Assessment of Surface-water Quality and Water-quality Control Alternatives, Johnson Creek Basin, Oregon

By Thomas K. Edwards

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in)	25.40	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
acre-feet (acre-ft)	1233.	cubic meter
pound, avoirdupois (lb)	0.4536	kilogram
gallon (gal)	3.785	liter

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

$$°F = (°C/0.555)+32$$

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

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ASSESSMENT OF SURFACE-WATER QUALITY AND WATER-QUALITY CONTROL ALTERNATIVES, JOHNSON CREEK BASIN, OREGON

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ABSTRACT

Johnson Creek flows through a basin of approximately 51 square miles with mixed land uses over a reach of approximately 24 river miles from southeast of Gresham, Oregon, to its confluence with the Willamette River in Milwaukie, Oregon. Land uses within the basin include forested and agricultural lands, suburban residential, urban, and light industrial. Surface runoff and ground-water flow from the basin's areas of various land use result in concentrations of some nutrients, trace elements, and organic compounds at levels exceeding U.S. Environmental Protection Agency (USEPA) criteria. Concentrations of dissolved cadmium, copper, lead, mercury, and silver, total recoverable chlordane, dieldrin, and dichlorodiphenyltrichloroethane (DDT) plus metabolites indicate that sources of at least one or more of these constituents exist in virtually every reach of Johnson Creek. Crystal Springs Creek is a major source of nutrients in lower Johnson Creek. Concentrations of dissolved nitrate and orthophosphorus in Johnson Creek are elevated at low flow, and are reduced by dilution when urban runoff flows into the creek during storms. Total-phosphorus concentrations exceed USEPA criteria at several sites in Johnson Creek during low flow, and at all sites during periods of storm runoff. Three organochlorine pesticide compounds were found at elevated concentrations. Even though total-recoverable chlordane, dieldrin, and DDT plus its metabolites are elevated at some sites during low flow, increased concentrations and expanded areal distribution during storms, when heavy sediment loads are entrained, reflect their hydrophobic nature and long-term persistence in the environment. The low-flow concentration of dissolved silver exceeded hardness-dependent USEPA Fresh Water Chronic Toxicity (FWCT) criterion only in Crystal Springs Creek. Concentrations of dissolved cadmium, copper, lead, and mercury exceeded their respective FWCT criteria at selected sites in Johnson Creek Basin during storm runoff.

Water quality in the basin could be improved by implementing one or a combination of management practices. These practices could include control of contaminants at their source and removal of contaminant-laden sediment by constructed settling basins and (or) natural or constructed wetland. Wetlands can act as biofilters to reduce contaminant concentrations carried by flows released downstream.

INTRODUCTION

A variety of land uses are affecting the quality of water in Johnson Creek, a tributary to the Willamette River (fig. 1). Water managers with the city of Portland, Oregon, and Oregon Department of Environmental Quality (ODEQ) have become concerned about the poor quality of water in Johnson Creek. Presently, they are mandated by the U.S. Environmental Protection Agency to develop and implement water-quality-improvement procedures.

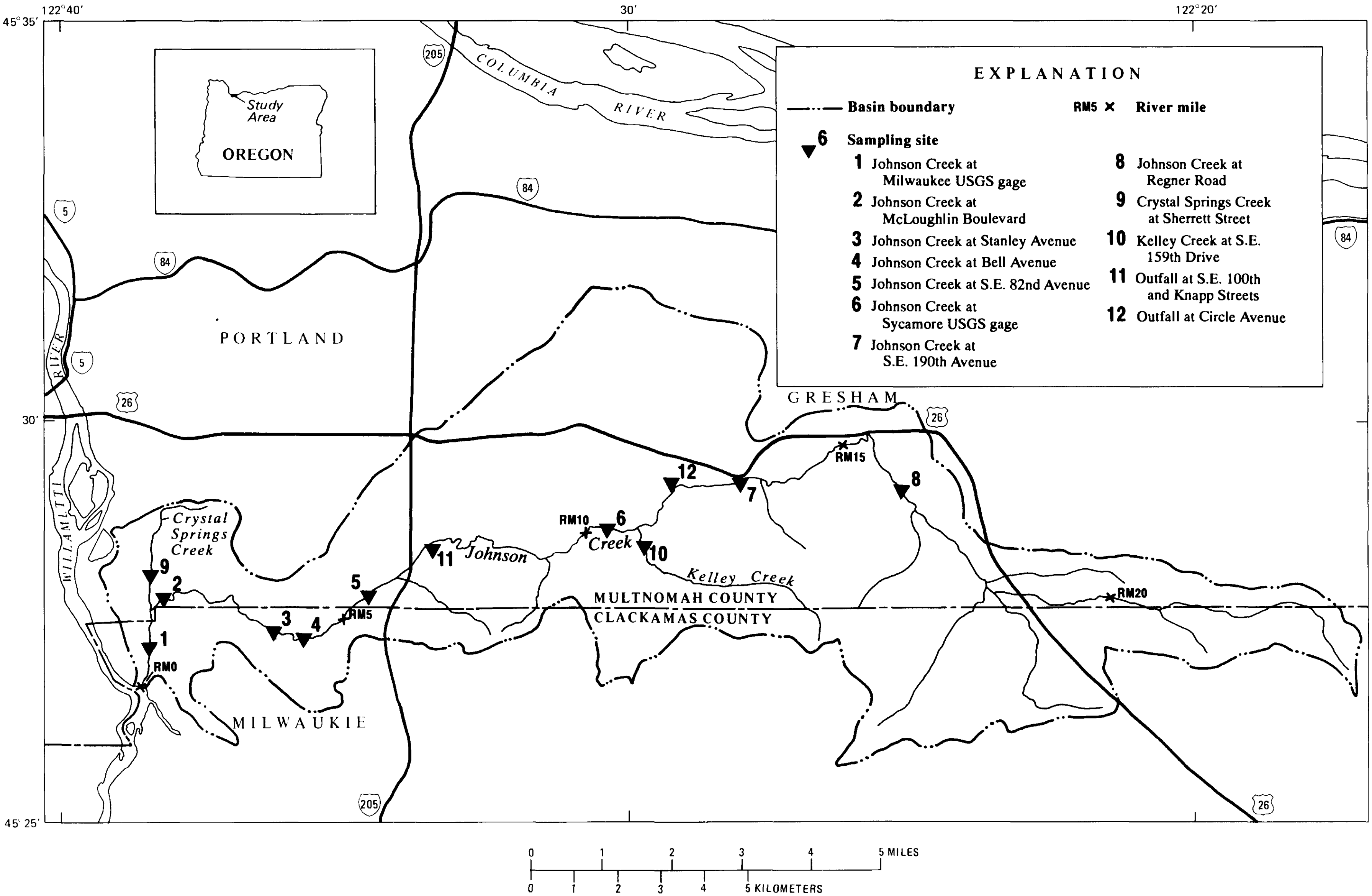

Figure 1. Location of sampling sites in Johnson Creek Basin.

In 1988, the U.S. Geological Survey (USGS), in cooperation with the city of Portland, Bureau of Environmental Services (PBES), began a two-phase assessment of water-quality characteristics of Johnson Creek. In the first phase of assessment, an evaluation of historical water-quality data and a reconnaissance-level survey were done to determine amounts of trace-element and organic compounds associated with bottom material in Johnson Creek Basin (Edwards and Curtiss, 1993; and Edwards, 1991). The second phase was an assessment of current water-quality conditions in Johnson Creek. This assessment included: (1) collection of synoptic water samples during periods of low flow (August to October 1989) and during two storms (December 4-5, 1989, and January 25-26, 1990) for analysis of inorganic constituents and organic compounds; (2) presentation and interpretation of these data as related to water and suspended sediment; (3) subsequent identification of potential contaminant-source reaches in the basin; and (4) consideration of possible management alternatives to improve the quality of water in Johnson Creek.

Purpose and Scope

This report presents a current assessment of existing water-quality conditions in Johnson Creek. The information here will be be useful in making management decisions regarding alternatives for improving the quality of water in the creek.

This report presents an interpretation of water-quality and sediment data for Johnson Creek from Regner Road at river mile (RM) 16.30 to Milport Road crossing in Milwaukie at RM 0.60, including two tributaries (Kelley Creek at RM 10.70 and Crystal Springs Creek at RM 1.20), and two outfalls (S.E. 100th and Knapp at RM 6.25) and Circle Avenue at RM 11.60). Measurements and determinations include stream discharge, temperature, pH, specific conductance, alkalinity, dissolved oxygen, bacteria, turbidity, nutrients, trace elements, synthetic organic compounds, and suspended sediment.

Description of Study Area

Johnson Creek flows in a westerly direction, over a 24-mile reach, through a forested and agricultural headwater area southeast of Gresham, and through the cities of Gresham, Portland, and Milwaukie, where it discharges into the Willamette River (fig. 1). Johnson Creek drains an area slightly larger than 51 square miles (mi^2) and represents approximately 0.5 percent of the area drained by the Willamette River.

The slope of the stream channel varies markedly over its length from about 14 feet per mile (ft/mi) above RM 7.50 to about 7 ft/mi from RM 7.50 to RM 5.50, and about 31 ft/mi from RM 5.50 to the mouth (fig. 2). The particle-size distribution of stream bottom material observed during reconnaissance reflects the variability of channel slope (Edwards and Curtiss, 1993). In the upper part of the basin, bottom-material deposits consist of predominately fine-grained particles (sands, silts, and finer material). Channel reaches in the lower part of the basin, however, consist of predominately coarse-grained particles (gravels, cobbles and coarser material). This channel-slope configuration and bottom-material size distribution is atypical, and characterizes a

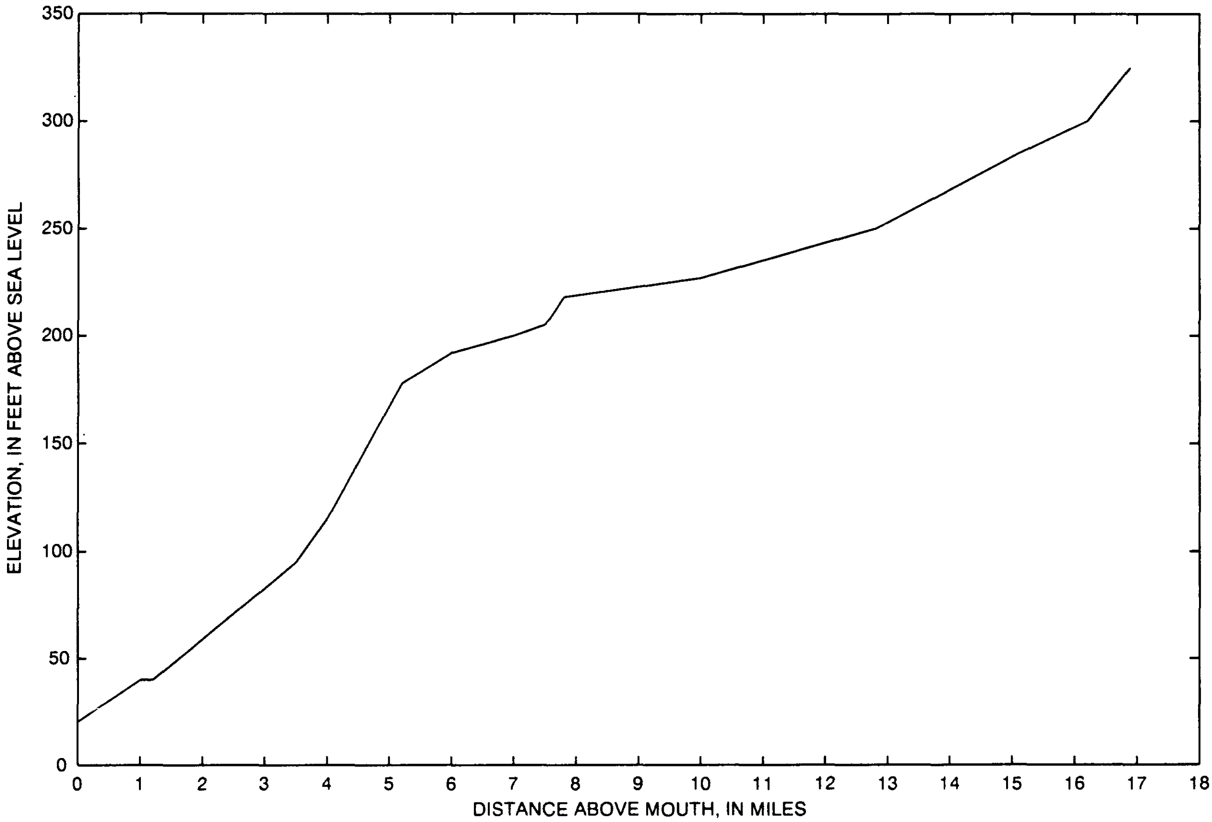

Figure 2. Channel slope of Johnson Creek.

geomorphologically inverted condition; a typical slope and bottom-material configuration is characterized by steeper slope and coarse-material dominance in headwater reaches grading to flatter slope with finer material in the lower reaches (Leopold and others, 1964).

Two major tributaries enter the main channel of Johnson Creek as it flows through the city of Portland. Kelley Creek drains a small subbasin to the south, in the middle of the basin, and flows into Johnson Creek at RM 10.70, above the USGS's gaging station at Sycamore. Crystal Springs Creek emanates from a large spring complex to the north, in the lower end of the basin, and enters Johnson Creek at RM 1.20, above the USGS's gaging station at Milwaukie.

Some storm drains transport water and constituents from nonpoint sources into Johnson Creek during storms. Most of these drains are located near major street crossings. After consultation with PBES, two storm drains were selected for runoff sampling: (1) the drain at S.E. 100th and Knapp (site 11 on fig. 1) that carries water from a residential area to Johnson Creek (RM 6.25); and (2) the drain at Circle Avenue (site 12 on fig. 2) that carries runoff from a sparsely populated area to Johnson Creek (RM 11.60).

From RM 10.25 to the mouth, debris accumulations along the Johnson Creek channel can create dams, which restrict flow and result in localized flooding during storm runoff. Along this same reach, however, most of the channel has been protected by rocks that were put in place by the Work Projects Administration (WPA) during the 1930s. Though heavily overgrown by vegetation in some locations, this manmade streambank protection is still in good condition and greatly minimizes bank erosion during high flows.

A USGS stream-gaging station (site 6 on fig. 1), located at Sycamore (RM 10.25), records stream stage continuously, and stream discharge is measured regularly at this site since 1940. A good stage-discharge relation has been established at this location.

A second USGS stream-gaging station, located at the bridge crossing at Milport Road in Milwaukie (site 1 on fig. 1), has recorded stage from 1989 to present. The stage record is unpublished, but is available from the Portland Office of USGS. This site is located downstream from all tributaries and outfalls, as close to the mouth of Johnson Creek as possible without being influenced by backwater effects from the Willamette River during high flow.

DATA COLLECTION AND SAMPLE PREPARATION

Discharge and Stage Data

Miscellaneous measurements of discharge and stage were made at all mainstream and tributary water-quality sites in accordance with USGS procedures (Rantz and others, 1982). Stage-discharge ratings based on the measurements were developed, according to the procedures described by Kennedy (1984), and were used to estimate the stream discharge during storm sampling. Stream discharge also was computed for the outfall sites during storm sampling using indirect methods as prescribed by Matthai (1968).

Water-Quality Data

Selection of low-flow and storm-sampling locations (table 1, fig. 1) was based on the results of reconnaissance bottom-material sampling (Edwards and Curtiss, 1993), the location of major storm-sewer outfalls, and the proximity of bridge crossings that would facilitate the collection of representative samples during all expected stream stages.

Water samples were collected by the equal-width-increment (EWI) method (Edwards and Glysson, 1988). Samples for nutrient, trace-element, and suspended-sediment analyses were collected in acid-rinsed glass or plastic bottles using an epoxy-coated sampler fitted with proper nylon nozzle. Samples for organic-constituent determinations were collected in a baked glass bottle using a standard sampler not coated with epoxy, and fitted with the proper brass nozzle.

Water-quality assurance and control were provided by analysis of replicate and spiked samples. Replicates of a minimum of 10 percent of the samples were analyzed for nutrients, trace elements and suspended-sediment concentration. Spiked samples were prepared and analyzed to check results of organic-compound analyses.

Table 1.--Water-quality sampling sites in Johnson Creek Basin

[Location of sites is shown in figure 1]

Map reference number	Station number	Station name	Distance above mouth (miles)
		Main Stream Sites	
1	14211550	Milwaukie USGS gaging station at Milport Road	0.60
2	452751122381400	McLoughlin Boulevard	1.50
3	452722122361100	Stanley Avenue	3.60
4	452731122353000	Bell Avenue	4.20
5	452717122344000	S.E. 82nd Avenue	5.50
6	14211500	Sycamore USGS gaging station near S.E. 145th and Foster Road	10.25
7	452917122275700	S.E. 190th Avenue	12.60
8	452910122251500	Regner Road	16.30
		Tributary and Outfall Sites	
9	452746122382800	Crystal Springs Creek at Sherrett Street	1.20
10	452837122295000	Kelley Creek at S.E. 159th Drive	10.70
11	452911122291200	Outfall at S.E. 100th and Knapp	6.25
12	452810122332700	Outfall at Circle Avenue	11.60

Low-Flow Samples

Samples collected from August to October 1989 were prepared for analytical determinations of selected dissolved and total nutrients, dissolved trace elements, total-recoverable organochlorine pesticides and polychlorinated biphenyls (PCBs), suspended-sediment concentrations, and selected particle-size determinations. Samples for total or total-recoverable analyses were subsampled from the appropriate composite sample prior to removal of the subsample for dissolved constituent determination, and preserved as prescribed in the USGS National Water Quality Laboratory Services Catalog (Pritt and Jones, 1989). Samples to be analyzed for dissolved constituents were filtered through a 0.45-μm-filter membrane and preserved in accordance with the USGS National Water Quality Laboratory Services Catalog (Pritt and Jones, 1989). Suspended sediment was removed from each sample composite for total trace-element determination by using a Centra-8 centrifuge from International Equipment Company and computing the centrifuge spin rate and time required to remove all particles greater than 0.45 μm. Particle settling was simulated according to Stoke's Law. Suspended sediment from the two low-flow samples were composited for analysis on a site-by-site basis to obtain the required sample mass for trace-element determinations.

Storm Samples

Subsamples collected over the duration of each of the two storms were composited into one storm sample at each site with the exception of three selected sites; at these three sites, subsamples were composited into three samples corresponding to the rise, peak, and recession of Johnson Creek stage, when possible. Subsamples were composited on the basis of the percentage of the total sample weight represented by each subsample, and were selected on the basis of turbidity, specific conductance, and timing relative to the discharge hydrograph for the storm (fig. 3). After representative composites were obtained, the samples were handled and preserved for analysis as described for the low-flow samples.

Because the composited sample collected during the storm runoff represents only a part of the storm, direct site to site comparisons of constituent loads are not meaningful; the part of the storm sampled at each site does not represent a discrete module of water moving through the basin. For example, a subsample was collected at three sites at nearly the same time (2015 to 2020) on December 4, 1989 (fig. 3). At Regner Road (RM 16.30), the subsample represents near peak conditions, at the Sycamore gage (RM 10.25) it represents the end of the rising limb, and at Milwaukie gage (RM 0.60) it represents an earlier point in the rising limb of the storm hydrograph. Because the duration and timing of the storm hydrographs vary from the headwater area to the mouth, site-to-site comparisons of the December 1989 and January 1990 storm-composite data will be made using only constituent concentrations. Intersite comparisons of loads and yield are made for the low-flow period.

ASSESSMENT OF WATER QUALITY

Low-flow samples were collected from August to September, 1989, and represented steady-state conditions because the stream discharge remained virtually constant over the sampling period.

