WATER-QUALITY VARIATIONS IN THE BULL RUN WATERSHED, OREGON, UNDER 1978 TO 1983 MANAGEMENT CONDITIONS

By Frank A. Rinella

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CONVERSION FACTORS

For use of those readers who may prefer to use metric (International System) units rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

Multiply inch-pound units	By	To obtain metric unit
	Length	
inch (in)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square inch (in^2)	6.452	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Temperature	
degree Fahrenheit (°F)	(1/)	degree Celsius (°C)

1/ Temp °C = (temp °F-32)/1.8.

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level of 1929."

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ABSTRACT

During the period October 1978 to September 1983, the U.S. Geological Survey, in cooperation with the City of Portland Water Bureau, conducted a study in the Bull Run River basin to define the hydrologic characteristics of the basin and to examine relations between basin characteristics (both natural and man-made) and stream water quality and quantity within the basin.

Hydrologically, the 1978-1983 period can be characterized as representative of the long-term average, with no records of extreme events. Likewise, water-quality constituent concentrations affected by quantity of streamflow are representative of average values and ranges and exclude values that would be obtained during periods of extreme events. Ranges of concentration of major anions and cations for surface water collected October 1978 to September 1983 are similar to values collected historically.

The ratio of constituent to chloride values determined for precipitation data collected during the period June 1980 to September 1981 indicated that other sources besides seawater contributed to its composition. In the range in ratios of constituents in precipitation, Bull Run values are similar to those of other remote sites in Alaska, Washington, and California.

Comparison of storm-related suspended-sediment load to annual suspended-sediment loads indicated that 62 to 78 percent of the total annual loads occurred in 3 to 4 days during an average year.

Multiple-linear regression analysis using discharge, suspended sediment and specific conductance indicated that most of the variation in the annual values could be explained by naturally occurring processes within the basin.

A nonparametric time-trend analysis of 24 water-quantity and -quality constituents showed no statistically significant trends with estimated slopes large enough to be readily measurable for a particular year. Four constituents that were sampled weekly (turbidity, specific conductance, silica, and phytoplankton) had statistically significant trends with slope indicators that might be measureable after 6 years. However, trend analysis on daily mean specific-conductance and suspended-sediment values does not confirm the weekly constituent trend results.

INTRODUCTION

Since the late 1800's, the Bull Run River basin has been the predominant municipal water-supply source for the city of Portland, Oregon. The 102-square-mile watershed, located 25 to 30 miles east of the city, is part of the Bull Run Reserve in the Mount Hood National Forest (fig. 1). The Reserve was established by Presidential Proclamation in 1892 to protect the water supply.

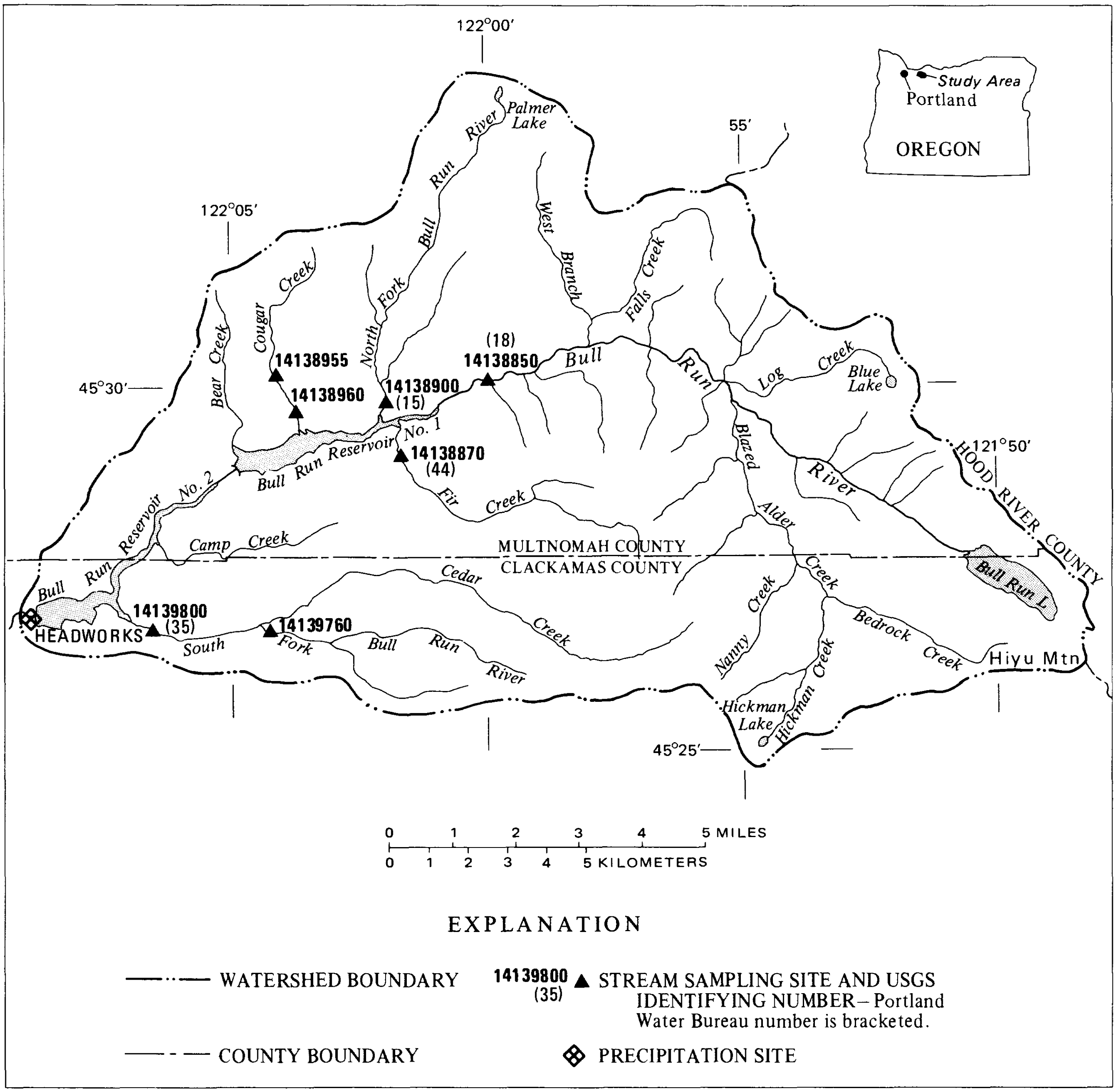

FIGURE 1.--Location of sampling sites in the Bull Run watershed.

In 1904, Congress enacted the Bull Run Trespass Act, which prohibited entry into the Reserve except for those persons acting in an official capacity. The Reserve remained closed to all but official entry until 1959, when an administrative order issued by the Regional Forester for the U.S. Forest Service (USFS) opened 42,500 acres of the Bull Run Reserve to public use. In addition, the Regional Forester implemented an active timber management program within the reserve.

In 1960, Congress passed the Multiple-Use Sustained-Yield Act, which further substantiated the USFS philosophy of using the diverse resources of natural forests. In 1973, resistance by private concerns to any increases in timber activity within the watershed led to a private lawsuit against the Forest Service's management practices within the Reserve.

In 1976, the USFS ceased issuing contracts for timber harvesting, and recreational usage of the previously open 42,500 acres of the Reserve was discontinued. Because the administration of the Reserve had been caught between two conflicting Congressional directives (the limitations imposed by the 1904 Trespass Act and those of the 1960 Multiple-Use Sustained-Yield Act), Congress passed PL (Public Law) 95-200 to resolve boundary and management issues. The primary management objective of PL 95-200 was the continued production of pure, clear, raw, potable water for the Portland metropolitan area. A secondary management objective was the protection, management, and use of the renewable resources within the reserve, as long as management of these resources did not significantly affect water quality. The new law provides for the Secretary of Agriculture, through the Forest Service, to administer the Bull Run watershed in accordance with USFS policy, except for policy that the Secretary determines would have an adverse effect on water quality. The law also called for public participation in management discussions and for consultation and coordination with the City of Portland (represented by the Water Bureau). The law specifically required adoption of water-quality standards which would provide the means necessary to determine significant effects of management practices on water quality.

In order to evaluate the effect of a particular management activity on water quality, a series of standards defining the natural variability of stream water quality were needed. Over the years the USFS has devoted considerable effort to defining such standards for each of the following five subbasins within the Bull Run drainage: Headworks, North Fork, Main Stem, South Fork, and Fir Creek (Stations 2, 15, 18, 35, and 44, respectively; fig. 1). Fir Creek has been retained as a control basin (free of past and future management activities) for long-term monitoring of natural water-quality variability. Station 18, called "Main Stem" in this report, refers to Geological Survey station name, "Bull Run River near Multnomah Falls," as listed in the Survey's annually published water-resources data for Oregon (U.S. Geological Survey, 1980-1981).

Once the water-quality standards were developed, any management practice found to have a significant adverse effect on water quality, based on the standards, would be modified. Revision of these water-quality standards would occur periodically to reflect better monitoring techniques or acquisition of more representative water-quality data.

Development of these standards did not consider the relations between various basin characteristics (climate, topography, hydrology, geology, soils, land use, or vegetation) and observed water-quality characteristics. To examine these relations within the watershed, the U.S. Geological Survey, in cooperation with the City of Portland Water Bureau, began in 1978 a 6-year study to develop and maintain a water-quantity and -quality monitoring program.

Purpose and Scope

This report describes the results of a study conducted to (1) define the hydrologic characteristics of the Bull Run River basin and (2) examine various relations between basin characteristics (both natural and man-made) and the water quality and quantity in the basin. Geological Survey data, along with the water-quality data collected throughout the watershed by the Forest Service and the Water Bureau, were used in the analyses.

Approach

The overall plan of study included continuous stream-discharge measurement and daily collection of data on stream temperature, specific conductance, suspended-sediment concentration and suspended-sediment load (including storm event sampling) at four stations (15, 18, 35, and 44) shown in figure 1. These four sites were sampled during WY (water years) 1978-1983. Also included in the above data base were water-quality data collected by the Water Bureau.

In addition to the data collected and used to describe the basin hydrology and stream water quality, data on basin characteristics were also collected. Through the use of multiple-linear regression, relations between basin characterics and stream water quality and quantity were examined. Also, several water-quality variables were examined for time trends to determine if changes had occurred which might relate to changes of management practices or to natural basin changes.

Acknowledgments

Because a report of this magnitude is a cooperative effort between City and Federal interests, it is only fitting to acknowledge a few of the organizations and individuals who have contributed.

The City of Portland Water Bureau has been a constant advisor and contributor; the author wishes especially to thank Joseph Glicker and Jim Ingwerson for their contributions.

Glen McDonald and George Breazeale of the U.S. Forest Service, Columbia Gorge Ranger District, have provided valuable suggestions and important information throughout the study.

Invaluable aid during all phases of the project was given by Stuart W. McKenzie and Joseph F. Rinella of the Oregon Office of the Pacific Northwest District, U.S. Geological Survey, Water Resources Division. Special thanks to Timothy L. Miller of the same office for his technical insights, thoughtful suggestions, and thorough editorial review of the report.

BASIN DESCRIPTION

The Bull Run River basin lies in the Western Cascades of northwestern Oregon between Mount Hood and Portland (fig. 1). The 102-square-mile basin is roughly trianglar in shape, with a maximum north-south dimension of about 10 miles and an east-west dimension of about 18 miles.

Moist cool air masses moving inland from the Pacific Ocean influence the climatic conditions during the winter; precipitation from October to April accounts for about 80 percent of the annual average. During the summer, dry high-pressure air masses result in a drier, warmer climate. During the WY period 1978-1983, daily air temperature at the Headworks ranged from 9 to 102 degrees Fahrenheit, with a mean near 52 degrees Fahrenheit. Annual precipitation at the Headworks during the same period averaged 80.45 inches and ranged from 65.61 inches (1979) to 94.84 inches (1983). Annual rainfall at the higher elevations probably averaged over two times that observed at the Headworks. Snowfall is usually light and temporary at the lower elevations, but can remain until spring at the higher elevations. Overland and subsurface runoff occurs during the winter when soil layers have been saturated and evapotranspiration losses are small.

The topography of the basin is characterized by steep canyon walls, especially evident in the basin's upper reaches, and heavily forested slopes. Elevation ranges from about 750 feet at the Headworks to about 4,600 feet on Hiyu Mountain overlooking Bull Run Lake (fig. 1).

Most of the basin consists of volcanic rock with some sedimentary deposits at the westernmost end of the basin. Glaciation has scoured out small U-shaped valleys in the upper reaches of the basin, forming Bull Run Lake and several smaller lakes.

Virtually all major subbasins in the Bull Run watershed, with the exception of most of Fir Creek above station 44, have been logged to some degree. The watershed is densely forested with a variety of conifers, the most common being Douglas fir, western hemlock, western red cedar, and grand fir. Undergrowth vegetation includes varieties of sword fern and oxalis. Highlead and skyline cable-logging systems have been used almost exclusively in the past to reduce the impact on the soils. Management practices have included both patch clear-cutting and partial cutting methods. The slash remaining after timber harvesting has been either broadcast burned or piled in selected areas and burned. During the 6 years of study (1978 to 1983), road construction has been minimal. Approximately 160 miles of system roads have been constructed within the watershed; these roads have been paved to reduce erosion potential.

Wildlife is common in this protected area. Deer, bear, elk, beaver, coyote, cougar, rainbow and brook trout, and a variety of birds (some of which are endangered species) inhabit the watershed.

In addition to forest-management and water-supply activities, hydroelectric power generation has been developed at Bull Run Reservoir Dams 1 and 2 to a combined capacity of 36 megawatts, sufficient to power 8,700 Portland residences.

DATA COLLECTION NETWORK

The U.S. Geological Survey has seven continuous streamflow monitoring stations and two reservoir-elevation monitoring stations in the Bull Run watershed (table 1). In addition to stage-recording equipment at the seven streamflow monitoring stations, four stations are equipped with automatic pumping samplers for collection of suspended-sediment samples and water-quality minimonitors for recording stream temperature and specific conductance (Stations 15, 18, 35, and 44). Five partial-record stations are also maintained with rated staff gages to provide streamflow at times of water-quality sampling.

Stage, temperature, and specific-conductance data are automatically recorded at half-hour intervals on 16-channel punch tape and are also relayed every 3 hours to GOES (Geostationary Orbital Environmental Satellite). The GOES system provides water-supply managers with fast (but not real-time) access to data on streamflow, reservoir elevations, and two water-quality characteristics (temperature and specific conductance) at these stations. The GOES system also provides a convenient means of monitoring equipment operation at these remote sites.

The automatic-pumping suspended-sediment samplers at the four water-quality monitoring stations are equipped with 72 1-liter plastic sample bottles. The automatic starting mechanism for the suspended-sediment sampler consists of a solid-state timer that can be preset for two sampling frequencies and two float switches (one placed at a lower stage and the other at a higher stage) that act as frequency and stage selectors. During the period May to September, the normal sampling frequency is twice per day; from October to April, it is four times per day. When the streamflow increases, the rising stage triggers the float switch, which in turn increases sampling frequency to every 90 minutes. The increased sampling frequency provides additional definition of the suspended-sediment concentrations at higher streamflows. The frequency of sampling is recorded on a strip-chart stage recorder. Depth-integrated cross-sectional suspended-sediment samples are collected at various stages to manually calibrate the single-point samples collected by the automatic sampler.

Since 1978, periphyton (attached microscopic plants and animals) samples have been collected at five to six stations per year. North and South Fork Bull Run Rivers, Fir Creek, and Upper and Lower Cougar Creek have been sampled from September 1977 to September 1983; the Cedar Creek station (Cedar Creek near South Fork Bull Run River) was sampled from WY 1978 to 1981. The samples were collected on paired artificial substrates (plastic slides) attached to float devices which keep the substrate approximately 2 inches below water surface. The first substrate pair was placed in the stream about June of each year. Within 4 to 6 weeks, the first pair was removed and the next set put in its place. The procedure was repeated through October, at which time the last pair was removed. Some periphyton slides have been lost or damaged due to high streamflow or to application of copper sulfate to the stream (WY 1979), reducing the size of this data set. Chlorophyll a and b, total biomass, and periphyton populations (to species) were analyzed on each substrate pair. A detailed description and interpretation of the biological data collected within the Bull Run watershed for the water-year period 1978-1983 is provided in a report by Clifton (1985).

Table 1.--Summary of the Geological Survey data-collection network in the Bull Run watershed

Station number	Station name	Description of hydrologic activity	Beginning of hydrologic record[1/]	Suspended-sediment and mini-monitor station	Periodic Water Bureau station	Intermittent Geological Survey biological station
Stream stations						
14138800	Blazed Alder Creek nr Rhododendron	Stream gaging and satellite data relay	October 1963	--	--	X
14138850	Bull Run River nr Multnomah Falls [18] ("Main Stem")	do.	August 1966	X	X	X
14138870	Fir Creek nr Brightwood [44]	do.	October 1975	X	X	X
14138900	North Fork Bull Run River nr Multnomah Falls [15]	do.	August 1965	X	X	X
14139700	Cedar Creek nr Brightwood	do.	July-Nov. 1964; June 1965	--	--	X[2/]
14139800	South Fork Bull Run River nr Bull Run [35]	do.	October 1974	X	X	X
14140001	Bull Run River nr Bull Run Reservoirs	do.	September 1907	--	--	--
14139000	Bull Run Reservoir 1 nr Bull Run	Daily elevations	October 1928	--	--	--
14139900	Bull Run Reservoir 2 nr Bull Run	Daily elevations and satellite data relay	December 1961	--	--	--
Partial-record stations						
14138950	Deer Creek nr Bull Run	Staff gage with crest stage gage	October 1977	--	X	--
14138960	Cougar Creek nr Bull Run	do.	October 1977	--	X	X[3/]
14138990	Bear Creek nr Bull Run	do.	October 1977	--	X	--
14139510	Fivemile Creek nr Bull Run	do.	October 1977	--	X	--
14139600	Camp Creek nr Bull Run	do.	October 1977	--	X	--

[1/] Data are still being collected for all stations.

[2/] Intermittent biological data were collected at a station slightly downstream from where the discharge data were recorded (Station No. 14139760 - Cedar Creek near South Fork Bull Run River).

[3/] Intermittent biological data were also collected at a station slightly upstream (Station No. 14138955 - Upper Cougar near Bull Run).

During the summers of WY's 1977-1981, 24-hour intensive monitoring was conducted at selected stations to continuously monitor the temperature, pH, specific conductance, and dissolved-oxygen concentrations. Water-quality samples were taken, benthic communities (organisms living on the stream bottom) were sampled, and the benthic organisms were identified by species.

Since the mid-1970's extensive water-quality sampling with manual samplers has been conducted by personnel from the City of Portland Water Bureau Laboratory on a periodic (weekly, monthly, quarterly, or yearly) basis at this project's four water-quality stations and at the five partial-record stations. These samples have been analyzed in a timely manner because the laboratory at the Headworks is in close proximity to the stations.

