UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

QUANTITY AND QUALITY OF URBAN RUNOFF FROM THE CHESTER CREEK BASIN ANCHORAGE, ALASKA

By Timothy P. Brabets

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Prepared in cooperation with the

MUNICIPALITY OF ANCHORAGE

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DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
Water Resources Division
4230 University Drive, Suite 201
Anchorage, Alaska 99508-4664

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CONVERSION TABLE

For the convenience of readers who may prefer to use metric (International System) units rather than the inch-pound units used in this report, values may be converted by using the following factors:

Multiply inch-pound unit	by	to obtain metric unit
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	0.4047	hectare (ha)
square foot (ft^2)	0.09294	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]
pound, avoirdupois (lb)	453.6	gram (g)
ton, short	0.9072	megagram (Mg)
ton per square mile (ton/mi^2)	0.3503	megagram per square kilometer (Mg/km^2)
pound per acre (lb/acre)	1.121	kilogram per hectare (kg/ha)
pound per acre per inch [(lb/acre)/in.]	44.13	kilogram per hectare per meter [(kg/ha)/m]
degree Fahrenheit (°F)	°C=5/9 (°F-32)	degree Celsius (°C)

Other abbreviations in this report are:

mg/L, milligram per liter
µg/L, microgram per liter
µg/g, microgram per gram
colonies/100 mL, fecal coliform colonies per 100 milliliters
µS/cm, microsiemens per centimeter at 25 degrees Celsius

National Geodetic Vertical Datum of 1929 (NGVD 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."

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ABSTRACT

Urbanization has affected both the flow characteristics and water quality of streams in the Chester Creek basin. Peak flows are higher in the urbanized than in the rural parts of the basin, and the percent of effective impervious area has a significant effect on storm runoff volumes and peaks.

Water quality in the Chester Creek basin varies according to season and flow conditions. During low or base-flow conditions, concentrations of most water-quality constituents measured are within State of Alaska drinking water standards, except for fecal coliform bacteria. During periods of high flow due to snowmelt or rainfall, concentrations of the trace metal lead usually exceed recommended maximum levels. The primary source of the trace metal lead and suspended sediment originates from commercial areas, whereas the primary source of nutrients and fecal coliform bacteria is from residential areas.

The streamflow and water-quality data collected at five sites representing different land-use categories were used to calibrate and verify three U.S. Geological Survey computer-based models: the Distributed Routing Rainfall-Runoff Model-Version II (DR3M-II), the Multi-Event Urban Runoff Quality Model (DR3M-QUAL), and the Precipitation Runoff Modeling System (PRMS).

INTRODUCTION

More than 245,000 people, approximately half the population of the State of Alaska, live within the Municipality of Anchorage. Current projections indicate that by the year 2000, the population of Anchorage will be approximately 300,000. To accommodate this greater number of people, more land will have to be developed. How this increased development will affect the area's surface waters--its streams and lakes--is of concern to planners, policy makers, and the general public.

Data adequate to describe general flow conditions have been collected on most major streams in the Anchorage area, but comparable water-quality data needed to determine the effect of urbanization on the streams are scarce. Thus, in 1980 the U.S. Geological Survey, in cooperation with the Municipality of Anchorage, began a study of the effects of urban runoff on stream-water quality. The first phase of this study consisted of a general overview of the Campbell Creek basin (fig. 1) and was completed in 1983 (Brabets and Wittenberg, 1983).

Purpose and Scope

Based on the results and recommendations of the Campbell Creek work, a study of the more extensively urban Chester Creek basin (fig. 1) was formulated with the following objectives: (1) to determine the quality of surface water in the Chester Creek basin, (2) to determine if any differences in water-quality and streamflow characteristics could be related to different land uses, and (3) to provide methods that could be used to predict runoff characteristics for ungaged sites in the Anchorage urban area.

Data were collected for a 2-year period (beginning in 1982) to evaluate the effects of urbanization in the Chester Creek basin. Runoff characteristics such as peak flows and mean daily flows, and water-quality characteristics such as specific conductance and suspended-sediment loads were determined for different land-use basins. These characteristics were then analyzed by statistical and modeling efforts in order to better understand the "hydrologic" system of Chester Creek.

Physical Setting

Chester Creek heads in the Chugach Mountains (fig. 2) and drains about 30 mi^2 above Westchester Lagoon; about half the basin is urbanized. The creek has three major forks: North Fork, Middle Fork, and South Branch South Fork. The longest fork, South Branch South Fork, originates in the Chugach Mountains and drains an undeveloped "natural" area east of Muldoon Road. West of Muldoon Road the South Fork has been channelized, straightened, and lowered to its intersection with the main stem. The Middle Fork originates at Russian Jack Springs; several sections have been rerouted through storm sewers. The North Fork now serves primarily as a storm sewer.

There are three impoundments within the Chester Creek basin: University Lake, which South Branch South Fork flows through; Hillstrand Pond, which is located just west of Lake Otis Parkway and downstream from the confluence of the Middle Fork and South Branch South Fork; and Westchester Lagoon, at the mouth of Chester Creek. The dominant land-use category in the basin is single-family housing (fig. 3).

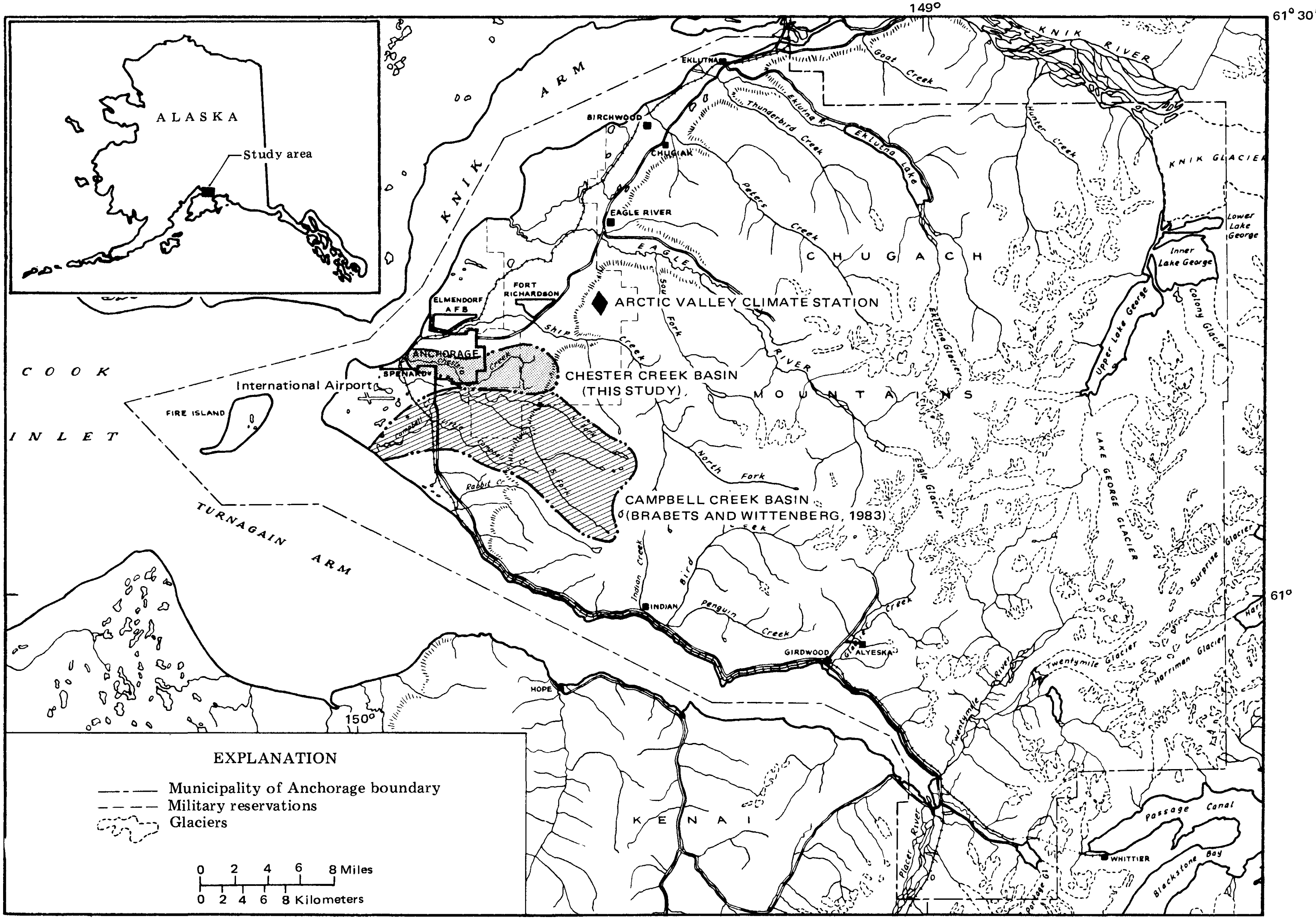

Figure 1. -- Location of Municipality of Anchorage and basins studied.

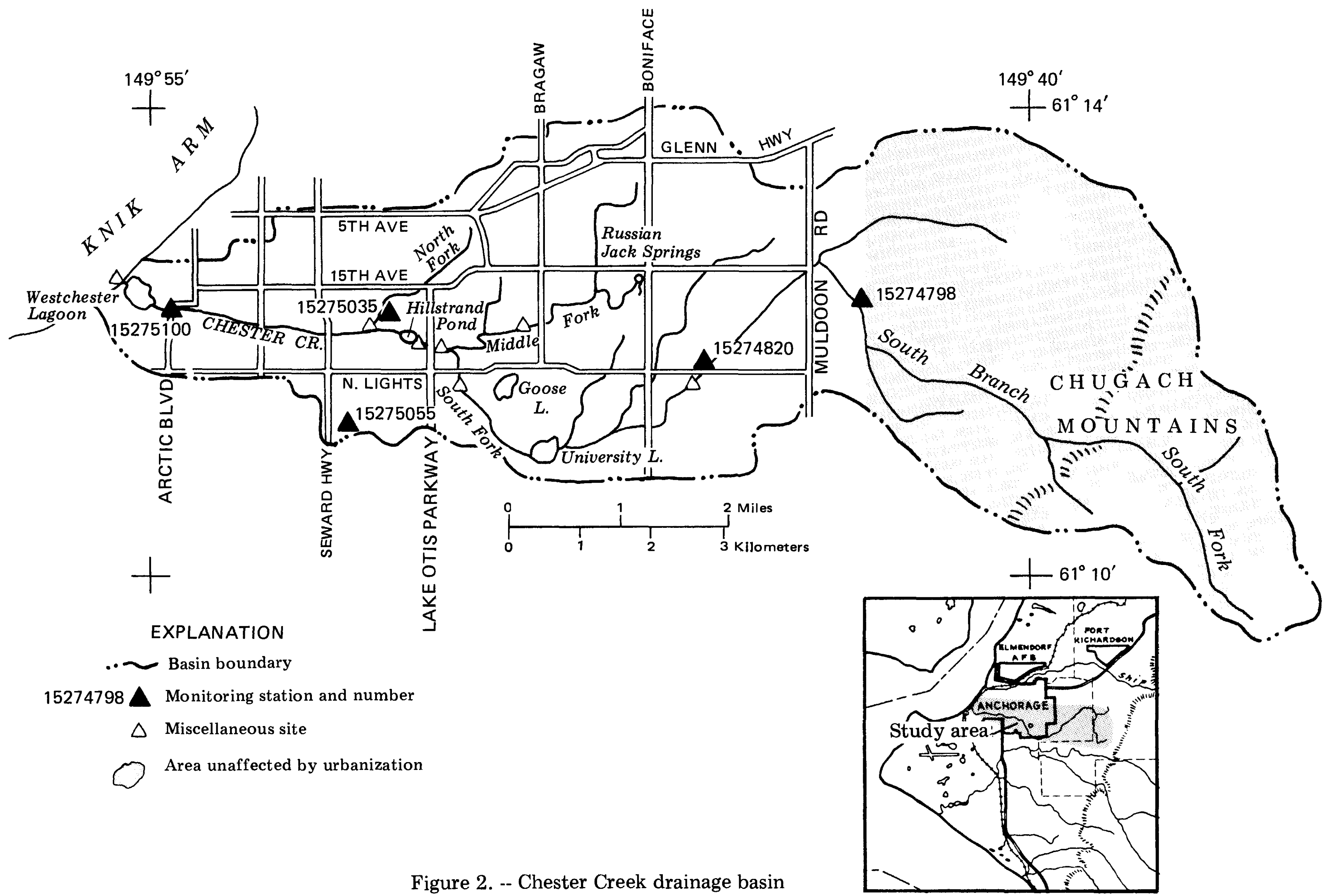

Figure 2. -- Chester Creek drainage basin

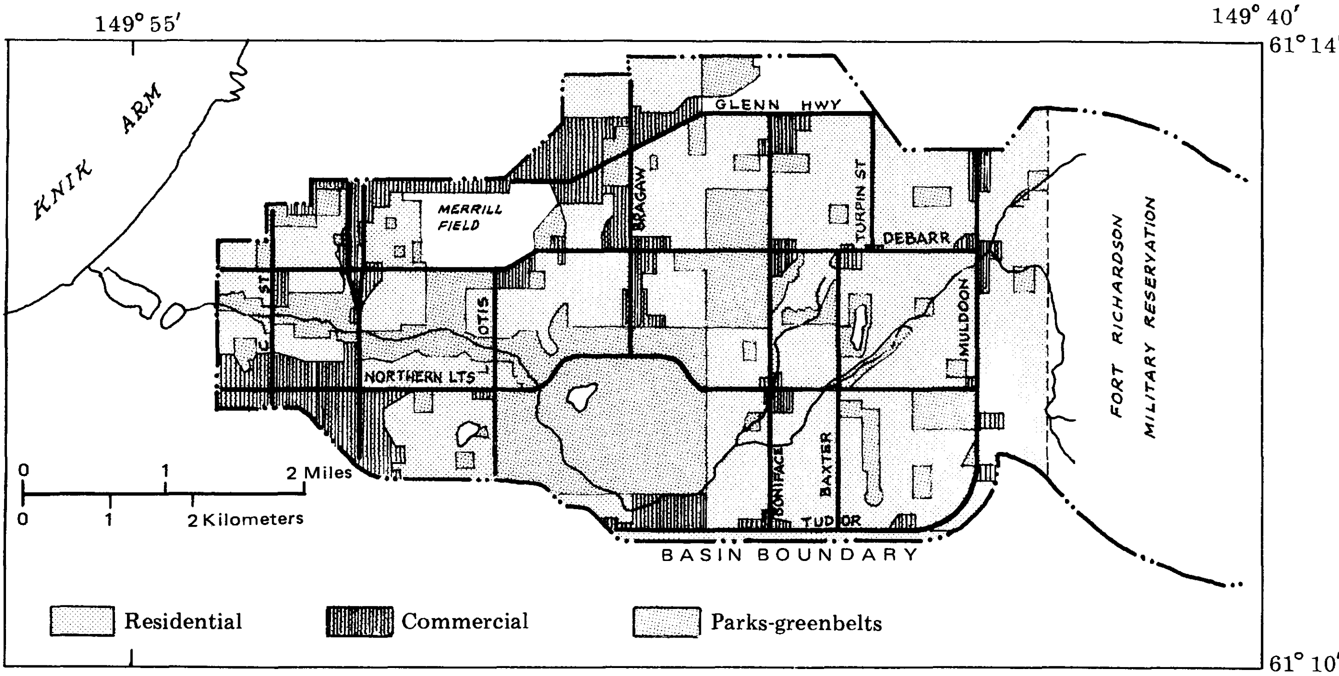

Figure 3. -- Generalized land-use plan of Chester Creek basin.

Approach

Five monitoring stations (fig. 2 and table 1) were established in the Chester Creek basin. Tipping-bucket and weighing-bucket raingages, water level recorders, and automatic water samplers were installed at stations 15274820, 15275035, and 15275055, each representing a specific land use. Wet and dry atmospheric deposition were also collected at station 15275055, within the predominantly commercial-use area. A water-level recorder and tipping-bucket raingage were installed at South Branch South Fork Chester Creek. Discharge records have been collected at the Arctic Boulevard station since 1966, and a water temperature/specific conductance recorder was installed in 1981.

The five monitoring stations were operated on a continuous basis for 2 years, from spring 1982 to spring 1984. Water samples were collected during periods of base flow, rainfall runoff, and snowmelt runoff. Samples were analyzed for a variety of constituents associated with urban runoff, such as lead, nitrogen, phosphorus, and fecal coliform bacteria (table 2).

Discharge measurements were made and water-quality samples were collected periodically at seven other miscellaneous stream sites (fig. 2). In addition, a climate station was established at an altitude of about 2,000 ft (NGVD of 1929) in Arctic Valley (fig. 1) in the adjacent Ship Creek basin. Analysis of data (precipitation, air temperature, solar radiation, relative humidity, wind speed and direction, and wet and dry deposition) from this site and the five monitoring stations allowed better definition of areal distribution of certain meteorological variables.

Water-quality and streamflow data collected during the study period are published in annual data reports of the U.S. Geological Survey (1983, 1984, and 1985). Data collected at the Arctic Valley climate station and the wet/dry deposition data are not published but are available for inspection at the Geological Survey's Water Resources Division Office, 1209 Orca Street in Anchorage.

STREAMFLOW CHARACTERISTICS

In any investigation of urban water resources, streamflow is a key variable. For example, in storm drainage design or in determining water-quality loads, accurate stream discharge is essential. The runoff from a catchment or basin is highly dependent on the amount of precipitation which falls within its drainage area and precipitation is also the major input variable to runoff modeling. Thus, accurate measurements of this variable also are necessary.

Precipitation

Average annual precipitation at the Anchorage International Airport (fig. 1) is 15.06 in. with about 8.5 in. consisting of rainfall. Precipitation as rainfall occurs from about mid-April to about mid-October. About 70 in. of snow falls during the winter months. During the study period, precipitation at the airport totaled 17.42 in. from July 1982 to June 1983 and 14.56 in. from July 1983 to June 1984.

Table 1.--Monitoring stations and description of drainage basins

Station number (fig. 2)	Station name	Drainage basin: Area (acres)	Drainage basin: Description	Drainage basin: Effective impervious area (percent)
15274798	South Branch South Fork Chester Creek near 20th Avenue	6,000	Drains undeveloped (natural) land. Approximately half the area is wetlands; other half mountain terrain.	0
15274820	South Branch South Fork Chester Creek tributary near Baxter Road	9.6	Drains area of low-density single family homes.	30
15275035	North Fork Chester Creek tributary near 20th Avenue	2.6	Drains medium-density residential area consisting entirely of townhouses.	40
15275055	Chester Creek tributary near 36th Avenue	38.4	Drains mostly commercial land with small percentage of single family homes.	70
15275100	Chester Creek at Arctic Boulevard	17,400	Drains the entire Chester Creek basin above Westchester Lagoon.	7

Table 2.--Analyses made on water samples and stream-bottom materials collected during the study period

Field parameters

- pH
- Water temperature
- Specific conductance
- Streamflow
- Fecal coliform bacteria

Dissolved constituents

- Alkalinity
- Calcium
- Chloride
- Fluoride
- Hardness
- Magnesium
- Silica
- Sodium
- Sulfate
- Solids, residue at 180 °C

Nutrients

- Nitrogen, $NO_2 + NO_3$, total and dissolved
- Nitrogen, ammonia, total and dissolved
- Nitrogen, organic, total and dissolved
- Nitrogen, ammonia + organic, total and dissolved
- Nitrogen, total
- Phosphorus, total and dissolved

Trace elements

- Aluminum, total and dissolved
- Cadmium, total and dissolved
- Chromium, total and dissolved
- Cobalt, total and dissolved
- Copper, total and dissolved
- Iron, total and dissolved
- Lead, total and dissolved
- Manganese, total and dissolved
- Nickel, total and dissolved
- Zinc, total and dissolved

Bottom materials

- Aluminum
- Cadmium
- Chromium
- Copper
- Iron
- Lead
- Zinc
- NH_4 + organic nitrogen
- $NO_2 + NO_3$ nitrogen
- NH_4 nitrogen
- Phosphorus

Suspended sediment

- Particle size
- Concentration

Precipitation totals measured at stations 15274820, 15275035, and 15275055 were within 10 percent of each other (table 3), indicating that precipitation was fairly uniform over this range of altitude in the Chester Creek basin. Slightly greater precipitation was measured at the Arctic Valley climate station.

Most precipitation events totaled about 0.50 in. or less. Duration of these storms, both as rainfall and snowfall, ranged from about 1 to 7 hours. Precipitation intensities ranged from 0.02 in. per hour to 0.30 in. per hour.

Runoff

Average annual runoff from the Chester Creek basin is about 9.0 in. Although annual runoff from the mostly undeveloped upper part of the basin is about equal to that from the urbanized lower part, differences in monthly runoff are evident (fig. 4). During snowmelt periods, runoff is higher at the Arctic Boulevard station near the mouth of Chester Creek than at South Branch South Fork Chester Creek. These differences are probably due to runoff from impervious areas between the two stations and because snowmelt does not begin in the upland areas east of Muldoon Road until late May or June. Only minor differences in runoff are observed during fall and winter periods while differences in summer period runoff vary depending on the distribution of rainfall.

No runoff occurred from the three land-use basins during base-flow periods. During rainfall periods, however, runoff from these sites (stations 15274820, 15275035, and 15275055) ranged from 8 to 82 percent of rainfall (tables 4, 5, and 6). Runoff from the commercial use area (station 15275055) averaged 50 percent of rainfall; runoff from the two residential areas (stations 15274820 and 15275035) averaged 29 and 26 percent of rainfall.

Peak Flows

Differences in both magnitude and character of flow are apparent from inspection of discharge hydrographs (fig. 5) for South Branch South Fork Chester Creek and Chester Creek at Arctic Boulevard. Mean daily flows at the former station range from 4 to 16 ft^3/s; the smooth hydrograph and relatively subdued peaks reflect runoff from the undisturbed terrain in the headwaters of the Chester Creek basin. At Arctic Boulevard near the mouth of the creek, mean daily discharges from this much larger drainage area range from 15 to 60 ft^3/s; the short, sharp peaks (i.e. rapid rise and fall of the hydrograph trace) at this point on the creek reflect runoff from paved areas and other impervious surfaces in the drainage basin above this site.

If peak flows for all five monitoring stations are considered on a unit discharge basis (cubic feet per second per square mile), the greatest range and highest values are those for the three smaller, urbanized subbasins that lie between the headwaters station, South Branch South Fork Chester Creek, and the station at Arctic Boulevard (fig. 6). The nature of the discharge hydrograph for Chester Creek at Arctic Boulevard (fig. 5) is due, in part, to the combined effects of the peak flows from these three subbasins.

STREAM WATER-QUALITY CHARACTERISTICS

Chester Creek is a popular recreational stream. The stream flows through heavily used park and recreational areas and the three impoundments are used frequently by canoeists and kayakers. Thus, knowing the quality of its water is vital, both from an aesthetic perception as well as for public health reasons.

To describe the water quality of Chester Creek in complete detail one must determine the sources of the various water-quality constituents as well as the variation in water quality under different flow conditions. This approach was taken in characterizing the water quality of Chester Creek.

In general, the source of a particular water-quality constituent may be classified as either "point" or "non-point." An example of a point source would be the outlet into a stream of a municipal sewerage system or of an on-site septic system. The "point" of origin of these constituents may be easily observed and identified. A non-point source consists of constituents derived from a broader area such as the entire drainage basin or an extensive residential or commercial development, and the origin of a particular water-quality constituent is not easy to identify and observe or to control.

There is little or no runoff from urbanized areas during base-flow periods. During periods of rainfall and subsequent runoff, particulates from the urbanized areas enter Chester Creek, causing an increase of constituents such as sediment or nutrients. The same type of constituents are washed into the stream by runoff during snowmelt periods (approximately from the first part of March to the end of April). Snowmelt runoff also commonly contains sodium chloride or calcium chloride derived from road de-icing materials.

Tables 7, 8, and 9 present results of analyses of water-quality constituents in samples collected during the study period. No attempt was made to assign the water-quality data from South Branch South Fork Chester Creek to distinct flow periods because it was difficult to distinguish any significant differences. However, valid comparisons can still be made between this site, which represents natural conditions, and the remaining four sites.