The first major storm that was sampled in the Johnson Creek Basin occurred December 4 and 5, 1989 (hereafter referred to as December 1989 storm). Total rainfall accumulation during the storm was nearly 2 inches. Based on the peak discharge at the Sycamore gaging station, the resultant runoff had a recurrence interval of 1.5 years and was the first flood of that size since the winter of 1986. Therefore, it is

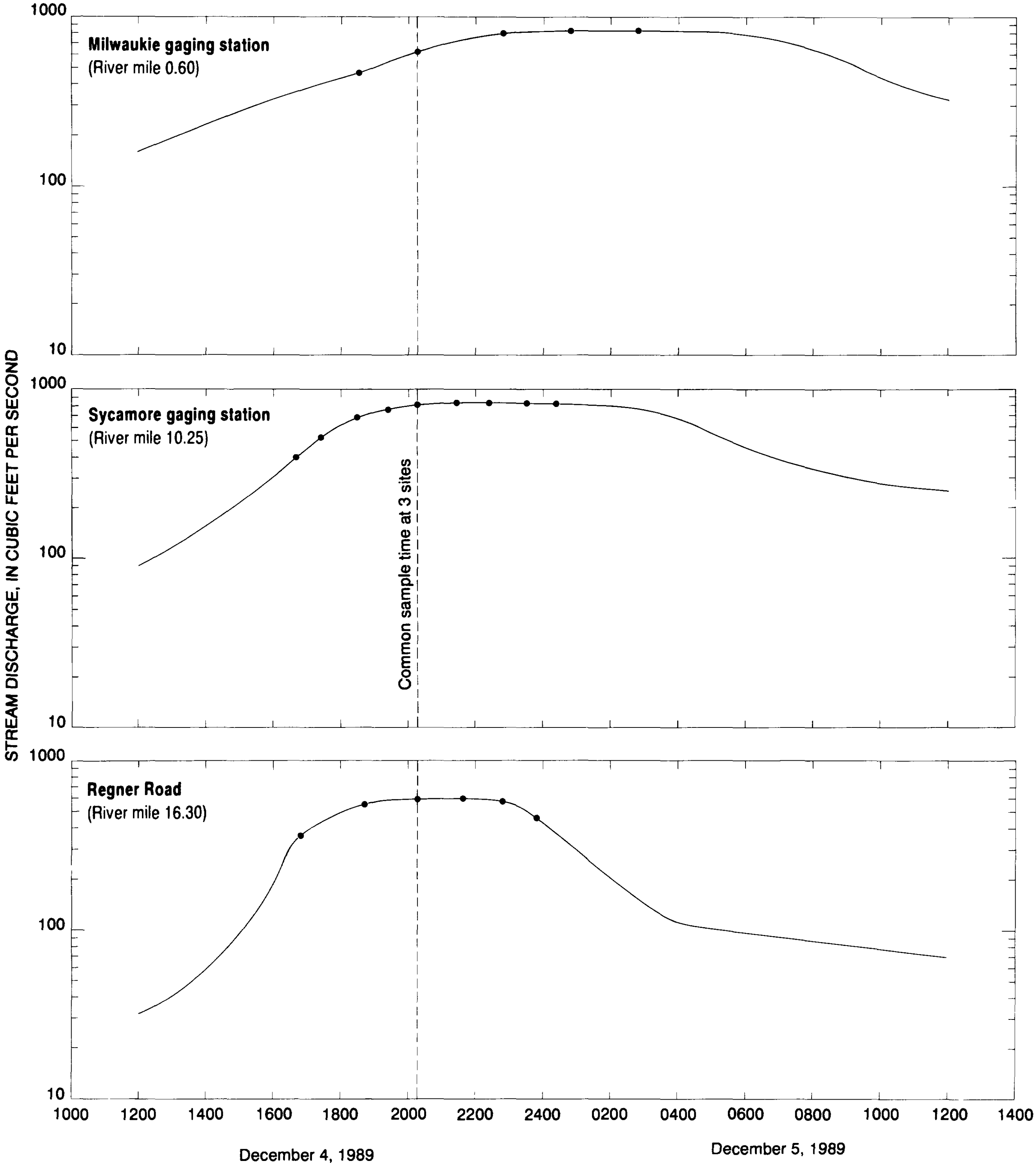

Figure 3. Discharge hydrographs and sampling times at selected sites on Johnson Creek, December 4-5, 1989.

likely the December 1989 storm carried some debris that had been stored in the basin for nearly 4 years, particularly material deposited on the streambank.

The second storm that was sampled occurred on January 25 and 26, 1990 (hereafter referred to as the January 1990 storm). Total rainfall accumulation during the storm was about 1 inch. This storm was typical of a mid-winter storm in the basin. Small amounts of debris were transported because the basin had been flushed by the December 1989 storm and an earlier, smaller storm in January 1990.

Nutrients

Phosphorus and nitrogen are essential nutrients for aquatic plant growth and, in sufficiently large concentrations, can adversely affect water quality through eutrophication or toxicity to fish and other aquatic life. In this study, water samples were collected and analyzed for total-organic nitrogen, total and dissolved ammonia, dissolved nitrite, dissolved nitrite plus nitrate, total ammonia plus organic nitrogen, total and dissolved phosphorus, and dissolved orthophosphorus. All analytical results are contained in a data report by Edwards (1991).

Dissolved Nitrate

During low flow in 1989, concentrations of nitrate as nitrogen in Johnson Creek ranged from 0.4-4.8 milligrams per liter (mg/L), and, in the lower basin, these concentrations fall in the range of concentrations reported by ODEQ in 1975 (Oregon Department of Environmental Quality, 1975). Nitrate concentrations (0.12 - 0.22 mg/L, Oregon Department of Environmental Quality, 1975) at sites in the upper part of the basin, however, significantly increased (3.7 to 8 times) during low flow, since 1975 (table 2). This increase may be the result of expanded residential development in the upper part of the basin and agricultural practices, even though total acreage for agricultural land use has decreased since 1975 with expansion of urban and residential land use.

Variations in concentrations of nitrate (fig. 4; table 2) above Stanley Avenue (RM 3.60) are likely the result of ground-water seepage into the creek and nutrient uptake by aquatic and riparian plant life. The marked increase between Stanley Avenue (RM 3.60) and McLoughlin Boulevard (RM 1.50) is probably associated with ground-water inflow, because stream discharge at low flow typically more than doubles through this reach. The large concentration of nitrate measured at Crystal Springs Creek (RM 1.20) is probably due to the combination of septic-tank seepage into the shallow ground water in the area, and the year-round duck and goose populations residing in the channel from near Reed College to its mouth (fig. 1).

During low flow, daily dissolved-nitrate loads in Johnson Creek ranged from 2.7 to 447 pounds (lbs) from Regner Road to the Milwaukie gage (table 2). The smallest dissolved-nitrate loads for Johnson Creek sites are from the headwater area of the basin. Although, there is a significant increase (about sevenfold) between Stanley Avenue (RM 3.60) and McLoughlin Boulevard (RM 1.50), the major source of dissolved-nitrate in Johnson Creek during low flow is Crystal Springs Creek

Table 2.--Mean nutrient concentrations, loads, and yields during low flow (August - October 1989), and composite concentrations and partial loads during storm runoff (December 1989 and January 1990) in Johnson Creek Basin

[LF = low flow; DS = December storm runoff; JS = January storm runoff; mi^2 = square mile; ft^3/s = cubic feet per second; mg/L = milligrams per liter; lbs = pounds; and lbs/mi^2 = pounds per square mile; RM = river mile; - = no data; and -- = data inadequate for computation]

Station name/ river mile	Flow condi- tion	Repre- senta- tive sample interval (days)	Drain- age area (mi^2)	Stream dis- charge (ft^3/s)	Dissolved ammonia as nitrogen: Concen- tra- tion (mg/L)	Daily load (lbs)	Partial storm load (lbs)	Yield (lb/mi^2)	Dissolved nitrate as nitrogen: Concen- tra- tion (mg/L)	Daily load (lbs)	Partial storm load (lbs)	Yield (lb/mi^2)	Dissolved orthophosphorus as phosphorus: Concen- tra- tion (mg/L)	Daily load (lbs)	Partial storm load (lbs)	Yield (lb/mi^2)	Total phosphorus as phosphorus: Concen- tra- tion (mg/L)	Daily load (lbs)	Partial storm load (lbs)	Yield (lb/mi^2)
Milwaukie	LF	1.0	51.4	18.0	0.05	4.9	-	0.1	4.6	447	-	8.7	0.08	7.8	-	0.2	0.10	9.7	-	0.2
gage/RM 0.60	DS	.34	51.4	740	.02	--	27.2	--	2.6	--	3,530	--	.03	--	40.8	--	.48	--	652	--
	JS	.89	51.4	380	.03	--	54.8	--	2.0	--	3,650	--	.03	--	54.8	--	.25	--	457	--
McLoughlin	LF	1.0	47.3	4.15	.04	.9	-	.01	4.5	101	-	2.1	.05	1.1	-	.02	.08	1.9	-	.04
Boulevard/	DS	.46	47.3	740	.04	--	73.5	--	2.5	--	4,600	--	.02	--	36.8	--	.43	--	790	--
RM 1.50	JS	.47	47.3	390	.03	--	29.7	--	1.8	--	1,780	--	.03	--	29.7	--	.39	--	386	--
Stanley	LF	1.0	45.8	1.9	.05	.5	-	.01	1.4	14.3	-	.3	.04	.4	-	.01	.06	.6	-	.01
Avenue/	DS	.40	45.8	750	.07	--	113	--	2.5	--	4,050	--	.03	--	48.6	--	1.2	--	1,940	--
RM 3.60	JS	.45	45.8	400	.06	--	58.3	--	1.7	--	1,650	--	.03	--	29.2	--	.41	--	399	--
Bell Avenue/	LF	1.0	45.3	1.8	.04	.4	-	.01	.76	7.4	-	.2	.04	.3	-	.01	.06	.6	-	.01
RM 4.20	DS	.46	45.3	750	.07	--	130	--	2.5	--	4,660	--	.03	--	55.9	--	.95	--	1,770	--
	JS	.44	45.3	335	.04	--	31.8	--	1.7	--	1,350	--	.02	--	15.9	--	.19	--	151	--
S.E. 82nd	LF	1.0	43.8	1.6	.08	.7	-	.02	.38	3.3	-	.07	.04	.3	-	.01	.08	.6	-	.01
Avenue/	DS	.48	43.8	750	.05	--	97.2	--	2.6	--	5,050	--	.03	--	58.3	--	1.0	--	1,940	--
RM 5.50	JS	.53	43.8	360	.04	--	41.2	--	1.8	--	1,850	--	.02	--	20.6	--	.35	--	361	--
Sycamore	LF	1.0	26.3	1.1	.06	.4	-	.01	.73	4.3	-	.2	.04	.2	-	.01	.09	.5	-	.02
gage/	DS	.32	26.3	740	.02	--	25.6	--	2.7	--	3,320	--	.04	--	51.1	--	.92	--	1,180	--
RM 10.25	JS	.52	26.3	360	.07	--	70.8	--	1.7	--	1,720	--	.04	--	40.4	--	.40	--	404	--
S.E. 190th	LF	1.0	20.0	1.3	.06	.4	-	.02	.84	5.9	-	.3	.04	.3	-	.02	.10	.7	-	.04
Avenue/	DS	.39	20.0	660	.06	--	83.4	--	2.9	--	3,510	--	.03	--	41.7	--	.89	--	1,240	--
RM 12.60	JS	.48	20.0	330	.05	--	42.8	--	1.9	--	1,630	--	.03	--	25.7	--	.33	--	282	--
Regner Road/	LF	1.0	15.4	.55	.06	.2	-	.01	.92	2.7	-	.2	.06	.2	-	.01	.10	.3	-	.02
RM 16.30	DS	.34	15.4	500	.04	--	36.7	--	3.5	--	3,210	--	.04	--	36.7	--	1.1	--	1,010	--
	JS	.41	15.4	103	.09	--	20.5	--	2.4	--	547	--	.03	--	6.8	--	.30	--	68.4	--
Crystal	LF	1.0	-	13.0	.07	4.9	-	--	5.5	386	-	--	.09	6.3	-	--	.12	8.4	-	--
Spring Creek/	DS	.35	-	12.0	.07	--	1.6	--	5.2	--	118	--	.12	--	2.7	--	.19	--	4.3	--
RM 1.20	JS	.43	-	12.0	.04	--	1.1	--	5.5	--	153	--	.10	--	2.8	--	.12	--	3.3	--
Kelley Creek/	LF	1.0	-	.25	.26	.4	-	--	.43	.58	-	--	.05	.07	-	--	.13	.18	-	--
RM 10.70	DS	.33	-	260	.05	--	23.2	--	2.9	--	1,340	--	.07	--	32.4	--	1.7	--	788	--
	JS	.39	-	85.0	.07	--	12.5	--	1.3	--	233	--	.07	--	12.5	--	.42	--	75.2	--

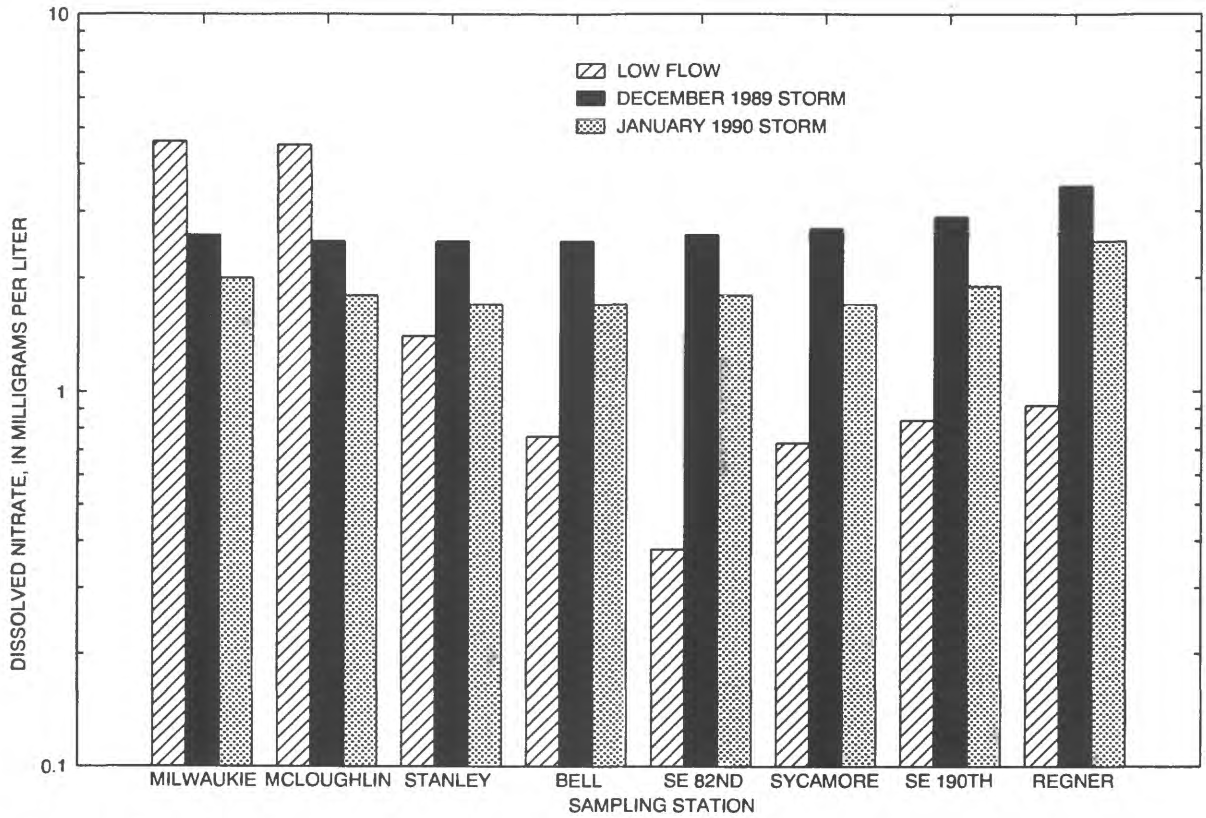

Figure 4. Concentrations of dissolved nitrate in Johnson Creek during low flow and storm runoff.

entering Johnson Creek between McLoughlin Boulevard (RM 1.50) and the Milwaukie gage (RM 0.60). Crystal Springs Creek contributed 386 lbs of dissolved-nitrate load of the 449 lbs measured at the Milwaukie gage (RM 0.60), comprising 86 percent of the daily low-flow load of dissolved nitrate delivered to the Willamette River from Johnson Creek.

During low flow, the largest increase in daily dissolved-nitrate yield occurs in the reach between Stanley Avenue (RM 3.60) and McLoughlin Boulevard (RM 1.50). At low flow, increases in dissolved-nitrate yield, occur primarily in reaches with significant discharge gains from ground-water inflow. From Regner Road (RM 16.30) to S.E. 190th Avenue (RM 12.60), the dissolved-nitrate yield increases by 50 percent while the discharge shows an increase of 136 percent. Between S.E. 82nd Avenue (RM 5.50) and the Milwaukie gage (RM 0.60), the dissolved-nitrate yield shows a greater than 120-fold increase while the stream discharge increases by a factor of more than 10.

Concentrations of dissolved nitrate during high flow are nearly the same from site to site in the main stream with a slight decrease in the downstream direction. This trend of nitrate concentrations during storms is likely the result of increased runoff through the urban areas of the basin effectively diluting the more nitrate-rich flow from the agricultural land in the upper part of the basin.

During the December 1989 storm, 3,210 lbs of dissolved nitrate was transported past the Regner Road site (RM 16.30) over a period of about 8 hours (1650 to 0100), while 3,530 lbs was transported past the Milwaukie gage (RM 0.60) and delivered to the Willamette River over a nearly coincident 8-hour period (1835 to 0300). The January 1990 storm runoff carried 547 lbs of dissolved nitrate past the Regner Road site during a period of slightly less than 10 hours (1530 to 0115), while 3,650 lbs were transported past the Milwaukie gage and delivered to the Willamette River in about 21-1/2 hours (1525 to 1250).

Dissolved Ammonia

Concentrations of dissolved ammonia in Johnson Creek during low flow were small (fig. 5 and table 2) and nearly constant from Regner Road (RM 16.30) to the Milwaukie gage (RM 0.60). Kelley Creek had the largest concentration (0.26 mg/L) of dissolved ammonia in the basin. The resultant effect to Johnson Creek downstream from the Kelly Creek inflow is minimal, however, because the discharge from Kelly Creek was less than 25 percent of the discharge at the Sycamore gage (RM 10.25).

Concentrations of dissolved ammonia in Johnson Creek during high flow do not differ significantly from the concentrations during low flow. The concentration of dissolved ammonia in Kelley Creek during high flow, however, was only 23 percent of the low-flow concentration.

Similar to the other nutrients, the major source of dissolved-ammonia load during low flow is Crystal Springs Creek, representing most of the ammonia load entering the Willamette River from Johnson Creek. The ammonia loads upstream of the Crystal Springs Creek confluence during low flow were small.

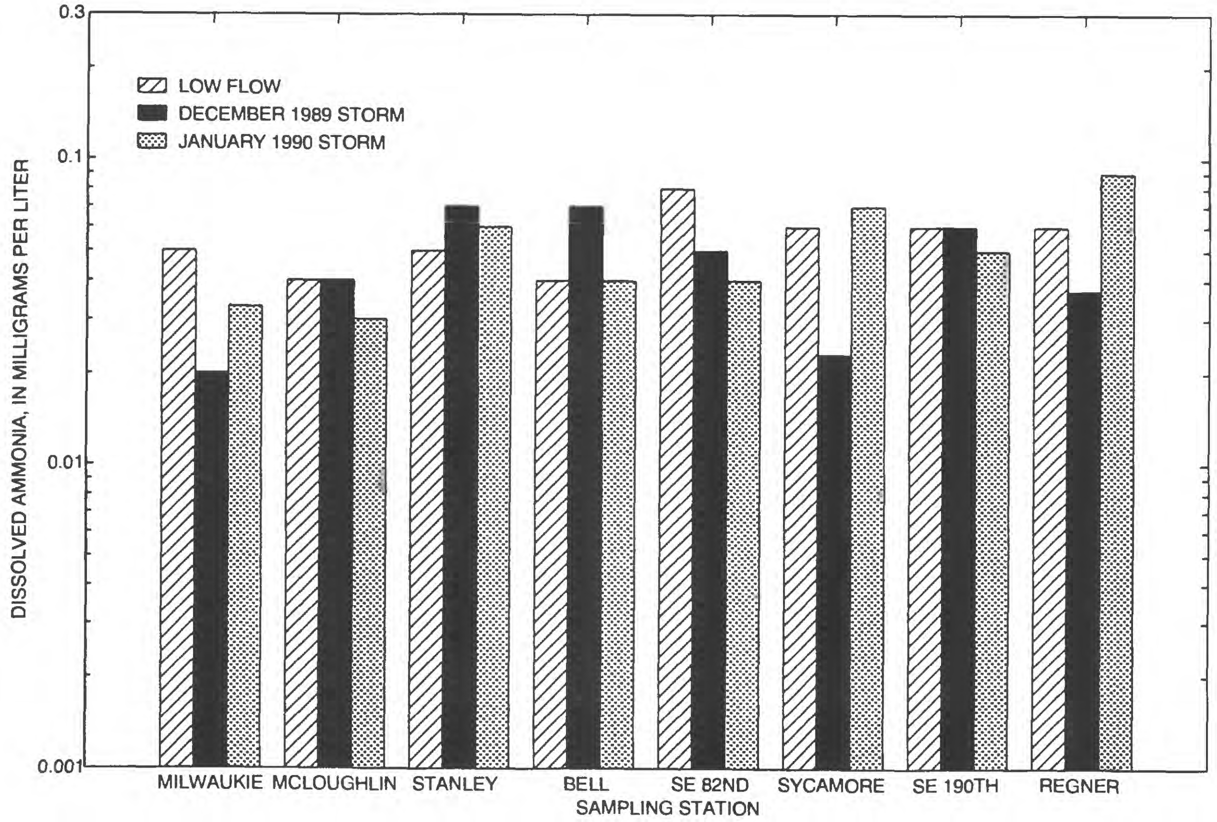

Figure 5. Concentrations of dissolved ammonia in Johnson Creek during low flow and storm runoff.

