Analysis of Urban Storm-Water Quality from Seven Basins near Portland, Oregon

U.S. GEOLOGICAL SURVEY
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Prepared in cooperation with the
U.S. Army Corps of Engineers
Columbia Region Association of Governments

ANALYSIS OF URBAN STORM–WATER–QUALITY FROM SEVEN BASINS NEAR PORTLAND, OREGON

By T. L. Miller and S. W. McKenzie

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Conversion factors for U.S. customary Units and International System Units (SI)

[For use of those readers who may prefer to use metric units rather than U.S. customary units, the conversion factors for the terms used in this report are listed below:]

Multiply U.S. customary unit	By	To obtain metric unit
	Length	
inch (in)	25.4	millimeter (mm)
foot (ft)	.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Specific combinations	
cubic foot per second (ft^3/s)	0.0283	cubic meter per second (m^3/s)
foot per mile (ft/mi)	.1894	meter per kilometer (m/km)
cubic yard per square mile (yd^3/mi^2)	.2953	cubic meter per square kilometer (m^3/km^2)
ton per square mile (ton/mi^2)	.3503	megagram per square kilometer (Mg/km^2)
colony x 10^9 per square mile (colony x $10^9/mi^2$)	.3861	colony x 10^9 per square kilometer (colony x $10^9/km^2$)
	Temperature	
degrees Fahrenheit (°F)	5/9 after subtracting 32 degrees	degrees Celsius (°C)

ANALYSIS OF URBAN STORM-WATER QUALITY FROM SEVEN BASINS NEAR PORTLAND, OREGON

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By Timothy L. Miller and Stuart W. McKenzie

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ABSTRACT

Over a $1\frac{1}{2}$-year period, water-quality data were collected for seven small drainage basins in urban areas of Portland, Oreg. Analysis of the data followed three approaches. First, the constituent concentrations were analyzed. Average concentrations of suspended sediment, settleable solids, and fecal coliform bacteria generally exceeded levels expected for secondary waste-treatment plant effluent, whereas biochemical oxygen demand concentrations were lower than expected. The second analytical approach established correlations and bivariate regression relationships between constituents for individual storms in each basin, for all storms in each basin, and for all storms in all basins. Generally, correlation coefficients decreased when progressing from data for individual storms in each basin, to data for all storms in each basin, to data for all storms in all basins. In the third approach, storm yields for 10 constituents were related to basin and precipitation characteristics by use of multiple-linear-regression techniques. Storm yields for suspended sediment varied by about four orders of magnitude. Generally, results of the multiple-regression analysis indicated that variations in storm yields were highly dependent on precipitation characteristics, with total rainfall of the storm frequently explaining most of the variation of the dependent variable.

INTRODUCTION

Background

Storm-water runoff has long been recognized as a significant source of nonpoint-source pollution (Sliter, 1976). Data have been collected for many studies over the last 25 years to determine the quantity and quality of storm-water runoff. The results of 35 studies in which data were collected from drainage basins with separate sanitary and storm-water systems were reviewed by McElroy, Mattox, Hartman, and Bell (1976). These studies cover urban areas in the United States and other parts of the world. Concentrations of constituents varied widely, not only from study to study, but within studies from storm to storm, with concentrations varying two orders of magnitude and more.

Lager and Smith (1974) found that constituent loading from storm-water runoff often exceeds levels that are typical for raw domestic sewage. Bradford (1977) also noted that data from some studies provided strong evidence that storm water could contain constituent loads 100 to 1,000 times greater than sanitary waste water. The literature review by McElroy, Mattox, Hartman, and Bell (1976) supports the observation made by Lager and Smith (1974) concerning the concentrations of constituents in storm-water runoff; however, many investigations cite maximum values for constituents that are lower than values typical of secondary waste-treatment effluent. For example, in some storm-water studies, biochemical oxygen demand had maximum values of less than 10 mg/L (milligrams per liter). The wide range in maximum constituent values reported in the literature is indicative of the need for site-specific data.

Objective

The objective of this study was twofold. The first was to collect site-specific data. These data from the seven selected basins provided information on 20 water-quality constituents in addition to basin and precipitation characteristics. The data were collected to help gain an understanding of constituent concentration ranges and interrelationships between constituents for each basin. The second part of the objective was to provide a method of approach to both data collection and data analysis that could be used to transfer results to ungaged sites in this area or to provide an approach for sites in other areas.

Analytical Approach

Three different data-analysis approaches were used in this study. The first approach was to analyze constituent concentrations. Second, correlation and bivariate regression of constituents were used. The final approach was a multiple-linear regression analysis of storm yields.

Each approach was used to better understand the urban basins selected and was not intended to be an end in itself. For example, the multiple-linear regression equations obtained in the final approach indicate the important parameters affecting a particular constituent yield. The equations were not intended solely for the purpose of calculating constituent yields in the Portland area. Even though regression analysis does not imply cause-effect relationships (Riggs, 1968), the multiple-linear regression equations improved knowledge of the urban drainage system.

Acknowledgments

This study was made by the U.S. Geological Survey, in cooperation with the U.S. Army Corps of Engineers and the Columbia Region Association of Governments (CRAG). The North Pacific Division Materials Laboratory of the U.S. Army Corps of Engineers at Troutdale, Oreg., analyzed samples for several chemical constituents.

DATA COLLECTION

Basin Locations

Locations of the seven streamflow and sampling stations are shown in figure 1, and each is identified by an eight-digit station number. Rain gages not adjacent to streamflow stations are identified by separate eight-digit station numbers. Station numbers, names, and locations are given in table 1.

Basin Characteristics

Characteristics used to describe each drainage basin are defined below and listed in table 2.

Drainage area.--Area of the basin (AREA), in square miles, planimetered from Geological Survey topographic maps. Basin boundaries were determined by first outlining drainage divides on 7½-minute quadrangle maps and then adjusting for existing storm-sewer diversions according to information from city and county agencies. A field determination was made where sewer intakes were undefined or where drainage divides could not be determined on 7½-minute maps.

Basin slope.--The average slope of the basin (BSLOPE), described by Wisler and Brater (1959), in percent, calculated from Geological Survey 7½-minute topographic maps. The basin slopes were computed by:

$$BSLOPE = \frac{DL}{A} \times 100 \qquad (1)$$

where

D = contour interval, in feet,
L = total length of contours, in feet, and
A = drainage area of the basin, in square feet.

Channel slope.--The average channel slope (CHNSLOP), in feet per mile, for the basin as determined from 7½-minute topographic maps. Channel slope was defined as the difference in elevation at points 10 percent and 85 percent of the distance along the various stream channels in the basin, measured from a gaging station upstream to the watershed divide, divided by the distance between the two points. For each of the seven basins, more than one well-defined channel was present, so the basin channel slope was a length-weighted average for the basin computed by:

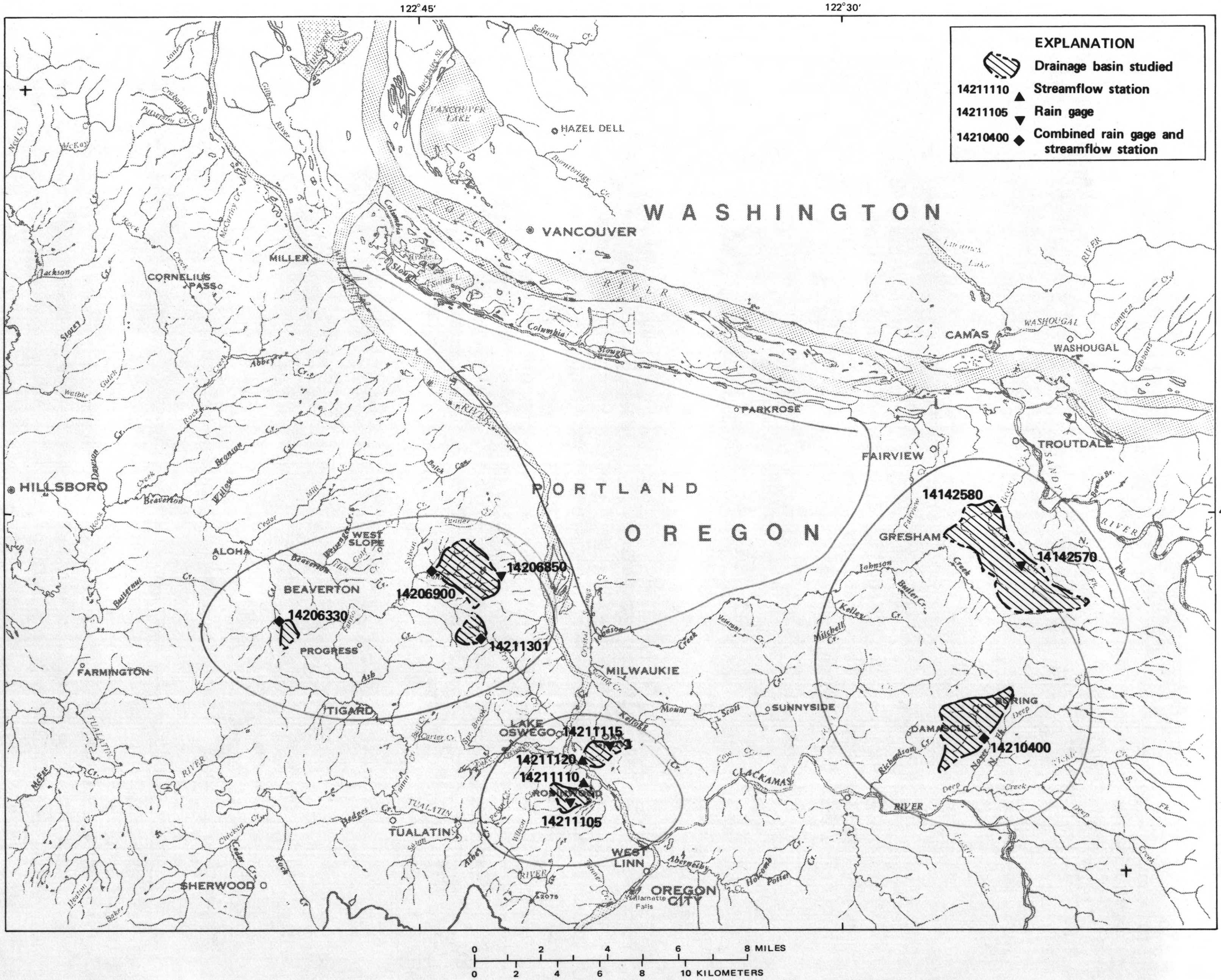

Figure 1.—Locations of streamflow stations and rain gages used for urban storm-water-quality study.

Table 1.--Locations of streamflow stations and rain gages

Station number	Name and location
14142570	Rain gage.--Powell Valley Grade School near Gresham, lat 45°29'26", long 122°22'54", in SW¼ sec.12, T.1 S., R.3 E., Multnomah County.
14142580	Streamflow station.--Kelly Creek on Kane Road near Gresham, lat 45°30'44", long 122°23'56", in NE¼ sec.2, T.1 S., R.3 E., Multnomah County.
14206315	Rain gage.--Beaverton City Hall, lat 45°29'02", long 122°48'11", in SW¼ sec.15, T.1 S., R.1 W., Washington County.
14206330	Rain gage and streamflow station.--Beaverton Creek tributary at SW. Murray Blvd. in Beaverton, lat 45°28'08", long 122°49'28", in SW¼ sec.21, T.1 S., R.1 W., Washington County.
14206850	Rain gage.--KPAM FM radio station on Council Crest in Portland, lat 45°29'21", long 122°41'41", in NW¼ sec.16, T.1 S., R.1 E., Multnomah County.
14206900	Rain gage and streamflow station.--Fanno Creek at SW. 56th Ave. in Portland, lat 45°29'17", long 122°44'01", in NW¼ sec.18, T.1 S., R.1 E., Multnomah County.
14210400	Rain gage and streamflow station.--Noyer Creek on State Highway 212 near Damascus, lat 45°25'06", long 122°24'31", in SW¼ sec.2, T.2 S., R.3 E., Clackamas County.
14211105	Rain gage.--View Drive in Robinwood, lat 45°23'24", long 122°38'53", in SE¼ sec.14, T.2 S., R.1 E., Clackamas County.
14211110	Streamflow station.--Willamette River tributary on Old River Road in Robinwood, lat 45°24'01", long 122°38'37", in NE¼ sec.14, T.2 S., R.1 E., Clackamas County.
14211115	Rain gage.--Oak Lodge RFPD No. 4 in Oak Grove, lat 45°24'57", long 122°37'53", in NW¼ sec.12, T.2 S., R.1 E., Clackamas County.
14211120	Streamflow station.--Willamette River tributary on SE. River Road in Oak Grove, lat 45°24'34", long 122°38'39", in SE¼ sec.11, T.2 S., R.1 E., Clackamas County.
14211301	Rain gage and streamflow station.--Tryon Creek tributary at Portland, lat 45°27'43", long 122°42'18", in SE¼ sec.20, T.1 S., R.1 E., Multnomah County.
14211450	Rain gage.--Johnson Creek tributary on Roberts Ave. in Gresham, lat 45°29'26", long 122°25'22", in SE¼ sec.10, T.1 S., R.3 E., Multnomah County.

Table 2.--Basin characteristics

Station no. and name	Drainage area (mi^2)	Basin slope (percent)	Average channel slope (ft/mi)	Impervious area (percent)	Land use, in percent					Area under construction		K erosion factor	Basin shape factor
					I	II	III	IV	V				
					Rural	Single family	Multi-family	Commercial	Industrial	(percent)	Date		
14142580 Kelly Creek	4.16	5.0	43	9	83	11	4	2	0	0.7	2- 4-76	0.33	3.69
14206330 Beaverton Cr. tributary	.21	7.3	178	19	42	53	5	0	0	.2	2- 5-76	.30	1.43
14206900 Fanno Creek	2.37	16.2	229	32	12	76	6	6	0	.2	2- 5-76	.28	1.62
14200400 Noyer Creek	2.04	6.0	126	4	93	6	0	1	0	.05	2- 4-76	.38	.94
14211110 Willamette R. trib. in Robinwood	1.03	16.9	420	10	69	29	0	2	0	.7	5-26-76	.37	1.92
14211120 Willamette R. trib. in Oak Grove	.74	5.2	133	36	15	73	4	8	0	.2	2- 5-76	.39	2.83
14211301 Tryon Creek	.36	8.3	181	32	13	72	10	5	0	.4	5-28-76	.28	1.19

$$CHNSLOP = \frac{L_1(X_1)+\ldots+L_n(X_n)}{L_1+\ldots+L_n} \quad (2)$$

where

n = the number of defined channels,
L = the length, in miles, of each major basin channel, and
X = the channel slope, in feet per mile, for each major basin channel.

Impervious area.--Percentage of the basin impervious to infiltration of rain (IMPAREA), such as asphalt roads, paved parking lots, and roofs. The area was determined by CRAG from aerial photographs (scale: 1 in. = 600 ft) taken in 1974.

Land use.--Percentage of the basin, with land use of types I through V, as mapped by CRAG personnel from aerial photographs taken in 1974. Land-use types are defined below:

I. Rural (LU1) - Includes all undeveloped land, agricultural land, parks, cemeteries, and school playgrounds.

II. Single-family residential (LU2) - Includes single-family detached dwellings and duplexes.

III. Multifamily residential (LU3) - Includes multifamily housing units and trailer parks.

IV. Commercial - (LU4) - Includes general wholesale and retail buildings, school buildings, churches, light industry, and airports.

V. Industry - (LU5) - Includes heavy industry.

Area under construction.--Percentage of drainage basin disturbed by construction (ARUCON) on an arbitrarily selected date.