Table 3.--Precipitation measured at various locations during the study period

Location	Altitude (feet) (NGVD of 1929)	Precipitation July 1982 to June 1983 (inches)	Precipitation July 1983 to June 1984 (inches)
South Branch South Fork Chester Creek tributary (15274820)	230	13.28	13.58
North Fork Chester Creek tributary (15275035)	82	13.16	12.77
Chester Creek tributary (15273055)	115	12.19	12.33
Arctic Valley climate station	2,000	15.76	14.85
Anchorage International Airport	114	17.42	14.56

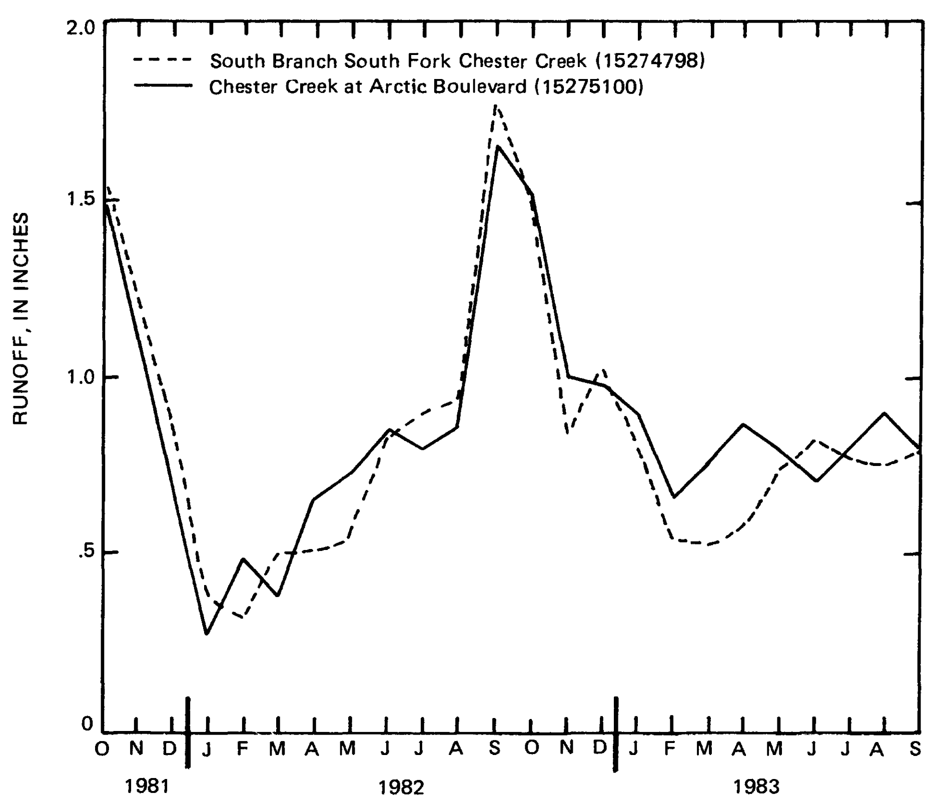

Figure 4.--Monthly runoff from South Branch South Fork and Arctic Boulevard monitoring sites on Chester Creek.

Table 4. -- Rainfall-runoff data for South Branch South Fork Chester Creek tributary (station 15274820)

(Low-density residential area; drainage area, 9.6 acres)

Date	Rainfall (in.)	Runoff volume (in.)	Runoff as percent of rainfall
1982			
7-29	0.08	0.02	25
7-29	.08	.02	25
7-30	.19	.04	21
8-10	.14	.04	28
8-11	.17	.07	41
8-15	.13	.04	31
8-25	.08	.04	50
8-30	.51	.14	27
9-2	.19	.06	32
9-5	.31	.09	29
9-12	1.32	.41	31
9-14	.50	.16	32
9-18	.30	.09	30
9-19	.21	.07	33
9-26	.13	.04	31
1983			
4-29	0.12	0.04	33
5-8	.11	.02	18
5-30	.13	.03	23
6-2	.16	.04	25
6-9	.18	.05	28
7-1	.17	.04	23
7-6	.48	.13	27
7-21	.10	.04	40
7-23	.05	.01	20
8-4	.14	.05	36
8-13	.54	.20	37
9-1	.23	.07	30
9-19	.16	.04	25
9-20	.35	.11	31
9-21	.10	.02	20
9-22	.22	.06	27
Average	--	--	29

Table 5.--Rainfall-runoff data for North Fork Chester Creek tributary (station 15275035)
(Medium-density residential area; drainage area, 2.6 acres)

Date	Rainfall (in.)	Runoff volume (in.)	Runoff as percent of rainfall
1982			
7-29	0.11	0.02	18
7-29	.09	.02	22
7-30	.17	.03	18
8-10	.14	.03	21
8-11	.18	.04	22
8-15	.13	.04	31
8-25	.23	.02	8
8-30	.51	.19	37
9-2	.10	.02	20
9-5	.31	.08	26
1983			
4-29	0.18	0.03	17
5-30	.13	.04	31
6-9	.12	.05	42
7-1	.21	.03	14
7-6	.49	.13	26
8-8	.07	.01	14
8-14	.46	.22	48
8-17	.12	.05	41
8-20	.07	.02	28
8-21	.30	.08	27
8-22	.69	.31	45
Average	--	--	26

Table 6.--Rainfall-runoff data for Chester Creek tributary (station 15275055)
(Commerical area; drainage area, 38.4 acres)

Date	Rainfall (in.)	Runoff volume (in.)	Runoff as percent of rainfall
1982			
7-15	0.42	0.23	55
7-23	.19	.06	32
7-23	.22	.12	54
7-29	.11	.03	27
7-29	.09	.04	44
7-29	.11	.03	27
9-3	.10	.06	60
9-5	.31	.19	61
9-14	.56	.34	61
9-18	.34	.22	65
9-19	.28	.18	64
9-26	.14	.09	64
9-29	.33	.20	61
9-30	.24	.11	46
1983			
4-29	0.16	0.07	44
5-1	.11	.09	82
5-30	.15	.04	27
9-19	.26	.08	31
9-20	.19	.05	26
9-21	.12	.08	67
9-29	.28	.16	57
Average	--	--	50

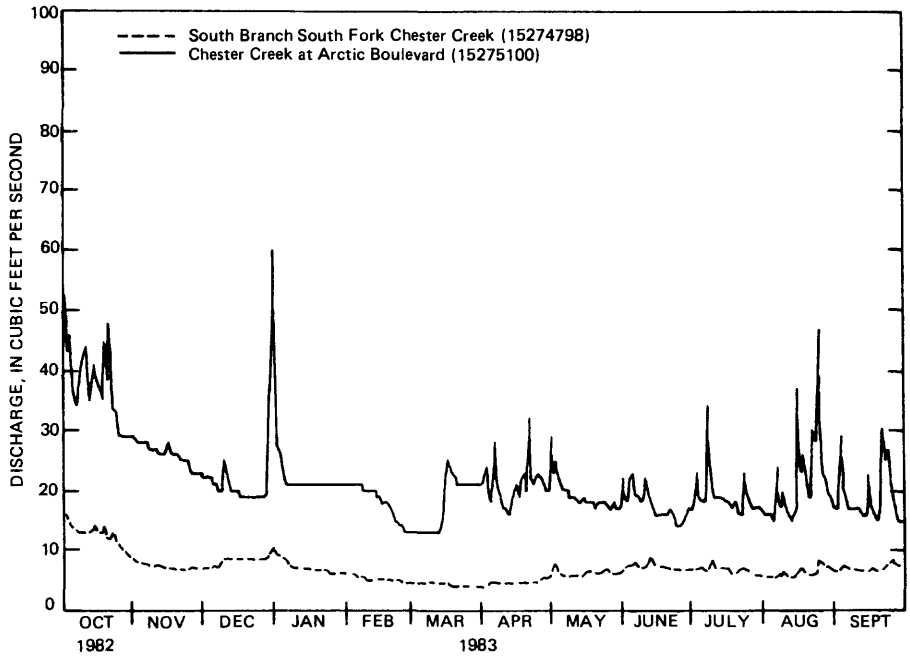

Figure 5.--Comparison of daily discharges at South Branch South Fork Chester Creek and Chester Creek at Arctic Boulevard.

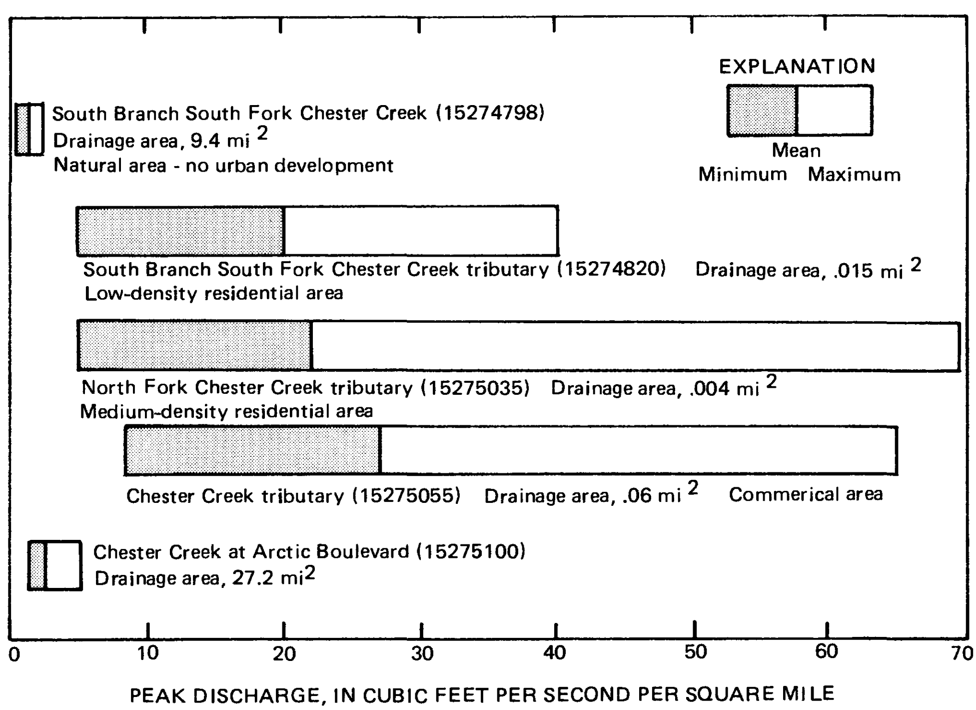

Figure 6.--Comparison of peak discharge at five monitoring sites in the Chester Creek basin (1982-83).

Table 7.--Summary of analyses of water-quality constituents during base-flow periods for South Branch South Fork Chester Creek and Chester Creek at Arctic Boulevard

Water-quality constituent	Number of samples	Mean	Median	Minimum	Maximum	Number of samples	Mean	Median	Minimum	Maximum
	South Branch South Fork Chester Creek (15274798)					Chester Creek at Arctic Boulevard (15275100)				
Specific conductance (µS/cm)	12	136	136	110	165	11	275	274	243	330
pH (units)	12	7.8	7.9	7.3	8.2	13	7.8	7.9	7.3	8.1
Calcium (mg/L)	12	19	20	15	21	11	33	32	31	37
Magnesium (mg/L)	12	3.6	3.6	2.9	4.2	13	7.7	7.7	6.9	8.3
Chloride (mg/L)	12	.8	.8	.6	1.0	11	14	14	10	22
Potassium (mg/L)	10	.5	.5	.3	.9	11	1.1	1.0	.8	2.2
Sodium (mg/L)	12	2.2	2.1	1.8	2.5	11	7.6	7.1	6	11
Sulfate (mg/L)	12	10.1	10.5	5.0	12.0	13	24	23	21	27
Dissolved solids (mg/L)	12	80	80	48	94	13	154	159	105	207
NO_2+NO_3, total as N (mg/L)	12	.7	.4	.2	4.2	14	.54	.5	.3	.8
NO_2+NO_3, dissolved as N (mg/L)	11	.39	.4	.17	.57	11	.56	.56	.29	.74
Ammonia nitrogen as N, total (mg/L)	12	.11	.1	.06	.22	11	.14	.10	.06	.29
Ammonia nitrogen as N, dissolved (mg/L)	12	.10	.08	.06	.17	12	.12	.10	.06	.22
Organic nitrogen as N, total (mg/L)	10	.54	.51	.29	.79	9	.54	.52	.34	.79
Organic nitrogen as N, dissolved (mg/L)	11	.44	.43	.22	.70	11	.42	.39	.11	.79
Phosphorus as P, total (mg/L)	12	.02	.02	.01	.04	12	.05	.04	.01	.11
Phosphorus as P, dissolved (mg/L)	12	.02	.02	.01	.07	12	.02	.02	.01	.06
Aluminum, total (µg/L)	12	90	65	40	65	12	540	415	210	1,800
Aluminum, dissolved (µg/L)	--	--	--	--	--	2	25	--	--	--
Cadmium, total (µg/L)	12	all samples less than 1.0 µg/L				12	all samples less than 1.0 µg/L			
Cadmium, dissolved (µg/L)	--	--	--	--	--	2	1	--	--	--
Chromium, total (µg/L)	11	2.8	1.0	1.0	10	12	8.3	4.5	1	55
Chromium, dissolved (µg/L)	--	--	--	--	--	2	10	--	--	--
Copper, total (µg/L)	11	6.8	3.0	1.0	42	11	7.5	5	1	31
Copper, dissolved (µg/L)	--	--	--	--	--	2	2	--	--	--
Iron, total (µg/L)	12	225	145	40	750	12	1,630	1,400	910	3,400
Iron, dissolved (µg/L)	--	--	--	--	--	2	205	--	--	--
Lead, total (µg/L)	12	1.5	1.0	1.0	3.0	12	6	4	1	22
Lead, dissolved (µg/L)	--	--	--	--	--	2	1	--	--	--
Zinc, total (µg/L)	12	93	20	8	860	11	76	70	40	170
Zinc, dissolved (µg/L)	--	--	--	--	--	2	31	--	--	--
Suspended sediment (mg/L)	12	10	4.5	1	35	11	21	16	6	38
Fecal coliform bacteria (colonies/100 mL)	11	14	10	1	78	12	373	340	120	1,700

Table 8.--Summary of analyses of water-quality constituents during rainfall-runoff periods for South Branch South Fork Chester Creek tributary, North Fork Chester Creek tributary, Chester Creek tributary, and Chester Creek at Arctic Boulevard

Water-quality constituent	Number of samples	Mean	Median	Minimum	Maximum	Number of samples	Mean	Median	Minimum	Maximum
	South Branch South Fork Chester Creek tributary (15274820)					North Fork Chester Creek tributary (15275035)				
Specific conductance (µS/cm)	584	76	45	18	850	99	77	62	25	300
pH (units)	21	7.1	7.1	6.5	7.9	13	7.2	7.1	6.8	7.8
Calcium (mg/L)	19	27	7.3	.1	120	13	10	9.3	5.5	17
Magnesium (mg/L)	19	4.4	1.9	.1	19	13	.9	.6	.3	2.1
Chloride (mg/L)	18	7.3	3.3	.7	30	13	1.9	1.6	.7	4.1
Potassium (mg/L)	18	2.0	1.4	.7	4.9	13	1.0	.9	.5	1.7
Sodium (mg/L)	19	8.7	5.3	2.6	19	13	2.3	2.1	.8	4.0
Sulfate (mg/L)	18	50.4	12	5	260	13	13	10	7	29
Dissolved solids (mg/L)	18	158	64.5	17	594	13	59	52	30	115
NO_2+NO_3, total as N (mg/L)	85	.57	.3	.1	2.4	18	.8	.2	.1	9
NO_2+NO_3, dissolved as N (mg/L)	17	.13	.13	.1	.28	12	.16	.18	.1	.25
Ammonia nitrogen as N, total (mg/L)	85	.61	.33	.1	3.4	18	.29	.28	.16	.49
Ammonia nitrogen as N, dissolved (mg/L)	17	.24	.26	.14	.32	12	.31	.31	.16	.44
Organic nitrogen as N, total (mg/L)	84	2.3	1.4	.18	13	18	1.3	1.2	.39	2.7
Organic nitrogen as N, dissolved (mg/L)	17	1.1	1.1	.83	2.0	12	1.4	1.5	.54	2.3
Phosphorus as P, total (mg/L)	85	1.1	.63	.1	6.0	18	.22	.18	.07	.73
Phosphorus as P, dissolved (mg/L)	17	.17	.16	.12	.23	12	.14	.12	.07	.33
Aluminum, total (µg/L)	78	5,080	2,900	490	26,000	22	9,940	2,750	390	75,000
Aluminum, dissolved (µg/L)	9	86	80	40	130	9	98	100	60	160
Cadmium, total (µg/L)	78	all samples less than 1.0 µg/L				20	14	5	1	130
Cadmium, dissolved (µg/L)	9	all samples less than 1.0 µg/L				9	all samples less than 1.0 µg/L			
Chromium, total (µg/L)	23	21	17	5	53	9	18	15	4	44
Chromium, dissolved (µg/L)	9	all samples less than 10 µg/L				9	all samples less than 10 µg/L			
Copper, total (µg/L)	54	44	37	18	110	21	72	24	12	630
Copper, dissolved (µg/L)	9	12	12	9	17	9	13	14	3	18
Iron, total (µg/L)	78	8,920	5,450	800	40,000	19	7,070	2,500	520	32,000
Iron, dissolved (µg/L)	9	105	110	50	200	9	88	80	30	140
Lead, total (µg/L)	78	173	110	8	1,100	21	109	55	14	500
Lead, dissolved (µg/L)	9	3.1	1	1	10	9	all samples less than 1.0 µg/L			
Zinc, total (µg/L)	54	172	130	50	590	19	190	110	70	850
Zinc, dissolved (µg/L)	9	29	30	20	40	9	32	30	10	50
Suspended sediment (mg/L)	397	147	68	1	4,700	50	208	50	14	4,570
Fecal coliform bacteria (colonies/100 mL)	65	3,200	1,900	8	9,500	11	4,000	3,200	270	11,000

Water-quality constituent	Number of samples	Mean	Median	Minimum	Maximum	Number of samples	Mean	Median	Minimum	Maximum
	Chester Creek tributary (15275055)					Chester Creek at Arctic Boulevard (15275100)				
Specific conductance (µS/cm)	324	89	55	20	800	3	76	--	--	--
pH (units)	38	6.6	6.5	5.9	8.3	3	7.6	--	--	--
Calcium (mg/L)	23	11	6.7	1.9	52	3	7.6	--	--	--
Magnesium (mg/L)	23	2.5	.89	.1	19	3	1.8	--	--	--
Chloride (mg/L)	23	16	5.6	1.7	64	3	4.6	--	--	--
Potassium (mg/L)	19	1.1	1.0	.6	2.3	3	1.0	--	--	--
Sodium (mg/L)	23	12	6.8	2.3	40	3	3.1			
Sulfate (mg/L)	23	14	11	5.0	35	3	8.0	--	--	--
Dissolved solids (mg/L)	27	104	52	26	385	3	55	--	--	--
NO_2+NO_3, total as N (mg/L)	15	.23	.19	.10	.40	8	.26	.25	.1	.6
NO_2+NO_3, dissolved as N (mg/L)	10	.17	.14	.10	.33	3	.11	--	--	--
Ammonia nitrogen as N, total (mg/L)	16	.45	.43	.15	1.1	10	.16	.14	.07	.36
Ammonia nitrogen as N, dissolved (mg/L)	10	.42	.32	.19	1.0	3	.08	--	--	--
Organic nitrogen as N, total (mg/L)	16	1.5	1.5	.90	2.3	10	1.2	1.0	.4	2.0
Organic nitrogen as N, dissolved (mg/L)	10	1.0	.98	.74	1.8	3	.51	--	--	--
Phosphorus as P, total (mg/L)	16	.39	.32	.10	1.5	10	.22	.14	.03	.95
Phosphorus as P, dissolved (mg/L)	10	.11	.08	.06	.18	3	.03	--	--	--
Aluminum, total (µg/L)	25	11,900	9,500	2,900	45,000	9	5,200	5,600	2,100	9,200
Aluminum, dissolved (µg/L)	13	170	160	120	290	3	53	--	--	--
Cadmium, total (µg/L)	25	7	3	2	70	10	all samples less than 1.0 µg/L			
Cadmium, dissolved (µg/L)	13	all samples less than 1.0 µg/L				3	1	--	--	--
Chromium, total (µg/L)	25	197	52	10	3,300	4	21	--	--	--
Chromium, dissolved (µg/L)	13	all samples less than 10 µg/L				3	all samples less than 10 µg/L			
Copper, total (µg/L)	25	72	70	18	440	9	30	30	17	43
Copper, dissolved (µg/L)	13	12	11	8	16	3	5	--	--	--
Iron, total (µg/L)	24	15,100	14,000	1,100	40,000	10	9,860	9,950	1,400	17,000
Iron, dissolved (µg/L)	13	186	160	110	390	3	101	--	--	--
Lead, total (µg/L)	25	460	440	96	1,500	8	76	71	39	130
Lead, dissolved (µg/L)	13	17	14	11	32	3	1	--	--	--
Zinc, total (µg/L)	24	358	320	110	720	7	171	160	110	270
Zinc, dissolved (µg/L)	13	83	70	60	150	3	18	--	--	--
Suspended sediment (mg/L)	186	177	194	20	6,530	14	181	150	99	318
Fecal coliform bacteria (colonies/100 mL)	10	211	200	23	566	10	3,200	1,750	670	7,200

Table 9.--Summary of analyses of water-quality constituents during snowmelt periods in Chester Creek

Water-quality constituent	Number of samples	Mean	Median	Minimum	Maximum	Number of samples	Mean	Median	Minimum	Maximum
	South Branch South Fork Chester Creek tributary (15274820)					Chester Creek tributary (15275055)				
Specific conductance (µS/cm)	5	132	130	70	200	6	750	733	549	1,140
pH (units)	7	6.9	6.8	6.5	7.4	6	6.9	7.0	6.5	7.0
Calcium (mg/L)	7	13	10	7.7	23	6	30	27	16	48
Chloride (mg/L)	7	102	83	59	210	6	205	195	130	330
Magnesium (mg/L)	7	1.4	1.1	.8	3.0	6	1.3	1.2	1.1	1.5
Sodium (mg/L)	7	55	54	37	120	6	103	83	72	180
Sulfate (mg/L)	7	10	9.8	8.4	11	6	8.4	8.8	6.1	11
Dissolved solids (mg/L)	7	221	185	138	396	6	385	380	276	580
Aluminum, total (µg/L)	5	7,860	7,000	4,100	11,000	6	31,500	27,500	24,000	53,000
Cadmium, total (µg/L)	5	all samples less than 10 µg/L				6	all samples less than 10 µg/L			
Iron, total (µg/L)	5	13,500	14,000	7,400	19,000	6	52,500	46,500	42,000	86,000
Lead, total (µg/L)	5	238	180	91	600	6	1,120	815	560	2,500
Zinc, total (µg/L)	5	132	130	70	200	6	798	690	620	1,400
Suspended sediment (mg/L)	8	202	213	101	280	6	1,030	896	790	1,790
	Chester Creek at Arctic Boulevard (15275100)									
Specific conductance (µS/cm)	11	639	703	356	894					
pH (units)	10	7.6	7.7	7.2	7.9					
Calcium (mg/L)	12	36	36	29	40					
Chloride (mg/L)	12	130	145	39	250					
Magnesium (mg/L)	10	7.1	6.9	5.8	8.3					
Sodium (mg/L)	12	71	79	21	140					
Sulfate (mg/L)	10	22	21	20	24					
Dissolved solids (mg/L)	10	371	398	200	530					
Aluminum, total (µg/L)	17	6,600	2,200	400	19,000					
Cadmium, total (µg/L)	16	all samples less than 10 µg/L								
Iron, total (µg/L)	17	15,300	13,000	1,900	61,000					
Lead, total (µg/L)	17	119	110	7	400					
Zinc, total (µg/L)	17	278	200	80	800					
Suspended sediment (mg/L)	18	210	145	18	683					

Specific Conductance

Specific conductance is a measure of the ability of water to conduct an electric current, expressed in microsiemens per centimeter at 25 °C. Specific conductance is determined by the type and concentration of ions in solution. It is a readily measured property that can be used to indicate the dissolved-solids or ion content in water.

During distinct, summer base-flow periods, proceeding from the headwaters to the mouth of Chester Creek, specific conductance increases (fig. 7). Values of conductance have also increased from 1960 to 1980. This increase during the last 20 years could result from inflow from septic systems, from small undetected leaks in the sanitary sewers, or from an increase in the number of point sources of discharge.