During low flow, dissolved-ammonia yields remain nearly constant from Regner Road (RM 16.30) to McLoughlin Boulevard (RM 1.50) increasing by only 0.01 lb/mi^2 between Regner Road (RM 16.30) and S.E. 190th Avenue (RM 12.60), and between the Sycamore gage (RM 10.25) and S.E. 82nd Avenue. The largest dissolved-ammonia yield increase during low flow was between McLoughlin Boulevard (RM 1.50) and the Milwaukie gage (RM 0.60) where the yields increased from 0.01 to 0.1 lbs/mi^2.

During the December 1989 storm, partial loads of 36.7 and 27 lbs of dissolved ammonia were transported past the Regner Road (RM 16.30) and Milwaukie (RM 0.60) gage sites. The January 1990 storm runoff carried partial loads of 20.5 and 54.8 lbs of dissolved ammonia past the Regner Road (RM 16.30) and Milwaukie (RM 0.60) gage sites.

Dissolved Orthophosphorus

In Johnson Creek, the concentrations of dissolved orthophosphorus were equal to or greater than the 0.025 mg/L level for all low-flow samples and for most of the storm samples. If the critical concentration for biologically available orthophosphorus as phosphorus (P) exceeds 0.025 mg/L, it can cause nuisance growths of algae and other aquatic plants (U.S. Environmental Protection Agency, 1986).

Concentrations of orthophosphorus (as P) were nearly constant at low flow in Johnson Creek from Regner Road (RM 16.30) to McLoughlin Boulevard (RM 1.50), averaging 0.04 mg/L (fig. 6 and table 2). The large increase in dissolved orthophosphorus concentration between McLoughlin Boulevard (RM 1.50) and the Milwaukie gage (RM 0.60) is from Crystal Springs Creek entering Johnson Creek at RM 1.20.

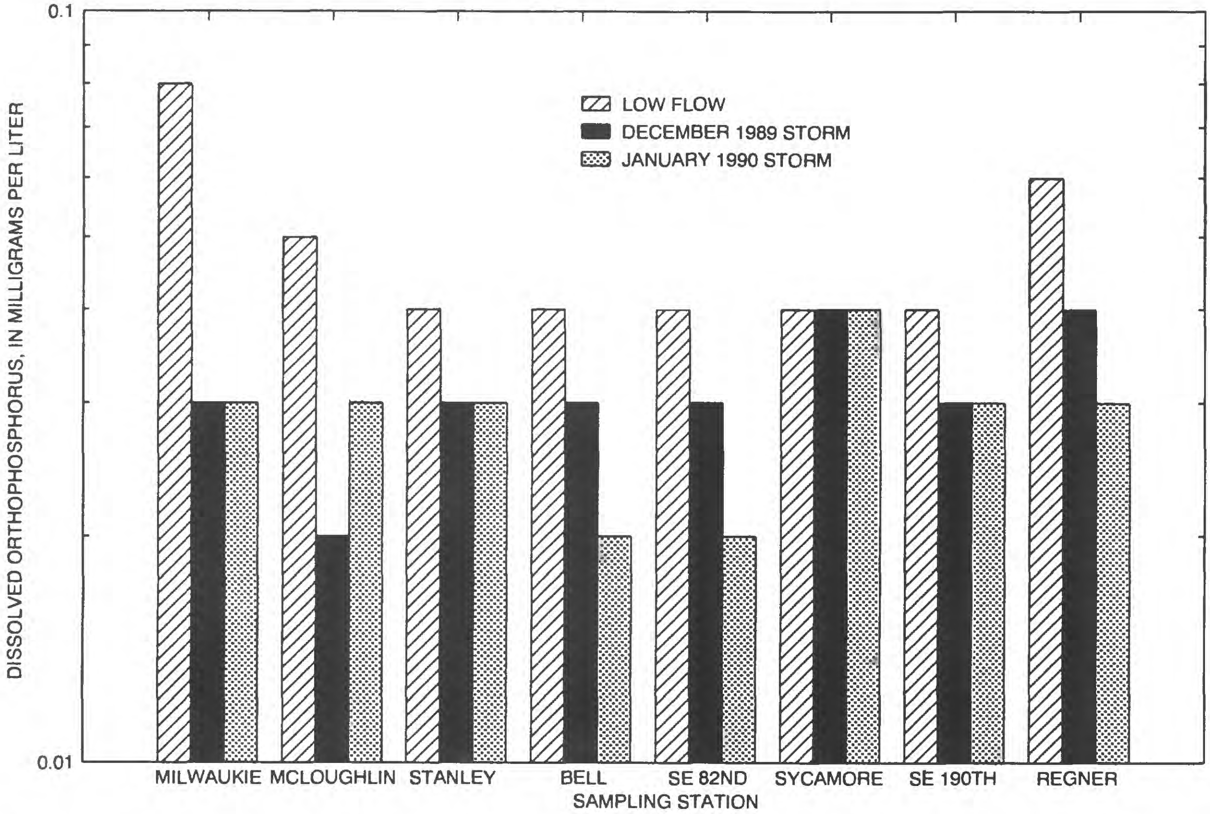

Figure 6. Concentrations of dissolved orthophosphorus in Johnson Creek during low flow and storm runoff.

The dissolved orthophosphorus loads in Johnson Creek during low flow were small and nearly constant in the upper basin from Regner Road (RM 16.30) to Stanley Avenue (RM 3.60). Between Stanley Avenue (RM 3.60) and the Milwaukie gage (RM 0.60), the dissolved orthophosphorus load increased nearly 20 fold, and most of the increase was from Crystal Springs Creek. Eighty-one percent of the low-flow dissolved orthophosphorus load entering the Willamette River from Johnson Creek is the result of high discharge and high concentrations from Crystal Springs Creek.

During low flow, the dissolved orthophosphorus yield remained nearly constant with little variation from Regner Road (RM 16.30) to Stanley Avenue (RM 3.60) [fig. 6]. Between Stanley Avenue (RM 3.60) and the Milwaukie gage (RM 0.60), however, the dissolved orthophosphorus yield showed a nearly 20-fold increase, similar to the loads discussed above. The large increase in dissolved orthophosphorus yield in the reach between Stanley Avenue (RM 3.60) and the Milwaukie gage (RM 0.60) was associated with the large increase in stream flow in this reach, most of which came from Crystal Springs Creek.

Dissolved orthophosphorus concentrations in the upper basin during storm runoff were only slightly smaller than during low flow. In the lower part of the basin, concentrations during storm runoff were approximately one-half to one-third of the concentrations during low flow because as the discharge in Johnson Creek increases the effects of Crystal Springs Creek are diminished on Johnson Creek.

During the December 1989 storm, partial loads of 36.7 and 48 lbs of dissolved orthophosphorus were transported past the Regner Road (RM 16.30) and Milwaukie (RM 0.60) gage sites. The January 1990 storm runoff carried partial loads of 6.8 and 54.8 lbs of dissolved orthophosphorus past the Regner Road (RM 16.30) and Milwaukie (RM 0.60) gage sites.

Total Phosphorus

Total phosphorus is a measure of the organic and inorganic forms of dissolved and suspended phosphorus. To reduce the likelihood of excessive growth of aquatic plants in flowing water, it is recommended that total phosphorus (as P) should not exceed 0.10 mg/L (U.S. Environmental Protection Agency, 1986). Total phosphorus concentrations in Johnson Creek at Regner Road (RM 16.30), S.E. 190th Avenue (RM 12.60), and Milwaukie gage (RM 0.60) were 0.10 mg/L during 1989 low flow, and the two tributaries, Kelley Creek and Crystal Springs Creek, had concentrations of 0.13 and 0.12 mg/L, respectively (fig. 7; table 2).

The total phosphorus load during low flow increased from 0.3 to 0.7 lbs between Regner Road (RM 16.30) and S.E. 190th Avenue (RM 12.60), corresponding to about a 135 percent increase in stream discharge. The large increase in total phosphorus load between Stanley Avenue (RM 3.60) and McLoughlin Boulevard (RM 1.50) is mostly from Crystal Springs Creek, contributing 87 percent of the total phosphorus load at the Milwaukie gage (RM 0.60).

At low flow, total phosphorus yields fluctuated within the range 0.01 to 0.04 lbs/mi^2 at Johnson Creek sites from Regner Road (RM 16.30) to McLoughlin Boulevard (RM 1.50). The largest total phosphorus yield (0.2 lbs/mi^2) was detected at the Milwaukie gage (RM 0.60). The largest increase occurred between Stanley Avenue (RM 3.60) and the Milwaukie gage (RM 0.60) where the total phosphorus yield increased from 0.04 to 0.2 lbs/mi^2.

During the December 1989 storm, concentrations of total phosphorus were large and nearly constant from Regner Road (RM 16.30) to Stanley Avenue (RM 3.60). Downstream of Stanley Avenue (RM 3.60), however, total phosphorus concentrations decreased from 1.2 to 0.43 mg/L while stream discharge stayed nearly constant (fig. 7). The largest concentration of total phosphorus was measured in Kelley Creek tributary (table 2). During the January 1990 storm, total phosphorus concentrations were nearly constant from Regner Road (RM 16.30) to S.E. 82nd Avenue (RM 5.50), decreased to the smallest concentration in the main stem (0.19 mg/L) at Bell Avenue (RM 4.20), and then increased to the largest concentration in the main stem (0.41 mg/L) at Stanley Avenue (RM 3.60). During both storms, major increases in total phosphorus concentration occurred between Bell Avenue (RM 4.20) and Stanley Avenue (RM 3.60), suggesting a source of total phosphorus in this reach. All concentrations for both storms exceeded the recommended limit of 0.10 mg/L.

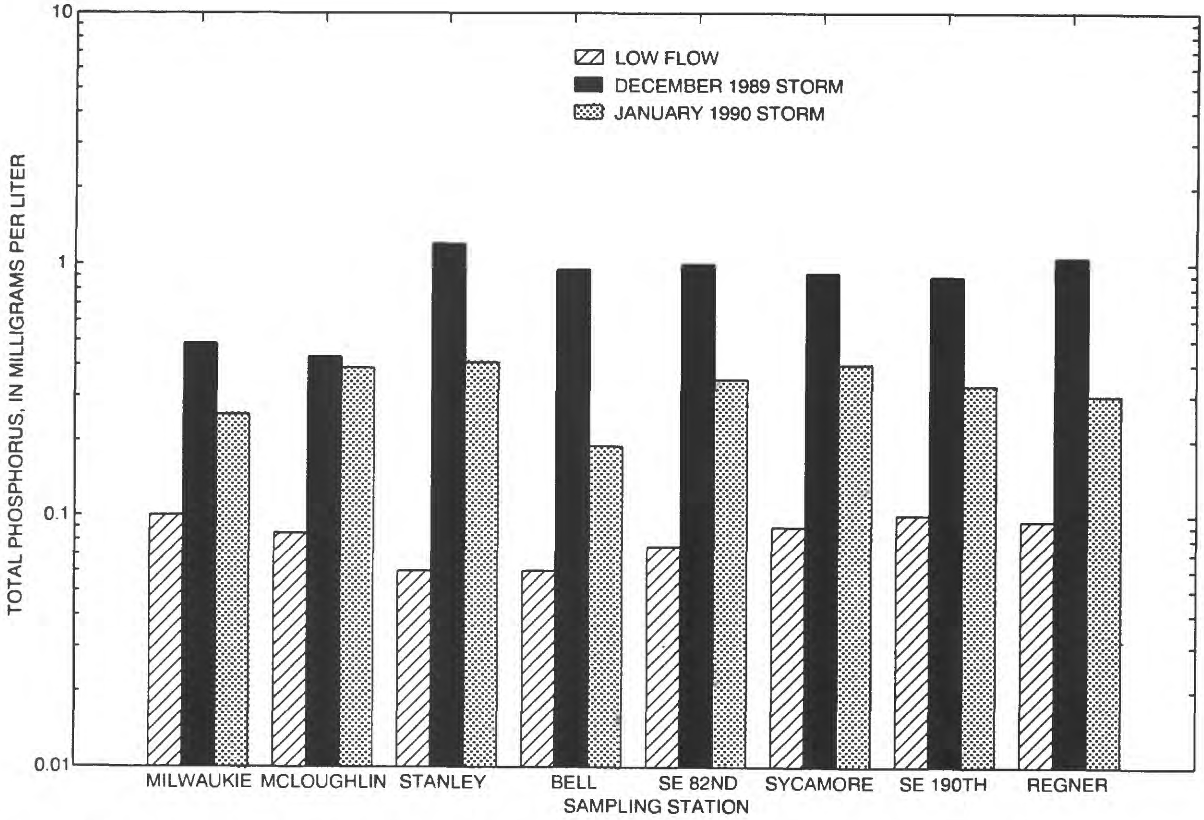

Figure 7. Concentrations of total phosphorus in Johnson Creek during low flow and storm runoff.

During the December 1989 storm, partial loads of 1,010 and 652 lbs of total phosphorus were transported past the Regner Road (RM 16.30) and Milwaukie gage (RM 0.60) sites. The January 1990 storm runoff carried partial loads of 68.4 and 457 lbs of total phosphorus past the Regner Road (RM 16.30) and Milwaukie (RM 0.60) gage sites.

Synthetic-Organic Compounds

When used properly, synthetic-organic compounds can be beneficial and often invaluable to human activities. One such use is the application of pesticides to control insects and weeds which are damaging to agriculture. Some pesticides that are soluble in water will percolate down to ground-water supplies and possibly seep to surface water as subsurface drainage. Other pesticides will sorb to sediment particles and possibly be transported from fields to surface water by erosion.

Even in small concentrations, many pesticides are harmful and even toxic to aquatic organisms. Some pesticide compounds bioaccumulate (become concentrated in tissues of aquatic plants and animals) to concentrations that are orders of magnitude larger than those present in water and sediment in which the organisms live. A few pesticides are resistant to biological degradation and many persist in sediment and water for many years.

During this study, samples were collected and analyzed for total-recoverable organochlorine pesticides plus PCBs. These compounds include perthane, DEF, naphthalenes polychlor, aldrin, lindane, chlordane, DDD (dichlorodiphenyldichloroethane), DDE (dichlorodiphenyl-dichloroethene), DDT (dichlorodiphenyltrichloroethane), dieldrin, endosulfan, endrin, toxaphene, heptachlor, heptachlor epoxide, methoxychlor, mirex, and PCBs. All the analytical results are listed in a data report by Edwards (1991). The interpretive discussion, however, is limited to those compounds found to exceed an USEPA criteria (U.S. Environmental Protection Agency, 1986).

Total-recoverable Chlordane

Chlordane, a chlorinated hydrocarbon insecticide, was used extensively in the past as a control for termites, as an insecticide for homes and gardens, and as a control for soil insects. Chlordane is listed by USEPA as a priority pollutant and carcinogen (U.S. Environmental Protection Agency, 1986). The maximum permissible concentration in water established to protect freshwater aquatic life is 0.0043 μg/L (micrograms per liter) as a 24-hour average, not to exceed 2.4 μg/L at anytime.

Total-recoverable chlordane was reported at the three upper sites on Johnson Creek during storm runoff at concentrations equal to the reporting level of 0.1 μg/L (table 3). Also, during the December 1989 storm a relatively large concentration (1.9 μg/L) of total-recoverable chlordane was detected at the Milwaukie gage (RM 0.60). During the December 1989 storm, partial-storm loads (table 3) of 0.09 and 2.6 lbs were transported past Regner Road (RM 16.30) and the Milwaukie gage (RM 0.60) in representative sample intervals of slightly greater than 8 hours. The partial-storm load of total-recoverable chlordane

Table 3.--<u>Mean organic compound concentrations, loads and yields during low flow (August - October 1989), and composite concentrations and partial loads during storm runoff (December 1989 and January 1990) in Johnson Creek Basin</u>

[LF = low flow; DS = December storm runoff; JS = January storm runoff; mi^2 = square miles; ft^3/s = cubic feet per second; ug/L = micrograms per liter; lbs = pounds; lbs/mi^2 = pounds per square mile; RM = river mile; < = less than; - = no data; and -- = data inadequate for computation; DDT = dichlorodiphenyltrichloroethane; DDD = dichlorodiphenyldichloroethane; DDE = dichlorodiphenyldichloroethylene]

					Total recoverable chlordane				Sum of total recoverable DDT plus DDD plus DDE				Total recoverable dieldrin			
Station name/ river mile	Flow condition	Representative sample interval (days)	Drainage area (mi^2)	Stream discharge (ft^3/s)	Concentration (ug/l)	Daily load (lbs)	Partial storm load (lbs)	Yield (lb/mi^2)	Concentration (ug/l)	Daily load (lbs)	Partial storm load (lbs)	Yield (lb/mi^2)	Concentration (ug/l)	Daily load (lbs)	Partial storm load (lbs)	Yield (lb/mi^2)
Milwaukie gage/ RM 0.60	LF	1.0	51.4	18.0	<0.1	<0.01	-	<0.0002	<0.03	<0.003	-	<0.00006	<0.01	<0.001	-	<0.00002
	DS	.34	51.4	740	1.9	--	2.6	--	.14	--	.19	--	.02	--	0.03	--
	JS	.89	51.4	380	<.1	--	<.20	--	.060	--	.11	--	.01	--	.02	--
McLoughlin Boulevard/ RM 1.50	LF	1.0	47.3	4.15	<.1	<.002	-	<.00005	<.03	<.0007	-	<.00001	<.01	<.0002	-	<.000005
	DS	.46	47.3	740	<.1	--	<.20	--	.11	--	.20	--	.02	--	.04	--
	JS	.47	47.3	390	<.1	--	<.10	--	.053	--	.05	--	.012	--	.01	--
Stanley Avenue/ RM 3.60	LF	1.0	45.8	1.9	<.1	<.001	-	<.00002	<.03	<.0003	-	<.000007	.01	.0001	-	.000002
	DS	.40	45.8	750	<.1	--	<.20	--	.15	--	.20	--	.03	--	.05	--
	JS	.45	45.8	400	<.1	--	<.10	--	.072	--	.07	--	.016	--	.02	--
Bell Avenue/ RM 4.20	LF	1.0	45.3	1.8	<.1	<.001	-	<.00002	<.03	<.0003	-	<.000006	.01	.0001	-	.000002
	DS	.46	45.3	750	<.1	--	<.20	--	.29	--	.54	--	.02	--	.04	--
	JS	.44	45.3	335	<.1	--	<.08	--	.073	--	.06	--	.016	--	.01	--
S.E. 82nd Avenue/ RM 5.50	LF	1.0	43.8	1.6	<.1	<.0009	-	<.00002	<.03	<.0003	-	<.000006	.01	.00009	-	.000002
	DS	.48	43.8	750	<.1	--	<.20	--	.07	--	.14	--	.02	--	.04	--
	JS	.53	43.8	360	<.1	--	<.10	--	.073	--	.08	--	.017	--	.02	--
Sycamore gage/ RM 10.25	LF	1.0	26.3	1.1	<.1	<.0006	-	<.00002	<.03	<.0002	-	<.000007	.01	.00006	-	.000002
	DS	.32	26.3	740	.1	--	0.13	--	.20	--	.26	--	.03	--	0.04	--
	JS	.52	26.3	360	<.1	--	<.10	--	.092	--	.09	--	.02	--	.02	--
S.E. 190th Avenue/ RM 12.60	LF	1.0	20.0	1.3	<.1	<.0007	-	<.00004	<.03	<.0002	-	<.00001	.01	.00007	-	.000004
	DS	.39	20.0	660	<.1	--	<.14	--	.28	--	.39	--	.04	--	.06	--
	JS	.48	20.0	330	.1	--	.09	--	.097	--	.08	--	.02	--	.02	--
Regner Road/ RM 16.30	LF	1.0	15.4	.55	<.1	<.0003	-	<.00002	<.03	<.00009	-	<.000006	.01	.00003	-	.000002
	DS	.34	15.4	500	.1	--	.09	--	.39	--	.36	--	.04	--	.04	--
	JS	.41	15.4	103	.1	--	.02	--	.156	--	.04	--	.028	--	.006	--
Crystal Spring Creek/ RM 1.20	LF	1.0	-	13.0	<.1	<.007	-	--	<.03	<.002	-	--	<.01	<.01	-	--
	DS	.35	-	12.0	<.1	--	<.002	--	<.03	--	<.0007	--	.01	--	.0002	--
	JS	.43	-	12.0	<.1	--	<.003	--	<.003	--	<.00008	--	.006	--	.0002	--
Kelley Creek/ RM 10.70	LF	1.0	-	.25	<.1	<.0001	-	--	<.03	<.00004	-	--	.01	.00001	-	--
	DS	.33	-	260	<.1	--	<.05	--	.14	--	.06	--	.05	--	.02	--
	JS	.39	-	85.0	<.1	--	<.02	--	.084	--	.02	--	.028	--	.005	--

transported during the January 1990 storm was 0.02 lbs at Regner Road (RM 16.30) over a sample interval of nearly 10 hours. At the Milwaukie gage (RM 0.60), the partial-storm load is reported as less than 0.20 lbs for the January 1990 storm, because the concentration was less than the reporting level. The reason for the large concentration associated with the composite sample at that site is not known.