In addition to the extensive surface-water quantity and quality data available for interpretation, daily precipitation samples were collected and analyzed for June 1980 through September 1981. Also, water samples from a spring near the South Fork Bull Run station were collected in October of 1981; in July, August, and September of 1982; and in January of 1983. The water-quality characteristics of the spring were considered indicative of subsurface water contributions to surface-water quality.

HYDROLOGIC CHARACTERISTICS

Annual Mean Streamflow

In order to evaluate stream water-quality characteristics associated with streamflow in the Bull Run watershed, an analysis was made of the hydrologic record for the time period in which these constituents were measured. Although there has been some road building within the watershed, it was assumed that this type of modification had not greatly altered the watershed hydrologically over what was observed historically. The period of data collection covered by this study is WY 1978 through 1983 (October 1977 to September 1983). It is important to evaluate the historic hydrologic setting to understand whether the 1978-83 WY sampling period encompasses a full spectrum of measured historic variation in annual streamflow. If this period shows a variation in streamflow similar to that of the longer historic streamflow record for the region, it can be assumed that water-quality constituents related to flow are also representative of historic natural variation.

Because the 1978-83 WY period represents a relatively short timeframe, it was first necessary to compute annual mean flows for each of the Bull Run stations for a longer timeframe. An evaluation of long-term streamflow records in western Oregon (C. W. Alexander, written commun., 1984) indicated that the period WY 1929-83 contains a wide range of measured annual mean streamflow. The author has also chosen the WY period 1929-83 to define the norm for this report, since the mean annual streamflow for the WY period 1929-45 defines below-normal streamflow and the WY period 1946-83 defines above-normal streamflow. Because annual mean streamflow for an adjacent basin, the Little Sandy River near Bull Run (station number 14141500, period of record 1920-83; drainage area of 22.3 square miles), correlated well with the existing record of the four Bull Run stations (R-squared values ranging from 0.81-0.98), its record was used to estimate the mean annual streamflows for the WY period 1929-83 for each of the Bull Run stations (table 2). Mean annual streamflows for the Bull Run stations were also generated for comparison of WY periods 1929-45 and 1946-83.

The average ratio of the annual mean 1978-83 WY streamflow to mean annual 1929-83 WY streamflows was 95 percent and ranged on a yearly basis from 80 percent (1979 WY) to 108 percent (1983 WY).

Table 2.--Mean daily streamflow statistics for selected stations in the Bull Run watershed

[Streamflow values are shown in cubic feet per second, ft^3/s]

Water years	Mean daily streamflow			
	North Fork Station 15	Main Stem Station 18	South Fork Station 35	Fir Creek Station 44
1978	79.8	436	124	38.2
1979	56.8	342	92.4	30.6
1980	60.3	360	108	32.9
1981	68.2	381	99.1	32.9
1982	78.0	424	109	38.8
1983	84.2	451	117	39.9
	Estimated mean annual streamflow[1]			
1978-83	71.2	399	108	35.6
1929-83	76.3	413	112	37.4
1929-45	66.4	360	97.5	32.6
1946-83	80.7	437	118	39.6

[1]Mean annual streamflows estimated by regression with station 14141500 (Little Sandy River near Bull Run).

Because annual streamflow for the Little Sandy River near Bull Run (a long-term streamflow station) correlated well with the existing records of the four Bull Run stations, its measured streamflow was used as an indicator of how annual streamflow for the 1978-83 WY period at the Bull Run stations compared to that of the 1929-83 WY period. Analysis of the annual streamflow for the Little Sandy River near Bull Run indicated that about 20 percent of the annual mean streamflows for the 1929-83 WY period were less than that of WY 1979 (the lowest annual mean streamflow for the study period) and that 35 percent had streamflows greater than WY 1983 (the highest annual mean streamflow for the study period). This comparison indicates that the range of annual mean streamflows during the 6-year study period encompassed less than 50 percent of the annual mean streamflows for the 1929-1983 WY period and did not reproduce the extreme high or low historic streamflows measured in the area. In fact, the ratios previously generated for the Bull Run stations indicated that the study period is an average flow period.

Peak streamflows for the Bull Run stations during the study occurred in the winter of WY 1978. The Little Sandy River streamflow record indicated that the WY 1978 peak flow had a 3.2-year recurrence interval (log Pearson computation). Minimum daily mean streamflows (baseflow conditions) for the period occurred in WY 1980 and had a recurrence interval of about 5 years.

Thus, because streamflow and related variables did not exhibit as wide a variation as could be expected historically, standards for streamflow and related variables based on data collected during the study period will probably not account for the expected natural extreme variations.

Daily Mean Streamflow

Variations in the median daily mean streamflows for the period are shown in table 3. All streamflow data were made comparable by dividing each daily mean streamflow by the appropriate station's drainage area.

Table 3.--Analysis of the variation in the median daily mean streamflow in the Bull Run watershed, Oregon

[WY = water year; streamflow values are shown in cubic feet per second per square mile, $ft^3/s/mi^2$]

Streamflow ranked from high to low for all the stations

Water year	Streamflow
1983	5.32
1980	5.26
1978	4.86
1982	4.57
1981	4.32
1979	3.30

Streamflow ranked from high to low based on WY

Station 15		Station 18		Station 35		Station 44	
WY	Streamflow	WY	Streamflow	WY	Streamflow	WY	Streamflow
1983	6.49	1983	5.82	1980	5.26	1980	4.63
1980	5.61	1980	5.56	1978	5.19	1983	4.21
1982	5.53	1978	5.14	1983	5.06	1978	3.94
1978	5.17	1982	4.78	1981	4.05	1982	3.85
1981	4.81	1981	4.61	1982	4.02	1981	3.71
1979	3.60	1979	3.82	1979	3.12	1979	2.75

Streamflow ranked from high to low based on time of the year

October-September		July-August	
Station	Streamflow	Station	Streamflow
15	5.17	15	2.16
18	5.11	18	1.56
35	4.54	35	1.38
44	3.89	44	.98

Comparing median daily mean streamflows per square mile for all stations combined indicated the following ordering of water years, from largest streamflow to smallest: 1983, 1980, 1978, 1982, 1981, 1979. Analysis of the variation in the median daily mean streamflows for individual stations generally ranked WY 1983 streamflow either first or second (with the exception of South Fork [35] data), whereas WY 1979 streamflow ranked last. For water years other than 1979 and 1983, variations in the median daily mean streamflows generally did not demonstrate any distinct ordering. The fact that median daily mean streamflow for WY 1979 (ranked lowest) was only about 60 percent of that of WY 1983 (generally ranked highest) suggests that any water-quality standards based on streamflow-related data collected unevenly during the study period may not be representative of the entire period.

Examination of the cumulative percentile plot of the daily mean streamflows for the four stations generally indicated that the streamflow data was highest for the North Fork [15], then Main Stem [18], South Fork [35], with Fir Creek [44] having the lowest values (fig. 2). Examining the variation in the median daily mean streamflows showed that the North Fork station [15] value was 33 percent greater than that for Fir Creek [44] (table 3).

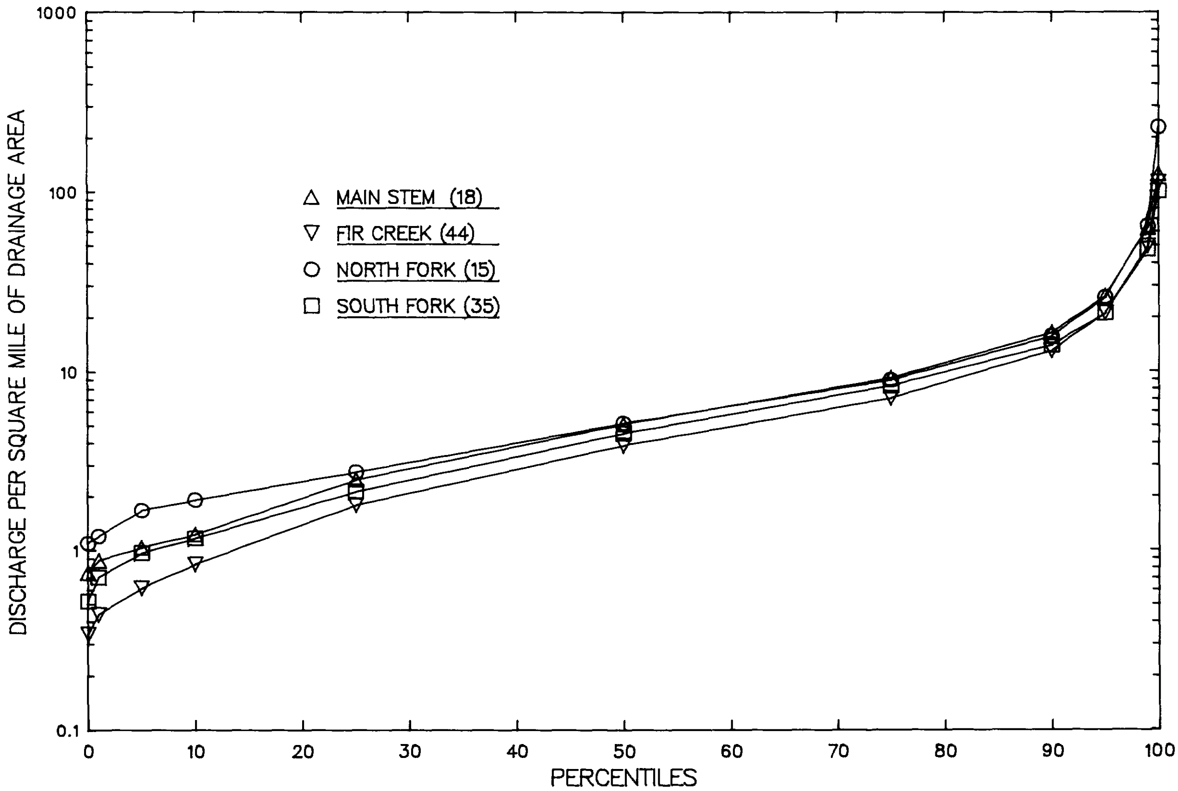

FIGURE 2.--Cumulative percentile plot of discharge per square mile for selected Bull Run stations, water years 1978-1983.

Baseflow Daily Mean Streamflow

Summertime flow conditions, the July-through-August daily mean streamflows (baseflow conditions), indicated that the North Fork Bull Run station had the largest median streamflow, followed by that of the Mainstem Bull Run, the South Fork Bull Run, and Fir Creek (table 3). The computed median daily mean streamflow per square mile during baseflow for the North Fork Bull Run was 2.2 times greater than that of Fir Creek. The differences noted at low flow may reflect the different geology in the basins, but the flow characteristics are also affected by permeability of the formation, character of the underlying formation, incision of the stream, and presence of multiple formations draining the stream (Searcy, 1959). In summary, the findings of the hydrologic analyses indicate that streamflow conditions during the study period are similar to the long-term average, with little evidence of extreme events.

WATER-QUALITY CHARACTERISTICS

Daily and Periodic Surface-water Quality

The range and frequency distribution of instantaneous and daily mean surface water-quality and -quantity data collected in the Bull Run watershed are summarized in tables 4 through 7. As was pointed out in the previous section, the 1978-1983 WY period is indicative of the average historic hydrologic cycle in the area, and therefore water-quality constituents related to streamflow (for example, suspended-sediment concentration, turbidity, or temperature) would not be expected to represent long-term extreme values.

Comparison of constituent values (using tables 4 through 7) does not yield many differences between stations that can be directly attributed to differences in basin characteristics. The higher instantaneous turbidity, total solids, and suspended-sediment concentrations observed at North Fork Bull Run River may be related to the geology of the subbasin. The North Fork subbasin includes pyroclastic parts of the Rhododendron Formation containing pods of varicolored clays (Beaulieu, 1974) which can be highly erodible when exposed to runoff. The four stations represent the most downstream locations of four subbasins within the Bull Run watershed.

To describe the chemical changes occurring in precipitation entering the Bull Run watershed, a trilinear diagram was constructed to examine major ion and silica concentrations in precipitation, springs, and surface waters in the watershed during both high- and low-flow seasons (fig. 3). Major ion and silica concentrations found in ocean water (Weast, 1977) were added to the diagram, in order to contrast the watershed precipitation chemistry with that of its origin. Rain falling within the watershed generally has three avenues of transport to the stream (other than the minor route of direct entry): (1) overland flow, (2) subsurface "quick-return" flow, and (3) ground-water inflow. Ground water has the most intimate and longest contact with the surrounding geology; thus, in figure 3 the chemistry of spring waters shows the largest concentrations of silica, calcium and magnesium, and bicarbonate. The chemistry of surface waters sampled during lower flows (June to October) show the next largest concentrations because of a proportionally larger ground-water influence. Surface water sampled during higher flows (November to April) show chemistry more characteristic of waters influenced by overland and subsurface runoff. A straight line can be drawn from the precipitation data through the surface-water data, further emphasizing the diluting effect of precipitation waters on surface-water chemistry.

Table 4.--Summary of instantaneous and daily mean data at North Fork Bull Run River, October 1977 to September 1983

[N = number of observations]

Constituent[1/]	N	Range		Percent of samples in which values are less than or equal to those shown				
		Maximum	Minimum	95	75	50	25	5
	Instantaneous data							
Temperature, °C	350	13.0	0.0	11.0	9.3	7.0	4.5	2.5
Streamflow, ft^3/s	368	2,650	8.7	809	88.2	43.0	24.3	14.2
Turbidity, NTU	343	75.0	.04	2.3	.30	.20	.16	.11
Solids, mg/L total	288	119	10.7	41.8	33.4	26.2	21.7	17.5
Color, platinum cobalt units	334	60	<5.0	10	<5.0	<5.0	<5.0	<5.0
Specific conductance, umhos/cm at 25 °C	366	48	9	42	33	26	21	14
pH, units	357	7.7	6.5	7.6	7.5	7.3	7.2	6.9
Alkalinity as $CaCO_3$, mg/L	21	19.2	3.0	19.2	15.5	8.3	7.0	3.3
Ammonia as N, mg/L total	134	.16	<.02	<.02	<.02	<.02	<.02	<.02
Nitrate as N, mg/L total	130	.13	<.01	.06	.03	.03	.02	<.01
Orthophosphorus as P, mg/L total	122	.029	<.003	.020	.010	.007	.005	<.003
Organic carbon, mg/L total	90	3.9	.4	2.5	1.4	1.1	.8	.6
Calcium, mg/L total	22	4.0	1.1	3.9	3.4	2.0	1.7	1.1
Magnesium, mg/L total	22	1.4	.45	1.4	1.2	.65	.59	.46
Sodium, mg/L total	22	2.3	.86	2.3	1.8	1.2	1.2	.90
Potassium, mg/L total	22	.50	.12	.50	.39	.22	.19	.12
Chloride, mg/L total	25	2.8	<.25	2.3	.60	.30	<.25	<.25
Sulfate as SO_4, mg/L total	28	5.2	<.50	4.7	.50	<.50	<.50	<.50
Silica as SiO_2, mg/L total	126	18.6	4.0	18.0	13.7	10.7	8.5	5.8
Arsenic, µg/L total	25	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Barium, µg/L total	25	10	<5.0	10	<5.0	<5.0	<5.0	<5.0
Cadmium, µg/L total	25	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Chromium, µg/L total	25	10	<1.0	7.9	2.0	2.0	<1.0	<1.0
Copper, µg/L total	25	20	<1.0	17	5.0	3.0	2.0	<1.0
Iron, µg/L total	25	190	9.0	169	64	27	18	9.9
Lead, µg/L total	25	7.0	<1.0	6.4	1.0	<1.0	<1.0	<1.0
Manganese, µg/L total	25	20	<1.0	17	2.5	<1.0	<1.0	<1.0
Mercury, µg/L total	23	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Silver, µg/L total	25	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Zinc, µg/L total	25	430	<1.0	322	8.0	4.0	<1.0	<1.0
Aluminum, µg/L total	22	780	16	720	93	36	25	16
Selenium, µg/L total	25	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Coliform, total per 100 ml	308	80	<1	30	8	2	1	<1
Coliform, fecal per 100 ml	306	66	<1	14	2	1	<1	<1
Streptococci, fecal per 100 ml	304	70	<1	12	3	1	<1	<1
Phytoplankton, count per one ml	276	553	4	218	109	70	39	13
Periphyton, total per mm^2	15	21,300	332	21,300	11,200	3,580	1,270	332

Table 4.--Summary of instantaneous and daily mean data at North Fork Bull Run River, October 1977 to September 1983--continued

[N = number of observations]

Constituent[1/]	N	Range		Percent of samples in which values are less than or equal to those shown				
		Maximum	Minimum	95	75	50	25	5
	Instantaneous data							
Periphyton biomass-chlorophyll ratio	17	1,360	0	1,360	350	134	62	0
Periphyton chlorophyll a, mg/m^2	20	56.8	.43	54.6	8.7	2.8	1.8	.44
Periphyton chlorophyll b, mg/m^2	20	25.8	0	24.6	0.94	.40	.10	.00
Periphyton biomass, ash weight, g/m^2	22	17.3	.00	15.1	1.8	.75	.28	.00
Periphyton biomass, dry weight, g/m^2	22	23.2	.08	21.8	2.9	1.1	.69	.09
Suspended sediment, mg/L	341	1,032	<.1	55	1.0	.4	.2	<.1
	Daily mean data							
Temperature, °C[2/]	1,801	12.4	0.0	11.0	9.5	6.9	4.2	2.4
Streamflow, ft^3/s	2,190	1,910	9.1	216	75.0	43.0	23.0	14.0
Specific conductance, umhos/cm at 25 °C[2/]	1,794	[3/]56	10	43	35	26	21	16
Suspended-sediment concentration, mg/L[2/]	1,823	205	0	4	1	1	0	0
Suspended-sediment load, tons/day[2/]	1,823	633	0	1.9	.2	.1	0	0

1/ Selected constituent listing of the weekly and daily mean data may be found in the annual U.S. Geological Survey Water Resources Data Reports for Oregon (1978-1983).

2/ For the period October 1978-September 1983.

3/ Maximum value occurred during an accidental cement spill made while reinforcing portion of an embankment. Excluding the period of record affected by the spill (January 13-23, 1981), maximum specific conductance was 47 micromhos/cm 25° C.

