrations also were greater in snowmelt runoff. Trace elements most commonly found in larger quantities were iron, manganese, lead, and zinc. The increase of suspended-sediment and dissolved-solids concentrations is probably due to sand and debris from the streets and earth from construction activity.

During snowmelt runoff the number of samples and constituents exceeding agricultural water-quality standards for Colorado was greater than for dry-weather flow constituents (table 8). For example, at site 2 the number of samples analyzed for lead and manganese was about the same, but the percentages of both lead and manganese concentrations exceeding the standards increased from 6 percent in dry-weather flow to 47 percent in snowmelt runoff.

Table 7.--*Summary of the concentrations of chemical constituents and values of the December 1977 through*

[ft³/s=cubic feet per second; µmho/cm=micromho per centimeter at 25°Celsius; °C=degrees Celsius; SAR=sodium adsorption ratio; T/d=ton per day;

Constituent or physical characteristic	Number of samples	Minimum	Median	Mean	Maximum
	Site 2				
Streamflow (ft^3/s)	19	0.07	0.47	3.8	18
Specific conductance (µmho/cm)	19	90	2,690	2,650	9,190
pH[1] (units)	19	6.9	7.4	7.3	7.9
Temperature (°C)	15	.0	2.0	2.1	5.5
Fecal-coliform bacteria[2] (colonies/100 mL)	1	------	300	300	---------
Hardness (mg/L as $CaCO_3$)	18	27	410	590	1,700
Calcium, dissolved (mg/L)	18	8	130	140	290
Magnesium, dissolved (mg/L)	18	1.6	20	56	340
Sodium, dissolved (mg/L)	18	8.9	330	430	1,900
Sodium-adsorption ratio (SAR)	18	.8	4.8	8.1	41
Chloride, dissolved (mg/L)	19	7.0	200	570	3,700
Fluoride, dissolved (mg/L)	11	.2	1.2	1.1	1.5
Solids, residue at 105°C, suspended (mg/L)	18	3	59	155	530
Solids, volatile, suspended (mg/L)	16	3	18	50	152
Sediment, suspended (mg/L)	5	12	22	139	347
Sediment discharge, suspended (T/d)	5	0	.01	.09	.26
Sediment, suspended, sieve diameter, percent finer than 0.062 mm	--	------	--------	--------	--------
Oxygen demand, chemical (mg/L)	18	36	72	170	570
Nitrate, dissolved as N (mg/L)	19	.27	1.9	2.1	4.2
Nitrite, dissolved as N (mg/L)	19	.04	.08	.11	.24
Ammonia, total as N (mg/L)	19	.04	.20	.32	.95
Organic nitrogen, total as N (mg/L)	19	.00	1.2	1.7	5.4
Kjeldahl nitrogen, total as N (mg/L)	19	.33	1.4	2.0	5.8
Nitrogen, total as N (mg/L)	19	1.3	4.2	4.1	6.6
Phosphorus, dissolved as P (mg/L)	19	.04	.07	.09	.22
Orthophosphorus, total as P (mg/L)	19	.01	.04	.05	.12
Organic carbon, total as C[2] (mg/L)	5	11	13	24	44
Organic carbon, dissolved as C (mg/L)	6	10	11	20	39
Organic carbon, suspended as C[2] (mg/L)	5	.5	.7	2.4	5
Oil and grease (mg/L)	2	0	0	0	0
Arsenic, total (µg/L)	14	1	1	1	3
Beryllium, total recoverable (µg/L)	11	0	0	0	0
Boron, total recoverable (µg/L)	16	120	360	390	600
Cadmium, total recoverable (µg/L)	19	1	2	4	16
Chromium, total recoverable (µg/L)	16	0	10	20	40
Copper, total recoverable (µg/L)	19	5	13	19	47
Iron, total recoverable (µg/L)	19	180	1,400	3,900	14,000
Lead, total recoverable (µg/L)	19	18	81	300	1,600
Manganese, total recoverable (µg/L)	19	40	200	240	630
Nickel, total recoverable (µg/L)	11	4	8	10	26
Selenium, dissolved (µg/L)	5	0	5	6	11
Zinc, total recoverable (µg/L)	14	60	100	150	500

[1]Mean pH values were calculated as hydrogen ion activities.
[2]Greater than qualifications were ignored for these calculations.

physical characteristics of snowmelt runoff in streams in the Grange Hall Creek basin, December 1978

colonies/100 mL=colonies per 100 milliliters; $CaCO_3$=calcium carbonate; mg/L=milligram per liter; mm=millimeter; ug/L=microgram per liter]

Number of samples	Minimum	Median	Mean	Maximum	Number of samples	Minimum	Median	Mean	Maximum
Site 4					Site 5				
--	------	--------	--------	--------	27	0.10	7.2	11	42
4	650	2,300	1,930	2,400	19	320	2,370	2,650	5,890
3	6.7	6.8	6.8	6.8	15	6.4	6.8	6.9	7.9
3	4.0	4.5	4.67	5.0	13	.0	.5	.9	3.0
--	------	--------	--------	--------	6	50	50	110	300
4	170	610	500	610	18	88	720	610	1,500
4	49	200	160	200	18	26	210	180	510
4	12	26	23	27	18	5.2	43	39	84
4	68	330	270	350	18	31	340	400	1,000
4	2.3	5.8	5.1	6.2	18	1.4	7.5	6.8	12
4	19	90	90	130	19	10	320	400	1,300
4	.7	1.0	.9	1.0	10	.6	1.0	1.0	1.2
4	24	41	48	79	18	38	1.80	240	579
4	15	15	19	23	18	22	44	52	129
6	126	158	301	627	13	124	1,270	1,200	3,110
--	------	--------	--------	---------	13	.03	18	35	151
3	93	94	95	97	9	77	82	83	90
4	28	.28	38.2	65	18	48	87	110	470
4	52	2.4	2.1	2.9	19	.00	2.4	1.9	3.4
4	.02	.05	.04	.05	19	.00	.08	.11	.28
4	.04	.12	.15	.24	19	.03	.31	.37	.92
4	.86	.90	1.1	1.4	19	.09	1.5	2.0	5.2
4	1.1	1.1	1.2	1.5	19	1.0	1.8	2.3	5.6
4	1.6	3.5	3.2	3.9	19	1.4	4.4	4.3	7.8
4	.04	.05	.05	.05	19	.02	.06	.06	.19
4	.02	.02	.02	.02	19	.01	.02	.03	.12
--	------	--------	--------	---------	5	15	22.8	23	31
--	------	--------	--------	---------	5	14	18	20	30
--	------	--------	--------	---------	5	1.0	2.9	3.4	5
--	------	--------	--------	---------	2	0	0	1	2
4	1	3	3	4	14	1	2	2	3
4	0	0	0	0	10	0	0	1	10
4	160	360	320	370	15	150	385	380	550
4	0	2	2	2	19	1	1.5	3	7
4	0	10	7	10	15	0	10	15	40
4	4	9	10	15	19	6	19	22	55
4	1,300	1,600	1,700	1,900	19	1,500	5,000	7,000	20,000
4	6	19	34	84	19	16	78	260	1,200
4	120	480	460	630	19	160	620	570	920
4	4	7	10	21	10	6	14	14	23
1	------	0	--------	---------	4	0	17	13.0	18
4	40	40	40	50	14	60	100	110	210

Table 8.--*Numbers of snowmelt-runoff samples exceeding Colorado water-quality standards for agricultural water*

Constituent[1]	Water-quality standard[2] (milligrams per liter unless otherwise indicated)	Site 2		Site 4		Site 5	
		Number of samples	Number exceeding standard	Number of samples	Number exceeding standard	Number of samples	Number exceeding standard
Nitrate (as nitrogen)--	100	19	0	4	0	19	0
Nitrite (as nitrogen)--	10	19	0	4	0	19	0
Beryllium-------------	.1	11	0	4	0	10	0
Boron-----------------	.75	16	0	4	0	15	0
Cadmium---------------	.01	19	2	4	0	19	0
Chromium[3]-------------	.1	16	0	4	0	15	0
Copper----------------	.2	19	0	4	0	19	0
Lead------------------	.1	19	9	4	0	19	9
Manganese-------------	.2	19	9	4	3	19	18
Nickel----------------	.2	11	0	4	0	10	0
Selenium--------------	.02	5	0	1	0	4	0
Zinc------------------	2	14	0	4	0	14	0

[1]All constituents are total recoverable except nitrate and nitrite are dissolved.