During the study period, specific conductance measured at base-flow conditions averaged 136 µS/cm at South Branch South Fork Chester Creek and 275 µS/cm at Arctic Boulevard. Specific conductance values during periods of rainfall runoff ranged from 18 to 850 µS/cm. The largest values of conductance were generally found at the beginning of a storm and then rapidly decreased (fig. 8). Mean values of conductance in runoff from the three land-use basins (stations 15274820, 15275035, and 15275055) showed no significant differences (table 8).

During periods of snowmelt runoff, mean values of specific conductance at Arctic Boulevard, South Branch South Fork tributary, and Chester Creek tributary were higher than mean values for rainfall-runoff periods. These higher values result from the greater concentrations of dissolved constituents such as chloride and sodium in the snowmelt runoff. The highest value of specific conductance (1140 µS/cm) was measured at the commercial site (station 15275055).

Dissolved Constituents

Samples were collected at all five monitoring stations for analysis of major dissolved constituents. During base-flow periods the concentrations of these individual constituents increased from South Branch South Fork Chester Creek to Chester Creek at Arctic Boulevard. However, the concentrations of all constituents were well within State drinking water standards (Alaska Department of Environmental Conservation, 1979).

Concentrations of dissolved constituents at Arctic Boulevard were lower during rainfall-runoff periods than at base-flow conditions. This is not an uncommon occurrence because rainwater is relatively low in dissolved constituents and will dilute the concentration of dissolved material in the stream.

The highest concentrations of chloride, sodium, and total dissolved constituents were sampled during snowmelt periods. The highest values of calcium were noted at Chester Creek tributary which drains the commercial land use. The high concentrations of these constituents probably result from washoff of road de-icing materials such as calcium chloride and sodium chloride. The State drinking water limits of 250 mg/L chloride and 500 mg/L dissolved solids were exceeded in several samples.

Phosphorus and Nitrogen

Aquatic vegetation such as algae depends on nitrogen and phosphorus compounds for its nutrient supply. Excessive algal growth or "blooms" sometimes occur, however, in water bodies that periodically receive increased concentrations of nitrogen and phosphorus. These growths are generally undesirable to water users.

Samples were collected at the five monitoring sites for analysis of phosphorus and several nitrogen species: nitrite-plus-nitrate nitrogen, ammonia nitrogen, and organic nitrogen. Most samples were analyzed for "total" concentrations, although some "dissolved" analyses were made.

During base-flow periods phosphorus concentrations averaged 0.02 mg/L at the South Branch South Fork Chester Creek and 0.05 mg/L at Arctic Boulevard. Phosphorus at the upstream site is present primarily in the dissolved phase; at Arctic Boulevard about one-half of the total amount of phosphorus present is dissolved. The higher amounts in Chester Creek at Arctic Boulevard could be due to seepage from faulty septic systems located along the creek or to runoff from fertilized lawns.

Total phosphorus concentrations during rainfall-runoff periods showed a fivefold increase over base-flow levels at Arctic Boulevard. At the three land-use sites, mean concentrations of total phosphorus ranged from 0.22 to 1.1 mg/L and mean dissolved concentrations ranged from 0.11 to 0.17 mg/L. Because the highest concentrations of phosphorus were noted from the residential land-use site (15274820), it appears that the application of fertilizers to lawns has a measurable effect on the chemical makeup of rainfall runoff.

Nitrate-plus-nitrite concentrations did not vary markedly among the five monitoring sites during either base-flow or rainfall-runoff periods. Concentrations greater than 1 mg/L nitrite (as N) and 10 mg/L nitrate (as N) in drinking water may cause methemoglobinemia (oxygen starvation) in infants. Chester Creek is not a source of public water supply, but concentrations of $NO_2 + NO_3$ were significantly less than the above limits.

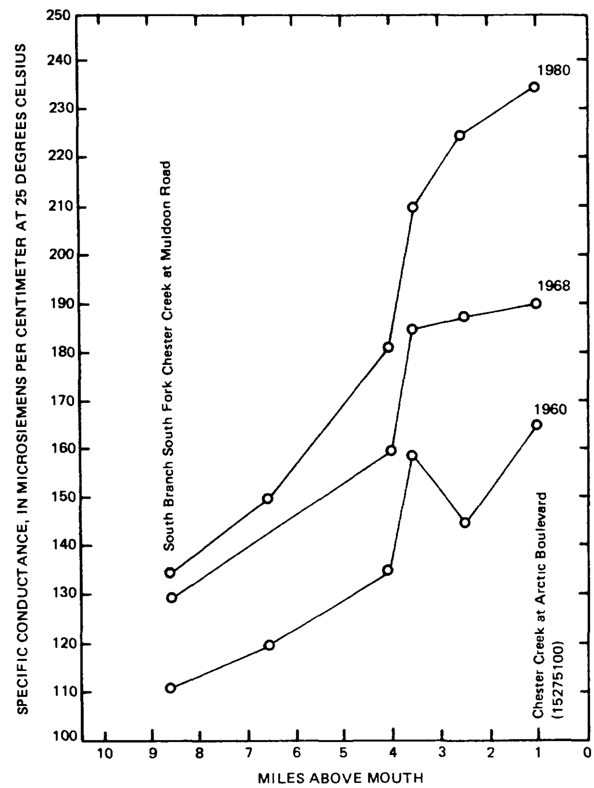

Figure 7.--Relation between specific conductance and distance along Chester Creek during discrete, distinct base-flow periods.

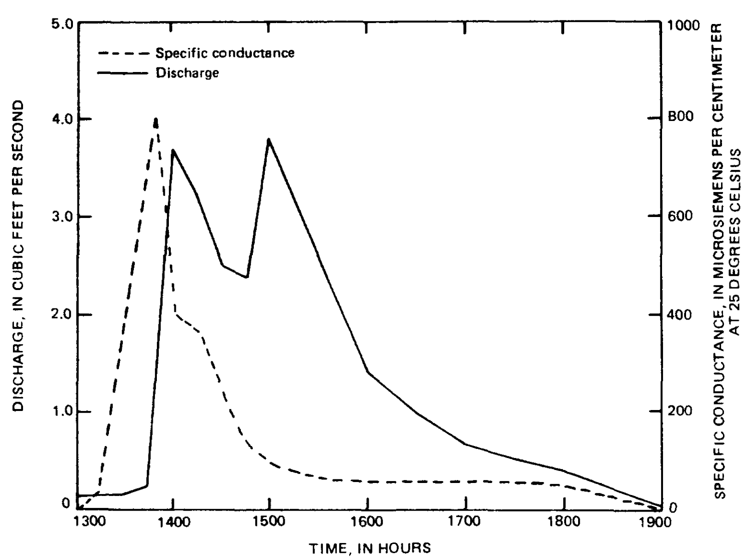

Figure 8.--Specific conductance and discharge hydrograph for storm of May 30, 1983 at Chester Creek tributary (15275055).

Because trace concentrations of ammonia nitrogen can be toxic to aquatic life, the U.S. Environmental Protection Agency (1977) suggests that un-ionized ammonia not exceed 0.02 mg/L. Based on average temperature and pH in Chester Creek, the total ammonia (ionized plus un-ionized) should not exceed about 1.5 mg/L. During base-flow conditions, concentrations of ammonia nitrogen were approximately the same above Muldoon Road (the South Branch South Fork site) and at Arctic Boulevard. Most of the ammonia nitrogen was in the dissolved phase and averaged 0.10 mg/L. During rainfall-runoff periods concentrations of ammonia nitrogen were higher in runoff from the three land-use areas but did not change significantly at Arctic Boulevard.

Mean organic nitrogen concentrations were 0.54 mg/L at both South Branch South Fork and at Arctic Boulevard during base-flow periods. Most of the organic nitrogen was in the dissolved phase. Rainfall-runoff periods produced a twofold increase in concentrations of organic nitrogen at Arctic Boulevard. Organic nitrogen concentrations in rainfall runoff at the three land-use sites ranged from 1.3 to 2.3 mg/L; fertilizers applied to lawns that ultimately drain to the creek are the probable source of such elevated nitrogen levels.

Data collected during the NURP (Nationwide Urban Runoff Program) (U.S. Environmental Protection Agency, 1983) were compared to data collected in the Chester Creek basin. The NURP data showed median concentrations of 0.33 mg/L total phosphorus and 1.5 mg/L total nitrate-plus-nitrite nitrogen. The only comparable value for the Chester Creek basin that exceeded NURP concentrations was 0.63 mg/L total phosphorus at the South Branch South Fork tributary site. Median values for total organic nitrogen and total $NO_2 + NO_3$ were similar to or lower than the NURP values.

Trace Metals

Although there is no precise definition of "trace metals", the term is generally applied to metals that occur in concentrations less than 1.0 mg/L (1,000 µg/L). During the first year of the study, trace-metal samples were analyzed for both total and dissolved phases. Because initial results indicated that the dissolved phase accounted for only 10 percent of the total concentration, samples were subsequently analyzed only for their total content of trace metals.

During base-flow conditions, mean concentrations of total cadmium, chromium, copper, lead, and zinc showed no significant increases from South Branch South Fork Chester Creek to Chester Creek at Arctic Boulevard, but concentrations of total aluminum and total iron were higher at Arctic Boulevard. The increase in aluminum is associated with the slight increase in suspended sediment (alumino-silicate particles) while the increase in total iron is probably due to the presence of iron in ground water that enters the creek below the upstream site.

Rainfall-runoff periods showed increased concentrations of all trace metals except cadmium. The highest mean concentrations were found at the commercial site, Chester Creek tributary. All trace metals except total lead were below State and EPA (U.S. Environmental Protection Agency) limits for drinking water.

Because lead can be detrimental to fish life and concentrations of lead in Chester Creek exceeded State drinking water standards during rainfall periods, a statistical method was used to determine if significant differences existed between the various land uses. Boxplots, which are a graphical means of summarizing data, were developed for the three land-use sites (fig. 9). Boxplots show the median, the 25- and 75-percent values (the middle of the "batch") and the corresponding low and high extremes. A confidence interval around the median is defined. The significance of the confidence interval is in comparing more than one group of data. When comparing two or more groups of data, if the intervals do not overlap, the population medians are different at the 95-percent level (Velleman and Hoaglin, 1981). Inspection of the boxplots indicates a significant difference between total lead levels in runoff from residential areas versus those from the commercial area.

Snowmelt runoff generally contained higher mean concentrations of total aluminum, iron, lead, and zinc than did rainfall runoff. Concentrations of these elements in snowmelt runoff were about 30 to 50 percent higher (than in rainfall runoff) for the South Branch South Fork Chester Creek tributary, but 200 to 350 percent higher for Chester Creek tributary, the commercial site.

Fecal Coliform Bacteria

The extent of bacteria contamination is one of the most important indicators of water quality, especially water intended for human consumption or body contact. The principal sources for bacteria are human and animal excreta, decaying plant or animal matter, and soil. The primary concern over bacteria relates to the transmission of disease.

Fecal coliform bacteria counts may not exceed 20 colonies/100 mL in order to meet Alaska State drinking water standards and 200 colonies/100 mL to meet State standards for secondary contact recreation. All samples of fecal coliform bacteria collected at South Branch South Fork Chester Creek contained fewer than 200 colonies/100 mL and only two samples were above 20 colonies/100 mL. Coliform counts were above 20 colonies/100 mL for all samples collected at Arctic Boulevard, and during base-flow periods about half of the samples from this site contained more than 200 colonies/100 mL.

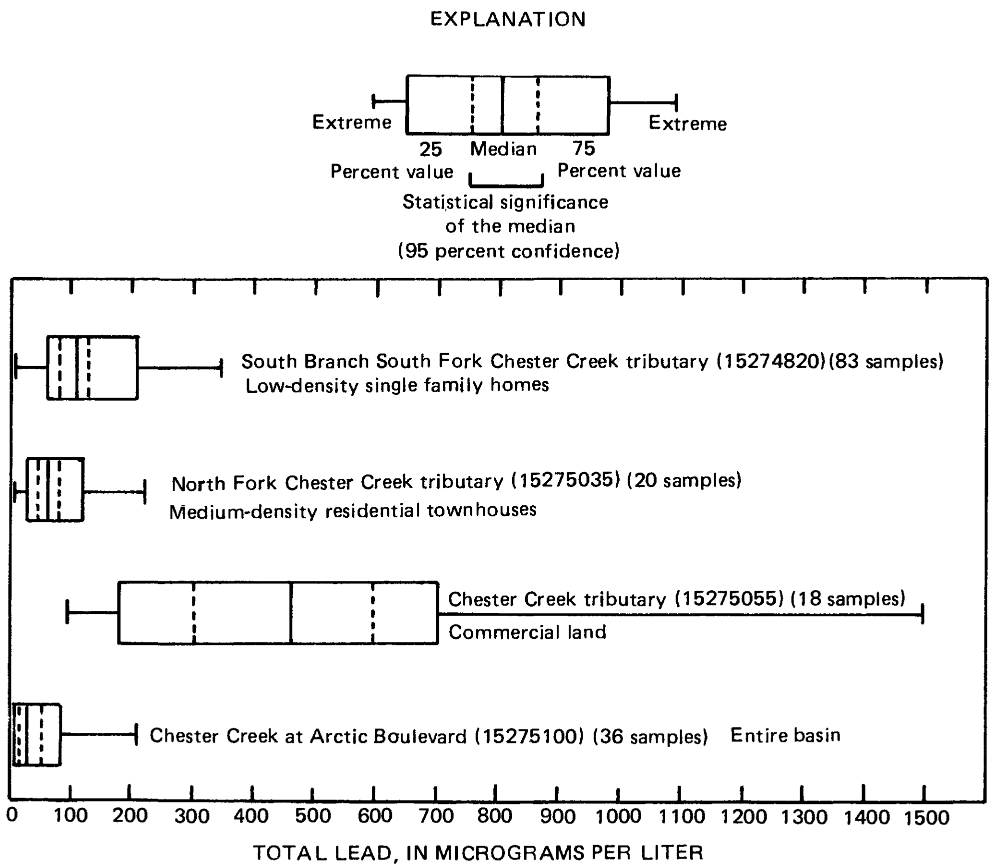

Figure 9.--Boxplots of total lead for the three land-use basins and Chester Creek at Arctic Boulevard (1982-84).

During rainfall-runoff periods coliform levels increased about 10 times at Arctic Boulevard. Average coliform counts ranged from 211 colonies/100 mL at Chester Creek tributary to 4,000 colonies/100 mL at North Fork Chester Creek tributary. Summarizing the coliform data with boxplots (fig. 10) indicates a significant difference between the residential areas and the commercial area. Results indicate that residential areas may be the primary source of fecal coliform bacteria.

Suspended Sediment

There are no formal water-quality criteria for suspended sediment relating to either human health or aquatic life. However, sediment is a stormwater pollutant that not only poses an aesthetic issue; it can exert harmful physical effects by covering fish spawning sites or altering habitat of benthic organisms. Suspended sediment in urban runoff also is likely to have other contaminants adsorbed onto it.

Chester Creek is a clear stream during base-flow periods. Concentrations of suspended sediment ranged from 1 to 35 mg/L at South Branch South Fork Chester Creek and from 6 to 38 mg/L at Arctic Boulevard (table 7). These relatively low values would be expected because no runoff occurs from the urbanized areas.

During rainfall-runoff periods suspended sediment is washed off from the urbanized areas into the main stem of Chester Creek. Most of the suspended sediment is composed of material finer than sand (less than .062 mm) (table 10). Suspended-sediment concentrations during these periods followed one of two patterns: (1) concentrations were highest during the initial part of the storm, commonly referred to as the "first flush", and then rapidly decreased (figs. 11 and 12), or (2) concentrations followed fluctuations in water discharge throughout the storm (figs. 13 and 14).

Ranges of suspended sediment generally were from 1 to 6,530 mg/L; mean concentrations rsnged from 147 to 208 mg/L (table 8). Summarizing the sediment data by using boxplots (fig. 15) indicates that the suspended-sediment concentrations from the two residential areas are not significantly different. However, they are significantly different from values for the commercial land-use site.

Some general observations can be made from the 11 suspended-sediment samples taken during snowmelt runoff periods. Suspended-sediment concentrations would peak during mid- or late afternoon when discharge was at its highest (fig. 16). As temperatures would fall during the night, discharge would decrease as would suspended-sediment concentrations.

During snowmelt periods mean concentrations of suspended sediment were 37 percent higher than for rainfall-runoff periods at South Branch South Fork tributary and 16 percent higher at Arctic Boulevard. At Chester Creek tributary mean concentrations were almost six times as high, which suggests that during this period commercial areas yield the highest concentrations of suspended sediment.

Relation Between Suspended Sediment and Trace Elements

During periods of high suspended-sediment concentrations, corresponding high levels of trace elements were noted (figs. 17 and 18). Because these metals have an affinity for sorption on sediment, linear regression techniques were used to relate suspended-sediment concentrations to trace-element concentrations. Because concentrations of cadmium were less than 10 µg/L for all samples, no regression analyses were made for this element.

Most of the trace elements show a good relation with suspended sediment (table 11). Poor relations exist between concentrations of zinc and suspended sediment at station 15275035 and between manganese and nickel at station 15275055. However, the equations suggest that certain trace elements are absorbed on the suspended sediment.

Bottom Sediments

On June 30, 1983, bottom material samples were collected at points along Chester Creek and analyzed for concentrations of selected trace metals and nutrients. The premise for this sampling was to determine if certain constituents are deposited in the streambed of Chester Creek or if these constituents flow completely out of the basin.

Proceeding downstream from the South Branch South Fork Chester Creek station concentrations of elements such as lead and zinc increase to elevated values of 230 µg/g lead and 400 µg/g zinc and then decrease to 80 µg/g lead and 40 µg/g zinc at Arctic Boulevard (fig. 19). Other elements such as aluminum, chromium, copper, iron, ammonia plus organic nitrogen, ammonia nitrogen, and phosphorus showed this same trend, but cadmium and nitrate-plus-nitrite nitrogen were below detection limits throughout the length of the stream. These data indicate that certain constituents are being deposited in the streambed of Chester Creek. However, more data would be needed to determine the exact locations of these sinks.

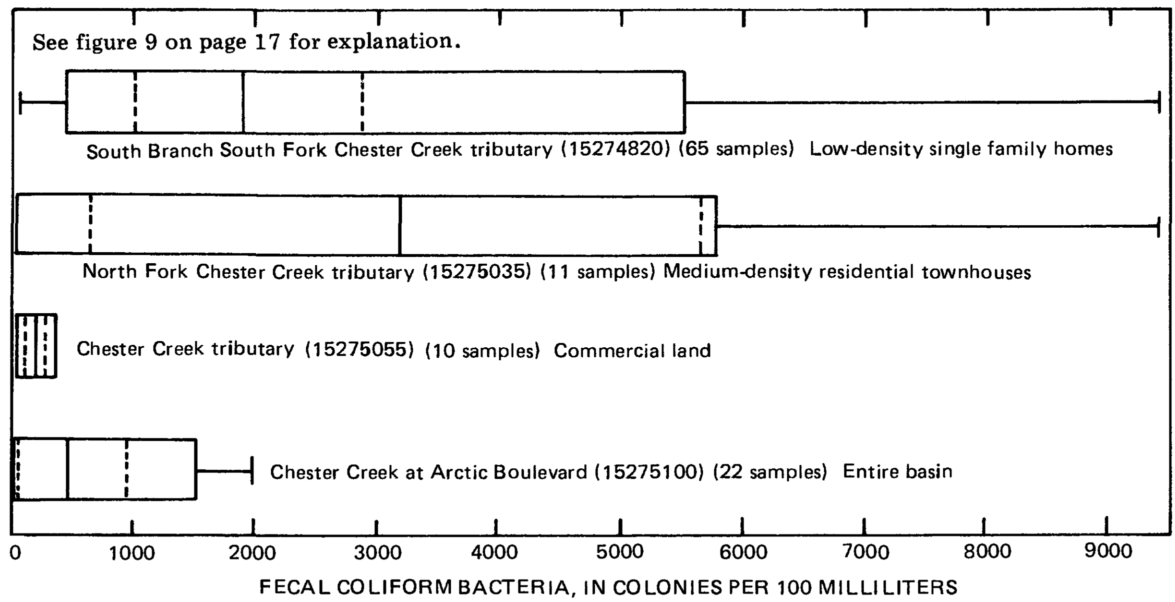

Figure 10.--Boxplots of fecal coliform bacteria for the three land-use basins and Chester Creek at Arctic Boulevard (1982-83).

Table 10.--Percentage of suspended sediment finer than 0.062 millimeters and concentrations for various samples

Station name (and number)	Date	Percent finer than 0.062 millimeters	Concentration (mg/L)
South Branch South Fork Chester Creek tributary (15274820)	8-11-82	83	20
	8-15-82	92	55
	8-15-82	98	68
	8-15-82	99	109
	9-03-82	98	20
	9-03-82	95	188
	9-03-82	97	20
	9-19-82	91	35
Chester Creek tributary (15275055)	8-15-82	90	102
	9-03-82	75	1,235
	9-03-82	99	518
	9-19-82	88	272
	9-19-82	97	245
	9-26-82	93	521
	9-26-82	97	482
	9-28-82	99	349
	9-28-82	88	392
Chester Creek at Arctic Boulevard (15275100)	7-10-81	91	299

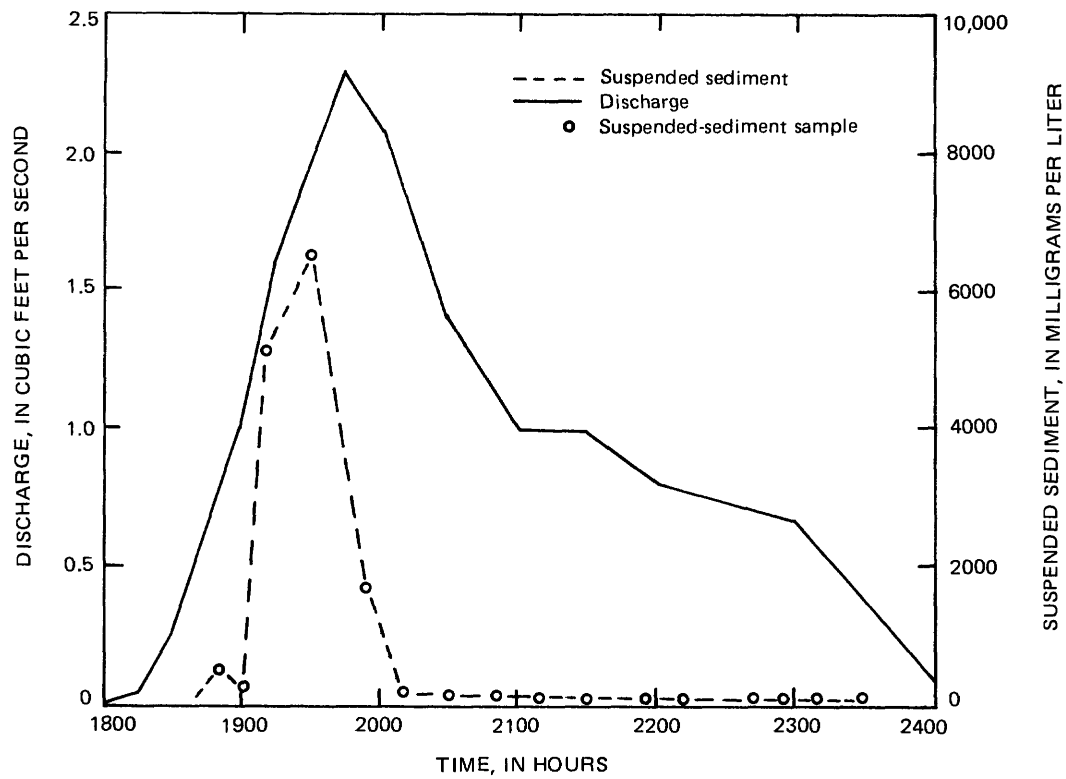

Figure 11.--Suspended-sediment and discharge hydrographs for storm of September 5, 1982 at Chester Creek tributary (15275055).