Table 5.--Summary of instantaneous and daily mean data at Main Stem Bull Run River, October 1977 to September 1983

[N = number of observations]

Constituent[1/]	N	Range		Percent of samples in which values are less than or equal to those shown				
		Maximum	Minimum	95	75	50	25	5
	Instantaneous data							
Temperature, °C	315	14.0	0.0	12.2	9.6	6.4	4.0	2.0
Streamflow, ft^3/s	330	8,510	35.8	2,860	474	250	120	45.7
Turbidity, NTU	314	43	.07	1.0	.24	.19	.12	.11
Solids, mg/L total	274	97.0	15.5	31.0	25.8	22.7	20.0	18.2
Color, platinum cobalt units	311	60	<5	10	<5	<5	<5	<5
Specific conductance, umhos/cm at 25 °C	316	32	11	29	25	20	18	14
pH, units	314	7.7	6.4	7.5	7.3	7.2	7.1	6.8
Alkalinity as $CaCO_3$, mg/L	18	12.4	5.7	12.4	11.0	7.1	6.4	5.7
Ammonia as N, mg/L total	125	.02	<.02	<.02	<.02	<.02	<.02	<.02
Nitrate as N, mg/L total	126	.19	<.01	.08	.05	.04	.03	.02
Orthophosphorus as P, mg/L total	122	.024	<.003	.008	.004	<.003	<.003	<.003
Organic carbon, mg/L total	89	3.7	0.6	2.8	1.4	1.0	0.8	0.6
Calcium, mg/L total	22	2.5	1.3	2.5	2.2	1.6	1.4	1.3
Magnesium, mg/L total	22	.82	.35	.82	.69	.50	.46	.35
Sodium, mg/L total	22	1.7	0.6	1.7	1.4	1.2	1.1	.64
Potassium, mg/L total	22	.31	.10	.31	.28	.23	.18	.11
Chloride, mg/L total	19	1.0	<.25	1.0	0.5	0.4	<.25	<.25
Sulfate as SO_4, mg/L total	19	<.50	<.50	<.50	<.50	<.50	<.50	<.50
Silica as SiO_2, mg/L total	120	13.1	5.2	12.3	10.6	9.4	8.5	6.9
Arsenic, µg/L total	22	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Barium, µg/L total	22	5.0	<5.0	5.0	<5.0	<5.0	<5.0	<5.0
Cadmium, µg/L total	22	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Chromium, µg/L total	22	3.0	<1.0	3.0	2.0	1.0	<1.0	<1.0
Copper, µg/L total	22	7.0	<1.0	6.8	5.0	2.0	1.0	<1.0
Iron, µg/L total	22	140	10	136	37	23	16	10
Lead, µg/L total	22	4.0	<1.0	3.8	2.0	<1.0	<1.0	<1.0
Manganese, µg/L total	22	9.0	<1.0	8.2	<1.0	<1.0	<1.0	<1.0
Mercury, µg/L total	22	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Silver, µg/L total	22	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Zinc, µg/L total	22	11.0	<1.0	10.6	5.2	4.0	<1.0	<1.0
Aluminum, µg/L total	22	270	8.0	253	72.5	43	20	8.8
Selenium, µg/L total	22	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Coliform, total per 100 ml	305	98	<1	38	12	4	1	<1
Coliform, fecal per 100 ml	304	90	<1	19	5	2	1	<1
Streptococci, fecal per 100 ml	302	92	<1	20	6	2	<1	<1
Phytoplankton, count per one ml	275	764	6	319	190	119	58	19
Periphyton, total per mm^2	2	9,137	3,875	9,137	9,137	6,506	3,875	3,875
Periphyton biomass-chlorophyll ratio	1	101	101	--	--	--	--	--

Table 5.--Summary of instantaneous and daily mean data at Main Stem Bull Run River, October 1977 to September 1983--continued

[N = number of observations]

Constituent[1/]	N	Range: Maximum	Range: Minimum	Percent of samples in which values are less than or equal to those shown: 95	75	50	25	5
				Instantaneous data				
Periphyton chlorophyll a, mg/m^2	1	3.9	3.9	--	--	--	--	--
Periphyton chlorophyll b, mg/m^2	1	1.19	1.19	--	--	--	--	--
Periphyton biomass, ash weight, g/m^2	1	.217	.217	--	--	--	--	--
Periphyton biomass, dry weight, g/m^2	1	.612	.612	--	--	--	--	--
Suspended sediment, mg/L	316	333	<.1	11	0.9	0.4	0.2	<0.1
				Daily mean data				
Temperature, °C	1,871	15.9	0.0	13.0	10.1	6.5	4.2	1.8
Streamflow, ft^3/s	2,191	6,020	36.0	1,262	443	245	120	50.0
Specific conductance, umhos/cm at 25 °C	1,805	37	11	30	25	21	19	16
Suspended-sediment concentration, mg/L	2,191	366	0	4	2	1	0	0
Suspended-sediment load, tons/day	2,191	5,930	0	12.4	1.5	.6	0	0

1/ Selected constituent listing of the weekly and daily mean data may be found in the annual U.S. Geological Survey Water Resources Data Reports for Oregon (1978-1983).

Table 6.--Summary of instantaneous and daily mean data at South Fork Bull Run River, October 1977 to September 1983

[N = number of observations]

Constituent[1/]	N	Range		Percent of samples in which values are less than or equal to those shown				
		Maximum	Minimum	95	75	50	25	5
	Instantaneous Data							
Temperature, °C	348	16.0	0.0	14.5	11.0	7.5	5.0	2.7
Streamflow, ft^3/s	353	2,100	10.0	549	139	65.1	30.8	14.3
Turbidity, NTU	325	12.0	.11	1.6	.32	.24	.18	.13
Solids, mg/L total	289	52.9	12.5	37.0	30.4	25.6	22.2	19.0
Color, platinum cobalt units	319	50	<5.0	15	5.0	<5.0	<5.0	<5.0
Specific conductance, umhos/cm at 25 °C	342	50	11	40	31	24	21	15
pH, units	341	7.7	6.6	7.6	7.4	7.3	7.2	6.9
Alkalinity as $CaCO_3$, mg/L	20	18.0	36	18.0	14.9	8.7	7.4	3.8
Ammonia as N, mg/L total	129	.16	<.02	<.02	<.02	<.02	<.02	<.02
Nitrate as N, mg/L total	131	.12	<.01	.06	.03	.03	.02	<.01
Orthophosphorus as P, mg/L total	124	.013	<.003	.007	.004	<.003	<.003	<.003
Organic carbon, mg/L total	92	5.6	.1	3.0	1.7	1.1	.90	.66
Calcium, mg/L total	24	3.6	1.4	3.6	2.7	1.8	1.6	1.4
Magnesium, mg/L total	24	1.3	.50	1.3	.99	.70	.65	.53
Sodium, mg/L total	24	1.9	.63	1.9	1.5	1.2	1.1	.66
Potassium, mg/L total	24	.29	.04	.29	.23	.17	.15	.05
Chloride, mg/L total	23	1.3	<.25	1.2	.65	.50	<.25	<.25
Sulfate as SO_4, mg/L total	28	2.1	<.50	1.7	<.50	<.50	<.50	<.50
Silica as SiO_2, mg/L total	123	16.0	4.9	15.0	12.0	10.5	9.0	6.4
Arsenic, µg/L total	24	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Barium, µg/L total	24	16	<5.0	16	<5.0	<5.0	<5.0	<5.0
Cadmium, µg/L total	24	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Chromium, µg/L total	24	6.0	<1.0	6.0	3.0	2.0	<1.0	<1.0
Copper, µg/L total	24	7.0	<1.0	6.8	3.8	2.5	<1.0	<1.0
Iron, µg/L total	25	1,200	22.0	1,200	64.0	40	36	22
Lead, µg/L total	24	5.0	<1.0	4.5	<1.0	<1.0	<1.0	<1.0
Manganese, µg/L total	24	26	<1.0	26	1.8	<1.0	<1.0	<1.0
Mercury, µg/L total	24	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Silver, µg/L total	24	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Zinc, µg/L, total	24	31	<1.0	28	3.8	1.5	<1.0	<1.0
Aluminum, µg/L total	24	780	10	748	100	62	36	12
Selenium, µg/L total	24	<5	<5	<5	<5	<5	<5	<5
Coliform, total per 100 ml	304	122	<1	34	12	4	1	<1
Coliform, fecal per 100 ml	301	102	<1	14	3	1	<1	<1
Streptococci, fecal per 100 ml	298	78	<1	21	5	1	<1	<1
Phytoplankton, count per one ml	278	268	1	171	104	75	44	14
Periphyton, total per mm^2	10	46,550	1,152	46,550	5,310	2,658	2,005	1,152

Table 6.--Summary of instantaneous and daily mean data at South Fork Bull Run River, October 1977 to September 1983--continued

[N = number of observations]

Constituent [1/]	N	Range		Percent of samples in which values are less than or equal to those shown				
		Maximum	Minimum	95	75	50	25	5
	Instantaneous Data							
Periphyton, biomass-chlorophyll ratio	13	1,465	10.9	1,465	758	280	99.8	10.9
Periphyton chlorophyll a, mg/m^2	14	7.34	.41	7.34	5.46	3.50	1.80	.41
Periphyton chlorophyll b, mg/m^2	14	1.98	.05	1.98	.90	.39	.10	.05
Periphyton biomass, ash weight, g/m^2	15	7.64	.39	7.64	3.31	1.65	.95	.39
Periphyton biomass, dry weight, g/m^2	15	10.8	.55	10.8	4.10	2.36	1.26	.55
Suspended sediment, mg/L	313	110	<.1	6	1	.5	.3	<.1
	Daily mean data							
Temperature, °C [2/]	1,723	16.0	0.0	13.6	10.6	7.0	4.7	2.7
Streamflow, ft^3/s	2,191	1,550	8.0	326	129	70.0	33.0	15.0
Specific conductance, umhos/cm at 25 °C [2/]	1,711	44	12	40	32	25	21	18
Suspended-sediment concentration, mg/L	1,817	62	0	3	1	1	0	0
Suspended-sediment load, tons/day [2/]	1,817	265	0	2.3	.3	.1	0	0

1/ Selected constituent listing of the weekly and daily mean data may be found in the annual U.S. Geological Survey Water Resources Data Reports for Oregon (1978-1983).

2/ For the period October 1978 to September 1983.

Table 7.--Summary of instantaneous and daily mean data at Fir Creek near Brightwood October 1977 to September 1983

[N = number of observations]

Constituent[1/]	N	Range: Maximum	Range: Minimum	Percent of samples in which values are less than or equal to those shown: 95	75	50	25	5
				Instantaneous data				
Temperature, °C	343	14.0	0.0	12.0	9.6	7.0	4.5	3.0
Streamflow, ft^3/s	366	916	1.9	347	42.3	21.6	9.6	3.3
Turbidity, NTU	322	8.4	.05	.94	.25	.18	.13	.09
Solids, mg/L total	279	45.8	6.1	29.4	24.7	21.9	20.0	17.5
Color, platinum cobalt units	313	40	<5	10	<5	<5	<5	<5
Specific conductance, umhos/cm at 25 °C	341	30	11	28	24	21	19	15
pH, units	335	7.6	6.6	7.4	7.3	7.2	7.1	6.9
Alkalinity as $CaCO_3$, mg/L	19	16.0	3.1	16.0	9.6	7.0	6.3	3.1
Ammonia as N, mg/L total	127	.15	<.02	<.02	<.02	<.02	<.02	<.02
Nitrate as N, mg/L total	127	.19	<.01	.08	.05	.04	.03	<.01
Orthophosphorus as P, mg/L total	126	.041	<.003	.012	.005	.003	<.003	<.003
Organic carbon, mg/L total	87	4.7	.1	2.5	1.4	.9	.8	.6
Calcium, mg/L total	23	2.2	1.3	2.2	1.9	1.5	1.4	1.3
Magnesium, mg/L total	23	.88	.41	.87	.68	.59	.49	.41
Sodium, mg/L total	22	1.6	.79	1.6	1.3	1.2	1.1	.80
Potassium, mg/L total	23	.21	.05	.21	.18	.15	.11	.06
Chloride, mg/L total	22	1.30	<.25	1.24	.65	.50	<.25	<.25
Sulfate as SO_4, mg/L total	26	1.60	<.50	1.46	.53	<.50	<.50	<.50
Silica as SiO_2, mg/L total	123	14.0	4.8	12.6	10.3	9.3	8.4	6.6
Arsenic, µg/L total	23	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Barium, µg/L total	23	9.0	<5.0	<9.0	<5.0	<5.0	<5.0	<5.0
Cadmium, µg/L total	23	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Chromium, µg/L total	23	4.0	<1.0	4.0	3.0	1.0	<1.0	<1.0
Copper, µg/L total	23	11.0	<1.0	10.2	4.0	3.0	<1.0	<1.0
Iron, µg/L total	24	510	6.0	510	40	17	13	6.0
Lead, µg/L total	23	6.0	<1.0	5.6	1.2	<1.0	<1.0	<1.0
Manganese, µg/L total	23	23.0	<1.0	23.0	<1.0	<1.0	<1.0	<1.0
Mercury, µg/L total	23	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Silver, µg/L total	23	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Zinc, µg/L total	23	39.0	<1.0	36.8	5.0	2.0	<1.0	<1.0
Aluminum, µg/L total	23	630	<5.0	630	66	31	18	5.2
Selenium, µg/L total	23	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Coliform, total per 100 ml	302	116	<1	30	10	4	<1	<1
Coliform, fecal per 100 ml	298	77	<1	10	2	1	<1	<1
Streptococci, fecal per 100 ml	295	104	<1	29	4	1	<1	<1
Phytoplankton, count per one ml	275	350	2	108	68	51	30	11
Periphyton, total per mm^2	11	10,040	503	10,040	6,705	2,882	1,352	503

Table 7.--Summary of instantaneous and daily mean data at Fir Creek near Brightwood October 1977 to September 1983--Continued

[N = number of observations]

Constituent 1/	N	Range: Maximum	Range: Minimum	Percent of samples in which values are less than or equal to those shown: 95	75	50	25	5
				Instantaneous data				
Periphyton biomass-chlorophyll ratio	18	2,000	60.8	2,000	689	390	92.0	60.8
Periphyton chlorophyll a, mg/m^2	19	19	.10	19.0	6.9	2.4	1.6	0.10
Periphyton chlorophyll b, mg/m^2	19	9.0	.00	9.0	.99	.60	.10	.00
Periphyton biomass, ash weight, g/m^2	20	4.2	.08	4.2	1.6	.88	.57	.09
Periphyton biomass, dry weight, g/m^2	20	6.5	.32	6.4	2.6	1.9	.91	.33
Suspended sediment, mg/L	318	410	<.1	18	.8	.4	.2	<.1
				Daily mean data				
Temperature, °C	2,061	14.1	0.0	11.8	9.2	6.3	4.4	2.8
Streamflow, ft^3/s	2,191	616	1.9	116	39.0	21.2	9.8	3.4
Specific conductance, umhos/cm at 25 °C	2,080	30	12	27	24	21	19	17
Suspended-sediment concentration, mg/L	2,191	208	0	2	1	0	0	0
Suspended-sediment load, tons/day	2,191	345	0	0.6	0.1	0	0	0

1/ Selected constituent listing of the weekly and daily mean data may be found in tha annual U.S. Geological Survey Water Resources Data Reports for Oregon (1978-1983).

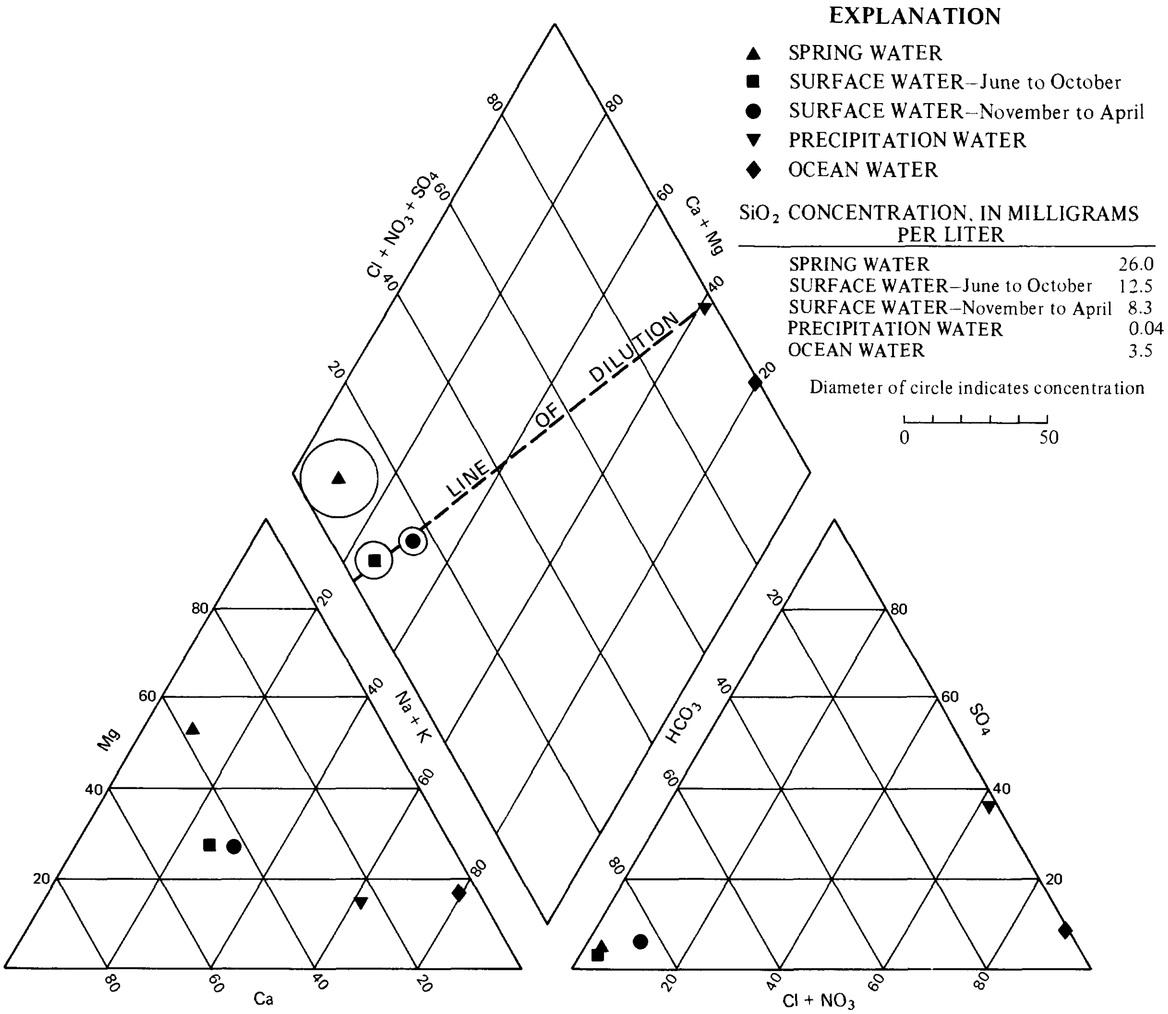

FIGURE 3.--Comparison of major ion and silica concentrations, Bull Run watershed (major ion concentrations are in percent).

