ANALYSIS OF URBAN STORM-RUNOFF DATA AND THE EFFECTS ON THE SOUTH PLATTE RIVER, DENVER METROPOLITAN AREA, COLORADO

By Sherman R. Ellis, John T. Doerfer, Martha H. Mustard,
Steven R. Blakely, and Johnnie W. Gibbs

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WILLIAM P. CLARK, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

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

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Denver, CO 80225
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METRIC CONVERSION FACTORS

The inch-pound units used in this report may be converted to International System of Units (SI) by the following conversion factors:

Multiply	*By*	*To obtain*
inch	25.40	millimeter
foot	0.3048	meter
acre	0.4047	hectare
cubic foot	0.02832	cubic meter
cubic foot per second	0.02832	cubic meter per second
mile	1.609	kilometer
ton (short) per day	0.9072	megagram per day
inch per hour	25.40	millimeter per hour
square foot	0.09290	square meter
pound per second	0.4536	kilogram per second
pound	0.4536	kilogram

To convert degrees Celsius (°C) to degrees Fahrenheit (°F), use the following formula: (°C x 9/5) + 32 = °F.

National Geodetic Vertical Datum of 1929: A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level, and referred to as sea level in this report.

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ABSTRACT

The Denver metropolitan area has been the site of urban-runoff studies for several years. Denver was selected for inclusion in the Nationwide Urban Runoff Program (NURP), a program sponsored by the U.S. Environmental Protection Agency and the U.S. Geological Survey. This report, prepared in cooperation with the Denver Regional Council of Governments, is based on data from nine small basins, two of which are at the outlets of detention ponds, and six tributary basins and presents regression analyses of selected small basins and selected combined small and tributary basins, and the effects of urban storm runoff on the South Platte River in the Denver metropolitan area.

The data from six of the small and five of the tributary basins were analyzed using regression analysis, resulting in two sets of regression equations to predict the storm-runoff volume and selected constituent loads. The first set of equations may be used for basins with drainage areas of 15 to 600 acres in size, with 15- to 90-percent effective impervious area. This set of equations was derived from the six small basins. The second set of regression equations, derived from the combined small and tributary basins, is to be used for basins from 600 to 16,000 acres in size, with 15- to 90-percent effective impervious area.

A comparison was made between the mean seasonal storm-runoff volumes and selected constituent loads estimated by deterministic and regression models. The estimated mean seasonal values were equivalent for three of four basins compared. One basin, Villa Italia, where the results differed by as much as 400 percent, probably had better results using deterministic models. Due to the costs of using deterministic models and the uncertainty in their use on unmonitored basins, regression models probably are sufficient for planning purposes on most unmonitored basins.

The effects of urban runoff on the South Platte River in the Denver area were compared in three ways. The first comparison was between selected constituent concentrations during dry-weather flow and storm-runoff periods. Dry-weather flow concentrations were larger for total nitrite, total nitrate, and total manganese. The concentrations were larger during storm-runoff periods for total organic carbon, total iron, total manganese, total lead, and total zinc. Concentrations were about the same for both flow periods for total nitrogen, total ammonia, total phosphorus, total cadmium, and total copper.

The second comparison was between the percent exceedance of stream-quality standards during dry-weather flow and storm-runoff periods. Constituents that exceeded the standards more than 50 percent of the time during storm-runoff periods were total cadmium, total copper, total iron, total manganese, dissolved manganese, total lead, and total zinc. Constituents that exceeded the standards more than 50 percent of the time in dry-weather flows were total copper, total iron, total manganese, and dissolved manganese.

The third comparison was between the percentage of total flow volume and constituent loads in the point-source, base, and storm-runoff flows. Base flows had a significant percentage of the total flow volume and constituent loads of total lead and total zinc. The point-source flows had a significant percentage of total constituent loads of total organic carbon, total nitrogen, total phosphorus, and total zinc. Storm runoff had a significant percentage of the total constituent loads of total suspended solids, total organic carbon, total lead, and total zinc.

INTRODUCTION

The Denver metropolitan area has been involved in urban-runoff studies for several years. The lead local agenices have been the Denver Regional Council of Governments (DRCOG) and the Urban Drainage and Flood Control District (UDFCD). The City of Northglenn and the Denver Water Board also have participated in the study of urban runoff. The Denver area was selected in 1979 as one of the cities to be included in the Nationwide Urban Runoff Program (NURP), a program sponsored by the U.S. Environmental Protection Agency (EPA) and the U.S. Geological Survey. This report is one phase of the NURP study in the Denver metropolitan area. The NURP study in Denver was named the Denver Regional Urban Runoff Program (DRURP).

Seven basins and the outlets of two detention ponds were instrumented to monitor rainfall, runoff, and atmospheric deposition and to collect urban runoff water-quality samples. The data collected at these basins were used to characterize runoff loads of constituents. The land use of the basins included two single-family housing basins, two multifamily housing basins, a light commercial and multifamily housing, a shopping center, and a natural basin.

Several small-scale studies also were included in the Survey's tasks. Storm loads derived from discrete and storm loads derived from composite samples were compared to determine if composite samples were adequate to define the total storm loads. Water-quality samples were analyzed for total and dissolved constituents to determine the fraction of the total constituent load that is particulate and what fraction is dissolved. Runoff samples were separated by particle sizes, and the various particle fractions of the sample were analyzed for selected constituents to determine the runoff loads that were associated with discrete particle sizes. The data from the atmospheric-deposition collectors were used to determine the effects of wet fall and dry fall on the runoff loads from the basins. The runoff from three basins was sampled to determine if the U.S. Environmental Protection Agency's 126 priority pollutants were present.

PURPOSE AND SCOPE

The purposes of this report are to present analyses of rainfall, constituent-load, and atmospheric-deposition data, statistical techniques to estimate storm volumes and loads, results of long-term simulation of storm peaks and loads, and the effect of urban runoff on the receiving water--the South Platte River. This report may be used by Federal, State, and local agencies interested in urban runoff in the semiarid west and particularly in the Denver area.

DESCRIPTION OF THE STUDY AREA AND BASINS

The Denver metropolitan area is in the Piedmont region of Colorado between the Rocky Mountains on the west and the High Plains on the east. The climate is characterized as being semiarid, with about 14 to 15 inches of precipitation per year. The greater portion of the Denver metropolitan area lies within the study area (fig. 1). The study area is about 120,000 acres (187 square miles). The area is defined by the drainage area of a 14.5-mile reach of the South Platte River between two U.S. Geological Survey streamflow-monitoring stations--South Platte River at Littleton (U.S. Geological Survey station 06710000) and South Platte River at 50th Avenue, at Denver (U.S. Geological Survey station 06714130)--and downstream from two tributary reservoirs--Cherry Creek Lake and Bear Creek Lake (fig. 2). The elevation of the study area ranges from 7,965 feet in the western foothills to 5,310 feet on the eastern side of the basin, with the South Platte River valley extending south to north, ranging in elevation from 5,310 feet on the south to 5,140 feet on the north. The study area is characterized by steep slopes and soils that have a relatively high infiltration rate, except in the western section where clay-bentonite soils are common.

There are a total of 19 monitoring sites shown on figure 2. These 19 monitoring sites consist of nine sites, hereafter referred to as small basins, that were operated as part of the NURP; four sites on the main stem of the South Platte River; and six sites on tributary streams.

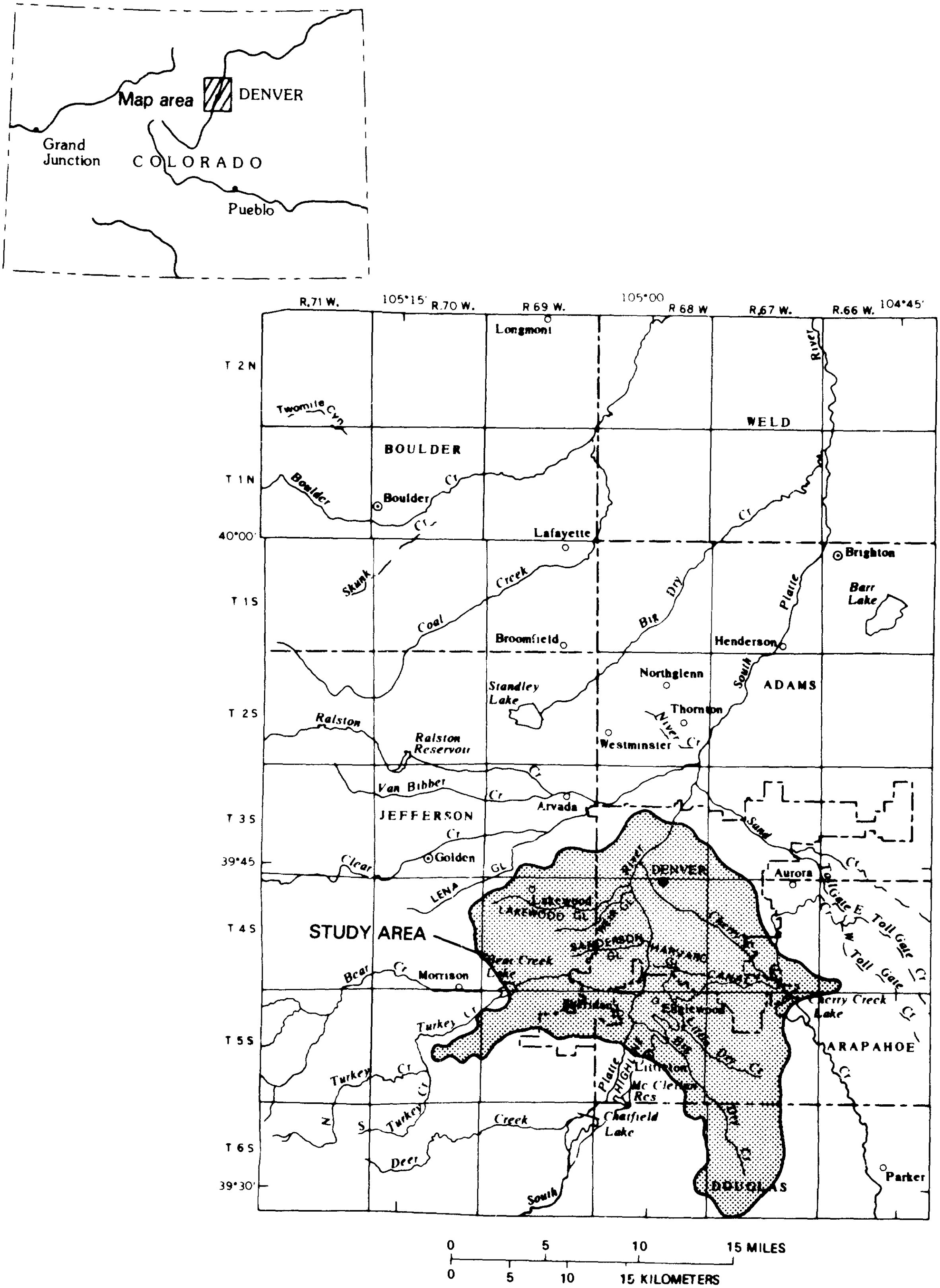

Figure 1.--Location of study area and general features.

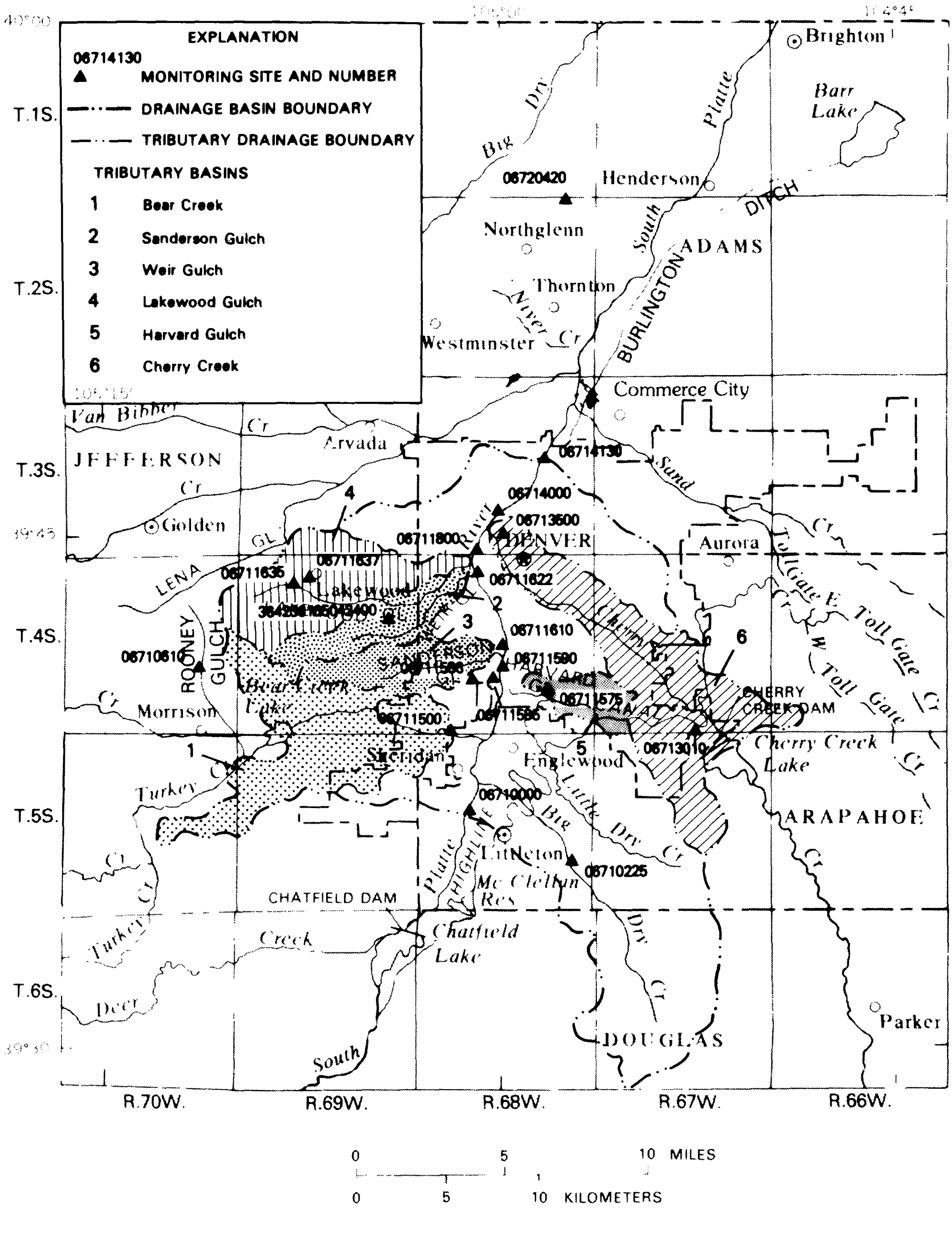

Figure 2.--Location of monitoring sites for the small and tributary basins and main stem South Platte River.

The land-use distribution in the study area is about 43-percent residential, 19-percent commercial and industrial, and 38-percent open space (parks, vacant, and agricultural land uses). The residential land use includes all aspects of a residential area--old and new homes, cluster homes, large estates, apartments, and townhomes. The industrial areas are mainly light manufacturing, with coal-fired electric-generating plants, small factories, and no heavy industrial factories. The effective impervious area is approximately 23 percent of the total area.

The Colorado Water Control Commission has classified the reach of the South Platte River in the study area (Segment 14) as a Class 1, Warm Water Fishery (Colorado Water Quality Control Commission, 1980). Beneficial uses of the South Platte River include recreation, agriculture, and water supply. The city of Englewood obtains its water supply from the South Platte River near the northern end of the study area. The city of Thornton obtains a portion of its water supply from a well field adjacent to storage ponds, which are fed by the South Platte River. The Burlington Ditch and other agricultural ditch headgates are located immediately downstream from the study area.

Small Basins

Some descriptive data for the nine small basins are presented in table 1. The location of the rain gages for each basin and aerial photographs showing the outline of the basins and subcatchments and location of the rain gages and monitoring sites were presented by Gibbs (1981) and Gibbs and Doerfer (1982). See figure 2 for the general location of monitoring sites.

Big Dry Creek tributary at Easter Street, near Littleton--the monitoring sites for a basin hereafter called the Southglenn basin--drains a multifamily residential area located in southwest metropolitan Denver. The basin contains 33 acres, of which 41 percent is effective impervious area, and contains two small (less than an acre) open-space areas. Two rain gages were located in the basin. A 2-foot Parshall flume was used to measure flow.

Rooney Gulch at Rooney Ranch, near Morrison--the monitoring site for a basin hereafter called the Rooney Gulch basin--drains an open-space area in Jefferson County. The basin had an area of 405 acres of normally contributing area and an additional 200 acres of normally noncontributing area. The normally noncontributing area only contributed runoff to the basin during May 1980 due to the construction of an emergency drainage ditch. A 1-foot Parshall flume was used to measure flow. The basin contained three rain gages.

Table 1--*Selected data for the small basins in the Denver Regional Urban Runoff Program*

U.S. Geological Survey site number	Name of monitoring site	Latitude-longitude	Name used in report	Drainage area, in acres	Percent of area covered by effective impervious surface
06710225	Big Dry Creek tributary at Easter Street, near Littleton.	39°35'17", 104°57'20"	Southglenn basin	33	41
06710610	Rooney Gulch at Rooney Ranch, near Morrison.	39°41'27", 105°11'32"	Rooney Gulch basin	405	.6
06711585	Asbury Park storm drain at Denver.	39°40'52", 105°00'42"	Asbury Park basin	121	22
06711586	Asbury Park storm drain at Asbury Avenue, at Denver.	39°40'51", 105°00'41"	Asbury Park detention basin	127	22
06711635	North Avenue storm drain at Denver Federal Center, at Lakewood.	39°43'21", 105°07'47"	North Avenue basin	69	50
06711637	North Avenue storm drain at Denver Federal Center North Avenue at Lakewood	39°43'22", 105°07'36"	North Avenue detention basin	80	46
06713010	Cherry Knolls storm drain at Denver.	39°38'58", 104°52'47"	Cherry Knolls basin	57	38
06720420	Storm Drain at 116th Avenue and Claude Court, at Northglenn.	39°54'23", 104°57'34"	Northglenn basin	67	24
394236-105042400	Villa Italia storm drain at Lakewood.	39°42'36", 105°04'24"	Villa Italia basin	74	91

Asbury Park storm drain at Denver--the monitoring site for a basin hereafter called the Asbury Park basin--drains a mixed commercial and residential area in southwest Denver. The basin contains 121 acres, of which 14 percent is light commercial, 52 percent is low-density single-family residential (1/2-acre lots), and 34 percent is high-density single-family residential (1/6-acre lots). The effective impervious area is 22 percent of the basin area. The monitoring site was a 48-inch storm drain at the inlet to a detention pond, and a velocity-modified flow meter was used to monitor flow. Two rain gages were located in the basin. This basin did not produce sufficient runoff from precipitation to allow for calibration of flow or quality models.

