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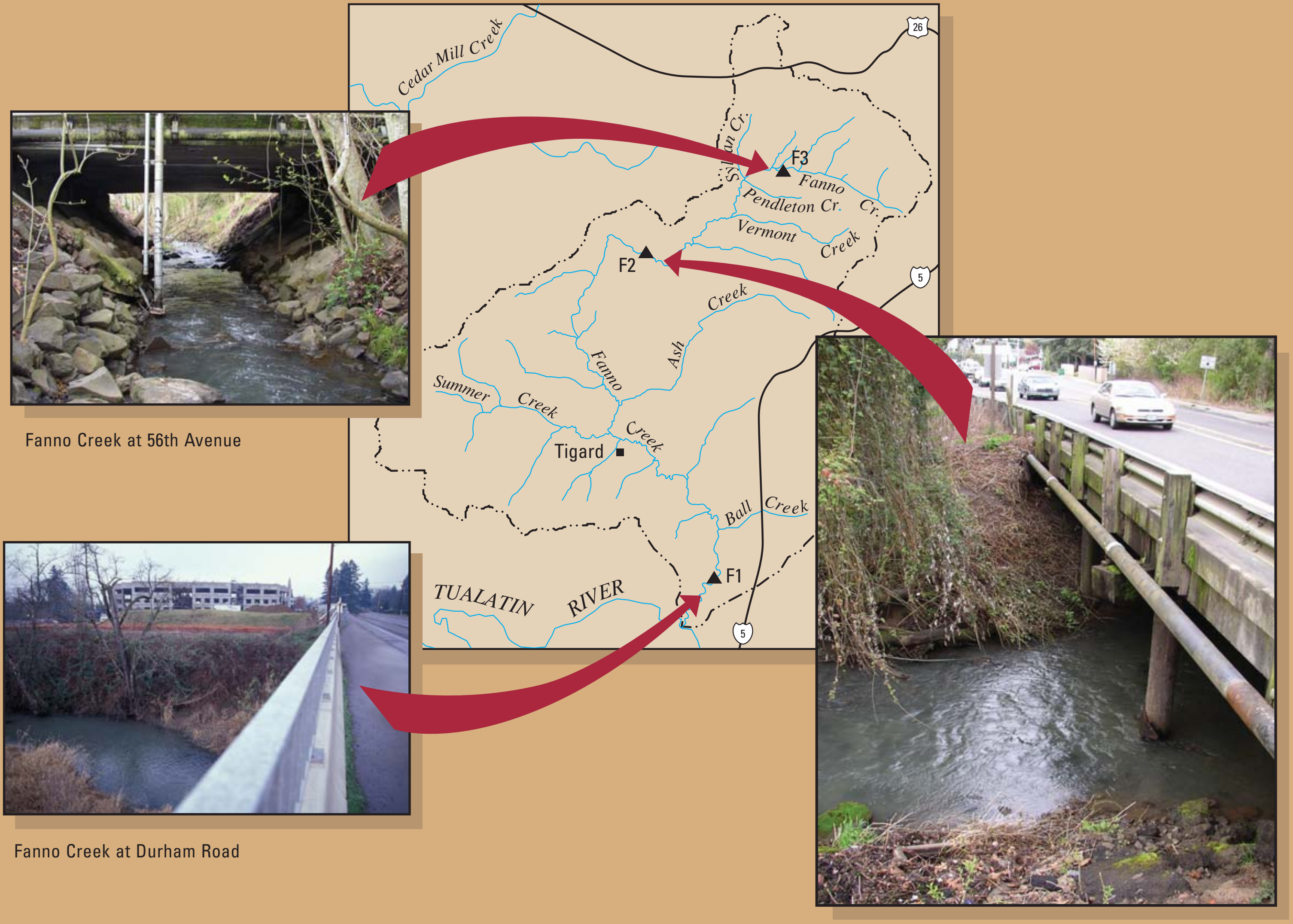
Phosphorus and *E. coli* and Their Relation to Selected Constituents During Storm Runoff Conditions in Fanno Creek, Oregon, 1998-99

Water-Resources Investigations Report 02-4232



Fanno Creek at 56th Avenue

Fanno Creek at Durham Road

Fanno Creek at Scholls Ferry Road near Allen Boulevard

Prepared in cooperation
with **CLEAN WATER SERVICES**

Photographs of Fanno Creek at 56th Avenue and Fanno Creek at Scholls Ferry Road near Allen Boulevard were taken by Steward Rounds, U.S. Geological Survey. Photograph of Fanno Creek at Durham Road was taken by Dennis A. Wentz, U.S. Geological Survey

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Phosphorus and *E. coli* and Their Relation to Selected Constituents During Storm Runoff Conditions in Fanno Creek, Oregon, 1998–99

By Chauncey W. Anderson *and* Stewart A. Rounds

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 02-4232

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CLEAN WATER SERVICES

Portland, Oregon
2003

U.S. DEPARTMENT OF THE INTERIOR

GALE A. NORTON, *Secretary*

U.S. GEOLOGICAL SURVEY

Charles G. Groat, *Director*

For additional information write to:

District Chief
U.S. Geological Survey
10615 S.E. Cherry Blossom Drive
Portland, Oregon 97216-3159
Email: info-or@usgs.gov
Internet: http://oregon.usgs.gov

Copies of this report can be purchased from:

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Box 25286, Federal Center
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GLOSSARY

Terms and abbreviations, as used in this report

BOD_5	5-day biochemical oxygen demand
BOD_{rate}	First-order decay rate for biochemical oxygen demand
BOD_{ult}	Ultimate biochemical oxygen demand, or BOD when taken to steady dissolved-oxygen concentration
CWS	Clean Water Services, formerly Unified Sewerage Agency
DO	Dissolved Oxygen
E. coli	*Escherchia coli,* a bacterium
hydrograph	The pattern of water flow during a specified period of time
hysteresis	A pattern of water-quality constituents having different concentrations for a given discharge depending on their sequence over a storm hydrograph. The pattern results in a loop when discharge is plotted against the constituent concentration
load	The amount of material in transport in a stream, in units of mass per unit time
nitrification	The oxidation of ammonia-nitrogen to nitrate nitrogen by microbes
nonpoint sources	Input of materials from diffuse, poorly defined locations
NH_3-N	Ammonia nitrogen, analyzed in a filtered, undigested sample
NO_3-N	Nitrate nitrogen, analyzed in a filtered, undigested sample
NPDES	National Pollutant Discharge Elimination System
ODEQ	Oregon Department of Environmental Quality
p	Probability
ρ, rho	Spearman’s correlation coefficient, a nonparametric indicator of the degree of correlation between two variables
sediment oxygen demand	The consumption of dissolved oxygen by various processes in streambed sediment, also known as SOD
SRP	Soluble reactive phosphorus, analyzed in a filtered, undigested sample and usually dominated by orthophosphorus
TMDL	Total Maximum Daily Load, a regulated amount of a constituent that can be transported by a stream. Required under the Clean Water Act for rivers and streams that do not meet water-quality standards under certain conditions
TP	Total phosphorus, analyzed in an unfiltered, digested sample
trip blank	A sample of analyte-free water prepared prior to a field trip, and transported and processed identically to other

	environmental samples. Used to check for contamination in field transport and laboratory analysis of water samples
TS	Total solids, the mass of all particulate materials in an aliquot of a water sample, upon evaporation at 103-105 degrees Celsius. TS is inclusive of TSS, TVSS, and TDS (see below).
TDS	Total dissolved solids, the portion of total solids that passes through a filter
TSS	Total suspended solids, the portion of total solids retained on a filter
turbidity	An optical measurement of the scattering of light in water
TVSS	Total volatile suspended solids, the portion of total suspended solids lost upon ignition at 550 ^{o}C
USA	Unified Sewerage Agency, now Clean Water Services (CWS)
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
yield	Mass of material derived from a given area upstream, in units of mass per area

CONVERSION FACTORS

Multiply	By	To obtain
Length		
inch (in)	2.54	centimeter (cm)
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
cubic foot (ft^3)	0.02832	cubic meter (m^3)
Flow Rate		
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
Mass		
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
pound per day (lb/d)	0.4536	kilogram per day (kg/d)
pound per hour (lb/hr)	0.4536	kilogram per hour (kg/hr)
pound per square mile (lb/mi^2)	0.4536	kilogram per square mile (kg/mi^2)
ton per day (ton/d)	0.9072	metric ton per day (mton/d)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F= (1.8\ °C)+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C= (°F-32)/1.8$$

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L). One milligram per liter is equivalent to one thousand micrograms per liter (µg/L). One microgram per liter is equivalent to “parts per billion.”

Bacterial concentrations in water are given in colonies per 100 milliliters (mL) of a water sample.

Phosphorus and *E. coli* and Their Relation to Selected Constituents During Storm Runoff Conditions in Fanno Creek, Oregon, 1998–99

By Chauncey W. Anderson *and* Stewart A. Rounds

SIGNIFICANT FINDINGS

As part of an ongoing cooperative study between Clean Water Services of Washington County, Oregon, and the U.S. Geological Survey, water-quality data were collected from Fanno Creek, Oregon, during three storms from June 1998 to December 1999. Samples were collected over the discharge hydrograph from three sites during one summer storm, one fall storm, and one winter storm. From these data, the following conclusions were reached for water-quality conditions and processes in Fanno Creek during storm runoff:

- Discharge was significantly correlated with total solids (TS), total suspended solids (TSS), total volatile suspended solids (TVSS), turbidity, and total phosphorus (TP).
- Of the different fractions of TS measured, TS was most directly correlated with TSS.
- Rising limbs of discharge hydrographs had higher concentrations of sediment and TP, possibly indicating that sources were nearby (resuspension of streambed, bank erosion, close upland sources) and that available supplies limited downstream transport.
- Concentrations of sediment (TS, TSS), TP, and bacteria (*E. coli*) were greatest and most variable at the most upstream site. Peak bacterial loads were similar at upstream and downstream sites, so additional sources were not evident, or downstream sources were offset by settling or losses of bacteria from upstream.
- Biochemical oxygen demand during storms was primarily associated with decomposable materials on particulate matter.
- *E. coli* concentrations exceeded the State of Oregon single-sample water-quality standard of 406 colonies/100 mL in almost all samples. *E. coli* concentrations measured during the summer storm were an order of magnitude greater than those measured during the fall or winter storms, primarily due to warmer water and less dilution during the summer storm.
- *E. coli* were correlated with suspended sediment (TSS and turbidity), indicating that they were either transported to streams attached to particles bound to resuspended streambed particles, or they had an affinity for particulate material in water.
- TP concentrations exceeded both the 1998 and 2001 Total Maximum Daily Load (TMDL) criterion concentrations in almost all samples.
- Soluble Reactive Phosphorus (SRP) in the stream may have originated primarily from ground-water discharge, whereas TP was mostly associated with particulates.

INTRODUCTION

Water-quality problems in the Tualatin River Basin, Oregon, include low dissolved oxygen (DO), high pH, high water temperature, and high bacterial (*Escherichia coli*, or *E. coli*) counts, all of which episodically exceed State of Oregon water-quality standards. Excursions of pH typically are caused by algal blooms that grow in response to long travel times, warm water, and excessive nutrient inputs. In the reservoir system of the Tualatin River, low DO concentrations are most typically caused by sediment oxygen demand and long travel times in the absence of significant levels of photosynthesis and reaeration, although DO in the main stem also can be reduced by nitrification when ammonia concentrations are high (Rounds and Wood, 2001). In response to these and other water-quality problems, the State implemented Total Maximum Daily Loads (TMDLs) in 1988 for the Tualatin River Basin, as required under the Clean Water Act (Oregon Department of Environmental Quality, 1994a, 2001a). During 2001, the original phosphorus and ammonia TMDLs were revised, with new TMDLs added for water temperature, oxygen-consuming substances, and *E. coli* (Oregon Department of Environmental Quality, 2001b).

In 1990, the U.S. Geological Survey (USGS) entered into a cooperative agreement with Clean Water Services (CWS — formerly the Unified Sewerage Agency) to investigate causes of water-quality problems in the river and evaluate alternatives for their management. Previous reports have described the TMDLs and USGS projects characterizing DO in the Tualatin River during winter (Kelly, 1997), nutrient sources and transport during low flows (Kelly and others, 1999), temperature modeling (Risley, 2000), sediment-oxygen demand (Rounds and Doyle, 1997), water-quality modeling (Rounds and Wood, 2001; Rounds and others, 1999), and phosphorus and bacteria in various tributaries during low-flow conditions (McCarthy, 2000).

Technological improvements and programmatic changes have reduced loads of phosphorus and ammonia to the Tualatin River from point sources since 1991 (Rounds and Wood, 2001). However, because of continuing water-quality problems and ongoing urbanization, attention has increasingly turned to nonpoint sources for opportunities to further reduce contaminant loads. Tributary streams, which integrate nonpoint runoff from their entire watersheds, can be important transport pathways; however, water quality is a concern in some tributaries regardless of the effects on downstream receiving waters. Whereas the 1988 TMDL considered tributaries as a source of the phosphorus that was causing problems in the main stem, the 2001 TMDL focuses on problems in both the tributaries and the main stem. For instance, in the 2001 TMDL, Fanno Creek is allowed a summer median concentration of total phosphorus (TP) of 0.13 milligram per liter (mg/L) (Oregon Department of Environmental Quality, 2001a), and its phosphorus load during summer is considered part of the total 1,272 pounds allowed in the lower Tualatin during the same season. Thus, CWS and other resource managers are faced with the necessity of either controlling the concentration of TP in runoff or reducing the volume of runoff over the summer months. Loads of *E. coli* bacteria from point sources also are regulated on a seasonal basis, with higher cumulative concentrations allowed from these sources during summer storms (12,000 counts/100 mL) than during winter storms (5,000 counts/100 mL) (Oregon Department of Environmental Quality, 2001a). The State Standard for *E. coli* bacteria in a single, instantaneous stream sample is 406 counts/100 mL, or a monthly geometric mean of 126 colonies/100 mL for multiple samplings. Chlorophyll *a* concentrations in Fanno Creek occasionally exceed the State's action level of 15 micrograms per liter (µg/L) (Oregon Department of Environmental Quality, 2001a), although concentrations appear to have been decreasing in recent years (Jan Miller, Clean Water Services, written commun., April 2002). Total volatile suspended solids (TVSS) is regulated in the Tualatin River TMDL for control of sediment oxygen demand.

McCarthy (2000) documented nutrients and bacteria concentrations in selected Tualatin River tributaries, including Fanno Creek, during summer low-flow conditions. Among her findings were that ground-water discharge could account for the phosphorus concentrations measured at most sites in the subbasin, but that local sources other than ground water were evident, possibly including avian waste materials and sediments resuspended from off-channel ponds. *E. coli* concentrations also were elevated at 70 percent of the sites sampled, possibly due to domestic pet and wildlife wastes, septic systems, or hobby farms. That study provided indications of the processes contributing nutrients during summer steady state, low-flow conditions, a period that is arguably the most sensitive regarding the effects of nutrients on eutrophication. Nonetheless, nutrients that enter creeks during other periods may be retained in the system, for example as particulate material in the bed sediments, and become biologically available during critical periods. Storm runoff is a significant process contributing sediment, nutrients, and bacteria to streams in urban areas, and likely provides part of the loads of these and other constituents to Fanno Creek.

Purpose and Scope

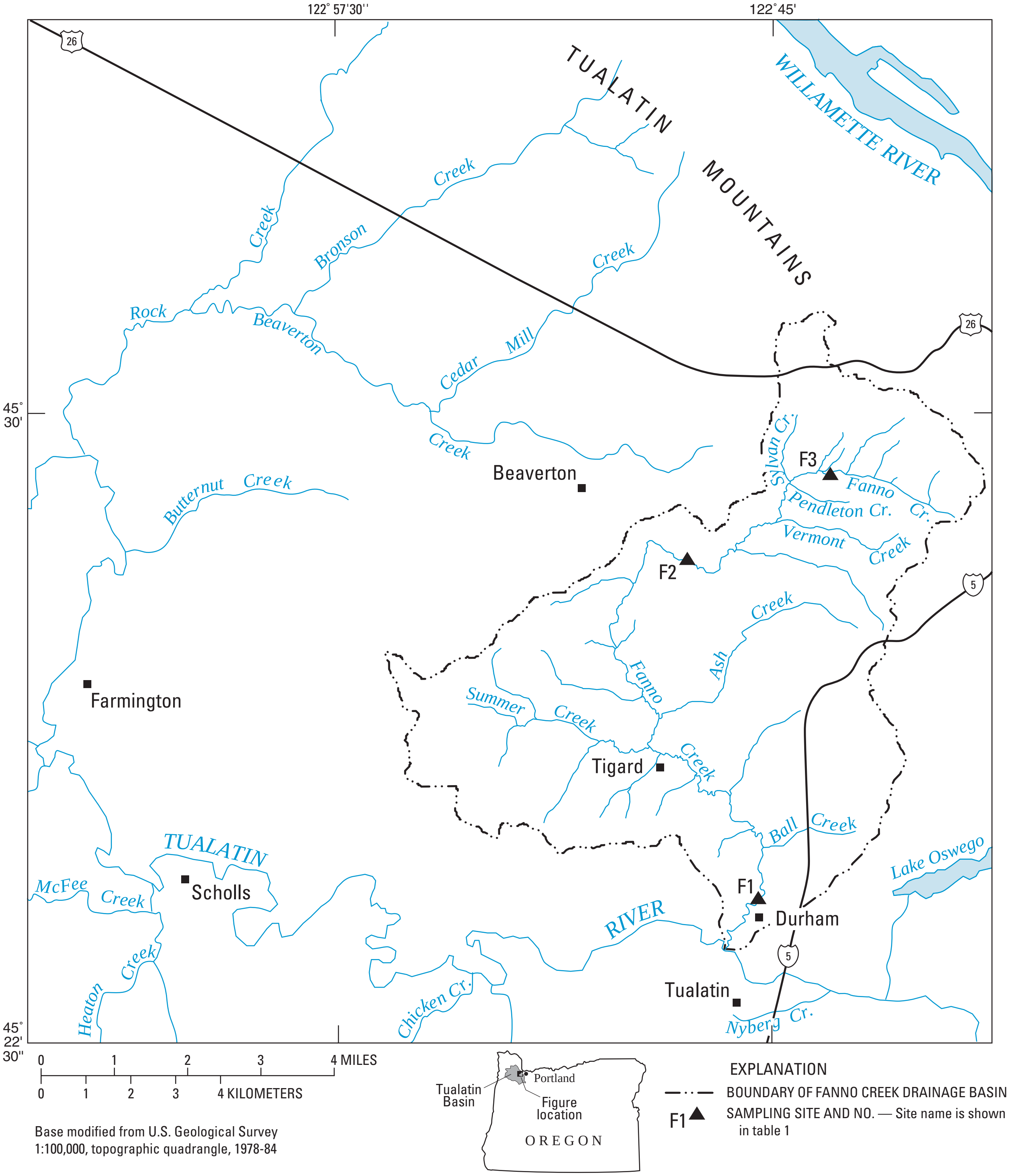
The purpose of this report is to characterize water quality, including sources and transport of nutrients and bacteria, during storm runoff conditions in the Fanno Creek Subbasin. Findings from this report ultimately will improve the understanding of dominant sources and transport processes in the basin and help improve water quality by strengthening the management of urban streams. During three storms from 1998 to 1999, data on nutrients, bacteria (*E. coli*), and constituents relating to their sources or transport (discharge, suspended solids) or their effects on water quality (biochemical oxygen demand, DO) were collected. Samples also were collected for analysis of trace elements and other inorganic constituents in water — data for those samples are stored in the CWS database but are not interpreted in this report. Multiple samples were collected at three sites during each storm, with the intent of characterizing conditions throughout individual storm hydrographs. Statistical relations among constituents are analyzed among all samplings, with exceptions unique to individual storms evaluated where they indicate important processes. Patterns and linkages from upstream to downstream also are explored.