Comparison of Historical with Current Stream Water-quality Data

A comparison was made of data from the 1978-1983 WY weekly grab samples from the Bull Run River near Multnomah Falls with historical Geological Survey data for the periods 1911-1912 (Winkle, 1914) and 1951-1953 (Madison, 1966) from Bull Run River near Bull Run. Making allowances for the facts that (1) this comparison is of two different stations within the same drainage basin, (2) analytical techniques have changed with time, and (3) the 1978-1983 data base is much more extensive than the two earlier data bases, there are relatively few apparent differences among the three data bases (table 8). There are slight decreases in sodium, potassium, chloride, and sulfate concentrations that may have occurred with time. The reasons for these decreases are not known; nor is it certain that they are not artifacts of the way data were collected and analyzed or changes in land-use (the construction of two reservoirs).

Table 8.--Comparison of historical water-quality data at Bull Run River near Bull Run with current water-quality data at Bull Run River near Multnomah Falls ("Main Stem")

[N = number of observations]

Constituent	Bull Run River nr Bull Run								Main Stem Bull Run River nr Multnomah Falls			
	1911-1912				1951-1953				1978-1983			
	N	minimum	maximum	median	N	minimum	maximum	median	N	minimum	maximum	median
Temperature, °F	--	--	--	--	3	41	47	43	315	32	57	44
Streamflow, ft^3/s	35	97	3743	502	4	334	5600	2100	330	35.8	8510	250
Turbidity	36	trace	7	trace	--	--	--	--	314	0.07	43	0.19
Color, platinum cobalt units	36	trace	12	4	--	--	--	--	311	<5	60	<5
Specific conductance, micromhos at 25 °C	--	--	--	--	4	19	26	20	316	11	32	20
pH, units	--	--	--	--	3	6.2	7.4	6.3	314	6.4	7.7	7.2
Bicarbonate (HCO_3), mg/L	35	8.1	20	11	4	10	13	12	18	6.9	15	8.6
Nitrate (NO_3), mg/L	35	trace	1.1	0.26	4	0	0.6	0.3	126	<.04	0.80	0.18
Calcium (Ca), mg/L	36	1.7	6.1	2.6	3	1.4	2.6	1.6	22	1.3	2.5	1.6
Magnesium (Mg), mg/L	36	0.04	1.7	.37	3	0.2	.8	.3	22	.35	.82	.50
Sodium and Potassium (Na + K), mg/L	35	1.8	6.4	3.3	4	1.9	2.6	2.3	22	.7	2.0	1.4
Chloride (Cl), mg/L	36	.25	3.5	1.3	4	.5	1.2	1.0	19	<.25	1.0	0.4
Sulfate, (SO_4) mg/L	36	1.1	5.8	3.1	4	.3	.8	.5	19	<.5	<.5	<.5
Silica, (SiO_2), mg/L	36	4.1	16	8.4	4	7.5	10	8.5	120	5.2	13.1	9.4
Iron (Fe), mg/L	36	trace	0.13	.02	3	trace	.10	.02	22	.010	.140	.023
Suspended sediment, mg/L	33	.0	5.4	.6	--	--	--	--	316	<.1	333	.4

Precipitation Quality

Because of the May 1980 eruption of Mount St. Helens (located in the State of Washington about 50 miles north of the Bull Run watershed) special stream and precipitation samples were collected to determine the impacts of ash fall on water quality in the Bull Run watershed. Analysis of stream samples for the period March to June 1980 by Shulters and Clifton (1980) indicated that no detectable changes had occurred in stream water-quality due to the ash fall. However, as discussed in their report, the historical precipitation data needed to understand the naturally occurring variability of precipitation chemistry was lacking. To document the chemical variability, precipitation data were collected at the Headworks from June 1980 through September 1981. These data are summarized in table 9.

Table 9.--Summary of data on rainfall quantity and composition collected in the Bull Run watershed, June 1980 to September 1981

[Daily storm event samples collected at the Headworks at 750-foot elevation. All analyses done on samples prefiltered through a 0.45-μm filter, except for precipitation quantity, specific conductance, pH, and acidity]

Constituent[1/]	Number of observations	Range Maximum	Range Minimum	Percent of samples in which values were less than or equal to those shown: 95	75	Median 50	25	5
Daily precipitation, inches	136	2.20	0.10	1.41	0.72	0.38	0.21	0.12
Specific conductance, micromhos/cm at 25 °C	130	44	3	28	13	8	6	4
pH, units	133	6.2	4.0	5.7	5.2	5.0	4.7	4.3
Calcium, mg/L	131	.80	<.02	.40	.20	.10	.04	<.02
Magnesium, mg/L	132	.480	<.004	.25	.12	.04	<.004	<.004
Sodium, mg/L	130	3.00	<.20	1.60	.60	.30	<.20	<.20
Bromide, mg/L	132	.25	<.05	.05	.05	.05	.05	.05
Chloride, mg/L	130	7.60	<.01	3.02	1.00	.50	.20	<.01
Fluoride, mg/L	131	1.00	<.01	.24	.08	.05	.02	<.01
Sulfate, mg/L	132	3.07	<.05	2.39	1.00	.58	.24	<.05
Nitrate as N, mg/L	129	1.52	<.01	.54	.18	.09	.02	<.01
Orthophosphate as P, mg/L	131	.24	<.10	<.10	<.10	<.10	<.10	<.10
Silica as SiO_2, mg/L	133	1.20	<.01	.43	.09	.04	<.01	<.01
Barium, μg/L	116	10	<2	2	<2	<2	<2	<2
Beryllium, μg/L	133	1	<1	<1	<1	<1	<1	<1
Cadmium, μg/L	133	3	<1	2	<1	<1	<1	<1
Cobalt, μg/L	133	3	<3	<3	<3	<3	<3	<3
Copper, μg/L	133	21	<10	<10	<10	<10	<10	<10
Iron, μg/L	133	80	<10	20	<10	<10	<10	<10
Lead, μg/L	133	30	<10	20	<10	<10	<10	<10
Manganese, μg/L	133	27	<1	6	2	1	<1	<1
Molybdenum, μg/L	133	45	<10	<10	<10	<10	<10	<10
Strontium, μg/L	133	6	<1	2	1	<1	<1	<1
Vanadium, μg/L	133	7	<6	<6	<6	<6	<6	<6
Zinc, μg/L	133	30	<3	18	7	4	<3	<3
Lithium, μg/L	133	11	<4	8	<4	<4	<4	<4
Acidity as $CaCO_3$, mg/L	7	9	4	9	8	6	5	4
Hardness as $CaCO_3$, mg/L	79	3	<1	2	1	1	<1	<1
Sodium Adsorption Ratio	61	1.3	.1	.9	.5	.3	.3	.1

1/ Selected constituent listing of the daily storm event samples may be found in the 1980 and 1981 U.S. Geological Survey Water Resource Data for Oregon reports.

Because the Bull Run watershed is located within the marine climatological pattern of the Pacific Northwest, a comparison was made to find the relative proportion of the major dissolved ions in seawater to those found in Bull Run precipitation (table 10). To determine if there were any statistically significant differences between the composition of Bull Run precipitation and those values obtained from seawater, the differences (residuals) between the log-transformed Bull Run constituent-to-chloride ratios and those obtained from seawater were subjected to the Student's T test. The Student's T test, when applied in this manner, determines if the population residual means are statistically equal to zero.

Table 10.--Relative proportion of dissolved constituents in seawater compared to that in Bull Run precipitation, normalized to unit chloride concentration, for the period June 1980 to September 1981

Constituent	Bull Run precipitation				Seawater
	Number of observations	Minimum	Maximum	Median	
Sodium	76	0.164	3.08	0.769	0.556
Calcium	109	.020	5.00	.190	.021
Magnesium	76	.006	9.90	.100	.067
Sulfate (SO_4)	111	.025	8.09	1.11	.140
Nitrate (NO_3)	103	.009	48.1	.922	1.8×10^{-5}
Silica (SiO_2)	91	.003	2.00	.118	1.8×10^{-4}

Test results indicated that at the 99.9-percent confidence level, the Student test rejected the null hypothesis that the population residual means for all the constituents listed in table 10 were equal to zero. The inference from the test is that other sources besides seawater were contributing to the chemical composition of the Bull Run precipitation.

To determine if other-source contributions to Bull Run precipitation chemistry were large, a comparison was made with three other remote precipitation sites located in Poker Flat, Alaska (Galloway and others, 1982); Copper Lake Basin, Washington (Dethier, 1979); and Redwood National Park, California (Bradford and Iwatsubo, 1978). In most cases (11 out of 16 variables)--based on the ranges shown in table 11--the variability of the precipitation chemistry in the Bull Run watershed was not that different from the ranges observed at the other remote sites. Several constituents in the Bull Run data have a wider range than found at the other sites. These constituents are pH, Cl, F, NO_3, and orthophosphate.

Significant Discharge Water-Quality Constituent Relations

Discharge-concentration regression models were developed for a selected list of constituents. The best of seven model types was selected for each constituent.

Of the various models that can be used for the discharge-concentration relation, the following represent the model types used in this study:

Type	Model
1.	$C = a + bQ$
2.	$C = a + bQ + cQ^2$
3.	$C = a + b\text{LOG } Q$
4.	$C = a + b\text{LOG } Q + c(\text{LOG } Q)^2$
5.	$C = a + b(1/Q)$
6.	$\text{LOG } C = a + b\text{LOG } Q$
7.	$\text{LOG } C = a + b\text{LOG } Q + c(\text{LOG } Q)^2$

where

C = the instantaneous or daily mean concentration or magnitude of the water-quality variable;

Q = the instantaneous or daily mean stream discharge;

LOG Q = the base 10 logarithm of Q; and

a,b,c = model coefficients.

Table 11.--Comparison of remote-site precipitation-chemistry variability extending from Alaska to California

Poker Flat, Alaska, for the period December 1979 through May 1981 (Galloway and others, 1982); Copper Lake basin, Washington, for the period 1974 and 1975 (Dethier, 1979); Bull Run watershed, Oregon, for the period June 1980 through September 1981; and Redwood National Park, California, for the period 1975 and 1976 (Bradford and Iwatsubo, 1978).

Constituent	Poker Flat, Alaska		Copper Lake basin, Washington		Bull Run watershed, Oregon		Redwood National Park, California	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Specific conductance, micromhos/cm at 25 °C	2	8	--	--	3	44	26	35
pH, units	4.5	5.6	--	--	4.0	6.2	--	--
Calcium, mg/L	.0	.13	0.025	0.21	<.02	.80	0.1	1.2
Magnesium, mg/L	.0	.036	.008	.048	<.004	.480	.0	.7
Sodium, mg/L	.0	.35	.055	.480	<.20	3.00	.3	1.8
Potassium, mg/L	--	--	<.010	.180	--	--	.1	.5
Chloride, mg/L	.02	.81	--	--	<.01	7.60	.4	2.0
Fluoride, mg/L	--	--	--	--	<.01	1.00	.0	.1
Sulfate, mg/L	.0	1.4	<.70	2.50	<.05	3.07	.5	2.0
Nitrate as N, mg/L	.07	.35	--	--	<.01	1.52	.02	.06
Orthophosphate as P, mg/L	--	--	--	--	<.01	.24	.0	.02
Silica as SiO_2, mg/L	--	--	<.10	.160	<.01	1.20	.0	1.2
Bicarbonate, mg/L	--	--	0	<.100	--	--	0	7
Hardness as $CaCO_3$, mg/L	--	--	--	--	<1	3	2	3
Copper, µg/L	--	--	1.2	7.8	<10	21	--	--
Iron, µg/L	--	--	2.0	115	<10	80	10	40
Lead, µg/L	--	--	1.9	15.5	<10	30	--	--
Zinc, µg/L	--	--	2.1	22.0	<3	30	--	--

The model selected as most appropriate was one that yielded the largest model correlation coefficient, with regression coefficients statistically significant at a 90-percent confidence level and regression residual plots appearing random. Only those discharge-concentration models that yielded multiple-correlation coefficients greater than 0.70 (49 percent of variation explained) were considered substantial.

Discharge-concentration models that yielded multiple correlation coefficients between 0.90 and 1.00 (81 to 100 percent of variation explained) were considered excellent model fits, while those that gave correlation coefficients between 0.70 and 0.90 (49 to 81 percent of variation explained) were considered good model fits (table 12). Only seven of the eighteen constituents collected weekly had discharge-concentration models with good to excellent model fits at three or more stations. Those constituents were turbidity, color, specific conductance, pH, total silica, total solids, and suspended-sediment concentration. Daily mean specific conductance and suspended-sediment concentration also gave good to excellent model fits at three or more of the same stations.

Variables that related strongly to flow were representative of three processes: (1) transport due to higher stage and increased stream velocity, (2) dilution by increased volume of water (from precipitation) at higher flows, and (3) biological processes. Transport mechanisms resulted in positive relations between flow and turbidity, total solids, and suspended-sediment concentration. Dilution from precipitation resulted in the inverse relations between flow and specific conductance, pH, and total silica. The decrease of pH with increasing flow probably results from the lower pH in precipitation, which causes dilution and results in reduced buffering capacity in the water. Ground-water and biological processes also contribute to the inverse relation between total silica and flow because total silica in the water column increases late in the summer (when there is less overland flow) with increasing phytoplankton (especially diatoms) in the water column. Those constituents that gave less than good model fits at three or more of the stations included temperature, total nitrate, total organic carbon, total iron, total zinc, total aluminum, total orthophosphate, total coliform, fecal coliform, fecal streptococci, and total phytoplankton.

Table 12.--Summary of best-fit discharge-concentration model regression coefficients and statistics for selected water-quality constituents at four stations in the Bull Run watershed (WY period 1978-1983)

[Q = discharge; N = number of observations]

Constituent	Model type	Regression constant	Q	Q^2	Log(Q)	$(Log(Q))^2$	Standard error of estimate[1/] (percent)	Percent of variation explained[2/]	N	Number of observations less than lower limit
Station No. 14138900 [15] North Fork Bull Run										
Daily mean values										
Specific conductance	4	99.5	--	--	-64.5	12.2	8.4	93	1794	--
Suspended-sediment concentration	2	.401	0.00620	$7.63x10^{-5}$	--	--	250	60	1823	--
Instantaneous weekly values										
Turbidity	7	.345	--	--	-1.66	.621	47	83	325	--
Color	2	2.21	.0143	$1.19x10^{-5}$	--	--	64	84	334	276
Specific conductance	4	90.9	--	--	-56.3	10.2	13	83	366	--
pH	4	8.45	--	--	-.883	.108	1.7	73	357	--
Silica, total	4	34.9	--	--	-19.5	3.15	13	83	126	--
Solids, total	4	130	--	--	-110	27.6	22	59	288	--
Suspended-sediment concentration	7	1.48	--	--	-2.75	.962	76	83	325	--
Station No. 14138850 [18] Main Stem Bull Run										
Daily mean values										
Specific conductance	4	67.6	--	--	-28.8	3.92	8.8	82	1805	--
Suspended-sediment concentration	2	3.31	-.0111	7.11	--	--	240	74	2191	--

Table 12.--Summary of best-fit discharge-concentration model regression coefficients and statistics for selected water-quality constituents at four stations in the Bull Run watershed (WY period 1978-1983)--continued

Constituent	Model type	Regression constant	Q	Q^2	Log(Q)	$(Log(Q))^2$	Standard error of estimate[1/] (percent)	Percent of variation explained[2/]	N	Number of observations less than lower limit
Station No. 14138850 [18] Main Stem Bull Run										
Instantaneous weekly values										
Turbidity	7	2.01	--	--	-2.74	0.654	29	89	314	--
Color	2	2.73	-0.000154		$1.28x10^{-6}$	--	70	72	311	270
Specific conductance	4	56.5	--	--	-20.6	2.35	9.3	82	316	--
pH	3	7.96	--	--	-.318		1.9	52	314	--
Silica, total	4	20.8	--	--	-5.80	.475	6.4	88	120	--
Aluminum, total[3/]	4	787	--	--	-765	189	77	52	20	--
Solids, total	2	26.2	-.0116	$3.83x10^{-6}$	--	--	15	68	274	--
Suspended-sediment concentration	7	3.51	--	--	-3.79	.891	59	82	315	--
Station No. 14139800 [35] South Fork Bull Run										
Daily mean values										
Temperature	4	31.5	--	--	-21.2	4.20	34	50	1723	--
Specific conductance	4	77.9	--	--	-41.4	6.97	7.3	92	1711	--
Suspended-sediment concentration	2	.609	.00214	$1.90x10^{-5}$	--	--	120	72	1817	--
Instantaneous weekly values										
Turbidity	7	0.232	--	--	-1.34	0.463	40	72	323	--
Specific conductance	4	73.8	--	--	-37.9	6.14	10	85	342	--
pH	4	8.17	--	--	-.590	.0568	1.6	68	341	--
Silica, total	4	24.9	--	--	-10.4	1.39	7.6	89	123	--
Solids, total	4	73.7	--	--	-42.7	8.77	12	68	289	--
Suspended-sediment concentration	7	1.47	--	--	-2.42	.763	66	66	311	--
Station No. 14138870 [44] Fir Creek										
Daily mean values										
Temperature	4	17.1	--	--	-12.6	3.18	30	52	2061	--
Specific conductance	4	32.1	--	--	-10.4	1.59	7.3	77	2080	--
Suspended-sediment concentration	2	1.84	-.0582	.000346	--	--	270	61	2191	--

Table 12.--Summary of best-fit discharge-concentration model regression coefficients and statistics for selected water-quality constituents at four stations in the Bull Run watershed (WY period 1978-1983)--continued

Constituent	Model type	Regression constant	Q	Q^2	Log(Q)	$(Log(Q))^2$	Standard error of estimate[1] (percent)	Percent of variation explained[2]	N	Number of observations less than lower limit
Station No. 14138870 [44] Fir Creek										
Instantaneous weekly values										
Temperature	4	16.1	--	--	-10.6	2.42	29	53	343	--
Turbidity	7	-.408	--	--	-.874	.423	41	69	322	--
Color	2	2.45	.0152	3.41×10^{-5}	--	--	69	57	313	272
Specific conductance	4	31.1	--	--	-8.79	0.895	9.5	71	341	--
Silica, total	4	14.3	--	--	-4.16	.364	7.6	84	123	--
Suspended-sediment concentration	7	.362	--	--	-1.64	.742	70	77	318	--

1/ For model types 1-5, the percent standard error of estimate is equivalent to the root mean square error divided by the mean value of the constituent; for model types 6 and 7, the percent standard error of estimate is equivalent to the root mean square error, in log units, transformed using the method given by Tasker (1978).

2/ The percent of variation explained is equivalent to the square of the multiple correlation coefficient, multiplied by 100.

3/ Regression analysis computed for the 1978-81 WY period.

Paired-basin Approach for Defining Baseline Water-quality Variability

Once baseline water-quality conditions have been adequately defined, man-related activities can be assessed within particular subbasins to determine if current water-quality concentrations exceed baseline water-quality values. Thus, man-related activities may be tested to see if they are causing significant impacts on water quality within the watershed.