The Asbury Park storm drain at Asbury Avenue, at Denver--the monitoring site for a basin hereafter called the Asbury Park detention basin--is located at the outlet of the detention pond that drains the Asbury Park basin. The detention pond did not detain any monitored flows during the study period. All data collected upstream and downstream from the pond may be considered to be representative of the Asbury Park basin.

North Avenue storm drain at Denver Federal Center, at Lakewood--the monitoring site for a basin hereafter called the North Avenue basin--drains a mixed light commercial and multifamily residential area in southwest Lakewood. The basin contains 69 acres, with 50 percent of the basin being effective impervious area. The basin was approximately 33-percent multifamily residential, 30-percent light commercial, and 37-percent open space at the time of the study. Since the study ended (October 1981), additional areas now drain into the basin, and some of the open space has been developed. The flow was measured using a V-notched weir. One rain gage was located at the monitoring site.

The North Avenue storm drain at Denver Federal Center North Avenue, at Lakewood--the monitoring site for a basin hereafter called the North Avenue detention basin--is approximately 150 yards downstream from the North Avenue basin. The detention pond has a capacity of about 200,000 ft^3, and culvert computations and discharge measurements were used to determine flow from the basin. Drainage area for the detention pond basin includes about 11 acres more than the North Avenue basin, but for all storm-runoff periods used to determine the effectiveness of the detention basin, no storm runoff came from the additional 11 acres.

Cherry Knolls storm drain at Denver--the monitoring site for a basin hereafter called the Cherry Knolls basin--is a multifamily residential area in southeast Denver containing 57 acres, of which 38 percent was effective impervious area. The monitoring site was located at the outlet of a small detention basin, which had no effect on the outflow from the basin during the study. Flow was determined using culvert computations. Two rain gages were located in the basin.

Storm Drain at 116th Avenue and Claude Court, at Northglenn--the monitoring site for a basin hereafter called the Northglenn basin--is a single-family residential area of about 1/6-acre lots located in northeast Northglenn. The basin contains 167 acres, of which 24 percent is effective impervious area. A 4-foot Parshall flume was used to measure flow. The basin contains three rain gages.

The Villa Italia storm drain at Lakewood--the monitoring site for a basin hereafter called the Villa Italia basin--is a shopping center located in Lakewood. The basin contains 74 acres, of which 91 percent is effective impervious area. The shopping center was designed so that no inflow from the adjacent area enters the basin. The monitoring site utilized a 42-inch diameter storm drain instrumented with a velocity-modified flow meter. The flow meter was calibrated using dye-dilution methods of measuring discharge. One rain gage was located in the basin near the monitoring site.

Tributary Basins

Six tributaries to the South Platte River (fig. 2) in the study area were monitored for urban runoff. Site-identification and basin-characteristics data are presented in table 2 for the six tributary basin and for four main-stem stations. All tributary basins were sampled manually for water-quality samples. Staff gages were read to obtain flow data at all sites except Bear Creek at mouth, at Sheridan and Cherry Creek at Denver, where continuous recordings of stage were obtained. All the area of the tributaries were within the study area except Bear Creek and Cherry Creek.

The Bear Creek basin between the site at Bear Creek at mouth, at Sheridan and Mount Carbon Dam (Bear Creek Lake) consists of 15,400 acres, having an effective impervious area of 16 percent. The basin upstream from Bear Creek Lake is considered to have an insignificant effect on urban storm runoff, and the outflow from the reservoir usually remained relatively constant during storm periods. The Bear Creek basin is about 33-percent residential (single-family and multifamily), 56-percent open space, and 11-percent light commercial.

The Harvard Gulch basin--monitored at the Harvard Gulch at Harvard Park, at Denver site--consists of 2,830 acres upstream from Harvard Park, of which 2,000 acres are downstream from the Highline Canal and contribute runoff to the basin. The monitored part of the basin is about 72-percent residential, 17-percent light commercial, and 11-percent open space, and the effective impervious area is 30 percent of the total area.

The Sanderson Gulch basin--monitored at the Sanderson Gulch at mouth, at Denver site--consists of 4,720 acres, of which 24 percent is effective impervious area. The basin is about 65-percent residential, 15-percent light commercial, and 20-percent open space.

Table 2.--*Selected data for the tributary basins and main stem South Platte River sites*

[NA = Not applicable]

U.S. Geological Survey site number	Name of monitoring site	Latitude	Longitude	Drainage area in study area, in acres	Percent of area covered by effective impervious surface
06710000	South Platte River at Littleton------	39°37'08"	105°01'07"	0	NA
06711500	Bear Creek at mouth, at Sheridan-------	39°39'08"	105°01'57"	15,400	16
06711575	Harvard Gulch at Harvard Park, at Denver---------	39°40'21"	104°58'35"	2,830	30
06711590	South Platte River at Florida Avenue, at Denver---------	39°41'23"	104°59'57"	58,810	16
06711610	Sanderson Gulch at mouth, at Denver--	39°41'24"	104°59'57"	4,720	24
06711622	Weir Gulch at mouth, at Denver---------	39°43'52"	105°01'04"	4,790	22
06711800	Lakewood Gulch at mouth, at Denver--	39°44'14"	105°01'21"	10,400	33
06713500	Cherry Creek at Denver------------	39°44'58"	105°00'08"	15,800	27
06714000	South Platte River at Denver---------	39°45'35"	105°00'10"	108,000	22
06714130	South Platte River at 50th Avenue, at Denver---------	39°47'13"	104°58'28"	120,000	23

The Weir Gulch basin--monitored at the Weir Gulch at mouth, at Denver site--consists of 4,790 acres, of which 22 percent is effective impervious area. The basin contains about 65-percent residential, 11-percent commercial, and 24-percent open space. The basin contains a large wet-detention pond upstream from the monitoring site. The pond settles out some of the particulate materials.

The Lakewood Gulch basin--monitored at the Lakewood Gulch at mouth, at Denver site--consists of 10,400 acres, of which about 33 percent is effective impervious area. The basin is about 55-percent residential, 25-percent commercial, and 20-percent open space. The upper reaches of the basin were in various stages of development during the study.

The Cherry Creek basin--monitored at the Cherry Creek at Denver site--consists of 15,800 acres, including a large area of downtown Denver. The area below Cherry Creek Dam is the contributing area in the basin, with no outflow from the dam during the study. The basin is about 27-percent effective impervious area, and the land use is about 41-percent residential, 11-percent commercial and industrial, and 48-percent open space.

Main Stem South Platte River Sites

Four streamflow-monitoring sites (fig. 2) were located in the study reach on the main stem of the South Platte River. These sites were used to determine the effect of urban runoff on the South Platte River as it flowed through the Denver metropolitan area. The basin areas and land-use data are presented for that part of the basin which is between the given site and the South Platte River at Littleton site. The U.S. Geological Survey downstream-order number, location, and drainage area are presented in table 2.

The South Platte River at Littleton site was on the upstream boundary of the study area. The basin above the site was considered to have an insignificant effect on the urban runoff. The flows at the site are regulated by releases from Chatfield Dam.

The basin monitored at the South Platte River at Florida Avenue, at Denver site contains 58,810 acres in the study area, of which 16 percent is effective impervious area. The site was monitored to provide information on the river just upstream from the major urbanization. The basin is 34-percent residential, 12-percent commercial and industrial, and 54-percent open space.

The basin monitored at the South Platte River at Denver site consists of 108,000 acres in the study area, of which 22 percent is effective impervious area. The site is part of the Colorado State Engineer's streamflow-monitoring network. The basin is about 43-percent residential, 17-percent commercial and industrial, and 40-percent open space.

The basin monitored at the South Platte River at 50th Avenue, at Denver site consists of 120,000 acres in the study area, of which 23 percent is effective impervious area. The site was established to define the downstream end of the study area. The basin is about 43-percent residential, 19-percent commercial and industrial, and 38-percent open space.

SUMMARY OF SMALL-BASIN DATA

Ratios of Storm Runoff to Rainfall and Estimations of Impervious Retention

The maximum, minimum, and mean values of rainfall, storm runoff, and the ratio of storm runoff to rainfall are presented in table 3 for seven of the small basins. The two detention ponds (06711586 and 06711637) are not included. The ratio of storm runoff to rainfall was omitted for the Villa Italia basin because the fluctuation in dry-weather flow introduced error into the separation of the dry-weather flow and storm runoff. The range of rainfall was 0.03 to 1.99 inches, which represents the majority of rainfall storms in the Denver metropolitan area.

A linear-regression equation was developed between storm runoff and rainfall to estimate impervious retention. Impervious retention is determined as the intercept of the regression equation. The regression equation was based on the six urban basins; Rooney Gulch, a rural basin, was not used. The regression equation is:

$$\text{Rainfall} = A \times \text{storm runoff} + \text{impervious retention},$$

where A is the regression coefficient, and rainfall, storm runoff, and impervious retention are in inches.

Table 3.--*Summary of rainfall, storm runoff, and ratios of storm runoff to rainfall for all rainstorms monitored at the small basins*

Basin	Number of storms	Storm rainfall (inches)			Storm runoff (cubic feet)		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
Southglenn------	15	1.12	0.06	0.43	46,800	838	18,300
Rooney Gulch----	7	1.97	.25	.91	550,000	[1]4,840	[1]131,000
Asbury Park-----	15	.65	.12	.31	68,000	3,230	23,200
North Avenue----	33	1.01	.03	.22	81,600	1,260	17,300
Cherry Knolls---	15	1.14	.14	.39	48,800	1,860	15,400
Northglenn------	25	1.20	.09	.34	254,000	6,670	50,500
Villa Italia----	29	1.99	.04	.36	[2]387,000	[2]7,490	[2]85,100

Basin	Number of storms	Ratio of storm runoff to rainfall			Effective impervious area (the percent)
		Maximum	Minimum	Mean	
Southglenn--------	15	0.56	0.12	0.33	41
Rooney Gulch------	7	.22	[1].01	[1].10	.6
Asbury Park-------	15	.87	.05	.18	22
North Avenue------	33	.57	.13	.28	50
Cherry Knolls-----	15	.34	.06	.17	38
Northglenn--------	25	.40	.08	.17	24
Villa Italia------	29	([2])	([2])	([2])	91

[1]Minimum and mean storm-runoff values at Rooney Gulch represent only those storms producing runoff.

[2]The continually changing amount of base flow at Villa Italia storm drain introduced error into the calculation of storm runoff; therefore, the ratio of storm runoff to rainfall also was in error and is not included here.

The data from all rainstorms were used in the regression with the following exceptions: (1) Excluded those storms with 0.25 inch or more of rainfall; (2) excluded storms where the runoff-to-rainfall ratio was more than the ratio of effective impervious area to total basin area; and (3) excluded storms where the basin had dry-weather flow. The reason for the first two exceptions was that pervious-area runoff may have occurred under these conditions. The reason for the last exclusion is that any fluctuation in dry-weather flow could introduce large errors in this type of analysis.

The impervious retention values obtained from this regression equation are presented in table 4 for each basin except Rooney Gulch basin, which has little impervious area (0.6 percent). The values for impervious retention range from 0.027 inch for the North Avenue basin to 0.13 inch for the Asbury Park and Cherry Knolls basins. It should be noted that the Asbury Park basin equation is a line between two data points and not a true regression equation. The impervious retention estimated from this method using the data from all basins lumped together was 0.092 inch. The lumped value may be used as an estimate where little or no data are available for a basin, but it could be in error as much as +0.07 inch and as much as -0.04 inch.

Constituent Runoff Loads

The loads of selected constituents carried in the monitored storm runoff, including the dry-weather flow component, are presented in tables 5 through 11 for each of the small basins. The arithmetic mean constituent load is shown at the bottom of each table. The tables include loads carried by snowmelt runoff. For most of the storm-runoff periods, there was no dry-weather flow, except for the Villa Italia basin. The storm-runoff periods where dry-weather flow occurs are footnoted, and the dry-weather flow volumes are given.

Dry-weather flow is difficult to quantify and qualify at an urban-runoff station because the flow and quality of the dry-weather flow may vary considerably. Sources of urban basin dry-weather flow are lawn irrigation, car washing, air-conditioning overflows, and illegal connections to the storm sewers. Dry-weather flow during the storm-runoff periods is estimated from the dry-weather flow occurring immediately before and after the storm-runoff period, since there are no independent methods of measuring dry-weather flow during a storm-runoff period. Load calculations are more accurate for storm-runoff periods with no dry-weather flow. The samples taken during the storm-runoff periods represent integrated storm runoff and dry-weather flow constituent concentrations. In the small basins, fluctuations in dry-weather flow may indicate changes in sources, and consequently changes in water quality. Therefore, the water quality of the dry-weather flow at the start of the storm may be greatly different than that during or at the end of the storm.

Table 4.--*Regression equations used to estimate impervious retention in the small basins*

[Dashes, not applicable]

Basin	Equation	Impervious retention (inches)	Number of storms	Coefficient of determination (r^2)
Southglenn	Rainfall=3.5 X storm runoff + 0.031	0.031	5	0.96
Asbury Park[1]	Rainfall=2.6 X storm runoff + 0.13	.13	2	----
North Avenue	Rainfall=3.2 X storm runoff + 0.027	.027	22	.88
Cherry Knolls	Rainfall=1.8 X storm runoff + 0.13	.13	4	.90
Northglenn	Rainfall=5.4 X storm runoff + 0.046	.046	12	.63
Villa Italia	Rainfall=1.1 X storm runoff + 0.039	.039	5	.82
Combined basins	Rainfall=1.4 X storm runoff + 0.092	.092	50	.31

[1]Because there were only two observations in the data set for the Asbury Park equation, the equation is a line, not a linear regression.

Table 5.--*Storm-runoff loads of selected constituents for all storms sampled in the Southglenn basin*

[All loads in pounds; dashes, not determined]

Date of storm	Rain fall (inches)	Storm dur-ation (hours)	Storm run-off (cubic feet)	Total sus-pended solids	Total nit-rogen	Total phos-phorus	Total ortho-phos-phate	Total organic carbon	Chem-ical oxygen demand	Total lead	Total mangan-ese	Total zinc
1980												
May 15-16	0.65	18	37,700	631	5.2	1.2	0.51	91	230	0.46	0.59	0.34
May 17	.39	8.3	26,300	323	3.0	.75	.44	22	97	.17	.36	.17
July 1	.27	6.6	16,000	1,070	4.1	1.0	.54	45	170	.18	.35	.32
1981												
March 4	Snow	-----	22,500	1,620	2.7	2.8	.49	65	330	.57	1.4	.63
March 20-21	Snow	-----	20,700	312	3.8	.26	.13	33	190	.23	.29	.22
March 28	Snow	-----	15,800	269	2.1	.32	.089	23	120	.18	.22	.15
March 29	Snow	-----	26,700	207	2.9	.48	.23	20	93	.11	.17	.12
April 3	Snow	-----	21,200	510	3.9	.44	.040	34	130	.17	.38	.24
May 3 a.m.	.22	2.3	5,740	91.7	3.0	.75	.57	24	100	.16	.16	.13
May 3 p.m.	.38	.42	14,200	1,440	5.8	1.7	.34	49	350	.51	.96	.51
May 9	Snow	-----	5,560	35.7	.73	.081	.027	3.6	17	.015	.028	.020
May 12-13	.29	4.9	8,980	75.7	1.3	.16	.000	10	38	.037	.062	.050
May 17-18	1.12	18	40,400	255	3.5	.63	.29	29	140	.17	.20	.20
May 28	.25	2.2	7,840	73.4	1.0	.18	.069	10	36	.055	.085	.058
May 28-29	.55	20	19,400	173	2.7	.35	.17	16	68	.084	.16	.10
June 11-12	.71	2.4	46,800	1,030	7.4	2.1	.68	45	350	.43	.94	-----
July 17	.59	.58	23,900	362	---	.75	.51	3.6	120	.15	.30	.21
July 26	.64	6.4	18,800	165	2.8	.38	.23	11	77	.076	.15	.13
Mean storm loads				480	3.3	.80	.30	30	150	.21	.38	.21

Table 6.--*Storm-runoff loads of selected constituents for all storms sampled in the Rooney Gulch basin*

[All loads in pounds]

Date of storm	Rain fall (inches)	Storm dur-ation (hours)	Storm run-off (cubic feet)	Total sus-pended solids	Total nit-rogen	Total phos-phorus	Total ortho-phos-phate	Total organic carbon	Chem-ical oxygen demand	Total lead	Total mangan-ese	Total zinc
1980												
April 23-24	1.77	15	24,800	719	9.5	0.83	0.24	33	110	0.062	0.62	0.19
April 30-May 2	1.97	32	550,000	19,300	130	19	8.4	790	2,400	.85	12	3.0
May 8-9	.25	5.8	52,300	634	6.9	.81	.36	42	220	.49	.64	.31
May 15-16	.59	18	122,000	1,970	16	2.1	.51	210	400	.17	2.0	.40
May 16-18	.48	37	155,000	1,970	14	2.0	1.3	140	410	.16	1.7	.39
1981												
May 17-18	.91	23	9,070	45	.78	.078	.018	12	20	.0055	.23	.026
June 3	.42	13	4,840	261	1.2	.20	.037	6.9	31	.024	.35	.056
Mean storm loads				3,560	25	3.6	1.5	180	520	.25	2.5	62
Median storm loads				719	9.5	.83	.24	33	110	.062	.62	.19

Table 7.--*Storm-runoff loads of selected constituents for all storms sampled in the Asbury Park basin*

[Dry-weather flow occurred during two of these storms. These storms are footnoted and the dry-weather flow is given in the footnotes. The storm runoff given for these storms does not include the dry-weather flow. The storm loads given for these storms include the loads carried by the dry-weather flow. All loads in pounds; dashes, not determined]

Date of storm	Rain fall (inches)	Storm dur- ation (hours)	Storm run- off (cubic feet)	Total sus- pended solids	Total nit- rogen	Total phos- phorus	Total ortho- phos- phate	Total organic carbon	Chem- ical oxygen demand	Total lead	Total mangan- ese	Total zinc
1981												
March 4	Snow	---	17,900	250	2.5	0.53	0.21	30	190	0.46	0.25	0.23
March 20	0.14	1.2	15,500	450	5.1	.43	.083	43	280	.42	.40	.33
March 21	Snow	---	13,600	131	2.2	.29	.11	13	82	.10	.12	.10
May 28	.17	1.2	68,000	7,060	19	5.2	.82	260	1,200	2.8	5.5	2.7
May 28-29	.47	6.8	17,200[1]	-----	4.8	1.3	.52	34	140	.32	.61	.29
July 26-27	.52	4.5	24,800[2]	-----	7.2	1.1	.57	43	280	.40	.53	.51
Mean storm loads[3]				1,970	7.2	1.6	.31	86	430	.95	1.6	.85

[1]Dry-weather flow is 13,400 cubic feet.
[2]Dry-weather flow is 5,500 cubic feet.
[3]Mean storm loads are calculated from the four storms during which no dry-weather flow occurred.