Description of Study Area

Fanno Creek is one of several major tributaries to the Tualatin River and is classified as 100 percent urban (fig. 1). It originates within the Portland city limits and flows 15 miles through parts of the neighboring suburbs of Beaverton, Tigard, and Durham before emptying into the Tualatin River at river mile 9.3. The 32 square-mile Fanno Creek drainage basin includes a number of smaller tributaries such as Sylvan, Vermont, Ash, Summer, and Ball Creeks. Approximately 69 percent of the urban area is composed of residential communities, 21 percent is classified as industrial and commercial, and the remaining 10 percent is open space (including public parks and schools). Approximately 33 percent of the area is considered impervious, two-thirds of which contains storm drains that empty directly into a stream. The soils generally are highly consolidated silts and clays, and infiltration rates are relatively low, with moderately high soil phosphorus availability (Kurahashi and Associates, Inc., 1997). There are 27 direct and indirect National Pollutant Discharge Elimination System (NPDES) permittees along the stream, several of which are temporary for the duration of short term projects such as construction (Oregon Department of Environmental Quality, 2002). Fanno Creek's streamflow is typical of an urban stream in the Pacific Northwest, with flashy and relatively high flow during winter rainfall periods and low flows dominated by ground-water discharge during the dry summer (McCarthy, 2000).

Acknowledgments

This project was funded in partnership with Clean Water Services (CWS). Jan Wilson and Jan Miller of CWS provided the impetus and direction for investigating Fanno Creek, and provided the laboratory analyses. Special thanks to Korin Henderson and others at the CWS laboratory for setting up and processing *E. coli* analyses at night and on weekends to meet sample holding-time requirements. Within the U.S. Geological Survey, Micelis 'Clyde' Doyle provided major logistical and field assistance. Other sampling help came from Matt Johnston, Kurt Carpenter, Amy Brooks, Doug Lee, and Tirian Mink. Roy Wellman measured streamflow at Scholls Ferry Road near Allen Boulevard and developed a stage-discharge rating curve for that site.



Base modified from U.S. Geological Survey
1:100,000, topographic quadrangle, 1978-84

Figure 1. Location of study area and storm sampling sites, Fanno Creek, Oregon.

METHODS AND QUALITY ASSURANCE

Samples were collected at three sites (table 1) during storms occurring in the summer, winter, and fall. Typically, 8 to 10 water-quality samples were collected from each site during each storm, including samples near the beginning and ending of the storm. Samples were intended to represent the initial conditions, rising limb, peak discharge, falling limb, and the tail of hydrographs at each site, with additional samples to fill data gaps (see fig. 2 for an example).

Discharge and Water Quality

Discharge at the 56th Avenue site was measured and continuously gaged according to standard USGS techniques (Rantz and others, 1982a). Discharge data for Fanno Creek at Durham Road were provided by the Oregon Water Resources Department (OWRD). Discharge at Scholls Ferry Road near Allen Boulevard (herein referred to as Allen Boulevard) was not gaged continuously, but was estimated (Rantz and others, 1982a) from a rating curve developed by USGS using periodic streamflow measurements and stage readings from a staff plate. Precipitation was measured at several sites in the subbasin by USGS and the City of Portland using standard tipping bucket gages; data presented in this report are from a raingage at the Vermont Hills Pump Station (City of Portland, 2002).

Field parameters (water temperature, dissolved oxygen, pH, and specific conductance) were measured inplace using Hydrolab™ multiparameter probes, calibrated in the field according to manufacturer's recommendations and standard USGS protocols (Wilde and Radtke, 1998). Water samples were collected along a cross section (minimum 3 verticals) using a weighted bottle sampler suspended from a bridge, and composited into a churn splitter. Subsamples were drawn from the churn splitter, processed immediately using standard protocols, and stored on ice for no more than 6 hours, until they could be transferred to the laboratory at CWS for analysis. Analysis of bacteria samples by CWS was started immediately upon receipt, and analysis of water samples was typically completed within 1-3 days for all other constituents except measurements of 5-day and ultimate biochemical oxygen demands (BOD_5, BOD_{ult}). Measurements of BOD_5 and BOD_{ult}, which were made locally by USGS personnel, required up to 30 days for completion.

Water samples were analyzed by CWS for several measurements of suspended solids, oxygen demand, nutrients, and bacteria (table 2) using methods previously described (Doyle and Caldwell, 1996). Initially, subsamples for suspended solids, BOD, total nutrients, and bacteria were drawn from the churn splitter, following which subsamples for dissolved nutrients were taken. Subsamples for bacteria were drawn directly into certified-sterile plastic bottles; subsamples for BOD were drawn into standard 300-mL glass BOD bottles. Filtration in the field for dissolved nutrients was accomplished by passing water from syringes through 22-mm diameter, 0.45 µm pore-size, cellulose-nitrate disc filters. Subsamples for nutrients were unpreserved, with the exception of samples provided to the Oregon Department of Environmental Quality (ODEQ) for an interlaboratory split. ODEQ samples were processed and preserved as described by the Oregon Department of Environmental Quality (1994b).

Table 1. Storm sampling sites in Fanno Creek, Oregon, 1998–99

[**Latitude and Longitude** are given in degrees, minutes, and seconds. **Abbreviations**: USGS, U.S. Geological Survey; CWS, Clean Water Services. mi^2, square miles]

Site name	Map No. (fig. 1)	USGS site ID	CWS site ID	Latitude	Longitude	River mile	Drainage area (mi^2)
Fanno Creek at Durham Road	F1	14206950	3840012	45N 24 13	122W 45 13	1.2	31.5
Fanno Creek at Scholls Ferry Road near Allen Boulevard	F2	14206925	3840095	45N 28 16	122W 46 25	9.5	12.0
Fanno Creek at 56th Avenue	F3	14206900	3840126	45N 29 17	122W 44 01	12.6	2.37

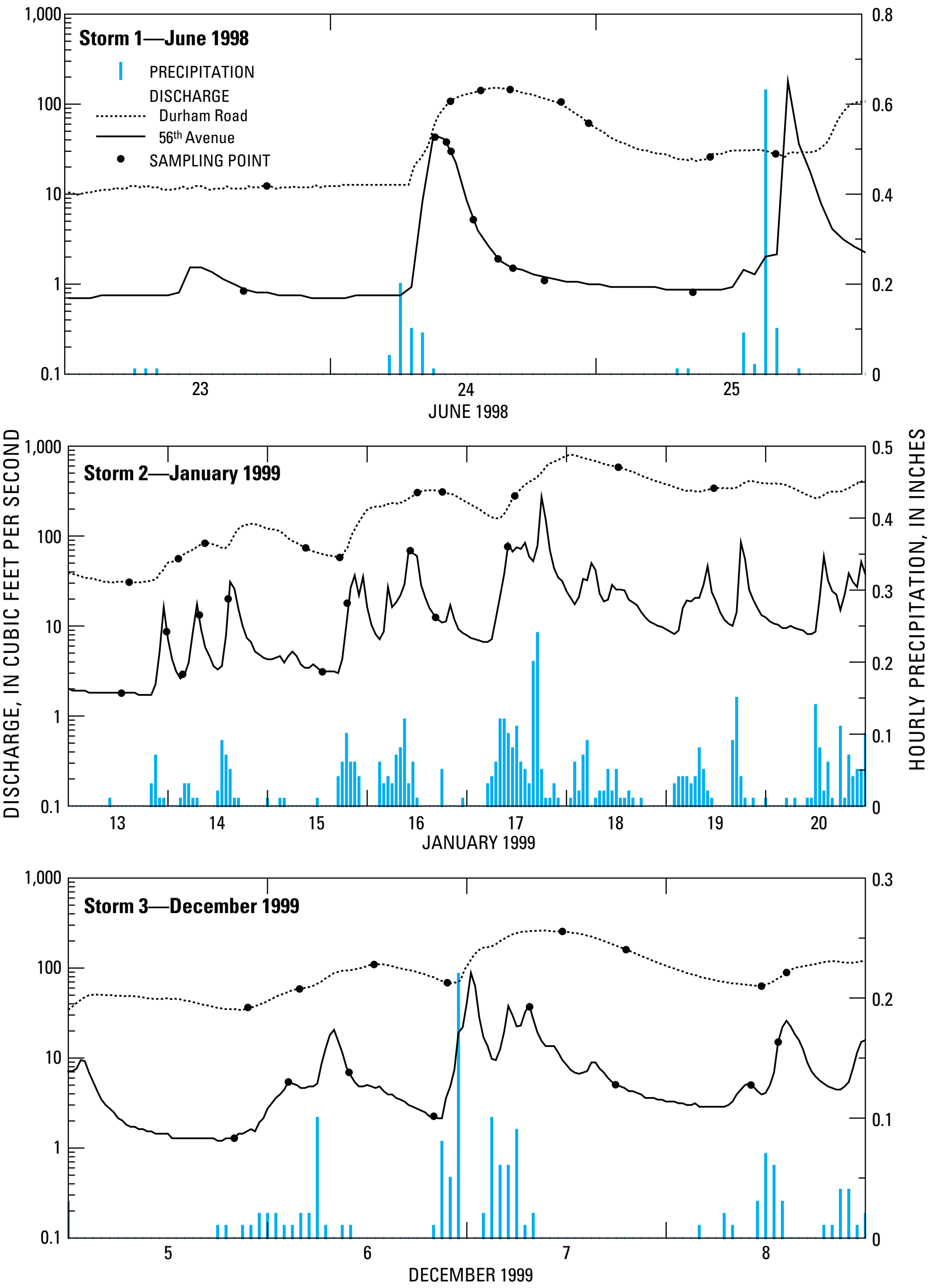


Figure 2. Discharge, precipitation, and sampling times at 56th Avenue (14206900) and at Durham Road (14206950) during three storms, Fanno Creek, Oregon, June 1998 to December 1999.

Discharge at the Allen Boulevard site (14206925) was not gaged continuously, so hydrographs from that site are not shown in this or other figures. Precipitation was recorded at the Vermont Hills Pump Station near the 56th Avenue sampling site.

Table 2. Constituents analyzed from water samples collected during stormflows in Fanno Creek, Oregon, 1998–99

[**Analyzing Laboratory:** CWS, Clean Water Service, USGS, U.S. Geological Survey. **Abbreviations:** mg/L, milligrams per liter; mL, milliliters; NTU, nephelometric turbidity units]

Parameter (abbreviation)	STORET code	Unit	Reporting level	Analyzing laboratory
Total solids (TS)	500	mg/L	2	CWS
Total Suspended Solids (TSS)	530	mg/L	0.2	CWS
Total Volatile Suspended Solids (TVSS)[1]	535	mg/L	.2	CWS
Total Dissolved Solids (TDS)[2]	515	mg/L	2	CWS
Turbidity	76	NTU	.1	CWS
Biochemical oxygen demand, rate (BOD_{rate})	—	day^{-1}	.01	USGS
Biochemical oxygen demand, 5-day (BOD_5)	310	mg/L	.1	USGS
Biochemical oxygen demand, ultimate (BOD_{ult})	319	mg/L	.1	USGS
Ammonia-nitrogen (NH_3-N)	608	mg/L	.01	CWS
Nitrate plus nitrite nitrogen (NO_3+NO_2-N)	631	mg/L	.01	CWS
Total Phosphorus (TP)	665	mg/L	.025	CWS
Soluble Reactive Phosphorus (SRP)	671	mg/L	.005	CWS
E. coli bacteria	31648	$(100\ mL)^{-1}$	1	CWS

[1] TVSS is a component of TSS.

[2] Calculated as TS minus TSS.

Quality Assurance Results

The Quality Assurance (QA) program and results for this study are given in Appendix A (at back of report). In general, the QA program indicated few limitations for the data in this report because variability associated with changing flow conditions was typically much greater than variability associated with field and laboratory procedures, and no large biases were evident. On the basis of split sample results, the largest source of variability and bias appears to have been the laboratory used for analysis (see Appendix A). For this study, all environmental samples were processed at the CWS laboratory so the dataset is internally consistent. No major concerns were otherwise noted for that laboratory, so the data are considered acceptable. Results of quality control tests are provided in table A1 and are discussed in greater detail in the appendix.

RESULTS

Storms Sampled

One storm each was sampled during summer, fall, and winter from 1998 to 1999 (figs. 2 and 3 and table 3). The magnitude of discharge during these storms was variable, in keeping with the flashy nature of urban streams, but represented a typical range of flows during the study period. The biggest storm sampled was storm 2, in January 1999, with a peak storm discharge of 800 ft^3/s at Durham Road, representing the third highest peak flow during the study period. Peak discharge during storm 3 was low (maximum 262 ft^3/s) compared to that during storm 2 but it was representative of fall storms during 1999 up to that date. Peak discharge during storm 1 (maximum 152 ft^3/s) was the lowest sampled but was nonetheless typical of spring and summer storms during 1998–99.

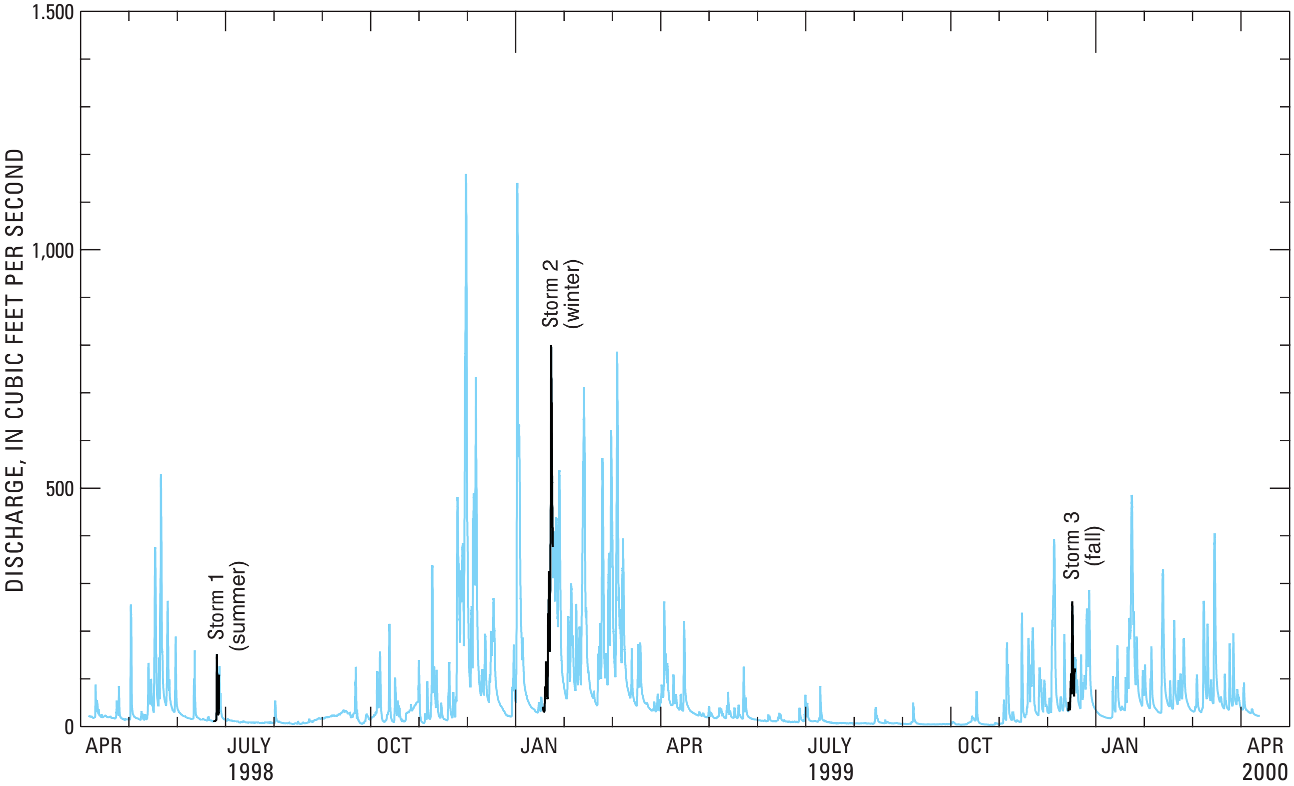


Figure 3. Discharge and storms sampled at Durham Road (14206950), Fanno Creek, Oregon, April 1998 to April 2000.