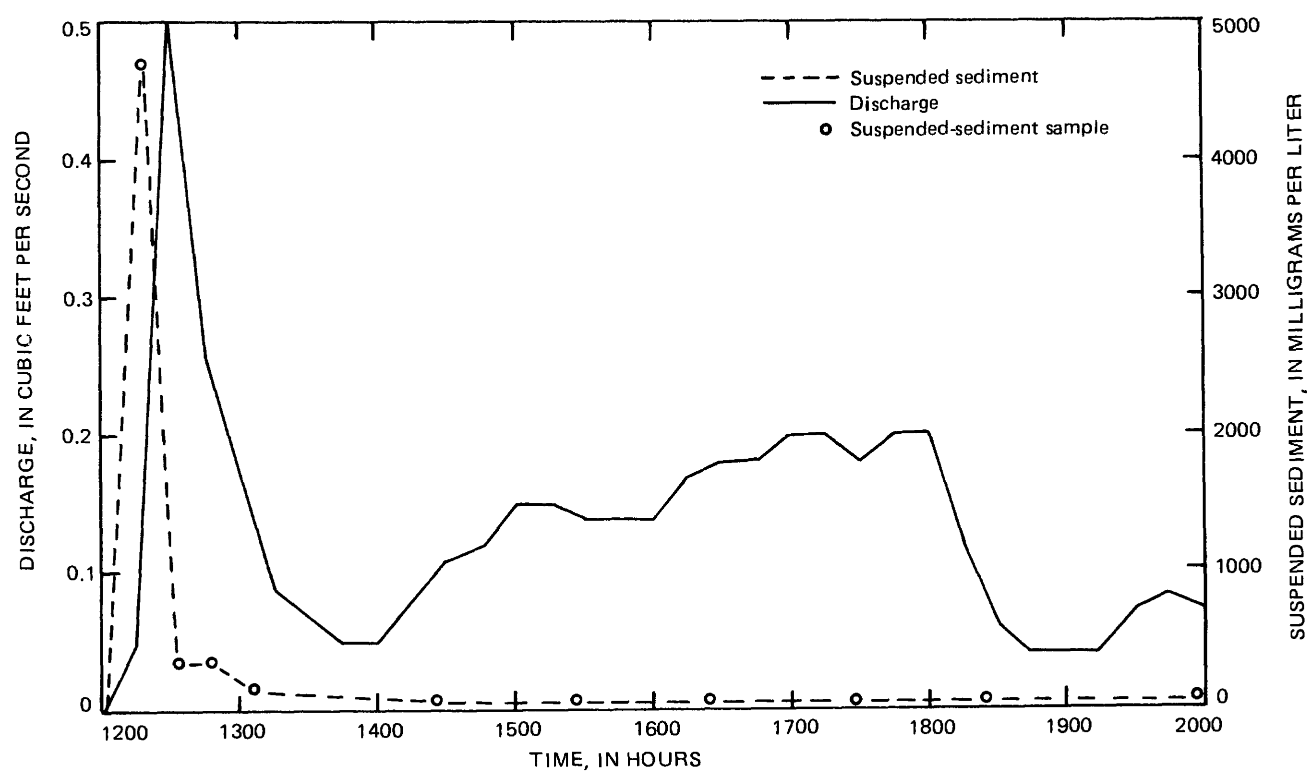

Figure 12.--Suspended-sediment and discharge hydrographs for storm of September 20, 1983 at South Branch South Fork Chester Creek tributary (15274820).

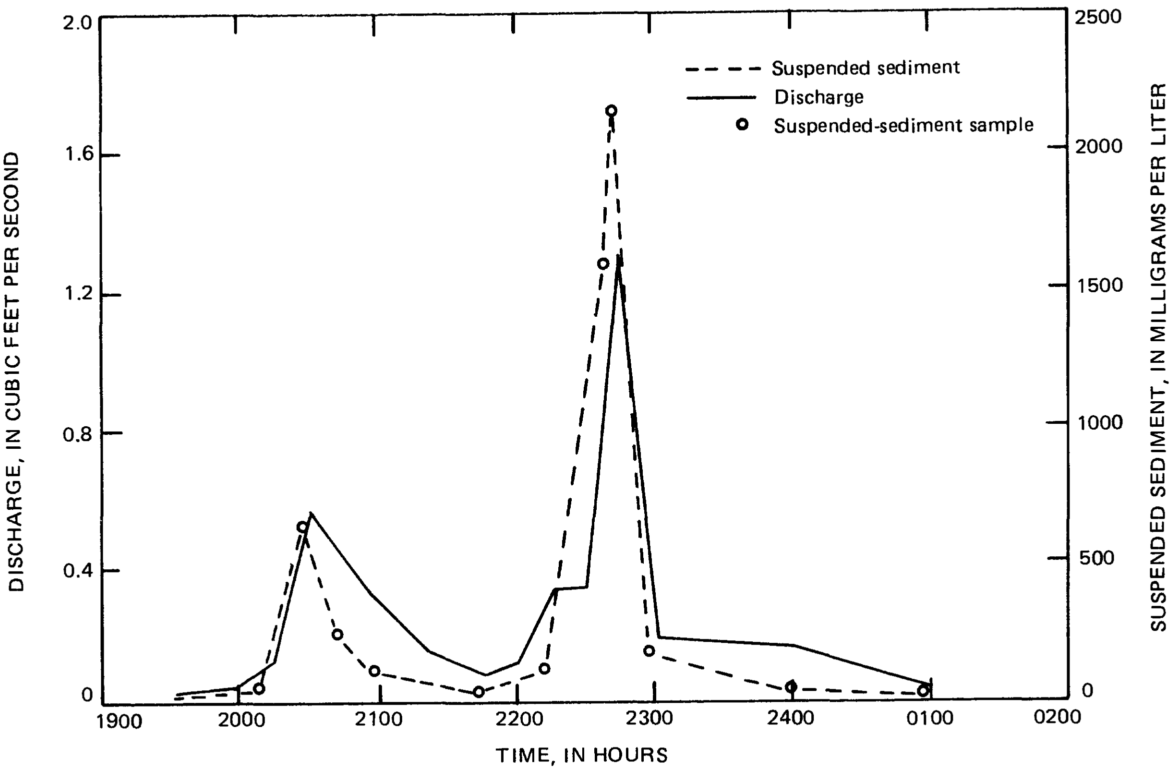

Figure 13.--Suspended-sediment and discharge hydrographs for storm of August 22, 1983 at South Branch South Fork Chester Creek tributary (15274820).

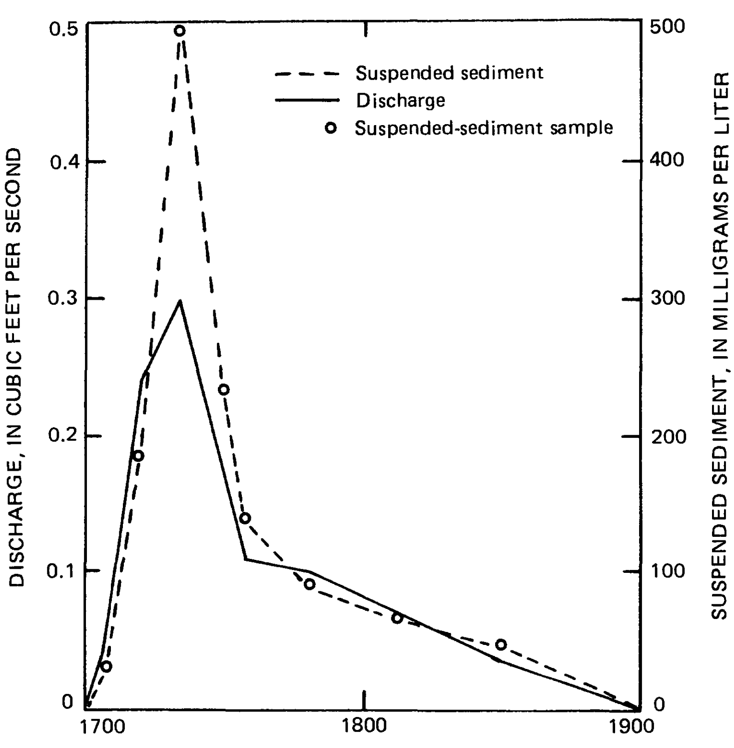

Figure 14.--Suspended-sediment and discharge hydrographs for storm of July 29, 1982 at Chester Creek tributary (15275055).

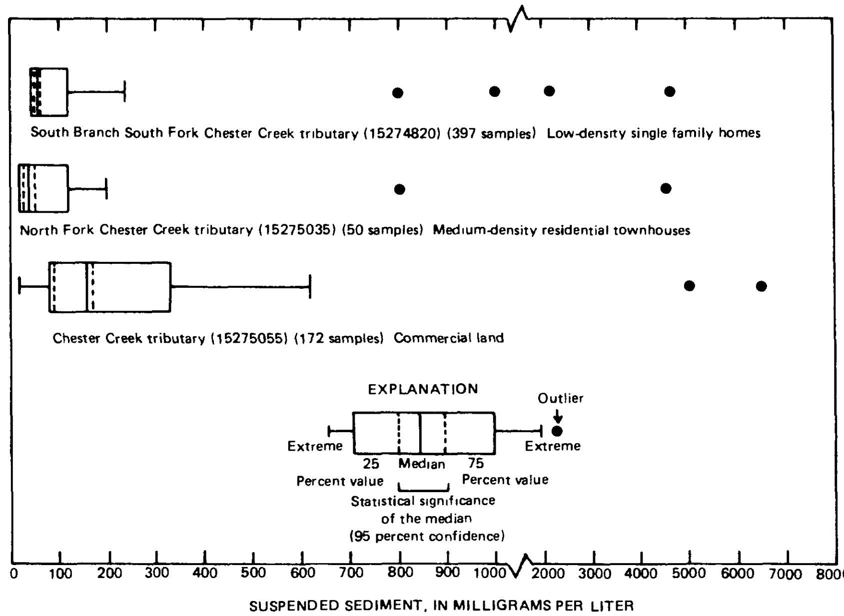

Figure 15.--Boxplots of suspended-sediment data for three land-use basins (1982-83).

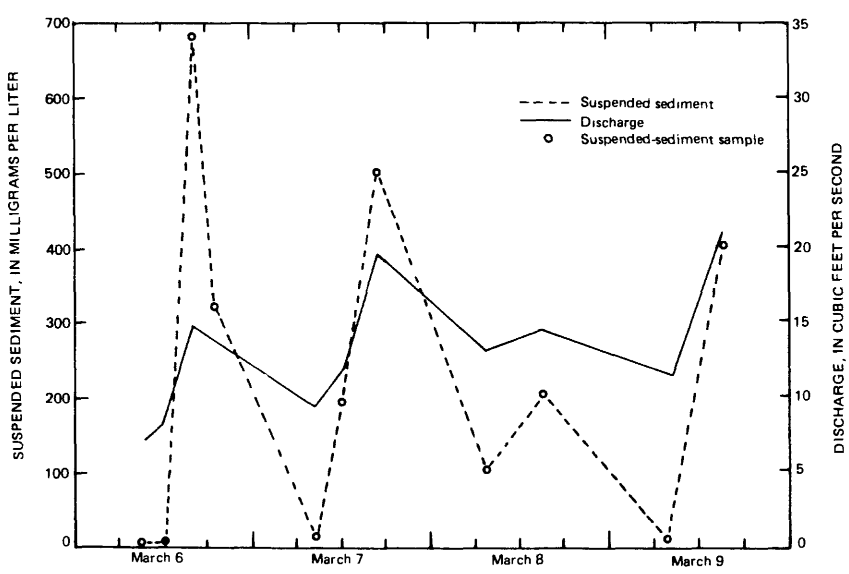

Figure 16.--Suspended-sediment and discharge hydrographs for Chester Creek at Arctic Boulevard (15275100) March 6-9, 1984.

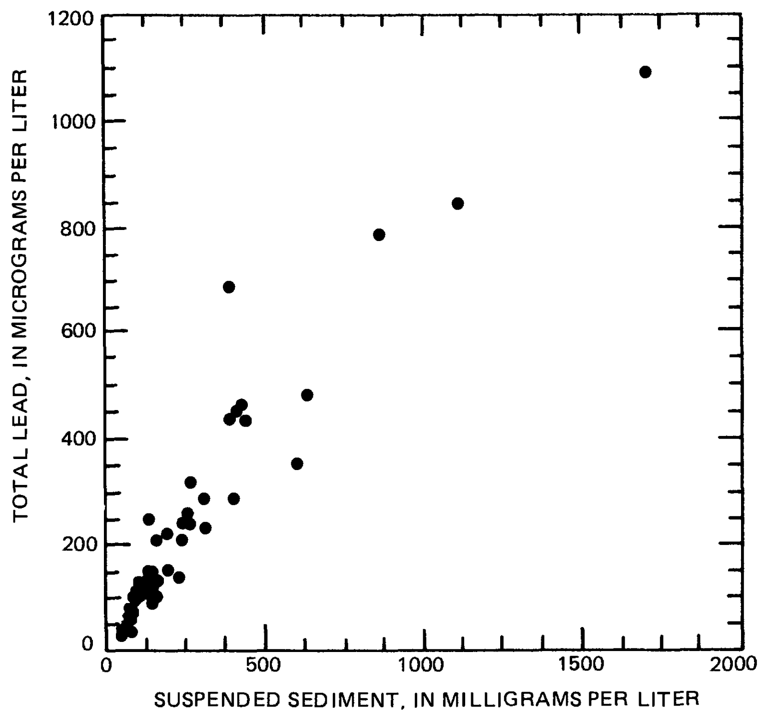

Figure 17.--Relation between total lead and suspended sediment for South Branch South Fork Chester Creek tributary (15274820), 1982-83.

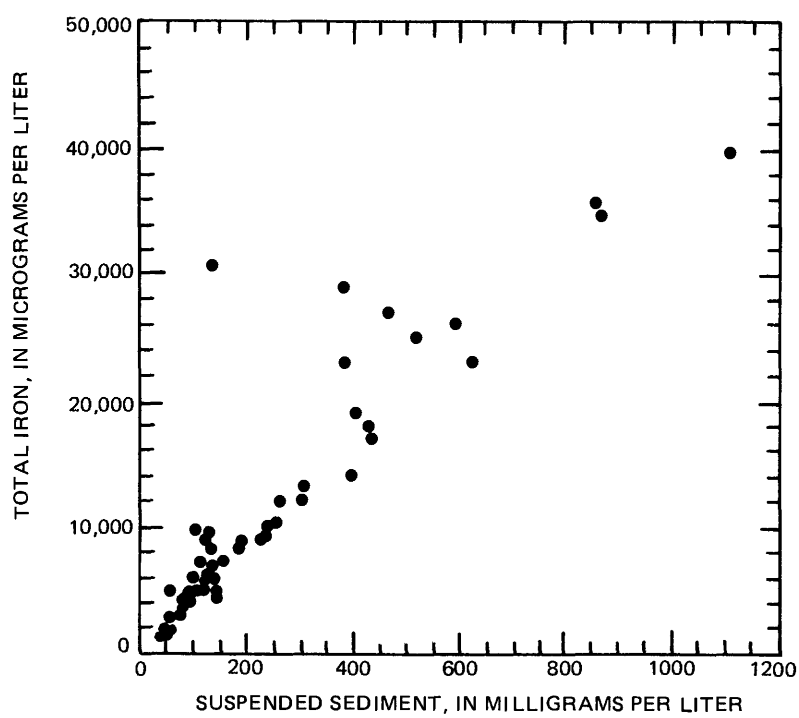

Figure 18.--Relation between total iron and suspended sediment for South Branch South Fork Chester Creek tributary (15274820), 1982-83.

Table 11.--Summary of regression analysis between selected trace metals and suspended sediment for the three land-use basins

[Al, Aluminum; Cr, Chromium; Cu, Copper; Fe, Iron; Pb, Lead; Mn, Maganese; Ni, Nickel; Zn, Zinc; all in micrograms per liter. SS, Suspended sediment, in milligrams per liter]

Station name and number (Land-use type)	Equation	Coefficient of determination	Standard error of estimate (µg/L)	Number of samples
South Branch South Fork Chester Creek tributary (15274820) (Low density)	Al=24.8(SS) + 755	0.90	1,740	83
	Cr=0.029(SS) + 13.8	.65	8.4	23
	Cu=0.098(SS) + 26.3	.66	14.3	54
	Fe=39.0(SS) + 2,090	.83	3,600	83
	Pb=0.69(SS) + 47.7	.79	90	83
	Mn=1.33(SS) + 11.8	.90	18.3	9
	Ni=0.09(SS) - 1.72	.81	1.8	9
	Zn=0.58(SS) + 64.3	.80	57.2	59
North Fork Chester Creek tributary (15275035) (Medium density)	Al=16.8(SS) + 2,570	0.96	3,500	21
	Cr=0.08(SS) + 6.4	.77	5.0	8
	Cu=0.13(SS) + 14.2	.98	19.2	20
	Fe=39.1(SS) - 92.0	.98	1,390	18
	Pb=0.41(SS) + 9.5	.98	16.8	20
	Mn=1.05(SS) + 90.3	.96	22.4	8
	Ni=0.05(SS) + 1.7	.81	2.6	8
	Zn=0.32(SS) + 131	.18	175	18
Chester Creek Tributary (15275055) (Commercial)	Al=22.9(SS) + 2,774	0.90	5,000	18
	Cr=1.36(SS) - 209	.94	236	12
	Cu=0.16(SS) + 8.3	.95	24.3	12
	Fe=50.3(SS) - 1,865	.97	4,164	17
	Pb=0.62(SS) + 192	.40	516	18
	Mn=-0.21(SS) + 122	.06	.2	5
	Ni=1.15(SS) - 70.6	.32	34	5
	Zn=0.63(SS) + 132	.88	117	17
Chester Creek at Arctic Boulevard (15275100) (Entire basin)	Al=29.5(SS) - 142	0.98	745	36
	Cr=0.08(SS) + 2.3	.96	2.0	16
	Cu=0.11(SS) + 5.4	.77	7.0	21
	Fe=69.5(SS) - 687	.92	3,370	36
	Pb=0.49(SS) + 1.2	.81	42.4	35
	Mn=1.6(SS) + 152	.96	39.0	12
	Ni=0.12(SS) + 4.2	.96	3.6	10
	Zn=0.87(SS) + 55.7	.83	69.5	35

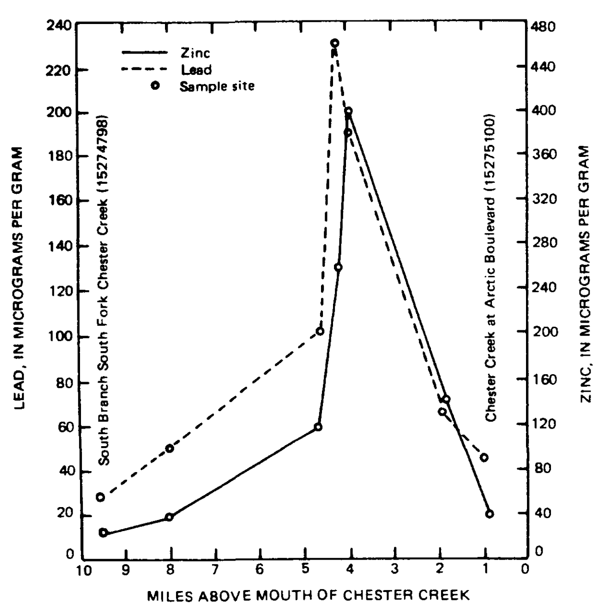

Figure 19.--Relation between lead and zinc in bottom materials and distance along Chester Creek.

LOADS OF SELECTED CONSTITUENTS

Loads of various water-quality constituents can be useful for various applications. For example, the annual or seasonal loads of a water-quality constituent may provide information in determining the cumulative impact on a stream. In designing water-quality control structures such as detention ponds or oil-grease separators, water-quality loads are important in the proper design. Therefore, this section provides information on loads of selected water-quality constituents.

Sodium and Chloride

Because sodium and chloride concentrations relate quite well to specific conductance (figs. 20 and 21) and daily records of specific conductance and discharge are available at Chester Creek at Arctic Boulevard, loads for these two constituents were determined as follows:

1) Given mean daily specific conductance (SC) in microsiemens per centimeter, then:

   Mean daily chloride concentration
   $Cl = 0.29(SC) - 54.3$ mg/L, and

   Mean daily sodium concentration
   $Na = 0.16(SC) - 30.4$ mg/L

2) Daily loads, in tons

   $\text{Chloride} = (Cl)\ (Q)\ (0.0027)$ and
   $\text{Sodium} = (Na)\ (Q)\ (0.0027)$
   where Q is mean daily discharge, in cubic feet per second.

Monthly and annual loads for chloride and sodium were computed for the 1982, 1983, and 1984 water years (table 12). The highest monthly loads usually occurred in March and April, the normal snowmelt period, and account for 20 to 38 percent of the total annual load. During certain months, such as October, loads vary widely due to combinations of snowfall and snowmelt occurring within the same month.

Annual loads ranged from 394 to 635 tons chloride and from 214 to 342 tons sodium. The higher loads result from the greater use of de-icing salts during times of more frequent and/or greater snowfall.

Suspended Sediment

The simplest relation between suspended-sediment load and water discharge is represented by an instantaneous sediment rating curve (fig. 22). Ideally, to compute the annual sediment discharge, sediment samples should be collected over several years. Although the sediment rating curves represent only the 2-year data collection for this project, some general observations can be made. For example it appears that relatively low amounts of sediment are transported past the South Branch South Fork Chester Creek gage compared to the Chester Creek at Arctic Boulevard gage. Also, for a given discharge, more sediment will be transported past the Arctic Boulevard gage during snowmelt periods than during stormflow periods at the same discharge.

Annual sediment yields for South Branch South Fork Chester Creek and Chester Creek at Arctic Boulevard, were determined by the transport-duration technique. This technique makes use of (1) sediment discharge/water discharge curves and (2) streamflow duration curves that define the percentage of time that any flow value was equaled or exceeded. Using this technique, the suspended-sediment yield from South Branch South Fork Chester Creek for the study period was calculated to be 1.8 ton/mi^2 while the annual yield past the Chester Creek at Arctic Boulevard gage was 25.4 ton/mi^2.

Storm loads of suspended sediment were determined for the South Branch South Fork Chester Creek tributary, North Fork Chester Creek tributary, and Chester Creek tributary. The method of computation was to estimate a constituent concentration corresponding to each discharge. This is done by linear interpolation between measured concentrations. The corresponding discharge is then multiplied by the constituent concentration and an appropriate conversion factor to compute instantaneous loads. The "load curve" is then integrated to determine the storm-runoff load (fig. 23). Loads were computed only if a sufficient number of samples were collected throughout the storm.

Suspended-sediment loads ranged from 4.8 to 87.9 (lb/acre)/in. of runoff (table 13) at the three sites. The wide variation in loads could be due to a number of factors, such as antecedent precipitation conditions, rainfall intensity, and storm duration. Chester Creek tributary had the highest average value of sediment loads: 47.7 (lb/acre)/in. of runoff.

For purposes of comparison, suspended-sediment loads were determined for a snowmelt period, March 6-14, 1984 at the South Branch South Fork tributary and at Chester Creek tributary (table 14). Loads at both these stations were higher during snowmelt periods than during rainfall periods. The average load was approximately six times greater during snowmelt periods at South Branch South Fork tributary and approximately four times greater at Chester Creek tributary.

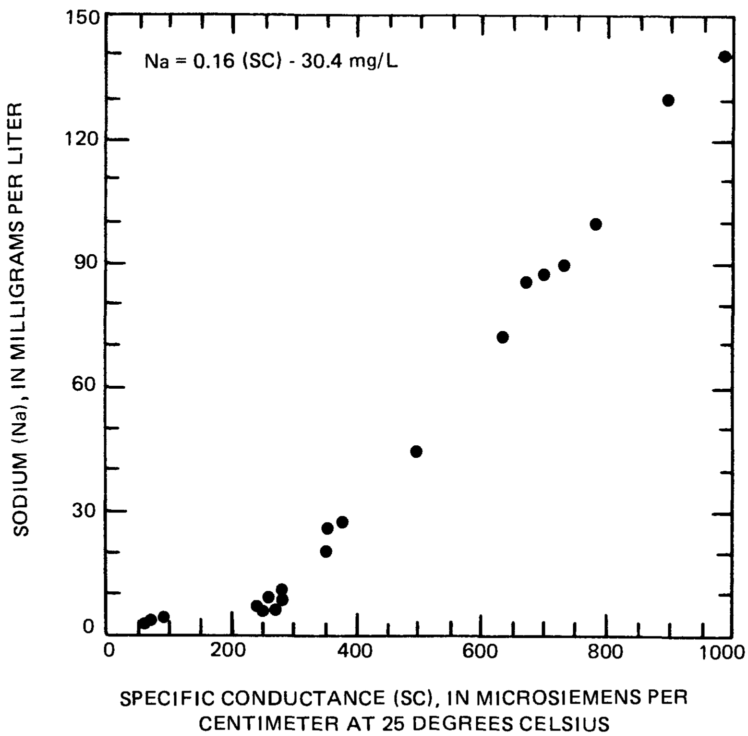

Figure 20.--Relation between sodium and specific conductance at Chester Creek at Arctic Boulevard (15275100).