The paired-basin approach for testing impacts of activities on water quality relies on the natural degree of correlation that may exist for a given water-quality constituent between paired basins that meet specific criteria of similarity (Ponce, and others, 1982). For paired basins within the Bull Run watershed, similarities in elevation, aspect (orientation), soils, vegetation, climate, and streamflow have been met. Fir Creek (station 44) represents the control basin (in which minimal man-related activities have occurred) while North Fork, Main Stem, and South Fork Bull Run represent treatment basins in which man-related activities have taken place. A period of time is selected, prior to treatment or when a minimum of activities have occurred, in which water-quality measurements (paired in time) are collected in both the pretreatment and control basins.

These paired-basin data are used in a linear regression analysis to compare the variability of each water-quality constituent in the pretreatment basin with the variability in the control basin (the regression calibrations). After the calibration period, a treatment is applied to some portion of the treated basin, while collection of water-quality data continues in both the treated and the control basins. Paired-basin data taken during the treatment period are used to define a second linear-regression line. If hydrologic conditions are similar for both periods (pretreatment and treatment periods), analysis of covariance can then be used to determine if there are statistically significant differences in the regressions developed for the two periods.

Sufficient data now exist to define regression calibrations during a period of average hydrologic variability. Regression equations of daily mean stream temperature, specific conductance, suspended-sediment concentration, and suspended-sediment load were computed for Main Stem Bull Run versus Fir Creek for the period 1978-83 WY and for North Fork and South Fork Bull Run versus Fir Creek for the 1979-83 WY period. Paired-basin regression analyses of daily mean streamflow for all the station pairs were computed for the 1978-83 WY period. After preliminary linear regression analyses, it was determined that not all of the paired-basin water-quality constituents responded in a linear manner. For those constituents not responding linearly, other regression models were used to increase the percent of variation explained and to obtain more satisfactory residual model plots.

The best-fit paired-basin models are summarized in table 13. In general, the models have good to excellent fits. With the exception of the suspended-sediment concentration models, percent of variation explained ranged from 79 to 98 percent. Because the variability of suspended-sediment concentration is quite large, especially at lower flows, these models explaining from 63 to 85 percent of the variation are still considered acceptable model fits. These best-fit models, about which prediction-confidence bands can be developed, form the basis for comparison between present and future water quality as it might be affected by changes in man-related activities.

Verification of Air-temperature Models Used to Predict Daily Stream Temperatures

The paired-basin technique assumes that all man-related activities occur only in the treatment basin, with all other factors occurring equally in both basins. Because other occurrences, such as forest fires, tree disease, or stream impoundments, could impact the control basin independently of the treatment basin, other types of water-quality models should be developed to assess the impacts of man-related or naturally occurring activities within the watershed. Because air temperature is directly relatable to basin stream temperature and is essentially independent of basin activities, it can be a useful variable in modeling stream temperature. Air temperature as measured at the Headworks was used to model stream temperatures at the four Bull Run stations.

Table 13.--Paired-basin analysis of daily-values water-quality data, Bull Run watershed, WY period 1978-1983

Water-quality constituent/model	Period of record	Number of samples	Standard error of estimate 1/ (absolute)	Variation explained 2/ (percent)
Daily mean temperature (°C) 3/				
$T15 = -1.349 + 1.606(T44) - 0.04737(T44)^2$	1979-83	1746	0.63	95
$T18 = -0.8188 + 1.190(T44)$	1978-83	1798	.60	97
$T35 = -0.3327 + 1.185(T44)$	1979-83	1668	.46	98
Daily mean streamflow (ft^3/s)				
$Q15 = 12.97 + 1.428(Q44) + 0.001892(Q44)^2$	1978-83	2191	22.1	96
$Q18 = 24.16 + 10.53(Q44)$	1978-83	2191	82.0	98
$Q35 = 14.35 + 2.640(Q44)$	1978-83	2191	27.8	96
Specific conductance (umhos/cm at 25 °C)				
$C15 = -24.32 + 2.381(C44)$	1979-83	1741	3.6	82
$C18 = -5.368 + 1.267(C44)$	1978-83	1772	2.0	79
$C35 = -14.94 + 1.915(C44)$	1979-83	1673	3.0	81
Suspended-sediment concentration (mg/L)				
$S15 = -0.9718 + 4.696(S44) - 0.04921(S44)^2$	1979-83	1823	4.8	63
$S18 = 0.02310 + 2.368(S44) - 0.002989(S44)^2$	1978-83	2191	4.0	85
$S35 = 0.1817 + 1.743(S44) - 0.01383(S44)^2$	1979-83	1817	1.7	68
Suspended-sediment load (tons/day)				
$SL15 = -0.7271 + 14.72(SL44) - 0.1223(SL44)^2$	1979-83	1823	9.3	83
$SL18 = 1.534 + 25.40(SL44) - 0.02424(SL44)^2$	1978-83	2191	45	92
$SL35 = 0.1505 + 5.457(SL44) - 0.03075(SL44)^2$	1979-83	1817	3.8	86

1/ The absolute standard error of estimate is equivalent to the root mean square error.

2/ The percent of variation explained is equivalent to the square of the multiple-correlation coefficient, multiplied by 100.

3/ T15 = daily mean temperature for North Fork Bull Run River near Multnomah Falls station; T18 = daily mean temperature for Bull Run River near Multnomah Falls station; T35 = daily mean temperature for South Fork Bull Run River near Bull Run station; and T44 = daily mean temperature for Fir Creek near Brightwood station.

A multiple-linear regression technique was used to relate air temperature at the Headworks to stream temperature. Data used for the regression analyses were from WY 1978-1981, for Main Stem Bull Run and Fir Creek, and from WY 1979-1981 for North Fork and South Fork Bull Run. These models represent the calibration time frames.

The form of the final equation used in the analysis was

$$Y = a + b_1 \text{ (TMEAN)} + b_2 \sin(BT + c)$$

where

Y = the daily maximum, minimum, or mean stream temperature, in degrees C;

TMEAN = the average of the daily maximum and minimum air temperature in degrees F;

B = a constant to convert Julian day to an angle, in radians (one day equals 2xPi divided by 365.25);

T = the Julian day of the year (January 1, T = 1);

c = the phase coefficient of the harmonic, in radians;

a = the regression constant; and

b_1, b_2 = the regression coefficients.

The phase coefficient, c, was computed simultaneously with the other coefficients by using a slightly modified form of the final equation:

$$Y = a + b_1 \text{ (TMEAN)} + S_1 \sin(BT) + S_2 \cos(BT)$$

where

$c = \arctan(|S_2/S_1|) + Pi$ (Pi was added to the computation of c since both S_1 and S_2 values were less than zero), and

$b_2 = (S_1 \times S_1 + S_2 \times S_2)^{1/2}$ (b_2 is the regression coefficient as defined for the final equation).

The model results were excellent, explaining 90 to 94 percent of the variation in the daily stream temperature (maximum, minimum, and mean) with only a 10- to 16-percent (0.8 to 1.0 degrees Celsius) range in the standard error of estimates (F. A. Rinella, unpublished data, 1984).

To verify the reliability of the models to predict daily maximum, minimum, or mean stream temperature, a dataset independent of that used to calibrate the models was used. Data from WY 1982-1983 were selected to define the model verification period. In all cases (except for minimum stream temperature at Main Stem Bull Run for WY 1982), less than 5 percent (ranging from 2.5 to 4.2 percent) of the observed stream temperatures from the verification period fell outside of the model's prediction range at 95-percent confidence. Careful inspection of the minimum temperature record for Main Stem Bull Run WY 1982 indicated the presence of erroneous data that resulted in more than 5 percent of the data falling outside of the 95-percent confidence band. Thus, the model is also useful for isolating portions of record needing additional review.

Comparison of Storm Loads and Annual Suspended-sediment Loads

Daily mean suspended-sediment concentrations and loads were computed for WY 1978-83, for the Main Stem Bull Run and Fir Creek, and for WY 1979-83, for the North Fork and South Fork Bull Run stations. Because daily mean suspended-sediment loadings were computed for the entire period of record, the frequency values listed in tables 4 to 7 represent directly the percentage of time a daily mean load was less than or equal to the value shown. This factor allows determination (in an average year during the collection period) of the fraction of time associated with a specific percentage of the annual suspended-sediment load. As shown in table 14, approximately 70 percent (62 to 78 percent) of the annual load for the basins occurred in 1 percent of the time, or about 3 to 4 days a year. Therefore, if water-quality sampling programs are not designed to sample the 3- to 4-day period each year when a majority of the annual suspended-sediment load occurs, the annual distribution and loading of suspended-sediment and related constituents could be misrepresented. Also, approximately 90 percent (85 to 94 percent) of the annual load occurred in 5 percent of the time, or roughly 18 days of the year.

Mean annual suspended-sediment yields computed (in tons/m^2/yr) for each basin indicated that the yields for the Main Stem and North Fork stations were about the same magnitude and were three times the yields computed for the South Fork and Fir Creek stations (table 14). Higher sediment yields in the North Fork basin were probably due to significant landslide activities providing readily transportable material, as noted by Beaulieu (1974), and to a higher runoff yield. Similar sediment yields for the Main Stem Bull Run basin and for North Fork basin may be reflective of comparable geology and runoff yields.

Table 14.--Percentage of the mean annual suspended-sediment load which occurred in 1, 5, and 10 percent of the time

[mi = miles; mi^2 = square miles; yr = year]

Stream	Drainage area (mi^2)	Years of record	Period of record	Mean annual load (tons/yr)	Mean annual yield ([tons/ mi^2]/yr)	Percentage of the mean annual load 1 (percent time)	5	10
Main Stem Bull Run 14138850	47.9	6	1978-83	4,510	94.2	72	92	95
Fir Creek 14138870	5.46	6	1978-83	178	32.6	78	91	94
North Fork Bull Run 14138900	8.32	5	1979-83	796	95.7	74	94	96
South Fork Bull Run 14139800	15.4	5	1979-83	484	31.4	62	85	90

TIME TREND ANALYSIS

The time-trend analysis used in this study was developed to detect trends in water-quality data. This technique is suitable for detecting time trends in water-quality datasets that have non-normal distributions, seasonality, flow-relatedness, missing values, and values below the limit of detection (Hirsch, Slack, and Smith, 1982). The analysis was applied to time-series water-quantity and -quality data, to instantaneous transport (load), and to flow-adjusted concentrations. An FAC (flow-adjusted concentration) is defined as the residual from a regression of concentration as a function of stream discharge (Smith, Hirsch, and Slack, 1982). The analysis uses three procedures: (1) a modified form of Kendall's tau, called the seasonal Kendall, for the trend test; (2) the seasonal Kendall slope indicator, for estimating the magnitude of the trend; and (3) computation of the seasonal Kendall test on the flow-adjusted concentrations. The seasonal Kendall trend test has been adapted for use with SAS, a proprietary Statistical Analysis System (Crawford, Slack, and Hirsch, 1983).

The seven model types used to flow-adjust concentration for this analysis are given in the section titled "Significant Discharge Water-quality Constituent Relations." Choice of the discharge-concentration model best suited for each water-quality characteristic was based on which model type had coefficients significant at the 90-percent or greater confidence level, which yielded the largest correlation coefficient, and which had regression residual plots that appeared random. If none of the first seven model types met the above criteria, a median concentration was used to maintain continuity (although it does not represent an actual flow adjustment of the constituent value).

Data for the trend analysis had to pass three acceptance criteria in order to be used: (1) the number of observations for a particular water-quality constituent had to be greater than 19; (2) if the total number of observations for a constituent was near 20, the number of "less than" value observations could not exceed 20 percent; and (3) the distribution of the water-quality constituent had to be spatially and hydrologically representative of the period of interest (as a rule, a minimum of 3 to 4 years of data collection were needed). With these criteria, the number of water-quality constituents used in this trend analysis was considerably reduced from those discussed in the water-quality characteristics section.

Summary Statistics

The seasonal Kendall trend test was run using 12 seasons per year. In this analysis the median value for a particular constituent was computed for each season and tested for a monotonic trend in time, using a modified form of Kendall's tau. In this modified Kendall's tau, only median values from the same season for different years are compared; using 12 seasons per year (monthly intervals), January data of one year are compared with January data of another year, and so on through the 12 monthly intervals. The seasonal Kendall test results for the daily mean observations are summarized in tables 15 and 16. The seasonal Kendall test results for the weekly observations are listed in table 17. The median concentration units shown in the tables are the same units as expressed in tables 4 to 7, except that observations of "less than" values were set equal to one-half of the lower detection limit.

Table 15.--Summary of monthly seasonal Kendall trend analysis on daily mean concentrations and loads in the Bull Run watershed

[Water years 1978-1983 for station numbers 14138850 and 14138870; Water Years 1979-1983 for station numbers 14138900 and 14139800; N = Number of observations; FAC = flow-adjusted concentration; * indicates those trends in which the P-level is less than or equal to 0.100]

Station number and name	Constituent	N	Median value	Concentration		Transport		FAC		Discharge model	
				P-level	Slope 1/	P-level	Slope 1/	P-level	Slope 1/	Type 2/	R-squared 3/
14138850	Temperature	1871	6.5	0.420	-0.05	--	--	0.492	0.05	4	40
[18]	Discharge	2191	245	.116	5.8	--	--	--	--	--	--
Main Stem	Conductance	1805	21	.248	-.1	--	--	.770	-.0	4	82
Bull Run	Sediment conc.	2191	1.0	.764	.00	--	--	.212	.14	2	74
	Sediment load	2191	.56	--	--	0.203	0.04	--	--	--	--
14138870	Temperature	2061	6.3	.327	-.06	--	--	.957	.01	4	52
[44]	Discharge	2191	21.2	.416	.56	--	--	--	--	--	--
Fir	Conductance	2080	21	.021*	-.2	--	--	.255	-.1	4	77
Creek	Sediment conc.	2191	.0	.480	-.00	--	--	.587	-.01	2	61
	Sediment load	2191	.0	--	--	.584	-.00	--	--	--	--
14138900	Temperature	1801	6.9	.136	.08	--	--	.001*	.30	4	37
[15]	Discharge	2191	43.0	.014*	1.9	--	--	--	--	--	--
North	Conductance	1794	26	.000*	-1.0	--	--	.777	-.1	4	93
Fork	Sediment conc.	1823	1.0	.244	.00	--	--	.619	-.01	2	60
Bull Run	Sediment load	1823	.08	--	--	.249	.00	--	--	--	--
14139800	Temperature	1723	7.0	.522	.10	--	--	.002*	.33	4	50
[35]	Discharge	2191	70.0	.587	.92	--	--	--	--	--	--
South	Conductance	1711	25	.165	-.4	--	--	.525	-.1	4	92
Fork	Sediment conc.	1817	1.0	.122	.00	--	--	.179	-.03	2	72
Bull Run	Sediment load	1817	.09	--	--	.074*	-.01	--	--	--	--

1/ The median of the differences (in concentration units) per year of the ordered pairs of observations or residuals (as in the FAC test).

2/ See text under "Significant Discharge Water-Quality Constituent Relations" for model type designations.

3/ R-squared is the square of the correlation coefficient multiplied by 100 (percent of variation explained).

Results that yielded P-levels less than 0.10 were considered significant, and results that yielded P-levels less than 0.05 were considered highly significant. Using a P-level of less than 0.10 to indicate significant differences should not be considered an inflexible rule, but should be tempered with a willingness to reject the null hypothesis with a slightly larger chance of being incorrect in interpreting a particular constituent trend. For instance, a rejection P-level of 0.11 should not be considered necessarily different from a P-level of 0.10 in this analysis. The seasonal Kendall slope indicator represents the median of the differences in concentration units per year of the ordered pairs of observations or residuals (as in the FAC test). A positive seasonal Kendall slope indicator is indicative of an increasing trend over the period of interest, whereas the opposite is true with a negative seasonal Kendall slope indicator.

Although at first inspection the magnitudes of most of the positive seasonal Kendall slope indicators do not seem large, over a much longer period of time they could represent important increases.

Table 16.--Summary of monthly seasonal Kendall trend analysis on the climatologically adjusted daily mean stream temperature in the Bull Run watershed

[Water years 1978-1983 for station numbers 14138850 and 14138870; water years 1979-1983 for station numbers 14138900 and 14139800; N = number of observations; * indicates those trends in which the value of the P-level is less than or equal to 0.100]

Station name and number	N	Median value	Residual trend P-level	Residual trend Slope[1]	Climatological model[2] variation explained[3]
Main Stem 14138850 [18]	1868	6.5	0.002*	-0.09	93
Fir Creek 14138870 [44]	2056	6.3	.626	-.04	91
North Fork 14138900 [15]	1799	6.9	.013*	.09	94
South Fork 14139800 [35]	1721	7.0	.437	.07	92

[1] The median of the differences (in °C) per year of the ordered pair of residuals.
[2] $Y = a + b_1 \text{ (TMEAN)} + b_2 \sin \text{ (BT + C)}$
[3] Variation explained is the square of the correlation coefficient multiplied by 100.

The seasonal Kendall trend test is a statistical tool that assigns a probability level to the occurrence of a trend for each constituent-value time series. It should be understood that when a probability level of 0.10 is assigned to a constituent trend, there is a one-in-ten chance of rejecting a correct hypothesis that no trend is present. The Seasonal Kendall trend test should therefore be treated similarly to other statistical tests in that they represent statistical inferences regarding populations. The statistical statements can be precise, but the hydrologic significance and interpretation require careful thought and insight into the system's operation.