Table 8.--*Storm-runoff loads of selected constituents for all storms sampled in the North Avenue basin*

[Dry-weather flow occurred during three of these storms. These storms are footnoted and the dry-weather flow is given in the footnotes. The storm runoff given for these storms does not include the dry-weather flow. The storm loads given for these storms include the loads carried by the dry-weather flow. All loads in pounds; dashes, not determined]

Date of storm	Rain fall (inches)	Storm dur-ation (hours)	Storm run-off (cubic feet)	Total sus-pended solids	Total nit-rogen	Total phos-phorus	Total ortho-phos-phate	Total organic carbon	Chem-ical oxygen demand	Total lead	Total mangan-ese	Total zinc
1980												
May 8	0.24	6.9	30,200	1,240	7.3	1.3	0.39	57	220	0.41	0.97	0.52
May 11	.07	2.7	6,930[1]	213	2.7	.21	.021	30	94	.12	.19	.23
May 12	.03	.33	3,420	117	.93	.10	.0083	12	34	.048	.060	.089
May 15-16	.52	8.2	57,400	1,220	9.2	1.2	.27	82	290	.53	.93	.66
May 17	.28	11	40,000[2]	1,210	8.4	1.2	.22	64	360	.67	1.1	.78
July 24	.13	4.8	9,180	319	5.7	.62	.11	46	180	.26	.33	.34
August 10	.05	1.8	1,750	61.6	1.6	.087	.020	13	70	.049	.057	.070
September 8-9	.74	15	81,600	753	14	1.4	.58	120	510	.49	.62	.84
September 10 a.m.	.08	2.9	5,740[3]	58.5	1.2	.11	.041	9.6	78	.044	.055	.078
September 10 p.m.	.15	.25	7,920	364	1.8	.39	.049	25	140	.17	.25	.16
1981												
February 21 a.m.	Snow	---	4,600	86.7	1.4	.15	.10	---	84	.13	.10	.20
February 21 p.m.	Snow	---	5,470	112	1.3	.24	.078	---	120	.19	.15	.24
March 3	.17	6.3	7,620	181	1.6	.27	.13	31	150	.21	.21	.34
March 4	Snow	---	30,900	1,030	3.8	1.4	.56	86	530	1.0	.84	1.0
March 5	Snow	---	12,600	12.6	2.1	.28	.10	20	94	.16	.16	.20
March 21	Snow	---	22,900	560	3.9	.44	.17	58	270	.38	.56	.47
May 3 a.m.	.22	2.5	12,900	---	3.6	.49	.34	52	220	.27	.26	.58
May 3 p.m.	.14	9.3	5,490	110	1.5	.22	.11	20	110	.12	.14	.15
May 5	.08	2.1	2,890	102	1.2	.32	.096	10	83	.078	.092	.10
May 9	Snow	---	23,200	311	5.4	.62	.000	39	140	.25	.26	.30
May 16	.14	5.7	6,880	152	2.3	.30	.064	31	100	.12	.14	.14
May 17-18	.78	21	64,500	740	8.7	1.2	.32	68	320	.32	.56	.48
May 28	0.04	0.25	2,190	74.9	0.65	0.090	0.000	10	33	0.036	0.064	0.055
May 28-29	.22	7.9	16,500	403	3.4	.54	.020	44	160	.20	.38	.27
June 2-3	.28	6.0	16,500	608	4.8	.55	.15	26	270	.33	.51	.46
July 2	.12	5.8	7,540	207	---	.24	.13	11	140	.13	.024	.024
July 15	.20	.50	12,700	1,080	3.1	1.2	.31	29	240	.36	.75	.60
July 22	.05	.50	2,280	71.7	2.1	.14	.016	10	77	.048	.081	.087
July 26-27	1.01	4.8	58,200	2,720	13	2.7	.80	100	580	.91	2.0	1.6
August 12	.08	3.3	4,600	147	1.8	.37	.043	27	95	.080	.12	.13
August 12-13	.16	5.3	11,000	365	2.0	.49	.10	15	120	.075	.29	.23
August 16	.04	1.4	1,260	22.2	.64	.045	.0063	8.6	---	.019	.027	.034
August 29	.03	.33	1,630	34.8	.92	.072	.018	11	44	.030	.048	.049
August 31	.05	1.2	1,860	8.82	1.3	.10	.026	11	72	.049	.079	.092
Mean storm loads[4]				440	3.7	.57	.20	37	180	.24	.36	.34

[1]Dry-weather flow is 2,540 cubic feet.
[2]Dry-weather flow is 5,000 cubic feet.
[3]Dry-weather flow is 1,590 cubic feet.
[4]Mean storm loads are calculated from the 31 storms during which no dry-weather flow occurred.

Table 9.--*Storm-runoff loads of selected constituents for all storms sampled in the Cherry Knolls basin*

[All loads in pounds; dashes, not determined]

Date of storm	Rain fall (inches)	Storm dur-ation (hours)	Storm run-off (cubic feet)	Total sus-pended solids	Total nit-rogen	Total phos-phorus	Total ortho-phos-phate	Total organic carbon	Chem-ical oxygen demand	Total lead	Total mangan-ese	Total zinc
1980												
August 14	0.69	2.5	48,800	287	8.9	1.2	0.82	78	270	0.49	0.36	0.51
1981												
March 29	Snow	---	1,260	71.5	.19	.020	.0086	.86	5.7	.0067	.0055	.0094
April 3	Snow	---	1,630	12.1	.30	.026	.0096	2.5	10	.017	.012	.015
May 3 p.m.	.36	.75	18,200	622	5.3	1.2	.36	49	460	.68	.48	.57
May 12-13	.28	5.1	5,640	15.2	.92	.078	.0025	5.0	19	.019	.020	.027
May 17-18	1.14	21	28,500	81.7	3.4	.52	.24	15	69	.086	.069	.12
May 27-28	.26	7.7	6,770	56.6	1.2	.13	.054	9.0	61	.068	.044	.060
May 28	.18	1.6	7,280	231	1.8	.30	.023	18	82	.25	.13	.17
May 29	.35	5.2	11,900	29.7	1.3	.15	.071	7.3	36	.048	.033	.069
June 29	.20	2.0	7,440	149	2.7	.21	.18	---	71	.14	.10	.16
July 7	.34	2.2	15,200	129	4.5	.80	.60	22	140	.16	.14	.19
July 12	.62	5.7	31,600	292	5.6	.73	.34	39	170	.32	.20	.32
July 26-27	.38	3.8	10,900	85.2	1.9	.29	.15	13	58	.055	.082	.095
August 9	.27	12	5,450	50.5	1.3	.093	.070	6.2	40	.038	.047	.065
Mean storm loads				151	2.8	.41	.21	20	110	.17	.13	.17

Table 10.--*Storm-runoff loads of selected constituents for all storms sampled in the Northglenn basin*

[All loads in pounds; dashes, not determined]

Date of storm	Rain fall (inches)	Storm dur-ation (hours)	Storm run-off (cubic feet)	Total sus-pended solids	Total nit-rogen	Total phos-phorus	Total ortho-phos-phate	Total organic carbon	Chem-ical oxygen demand	Total lead	Total mangan-ese	Total zinc
1980												
May 7-8	0.81	8.0	165,000	1,640	227	3.5	2.4	120	620	1.2	1.1	1.2
July 1-2	.19	8.2	13,900	173	4.1	.55	.21	40	150	.13	.10	.13
July 2	.38	3.6	44,800	1,720	19	2.7	.44	140	720	2.1	1.1	1.1
August 15	.37	8.6	33,200	255	6.2	1.5	.43	62	210	.54	.99	.52
August 25-26	.24	1.8	18,800	132	5.7	.74	.39	52	140	.17	.13	.15
August 26-27	.34	3.9	37,000	252	8.5	1.2	.34	31	240	.44	.31	.30
1981												
March 4	Snow	----	67,600	2,380	9.0	2.7	1.2	94	360	1.3	1.1	.73
March 21	Snow	----	62,300	979	7.3	.97	.54	62	380	.58	.54	.51
April 3	Snow	----	9,200	71.5	1.0	.13	.041	6.4	28	.062	.040	.044
April 19-20	.35	18	32,100	652	6.5	1.3	.51	51	410	.66	.40	.50
May 3 a.m.	.20	2.8	21,900	451	6.8	1.1	.57	61	370	.63	.28	.34
May 3 p.m.	.37	7.6	48,300	1,940	140	2.9	.75	120	1,100	1.8	.98	1.3
May 12-13	.31	4.1	33,000	214	5.8	.72	.000	35	140	.20	.14	.16
May 16-18	1.20	37	144,000	749	14	2.1	.90	71	270	.55	.45	.54
June 2-3	----	----	254,000	20,400	56	15	5.5	280	2,000	4.4	13	5.5
June 3	.93	.58	223,000	38,500	91	24	5.2	230	1,900	3.4	13	5.5
July 26	.62	5.3	63,000	598	10	1.3	.67	41	230	.32	.34	.46
August 9	.29	11	30,300	369	6.8	1.1	.38	57	190	.27	.27	.47
Mean storm loads				3,970	24	3.5	1.1	87	530	1.0	1.9	1.1

Table 11.--*Storm-runoff loads of selected constituents for all storms sampled in the Villa Italia basin*

[Dry-weather flow occurred during 15 of these storms. These storms are footnoted and the dry-weather flow is given in the footnotes. The storm runoff given for these storms does not include the dry-weather flow. The storm loads given for these storms include the loads carried by the dry-weather flow. All loads in pounds; dashes, not determined]

Date of storm	Rain fall (inches)	Storm duration (hours)	Storm runoff (cubic feet)	Total suspended solids	Total nitrogen	Total phosphorus	Total orthophosphate	Total organic carbon	Chemical oxygen demand	Total lead	Total manganese	Total zinc
1980												
July 1-2	0.44	7.3	98,000	698	29	1.8	0.51	250	960	1.0	1.4	1.8
July 11	.13	3.6	13,000	156	7.1	.35	.065	44	230	.25	.22	.32
July 30	.06	1.5	11,400[1]	192	18	1.4	.42	160	670	.52	.79	1.1
August 7	.07	.17	13,000[1]	319	14	1.3	.52	99	110	.72	.62	.73
August 10	.04	.75	8,100[2]	193	14	.71	.34	91	470	.32	.42	.53
August 14-15	1.99	17	387,000	3,220	58	5.3	1.5	460	1,600	3.9	3.0	4.8
August 25	.34	1.8	79,400	283	14	1.4	.44	130	480	.50	.40	.70
September 8	.05	.58	7,490	127	4.6	.36	.000	41	200	.15	.17	.29
September 8-9	.72	14	100,000[3]	215	18	1.5	.77	140	630	.38	.63	1.0
September 10 a.m.	.08	5.8	14,000[4]	61.1	9.6	.66	.26	65	480	.20	.26	.35
1981												
March 20	.13	1.2	20,900	298	7.9	.51	.22	56	300	.36	.30	.36
March 21	Snow	---	43,400	276	6.8	2.1	1.8	62	300	.38	.46	.54
March 24	Snow	---	13,100	59.7	2.7	.31	.19	26	150	.36	.18	.24
March 28	Snow	---	97,300[5]	1,140	13	1.8	.54	150	770	1.3	1.0	1.2
March 29	Snow	---	19,700[2]	84.7	4.1	.34	.086	29	100	.10	.16	.52
May 3 a.m. No. 1	.18	2.5	38,300[5]	462	24	3.4	2.6	220	1,000	.85	.73	1.1
May 3 p.m. No. 2	.09	.42	20,900[6]	327	6.5	.86	.49	72	460	.68	.30	.46
May 3 p.m. No. 3	.07	2.0	10,600[7]	52	6.7	.78	.29	69	480	.17	.23	.32
May 5	.04	5.7	7,800[8]	291	13	1.5	1.3	230	---	---	.52	.80
May 9	Snow	---	110,000	295	16	1.6	1.1	140	620	.49	.62	.89
May 16	.30	7.1	66,800[2]	602	14	1.5	.51	190	800	1.2	.84	1.2
May 17-18	.79	14	178,000[9]	1,100	24	2.8	1.2	230	93	1.2	1.4	1.9
May 27	.21	.75	67,400	1,040	12	1.3	2.7	75	660	1.1	.71	1.1
June 2-3	.71	7.2	303,000[10]	-----	49	4.7	1.8	180	1,400	3.2	2.6	3.4
June 3	.97	1.2	242,000[11]	7,320	52	8.1	2.1	310	1,800	4.2	5.5	4.4
July 26	.91	4.4	217,000	1,330	28	4.6	2.9	120	650	1.0	1.7	2.2
August 9	.44	12	137,000	14,200	48	19	3.0	400	2,400	4.0	12	5.3
Mean storm loads[12]				1,830	19	3.2	1.2	150	710	1.1	1.8	1.6

[1]Dry-weather flow is 5,340 cubic feet.
[2]Dry-weather flow is 8,000 cubic feet.
[3]Dry-weather flow is 24,000 cubic feet.
[4]Dry-weather flow is 56,000 cubic feet.
[5]Dry-weather flow is 26,700 cubic feet.
[6]Dry-weather flow is 9,600 cubic feet.
[7]Dry-weather flow is 13,900 cubic feet.
[8]Dry-weather flow is 29,800 cubic feet.
[9]Dry-weather flow is 114,000 cubic feet.
[10]Dry-weather flow is 12,800 cubic feet.
[11]Dry-weather flow is 15,500 cubic feet.
[12]Mean storm loads are calculated from the 12 storms during which no dry-weather flow occurred.

The constituent loads were calculated in two different ways. When a storm was represented by one flow-weighted composite water-quality sample, the sample concentration was multiplied by the runoff volume, and a conversion factor was used to obtain the runoff load. In the second method, several discrete water-quality samples were used to represent the storm-runoff quality.

The calculation of the runoff constituent load was more complex for storms represented by discrete water-quality samples. First, the flow rates were determined at numerous discrete points in time, usually at 5-minute intervals, over the runoff hydrograph. These instantaneous flow rates were assumed to be valid for the period of time halfway (time-wise) from the previous instantaneous flow rate to halfway to the next-flow-rate point. The volume of flow was calculated for the determined time interval as a product of flow rate and the elapsed time. The discrete constituent concentrations were linearly interpolated to provide an estimate of the concentrations for those times when flow rates were obtained. The estimated concentration then was multiplied by the respective flow volumes and a conversion factor to provide loads of constituents for each incremental time period. Finally, the total constituent load was determined as the sum of the incremental loads over the storm hydrograph.

A special study was conducted to determine if storm loads of constituents could be adequately measured using one flow-weighted composite sample and the volume of runoff. For 16 storms at the small sites, discrete samples were collected throughout the runoff period. Four to ten of the discrete samples were analyzed, and their concentrations were used to determine the storm-runoff loads of selected constituents. A flow-weighted composite sample was obtained from all the discrete samples (as many as 24) collected during each storm. The flow-weighted composite sample was analyzed for the selected constituents, and the flow-weighted concentrations and total storm volume were used to obtain the storm-runoff loads of selected constituents for each storm.

A two-tailed t-test (Rickmers and Todd, 1967) was performed on the storm constituent loads obtained by the discrete- and composite-sample techniques to determine if the loads were significantly different. For all constituents, the test determined that there was no difference between the two methods at the 90-percent confidence interval. The average difference between the discrete and flow-weighted sample techniques were: Nutrients, -3 percent; total suspended solids, -18 percent; trace elements, -11 percent; total organic carbon, -4 percent; and chemical oxygen demand, -1 percent. The flow-weighted composite technique resulted in overall lower loads than the discrete-sample technique.

Selected Constituent Concentrations

The maximum, minimum, and mean concentration of selected constituents for all discrete samples are presented in table 12 for each of the basins. Snowmelt samples are included in the tables. These values indicate ranges of instantaneous concentrations that may be expected in urban storm runoff in the Denver metropolitan area because the small basins represent a cross section of the land uses in the area.