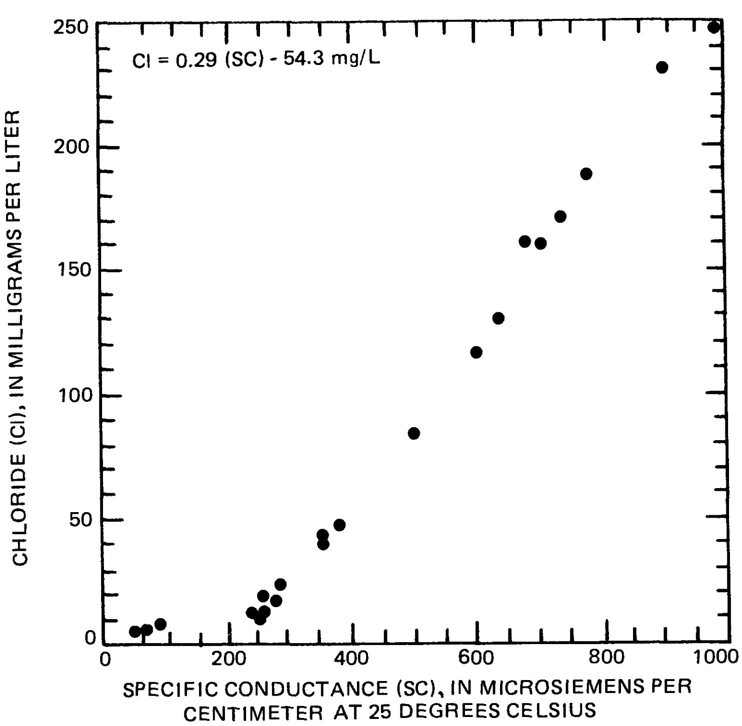

Figure 21.--Relation between chloride and specific conductance at Chester Creek at Arctic Boulevard (15275100).

Table 12.--Monthly loads of chloride and sodium for Chester Creek at Arctic Boulevard (station 15275100) [Values in short tons]

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total	Snow (in.)
						Chloride								
1982	48.3	23.5	14.9	4.1	42.9	34.4	46.6	32.9	32.3	33.1	32.2	34.0	394	46.3
1983	109	58.6	68.0	40.1	32.7	72.5	66.3	58.2	38.8	33.5	27.3	28.5	630	71.4
1984	50.3	44.6	40.4	46.0	23.2	107	137	57.7	39.0	32.2	21.7	30.0	635	80.2
						Sodium								
1982	27.5	14.8	9.7	3.3	22.7	18.2	25.4	18.1	17.8	18.1	17.7	20.9	214	--
1983	59.6	32.5	35.6	22.3	17.5	39.5	35.9	28.4	21.6	18.0	15.7	15.7	342	--
1984	27.4	22.4	22.3	24.8	13.1	58.4	74.7	30.9	20.8	17.8	12.6	15.0	340	--

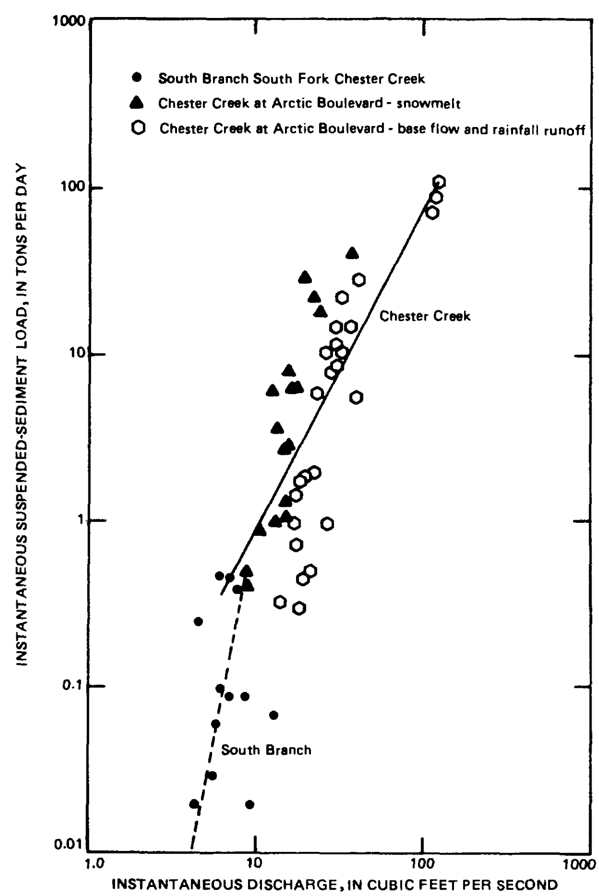

Figure 22.--Relation between suspended-sediment load and discharge for South Branch South Fork Chester Creek (15274798) and Chester Creek at Arctic Boulevard (15275100).

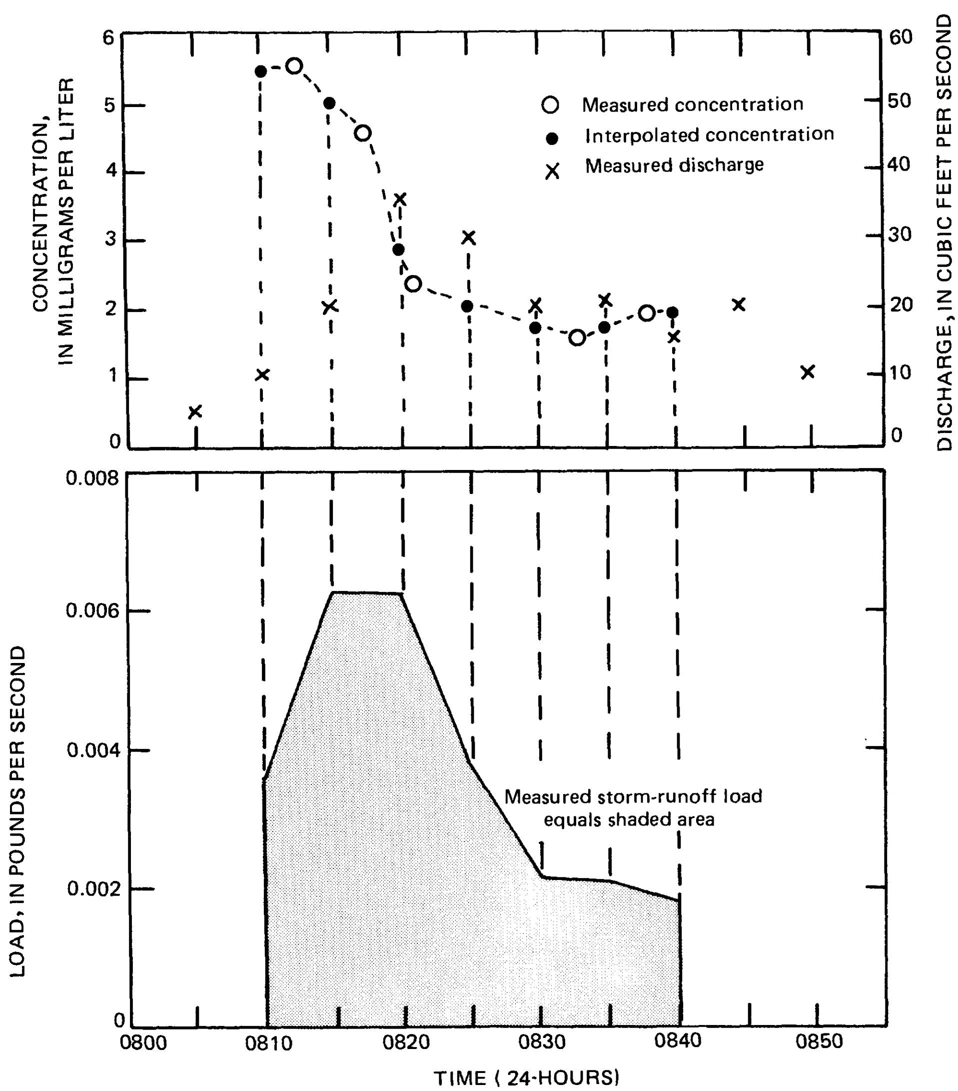

Figure 23.--Computation of measured storm-runoff loads (hypothetical example).

Table 13.--Storm loads of suspended sediment for South Branch South Fork Chester Creek tributary, North Fork Chester Creek tributary, and Chester Creek tributary

Station name and number (Land-use type)	Drainage area (acres)	Date	Rainfall (in.)	Runoff volume (in.)	Suspended sediment (lb)	Suspended sediment [(lb/scre)/in.] of runoff
South Branch South Fork Chester Creek tributary (15274820) (Low density)	9.6	7-29-82	0.08	0.024	12.4	53.8
		8-25-82	.08	.01	6.4	66.7
		9-05-82	.31	.06	6.0	10.4
		9-14-82	.50	.133	9.6	7.5
		9-15-82	.19	.03	3.9	13.5
		9-16-82	.23	.11	5.1	4.8
		9-18-82	.30	.09	8.3	9.6
		9-19-82	.22	.06	5.7	9.9
		5-08-83	.11	.025	21.1	87.9
		5-30-83	.13	.029	19.0	68.2
		6-02-83	.16	.026	9.7	38.9
		6-09-83	.18	.046	17.8	40.3
		7-01-83	.17	.041	4.3	10.9
		7-06-83	.48	.129	57.4	46.4
		7-21-83	.10	.039	22.5	60.1
		7-23-83	.06	.01	1.2	12.5
		8-05-83	.14	.022	5.0	23.7
		8-13-83	.54	.133	55.4	43.4
		8-15-83	.08	.037	9.5	26.7
		8-22-83	.55	.09	17.1	19.8
		9-01-83	.23	.059	22.9	40.4
		9-14-83	.23	.042	16.9	41.9
		9-19-83	.16	.04	6.5	16.9
		9-20-83	.35	.11	25.6	24.2
					Average:	32.4
North Fork Chester Creek tributary (15275035) (Medium density)	2.6	7-23-82	0.12	0.013	11.6	34.8
		8-10-82	.14	.013	.9	26.6
		8-15-82	.13	.011	.2	7.0
		8-23-83	.30	.04	1.2	11.5
					Average:	20.0
Chester Creek tributary (15275055) (Commercial)	38.4	7-08-82	0.08	0.027	76.7	74.0
		7-11-82	.09	.034	67.3	51.5
		7-15-82	.42	.037	44.0	31.0
		7-30-82	.19	.011	16.4	38.8
		7-30-82	.22	.002	3.3	43.0
		9-03-82	.10	.01	15.0	39.0
		9-05-82	.31	.15	203	35.2
		9-26-82	.14	.05	103	53.6
		4-29-83	.16	.07	124	46.1
		5-30-83	.15	.06	136	59.0
		6-02-83	.18	.07	130	48.4
		7-23-83	.12	.06	122	53.0
					Average:	47.7

Table 14.--Suspended-sediment loads for snowmelt periods at South Branch South Fork Chester Creek tributary and Chester Creek tributary

Station name and number (Land-use type)	Drainage area (acres)	Date	Runoff volume (in.)	Suspended sediment (lb)	Suspended sediment [(lb/acre)/in.] of runoff
South Branch South Fork Chester Creek tributary (15274820) (Low density)	9.6	3-07-84	0.05	97	202
		3-08-84	.07	143	212
		3-09-84	.11	213	202
		3-10-84	.11	184	174
		3-11-84	.09	146	169
		3-12-84	.07	102	152
		3-13-84	.05	73	152
		3-14-84	.002	3	156
				Mean:	177
Chester Creek tributary (15275055) (Commercial)	38.4	3-07-84	0.18	1,458	210
		3-08-84	.12	1,400	304
		3-09-84	.16	1,400	228
		3-10-84	.18	1,400	202
		3-11-84	.20	1,600	208
		3-12-84	.14	1,000	186
		3-13-84	.09	600	174
		3-14-84	.08	600	195
				Mean:	213

Atmospheric Fallout

Land surfaces are continuously subjected to dry fallout from the atmosphere. One widely accepted theory (Alley, 1976) is that airborne particles may contribute significantly to the load of chemical constituents washed off land surfaces during storm events. These constituents reach the land surface either as dustfall (dry deposition) or are contained in precipitation (wet deposition).

Properties of atmospheric fallout are of concern, if interest is centered on non-point source contributions to water-quality impairment, or on the ambient quality of rainfall before it reaches the land surface. Although the state of knowledge in collection of atmospheric fallout data is limited and somewhat controversial, samples of wet deposition (rain and snow) and dry deposition (particulates, aerosols, gases) were collected in this study. The results presented are intended to serve as only a qualitative indicator of the magnitude of ambient sources rather than as a quantitative measure of deposition over a watershed.

Samples were collected at two locations: at Chester Creek tributary, the commercial land use area, and at the Arctic Valley climate station, which is unaffected by urban development. Most dry-deposition samples were collected at fixed intervals, usually once a month. Wet-deposition samples also were collected on a monthly basis, although some samples were collected more frequently if several precipitation events occurred within a shorter time span. Samples were analyzed for suspended solids, lead, ammonia nitrogen, nitrate-plus-nitrite nitrogen, and phosphorus.

No apparent differences were found in wet deposition at the two sites (tables 15 and 16). Specific conductance of the samples ranged from 4 to 22 μS/cm which indicates that concentrations of any dissolved constituents were low. Concentrations and loads of suspended solids, lead, nitrogen, and phosphorus at the two sites were also similar.

Analyses of dry-deposition samples from the two sites (tables 17-18) do indicate differences in suspended solids and lead loads. Higher amounts of these two constituents probably are deposited on the land surfaces in the urban areas. Loads of nitrogen and phosphorus show no apparent differences.

The suspended-sediment load in the stream at the Chester Creek tributary station for the 1983 rainfall season (April to September) was determined as follows:

$$LOAD = (PR)(RAIN)(MSS)(0.23)$$

where PR is percent rainfall that is runoff = 0.50 (table 6);
RAIN is total rainfall for April to September, 1983;
MSS is mean suspended sediment concentration in milligrams per liter (table 8) = 177 mg/L; and
0.23 is conversion factor.

This load was then compared with wet-deposition and dry-deposition loads from Arctic Valley climate station and Chester Creek tributary (fig. 24).

Indications are that wet deposition does not contribute a significant seasonal suspended-sediment load in Chester Creek, but analysis of dry-deposition data is inconclusive. Suspended-solids load in dry fallout at Arctic Valley climate station was 10 lb/acre; the comparable load at Chester Creek tributary was 60 lb/acre, about half the suspended-sediment load in the stream at this site. However, it is unlikely that the data collection site at Chester Creek tributary is representative of the entire basin. The collection site is near a main highway with a significant amount of truck traffic. Also, it is uncertain whether traffic merely resuspends sediments already on ground surfaces. More study in this area is needed.

PLANNING TOOLS

Currently, attention is being focused on the effects of future development on Chester Creek and other local streams. Although no exact answers can be given, several statistical and mathematical models which may be useful are described. These techniques could be useful in estimating the effects of different development schemes, thereby obtaining answers to planning and design problems such as the cause and effect relationships of urban runoff and water pollution. The methods can be used with relative ease and low computer costs.

Statistical Equations

Using the stormflow data collected at the three land-use basins (stations 15274820, 15275035, and 15275055) regression techniques were used to estimate storm and peak discharge from various physical and climatological variables. The variables considered were: total rainfall for the storm, average rainfall intensity, previous 7-day rainfall, basin area, percent effective impervious area, and basin slope. Variables that proved to be statistically significant were: basin area, percent effective impervious area, and total rainfall for the storm (significant variables are those that the F test indicated were

Table 15.- Quality of wet deposition at Chester Creek tributary (station 15275055)

[Load of constituent = (concentration of constituent) (volume collected)/ cross sectional area at the top of the collection cylinder]

Period	Total precipitation (in.)	pH	Specific conductance (µS/cm)	Suspended solids (mg/L)	Suspended solids load (lb/acre)	Total lead (µg/L)	Total lead load (lb/acre)
1983							
4-1 to 4-27	0.73	6.2	11	--	--	5.0	0.0006
4-27 to 5-19	.38	5.4	13	14	2.26	--	--
5-19 to 6-14	.57	5.4	11	--	--	--	--
6-14 to 7-7	.66	5.6	6	1	.20	2.9	.0005
7-7 to 8-1	.18	--	--	--	--	--	--
8-1 to 8-15	.99	6.0	5	1	.20	--	--
8-15 to 9-2	1.47	5.1	8	1	.39	--	--
9-2 to 11-1	3.26	6.4	10	11	1.72	--	--
11-1 to 1-9	.86	6.0	--	--	--	--	--
1984							
1-9 to 2-1	0.65	5.0	16	9	1.36	1.0	0.0003
2-1 to 2-29	.87	4.4	9	6	1.09	--	--
2-29 to 4-9	.10	4.7	10	15	.58	--	--

Period	Total ammonia nitrogen-as N (mg/L)	Total ammonia nitrogen-as N load(lb/acre)	Total NO_2+NO_3 (mg/L)	Total NO_2+NO_3 load (lb/acre)	Total phosphorus (mg/L)	Total phosphorus load (lb/acre)
1983						
4-1 to 4-27	0.240	0.029	0.160	0.020	0.008	0.001
4-27 to 5-19	.140	.023	.275	.044	.021	.003
5-19 to 6-14	.261	.041	.119	.019	.012	.002
6-14 to 7-7	.271	.055	.100	.020	.006	.001
7-7 to 8-1	--	--	--	--	--	--
8-1 to 8-15	.078	.016	.051	.010	.005	.001
8-15 to 9-2	.203	.080	.102	.040	.005	.002
9-2 to 11-1	.243	.038	.132	.021	.021	.003
11-1 to 1-9	--	--	--	--	--	--
1984						
1-9 to 2-1	0.126	0.043	0.077	0.026	0.005	0.002
2-1 to 2-29	.209	.038	.489	.089	.003	.001
2-29 to 4-9	.628	.110	.249	.044	.006	.001

Table 16.--Quality of wet deposition at Arctic Valley climate station
[Load of constituent = (concentration of constituent) (volume collected)/ cross sectional area at the top of the collection cylinder]

Period	Total precipitation (in.)	pH	Specific conductance (µS/cm)	Suspended solids (mg/L)	Suspended solids load (lb/acre)	Total lead (µg/L)	Total lead load (lb/acre)
1982							
11-23 to 12-10	0.97	7.6	4	---	---	---	---
12-10 to 1-14	.33	4.9	6	---	---	---	---
1983							
1-14 to 1-21	0.32	7.7	10	---	---	---	---
1-21 to 2-10	.38	5.8	6	---	---	---	---
2-10 to 4-7	.40	5.7	5	1	.15	5	0.007
4-10 to 4-25	1.08	---	---	---	---	---	---
4-25 to 5-19	.20	5.4	13	11	.86	---	---
5-19 to 6-16	1.15	5.3	8	1	.32	4.6	.0014
6-16 to 7-8	.92	5.3	4	2	.49	.6	.001
7-8 to 7-29	1.08	5.4	5	1	.26	---	---
7-29 to 8-17	1.78	5.2	9	1	.46	3.1	.0014
8-17 to 8-29	1.23	5.5	22	1	.36	---	---
8-29 to 10-12	3.26	4.6	4	1	1.57	---	---
10-12 to 12-8	2.54	4.3	4	3	.94	---	---
12-8 to 1-17	.51	4.3	4	3	.66	---	---
1984							
1-17 to 2-1	0.14	4.8	---	---	---	---	---
2-1 to 3-1	.38	4.7	14	11	3.10	---	---
3-1 to 4-6	.35	4.1	5	5	1.10	2.0	0.0004
4-6 to 5-7	1.43	4.2	9	2	.71	---	---
5-7 to 6-8	.48	4.1	6	4	.69	4.0	.0006
6-8 to 7-7	1.63	4.8	5	---	---	---	---
7-7 to 8-3	2.77	4.2	8	10	3.77	1.0	.0003
8-3 to 8-29	1.63	4.8	4	1	.52	4.0	.0020
8-29 to 10-3	1.60	5.5	4	2	.94	---	---

Period	Total ammonia nitrogen-as N (mg/L)	Total ammonia nitrogen-as N load (lb/acre)	Total NO_2+NO_3 (mg/L)	Total NO_2+NO_3 load (lb/acre)	Total phosphorus (mg/L)	Total phosphorus load (lb/acre)
1982						
11-23 to 12-10	---	---	---	---	---	---
12-10 to 1-14	---	---	---	---	---	---
1983						
1-14 to 1-21	---	---	---	---	---	---
1-21 to 2-10	---	---	---	---	---	---
2-10 to 4-7	0.067	0.010	0.033	0.005	0.010	0.001
4-10 to 4-25	---	---	---	---	---	---
4-25 to 5-19	.089	.007	.151	.012	.024	.002
5-19 to 6-16	.072	.023	.171	.055	.006	.002
6-16 to 7-8	.090	.022	.036	.009	.007	.002
7-8 to 7-29	.085	.022	.130	.034	.010	.002
7-29 to 8-17	.073	.033	.089	.040	.005	.002
8-17 to 8-29	.135	.048	.072	.026	.005	.002
8-29 to 10-12	.059	.093	.055	.086	.005	.008
10-12 to 12-8	.035	.011	.034	.011	.005	.002
12-8 to 1-17	.181	.040	.209	.046	.009	.002
1984						
1-17 to 2-1	---	---	---	---	---	---
2-1 to 3-1	0.205	0.058	0.449	0.127	0.006	0.002
3-1 to 4-6	.223	.050	.111	.025	.005	.001
4-6 to 5-7	.101	.036	.100	.035	.005	.002
5-7 to 6-8	.127	.022	.271	.047	.010	.002
6-8 to 7-7	---	---	---	---	---	---
7-7 to 8-3	.098	.037	.099	.037	.007	.003
8-3 to 8-29	.048	.025	.044	.023	---	---
8-29 to 10-3	.015	.007	.030	.014	.005	.002

Table 17.--Quality of dry deposition at Chester Creek tributary (station 15275055)
[Values in pounds per acres; load of consituent = (amount of constituent collected)/(cross-sectional area at the top of the collection cylinder)]

Period	Suspended solids load	Total lead load	Total ammonia nitrogen-as N load	Total NO_2+NO_3 load	Total phosphorus load
1983					
4-1 to 4-27	17.3	0.010	0.017	--	0.014
4-27 to 5-19	11.4	--	.015	0.031	.021
5-19 to 6-14	7.8	.007	.001	.016	.008
6-14 to 7-7	2.9	.004	.006	.017	.006
7-7 to 8-1	6.7	.010	.010	.017	.001
8-1 to 8-15	3.7	.003	.008	.011	.002
8-15 to 9-2	5.0	.003	.007	.010	.000
9-2 to 11-1	1.5	.007	.026	.032	.018
11-1 to 1-9	4.4	.009	.111	.059	.063
1984					
1-9 to 2-1	1.2	0.006	0.041	0.021	0.001
2-1 to 2-29	.3	--	.015	.032	.000
2-29 to 4-9	25.5	.028	.033	.046	.016

Table 18.--Quality of dry deposition at Arctic Valley climate station
[Values in pounds per acre; load of constituent = (amount of constituent collected/(cross-sectional area at the top of the collection cylinder)]

Period	Suspended solids load	Total lead load	Total ammonia nitrogen-as N load	Total NO_2+NO_3 load	Total phosphorus load
1982					
11-23 to 12-10	0.03	--	--	--	--
12-10 to 1-14	1.10	--	--	--	--
1983					
2-10 to 4-7	0.86	0.0	0.006	--	0.00
4-10 to 4-25	.08	--	.002	--	.001
4-25 to 5-19	1.80	--	.013	0.023	.004
5-19 to 6-16	5.02	.001	.011	.026	.005
6-16 to 7-8	3.30	.001	.019	.028	.004
7-8 to 7-29	.16	.001	.010	.025	.003
7-29 to 8-17	1.26	.002	.018	.014	.001
8-17 to 8-29	.47	.001	.016	.015	.030
8-29 to 10-12	.16	--	.008	.002	.001
10-12 to 12-8	.62	--	.022	.017	.024
12-8 to 1-17	1.88	.001	.017	.030	.001
1984					
1-17 to 2-1	0.94	0.00	0.004	0.003	0.001
2-1 to 3-1	1.10	--	.022	.073	.001
3-1 to 4-6	.16	.001	.023	.024	.000
4-6 to 5-7	.16	.003	.006	.010	.001
5-7 to 6-8	4.08	.002	.012	.002	.022
6-8 to 7-7	2.51	.001	.006	.021	.006
7-7 to 8-3	1.10	.000	.046	.044	.009
8-3 to 8-29	1.57	.001	.006	.027	--
8-29 to 10-3	1.72	--	.002	.002	.018

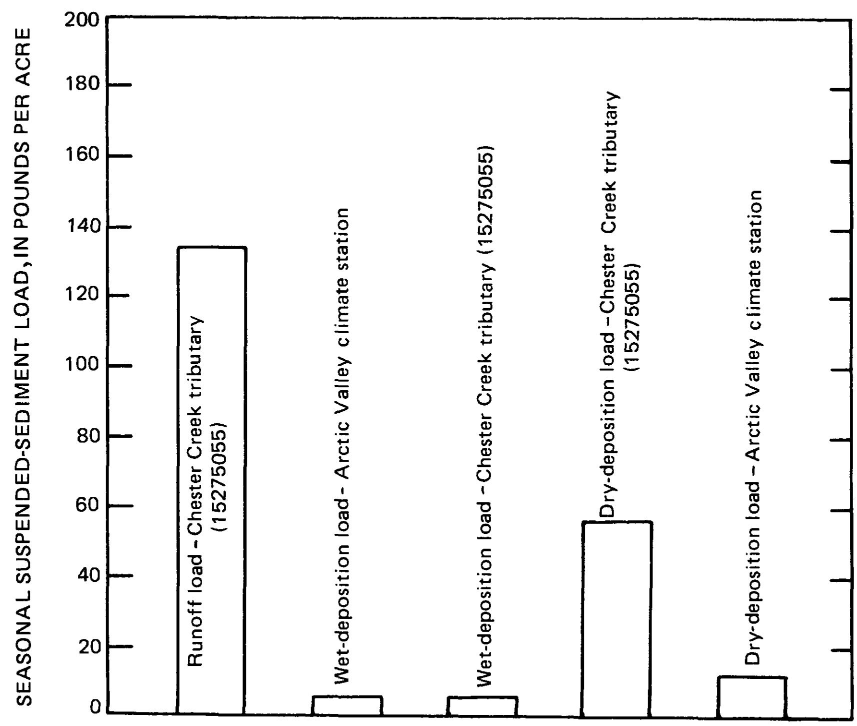

Figure 24.--Comparison of seasonal loads of suspended sediment from runoff, wet deposition, and dry deposition.

significant at the 5 percent level and those that increased the coefficient of determination by 5 percent or decreased the standard error of estimate by 5 percent). The regression analysis produced the following equations:

$$VOL = 0.39\ (RF)^{1.10}\ (DA)^{0.14}\ (PEIA)^{0.38}$$

Number of observations = 62
Coefficient of determination = 0.76
Standard error of estimate (percent) = 43

where VOL is volume of runoff, in inches;
RF is rainfall, in inches;
DA is drainage area in acres; and
PEIA is percent effective impervious area.

$$QPEAK = 0.09\ (RF)^{0.68}\ (DA)^{1.08}\ (PEIA)^{0.24}$$

Number of observations = 72
Coefficient of determination = 0.85
Standard error of estimate (percent) = 54

where QPEAK is peak discharge, in cubic feet per second;
RF is rainfall, in inches;
DA is drainage area, in acres; and
PEIA is percent effective impervious area.