Table 17.--Summary of monthly seasonal Kendall trend analysis on the instantaneous weekly concentrations and loads in the Bull Run watershed, for the WY period 1978-1983

[N = number of observations; FAC = flow-adjusted concentration; * indicates those trends in which the value of the P-level is less than or equal to 0.100]

Station number and name	Constituent	N	Median value 1/	Concentration P-level	Concentration Slope 2/	Transport P-level	Transport Slope 2/	FAC P-level	FAC Slope 2/	Discharge model Type 3/	Discharge model R-squared 4/
14138900	Temperature	349	7.0	0.741	0.00	--	--	0.255	0.12	4	39
[15]	Discharge	368	43.0	.303	.69	--	--	--	--	--	--
North Fork	Turbidity	325	.20	.000*	.020	--	--	.000*	.018	7	83
Bull Run	Color	334	2.5	.374	-.00	--	--	.011*	-.02	2	84
	Conductance	366	26	.380	.3	--	--	.015*	.6	4	83
	pH	357	7.3	.402	.00	--	--	.045*	.02	4	73
	Nitrate as N, total	130	.03	.031*	.001	--	--	.016*	.002	5	49
	Organic carbon, total	90	1.1	.126	.03	--	--	.157	.03	3	45
	Silica, total	126	10.7	.726	.07	--	--	.004*	.16	4	83
	Iron, total 5/	22	27	1.000	28.0	--	--	1.000	28.00	median	--
	Zinc, total 5/	22	4.0	.683	2.75	--	--	.683	2.75	median	--
	Aluminum, total 5/	19	36	.023*	70.0	--	--	.023*	70.0	median	--
	Solids, total	288	26.2	.503	-.38	--	--	.361	.24	4	59
	Orthophosphorus as P, total	122	.007	.008*	-.0005	--	--	.012*	-.0004	5	37
	Suspended-sediment										
	Concentration	326	.4	.049*	.02	--	--	.034*	.02	7	83
	Load	326	--	--	--	0.212	0.00	--	--	--	--
	Coliform, total	308	2	.011*	-.4	--	--	.003*	-.2	2	6.5
	Coliform, fecal	306	1	.378	.0	--	--	.074*	.2	2	10
	Streptococci, fecal	304	1	.861	.0	--	--	.957	-.0	4	1.2
	Phytoplankton, total	276	70	.121	4.6	--	--	.551	3.1	3	2.9
14138850	Temperature	315	6.4	.444	-.04	--	--	.212	.11	4	45
[18]	Discharge	330	250	.175	6.0	--	--	--	--	--	--
Main Stem	Turbidity	314	.19	.002*	.010	--	--	.000*	.013	7	89
Bull Run	Color	311	2.5	1.000	-.00	--	--	.175	-.00	2	72
	Conductance	316	20	.102*	.3	--	--	.000*	.4	4	82
	pH	314	7.2	.052*	.00	--	--	.002*	.01	3	52
	Nitrate as N, total	126	.04	.038*	-.002	--	--	.052*	-.002	3	3.0
	Organic carbon, total	89	1.0	.804	-.01	--	--	.869	.01	2	44
	Silica, total	120	9.4	.143	.11	--	--	.000*	.18	4	88
	Iron, total 5/	20	23	.198	6.0	--	--	1.000	5.4	1	46
	Zinc, total 5/	20	4.0	.734	2.25	--	--	.198	1.91	4	44
	Aluminum, total 5/	20	43	.198	47.0	--	--	.198	29.8	4	52
	Solids, total	274	22.7	.715	-.07	--	--	.855	.07	2	68
	Orthophosphorus as P, total	122	.0015	.796	.0000	--	--	.892	.0000	median	--
	Suspended-sediment										
	Concentration	316	.4	.295	-.06	--	--	.626	-.00	7	82
	Load	316	--	--	--	0.786	0.00	--	--	--	--

Table 17.--Summary of monthly seasonal Kendall trend analysis on the instantaneous weekly concentrations and loads in the Bull Run watershed, for the WY period 1978-1983--continued

Station number and name	Constituent	N	Median value[1]	Concentration		Transport		FAC		Discharge model	
				P-level	Slope[2]	P-level	Slope[2]	P-level	Slope[2]	Type[3]	R-squared[4]
14138850	Coliform, total	305	4	.062*	-.5	--	--	.158	-.4	4	2.2
[18]	Coliform, fecal	304	2	.018*	.2	--	--	.003*	.2	4	2.4
Main Stem	Streptococci, fecal	302	2	.526	.0	--	--	.143	.2	4	13
Bull Run	Phytoplankton, total	275	119	1.000	1.4	--	--	.284	8.9	5	18
14139800	Temperature	348	7.5	.956	.00	--	--	.255	.08	4	48
[35]	Discharge	348	65.1	.957	-.48	--	--	--	--	--	--
South Fork	Turbidity	323	.24	.000*	.020	--	--	.000*	.025	7	72
Bull Run	Color	319	2.5	.119	.00	--	--	.481	-.01	2	39
	Conductance	342	24	.055*	.5	--	--	.002*	.4	4	85
	pH	341	7.3	.024*	.01	--	--	.034*	.01	4	68
	Nitrate as N, total	131	.03	.597	.000	--	--	.638	.000	median	--
	Organic carbon, total	92	1.1	1.000	-.00	--	--	.568	-.01	2	24
	Silica, total	123	10.5	.037*	.24	--	--	.003*	.20	4	89
	Iron, total[5]	22	40	.358	5.0	--	--	.759	--	4	38
	Zinc, total[5]	21	1.5	.734	.75	--	--	1.000	--	4	22
	Aluminum, total[5]	21	62	0.126	43.5	--	--	0.126	--	median	--
	Solids, total	289	25.6	.626	-.08	--	--	.301	.17	4	68
	Orthophosphorus as P, total	123	.0015	1.000	.0000	--	--	.695	.0000	median	--
	Suspended-sediment										
	Concentration	311	.5	.062*	.03	--	--	.015*	.04	7	66
	Load	311	--	--	--	0.255	0.00	--	--	--	--
	Coliform, total	304	4	.000*	-.9	--	--	.001*	-.8	4	2.4
	Coliform, fecal	301	1	.312	.0	--	--	.255	.0	4	1.0
	Streptococci, fecal	298	1	.710	.0	--	--	.481	.1	4	14
	Phytoplankton, total	278	75	.551	1.8	--	--	.057*	4.0	4	6.1
14138870	Temperature	343	7.0	.785	.01	--	--	.255	.07	4	53
[44]	Discharge	366	21.6	.957	-.12	--	--	--	--	--	--
Fir Creek	Turbidity	322	.18	.000*	.025	--	--	.000*	.028	7	69
	Color	313	2.5	.180	-.00	--	--	.416	-.01	2	57
	Conductance	341	21	.055*	.4	--	--	.001*	.3	4	71
	pH	335	7.2	.000*	.02	--	--	.000*	.02	4	43
	Nitrate as N, total	127	.04	.954	-.000	--	--	1.000	-.000	5	2.7
	Organic carbon, total	87	0.9	.727	-.01	--	--	1.000	-.00	4	19
	Silica, total	123	9.3	.061*	.07	--	--	.004*	.13	4	84
	Iron, total[5]	21	17	.308	1.0	--	--	1.000	.8	4	29
	Zinc, total[5]	20	2.0	.734	2.75	--	--	1.000	.29	4	22
	Aluminum, total[5]	20	31	.198	39.0	--	--	.198	25.3	1	15
	Solids, total	279	21.9	.903	.01	--	--	.162	.15	4	43
	Orthophosphorus as P, total	125	.003	.486	-.0000	--	--	.683	-.0000	1	5.9

Table 17.--Summary of monthly seasonal Kendall trend analysis on the instantaneous weekly concentrations and loads in the Bull Run watershed, for the WY period 1978-1983--continued

Station number and name	Constituent	N	Median value 1/	Concentration P-level	Concentration Slope 2/	Transport P-level	Transport Slope 2/	FAC P-level	FAC Slope 2/	Discharge model Type 3/	Discharge model R-squared 4/
14138870	Suspended-sediment										
[44]	Concentration	318	0.4	0.098*	0.02	--	--	0.116	0.01	7	77
Fir Creek	Load	318	--	--	--	0.357	0.00	--	--	--	--
	Coliform, total	302	4	.000*	-1.0	--	--	.000*	-1.0	4	5.6
	Coliform, fecal	298	1	.805	.0	--	--	.212	.0	4	2.9
	Streptococci, fecal	295	1	.590	.0	--	--	.481	.1	4	17
	Phytoplankton, total	275	51	.003*	4.0	--	--	.001*	4.2	5	1.3

1/ Calculated with "less than" values set equal to half of its lower detection limit.

2/ The median of the differences (in concentration units) per year of the ordered pairs of observations or residuals (as in the FAC test).

3/ See test under "Time Trend Analysis" for model type designations.

4/ R-squared is the square of the correlation coefficient multiplied by 100 (percent of variation explained).

5/ Trend analysis for this constituent was computed for the WY period 1978-1981 since a sampling frequency change for WY 1982-1983 negates usage of the entire period.

Daily Mean Values

Temperature

No trends were observed in the unadjusted daily mean stream temperature, but when stream temperatures were flow-adjusted, North Fork and South Fork Bull Run showed highly significant positive trends of 0.3 degrees Celsius per year (table 15). Because the FAC temperature trends reflect the subtraction of only the hydrologically controlled portion of stream temperature, and not necessarily other climatic relations such as incident solar radiation or air temperature, an alternative adjustment to stream temperature was used. The climatic model presented earlier, which was designed to predict daily mean stream temperature using the average air temperature at the Headworks, was used to subtract that component of stream temperature that is due to climatic conditions. Table 16 contains the Seasonal Kendall trend test results as computed on these adjusted stream temperatures. The results of the FAC temperature-trend analysis (table 15) cannot be directly compared to the adjusted climatic-model temperature-trend analysis (table 16), because each adjustment represents subtraction of different components. Conceptually, the results in table 16 show more precisely the effect of long-term changes in air temperature on stream temperature. The relative importance of the secondary component (streamflow) is not known at this time. Results shown in table 16 indicate that effects other than those from air temperature are causing a net decrease of approximately 0.1 degree Celsius per year in stream temperature for Main Stem Bull Run and a net increase of about 0.1 degree Celsius per year in stream temperature for North Fork Bull Run.

Streamflow

For North Fork Bull Run, the seasonal Kendall trend test indicates that there is a highly significant net increase of about 1.9 ft^3/s per year in the streamflow; none of the other stations showed any trends in daily mean streamflow.

Specific Conductance

Fir Creek and North Fork Bull Run showed highly significant decreases in specific conductance of 0.2 and 1.0 micromhos per year, respectively. When specific conductances for these two stations were flow adjusted, the trends disappeared. The decrease in specific conductance and increase in streamflow for the North Fork Bull Run tend to confirm one another.

Suspended-sediment Concentration and Load

No significant trends were observed in the suspended-sediment concentration or load for the Bull Run stations, except for the suspended-sediment load for South Fork Bull Run. Although the trend for the suspended-sediment load for South Fork Bull Run is statistically significant, the yearly slope indicator of -0.01 tons per year (-0.05 tons for 5 years) cannot be measured.

Periodic Observations

Out of a large list of chemical constituents measured by the Water Bureau at the four key sampling stations on a weekly, monthly or quarterly basis (tables 4 through 7), 20 water-quality constituents were found suitable for the trend test. Of the 20 constituents, eight (stream temperature, streamflow, total organic carbon, total iron, total zinc, total solids, suspended-sediment load and fecal streptococci bacteria) had no significant trends at the four stations for the WY period 1978-1983. The remaining 12 coefficients (table 17) have significant trends and were grouped for discussion as follows: (1) physical, (2) metal, (3) plant nutrients, and (4) biological constituents.

Physical Characteristics

Five physical water-quality constituents had significant trends: (1) turbidity, (2) color, (3) specific conductance, (4) pH, and (5) suspended-sediment concentration.

Increasing trends for turbidity were found at the four stations. After flow adjustment of the turbidity data, all four stations still showed increasing trends. The average FAC slope indicator for these stations was 0.021 NTU (Nephelometric Turbidity Units) per year, which would be equivalent to a 0.126-NTU increase in turbidity values over the 6-year time frame. Suspended-sediment concentration showed significant increasing trends for three of the four sites, but the P-levels were not nearly as low as those for the turbidity trends. After suspended-sediment concentrations were flow-adjusted, only North Fork Bull Run and South Fork Bull Run showed highly significant increasing trends of about 0.03 mg/L (milligrams per liter) per year, which translated to a 0.18-mg/L increase during the 6 years.

Both specific conductance and pH showed similar significantly increasing trends, with only North Fork Bull Run having no significant trends for either constituent. When both constituents were flow adjusted, highly significant increasing trends emerged at all the stations. The flow-adjusted concentration slope indicator for specific conductance averaged 0.4 μmhos/cm (micromhos per centimeter) for the four stations, or about 2.4 μmhos/cm for the 6-year timeframe; pH increases averaged about 0.02 pH units/year or about 0.12-pH units over 6 years. An increase of 2.4 μmhos/cm in specific conductance values over 6 years or a 0.12-pH-unit rise in station pH values over the same period cannot be easily measured.

No water-quality trends were observed for color, but when color values were flow adjusted, North Fork Bull Run showed a significantly decreasing trend (-0.02 platinum cobalt units per year). The magnitude of the color FAC slope indicator for North Fork Bull Run is not easily measurable, when considering the small changes that this slope represents in the constituent over the period.

Metals

Seasonal Kendall trend analyses were computed only on total iron, total zinc, and total aluminum concentrations, because only these three metals met the minimum criteria of 19-20 measurements with less than 20 percent having values below the lower limit of detection. Because the sampling frequency for WY 1978-81 had been either monthly or bimonthly, while the data for the 1982-1983 WY period consisted of one measurement per year, only data from the 1978-1981 WY period was used for the trends test. Metal trend analysis on the 1978-1981 WY period indicated no trends, except for North Fork Bull Run, which showed a highly significant increasing trend of 70 μg/L (micrograms per liter) per year for aluminum. No significant relation between streamflow and aluminum concentration was found at North Fork Bull Run, so no FAC trend analysis was made. Because the 70-μg/L per year increase in aluminum concentration was found over a very short time period (calendar years 1979 and 1980), the aluminum trend for the North Fork Bull Run station was not considered reliable. In order to verify the reliability of the aluminum trend for the North Fork Bull Run station, an additional 3 or 4 years of monthly or bimonthly aluminum data collection (beyond Water Years 1982 and 1983) would be needed.

Plant Nutrients

Total nitrate as N, orthophosphorus as PO_4, and silica as SiO_2 concentrations were used in the seasonal Kendall trend test. The total nitrate trends test indicated mixed results, with Main Stem Bull Run showing a highly significant decreasing trend of -0.002 mg/L per year, while North Fork Bull Run showed a highly significant increasing trend of 0.001 mg/L per year. Seasonal Kendall trend analysis on FAC total nitrate yielded similar results. In either case, the absolute change in the FAC total nitrate slope indicator at these two stations over the 6-year time frame amounts to only about a 0.01-mg/L concentration change, an amount extremely difficult to measure. Trend analysis on total orthophosphorus for North Fork Bull Run resulted in highly significant decreasing concentration and FAC trends of -0.0005 mg/L and -0.0004 mg/L per year, respectively. The FAC slope indicator of -0.0004 mg/L per year amounts to a fractional decrease of -0.0024 mg/L in total orthophosphorus concentration for the 6-year period.

Trend analysis on silica concentration showed a significant increasing trend for Fir Creek, with 0.07 mg/L per year, and for South Fork Bull Run, with 0.24 mg/L per year. When silica concentrations were flow adjusted, highly significant increasing trends were identified for all four stations. Average FAC slope indicator for silica at the four stations was 0.17 mg/L per year, which translates to about 1.02 mg/L of increase in silica concentration during the 6-year timeframe.

Biological Constituents

Trend analyses of total coliform bacteria data indicated highly significant decreasing trends, with slope indicators ranging from -0.4 to -1.0 colonies/100 ml (colonies per hundred milliliters) per year for all four stations. When total coliform counts were flow adjusted, highly significant decreasing trends were observed at Fir Creek and at both North and South Forks Bull Run, with an average FAC slope indicator of about -0.7 colonies/100 ml per year. Trend analysis on fecal coliform bacteria gave only highly significant increasing concentration and FAC trends for Main Stem Bull Run and only significant increasing FAC trends for North Fork Bull Run. The average fecal coliform bacteria FAC slope indicator for Main Stem and North Fork Bull Run was 0.2 colonies/100 ml per year, or about 1.2 colonies/100 ml for 6 years. Seasonal Kendall trend analysis on total phytoplankton counts indicated highly significant increasing trends for Fir Creek. Significant trends emerged for Fir Creek and South Fork Bull Run, when the algal counts were flow adjusted. Average total phytoplankton FAC slope indicator for both stations was about 4 cells/100 ml per year, or about 24 cells/100 ml of increase in algal concentrations over the 6 years.

Conclusions of the Kendall Trend Analyses

For the development of water-quality standards, data that have produced statistically significant increasing trends (with the possible exceptions of streamflow and pH) deserve the most attention. Those water-quality constituents having statistically significant increasing trends should be divided also into two groups: those constituent trends that can be analytically and reliably measured and those that cannot. Interpretation of trends for cause-and-effect relations (causes other than those related to flow or climate) involves explaining those trends characterized by the flow adjusted constituent values. In general, the following constituents exhibit increasing trends, after FAC, at some or all of the Bull Run stations: (1) daily mean streamflow and temperature and (2) periodic measurements of turbidity, specific conductance, pH, total nitrate, silica, total aluminum, suspended-sediment, fecal coliform, and phytoplankton.

North Fork Bull Run exhibited a highly significant increasing trend in streamflow, which might be related to basin orientation, but is most likely related to the short duration of the study period (an insufficient size database). Using the climatically adjusted stream-temperature values also results in a slight increase in stream temperature at North Fork at a rate of 0.1 degree Celsius per year, or about 0.5 degree Celsius over the 5-year period.

Of the nine periodic water-quality constituents exhibiting significant increasing trends, only four constituents (turbidity, specific conductance, silica, and phytoplankton) have slope indicators that may be large enough to exhibit analytically measureable trends after 6 years.

Aluminum concentration, although showing a significant increasing trend for North Fork Bull Run, was eliminated from the above list because the trend occurred only over 2 calendar years (1979 and 1980) for which data were available. The turbidity, specific conductance, and silica increases might be related to erosional phenomena, occurring either within the channel or on land, while the algal increases might be a response to nutrient buildup as a result of the erosional phenomena. However, these weekly trends were not confirmed by the trend analysis made on the daily mean values. The seasonal Kendall trend analysis computed on the flow-adjusted daily mean specific-conductance and suspended-sediment values at all four stations indicated no trends. At this time, the author is more inclined to accept the trend findings based on daily values over those computed on the weekly observations, because the daily values represent a more continuous database.

MULTIPLE-LINEAR REGRESSION ANALYSIS

The multiple-linear regression technique was used to relate selected stream water-quantity and -quality characteristics to possible sources and processes affecting those characteristics in the Bull Run watershed. It also may be used as a method for extending or "filling in" stream water-quantity and -quality records at the four Bull Run stations. These sources and processes, collectively called basin characteristics, fall into categories of climate, land use, topography, geology, soils, and other miscellaneous factors. Because in several of the multiple-linear regression models, certain water-quality characteristics have been used as basin characteristics in other models, the reader may be tempted to use the results of certain regression models as inputs to other regression models. This might be especially tempting if one were trying to make an estimate at an ungaged site. The estimating of information in this manner would be an inappropriate use of these models because of the problems that result from cascading regressions (the compounding of predictive errors when using models in this manner).

A generalized form of the multiple-linear regression equation is

$$Y = a + b_1 X_1 + b_2 X_2 + \ldots + b_n X_n \qquad (1)$$

where

Y = the water-quality characteristic for a particular station and year;
the X's = various basin characteristics (some characteristics are constant over time, while others change from one year to another);
a = a regression constant;
the b's = regression coefficients; and
n = the number of basin characteristics used in the regression model.