[2]Colorado Department of Health, 1979.

[3]Neither trivalent nor hexivalent chromium may exceed the standard of 0.1 milligram per liter. Analyses here are for all chromium species.

In water-quality samples of dry-weather flow at site 5, no lead concentrations and 39 percent of manganese concentrations exceeded the standard, but during snowmelt runoff 47 percent of lead concentrations and 95 percent of manganese concentrations exceeded the Colorado water-quality standard. Of 40 samples analyzed for cadmium during snowmelt runoff, only two samples, both from site 2, exceeded the standard.

Instantaneous streamflow, specific conductance, and concentrations and instantaneous loads of dissolved chloride, total nitrogen, and total lead in runoff from two snowstorms--a winter storm and a spring storm--are graphed in figures 10 and 11. In snowmelt runoff, concentrations and loads changed in a parallel manner. In the winter storm (Jan. 24, 1978; fig. 10), dissolved chloride, total nitrogen, and specific conductance follow the same pattern, generally increasing with snowmelt runoff. Total lead concentrations and instantaneous loads increased initially and then gradually decreased.

In the spring storm (May 6 and 7, 1978; fig. 11), dissolved chloride load, total nitrogen load, and total lead concentration and load increased initially and then decreased, much as the streamflow increased and decreased. Specific conductance and dissolved chloride concentration decreased initially and then increased as the flow gradually subsided. Only lead in the winter storm seemed to undergo a first-flush.

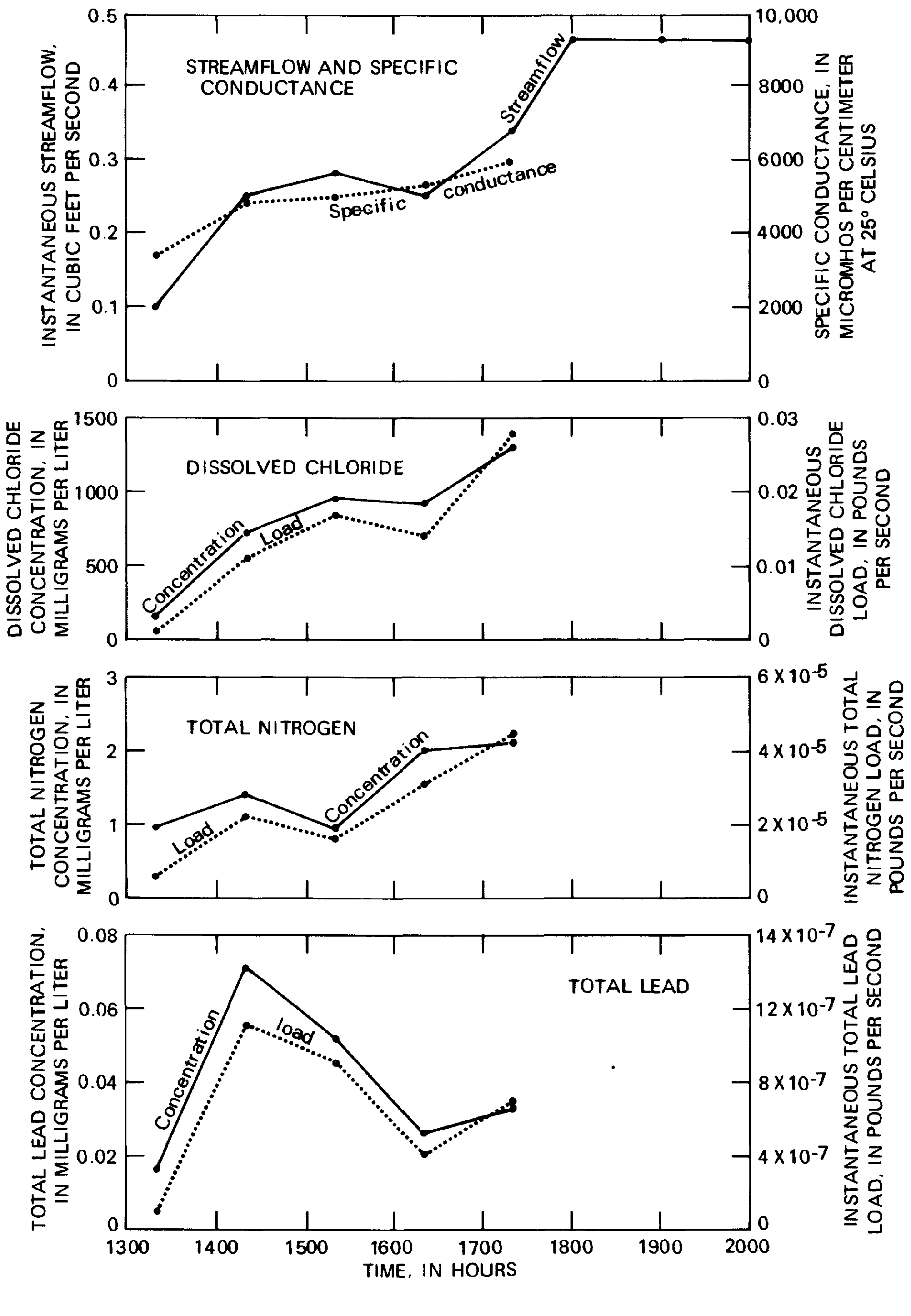


Figure 10.--Streamflow, specific conductance, and concentrations and loads of dissolved chloride, total nitrogen, and total lead for snowmelt runoff at site 5, January 24, 1978.