Total-Recoverable Dieldrin

Total-recoverable dieldrin was measured at detectable concentrations (0.01 μg/L) during low flow at the six sites on Johnson Creek from Regner Road (RM 16.30) to Stanley Avenue (RM 3.60), and at Kelly Creek tributary (RM 10.70) [table 3]. This concentration exceeds the Fresh Water Chronic Toxicity (FWCT) criterion concentration of 0.0019 μg/L (U.S. Environmental Protection Agency, 1986). Dieldrin concentrations determined during low flow at the remaining mainstream and tributary sites were reported as less than reporting levels. The source of dieldrin during low flow is not known, but because it is a hydrophobic compound, its occurrence may be associated with colloidal material and other fine sediment in the sample. The detection of dieldrin illustrates its persistence in the environment even though the manufacture of dieldrin was prohibited in the United States in 1974. (Note: Low-flow concentrations determined during this study are averages of flow-weighted samples and represent daily conditions at low flow, and storm-runoff concentrations are determined from composites of flow-weighted samples representing time intervals equal to the parts of the storms sampled at each site. The 1-hour or 4-day FWCT criteria, therefore, should be used only as a reference point; no measurements were made to determine the average concentration of any constituent over a 1-hour or 4-day time period.)

Daily loads of total-recoverable dieldrin ranged from 0.00003 to 0.0001 lbs at sites on Johnson Creek from Regner Road (RM 16.30) to Stanley Avenue (RM 3.60), during low flow. The daily load transported by Kelley Creek tributary was 0.00001 lbs. The largest daily loads (0.0001 lbs) were determined at Bell Avenue (RM 4.20) and Stanley Avenue (RM 3.60). The largest daily load increase in total-recoverable dieldrin, however, occurred in the agriculturally dominant upper part of the basin between Regner Road (RM 16.30) and S.E. 190th Avenue (RM 12.60).

During low flow, the yield of total-recoverable dieldrin increased between Regner Road (RM 16.30) and S.E. 190th Avenue (RM 12.60). The yield decreased between S.E. 190th Avenue (RM 12.60) and the Sycamore gage (RM 10.25) and remained constant from the Sycamore gage (RM 10.25) to Stanley Avenue (RM 3.60).

During the December 1989 storm, concentrations of total-recoverable dieldrin in Johnson Creek range from 0.02 μg/L at several sites to 0.04 μg/L at S.E. 190th Avenue (RM 12.60). The largest concentration (0.05 μg/L) was measured in Kelley Creek tributary [RM 10.70] (table 3). During the January 1990 storm, concentrations of total-recoverable dieldrin ranged from 0.012 μg/L at McLoughlin Boulevard (RM 1.50) to 0.028 μg/L at Regner Road (RM 16.30) and Kelley Creek tributary (RM 10.70). Concentrations at all sites for both storms exceeded the FWCT criterion concentration of 0.0019 μg/L (U.S. Environmental Protection Agency, 1986).

Partial-storm loads of total-recoverable dieldrin of 0.04 and 0.03 lbs were transported past Regner Road (RM 16.30) and the Milwaukie gage (RM 0.60) over slightly greater than 8-hour-sample intervals during the December 1989 storm. During the January 1990 storm, partial-storm loads of 0.006 and 0.02 lbs of total-recoverable dieldrin were transported during representative sample intervals of about 10 and 21.5 hours at Regner Road (RM 16.30) and Milwaukie gage (RM 0.60).

Total Recoverable Dichlorodiphenyltrichloroethane (DDT) plus Metabolites

Total-recoverable DDT plus metabolites (DDT + DDD + DDE) are pesticides that are highly resistant to degradation. In 1972, USEPA banned the use of DDT because of hazards to health and the environment, but DDT is still detected in waterways and bottom sediment. Because DDT plus metabolites sorb to sediment, these compounds generally are transported into streams by erosion.

In Johnson Creek, concentrations as large as 1.18 ppm of total-recoverable DDT plus metabolites in bottom material were measured in the upper basin above Regner Road (RM 16.30) where agriculture is the primary land use (Edwards and Curtiss, 1993).

During low flow, concentrations of DDT plus metabolites in Johnson Creek Basin were less than the reporting level (table 3). The analytical method used for low flow and the December 1989 storm samples, however, had a reporting level of only 0.01 μg/L each for DDT, DDE and DDD. Concentrations reported as less than this reporting level should not be interpreted as meeting USEPA's FWCT chronic criterion of 0.001 μg/L (U.S. Environmental Protection Agency, 1986). The analytical method used for the January 1990 storm samples had a reporting level of 0.001 μg/L each for DDT, DDD, and DDE, equal to the FWCT criterion.

During the December 1989 storm, total-recoverable DDT concentrations were greater than the reporting level (0.01 μg/L) at all sites except for Crystal Springs Creek tributary. The largest concentration (0.39 μg/L) of DDT plus metabolites occurred at the uppermost site at Regner Road (RM 16.30). The largest increase in concentration occurred between S.E. 82nd Avenue (RM 5.50) and Bell Avenue (RM 4.20) where the concentration increased from 0.07 to 0.29 μg/L. Concentrations decreased to 0.15 μg/L between Bell Avenue (RM 4.20) and Stanley Avenue (RM 3.60) and remained nearly constant from Stanley Avenue to the Milwaukie gage (RM 0.60). During the January 1990 storm, total-recoverable DDT plus metabolite concentrations were greater than reporting level at all sites in the basin except Crystal Springs Creek, exceeding the FWCT criterion of 0.001 μg/L. The maximum concentration of total-recoverable DDT plus metabolites (0.156 μg/L) occurred at Regner Road (RM 16.30). Concentrations decreased steadily to S.E. 82nd Avenue (RM 5.50), then remained nearly constant to the Milwaukie gage (RM 0.60).

Partial-storm loads of total-recoverable DDT plus metabolites were 0.36 and 0.19 lbs, respectively, at Regner Road (RM 16.30) and Milwaukie gage (RM 0.60) during the December 1989 storm. During the January 1990 storm, partial-storm loads of 0.04 and 0.11 lbs were transported at Regner Road (RM 16.30) and Milwaukie gage (RM 0.60), respectively, over intervals of nearly 10 and 21.5 hours.

Dissolved Trace Elements

Concern about trace metals in the aquatic environment has been increasing over the last several decades because these elements (1) are widely distributed throughout the environment; (2) are toxic in small concentrations to plants, humans, and other animals; and (3) can bioaccumulate in plants and animals moving up the food chain into edible fish. Although some trace elements are essential nutrients for growth of aquatic life and many have no harmful effects in aquatic environments, many trace elements are toxic at enriched concentrations.

Constituents evaluated in this study include the metals (barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, silver, strontium, vanadium, zinc, and lithium); major ions (calcium, magnesium, and sodium); silica and hardness. Concentrations of dissolved trace elements were determined during this study; however, USEPA's criteria concentrations are based on total-recoverable analyses. Because dissolved concentrations are equal to or less than total-recoverable concentrations, comparing the dissolved trace-metal concentrations with USEPA criteria should be done with the understanding that total-recoverable concentrations in a sample may be larger and, therefore, might be greater and exceed the criteria. Except for hardness, U.S. Environmental Protection Agency (1986) does not include criteria for concentrations of major ion determinations. Comparisons of hardness data from Johnson Creek Basin with U.S. Environmental Protection Agency (1986) criteria, however, indicates that during low flow, water in the basin is generally soft except at the Milwaukie gage (RM 0.60) and Crystal Springs Creek (RM 1.20) sites. Hardness at both of these sites falls in the concentration range of moderately hard for low flow. During the December 1989 and January 1990 storms, all hardness concentrations are classified as soft.

Dissolved barium was detected at all sampling sites in Johnson Creek Basin, but concentrations were small and pose no threat to the aquatic environment. Likewise, dissolved strontium and manganese were detected at every sampling site, but concentrations were small. Molybdenum and vanadium are not on USEPA's priority pollutant list, but molybdenum was detected at concentrations of 10 μg/L in Johnson Creek during low flow at Regner Road (RM 16.30), the Sycamore gage (RM 10.25), and at McLoughlin Boulevard (RM 1.50). Vanadium was not detected in Johnson Creek, but was detected in Crystal Springs Creek during low flow (8 μg/L) and December 1989 storm runoff (7 μg/L). Dissolved chromium, cobalt, and lithium were not detected at any sampling sites in the basin during low flow or storm runoff.

Beryllium

During the January 1990 storm, concentrations of dissolved beryllium of 1.0 μg/L were measured at four Johnson Creek main-stream sites from Regner Road (RM 16.30) to the Milwaukie gage (RM 0.60) and 0.8 μg/L at S.E. 190th Avenue (RM 12.60). Beryllium was less than the reporting level of 0.5 μg/L for all low flow and December 1989 storm samples (table 4). The FWCT criterion for beryllium to protect aquatic life is a 1-hour average total-recoverable concentration of 5.3 μg/L (U.S. Environmental Protection Agency, 1986) and was never exceeded during this study.

Table 4.--Mean dissolved trace-element concentrations, loads and yields during low flow (August - October 1989), and composite concentrations and partial loads during storm runoff (December 1989 and January 1990) in Johnson Creek Basin

[LF = low flow; DS = December storm runoff; JS = January storm runoff; mi^2 = square miles; ft^3/s = cubic feet per second; µg/L = micrograms per liter; lbs = pounds; lbs/mi^2 = pounds per square mile; and < = less than]

Station name/ river mile	Flow condi- tion	Represen- tative sample interval (days)	Drain- age area (mi^2)	Stream dis- charge (ft^3/s)	Dissolved beryllium Concen- tra- tion (µg/l)	Dissolved beryllium Daily load (lbs)	Dissolved beryllium Partial storm load (lbs)	Dissolved beryllium Yield (lb/mi^2)	Dissolved cadmium Concen- tra- tion (µg/l)	Dissolved cadmium Daily load (lbs)	Dissolved cadmium Partial storm load (lbs)	Dissolved cadmium Yield (lb/mi^2)	Dissolved copper Concen- tra- tion (µg/l)	Dissolved copper Daily load (lbs)	Dissolved copper Partial storm load (lbs)	Dissolved copper Yield (lb/mi^2)	Dissolved iron Concen- tra- tion (µg/l)	Dissolved iron Daily load (lbs)	Dissolved iron Partial storm load (lbs)	Dissolved iron Yield (lb/mi^2)	Dissolved manganese Concen- tra- tion (µg/l)	Dissolved manganese Daily load (lbs)	Dissolved manganese Partial storm load (lbs)	Dissolved manganese Yield (lb/mi^2)
Milwaukie gage/ RM 0.60	LF	1.0	51.4	18.0	<0.5	<0.05	-	<0.0009	<1.0	<0.1	-	<0.002	<10.0	<1.0	-	<0.02	106	10.0	-	0.2	16.0	1.5	-	0.03
	DS	.34	51.4	740	< .5	--	< .7	--	<1.0	--	<1.4	--	10.0	--	13.6	--	180	--	245	--	2.5	--	3.4	--
	JS	.89	51.4	380	1.0	--	1.8	--	1.0	--	1.8	--	<10.0	--	<18.3	--	81.0	--	148	--	1.0	--	1.8	--
McLoughlin Boulevard/ RM 1.50	LF	1.0	47.3	4.15	< .5	< .01	-	< .0002	<1.0	< .02	-	< .0005	<10.0	< .2	-	< .005	160	3.6	-	.08	12.0	.3	-	.005
	DS	.46	47.3	740	< .5	--	< .9	--	<1.0	--	<1.8	--	<10.0	--	<18.4	--	210	--	386	--	7.0	--	12.9	--
	JS	.47	47.3	390	< .5	--	< .5	--	<1.0	--	<1.0	--	<10.0	--	< 9.9	--	58.0	--	57.4	--	< 1.0	--	< 1.0	--
Stanley Avenue/ RM 3.60	LF	1.0	45.8	1.9	< .5	< .005	-	< .0001	1.0	.01	-	.0002	<10.0	< .1	-	< .002	300	3.1	-	.07	26.0	.3	-	006
	DS	.40	45.8	750	< .5	--	< .8	--	<1.0	--	<1.6	--	<10.0	--	<16.0	--	150	--	243	--	9 0	--	15.0	--
	JS	.45	45.8	400	< .5	--	< .5	--	<1.0	--	<1.0	--	<10.0	--	< 9.7	--	100	--	97.2	--	2.0	--	1.9	--
Bell Avenue/ RM 4.20	LF	1.0	45.3	1.8	< .5	< .005	-	< .0001	<1.0	< .01	-	< .0002	<10.0	< .1	-	< .002	365	3.5	-	.08	24.0	.2	-	.005
	DS	.46	45.3	750	< .5	--	< .9	--	<1.0	--	<1.9	--	20.0	--	37.3	--	110	--	205	--	7.0	--	13.0	--
	JS	.44	45.3	335	1.0	--	.8	--	<1.0	--	< .8	--	<10.0	--	< 8.0	--	160	--	127	--	14.0	--	11.9	--
S.E. 82nd Avenue/ RM 5.50	LF	1.0	43.8	1.6	< .5	< .004	-	< .0001	<1.0	< .006	-	< .0002	<10.0	< .09	-	< .002	465	4.0	-	.09	56.0	.5	-	.01
	DS	.48	43.8	750	< .5	--	<1.0	--	<1.0	--	<1.9	--	10.0	--	19.4	--	67.0	--	130	--	7.0	--	13.6	--
	JS	.53	43 8	360	< .5	--	< .5	--	1.0	--	.9	--	<10.0	--	<10.3	--	110	--	113	--	8.0	--	8.2	--
Sycamore gage/ RM 10.25	LF	1.0	26.3	1.1	< .5	< .003	-	< .0001	<1.0	< .006	-	< .0002	<10.0	< .06	-	< .002	370	2.2	-	.08	64.0	.4	-	.01
	DS	.32	26.3	740	< .5	--	< .6	--	<1.0	--	<1.3	--	<10.0	--	<12.8	--	130	--	166	--	2.7	--	3.5	--
	JS	.52	26.3	360	1.0	--	1.0	--	2.0	--	2.0	--	<10.0	--	<10.1	--	140	--	142	--	5.7	--	5.8	--
S.E 190th Avenue/ RM 12.60	LF	1.0	20.0	1.3	< .5	< .004	-	< .0002	<1.0	< .007	-	< .0004	<10.0	< .07	-	< .004	880	6.2	-	.3	195	1.4	-	.07
	DS	.39	20.0	660	< .5	--	< .7	--	<1.0	-	<1.4	--	<10.0	--	<13.9	--	95.0	--	132	--	19.0	--	26.4	--
	JS	.48	20.0	330	.8	--	.7	--	<1.0	--	< .9	--	<10.0	--	< 8.6	--	110	--	94.0	--	2.0	--	1.7	--
Regner Road/ RM 16.30	LF	1.0	15.4	.55	< .5	< .001	-	< .0001	<1.0	< .003	-	< .0002	<10.0	< .03	-	< .002	505	1.5	-	.1	22.0	.07	-	.004
	DS	.34	15.4	500	< .5	--	< .5	--	<1.0	--	< .9	--	<10.0	--	< 9.2	--	113	--	104	--	4.0	--	3.7	--
	JS	.41	15.4	103	1.0	--	.2	--	2.5	--	.6	--	<10.0	--	< 2.3	--	82.0	--	18.7	--	2.3	--	.5	--
Crystal Spring Creek/ RM 1.20	LF	1.0	-	13.0	< .5	< .04	-	--	<1.0	< .07	-	--	<10.0	< .7	-	--	46.0	3.2	-	--	7.5	.5	-	--
	DS	.35	-	12.0	< .5	--	< .01	--	<1.0	--	< .02	--	<10.0	--	< .2	--	50.0	--	1.1	--	7.0	--	.2	--
	JS	.43	-	12.0	< .5	--	< .01	--	<1.0	--	< .03	--	<10.0	--	< .3	--	22.0	--	.6	--	<1.0	--	< .03	--
Kelley Creek/ RM 10.70	LF	1.0	-	.25	< .5	< .0007	-	--	<1.0	< .001	-	--	<10.0	< .01	-	--	465	.6	-	--	130	.2	-	--
	DS	.33	-	260	< .5	--	< .2	--	<1.0	--	< .5	--	<10.0	--	< 4.6	--	94.0	--	43.6	--	6 0	--	2.8	--
	JS	.39	-	85.0	< .5	--	< .09	--	<1.0	--	< .2	--	<10.0	--	< 1.8	--	190	--	34.0	--	2.0	--	.4	--

Table 4.---Mean dissolved trace-element concentrations, loads and yields during low flow (August - October 1989), and composite concentrations and partial loads during storm runoff (December 1989 and January 1990) in Johnson Creek Basin--Continued

Station name/ river mile	Flow condi- tion	Repre- senta- tive sample interval (days)	Drain- age area (mi²)	Stream dis- charge (ft³/s)	Dissolved lead: Concen- tra- tion (µg/l)	Dissolved lead: Daily load (lbs)	Dissolved lead: Partial storm load (lbs)	Dissolved lead: Yield (lb/mi²)	Dissolved mercury: Concen- tra- tion (µg/l)	Dissolved mercury: Daily load (lbs)	Dissolved mercury: Partial storm load (lbs)	Dissolved mercury: Yield (lb/mi²)	Dissolved nickel: Concen- tra- tion (µg/l)	Dissolved nickel: Daily load (lbs)	Dissolved nickel: Partial storm load (lbs)	Dissolved nickel: Yield (lb/mi²)	Dissolved silver: Concen- tra- tion (µg/l)	Dissolved silver: Daily load (lbs)	Dissolved silver: Partial storm load (lbs)	Dissolved silver: Yield (lb/mi²)	Dissolved zinc: Concen- tra- tion (µg/l)	Dissolved zinc: Daily load (lbs)	Dissolved zinc: Partial storm load (lbs)	Dissolved zinc: Yield (lb/mi²)
Milwaukie gage/	LF	1.0	51.4	18.0	< 10	< 1.0	-	<0.02	<0.10	<0.03	-	<0.0005	< 10	<1.0	-	<0.02	<1.0	<0.1	-	<0.002	15.0	1.5	-	0.03
RM 0.60	DS	.34	51.4	740	< 10	--	<13.6	--	.30	--	.4	--	< 10	--	<13.6	--	<1.0	--	<1.4	--	14.0	--	19.0	--
	JS	.89	51.4	380	< 10	--	<18.3	--	.10	--	.2	--	< 10	--	<18.3	--	<1.0	--	<1.8	--	14.0	--	25.6	--
McLoughlin	LF	1.0	47.3	4.15	< 10	< .2	-	< .005	< .10	< .002	-	< .00005	< 10	< .2	-	< .005	<1.0	< .02	-	< .0004	16.0	.3	-	.007
Boulevard/	DS	.46	47.3	740	< 10	--	<18.4	--	.60	--	1.1	--	< 10	--	<18.4	--	<1.0	--	<1.8	--	14.0	--	25.7	--
RM 1.50	JS	.47	47.3	390	< 10	--	< 9.9	--	.10	--	.1	--	< 10	--	< 9.9	--	<1.0	--	<1.0	--	9.0	--	8.9	--
Stanley Avenue/	LF	1.0	45.8	1.9	< 10	< .1	-	< .002	.10	.001	-	.00002	< 10	< .1	-	< .002	<1.0	< .01	-	< .0002	19.0	.2	-	.004
RM 3.60	DS	.40	45.8	750	< 10	--	<16.2	--	.50	--	.8	--	< 10	--	<16.2	--	<1.0	--	<1.6	--	11.0	--	18.0	--
	JS	.45	45.8	400	< 10	--	< 9.7	--	.10	--	.1	--	< 10	--	< 9.7	--	<1.0	--	<1.0	--	11.0	--	10.7	--
Bell Avenue/	LF	1.0	45.3	1.8	< 10	< .1	-	< .002	.10	.001	-	.00002	< 10	< .1	-	< .002	<1.0	< .01	-	< .0002	8.0	.08	-	.002
RM 4.20	DS	.46	45.3	750	< 10	--	<18.6	--	.50	--	.9	--	< 10	--	<18.6	--	<1.0	--	<1.9	--	10.0	--	18.6	--
	JS	.44	45.3	335	< 10	--	< 8.0	--	.10	--	.09	--	< 10	--	< 8.0	--	<1.0	--	< .9	--	12.0	--	10.2	--
S.E. 82nd Avenue/	LF	1.0	43.8	1.6	< 10	< .09	-	< .002	< .10	< .0009	-	< .00002	< 10	< .09	-	< .002	<1.0	< .009	-	< .0002	9.5	.08	-	.002
RM 5.50	DS	.48	43.8	750	< 10	--	<19.4	--	.50	--	1.0	--	< 10	--	<19.4	--	<1.0	--	<1.9	--	6.0	--	11.7	--
	JS	.53	43.8	360	< 10	--	<10.3	--	.10	--	.1	--	10	--	10.3	--	<1.0	--	<1.0	--	< 3.0	--	< 3.1	--
Sycamore gage/	LF	1.0	26.3	1.1	< 10	< .06	-	< .002	.20	.001	-	.00005	< 10	< .06	-	< .002	1.0	.006	-	.0002	11.0	.07	--	.002
RM 10.25	DS	.32	26.3	740	< 10	--	<12.8	--	.23	--	.3	--	< 10	--	<12.8	--	<1.0	--	<1.3	--	9.0	--	11.5	--
	JS	.52	26.3	360	< 10	--	<10.1	--	.10	--	.1	--	10	--	10.1	--	<1.0	--	<1.0	--	13.0	--	13.1	--
S.E. 190th Avenue/	LF	1.0	20.0	1.3	< 10	< .07	-	< .004	< .10	< .0007	-	< .00004	< 10	< .07	-	< .004	1.0	.007	-	.0004	13.0	.1	-	.005
RM 12.60	DS	.39	20.0	660	< 10	--	<13.9	--	.50	--	.7	--	< 10	--	<13.9	--	<1.0	--	<1.4	--	4.0	--	5.6	--
	JS	.48	20.0	330	< 10	--	< 2.3	--	.10	--	.09	--	< 10	--	< 8.6	--	<1.0	--	< .9	--	7.0	--	6.0	--
Regner Road/	LF	1.0	15.4	.55	< 10	< .03	-	< .002	.10	.0003	-	.00002	< 10	< .03	-	< .002	2.0	.006	-	.0004	16.0	.05	-	.003
RM 16.30	DS	.34	15.4	500	< 10	--	< 9.2	--	.27	--	.2	--	< 10	--	< 9.2	--	<1.0	--	< .9	--	13.0	--	11.9	--
	JS	.41	15.4	103	< 10	--	< 2.3	--	.10	--	.02	--	< 10	--	< 2.3	--	<1.0	--	< .2	--	10.0	--	2.2	--
Crystal Spring	LF	1.0	-	13.0	< 10	< .7	-	--	< .10	< .007	-	--	< 10	< .7	-	--	3.0	.2	-	--	11.0	.8	-	--
Creek/	DS	.35	-	12.0	10	--	.2	--	.20	--	.005	--	< 10	--	< .2	--	1.0	--	.02	--	61.0	--	1.4	--
RM 1 20	JS	.43	-	12.0	< 10	--	< .3	--	.10	--	.003	--	20	--	.6	--	<1 0	--	< .03	--	< 3.0	--	< .08	--
Kelley Creek/	LF	1.0	-	.25	20	.03	-	--	< .10	< .0001	-	--	< 10	< .01	-	--	<1.0	< .001	-	--	16.0	.02	-	--
RM 10 70	DS	.33	-	260	< 10	--	< 4.6	--	.40	--	.2	--	< 10	--	< 4.6	--	1.0	--	.5	--	< 3.0	--	<1.4	--
	JS	.39	-	85.0	< 10	--	< 1.8	--	.10	--	.02	--	10	--	1.8	--	<1.0	--	< .2	--	< 3.0	--	< .5	--

Partial-storm loads of dissolved beryllium were 0.2 and 1.8 lbs at Regner Road (RM 16.30) and Milwaukie gage (RM 0.60) over representative sample intervals of nearly 10 and 21.5 hours during the January 1990 storm.