Table 3. Storm dates and number of samples at each site in the Fanno Creek drainage basin, Oregon

[**Peak storm discharge**: Estimates of peak storm discharge are not available for Fanno Creek at Allen Boulevard because that site is ungaged. **Approximate storm precipitation**: Precipitation data are from a raingage at the City of Portland's Vermont Hills Pumping Station, and include the overall rainfall during the sampling period. **Abbreviations**: ft^3/s, cubic feet per second; in., inches]

Storm No.	Date	Sampling site	Number of samples	Peak discharge sampled (ft^3/s)	Peak storm discharge (ft^3/s)	Approximate storm precipitation (in.)
1 (summer)	June 23–25, 1998	56th Avenue	8	43	44	2.3
		Allen Boulevard	9	85	—	
		Durham Road	8	145	152	
2 (winter)	January 13–19, 1999	56th Avenue	10	76	277	3.7
		Allen Boulevard	10	135	—	
		Durham Road	10	584	800	
3 (fall)	December 5–8, 1999	56th Avenue	9	37	92	1.5
		Allen Boulevard	9	82	—	
		Durham Road	8	261	262	

Hydrographs during individual sampling periods typically included several discharge peaks due to variations in precipitation patterns (fig. 2), with 8 to 10 samples collected at each site during each storm. Discharge in Fanno Creek at 56th Avenue was the flashiest, often with several peaks for every one at Durham Road. Downstream attenuation of discharge into broad peaks was pronounced at Durham, even though the magnitude of discharge was usually greater due to the additional contributing drainage basin area. Nonetheless, peak discharge at 56th Avenue was occasionally almost as high as that eventually measured at Durham, and in one case (during a new storm after sampling had ended during June 1998) was higher because of the flashiness at 56th Avenue (fig. 2). Discharges and attenuation of hydrographs at the midbasin site, Allen Boulevard, were intermediate to those at 56th Avenue and Durham Road. Because of this pattern, samples collected at 56th Avenue typically did not represent just one cycle of rising and falling discharge but rather a series of fluctuations in discharge. In contrast, at Durham there was usually a steadily increasing hydrograph during the sampling period, albeit with some minor fluctuations. The exception was storm 1, which was a single, discreet rainfall event and had just one discharge peak at all locations during the sampling period.

Water Quality

A simple spearman's correlation matrix (table 4) of all data (Appendix B) indicates that several constituents were correlated with many other constituents, whereas others were correlated with few to no other constituents. These results are evaluated in more detail in the following sections to help develop hypotheses regarding the sources of various constituents and their mechanisms of transport. Data also are examined for upstream-downstream processes or linkages, and for variability within and among storms that may indicate different sources or processes. Water-quality data from each storm are given in Appendix B.

Discharge

Discharge was significantly correlated ($p<0.0001$) with TS, TVSS, TSS, turbidity, and TP, and all correlations were positive. However, all combinations had correlation coefficients (Spearman's *rho*, or ρ) between 0.5 and 0.7, indicating that similar processes may have controlled the effect of discharge on each of these parameters. All are measures of, or are commonly associated with, particulates in water. None of the dissolved constituents (for example, NO_3-N, NH_3-N, SRP, TDS) were significantly correlated with discharge. Interestingly, bacterial concentrations also were not significantly correlated with discharge, even though bacteria are commonly associated with particulates (Schillinger and Gannon, 1985). However, stream energetics dictate that the ability of streamflow to suspend particulate material is typically greater on the rising limb of a discharge hydrograph than on the falling limb (Leopold, and others, 1995). Therefore, such correlations with discharge are not likely to be clear or consistent without more data over a greater range of discharges.

Solids

Of the five measurements of solids in water, TS, TVSS, TSS, and turbidity were significantly correlated with discharge, but TDS was not (table 4). TS was significant and strongly correlated with TVSS, turbidity, and TSS (fig. 4), but all four were weakly and negatively correlated with TDS. These findings are reasonable, because TS incorporates TSS (and thereby TVSS), representing particulates brought in or resuspended during storms, whereas TDS typically is reduced at higher flows due to dilution (Hem, 1989). Although the correlation coefficients for TSS and TVSS with TS were equivalent (0.82 and 0.84, respectively), the slope of the line was much steeper for the relation between TS and TSS (fig. 4). In terms of a surrogate measurement, TSS is much more representative of total solids in transport in the Fanno Creek drainage basin than is TVSS. Nonetheless, TVSS may be of interest if the component of particulates that is composed of biological or decomposable materials is a large fraction of the TS load. TVSS might be expected to undergo significant seasonal variation if the source area includes suitable habitat for algal growth (SoloGabriele and Perkins, 1997). Other potential sources for TVSS include leaves, riparian vegetation, and detritus.

Table 4. Correlations for selected water-quality constituents during storm conditions in Fanno Creek, Oregon, 1998–99

[Within a table cell, the upper row shows Spearman's correlation coefficient (*rho* or ρ), the middle row shows probability (*p*) that the null hypothesis of no correlation is true, and the lower row shows number of samples (*n*). Numbers in **bold** indicate correlations that are significant at $p<0.01$]

	Discharge	**TS**	**TDS**	**TVSS**	**TSS**	**Turbidity**	**BOD$_{rate}$**	**BOD$_5$**	**BOD$_{ult}$**	**TP**	**NH$_3$-N**	**NO$_3$-N**	**SRP**	***E. coli***
Discharge	1 — 80													
TS	**0.6387** **<0.0001** **80**	1 — 81												
TDS	-0.2553 0.0232 79	-0.0283 0.8032 80	1 — 80											
TVSS	**0.6482** **<0.0001** **81**	**0.8221** **<0.0001** **81**	**-0.4832** **<0.0001** **80**	1 — 81										
TSS	**0.7022** **<0.0001** **80**	**0.8441** **<0.0001** **81**	**-0.4635** **<0.0001** **80**	**0.9885** **<0.0001** **81**	1 — 81									
Turbidity	**0.5544** **<0.0001** **80**	**0.7475** **<0.0001** **81**	**-0.4347** **<0.0001** **80**	**0.8720** **<0.0001** **81**	**0.8890** **<0.0001** **81**	1 — 81								
BOD$_{rate}$	0.0507 0.7218 53	0.0231 0.8682 54	-0.1104 0.4314 53	0.1134 0.4143 54	0.0732 0.5988 54	-0.0638 0.6467 54	1 — 54							
BOD$_5$	0.2798 0.0425 53	**0.4100** **0.0021** **54**	**-0.5516** **<0.0001** **53**	**0.6801** **<0.0001** **54**	**0.6325** **<0.0001** **54**	**0.4495** **0.0006** **54**	**0.5680** **<0.0001** **54**	1 — 54						
BOD$_{ult}$	**0.4067** **0.0025** **53**	**0.5074** **<0.0001** **54**	**-0.6659** **<0.0001** **53**	**0.8074** **<0.0001** **54**	**0.7734** **<0.0001** **54**	**0.6280** **<0.0001** **54**	0.1730 0.2108 54	**0.8781** **<0.0001** **54**	1 — 54					
TP	**0.5703** **<0.0001** **80**	**0.7422** **<0.0001** **81**	**-0.4986** **<0.0001** **80**	**0.9105** **<0.0001** **81**	**0.9120** **<0.0001** **81**	**0.8785** **<0.0001** **81**	0.0224 0.8725 54	**0.5174** **<0.0001** **54**	**0.6817** **<0.0001** **54**	1 — 81				
NH$_3$-N	0.1606 0.1548 80	**0.4161** **0.0001** **81**	-0.0557 0.6235 80	**0.4870** **<0.0001** **81**	**0.4383** **<0.0001** **81**	**0.3233** **0.0032** **81**	0.2882 0.0346 54	0.2421 0.0777 54	0.1358 0.3276 54	**0.4049** **0.0002** **81**	1 — 81			
NO$_3$-N	-0.1548 0.1703 80	-0.0560 0.6197 81	**0.6083** **<0.0001** **80**	**-0.3248** **0.0031** **81**	**-0.2900** **0.0086** **81**	-0.1001 0.3739 81	0.0444 0.7499 54	**-0.5057** **<0.0001** **54**	**-0.6401** **<0.0001** **54**	**-0.3904** **0.0003** **81**	-0.0829 0.4622 81	1 — 81		
SRP	0.1208 0.2858 80	-0.1074 0.3398 81	**-0.3342** **0.0024** **80**	0.0458 0.685 81	0.0546 0.6284 81	-0.0117 0.9175 81	-0.0337 0.8089 54	0.0415 0.7658 54	0.0594 0.6695 54	0.2252 0.0432 81	-0.1670 0.1361 81	**-0.4324** **<0.0001** **81**	1 — 81	
E. coli	-0.0271 0.8117 80	0.1130 0.3152 81	**-0.6398** **<0.0001** **80**	**0.4516** **<0.0001** **81**	**0.4197** **<0.0001** **81**	**0.4070** **0.0002** **81**	-0.0789 0.5708 54	**0.4583** **0.0005** **54**	**0.6225** **<0.0001** **54**	**0.6022** **<0.0001** **81**	0.1763 0.1153 81	**-0.6134** **<0.0001** **81**	**0.4739** **<0.0001** **81**	1 — 81

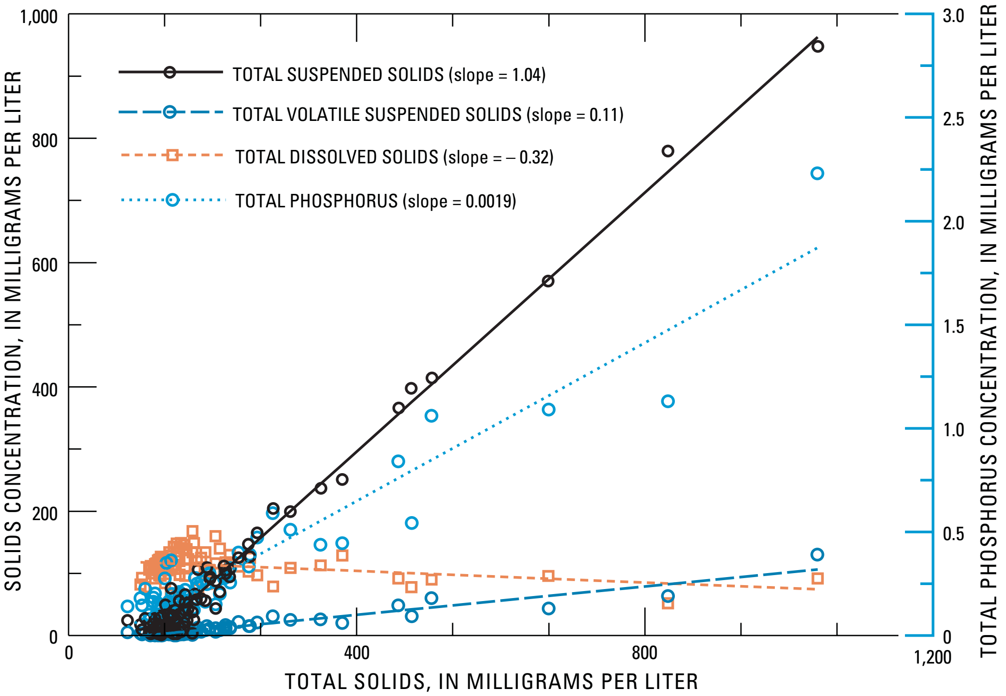


Figure 4. Correlation of total solids (TS) with total suspended solids (TSS), total volatile suspended solids (TVSS), total dissolved solids (TDS), and total phosphorus (TP) at all sampling sites during three storms, Fanno Creek, June 1998 to December 1999.

Clearly, solids concentrations are dependent on discharge and changes in discharge; however, these correlations indicate that discharge only accounted for about 35 to 50 percent of variation (taken as the square of the correlation coefficient, *rho*) in the concentrations of TS, TSS, and TVSS. It is well established that sediment concentration during stormflow in most streams tends to peak prior to the discharge peak (Leopold and others 1995), as was observed in Fanno Creek during this study (fig. 5). Portraying the chronological sequence of sediment concentrations as a function of discharge therefore can result in a loop (Dunne and Leopold, 1978) illustrating that for a given storm and discharge, sediment concentrations may be different on the rising and falling limbs of the hydrograph. During storm 1 in Fanno Creek, the only storm for which one distinct hydrograph was sampled, a clockwise loop was observed in TSS concentrations (fig. 6). This pattern suggests that sediment delivery was limited by available supplies (Richards, 1982; Ferguson, 1987; Knighton, 1998), and that therefore the sediment was more likely from nearby sources, such as previously deposited materials within the streambed, bank erosion, immediate channel margins, or small tributaries, than from more distant upland sources and transported to the stream by overland runoff (Richards, 1982). However, many of the observations in the literature were developed for unimpacted streams, and it is unclear whether a similar pattern in urban streams, with their distinctive hydrologic and morphological characteristics (flashy hydrographs, limited channel change due to reinforcements, upland impervious surfaces, and construction) can be interpreted in the same manner.

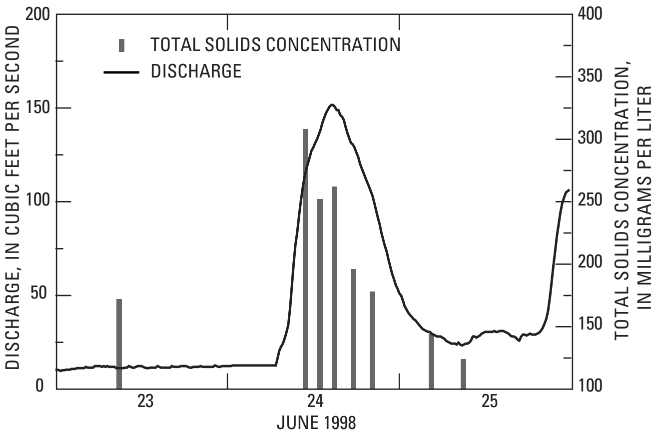


Figure 5. Discharge and total solids concentrations at Durham Road (14206900) during storm 1, Fanno Creek, Oregon, June 23-25, 1998.

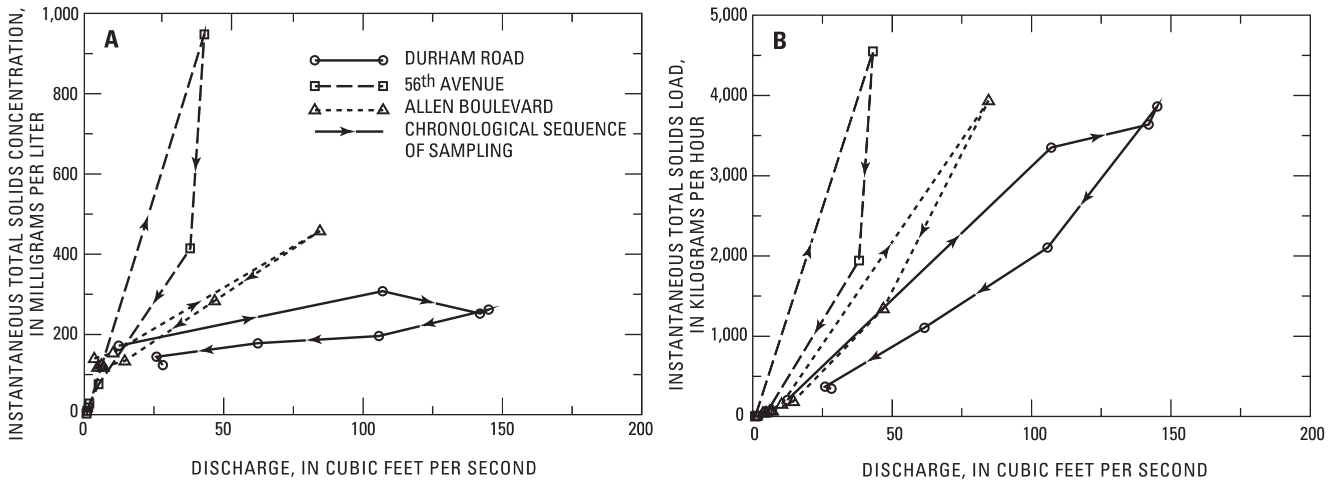


Figure 6. Relation of instantaneous concentrations and loads with discharge at all sampling sites during storm 1, Fanno Creek, Oregon, June 23-25, 1998. Arrows indicate the chronological sequence of sampling, with the loops illustrating that a given discharge can produce different sediment concentrations or loads depending on the stage of the hydrograph.

Techniques such as baseflow separation and semi-empirical models for characterizing the properties of sediment-discharge loops have been used elsewhere to evaluate the relative importance of point and nonpoint sources in stream basins (House and Warwick, 1998; SoloGabriele and Perkins, 1997). For this report, data are not available to conclusively ascribe different parts of the sediment or solute hydrographs to different processes or sources within the basin. However, it is reasonable to conclude that much of the sediment in transport in Fanno Creek was existing streambed material that was simply resuspended during increases in streamflow. If that conclusion is correct, it follows that multiple storms, if they are of similar magnitude as storm 1, would be required to transport sediment from the upstream reaches throughout the entire length of Fanno Creek and into the Tualatin River. Alternatively, existing storm drains that discharge to the creek could cause a short circuiting of normal sediment delivery routes, bringing sediment from upland sources to the stream faster than would otherwise occur. This process could confound the interpretation of data from this study and must be considered as an alternate explanation for the higher sediment concentrations on the rising limbs of hydrographs, particularly at the downstream sites (Allen Boulevard and Durham Road).