Table 12.--*Maximum, minimum, and mean concentrations of selected constituents for all discrete storm-runoff samples from the small basins*

[mg/L, milligrams per liter; μg/L, micrograms per liter]

	Total suspended solids (mg/L)	Total lead (μg/L)	Total zinc (μg/L)	Total manganese (μg/L)	Total nitrogen (mg/L)	Total phosphorus (mg/L)	Total orthophosphate (mg/L)	Total organic carbon (mg/L)	Chemical oxygen demand (mg/L)
				Southglenn basin					
Maximum	2,340	840	820	1,900	8.5	2.9	0.49	86	490
Minimum	32	16	30	40	1.1	.13	.00	6.4	17
Mean	390	180	180	320	2.5	.58	.19	29	130
Number of samples	(50)	(50)	(50)	(50)	(50)	(50)	(50)	(50)	(50)
				Rooney Gulch basin					
Maximum	1,590	410	230	1,300	4.9	1.6	.62	49	150
Minimum	23	4	20	50	1.2	.09	.010	11	27
Mean	295	32	71	370	2.3	.35	.13	22	58
Number of samples	(48)	(48)	(48)	(48)	(47)	(48)	(48)	(48)	(48)
				Asbury Park basin					
Maximum	2,460	900	840	1,900	9.7	2.7	1.8	80	620
Minimum	54	110	110	120	2.0	.32	.05	12	96
Mean	620	470	370	560	4.8	1.1	.23	44	260
Number of samples	(22)	(24)	(24)	(24)	(24)	(23)	(24)	(24)	(24)
				North Avenue basin					
Maximum	2,560	1,100	1,900	2,200	14	2.5	.63	130	620
Minimum	52	27	90	50	1.3	.12	.00	9.7	32
Mean	520	330	450	440	4.5	.59	.16	45	210
Number of samples	(72)	(72)	(72)	(72)	(70)	(72)	(72)	(63)	(71)
				Cherry Knolls basin					
Maximum	1,010	1,000	840	680	12	2.5	1.2	66	510
Minimum	0	2	10	20	.86	.070	.00	5.2	23
Mean	163	150	170	140	3.4	.42	.22	21	120
Number of samples	(64)	(65)	(65)	(65)	(62)	(65)	(65)	(59)	(65)
				Northglenn basin					
Maximum	4,470	1,600	870	2,000	12	3.0	1.3	91	520
Minimum	13	3	30	30	.95	.21	.00	5.0	31
Mean	513	300	240	310	4.1	.72	.24	25	150
Number of samples	(73)	(74)	(74)	(74)	(68)	(74)	(74)	(73)	(73)
				Villa Italia basin					
Maximum	2,270	950	820	2,000	16	1.3	.38	150	490
Minimum	3	18	80	50	1.4	.10	.00	5.9	32
Mean	203	200	260	220	3.8	.37	.14	31	130
Number of samples	(71)	(71)	(71)	(71)	(67)	(70)	(70)	(70)	(71)

The maximum, minimum, and mean values of event mean concentrations for all storms without dry-weather flow that were monitored at each of the small basins are presented in table 13. Snowmelt periods are included in the tables. The event mean concentrations do not have the range of values shown for the discrete samples because they are a calculation of the flow-weighted mean concentration for the storm-runoff periods. The event mean concentration was calculated by dividing the total storm constituent load by the storm-runoff volume times a conversion factor for those storms that had discrete samples. The event mean concentration for a storm represented by a composite sample was the concentration of the composite sample. The storm-runoff periods that contained a dry-weather flow component were not included in the calculations due to the possible changing flow rate and constituent concentrations in the dry-weather flow.

A special study was conducted to determine whether most trace elements in urban storm runoff were in the dissolved or particulate phase. A total of 68 samples, including some composite samples, were analyzed for both the dissolved and total phase for selected trace elements. The average percent of each total trace element that occurred in the dissolved phase was cadmium, 39 percent; copper, 42 percent; iron, 2 percent; lead, 6 percent; manganese, 26 percent; and zinc, 23 percent. A possible explanation for the high percent of cadmium in the dissolved phase is due to the low concentrations of the metal relative to the analytical detection limits. The average total cadmium concentration was 3.2 μg/L, and the detection limit was 1 μg/L.

Atmospheric Deposition

Atmospheric deposition, both dry and wet, was collected at seven of the small basin sites--all sites except the North Avenue and Asbury Park detention ponds. These data were presented by Gibbs and Doerfer (1982). The atmospheric-deposition data from five of the collection sites--Southglenn, North Avenue, Cherry Knolls, Northglenn, and Villa Italia basins--were used to calculate the amount of constituent wet and dry deposition that accumulated on the effective impervious area within the basins. The deposition was summed for the rainfall period April through September 1981 and are presented in tables 14 through 18.

Table 13.--*Maximum, minimum, and mean event mean concentrations for storms sampled from the small basins*

[mg/L, milligrams per liter; µg/L, micrograms per liter]

	Total suspended solids (mg/L)	Total lead (µg/L)	Total zinc (µg/L)	Total man-ganese (µg/L)	Total nitro-gen (mg/L)	Total phos-phorus (mg/L)	Total ortho-phos-phate (mg/L)	Total organic carbon (mg/L)	Chemical oxygen demand (mg/L)
				Southglenn basin					
Maximum	1,630	570	580	1,100	8.4	2.1	1.6	67	400
Minimum	101	43	57	80	1.4	.21	.00	2.4	48
Mean	387	180	190	300	2.9	.67	.28	25	120
Number of samples	(18)	(18)	(17)	(18)	(17)	(18)	(18)	(18)	(18)
				Rooney Gulch basin					
Maximum	864	150	180	1,200	6.1	.66	.24	28	100
Minimum	79.5	9.8	40	180	1.4	.14	.031	13	34
Mean	376	49	89	420	3.0	.37	.12	20	63
Number of samples	(7)	(7)	(7)	(7)	(7)	(7)	(7)	(7)	(7)
				Asbury Park basin					
Maximum	1,660	670	640	1,300	5.3	1.2	.19	61	290
Minimum	154	120	120	140	2.2	.34	.086	16	96
Mean	627	410	330	520	3.7	.62	.15	37	210
Number of samples	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)
				North Avenue basin					
Maximum	1,360	550	790	950	15	1.8	.53	120	640
Minimum	16.0	80	50	50	2.0	.27	.00	17	79
Mean	449	310	440	410	5.4	.70	.19	55	270
Number of samples	(30)	(31)	(31)	(31)	(30)	(31)	(31)	(29)	(30)
				Cherry Knolls basin					
Maximum	548	600	500	430	5.8	1.0	0.63	44	410
Minimum	40.0	48	67	39	1.8	.20	.0072	8.3	39
Mean	179	190	190	140	3.3	.43	.20	21	120
Number of samples	(14)	(14)	(14)	(14)	(14)	(14)	(14)	(13)	(14)
				Northglenn basin					
Maximum	2,770	740	430	960	46	1.7	.42	52	370
Minimum	83.3	61	60	50	1.6	.22	.00	7.9	30
Mean	453	250	210	260	5.9	.64	.22	25	130
Number of samples	(18)	(18)	(18)	(18)	(18)	(18)	(18)	(18)	(18)
				Villa Italia basin					
Maximum	1,660	460	620	1,500	9.9	2.2	.68	87	440
Minimum	43.0	72	130	80	2.1	.22	.00	8.6	48
Mean	269	230	300	290	4.4	.55	.23	35	180
Number of samples	(12)	(12)	(12)	(12)	(12)	(12)	(12)	(12)	(12)

Table 14.--*Atmospheric-deposition loads of selected constituents, April through September 1981, for the effective impervious area of the Southglenn basin*

[Loads in pounds]

Constituent	Load	
	Dry	Wet
Chemical oxygen demand------	330	690
Total suspended solids------	120	560
Total nitrogen-------------	34	29
Total phosphorus------------	.43	2.3
Total lead------------------	.28	.46
Total manganese-------------	.22	.49
Total zinc------------------	.37	.88

Table 15.--*Atmospheric-deposition loads of selected constituents, April through September 1981, for the effective impervious area of the North Avenue basin*

[Loads in pounds]

Constituent	Load	
	Dry	Wet
Chemical oxygen demand-------	1,700	3,600
Total suspended solids-------	640	2,200
Total nitrogen---------------	290	210
Total phosphorus-------------	12	34
Total lead-------------------	.85	2.6
Total manganese--------------	.74	2.1
Total zinc-------------------	1.6	3.8

Table 16.--*Atmospheric-deposition loads of selected constituents, April through September 1981, for the effective impervious area of the Cherry Knolls basin*

[Loads in pounds; E indicates estimated load]

Constituent	Load	
	Dry	Wet
Chemical oxygen demand	640	1,200
Total suspended solids	220	920
Total nitrogen	42	E100
Total phosphorus	1.5	33
Total lead	.24	.79
Total manganese	.29	.96
Total zinc	.42	1.5

Table 17.--*Atmospheric-deposition loads of selected constituents, April through September 1981, for the effective impervious area of the Northglenn basin*

[Loads in pounds]

Constituent	Load	
	Dry	Wet
Chemical oxygen demand	1,300	1,900
Total suspended solids	510	2,200
Total nitrogen	140	85
Total phosphorus	3.9	9.3
Total lead	.63	1.1
Total manganese	.95	1.8
Total zinc	1.3	2.7

Table 18.--*Atmospheric-deposition loads of selected constituents, April through September 1981, for the effective impervious area of the Villa Italia basin*

[Loads in pounds]

Constituent	Load	
	Dry	Wet
Chemical oxygen demand------	1,900	4,200
Total suspended solids------	670	5,200
Total nitrogen--------------	170	150
Total phosphorus------------	14	11
Total lead------------------	1.8	5.4
Total manganese-------------	.42	4.6
Total zinc------------------	1.9	7.9

The atmospheric deposition was collected in an AeroChemmetric 301 Collector[1], which is a two-section collector. The dry section of the collector remains open to the atmosphere until precipitation occurs; then a mechanism closes the dry side and opens the wet side. The wet side of the collector is open to the atmosphere until precipitation ceases; then the mechanism again closes the wet side, while opening the dry side. The collectors were placed on the roofs of the monitoring buildings, about 12 feet above the land surface, except at the Villa Italia site, where the collector was placed on the roof of a large building, about 25 feet above the land surface. The samples from the collector usually were collected on the first Tuesday or Wednesday of each month.

REGRESSION ANALYSIS OF DATA FROM THE SMALL AND TRIBUTARY BASINS

The urban-runoff data from six of the small and five of the tributary basins were analyzed using regression techniques. The six small basins were North Avenue, Asbury Park, Southglenn, Cherry Knolls, Northglenn, and Villa Italia basins. The Rooney Gulch basin was not included in the regression analysis because of its small effective impervious area (0.6 percent) and because several rain storms did not result in runoff. Cherry Creek basin, a tributary basin, also was included in the DRURP study but was not included in this analysis because water was spilled from the Highline Canal into the basin during some runoff periods. Because only eight data sets were available for the tributary basins, the data were not sufficient to apply regression analysis to these basins alone. Two sets of regression equations were developed from the small- and tributary-basins data, the first using only the

[1]Use of the brand name in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

small-basin data and the second using the combined small- and tributary-basins data. The regression equations can be used to predict storm-runoff volume and loads of selected water-quality constituents for each specific basin on a seasonal basis, April through September. The April through September period was basic because it represented the usual rainfall season in the Denver metropolitan area. Hereafter, seasonal refers to the period April through September.

Snowmelt data were not used in the regression analysis because factors other than precipitation and basin characteristics control the quantity and quality of snowmelt runoff. Alley and Ellis (1978, 1979) and Ellis and Alley (1979) have shown that the length of time the snow was on the ground, sanding and salting operations, climatic conditions, and vehicular traffic are the important parameters in determining quantity and quality of snowmelt runoff. Dr. E. R. Bennett (University of Colorado, oral commun., 1983) has shown that the length of time automobiles are left running in parking lots is an important factor in determining the quantity and quality of the snowmelt runoff from the parking lots. Dr. Bennett also has shown that the amount of automobile traffic is an important factor in determining the quality of snowmelt runoff from streets. Data on the factors that determine the quantity and quality of snowmelt runoff are not routinely collected or even readily available. Therefore, snowmelt was not included in the regression analysis--either combined with rainfall runoff or separately.

Regression Analysis

Two types of multiple linear-regression analysis were used--one using untransformed numbers and the other using log-transformed numbers. The log form of the multiple-linear regression equations gave the higher r^2 and the lower standard error of estimation. The dependent variables, storm-runoff volume, and constituent loads were analyzed by first inputting the volumes and loads for each storm and basin and second by dividing the volumes and loads by the total or effective impervious area for each basin (the normalized volume or load), and then entering the resulting values into the analysis. The nonnormalized storm-runoff volumes and constituent loads produced the higher r^2 and lowest standard error of estimation. Therefore, the final equations are the log form of the multiple-linear regression using nonnormalized variables.

The dependent variables selected for regression analysis were storm-runoff volume and storm-runoff loads of total suspended solids, chemical oxygen demand, total nitrogen, total phosphorus, total lead, total manganese, and total zinc. The independent variables selected were total rainfall, storm duration, average rainfall intensity, dry days (days since 0.20 inch of rain had fallen), basin area, percent effective impervious area, street miles, curb miles, and land use. Several other basin characteristics, such as basin slope, shape, and channel geometry, had been tried earlier in the study and proven not to be significant; therefore, they were not used in this analysis.

The independent variables that were significant for the regression equations for the small and tributary basins were basin area, percent effective impervious, and total rainfall. Storm duration also was significant for the small-basin specific-regression equations. Significant variables are those that the F test indicated were significant at the 5-percent level and those that increased the coefficient of determination (r^2) by 5 percent or decreased the standard error of estimate by 5 percent.

Several rainfall and basin characteristics that have been used in other regression and deterministic models were not significant in this study. Land use was not significant, but has been used extensively in the description of both runoff volumes and constituent loads. Alley and Veenhuis (1979) have shown a high correlation between land use and percent effective impervious area. This study indicates that land use probably has been used as a surrogate for effective impervious area. While land use may be a small factor in actual determination of runoff volumes and loads of constituents, effective impervious area is a more descriptive term relating to the rainfall-runoff processes.

Dry days were not significant, although most deterministic models use dry days as a measure of the accumulation of constituent loads on impervious surfaces. Lindner and Ellis (1983) showed that while dry days were important in some cases, the length of time that was required to reach a high level of constituent accumulation was short, usually less than 3 days, and that most storms did not wash off most of the deposition in the Denver area. Therefore, dry days may be important in other areas, but due to the small number of storms in Denver, the rapid constituent build-up rate, and the fact that most storms did not wash off most of the deposition, it is not significant in the Denver area.

The basin characteristics of street length, lane miles, and curb miles were not significant in the regression analysis; these characteristics may be accounted for in the effective impervious area. Most of the effective impervious areas are streets and parking lots; therefore, the street characteristics may be important but they were not significant in this regression analysis. The storm characteristics of storm duration and average intensity were not significant, and the reasons are not fully understood. It is possible that these storm characteristics are not significant because the majority of the rainfall is of short duration (less than 1 hour), and the average intensities vary greatly, with the same runoff volumes. This study has shown that runoff volume is the most significant characteristic in determination of runoff constituent loads but, storm-runoff volume was not selected as the independent variable in the load-regression analysis because storm-runoff volume is not readily available except from regression equations. Storm-runoff volume could be obtained from a regression analysis of rainfall and basin characteristics and then used as an independent variable in the load equations. B.M. Troutman and M.R. Karlinger (U.S. Geological Survey, written commun., 1983) have shown that the use of a dependent variable from one regression equation as an independent variable in another regression equation may produce biased and erroneous results. Therefore, since rainfall is the most readily available factor from which storm-runoff volumes and constituent loads can be estimated, rainfall was selected as the independent variable in the regression equations.

Small Basins

The results of the regression analysis for the combined small basins are presented in table 19. The value of the r^2 was 0.90 and the standard error of estimate was 39 percent for storm-runoff volume. The r^2 for different constituent loads ranged from 0.44 for total suspended solids to 0.67 for total nitrogen. The standard errors of estimates for the constituent loads ranged from 67 percent for total nitrogen to 114 percent for total phosphorus. The independent variables of basin area, percent effective impervious area, and total rainfall were significant at the 99-percent level.

An examination of the results of the regression analysis suggests that that the constituent-load data are possibly site-specific. Regression analyses were run for each small basin. The results of these analyses were larger values of r^2 and smaller standard errors of estimates than the analysis using all basins. The results of the analysis did not prove that the load data was site-specific, but rather that there was less variability in basins than between basins. The results also indicate that basin, climate, traffic, and other characteristics than those used in the regression analysis may be important in determining the storm-runoff constituent loads.

Although the regression analyses indicate less variability within basins than between basins, the regression analysis using all small basins may be useful in estimating constituent loads from unmonitored basins that are similar in size and effective impervious area. The suggested range in basin sizes is from 15 to 600 acres, and the range of percent effective impervious areas is from 15 to 90 percent for use of the regression equations presented in table 19. The standard errors of estimates are less than 115 percent for the given constituent loads; when compared to other methods of estimating constituent loads, these errors are not unreasonably large. These regression equations may be useful in predicting the seasonal constituent loads from similar unmonitored basins and may be useful for planning purposes.

The basin-specific regression equations are not presented in this report because they are site- and time-specific; the use of these equations on unmonitored basins could result in unrealistic estimates of storm-runoff volumes and constituent loads. The basin-specific regression equation will be used in this report to compare the results of regression analysis and deterministic modeling for the mean seasonal runoff volume and constituent loads.

Combined Small and Tributary Basins

The results of the regression analyses for the combined small and tributary basins are presented in table 20. The r^2 value for storm-runoff volume was 0.94, and the standard error of estimate was 42 percent. The constituent loads r^2 ranged from 0.76 for the load of total phosphorus to 0.85 for the load of total zinc. The standard errors of estimates ranged from 70 percent for loads of chemical oxygen demand and total nitrogen to 110 percent for load

Table 19.--*Regression equations to estimate storm-runoff volume and loads of selected constituents derived from the small basins*

[Storm-runoff volume in cubic feet; constituent load in pounds; TA, total area, in acres; PEIA, effective impervious area; RF, total rainfall, in inches]

Dependent variable	Independent variables and constants	Coefficient of determination (r^2)	Standard error of estimate (percent)	Number of observations
Storm runoff volume =	$4.0\ TA^{1.17}\ PEIA^{1.34}\ RF^{1.19}$	0.90	39	81
Total suspended solids =	$0.41\ TA^{0.96}\ PEIA^{0.949}\ RF^{0.883}$	.44	113	80
Chemical oxygen demand =	$2.4 \times 10^{-3}\ TA^{1.40}\ PEIA^{1.59}\ RF^{0.582}$	.58	70	80
Total nitrogen =	$4.3 \times 10^{-5}\ TA^{1.56}\ PEIA^{1.59}\ RF^{0.764}$	.67	67	80
Total phosphorus =	$4.9 \times 10^{-4}\ TA^{1.15}\ PEIA^{0.919}\ RF^{0.956}$	.48	114	81
Total lead =	$2.6 \times 10^{-6}\ TA^{1.58}\ PEIA^{1.51}\ RF^{0.808}$	.59	85	81
Total manganese =	$1.7 \times 10^{-6}\ TA^{1.17}\ PEIA^{1.52}\ RF^{0.780}$	.50	93	80
Total zinc =	$1.9 \times 10^{-6}\ TA^{1.42}\ PEIA^{1.81}\ RF^{0.775}$	.62	76	81

Table 20.--*Regression equations to estimate storm-runoff volume and loads of selected constituents derived from the combined small and tributary basins*

[Storm runoff volume in cubic feet; constituent load in pounds; TA, total area, in acres; PEIA, percent effective impervious area; RF, total rainfall, in inches]

Dependent variable	Independent variables and constants	Coefficient of determination (r^2)	Standard error of estimate (percent)	Number of observations
Storm runoff volume =	$8.61\ TA^{1.07}\ PEIA^{1.25}\ RF^{1.18}$	0.94	42	89
Total suspended solids =	$0.0483\ TA^{1.36}\ PEIA^{1.07}\ RF^{0.882}$	.79	110	88
Chemical oxygen demand =	$0.0105\ TA^{1.15}\ PEIA^{1.49}\ RF^{0.600}$	.83	70	88
Total nitrogen =	$4.93 \times 10^{-4}\ TA^{1.15} PEIA^{1.40}\ RF^{0.763}$	.84	70	88
Total phosphorus =	$3.76 \times 10^{-4}\ TA^{1.20}\ PEIA^{0.929}\ RF^{0.950}$	.76	110	89
Total lead =	$1.83 \times 10^{-5}\ TA^{1.23}\ PEIA^{1.40}\ RF^{0.844}$	.80	88	89
Total manganese =	$3.6 \times 10^{-6}\ TA^{1.46}\ PEIA^{1.60}\ RF^{0.792}$	.84	93	88
Total zinc =	$4.37 \times 10^{-6}\ TA^{1.29}\ PEIA^{1.74}\ RF^{0.780}$	.85	80	89

of total suspended solids and total phosphorus. The regression analysis for the combined small- and tributary-basin data had larger values of r^2 and about the same standard errors of estimates as the analysis using only the small-basin data. The larger values of r^2 are probably due to the increase in the range of dependent variables, because the standard errors of estimates were about the same for both analyses.