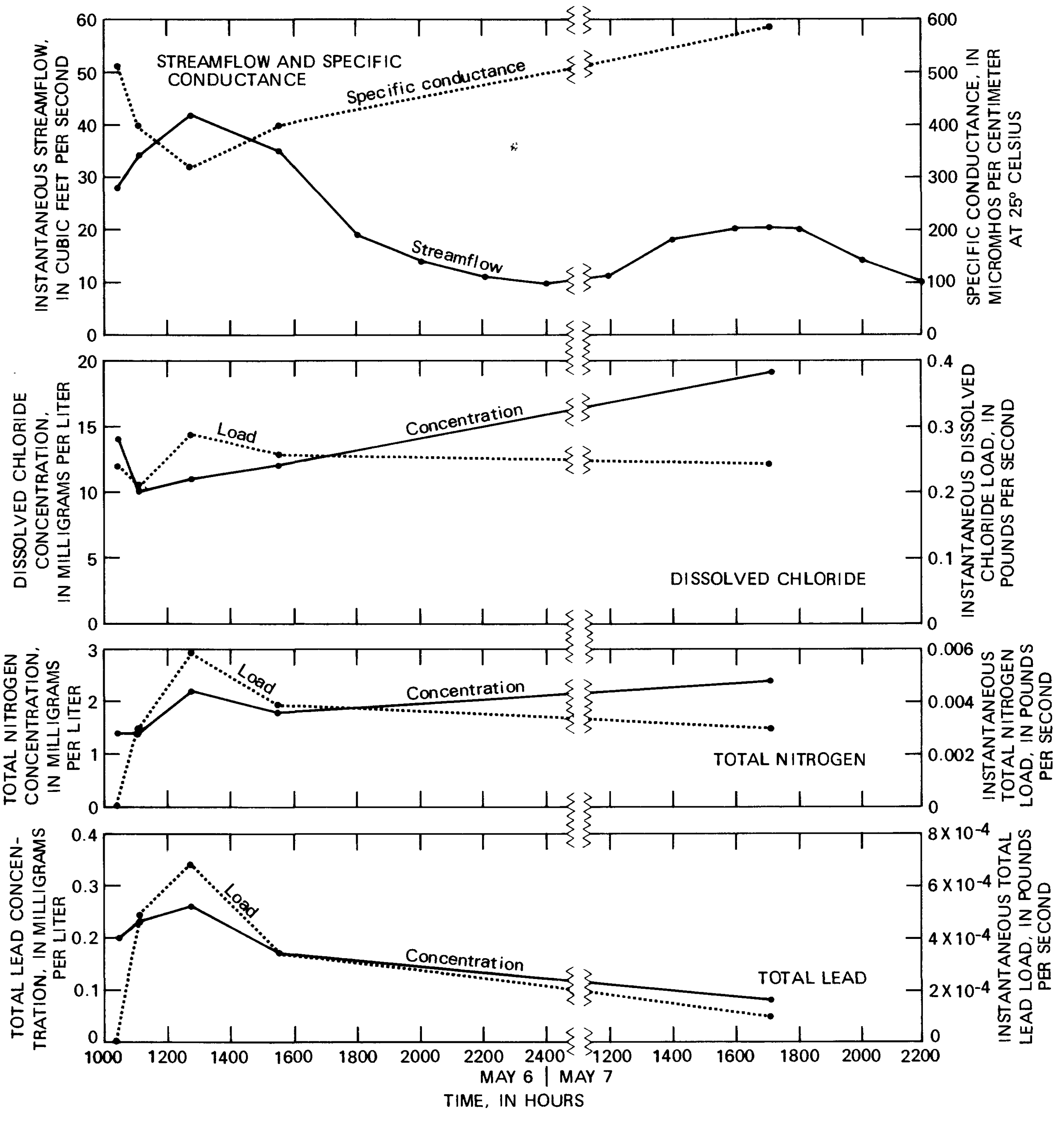


Figure 11.--Streamflow, specific conductance, and concentrations and loads of dissolved chloride, total nitrogen, and total lead for snowmelt runoff at site 5, May 6 through 7, 1978.

Quality of Rainfall Runoff

Of 54 rainfall-runoff peak flows that occurred during the study, 15 were sampled for selected water-quality properties and constituents at site 2, 16 at site 5, and 2 at site 4. The minimum, median, mean, and maximum values of these selected constituents are presented in table 9 for sites 2, 4, and 5.

As with snowmelt runoff, the constituent concentrations varied considerably during events. Site 4, based on a limited number of samples, had the greatest constituent concentrations, and site 2 generally had the smallest concentrations. There was a decrease in mean concentrations of the major ions in rainfall runoff as compared to snowmelt runoff and dry-weather flow. As with snowmelt runoff, the largest concentrations of trace elements were generally found for boron, iron, manganese, lead, and zinc. Suspended-sediment and suspended-solids concentrations were greater during rainfall than during snowmelt. Suspended-sediment and suspended-solids concentrations at site 5 were in large part due to construction and other activities of man and were not necessarily representative of usual sediment loads being carried in Grange Hall Creek. Installation of a culvert just below site 2 during the spring and summer of 1979 caused the largest disruption of the land during the study.

As shown in table 10, the number of rainfall-runoff samples exceeding the agricultural water-quality standards was greater than for constituents in dry-weather flow and snowmelt runoff. At site 5, lead concentrations in rainfall runoff exceeded the standard in 74 percent of the samples. Manganese concentrations exceeded the standard in 90 percent of the samples--a slight decrease from snowmelt runoff. Five percent of the cadmium and copper samples exceeded the standards, and only 2 percent of the chromium samples exceeded the standard. Trivalent or hexavalent chromium, separately, may not have exceeded the standard, which was modified after the analyses were made.

Pesticide samples were collected only at site 5 during rainfall runoff on three separate occasions. As was the case with dry-weather flow, significant concentrations were found of total diazinon (0.61 μg/L), total malathion (0.18 μg/L), total 2,4-D (18 μg/L), total 2,4,5-T (0.23 μg/L), and total silvex (0.76 μg/L).

Rainfall, streamflow, specific conductance, and concentrations and instantaneous loads of dissolved chloride, total nitrogen, and total lead in runoff are graphed for two storms at site 5--a short-duration storm (May 17, 1978; fig. 12), and a longer duration storm (May 20, 1979; fig. 13). In runoff from the short-duration thunderstorm-type rainstorm, specific conductance and dissolved chloride concentration increased throughout 2 hours of runoff, although maximum flow was observed in the first hour. Total nitrogen and total lead concentrations decreased throughout this period. Instantaneous loads of dissolved chloride, total nitrogen, and total lead closely followed the runoff. In runoff from the longer-lived storm, specific conductance and concentrations and loads of the three constituents reached maximum values during the first quarter of the runoff peak and then decreased.

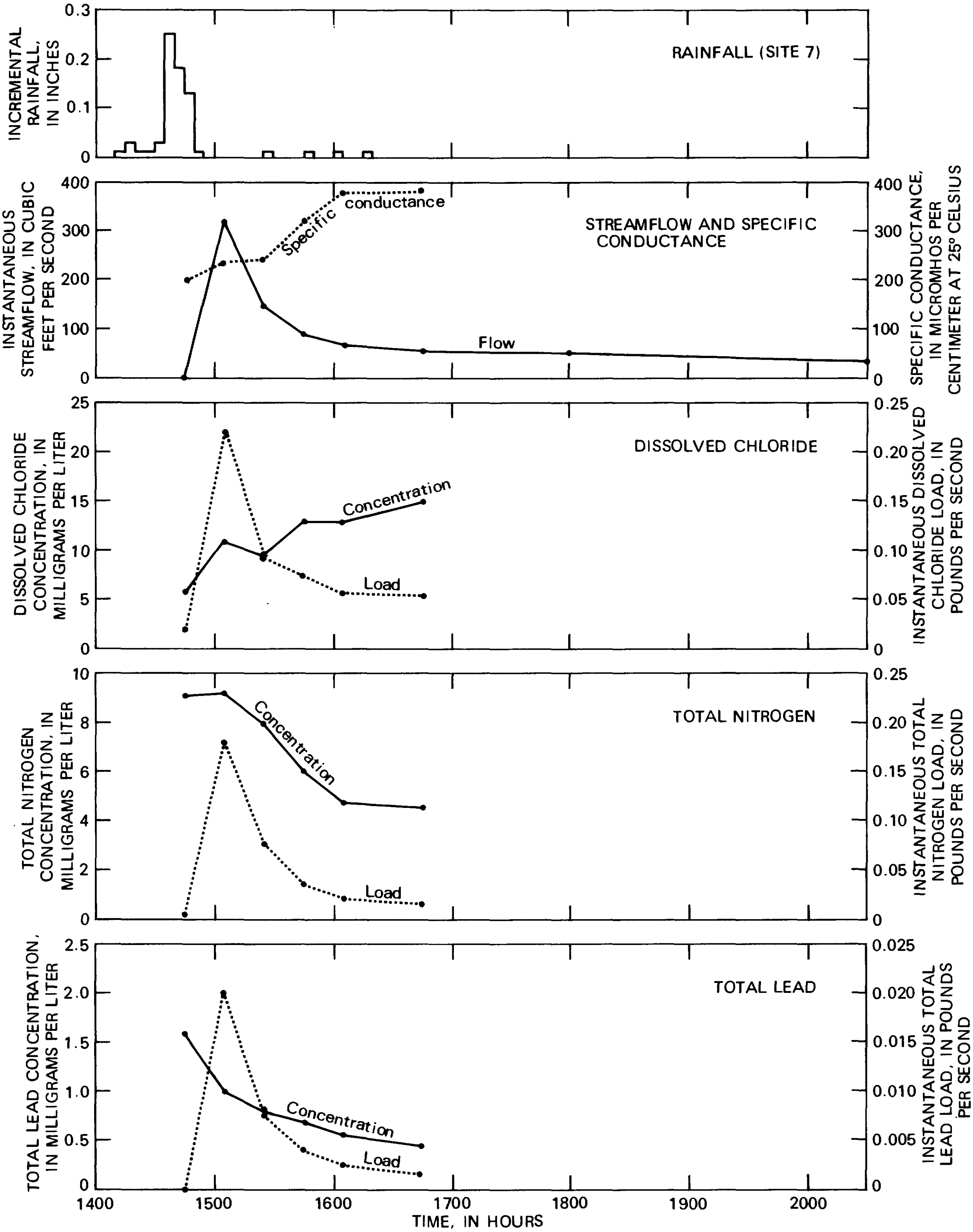


Figure 12.--Rainfall at site 7, and streamflow, specific conductance, and concentrations and loads of dissolved chloride, total nitrogen, and total lead at site 5, May 17, 1978.