Although peak suspended-solids concentrations during storm 1 were highest at 56th Avenue, as illustrated by discharge-sediment concentration loops (fig. 6*A*), peak loads were similar at the three sites (fig. 6*B*). Furthermore, the cumulative amount of material transported was much greater at the Durham site owing to the higher discharges there and the larger contributing area (fig. 7*A*). Nonetheless, when normalized for the contributing area (that is, divided by the area of the upstream drainage basin), the yield of TS at 56th Avenue was much greater than the yield at Durham Road (fig. 7*B*). This may reflect a combination of the higher gradient near 56th Avenue, which results in higher velocities and energy to suspend particles, and differences in impervious surface area, riparian conditions, temporary construction activities, or other dynamic factors in urban environments. Additionally, several large ponds and some slow moving reaches between 56th Avenue and the Durham site provide opportunities for deposition of suspended material transported from upstream.

Sampling during storms 2 and 3 was conducted over fluctuating flows that were less indicative of an individual storm hydrograph than of common flow conditions during fall and winter in Pacific maritime urban communities (fig. 2). With these kinds of variations in streamflow, solids concentrations also were highly variable (fig. 8). Consequently, no particular pattern is discernible other than the general correlations indicated in table 4. TS concentrations did not increase significantly between 56th Avenue and Durham Road, despite the increase in loads, possibly due to the higher channel gradient at 56th Avenue and deposition sites, including ponds and wetlands, downstream.

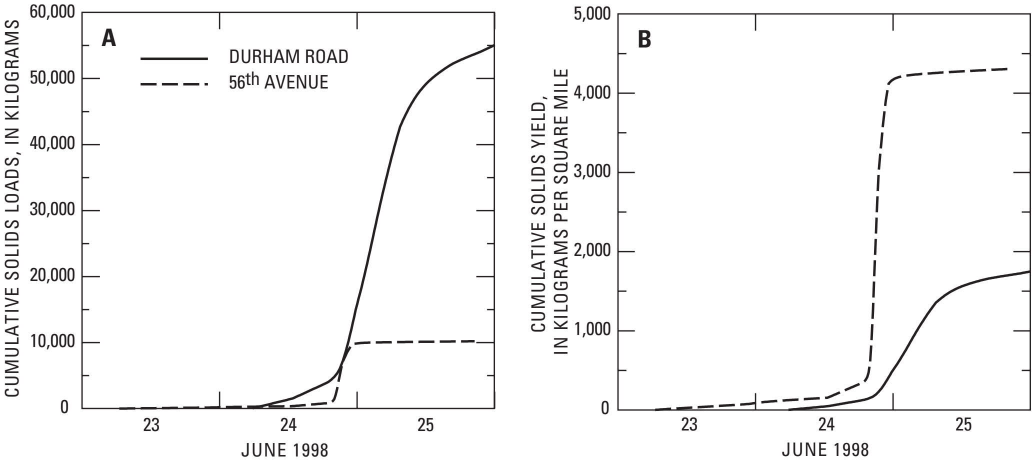


Figure 7. Cumulative loads and yields at 56th Avenue (upstream site; 14206900) and at Durham Road (downstream site; 14206950) during storm 1, Fanno Creek, Oregon, June 23–25, 1998.

[Cumulative loads and yields were calculated by simple indexing of concentrations at midpoints between times of samplings and multiplying by cumulative discharge obtained from 15 minute readings.]

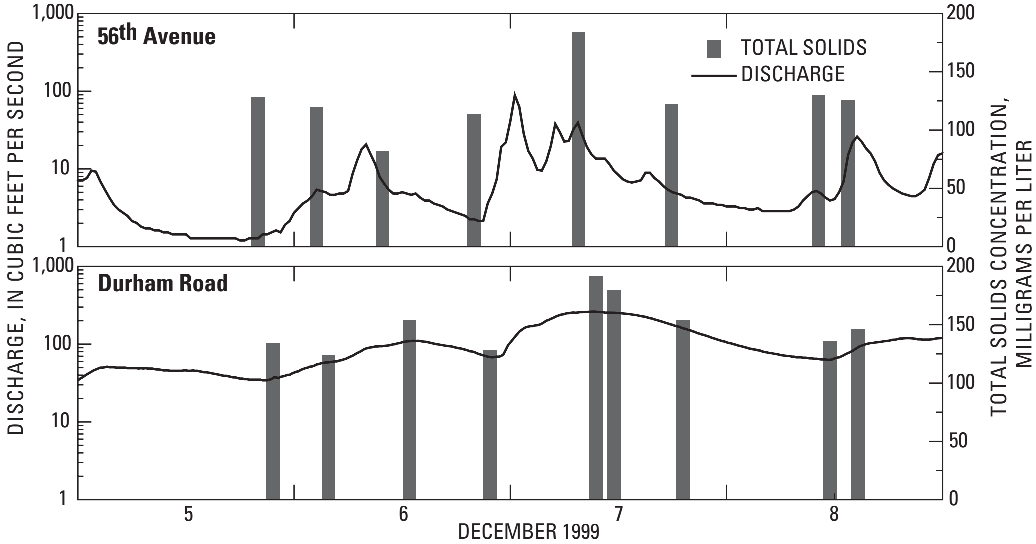


Figure 8. Discharge and total solids (TS) concentrations at 56th Avenue (14206900) and at Durham Road (14206950) during storm 3, Fanno Creek, Oregon, December 5-8, 1999.

Biochemical Oxygen Demand

Both BOD$_5$ and BOD$_{ult}$ were significantly correlated ($p<0.01$ – $p<0.0001$) with concentrations of solids (TS, TDS, TSS, TVSS, turbidity), some nutrients (TP and NO$_3$-N), and bacteria, although the BOD$_{rate}$, which is the first-order BOD loss rate and commonly is used in modeling, was correlated only with BOD$_5$ (table 4). Nonetheless, most correlations were relatively weak, the strongest correlation coefficients being 0.81 and 0.77 for BOD$_{ult}$ with TVSS and TSS, respectively. These associations are reasonable, because TVSS represents much of the material that decomposes to create BOD, and support the use of TVSS as a surrogate for BOD in TMDL considerations. Correlations of BOD with TDS and NO$_3$-N were negative, reinforcing the hypothesis that most of the BOD during storms is due to decomposable particulate material. Interestingly, the different measures of BOD were correlated only poorly with discharge (for BOD$_5$, $p<0.05$), which is likely an outcome of variability associated with the differences in solids concentration over the discharge hydrograph (figs. 5 and 6).

Bacteria

The State of Oregon, following guidelines from the U.S. Environmental Protection Agency (USEPA) has set a standard of no more than 406 *E. coli* colonies per 100 mL in a single sample of stream water (Oregon Department of Environmental Quality, 2001a). Bacterial counts exceeded the single sample standard in most of the samples taken during this study, including each sample from storm 1. Overall, *E. coli* counts were higher during storm 1 than during any other storm (fig. 9), most likely as a result of lower stormflows and

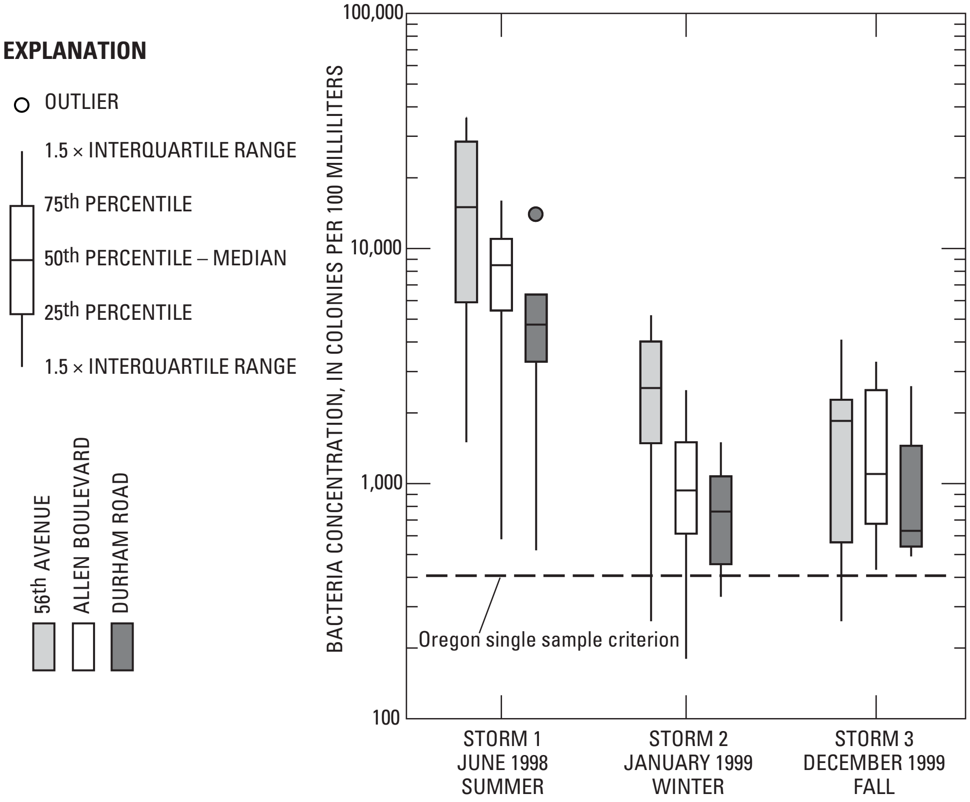


Figure 9. *E. coli* bacteria concentrations at each sampling site during three storms, Fanno Creek, Oregon, June 1998 to December 1999.

Dashed line shows the State of Oregon *E. coli* single-sample criterion. Allowable cumulative concentrations from point sources in storm runoff are 5,000 colonies/100 mL during winter and 12,000 colonies/100 mL during summer, as defined by a Total Maximum Daily Load (TMDL) for the Tualatin River Basin (Oregon Department of Environmental Quality, 2001b).

warmer water temperatures in the days and weeks preceding and during that storm (median 15.2 ^{o}C) than during storms 2 and 3 (medians 8.2 and 8.4 ^{o}C, respectively). *E. coli* counts (50 to 90 percentiles) also were higher at 56th Avenue than at either of the downstream sites during storm 1 and to a lesser extent (medians only) during storms 2 and 3. Bacteria were weakly associated with TSS and turbidity ($\rho \approx 0.41$ for both — see table 4), so the relatively high solids concentrations at 56th Avenue compared to the downstream sites, particularly during storm 1, may partially explain the higher bacteria counts at that site. Bacteria in streams are commonly associated with suspended particles (Schillinger and Gannon, 1985; Hunter and others, 1999), either because they were transported to the streams attached to the particles, they were bound to streambed sediment (Matson and others, 1978) that has been resuspended (Grimes, 1975; Matson and others, 1978; Hunter and others, 1999) or because of specific bacterial affinities for sediment particles (Scholl and Harvey, 1992; Mills and others, 1994; Bolster and others, 2001) that may occur in the water column.

E. coli counts were weakly correlated with TSS, turbidity, BOD_5 and BOD_{ult}, TP, and SRP, and were not correlated with discharge or TS. Negative correlations with *E. coli* were found for TDS and NO_3-N, reinforcing the positive association between *E. coli* and particulate material. Although bacterial transport has been correlated with stream stage (Hunter and others, 1992) and discharge (Davis and others, 1977) during storms and also tends to be associated with the transport of suspended sediment (Davis and others, 1977), these associations are not always evident (Qureshi and Dutka, 1979). In Fanno Creek, the lack of correlations may indicate that contributing sources or processes for bacteria were different from storm to storm. In an analysis of microbiological data from a national database, Francy and others (2000) also found *E. coli* concentrations, at a mixture of urban and agricultural sites, to be uncorrelated with discharge (or temperature), though they were correlated with concentrations of suspended sediment, TP, and NO_3-N.

Bacterial sources

Potential sources of bacteria to streams are numerous. Reports from several studies (Young and Thackston, 1977; Hunter and others, 1992, 1999) have indicated that upland soils are able to maintain a pool of bacteria and other pathogens that are transported to streams during runoff, often with higher concentrations during summer (Hunter and others, 1999). Other upland sources have included sewage outfalls (Matson and others, 1978; Jacobs and Ellis, 1991), septic systems (Young and Thackston, 1977), and wastes from birds, dogs (Young and Thackston, 1977), and other animals. In urban sections of the Boise River, Idaho, principle bacterial sources (identified semiquantitatively by analysis of bacterial DNA) included birds (about 30 percent), pets (about 22 percent), and humans (about 17 percent) (CH2MHill, 2002). However, in that case the study reaches contained sewage outfalls, whereas Fanno Creek contains storm drains but not sewage outfalls. Thus, the relative contribution of human sources to indicator bacteria in Fanno Creek may be less than in the Boise River. McCarthy (2000) suggested that domestic pets, birds, and improperly managed wildlife may have been important sources of *E. coli* to various Tualatin River tributaries, including Fanno Creek, during summer low-flow conditions.

Qureshi and Dutka (1979) found that ground-water seepage into storm drains in urban areas, even during non-runoff periods, contained sufficiently large quantities of bacteria to confound correlations with streamflow. Other studies have implicated streambed sediment and its resuspension (Grimes, 1975; Matson and others, 1978), and suspended sediment in general (Davis and others, 1977; Schillinger and Gannon, 1985; Francy and others, 2000; Embrey, 2001), as sources and principal transport vectors for bacteria.

In this study, data are not available to conclusively determine specific sources of bacteria during storms in Fanno Creek. Correlations of *E. coli* with TSS, TVSS, turbidity, and TP indicate associations with particulate material, but it is unclear if that particulate material resulted from soils transported to the stream from upland sources or from erosion and resuspension of sediment already in the streambed. To the extent that clockwise sediment-discharge loops, as observed in this study, suggest a limit to the available sediment supply during storms, bacteria associated with particulates may have primarily come from resuspension of streambed sediment (Grimes, 1975; Matson and others, 1978). However, there also is an indication that some particulates sampled at 56th Avenue may have originated in upland areas, on the basis of higher concentrations (fig. 6*A*) and yield (fig. 7*B*) at that site, so it is possible that bacteria associated with those particulates also may have come from upland sources. Nonetheless, these associations cannot be fully determined without additional data collection designed to answer specific questions about bacterial sources.

E. coli in streams are considered indicators of waste contamination by warm-blooded animals (Embrey, 2001). Aside from the suggestion that the area upstream from 56th Avenue may have been the largest contributor of *E. coli* to Fanno Creek, data from this study are insufficient to determine geographic sources of bacteria or the types of animals from which the bacteria originated. Future studies to identify possible sources and organisms for fecal indicator bacteria might benefit from the emerging field of Bacterial Source Tracking (BST) (Field and Bernhard, 2001; Hagedorn, no date); which uses molecular techniques to match genetic material of the sampled bacteria with known, species-specific "fingerprints" of different organisms. Use of these techniques might help to determine, for instance, whether the main bacterial source is avian, canine, human, or other species.

Phosphorus

At the time of this investigation, the Total Maximum Daily Load in effect for the Tualatin River Basin, including tributaries, required that surface-water concentrations of TP remain less than or equal to 0.07 mg/L as a monthly median during the period from May 1 through October 31 (Oregon Department of Environmental Quality, 1994a). The subsequent revision of the TMDL (Oregon Department of Environmental Quality, 2001b) sets a median summertime TP concentration criterion of 0.13 mg/L in Fanno Creek; during other times of the year TP is not regulated. During this study, TP concentrations in samples from Fanno Creek equaled or exceeded 0.07 mg /L of P in all but one sample from storm 3 (December 1999) at Durham Road (fig. 10).

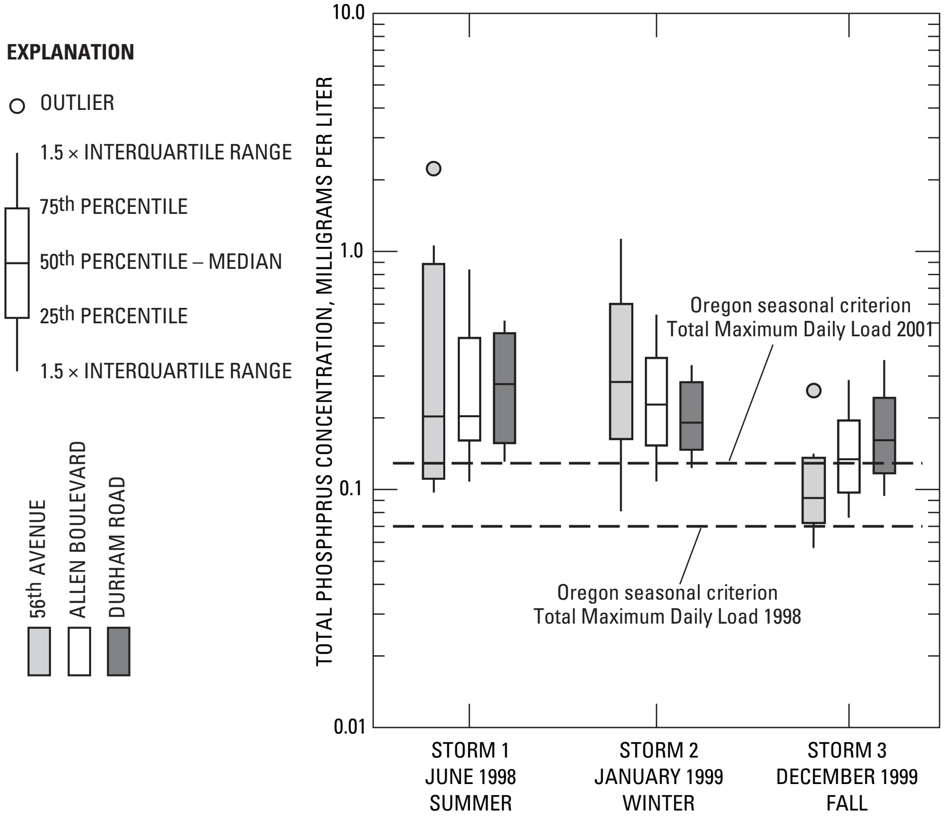


Figure 10. Total phosphorus (TP) concentrations at each sampling site during three storms, Fanno Creek, June 1998 to December 1999.