Because equation 1 gave good to excellent definition of the variability of each water-quality characteristic used for this study, no data transformations were needed.

A system of statistical computer programs utilizing SAS was chosen to select basin characteristics and to calculate various regression coefficients and constants for each regression model (SAS Institute, 1979). As an initial step in the regression analysis, SAS was used to generate a coefficient matrix of bivariate cross-correlation between the water-quantity or -quality and basin characteristics.

The matrix was used as an initial guide in the selection of basin characteristics for each regression model. Various SAS stepwise regression procedures were used with different combinations of basin characteristics to derive the best regression model for each water-quality characteristic (table 18). The ranges of values observed in the water-quality and basin characteristics are shown in table 19, as is a list of selected bivariate correlations that are needed to assess the interpretive value of the regressions.

The final selection of basin characteristics for each regression equation was made using the following criteria:

(1) The coefficient of each basin characteristic must be statistically significant at the 95-percent level of confidence or higher as measured by the F-test.

(2) The selected combination of basin characteristics should explain the greatest percent variation of the water-quality characteristic and have the lowest percentage standard error of estimate.

(3) Cross correlations between combinations of basin characteristics in a particular regression should be minimized (correlation coefficients should be 0.6 or less, where possible).

(4) Basin characteristics and the accompanying coefficients should be conceptually realistic in order to better understand cause-and-effect relations. Surrogate variables are sometimes necessary when a particular basin characteristic cannot be defined directly.

Water-quality Characteristics

The 12 water-quality characteristics for which regression equations were created are:

(1) Annual discharge (ANNUALQ): The sum over a year of the daily mean streamflows, in ft^3/s.

(2) Annual discharge yield (Q_SM): The ANNUALQ divided by the station's drainage area (AREA), in $ft^3/s/mi^2$.

(3) Annual maximum instantaneous discharge (QPEAK): The yearly instantaneous peak streamflow, in ft^3/s.

(4) Annual maximum instantaneous discharge yield (QPEAK_SM): The QPEAK divided by the station's drainage area (AREA), in $ft^3/s/mi^2$.

(5) Annual minimum instantaneous discharge (QMIN): The yearly instantaneous minimum streamflow, in ft^3/s.

(6) Annual minimum instantaneous discharge yield (QMIN_SM): The QMIN divided by the station's drainage area (AREA), in $ft^3/s/mi^2$.

(7) Annual suspended-sediment load computed using complete sediment concentration and discharge records at each of the four Bull Run stations (SEDLOAD): The sum over a year of the daily suspended-sediment load, in tons.

Table 18.--Results of multiple-linear regression analysis, Bull Run watershed, for WY 1978-83

[N = number of observations]

Water-quality characteristic[1/,2/]	Regression coefficient, b's[2/] (Basin characteristics, X's)[1/,2/]	Regression constant[2/]	Standard error of estimate (percent)[3/]	Percent of variation explained (percent)[4/]	N
ANNUALQ - annual discharge, in ft^3/s	$3.18x10^3$(AREA)$3.36x10^2$(PRECIP)	$-5.03x10^4$	16	99	24
Q_SM - annual discharge yield, in $(ft^3/s)/mi^2$	$7.46x10^3$(DDI)$1.76x10^1$(PRECIP)$-1.70x10^3$(STORAGE)$1.66x10^2$(I24)	$-1.01x10^4$	6.0	89	24
QPEAK - annual maximum instantaneous discharge, in ft^3/s	$1.20x10^2$(AREA)$8.38x10^2$(I24)$6.31x10^1$(MINJAN)	$-4.65x10^3$	26	93	24
QPEAK_SM - annual maximum instantaneous discharge yield, in $(ft^3/s)/mi^2$	$2.42x10^{-1}$(Q_SM)$-1.43x10^2$(STORAGE)-3.66(PRECIP)-5.02(F)	$1.62x10^2$	28	72	24
QMIN - annual minimum instantaneous discharge, in ft^3/s	$9.79x10^{-1}$(AREA)3.45(I24)1.42(PART_4)	$-1.58x10^1$	26	94	24
QMIN_SM - annual minimum instantaneous discharge yield, in $(ft^3/s)/mi^2$	$4.74x10^{-4}$(Q_SM)$1.17x10^{-1}$(OPENAREA)$5.11x10^{-2}$(PART_4)	$-5.74x10^{-1}$	13	93	24
SEDCONC - annual discharge-weighted suspended-sediment concentration, in mg/L	$9.90x10^{-2}$(QPEAK_SM)$3.42x10^{-1}$(COLUMBIA)	-7.16	48	70	22
SEDLOAD - annual suspended-sediment load, in tons	2.18(QPEAK)$-1.71x10^2$(AREA)	$-6.47x10^2$	60	89	22
SEDYLD - annual suspended-sediment yield, in $tons/mi^2$	$8.70x10^{-1}$(QPEAK_SM)3.47(COLUMBIA)	$-7.24x10^1$	52	72	22
CONDCONC - annual discharge-weighted specific conductance as equivalent dissolved-solids concentration, in mg/L	$-2.40x10^{-2}$(PRECIP)$-6.61x10^{-3}$(BSLOPE)$-9.33x10^{-1}$(I24)1.34(CLEAR)	$3.62x10^1$	3.5	86	22

Table 18.--Results of multiple-linear regression analysis, Bull Run watershed, Oregon for WY 1978-83--continued

Water-quality characteristic[1/,2/]	Regression coefficient, b's[2/] (Basin characteristic, X's)[1/,2/]	Regression constant[2/]	Standard error of estimate (percent)[3/]	Percent of variation explained (percent)[4/]	N
CONDLOAD - annual specific conductance as equivalent dissolved-solids load, in tons	$1.54x10^{2}$(AREA)$1.16x10^{1}$(PRECIP)	$-1.65x10^{-3}$	9.6	99	22
CONYLD - annual specific conductance as equivalent dissolved-solids yield, in tons/mi^{2}	-2.74(D)$7.12x10^{-1}$(PRECIP)$4.72x10^{-1}$(AREA)	$7.20x10^{1}$	4.4	93	22

1/The water-quality and basin characteristic acronyms are defined in sections entitled "Water-Quality Characteristics" and "Basin Characteristics."

2/According to equation, $Y = a + b_1X_1 + b_2X_2 +...+ b_nX_n$.

3/The standard error of estimate, in percent, is equivalent to the root mean square error divided by the mean of Y, multiplied by 100.

4/The percentage of variation explained is equivalent to the square of the multiple-correlation coefficient, multiplied by 100.

(8) Annual discharge-weighted suspended-sediment concentration (SEDCONC): The sum over a year of the daily suspended-sediment load (SEDLOAD) divided by the annual discharge (ANNUALQ), in mg/L.

(9) Annual suspended-sediment yield (SEDYLD): The SEDLOAD divided by the station's drainage area (AREA), in tons/mi^2.

(10) Annual specific conductance as equivalent dissolved-solids load (CONDLOAD): The sum over a year of specific conductance as equivalent to the daily dissolved-solids load, in tons. (See section titled, "Specific Conductance" for method of computation.)

(11) Annual discharge-weighted specific conductance as equivalent dissolved-solids concentration (CONDCONC): The sum over a year of daily specific conductance as equivalent dissolved-solids load (CONDLOAD) divided by the annual discharge (ANNUALQ), in mg/L.

(12) Annual specific conductance as equivalent dissolved-solids yield (CONYLD): The CONDLOAD divided by the station's drainage area (AREA), in tons/mi^2.

Table 19.--Maximum and minimum observed water-quality and basin characteristics with selected bivariate correlation coefficients for WY period 1978-1983

Water-quality characteristic[1]			Basin characteristics[1/2]				Basin-characteristic pair bivariate correction coefficient[3]
Minimum	Maximum	Mean	minimum-maximum				
	ANNUALQ		AREA	PRECIP			
11,100	164,000	56,000	5.46-47.9	100-168			
	Q_SM		DDI	PRECIP	STORAGE	I24	DDI-STORAGE
2,040	3,690	2,780	1.32-1.71	100-168	0.2-1.5	2.8-4.9	0.97
	QPEAK		AREA	I24	MINJAN		
391	8,510	2,600	5.46-47.9	2.8-4.9	15.7-32.3		
	QPEAK_SM		Q_SM	STORAGE	PRECIP	F	
64.5	383	145	2,040-3,690	0.2-1.5	100-168	10.6-36.6	
	QMIN		AREA	I24	PART_4		
1.4	63	18	5.46-47.9	2.8-4.9	0.0-7.2		
	QMIN_SM		Q_SM	OPENAREA	PART_4		
.35	1.92	.94	2,040-3,690	0.1-3.7	0.0-7.2		
	SEDCONC		QPEAK_SM	COLUMBIA			
1.0	27.8	8.0	64.5-383	0.1-15.6			
	SEDLOAD		QPEAK	AREA			QPEAK-AREA
32.8	11,900	1,570	391-8,510	5.46-47.9			.92
	SEDYLD		QPEAK_SM	COLUMBIA			
6.0	249	63.5	64.5-383	0.1-15.6			
	CONDCONC		PRECIP	BSLOPE	I24	CLEAR	
17.7	22.7	19.7	100-168	1,330-1,670	2.8-4.9	0.0-1.3	
	CONDLOAD		AREA	PRECIP			
595	7,950	2,960	5.46-47.9	100-168			
	CONDYLD		D	PRECIP	AREA		
109	196	145	2.2-20.5	100-168	5.46-47.9		

1/Defined in sections entitled "Water-quality Characteristics" and "Basin Characteristics."

2/The order in which the basin characteristics are listed corresponds to the decreasing amount of variation in the water-quality characteristic explained.

3/Only those correlation coefficients greater than the absolute value of 0.6 are shown.

The water-quality characteristics used in the regression models are summarized in table 20. For WY 1978, the suspended-sediment and specific-conductance characteristics were not computed for the North Fork and South Fork Bull Run, because these stations became operational for water quality in WY 1979.

Table 20.--Summary of the annual water-quality characteristics used in the multiple-linear regression analysis in the Bull Run watershed for the WY period 1978-1983

[See Glossary of Terms Used in Regression Analysis for water-quality definitions and units of measurement]

Station number	Water year	ANNUALQ[1/]	Q_SM[1/]	QPEAK[1/]	QPEAK_SM[1]	QMIN[1/]	QMIN_SM[1/]	SEDCONC	SEDLOAD	SEDYLD	CONDCONC	CONDLOAD	CONDYLD
14138850	1978	159,000	3,320	8,510	178	52	1.09	27.8	11,900	249	17.7	7,620	159
	1979	125,000	2,600	5,570	116	41	.86	4.7	1,580	32.9	18.8	6,320	132
	1980	132,000	2,750	4,320	90	36	.75	3.1	1,120	23.3	20.1	7,140	149
	1981	139,000	2,900	6,020	126	42	.88	10.4	3,890	81.2	17.9	6,710	140
	1982	155,000	3,230	6,690	140	47	.98	13.4	5,600	117	17.7	7,380	154
	1983	164,000	3,430	5,490	115	63	1.32	6.8	3,000	62.7	17.9	7,950	166
14138870	1978	14,000	2,560	1,050	192	3.5	.64	16.1	606	111	17.7	666	122
	1979	11,100	2,040	519	95	2.7	.49	2.5	74.3	13.6	19.8	595	109
	1980	12,100	2,210	391	72	2.1	.38	1.0	32.8	6.0	20.4	666	122
	1981	12,000	2,200	583	107	1.9	.35	2.4	79.2	14.5	18.8	606	111
	1982	14,200	2,600	860	158	2.3	.42	5.5	209	38.3	18.2	693	127
	1983	14 600	2,670	550	101	4.1	.75	1.7	66.6	12.2	18.0	710	130
14138900[2/]	1978	29,100	3,500	3,190	383	14	1.68	--	--	--	--	--	--
	1979	20,700	2,490	1,240	149	9.5	1.14	10.4	581	69.8	22.5	1,260	152
	1980	22,000	2,650	672	81	9.1	1.09	4.6	276	33.2	22.2	1,320	159
	1981	24,900	2,990	1,790	215	12	1.44	17.5	1170	141	20.5	1,380	166
	1982	28,500	3,420	2,290	275	14	1.68	17.3	1330	160	19.7	1,510	182
	1983	30,700	3,690	1,410	169	16	1.92	7.5	617	74.1	19.6	1,630	196
14139800[2/]	1978	45,400	2,950	2,520	163	12	.78	--	--	--	--	--	--
	1979	33,700	2,190	1,710	111	11	.71	3.9	357	23.2	21.1	1,920	125
	1980	39,700	2,580	994	65	8.0	.52	2.4	260	16.9	22.7	2,430	158
	1981	36,200	2,350	1,750	114	9.1	.59	4.9	476	30.9	22.0	2,140	139
	1982	39,600	2,570	2,440	158	13	.84	7.6	816	53.0	20.6	2,200	143
	1983	42,500	2,760	1,840	119	18	1.17	4.5	511	33.2	20.5	2,360	153

1/ These water-quality characteristics also were used as basin characteristics for suspended-sediment and dissolved-solid regression models.

2/ The suspended-sediment and dissolved-solids characteristics could not be computed for WY 1978 because data collection for these sites began in WY 1979.

Suspended Sediment

The daily suspended-sediment load was complete for the study period for the four Bull Run stations. This record was used to compute the annual suspended-sediment load (SEDLOAD) for each station by summing the daily load for each year.

The annual discharge-weighted suspended-sediment concentration (SEDCONC), in mg/L, was computed according to the equation

$$SEDCONC = \frac{SEDLOAD}{0.0027\ (ANNUALQ)},$$

where

SEDLOAD = the annual suspended-sediment load, in tons;
ANNUALQ = the annual streamflow, in ft^3/s; and
0.0027 = the unit conversion factor.

Specific Conductance

Specific-conductance values from two data sources were used to compute equivalent dissolved-solids loads and concentrations for the four Bull Run stations. The first data source involved the synthesis of daily mean specific-conductance values for time periods where missing records occurred. Generation of missing daily mean conductance records was accomplished by developing a regression model between daily mean discharge and daily mean specific conductance. Least-square regression lines were developed using a second degree logarithmic polynominal of the daily mean steamflow and the daily mean specific conductance, on an annual basis, for each of the four stations. The form of the regression equation is:

$$COND\_DAILY = a + bLOG(Q) + c(LOG(Q))^2,$$

where

COND_DAILY = the daily mean specific conductance;
Q = the daily mean discharge; and
a,b,c = the model constant and coefficients.

Variation explained for the regression lines ranged, on an annual basis, from 61 to 96 percent, with standard errors of estimate ranging from 3.7 to 11 percent. These equations were used to "fill in" a small percentage of the annual record where steamflow information existed but specific conductance information was missing.

The second source of data was a method for computing dissolved-solids loads and concentrations by converting daily mean specific conductance data to a daily mean dissolved-solids concentration. Because the ratio of total-solids concentration to the specific-conductance value approached 1.0 during periods of record in which the suspended-sediment concentrations were low, the daily specific conductance values were used directly to compute a specific conductance as equivalent dissolved-solids concentration or load.

Basin Characteristics

The basin characteristics used in the regression models are summarized in table 21. These characteristics have been categorized as (1) climatic, (2) land-use, (3) topographic, (4) geologic, (5) soil, and (6) miscellaneous.

Table 21.--Summary of the annual basin characteristics used in the multiple-linear regression analysis for the Bull Run watershed for the WY period 1978-1983

Station number	Water year	Climate PRECIP	I24	MINJAN	Land use CLEAR	CLEAR_4	PARTIAL	PART_4
14138850	1978	132	4.9	29.6	0.0	4.4	0.0	0.4
	1979	105	4.6	15.7	.0	3.0	.9	.3
	1980	129	3.1	21.7	.2	1.8	.6	.9
	1981	120	3.4	31.2	.1	0.9	.0	1.5
	1982	136	4.0	25.8	.1	.3	.4	1.5
	1983	152	4.2	31.1	.0	.4	.5	1.9
14138870	1978	146	4.7	29.8	.0	.0	.0	.0
	1979	117	4.5	16.0	.0	.0	.0	.0
	1980	142	3.0	21.9	.0	.0	.0	.0
	1981	133	3.3	31.3	.0	.0	.0	.0
	1982	150	3.8	25.9	.0	.0	.0	.0
	1983	168	4.1	31.2	.0	.0	.0	.0
14138900	1978	144	4.9	30.3	.0	2.3	.0	1.2
	1979	115	4.7	16.8	1.3	1.9	.5	1.2
	1980	140	3.1	22.5	.5	3.2	.0	1.1
	1981	131	3.4	31.9	.0	3.7	5.9	1.1
	1982	148	4.0	26.9	.0	1.8	.8	6.4
	1983	166	4.2	32.0	.0	1.8	.0	7.2
14139800	1978	125	4.5	30.7	.4	4.5	.0	.3
	1979	100	4.2	17.2	.8	4.7	.0	.3
	1980	122	2.8	22.9	.0	4.1	.0	.0
	1981	114	3.1	32.3	.0	4.0	3.3	.0
	1982	129	3.6	26.5	.0	1.1	1.3	3.3
	1983	144	3.8	31.7	.0	.8	1.4	4.6

Station number	Topography AREA	CSLOPE	CLENGTH	BSLOPE	BSHAPE	AZIMUTH	BSLPGT25	BSLPGT50	ELEV	ELT2600	EGT2600	DDI
14138850	47.9	180	10.6	1670	1.47	107	76.2	18.7	3080	27.0	73.0	1.71
14138870	5.46	390	5.1	1560	2.77	102	83.7	10.8	3020	31.6	68.4	1.32
14138900	8.32	380	6.4	1330	3.86	31	42.8	10.9	2820	31.5	68.5	1.40
14139800	15.4	350	6.5	1330	2.29	93	53.0	7.6	2700	51.4	48.6	1.37

Station number	Geology COLUMBIA	RHODODEN	PLIOQUAT	QUATLAND	Soils A	B	C	D	E	F	G	Miscellaneous NC_ROCK	OPENAREA	STORAGE
14138850	15.6	2.3	80.6	0.0	1.1	6.6	5.6	13.4	7.6	17.0	47.1	15.0	0.2	1.5
14138870	.1	7.1	92.8	.0	1.0	12.5	.0	20.5	.0	10.6	55.4	14.8	.1	.3
14138900	5.5	8.5	84.7	1.3	4.0	3.4	.0	2.2	.6	33.3	56.5	4.8	3.7	.2
14139800	.2	3.3	96.5	.0	1.3	1.2	1.3	7.3	12.2	36.6	40.1	4.4	.2	.2

Climate

The three climatic characteristics, the methods used for their computations, and the data sources are:

(1) Annual precipitation (PRECIP), in inches. The annual precipitation for each subbasin was determined by computing the ratio of the annual precipitation for the year of interest at the Headworks to long-term mean annual precipitation at the same location and then multiplying that ratio by the area-weighted long-term mean annual precipitation for each subbasin. The yearly and long-term mean annual precipitation values are published by the National Oceanic and Atmospheric Administration (NOAA) in its annual climatological data reports. The area-weighted long-term mean annual precipitation in each subbasin was determined from a Bureau of Water Works isohyetal map of the Bull Run watershed (Palmer, 1974).