Table 9.--*Summary of the concentrations of chemical constituents and values of the April 1978 through*

[ft^3/s=cubic feet per second; umho/cm=micromho per centimeter at 25°Celsius; °C=degrees Celsius; SAR=sodium adsorption ratio; T/d=ton per day;

Constituent or physical characteristic	Number of samples	Minimum	Median	Mean	Maximum
			Site 2		
Streamflow (ft^3/s)	60	0.24	7.8	16	90
Specific conductance (µmho/cm)	60	76	205	401	2,520
pH[1] (units)	60	6.7	7.5	7.3	8.3
Temperature (°C)	29	2.0	10.8	11.8	17.0
Fecal-coliform bacteria[2] (colonies/100 mL)	3	1,000	1,500	3,700	8,000
Hardness (mg/L as $CaCO_3$)	60	21	58	130	950
Calcium, dissolved (mg/L)	60	6.9	17	36	250
Magnesium, dissolved (mg/L)	60	.9	33	9.0	80
Sodium, dissolved (mg/L)	60	5.3	15	37	280
Sodium-adsorption ratio (SAR)	60	.5	.9	1.2	4.0
Chloride, dissolved (mg/L)	60	2.1	8.2	17	93
Fluoride, dissolved (mg/L)	8	.2	.4	.5	1.0
Solids, residue at 105°C, suspended (mg/L)	60	3	146	199	848
Solids, volatile, suspended (mg/L)	60	0	38	51	168
Sediment, suspended (mg/L)	22	45	191	301	1,240
Sediment discharge, suspended (T/d)	15	.21	2.4	14	105
Sediment, suspended, sieve diameter, percent finer than 0.062 mm	1	--------	97	97	--------
Oxygen demand, chemical (mg/L)	58	19	90	120	150
Nitrate, dissolved as N (mg/L)	60	.00	1.0	1.0	4.6
Nitrite, dissolved as N (mg/L)	60	.02	.05	.08	.95
Ammonia, total as N (mg/L)	60	.01	.46	.62	1.7
Organic nitrogen, total as N (mg/L)	60	.00	1.2	1.7	8.4
Kjeldahl nitrogen, total as N (mg/L)	60	.58	2.0	2.3	8.4
Nitrogen, total as N (mg/L)	60	.83	3.1	3.5	8.4
Phosphorus, dissolved as P (mg/L)	60	.07	.17	.20	.90
Orthophosphorus, total as P (mg/L)	60	.03	.14	.14	.53
Organic carbon, total as C[2] (mg/L)	23	11	26	28	66
Organic carbon, dissolved as C (mg/L)	7	12	21	21	28
Organic carbon, suspended as C[2] (mg/L)	7	2	5.6	7.9	20
Oil and grease (mg/L)	3	5	6.5	9.7	16
Arsenic, total (µg/L)	28	1	3	4	18
Beryllium, total recoverable (µg/L)	8	0	0	2	10
Boron, total recoverable (µg/L)	13	100	180	210	510
Cadmium, total recoverable (µg/L)	60	1	2	3	16
Chromium, total recoverable (µg/L)	47	0	10	10	60
Copper, total recoverable (µg/L)	28	9	25	31	78
Iron, total recoverable (µg/L)	31	490	4,000	4,300	12,000
Lead, total recoverable (µg/L)	60	2	170	220	930
Manganese, total recoverable (µg/L)	53	30	140	160	700
Nickel, total recoverable (µg/L)	8	5	12	12	20
Selenium, total (µg/L)	13	0	0	.5	1
Selenium, dissolved (µg/L)	7	0	1	2	6
Zinc, total recoverable (µg/L)	57	60	150	200	750

[1]Mean pH values were calculated as hydrogen ion activities.
[2]Less than and greater than qualifications were ignored for these calculations.

physical characteristics of rainfall runoff in streams in the Orange Hall Creek basin, August 1979

colonies/100 mL=colonies per 100 milliliters; $CaCO_3$=calcium carbonate; mg/L=milligram per liter; mm=millimeter; µg/L=microgram per liter]

Number of samples	Minimum	Median	Mean	Maximum	Number of samples	Minimum	Median	Mean	Maximum
		Site 4					Site 5		
--	----------	----------	----------	----------	89	1.7	22	39	320
3	416	512	555	640	83	161	400	492	2,090
3	8.3	9.1	8.7	9.2	83	7.2	7.8	7.7	9.1
3	6.0	7.0	7.5	8.5	60	4.0	11	11.6	18.5
--	----------	----------	----------	----------	34	63	4,000	5,500	18,000
3	110	130	140	150	80	39	110	140	790
3	38	41	44	50	80	12	31	40	190
3	3	4.4	6.1	9.5	80	2.3	7.0	9.6	77
3	46	47	52	61	79	12	34	50	230
3	1.7	1.8	1.9	2.2	79	.8	1.45	1.7	5
3	29	35	38	45	80	4.5	17	20.1	80
1	----------	1.7	1.7	----------	14	.3	.6	1.0	3.0
3	115	266	774	1,790	82	74	642	1,150	14,900
3	21	56	125	264	81	10	106	124	448
2	401	1,130	1,130	1,860	22	427	1,210	2,570	15,300
--	----------	----------	----------	----------	22	16	99	730	6,650
--	----------	----------	----------	----------	6	18	71	56	74
3	44	102	270	600	82	20	110	180	1,200
3	.38	.84	1.0	1.4	79	.00	.88	1.0	3.6
3	.021	.060	.09	.14	79	.01	.06	.07	.18
3	.56	.66	.81	1.1	82	.01	.46	.44	1.00
3	.74	2.4	3.4	5.5	82	.69	1.9	2.6	8.2
3	1.3	3.0	4.2	6.6	82	.86	2.4	3.1	8.9
3	1.6	3.7	5.2	8.2	82	1.00	3.4	4.0	11
3	.16	.197	.23	.3	80	.02	.09	.10	.32
3	.10	.13	.16	.23	82	.01	.08	6.9	340
--	----------	----------	----------	----------	34	7.4	24	32	91
--	----------	----------	----------	----------	16	6.4	14	20	41
--	----------	----------	----------	----------	9	1.0	5	6.0	13
--	----------	----------	----------	----------	1	----------	3	----------	----------
2	5	5	7.5	10	39	1	4	5	12
1	----------	0	0	----------	14	0	0	3	10
1	----------	260	260	----------	16	100	150	180	300
3	1	2	3	5	82	0	1	3	14
2	10	30	30	50	59	0	20	30	120
2	29	52	52	75	39	10	46	80	1,000
2	10,000	20,500	20,500	31,000	42	1,600	13,000	20,000	78,000
3	44	152	468	1,100	82	15	240	330	1,600
3	220	315	643	1,300	82	130	530	710	3,800
1	----------	50	50	----------	15	2	16	19	45
--	----------	----------	----------	----------	11	0	2	2	5
2	2	2	2	3	14	0	0	2	6
3	70	150	380	830	79	20	220	280	1,100