Dashed lines indicate the median concentration allowed by the Total Maximum Daily Load (TMDL) in effect at the time of this study (1998–99) and the revised TMDL (2001), respectively.

TP concentrations also exceeded the updated criterion concentration of 0.13 mg/L in more than 22 of the 24 samples from storm 1. Concentrations were similar among sites, although variability tended to decrease in a downstream direction, a finding that is likely a result of the flashy nature of the upstream sites such as Fanno Creek at 56th Avenue. The highest overall concentrations of TP tended to occur at 56th Avenue, but many of the lowest concentrations were at that site as well.

Concentrations of SRP were consistently much lower than those for TP, indicating that most of the phosphorus being transported was in the particulate phase. During all three storms, SRP was relatively stable, varying less than an order of magnitude, whereas discharge, TS, and TP fluctuated by larger amounts. Figure 11 illustrates this phenomenon during storm 1; similar patterns were observed during storms 2 and 3. In fact, long-term data collected by CWS near the mouth of Fanno Creek (near the Durham Road site used in this study) indicate a robust seasonal pattern for SRP, with peak concentrations occurring in late summer, minimum concentrations in late winter and early spring, and overall variability that is substantially less than for TP (fig. 12). During low flows, SRP can constitute more than one-half of TP in the stream, whereas during stormflows in winter SRP can be only a small fraction of TP. In the current study, SRP was only poorly correlated with TP ($p<0.05$, table 4), was not correlated with discharge, TS, or TSS, and was negatively, but weakly, correlated ($p<0.01$) with TDS and nitrate concentrations. This pattern indicates that the sources for SRP are not strongly associated with those for TP or for particulates, nor were they strongly diluted by increased flow. Much of the SRP may instead have originated with a relatively constant shallow ground-water discharge, and higher flows during rainstorms may partly accelerate a flushing of local ground water into the streams.

The consistently low SRP concentrations in the stream (median 0.046 mg/L) probably do not reflect direct phosphorus deposition in precipitation; limited available data indicate that phosphorus concentrations in precipitation in the Pacific Northwest are much lower than was observed in this study. For instance, in the Bull Run watershed, a pristine drinking water supply for the City of Portland in the Western Cascade Mountains, SRP in precipitation is typically less than 0.01 mg/L (U.S. Geological Survey, 1983–93), and in the Andrews Experimental Forest near Eugene, Oregon, concentrations are typically about 0.006 to 0.015 mg/L (Sollins and others, 1980; Martin and Harr, 1988). Data are limited for SRP in precipitation in the Portland Metropolitan Area, but samples collected and analyzed at the USGS Oregon District Laboratory in November 2001 had SRP concentrations of 0.001 mg/L. Thus, another source, such as ground water, is likely for the SRP measured in the stream.

The proportion of soluble P in the stream, calculated as the ratio of SRP:TP, was mostly in the range of about 5 to 45 percent during storms and was negatively correlated with the log of discharge (fig. 13); thus, at higher discharges, an increasing amount of the phosphorus in the stream was in particulate form. Yet, the amount of soluble phosphorus in transport, (load, in kilograms per day) continued to increase as the discharge increased, meaning that a larger mass of SRP was being discharged to the stream even if concentrations remained relatively unchanged. During summer low-flows, McCarthy (2000) found that the proportion of soluble phosphorus in Fanno Creek ranged from 30 to 50 percent, similar to that seen in this study. Maximum SRP concentrations in the summer, typically reaching about 0.1 mg/L at low flow, are indicative of the likely deep ground-water source in the basin (fig. 12). These findings also are consistent with the hypothesis that much of the SRP during fall and winter storms in Fanno Creek originated as ground water. Investigations of hydrologic flowpaths in Fanno Creek, including differentiating between deep and shallow ground-water inputs during storms, could be aided through the use of stable isotopes of oxygen (Buttle and others, 1995; Iqbal, 1998; Brown, and others, 1999), hydrogen (Turner and others, 1987; Kendall and others, 1995), and/or sulfur (Krouse and Mayer, 2000), or with ground-water dating techniques (Cook and Herczeg, 2000).

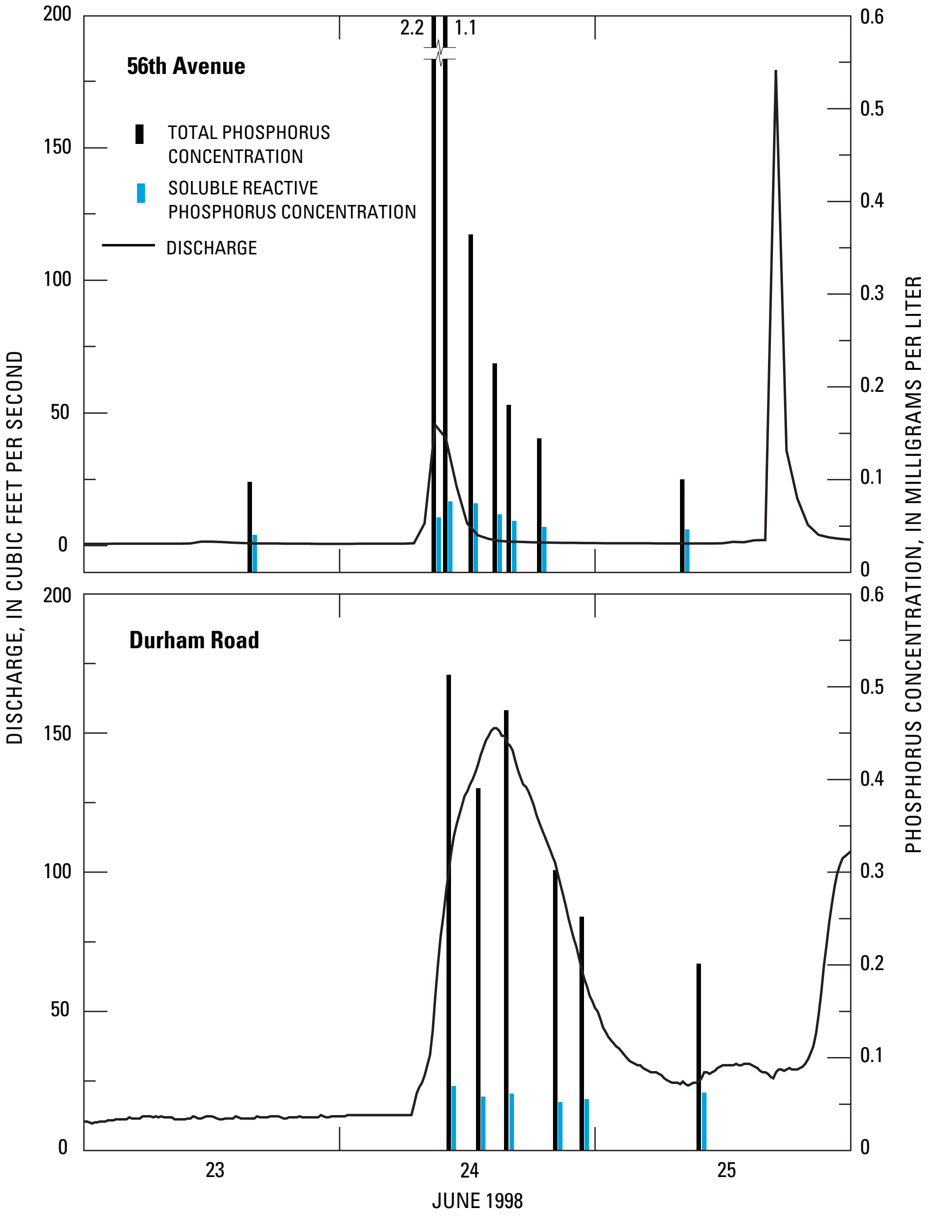


Figure 11. Variability of total phosphorus (TP) and soluble reactive phosphorus (SRP) concentrations with discharge at 56th Avenue (14206900) and at Durham Road (14206950) during storm 1, Fanno Creek, Oregon, June 23-25, 1998.

Y-axis minimum for discharge at 56th Avenue is shifted below zero to allow low flow to be portrayed.

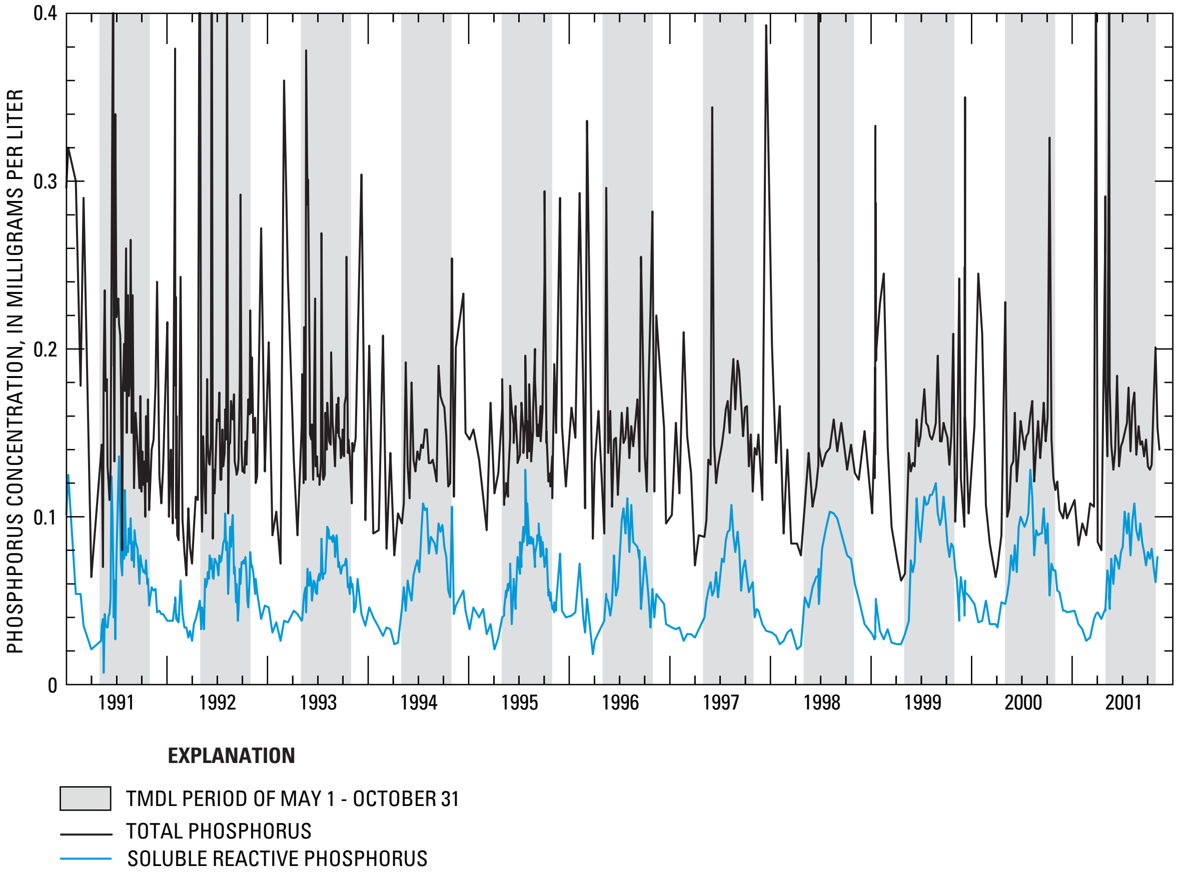
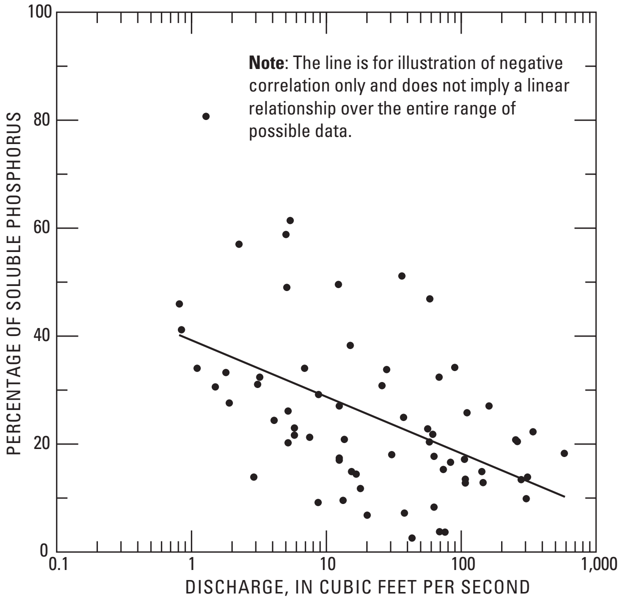


Figure 12. Seasonal patterns in monthly phosphorus concentrations in Fanno Creek, Oregon, 1991–2001.



Note: The line is for illustration of negative correlation only and does not imply a linear relationship over the entire range of possible data.

Figure 13. Relation of soluble fraction of phosphorus with discharge at all sampling sites during three storms, Fanno Creek, Oregon, June 1998 to December 1999.

Percentage of soluble phosphorus is calculated as 100* (SRP/TP).

In contrast to soluble phosphorus, TP was significantly correlated ($p<0.001$), either positively or negatively, with most of the constituents analyzed except SRP (table 4). The relations between TP and various measures of particulates (TS, TVSS, TSS, and turbidity) were particularly strong, with Spearman's *rho* (ρ) values ranging from 0.74 to 0.91, further indicating that sources of TP were largely particulate, either as erosion and overland runoff, bank erosion, or resuspension of bed materials. For example, the similarities between TS and TP are evident when comparing figures 5 and 11. Additionally, a clockwise looping pattern of TP concentrations with discharge during storm 1 (fig. 14) was very similar to the pattern of TS concentrations at the same sites (fig. 6), indicating concentration differences between the rising and falling limb of the storm hydrograph. TP was negatively correlated with TDS and NO_3-N, suggesting dilution of those parameters as TP and other particulates increased during storms.

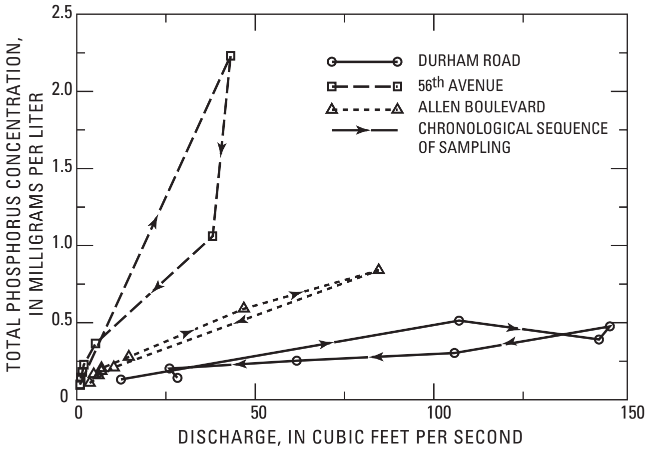


Figure 14. Relation of total phosphorus (TP) concentrations with discharge at all sampling sites during storm 1, Fanno Creek, Oregon, June 23-25, 1998.

Arrows indicate the chronological sequence of sampling, with the loops illustrating that a given discharge can produce different phosphorus concentrations depending on the stage of the hydrograph.

Nitrogen

Concentrations of NH_3-N, which were mostly between 0.03 and 0.1 mg/L, were positively correlated with measures of particulates (TS, TVSS, TSS, turbidity) and TP, and negatively correlated with NO_3-N. NH_3-N is commonly associated with the decomposition of the organic fraction of particles in streams, such as leaf litter and other vegetative material from riparian and upland sources or algal and plant material from within the stream channel. The strongest correlation coefficient for NH_3-N was with TVSS (*rho*=0.487), probably reflecting this association. The highest NH_3-N concentrations, and most variable, occurred during the summer storm (storm 1), probably also reflecting accelerated decomposition of organic material.

NO_3-N concentrations were lowest during the summer storm in June 1998 (fig. 15), possibly reflecting nitrate consumption by upland plants, denitrification by microbial communities in the stream

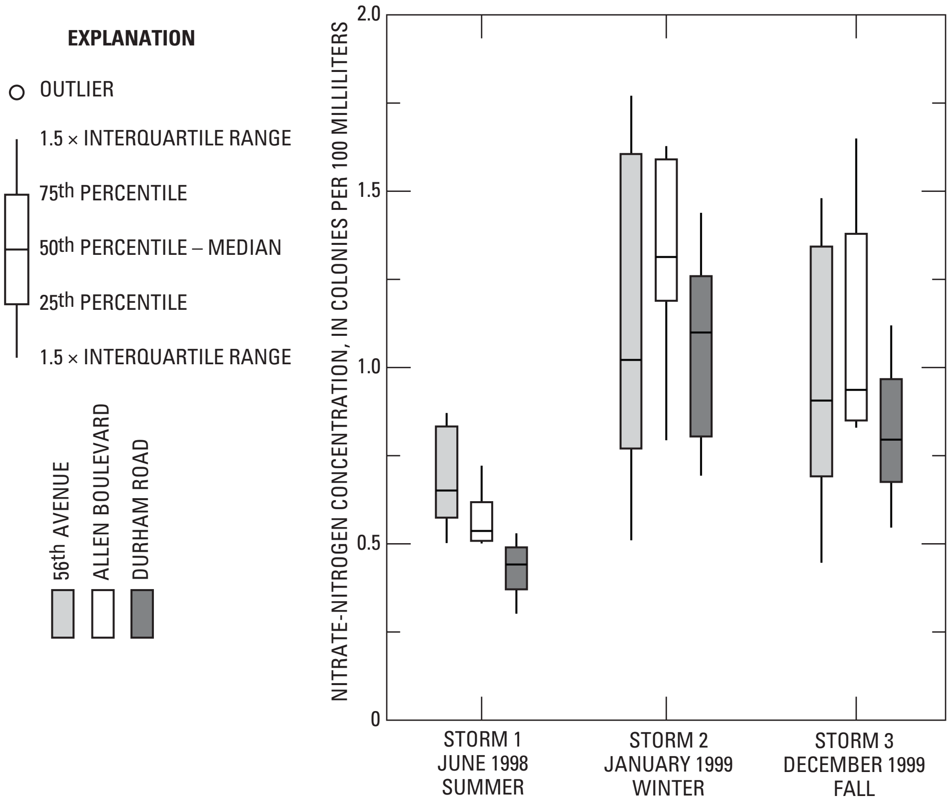


Figure 15. Nitrate nitrogen concentrations at each sampling site during three storms in Fanno Creek, Oregon, June 1998 to December 1999.

margins, and/or uptake by algae and aquatic macrophytes in the stream. Concentrations during the fall and winter storms were higher than during the summer storm, with concentrations during the winter storm being the highest overall. This seasonal pattern in Fanno Creek, with low nitrate concentrations in the summer and high concentrations during winter runoff, is clearly evident when monthly monitoring data from many consecutive years are examined (fig. 16). Wintertime increases in streamwater NO_3-N concentrations are common in Willamette Basin streams. Bonn and others (1996) demonstrated that median stream NO_3-N concentrations peaked in December through February in the basin, and Rinella and Janet (1998) observed a similar pattern in both small and large streams in the valley. The source for this winter NO_3-N may be shallow ground water, containing NO_3-N resulting from fertilization, nitrification, and microbial mineralization of organic nitrogen.