(2) Annual maximum 24-hour rainfall intensity (I24), in inches. The annual maximum 24-hour rainfall intensity for each subbasin was determined by computing the ratio of the yearly maximum 24-hour rainfall intensity (as recorded at the Headworks) to the 2-year maximum long-term 24-hour rainfall intensity at the same location, then multiplying the ratio by the area-weighted 2-year maximum long-term 24-hour rainfall intensity for each subbasin. The yearly maximum 24-hour rainfall intensities are published by NOAA in its monthly climatological data reports. The area-weighted 2-year maximum long-term 24-hour rainfall intensity for each subbasin and the single value at the Headworks was determined from an isopluvial map (Harris and others, 1979, pl. 2).

(3) Annual mean minimum January air temperature (MINJAN), in degrees Fahrenheit. A least-squares best-fit relation for the annual mean minimum January air temperature of five NOAA stations at varying elevations was first developed. These five stations are meteorologically similar to the Bull Run stations.
The annual mean minimum January air temperature for each Bull Run subbasin was determined by "plugging" into the annual least-square best-fit equation the area-weighted elevation (ELEV) of each subbasin. The annual mean minimum January temperature and elevation for the five NOAA stations was tabulated from the NOAA monthly climatological reports. See ELEV under the Topography section for information on how the mean basin elevation for each subbasin was computed.

Land Use

Timber harvesting activities in the Bull Run watershed can be categorized into either clear-cut or partial-cut activities. The annual tabulated acreage of clear-cut and partial-cut activities for each subbasin is published by the USFS in their Mount Hood National Forest Annual Activity Schedule Reports. The number of road miles constructed in each subbasin is also tabulated in the annual activity reports, but the minor amount of road construction which occurred during the study period was deemed to have an insignificant effect on water quality.

The following are the four land-use activities considered for the analysis and the methods for their computation.

(1) Annual clear-cut area (CLEAR), in percent of subbasin drainage area (AREA).

(2) Total clear-cut area during the previous 4 years (CLEAR_4). Summation of the 4 years of clear-cut area prior to the present year as percent of subbasin AREA.

(3) Annual partial-cut area (PARTIAL), in percent of subbasin AREA.

(4) Total partial-cut area during the previous 4 years (PART_4). Summation of the 4 years of partial-cut area prior to the present year as percent of subbasin AREA.

Topography

The following 12 topographic characteristics have been tabulated from published sources or computed from maps:

(1) Drainage area (AREA), in square miles. Obtained from the latest Geological Survey annual-streamflow and water-quality report for Oregon.

(2) Main channel slope (CSLOPE), in feet per mile. Determined from Geological Survey topographic maps, expressed as the difference in elevation at points 10 and 85 percent of the distance upstream from the gage site to the basin divide, divided by the channel distance between the two points.

(3) Main channel length (CLENGTH), in miles. Determined from Geological Survey topographic maps as the distance between the gage site along the channel to the basin divide.

(4) Mean basin slope (BSLOPE), in feet per mile. Obtained from Geological Survey topographic maps using the following equation (Wisler and Brater, 1967):

$$\text{BSLOPE} = (\text{C})(\text{L})/(\text{AREA}),$$

where
C = Contour interval, in feet;
L = Total length of contours, in miles; and
AREA = Drainage area, in square miles.

(5) Basin shape (BSHAPE), dimensionless. Obtained from Geological Survey topographic maps using the following formula:

$$\text{BSHAPE} = (\text{Lc})^2 /(\text{AREA}),$$

where
Lc = The straight-line distance from basin outlet to the main channel divide, in miles, and
AREA = Drainage area, in square miles.

(6) Basin channel orientation (AZIMUTH), in degrees from North. Obtained from Geological Survey topographic maps as the direction of a straight line joining points defining 10 and 85 percent of the distance between the gage site and the basin divide.

(7) Basin area slope greater than 25 percent (BSLPGT25), in percent. Obtained from a hazards map of the Bull Run watershed (Beaulieu, 1974), as the percentage of the subbasin drainage area with slope greater than 25 percent.

(8) Basin area slope greater than 50 percent (BSLPGT50), in percent. Obtained from a hazards map of the Bull Run watershed (Beaulieu, 1974), as the percentage of the subbasin drainage area with slope greater than 50 percent.

(9) Mean basin elevation (ELEV), in feet above mean sea level. Obtained from Geological Survey topographic maps by use of the grid method to compute an average basin elevation.

(10) Basin area less than 2,600 feet elevation (ELT2600), in percent. Obtained from a hazards map of the Bull Run watershed (Beaulieu, 1974), as the percentage of the subbasin drainage area less than the 2,600-foot elevation contour.

(11) Basin area greater than 2,600 feet elevation (EGT2600), in percent. Obtained from the formula,

$$EGT2600 = 100 - ELT2600.$$

(12) Drainage density index (DDI), in miles per square mile. Obtained from Geological Survey topographic maps as the ratio of the total length of stream channels divided by drainage area.

Geology

Four geologic characteristics, in percent of drainage area, were obtained from a geologic map of the Bull Run watershed (Beaulieu, 1974):

(1) Columbia River Basalt (COLUMBIA).

(2) Rhododendren Formation (RHODODEN).

(3) Pliocene and Quarternary volcanic rock (PLIOQUAT).

(4) Quaternary landslide deposits (QUATLAND).

Soils

Soil groups (A-G) represent soils in the Bull Run watershed that, at the best estimate by a forest soils scientist, would react similarly within each group if impacted by some activity. The soil units described under each soil grouping are more fully detailed in the Mount Hood Soil Resource Inventory (SRI) report (Howes, 1979):

(1) Soil group A, in percent of drainage area, composed of wet meadows and poorly drained forested bottomlands. Soil units 3, 4, and 3-4.

(2) Soil group B, in percent of drainage area, composed of unvegetated talus and rubbleland, igneous rock outcrops, and felsenmeer slopes. Soil units 6, 6-7, 6-13, 7, and 7-6.

(3) Soil group C, in percent of drainage area, composed of wet talus and felsenmeer slopes. Soil units 12 and 12-13.

(4) Soil group D, in percent of drainage area, composed of high-elevation cirques and glacially scoured areas, felsenmeer slopes, unvegetated talus and rubbleland, and wet talus. Soil units 9, 13, 13-6, and 13-12.

(5) Soil group E, in percent of drainage area, consists of soil units 326 and 330 and of inclusions of soils 3, 4, 6, 7, 13, 327, 328, and 329. See SRI for descriptive characteristics.

(6) Soil group F, in percent of drainage area, consists of soil units 338, 339, and 340 and of inclusions of soils 3, 6, 7, and 371. See SRI for descriptive characteristics.

(7) Soil group G, in percent of drainage area, consists of soil units 341, 342, 343, and 348 and of inclusions of soils 3, 6, 7, 347, and 349. See SRI for descriptive characteristics.

Miscellaneous Characteristics

Three additional characteristics, in percent of drainage area, were determined from the latest USFS timber-type maps:

(1) Basin area composed of non-commercial rock (NC_ROCK).

(2) Basin area composed of meadows and brush (OPENAREA).

(3) Basin area composed of lakes, ponds, and marsh (STORAGE).

Multiple-linear Regression Results

The results of the multiple-linear regression analysis covering WY period 1978-1983 are summarized in table 18. In general, the multiple-linear regressions for discharge, suspended sediment, and dissolved solids were found to be quite successful in explaining a large percentage (70 to 99 percent) of the variation of the water-quality characteristics with a relatively low standard error of estimate (3.5 to 60 percent).

To demonstrate the use of the table, the model for annual discharge (ANNUALQ) is presented:

$$\text{ANNUALQ} = (-5.03 \times 10^4) + (3.18 \times 10^3)(\text{AREA}) + (3.36 \times 10^2)(\text{PRECIP})$$

The above model indicates that, in the Bull Run watershed, the size of subbasin drainage area and the amount of annual precipitation on the subbasin can be used to explain 99 percent of the annual discharge variability. The absolute standard error of estimate (a slightly different calculation from that shown in table 18) is a measure of the variability of ANNUALQ about the best-fit line through the data. Approximately two-thirds of the ANNUALQ will be within plus or minus the absolute standard error of estimate. Computation of the error term as a percentage of the mean (results shown in table 18) indicates that observations about the mean ANNUALQ will be plus or minus 16 percent of the mean value. The percent of variation explained (table 18) is a measure of how well the model explains the data variation.

Table 19 should be used in conjunction with table 18 in evaluating the significance of each water-quality regression model. Tabulated in table 19 are (1) the observed range and mean of the water-quality and range of basin characteristics used in the regression models, (2) the relative order (highest to lowest) for which the basin characteristics explain the variation in water-quality characteristics, and (3) the estimated significant bivariate correlations among basin characteristics. The observed range in water-quality and basin characteristics specifies the conditions under which the regression coefficients and constants were determined. For instance, if basin characteristic values outside the range used in developing the regression model were selected to predict water-quality characteristic values, the predictive reliability model would depend on the extent of the extrapolation.

If bivariate correlations for a regression model's independent variables are small, the order in which they are listed in table 19 corresponds to their relative importance in explaining variation in the dependent variable. If bivariate correlations are large, the relative importance of each independent variable cannot be assigned, and the entire regression model should be considered in evaluating the explanation of variation for the dependent variable.

Streamflow Models

Generally, the streamflow models were quite good (table 18). Standard errors of estimate ranged from 6.0 to 28 percent while explaining 72 to 99 percent of the streamflow variability. The subbasin drainage area (AREA) and the two precipitation factors, annual precipitation (PRECIP) and annual maximum 24-hr precipitation (I24), were major contributors and appeared in all but one of the six streamflow regression models. In general, many of the basin characteristics used in the regression models can be conceptually related to the dependent model variables. For instance, for the QPEAK_SM regression model it is rational to conclude that increasing the annual discharge per square mile (Q_SM) and reducing storage (STORAGE) within the basins increases QPEAK_SM; but it is not logical to assume that increasing annual precipitation (PRECIP) will reduce QPEAK_SM. As it turns out in the QPEAK_SM regression model, Q_SM is positively influenced by PRECIP (r-squared of 0.25). Dropping Q_SM as an independent variable in the model causes the coefficient on PRECIP to go positive; however, dropping Q_SM from the model also causes the coefficients on the remaining basin characteristics to be statistically rejected at the 95-percent level of confidence by the F-test. Only approximately 17 percent of the variation in the QPEAK_SM characteristic can be explained by the new model. In the QMIN and QMIN_SM regression models, there appears to be a relation with the amount of partial cut done in the previous four years (PART_4). The addition of PART_4 into these models only increases the models' percent of variation explained by about 3 percent and therefore does not exert a major influence in the QMIN and QMIN_SM models.

Suspended-sediment Models

The suspended-sediment regression models, in general, fit the data well, but do not fit nearly as well as the streamflow models. Standard errors of estimate ranged from 48 to 60 percent while explaining 70 to 89 percent of the suspended-sediment characteristic variations. Two factors that complicate developing suspended-sediment regression models in the Bull Run watershed are (1) the physical processes governing the variability of stream suspended-sediment concentrations and loads are complex, and (2) the magnitude and range of suspended-sediment characteristics are relatively small in comparison to other less pristine watersheds. Basically, only three basin characteristics, annual peak streamflow (QPEAK or QPEAK_SM), drainage area (AREA), and Columbia River Basalt (COLUMBIA), were needed to model suspended-sediment characteristics. Peak streamflow has a direct relation to the water-quality characteristic, while drainage area may be acting as a surrogate variable for a sediment-delivery ratio. Percent of drainage in Columbia River Basalt may at first seem to be a strange component in these models because of the basalt's resistance to weathering. However, its inclusion may be understandable when the fact is considered that Columbia River Basalt is a "tight" unit with low permeability that causes high runoff, a condition which enhances transport of sediment.

Specific-conductance Models

The specific-conductance regression models (equated as dissolved solids) showed excellent model fits. Percent of variation explained ranged from 86 to 99, with standard errors of estimate ranging from 4.4 to 9.6 percent. Climatic and topographic characteristics comprised a majority of the basin characteristics used in these regressions. In the CONDCONC model, PRECIP and I24 appear to be acting as dilution components, because the increased amount of precipitation or rainfall intensity dilutes the dissolved-solids concentration in the stream. BSLOPE in the CONDCONC model may indicate that, as mean basin slope increases, basin runoff increases, resulting in more dilution of dissolved constituents. In the CONDLOAD and CONDYLD models, AREA and PRECIP appear to be related to the ANNUALQ component of conductance load and yield. It is interesting to note that AREA in the CONDYLD model may have more than one relation to CONDYLD, because in the other annual yield models (Q_SM, QPEAK_SM, QMIN_SM, and SEDYLD), AREA was found not to be a significant basin characteristic. Two other basin characteristics were found to be significant in the specific-conductance models were land use and soils. The amount of annual clear-cut area (CLEAR) appears to have some minor relation to CONDCONC, but its introduction in this model only increased the percent of variation explained by 5 percent. The soil group D was found to be inversely related to CONDYLD.

SUMMARY

Hydrologically, stream discharge during the 6 years of the study period closely approximated the average long-term (1929 to 1983) streamflow for the area. As a result, the collected data set does not contain any extreme variability. Therefore, water-quality models and water-quality standards based on the study period will not account for extreme conditions. To describe additional natural variability, the models developed should be updated as future data becomes available.

Examination of streamflow data indicated that streamflow at the North Fork and Main Stem Bull Run stations was substantially different from that at the other two sites. North Fork and Main Stem, in addition to providing the highest streamflow yield, also produced the highest suspended-sediment concentrations and yields for the four subbasins.

All four subbasins tend to produce annual sediment loads within a small fraction of the year. Generally, 62 to 78 percent of the average annual sediment load occurs in 3 to 4 days. This indicates the potential difficulty in accurately describing annual sediment values and values for sediment-related constituents.

Seasonal Kendall time-trend analyses of 24 water-quantity and water-quality constituents did not reveal any strong time trends within the subbasins. Although 11 constituents (daily mean streamflow and temperature and periodic measurements of turbidity, specific conductance, pH, total NO_3, silica, total aluminum, suspended-sediment, fecal coliform bacteria, and phytoplankton) revealed statistically significiant increasing trends, the estimated slopes of these trends usually were small and would be difficult to measure on an annual basis. In addition, the significant trends were measured over a 4- to 6-year period, which is a short timeframe for a trend; thus extrapolation of the indicated slope beyond the study period would not be prudent. However, because several trends did test to be significant, potential trends should be examined as additional data becomes available.

Because a majority of the basin characteristics are similar from subbasin to subbasin and the amount of man-related activity has been minimal during this study period, the different water-quality characteristics are commonly related to the same basin characteristics in the regression analysis. This similar response made it difficult to pinpoint the cause of responses within individual subbasins by using a multiple-linear regression approach. Generally, the variability of water-quality characteristics was found to be most related to climatic, topographic, and hydrologic basin characteristics, with some influence by geographic and soil characteristics. From a forest-management standpoint, the list of basin characteristics represents parameters that cannot be used to control stream water-quality variability. Two land-use factors, the total partial-cut area during the previous 4 years and the annual clear-cut area, showed some importance in the annual discharge-weighted specific conductance as equivalent dissolved-solids concentration models. The influence of these two land-use factors, based on the magnitude of the activity occurring within the watershed, is considered minor.

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GLOSSARY OF TERMS USED IN REGRESSION ANALYSIS

Water-quantity and Water-quality Characteristics

ANNUALQ — Annual discharge, in ft^3/s.

Q_SM — Annual discharge yield, in $(ft^3/s)/mi^2$.

SEDCONC — Annual discharge-weighted suspended-sediment concentration, in mg/L.

SEDLOAD — Annual suspended-sediment load, in tons.

SEDYLD — Annual suspended-sediment yield, in $tons/mi^2$.

CONDCONC — Annual discharge-weighted specific conductance as equivalent dissolved-solids concentration, in mg/L.

CONDLOAD — Annual specific conductance as equivalent dissolved-solids load, in tons.

CONYLD — Annual specific conductance as equivalent dissolved-solids yield, in $tons/mi^2$.

Basin Characteristics

Climate

PRECIP — Annual precipitation, in inches.

I24 — Annual maximum 24-hour precipitation, in inches.

MINJAN — Annual mean minimum January air temperature, in degrees Fahrenheit.

Streamflow

Q_SM — Annual discharge yield, in $(ft^3/s)/mi^2$.

QPEAK — Annual maximum instantaneous discharge, in ft^3/s.

QMIN — Annual minimum instantaneous discharge, in ft^3/s.

Topography

AREA — Total drainage area, in mi^2.

CSLOPE — Main channel slope, in ft/mi.

CLENGTH — Main channel length, in mi.

BSLOPE — Mean basin slope, in ft/mi.

BSHAPE — Basin shape, dimensionless.

AZIMUTH — Basin channel orientation, in degrees from North.

BSLPGT25	Basin area in which slope is greater than 25 percent, in percent of drainage area.
BSLPGT50	Basin area in which slope is greater than 50 percent, in percent of drainage area.
ELEV	Mean basin elevation, in ft.
ELT2600	Basin area less than 2,600 feet elevation, in percent of drainage area.
EGT2600	Basin area greater than 2,600 feet elevation, in percent of drainage area.
DDI	Drainage-density index, in mi/mi^2.

Geology

COLUMBIA	Columbia River basalt, in percent of drainage area.
RHODODEN	Rhododendren formation, in percent of drainage area.
PLIOQUAT	Pliocene and quaternary volcanic rock, in percent of drainage area.
QUATLAND	Quaternary landslide deposits, in percent of drainage area.

Soils

A	Basin area composed of soil units 3, 4, in percent of drainage area.
B	Basin area composed of soil units 6, 7, in percent of drainage area.
C	Basin area composed of soil unit 12, in percent of drainage area.
D	Basin area composed of soil units 9, 13, 172, in percent of drainage area.
E	Basin area composed of soil units 326, 330, in percent of drainage area.
F	Basin area composed of soil units 15, 338, 339, 340, in percent of drainage area.
G	Basin area composed of soil units 341, 342, 343, 348, in percent of drainage area.

Land Use

NC_ROCK	Area of non-commercial rock, in percent of drainage area.
OPENAREA	Area of meadows and brush, in percent of drainage area.
STORAGE	Area of lakes, ponds, and marsh, in percent of drainage area.

CLEAR	Annual clear-cut area, in percent of drainage area.
CLEAR_4	Total clear-cut area during previous four years, in percent of drainage area.
PARTIAL	Annual partial cut, in percent of drainage area.
PART_4	Total partial cut during previous four years, in percent of drainage area.

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