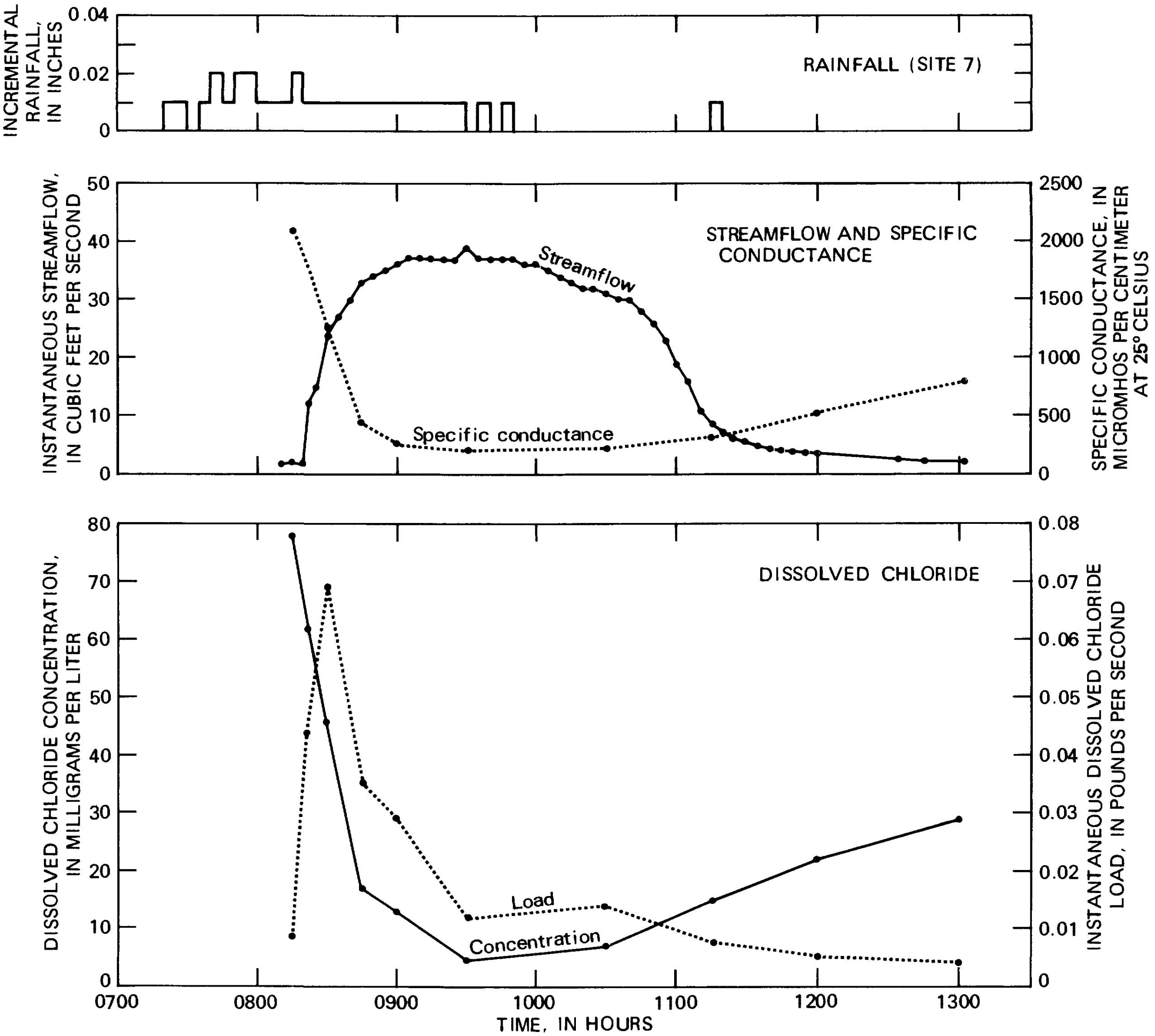


Figure 13.--Rainfall at site 7, and streamflow, specific conductance, and concentrations and loads of dissolved chloride, total nitrogen, and total lead at site 5, May 20, 1979.

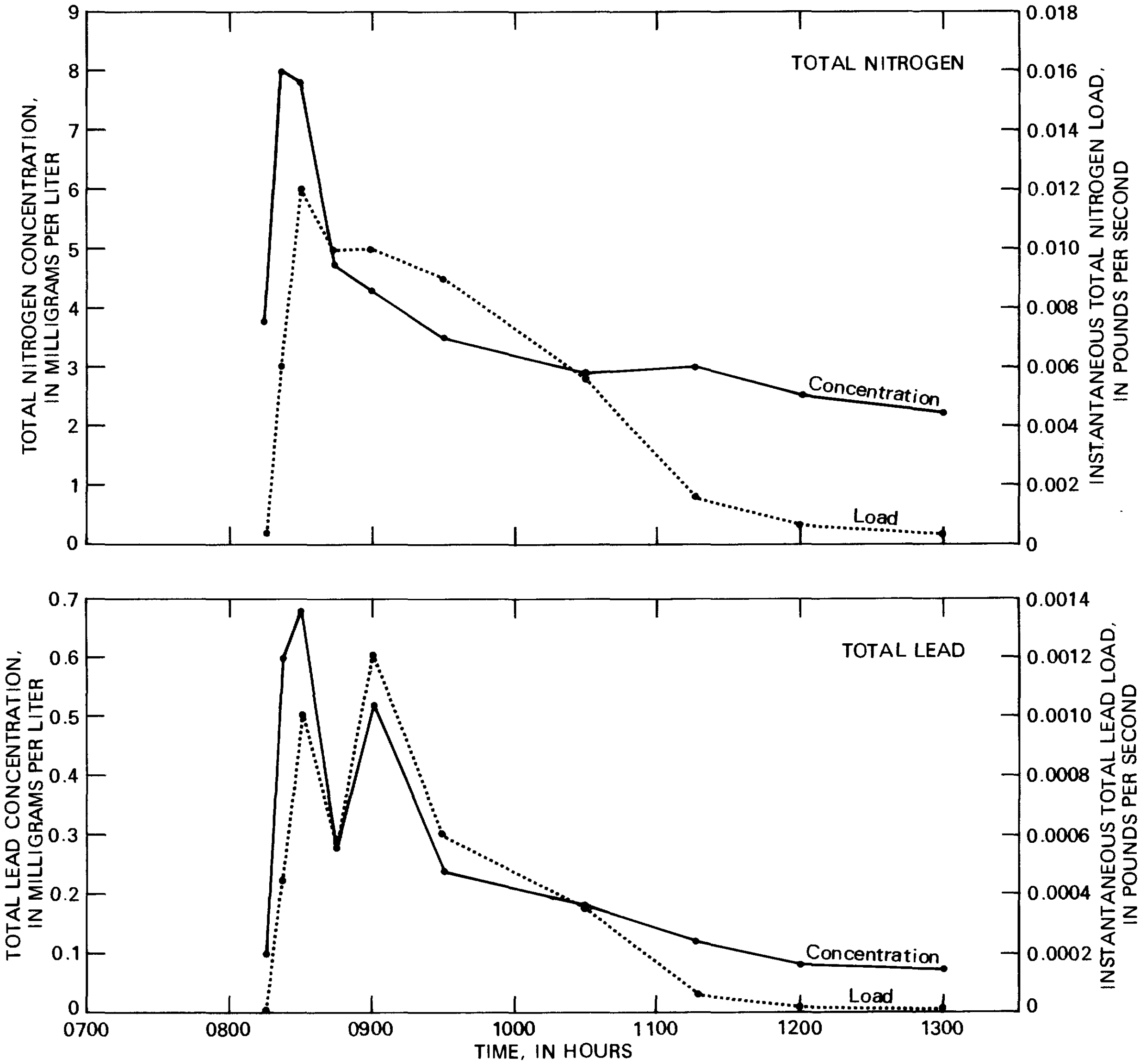


Figure 13.--Rainfall at site 7, and streamflow, specific conductance, and concentrations and loads of dissolved chloride, total nitrogen, and total lead at site 5, May 20, 1979--Continued.