K - erosion factor.--The soil erodibility factor (K) from the universal soil-loss equation is a measure of the susceptibility of soil particles to being detached and transported by rainfall and runoff. It is a value determined experimentally for selected benchmark soils. K values that have been obtained experimentally range from 0.02 to 0.69 (Wishmeier and others, 1971). The values used for the seven basins are area-weighted averages taken from Soil Interpretive Reports for Oregon by the U.S. Soil Conservation Service, unpublished Soil Conservation Service soil maps, and a soil-erodibility nomograph (Wishmeier and others, 1971). K values for the seven study basins ranged from 0.28 to 0.39.

Basin shape.--The ratio of the length to average basin width (BASHAPE), described by Office of Water Data Coordination in chapter 7 (1977), was calculated using the formula:

$$\text{BASHAPE} = \frac{(L_c)^2}{A} \qquad (3)$$

where

L_c = straight-line distance from the basin outlet to the point on the basin divide used to measure main channel length, and

A = area of the drainage basin.

A more detailed description of each basin is given in a report by McKenzie and Miller (1976).

The basins were chosen to provide a range in values for the different characteristics of drainage-area size, basin slope, and land use. Geographical location, hydraulics of the basin, and feasibility of collecting accurate streamflow data at the gage sites were also considered.

Rainfall, Streamflow

Both rainfall and stream-stage data were collected for each site at 5-minute intervals. Rainfall was recorded to the nearest 0.01 in. If a rain gage was not working during a storm, the rainfall was estimated from the record for a nearby basin. Stage data were recorded to the nearest 0.01 ft and were converted to discharge using theoretical stage-discharge relationships that were partially verified by discharge measurements using standard current-meter techniques.

Water-Quality Sampling and Analysis

Water-quality samples were taken by a SERCO_/ automatic-point sampler. The sampler consists of 24 1/2-gal glass bottles which are vacuum evacuated and sealed by means of individual pressure switches. Sampling intervals were generally 15 minutes, 30 minutes, or 1 hour, depending on basin size and predicted rainfall intensity and duration. In addition to the samples collected by the SERCO sampler, a depth-integrating suspended-sediment sampler, US DH-48TM, was used manually to obtain depth- and width-integrated water samples. These hand-collected samples, one to five per storm, were used (1) to ensure that representative samples were collected by the point samplers, and (2) to collect extra sample volume for various analytical tests, such as microbiological analysis of indicator bacteria. Laboratory methodologies are described by McKenzie and Miller (1976).

_/ The use of brand names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

Concentrations of samples taken with the hand sediment sampler generally agreed within 20 percent of those taken by the SERCO sampler. For three of the basins, however, suspended sediment differences greater than 30 percent were noted, with the concentrations from the sampler generally higher than from hand sampling. Differences in concentration exceeding 100 percent were attributed by the authors to the improper placement of the SERCO sampling intake. When the intake tubes were adjusted so they were not too near the channel bottom or so that the intake tubes were more nearly vertical, the difference between hand and automatic sampling was greatly reduced.

During the study, analyses were made for the following constituents:

1. Physical characteristics
   a. Turbidity
   b. Settleable solids
   c. Specific conductance
   d. Suspended sediment
   e. Temperature

2. Chemical characteristics
   a. Dissolved oxygen
   b. pH
   c. Alkalinity
   d. Chemical oxygen demand
   e. Dissolved solids

3. Biochemical oxygen demand
   a. 5-day (BOD_5)
   b. Ultimate (BOD_u)
   c. Rate of BOD satisfaction

4. Bacteriological characteristics
   a. Fecal coliform
   b. Fecal streptococci
   c. Total coliform

5. Major nutrients
   a. Total phosphorus
   b. Total organic nitrogen
   c. Ammonia
   d. Dissolved nitrite plus nitrate

6. Major ions
   a. Silica
   b. Calcium
   c. Magnesium
   d. Iron
   e. Potassium
   f. Sodium
   g. Chloride
   h. Sulfate

7. Trace metals
   a. Lead
   b. Zinc
   c. Mercury
   d. Arsenic
   e. Copper
   f. Chromium
   g. Cadmium

8. Oil and grease

The total number of analyses for many of the above characteristics are shown in table 3. Some analyses for trace metals, major ions, and oil and grease were run only once during the study. Turbidity and specific conductance were measured on almost every sample to indirectly indicate the suspended and dissolved concentrations, respectively, of material in the samples. A sufficient number of samples were selected for analysis of settleable solids, suspended sediment, and biochemical oxygen demand to account for the variation of constituent concentrations over the storm

Table 3.--*Total number of analyses for major constituents.* [620 total samples collected].

	Specific conductance	Settleable solids	Turbidity	Suspended sediment	BOD_5	Ultimate BOD	Bacteria: Fecal coliform	Bacteria: Fecal streptococci	Bacteria: Total coliform	Temperature	Dissolved oxygen	pH and alkalinity	1/ Chemical oxygen demand	1/ Dissolved solids	1/ Total phosphorus as P	1/ Total organic nitrogen as N	1/ Ammonia as N	1/ Dissolved nitrite plus nitrate as N
Number of analyses	619	479	618	380	343	266	142	68	39	74	56	233	69	121	68	63	65	69
Percent of total samples	100	77	100	61	55	43	23	11	6	12	9	38	11	20	11	10	10	11

1/ Indicates values obtained by U.S. Army Corps of Engineers laboratory. All other analyses were made by the U.S. Geological Survey in Portland.

duration. Alkalinity and pH were measured over the range of specific-conductance values. Samples collected near the beginning, at the peak, and near the end of the storm were analyzed for fecal coliform and occasionally for fecal streptococci or total coliform bacteria. To minimize cost, only a few analyses were made of nutrients, chemical oxygen demand, and dissolved solids. To extend their values over the storm hydrograph, these constituents were estimated by using correlations and bivariate regression relationships with other constituents such as flow, suspended sediment, and specific conductance.

ANALYSIS OF CONCENTRATIONS

The first method of data analysis included a study of range and average concentrations. The analysis also briefly considered the effects of settling on several concentrations. Using limited data, a possible connection was considered between constituent concentrations on impervious areas and those found in storm water. Both of the last two considerations have transfer value for areas other than the seven basins used in this study.

Variation of Concentrations

Table 4 shows the ranges of measured concentrations for selected constituents from each basin. Two concentrations are provided for six of the maximum values in the table. The numbers in parentheses are the maximum values, excluding the April 14-15, 1976, storm on Noyer Creek. Samples from this particular storm had concentrations of specific conductance, dissolved solids, ammonia, and total organic nitrogen two to four times higher than maximum concentrations measured for all other storms on Noyer Creek basin. The extremely high values noted in four consecutive samples taken after storm runoff began possibly could be attributed to application of fertilizer in the area. These samples were the 3d through 6th samples out of 12 collected during the storm.

Data collected for individual storms may cover only a part of the range of values listed in table 4. Both turbidity and suspended-sediment concentrations varied in proportion to the variations in rainfall and flow. Therefore, larger storms provided data spanning more of the range of values. But other measurements such as specific conductance, dissolved solids, and occasionally BOD, varied widely for both high and low flows. Thus, for these constituents it was possible to obtain a much wider range of values from smaller storms. Many constituents did not relate directly or inversely to flow or rainfall. One example was temperature, which seemed to be most closely related to seasonal air temperature and varied little over the storm event.

Figures 2 and 3 show the time trace of rainfall intensity, streamflow, and four water-quality constituents that were most frequently measured for two basins during the same storm. Drainage areas of the two basins, Kelly Creek and Beaverton Creek tributary, are 4.16 and 0.21 mi^2, respectively. Because of its smaller drainage area, the discharge on Beaverton Creek tributary responds more rapidly to precipitation than does Kelly Creek. Accordingly, the response of turbidity, suspended sediment, and specific conductance are also more rapid for the smaller basin.

Table 4.--*Range of concentration of selected constituents for seven basins from October 17, 1975 to February 20, 1977.*

(The numbers in parentheses are the maximum values excluding the April 14-15, 1976, storm on Noyer Creek.)

		Specific cond. (µmhos/cm at 25°C)	Settleable solids (mL/L)	Turbidity (Jtu)	Suspended sediment (mg/L)	Ultimate BOD (mg/L)	**Fecal coliform (organisms per 100 mL)**	Dissolved oxygen (mg/L)	pH (units)	Alkalinity as $CaCO_3$ (mg/L)	COD (mg/L)	Dissolved solids (mg/L)	Total phosphorus as P (mg/L)	Total organic nitrogen as N (mg/L)	Ammonia as N (mg/L)	Dissolved nitrite plus nitrate as N (mg/L)
All basins	Max	284	10.0	900	2,220	120	27,000	12.2	8.2	120	210	180	1.1	5.4 (5.2)	0.98 (.41)	7.0
	Min	32	.00	3	1	1.6	5	7.8	6.4	8	10	20	.01	.25	.02	.08
14142580	Max	260	3.8	210	934	24	17,000	12.2	8.2	120	100	175	1.1	4.2	.24	7.0
Kelly Creek	Min	44	.0	15	8	3.9	16	10.0	6.6	13	17	30	.08	.81	.03	1.3
14206330	Max	284	1.6	200	610	39	7,600	10.4	7.9	100	50	180	.49	1.4	.18	4.4
Beaverton Creek tributary	Min	32	.05	4	5	3.2	29	7.8	6.4	10	10	20	.07	.37	.02	.08
14206900	Max	232	5.5	600	2,220	120	27,000	11.3	7.8	92	130	145	1.0	2.3	.22	5.3
Fanno Creek	Min	54	.04	3	3	3.5	71	10.0	6.8	16	18	58	.01	.47	.02	1.2
14210400	Max	230 (62)	1.3	900	1,580	65	1,800	11.3	7.0	17	83	162 (63)	.95	5.4 (1.9)	.98 (.41)	2.5
Noyer Creek	Min	38	.02	4	1	1.6	5	9.0	6.4	8	12	34	.06	.25	.04	1.0
14211110	Max	205	5.3	200	1,740	18	7,800	12.0	7.8	84	120	162	1.1	3.6	.15	7.0
Willamette R. trib. in Robinwood	Min	54	.1	10	11	2.5	220	10.3	6.7	14	10	64	.07	.47	.03	1.6
14211120	Max	245	10.0	340	1,280	49	6,900	11.7	7.9	110	210	160	1.1	5.2	.20	5.3
Willamette R. trib. in Oak Grove	Min	44	.01	5	9	3.3	91	8.9	6.7	15	16	51	.07	.25	.01	.32
14211301	Max	205	9.5	300	1,550	96	12,000	10.3	7.5	62	160	139	1.1	4.1	.08	6.6
Tryon Creek	Min	38	.05	6	5	3.4	60	8.6	6.4	11	25	40	.11	.74	.02	1.0

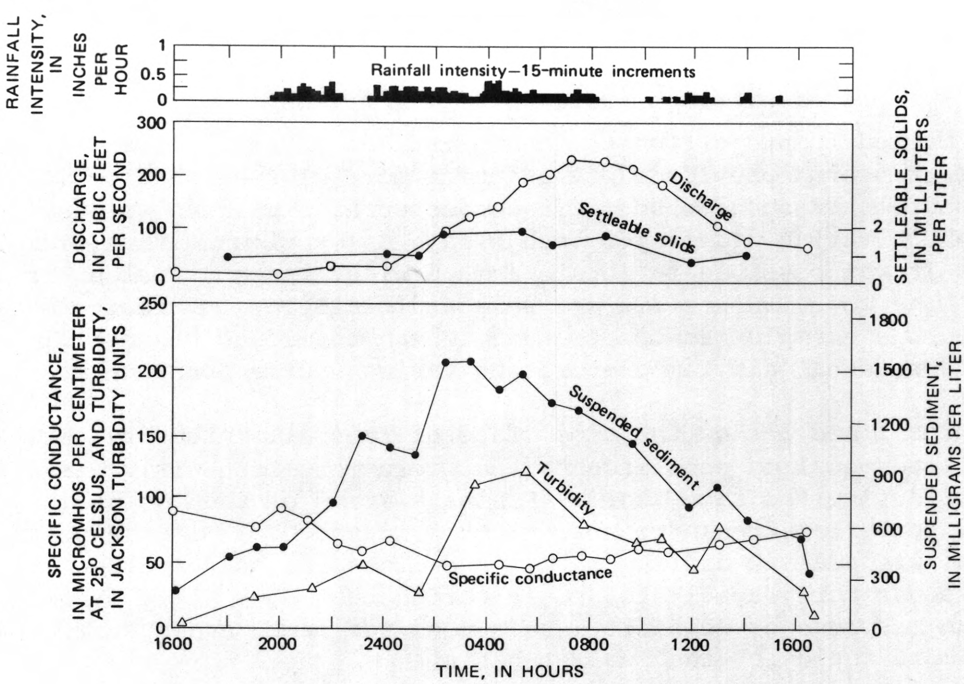

Figure 2.—Rainfall intensity, streamflow, and constituent concentrations for Kelly Creek during storm of December 3-4, 1975.

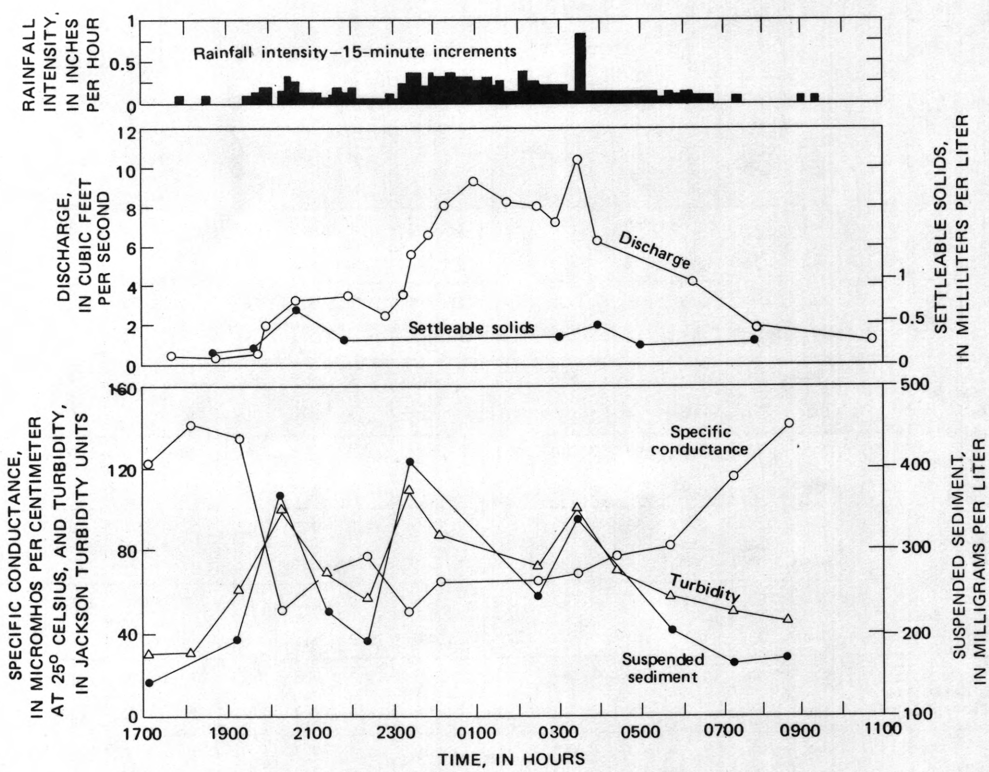

Figure 3.—Rainfall intensity, streamflow, and constituent concentrations for tributary to Beaverton Creek during storm of December 3-4, 1975.