Two dummy independent variables were put into the regression analysis of the combined basins to determine if the dependent variables were significantly dependent on basin size. The variables were used to distinguish between the basins larger than 200 acres and those smaller. Both variables were not significant at the 90-percent level for any dependent variable and were discarded from the regression analysis. A possible explanation for the dummy variables not being significant is that most of the data--all but eight data sets--were from the small basins. Therefore the regression equations presented in table 20, derived from the combined small- and tributary-basin data, may be useful for basins with areas between 600 and 16,000 acres and percent effective areas of between 15 and 90 percent.

The users of the regression equations derived from the combined small and tributary basins are advised that estimates of storm-runoff volume and constituent loads become less accurate as the size of the basin increases above 300 acres, and the percent of effective impervious area increases above 50 percent. The reason for this decrease in accuracy is that most of the data used to derive the regression equations were for basins with smaller than 300 acres and less than 50-percent effective impervious area. The regression equations may be useful, nevertheless, for planning purposes where no data have been collected.

APPLICATION OF DR_3M-II, DR_3M-QUAL, AND STATISTICAL MODELS

DR_3M-II is a watershed model for routing storm runoff through a branched system of pipes or natural channels. The model provides detailed simulation of storm-runoff periods and a daily soil-moisture accounting between storms. The model is capable of continuous simulation of storm runoff or single-storm runoff events. DR_3M-QUAL is a model for simulating the quality of surface runoff from urban watersheds. The model was run in the lumped-parameter mode, with no spatial variations in model parameter, and a flow hydrograph is required only at the outlet of the watershed. The model contains a daily accounting of accumulation and washoff of water-quality constituents on the effective impervious areas. DR_3M-II and DR_3M-QUAL were calibrated and verified on selected small basin monitoring sites. The calibration and verification of the models is presented in Lindner and Ellis (1983). Statistical models used in this section were described in the section "Regression analysis of data from the small and tributary basins."

DR_3M-II was used to estimate mean seasonal peak flow from the North Avenue, Southglenn, Cherry Knolls, Northglenn, and Villa Italia basins. Mean seasonal peak flow is the rainfall derived peak flow during April through September that has a 0.50 probability of being exceeded in any given year. Estimations of peak flows of greater magnitude than the mean seasonal are not warranted due to possible future changes in the basins. Ellis and others (1983) documented several changes in the North Avenue basin from 1976 to 1980 which altered the peak flows from the basin, as well as other runoff characteristics. The changes documented in the North Avenue basin may occur in other basins; therefore, estimations of peak flows of greater magnitudes than the mean seasonal are not warranted. The 5-minute incremental rainfall data for the three to five storms per year that would produce the greatest runoff were obtained from the National Weather Service Stapleton Airport weather station for the period 1898 through 1970. The model was applied to the North Avenue, Southglenn, Cherry Knolls, Northglenn, and Villa Italia basins. The results from this model application are presented in table 21.

Table 21.--*Mean seasonal rainfall-runoff peak flows derived from the Distributed Routing Rainfall-Runoff Model--Version II (DR_3M-II) for the small basins*

[Flow in cubic feet per second]

Basin				
North Avenue	Southglenn	Cherry Knolls	Northglenn	Villa Italia
51	24	19	68	73

The second application of DR_3M-II was to use hourly rainfall data to estimate the mean seasonal storm-runoff volume from the small basins. Mean seasonal storm-runoff volume is the total volume of runoff derived from rainfall during April through September which has a 0.50 probability of being exceeded in any given year. Although the model was calibrated and verified with 5-minute data, the results of model predictions using both 5-minute and hourly rainfall data were similar for storm-runoff volume. Therefore, DR_3M-II was run using hourly rainfall data for April through September for the years 1951 through 1970, from the National Weather Service Stapleton Airport weather station to estimate individual storm-runoff volumes and hourly hydrographs. Hourly hydrographs are required input data for the DR_3M-QUAL model. The storm-runoff volumes for each storm were summed to obtain a seasonal runoff volume, and these values were analyzed using a Log Pearson Type III distribution (Interagency Advisory Committee on Water Data, 1981) to estimate the mean seasonal runoff volume from the small basins. The hourly hydrographs were used as runoff data for the DR_3M-QUAL model to estimate seasonal loads of selected constituents from the modeled basins.

DR_3M-QUAL was applied in the lumped-parameter mode, in which, according to W.M. Alley (U.S. Geological Survey, oral commun., 1982), the constituent loads are not a function of flow time steps, but of the total runoff volume. The seasonal hourly runoff data, 1951-70, from DR_3M-II was used as runoff flow and the values of K1, K2, K3, and basin characteristics, as presented by Lindner and Ellis (1983), were used as runoff and model parameters in DR_3M-QUAL for the simulation of storm-runoff volume and constituent loads. The storm loads of the constituents were summed on a seasonal basis and analyzed using a Log Pearson Type III distribution (Interagency Advisory Committee on Water Data, 1981). The mean seasonal constituent loads from the North Avenue, Cherry Knolls, Northglenn, and Villa Italia basins are presented in table 22. The mean seasonal constituent load is that total constituent load, derived from rainfall during April through September, which has a 0.50 probability of being exceeded in any given year.

An application of the regression models was to determine which water-quality constituents in the storm runoff were associated with atmospheric deposition. The combined small-basin regression equations were used to estimate the April through September 1981 runoff loads of selected constituents from the Southglenn, North Avenue, Cherry Knolls, Northglenn, and Villa Italia basins. The basin-specific regression equations were not used to estimate the runoff loads because storm duration, which was a regression parameter, was not available for all storms. The estimated storm loads then were plotted along with the wet and dry atmospheric-deposition loads for the effective impervious areas and are presented in figures 3 through 7.

Table 22.--*Mean seasonal storm runoff and loads of selected constituents predicted by deterministic and regression models*

[Storm runoff in thousands of cubic feet; loads in pounds]

Model Parameter	North Avenue basin model		Cherry Knolls basin model	
	Deterministic	Regression	Deterministic	Regression
Storm runoff------	930	780	430	370
Total suspended solids----------	14,000	22,000	1,200	2,400
Chemical oxygen demand----------	5,200	5,800	1,900	850
Total nitrogen----	140	150	35	59
Total phosphorus--	18	24	4.4	8.8
Total lead--------	7.0	8.5	1.3	2.8
Total zinc--------	8.6	12	1.4	2.2
Total manganese---	8.6	14	1.3	2.3

Model Parameter	Northglenn basin model		Villa Italia basin model	
	Deterministic	Regression	Deterministic	Regression
Storm runoff-------	1,300	1,300	2,200	1,200
Total suspended solids-----------	5,300	12,000	5,800	16,000
Chemical oxygen demand-----------	3,600	7,000	4,000	16,000
Total nitrogen-----	92	250	180	420
Total phosphorus---	14	33	14	66
Total lead---------	4.6	12	5.3	19
Total zinc---------	4.7	10	9.4	28
Total manganese----	3.6	9.2	7.3	28

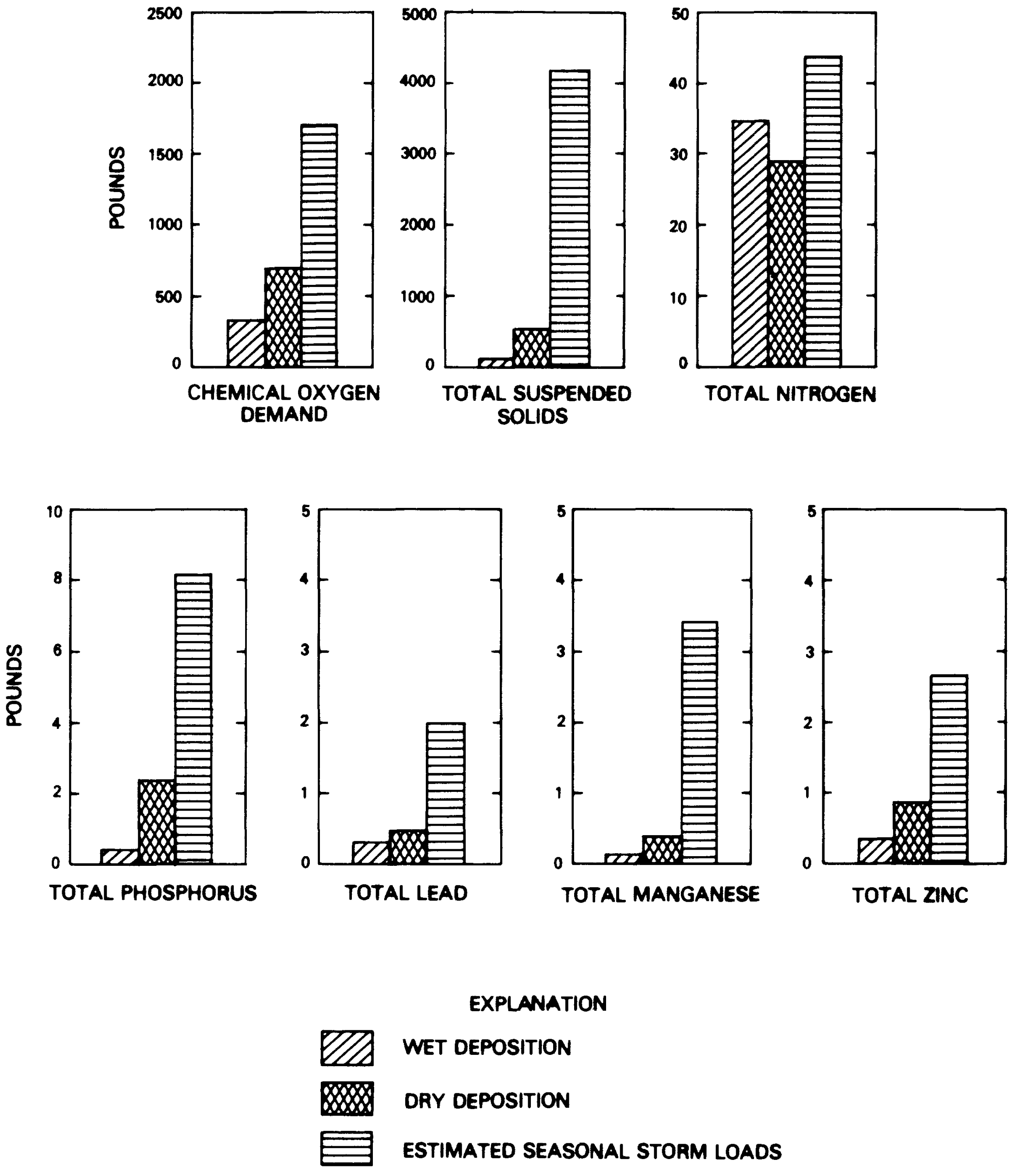

Figure 3.--Atmospheric deposition and estimated storm-runoff loads of selected constituents, April through September 1981, for the Southglenn basin.

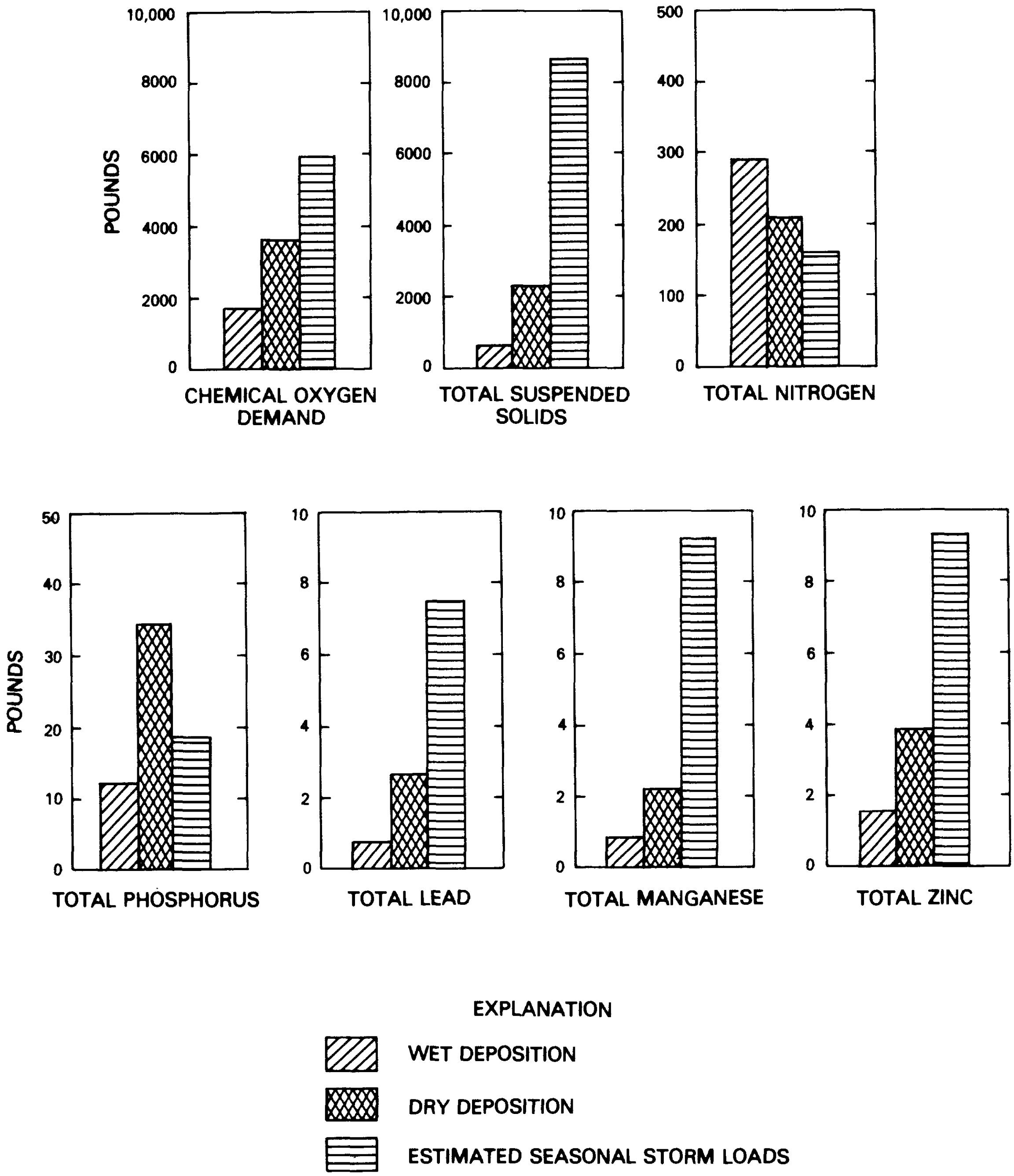

Figure 4.--Atmospheric deposition and estimated storm-runoff loads of selected constituents, April through September 1981, for the North Avenue basin.

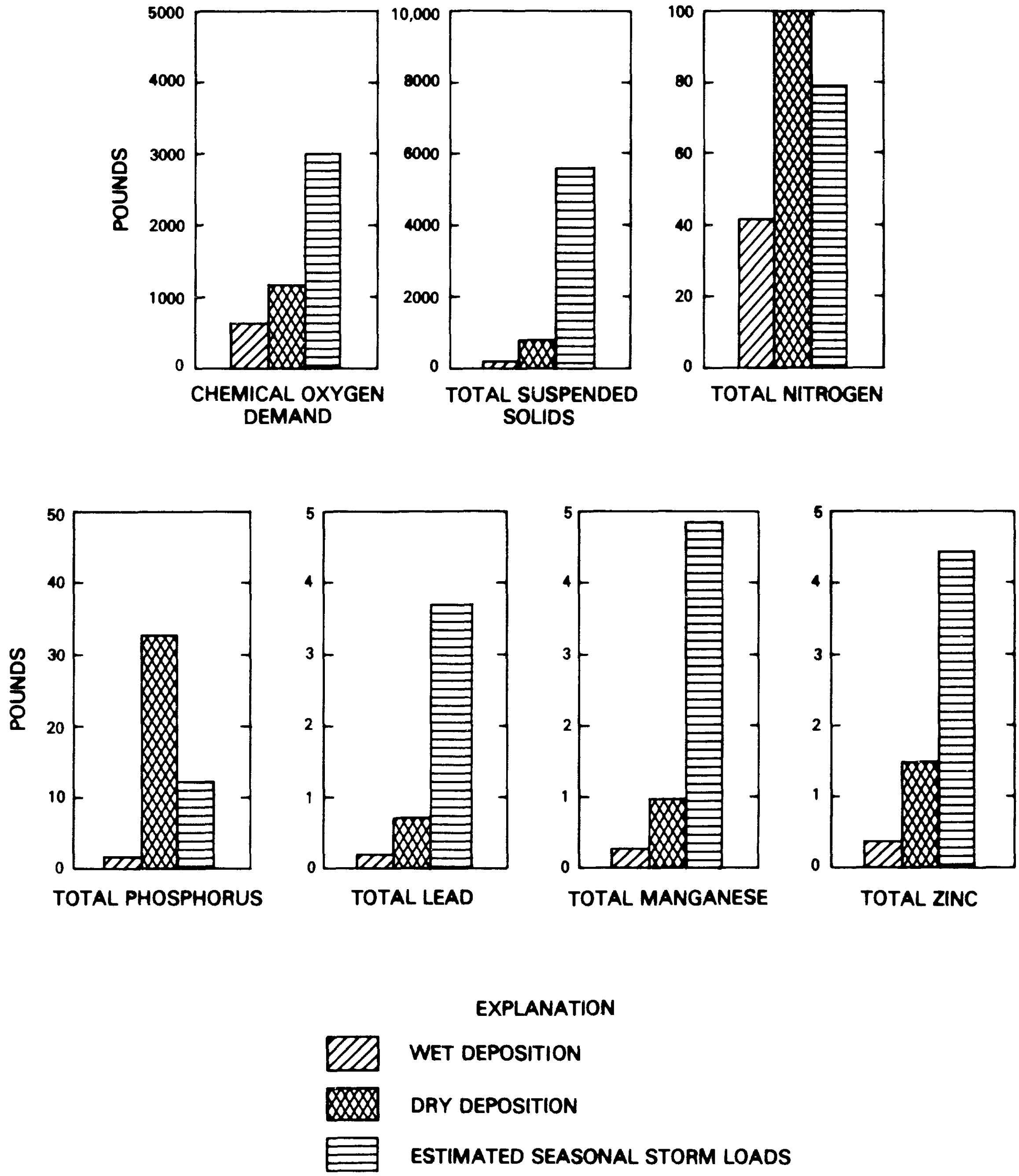

Figure 5.--Atmospheric deposition and estimated storm-runoff loads of selected constituents, April through September 1981, for the Cherry Knolls basin.