Table 10.--*Numbers of rainfall-runoff samples exceeding Colorado water-quality standards for agricultural water*

Constituent[1]	Water-quality standard[2] (milligrams per liter unless otherwise indicated)	Site 2		Site 4		Site 5	
		Number of samples	Number exceeding standard	Number of samples	Number exceeding standard	Number of samples	Number exceeding standard
Nitrate (as nitrogen)--	100	60	0	3	0	79	0
Nitrite (as nitrogen)--	10	60	0	3	0	79	0
Beryllium-------------	.1	8	0	1	0	14	0
Boron-----------------	.75	13	0	1	0	16	0
Cadmium---------------	.01	60	3	3	0	82	4
Chromium[3]-------------	.1	47	0	2	0	52	1
Copper----------------	.2	28	0	2	0	39	2
Lead------------------	.1	60	42	3	2	82	61
Manganese-------------	.2	53	10	3	3	82	74
Nickel----------------	.2	8	0	1	0	15	0
Selenium--------------	.02	20	0	2	0	25	0
Zinc------------------	2	57	0	3	0	79	0

[1]All constituents are total recoverable except nitrate and nitrate, and 29 of 47 selenium analyses are dissolved.

[2]Colorado Department of Health, 1979.

[3]Neither trivalent nor hexivalent chromium may exceed the standard of 0.1 milligram per liter. Analyses here are for all chromium species.

The evidence suggests that a first-flush of constituents does not occur in runoff from short-duration rainstorms, but does occur in runoff from longer duration rainstorms.

To compare loads of dissolved chloride, total nitrogen, and total lead between subbasins, the storm of August 14, 1979, was used because the most complete data were available for both sites 2 and 5 for this storm (table 11). The loads are the same order of magnitude for both the upstream and downstream subbasins. Pounds of total nitrogen per acre per inch of runoff were about twice as great for the upstream basin, and dissolved chloride and total lead were about equal for the two subbasins. Also, it was previously shown that median runoff as percentage rainfall was 54 percent for the upstream subbasin and 24 percent for the downstream subbasin, or twice as great a percentage of runoff for the upstream subbasin. Therefore, the loads of dissolved chloride and total lead per unit area would be about twice as great for the upstream subbasin as compared to the downstream subbasin, and loads of total nitrogen per unit area would be about four times greater from the upstream basin.

Table 11.--*Comparison between upper Grange Hall Creek subbasins of loads of dissolved chloride, total nitrogen, and total lead in rainfall runoff, August 14, 1979*

Basin or subbasin	Total load (pounds per acre per inch of runoff)		
	Dissolved chloride	Total nitrogen	Total lead
Upper Grange Hall Creek basin----------	1.67	0.328	0.0357
Upstream subbasin----------------------	1.86	.531	.0348
Downstream subbasin--------------------	1.63	.235	.0374

	Ratio		
	Dissolved chloride	Total nitrogen	Total lead
Upstream subbasin/ downstream subbasin------------------	1.1	2.3	0.93

CORRELATIONS BETWEEN CONSTITUENT CONCENTRATIONS, SPECIFIC CONDUCTANCE, AND STREAMFLOW

Linear and log-linear correlation coefficients between instantaneous streamflow and water-quality constituent concentrations and between specific conductance and water-quality constituent concentrations are listed in tables 12 through 14. Thirty-five percent of the correlation coefficients in these tables reflect significant relationships at the 95-percent or greater level of confidence. Fifty-seven percent of the relationships are positive, and the magnitudes of the log-linear coefficients were greater than or equal to the linear coefficients 58 percent of the time. The correlation coefficients between streamflow and calcium, sodium, chloride, or nitrate were usually negative and significant. The correlations between specific conductance and these variables were usually positive and significant. Generally, other relations were either inconsistent or not significant at the 95-percent confidence level. From the above data, it can be seen that simple regression models could be developed for water-quality constituents, as was done by Ellis and Alley (1979).

CONSIDERATIONS FOR URBAN-RUNOFF MANAGEMENT

Concentrations of sampled major chemical constituents and fecal-coliform bacteria in storm runoff in Grange Hall Creek generally were less than water-quality standards for agricultural supplies. However, concentrations of lead, manganese, chromium, and copper at times exceeded the standards, sometimes by as much as 19 fold.

Because dilution of storm runoff by 19 volumes may not be practical, alternate methods of improving water quality might be investigated. Alley and Ellis (1978) found average ratios of suspended to dissolved trace-metal concentrations in rainfall runoff to be 20 to 1. The flood-detention reservoir on Grange Hall Creek at Washington Street possibly could be modified to increase detention times and thereby increase settling of the finer sediments which carry much of the trace element and nutrient loads in turbulent streams. Retention in Stonehocker Reservoir, the proposed facility for collecting storm runoff, also would result in removal of much sediment and associated reductions in many constituent loads.

Future development along the unnamed southern tributary to Grange Hall Creek undoubtedly will have noticeable effects on the quantity and quality of urban runoff from the upper Grange Hall Creek basin. Runoff as percent of rainfall from the more developed upstream subbasin is more than twice that of the downstream subbasin. As urbanization proceeds along the tributary, the volume of runoff will increase. With increased storm runoff, total loads also should increase considerably in runoff from the downstream subbasin. Concentrations of water-quality constituents in dry-weather flow are generally greater in the developed upstream subbasin and also would be expected to increase with urbanization in the downstream subbasin.

Table 12.--*Correlation coefficients for streamflow and*

[Numbers in parentheses indicate number of pairs used in
a=significant at the 0.05 level;

Variables	Number of observations	Correlation coefficients Linear	Log-linear
		SITE 2	
Streamflow and:			
Specific conductance	16	-0.479	a-0.531
Calcium, dissolved	16	-.249	-.290
Sodium, dissolved	16	.204	-.093
Chloride, dissolved	16	b-.616	b-.705
Oxygen demand, chemical	16	a.559	.358
Nitrate, dissolved	15	.114	-.016
Ammonia, total	15	a.546	.413
Organic nitrogen, total	15	a.614	a.531
Nitrogen, total	15	a.497	.261
Phosphorus, dissolved	16	-.006	.269
Orthophosphorus, total	15	.067	.269
Organic carbon, total	10	.235	.219
Organic carbon, dissolved	12	.183	.135
Boron, total recoverable	13	.159	.080
Chromium, total recoverable	14 (10)	.282	-.330
Copper, total recoverable	15	.283	.219
Iron, total recoverable	15	.364	.075
Lead, total recoverable	16	.140	.173
Manganese, total recoverable	14	a.638	.287
Zinc, total recoverable	16	.479	.190
Specific conductance and:			
Calcium, dissolved	18	b0.842	b0.858
Sodium, dissolved	18	b.595	b.683
Chloride, dissolved	18	b.845	b.876
Oxygen demand, chemical	18	-.335	-.335
Nitrate, dissolved	17	b.616	a.586
Ammonia, total	17	-.402	-.450
Organic nitrogen, total	17	-.443	a-.506
Nitrogen, total	17	.291	.335
Phosphorus, dissolved	18	-.229	-.442
Orthophosphorus, total	17	-.084	-.254
Organic carbon, total	12	-.501	-.540
Organic carbon, dissolved	14	-.486	a-.528
Boron, total recoverable	15	.065	-.072
Chromium, total recoverable	16 (12)	-.248	.108
Copper, total recoverable	17	.283	.152
Iron, total recoverable	17	-.035	-.015
Lead, total recoverable	18	-.126	-.214
Manganese, total recoverable	16	-.126	-.173
Zinc, total recoverable	17	-.213	-.253

water-quality variables for dry-weather flow

calculation of log-linear correlation coefficient.
b=significant at the 0.01 level]