Table 5. – *Summary of concentrations from 60 storms on seven basins from October 17, 1975, to February 20, 1977*

Station	Number of storms	Settleable solids: Number of values	Settleable solids: Average concentration (mL/L)	Settleable solids: Maximum concentration (mL/L)	Suspended sediment: Number of values	Suspended sediment: Average concentration (mg/L)	Suspended sediment: Maximum concentration (mg/L)	Five-day biochemical oxygen demand: Number of values	Five-day biochemical oxygen demand: Average concentration (mg/L)	Five-day biochemical oxygen demand: Maximum concentration (mg/L)	Five-day biochemical oxygen demand: Number of values >10 mg/L	Five-day biochemical oxygen demand: Number of values >20 mg/L	Fecal coliform bacteria: Number of values	Fecal coliform bacteria: Average concentration (Colonies/100 mL)	Fecal coliform bacteria: Maximum concentration (Colonies/100 mL)	Fecal coliform bacteria: Number of values >200	Fecal coliform bacteria: Number of values >1,000
Kelly Creek	8	79	0.77	3.8	58	219	934	48	5.5	14	6	0	18	2,800	17,000	16	11
Beaverton Creek tributary	8	52	.42	1.6	49	106	610	36	5.9	14	4	0	20	2,100	7,600	18	13
Fanno Creek	9	82	1.05	5.5	64	364	2,220	58	7.2	25	8	1	24	6,100	27,000	22	18
Noyer Creek	8	45	.31	1.3	52	160	1,580	50	5.2	24	4	1	14	710	1,800	11	5
Willamette River tributary in Robinwood	7	47	.99	5.3	35	275	1,740	32	3.6	8.8	0	0	14	2,000	7,800	14	7
Willamette River tributary in Oak Grove	11	94	1.01	10	66	199	1,280	64	5.9	24	7	2	29	3,000	6,900	27	21
Tryon Creek	9	80	.88	9.5	56	288	1,550	55	8.0	28	11	3	23	3,200	12,000	20	18
All values	60	479	.82	10	380	233	2,220	343	6.1	28	40	7	142	3,100	27,000	128	93

Average Concentrations

Average and maximum concentrations of four selected analyses are summarized in table 5. These data show that for both suspended sediment and settleable solids, the highest average concentrations were about 3.4 times the lowest averages. The average suspended-sediment concentrations were much greater than the 5 to 20 mg/L allowed for secondary waste effluent by the Oregon Department of Environmental Quality (1976). Although all dissolved-oxygen values measured were at or above saturation, the average 5-day biochemical oxygen demand for "all values" (6.1 mg/L) and the average BOD in Fanno Creek and the Beaverton Creek tributary exceed the 5.0 mg/L limit for tributaries to the Tualatin River (Oregon Dept. Environmental Quality, 1976). The average fecal coliform concentrations in all basins were considerably higher than the 200 colonies/100 mL suggested for bathing water (U.S. Environmental Protection Agency, 1976).

Information in table 5 indicates that, on the average, samples frequently exceeded the concentration limits established by the Department of Environmental Quality. The constituents exceeded the limits with the following frequency: (1) for suspended sediment, 20 mg/L was exceeded by 91 percent of the samples and 100 percent of the storms; (2) for fecal coliform bacteria, 200 colonies/100 mL was exceeded by 90 percent of the samples and 93 percent of the storms; and (3) for BOD, 5 mg/L was exceeded by 53 percent of the samples and 82 percent of the storms, but 10 mg/L was exceeded by only 12 percent of the samples and 35 percent of the storms.

Average concentrations and average discharge-weighted concentrations are compared in table 6. The average concentrations from all storm data and from the 34 storms used to calculate storm loads were similar. However, the discharge-weighted values are significantly greater than the arithmetic mean value. These discharge-weighted values are probably more representative of storm-load concentrations than the storm-data averages.

Table 6.--Comparison of average and discharge-weighted concentrations

Source	Settleable solids (mL/L)	Suspended sediment (mg/L)	5-day BOD (mg/L)	Fecal coliform (colonies/100 mL)
Average from all storm data	0.82	233	6.1	3,100
Average from the 34 storm events listed in table 13	.87	263	5.7	3,400
Discharge-weighted average from the 34 storm events listed in table 13	1.49	557	5.4	4,200

One unfiltered sample each from Kelly Creek and Oak Grove was collected and analyzed for lead, zinc, mercury, arsenic, copper, cadmium, and chromium. Of these constituents, only lead exceeded the limit for filtered water (Oregon Dept. Environmental Quality, 1976).

Effects of Settling

An additional data analysis of concentrations was made to determine the effects of settling on several concentrations. Settling was used to determine the possible effect of detention ponds as a form of treatment for urban runoff. Samples from five of the seven basins were analyzed before and after 1 hour of settling in the laboratory. The results of these analyses (see table 7) indicate that, during settling, concentrations of four of the five constituents were reduced significantly.

Comparison of Storm Concentration With Street-Sweepings Analysis

Contaminants that accumulate on street surfaces and other impervious areas are thought to be significant sources of constituent loading in urban storm-water runoff. In fact, an assumption made for the Corps' model, STORM (Storage, Treatment, Overflow, Runoff Model), is that all pollutants are associated with dust and dirt accumulation on streets (U.S. Army Corps of Engineers, 1976). Sartor and Boyd (1972) stated that runoff from streets is highly contaminated, and they showed that steet material contained a significant accumulation of heavy metals, especially lead and zinc.

Table 7.--Reductions in concentrations after 1 hour of settling

Constituents	Number of samples	Average percent reduction
5-day BOD	15	30
COD	6	45
NH_4	6	14
Total organic nitrogen	6	36
Total phosphorus	6	54

Because of the expected importance of street sweepings and their relation to measured storm-water concentrations for several constituents, a brief analysis was made of lead and zinc for two basins. First, for a whole water sample (a mixture of discharge-integrated water and suspended sediment) a ratio was formed by dividing measured lead and zinc concentrations by the suspended-sediment concentration. Next, the resultant microgram-per-kilogram ratio was compared to the microgram-per-kilogram concentrations of lead and zinc measured for street sweepings taken from the basins.

The comparison between the calculated ratio and the street-sweeping material concentrations (table 8) indicates the possibility of establishing a useful relationship between the street sweepings and water concentrations for lead. A relationship was not evident for zinc.

Table 8.—*Comparison between the ratio of lead and zinc to suspended sediment in storm-water samples and the ratio of lead and zinc to street-sweepings sediment samples*

Station	Source	Lead	Zinc
Kelly Creek	Street-sweepings sample	1/820 ($\frac{\mu g}{g\ sweepings}$)	1/176 ($\frac{\mu g}{g\ sweepings}$)
Do	Storm-water sample	630 ($\frac{\mu g}{g\ sediment}$)	2,200 ($\frac{\mu g}{g\ sediment}$)
Willamette River tributary in Oak Grove	Street-sweepings sample	1/750 ($\frac{\mu g}{g\ sweepings}$)	1/150 ($\frac{\mu g}{g\ sweepings}$)
Do	Storm-water sample	260 ($\frac{\mu g}{g\ sediment}$)	540 ($\frac{\mu g}{g\ sediment}$)

1/From Miller, Rinella, McKenzie, and Parmenter (1977).

BIVARIATE CORRELATION AND REGRESSION ANALYSIS OF CONSTITUENTS

The second analytical approach derived correlations between constituents for all data collected. Bivariate correlation coefficients define the degree of association between two variables. Correlation coefficients are, by definition, mathematical associations and do not of themselves imply a cause-and-effect relation nor even that the association is the result of a common cause (Riggs, 1968). Multiple-linear regression analysis identifies mathematical dependencies which then may be further examined for possible hydrologically feasible cause-and-effect relationships, but cautious interpretation is necessary.

Grouped Data

Bivariate correlations were computed for water-quality characteristics, using three different groupings of data. The three groupings were (1) characteristics from individual storms on single sites (data group I), (2) characteristics from all storms on a single site (data group II), and (3) characteristics from all storms on all sites (data group III).

Correlations resulting from the first two groups of data were most useful, whereas the third group yielded few useful correlations. Correlation analysis of group I was used to select bivariate regression equations to estimate constituents where data were missing.

Data group II correlations and bivariate regression equations provided three principal uses. First, the correlations resulting from the earliest data were used as guidelines for selecting samples for particular analyses (that is, dissolved solids, nutrient analysis, COD) from individual storm events. This helped to ensure that a wide range and even distribution of constituent values were measured for each storm and basin. For example, the regression relationship between specific conductance and dissolved solids was used in selecting samples for dissolved-solids analysis. (See "Results of bivariate regression.") Thus, knowing the specific conductance of each sample collected during a storm allowed the selection of appropriate samples for dissolved-solids analysis. Second, the correlations from data group II also provided analytical quality control. If the results of an analysis showed a large deviation from the correlation, the analysis was rerun. And, third, the correlations resulting from data group II were used as guidelines to augment data during storm events for load calculations, as with data group I.

The constituent correlations for the first two groups of data provide insight into the interrelationships between measured constituents in the urban storm-water-quality system. This insight helped to improve sampling and analysis frequencies and to better understand each basin.

Results of Correlation Analysis

A key to the abbreviations used in the correlation listings is shown in table 9.

Table 9.--Key to abbreviations used in correlations

Abbreviation	Description	Unit
Q	Streamflow	ft^3/s
S	Suspended sediment	mg/L
T	Turbidity	Jtu
C	Specific conductance	umhos/cm at 25°C
U	Biochemical oxygen demand - ultimate	mg/L
B	Biochemical oxygen demand - 5-day	mg/L
K	Rate of BOD satisfaction	day^{-1}
I	Settleable solids	mL/L
COD	Chemical oxygen demand	mg/L
FC	Fecal coliform	colonies/100 mL
FS	Fecal streptococci	colonies/100 mL
TC	Total coliform	colonies/100 mL
pH	pH	units
A	Alkalinity	mg/L
DS	Dissolved solids	mg/L
TP	Total phosphorus as P	mg/L
TON	Total organic nitrogen as N	mg/L
NO_2+NO_3	Nitrite plus nitrate as N	mg/L
NH_4	Ammonia as N	mg/L

The following is a list of 52 combinations of variables for which bivariate correlation coefficients were computed for data groups II and III:

1. Q vs. S1/
2. Q vs. T1/
3. Q vs. C1/
4. Q vs. U1/
5. Q vs. B
6. Q vs. K
7. Q vs. I1/
8. Q vs. DS
9. Q vs. COD
10. Q vs. pH
11. Q vs. A
12. Q vs. TP
13. Q vs. TON
14. Q vs. NO_2+NO_3
15. Q vs. FC
16. Q vs. FS
17. Q vs. TC
18. S vs. C1/
19. S vs. U1/
20. S vs. B
21. S vs. K
22. S vs. I1/
23. S vs. COD
24. S vs. TP
25. S vs. TON
26. S vs. FC
27. S vs. FS
28. S vs. TC
29. T vs. S1/
30. T vs. C1/
31. T vs. U1/
32. T vs. I1/
33. T vs. COD
34. C vs. U
35. C vs. DS
36. C vs COD
37. C vs. pH
38. C vs. A
39. C vs. NO_2+NO_3
40. C vs. NH_4
41. I vs. U1/
42. COD vs. U
43. COD vs. B
44. COD vs. K
45. COD vs. I
46. COD vs. DS
47. COD vs. TON
48. TON vs. NO_2+NO_3
49. TON vs. NH_4
50. NO_2+NO_3 vs. NH_4
51. FC vs. FS
52. FC vs. TC

1/ Correlation coefficients were also computed for data group I.

Tables 10a through 10g, 11, and 12 tabulate correlation coefficients resulting from correlation analysis of data groups I through III. Also, the number of data points available for each correlation are shown in parentheses. Only correlation coefficients greater than ±0.7 and based on four or more data points were listed. Correlation coefficients of less than ±0.7 were not considered significant because below this value, less than 50 percent of the variation of the dependent variable is being explained by the independent variable.

Data from group I (tables 10a-10g) show that the number of significant correlations for a particular basin may vary greatly from storm to storm. It is also apparent that the correlation coefficients for a pair of variables may vary considerably from storm to storm. Also, correlation coefficients for the same storm and the same pair of variables varies from basin to basin. As an example, the correlation coefficients for Q versus S from the storm on December 3-4, 1975, range from less than 0.7 to 0.92. A greater number of data points will increase the reliability of a correlation coefficient, but does not necessarily provide a better correlation.

Comparisons of correlation coefficients from data group I with data group II show that, in general, the effect of lumping together the data from all storms for a single basin is to decrease the correlation coefficient. (See tables 10a-10g.) For example, the correlation coefficients of Q versus S for the Willamette River tributary in Oak Grove (table 10f) and Tryon Creek (table 10g) are significant (greater than ±0.7) for each storm but not significant for data group II. Other similar examples imply that correlations for several pairs of variables may be significantly affected by the differences in rainfall characteristics and possibly antecedent conditions for each storm. Thus, the precipitation characteristics appear to be important when evaluating correlations for a basin.

Table 12 shows a comparison of correlation coefficients from data groups II and III. Correlation coefficients for group III are based on data for all storms from all basins. For all correlations, the median coefficient from group II is greater than from group III. This implies that not only are the precipitation characteristics from storm to storm important, but so are the basin characteristics from basin to basin.