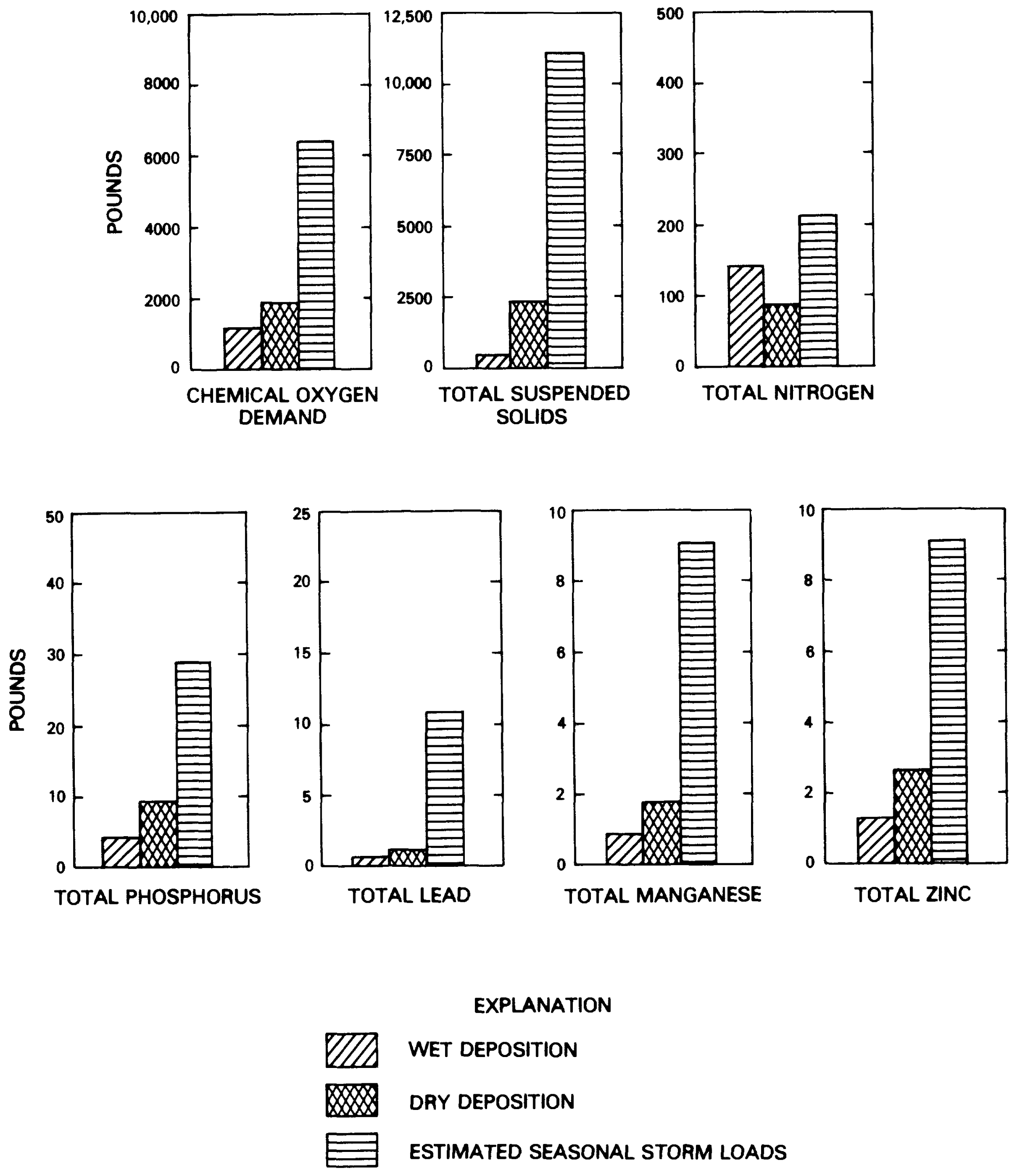

Figure 6.--Atmospheric deposition and estimated storm-runoff loads of selected constituents, April through September 1981, for the Northglenn basin.

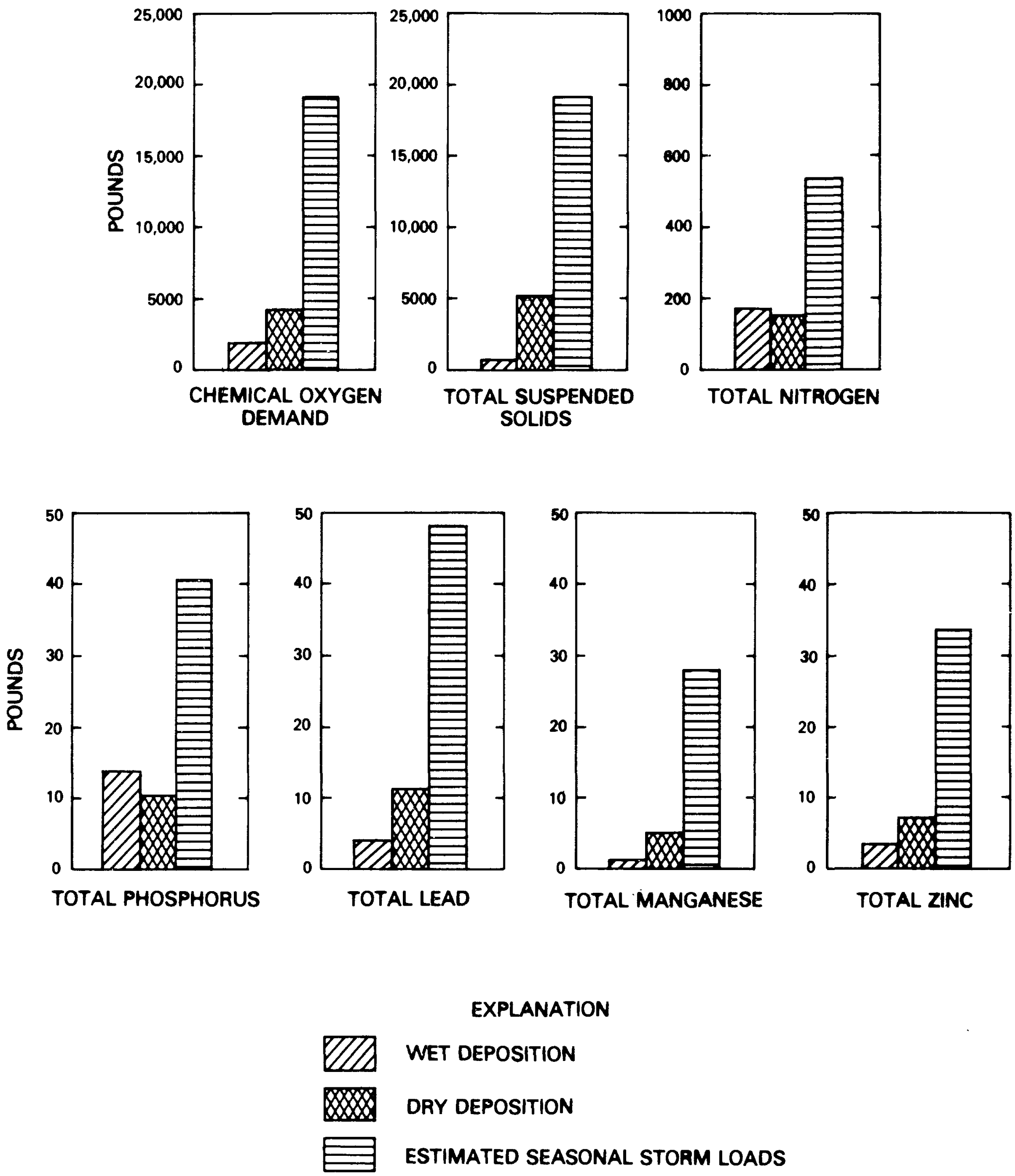

Figure 7.--Atmospheric deposition and estimated storm-runoff loads of selected constituents, April through September 1981, for the Villa Italia basin.

An analysis of the graphs in figures 3 through 7 indicates that chemical oxygen demand, total nitrogen, and possibly total phosphorus are associated with either wet or dry atmospheric deposition. The load of total nitrogen in the atmospheric deposition is greater than the estimated runoff load and is associated with both wet and dry deposition. Total phosphorus is more prevalent in the dry than wet deposition and probably is derived from windblown soils. Ellis and others (1983) have shown a high correlation between total phosphorus and soils and total suspended solids in the Denver area. Chemical oxygen demand has a larger load in the dry deposition than in the wet deposition. The total measured atmospheric-deposition loads of these constituents are either nearly as large or larger than the estimated storm-runoff loads for the period. The North Avenue basin had a greater constituent load of atmospheric deposition of chemical oxygen demand, total nitrogen, and total phosphorus than was estimated to have been washed off by storms.

The constituent loads of total suspended solids, total lead, total manganese, and total zinc are much larger in the estimated runoff loads than in the combined wet and dry deposition. Loads of these constituents from street vacuuming from the North Avenue basin were much higher than the runoff loads. It is possible that these constituents are deposited and transported close to the street surfaces either by automobiles or by wind currents at the surface and are not collected in the atmospheric-deposition collectors. Therefore, it can be concluded that the atmospheric collectors do not measure the transport mechanisms for these constituents.

The atmospheric-deposition collectors may not be an effective means of measuring atmospheric deposition when they are placed several feet above the ground. The North Avenue basin's deposition collector was the closest to the ground, being placed on the monitoring building located next to an elevated roadway. The Villa Italia deposition collector was the highest above ground level--about 30 feet. An analysis of the data indicates that the North Avenue basin had the higher percentage of atmospheric deposition compared with storm loads from the other sites, and the Villa Italia basin had the lowest percentage of atmospheric deposition. A rainfall-simulation study, conducted as part of the Denver Urban Runoff study, showed that atmospheric-deposition collectors placed near a street collected more deposition than those placed about 100 yards from the street. It is then reasonable to conclude that the location of the collectors may be an important factor in the amount of deposition that is collected.

COMPARISON OF DETERMINISTIC AND REGRESSION MODELS

Comparison of the results of constituent estimation from deterministic and regression models is important because either type of model may be used in decision-making processes. There are several means of comparing the results from the two types of models, such as a comparison of the standard error of estimation for individual storms or a comparison of the models' estimation of a constituent with the observed values. These comparisons have limited use when the constituent estimations are made on a seasonal basis. This section will compare the mean seasonal runoff load of the selected constituents and try to determine if the difference between the model results is significant or is within the error of the estimations.

The predicted mean seasonal storm-runoff and selected constituent loads are presented in table 22 (p. 38). The predicted mean seasonal results from the North Avenue and Cherry Knolls basins for the two methods are within the error of deterministic (Lindner and Ellis, 1983) and regression models. Therefore, the results from either method will produce about the same results on a seasonal basis, given the error of each method. The difference in the results from the Northglenn basin is more than the combined error of each method (the combined error of the two methods is about 100 percent), but for planning purposes both estimates generally are considered acceptable. Either type of model probably will provide equivalent results within the errors of estimation.

The results from the two types of models of the Villa Italia basin are substantially different. The regression model estimated the mean seasonal constituent loads to be about three to four times higher than the deterministic model, whereas the estimate for the mean seasonal storm runoff is about one-half of the results from the deterministic model. One possible reason for the difference between the results from the two methods is that buildup rates are not in the regression models. Lindner and Ellis (1983) showed that the deterministic model (DR_3M-QUAL) had a tendency to greatly underpredict the runoff loads of the selected constituents when a storm followed other storms by less than 2 or 3 days. A large percent of the storms used in the data sets occurred in May when the storms usually are low-intensity long-duration storms and usually occur in succession. Therefore, it is possible that the deterministic model underpredicted the constituent loads for these storms, and it is also possible that the regression model overpredicted the constituent loads from these storms. It should be noted that dry days were not significant in the combined small-basin regression analysis and did not significantly improve the standard error of estimate or r^2 in the basin-specific regression.

The results of the comparison of the deterministic and regression models are that either method may be used to estimate the mean seasonal runoff volumes and, with a larger error, storm-runoff constituent loads. Although there are differences between the two methods, neither method was shown to be a better estimator of the mean seasonal storm-runoff constituent loads. Users of one of the two methods of estimating the mean seasonal data are cautioned that the other method may produce different results, but the difference between the two results is probably within the combined errors of both methods. The regression models require the least basin and drainage-network data, and the results from the regression models are within the error of the deterministic models. Therefore, for planning purposes, the regression model results may be used with confidence that the deterministic model results would not be significantly less in error. In addition, the regression models are less expensive to apply.

EFFECTS OF URBAN RUNOFF ON THE SOUTH PLATTE RIVER

This section represents an analysis of the effects of urban runoff on the South Platte River in the Denver metropolitan area. DRCOG was the prime investigating and reporting agency for the information provided in this section. The effects of urban runoff on the South Platte River were determined by analysis of data collected at the South Platte River at 50th Avenue in three different ways for the study period, April through September 1981. The first was to compare selected constituent concentrations during dry-weather flow with those during storm-runoff periods. The second was to compare the percent of time that selected constituents exceeded the stream-quality standards during dry-weather flow with the percent exceedance during storm-runoff periods. The third was to compare the distribution of selected constituent loads in point source (mainly secondary treated effluents) base flow, and storm runoff and to determine the total seasonal loads of each component.

A different approach to determine the effects of urban storm runoff on the South Platte River was used by DRCOG (1983). The DRCOG approach was to estimate the loads at the upstream boundary of the study area on the South Platte River, using the monitoring station South Platte River at Littleton; to estimate the loads of Bear Creek, using the monitoring station Bear Creek at mouth, near Sheridan; and to subtract these loads from those determined at the station at the downstream boundary of the study area, South Platte River at 50th Avenue, at Denver. The DRCOG method assumed that all other flows were from point sources, were dry-weather flows (mainly lawn-irrigation return flows), or were urban storm runoff. DRCOG, using the above assumptions, estimated the volume and selected constituent loads that originated in the point sources, upstream base flows, dry-weather flows, and urban storm runoff. The results obtained by the method used by DRCOG agreed with the results presented in this study.

The terms used in this report are defined as follows:

1. Dry-weather flow or load is the flow or load in the South Platte River at 50th Avenue, at Denver, during nonrunoff periods. Dry-weather flow is composed of industrial discharges, irrigation return flows, ground-water discharge to the river, secondary effluents, materials eroded from the riverbed, dry-weather storm sewer and tributary flows, and the residual effects of urban storm runoff.
2. Point-source flow or load is the secondary effluent flows or loads.
3. Base flow or load is the dry-weather flow or load minus the point-source flow or load.
4. Total flow, volume, or load is the total flow, volume, or load during a storm-runoff period or season; and
5. Storm flow, volume, or load, is the flow, volume, or load that is a result of storm runoff (total minus dry weather during a storm-runoff period or season).

Description of the South Platte River System

The South Platte River lies within a broad alluvial flood plain and has experienced large extremes in streamflow, alternately resulting in little or no flow during drought years or extensive flooding during wet years. Three major flood-control structures have been built in the drainage system--Chatfield Dam on the South Platte River, Bear Creek Dam on Bear Creek, and Cherry Creek Dam on Cherry Creek (fig. 2). Chatfield Dam, located about 6.5 miles upstream from the streamflow-monitoring site at Littleton, regulates streamflow in the South Platte River below the dam. The streamflow-monitoring site South Platte River at Littleton is on the upstream boundary of the study area. Bear Creek Dam on Bear Creek and Cherry Creek Dam on Cherry Creek also are considered to be on the upstream boundaries of the study area. Cherry Creek Dam usually has no outflow, except during extreme high-flow periods in the upper Cherry Creek basin and had no outflow during the study period. The downstream boundary of the study area crosses the streamflow-monitoring site South Platte River at 50th Avenue, at Denver. The land-use distribution for the South Platte River at 50th Avenue basin is about 43-percent residential, 19-percent commercial and industrial, and 38-percent open space. The effective impervious area is about 23 percent of the total area (Gibbs and Doerfer, 1982).

Three municipal wastewater-treatment plants discharge their effluents into the South Platte River in the study area. The service areas and location of each plant are shown in figure 8. The Littleton-Englewood treatment plant, called the Bi-City treatment plant, is situated in the southern part of the area and had an average discharge of 15.7 million gallons per day (Mgal/d) (DRCOG, 1983). The Lakewood treatment plant is located in the western section of the area and discharges an average of 1.8 Mgal/d (DRCOG, 1983). The Lakewood plant discharges its effluent into the South Platte River just upstream from Lakewood Gulch (fig. 8). The Glendale treatment plant discharges its effluent, about 1.0 Mgal/d, into Cherry Creek about 5.5 miles upstream from the confluence with the South Platte River.