Cadmium

Dissolved cadmium was detected at Stanley Avenue (RM 3.60) during low flow at a concentration of 1.0 μg/L, while concentrations at all other sites for the same period were less than analytical detection (<1 μg/L). The USEPA FWCT criteria for cadmium to protect freshwater aquatic organisms are a 4-day average concentration of 0.56 μg/L, and a 1-hour average concentration of 1.4 μg/L (U.S. Environmental Protection Agency, 1986). This single occurrence exceeds the FWCT 4-day average concentration of 0.56 μg/L, however, because the analytical detection level is greater than this USEPA criterion, concentrations at other sites also may exceed the criteria.

At Stanley Avenue (RM 3.60), the low-flow dissolved-cadmium load was 0.01 lbs, and the yield was 0.0002 lbs/mi^2 (table 4). The estimated dissolved-cadmium load delivered to the Willamette River by Johnson Creek, during low flow, was <0.1 lbs at a yield of <0.002 lbs/mi^2.

Concentrations of dissolved cadmium measured at all sites during the December 1989 storm were less than the analytical detection (<1 μg/L). During the January 1990 storm, dissolved cadmium was detected at sites on Johnson Creek from Regner Road (RM 16.30) to S.E. 82nd Avenue (RM 5.50) and at the Milwaukie gage (RM 0.60). Additionally, cadmium was detected in samples from two outfalls, Circle Avenue (RM 11.60) and S.E. 100th and Knapp (RM 6.25). The largest concentration (4 μg/L) was at the S.E. 100th and Knapp outfall, and was almost three times greater than the FWCT 1-hour average criteria of 1.4 μg/L. Concentrations at Circle Avenue (RM 11.60), Regner Road (RM 16.30), and the Sycamore gage (RM 10.25) also exceeded the FWCT 1-hour average criteria.

Partial-storm loads of dissolved cadmium were 0.6 and 1.8 lbs at Regner Road (RM 16.30) and Milwaukie gage (RM 0.60) over representative samples intervals of nearly 10 and 21.5 hours during the January 1990 storm.

Copper

Dissolved-copper concentrations for samples collected during low flow and the January 1990 storm were less than the reporting level (table 4). Copper was detected at S.E. 82nd Avenue (RM 5.50), Bell Avenue (RM 4.20), and the Milwaukie gage (RM 0.60) during the December 1989 storm. The largest concentration was 20 μg/L at Bell Avenue (RM 4.20).

The 1-hour and 4-day FWCT average criteria during total-recoverable copper are 7.55 and 5.45 μg/L, respectively; both criteria are less than the reporting level of 10 μg/L. All concentrations, therefore, that are less than reported have the potential for exceeding the USEPA criteria.

A dissolved-copper load of 13.6 lbs at Milwaukie gage (RM 0.50) was delivered to the Willamette River over a slightly greater than 8-hour sample interval during the December 1989 storm.

Iron

Common in many rocks, iron is an important component of many soils, especially the clayey soils, and is essential to aquatic plants and animals. The FWCT criterion for total-recoverable iron is 1,000 μg/L (U.S. Environmental Protection Agency, 1986). Dissolved-iron concentrations measured during this study do not exceed that criterion except for a single low-flow concentration of 1,100 μg/L measured at S.E. 190th Avenue (RM 12.60). The mean concentration at this site, during low flow, was 880 μg/L, however, and represents the largest concentration of dissolved iron in the basin (table 4). The smallest concentration of dissolved iron during low flow was 106 μg/L at the Milwaukie gage (RM 0.60), the result of the relatively small concentration (46 μg/L) and large discharge of Crystal Springs Creek entering Johnson Creek above the Milwaukie gage (fig. 8).

The low-flow load of dissolved iron ranged from 1.5 lbs at Regner Rd (RM 16.30) to 10 lbs at the Milwaukie gage (RM 0.60). The largest increase in low-flow load, however, occurred between Regner Road (RM 16.30) and S.E. 190th Avenue (RM 12.60). Ten pounds of dissolved iron were delivered to the Willamette River from Johnson Creek in a 1-day period during low flow.

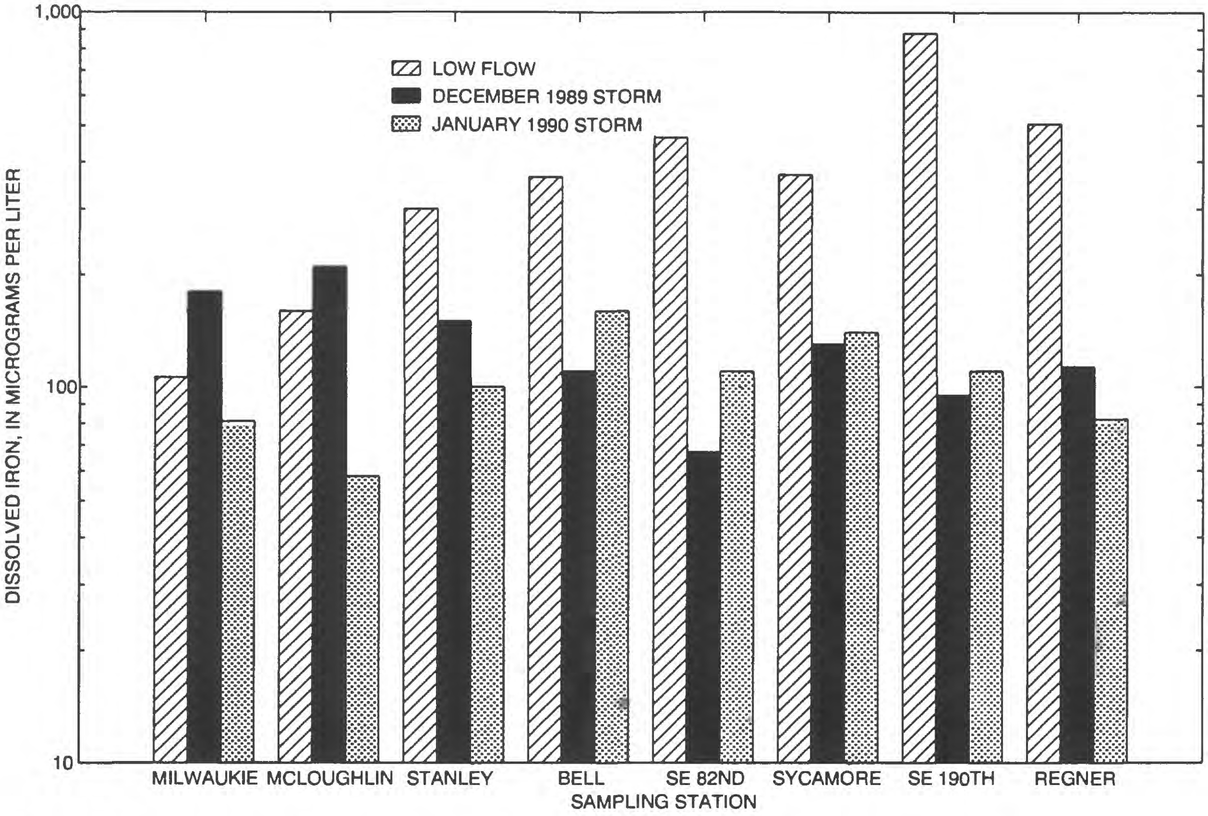

Figure 8. Concentrations of dissolved iron in Johnson Creek during low flow and storm runoff.

During low flow, the dissolved-iron yield ranged from 0.07 to 0.3 lbs/mi^2 at main stem sites. The largest yield (0.3 lbs/mi^2) was measured at S.E. 190th Avenue (RM 12.60), but the largest increase in yield occurred between McLoughlin Boulevard (RM 1.50) and the Milwaukie gage (RM 0.60).

During the December 1989 storm, dissolved-iron concentrations in Johnson Creek ranged from 67 $\mu g/L$ at S.E. 82nd Avenue (RM 5.50) to 210 $\mu g/L$ at McLoughlin Boulevard (RM 1.50). Concentrations of dissolved iron in Johnson Creek during the January 1990 storm ranged from 58 $\mu g/L$ at McLoughlin Boulevard (RM 1.50) to 160 $\mu g/L$ at Bell Avenue (RM 4.20). During the January 1990 storm, the largest concentration (190 $\mu g/L$) in the basin was from Kelley Creek tributary. The partial dissolved-iron loads were 104 and 245 lbs at Regner Road (RM 16.30) and Milwaukie gage (RM 0.60) for the 8-hour sample intervals during the December 1989 storm. Partial-storm loads of 18.7 and 149 lbs were transported over nearly 10- and 21.5-hour sample intervals of Regner Road (RM 16.30) and Milwaukie gage (RM 0.60) during the January 1990 storm.

Lead

During this study, concentrations of dissolved lead were less than reporting levels (10 $\mu g/L$) at all sites on Johnson Creek (table 4). Lead was detected in samples from Kelley Creek (20 $\mu g/L$), during low flow, and from Crystal Springs Creek (10 $\mu g/L$), during the December 1989 storm. Both of these concentrations exceed the FWCT criterion 1-hour average of 1.9 $\mu g/L$ for Crystal Springs Creek, and 1.3 $\mu g/L$ for Kelley Creek; the FWCT criterion for lead varies with hardness (U.S. Environmental Protection Agency, 1986). Because the FWCT criterion 1-hour average is less than the reporting level, all dissolved-lead concentrations listed as less than reporting level during this study could potentially exceed the FWCT 1-hour average criterion.

Mercury

During low flow, the concentration of dissolved mercury was above the reporting level at four sites on Johnson Creek; the largest concentration (0.20 $\mu g/L$) was measured at the Sycamore gage (RM 10.25), and 0.10 $\mu g/L$ was measured at the other three sites (fig. 9).

Dissolved mercury was detected at all sites in the basin during the December 1989 storm, and ranged from 0.20 $\mu g/L$ in Crystal Springs Creek tributary to 0.60 $\mu g/L$ in Johnson Creek at McLoughlin Boulevard (RM 1.50). During the January 1990 storm, dissolved mercury was measured at 0.10 $\mu g/L$ at all sites in the basin.

The dissolved-mercury FWCT criteria for 1-hour and 4-day average concentrations are 2.4 $\mu g/L$ and 0.012 $\mu g/L$, respectively (U.S. Environmental Protection Agency, 1986). Because the analytical reporting level for mercury is greater than the 4-day average criterion, all samples with detectable concentrations of mercury exceed the 4-day average criterion, and those listed as less than reporting level may exceed the criterion. None of the reported dissolved-mercury concentrations exceeded the 1-hour average criterion (table 4).

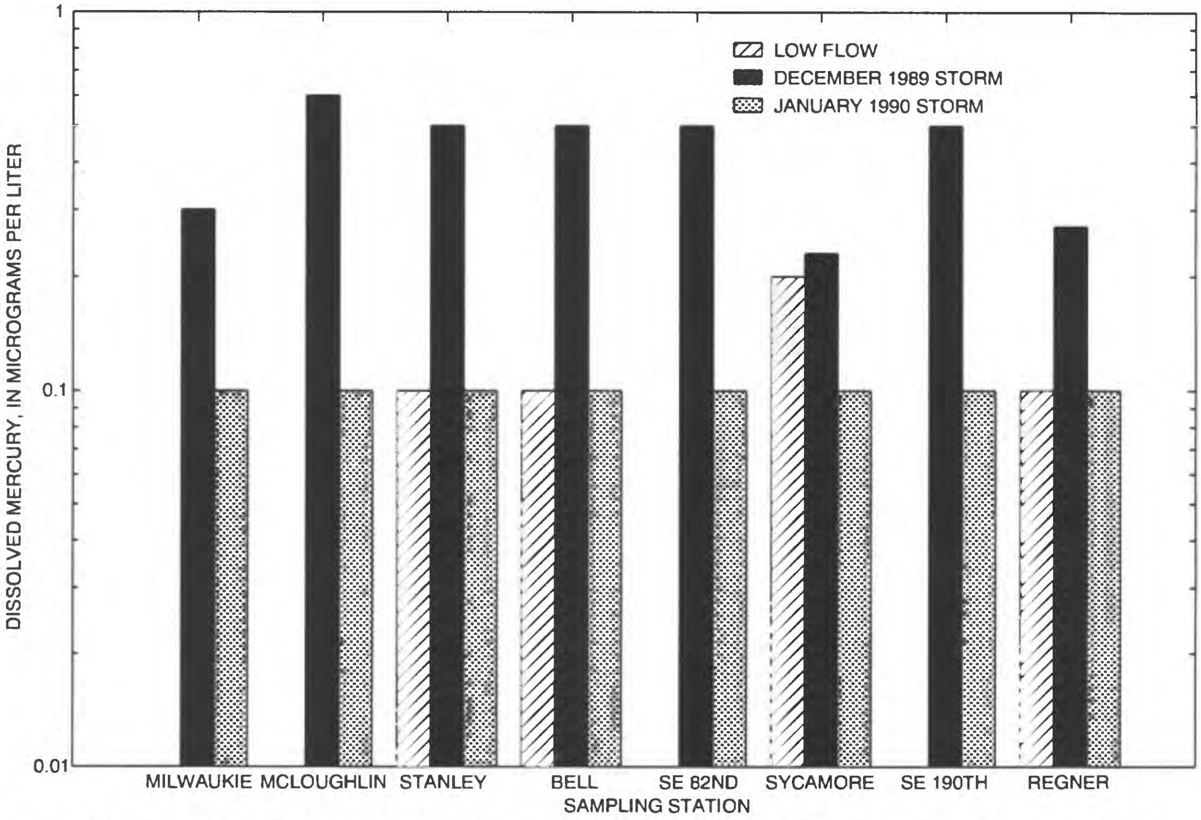

Figure 9. Concentrations of dissolved mercury in Johnson Creek during low flow and storm runoff. (Low-flow concentrations for Milwaukie gage, McLoughlin Blvd, SE 82nd Ave, and SE 190th Ave were less than the analytical detection of 0.01 micrograms per liter.)

Partial-storm loads of dissolved mercury were 0.2 and 0.4 lbs at Regner Road (RM (16.30) and Milwaukie gage (RM 0.60) for representative sample intervals of slightly greater than 8 hours during the December 1989 storm. During the January 1990 storm, partial-storm loads of dissolved mercury were 0.02 and 0.2 lbs over intervals of nearly 10 and 21.5 hours at Regner Road (RM 16.30) and Milwaukie gage (RM 0.60). Partial-storm loads for the December 1989 storm may be more representative than partial-storm loads for the January 1990 storm, however, because they were based on a concentration 2.7 to 3.0 times greater than the reporting level on which the January loads were based.

Nickel

Dissolved nickel was detected only during the January 1990 storm at two sites on Johnson Creek, and two tributaries (table 4). Concentrations of 10 μg/L were measured at Sycamore gage (RM 10.25), S.E. 82nd Avenue (RM 5.50), and Kelley Creek tributary. Crystal Springs Creek had a 20 μg/L concentration of dissolved nickel. The FWCT 4-day average criterion for nickel is 37 μg/L for Johnson Creek and Kelley Creek tributary, and is 118 μg/L for Crystal Springs Creek (criteria varies with hardness; U.S. Environmental Protection Agency, 1986). All concentrations were below the FWCT 4-day and 1-hour average criteria.

Silver

Dissolved silver was reported in Johnson Creek during low flow at Regner Road (RM 16.30), S.E. 190th Avenue (RM 12.60), and the Sycamore gage (RM 10.25), and in Crystal Springs Creek (table 4). The FWCT criteria for total-recoverable silver are 1.0 μg/L for Johnson Creek and Kelley Creek, and 3.2 μg/L for Crystal Springs Creek (criteria varies with hardness; U.S. Environmental Protection Agency, 1986). The concentration of dissolved silver in Johnson Creek at Regner Road (RM 16.30) exceeded the FWCT criteria. The only other reports of dissolved silver were during the December 1989 storm in Kelley Creek and Crystal Springs Creek tributaries.

The loads of dissolved silver for Johnson Creek, during low flow, averaged about 0.006 lbs at the three upper sites and 0.2 lbs from Crystal Spring Creek tributary. Dissolved-silver yields during low flow were 0.0004 lbs/mi^2 at Regner Road (RM 16.30) and S.E. 190th Avenue (RM 12.60), and 0.0002 lbs/mi^2 at the Sycamore gage (RM 10.25).

Zinc

Concentrations of dissolved zinc in Johnson Creek ranged from 8.0 μg/L at Bell Avenue (RM 4.20) to 19.0 μg/L at Stanley Avenue (RM 3.60) during low flow (table 4). The largest increase in dissolved-zinc concentration was in a 0.6 mile reach between Bell Avenue (RM 4.20) and Stanley Avenue (RM 3.60).

The FWCT criterion for total-recoverable zinc is 47 μg/L as a 1-day average, and the concentration should not exceed 145 μg/L for Johnson Creek and Kelley Creek, and 280 μg/L for Crystal Springs Creek at any time (criteria vary with hardness, U.S. Environmental Protection Agency, 1986).

Low-flow loads of dissolved zinc ranged from 0.05 to 1.5 lbs at sites on Johnson Creek. The largest low-flow load (1.5 lbs) was at the Milwaukie gage (RM 0.60). The dissolved-zinc load (0.8 lbs) from Crystal Springs Creek (RM 1.20) accounted for 53 percent of the low-flow load delivered to the Willamette River.

Low-flow yields of dissolved zinc ranged from 0.002 to 0.03 lbs/mi^2 at sites on Johnson Creek. The largest yield of dissolved zinc (0.03 lbs/mi^2) was at the Milwaukie gage (RM 0.60), and was nearly an order of magnitude greater than the yields at upstream sites.

During the December 1989 storm, concentrations of dissolved zinc in Johnson Creek were small, ranging from 4.0 μg/L at S.E. 190th Avenue (RM 12.60) to 14.0 μg/L at McLoughlin Boulevard (RM 1.50) and the Milwaukie gage (RM 0.60). The concentration in Crystal Springs Creek, however, was 61 μg/L, the largest measured in the basin during the December 1989 storm (table 4). During the January 1990 storm, concentrations of dissolved zinc ranged from 7.0 to 14.0 μg/L at sites on Johnson Creek. The largest concentration (14 μg/L) was measured at the Milwaukie gage (RM 0.60).