Table 10.—*Correlation coefficients (and number of data points shown in parentheses) resulting from correlation analysis of concentrations from data groups I and II*

[Only correlation coefficients greater than ±0.7 and based on four or more data points are listed]

(a) KELLY CREEK

Correlations	DATA GROUP I STORM DATES								DATA GROUP II	
	10-17-75		10-29-75		12-3, 4-75		3-30, 31-76			
Q vs. S		(6)	0.94	(11)	0.75	(13)	0.90	(7)		(46)
Q vs. T	0.72	(10)	.73	(18)	.72	(22)		(10)		(76)
Q vs. C		(10)	-.77	(19)	-.78	(22)		(10)		(78)
Q vs. U	.97	(4)	.71	(6)		(5)	-.89	(6)		(26)
Q vs. I		(10)		(18)		(10)		(10)		(57)
S vs. C	.85	(6)	-.90	(11)	-.80	(13)	-.80	(7)		(46)
S vs. U				(6)		(4)		(5)		(21)
S vs. I	.82	(6)		(11)		(4)		(7)		(32)
T vs. S		(6)	.83	(11)	.82	(13)		(7)	0.80	(45)
T vs. C		(10)	-.93	(18)	-.93	(22)	-.70	(10)	-.71	(76)
T vs. U	1.00	(4)		(6)	.92	(5)		(6)		(26)
T vs. I		(10)		(17)	.89	(10)		(10)		(56)
I vs. U		(4)	.91	(6)			.82	(6)		(18)

(b) BEAVERTON CREEK TRIBUTARY

Correlations	DATA GROUP I STORM DATES										DATA GROUP II	
	12-3, 4-75		2-11, 12-76		2-17-76		3-22-76		4-23, 24-76			
Q vs. S	0.75	(11)	0.77	(4)		(7)	0.98	(5)		(8)		(45)
Q vs. T	.82	(14)	.72	(6)		(9)	.92	(6)	0.71	(11)	0.72	(61)
Q vs. C	-.82	(14)		(6)	-0.88	(9)	-.88	(6)	-.89	(11)	-.72	(62)
Q vs. U	.97	(5)						(5)	.71	(4)		(25)
Q vs. I		(9)		(5)	.76	(9)				(7)		(47)
S vs. C	-.78	(11)		(4)		(7)		(5)	-.76	(8)		(44)
S vs. U	.92	(4)						(5)	.92	(4)		(22)
S vs. I	.92	(7)	.82	(4)		(7)			.92	(4)		(33)
T vs. S	.98	(11)	.98	(4)		(7)	.96	(5)	.98	(8)	.86	(44)
T vs. C	-.82	(14)		(6)		(9)	-.87	(6)	-.78	(11)		(61)
T vs. U	.92	(5)						(5)	.92	(4)		(25)
T vs. I	.86	(9)	.74	(5)	.90	(9)				(7)		(47)
I vs. U												(15)

Table 10.—*Correlation coefficients (and number of data points shown in parentheses) resulting from correlation analysis of concentrations from data groups I and II*—Continued

(c) FANNO CREEK

Correlations	DATA GROUP I STORM DATES				DATA GROUP II
	12-3, 4-75	2-17-76	3-22-76	4-23-76	
Q vs. S	0.97 (12)	0.90 (7)	0.81 (7)	(14)	0.76 (49)
Q vs. T	.98 (18)	.85 (9)	.86 (10)	0.90 (17)	.74 (81)
Q vs. C	-.86 (18)	-.89 (9)	(10)	-.71 (17)	(82)
Q vs. U	(6)	.96 (4)	.83 (6)	(8)	(31)
Q vs. I	.77 (13)	.91 (9)	.88 (7)	(16)	(70)
S vs. C	-.80 (12)	-.79 (7)	(7)	(14)	(49)
S vs. U	(5)	1.00 (4)	.91 (6)	(8)	(27)
S vs. I	.89 (9)	.98 (7)	1.00 (5)	(14)	.74 (42)
T vs. S	.79 (12)	.92 (7)	.94 (7)	.88 (14)	(48)
T vs. C	-.85 (18)	-.95 (9)	-.83 (10)	(17)	(81)
T vs. U	(6)	.95 (4)	.96 (6)	(8)	(31)
T vs. I	(13)	.91 (9)	.92 (7)	(16)	(70)
I vs. U	(4)	.97 (4)	.95 (4)	(8)	(26)

(d) NOYER CREEK

Correlations	DATA GROUP I STORM DATES				DATA GROUP II
	3-30, 31-76	4-8, 9-76	4-14, 15-76	4-23-76	
Q vs. S	(8)	(9)	0.86 (7)	(8)	(45)
Q vs. T	(10)	(10)	(12)	(9)	(63)
Q vs. C	-0.85 (10)	(10)	(12)	(9)	(64)
Q vs. U	(8)	(8)	(6)		(37)
Q vs. I	(9)	(8)		(6)	(34)
S vs. C	(9)	(9)	.77 (7)	.99 (8)	(47)
S vs. U	(8)	(8)	(4)		(35)
S vs. I	(8)	.82 (7)		(5)	(28)
T vs. S	.96 (9)	.70 (9)	.95 (7)	1.00 (8)	0.78 (46)
T vs. C	(12)	(10)	(12)	.99 (9)	(66)
T vs. U	(8)	(8)	(6)		(38)
T vs. I	(10)	.78 (8)		(6)	(36)
I vs. U	(7)	(6)			(21)

Table 10.—*Correlation coefficients (and number of data points shown in parentheses) resulting from correlation analysis of concentrations from data groups I and II*—Continued

(e) WILLAMETTE RIVER TRIBUTARY IN ROBINWOOD

Correlations	DATA GROUP I STORM DATES				DATA GROUP II
	10-29-75	12-3, 4-75	2-17-76	3-30, 31-76	
Q vs. S	0.96 (4)	0.88 (13)		(7)	0.75 (34)
Q vs. T	.86 (12)	.86 (20)	0.97 (8)	0.97 (8)	(60)
Q vs. C	(12)	-.78 (20)	-.97 (8)	-.90 (8)	-.84 (61)
Q vs. U		(6)		.79 (5)	.75 (20)
Q vs. I	(12)	.92 (11)	.93 (8)	.71 (8)	(42)
S vs. C	(4)	-.86 (13)		(7)	(34)
S vs. U		.76 (4)		.85 (5)	.84 (17)
S vs. I	.98 (4)	.94 (8)			.95 (25)
T vs. S	.98 (4)	.83 (13)		(7)	.84 (34)
T vs. C	(12)	-.87 (20)	-.97 (8)	-.82 (8)	(60)
T vs. U		(6)		.91 (5)	.88 (20)
T vs. I	.93 (12)	.71 (11)	.92 (8)	.81 (8)	.75 (42)
I vs. U		.82 (4)		.90 (5)	.85 (15)

(f) WILLAMETTE RIVER TRIBUTARY IN OAK GROVE

Correlations	DATA GROUP I STORM DATES				DATA GROUP II
	12-3, 4-75	3-30, 31-76	4-8-76	4-23-76	
Q vs. S	0.89 (11)	0.96 (6)	0.94 (8)	0.97 (6)	(45)
Q vs. T	.83 (17)	.97 (9)	.85 (11)	.97 (7)	(73)
Q vs. C	-.77 (17)	(9)	(11)	(7)	(73)
Q vs. U	(5)	.93 (6)	.90 (5)	.96 (5)	(32)
Q vs. I	.79 (12)	.97 (8)	.87 (8)	.94 (7)	(62)
S vs. C	-.83 (11)	(6)	(8)	(6)	(45)
S vs. U	.83 (5)	(5)	1.00 (5)	1.00 (5)	0.78 (29)
S vs. I	.99 (7)	.99 (5)	.88 (5)	.99 (6)	.85 (35)
T vs. S	.95 (11)	.97 (6)	.92 (8)	.97 (6)	.94 (45)
T vs. C	-.94 (17)	(9)	(11)	(7)	(73)
T vs. U	.97 (5)	(6)	.94 (5)	.98 (5)	.75 (32)
T vs. I	.95 (12)	.96 (8)	.86 (8)	.96 (7)	.78 (63)
I vs. U		.99 (5)		.98 (5)	(25)

Table 10.—*Correlation coefficients (and number of data points shown in parentheses) resulting from correlation analysis of concentrations from data groups I and II*—Continued

(g) TRYON CREEK

Correlations	DATA GROUP I STORM DATES										DATA GROUP II	
	12-3, 4-75		2-11, 12-76		2-17-76		3-22-76		4-23-76			
Q vs. S	0.92	(12)	0.96	(11)	0.95	(6)	0.76	(7)	0.90	(10)		(46)
Q vs. T	.91	(18)	.76	(8)	.92	(10)	.89	(10)	.90	(13)	0.73	(83)
Q vs. C	-.75	(18)		(8)	-.95	(10)	-.82	(11)	-.94	(13)		(85)
Q vs. U		(4)			.86	(5)	.91	(8)	.95	(5)		(30)
Q vs. I	.86	(13)	.96	(7)	.99	(8)	.83	(9)	.76	(13)		(73)
S vs. C	-.85	(12)		(4)	-.71	(6)	-.71	(7)	-.74	(10)		(46)
S vs. U	.78	(4)			.97	(4)	.88	(7)	.92	(5)		(26)
S vs. I	.95	(9)	.97	(4)	,99	(5)	.84	(6)	.76	(10)	.90	(39)
T vs. S	.99	(12)	.91	(4)	.75	(6)	.76	(6)		(10)		(44)
T vs. C	-.84	(18)	-.75	(8)	-.82	(10)	-.97	(10)	-.86	(13)		(83)
T vs. U	.74	(4)				(5)		(7)	.77	(5)		(29)
T vs. I	.93	(13)	.77	(7)	.76	(8)		(8)		(13)		(72)
I vs. U							.92	(7)	.76	(5)		(25)

Table 11. – *Correlation coefficients (and number of data points shown in parenthesis) resulting from correlation analysis of concentrations from data Group II*

[Only correlation coefficients greater than ±0.7 and based on four or more data points are listed]

Correlation	Kelly Creek		Beaverton Creek Tributary		Fanno Creek		Noyer Creek		Willamette River Tributary in Robinwood		Willamette River Tributary in Oak Grove		Tryon Creek	
Q vs. S		(46)		(45)	0.76	(49)		(45)	0.75	(34)		(45)		(46)
Q vs. T		(76)	0.72	(61)	.74	(81)		(63)		(60)		(73)	0.73	(83)
Q vs. C		(78)	-.72	(62)		(82)		(64)	-.84	(61)		(73)		(85)
Q vs. U		(26)		(25)		(31)		(37)	.75	(20)		(32)		(30)
Q vs. DS	-0.83	(12)	-.80	(17)	-.72	(16)	-0.74	(10)	-.87	(9)	-0.77	(14)		(16)
Q vs. COD		(8)	.88	(7)	.84	(8)		(6)	.75	(6)	.79	(9)	.85	(8)
Q vs. pH		(34)		(30)	-.77	(29)		(14)	-.82	(27)		(30)		(33)
Q vs. A	-.72	(34)	-.84	(30)	-.84	(29)		(14)	-.90	(27)	-.73	(30)	-.74	(33)
Q vs. TP		(8)	.85	(7)	.71	(8)		(7)		(6)	.85	(9)	.98	(8)
Q vs. TON		(7)		(6)	.88	(7)		(5)		(5)	.81	(6)		(8)
Q vs. NO_2+NO_3	-.85	(8)		(8)	.83	(6)	.73	(8)		(6)		(9)		(9)
Q vs. FC		(16)		(19)		(20)		(12)		(15)		(18)	.75	(20)
Q vs. FS		(4)		(8)	.79	(9)		(13)		(7)		(8)		(8)
Q vs. TC			-.91	(4)	-.97	(4)		(4)		(4)				
S vs. U		(21)		(22)		(27)		(35)	.84	(17)	.78	(29)		(26)
S vs. I		(32)		(33)	.74	(42)		(28)	.95	(25)	.85	(35)	.90	(39)
S vs. COD		(7)	.87	(6)	.97	(6)	.89	(6)	.97	(5)	.94	(9)	.97	(5)
S vs. TP	.97	(7)	.72	(6)	.73	(6)		(7)	.99	(5)		(9)		(5)
S vs. TON		(6)		(5)	.90	(5)		(5)	.99	(4)	.92	(6)		(5)
S vs. FS		(4)		(7)	.91	(8)		(11)		(6)		(7)		(7)
S vs. TC			-.90	(4)		(4)	.81	(4)		(4)				
T vs. S	.80	(45)	.86	(44)		(48)	.78	(46)	.84	(34)	.94	(45)		(44)
T vs. C	-.71	(76)		(61)		(81)		(66)		(60)		(73)		(83)
T vs. U		(26)		(25)		(31)		(38)	.88	(20)	.75	(32)		(29)
T vs. I		(56)		(47)		(70)		(36)	.75	(42)	.78	(63)		(72)
T vs. COD		(8)	.97	(7)	.97	(8)		(6)	.93	(6)	.87	(9)	.91	(8)
C vs. DS	.89	(12)	.91	(21)	.92	(21)		(10)	.97	(9)	.96	(15)	.96	(16)
C vs. COD		(8)	-.92	(7)	-.89	(8)		(6)		(6)		(9)	-.94	(8)
C vs. pH		(34)		(30)		(29)		(14)	.70	(27)		(30)		(33)
C vs. A	.75	(34)	.98	(30)	.96	(29)		(14)	.96	(27)	.95	(30)	.92	(33)
C vs. NO_2+NO_3		(8)		(8)	-.74	(6)		(8)		(6)		(9)		(9)
C vs. NH_4	.93	(8)		(7)	.76	(8)	.94	(6)	.92	(6)	.77	(9)	.77	(8)
I vs. U		(18)		(15)		(26)		(21)	.85	(15)		(25)		(25)
COD vs. U	.86	(8)	.84	(5)	.93	(6)	.84	(6)	.90	(5)	.93	(9)	.91	(6)
COD vs. B	.83	(8)	.83	(5)	.93	(6)	.85	(6)	.78	(6)	.86	(9)	.97	(6)
COD vs. DS		(8)	-.89	(5)	-.91	(4)		(4)		(5)		(9)	-.98	(6)
COD vs. TON	.83	(7)		(6)	.89	(7)		(5)	.98	(5)	.85	(6)		(8)
TON vs. NO_2+NO_3		(7)		(4)				(4)		(4)	.82	(5)		(6)
TON vs. NH_4	.75	(7)		(6)	.83	(7)	.81	(5)		(5)		(6)		(8)
FC vs. FS	.83	(4)		(8)	.85	(9)		(6)		(6)	.94	(5)	.90	(8)
FC vs. TC				(4)		(4)		(4)	.77	(4)				

Table 12.–*Comparison of correlation coefficients from data group III and data group II*
[r, correlation coefficient]

Correlations	Group III		Group II		
	r	Data points	Median r	Range of r values	Number of basins
Q vs. COD	0.63	52	0.84	0.75 - 0.88	5
S vs. I	.80	234	.88	.74 - .95	4
S vs. COD	.77	44	.96	.87 - .97	6
S vs. TP	.64	45	.85	.72 - .99	4
T vs. S	.66	306	.84	.78 - .94	5
T vs. COD	.66	52	.93	.87 - .97	5
C vs. DS	.70	94	.94	.87 - .97	6
C vs. A	.85	197	.96	.75 - .98	6
COD vs. U	.80	45	.90	.84 - .93	7

Results of Bivariate Regressions

Figures 4 through 12 are typical examples of constituent regressions. In comparing figure 4 with figure 5, it is apparent that the correlation coefficients are about equal; however, the deviations from the regression line are smaller in figure 4, as indicated by the standard errors of estimate (10.2 versus 21.3 mg/L). Figure 4 represents one of the better relationships of specific conductance (C) versus dissolved solids (DS) for the seven basins. The worst C versus DS relationship results for Noyer Creek (SEE=24.4 mg/L), where a typical range of values for specific conductance during a storm was 40 to 60 micromhos per centimeter at 25°C.

Figures 6 through 8 are plots of discharge (Q) versus suspended sediment (S) for the December 3-4, 1975, storm on three basins. From figure 6, a curve can be drawn through the data points in the chronological sampling order. This forms a loop about the linear least-squares fit line. In general, the data collected during rising streamflow are on the left side of the line and the data collected during falling streamflow are on the right. The loop is also evident in both figures 7 and 8, but it is much closer to the line in figure 7 than it is in either figure 6 or 8. Considerable increase in accuracy could be achieved by using the loop to predict sediment values for a known discharge rather than just using the linear least-squares fit to the data. The loop phenomenon that occurred in figures 6 through 8 is typical of many relationships.

Figures 9 through 12 show four different constituent relationships for one basin for the same storm. In figure 9, for Q versus S, the loop is also evident. In figure 10, for S versus ultimate BOD (U), also exhibits a loop, but here the loop progresses in the opposite direction from that of the previous figures, with the falling points plotting above the regression line. The direction of progression of the points could be reversed by exchanging variables on the axes. In figure 13, the constituents are plotted so that the maximum values are at the same level on the ordinate, thereby allowing the following observations to be made. Figures 10 and 13 show that suspended sediment and BOD rose at about the same rate, BOD peaked ahead of, and fell slower than, suspended sediment. In figures 11 and 13, the BOD values rose faster, peaked ahead of, and fell slower than the turbidity values. Figures 12 and 13 show that suspended-sediment values rose faster, peaked ahead of, and fell faster than the turbidity values. When regressions of data exhibiting the phenomenon described above were used for estimating a missing constituent value, separate curves were frequently used to define the rising and falling limbs of the loop to minimize the errors of estimate.