Number of observations	Correlation coefficients Linear	Correlation coefficients Log-linear	Number of observations	Correlation coefficients Linear	Correlation coefficients Log-linear
	SITE 5			SITE 4	
18	b-0.823	b-0.947	-----	------	------
18	b-.792	b-.937	-----	------	------
18	b-.813	b-.933	-----	------	------
18	b-.751	b-.927	-----	------	------
18	-.159	-.034	-----	------	------
17 (16)	b-.705	b-.885	-----	------	------
17	a-.521	b-.687	-----	------	------
17	-.390	-.452	-----	------	------
17	b-.714	b-.912	-----	------	------
18	.117	.348	-----	------	------
17	a.513	.280	-----	------	------
17	-.182	-.281	-----	------	------
16	-.220	-.328	-----	------	------
15	b-.848	b-.929	-----	------	------
17 (9)	.162	-.089	-----	------	------
16	.202	.187	-----	------	------
16	b.716	.380	-----	------	------
18	.273	.144	-----	------	------
17	a-.539	b-.752	-----	------	------
15	a-.502	a-.576	-----	------	------
19	b0.985	b0.979	9	b0.952	b0.971
19	b.996	b.996	9	b.999	b.999
19	b.950	b.975	9	a.742	b.909
19	.058	-.044	4	.740	.672
18 (17)	b.922	b.905	8 (7)	a.682	a.768
18	b.686	b.634	8	.041	-.041
18	a.503	.449	8	-.431	-.470
18	b.913	b.900	8	a.660	.559
19	-.218	-.379	9	-.498	a-.666
18	-.269	-.366	8 (6)	-.604	-.687
17	.178	.221	3	-.899	-.945
17	.242	.284	3	-.905	a-.955
16	b.939	b.972	4	b.994	b.986
18 (10)	.294	.074	4 (2)	.469	.000
17	-.084	-.059	9	-.041	-.099
17	-.463	a-.576	9	-.250	-.279
19	.269	.047	9	.235	.263
18	b.730	b.675	6	b.930	.733
16	b.661	b.660	8	-.033	-.085

Table 13.--*Correlation coefficients for streamflow and*

[Numbers in parentheses indicate number of pairs used in
a=significant at the 0.05 level;

Variables	Number of observations	Correlation coefficients Linear	Log li
		SITE 2	
Streamflow and:			
Specific conductance-------------	19	a-0.542	b-0.763
Calcium, dissolved---------------	18	b-.770	b-.954
Sodium, dissolved----------------	18	-.426	b-.711
Chloride, dissolved--------------	19	-.273	a-.528
Oxygen demand, chemical----------	18	.039	.295
Nitrate, dissolved---------------	19	b-.726	b-.888
Ammonia, total-------------------	19	.071	.290
Organic nitrogen, total----------	19 (18)	.073	.256
Nitrogen, total------------------	19	a-.543	a-.527
Phosphorus, dissolved------------	19	-.194	-.085
Orthophosphorus, total-----------	19	.322	a.521
Organic carbon, total------------	5	a.956	a.931
Organic carbon, dissolved--------	6	b.942	b.893
Boron, total recoverable---------	16	b-.760	b-.891
Chromium, total recoverable------	16 (13)	.211	a.514
Copper, total recoverable--------	19	.150	a.557
Iron, total recoverable----------	19	.093	a.550
Lead, total recoverable----------	19	.295	b.696
Manganese, total recoverable-----	19	-.390	a-.512
Zinc, total recoverable----------	14	-.308	-.252
Specific conductance and:			
Calcium, dissolved---------------	18	0.368	b0.852
Sodium, dissolved----------------	18	b.980	b.994
Chloride, dissolved--------------	19	b.924	b.935
Oxygen demand, chemical----------	18	.426	.324
Nitrate, dissolved---------------	19	a.470	b.727
Ammonia, total-------------------	19	-.030	.124
Organic nitrogen, total----------	19 (18)	-.148	.197
Nitrogen, total------------------	19	.387	b.771
Phosphorus, dissolved------------	19	-.056	.135
Orthophosphorus, total-----------	19	a-.450	a-.447
Organic carbon, total------------	5	b1.000	b.998
Organic carbon, dissolved--------	6	b.993	b.980
Boron, total recoverable---------	16	.253	b.722
Chromium, total recoverable------	16 (13)	.391	.263
Copper, total recoverable--------	19	.341	.037
Iron, total recoverable----------	19	.408	.032
Lead, total recoverable----------	19	-.183	-.269
Manganese, total recoverable-----	19	b.847	b.896
Zinc, total recoverable----------	14	b.892	a.564

water-quality variables for snowmelt runoff

calculation of log-linear correlation coefficient.
b=significant at the 0.01 level]

Number of observations	Correlation coefficients Linear	Correlation coefficients Log-linear	Number of observations	Correlation coefficients Linear	Correlation coefficients Log-linear
	SITE 5			SITE 4	
19	b-0.818	b-0.890	-----	------	------
18	b-.816	b-.972	-----	------	------
18	b-.797	b-.851	-----	------	------
19	b-.597	b-.709	-----	------	------
18	-.146	-.012	-----	------	------
19	b-.894	b-.900	-----	------	------
19	-.249	-.090	-----	------	------
19	-.092	.134	-----	------	------
19	b-.735	b-.656	-----	------	------
19	.047	.062	-----	------	------
19	a.473	b.724	-----	------	------
5	b.988	b.994	-----	------	------
5	b.959	a.906	-----	------	------
15	-b.800	b-.855	-----	------	------
15 (13)	.451	a.600	-----	------	------
19	.416	b.710	-----	------	------
19	.402	b.687	-----	------	------
19	.296	b.752	-----	------	------
19	b-.782	b-.805	-----	------	------
14	.006	.[illegible]22	-----	------	------
18	b0.910	b0.913	4	b0.999	b1.000
18	b.985	b.995	4	b.995	b.999
19	b.870	b.934	4	a.932	b.982
18	.052	.224	4	b-.992	b-.986
19 (18)	b.868	b.954	4	b.969	b.992
19	.165	.441	4	.343	.339
19	-.037	.214	4	-.080	-.146
19	b.666	b.863	4	b.980	b.991
19	-.175	.119	4	b.999	b1.000
19	a-.530	b-.610	4	.000	.000
5	.072	.210	-----	------	------
5	-.261	-.144	-----	------	------
15	a.566	b.802	4	b.996	b.999
15 (13)	-.427	-.262	4 (3)	b.999	.000
19	-.426	-.423	4	-.410	-.410
19	-.388	-.407	4	-.550	-.525
[illegible]	.364	a-.411	4	b-.970	.800
19	b.878	b.931	4	b.972	b.992
14	.281	.013	4	-.615	-.599

Table 14.--*Correlation coefficients for streamflow and*

[Numbers in parentheses indicate number of pairs used in
a=significant at the 0.05 level;