Partial-storm loads of dissolved zinc were 11.9 and 19.0 lbs at Regner Road (RM 16.30) and Milwaukie gage (RM 0.60) for representative sample intervals of slightly greater than 8 hours during the December 1989 storm. During the January storm, partial-storm loads were 2.2 and 25.6 lbs for sample intervals of nearly 10 and 21.5 hours at Regner Road (RM 16.30) and Milwaukie gage (RM 0.60). The partial-storm load computed for the January 1990 storm (25.6 lbs) was significantly larger than the 19.0 lbs partial-storm load computed for the December storm at the Milwaukie gage (RM 0.60), considering the smaller stream discharge used in the January computation. The magnitude of the January 1990 partial-storm load, however, is the result of using a representative sample interval more than 2.5 times larger than that used in computing the December 1989 partial-storm load and does not indicate an increase in dissolved zinc from a localized source.

Suspended Sediment

Various chemical constituents have an affinity for sorbing to particulate matter in the stream environment (Horowitz, 1985). Suspended-sediment concentrations, loads, and yields were determined during low flow and portions of storm runoff (table 5).

Suspended-sediment concentrations during low flow ranged from 9 mg/L at Bell Avenue site (RM 4.20) on Johnson Creek, and in Crystal Springs Creek and Kelley Creek, to 24 mg/L at Sycamore gage (RM 10.25). Concentrations increased from Regner Road (RM 16.30) to the Sycamore gage (RM 10.25), declined from Sycamore gage (RM 10.25) to Bell Avenue (RM 4.20), and increased between Bell Avenue (RM 4.20) and McLoughlin Boulevard (RM 1.50). The decrease between McLoughlin Boulevard (RM 1.50) and the Milwaukie gage (RM 0.60) may be the result of the small concentration (9 mg/L) and large discharge (13.0 ft^3/s [cubic feet per second]) contributed by Crystal Springs Creek in this reach. All suspended sediment during low flow consisted of particle sizes between 0.45 μm--the break between dissolved and suspended, and 63 μm--the break between sand and silt size particles.

During low flow, daily suspended-sediment loads transported by Johnson Creek ranged from 30 lbs at Regner Road (RM 16.30) to 972 lbs at the Milwaukie gage (RM 0.60). The suspended-sediment load increased steadily between Regner Road (RM 16.30) and the Sycamore gage (RM 10.25). Between the Sycamore gage (RM 10.25) and Bell Avenue (RM 4.20), the load declined, and from Bell Avenue (RM 4.20) to the Milwaukie gage (RM 0.60) the load increased substantially. The second largest suspended-sediment load (632 lbs) in the basin during low flow occurred in Crystal Springs Creek tributary.

Suspended-sediment yields followed the same pattern as the load during low flow at sites on Johnson Creek. The smallest yield (1.9 lbs/mi^2) was determined at Regner Road (RM 16.30) and Bell Avenue (RM 4.20). The largest yield (19.0 lbs/mi^2) was at the Milwaukie gage (RM 0.60). The largest increase in suspended-sediment yield occurred in the reach between Stanley Avenue (RM 3.60) and McLoughlin Boulevard (RM 1.50).

During the December 1989 storm, suspended-sediment concentration at Johnson Creek sites ranged from 555 mg/L at S.E. 82nd Avenue (RM 5.50) to 1,290 mg/L at Regner Road (RM 16.30). The largest suspended-sediment concentration was measured at the Regner Road site (RM 16.30) which receives eroded sediment from the predominantly agricultural head-water area (fig. 10). Particle-size analyses of suspended-sediment samples collected during the December 1989 storm from Regner Road (RM 16.30), the Sycamore gage (RM 10.25), and the Milwaukie gage (RM 0.60), indicate

Table 5.--Mean suspended-sediment concentrations, loads and yields during low flow (August - October 1989), and composite concentrations and partial loads during storm runoff (December 1989 and January 1990) in Johnson Creek Basin

[LF = low flow; DS = December storm runoff; JS = January storm runoff; RM = river mile; mi^2 = square mile; ft^3/s = cubic feet per second; mg/L = milligrams per liter; lbs = pounds; and lbs/mi^2 = pounds per square mile]

Station name/ river mile	Flow condition	Representative sample time (days)	Drainage area (mi^2)	Stream discharge (ft^3/s)	Suspended sediment: Concentration (mg/L)	Daily load (lbs)	Partial storm load (lbs)	Yield (lb/mi^2)
Milwaukie gage/	LF	1.0	51.4	18.0	10	972	-	19.0
RM 0.60	DS	.34	51.4	740	1077	--	1,460,000	--
	JS	.89	51.4	380	175	--	320,000	--
McLoughlin	LF	1.0	47.3	4.15	21	471	-	9.9
Boulevard/	DS	.46	47.3	740	615	--	1,130,000	--
RM 1.50	JS	.47	47.3	390	172	--	170,000	--
Stanley Avenue/	LF	1.0	45.8	1.9	14	144	-	3.1
RM 3.60	DS	.40	45.8	750	592	--	959,000	--
	JS	.45	45.8	400	174	--	169,000	--
Bell Avenue/	LF	1.0	45.3	1.8	9	87.0	-	1.9
RM 4.20	DS	.46	45.3	750	595	--	1,110,000	--
	JS	.44	45.3	335	170	--	135,000	--
S.E. 82nd Avenue/	LF	1.0	43.8	1.6	13	112	-	2.6
RM 5.50	DS	.48	43.8	750	555	--	1,080,000	--
	JS	.53	43.8	360	145	--	149,000	--
Sycamore gage/	LF	1.0	26.3	1.1	24	143	-	5.4
RM 10.25	DS	.32	26.3	740	1160	--	1,480,000	--
	JS	.52	26.3	360	216	--	218,000	--
S.E. 190th	LF	1.0	20.0	1.3	12	84.0	-	4.2
Avenue/	DS	.39	20.0	660	625	--	869,000	--
RM 12.60	JS	.48	20.0	330	155	--	133,000	--
Regner Road/	LF	1.0	15.4	.55	10	30.0	-	1.9
RM 16.30	DS	.34	15.4	500	1290	--	1,180,000	--
	JS	.41	15.4	103	176	--	40,000	--
Crystal Spring	LF	1.0	-	13.0	9	632	-	--
Creek/	DS	.35	-	12.0	29	--	658	--
RM 1.20	JS	.43	-	12.0	25	--	697	--
Kelley Creek/	LF	1.0	-	.25	9	12.0	-	--
RM 10.70	DS	.33	-	260	871	--	404,000	--
	JS	.39	-	85.0	303	--	54,000	--

that 97 to 98 percent was finer than 62 μm, and 21 to 38 percent was finer than 16 μm. The suspended-sediment concentration increased between S.E. 190th Avenue (RM 12.60) and the Sycamore gage (RM 10.25), and from S.E. 82nd Avenue (RM 5.50) and the Milwaukie gage (RM 0.60). The suspended-sediment concentration in Kelley Creek (871 mg/L) was 75 percent of the concentration measured at the Sycamore gage (RM 10.25) approximately 0.5 miles downstream from the confluence.

During the January 1990 storm, suspended-sediment concentration ranged from 145 mg/L at S.E. 82nd Avenue (RM 5.50) to 216 mg/L at the Sycamore gage (RM 10.25). Results of particle-size analyses of samples collected during the January 1990 storm from Regner Road (RM 16.30), the Sycamore gage (RM 10.25), and the Milwaukie gage (RM 0.60), indicate 97 to 98 percent were finer than 62 μm. The concentration increased between S.E. 190th Avenue (RM 12.60) and the Sycamore gage (RM 10.25), and between S.E. 82nd Avenue (RM 5.50) and Bell Avenue (RM 4.20). The suspended-sediment concentration in Kelley Creek (303 mg/L) was 140 percent of the concentration measured at the Sycamore gage (RM 10.25).

Suspended-sediment loads at Regner road (RM 16.30) and Milwaukie gage (RM 0.06) were nearly 1.2 and 1.5 million lbs transported during an interval of slightly greater than 8 hours during the December 1989 storm. During the January 1990 storm, partial-storm loads at Regner Road (RM 16.30) and Milwaukie gage (RM 0.60) were 40 and 320 thousand lbs for representative sample intervals of nearly 10 and 21.5 hours.

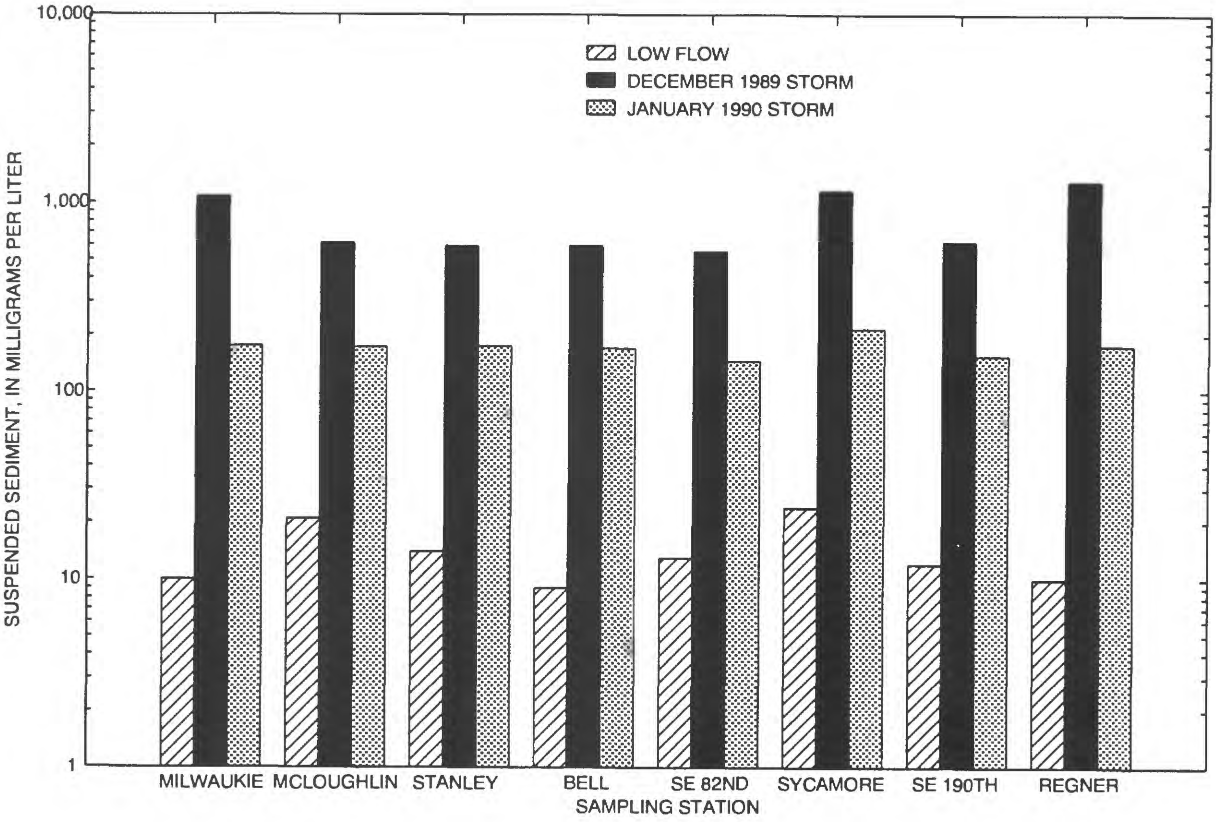

Figure 10. Concentrations of suspended sediment in Johnson Creek during lowflow and storm runoff.

Sediment Chemistry

Suspended sediment was extracted from samples by centrifuge, to simulate fall velocities of selected particle sizes (Edwards, 1991), and sent to Arthur Horowitz at the USGS Research Laboratory in Atlanta, Georgia for determination of total trace-element concentrations. Suspended sediment extracted from each low-flow sample consisted of particles >0.45 μm (greater than 0.45 micrometers). Suspended-sediment samples from the December 1989 and January 1990 storms also consisted of particles >0.45 μm at all sites except at Regner Road (RM 16.30), the Sycamore gage (RM 10.25), and the Milwaukie gage (RM 0.60) where sample splits of >63 μm, 63 μm to >16 μm, and 16 μm to >0.45 μm size fractions were approximated for individual analysis. Determinations of trace elements associated with suspended sediment include antimony, aluminum, arsenic, cadmium, cobalt, copper, chromium, iron, lead, manganese, mercury, nickel, selenium, titanium, and zinc. From this list, antimony, arsenic, cadmium, cobalt, copper, chromium, lead, mercury, nickel, selenium, and zinc are classified as priority pollutants by USEPA (U.S. Environmental Protection Agency, 1986).

Combining total trace-element concentrations in suspended sediment with the dissolved concentrations of the same trace elements provides an estimate of total-recoverable concentration for comparison with USEPA criteria. Comparing this approximated total-recoverable concentration with USEPA's total-recoverable criteria, however, is not as accurate as comparing the total-recoverable concentration resulting from analysis of a whole-water sample. Therefore, if the computed concentration exceeds the USEPA criterion there is no way of determining if the analytical result of a whole-water sample from the same site would exceed the criterion; however, if the computed concentration is less than the USEPA criterion then the result of analysis of a whole-water sample probably would be less than the criterion.

Trace-element concentrations in bottom material and suspended sediment from Johnson Creek, and trace-element concentrations in bottom material from elsewhere in the Willamette River Basin (Rickert and others, 1977) are listed in table 6. Bottom-material data, including method of collection, are included in a report by Edwards and Curtiss (1993). Arsenic concentrations in bottom material and low-flow suspended sediment (<63 μm) from Johnson Creek fall in the range of concentrations in bottom material (<20 μm) in the Willamette Basin. Median arsenic concentrations from Johnson Creek are generally smaller than from the Willamette River Basin, however. This may be the result of sediment dilution as the concentration associated with the sediment in the <63 μm sample is effectively reduced by the concentration associated with the larger (63 >20 μm) particle-size fraction portion of the Johnson Creek samples. Copper, chromium, and lead concentrations exceeded or nearly equalled the ranges and the medians of Willamette River Basin concentrations. Mercury in Johnson Creek bottom material exceeds the range of the Willamette River Basin; however, the median is nearly 40 percent smaller. Zinc was in the range of concentrations for all Willamette River Basin bottom material, encompassed nearly the same range as Willamette River Basin tributary bottom material and exceeded the medians for the Willamette River Basin. Comparison of the concentrations of these constituents suggests that the Johnson Creek Basin is a source area for copper, chromium, lead, mercury, and zinc in the Willamette River Basin.

Table 6.--Concentrations of trace elements in bottom material and suspended sediment from Johnson Creek and in bottom material from Willamette River Basin

[< = less than; µm = micrometer; ppm = part per million]

Trace element	Willamette River basin 1/		Johnson Creek basin					
					Storm runoff suspended sediment			
	All bottom material <20 µm	Tributary bottom material <20 µm	Bottom material 2/ <63 µm	Low-flow suspended sediment <63 µm	December storm <63 µm	January storm <63 µm	December storm <16 µm	January storm <16 µm
	(ppm)							
Arsenic:								
Range	10 - 20	10 - 20	2.0 - 3.6	4.0 - 10	8.1-10.5	4.5-12.8	7.1-13.4	0.9 - 11
Mean	10	13	2.9	7.3	8.9	8.4	10.2	7.0
Median	10	10	3.1	7.0	8.2	7.8	10.1	9.0
Chromium:								
Range	40 - 100	40 - 100	54 - 520	60 - 220	86 - 94	82 - 86	79 - 111	80 - 90
Mean	57	60	123	91	91	84	96	83
Median	50	55	70	75	92	84	99	80
Copper:								
Range	30 - 95	30 - 70	18 - 87	60 - 180	62 - 100	51 - 58	55 - 111	60 - 70
Mean	42	45	40	130	75	55	80	63
Median	40	40	36	145	64	55	55	60
Lead:								
Range	10 - 120	15 - 80	15 - 204	< 10 - 160	< 26 - 87	31 - 59	< 17 - 105	30 - 60
Mean	38	42	80	65	49	41	50	43
Median	35	32	74	40	35	34	28	40
Mercury:								
Range	.02 - .38	.05 - .31	.04 - .66	.30	.1 -.17	.19 -.26	.14	.33 -.35
Mean	.16	.15	.14	-	.14	.23	-	.34
Median	.13	.13	.08	.30	.14	.25	-	.34
Zinc:								
Range	115 - 1215	120 - 475	99 - 470	240 - 580	208 - 288	220 - 269	195 - 341	260 - 310
Mean	266	205	236	392	241	242	272	287
Median	185	132	232	370	226	236	277	290

1/ From Rickert and others, 1977.
2/ From Edwards and Curtiss, 1993.

Antimony

Total-antimony concentrations in low-flow suspended sediment were less than the analytical detection limit at all sites (table 7).

During the December 1989 storm, total antimony in suspended sediment ranged from less than detection to 1.3 parts per million (ppm) at sites on Johnson Creek. Total antimony in suspended sediment from Crystal Springs Creek was the largest concentration measured (16.0 ppm) during the December 1989 storm. The median concentration of total antimony (0.9 ppm) in suspended sediment for the December 1989 storm was equal to the median concentration in bottom material from Johnson Creek at low flow. During the January 1990 storm, total-antimony concentrations in suspended sediment ranged from 0.6 to 1.1 ppm at sites on Johnson Creek. Total antimony in suspended sediment at Crystal Springs Creek was the largest concentration detected in the basin (1.5 ppm) during the January 1990 storm. The median concentration of total antimony (0.95 ppm) in suspended sediment for the January 1990 storm was only slightly larger than the median concentration (0.9 ppm) in bottom material from Johnson Creek at low flow.

Table 7.--Concentrations of mean total trace elements in greater than 0.45 micrometer particle size suspended sediment during low flow and storm runoff, and in greater than 0.45 micrometer particle size bottom material during low flow and storm runoff, in Johnson Creek Basin

[LF = low flow; DS = December storm runoff; JS = January storm runoff; SS = suspended sediment; BM = bottom material; < = less than; ND = not detected; RM = river mile; ft^3/s = cubic feet per second; and ppm = parts per million]

Station name/river mile	Flow condition	Stream discharge (ft^3/s)	SS concentrations	Total Antimony SS	Antimony BM	Arsenic SS	Arsenic BM	Cadmium SS	Cadmium BM	Chromium SS	Chromium BM	Copper SS	Copper BM	Lead SS	Lead BM	Mercury SS	Mercury BM	Nickel SS	Nickel BM	Selenium SS	Selenium BM	Zinc SS	Zinc BM
			(ppm)																				
Milwaukie gage/	LF	18.0	10	< 1.0	--	4.0	--	< 5.0	--	110	--	160	--	< 10	--	ND	--	50	--	<1.0	--	350	--
RM 0.60	DS	740	1,077	1.3	--	9.3	--	< .5	--	90	--	98	--	89	--	ND	--	49	--	< .1	--	280	--
	JS	380	175	1.1	--	8.6	--	< .5	--	81	--	50	--	63	--	0.29	--	39	--	< .1	--	261	--
Ochoco Avenue/ RM 1 05	LF	--	--	--	2.6	--	3.6	--	<0.5	--	68	--	34	--	59	--	0.08	--	36	--	<0.2	--	171
Umatilla Street/ RM 1.37	LF	--	--	--	1.3	--	3.2	--	< .8	--	104	--	50	--	80	--	< .06	--	66	--	< .1	--	260
McLoughlin	LF	4 15	21	< 1.0	--	6.0	--	14.0	--	220	--	180	--	10	--	ND	--	140	--	<1 0	--	580	--
Boulevard/	DS	740	615	.9	--	8.9	--	1.5	--	87	--	54	--	70	--	.10	--	47	--	.4	--	240	--
RM 1.5	JS	390	172	1.1	--	7.3	--	.4	--	85	--	40	--	55	--	.12	--	38	--	.2	--	207	--
S E 44th and Umatilla/RM 2 6	LF	--	--	--	1.4	--	3.1	--	< .7	--	520	--	87	--	99	--	< .10	--	825	--	< .2	--	470
S E 44th and Harney/RM 2 7	LF	--	--	--	.7	--	2.4	--	< .7	--	81	--	41	--	74	--	.07	--	49	--	< .1	--	232
Stanley Avenue/	LF	1.9	14	< 1.0	--	8.0	--	< 5.0	--	80	--	130	--.	100	--	ND	--	50	--	<1.0	--	580	--
RM 3 6	DS	750	592	.9	--	9.3	--	3.1	--	83	--	64	--	70	--	.15	--	36	--	.4	--	230	--
	JS	400	174	.9	--	7.8	--	< .5	--	84	--	37	--	41	--	.14	--	33	--	.1	--	187	--
Linnwood Avenue/ RM 3.85	LF	--	--	--	.9	--	2.5	--	<1.2	--	70	--	39	--	204	--	< .10	--	35	--	< .1	--	290
Bell Avenue/	LF	1.8	9	< 1.0	--	10.0	--	< 5.0	--	70	--	170	--	130	--	ND	--	40	--	<1.0	--	430	--
RM 4.2	DS	750	595	.9	--	7.8	--	< .5	--	82	--	51	--	63	--	.13	--	34	--	.4	--	304	--
	JS	335	170	1.0	--	7.6	--	< .5	--	154	--	38	--	46	--	.11	--	50	--	.2	--	198	--
S.E. 82nd Avenue/	LF	1.6	13	< 1.0	--	9.0	--	< 5.0	--	80	--	100	--	130	--	ND	--	40	--	<1.0	--	430	--
RM 5.5	LF	--	--	--	.7	--	3.3	--	<1.0	--	78	--	35	--	62	--	.08	--	36	--	.1	--	255
	DS	750	555	.6	--	7.8	--	< .5	--	88	--	89	--	155	--	.13	--	32	--	.3	--	220	--
	JS	360	145	1.1	--	7.8	--	.6	--	126	--	39	--	38	--	.17	--	47	--	.2	--	198	--
S.E. 92nd Avenue/ RM 5.82	LF	--	--	--	.9	--	2.8	--	< .5	--	69	--	36	--	103	--	.07	--	30	--	.2	--	218
Sycamore gage/	LF	1.1	24	< 1.0	--	6.0	--	< 5.0	--	70	--	60	--	20	--	.30	--	40	--	<1.0	--	240	--
RM 10.25	LF	--	--	--	.5	--	3.1	--	< .4	--	61	--	20	--	20	--	.66	--	24	--	< .2	--	130
	DS	740	1,160	.9	--	7.7	--	< .5	--	84	--	61	--	34	--	ND	--	< 10	--	< .1	--	207	--
	JS	360	216	.6	--	6.9	--	< .5	--	77	--	51	--	30	--	.27	--	34	--	< .1	--	209	--
S.E. 190th Avenue/	LF	1.3	12	< 1.0	--	10.0	--	< 5.0	--	70	--	160	--	< 10	--	ND	--	30	--	<1.0	--	300	--
RM 12 6	DS	660	625	.7	--	6.8	--	< .5	--	82	--	45	--	49	--	.26	--	33	--	.4	--	200	--
	JS	330	155	.9	--	7.1	--	< .5	--	83	--	35	--	30	--	.17	--	29	--	.4	--	184	--
Regner Road/	LF	.55	10	< 1.0	--	6.0	--	< 5.0	--	90	--	90	--	160	--	ND	--	50	--	<1.0	--	310	--
RM 16 3	DS	500	1,290	< .5	--	7.0	--	< .5	--	84	--	51	--	< 10	--	ND	--	< 10	--	< .1	--	205	--
	JS	103	176	.8	--	4.3	--	< .5	--	77	--	56	--	31	--	ND	--	30	--	< .1	--	216	--
Hogan Road/ RM 17.4	LF	--	--	--	.5	--	2.0	--	< .5	--	54	--	18	--	15	--	.04	--	22	--	.2	--	99
Crystal Spring	LF	13.0	9	< 1.0	--	4.0	--	< 5.0	--	60	--	160	--	60	--	ND	--	40	--	<1.0	--	310	--
Creek/RM 1.2	DS	12.0	29	16.0	--	12.0	--	5.0	--	70	--	250	--	720	--	ND	--	30	--	< .1	--	340	--
	JS	12.0	25	1.5	--	10.5	--	9.0	--	65	--	65	--	115	--	ND	--	20	--	< .1	--	275	--
Kelley Creek/	LF	.25	9	< 1.0	--	10.0	--	10.0	--	60	--	90	--	20	--	ND	--	40	--	<1.0	--	390	--
RM 10.7	DS	260	871	.6	--	6.4	--	< .5	--	73	--	38	--	28	--	.06	--	29	--	.3	--	142	--
	JS	85.0	303	.7	--	7.4	--	.6	--	76	--	35	--	26	--	.10	--	30	--	.2	--	164	--