Most of the sewage originating within the study area receives primary treatment at the Denver Northside plant, and the effluent then is pumped to the Metropolitan Denver Sewage Disposal District Number 1 (MDSDD No. 1) plant for secondary treatment. The outflow of the Northside plant was monitored, and averaged 74 Mgal/d; for the purposes of this report, it was assumed that the total flow from the Northside plant originated in the study area. MDSDD No. 1 provides secondary treatment of sewage from areas other than the study area; about 135 Mgal/d is treated at the plant, of which about 55 percent is from the study area. The discharge point for the MDSDD No. 1 plant is located downstream from the monitoring site South Platte River at 50th Avenue, at Denver and the Burlington Ditch. The study area served by the MDSDD No. 1 plant and its discharge point are shown in figure 8.

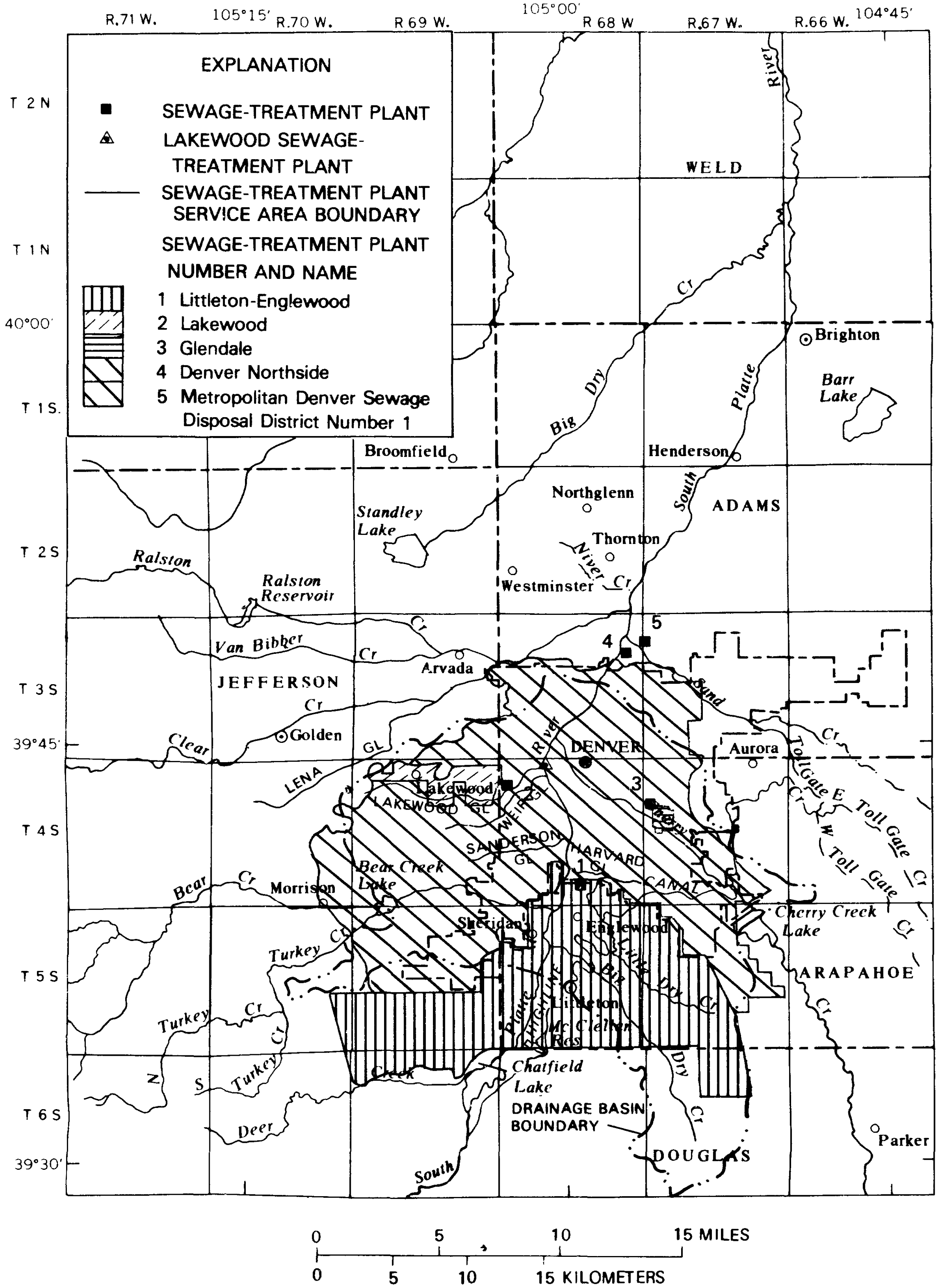

Figure 8.--Sewage-treatment-plant service areas and location of Littleton-Englewood, Lakewood, Glendale, Denver Northside, and Metropolitan Denver Sewage Disposal District Number 1 sewage-treatment plants.

Water-Quality Sampling

A water-quality sampling program was designed to monitor streamflow and water quality of the South Platte River at several locations during dry-weather and storm-runoff flow conditions. Water-quality sampling sites were located at streamflow-monitoring sites. The water-quality samples were sent to MDSDD No. 1 laboratory for chemical analysis. Streamflow data were obtained for each site from stage-discharge relations provided by the U.S. Geological Survey and the Colorado State Engineer's Office.

Water-quality constituents monitored for the dry-weather flow included total suspended solids, total organic carbon, total nitrogen, total ammonia as nitrogen, total nitrate as nitrogen, total nitrite as nitrogen, total phosphorus, total cadmium, total copper, total iron, dissolved iron, total manganese, dissolved manganese, total lead, and total zinc. The total metal concentrations were determined by the total method, EPA method 4.1.3, as opposed to the total recoverable method, EPA method 4.1.4 (EPA, 1979). These constituents were selected for monitoring for two reasons: First, stream standards are based on concentrations of nonionized ammonia, nitrite, nitrate, and the trace elements monitored. Nonionized ammonia values were not calculated due to the highly variable nature of this nitrogen species. The constituents and data necessary to calculate nonionized ammonia were collected and reported in Gibbs and Doerfer (1982). Second, sediment, organic matter, nutrients, and potentially toxic trace elements are of interest because they are known to be of sufficient concentrations in urban runoff to possibly have detrimental effects on the river system and aquatic life.

Determination of Flows and Constituent Loads

Dry-weather flows, for days with no storm runoff, were obtained from U.S. Geological Survey published streamflow records. On days when storm runoff occurred, the dry-weather flow was obtained by visual inspection of the continuous-stage records for the sites--usually a straight-line interpolation from just before the storm runoff until the streamflow again stabilized after the storm runoff had ceased. Rainfall records also assisted in estimating the beginning and end of storm runoff. Base streamflow--the dry-weather flow minus the point-source flow--then was computed for the selected sites.

Dry-weather flow constituent loads were obtained by using regression analysis of the relationship between constituent concentration and streamflow. The constituent concentrations and streamflow were used as inputs to statistical models, with curvilinear equations usually producing the smallest standard error of estimation and the higher r^2. The regression equations for the selected constituents and statistical data are presented in table 23. The regression equations were used to estimate the instantaneous loads. The values of r^2 ranged from 0.64 for total nitrogen and total phosphorus to 0.90 for total suspended solids. The instantaneous load was multiplied by the streamflow and a unit-conversion constant, resulting in the daily load of the selected constituents.

Table 23.--*Regression equations used to estimate daily dry-weather flow constituent loads and streamflow statistics for the South Platte River at 50th Avenue, at Denver*

Dependent variable		Independent variable and values of contents (Flow in cubic feet)	n[1]	[2] r^2	SEM[3]
Total suspended solids----------	=	$2.27 \times 10^{-5} \times flow^{1.86}$	78	0.90	146
Total organic carbon----------	=	$7.30 \times 10^{-4} \times flow^{0.978}$	78	.78	85
Total nitrogen----	=	$7.16 \times 10^{-3} \times flow^{0.407}$	76	.64	52
Total phosphorus--	=	$1.24 \times 10^{-3} \times flow^{0.436}$	78	.64	57
Total lead--------	=	$-1.69 \times 10^{-1} + 0.00283 \times flow$	78	.82	240
Total zinc--------	=	$9.61 \times 10^{-4} \times flow^{0.922}$	78	.84	68

[1]N means number of observations is regression analysis.
[2]r^2 means coefficient of determination.
[3]SEM means the standard error of the mean in percent.

The daily dry-weather loads were summed to produce monthly dry-weather loads, which included base and point-source loads. The monthly point-source loads, sewage effluent, was subtracted from the monthly loads, resulting in an estimation of the monthly base loads. Monthly base loads were obtained from April through September 1981.

Two estimations were made of seasonal point-source loads for total suspended solids, total organic carbon, total nitrogen, total phosphorus, total lead, and total zinc. First, the point-source loads discharged into the South Platte River in the study area were estimated. These point-source loads were from the Littleton-Englewood, Glendale, and Lakewood treatment plants. Second, the total point-source loads that originated within the study area were estimated. These point-source loads consist of the previously mentioned point-source loads and, for the purposes of this study, 55 percent of the effluent from the MDSDD No. 1 plant, which discharges to the South Platte River downstream from the study area.

Effluent-concentration data were obtained for the treatment plants from the National Pollution Discharge Elimination System, which requires the plants to perform certain self-monitoring programs, including monitoring the water-quality concentrations of the effluent. Average monthly values of the selected constituents and flow data were obtained from the plants; from these data the monthly loads were calculated. The Lakewood and Glendale treatment plants did not have data for all the selected constituents. The concentrations of the constituents were estimated, using the data from the Littleton-Englewood treatment plants. The effluent from the Littleton-Englewood plant should be comparable with that from the other two plants because they receive sewage from largely residential areas, each with a small percentage of light industrial land use. The MDSDD No. 1 plant maintained flow records of the effluent from the Denver Northside plant, which receives most of its sewage from the study area. The MDSDD No. 1 plant also maintains records of the constituent concentrations of the effluent that it discharges to the South Platte River. Data on the effluent concentrations and the flow rates from the Denver Northside plant were used to estimate the point-source loads from the study area that were processed by the MDSDD No. 1 plant.

Storm-runoff volumes were calculated from the continuous-stage recording gages at the selected sites. The stream stage was obtained from the records for each 15-minute interval during storm-runoff periods. The flow was obtained by using appropriate corrections to the stream stage and using stage-discharge relationships for each site. The instantaneous flows were summed over the storm-runoff period (April through September), resulting in a total flow for the period. The dry-weather flow volume then was subtracted from the total flow, producing the storm-runoff volume.

Three storm-runoff periods in 1980 and five storm-runoff periods in 1981 were monitored for selected water-quality constituent concentrations (the same constituents as for dry-weather flow). Usually six to eight water-quality samples were collected during each storm-runoff period. The volume of storm runoff ranged from 10 million to 95 million cubic feet, and about 56 percent of the storms during the runoff period were sampled for selected constituents from April through September 1981. Storm loads were obtained by multiplying the selected constituent concentration times the flow and a units constant, resulting in a pounds per second load. The individual instantaneous loads were plotted, and a curve was fitted through the data points. Hourly average loads were obtained from the curve, except for the beginning and end of the storm when the average loads were obtained for the hour fraction from the beginning or end of the storm to the nearest hour. The average loads were multiplied by the number of seconds (3,600, except for the beginning and ending times), and summed to produce a storm-runoff load. Storm event mean concentrations were obtained by dividing the storm load by the storm-runoff volume times a units constant.

The storm loads were regressed against storm volume, using linear and curvilinear regression analysis. Curvilinear regression equations produced the best estimators of storm load. The values of r^2 ranged from 0.49 for loads of total lead to 0.86 for loads of total nitrogen. The regression equations for storm loads of the selected constituents are presented in table 24. The regression equations then were applied to the individual storm-runoff periods; the loads for the storm-runoff periods then were summed, providing monthly and seasonal storm loads for the selected constituents, April through September 1981.

Two types of total loads were derived--first, the total loads of the constituents that flowed past the 50th Avenue station, and second, the total load derived from the study area. The first total load was the sum of the point-source, base, and storm loads that flowed past the station from April through September 1981. The second total load was the first total load plus the point-source load that originated from the study area, but was discharged downstream from the study area.

Table 24.--*Regression equations used to estimate storm loads of constituents in storm runoff in the South Platte River at 50th Avenue, at Denver*

Dependent variable in pounds		Independent variable is storm volume in cubic feet	[1]r^2	SEM[2]	SEE[3]
Total suspended solids----------	=	$2.19 \times 10^7 \times SV^{1.70}$	0.76	44	1.2×10^6
Total organic carbon----------	=	$1.80 \times 10^7 \times SV^{1.55}$	.85	86	2.8×10^5
Total nitrogen----	=	$5.08 \times 10^8 \times SV^{1.50}$	.86	67	5.2×10^4
Total phosphorus--	=	$3.60 \times 10^6 \times SV^{1.19}$	.77	113	1.4×10^4
Total lead--------	=	$2.66 \times 10^5 \times SV^{0.959}$	.49	38	1.9×10^2
Total zinc--------	=	$8.00 \times 10^{10} \times SV^{1.59}$	.83	38	4.5×10^2

[1]r^2 means coefficient of determination.
[2]SEM means the standard error of the mean in percent.
[3]SEE means standard error of estimate in pounds.

Comparison of Dry-Weather Flow and Storm-Runoff Mean Concentrations

Measured maximum, minimum, and mean dry-weather flow constituent concentrations for April through September 1981 are presented in table 25. The event mean concentrations of the storm-runoff periods varied considerably; therefore, the event mean concentrations of the monitored storms are presented in table 26.

Table 25.--*Dry-weather flow water-quality statistics for streamflow and selected constituents, April through September 1981, for the South Platte River at 50th Avenue, at Denver*

[Streamflow in cubic feet per second; trace element in micrograms per liter; and all others in milligrams per liter]

Constituent	Number of observations	Mean	Minimum	Maximum
Streamflow	26	192	42	333
Total suspended solids	26	48	11	193
Total organic carbon	26	13	6	33
Total nitrogen	25	6	4	11
Total ammonia as nitrogen	26	2.4	.8	4.6
Total nitrite as nitrogen	26	.3	.07	.6
Total nitrate as nitrogen	26	1.7	1.1	2.3
Total phosphorus	26	1.2	.55	2.2
Total cadmium	26	1	.5	8.0
Total copper	26	37	5	100
Total iron	26	1,600	320	8,000
Dissolved iron	26	25	5.0	330
Total manganese	25	230	170	340
Dissolved manganese	26	160	30	290
Total lead	26	12	5.0	30
Total zinc	26	90	60	160

Table 26.--*Event mean concentrations for monitored storm-runoff periods, April through September 1981, for the South Platte River at 50th Avenue, at Denver*

[Concentration of trace elements in micrograms per liter; all other concentrations in milligrams per liter]

Constituent	Storm date				
	April 3-4	May 12-13	May 16-18	May 28-30	July 26-27
Total suspended solids	190	210	500	800	915
Total organic carbon	31	27	28	37	40
Total nitrogen	7	4	5	5	6
Total ammonia as nitrogen	3.3	1.2	1.1	.95	1.1
Total nitrite as nitrogen	.08	.10	.09	.08	.13
Total nitrate as nitrogen	1.3	1.1	1.1	.9	1.0
Total phosphorus	1.4	.96	1.1	1.7	1.7
Total cadmium	2	1	3	4	1
Total copper	40	35	61	78	89
Total iron	5,900	6,500	12,000	23,000	7,400
Dissolved iron	130	39	33	45	86
Total manganese	340	360	470	650	980
Dissolved manganese	190	95	67	93	44
Total lead	76	59	130	230	180
Total zinc	190	180	230	460	370

Several constituents had greater mean concentrations in the storm runoff than in the dry-weather flow. These constituents were total suspended solids, total organic carbon, total iron, dissolved iron, total manganese, total lead, and total zinc. Analysis of the data indicates that these constituents are primarily associated with urban runoff, not point-source loads, in the South Platte River in the Denver metropolitan area. Analysis of data from the small basins also indicates that total suspended solids, total organic carbon, total iron, dissolved iron, total manganese, total lead, and total zinc are present in concentrations much greater than the dry-weather flow of the South Platte River. Effective control of these constituents in the urban runoff would improve the water quality of the South Platte River.

Some constituents have about the same concentrations in both the dry-weather flow and storm runoff. These constituents are total nitrogen, total ammonia as nitrogen, total phosphorus, total cadmium, and total copper. These constituents are associated with urban runoff, point-source, and nonpoint-source loads in the Denver metropolitan area. Control of these constituents in urban runoff is not practical because their concentrations are small as compared to their concentrations in the dry-weather flow, and they do not greatly impair the water quality of the South Platte River.

The constituents that had lower event mean concentrations in the storm runoff than in the dry-weather flow were total nitrite as nitrogen, total nitrate as nitrogen, and dissolved manganese. These constituents are therefore associated with point-source loads or base flows and not urban runoff. Attempts to reduce the loads of these constituents in urban runoff would not be economically feasible because the concentrations are small, and there would not be a significant improvement in the water quality of the South Platte River in the Denver metropolitan area.

Comparison of Stream-Quality Standards for Dry-Weather Flow and Storm Runoff

The percentage of time the stream-quality standards (Colorado Water Quality Control Commission, 1980) were exceeded during dry-weather flow and storm-runoff periods for the South Platte River at 50th Avenue during the study period are presented in table 27. Analysis of the monitoring data also indicated that the stream-quality standards for temperature (not more than 30° Celsius) and pH (not less than 6.5 or greater than 9.0 pH units) probably were not exceeded during the study period for dry-weather flow or storm-runoff periods. The standard of 2,000 colonies per 100 milliliters for fecal-coliform bacteria probably was exceeded most of the time during the storm-runoff periods and on a few occasions during dry-weather flow conditions, based on limited data collected during the study period. Nonionized ammonia also may have exceeded the water-quality standard of 0.06 milligram per liter during some storm-runoff periods and dry-weather flow, but was not calculated for each measurement and was not considered in this analysis.

Table 27.--*Percent exceedance of stream-quality standards for dry-weather and storm event mean concentrations, April through September 1981, for the South Platte River at 50th Avenue, at Denver*

Constituent	Stream standard[1]	Percent exceedance	
		Dry-weather flow	Storm runoff
Total nitrite as nitrogen--	0.5	8	0
Total nitrate as nitrogen--	10	0	0
Total cadmium-------------	1	31	100
Total copper--------------	25	69	100
Total iron----------------	1,000	54	100
Dissolved iron------------	300	0	0
Total manganese-----------	1,000	100	100
Dissolved manganese--------	50	96	80
Total lead----------------	25	8	100
Total zinc----------------	110	12	100

[1]From section 3.8 of "Water Quality Standards and Stream Classifications" (Colorado Water Quality Control Commission, 1980; adopted April 6, 1980). All stream standards are in micrograms per liter except for nitrite and nitrate, which are in milligrams per liter.