Variables	Number of observations	Correlation coefficients Linear	Log-linear
		SITE 2	
Streamflow and:			
Specific conductance--------------	58	b-0.356	b-0.723
Calcium, dissolved----------------	58	a-.328	b-.703
Sodium, dissolved-----------------	58	b-.345	b-.713
Chloride, dissolved---------------	58	b-.404	b-.710
Oxygen demand, chemical-----------	56	-.055	.011
Nitrate, dissolved----------------	58	-.181	b-.453
Ammonia, total--------------------	58	-.056	-.195
Organic nitrogen, total-----------	58 (57)	-.044	-.189
Nitrogen, total-------------------	58	-.124	b-.362
Phosphorus, dissolved-------------	58	-.150	-.133
Orthophosphorus, total------------	58	-.012	.134
Organic carbon, total-------------	21	.008	.107
Organic carbon, dissolved---------	7	-.002	a.284
Boron, total recoverable----------	13	b-.495	b-.728
Chromium, total recoverable-------	45 (39)	.096	.073
Copper, total recoverable---------	28	.019	-.015
Iron, total recoverable-----------	31	a.277	a.316
Lead, total recoverable-----------	58	.069	.164
Manganese, total recoverable------	53	-.019	.102
Zinc, total recoverable-----------	55	.004	.046
Specific conductance and:			
Calcium, dissolved----------------	60	b0.996	b0.990
Sodium, dissolved-----------------	60	b.994	b.979
Chloride, dissolved---------------	60	b.954	b.938
Oxygen demand, chemical-----------	58	.121	.128
Nitrate, dissolved----------------	60	b.869	b.719
Ammonia, total--------------------	60	a.267	b.402
Organic nitrogen, total-----------	60 (59)	b.344	b.449
Nitrogen, total-------------------	60	b.585	b.597
Phosphorus, dissolved-------------	60	-.061	.083
Orthophosphorus, total------------	60	-.225	-.220
Organic carbon, total-------------	23	-.152	-.044
Organic carbon, dissolved---------	7	-.646	-.477
Boron, total recoverable----------	13	b.900	b.930
Chromium, total recoverable-------	47 (41)	.085	.101
Copper, total recoverable---------	28	-.126	-.028
Iron, total recoverable-----------	31	-.335	a-.428
Lead, total recoverable-----------	60	-.067	-.053
Manganese, total recoverable------	53	.179	.186
Zinc, total recoverable-----------	57	.034	.055

water-quality variables for rainfall runoff

calculation of log-linear correlation coefficient.
b=significant at the 0.01 level]

Number of observations	Correlation coefficients Linear	Log-linear	Number of observations	Correlation coefficients Linear	Log-linear
	SITE 5			SITE 4	
83	b-0.365	b-0.283	-	------	------
80	b-.365	b-.689	-	------	------
79	b-.378	b-.725	-	------	------
80	b-.372	b-.660	-	------	------
80	b.320	.027	-	------	------
79 (78)	a-.256	b-.361	-	------	------
82	.107	-.029	-	------	------
82	.134	.001	-	------	------
82	.020	-.122	-	------	------
80	.146	a.259	-	------	------
82	-.048	a.246	-	------	------
34	a.407	.305	-	------	------
16	-.128	.029	-	------	------
16	-.302	a-.568	-	------	------
59 (57)	.105	.195	-	------	------
39	.108	b.419	-	------	------
42	b.556	b.537	-	------	------
82	a.222	a.280	-	------	------
82	.197	.163	-	------	------
79	a.230	b.297	-	------	------
80	b0.862	b0.394	3	0.795	0.831
79	b.957	b.441	3	.700	.696
80	b.888	b.372	3	-.398	-.414
82	.034	.105	3	b-.997	-.917
79 (78)	b.682	.185	3	-.675	-.629
82	a.250	.185	3	-.837	-.728
82	a.252	a.229	3	-.822	-.701
82	b.395	.186	3	-.852	-.739
80	-.146	a-.233	3	-.046	-.113
82	.054	-.136	3	-.821	-.763
34	.006	-.157	-	------	------
15	-.111	-.019	-	------	------
16	a.556	-.005	-	------	------
59 (57)	-.054	.034	-	------	------
39	a.340	.070	-	------	------
42	-.100	-.007	-	------	------
82	-.112	-.019	3	b-.998	-.888
82	.147	.078	3	b-.999	a-.970
79	-.053	-.069	3	b-.997	-.923

SUMMARY AND CONCLUSIONS

The quantity and quality of urban runoff in the upper Grange Hall Creek basin in Northglenn was studied during the 1978 and 1979 water years. Precipitation at Northglenn was below average during the first year and above average during the second year of this study. Streamflow from the basin (site 5) was about 1,190 acre-ft in 1978 and 1,510 acre-ft in 1979. Mean daily streamflows were about 1.65 ft^3/s in 1978 and 2.09 ft^3/s in 1979. Annual and mean annual flows from the upstream subbasin (site 2) were one-fifth to one-fourth of the flow for the basin for one-sixth of the area. Dry-weather flow generally ranged from 0.1 to 1.0 ft^3/s at site 5 and from 0.1 to 0.3 ft^3/s at site 2.

From December 8, 1977, through September 30, 1979, there were 104 storm-runoff peaks in Grange Hall Creek--50 from snowmelt and 54 from rainfall. Maximum peak flows at site 5 were 339 ft^3/s in water year 1978 and 876 ft^3/s in water year 1979. The largest peak flow in 1978 was approximately a 10-year flood.

Rainfall runoff as percent of rainfall was variable with a median of 54.5 percent for the upper subbasin and 24 percent for the entire basin (upper Grange Hall Creek basin). Runoff volumes increased almost linearly with the rainfall of a storm. Peak flows for runoff from thunderstorms also increased with rainfall, but the responses, especially for the basin, were two-phase linear. No simple relationships were observed between rainfall and percentage runoff or antecedent dry days and percentage runoff.

Specific-conductance values in dry-weather flow in Grange Hall Creek ranged from 500 to 3,930 micromhos per centimeter and in the unnamed southern tributary ranged from 430 to 2,500 and tended to be greater in the winter months and less in the summer months. Storm runoff decreased the specific conductance, except during snowmelt runoff when roads were sanded and salted.

Lead, manganese, cadmium, chromium, and copper occurred at concentrations exceeding Colorado water-quality standards for agricultural water. At site 5, the most downstream site in the upper Grange Hall Creek basin, lead exceeded the standard in none of the dry-weather flow samples, in 47 percent of snowmelt-runoff samples, and in 74 percent of rainfall-runoff samples. Manganese exceeded the standard in 39 percent of dry-weather flow samples, in 95 percent of snowmelt-runoff samples, and in 90 percent of rainfall-runoff samples. In addition, cadmium in rainfall-runoff samples exceeded the standard in 5 percent, chromium in 2 percent, and copper in 5 percent.

During storm runoff, major ion concentrations usually decreased with flow, and conversely loads increased with flow. There was evidence for a first-flush of constituents in runoff from longer rainstorms. Loads of water-quality constituents were proportional to runoff volume. Loads per acre per inch of runoff were about equal for the upstream subbasin compared to the downstream subbasin, but loads per acre were two to four times greater from the upstream subbasin--an increase partially due to greater runoff as percent of rainfall.

Considerable construction in the basin, especially during 1979, artificially increased the sediment concentrations and loads in storm runoff during the study. Consequently, the data are relevant only to the sampling period, and interpretation, therefore, was held to a minimum. It was evident sediment concentrations during storm runoff will likely be large, even in the absence of construction disturbances. Because of these large anticipated concentrations and because the finer sediments are known to be important in transporting water-quality constituents, a more extensive sediment sampling and analysis program, including quality analyses of the sediment fractions, might be warranted in the future.

Agricultural use of urban runoff from Grange Hall Creek will sometimes require that concentrations of constituents be reduced. Colorado water-quality standards will often be met with no treatment or simply by dilution with other supplies of water available to the City of Northglenn. Trace-element concentrations may be lowered by sediment trapping in a reservoir or perhaps by a more exotic treatment, such as filtration or precipitation of sediment.

Increased urbanization, especially along the unnamed southern tributary, will increase storm runoff as a consequence of increasing the impermeable area of the basin. Increased water-quality constituent loads also will be expected to increase because loads increase with flow. Concentrations also may increase in dry-weather flow due to a combination of factors, such as increased constituent input into the system and decreased removal in reservoirs and open space.

Correlation coefficients between selected water-quality constituents and specific conductance or streamflow indicate that simple linear or log-linear relationships could be developed in many cases. Such relationships could be used to rapidly obtain estimates of constituent concentrations from specific-conductance values or streamflow, or both. The strongest relationships were generally for the major ions and nutrients present in larger concentrations. These correlations were usually positive with specific conductance and negative with streamflow.

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