Arsenic

Total arsenic in low-flow suspended sediment ranged from 4 ppm at the Milwaukie gage (RM 0.60) to 10 ppm at S.E. 190th Avenue (RM 12.60) and Bell Avenue (RM 4.20). The total-arsenic concentration in suspended sediment from Kelley Creek (10 ppm) was equal to the largest concentration measured at sites on Johnson Creek during low flow. The median total-arsenic concentration in low-flow suspended sediment was 7 ppm, exceeding the median concentration (3.1 ppm) in bottom material from sites on Johnson Creek (table 7). The larger concentration in suspended sediment is likely the result of a larger percentage of the sediment in the <16 μm to 0.45 μm size fraction than in bottom-material samples.

During the December 1989 storm, total arsenic in suspended sediment ranged from 6.8 to 9.3 ppm in the main stem, and the largest concentration was measured at Stanley Avenue (RM 3.60) and the Milwaukie gage (RM 0.60). The largest total-arsenic concentrations measured during the December 1989 storm in suspended sediment was 12.0 ppm. Median total-arsenic concentration (7.8 ppm) at sites on Johnson Creek during the December 1989 storm was more than 150 percent larger than the median concentration (3.1 ppm) in bottom material during low flow.

During the January 1990 storm, total arsenic in suspended sediment ranged from 4.3 to 8.6 ppm sites on Johnson Creek with the largest concentration measured at Milwaukie gage (RM 0.60). Crystal Springs Creek had the largest total-arsenic concentration (10.5 ppm) in suspended sediment measured in the basin during the January 1990 storm. The median total-arsenic concentration (7.5 ppm) at sites on Johnson Creek was 140 percent larger than the median concentration in bottom material. Total-arsenic concentrations associated with different size ranges are listed in table 8. The concentration (0.9 ppm) in the 16 μm to >0.45 μm particle-size class at Regner Road (RM 16.30) during the January 1990 storm is an order of magnitude smaller than the concentrations measured at the Sycamore gage (RM 10.25), and the Milwaukie gage (RM 0.60) for the same particle-size fraction, and is unexplained at this time.

Cadmium

During low flow, total cadmium in suspended sediment was less than reporting level except at McLoughlin Boulevard (RM 1.50) with 14 ppm and Kelly Creek tributary (RM 10.70) with 10 ppm. Total cadmium in bottom material also was less than reporting level at all Johnson Creek sites (table 7).

During the December 1989 storm, total cadmium in suspended sediment was less than reporting level at all Johnson Creek sites except for 3.1 ppm at Stanley Avenue (RM 3.60) and 1.5 ppm at McLoughlin Boulevard (RM 1.50). Crystal Springs Creek had the largest concentration of total cadmium (5.0 ppm) in suspended sediment in the basin during the December 1989 storm. During the January 1990 storm, concentrations of total cadmium in suspended sediment were less than the analytical detection limit at all Johnson Creek sites except S.E. 82nd Avenue (RM 5.50) where the measured concentration was 0.6 ppm. Crystal Springs Creek had the largest concentration of total cadmium (9.0 ppm) in the basin during the January 1990 storm. Concentrations of total cadmium associated with different particle-size classes are listed in table 8.

Table 8.--Concentrations of total trace elements assocated with suspended sediment for indictaed particle-size classes at selected sites on Johnson Creek during December 1989 and January 1990 storms

[DS = December storm; JS = January storm: µm = micrometers; ft^3/s = cubic feet per second; m^3/g = square meters per gram; ppm = parts per million; > = greater than; < = less than; ND = not detected; and RM = river mile]

Station name/river mile	Flow condition	Particle size class (µm)	Stream discharge (ft^3/s)	Surface area (m^3/g)	Total (ppm) Antimony	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Selenium	Zinc
Milwaukie gage/ RM 0.60	DS	> 63	740	24.4	1.6	4.6	1.8	81	75	85	ND	59	<0.1	208
	"	63 > 16		49.7	1.4	7.5	1.3	87	89	71	0.17	47	< .1	237
	"	16 >.45		52.6	1.4	13.4	< .5	99	111	105	ND	45	< .1	341
	JS	> 63	380	8.57	1.0	4.0	< .5	75	45	80	.40	35	< .1	210
	"	63 > 16		18.87	1.2	7.4	.5	84	40	57	.18	38	.2	218
	"	16 >.45		22.93	1.0	11.0	< .5	80	60	60	.33	40	< .1	310
Sycamore gage/ RM 10.25	DS	> 63	740	51.4	.8	6.5	< .5	77	53	29	ND	< 10	< .1	203
	"	63 > 16		83.7	.9	8.9	< .5	91	70	40	ND	38	< .1	218
	"	16 >.45		55.5	1.1	7.1	< .5	79	55	28	ND	< 10	< .1	195
	JS	> 63	360	9.17	.5	3.0	2.0	40	35	25	.35	25	< .1	160
	"	63 > 16		18.52	.9	6.6	.4	82	50	33	.15	32	.4	177
	"	16 >.45		20.17	1.0	9.0	< .5	90	60	30	.35	40	< .1	260
Regner Road/ RM 16.3	DS	> 63	500	46.2	.5	3.0	< .5	54	51	18	.25	25	< .1	139
	"	63 > 16		75.0	.6	6.2	< .5	74	48	35	ND	33	.4	170
	"	16 >.45		78.3	< .1	10.1	< .5	111	55	< 10	ND	< 10	< .1	277
	JS	> 63	103	9.84	.5	3.5	< .5	50	45	20	.50	25	< .1	130
	"	63 > 16		21.72	.8	7.7	.8	87	48	28	.19	32	.4	188
	"	16 >.45		18.96	1.0	.9	2.0	80	70	40	ND	30	< .1	290

The concentration of cadmium sorbed to suspended sediment at McLoughlin Boulevard during low flow indicates that cadmium may be enriched in suspended sediment at one site in the lower part of Johnson Creek in the vicinity of RM 1.50. The largest concentration of cadmium associated with the <63 µm sized bottom material (see table 7) was measured downstream from the Bell Avenue site at RM 3.85. All of the concentrations for bottom material are shown as less than (<), however, because one or more of the concentrations used to compute the mean shown in table 7 was less than the reporting level. Therefore, relative increases or decreases in cadmium levels may be inferred from site to site but absolute concentrations are not provided.

The largest concentration of total cadmium in suspended sediment was measured in Crystal Springs Creek during the December 1989 and January 1990 storm runoff, indicating a possible cadmium source in the Crystal Springs Creek subbasin.

Chromium

Concentrations of total chromium in suspended sediment ranged from 70 to 220 ppm at Johnson Creek sites during low flow (see table 7). The largest concentration was measured at McLoughlin Boulevard (RM 1.50). The median concentration of total chromium (80 ppm) in suspended sediment was 8 percent larger than the median concentration (74 ppm) in bottom material.

During the December 1989 storm, concentrations of total chromium in suspended sediment ranged from 82 to 90 ppm at Johnson Creek sites. The median concentration (84 ppm) was 14 percent larger than the median for bottom material. Concentrations of total chromium in suspended sediment ranged from 77 to 154 ppm at Johnson Creek sites during the January 1990 storm. The median concentration (83.5 ppm) was nearly equal to the median for the December 1989 storm and 13 percent larger than the median for bottom material. Concentrations of total chromium associated with different particle-size classes are listed in table 8.

Copper

Concentrations of total copper in low-flow suspended sediment ranged from 60 to 180 ppm at Johnson Creek sites (table 7). The total-copper concentration in Crystal Springs Creek suspended sediment was 160 ppm, significantly contributing to the concentration at the Milwaukie gage (RM 0.60). During low flow, the median concentration of total copper (145 ppm) was over 300 percent larger than the median (36 ppm) for bottom material in Johnson Creek. This probably can be attributed to the fact that the low-flow suspended sediment providing the surface area for adsorption consisted of nearly 100 percent <16 μm size particles, compared to less than 50 percent of the surface area for adsorption provided by the <16 μm fraction in the bottom material sampled.

During the December 1989 storm, concentrations of total copper in suspended sediment ranged from 45 to 98 ppm at Johnson Creek sites (table 7). The concentration in suspended sediment from Crystal Springs Creek was 250 ppm. The median concentration of total copper (57.5 ppm) during the December 1989 storm was over 50 percent larger than the median for bottom material. During the January 1990 storm, total copper in suspended sediment ranged from 35 to 56 ppm at Johnson Creek sites. The concentration (65 ppm) in Crystal Springs Creek suspended sediment was the largest in the basin during the January 1990 storm. The median concentration of total copper (39.5 ppm) at Johnson Creek sites was only 4 percent larger than the median for bottom material. Concentrations of total copper associated with different particle-size classes are listed in table 8.

Concentrations of total copper in bottom material suggests that the lower part of the basin (below Sycamore gage--RM 10.25) is enriched with copper. December 1989 and January 1990 storm data generally show lower concentrations in suspended sediment than measured at low flow. The difference between low-flow and storm-runoff concentrations is the result of lower concentrations associated with coarser particle sizes (>16 μm) in transport during storm runoff.

Lead

Concentrations of total lead in suspended sediment ranged from <10 to 160 ppm during low flow (table 7). The largest concentration occurred at the uppermost Johnson Creek site (Regner Road--RM 16.30). The median concentration of total lead in low-flow suspended sediment (60 ppm) was more than 25 percent smaller than the median concentration (74 ppm) in bottom material at low flow.

During the December 1989 storm, concentrations of total lead in suspended sediment ranged from <10 to 155 ppm at Johnson Creek sites. The concentration of total lead (720 ppm) in suspended sediment in Crystal Springs Creek was significantly larger than at any of the Johnson Creek sites during the December 1989 storm. The median concentration of total lead (66.5 ppm) in suspended sediment during the December 1989 storm was 13 percent smaller than the median for bottom material at low flow. Concentrations of total lead in suspended sediment ranged from 30 to 63 ppm at Johnson Creek sites during the January 1990 storm. The concentration of total lead (115 ppm) in suspended sediment in Crystal Springs Creek was the largest concentration in the basin during the January 1990 storm. The median concentration of total lead (39.5 ppm) in suspended sediment during the January 1990 storm was 90 percent smaller than the median for bottom material at low flow. Concentrations of total lead associated with different particle-size classes analyzed for three Johnson Creek sites during the December 1989 and January 1990 storms are listed in table 8.

Mercury

The Sycamore gage (RM 10.25) was the only site in Johnson Creek Basin with a of concentration total mercury in suspended sediment measured above analytical detection (0.30 ppm) during low flow (table 7). Concentration of total mercury (0.58 ppm) measured in bottom material at the Sycamore gage (RM 10.25) also was the largest in the basin.

During the December 1989 storm, concentrations of total mercury in suspended sediment ranged from <0.10 to 0.26 ppm at Johnson Creek sites. The largest concentration (0.26 ppm) was measured at S.E. 190th Avenue (RM 12.60). The median concentration of total mercury in suspended sediment (0.12 ppm) was 42 percent larger than the median concentration (0.07 ppm) in bottom material.

During the January 1990 storm, concentrations of total mercury in suspended sediment ranged from <0.01 to 0.29 ppm. The largest concentration occurred at the Milwaukie gage (RM 0.60). The median concentration of total mercury (0.16 ppm) in suspended sediment was 129 percent larger than the median for bottom material (0.07 ppm) at low flow. Total-mercury concentrations associated with different particle-size classes are listed in table 8.

Concentrations of total mercury in <63 μm suspended sediment and bottom material during low flow indicate that some locations in Johnson Creek are enriched with mercury. The largest concentrations of total mercury in suspended sediment and bottom material were measured at the Sycamore gage (RM 10.25) in October 1989.

Concentrations of total mercury in bottom material (<63 μm sized particles) indicate that the lower part of the basin (below Sycamore gage--RM 10.25) is enriched with mercury (Edwards and Curtiss, 1993). In general, mercury concentrations in suspended sediment during the December 1989 and January 1990 storms are in the same range as those determined for the <63 μm size fraction in bottom material, with the exception of the bottom material at the Sycamore gage (RM 10.25).

Nickel

Concentrations of total nickel in suspended sediment ranged from 30 to 140 ppm at Johnson Creek sites during low flow (table 7). The largest concentration occurred in the lower part of the basin at McLoughlin Boulevard (RM 1.50), the first site downstream from S.E. 44th and Umatilla (RM 2.60) where the largest concentration (834 ppm) in bottom material occurred. The median concentration of total nickel (45 ppm) in suspended sediment was 25 percent larger than the median concentration (36 ppm) in bottom material.

During the December 1989 storm, concentration of total nickel in suspended sediment ranged from 32 to 49 ppm at Johnson Creek sites. The two largest concentrations of 49 and 47 ppm occurred at the Milwaukie gage (RM 0.60), and at McLoughlin Boulevard (RM 1.50), respectively. The median concentration (36 ppm) in suspended sediment was equal to the median for bottom material. During the January 1990 storm, concentrations of total nickel in suspended sediment ranged from 29 to 50 ppm at Johnson Creek sites. The largest concentrations were 50 ppm at Bell Avenue (RM 4.20) and 47 ppm at S.E. 82nd Avenue (RM 5.50). The median concentration of total nickel (36 ppm) in suspended sediment was equal to the median in bottom material. Concentrations of total nickel associated with different particle-size classes are listed in table 8.

Selenium

During low flow, concentration of total selenium in suspended sediment was less than reporting levels at all sites (table 7). Total selenium also was less than analytical detection in bottom material at all sites except Hogan Road (RM 17.40), S.E. 92nd Avenue (RM 5.82), and S.E. 82nd Avenue (RM 5.50) where it was 0.1, 0.2, and 0.1 ppm, respectively.

During the December 1989 storm, concentrations of total selenium in suspended sediment ranged from less than reporting levels to 0.4 ppm. During the January 1990 storm, total-selenium concentrations in suspended sediment ranged from less than analytical detection to 0.2 ppm. Concentrations of total selenium associated with different particle-size classes are listed in table 8.

Zinc

Concentrations of total zinc in suspended sediment ranged from 240 to 580 ppm during low flow (table 7). The largest concentration (580 ppm) was measured at Stanley Avenue (RM 3.60), and McLoughlin Boulevard (RM 1.50). The median concentration (390 ppm) in low-flow suspended sediment was 64 percent larger than the median concentration (239 ppm) in bottom material.

During the December 1989 storm, concentrations of total zinc in suspended sediment ranged from 200 to 280 ppm at Johnson Creek sites. The concentration at Crystal Springs Creek was 340 ppm and significantly contributed to the largest concentration measured at the Milwaukie gage (RM 0.60), approximately 0.60 miles downstream from the Crystal Springs Creek confluence. The median concentration of total zinc (216 ppm) in suspended sediment was 90 percent of the median concentration (239 ppm) in bottom material at low flow. During the January 1990 storm, concentrations of total zinc in suspended sediment ranged from 184 to 261 ppm at Johnson Creek sites. The concentration measured in Crystal Springs Creek was 275 ppm, contributing to the largest concentration (261 ppm) at the Milwaukie gage (RM 0.60). The median concentration of total zinc (202 ppm) in suspended sediment was 82 percent of the median concentration in bottom material at low flow. Concentrations of total zinc associated with different particle-size classes are listed in table 8.

WATER-QUALITY CONTROL ALTERNATIVES AND MANAGEMENT CONSIDERATIONS

Management alternatives for controlling and potentially improving water quality in Johnson Creek Basin are presented in the following sections. A single alternative, or a combination of alternatives, could be used to control and improve the quality of water throughout the basin. These management alternatives include source control, construction and implementation of detention and retention settling basins, and development of wetlands.

Source Control

Reduction of contaminants at their sources is one of the most effective water-quality control measures. Given sufficient funding, point sources could be identified with a high degree of accuracy, either by bracket sampling throughout a study area or by sampling every source of effluent. For this study, the sampling scheme was a coarse version of the bracket technique, and outfall contributions could be inferred between sampling points only if they were active during sampling. Source identification is, therefore, limited to tributaries and active outfalls terminating at the mainstream channel of Johnson Creek. The information contained in this report, coupled with PBES's knowledge of the drain system in the basin, however, could be used to more accurately locate suspected outfalls and subsequently identify potential point sources of contaminants within a subarea.

Identification of nonpoint sources is difficult, because of the lack of a single discharge point. In the Johnson Creek Basin, nonpoint sources include forested areas, agricultural lands, residential tracts, extensive urban areas, and light industrial zones. Many contaminants may reach Johnson Creek from nonpoint sources. Some urban and light industrial contaminants could be abated by dealing with the collective discharge from these areas as point sources; however, runoff from forested and agricultural lands, and city streets, and ground-water seepage from residential areas should be considered as nonpoint-source contaminants and managed as such.

This report identifies main-channel reaches of Johnson Creek where sources of contaminants likely exist, on the basis of increased concentrations through the reach. Both point and nonpoint sources may contribute to these reaches and no attempt was made to separate contributions from these sources. In most cases, a single outfall to the main channel delivers runoff from point and nonpoint sources.

Some methods for reducing contaminants from nonpoint sources include: (1) controlling the types and amounts of pesticides and herbicides applied to forested and agricultural lands, lawns, parks, and trees within residential and urban areas; (2) expansion and improvement of city sewer systems which would eliminate septic-tanks and drain-field seepage to shallow aquifers; (3) removal of debris from streambanks and streambeds; and (4) frequent street sweeping within urban areas, particularly during long periods of little or no precipitation, to reduce the amount of particulates available for transport during storm-runoff.

Settling Basins

Detention and retention basins are typically used to reduce the adverse effects of flooding during storm runoff by reducing peak flows downstream. A detention basin slows the flow passing through it for a time before it is released downstream. A retention basin is used to capture and hold flow from the stream at a predetermined rate, thus, eliminating or at least reducing contaminant releases downstream.