Users of these equations should note that estimates of storm volume and peak discharge become less accurate as the size of the basin increases above 38 acres, the percent effective impervious area increases above 70 percent, and the storm rainfall increases above 0.50 in., the largest factors used in the regression analysis. However, the regression equations could be useful for planning purposes where no data have been collected.

A similar regression analysis was done for suspended-sediment loads for the three basins with different land uses. The variables used in the analysis of storm volumes and peak discharges were also used for this analysis.

The variables rainfall, drainage area, and percent effective impervious area again were the only significant variables. However, the standard error of the resulting equation was greater than 150 percent. Volume was then considered as an independent variable and the following equation developed:

$$SSED = (42.6)\ (DA)^{1.01}\ (VOL)^{0.90}\ (PEIA)^{0.71}$$

Number of observations = 40
Coefficient of determination = 0.72
Standard error of estimate (percent) = 99

where SSED is suspended sediment load, in pounds;
DA is drainage area, in acres;
VOL is volume of runoff, in inches; and
PEIA is percent effective impervious area.

This equation is still considered to have a high standard error of estimate. The limitations associated with the equations for storm volume and peak discharge would also apply to this equation. However, the equation could provide some estimate, for planning purposes, in areas where no information is available.

Precipitation-Runoff Modeling System (PRMS)

Urbanization has already changed the daily flow characteristics of Chester Creek and increased urbanization will probably change these characteristics further. In order to estimate daily flow as development continues, the Precipitation Runoff Modeling System (PRMS) was tested within the Chester Creek basin.

The PRMS was developed to evaluate the impacts of various combinations of precipitation, climate, and land uses on surface-water runoff (Leavesly and others, 1983). The concept of PRMS is to partition a watershed into units--referred to as hydrologic response units (HRU's)--based on similar characteristics such as slope, aspect, vegetation type, soil type, and precipitation distribution. Partitioning provides the ability to impose land-use or climate changes on discrete parts or all of a watershed and to evaluate resulting hydrologic impacts. Input variables required to run PRMS are: physical and hydrologic data for each HRU of the watershed (table 19), daily precipitation, maximum and minimum daily air temperatures, and daily solar radiation. The PRMS can be used in the daily flow mode or in a stormflow mode. Only the daily flow mode was used for this study.

Table 19.--Parameters and definitions for PRMS

[Parameter definitions have been condensed; a more complete explanation is in the "Precipitation-Runoff Modeling System: User's Manual"(Leavesley and others, 1983)]

Parameter	Definition
	<u>One value for each HRU</u>
COVDNS	Summer vegetation cover density
COVDNW	Winter vegetation cover density
TRNCF	Winter radiation transmission coefficient
SNST	Winter vegetation storage capacity
CTX	Air temperature-evapotranspiration coefficient
TXAJ	Slope and aspect-maximum air temperature adjustment
TXNJ	Slope and aspect-minimum air temperature adjustment
SMAX	Maximum holding capacity of soil
SMAV	Current holding capacity of soil
REMX	Maximum holding capacity of recharge
RECHR	Current holding capacity of recharge
SRX	Maximum snowmelt infiltration capacity
SCX	Maximum proportion of HRU contributing
SCN	Minimum proportion of HRU contributing
RNSTS	Summer vegetation storage capacity
RNSTW	Winter vegetation storage capacity
SC1	Coefficient in moisture index relations
SEP	Maximum daily recharge rate (soil-ground water)
DRCOR	Rain correction for daily precipitation
DSCOR	Snow correction for daily precipitation
TST	Temperature index for start of transpiration
RETIP	Maximum retention storage on impervious area
IMPERV	Effective impervious area
	<u>One value for each subsurface flow-routing reservoir</u>
RCF	Subsurface flow-routing coefficient
RCP	Subsurface flow-routing coefficient
RSEP	Recharge from reservoir (I) to ground water (J)
RESMX	Recharge from reservoir (I) to ground water (J)
REXP	Recharge from reservoir (I) to ground water (J)
RES	Storage in each subsurface flow-routing reservoir
	<u>One value for each ground-water flow-routing reservoir</u>
RCB	Ground-water routing coefficient
GSNK	Coefficient for ground water to sink
GW	Storage in each ground-water flow-routing reservoir
	<u>One value for each month (12 values)</u>
TLX	Lapse rate for maximum daily air temperature
TLN	Lapse rate for minimum daily air temperature
RDM	Slope of air temperature-degree day relations
RDC	Air temperature-degree day intercept
EVC	Evaporation pan coefficient
PAT	Maximum air temperature for rain or snow
CECN	Convection-condensation energy coefficient
	<u>One value required</u>
CTS	Air temperature-evapotranspiration correlation value
BST	Rainfall-snowfall temperature
SETCON	Snowpack settlement constant
PARS	Summer precipitation-solar radiation correction factor
PARW	Winter precipitation-solar radiation correction factor
CSEL	Climate station elevation
RMXA	Rain-snow correlation value
RMXM	Snowpack-melt correlation value
CTW	Evapotranspiration-snow correlation value
EAIR	Emissivity of dry air
FWCAP	Holding capacity of snowpack
DENI	Initial density of new-fallen snow
DENMX	Average maximum snowpack density

Calibration Procedures

Because daily flows are available for South Branch South Fork Chester Creek and Chester Creek at Arctic Boulevard, the following calibration procedure was established. First, the Chester Creek basin was partitioned into five HRU's (fig. 25). The HRU's numbered 1-4 represent the non-urbanized part of the basin, or the South Branch South Fork Chester Creek drainage, and HRU's 1-5 represent the entire basin above Arctic Boulevard. Second, using the 1983 water year flow data for South Branch South Fork Chester Creek the "best fit" values for the parameters representing HRU's 1-4 were obtained. Third, using the 1983 flow data from Chester Creek at Arctic Boulevard and not changing the values of parameters for HRU's 1-4, the "best fit" values for HRU 5 were obtained.

Obtaining the "best fit" values for HRU's 1-4 was accomplished by first assigning values to the parameters listed in table 19, either by reviewing examples given by Leavesley and others (1983) or by reviewing local soil surveys and weather records. Climatological data used as input to PRMS were obtained from the Arctic Valley climate station, Anchorage International Airport, and the precipitation gage at South Branch South Fork Chester Creek. Initial runs of PRMS were made, and then utilizing the sensitivity option of the PRMS model, those parameters which are most sensitive to changes in values were determined. Results of the sensitivity analysis (table 20) indicated that BST (temperature above which precipitation is all rain and below which it is all snow), RCB (a ground-water routing coefficient), and SMAX (maximum available water-holding capacity of soil profile) were the most sensitive parameters. Parameter intercorrelations (table 21) indicate that a strong intercorrelation exists between COVDNW and TRNCF, between BST and CTW, and between SC1 and SCN. The large standard errors of certain parameters such as REMX indicate their "poor" fit.

The "best fit" values of the variables were then determined using the optimization option of PRMS and the 1983 flow data. Comparing simulated flow with observed flow (fig. 26, table 22) showed that PRMS predicted flow patterns quite well and predicted 100.3 percent of total runoff. The mean of the absolute differences between the simulated and observed runoff was 1.4 in. or 13.6 percent of the observed mean.

The next step was to calibrate HRU's 1-5, which represent the Chester Creek basin above Arctic Boulevard. During this process the values for HRU's 1-4 were not changed. Sensitivity analysis (table 23) showed that parameter BST was the most sensitive parameter and that a strong correlation exists between COVDNW and TRNCF and between SCN and SC1 (table 24). Following the same procedure used for HRU's 1-4 the "best fit" values for HRU No. 5 were obtained by optimization. Comparing the simulated flow data with the observed flow data for the 1983 water year (fig. 27, table 22) indicated that PRMS did predict the trends in flow quite well and predicted 104 percent of the total runoff. The mean of the absolute differences between the simulated and observed runoff was 3.4 in. or 17.8 percent of the observed mean.

Verification Procedures

As a verification procedure PRMS was tested using the 1984 water year data as a comparison. The values of the parameter used in the calibration process were not changed and the simulated output from PRMS was compared to the actual discharge. Results from the model runs (fig. 28, 29) showed that simulated discharge from PRMS followed the same trends as the actual discharge. For South Branch South Fork Chester Creek, PRMS predicted 92 percent of the runoff with a mean error (expressed as a percent) of 24.3 percent (table 22). For Chester Creek at Arctic Boulevard PRMS predicted 107 percent of the runoff with a mean error of 28.5 percent (table 22).

Based on the calibration and verification results it seems apparent that PRMS can be used to predict daily flows in the Chester Creek basin. One possible use of PRMS would be to predict the flow characteristics of Chester Creek as urbanization continues. For instance, when a particular development is proposed, the added effective impervious area (IMPERV) could be entered into PRMS to simulate the changes in flow. One example is shown in figure 30, in which the current effective impervious area was doubled. For this scenario, the daily discharge during rainfall or snowmelt events would increase by a factor of two to three times the current discharge.

Distributed Routing Rainfall Runoff Model-II (DR3M-II)

The Distributed Routing Rainfall Runoff Model-version II, referred to as DR3M-II, is a deterministic model designed to simulate urban storm rainfall-runoff processes. The concept of DR3M-II is to divide a basin into subbasins, each with its own distinct physical characteristics. A channel network, which represents the drainage patterns of subbasins, is also developed. For example, the South Branch South Fork Chester Creek tributary basin was divided into 16 subareas and 12 channel segments (fig. 31).

Physical characteristics of the subbasins and channel network such as slope, roughness, overland flow length, geometry, and effective impervious area serve as input to DR3M-II, along with unit rainfall, daily rainfall, and soil moisture parameters (table 25). The DR3M-II then provides detailed hydrographs at the outlet of the basin for selected storm runoff periods and performs daily soil-moisture accounting for the periods between storms.

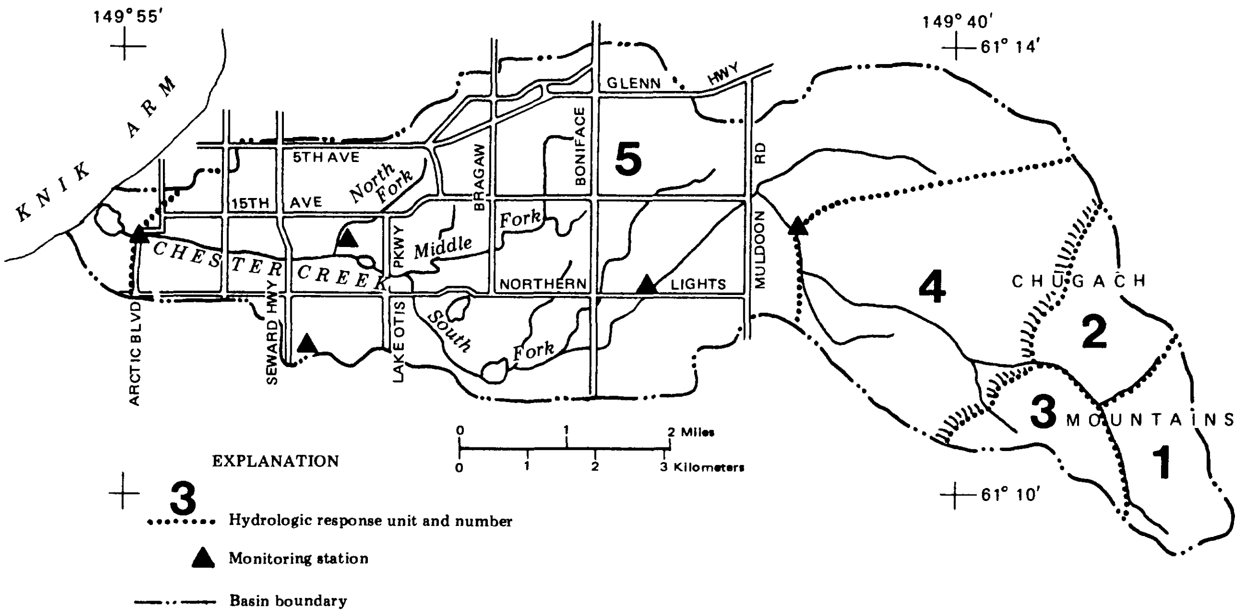

Figure 25. -- Chester Creek basin partitioned into hydrologic response units.

Table 20.--Mean-squares runoff-prediction error resulting from sensitivity analyses for South Branch South Fork Chester Creek, 1983 water year

Parameter (table 19)	Magnitude of parameter error			
	5 percent	10 percent	20 percent	50 percent
REMX	0.00000	0.00000	0.00000	0.00000
CTW	.00000	.00001	.00002	.00014
COVDNS	.00000	.00000	.00000	.00001
COVDNW	.00019	.00078	.00311	.01946
TRNCF	.00019	.00075	.00302	.01886
SMAX	.00025	.00099	.00395	.02468
RCB	.00030	.00119	.00475	.02969
BST	.00278	.01113	.04452	.27826
SCN	.00000	.00000	.00000	.00002
SC1	.00000	.00000	.00001	.00006

able 21.--Parameter correlation matrix for South Branch South Fork Chester Creek, 1983 water year

rameter able 19)	REMX	CTW	COVDNS	COVDNW	TRNCF	SMAX	RCB	BST	SCN	SC1
MX	1.000	-0.136	-0.617	0.085	-0.094	0.183	0.1144	-0.186	-0.109	0.268
W	--	1.000	-.123	-.315	.358	-.690	-.281	.925	.078	-.182
VDNS	--	--	1.000	-.032	.031	-.035	-.108	-.043	.522	-.444
VDNW	--	--	--	1.000	-.991	.453	.460	-.290	-.011	.044
NCF	--	--	--	--	1.000	-.487	-.479	.352	.012	-.050
AX	--	--	--	--	--	1.000	.765	-.790	-.029	.106
B	--	--	--	--	--	--	1.000	-.424	.014	.004
T	--	--	--	--	--	--	--	1.000	.044	-.152
N	--	--	--	--	--	--	--	--	1.000	.942
1	--	--	--	--	--	--	--	--	--	1.000
lue used	.32	.10	.85	.50	.25	3.1	.01	33.8	.0016	.300
					Standard Error					
int	15.160	0.325	8.249	0.375	0.192	0.601	0.001	2.860	0.026	2.418
dividual	6.134	.097	3.108	.041	.021	.225	.001	.731	.004	.435

Explanation

The closer the values are to the absolute value of 1, the greater the inter-correlation is between two parameters. A positive correlation indicates that an increase or decrease in the same direction of either parameter would have similiar effects on model results. A negative correlation, however, indicates that an increase of one parameter would require a decrease in the other parameter to produce similiar effects on model results.

The standard error is a measure of uncertainty that the value of a parameter is correct. Because approximately 95 percent of a population must fall within two standard deviations of the mean in a normal distribution, the standard error can be used in determining upper and lower confidence limits in fitting parameter values. For example, the correct value for parameter RCB has a 95 percent chance of being in the interval .01 + .002 if the joint error is used.

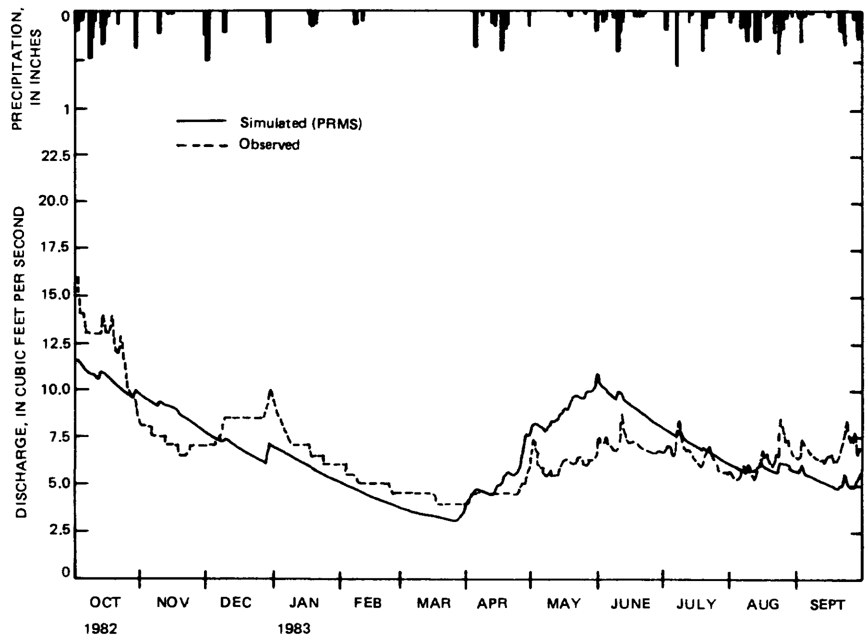

Figure 26.--Observed and simulated daily mean streamflow at South Branch South Fork Chester Creek - 1983 water year.

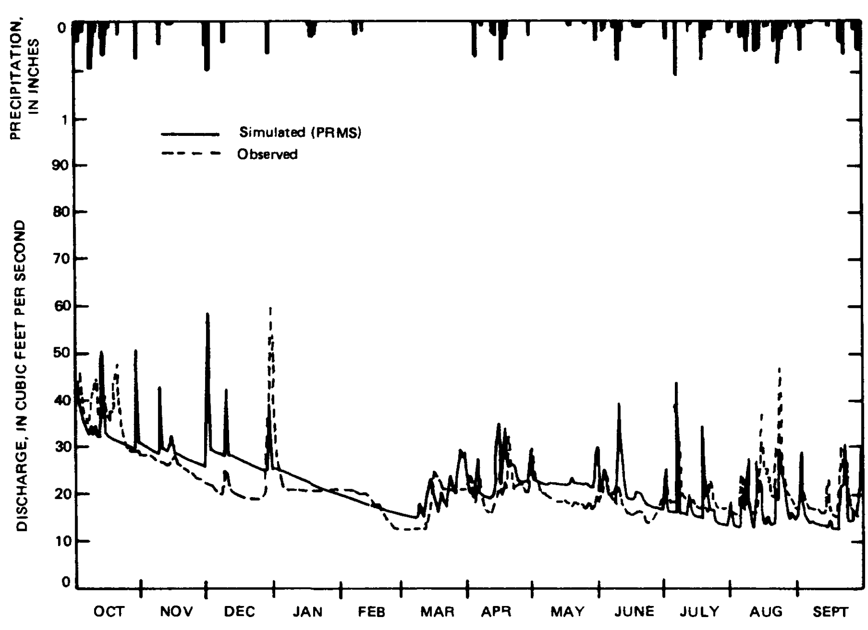

Figure 27.--Observed and simulated daily mean streamflow at Chester Creek at Arctic Boulevard - 1983 water year.

Table 22.- Summary of PRMS calibration and verification results for South Fork South Branch Chester Creek and Chester Creek at Arctic Boulevard

PRMS result and water year	Station	Total runoff (inches)		Mean daily discharge (ft^3/s)		Absolute values of observed minus simulated daily runoff (inches)		Mean error expressed as a percent of observed runoff
		Simulated	Observed	Simulated	Observed	Sum	Mean 1/	
Calibration 1983	South Branch South Fork Chester Creek	9.89	9.86	6.79	6.77	487.7	1.3	13.6
	Chester Creek at Arctic Boulevard	10.04	9.66	22.5	21.6	1,430	3.4	17.8
Verification 1984	South Branch South Fork Chester Creek	7.94	8.69	5.43	5.94	528.2	1.4	24.3
	Chester Creek at Arctic Boulevard	8.82	8.24	19.7	18.4	1,920	5.2	28.5

1/ 1983 mean is sum/365; 1984 mean is sum/366.