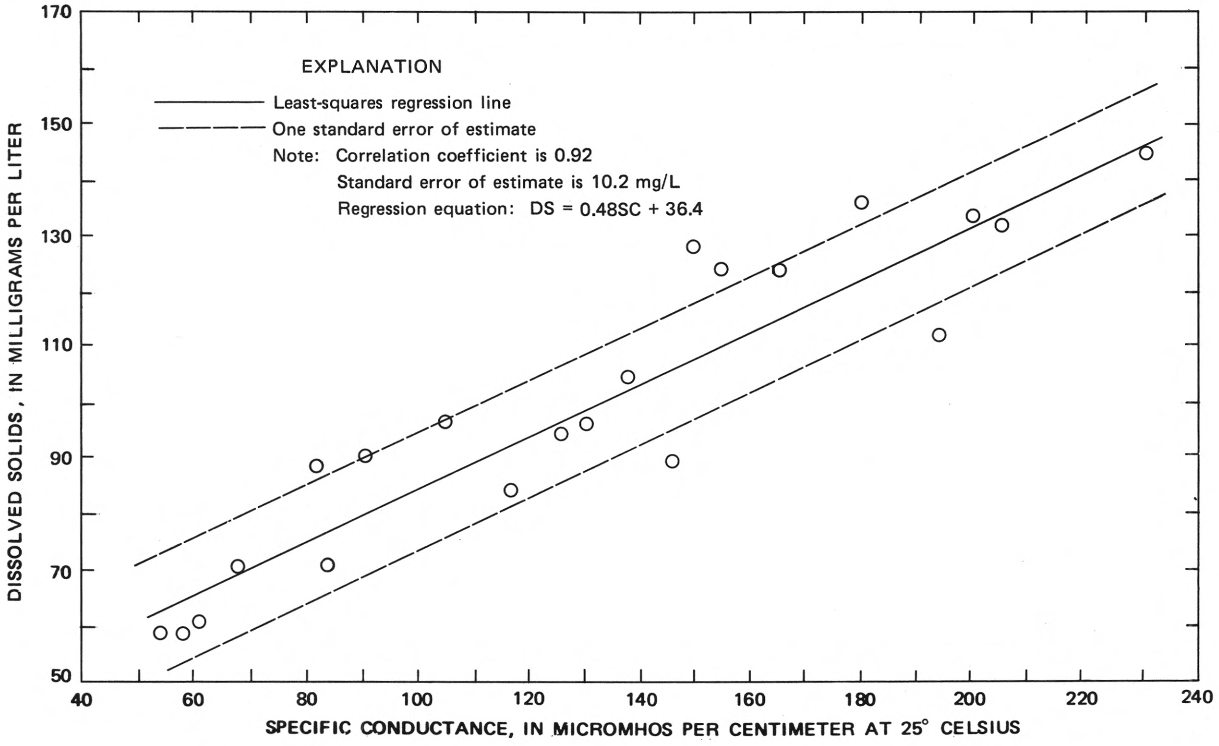

Figure 4.—Relationship between specific conductance and dissolved solids for Fanno Creek.

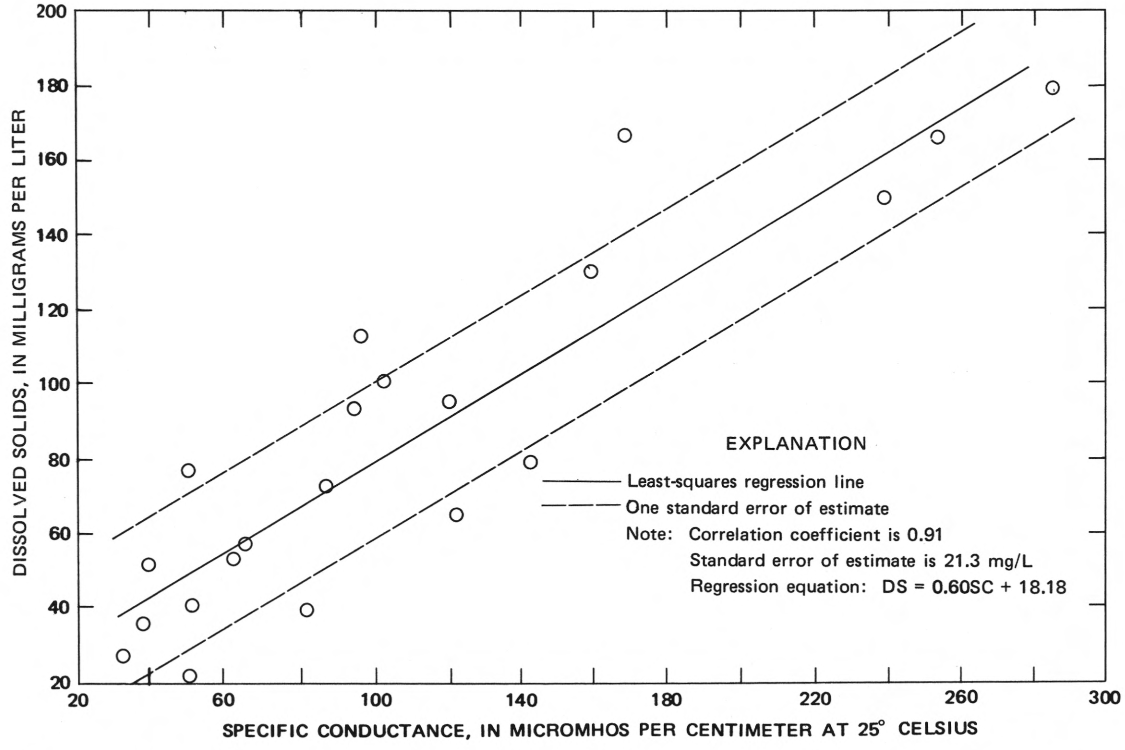

Figure 5.—Relationship between specific conductance and dissolved solids for Beaverton Creek tributary.

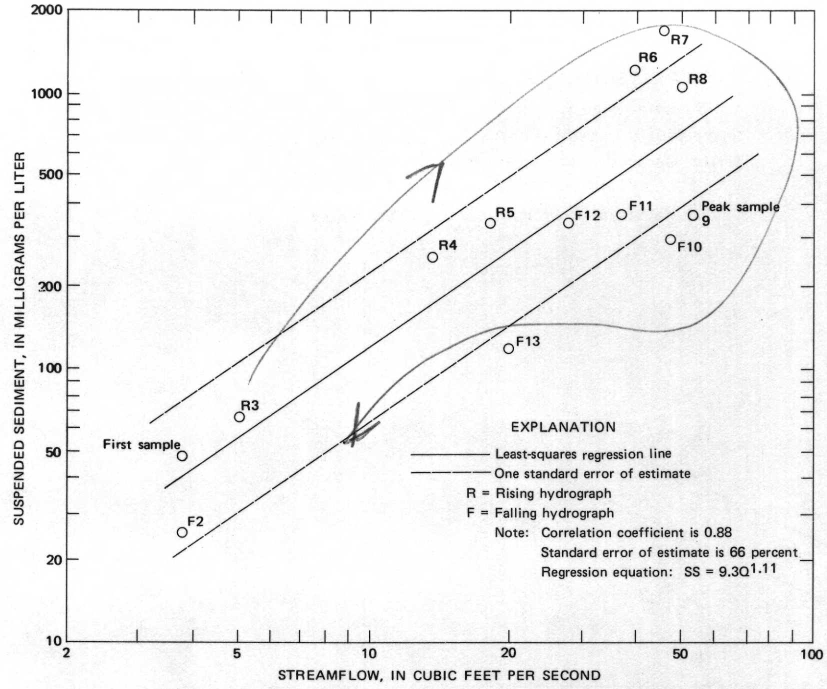

Figure 6.—Relationship between streamflow and suspended sediment for Willamette River tributary in Robinwood during storm of December 3-4, 1975.

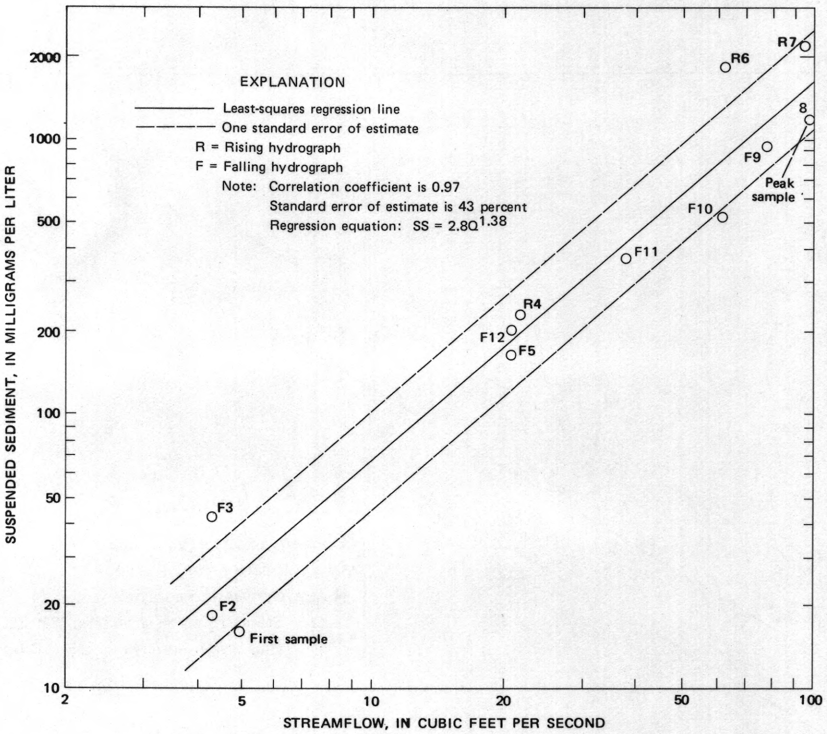

Figure 7.—Relationship between streamflow and suspended sediment for Fanno Creek during storm of December 3-4, 1975.

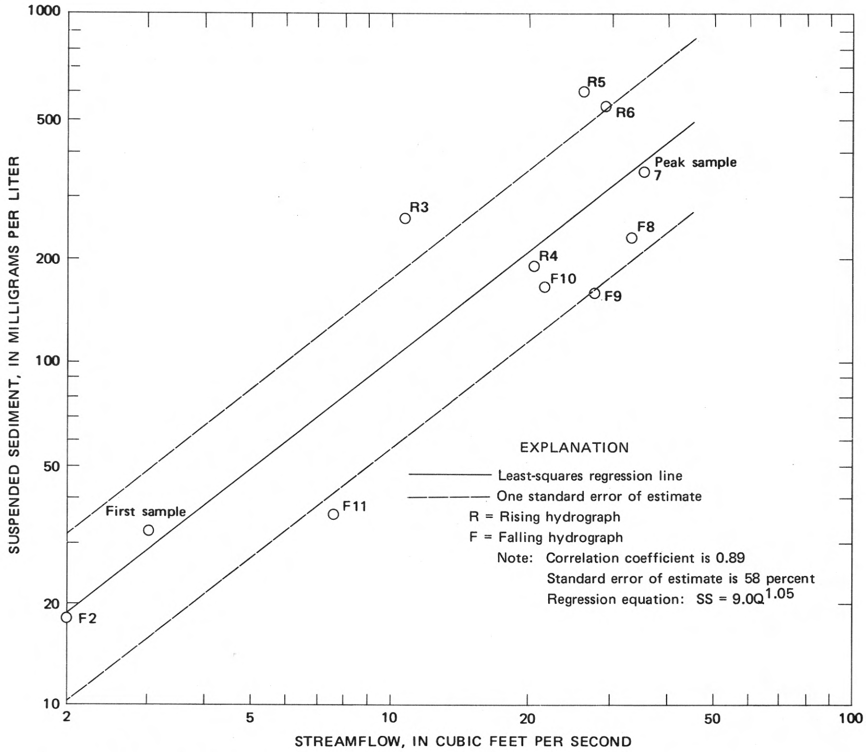

Figure 8.—Relationship between streamflow and suspended sediment for Willamette River tributary in Oak Grove during storm of December 3-4, 1975.

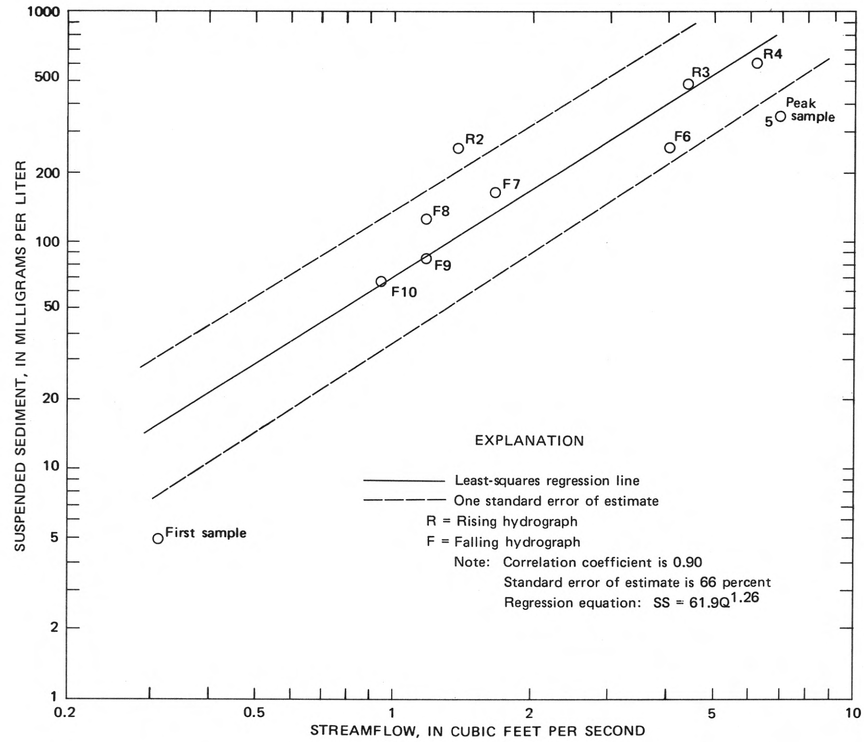

Figure 9.—Relationship between streamflow and suspended sediment for Tryon Creek during storm of April 23, 1976.

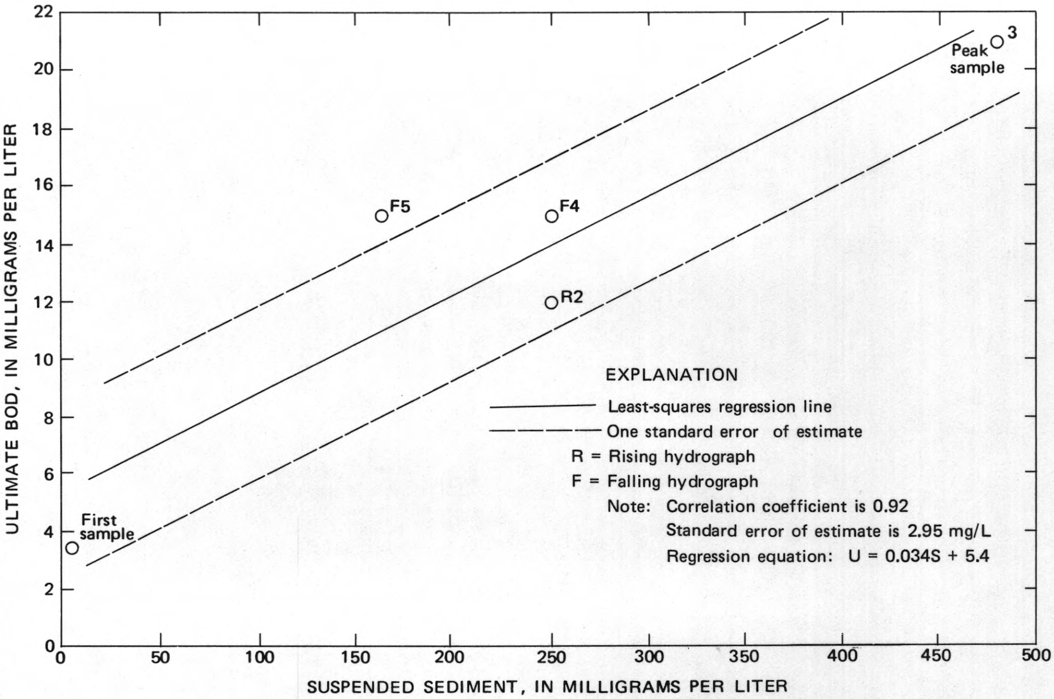

Figure 10.—Relationship between suspended sediment and ultimate-BOD for Tryon Creek during storm of April 23, 1976.