During all three storms in the current study, the lowest NO_3-N concentrations tended to occur at the most downstream location, Durham Road, whereas the variability was the greatest at 56th Avenue, the most upstream location studied. Median concentrations during storms 2 and 3 were typically highest at Allen Boulevard. The reasons for decreased NO_3-N concentrations at Durham Road are unknown but may by related to increased flow and therefore more dilution at that site.

As a highly mobile ion that is often associated with ground water, NO_3-N concentrations might be expected to increase with increasing stream discharge if ground water discharge increases during stormflow; however, such concentration increases with stream discharge are not evident in Fanno Creek. Overall, NO_3-N was negatively correlated with TVSS, TSS, BOD_5, BOD_{ult}, TP, SRP, and *E. coli* bacteria (table 4), was positively correlated with TDS and DO ($p<0.0001$, $rho=0.56$, not shown in table 4), and was not correlated

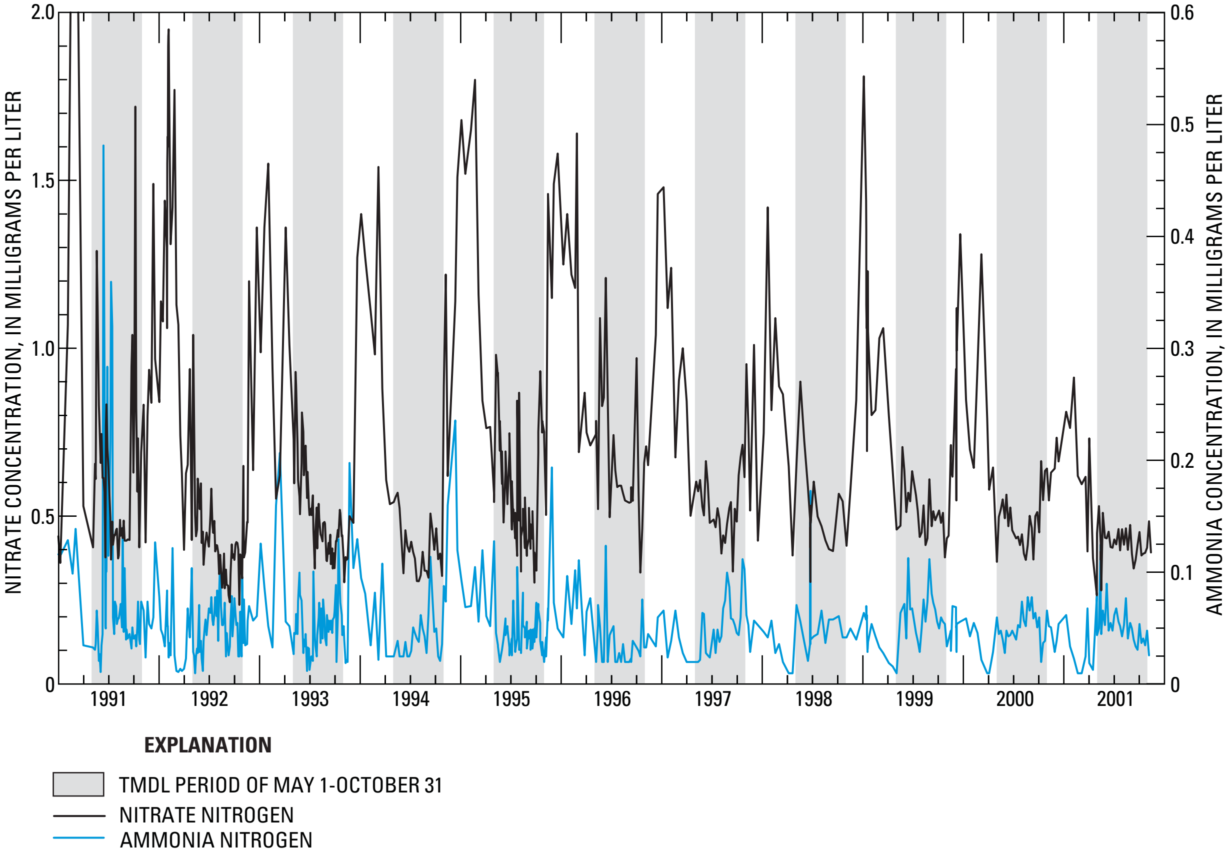


Figure 16. Seasonal patterns in monthly nitrate and ammonia nitrogen concentrations in Fanno Creek, Oregon, 1991–2001.

with discharge. Although a simple correlation is not evident between NO_3-N and discharge, there did appear to be a complex relation, whereby the *direction of change* in NO_3-N was opposite the *direction of change* in flow (fig. 17). Thus, NO_3-N was typically highest at a given site during lower flows, or just prior to an increase in flow, and concentrations decreased as flows increased. The lowest concentrations tended to occur just after the peak in discharge, with subsequent increases in concentrations as discharge continued to recede, probably reflecting dilution at the peak of the storm and subsequent flushing of shallow ground water between storm events.

The lack of a significant overall correlation between flow and NO_3-N may simply have been due to the fact that, unlike storm 1, samples during storms 2 and 3 were collected during varying flow conditions rather than over one discreet rise and fall sequence in stage. Additionally, NO_3-N concentrations might be dependent on other factors, such as antecedent flow conditions, dilution by rainfall, and the character of inflowing ground water. The patterns observed during storm 1 suggest that dilution, or perhaps some other process, was important (fig. 17). Deep ground water in the Fanno Creek and larger Tualatin River basins is known to be reduced, with relatively high levels of NH_3-N, low DO, and low NO_3-N (Kelly and others, 1999).

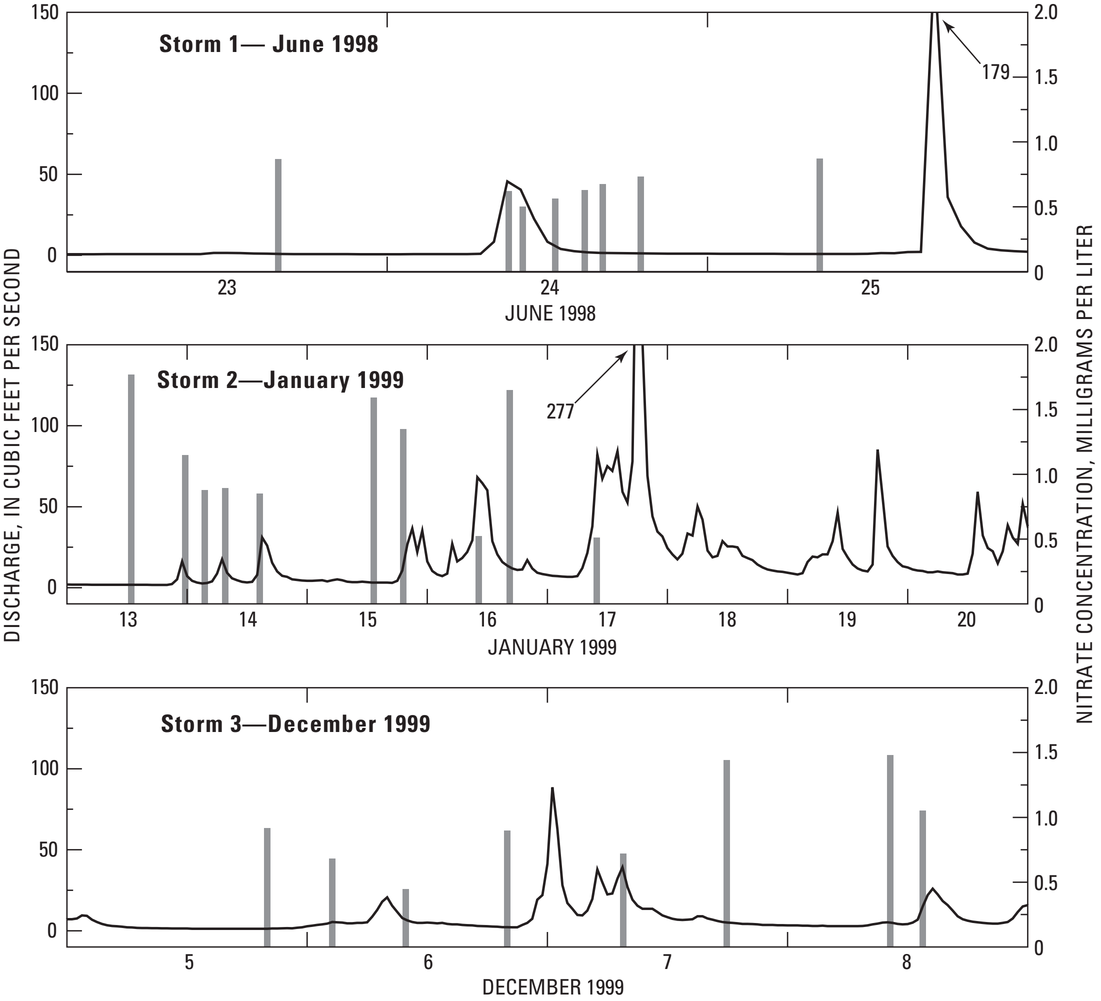


Figure 17. Nitrate concentrations at 56th Avenue (14206900) during three storms, Fanno Creek, Oregon, June 1998 to December 1999.

Y-axis minimum for discharge is shifted below zero to allow low flow to be portrayed.

Insufficient data were collected during this study to further investigate the hypotheses presented here regarding ground-water interactions with Fanno Creek during individual storms, and the possible sources of phosphorus or nitrogen. Multiyear data reveal that the likely sources for SRP appear to be deep ground water during the summer, with a possible shallow ground-water flushing and diluting that occurs during storms, whereas nitrate increases during winter as shallow ground-water exchange increases, but decreases during summer. Nitrate may be high during winter when nitrification and mineralization in the soils are increased and uptake decreased, but lower during summer due to high uptake in soils and streams and decreased nitrification. Therefore, the two nutrients apparently have different source waters (deep and shallow ground water), as well as different nonconservative processes that affect their occurrence and concentrations during different seasons. Future investigations to clarify these processes could include explicit measurement of nutrient dynamics in ground water in riparian and near-stream environments, the response of ground water to precipitation, and further definition of hydrologic pathways during storms.

SUMMARY

Multiple water samples were collected at three sites in Fanno Creek, an urban creek in Portland, Oregon, during three storms (one each in early summer, fall, and winter) from 1998 to 1999. Samples were analyzed for nutrients, bacteria, various measures of particulates and solids in water, and biochemical oxygen demand (BOD). Stream discharge was continuously gaged at two of the sites (Fanno Creek at 56th Avenue, Fanno Creek at Durham Road), and at the third site (Fanno Creek at Scholls Ferry Road near Allen Boulevard) it was estimated on the basis of instantaneous staff plate readings and discharge measurements. Discharges during the sampling periods were not exceptionally high but were typical of most other storms during their respective seasons, with the first storm (June 1998) having the most discrete, single storm hydrograph, and the winter and fall storms (January and December 1999) each having highly variable flow with several discharge peaks. Discharge at 56th Avenue was the most flashy due to its relatively high gradient, and discharge at downstream sites, particularly Durham Road, was somewhat attenuated.

A general matrix of Spearman’s correlations among all variables and all samples indicated that measures of particulates in water (Total Solids [TS], Total Suspended Solids [TSS], Total Volatile Suspended Solids [TVSS], and turbidity) were significantly and positively correlated ($p<0.01$) with discharge, total phosphorus (TP), BOD, and (with the exception of TS) *E. coli* bacteria. These correlations indicated that phosphorus, bacteria, and oxygen-demanding substances were associated largely with particulate materials suspended and transported downstream by the storm runoff. Controlling these particulate materials may therefore offer an opportunity to control water-quality constituents that are regulated under a Total Maximum Daily Load (TMDL) that has been promulgated for Fanno Creek. TSS, as a principle measurement of solids that is regulated under the TMDL, was positively correlated with TP (*rho* about 0.9) and discharge (*rho* about 0.7), was weakly correlated with *E. coli* bacteria (*rho* about 0.4), weakly and negatively correlated with nitrate-nitrogen (*rho* about -0.3), and was not correlated with soluble reactive phosphorus (SRP). Furthermore, the pattern of higher particulate concentrations on the rising limb of the stream hydrographs indicated that most of the suspended sediment may have been supplied primarily from in-stream processes (bank erosion or resuspension of bed sediment) and/or from nearby upland sources rather than transport from distant upland sources. Existing storm drains may have short-circuited the routing process, however, so some of the upland sources may have contributed disproportionately to the rising limbs of the discharge and sediment hydrographs.

Concentrations of *E. coli* bacteria exceeded the State of Oregon single sample criterion in almost all samples. TP concentrations exceeded the TMDL guidance criterion in most samples. Concentrations of TP, TS, and *E. coli* were greatest and most variable at 56th Avenue, the most upstream site. Despite increasing discharges, peak loads were similar at upstream and downstream sites, indicating that sources along the creek were offset by deposition or other losses along the length of the creek, or that additional sources from upstream to downstream were minimal.

Dissolved constituents, including total dissolved solids (TDS), SRP, nitrate-plus-nitrite-nitrogen (NO_3-N), and ammonia (NH_3-N), were not correlated with discharge, although NH_3-N was correlated with measures of particulates (TS, TSS, TVSS) and with TP. Sources for NH_3-N may therefore have included particulate organic material transported by the storm. The pattern of SRP concentrations was robust, with considerably less variation over storm hydrographs than for TP, although the overall SRP load did increase as discharge increased. These patterns suggested a ground water source for SRP in Fanno Creek that is separate from the sources for particulate P captured by the TP analysis.

In general, concentrations of NO_3-N were lower during the summer storm than the fall and winter storms, possibly reflecting plant or algal uptake in riparian areas and in the stream, or denitrification by microbial communities in stream margins, during the growing season. NO_3-N concentrations typically were highest during fall and winter baseflow, with concentrations being temporarily diluted during storm runoff, a pattern common to streams in the Willamette River Valley. Correlations between NO_3-N and TVSS, TSS, BOD, TP, SRP, and *E. coli* bacteria were negative and statistically significant, and NO_3-N was positively correlated with TDS, reflecting the dilution of NO_3-N during storm runoff.

Analysis of data in this study has posed additional questions regarding nutrients and particulates in Fanno Creek that could merit additional investigation. There are indications that ground-water flow is a variable, but important, source for phosphorus and nitrate during low- and high-flow periods, respectively. Naturally occurring, stable isotopes could be used to investigate interactions of ground water and stream water, and nutrient dynamics associated with them, to determine the relative importance of deep and shallow flow paths, and to refine the understanding of the role of precipitation in the stream's hydrologic response during storms. Suspended sediment appears to originate from in-stream or near-stream sources, but these conclusions are tenuous because of a lack of data targeted specifically at this question, and because the response of sediment to high flow has been poorly documented in highly modified, urban streams such as Fanno Creek. Additional synoptic sampling, preferably during several storms and at many sites, could help to define the relative importance of tributaries and upstream regions compared with downstream and in-stream sediment sources. Sources of bacteria also were difficult to ascribe from the data in this study, but new microbiological techniques, such as the use of RNA and DNA signatures to identify contributing animals (including humans), may provide opportunities for more definitive investigations. Additionally, streambed sediments could be sampled for bacteria during non-storm periods to determine the potential size of the bacterial "pool" that is resuspended and transported downstream during storms. Finally, data on near-stream land use, including the size and character of riparian areas, could be used in conjunction with various investigations mentioned above to help refine the role of riparian vegetation in reducing inputs of sediments, bacteria, and nutrients. These and other studies targeted at specific questions could help refine the understanding of the effects of different management options on the sources and transport of particles, nutrients, and bacteria in Fanno Creek.

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APPENDIX A.—QUALITY ASSURANCE PROGRAM

Quality Assurance Samples

Various types of quality control samples were collected and analyzed in addition to the environmental samples. These included equipment blank, method blank, end-plate blank, trip blank, replicate, field split, laboratory split, interlaboratory split, and standard reference samples as described below:

> **Equipment Blank Samples—**Used to test for contamination introduced by the sampling equipment, one equipment blank was collected per storm event. Laboratory deionized (DI) water was poured into sampling containers that had been cleaned according to standard procedures, and was subsequently composited, subsampled, filtered, and analyzed identically to environmental samples. For bacteria samples, a special buffer media rather than DI water was used for blank samples. Equipment blank samples were initially prepared in the field at a sampling site.
>
> **Method Blank Samples—**Used to test for contamination introduced during analysis, method blank samples have been used routinely as part of the quality assurance program in the CWS water-quality laboratory. Laboratory deionized water is poured directly into sample containers in the laboratory, and subsequently processed along with environmental samples using standard procedures.
>
> **End-plate Blank Samples—**Used to determine if any carryover occurs in the laboratory from one *E. coli* filter to the next, this test was used after processing all bacteria samples from a particular storm event. Sterile phosphate buffer media (a nutrient mixture typically used to grow bacterial cultures) was passed through the stainless steel apparatus used to filter bacteria samples, and the resulting filtrate tested for bacterial colonies as any standard sample.