Table 23.--Mean-squares runoff-prediction error resulting from sensitivity analyses for Chester Creek at Arctic Boulevard, 1983 water year

Parameter (table 19)	Magnitude of parameter error			
	5 percent	10 percent	20 percent	50 percent
REMX	0.00000	0.00000	0.00002	0.00009
CTW	.00000	.00000	.00001	.00009
COVDNS	.00002	.00007	.00029	.00179
COVDNW	.00001	.00005	.00021	.00133
TRNCF	.00162	.00647	.02589	.16183
SMAX	.00002	.00008	.00032	.00202
RCB	.00035	.00142	.00568	.03549
BST	.74146	2.96584	11.86337	74.14607
SCN	.00000	.00000	.00000	.00000
SC1	.00000	.00000	.00000	.00000

Table 24.--Parameter correlation matrix for Chester Creek at Arctic Boulevard, 1983 water year [See table 21 for explanation]

Parameter (table 19)	REMX	CTW	COVDNS	COVDNW	TRNCF	SMAX	RCB	BST	SCN	SC1
REMX	1.000	-0.492	-0.121	0.098	0.117	-0.626	-0.348	0.122	0.036	0.028
CTW	---	1.000	- .063	- .355	- .044	- .002	.367	.306	.007	- .006
COVDNS	---	---	1.000	.026	- .004	.217	.016	- .066	.080	- .075
COVDNW	---	---	---	1.000	- .891	- .015	- .074	- .155	.002	- .014
TRNCF	---	---	---	---	1.000	.005	- .054	.124	- .007	.019
SMAX	---	---	---	---	---	1.000	.313	- .220	- .092	.076
RCB	---	---	---	---	---	---	1.000	.282	- .074	.061
BST	---	---	---	---	---	---	---	1.000	.020	- .022
SCN	---	---	---	---	---	---	---	---	1.000	- .963
SC1	---	---	---	---	---	---	---	---	---	1.000
Value used	.16	.10	.85	.10	1.00	.50	.008	33.8	.0016	.30
Standard Error										
Joint	0.3256	0.3062	0.2383	0.1521	0.1299	0.1965	0.0006	0.566	0.840	44.64
Individual	.1886	.1196	.2307	.0315	.0285	.1276	.0005	.0450	.0224	11.93

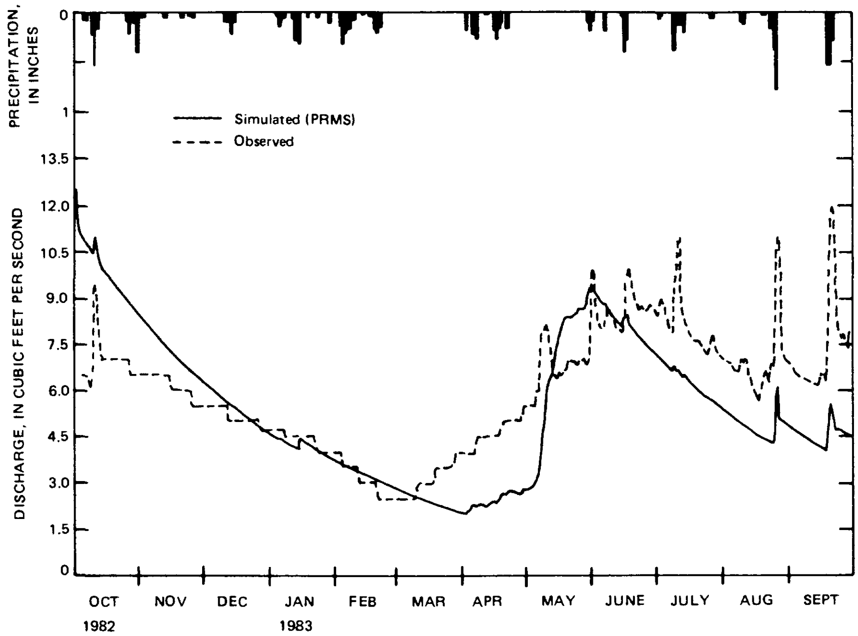

Figure 28.--Observed and simulated daily mean streamflow at South Branch South Fork Chester Creek - 1984 water year.

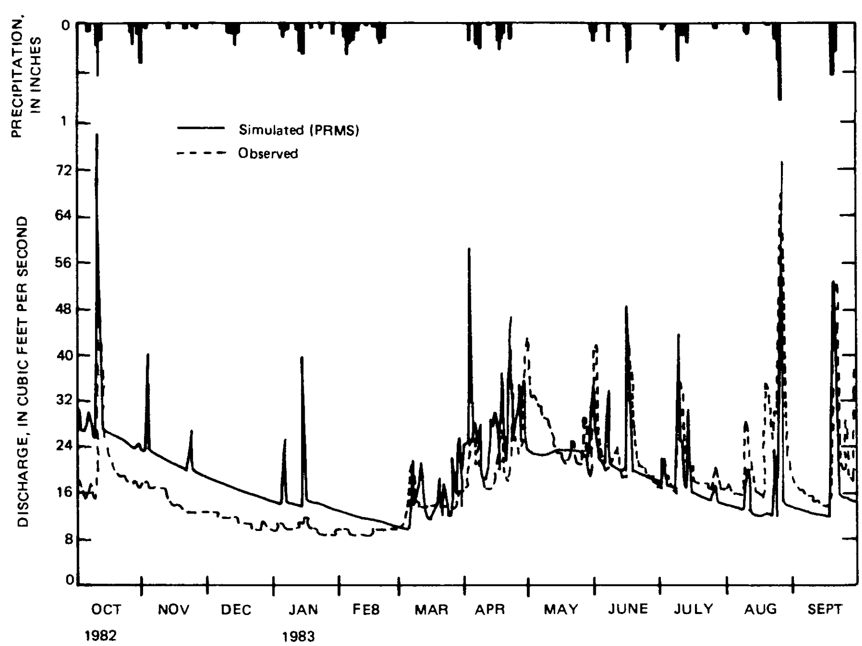

Figure 29.--Observed and simulated daily mean streamflow at Chester Creek at Arctic Boulevard - 1984 water year.

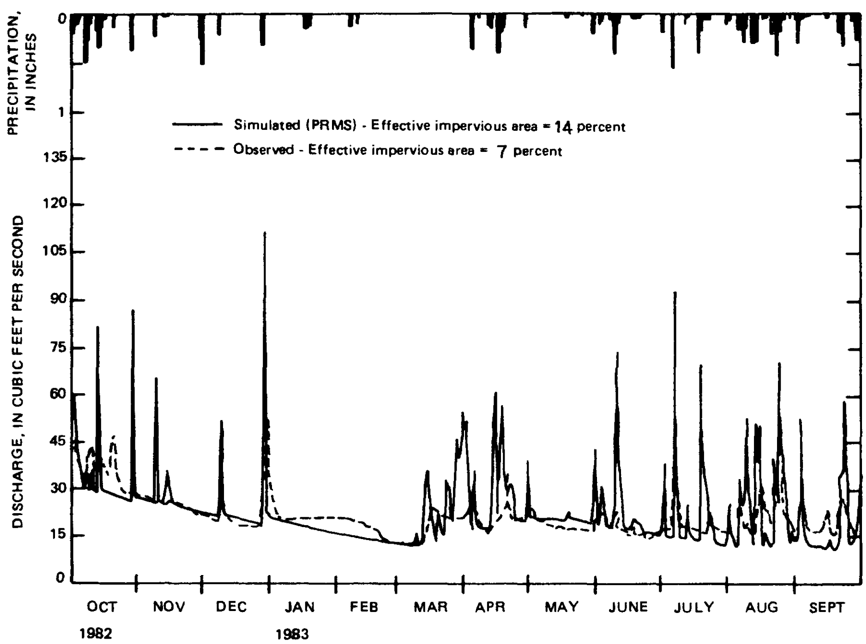

Figure 30.--Observed and simulated daily mean streamflow at Chester Creek at Arctic Boulevard showing effects of increased effective impervious area.

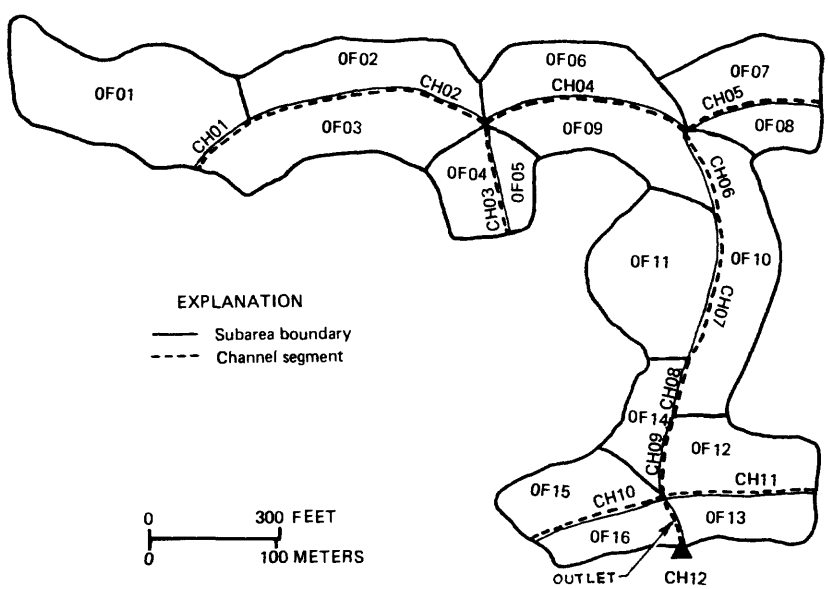

Figure 31.--Subareas and channel segments of the South Branch South Fork Chester Creek tributary (15274820) basin for DR3M-II.

Table 25.--Characteristics for South Branch South Fork Chester Creek tributary (station 15274820)

Location (fig. 31)	Area (ft^2)	Effective impervious area (ft^2)	Length (ft)	Slope (ft/ft)
Subarea				
OF01	60,832	10,087	608	0.170
OF02	37,598	15,458	90	.017
OF03	31,112	7,913	60	.021
OF04	11,978	4,613	70	.033
OF05	11,708	4,435	69	.033
OF06	31,898	11,964	80	.019
OF07	24,415	8.073	98	.019
OF08	12,876	4,773	52	.019
OF09	30,980	12,329	56	.019
OF10	43,128	14,751	82	.010
OF11	35,518	12,645	178	.008
OF12	22,959	6,817	100	.012
OF13	13,281	4,567	58	.012
OF14	18,265	6,757	65	.018
OF15	16,678	5,300	76	.012
OF16	16,777	4,210	76	.012
Total	420,003	134,692	--	--
Channel segment				
CH01	--	--	100	0.0038
CH02	--	--	420	.0045
CH03	--	--	170	.007
CH04	--	--	400	.0033
CH05	--	--	250	.0136
CH06	--	--	150	.005
CH07	--	--	200	.0013
CH08	--	--	180	.0045
CH09	--	--	100	.0041
CH10	--	--	220	.0026
CH11	--	--	230	.0160
CH12	--	--	180	.004

Calibration and Verification Procedures

Calibration and verification procedures used for DR3M-II were the same used by Lindner-Lunsford and Ellis (1984). The procedures are to calibrate and verify DR3M-II first for volume of runoff, second for peak flow, and third for hydrograph timing. The model is considered calibrated when the observation standard error (standard error of estimate x 100 divided by mean observed values) for volume and peak flow is less than 35 percent. A verification data set consisting of approximately the same number of storms as the calibration data set is then run using the calibrated parameters. If the OSE (observation standard error) for the verification data set is less than 35 percent, the model is assumed to be adequately calibrated.

Approximately 100 storms were monitored at stations 15274820, 15275035, and 15275055 during the study period, with between 30 and 35 storms monitored at each site. Data sets for those storm events in which instruments malfunctioned were not used in the modeling. This resulted in 73 storms being used for model calibration and verification. About half the storms were used for model calibration and the other half for model verification.

The initial estimates of parameters BMSN, KSAT, PSP, RGF, and RR (table 26) were those recommended by Alley and Smith (1982a). Parameter EVC (table 26) was assumed to be equal to 0.75 and not changed during calibration or verification runs. The maximum depth of retention on impervious surfaces, IMP, was determined for each station by use of the following equation for all storms:

$$IMP = (RF)\ (EIA) - (VOL)$$

where RF is total rainfall, in inches;
EIA is effective impervious area, as a decimal fraction;
VOL is volume of runoff, in inches

$$\text{Average IMP for each station equals } \frac{\Sigma\ IMP}{\text{Number of storms for the station}}$$

The average value of IMP was entered into the model and parameter EAC (table 26) optimized. The value of EAC was then held constant and the remaining soil moisture parameters optimized. If the OSE was less than 35 percent the model was considered calibrated. If the OSE was greater than 35 percent, IMP was changed and the procedure repeated.

Because the model-calculated runoff from pervious areas was zero or nearly zero in all cases, the soil moisture parameters (BMSN, KSAT, PSP, RGF, and RR) had little effect on runoff volumes. The percentage of effective impervious area, EAC, and the maximum depth of impervious retention, IMP, were found to be most sensitive to simulated runoff (table 27).

The verification procedure was to run the model using the verification data set without adjusting any model parameters. If the OSE was less than 35 percent, the model was considered calibrated and verified for runoff volume.

After calibration and verification of runoff volume was complete, the model was run to calibrate peak discharge and hydrograph timing. This was accomplished by adjusting the factor ALPADJ, (table 26) which modifies the roughness and slope of channels and subbasins. A value of ALPADJ greater than 1.0 effectively increases the slope and decreases the roughness, resulting in an increased peak flow and decreased time to the peak. Values of ALPADJ less than 1.0 produce the opposite results. Thus, the procedure used to calibrate peak discharges was to adjust the value of ALPADJ until the OSE of the calibration data set was less than 35 percent. If the verification data set produced an OSE less than 35 percent the model was considered calibrated and verified; if greater than 35 percent the procedure was repeated.

Results

Data for 31 storms were available for South Branch South Fork Chester Creek tributary. Seventeen storms were used for calibration and 14 for verification. Observed standard errors were 12 percent for calibration of runoff and 21 percent for calibration of peak flows (table 28). For verification, the OSE was 22 percent for volume and 35 percent for peak flows (table 29).

Changes in ALPADJ did not change the OSE significantly and, thus, ALPADJ was set equal to 1.0. The high value of the observed standard error for verification of peaks (35 percent) may indicate that the model overestimates peak discharges. However, hydrograph timing does appear to correlate well with the observed data (fig. 32).

Table 26.--Definitions of parameters used in DR3M-II
[Modified from Alley and Smith, 1982a]

Parameter	Definition
ALPADJ	A calibration factor for slope and roughness used in routing.
BMSN	Soil-moisture storage at field capacity, in inches.
EAC	A multiplication factor to adjust the initial estimates of effective impervious area. Effective impervious areas are those impervious surfaces that are directly connected to the channel drainage system.
EVC	A pan coefficient for converting measured pan evaporation to potential evapotranspiration.
IMP	The maximum depth of rainfall held in irregularities in impervious surfaces and unable to run off, in inches.
KSAT	The effective saturated value of hydraulic conductivity, in inches per hour.
PSP	Suction at wetting front for soil moisture at field capacity, in inches.
RGF	Ratio of suction at the wetting front for soil moisture at wilting point to that at field capacity.
RR	The proportion of daily rainfall that infiltrates into the soil for the period of simulation, excluding days for which detailed rainfall-runoff simulations are performed.

Table 27.--Final values for selected parameters for DR3M-II

Model parameter (table 26)	South Branch South Fork Chester Creek tributary (15274820)	North Fork Chester Creek tributary (15275035)	Chester Creek tributary (15275055)
PSP	0.56	5.7	1.52
KSAT	.18	1.18	.08
RGF	5.3	18.9	5.12
BMSN	3.4	5.9	2.15
EVC	.75	.75	.75
RR	.80	.71	.95
EAC	.94	.80	.96
IMP	.01	.04	.05
ALPADJ	1.00	1.00	1.00

Table 28.--Summary of DR3M-II calibration results for South Branch South Fork Chester Creek tributary (station 15274820)
[Runoff and rainfall in inches; peak flow in cubic feet per second]

Storm date	Rainfall	Runoff volume		Percent difference	Peak flow		Percent difference
		Observed	Simulated		Observed	Simulated	
1982							
July 29	0.08	0.02	0.02	0	0.09	0.14	55
July 29	.08	.02	.02	0	.30	.32	7
Aug. 10	.14	.04	.04	0	.14	.20	43
Aug. 15	.13	.04	.04	0	.30	.26	-15
Sept. 2	.19	.06	.06	0	.24	.30	20
Sept. 5	.31	.09	.09	0	.36	.42	17
Sept. 14	.50	.16	.15	-6	.28	.27	-4
Sept. 18	.30	.09	.10	11	.30	.34	12
Sept. 26	.13	.04	.04	0	.38	.46	21
1983							
April 29	0.12	0.04	0.03	-25	0.09	0.13	44
May 30	.13	.03	.04	33	.26	.30	15
June 9	.18	.05	.05	0	.20	.29	45
July 21	.10	.04	.03	-25	.57	.54	-6
Aug. 4	.14	.05	.04	-20	.22	.22	0
Sept. 1	.23	.07	.07	0	.47	.67	42
Sept. 19	.16	.04	.05	25	.17	.23	35
Sept. 21	.10	.02	.03	50	.24	.28	17
Observation standard error (percent)				12			21

Table 29.--Summary of DR3M-II verification results for South Branch South Fork Chester Creek tributary (station 15274820)

[Runoff and rainfall in inches; peak flow in cubic feet per second]

Storm date	Rainfall	Runoff volume Observed	Runoff volume Simulated	Percent difference	Peak flow Observed	Peak flow Simulated	Percent difference
1982							
July 30	0.19	0.04	0.06	50	0.17	0.24	41
Aug. 11	.17	.07	.05	29	.14	.19	36
Aug. 25	.08	.04	.02	-50	.14	.17	21
Aug. 30	.51	.14	.16	14	.36	.50	39
Sept. 12	1.32	.41	.51	24	.64	.83	30
Sept. 19	.21	.07	.06	-14	.36	.38	6
1983							
May 8	0.11	0.02	0.03	50	0.28	0.34	21
June 2	.16	.04	.05	25	.18	.16	-12
July 1	.17	.04	.05	25	.12	.16	33
July 6	.48	.13	.15	15	.57	.61	-7
July 23	.05	.01	.01	0	.07	.07	0
Aug. 13	.54	.20	.18	-10	.53	.78	47
Sept. 20	.35	.11	.10	-11	.50	.27	-54
Sept. 22	.22	.06	.07	16	.41	.46	12
Observation standard error (percent)				22			35

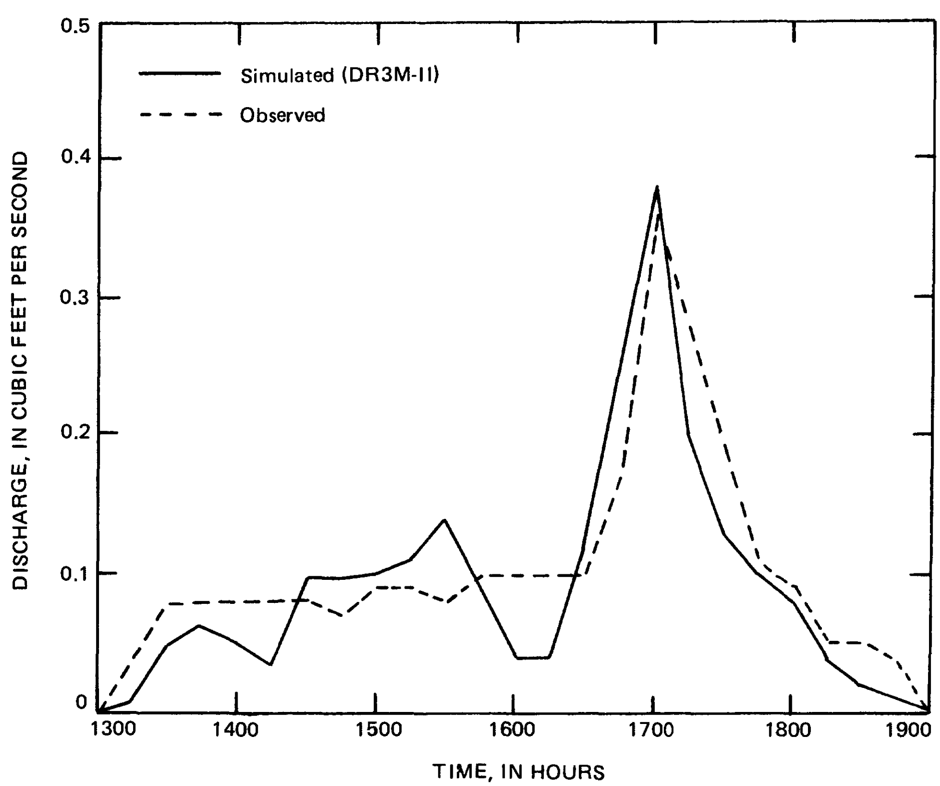

Figure 32.--Observed and simulated discharge for storm of September 19, 1982 at South Branch South Fork Chester Creek tributary (15274820).

Data for 21 storms were used at North Fork Chester Creek tributary: 13 for calibration and 8 for verification. Observed standard errors were 30 percent for calibration of runoff and 20 percent for calibration of peak flows (table 30). Observed standard errors for verification were 36 percent for volume and 39 percent for peak flows (table 31) and could not be lowered to 35 percent or less. The probable cause is due to the difficulty of obtaining reliable discharge measurements at this site. Flows at this site were determined by relating gage height to discharge by use of a theoretical rating curve computed for a culvert at the gage site.

Adjustments to ALPADJ did not change hydrograph timing significantly and thus ALPADJ was left at 1.0. Due to the difficulty of obtaining reliable discharge measurements, a typical storm hydrograph (fig. 33) did not show a good correlation between observed and simulated flows.

At Chester Creek tributary, data for 11 storms were used for calibration and data for 10 storms for verification. The OSE for calibration of volumes and peak flows were 23 percent and 30 percent respectively (table 32). The verification data set had an OSE of 23 percent for volume and 36 percent peak flow (table 33).

Adjustments to ALPADJ did not change observed standard errors significantly. The magnitude of observed and simulated peak discharges appears to correlate fairly well (fig. 34), but simulated discharges seem to occur before observed peak discharges.

In summary, DR3M-II can be a useful tool in predicting storm runoff volumes but caution should be used in predicting peak flows. Once calibrated, historical rainfall data could be used to construct runoff volume and peak flow probability distributions. Effects of increased urbanization and the corresponding increase in effective impervious area on the runoff volumes and peak flows could be estimated. However, it is recommended that the model be used only on drainage areas less than 40 acres because the model was not tested on drainage basins of larger size.

Table 30.--Summary of DR3M-II calibration results for North Fork Chester Creek tributary (station 15275035)

[Runoff and rainfall in inches; peak flow in cubic feet per second]

Storm date	Rainfall	Runoff volume Observed	Runoff volume Simulated	Percent difference	Peak flow Observed	Peak flow Simulated	Percent difference
1982							
July 29	0.11	0.02	0.03	50	0.02	0.04	100
July 29	.09	.02	.03	50	.06	.11	83
Aug. 10	.14	.03	.04	33	.02	.04	100
Aug. 15	.13	.04	.03	-25	.06	.06	0
Sept. 2	.10	.02	.02	0	.04	.06	50
Sept. 5	.31	.08	.10	25	.07	.09	22
1983							
April 29	0.18	0.03	0.05	67	0.03	0.04	33
May 30	.13	.04	.03	-25	.06	.05	-17
June 9	.12	.05	.03	-40	.04	.05	25
July 6	.49	.13	.17	30	.23	.17	-35
Aug. 14	.46	.22	.16	-28	.20	.16	-20
Aug. 20	.07	.02	.01	-50	.06	.05	-17
Aug. 22	.69	.31	.25	-24	.28	.17	-30
Observation standard error (percent)				30			20

Table 31.--Summary of DR3M-II verification results for North Fork Chester Creek tributary (station 15275035)

[Runoff and rainfall in inches; peak flow in cubic feet per second]

Storm date	Rainfall	Runoff volume Observed	Runoff volume Simulated	Percent difference	Peak flow Observed	Peak flow Simulated	Percent difference
1982							
July 30	0.17	0.03	0.05	66	0.03	0.04	33
Aug. 11	.18	.04	.05	25	.03	.05	66
Aug. 25	.23	.04	.07	75	.16	.18	12
Aug. 30	.51	.19	.18	-6	.29	.12	-59
1983							
July 1	0.21	0.03	0.06	100	0.05	0.07	40
Aug. 8	.07	.01	.01	0	.02	.02	0
Aug. 17	.12	.05	.03	-40	.09	.04	-56
Aug. 21	.30	.08	.10	12	.14	.08	-43
Observation standard error (percent)				36			39

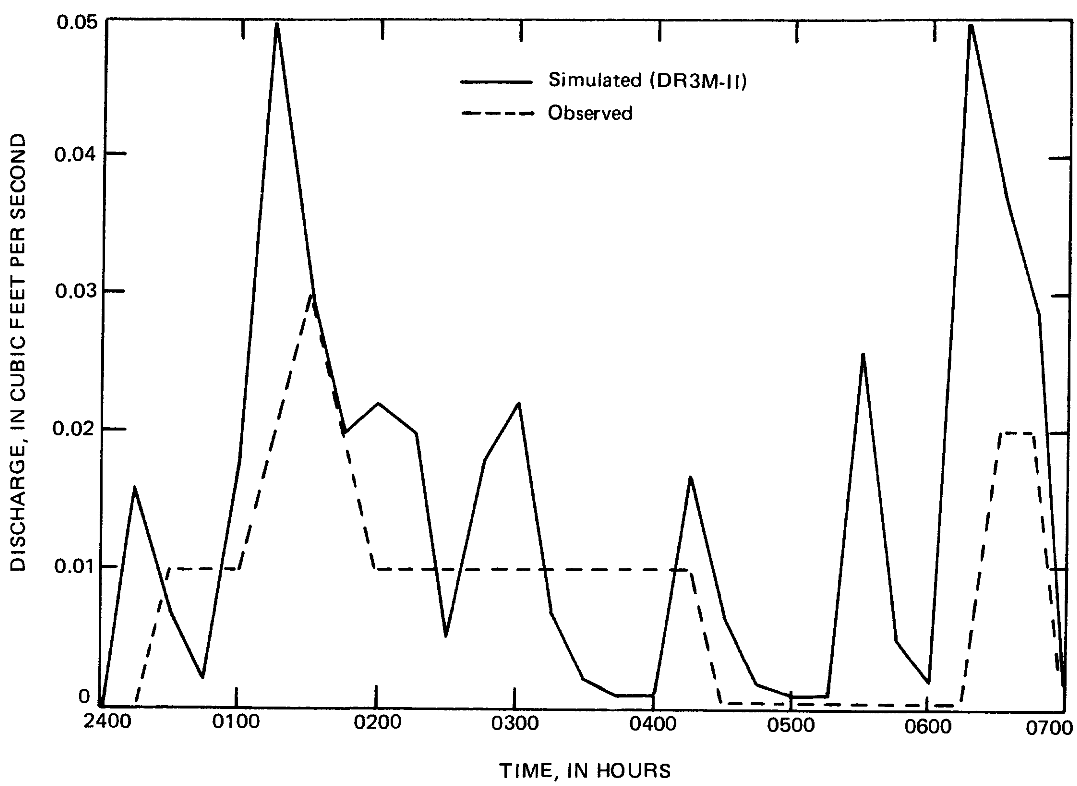

Figure 33.--Observed and simulated discharge for storm of August 11, 1983 at North Fork Chester Creek tributary (15275035).