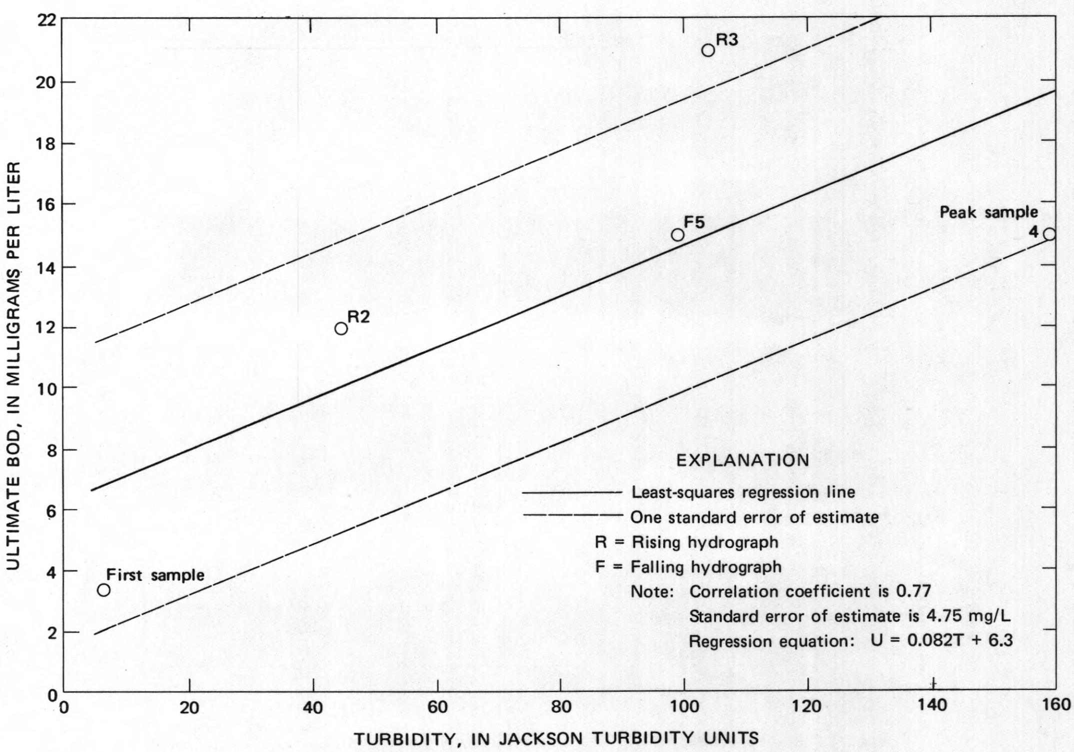

Figure 11.—Relationship between turbidity and ultimate BOD for Tryon Creek during storm of April 23, 1976.

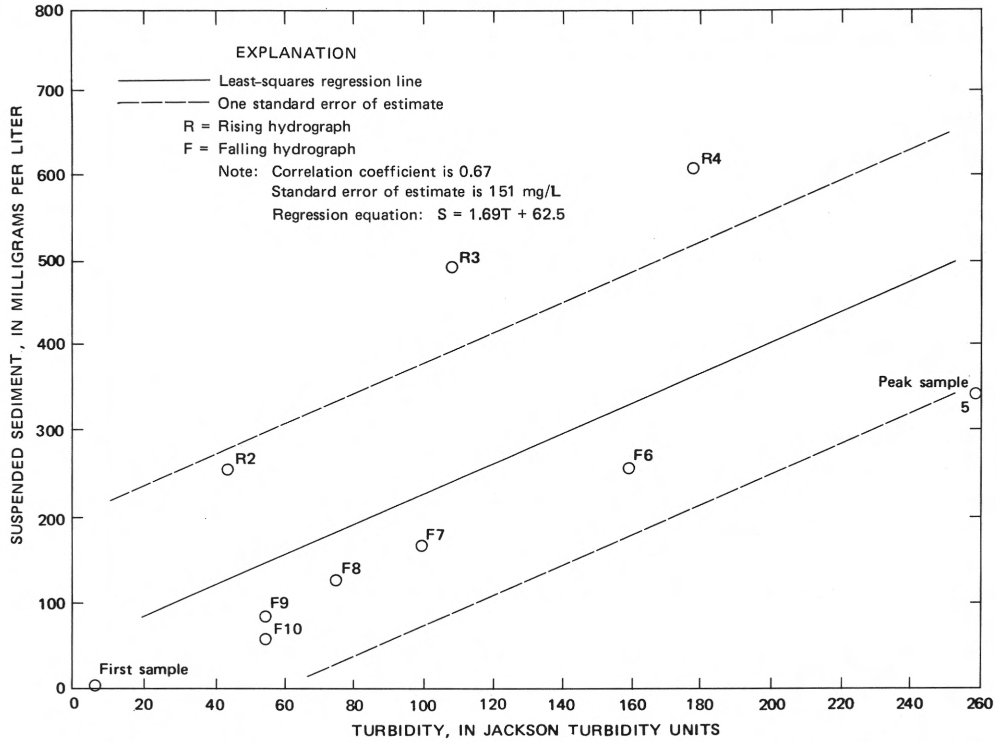

Figure 12.—Relationship between turbidity and suspended sediment for Tryon Creek during storm of April 23, 1976.

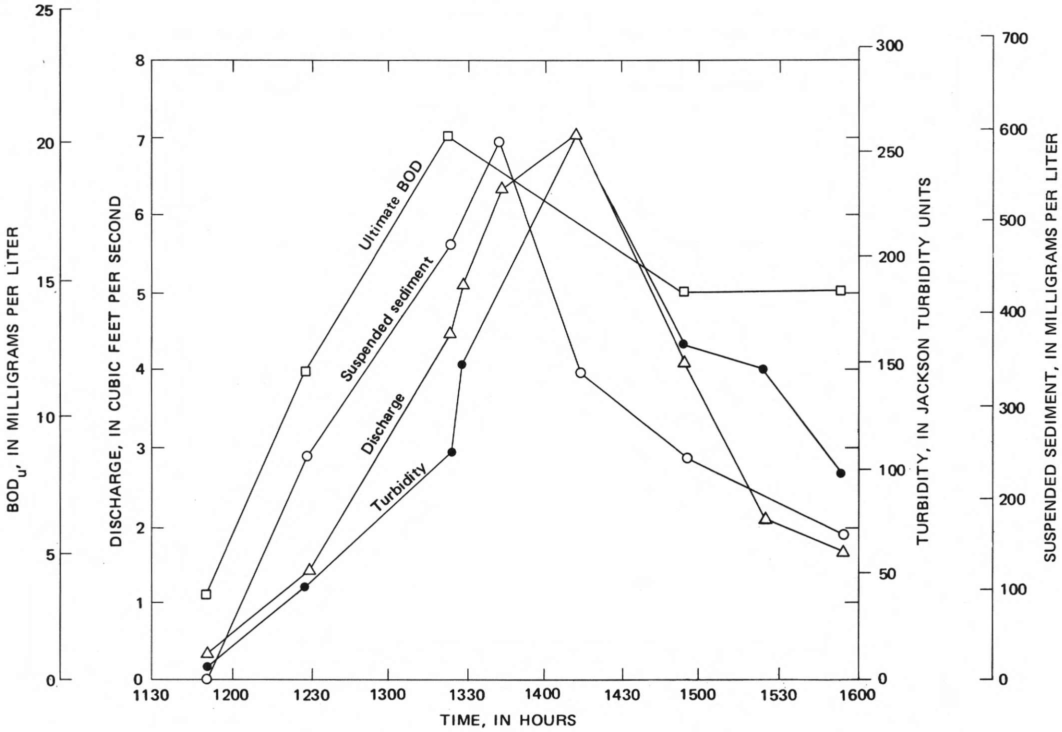

Figure 13.—Plot of four constituents versus time for Tryon Creek during storm of April 23, 1976.

The third analytical approach used was a multiple-linear-regression analysis. This analysis related storm yields (dependent variables) to selected watershed characteristics (independent variables) represented by physiographic characteristics, precipitation characteristics, and other hydrologic variables. This approach was used to identify the important independent variables and indicate how they relate to storm yields.

Yield Computations

Augmentation of Data

From table 3, it is apparent that the frequency of sampling different constituents varied considerably. Data augmentation was necessary for two reasons: (1) to determine the concentration of constituents at a minimum interval of 1 hour (to provide adequate definition of storm concentrations) and (2) to supplement data when sampling was not begun sufficiently before the hydrograph began rising or when sampling was terminated too soon on the recession of the hydrograph. Because discharge records were available throughout storm events, data augmentation was possible for either end of the storm by use of discharge versus constituent regressions.

The following guidelines were used to define storm durations for yield computations. The first significant increase in discharge or change in water-quality constituent concentration (for example, suspended sediment) after precipitation had begun was the initial point for yield computation. The final point for the yield computation occurred after (1) precipitation had ceased, (2) the discharge had decreased so that the stage had fallen to less than one-half the rise to peak stage, (3) the discharge was decreasing very slowly, and (4) the concentration of constituents had fallen to a low level with little change occurring. An exception to item 4 was bacteria counts, which often stayed high.

The correlations and bivariate regressions explained previously were used for data augmentation. Regressions of data from group I were considered to be the most reliable and were used, whenever possible, to augment data. Often, several correlations were used to augment data for a single constituent. For example, when sediment data were augmented, Q versus S, T versus S, and C versus S were used. The regression equation was used to predict both known and missing data. Then the predictions from several relationships were compared with measured values to ascertain the accuracy of each prediction. On the basis of the accuracy of each regression during the storm period, the best regression was selected for particular segments of a storm, or perhaps one regression was used for the entire storm. After selection of the best relationships, missing data values were estimated by using a single regression equation or taking into consideration rising or falling limbs of the hydrograph if the data formed a loop curve. In addition to using regressions, experience and judgment were also used in augmenting the data because some constituents did not correlate well with other variables in either data group I or data group II, or correlations based on less than five or six data points were not adequately defined.

Yield Calculations

Yield calculations were based on simultaneous water discharges and corresponding constituent concentrations. Concentrations were obtained directly from sample analyses or indirectly from the data augmentation procedure previously described. Storm yields were computed by summing incremental yields comprised of one-half the time interval from the previous sample plus one-half the time interval to the subsequent sample. Only one-half a time interval was applied to the first and last data points. Using this method, the following formulas were used for computing yields:

$$\text{YIELD} = \frac{K}{A} \sum_{i=1}^{n} Q_i C_i T_i \qquad (4)$$

$$\text{YIELD} = \frac{K}{A} \sum_{i=1}^{n} Q_i T_i \qquad (5)$$

Equation (4) was used for computing water-quality yields, and equation (5) was used for computing runoff. Variables are explained as follows:

Q_i = discharge at time of ith sample (ft^3/s),
C_i = concentration of ith sample (mg/L, mL/L, or colonies/100 mL),
T_i = time interval represented by the ith sample (minutes),
n = total number of samples used,
A = drainage area of basin for which yield is being computed (mi^2), and
K = constant to convert to yield units where

$K = 2.22 \times 10^{-3}$ for settleable solids,
$K = 1.70 \times 10^{4}$ for fecal coliform,
$K = 1.87 \times 10^{-6}$ for all other constituents, and
$K = 2.58 \times 10^{-5}$ for runoff.

Except for runoff, settleable solids, and fecal coliform, yields were calculated in units of tons per square mile. The three exceptions have the following units: (1) runoff, in inches, so it can be compared directly to the inches of precipitation; and (2) settleable solids, in cubic yards per square mile, chosen to represent the volume of material that could settle out of the storm water if held in a detention pond for 1 hour; and (3) fecal coliform bacteria, in number of organisms per square mile, indicating the number of organisms passing the gage during the storm event. Yields were computed per unit of drainage area so that basin size would not affect comparisons between basins.

To check the precision of the method for computing yields described above, selected storm yields were computed by a second method. First, the measured discharge and the measured and estimated concentrations were plotted over a storm event. Then a smooth curve was drawn through the data points. Values were taken from the curves for both discharge and concentration every 30 minutes during the storm. These values were used in equation (4) to compute storm yields. Thus, the yield calculation would include at least twice as many intervals over the storm. The difference between these two methods did not exceed 5 percent. The second method of computation was not used except as a check, because it required four to six times longer to perform than the first method cited and did not significantly improve the accuracy of the yield calculation.

To determine the loading due only to the storm, that portion of the yield attributed to base flow was subtracted. Base-flow yield is defined as the yield due to ground-water contribution or subsurface flow. Base-flow yield was determined by the following steps: (1) concentrations for constituents at base flow were those measured during the lowest flow at the beginning of the storm, and (2) discharge for base flow was the average of the lowest steady flow for a 1- or 2-hour period before precipitation began and the lowest steady flow after the storm. The poststorm flow was generally higher than the prestorm base flow.

The results after subtracting base-flow yields from the yields computed by equations (4) and (5) are listed in table 13. For the Beaverton Creek tributary and Noyer Creek basins, a substantial number of yields changed 10 percent or more, and several changed more than 50 percent owing to the subtraction of base flow. Because Noyer Creek basin is mostly undeveloped (impervious area, 4.1 percent) and has a low basin slope of 6 percent, base flow would be expected to contribute a substantial part of the storm yield. Table 2 shows that Kelly Creek has similar characteristics of impervious area and basin slope. The data in table 13 show that, for the storms sampled, Noyer Creek yields are influenced more by base flow than Kelly Creek yields. The different impact of base flow may be the result of subtle differences between basin characteristics, such as the location of most of the impervious area in Kelly Creek basin near the stream channel. But, comparison of the data from the only storm sampled simultaneously on both basins shows that storm yields are almost the same for both basins. Therefore, the available data are insufficient to conclude if the base-flow influence is due to subtle differences in basin characteristics, or if it is due to differences in precipitation characteristics of the storm.

Beaverton Creek tributary also has relatively high base-flow yields. The characteristics of basin slope and channel slope for Beaverton Creek tributary are similar to those for Noyer Creek. Beaverton Creek tributary has much more impervious area than either Noyer or Kelly basin, but its basin shape is more like that of Noyer. One of the more significant basin characteristics for Beaverton Creek tributary may be drainage area because it is the smallest basin studied (0.21 mi^2).

Dissolved-solids storm yield is the constituent most affected by subtracting the base flow, which might be expected, because the ground water generally has much higher dissolved solids than does storm runoff. The dilution effect caused by surface runoff results in a decrease in specific-conductance values with increasing discharge (figs. 2, 3).