Trip Blank Samples—Used to test for contamination obtained in transit, one trip blank was included per storm event. Trip blanks were samples of DI water or sterile *E. coli* phosphate buffer media that were prepared in the laboratory prior to sampling, and transported to and from the field during sampling, with subsequent analysis according to standard procedures. Trip blanks were not processed through any of the sampling equipment.

Sampling Method Replicate Samples—At the Durham Road site, one additional sample per storm was collected using standard USGS depth- and width-integrated clean sampling techniques and equipment. Results from this sample were used as a check against sampling bias from the weighted bottle sampler. The weighted bottle sampler was also used for multiple vertical pulls across a stream transect, with the individual subsamples composited together.

Sequential Replicate Samples—Used to test the replicability of the sampling method and the variability over the hydrograph. One replicate sample was collected during each storm using the same methods as ambient environmental samples, but was collected immediately after the environmental sample was taken.

Field Split Samples—Used to assess the combined variability of field and analytical methods, an environmental sample was collected and split into two samples in the field (from the churn splitter) for separate analysis.

Laboratory Split Samples—Used to assess the variability in the analytical method, environmental samples were split in the laboratory and analyzed separately.

Interlaboratory Split Samples— Used to assess the accuracy of the analytical method, one sample per storm was split in the field for analysis by separate laboratories. Split samples were processed by the Oregon Department of Environmental Quality (ODEQ) laboratory in Portland and the USGS National Water Quality Laboratory in Denver, Colorado (NWQL). Samples for dissolved constituents provided to the USGS and ODEQ laboratories were filtered using 0.45 micron pore-size capsule filters according to standard USGS protocols (Wilde and Radtke, 1998). Samples for *E. coli* were analyzed by the Oregon Health Division Laboratory.

Standard Reference Samples— Used to assess the accuracy of the analytical method, a sample of known concentration of an analyte in blank water is submitted by the USGS to the CWS laboratory on a regular basis. The CWS accepts Standard Reference Samples (SRS) monthly from the Oregon District and semiannually from the USGS Branch of Quality Systems (BQS). Samples from the Oregon District are submitted only to the CWS laboratory and to the NWQL, whereas samples from the BQS program are compared with dozens of laboratories nationally.

Quality Assurance Results

Results of quality control tests are provided in table A1 and are discussed below.

Blanks—On the basis of blank samples, there was no evidence of contamination that would compromise the analysis of Fanno Creek storm data. Among all chemical analyses of equipment and trip blanks (n=8), the only detection was for nitrate-N at a concentration of 0.015 mg/L during storm 2, a value that was close to the analytical reporting limit of 0.01 mg/L during that period and below the reporting limits for the other storms sampled. Of the physical analyses (turbidity and suspended solids), there were a few low-level detections at and slightly above the detection limits. These were more than an order of magnitude below environmental concentrations observed during storms. Hence, bias from low-level contamination did not interfere with the analysis of data for this report.

Replicates and splits—Data from all replicate and split tests are shown in table A1. Relative difference between replicates was greater than 10 percent in approximately a quarter (45 of 175 replications) of the analyses, but was generally acceptable overall. Most of the higher relative differences originated from variability of field processing and from differences among laboratories. The field sampling methods (method replicates) tended to have similar or lower variability than simple splits of individual samples in the field (field splits), which indicates that representative samples could be obtained reliably using the weighted bottle sampler as was done for all environmental samples.

Differences among laboratories are not surprising, and the opportunities for differences are greater by including three replicates (CWS, ODEQ, and USGS laboratories) in the tests from January and December 1999 rather than two replicates as in most other types of QA tests performed (table A1). Among the nutrient analyses, the ODEQ and USGS labs appeared to be intermittently biased high for NH_3-N, and the CWS lab was consistently highest for NO_3-N and SRP. There was no discernible pattern for TP. Only 2 bacteria samples were split between CWS and ODEQ (actually, the Oregon Health Division). One was qualitatively coded by ODEQ as having a concentration greater than 600, a result that is consistent with the value 2,100 counts/mL reported by CWS. For the other sample, CWS’ result was over an order of magnitude greater than ODEQ’s. On the basis of these limited data, the CWS lab appeared to produce higher counts of *E. coli* bacteria than the other laboratory. However, the data are insufficient to conclusively compare laboratory performance for bacteria samples.

One sequential replicate, from 56th Avenue on June 24, 1998, indicates the high temporal variability in water chemistry during storms (table A1). During the 20 minutes that elapsed between the primary sample and the sequential replicate on that date, stream stage dropped from 9.95 to 9.83 feet, and discharge decreased from 38 to 30 ft^3/s (not shown in table A1). Streamflow at 56th Avenue changes rapidly (fig. 2), and accordingly the initial sample on June 24 had substantially higher concentrations for most constituents that are frequently associated with suspended sediments (turbidity, TS, TSS, TP, *E. coli*) than the replicate had. Rather than indicating variability in sampling and analytical methods, these data indicate the rapid changes that are likely to occur in stream quality during storm conditions at such flashy sites, and suggest that actual temporal variations due to transient conditions can be more important than variability introduced by field and analytical methods.

Dissolved nutrients (NH_3-N, NO_3-N, and SRP) tended to have among the least variability overall. In contrast, two constituents that had the highest variability overall, turbidity and bacteria, are both commonly associated with suspended sediment. Other constituents often associated with sediment concentrations, including suspended solids (TS and TSS) and TP, had relatively low variability overall, indicating that the analytical data for these and most other constituents were reliable and can be used quantitatively in this report. On the basis of these data, values for turbidity and bacteria should be viewed with care and are primarily used in this report in a qualitative manner.

Standard Reference Samples—Results of semiannual (1998–2001) SRS comparisons by BQS indicate that the CWS overall is a good laboratory, and nutrient analyses are typically of good to excellent quality. On a scale of 0 to 4, indicating poor (0), questionable (1), satisfactory (2), good (3), and excellent (4) quality, average ratings for NO_3, NH_3, SRP, and TP were 3.57, 3.63, 3.25, and 2.71, respectively (U.S. Geological Survey, Branch of Quality Systems, written commun., August 2001). The most questionable results were for TP, although those data remained satisfactory to good and did not indicate any systematic bias. No other constituents analyzed in this study were included in the BQS interlaboratory comparison.

Results of the monthly SRS program, which also includes a native water sample split between the CWS and USGS laboratories, are in agreement with the results of the quarterly BQS program. For the months immediately preceding, during, and immediately following the storms sampled for this study, CWS analytical data showed good precision and accuracy, with almost no consistent biases evident. Results for nutrient SRS samples (low, medium, and high concentration ranges) were overwhelmingly within 10% of their expected values. SRS samples that were more than 10% different from the expected values included one sample for NH_3-N (+60% in low concentration SRS), two samples for TP (-15–25% in low concentration SRS), and one sample for NO_3-N (~ 1 order of magnitude lower than expected in a high concentration SRS). The NO_3-N sample was investigated in depth by the CWS laboratory and no errors were found, so it appears that the SRS sample was improperly prepared. Four sets of duplicate native-water samples (1 for TP, 2 for SRP, and 1 for NH_3-N) had higher concentrations (30%-450%) compared to those for the same samples reported by the USGS NWQL, but in each case the two duplicates analyzed by CWS agreed closely (within 5% of each other) so it is likely that the NWQL results were erroneously low. Finally, detections were noted for NH_3-N, TKN, and SRP in certified blank water on one occasion each (0.011, 0.025, and 0.013 mg/L, respectively), at concentrations below those reported in this study, so bias due to contamination is not considered a problem.

Table A1. Replicate sample results and relative percent differences during storm samplings, 1998–99

[Relative difference was calculated as 100*(range in replicate concentrations)/(average of replicate concentrations). Relative differences greater than 10 percent are bolded. Parameter abbreviations are described in the glossary or in table 2. CWS, Clean Water Services Laboratory; USGS, U.S. Geological Survey Laboratory, Denver, CO; ODEQ, Oregon Department of Environmental Quality Laboratory, Portland, OR. sample codes: N, normal; MR, method replicate (compares CWS vertical grab composite sampler and USGS equal width increment sampling methods); R, field replicate; SR, sequential replicate; LS, within-laboratory split; IS, interlaboratory split. Value qualifying codes: E, Estimated value; Q, Questionable value, poor quality control; G, Actual value is known to be greater than the value given; NA, not applicable]

Site	Date	Time	Sample code	Turbidity	Cond-Lab	BOD_{Rate}	BOD_5	BOD_{Ult}	COD	TS	TDS	TSS	TVSS	NH_3-N	NO_3-N	TP	SRP	*E. Coli*
Method replicates																		
Durham	6/24/98	20:30	N	26					21.5	196	105	91		0.036	0.304	0.302	0.052	6400
Replicate	6/24/98	20:30	MR	26					19.7	200	117	83		0.037	0.306	0.257	0.054	6700
Relative Difference (percent)				*0.0*					*8.7*	*2.0*	**10.8**	*9.2*		*2.7*	*0.7*	**16.1**	*3.8*	*4.6*
Durham	1/15/99	9:10	N	30					17.2	166	123	43.2		0.059	1.06	0.189	0.029	880
Replicate	1/15/99	9:10	MR	36					16.6	162	122	40.4		0.062	1.09	0.189	0.028	900
Relative Difference (percent)				**18.2**					*3.6*	*2.4*	*0.8*	*6.7*		*5.0*	*2.8*	*0.0*	*3.5*	*2.2*
Durham	12/7/99	11:30	N	42	88	0.0683	2.24	7.96	18.9	180	74	106		0.031	0.647	0.236	0.049	1,700
Replicate	12/7/99	11:30	MR	Q 44	88	0.0760	2.06	6.53	18.9	184	79	105		0.03	0.641	0.242	0.05	1,400
Relative Difference (percent)				*4.5*	*0.0*	**10.7**	*8.4*	**19.7**	*0.0*	*2.2*	*6.5*	*0.9*		*3.3*	*0.9*	*2.5*	*2.0*	**19.4**
Sequential replicates																		
Allen Blvd	6/24/98	19:50	N	27	102				16.7	120	92	27.5		0.044	0.56	0.203	0.044	Q 11,000
Allen Blvd	6/24/98	20:10	SR	28	102				19.9	120	94	26		0.044	0.558	0.192	0.046	9,400
Relative Difference (percent)				*3.6*	*0.0*				**17.5**	*0.0*	*2.2*	*5.6*		*0.0*	*0.4*	*5.6*	*4.4*	**20.0**
56th Ave.	6/24/98	10:10	N	128	51				28.9	504	90	414		0.097	0.502	1.06	0.076	36,000
56th Ave.	6/24/98	10:40	SR	108	48				33.6	364	60	304		0.089	0.502	0.858	0.085	25,000
Relative Difference (percent)				**16.9**	*6.1*				**15.0**	**32.3**	**40.0**	**30.6**		*8.6*	*0.0*	**21.1**	**11.2**	**36.1**
Allen Blvd	1/15/99	20:30	N	36	117	0.065	1.50	5.46	21.9	204		88	12.4	0.054	1.19	0.255	0.033	680
Allen Blvd	1/15/99	20:40	SR	38	127	0.072	1.42	4.69	21.6	202		87.6	13.2	0.059	1.29	0.26	0.034	680
Relative Difference (percent)				*5.4*	*8.2*	**11.1**	*5.5*	**15.2**	*1.4*	*1.0*		*0.5*	*6.2*	*8.8*	*8.1*	*1.9*	*3.0*	*0.0*
Field Splits																		
Allen Blvd	12/6/99	20:55	N	13	113				14.3	112		6.2	1.2	0.037	0.907	0.102	0.049	1,200
Replicate	12/6/99	20:55	R	13	118				18.4	108		6.4	1.6	0.034	0.914	0.102	0.047	1,000
Relative Difference (percent)				0.0	4.3				**25.1**	3.6		3.2	**28.6**	8.5	0.8	0.0	4.2	**18.2**
56th Ave.	1/14/99	3:30	N	48	104				32.7	148		41.2	7.6	0.069	0.876	0.187	0.026	1,800
Replicate	1/14/99	3:30	R	48	104				32.8	140		41.6	8	0.071	0.954	0.19	0.027	1,700
Relative Difference (percent)				*0.0*	*0.0*				*0.3*	*5.6*		*1.0*	*5.1*	*2.9*	*8.5*	*1.6*	*3.8*	*5.7*
Durham	1/18/99	12:30	N	78	80				18.1	176		67	8.5	0.029	1.07	0.278	0.051	E ,1500
Replicate	1/18/99	12:30	R	44	81				18.2	168		46	5.5	0.031	1.07	0.287	0.051	2,100
Relative Difference (percent)				**55.7**	*1.2*				*0.6*	*4.7*		**37.2**	**42.9**	*6.7*	*0.0*	*3.2*	*0.0*	**33.3**

Table A1. Replicate sample results and relative percent differences during storm samplings, 1998–99—*Continued*

[Relative difference was calculated as 100*(range in replicate concentrations)/(average of replicate concentrations). Relative differences greater than 10 percent are bolded. Parameter abbreviations are described in the glossary or in table 2. CWS, Clean Water Services Laboratory; USGS, U.S. Geological Survey Laboratory, Denver, CO; ODEQ, Oregon Department of Environmental Quality Laboratory, Portland, OR. sample codes: N, normal; MR, method replicate (compares CWS vertical grab composite sampler and USGS equal width increment sampling methods); R, field replicate; SR, sequential replicate; LS, within-laboratory split; IS, interlaboratory split. Value qualifying codes: E, Estimated value; Q, Questionable value, poor quality control; G, Actual value is known to be greater than the value given; NA, not applicable]

Site	Date	Time	Sample code	Turbidity	Cond-Lab	BOD_{Rate}	BOD_5	BOD_{Ult}	COD	TS	TDS	TSS	TVSS	NH_3-N	NO_3-N	TP	SRP	*E. Coli*
In-lab splits:																		
Durham	6/24/98	13:15	N	28	140				29.2	252	125	127		0.113	0.417	0.39		6300
Split	6/24/98	13:15	LS	28	140				29.1	248	116	132		0.114	0.412	0.411		6200
Relative Difference (percent)				*0*	*0*				*0.3*	*1.6*	*7.5*	*3.9*		*0.9*	*1.2*	*5.2*		*1.6*
56th Ave.	6/24/98	16:10	N	25	77				18.1	100	82	18		0.038	0.673	0.18		Q 14,000
Split.	6/24/98	16:10	LS	25	77				17.7	98	79	19		0.038	0.67	0.181		Q 15,000
Relative Difference (percent)				*0*	*0*				*2.2*	*2.0*	*3.7*	*5.4*		*0.0*	*0.4*	*0.6*		*6.9*
Durham	12/6/99	12:50	N	20	128				16.9	154	98	55.8		0.051	0.718		0.041	
Split	12/6/99	12:50	LS	20	128				17.1	154	97	56.8		0.048	0.712		0.038	
Relative Difference (percent)				*0*	*0*				*1.2*	*0.0*	*1.0*	*1.8*		*6.1*	*0.8*		*7.6*	
56th Ave.	12/7/99	17:55	N	15	128				15.3	122	116	6.2		E 0.016	1.44		0.051	
Split	12/7/99	17:55	LS	15	128				16.8	128	122	6.4		E 0.015	1.43		0.05	
Relative Difference (percent)				*0*	*0*				*9.3*	*4.8*	*5.0*	*3.2*		*6.5*	*0.7*		*2.0*	
Durham	12/7/99	9.31	N	35					10.4	192		109		0.038	0.547	0.249	0.051	2600
Duplicate	12/7/99	9.31	LS	35					10.6	194		109		0.038	0.548	0.245	0.052	2100
Relative Difference (percent)				*0*					*1.9*	*1*		*0.0*		*0.0*	*0.2*	*1.6*	*1.9*	**21.3**
Interlab Split:																		
Allen Blvd	6/24/98	13:25	CWS	66					36.7	284	79	205	31	0.087	0.501	0.589	0.049	
Allen Blvd	6/24/98	13:25	IS-ODEQ	129					39	350	90	270	100	0.12	0.48	0.35	0.039	
Relative Difference (percent)				**64.6**					*6.1*	**20.8**	**13.0**	**27.4**	**105.3**	**31.9**	*4.3*	**50.9**	**22.7**	
Allen Blvd	1/14/99	12:50	CWS		124				15.4	162	122	40		0.059	1.19	0.168	0.025	1100
Allen Blvd	1/14/99	12:50	IS-USGS		135						101			0.072	0.871	0.137	0.026	
Allen Blvd	1/14/99	12:50	IS-ODEQ						15	140		33		0.08	0.92	0.19	0.026	44
Relative Difference (percent)					*8.5*				2.6	**14.6**	**18.8**	**19.2**		**29.9**	**32.1**	**32.1**	*3.9*	**184.6**
Allen Blvd	12/7/99	8:15	CWS		85					218		105		0.036	0.861	0.288	0.055	2100
USGS	12/7/99	8:15	IS-USGS		91.6									0.032	0.755	0.308	0.039	
ODEQ	12/7/99	8:15	IS-ODEQ		89					210		120		0.08	0.734			G 600
Relative Difference (percent)					*7.5*					*3.7*		**13.3**		**97.3**	**16.2**	*6.7*	**34.0**	**NA**