Table 32.--Summary of DR3M-II calibration results for Chester Creek tributary (station 15275055)

[Runoff and rainfall in inches; peak flow in cubic feet per second]

Storm date	Rainfall	Runoff volume		Percent difference	Peak flow		Percent difference
		Observed	Simulated		Observed	Simulated	
1982							
July 15	0.42	0.23	0.25	8	1.2	2.0	60
July 23	.22	.12	.12	0	1.4	1.5	7
July 29	.11	.03	.04	25	1.2	2.1	43
Sept. 3	.10	.06	.03	-50	1.1	2.6	42
Sept. 14	.56	.34	.35	3	2.0	2.3	13
Sept. 18	.34	.22	.20	-10	3.9	3.5	-11
Sept. 26	.14	.09	.06	-50	2.9	1.8	-61
Sept. 30	.24	.11	.13	15	1.0	2.4	59
1983							
May 1	0.11	0.04	0.09	125	1.6	1.0	-65
Sept. 19	.26	.08	.14	43	3.0	2,3	-30
Sept. 21	.12	.08	.08	0	3.0	2.8	-7
Observation standard error (percent)				23			30

Table 33.--Summary of DR3M-II verification results for Chester Creek tributary (station 15275055)

[Runoff and rainfall in inches; peak flow in cubic feet per second]

Storm date	Rainfall	Runoff volume		Percent difference	Peak flow		Percent difference
		Observed	Simulated		Observed	Simulated	
1982							
July 23	0.19	0.06	0.10	60	1.1	1.7	35
July 29	.11	.03	.04	23	.5	.6	14
July 30	.11	.03	.07	133	.5	1.1	120
Sept. 5	.31	.19	.17	-6	1.4	2.3	64
Sept. 19	.28	.18	.16	-12	1.6	3.2	a
Sept. 29	.33	.20	.19	-5	1.2	2.0	60
1983							
April 29	0.16	0.07	0.08	12	1.0	0.8	-20
May 30	.15	.04	.07	57	1.1	1.6	31
Sept. 20	.19	.05	.10	100	.9	2.0	105
Sept. 29	.28	.16	.16	0	2.7	2.2	-23
Observation standard error (percent)				23			36

[a] Peak flow not used in verification

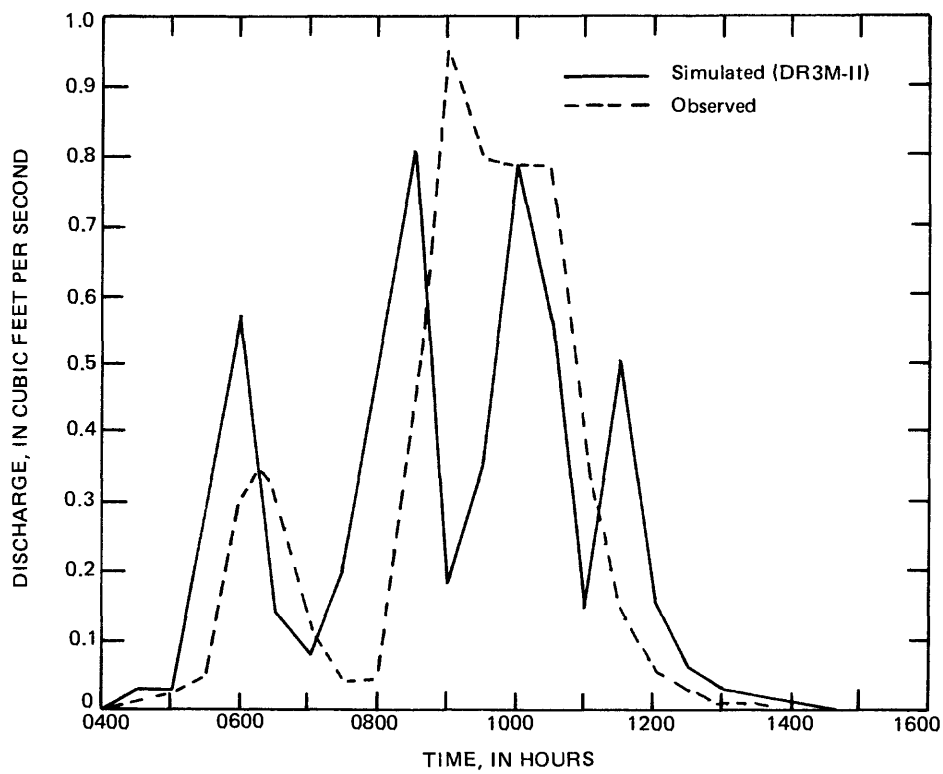

Figure 34.--Observed and simulated discharge for storm of April 29, 1983 at Chester Creek tributary (15275055).

Multi-Event Urban Runoff Quality Model (DR3M-QUAL)

The Multi-Event Urban Runoff Quality Model, referred to as DR3M-QUAL, was tested on the three land-use basins to determine its applicability. The DR3M-QUAL is designed to simulate the contributions of impervious area, pervious area, and precipitation to the quality of surface runoff. Variations in water quality of runoff can be simulated for selected storm periods, and a daily accounting of accumulation and washoff is maintained between storms. A complete explanation of DR3M-QUAL can be found in Alley and Smith (1982b). However, a brief explanation of the model follows.

Constituent Accumulation

DR3M-QUAL assumes that constituent accumulation on an impervious surface is:

$$L = K_1 \left(1-e^{-K_2 T}\right)$$

where L is the amount of the constituent on the effective impervious area, in pounds;

K_1 is the maximum amount of the constituent which can accumulate on the effective impervious area, in pounds;

K_2 is a rate constant for constituent removal, in day^{-1};

T is accumulation time, in days.

Constituent Washoff

The DR3M-QUAL simulates constituent washoff from effective impervious areas using the following equation:

$$W = L_o \left(1-e^{-K_3 \Delta TR}\right)$$

where W is the amount of constituent removed from effective impervious surface during a time step, in pounds;

L_o is the amount of constituent on effective impervious surfaces at the beginning of the time step, in pounds;

K_3 is the washoff coefficient, in inches^{-1};

R is the runoff rate, in inches per hour;

ΔT is the time step, in hours.

Input Data and Calibration-Verification Procedures

Input data required for DR3M-QUAL are flow values and constituent concentrations for the storm periods, daily rainfall during the simulation period, basin area, percentage of effective impervious area in the basin, and values of K_1, K_2, and K_3. Precipitation quality and street-sweeping data are optional inputs to the model.

A complete calibration and verification of DR3M-QUAL could not be done for all three basins and all the water-quality constituents because of insufficient data. The DR3M-QUAL could be calibrated and verified only for suspended sediment at South Branch South Fork Chester tributary. The calibration and verification procedures were as follows:

1) Approximately half the storms available were used for calibration.

2) Values of K_1, K_2, and K_3 were determined by the procedure outlined by Alley and Smith (1982b).

3) Runs of DR3M-QUAL were made using the values of K_1, K_2, and K_3 and the calibration data set.

4) If the OSE was less than 35 percent, DR3M-QUAL was considered calibrated; if the OSE was greater than 35 percent, values of K_1, K_2, and K_3 were changed and the model run again.

5) Once the OSE was less than 35 percent, DR3M-QUAL was run with the remaining storm data. If the OSE was less than 35 percent, the model was considered verified.

Results

Suspended-sediment data were available for 21 storms for South Branch South Fork Chester Creek tributary. Eleven storms were used for calibration and 10 storms used for verification. For most storms DR3M-QUAL did not simulate the concentration accurately (fig. 35). However, in simulating loads, the OSE for calibration was 28 percent and for verification 14 percent (tables 34-35). Comparing the total loads for the 1982 and 1983 seasons, the observed and simulated loads were within 11 percent for 1982 and equal for 1983.

Suspended-sediment data were available for 12 storms for Chester Creek tributary and for 5 storms for North Fork Chester Creek tributary. Using the values of K_1, K_2, and K_3 that were used for South Branch South Fork Chester Creek tributary, simulation runs of DR3M-QUAL were made for these two stations. The OSE for Chester Creek tributary was 22 percent (table 36), and the total observed and simulated loads for the five storms for North Fork Chester Creek tributary were approximately equal. Thus, it appears that the values of K_1, K_2, and K_3, used without calibration, could be used at all three sites.

The DR3M-QUAL was also used to simulate other water-quality constituents at all three sites. Not enough storms were available to do a complete calibration and verification procedure at each of the three sites. Although only a small number of storms was sampled, the most complete storm-data set available was that for South Branch South Fork Chester Creek tributary. These data were used to estimate values of K_1, K_2, and K_3 (table 37). A comparison of measured and simulated loads shows only "fair" agreement (table 38) perhaps a consequence of the limited data set.

In summary, DR3M-QUAL cannot be used to simulate concentrations or discrete event loads of a particular water-quality constituent. However, DR3M-QUAL could be used to estimate the seasonal loads of a particular water-quality constituent. Thus, the seasonal impact on a receiving stream could be assessed as a result of increased urbanization.

SUMMARY AND CONCLUSIONS

Quantity and quality of urban runoff in the Chester Creek basin have been studied. Significant findings are:

1) Urbanization has changed the flow characteristics of Chester Creek. Peak discharges (expressed as cubic feet per second per square mile) are two to three times higher in the developed part of the basin than in the undeveloped part of the basin.

2) With the exception of fecal coliform bacteria levels, water in Chester Creek at base-flow conditions meets State of Alaska drinking water standards. Rainfall-runoff periods show increased concentrations of suspended sediment, certain trace metals, nutrients, and fecal coliform bacteria. However, the highest concentrations of these constituents are found during snowmelt periods. Non-point sources account for most of these increased concentrations.

3) Fecal coliform bacteria concentrations near the mouth of Chester Creek exceed State of Alaska standards during all levels of flow. Lead concentrations exceed State standards during rainfall-runoff periods and snowmelt periods. Chloride concentrations exceed State standards during snowmelt periods.

4) Concentrations of trace metals are directly related to concentrations of suspended sediment and, thus, are likely to be adsorbed onto the sediment. Analyses of bed-material samples taken along the course of Chester Creek indicate that certain trace metals are being deposited in the streambed.

5) Annual loads of chloride and sodium transported from the Chester Creek basin range from 394 to 635 tons chloride, and 214 to 342 tons sodium. These loads are dependent on the amount of yearly snowfall. Approximately 680 tons of suspended sediment are transported from the Chester Creek basin. Most of the sediment originates from the urban part of the basin.

6) Wet-deposition quality does not change throughout the Chester Creek basin and does not appear to significantly add to seasonal loads of suspended sediment. Dry-deposition quality is different between the urban and non-urban parts of the Chester Creek basin. Dry deposition may account for some percentage of seasonal loads of suspended sediment, but further study in this area is needed.

7) Analysis of surface-water data from areas with three distinct land uses in the Chester Creek basin showed that drainage area, storm rainfall, and the percentage of effective impervious area are significant variables in determining runoff volumes and peak discharges.

8) Analysis of water-quality data from the three land-use sites indicates that the primary source of dissolved constituents, trace metals, and suspended sediment originates from commercial areas. The primary source of nutrients and fecal coliform bacteria is from residential areas.

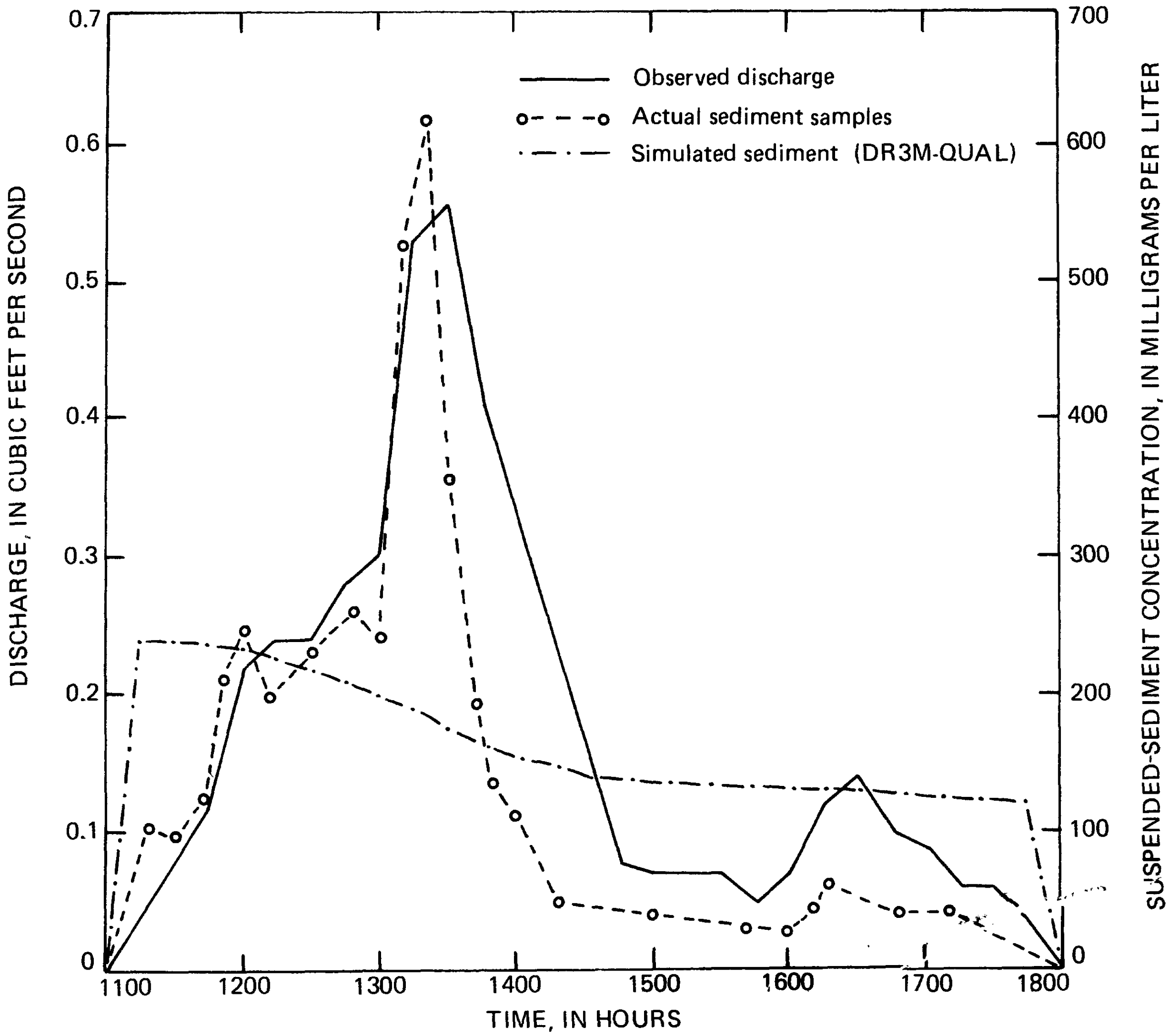

Figure 35.--Observed discharge, sediment samples, and simulated sediment concentration for storm of July 6, 1983 at South Branch South Fork Chester Creek tributary (15274820).

Table 34.--Summary of DR3M-QUAL calibration results for suspended sediment for South Branch South Fork Chester Creek tributary (station 15274820)

Storm date	Suspended sediment (pounds)		Percent difference
	Observed	Simulated	
1982			
July 29	12.4	8.8	-29
Sept. 5	6.0	9.9	65
Sept. 15	3.9	1.4	-64
Sept. 18	8.3	13.2	59
1983			
May 30	19.0	16.1	-15
June 9	17.8	20.1	13
July 21	22.5	17.6	-22
Aug. 13	13.1	11.6	-12
Aug. 15	9.5	10.1	6
Sept. 1	23.0	22.4	-3
Sept. 19	25.6	32.7	28
Total load	161.1	163.9	2
Observed standard error			28

Table 35.--Summary of DR3M-QUAL verification results for suspended sediment for South Branch South Fork Chester Creek tributary (station 15274820)

Storm date	Suspended sediment (pounds)		Percent difference
	Observed	Simulated	
1982			
Aug. 25	6.4	5.3	-17
Sept. 14	9.6	9.9	3
Sept. 16	5.1	7.5	47
Sept. 19	5.7	7.7	35
1983			
June 2	9.7	12.6	30
July 6	57.4	48.0	-16
July 23	1.2	3.1	>100
Aug. 14	42.3	39.5	-7
Aug. 22	17.1	21.1	23
Sept. 14	16.9	20.0	18
Total load	171.4	174.7	2
Observed standard error			14
1982-All storms	57.4	63.7	11
1983-All storms	275.0	275.0	0

Table 36.--Summary of DR3M-QUAL verification results for suspended sediment for Chester Creek tributary and North Fork Chester Creek tributary

Storm date	Suspended sediment (pounds) Observed	Simulated	Percent difference
	Chester Creek tributary - (15275055)		
1982			
July 8	76.7	62.0	-20
July 11	67.3	66.1	-2
July 15	44.0	75.2	71
July 30	16.4	17.6	7
July 30	3.2	2.7	-18
Sept. 5	15.3	8.2	-47
Sept. 5	202.0	147.0	-27
Sept. 26	103.0	74.0	-28
1983			
April 29	124.0	137.0	10
May 30	136.0	124.0	-9
June 2	130.0	140.0	8
July 23	122.0	116.0	-5
Total load	1,040.0	970.0	-7
Observed standard error			22
	North Fork Chester Creek tributary - (15275035) 1/		
1982			
July 23	11.6	12.6	8
Aug. 10	1.4	2.6	85
Aug. 15	.3	1.8	>100
1983			
May 4	7.3	3.1	-58
Aug. 23	1.2	1.8	50
Total load	21.8	21.9	0

1/ No observed standard error, due to insufficient number of storms

Table 37.--DR3M-QUAL coefficients for selected constituents for the three land-use basins

Station name and number (Land-use type)	Parameter	K_1	K_2	K_3	Daily K_3
South Branch South Fork Chester Creek tributary (15274820) (Low density)	Suspended sediment	35.0	0.13	1.8	1.8
	Aluminum	1.0	.13	1.8	1.8
	Nitrogen	.80	.13	1.8	1.8
	Phosphorus	.10	.13	1.8	1.8
	Lead	.02	.13	1.8	1.8
	Iron	2.0	.13	1.8	1.8
	Zinc	.08	.13	1.8	1.8
North Fork Chester Creek tributary (15275035) (Medium density)	Suspended sediment	35.0	0.13	1.8	1.8
	Aluminum	1.0	.13	1.8	1.8
	Lead	.02	.13	1.8	1.8
	Iron	2.0	.13	1.8	1.8
Chester Creek tributary (15275055) (Commercial)	Suspended sediment	35.0	0.13	1.8	1.8
	Aluminum	1.0	.13	1.8	1.8
	Lead	.02	.13	1.8	1.8
	Iron	2.0	.13	1.8	1.8

Table 38.--Loads of selected constituents simulated by DR3M-QUAL

Station name and number	Constituent	Date	Load (pounds) Measured	Load (pounds) Simulated	Percent difference
South Branch South Fork Chester Creek tributary (15274820)	Aluminum	5-8-83	0.96	0.35	-64
		5-30-83	.52	.41	-22
		6-2-83	.27	.33	22
		6-2-83	.05	.13	>100
		7-1-83	.04	.15	>100
		7-6-83	1.45	1.35	-7
		9-1-83	.75	.60	-20
		Total	4.04	3.32	-18
	Iron	5-8-83	1.17	0.54	-54
		5-30-83	.84	.83	-1.2
		6-2-83	.57	1.11	95
		7-1-83	.13	.66	>100
		7-6-83	2.54	2.70	6.3
		8-13-83	2.20	2.98	35
		9-1-83	1.37	1.20	-12
		Total	8.82	10.02	14
	Lead	5-30-83	0.02	0.01	-50
		6-2-83	.01	.01	0
		7-1-83	.01	.01	0
		8-13-83	.04	.03	-25
		9-1-83	.02	.01	-50
		Total	.10	.07	-30
	Zinc	5-8-83	0.02	0.03	50
		5-30-83	.02	.03	50
		7-1-83	.01	.01	0
		7-6-83	.05	.11	>100
		9-1-83	.03	.05	67
		Total	.13	.23	77
	Nitrogen	5-30-83	0.35	0.37	6
		6-2-83	.25	.26	4
		6-2-83	.05	.10	>100
		7-1-83	.10	.12	20
		7-6-83	.97	1.08	11
		9-1-83	.32	.48	50
		Total	2.04	2.41	18
	Phosphorus	5-30-83	0.18	0.05	-73
		6-2-83	.08	.03	-62
		6-2-83	.02	.01	-50
		7-1-83	.02	.02	0
		7-6-83	.25	.14	-44
		9-1-83	.07	.06	-14
		Total	.62	.31	-50
Chester Creek tributary (15275055)	Aluminum	7-15-82	0.6	1.1	83
		7-16-82	3.2	1.3	-59
		7-23-82	8.4	6.2	-26
		5-30-83	10.6	3.9	-63
		Total	22.8	12.5	-55
	Iron	7-15-82	0.20	2.2	>100
		7-16-82	5.0	2.6	-48
		7-23-82	11.7	12.2	4
		5-30-83	10.7	7.8	-27
		Total	23.1	24.8	7
	Lead	7-15-82	.02	.02	0
		7-16-82	.15	.03	-80
		7-23-82	.30	.12	-60
		5-30-83	.33	.08	-76
		Total	.80	.25	69
North Fork Chester Creek tributary (15275035)	Aluminum	8-10-82	0.01	0.05	>100
		5-4-83	.32	.05	-84
		8-23-83	.03	.05	67
		Total	.36	.15	-58
	Iron	8-10-82	0.03	0.09	>100
		5-4-83	.09	.03	-67
		8-23-83	.04	.10	>100
		Total	.16	.22	38
	Lead	8-10-82	0.001	0.001	0
		5-4-83	.002	.001	-50
		8-23-83	.001	.001	0
		Total	.004	.003	-25

9) Three USGS models -- PRMS (Precipitation Runoff Modeling System), DR3M-II (Distributed Routing Rainfall Runoff Model-II), and DR3M-QUAL (Multi-Event Urban Runoff Quality Model)--were calibrated and verified for different applications. The PRMS can be used to simulate the effects of increased urbanization on daily flows. The DR3M-II can be used to simulate storm effects on small basins of less than 40 acres. The DR3M-QUAL can be used to estimate seasonal loads of suspended sediment from basins of less than 40 acres.

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GLOSSARY

Base flow --Sustained or "fair weather" runoff. In most streams, base flow is composed largely of ground-water flow.

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

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

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

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

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

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