Table 13.–*Selected constituent yields and runoff for individual storms on seven basins.*

Station	Date	Runoff (inches)	Settleable solids (cubic yards per sq mile)	Suspended sediment (tons per sq mile)	Ultimate BOD (tons per sq mile)	Fecal coliform (billions of organisms per sq mile)	COD (tons per sq mile)	Dissolved solids (tons per sq mile)	Total phosphorus as P (tons per sq mile) X10^{-3}	Total organic nitrogen as N (tons per sq mile) X10^{-3}	Ammonia as N (tons per sq mile) X10^{-3}	Dissolved nitrite & nitrate as N (tons per sq mile) X10^{-3}	Storm duration (minutes)
Kelly Creek	10/17/75	0.012	0.90	0.19	0.020	39	0.056	0.061	0.42	3.2	0.14	1.5	225
	10/29/75	.047	1.8	.65	.024	95	.10	.20	1.0	3.8	.13	9.1	465
	12/3-4/75	.839	117	38	.60	1,892	3.5	1.9	42	126	1.6	138	1,340
	3/30-31/76	.059	3.2	.28	.050	291	.26	.19	.79	10	.17	7.7	770
Beaverton Creek tributary	12/3-4/75	.452	19	6.8	.41	1,141	1.3	1.3	17	40	.99	59	932
	2/11/76	.002	.433	.10	.014	4.7	.052	.009	.12	.33	.014	.26	305
	2/17/76	.068	3.1	.78	.048	30	.16	.27	1.3	2.9	.45	8.4	365
	3/22/76	.024	2.1	.38	.038	38	.084	.027	.40	1.4	.035	4.1	260
	4/23/76	.042	5.0	.40	.071	51	.13	.037	.95	1.3	.55	.12	465
	10/24/76	.010	.99	.21	.032	45	.062	.034	.27	1.0	.058	3.3	310
Fanno Creek	10/29/75	.053	4.1	1.6	.043	210	.18	.24	1.2	4.9	.072	8.4	350
	12/3-4/75	.486	120	43	.59	1,398	2.2	2.6	24	72	2.1	73	782
	2/17/76	.068	10	4.1	.072	171	.38	.29	1.8	8.3	.19	8.8	385
	3/22/76	.023	3.0	.73	.023	22	.084	.13	.60	2.0	.044	3.0	320
	4/23-24/76	.028	6.6	1.0	.038	115	.11	.11	.72	2.1	.066	4.2	440
	10/24/76	.016	3.2	.78	.051	252	.094	.14	.86	2.2	.046	5.7	485
Noyer Creek	3/30-31/76	.061	1.4	.37	.034	32	.11	.073	1.6	5.1	.066	3.1	730
	4/8/76	.007	.56	.44	.013	9.8	.054	.020	.27	.40	.020	.62	485
	4/14-15/76	.014	2.0	.25	.015	18	.044	.098	.25	6.5	1.5	1.8	725
	4/23/76	.014	.20	.27	.044	20	.051	.044	.80	1.0	.41	1.8	385
Willamette River tributary in Robinwood	10/29/75	.023	2.4	.85	.024	71	.12	.14	1.1	2.8	.15	4.0	358
	12/3-4/75	.809	151	33	.69	1,914	2.9	3.8	34	147	2.3	115	1,135
	2/17/76	.099	7.8	3.0	.074	79	.40	.46	2.3	8.0	.16	16	400
	3/30-31/76	.024	.96	.09	.011	21	.057	.14	.58	1.8	.40	2.7	580
Willamette River tributary in Oak Grove	12/3-4/75	.706	81	13	.48	1,664	2.7	3.3	33	101	2.1	92	1,180
	3/30-31/76	.075	3.5	.57	.041	27	.14	.42	.70	4.9	.17	7.2	780
	4/8/76	.055	5.8	1.6	.086	57	.32	.27	.75	6.1	.15	5.5	350
	4/23/76	.037	4.1	.58	.049	38	.11	.20	.63	2.9	.10	2.4	295
	9/14/76	.025	3.7	.66	.035	97	.082	.13	1.0	2.6	.33	3.2	225
Tryon Creek	12/3-4/75	.560	49	17	.51	4,006	2.1	2.6	37	64	1.8	64	968
	2/11-12/76	.015	1.8	.29	.12	31	.32	.096	.71	1.4	.056	1.7	285
	2/17/76	.071	18	4.6	.18	257	.63	.31	3.7	11	.19	4.2	240
	3/22/76	.075	11	3.2	.12	96	.38	.24	2.4	9.4	.16	5.7	493
	4/23/76	.064	8.2	1.6	.088	249	.45	.28	2.1	6.5	.20	6.4	305

–Indicates a change of < 10 percent by subtracting base flow.
–Indicates a change of ⩾ 10 percent by subtracting base flow.
–Indicates a change of ⩾ 50 percent by subtracting base flow.

Multiple-Regression Methodology

The multiple-linear-regression equation used is of the form:

$$Y = a + b_1X_1 + b_2X_2 + \ldots b_nX_n \quad (6)$$

where

Y = the dependent variable,
$X_1 \ldots X_n$ = the independent variables,
$b_1 \ldots b_n$ = the regression coefficients,
a = the regression constant, and
n = the number of independent variables.

Equation (6) provided better results for most of the constituents; however, a log transform provided good results for some constituents. The equation using the log-transform data is of the form:

$$\log Y = \log a + b_1 \log X_1 + b_2 \log X_2 + \ldots + b_n \log X_n \quad (7)$$

Equation (7) may be written in an equivalent form:

$$Y = a\, X_1^{b_1}\, X_2^{b_2} \ldots X_n^{b_n} \quad (8)$$

Coefficients and constants for equations (6) through (8) can be calculated by methods outlined by Riggs (1968). Statistical computer programs (STATPAC) (Sower, Eicher, and Selner, U.S. Geol. Survey, written commun., 1971) were used to calculate coefficients, constants, and statistical tests for equations (6) through (8).

Table 14 is a listing of all independent variables used in the regression analysis. Variables numbered 1 through 12 in the table are basin characteristics, variables numbered 13 through 22 are precipitation characteristics, and the remaining variables represent other hydrologic parameters. The basin characteristics are listed in table 2, and the precipitation and miscellaneous characteristics are listed in table 15.

Because some independent variables listed in table 14 occasionally have a value of zero, it was necessary to add a constant of 1.0 to each value to prevent taking the log of zero. Therefore, if a log equation contains an independent variable to which the constant had been added (see table 14), the user must also add the value of 1.0 to the variable when using the equation.

As the initial step in the regression analysis, STATPAC was used to generate a bivariate correlation-coefficient matrix for both the linear and log-transformed data. These matrixes were used as an initial guide for the selection of independent variables that reflect the known or assumed physical conditions of the system.

Table 14.--List of independent variables used in regression analysis

	Abbreviation	Explanation	Units
1.	DA	Drainage area of basin	Mi^2.
2.	BASLOP	Average basin slope	Percent.
3.	CHNSLOP	Average channel slope	Ft/mi.
4.	IMPAREA	Basin area impervious to rainfall (for example, streets and paved parking lots).	Percent.
5.	ARUCON	Area of the basin under construction	Do.
6.	LU1	Area of the basin in rural land use	Do.
7.	LU2	Area of the basin in single-family residence	Do.
1/8.	LU3	Area of the basin in multifamily residence	Do.
1/9.	LU4	Area of the basin in commercial land use	Do.
1/10.	LU5	Area of the basin in industrial land use	Do.
11.	K	Erodibility factor from the universal soil-loss equation - an area-weighted average for the basin.	None.
12.	BASHAPE	Basin-shape factor relating basin length to width.	Do.
1/13.	RFPR24H	Rainfall in 24-hour period prior to storm	Inches.
1/14.	RFPR48H	Rainfall in 48-hour period prior to storm	Do.
15.	RFPR14D	Rainfall in 14-day period prior to storm	Do.
16.	TRFSTM	Total rainfall during storm	Do.
17.	H5MRFI	Highest 5-minute rainfall intensity	In/h.
18.	H15MRFI	Highest 15-minute rainfall intensity	Do.
19.	H1HRFI	Highest 1-hour rainfall intensity	Do.
20.	H6HRFI	Highest 6-hour rainfall intensity, or average intensity if the storm was less than 6 hours.	Do.
1/21.	H15MPR48	Highest 15-minute rainfall intensity in the previous 48 hours.	Do.
22.	DRYDAYS	Time interval before storm with less than 0.1 inch of rain, or the hours to a prior 1-hour period that exceeded 0.02 inch in 1 hour.	Hours.
23.	BASFLW	Base flow of the stream as determined for the load calculation.	Ft^3/s.
24.	WATTEMP	Water temperature in situ	°C.
25.	H15MCHQ	The time period between the highest 15-minute rainfall intensity and the maximum positive 15-minute change in discharge.	Minutes.
26.	H15MXQ	The time period between the highest 15-minute rainfall intensity and the maximum discharge.	Do.
27.	STMMIN	The duration of sampling period used to calculate the storm load.	Do.

1/ Indicates independent variables to which the constant, 1.0, was added, for use in log equations.

Table 15.–*Values for precipitation characteristics and other independent variables used in regression analysis*

Station	Date	Rainfall characteristics										Basin response			
		Precipitation in previous 24 hours (inches)	Precipitation in previous 48 hours (inches)	Precipitation in previous 14 days (inches)	Dry hours previous to storm	Total rainfall of storm (inches)	Highest 5-minute rainfall intensity (inches per hour)	Highest 15-minute rainfall intensity (inches per hour)	Highest 1-hour rainfall intensity (inches per hour)	Highest 6-hour rainfall intensity (inches per hour)	Highest 15-minute rainfall intensity in previous 48 hours (inches per hour)	Time from highest 15-minute rainfall intensity to max Δ[1] discharge (minutes)	Time from highest 15-minute rainfall intensity to max discharge (minutes)	Base flow (inches)	Water temperature (degrees Celsius)
Kelly	10/17/75	0.03	0.03	2.57	58	0.66	0.48	0.40	0.28	0.12	0.12	–	90	0.0009	–
Creek	10/29/75	.03	.03	1.88	14	.37	.24	.20	.14	.09	.08	25	85	.0018	–
	12/3-4/75	.42	.47	5.90	3.5	1.90	.60	.40	.27	.18	.16	45	205	.1206	10.4
	3/30-31/76	.01	.03	3.11	72	.12	.12	.04	.03	.01	.04	–	–	.0325	7.5
Beaverton	12/3-4/75	.38	.38	2.24	1	1.89	.96	.56	.26	.23	.12	10	20	.0378	11.5
Creek	2/11/76	.04	.04	.12	73	.13	.12	.08	.06	.02	.04	35	50	.0109	–
tributary	2/17/76	.10	.69	1.74	25	.33	.24	.24	.14	.07	.16	55	60	.0144	–
	3/22/76	.00	.08	1.28	45.5	.23	.24	.16	.11	.10	.12	15	30	.0096	9.9
	4/23/76	.00	.05	1.00	80	.33	.24	.20	.14	.05	.12	–	40	.0200	11.2
	10/24/76	.02	.02	.02	11	.18	.12	.08	.06	.03	.04	–	20	.0031	12.0
Fanno	10/29/75	.47	.85	3.40	14	.46	.24	.16	.11	.08	.16	–	80	.0038	10.4
Creek	12/3-4/75	.28	.30	3.03	49	1.66	.60	.36	.25	.19	.12	40	50	.0145	10.5
	2/17/76	.13	.66	1.69	25	.30	.36	.24	.15	.09	.12	65	80	.0088	–
	3/22/76	.00	.08	1.36	48	.27	.24	.20	.12	.05	.04	55	75	.0045	8.5
	4/23/76	.07	.07	1.09	82	.31	.24	.20	.14	.05	.04	30	130	.0058	9.5
	10/24/76	.00	.00	.15	12	.33	.36	.28	.13	.05	.00	70	70	.0010	–
Noyer	3/30-31/76	.04	.05	2.69	77	.48	.24	.20	.12	.06	.04	–	260	.0029	7.0
Creek	4/8/76	.19	.24	1.89	9	.21	.84	.52	.16	.05	.08	20	35	.0111	–
	4/14-15/76	.00	.17	.99	44	.38	.36	.32	.13	.06	.12	10	45	.0138	7.0
	4/23/76	.00	.08	2.51	29	.38	.24	.20	.16	.06	.04	25	145	.0258	9.5
Willamette	10/29/75	.20	.64	2.40	8	.61	.36	.24	.15	.10	.08	90	125	.0057	10.7
River	12/3-4/75	.33	.40	2.76	41.5	2.02	2.04	.80	.33	.23	.08	155	295	.0768	9.4
tributary in	2/17/76	.23	.94	2.05	.1	.36	.36	.20	.14	.09	.12	75	115	.0431	–
Robinwood	3/30-31/76	.00	.00	3.25	74	.46	.24	.16	.12	.06	.00	185	210	.0145	7.2
Willamette	12/3-4/75	1.03	1.32	3.99	41.5	2.03	.84	.48	.37	.24	.08	35	45	.0659	9.0
River	3/30-31/76	.00	.00	3.71	74	.46	.24	.16	.12	.06	.00	–	–	.0152	8.6
tributary in	4/8/76	.40	.47	1.32	10	.40	1.08	.68	.33	.10	.20	–	–	.0033	–
Oak Grove	4/23/76	.00	.09	1.51	30	.36	.24	.24	.18	.08	.04	20	35	.0032	11.0
	9/14/76	.02	.04	.57	39	.47	.36	.24	.19	.10	.04	50	100	.0012	15.5
Tryon	12/3-4/75	.36	.41	2.70	1	1.73	.60	.32	.27	.18	.12	30	55	.0694	10.2
Creek	2/11-12/76	.03	.03	.11	74	.13	.24	.12	.07	.04	.04	50	60	.0006	–
	2/17/76	.13	.66	1.69	.1	.22	.36	.24	.15	.07	.12	100	110	.0121	–
	3/22/76	.00	.09	1.44	44	.44	.36	.24	.16	.07	.12	15	30	.0149	9.0
	4/23/76	.13	.19	1.74	16	.22	.24	.20	.15	.08	.08	20	50	.0050	11.0

Δ[1] Indicates change

Variables, such as the percent of the basin in a certain land use, may not be randomly distributed (Riggs, 1960). Therefore, the correlation coefficients for variables of this type may not be a valid measure of the relation between variables.

Many different combinations of independent variables were tried for each dependent variable because the interaction of independent variables could cause an independent variable to be significant in one equation and not significant in another. The selection of the independent variables was made using the following guidelines:

1. Independent variables were significant at the 90 percent or higher level of confidence as measured by Student's t-test.

2. The set of independent variables explained the highest practical percent variation of the dependent variable and the lowest standard error of estimate compared to other combinations of variables.

3. Two or more independent variables should not describe the same phenomenon; thus, high cross correlation between independent variables should be minimized.

The t-test value of 90-percent confidence is an arbitrary guideline. Almost all variables were selected at the 90-percent level and above. A few conceptually important variables that were selected tested in the 80- to 90-percent level of significance.

Multiple-Regression Results

The resulting equations for both the linear and log-transformed regressions are listed in table 16. The independent variables for each regression model appear in order of decreasing confidence for the coefficients as calculated by the Student's t-test. The percent variation explained of the dependent variable (VDV), the percent standard error of estimate (SEE) of the dependent variable, and the percent standard deviation of the dependent variable (SD) are provided with each model. Note that the percent standard error of estimate is given as a percentage of the mean value of the dependent variable and is shown as an average percentage of the measured storm yields for the log-transformed models.

All models except the total organic nitrogen model use 34 storm yields to compute the regression coefficients. Because data were not available for H15MXQ for 3 storms, the organic nitrogen model used 31 of the 34 storm events.