In Johnson Creek, detention and retention basins could be used to remove selected suspended-sediment size fractions and associated concentrations of contaminants. The desired result of employing one of these impoundment structures would be to improve the quality of water during periods of storm runoff. In the case of Johnson Creek, several points need to be considered before either of these options is determined as viable. First, an area adjacent to the stream may not be available to allow construction of an impoundment of adequate size. Second, the fine suspended-sediment particle sizes, which carry the largest concentrations of contaminants, may not be captured in the impoundment. Additionally, in the case of retention basins, the shallow ground-water flow potential needs to be away from the impoundment site, and the soils in the vicinity of the impoundment need to be permeable (Century West Engineering, 1985) to promote seepage from the basin. Potential for contamination of underlying aquifers needs to be considered in the location of retention basins.

During a moderately intense storm on March 4, 1981, USGS collected samples from Johnson Creek at the Sycamore gage (RM 10.25) for analysis of dissolved nutrients and nutrients associated with different suspended-sediment size classes. Results of analysis indicate that 95-100 percent of ammonia, nitrate, organic nitrogen, and orthophosphorus were either in the dissolved phase or associated with the <16 μm suspended-sediment size fraction, suggesting that reducing sediment loads in Johnson Creek by means of a settling basin would have little effect on reducing nutrient loads, except for total phosphorus (J.F. Rinella, U.S. Geological Survey, written commun., 1989).

Removal of the suspended-sediment particle sizes carrying the largest concentrations of contaminants is essential if the water quality is to be improved by using either a detention or retention basin. Analyses were done for 10 trace elements to determine their concentrations in suspended-sediment particle sizes >63 μm, 63 >16 μm, and 16 >0.45 μm at 3 Johnson Creek sites (Regner Road--RM 16.30, the Sycamore gage--RM 10.25, and the Milwaukie gage--RM 0.60), during the December 1989 and January 1990 storms (table 8). All the elements are

USEPA priority pollutants (U.S. Environmental Protection Agency, 1986). Generally the concentrations of these trace elements increase as the particle size decreases; however, there are some exceptions and the reasons for these uncharacteristic concentrations are not always apparent.

Using total-zinc concentration as an example, the concentration increased with a decrease in particle size during the December 1989 and January 1990 storms, except at the Sycamore gage (RM 10.25) during the December 1989 storm. In this case, the largest concentration measured (218 ppm) was in the 63 >16 μm particle-size class rather than in the finer 16 >0.45 μm class as expected. The surface area of the 63 >16 μm particle-size class (83.7 m^2/g--square meters per gram) was 1.5 times larger than the surface area of the 16 >0.45 μm (55.5 m^2/g) class, because a larger sample mass for the 63 >16 μm size class was extracted from the sample. This may account for the larger concentration in the larger particle-size range.

Settling rates for spherical particles, based on Stoke's Law, are shown in figure 11 (Guy, 1969). In water at 20 degrees Celsius, particles with 63 μm, 16 μm, and 0.45 μm diameters, will settle 16 ft (feet), 0.89 ft, and 0.00055 ft per hour, respectively.

If a detention structure is designed to detain the flow of Johnson Creek for 4 hours to allow contaminant-carrying particles to be removed by settling, all particles >16 μm would settle to the bottom if basin depth was 3.6 feet or less, assuming that settling was not affected by turbulence. During the December 1989 storm, 16.8 lbs, 24.5 lbs, and 22.8 lbs of total zinc would have been trapped with the >16 μm particles at Regner Road (RM 16.30), the Sycamore gage (RM 10.25), and the Milwaukie gage (RM 0.60), respectively, if detention structures had been in place at these sites. At Regner Road (RM 16.30), the Sycamore gage (RM 10.25), and the Milwaukie gage (RM 0.60), 7.3 lbs, 10.8 lbs, and 20.2 lbs of total zinc, respectively, would have been carried through these structures if all the <16 μm particles remained in suspension during the December 1989 storm. The particle-settling rate increases as the temperature increases, because lower temperatures increase the viscosity of the water and decrease the settling rate. The settling rate also can be reduced by cross currents and eddies that interfere with the vertical movement of the particles under the force of gravity.

A retention basin would have trapped all of the particles in transport, during the December 1989 storm, removing 24.1 lbs, 35.3 lbs, and 43.0 lbs of total zinc from the flows at Regner Road (RM 16.30), the Sycamore gage (RM 10.25), and the Milwaukie gage (RM 0.60), respectively. The effectiveness of a retention impoundment would primarily rely on its size and the amount of flow it could hold, along with the retentive capacity of the underlying soils for the dissolved contaminants found to exceed USEPA (1986) criteria.

Wetlands

For the context of this report, a wetland is a boggy or swampy area where slow moving or standing water contacts stands of hydrophytic plant species. Natural or constructed wetlands act as biofilters by reducing concentrations of certain contaminants. Robert A. Gearheart, who was

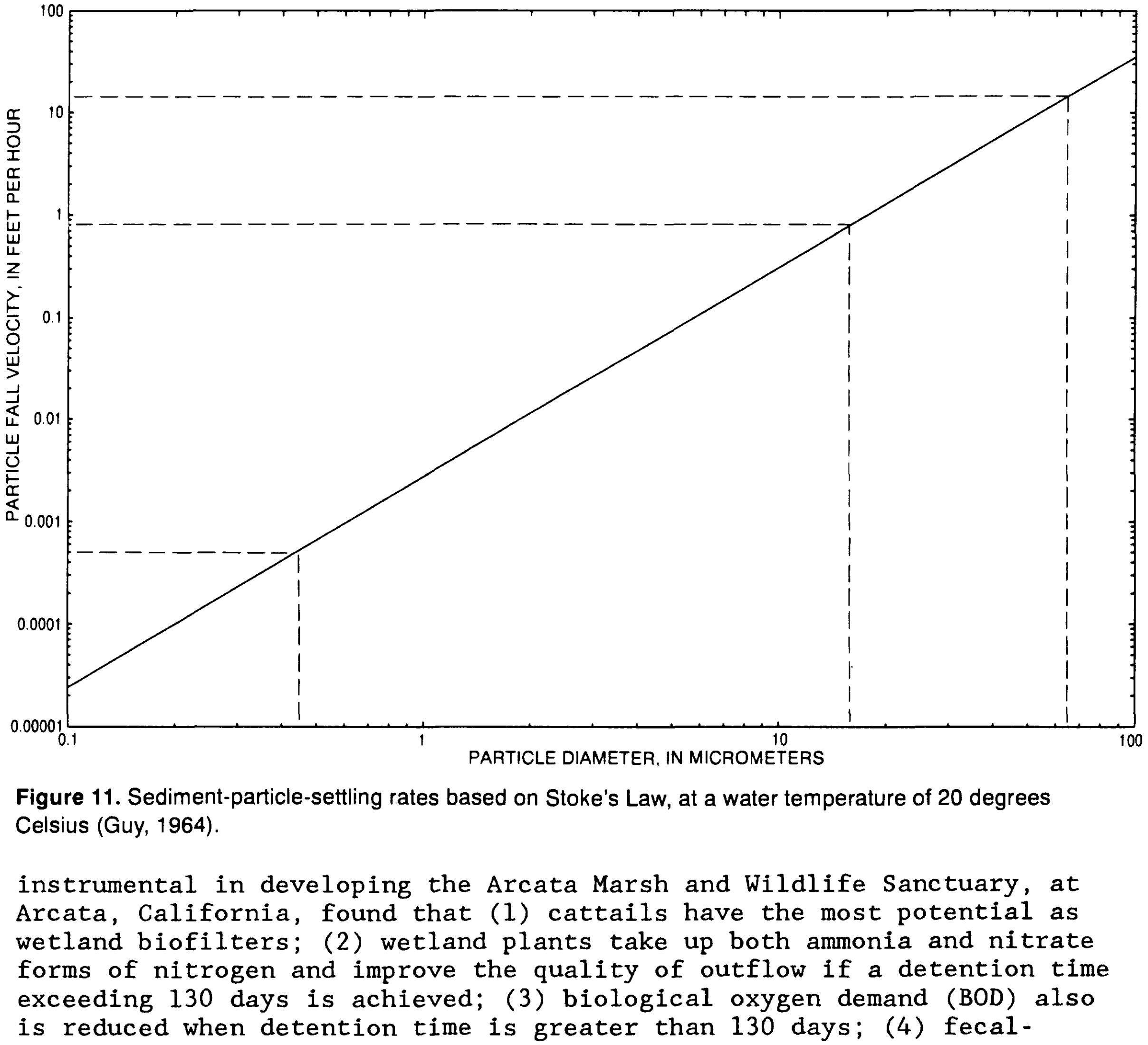

Figure 11. Sediment-particle-settling rates based on Stoke's Law, at a water temperature of 20 degrees Celsius (Guy, 1964).

instrumental in developing the Arcata Marsh and Wildlife Sanctuary, at Arcata, California, found that (1) cattails have the most potential as wetland biofilters; (2) wetland plants take up both ammonia and nitrate forms of nitrogen and improve the quality of outflow if a detention time exceeding 130 days is achieved; (3) biological oxygen demand (BOD) also is reduced when detention time is greater than 130 days; (4) fecal-coliform bacteria at the outflow is at higher levels than at the inflow after more than 130 days; and (5) 40 to 50 percent of the phosphorus is removed by passing the high-phosphorus water through alternating cells of open water and heavy vegetation (R.A. Gearheart, Humbolt State University, oral commun., 1989).

In the cattail dominated Irondequoit Wetland near Rochester, New York, nutrient retention occurs primarily through deposition and mineralization of particulate phosphorus and only partly through bioaccumulation by cattails (Kappel and others, 1986). Sediment trapped in this wetland is predominantly in the sand- and silt-size range (Kappel and others, 1986). Clays remain in suspension long enough to pass through small wetlands.

Wetlands are generally beneficial to waterfowl, amphibians, and lower benthic life forms; however, contaminants trapped by wetland vegetation may be concentrated to levels detrimental to the life cycles of the resident populations (Presser and Barnes, 1984). Another consideration relative to the implementation of a wetland to improve water quality in Johnson Creek Basin is the actual benefit that can be realized. The most frequently cited improvements are reduced nitrogen and phosphorus content (Kappel and others, 1986). Less research has been done to determine the effects of wetlands in decreasing concentrations of trace elements or organic compounds (W. Jarrell, Oregon Graduate Institute, written commun., 1990). Implementation of a wetland for water-quality improvement has many unknowns, including:

(1) Mechanisms by which constructed wetlands process metals, pesticides, and other toxic substances;

(2) The potential for bioaccumulation and toxicity of metals, pesticides, and other chemicals to wildlife that resides in wetland environment;

(3) The potential for viral or bacterial infection of wildlife;

(4) Appropriate indicators of wetland function and condition; and

(5) The potential for contaminating of local ground water by seepage from constructed wetlands (W. Jarrell, written commun., 1990).

The following is a list of considerations highlighted by Stockdale (1986) in a review of literature pertaining to the use of wetlands for storm-runoff management and water-quality enhancement.

1. Entrapment of sediment carrying large concentrations of pollutants is essential to improving storm-water quality. Some of the mechanisms that could be incorporated for this purpose are detention/retention basins, and directing flows over grassy swale areas prior to entering a wetland. A wetland is best not used purely as a sedimentation basin, because increased sedimentation rates may interfere with the biogeochemical cycles in the wetland that would otherwise serve to enhance the water quality.

2. Storm water needs to be detained for at least 20 to 36 hours to significantly improve the quality of water. Typical flood-control detention times are 1 to 12 hours, which may not be enough time for absorption and adsorption of all contaminants.

3. The wetland area needs to be of sufficient areal extent to reduce the potential for rapid flushing that might result in resuspension and transport of deposited sediment, nutrients, and other toxicants.

4. Sheet flow in a wetland is preferred over channelized flow to improve the effective surface-area contact time with vegetation and soils, and to maximize water-quality improvement.

5. Vegetation in a wetland needs to be as dense as possible to reduce flow velocities, aid in trapping fine particles, increase the effective contact-surface area, and maximize water-quality improvement.

SUMMARY AND CONCLUSIONS

Concentrations of dissolved nitrate during low flow in Johnson Creek ranged from 0.4 to 4.8 mg/L. The major source of dissolved-nitrate load during low flow is Crystal Springs Creek, contributing 86 percent of the dissolved-nitrate load measured at the Milwaukie gage (RM 0.60). During the December 1989 and January 1990 storms, the largest concentrations of dissolved nitrate were measured at Regner Road (RM 16.30), the uppermost sampling site in the basin.

Similar to other nutrients, the major source of dissolved-ammonia load during low flow was Crystal Springs Creek, contributing nearly 100 percent of the dissolved-ammonia load measured at the Milwaukie gage (RM 0.60). Concentrations of dissolved ammonia during storm runoff did not differ significantly from concentrations measured during low flow.

Concentrations of dissolved orthophosphorus were similar in Johnson Creek during low flow and storm runoff. The increase in dissolved orthophosphorus noted between McLoughlin Boulevard (RM 1.50) and the Milwaukie gage (RM 0.60) during low flow was from Crystal Springs Creek, contributing 77 percent of the dissolved orthophosphorus load measured at the Milwaukie gage (RM 0.60).

Concentrations of total phosphorus concentrations exceeded USEPA's recommended limit of 0.10 mg/L at several sites in Johnson Creek Basin during low flow and exceeded the limit at all sampling sites during storms. During the December 1989 and January 1990 storms, significant increases in concentrations of total phosphorus occurred between Bell Avenue (RM 4.20) and Stanley Avenue (RM 3.60), indicating a source of total phosphorus entering Johnson Creek in the 0.6 mile reach.

Total-recoverable chlordane, an organochlorine pesticide, was detected at the three upper-basin sampling sites on Johnson Creek (RM 16.30 to RM 10.25), and at the Milwaukie gage (RM 0.60), during storm runoff. Concentrations at these sites exceeded the FWCT 24-hour average criterion of 0.0043 μg/L.

Total-recoverable dieldrin was detected during low flow in Johnson Creek at Regner Road (RM 16.30) and Stanley Avenue (RM 3.60), and in Kelley Creek tributary. During the December 1989 and January 1990 storms, total-recoverable dieldrin was detected at all sampling sites in the basin. All of the concentrations detected during low flow and storm runoff exceeded the FWCT 24-hour average criterion of 0.0019 μg/L.

Total-recoverable DDT plus metabolites (DDD and DDE) were detected at all sampling sites in the basin during storm runoff except in Crystal Springs Creek tributary. The largest concentration (0.39 μg/L) occurred at the uppermost sampling site on Johnson Creek (Regner Road--RM 16.30). All total-recoverable DDT-plus-metabolite concentrations that were greater than the reporting level exceeded the FWCT 24-hour average criterion of 0.001 μg/L.

Concentrations of dissolved cadmium exceeded the FWCT 1-hour average criterion (1.4 μg/L) in Johnson Creek at Regner Road (RM 16.30) and the Sycamore gage (RM 10.25), and in the Circle Avenue and S.E.

100th and Knapp outfalls, during the January 1990 storm. The largest concentration of dissolved cadmium (4 μg/L) was measured at the S.E. 100th and Knapp outfall, and was nearly three times the FWCT 1-hour average criterion.

Dissolved copper was detected in Johnson Creek at S.E. 82nd Avenue (RM 5.50), Bell Avenue (RM 4.20), and the Milwaukie gage (RM 0.60) during the December 1989 storm. The FWCT 1-hour average criterion (7.55 μg/L) was exceeded at all three sites. Concentrations reported as less than the reporting level (<10 μg/L) also could exceed this criterion.

Dissolved lead was detected only in the Crystal Springs Creek and Kelley Creek tributaries during the December 1989 storm. The FWCT 1-hour average criterion (1.9 μg/L) was exceeded at both sites and all concentrations less than analytical detection could exceed this criterion because the reporting level is larger than the criterion.

Dissolved mercury was reported at several sampling sites on Johnson Creek during low flow and at all sampling sites in the basin during the December 1989 and January 1990 storms. The largest concentration of dissolved mercury (0.6 μg/L) was measured at McLoughlin Boulevard (RM 1.50) during the December 1989 storm. None of the concentrations of dissolved mercury exceeded the FWCT 1-hour average criterion (2.4 μg/L), however.

Dissolved silver was reported in Johnson Creek during low flow at Regner Road (RM 16.30), S.E. 190th Avenue (RM 12.60), and the Sycamore gage (RM 10.25), and in Crystal Springs Creek tributary. The largest concentration was 3.0 μg/L in Crystal Springs Creek. The hardness-dependent FWCT criterion for total-recoverable silver (1.0 μg/L) in Johnson Creek and Kelley Creek tributary was only exceeded at Regner Road (RM 16.30) during low flow, and the FWCT criterion for Crystal Springs Creek (3.2 μg/L) was never exceeded by concentrations of dissolved silver.

Dissolved zinc was reported at nearly all sampling sites in the basin during low flow and storms. Dissolved-zinc concentrations did not exceed the hardness-dependent FWCT criteria for total-recoverable zinc (145 μg/L) in Johnson Creek and Kelley Creek tributary, or (280 μg/L) in Crystal Springs Creek tributary.

Suspended-sediment concentrations in Johnson Creek Basin were small during low flow, and increased significantly (56 and 16 times on average) during the December 1989 and January 1990 storms, respectively.

Suspended-sediment loads delivered to the Willamette River were estimated at >970 lbs per day during low flow, >1.7 million lbs during the December 1989 storm, and >180,000 lbs during the January 1990 storm.

Suspended sediment transported during low flow consisted only of particles less than 63 μm in size. During storm runoff the suspended sediment in transport was 97 to 98 percent finer than 62 μm, and 21 to 38 percent finer than 16 μm.

Results of this study indicated that total concentrations of arsenic, copper, chromium, lead, mercury, and zinc measured in suspended sediment and bottom material from Johnson Creek equaled or exceeded concentrations in bottom material from the rest of the Willamette River Basin. Comparisons of these data indicate that Johnson Creek Basin adds to the enrichment of copper, chromium, lead, mercury, and zinc in the lower Willamette River.

The median total trace-element concentration for 10 priority pollutants at Regner Road (RM 16.30), the Sycamore gage (RM 10.25), and the Milwaukie gage (RM 0.60) in three particle-size classes during the December 1989 and January 1990 storms generally increase in the 63 >16 μm or 16 >0.45 μm particle sizes. Therefore, to significantly improve the quality of storm-runoff water by removing contaminant-carrying sediment, the <63 μm sized particles need to be removed from the flow. Trapping the >16 μm particles by detaining the flow and allowing particles to settle could be readily accomplished and some water-quality improvement realized. As the particle size decreases, however, excessive detention/retention time periods are required to significantly reduce the concentration of 16 >0.45 μm particles and improve the water quality further.

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GLOSSARY

(Terms are defined in the context of their use in this report.)

Anthropogenic -- Man caused or related to man's activities.

Bottom material -- Sediment residing on the stream bottom for long periods, but capable of being transported during high flow from its present location to a location of redeposition.

Detention basin -- An impoundment constructed to detain runoff flows for a time, and then gradually release it downstream.

Dissolved -- That part of a water sample which will pass through a 0.45 micrometer, pore-size membrane filter.

Eutrophication -- Abundant nutrient availability causing extensive aquatic plant growth.

FWCT (Fresh Water Chronic Toxicity) -- The Environmental Protection Agency criterion above which the life functions of exposed organisms would be adversely affected (for example, generally expressed in terms of exposure to a certain average concentration for a duration of 1 hour or 4 days per 3 years).

Hydrophobic -- Literally water hating, but specifically any waterborne compound or element that has a greater affinity for sediment or organic particulates than for water.

Low flow -- That part of the annual stream flow relying on and dominated by ground-water seepage to maintain a surface discharge within the confines of a stream channel.

Nonpoint source -- Source of contaminant distributed over a large area with no well defined point of origin, and commonly no well defined point of discharge.

Organochlorine pesticides and PCBs (polychlorinated biphenyls) -- A suite of manmade chlorinated organic compounds that are used either for control of pests or for industrial applications.

Point source -- Source of contaminant initiated and delivered from a single well defined point of origin.

Retention basin -- An impoundment constructed to capture and hold a volume of storm-runoff flow and release it through seepage to the local ground-water aquifer, seepage to the stream through the separating dike, and evapotranspiration.

Sorbed -- Attached to the surface of particulate matter.

Stream discharge -- The volume of water flowing within the confines of a stream channel past a given point in a given time.

Suspended sediment -- Those particles greater than 0.45 micrometers in size that are held in the water column by turbulent forces while being transported by the flow.

Synoptic sampling -- Simultaneously collected samples from several sites within an area to provide a "snapshot" overview of water-quality conditions.

Total -- Analytical procedure resulting in recovery of greater than or equal to 95 percent of the constituent of interest including the portion sorbed to the surfaces of particulates, the portion held in the matrix of the particulates, and the portion dissolved in the water.

Total recoverable -- Analytical procedure designed to recover the portion of a constituent sorbed to the surface of particulates, and the portion dissolved in the water, but not the portion held in the matrix of the particulates. (No procedure does this well for all constituents. This results in nearly complete recovery for some elements and less recovery of others using the same procedure. The total-recoverable analysis continues to be used to represent the concentration of a constituent that might be more likely to be available to aquatic organisms, nonetheless).

Wetland -- An area of land covered throughout most of the year by water, creating a boggy or swampy area dominated by hydrophytic plants.

Whole-water sample -- Sample containing a representative mixture of the sediment and water in transport at the time of sampling.

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