Table 27 shows that the percent exceedance of the water-quality standards for certain constituents in the dry-weather flow and storm-runoff ranges from 0 to 100 percent. The concentrations of total copper, total iron, total manganese, and dissolved manganese exceeded the standards in more than 50 percent of the dry-weather flow samples. The concentrations of total nitrite as nitrogen, total cadmium, total lead, and total zinc exceeded the standards in less than 32 percent of the dry-weather flow samples, while total nitrate as nitrogen and dissolved iron did not exceed the standards in any dry-weather flow samples. The storm event mean concentrations of total cadmium, total copper, total iron, total manganese, dissolved manganese, total lead, and total zinc exceeded the water-quality standards in 80 percent or more of the storm-runoff periods. The storm event concentrations of total nitrite as nitrogen, total nitrate as nitrogen, and dissolved iron did not exceed the standards during any storm.

Analysis of the data from table 27 indicated that there is an opportunity to improve the stream quality of the South Platte River by reducing the loads of total lead and total zinc in urban storm runoff. These constituents have concentrations in the storm-runoff periods that exceed the water-quality standards in all of the sampled storms, while the percent exceedance of the standards for dry-weather flow are less than 15 percent. Reductions of the loads of total copper, total iron, total manganese, and dissolved manganese in urban storm runoff to a point where the event mean concentrations are less than the standards would not greatly improve the water quality of the South

Platte River because during dry-weather flow the constituent concentrations would exceed the standards more than 50 percent of the time. The storm event mean concentrations of total cadmium exceeded the standards in all the monitored storms and in 31 percent of the monitored dry-weather flows; however, the opportunity to reduce the loads of total cadmium in urban storm runoff is poor due to the low concentrations in the storm runoff.

Comparison of Point-Source, Base, Storm-Runoff, and Total Volumes and Loads of the South Platte River at 50th Avenue, at Denver

Storm loads estimated for individual storm-runoff periods during April through September 1981 for the South Platte River at 50th Avenue are presented in table 28. The storm loads were estimated for all storms during the period, including the storms that were monitored. The storm loads were estimated using the regression equations in table 24. The May 16-18 storm-runoff period had the maximum storm-runoff volume and storm loads for the selected constituents. The June 12 storm-runoff period had the smallest runoff volume and runoff loads. About 56 percent of the total runoff volume from April through September 1981 was monitored.

The instream point-source, base, storm-runoff, and total volumes and loads summed for April through September 1981 are presented in table 29 for the South Platte River at 50th Avenue monitoring site. The same loads as a percentage of the total instream loads for the South Platte River at 50th Avenue are listed in table 30. The base flow volume was the largest component of the total flow volume; for the season, it was about 72 percent of the total flow. The base flows were 60 percent or more of the total flow for each month. Point-source and storm-runoff flows were about the same; point-source flows were 15 percent of the total flow, and storm-runoff flows were 14 percent of the total flows. Storm-runoff flows were greater than the point-source flows only during May, when the storm-runoff flows were three times the point-source flows.

The base flows contain a significant (greater than 30) percentage of the total constituent loads of total organic carbon (38 percent), total nitrogen (34 percent), total lead (45 percent), and total zinc (55 percent). These constituents, although carried by the base flow, are probably associated with both point source and storm runoff. The mean concentrations of these constituents in the base flow at the South Platte River at Littleton station were only one-half to one-third of those at the South Platte River at 50th Avenue station. Possible sources of these constituents are resuspension of point-source and storm-runoff loads, point-source loads from sources other than sewage-treatment plants, dry-weather urban runoff flows, and irrigation return flows. Reduction in the loads of these constituents would require the elimination of point sources other than sewage-treatment plants, irrigation return flows, and storm runoff (due to resuspension of these constituents).

Table 28.--*Storm-runoff volumes and loads of selected constituents, April through September 1981, for the South Platte River at 50th Avenue, at Denver*

[Volumes and loads were estimated using regression equations. Volume in millions of cubic feet and loads in pounds]

Date	Volume	Constituent loads					
		Total suspended solids ($x10^6$)	Total organic carbon ($x10^4$)	Total nitrogen ($x10^4$)	Total phos-phorus ($x10^3$)	Total lead ($x10^2$)	Total zinc ($x10^2$)
Apr. 2-4	25	0.87	5.0	0.67	2.2	3.3	4.5
Apr. 19-20	15	.38	2.4	.32	1.3	2.1	2.1
May 3-5	47	2.6	13	1.7	4.7	6.0	12
May 12-13	28	1.1	6.2	4.7	2.6	3.7	5.5
May 16-18	96	8.7	47	5.1	11	12	39
May 28-30	62	4.2	21	2.7	6.6	7.9	19
June 2-4	50	2.9	15	1.9	5.1	6.5	14
June 12	5.2	.06	.45	.063	.35	.73	.37
June 30	7.0	.10	.71	.10	.49	.98	.60
July 7-8	8.0	.13	.88	.12	.58	1.1	.75
July 12-13	18	.50	3.0	.41	1.5	2.4	2.7
July 15-16	15	.36	2.2	.30	1.2	2.0	1.9
July 26-27	41	2.0	11	1.4	4.1	5.3	9.9
Aug. 9-10	22	.73	4.3	.57	1.9	3.0	3.8

Table 29.--*Estimated instream point-source, base, and storm-runoff volumes and loads of selected constituents, April through September 1981, for the South Platte River at 50th Avenue, at Denver*

[Volume in millions of cubic feet and loads in pounds; figures may not add exactly, due to rounding]

Month and source	Volume	Constituent loads					
		Total suspended solids ($x10^6$)	Total organic carbon ($x10^5$)	Total nitrogen ($x10^4$)	Total phosphorus ($x10^4$)	Total lead ($x10^3$)	Total zinc ($x10^3$)
April:							
Point source--	65	0.050	0.97	7.8	1.9	0.060	0.22
Base----------	386	.90	1.9	7.2	1.1	.78	2.7
Storm runoff--	40	1.3	.74	.99	.35	.54	.66
Total-------	491	2.3	3.6	16	3.4	1.4	3.6
May:							
Point source--	74	.090	1.1	8.7	2.2	.040	.23
Base----------	460	1.2	2.4	7.3	1.1	1.1	3.2
Storm runoff--	233	17	8.1	10	2.5	3.0	7.6
Total-------	767	18	12	26	5.8	4.1	11
June:							
Point source--	84	.33	1.2	9.3	2.5	.050	.23
Base----------	249	.29	1.0	3.7	.060	.46	2.0
Storm runoff--	62	3.1	1.6	2.2	.59	.82	2.0
Total-------	395	3.7	3.8	15	3.2	1.3	4.2
July:							
Point source--	82	.21	1.1	9.3	2.6	.11	.13
Base----------	396	.81	2.0	7.7	.60	.79	3.0
Storm runoff--	82	3.0	1.7	2.2	.74	1.1	1.5
Total-------	560	4.0	4.8	19	3.9	2.0	4.6
August:							
Point source--	88	.12	1.3	11	2.8	.060	.20
Base----------	472	1.2	2.3	6.5	.60	1.0	3.3
Storm runoff--	22	.73	.43	.57	.19	.30	.38
Total-------	582	2.1	4.0	18	3.6	1.4	3.9
September:							
Point source--	87	.14	1.3	11	2.7	.050	.53
Base----------	370	.82	1.7	4.2	.36	.80	2.4
Storm runoff--	0	0	0	0	0	0	0
Total-------	457	.96	3.0	15	3.1	.85	2.9
Seasonal:							
Point source--	480	.94	7.0	57	15	.37	1.5
Base----------	2,330	5.2	11	37	3.8	4.9	17
Storm runoff--	439	25	13	16	4.4	5.8	12
Total-------	3,250	31	31	110	23	11	30

Table 30.--*Estimated instream point-source, base, and storm-runoff volumes and loads of selected constituents, April through September 1981, as a percent of total volumes and loads for the South Platte River at 50th Avenue, at Denver*

[Percentages may not sum to 100 percent due to rounding]

Month and source	Volume	Constituent					
		Total suspended solids	Total organic carbon	Total nitrogen	Total phos-phorus	Total lead	Total zinc
April:							
Point source--	13	2	27	49	57	4	6
Base----------	79	41	53	45	33	57	75
Storm runoff--	8	57	20	6	10	39	18
May:							
Point source--	10	0	9	33	38	1	2
Base----------	60	7	21	28	19	27	29
Storm runoff--	30	93	70	39	43	72	69
June:							
Point source--	21	9	32	62	79	4	5
Base----------	63	8	26	25	2	36	47
Storm runoff--	16	83	42	14	20	62	47
July:							
Point source--	15	5	25	48	66	6	3
Base----------	71	20	44	40	15	40	64
Storm runoff--	15	75	31	11	19	55	33
August:							
Point source--	15	6	32	60	78	5	5
Base----------	81	59	57	37	17	73	85
Storm runoff--	4	36	11	3	6	22	10
September:							
Point source--	19	16	43	72	88	6	18
Base----------	81	85	57	28	12	94	82
Storm runoff--	0	0	0	0	0	0	0
Seasonal:							
Point source--	15	3	23	52	64	3	5
Base----------	72	17	38	34	17	45	55
Storm runoff--	14	80	39	15	19	52	40

The point-source loads of total nitrogen and total phosphorus are significant--greater than 30 percent of the total loads. In addition, the point-source load of total organic carbon is about 23 percent of the total load. These constituents generally are found in effluents from sewage-treatment plants. To reduce these constituent loads would most likely require advance treatment of sewage.

The storm-runoff loads contain significant amounts of total suspended solids, total organic carbon, total lead, and total zinc. These constituents are found in storm runoff in other areas of the Nation, as well as in the Denver metropolitan area.

Comparison of Total Basin Point-Source, Base, Storm-Runoff, and Total Volumes and Loads of the South Platte River at 50th Avenue, at Denver

Total basin point-source, base, and storm-runoff flows and constituent loads for the South Platte River at 50th Avenue are presented in table 31. Total basin point-source, base, and storm-runoff flows and loads as a percent of the total basin flows and loads are presented in table 32. The total basin point-source loads include the sewage effluent that originates from the basin, although most of the effluent is discharged to the South Platte River about 2 miles below the South Platte River at 50th Avenue site.

The total basin point-source flows are the largest component of the total flow from the basin, being 47 percent of the total flow. During the low-flow months of June and September, the effluent is more than one-half of the total flow; even during the high-flow month of May, the effluent is 37 percent of the total flow. The base flow component of the total flow is 45 percent for the season, and the storm-runoff flow is only 8 percent of the total flow.

The base constituent loads are significant only for total lead (40 percent) and total zinc (37 percent) when compared to the total basin constituent loads. Since these constituents are associated with storm runoff and because these constituent concentrations are much less at the South Platte River at Littleton site, it is probable that the source of these loads is the resuspension of storm-runoff and point-source loads. In general, the base flows are only a minor source of the selected constituent loads for the total basin.

Table 31.--*Estimated total basin point-source, base, and storm-runoff volumes and loads of selected constituents, April through September 1981, for the South Platte River at 50th Avenue, at Denver*

[Volume in millions of cubic feet; loads in pounds; figures may not add exactly, due to rounding]

Month and source	Volume	Constituent loads					
		Total suspended solids ($x10^6$)	Total organic carbon ($x10^5$)	Total nitrogen ($x10^4$)	Total phosphorus ($x10^4$)	Total lead ($x10^3$)	Total zinc ($x10^3$)
April:							
Point source--	374	0.35	5.6	47	11	0.34	2.0
Base----------	386	.90	1.9	7.2	1.1	.78	2.7
Storm runoff--	40	1.3	.74	.99	.35	.54	.66
Total-------	800	2.6	8.2	55	12	1.7	5.4
May:							
Point source--	400	.40	6.0	47	11	.23	2.4
Base----------	460	1.2	2.4	7.3	1.1	1.1	3.2
Storm runoff--	233	17	8.1	10	2.5	3.0	7.6
Total-------	1,090	19	17	64	15	4.3	13
June:							
Point source--	425	.65	5.9	47	12	.25	3.1
Base----------	249	.29	1.0	3.7	.060	.46	2.0
Storm runoff--	62	3.1	1.6	2.1	.59	.82	2.0
Total-------	736	4.0	8.5	53	13	1.5	7.1
July:							
Point source--	406	.46	5.1	42	11	.24	4.2
Base----------	396	.81	2.0	7.7	.60	.79	3.0
Storm runoff--	82	3.0	1.7	2.2	.74	1.1	1.5
Total-------	884	4.3	8.8	52	12	2.1	8.7
August:							
Point source--	428	.39	6.2	49	9.7	.39	2.1
Base----------	472	1.2	2.3	6.5	.60	1.0	3.3
Storm runoff--	22	.73	.43	.57	.19	.30	.38
Total-------	922	2.3	8.9	56	10	1.7	5.8
September:							
Point source--	390	.45	5.3	51	11	.16	2.2
Base----------	370	.82	1.7	4.2	.36	.80	2.4
Storm runoff--	0	0	0	0	0	0	0
Total-------	760	1.3	7.0	55	11	.96	4.6
Seasonal:							
Point source--	2,420	2.7	34	280	65	1.6	16
Base----------	2,330	5.2	11	37	3.8	4.9	17
Storm runoff--	440	25	13	16	4.4	5.8	12
Total-------	5,190	33	58	330	73	12	45

Table 32.--*Estimated total basin point-source, base, and storm-runoff volumes and loads of selected constituents, April through September 1981, as a percent of total volumes and loads for the South Platte River at 50th Avenue, at Denver*

[Percentages may not add to 100 due to rounding]

Month and source	Volume	Constituent					
		Total suspended solids	Total organic carbon	Total nitrogen	Total phos-phorus	Total lead	Total zinc
April:							
Point source--	47	14	68	85	88	20	37
Base----------	48	36	23	13	9	47	50
Storm runoff--	5	50	9	2	3	33	12
May:							
Point source--	37	2	38	73	75	5	18
Base---------	42	7	15	11	8	26	24
Storm runoff--	21	91	48	16	17	70	58
June:							
Point source--	58	16	69	89	95	16	44
Base----------	34	7	12	7	0	30	28
Storm runoff--	8	76	19	4	5	54	28
July:							
Point source--	46	11	60	81	89	11	48
Base----------	45	19	24	15	5	38	34
Storm runoff--	9	70	16	4	6	51	18
August:							
Point source--	46	17	70	88	92	23	36
Base----------	51	52	26	12	6	59	57
Storm runoff--	2	31	5	1	2	18	7
September:							
Point source--	51	35	76	93	97	17	49
Base----------	49	65	24	8	3	83	52
Storm runoff--	0	0	0	0	0	0	0
Seasonal:							
Point source--	47	8	60	84	89	13	36
Base----------	45	16	20	11	5	40	37
Storm runoff--	8	75	21	5	6	47	27

The point-source loads of total organic carbon (60 percent), total nitrogen (84 percent), total phosphorus (89 percent), and total zinc (36 percent) are significant when compared to the total basin loads. All these constituents are found in sewage effluent except total zinc; the reasons for the large total zinc load are not known. These data indicate that in order to improve the stream quality for these constituents, sewage plants need to remove these constituents.

The storm-runoff loads of total suspended solids (75 percent), total lead (47 percent), and possibly total zinc (27 percent) are significant when compared to the total basin loads. These constituents are found in urban storm runoff. Sedimentation ponds, percolation pits, wetlands treatment or other treatment processes would be required to remove these constituents from the storm runoff. It is significant that 75 percent of the total suspended solids from the basin originates from the storm runoff because total suspended solids have detrimental effects on aquatic life. Therefore, to improve the stream habitat, total suspended solids may have to be reduced in storm runoff.

SUMMARY

The Denver metropolitan area has been the site of urban-runoff studies for several years. These studies have included several local government agencies, usually in cooperation with the U.S. Geological Survey. This report presents a summary of the data collected at the small basins in the area, the results of regression analyses of the small and tributary basins in the area, a section on the application of deterministic and regression models, and a section on the effects of urban runoff on the South Platte River.

The section on the small-basin data presents a summary of all data collected at the sites, including the maximum, minimum, and mean values of rainfall, storm runoff, and runoff-rainfall ratios, summary of the constituent runoff loads, and the maximum, minimum, and mean concentrations of selected constituents. This selection also presents a summary of the atmospheric data from each basin.

The analysis of the atmospheric data indicated that chemical oxygen demand, total nitrogen, and total phosphorus are associated with atmospheric deposition. Total nitrogen is associated with both wet and dry deposition, and chemical oxygen demand and total phosphorus are associated with dry deposition. The constituent loads of total suspended solids, total lead, total manganese, and total zinc were larger in the estimated storm runoff than in the atmospheric deposition. The results indicate that the currently used atmospheric collectors do not take into account the transport mechanism of certain constituents, such as solids and trace elements.

The results from the comparison of deterministic and regression models indicate that the two methods are comparable for the North Avenue and Cherry Knolls basins and, for planning purposes, are about the same for the Northglenn basin. The results for the Villa Italia basin differ by as much as 400 percent, with the deterministic model estimations being closest to the most probable results. Since the use of deterministic models requires extensive basin data and the use of computers, the regression models probably are more suitable for unmonitored basins, where the results could be used for planning purposes.

The analysis of the effects of urban storm runoff on the South Platte River indicate that an opportunity exists to improve the stream quality by reducing the loads of total lead and total zinc in the storm runoff. Analysis of the constituent loads at the downstream end of the study area (South Platte River at 50th Avenue, at Denver) indicate that point sources are major contributors of total nitrogen and total phosphorus and a significant contributor of organic carbon. Storm runoff was the major contributor of total suspended solids, total organic carbon, and total lead and a significant contributor of total zinc. Base flows were the major contributors of volume and total zinc and a significant contributor of total organic carbon, total nitrogen, and total lead. Analysis of the estimated total basin loads indicated that point sources were the major contributors of volume, total organic carbon, total nitrogen, and total phosphorus, and significant contributors of total zinc. Urban storm-runoff loads were the major contributors of total suspended solids and total lead and a significant contributor of total organic carbon. The base flow was the major contributor of total zinc and a significant contributor of volume, and total lead.

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