Table 16 indicates that some storm yields are best explained by the linear model, others by the log-transform model, and yet other storm yields seem to be explained equally by both models. The following sections discuss the models for each storm yield and provide comparisons between independent variables used in linear and log models for the same storm yield.

Table 16.—*Linear and log-transform multiple-regression equations*

[VDV, the percent variation of the dependent variable; SEE, the percent standard error of estimate; SD, the percent standard deviation of the dependent variable]

Basin yields	Type of model	Equations	VDV	SEE	SD
Settleable solids (yd^3/mi^2)	Linear	-27.3+31.0(TRFSTM)+404(BASFLW)+1.19(BASLOP)+19.9(H5MRFI)	78	98	200
	Log	$9.46x10^{-3}(IMPAREA)^{1.09}(H5MRFI)^{0.722}(STMMIN)^{1.09}(ARUCON)^{0.478}(BASFLW)^{0.376}$	80	84	230
Suspended sediment ($tons/mi^2$)	Linear	-7.19+11.9(TRFSTM)+0.473(BASLOP)+112(BASFLW)-5.06(RFPR48H)	72	120	210
	Log	$0.266(TRFSTM)^{1.37}(RFPR48H)^{2.40}(K)^{-2.88}(LU1)^{-0.330}$	78	94	260
Ultimate BOD ($tons/mi^2$)	Linear	-0.102+0.257(TRFSTM)+0.012(LU3)+1.58(BASFLW)	92	42	140
	Log	$0.258(TRFSTM)^{0.817}(LU3)^{0.648}(BASFLW)^{0.279}(DRYDAYS)^{-0.103}$	74	70	150
Fecal coliform ($coloniesx10^6/mi^2$)	Linear	$-6.32x10^5+8.51x10^5(TRFSTM)+7.60x10^4(LU3)+1.05x10^7(BASFLW)$	79	97	200
	Log	$4.79x10^6(TRFSTM)^{1.41}(ARUCON)^{0.600}(LU1)^{-0.534}$	67	120	260
Chemical oxygen demand ($tons/mi^2$)	Linear	-0.532+0.855(TRFSTM)+16.8(BASFLW)+0.012(IMPAREA)	93	46	160
	Log	$0.028(LU1)^{-0.522}(ARUCON)^{0.512}(RFPR24H)^{3.06}(STMMIN)^{0.852}(BASFLW)^{0.223}$	80	68	180
Dissolved solids ($tons/mi^2$)	Linear	-0.711+1.08(TRFSTM)+0.013(IMPAREA)+0.517(H5MRFI)+7.00(BASFLW)	89	59	170
	Log	$4.14x10^{-3}(LU1)^{-0.644}(STMMIN)^{1.28}(TRFSTM)^{0.775}(ARUCON)^{0.476}(DRYDAYS)^{-0.162}$	88	59	210
Total phosphorus ($tons/mi^2$)	Linear	$-7.81x10^{-3}+0.013(TRFSTM)+0.187(BASFLW)+6.04x10^{-4}(LU3)$	96	42	190
	Log	$0.012(TRFSTM)^{1.40}(LU3)^{0.556}(BASFLW)^{0.362}$	82	76	230
Total organic nitrogen ($tons/mi^2$)	Linear	No useful regression obtained VDV<40 percent	--	--	500
	Log	$4.12(H5MRFI)^{2.73}(H15MXQ)^{-0.515}(LU2)^{-0.358}$	73	130	320
Ammonia ($tons/mi^2$)	Linear	$-2.21x10^{-4}+8.46x10^{-4}(TRFSTM)+8.40x10^{-7}(STMMIN)-1.26x10^{-4}(RFPR14D)$	81	65	140
	Log	$5.40x10^{-3}(TRFSTM)^{1.11}(BASFLW)^{0.293}(BASLOP)^{-0.482}$	66	97	830
Dissolved nitrite+nitrate as N ($tons/mi^2$)	Linear	No useful regression obtained VDV<30 percent	--	--	580
	Log	$8.71x10^3(H6HRFI)^{8.80}(H1HRFI)^{-6.13}(BASFLW)^{0.860}(TRFSTM)^{-2.42}(RFPR48H)^{-3.51}$	56	370	190
Volume of runoff (in.)	Linear	$-0.138+0.235(TRFSTM)+3.77(BASFLW)+2.02x10^{-3}(IMPAREA)+0.052(H5MRFI)$	97	30	170
	Log	$5.08x10^{-6}(IMPAREA)^{0.688}(STMMIN)^{1.32}(DRYDAYS)^{-0.182}(RFPR14D)^{0.308}(TRFSTM)^{0.595}$	86	62	200

In each of the following discussions, the sign of the independent variables is discussed. A positive coefficient indicates a direct relation between the variables, whereas a negative sign indicates an inverse relation. If the sign is not coincident with a conceptual idea, possibly the conceptual idea is not correct, or errors in measurement of variables or variable interaction adversely affect the regression. Also, the independent variable selected may not properly measure a particular conceptual phenomenon and may be acting as a surrogate for some other basin or precipitation characteristic. For example, base flow may be a surrogate explaining the permeability and storage capacity of soil.

Settleable solids.--Both the linear and log-transform models explain equivalent percentages of the dependent variable; however, the latter has a lower SEE (84 percent versus 98 percent). The models indicate that all independent variables are related directly to the yield and are acceptable conceptually. The direct relation between base flow (BASFLW) and settleable solids is indicative of the typical winter-weather pattern for western Oregon, with frequent low-intensity storms providing a high base flow at the same time of year that the higher intensity rainfall occurs. The log model shows that two land-use variables are important (impervious area [IMPAREA] and area under construction [ARUCON]), whereas the linear model has no land-use variables. As both models appear to be about equal in ability to estimate storm yields, model selection can be based on the availability of the needed variables.

Suspended sediment.--The log model explains more of the variation in the dependent variable than does the linear model, and it also has the lowest standard error of estimate. The direct relationship in the log model to rainfall in the previous 48 hours (RFPR48H) suggests that soil erodibility increased prior to storms or that increased soil moisture allowed higher runoff volumes which therefore erode and transport more suspended sediment. The model shows an inverse relationship to the K variable, which would mean that more erodible soils yield less sediment. This paradox may be the result of the coarse method of determining K by area-weighted averaging for each basin, or possibly, K is a surrogate variable for some other soil characteristic. The linear model has an inverse relation between sediment yield and rainfall in the previous 48 hours, which is just the opposite from the log model. This could be indicative of errors in measurement or cross-correlation between variables, causing the sign to be opposite from what was expected.

Biochemical oxygen demand.--Of the two models, the linear model is substantially better, as indicated by both the standard errors of estimate and the variations explained. The linear model contains variables that are directly related to the yield. For BOD, multifamily residential land use (LU3) was found to be a significant basin characteristic. The log model uses the same three variables found in the linear model, and adds dry days (DRYDAYS). The inverse relationship between BOD and DRYDAYS is not considered to be conceptually valid. The number of dry days (maximum of 3½ days) measured for these storms may not have been sufficiently long to react in a positive direction. Dry days was left in the model to indicate that it did not conform to our expected result, and possibly it is not significant for storm yields of BOD in Portland. Whipple, Hunter, and Yu (1977) report that the number of dry days does not appear to be significant for storm yields of BOD in New Jersey.

Fecal coliform bacteria.--The linear model has a lower standard error of estimate and a higher variation explained; therefore, the linear model is preferable. The model contains the same three variables for fecal coliform bacteria as for biochemical oxygen demand. Again, all three variables are directly related to the yield values, and multifamily residential (LU3) parameter is significant to the fecal coliform bacteria yield. The log model indicates that rural land use (LU1) relates inversely to the fecal coliform bacteria yield.

Chemical oxygen demand.--The linear model is better statistically than the log model. The linear model again includes total storm rainfall (TRFSTM) and base flow (BASFLW), as in the two models discussed previously, but this time impervious area (IMPAREA) is the significant basin characteristic explaining the effects of land use. IMPAREA has a high cross correlation with all the land uses and is inversely related only to rural land use (LU1). Therefore, the model indicates that COD is increased by development of a basin, and the contributing development may be from any of the land uses except rural. In a similar manner, the log model shows an inverse relation to rural land use (LU1).

Dissolved solids.--Both models predict dissolved solids with about the same accuracy. All the signs for coefficients in the linear and log models are acceptable. The linear model indicates that impervious area relates directly to dissolved solids, whereas rural land use relates inversely to dissolved solids in the log model. Therefore, rural land use (LU1) may again be an inverse surrogate for impervious area. The inverse relationship of DRYDAYS in the log model may be acting as a surrogate for the ground-water contribution which provides much of the dissolved solids.

Total phosphorus.--The linear model is statistically better than the log model even though both models use the same independent variables. Again, total rainfall (TRFSTM) and base flow (BASFLW) are included, and both relate positively to the phosphorus yield. For both models, multifamily residential (LU3) is the significant land use, and in both models LU3 is directly related to the yield of total phosphorus.

Total organic nitrogen.--In all attempts to form a linear model, the variation explained was less than 40 percent. In the log model, single-family residential (LU2) relates inversely to organic nitrogen yield. Rural (LU1) was found to relate directly to organic nitrogen yield, but did not test significantly high according to the t-test. Therefore, it seems that the organic nitrogen may be available for overland runoff from rural areas even though rural land use (LU1) did not test significant with this data. The inverse relationship with H15MXQ (the time interval between high 15-minute rainfall intensity and maximum discharge) suggests that storms with a fast streamflow response to precipitation (thus lower H15MXQ values) contain higher yields of total organic nitrogen. The variable H15MXQ may be strongly influenced by soil moisture, basin slope, and impervious area.

Ammonia.--The linear model is statistically better than the log model, and the coefficients for independent variables are acceptable. The negative coefficient for rainfall in the previous 14 days (RFPR14D) indicates the tendency for material contributing to the ammonia yield to build up over time. For many of the storm events, ammonia concentrations were very low and remained relatively constant during the storm; therefore, it is understandable that total rainfall (TRFSTM) and the duration of the storm (STMMIN) would relate directly to ammonia yield.

Dissolved nitrite plus nitrate.--No useful linear model was obtained because the variation explained was less than 30 percent. The two most significant variables, according to the t-test, are the 6- and 1-hour rainfall intensities (H6HRFI and H1HRFI). These intensity characteristics have coefficients of opposite signs and together account for 44 percent of the 56 percent of the variation explained. When the two rainfall intensities are used separately in the model, H6HRFI accounts for 24 percent of the variation, and H1HRFI contributes 20 percent of the variation explained. Even though the two intensities cross correlate highly (r=0.90), the sum of their separate contributions to variation explanation is equal to their simultaneous contribution. Because the opposing signs of the coefficients could not be conceptually explained and the log model explains only 56 percent of the variation, the regression results for nitrite plus nitrates are of limited value. A better model for nitrite plus nitrate would require more investigation.

Volume of runoff.--The linear model is considered to be the better of the two models. All the coefficient signs are acceptable. Impervious area (IMPAREA) and total rainfall (TRFSTM) are related to the volume of runoff in both the linear and log models.

CONCLUSIONS

The data collected and the analytical techniques used in this study have provided a meaningful first step in understanding urban storm-water-runoff processes in the Portland area. Each of the analytical approaches are summarized separately, some implications of the approach for other geographical areas are noted, and suggestions are offered for future urban data-collection programs.

Results of Analytical Approaches

Concentration Analysis

In general, constituent concentrations of storm-water runoff exceeded domestic sewerage-treatment standards for settleable solids, suspended sediment, and fecal coliform. For the streams sampled, BOD concentrations were not high enough to indicate that treatment would be necessary. Trace-metal concentrations were very low, with the possible exception of lead. A possible relationship may exist between lead accumulating on streets and its concentrations in water. Detention ponds would substantially reduce concentrations of BOD, organic nitrogen, COD, total phosphorus, settleable solids, and possibly suspended sediment.

Correlation Analysis

In all basins, several strong correlations exist between certain water-quality constituents. Table 10 indicates that correlation coefficients vary from basin to basin and from storm to storm; thus, both rainfall and basin characteristics affect the association between constituents. Although an established correlation does not imply cause and effect, the knowledge of correlations between variables can be the first step toward defining cause-effect relationship. In addition, correlations may help to reduce unnecessary data collection and allow a data-collection and analysis effort that is more cost effective.

Multiple-Linear Regression Analysis

In general, the linear regression models related yields primarily to precipitation variables, whereas the log-transform models included almost an equal number of basin and precipitation characteristics. Total rainfall of the storm was the most significant variable explaining most of the variation of the dependent variable in 14 of 20 models. Even though basin characteristics were not as statistically significant as precipitation characteristics, further analysis should continue to consider data from as many different basins as possible in order to define the importance of basin characteristics on storm yields. The regression analysis might be improved if more storms with total rainfall in the ½- to 2-in. range could be sampled. Few storms in this precipitation range were sampled.

Marsalek (1976), in a similar regression analysis, with data from 19 storms on one basin in Toronto, Canada, found that dry days was the most significant variable. In this analysis of Portland data, dry days enters three log-transform models and is not the most significant variable in any model. The longest antecedent dry period, as defined for this study, was only 3½ days. In this report, total rainfall was the most significant variable in 14 of 20 regression models and was included in three other models. Possibly the difference in significance of variables in this area, compared to the Toronto study, is the difference in precipitation characteristics between the two regions studied.

Study Results

Two aspects of the study should be emphasized. The first is the analytical approach used for this study, and the second is the results of the multiple-linear regression models obtained.

The analytical approach used for this study could provide a means for investigators in other areas to meet two primary objectives. First, the analysis of concentrations allows the determination of the frequency and magnitude of violations for particular instream standards. Second, the correlation and multiple-regression approach provides an estimation of loads entering receiving waters.

Although the analytical approach is applicable to other study areas, the multiple-linear regression models listed in this report should be used only in the Portland study area. For example, records for several years of rainfall data from this area and available basin characteristics can be used in the models to estimate ranges of water-quality yields.

Suggestions for Future Data-Collection Efforts

The following are suggestions to (1) improve on the work done during this study, and (2) expand the collection and analysis of similar data to answer some questions that have arisen during the study:

1. Collect more nutrient data during storm events.
2. Reduce the amount of data collected where bivariate regressions with high correlations are well established.
3. Investigate the occurrence of the loop phenomenon demonstrated in the bivariate regression analysis. Try to establish higher order regressions and compare the accuracy with the first-order linear regression.
4. Sample an even distribution of total storm rainfall up to 2 inches, because most of the data for this analysis are from storms of less than one-half inch.
5. Select and study a network of drainage basins having a greater range of land uses and basin characteristics. Hammer (1973) mentioned that increasing differences in land uses among the watersheds resulted in decreasing correlations between independent variables. Thus, an attempt might be made to study basins that have a more homogeneous land use. A study with each basin completely homogeneous may not be desirable, however, because possible interactions between land uses in a basin could not be measured.
6. Describe land uses, if possible, according to their effect. For example, a new variable--effective impervious area--might be described as a function of the proximity and direct connection (by storm sewer) of the impervious area to the channel.
7. Combine several basin characteristics into one value. The erosion factor K did not seem to be important except in the log-transform model of suspended sediment. A more useful factor might be developed that simultaneously considers soil erodibility, slope, and land use.
8. An attempt should be made to place two sampling locations within one basin. For example, one could be positioned at the basin outflow site and the other at an upstream point to determine if loads can be routed downstream.
9. Further investigation is needed to study the relationship between street sweepings and in-stream concentrations of heavy metals. Also, study is needed to improve knowledge of concentration reductions achievable in various types of detention devices. Further investigation should include the settling characteristics of other constituents in addition to the five tested in this study.

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