APPENDIX B.—WATER QUALITY DATA FROM FANNO CREEK, OREGON

[Site details are given in table 1. Numbers in square brackets are Clean Water Services (CWS) parameter codes; ft^3/s, cubic feet per second; ft, feet; ºC, degrees Celsius; NTU, nephelometric turbidity units; SC, specific conductance; uS/cm, microsiemens per centimeter; DO, dissolved oxygen; mg/L, milligrams per liter; BOD, biochemical oxygen demand; d^{-1}, per day; BOD$_5$, 5-day BOD; BOD$_{ult}$, ultimate BOD; TS, total solids; TDS, total dissolved solids; TSS, total suspended solids; TVSS, total volatile suspended solids; NH$_3$-N, ammonia-nitrogen; NO$_3$-N, nitrate-plus-nitrite-nitrogen; TP, total phosphorus; SRP, soluble reactive (ortho- phosporus; *E. coli*, escherechia coliform bacteria; --, not measured; Q, questionable]

STORM 1, JUNE 1988

CWS sample number	Site name	Date and time	Flow (ft^3/s) [61]	Gauge height (ft) [65]	Temp (°C) [10]	Turb- idity (NTU) [76]	SC (μS/cm) [95]	DO (mg/L) [299]	BOD rate (d^{-1}) [--]	BOD$_5$ (mg/L) [310]	BOD$_{ULT}$ (mg/L) [319]	pH [400]	TS (mg/L) [500]	TDS (mg/L) [515]	TSS (mg/L) [530]	TVSS (mg/L) [535]	NH$_3$-N (mg/L) [608]	NO$_3$-N (mg/L) [631]	TP (mg/L) [665]	SRP (mg/L) [671]	*E. coli* (/100 mL) [31648]
9802238	56th	6/23/98 15:50	0.84	8.86	14.8	6	181	9.6	--	--	--	--	150	148	2.2	0.6	0.029	0.87	0.097	0.040	E 1500
9802239	56th	6/24/98 09:07	43	10.01	13.8	40	72	9.5	--	--	--	--	1040	92	948	130	.117	.62	2.23	.059	16000
9802240	56th	6/24/98 10:10	38	9.95	13.8	128	51	9.5	--	--	--	--	504	90	414	60	.10	.50	1.06	.076	36000
9802241	56th	6/24/98 12:35	5.2	9.21	14.0	41	55	9.4	--	--	--	--	142	66	76	12	.062	.56	.36	.074	32000
9802242	56th	6/24/98 14:49	1.9	9.0	14.0	31	69	9.2	--	--	--	--	106	78	28	4.5	.048	.63	.23	.062	Q 18000
9802243	56th	6/24/98 16:10	1.5	8.96	14.5	25	77	9.0	--	--	--	--	100	82	18	3.5	.038	.67	.18	.055	Q 14000
9802244	56th	6/24/98 19:00	1.1	8.91	14.9	18	94	8.7	--	--	--	--	102	93	9.4	1.6	.034	.73	.14	.049	14000
9802245	56th	6/25/98 08:25	.81	8.86	13.6	7.3	149	8.6	--	--	--	--	124	121	2.8	0.4	.032	.87	.10	.046	3200
9802228	Allen	6/23/98 16:50	3.52	.5	17.7	6	176	9.2	--	--	--	--	140	134	6.0	1.4	.034	.51	.11	.035	580
9802229	Allen	6/24/98 09:15	10.31	.68	15.2	15	165	8.2	--	--	--	--	154	120	34	6.0	.092	.54	.21	.061	E 8500
9802230	Allen	6/24/98 12:20	84.5	1.78	14.7	78	109	8.8	--	--	--	--	458	92	366	49	.10	.50	.84	.046	E 9500
9802231	Allen	6/24/98 13:25	46.74	1.25	14.9	66	100	8.6	--	--	--	--	284	79	205	31	.087	.50	.59	.049	16000
9802232	Allen	6/24/98 16:50	14.51	.76	15.2	35	99	8.8	--	--	--	--	134	84	50	9.0	.055	.53	.28	.047	Q 11000
9802233	Allen	6/24/98 19:50	6.85	.6	15.8	27	102	8.3	--	--	--	--	120	92	28	5.0	.044	.56	.20	.044	Q 11000
9802234	Allen	6/24/98 22:20	6.85	.6	15.2	25	104	8.3	--	--	--	--	118	100	19	3.5	.040	.58	.18	.042	Q 8300
9802235	Allen	6/25/98 09:05	4.70	.54	14.6	18	119	7.8	--	--	--	--	118	108	11	1.5	.050	.66	.16	.040	5600
9802236	Allen	6/25/98 15:20	6.07	.58	15.0	16	127	8.7	--	--	--	--	124	111	13	2.8	.070	.72	.16	.041	5300
9802218	Durham	6/23/98 17:55	12.3	1.86	18.0	5.5	221	8.8	--	--	--	--	172	168	3.6	0.8	.036	.49	.13	.065	520
9802219	Durham	6/24/98 10:30	107	3.38	15.0	36	126	8.5	--	--	--	--	308	109	199	25	.145	.41	.51	.069	5300
9802220	Durham	6/24/98 13:15	142	3.79	15.7	28	140	7.9	--	--	--	--	252	125	127	15	.113	.42	.39	.058	6300
9802221	Durham	6/24/98 15:55	145	3.83	15.7	37	120	7.7	--	--	--	--	262	97	165	21	.072	.36	.47	.061	14000
9802222	Durham	6/24/98 19:30	105.7	3.36	16.9	26	142	7.8	--	--	--	--	196	105	91	11	.036	.30	.30	.052	6400
9802223	Durham	6/24/98 23:00	61.5	2.76	16.7	23	145	7.7	--	--	--	--	178	120	58	8.0	.042	.47	.25	.055	4200
9802224	Durham	6/25/98 10:00	25.9	2.16	15.9	23	128	7.4	--	--	--	--	144	111	33	6.3	.173	.53	.20	.062	3300
9802225	Durham	6/25/98 15:55	28.1	2.2	15.7	12	145	8.3	--	--	--	--	124	113	11	2.2	.040	.48	.14	.048	3300

APPENDIX B.— WATER QUALITY DATA FROM FANNO CREEK, OREGON—*CONTINUED*

STORM 2, JANUARY 1999

CWS sample number	Site name	Date and time	Flow (ft^3/s) [61]	Gauge height (ft) [65]	Temp (°C) [10]	Turb-idity (NTU) [76]	SC (µS/cm) [95]	DO (mg/L) [299]	BOD rate (d^{-1}) [--]	BOD$_5$ (mg/L) [310]	BOD$_{ULT}$ (mg/L) [319]	pH [400]	TS (mg/L) [500]	TDS (mg/L) [515]	TSS (mg/L) [530]	TVSS (mg/L) [535]	NH$_3$-N (mg/L) [608]	NO$_3$-N (mg/L) [631]	TP (mg/L) [665]	SRP (mg/L) [671]	*E. coli* (/100 mL) [31648]
9901021	56th	1/13/99 12:50	1.8	9.00	8.4	8.9	167	10.6	0.10	1.4	3.4	7.4	156	149	6.6	2.4	0.054	1.8	0.081	0.027	260
9901022	56th	1/13/99 23:40	8.7	9.35	8.0	68	124	11.2	.13	5.0	10	7.4	236	111	125	22	.106	1.2	.40	.037	2300
9901023	56th	1/14/99 03:30	2.9	9.08	8.1	48	104	11.0	.09	2.4	6.8	7.3	148	107	41	7.6	.069	.88	.19	.026	1800
9901024	56th	1/14/99 07:35	13.3	9.49	8.3	62	100	11.2	.09	2.2	6.3	7.4	218	113	105	17	.069	.89	.31	.030	2000
9901025	56th	1/14/99 14:30	20.1	9.64	9.2	68	99	9.7	.10	3.2	7.8	7.3	350	113	237	26	.077	.85	.44	.030	2800
9901026	56th	1/15/99 13:15	3.1	9.10	8.7	15	145	10.8	.08	0.7	2.2	7.4	146	143	3.2	0.4	.049	1.6	.090	.028	540
9901027	56th	1/15/99 19:10	17.9	9.58	8.6	33	129	11.1	.09	2.0	5.5	7.4	224	117	107	14	.062	1.4	.25	.030	3000
9901028	56th	1/16/99 10:20	69.2	10.30	6.4	152	61	11.6	.08	3.9	11.6	7.0	832	52	780	64	.049	.52	1.13	.043	5200
9901029	56th	1/16/99 16:30	12.5	9.47	7.7	39	115	11.4	.06	0.9	3.6	7.1	164	139	25	2.8	.037	1.7	.19	.052	4100
9901030	56th	1/17/99 09:50	76.1	10.37	6.6	112	58	11.7	.08	2.8	8.6	7.2	666	96	570	44	.036	.51	1.09	.040	4000
9901011	Allen	1/13/99 13:35	9	0.65	8.2	22	161	10.8	.09	1.1	3.1	7.3	160	146	14	2.4	.053	1.6	.11	.023	180
9901012	Allen	1/14/99 00:40	18.0	0.83	8.1	28	157	10.9	.13	2.2	4.8	7.3	210	140	70	8.8	.063	1.6	.20	.029	700
9901013	Allen	1/14/99 06:32	14.5	0.76	8.2	33	146	10.8	.06	1.1	3.8	7.4	172	134	38	5.6	.062	1.5	.16	.028	920
9901014	Allen	1/14/99 12:50	17.4	0.81	8.6	31	124	9.6	.09	1.8	5.1	7.2	162	122	40	6.4	.059	1.2	.17	.025	1100
9901015	Allen	1/15/99 14:00	15.6	0.78	8.7	24	144	10.9	.05	0.80	3.6	7.2	154	141	13	2.0	.054	1.6	.13	.027	410
9901016	Allen	1/15/99 20:30	--	--	8.4	36	117	10.9	.06	1.5	5.5	7.2	204	116	88	12.4	.054	1.2	.26	.033	680
9901017	Allen	1/16/99 11:10	128	2.33	7.0	76	89	11.0	.10	3.0	7.8	6.9	476	78	398	31	.045	.79	.54	.038	2500
9901018	Allen	1/16/99 17:15	62.0	1.47	7.4	76	96	11.2	.06	1.4	5.2	7.0	224	130	94	12	.042	1.2	.33	.042	2400
9901019	Allen	1/17/99 10:50	135	2.42	7.2	64	102	11.2	.07	1.7	5.8	7.1	380	129	251	20	.038	1.2	.45	.039	950
9901020	Allen	1/18/99 11:50	100	1.99	8.1	64	98	10.7	.08	1.6	4.9	7.0	218	118	100	10.4	.038	1.4	.28	.051	1200
9901001	Durham	1/13/99 14:40	30.6	2.25	8.2	23	183	10.3	.08	1.3	4.1	7.3	204	160	44	6.0	.058	1.4	.15	.027	330
9901002	Durham	1/14/99 02:30	56.2	2.68	8.2	22	171	10.9	.14	2.0	3.9	7.4	174	149	25	3.6	.063	1.4	.12	.028	460
9901003	Durham	1/14/99 08:55	83.4	3.07	8.2	32	148	10.7	.08	1.5	4.3	7.4	190	134	56	8.4	.070	1.1	.16	.027	640
9901004	Durham	1/15/99 09:10	73.9	2.94	8.7	30	131	9.6	.07	1.3	4.4	7.2	166	123	43	6.4	.059	1.1	.19	.029	880
9901005	Durham	1/15/99 17:25	58.1	2.71	8.5	28	148	10.6	.06	0.90	3.4	7.3	160	140	20	3.2	.060	1.2	.14	.028	440
9901006	Durham	1/16/99 12:05	304	5.40	7.2	66	90	10.8	.10	2.4	6.1	7.1	250	103	147	15	.052	.69	.33	.033	900
9901007	Durham	1/16/99 18:10	310	5.45	7.2	60	87	11.0	.06	1.3	5.2	7.1	196	102	94	10	.045	.73	.30	.041	1300
9901008	Durham	1/17/99 11:35	279	5.18	7.0	48	94	11.0	.07	1.3	4.5	7.1	216	104	112	10	.040	.83	.28	.037	1000
9901009	Durham	1/18/99 12:30	584	7.62	8.1	78	80	10.0	.09	1.8	5.0	7.1	176	109	67	8.5	.029	1.1	.28	.051	E 1500
9901010	Durham	1/19/99 11:30	339	5.71	8.2	44	91	10.6	.08	1.3	3.7	7.1	162	108	54	5.6	.032	1.2	.19	.043	620

APPENDIX B.— WATER QUALITY DATA FROM FANNO CREEK, OREGON—*CONTINUED*

STORM 3, DECEMBER 1999

CWS sample number	Site name	Date and time	Flow (ft^3/s) [61]	Gauge height (ft) [65]	Temp (°C) [10]	Turbidity (NTU) [76]	SC (μS/cm) [95]	DO (mg/L) [299]	BOD rate (d^{-1}) [--]	BOD_5 (mg/L) [310]	BOD_{ULT} (mg/L) [319]	pH [400]	TS (mg/L) [500]	TDS (mg/L) [515]	TSS (mg/L) [530]	TVSS (mg/L) [535]	NH_3-N (mg/L) [608]	NO_3-N (mg/L) [631]	TP (mg/L) [665]	SRP (mg/L) [671]	*E. coli* (/100 mL) [31648]
9907662	56th	12/5/99 20:00	1.3	8.89	9.0	5.5	153	10.3	0.07	1.0	3.4	7.2	128	127	1.4	0.4	E .018	0.92	0.057	0.046	260
9907663	56th	12/6/99 02:30	5.41	9.16	8.7	6	143	10.2	.08	1.4	4.3	7.3	120	115	5.2	.6	.021	.68	.070	.043	540
9907664	56th	12/6/99 09:50	6.93	9.22	8.7	18	71	10.7	.08	1.9	5.6	7.1	82		25	5.0	E .020	.45	.14	.048	4100
9907665	56th	12/6/99 20:00	2.3	8.98	9.1	8	125	10.4	.07	1.0	3.6	7.4	114	112	2.2	.2	E .011	.90	.079	.045	2200
9907666	56th	12/7/99 07:35	37.2	9.91	7.4	36	66	11.2	.07	1.9	6.1	6.8	184	125	59	6.0	.022	.72	.26	.065	2300
9907667	56th	12/7/99 17:55	5.1	9.14	8.9	15	128	10.5	.07	0.9	3.3	7.1	122	116	6.2	1.2	E .016	1.4	.10	.051	1900
9907668	56th	12/8/99 10:15	5.0	9.15	8.4	9	154	10.8	.09	1.0	2.7	7.4	130	126	4.0	.4	.024	1.5	.080	.047	630
9907669	56th	12/8/99 13:30	15.1	9.47	8.3	14	111	10.7	.09	2.3	6.2	7.3	126	97	29	5.8	.043	1.1	.12	.046	E 1800
9907652	Allen	12/5/99 20:45	8.4	0.64	8.6	7	147	10	.10	1.7	4.3	7.0	126	122	4.0	1.0	.030	1.1	.076	.046	430
9907653	Allen	12/6/99 03:10	14.0	0.75	8.5	7	143	9.9	.08	1.6	4.9	7.1	130	125	5.4	.8	.029	.84	.092	.048	650
9907654	Allen	12/6/99 12:00	29.3	0.99	8.8	17	118	10.4	.09	1.6	4.7	7.1	138	105	33	4.8	.035	.83	.13	.047	1100
9907655	Allen	12/6/99 20:55	14.5	0.76	8.8	13	113	10.2	.08	1.5	4.3	7.0	112	106	6.2	1.2	.037	.91	.10	.049	1200
9907656	Allen	12/7/99 08:15	82.3	1.75	7.7	50	85	G 11.0	.08	2.3	6.8	6.7	218	113	105	13	.036	.86	.29	.055	2100
9907992	Allen	12/7/99 11:04	62.7	1.48	7.7	37	85	12.8	--	--	--	7.3	162	96	66	7.6	.036	.94	.22	.059	3300
9907657	Allen	12/7/99 17:10	32.6	1.04	8.4	30	106	10.6	.08	1.4	4.5	6.8	140	119	21	2.8	.037	1.3	.17	.064	2900
9907658	Allen	12/8/99 10:50	15.1	0.77	8.3	17	142	10.5	.09	1.3	3.5	7.1	142	129	13	2.0	.042	1.7	.13	.054	700
9907659	Allen	12/8/99 14:00	22.6	0.89	8.3	23	133	10.4	.12	2.1	4.6	7.1	150	126	24	4.0	.047	1.5	.16	.059	900
9907642	Durham	12/5/99 21:38	36.5	2.36	8.4	11	159	9.8	.08	1.3	4.2	7.1	134	123	11	1.6	.069	.94	.094	.048	520
9907643	Durham	12/6/99 03:50	58.6	2.72	8.6	13	144	9.9	.08	1.8	5.3	7.2	124	105	19	2.8	.061	.80	.10	.046	490
9907644	Durham	12/6/99 12:50	110	3.41	8.7	20	128	10.3	.09	1.9	5.0	7.2	154	98	56	7.2	.051	.72	.16	.041	700
9907645	Durham	12/6/99 21:40	68.5	2.86	8.9	18	124	10.1	.09	2.0	5.5	7.2	128	96	32	5.2	.052	.70	.14	.044	560
9907993	Durham	12/7/99 09:31	261	5.01	7.6	35	80	12.4	--	--	--	7.4	192	83	109	16	.038	.55	.25	.051	2600
9907646	Durham	12/7/99 11:30	254	4.94	7.8	42	88	10.2	.07	2.2	8.0	6.9	180	74	106	13	.031	.65	.24	.049	1700
9907647	Durham	12/7/99 19:10	160	3.99	8.2	36	94	10.9	.08	1.7	5.2	6.9	154	98	56	6.8	.029	.82	.20	.054	1200
9907648	Durham	12/8/99 11:30	62.9	2.78	8.4	20	132	10.3	.09	1.3	3.6	7.2	136	120	17	2.7	.045	1.1	.35	.062	630
9907649	Durham	12/8/99 14:30	89.4	3.15	8.2	23	128	10.4	.10	1.9	4.9	7.2	146	114	32	5.4	.054	.99	.16	.055	610

USGS Anderson and Rounds

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CONDITIONS IN FANNO CREEK, OREGON, 1998-99

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