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Rinella, F. A., S.W. McKenzie, & S.A. Wille

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Prepared in cooperation with the
OREGON DEPARTMENT OF ENVIRONMENTAL QUALITY

UNITED STATES
DEPARTMENT OF THE INTERIOR
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CONVERSION FACTORS

Factors for converting inch-pound units to the International System of metric units (SI) are given below to four significant figures.

To convert from	To	Multiply by
foot (ft)	meter (m)	0.3048
foot per second (ft/s)	meter per second (m/s)	0.3048
cubic foot per second (ft^3/s)	cubic meter per second (m^3/s)	0.02832
inch (in.)	centimeter (cm)	2.540
square inch (in^2)	square meter (m^2)	0.0006452
mile (mi)	kilometer (km)	1.609
square mile (mi^2)	square kilometer (km^2)	2.590
pound per day (lb/d)	kilogram per day (kg/d)	0.4536
British thermal unit per square foot per day ($Btu/ft^2/d$)	calorie per square centimeter per day ($calorie/cm^2/d$)	0.2712
degree Fahrenheit (°F)	degree Celsius (°C)	1/

1/ Temp °C = (temp °F-32)/1.8.

SYMBOLS

BOD - Biochemical-oxygen demand.

$CBOD_{ult}$ - Ultimate carbonaceous biochemical-oxygen demand.

k_1 - First-order carbonaceous deoxygenation rate ($\log_{10}$), as measured in the BOD bottle at 20°C.

k_r - First-order river carbonaceous deoxygenation rate ($\log_{10}$), adjusted to 20°C.

N - Nitrogen.

NBOD - Nitrogenous biochemical-oxygen demand.

k_n - First-order river nitrogenous deoxygenation rate ($\log_{10}$), adjusted to 20°C.

DO - Dissolved oxygen.

Q - Stream discharge.

RM - River mile.

T - Water temperature.

d - Day.

mg/L - Milligrams per liter.

MPN - Most probable number.

P - Daytime net biological production of oxygen.

R - Nighttime net biological consumption of oxygen, respiration.

P-R - Community metabolism or net production of oxygen.

P/R - Community trophic indicator.

STP - Municipal sewage-treatment plant.

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ABSTRACT

During July and August 1978, the U.S. Geological Survey, in cooperation with the Oregon Department of Environmental Quality, made three intensive river-quality dissolved-oxygen studies in the upper Willamette River basin. Two of the studies were done on the upper Willamette River and one study was done on the Santiam River, a Willamette River tributary. Nitrification, occurring in both the upper Willamette and South Santiam Rivers, accounted for about 62 percent and 92 percent of the DO sag in the rivers, respectively. Rates of nitrification were determined to be dependent on ammonia concentrations in the rivers. Periphyton and phytoplankton algal samples were collected on the main stem Willamette River and selected tributaries during August 1978. Diatoms were the dominant group in both the periphyton and phytoplankton samples. The most common diatom genera were <u>Melosira</u>, <u>Stephanodiscus</u>, <u>Cymbella</u>, <u>Achnanthes</u>, and <u>Nitzschia</u>. Comparisons with historical data indicate no significant difference from previous years in the total abundance or diversity of the algae.

INTRODUCTION

Background

This study is an extension of a river-quality assessment that began in 1973. In January of that year, the U.S. Geological Survey initiated a prototype intensive river-quality assessment study of the Willamette River basin, Oregon. The 1973-74 study was designed to collect data on which to base future management decisions. The decisions would deal with the effects on river quality of industrial and population growth. The Willamette River basin was selected for several reasons: (1) extensive historical water-quality data existed, (2) social and political attitudes in Oregon reflected a keen interest in environmental matters, (3) a river-basin management plan already existed for the basin, and (4) the Willamette River was the largest river in the United States on which all major point-source municipal and industrial discharges received secondary waste-water treatment (Rickert and Hines, 1975).

Four existing or potential problem areas were studied in the 1973-74 assessment: (1) dissolved-oxygen (DO) depletion, (2) potential for algal problems, (3) trace-metal occurrence, and (4) the impact of land-use activity on erosion. The U.S. Geological Survey Circular 715 series, entitled "River-Quality Assessment of the Willamette River Basin, Oregon," was written to present a case history and report the results of the intensive river-quality assessment.

A conclusion of the 1973-74 assessment was that continued monitoring of any DO depletion and potential impact of algal growth on the river would be of particular value in making sound management decisions.

Dissolved-Oxygen Depletion

Historically, the Willamette River had low DO concentrations during the summer due to a combination of low river flow, high water temperatures, and large organic waste loads from industrial and municipal sources. During summer low-flow periods, the DO concentration in the Portland Harbor had often dropped to zero (Velz, 1961; Gleeson, 1972), and for years Columbia River salmon migration up the Willamette was inhibited by these low DO levels. In recent years, because of a combined effort by industries and municipalities to reduce point-source loadings of carbonaceous biochemical-oxygen demand (CBOD), together with streamflow augmentation from reservoir storages, summer DO levels have increased significantly (Oregon Department of Environmental Quality, 1975). However, of foremost concern to the Department of Environmental Quality (DEQ) is whether high DO concentrations can be maintained in the future as population and industry continue to grow. To anticipate future conditions, an understanding of the cause-effect relationships involving DO depletion is needed.

During 1973-74, a comprehensive set of CBOD-DO data was collected on the Willamette River as part of the river-quality assessment study. Some of these data were used to calibrate and verify the Willamette Intensive River-Quality Assessment Study (WIRQAS) DO model for the critical reach from Salem to the lower Portland Harbor (river miles [RM's] 86.5 to 5) (Hines and others, 1977; McKenzie and others, 1979). The WIRQAS DO model provides an accurate simulation of DO (±5 percent of saturation) during summer steady-state low flows at or near calibration or verification conditions.

Another part of the data collected consisted of $CBOD_{ult}$ and nutrient samples and DO readings from Eugene to Salem on the Willamette River (RM's 186 to 86.5). Summer DO readings ranged from 80 to 115 percent of saturation, with daily means consistently above the 90 percent of saturation requirement of the State standard for this reach (Hines and others, 1977). Accordingly, it was concluded that the WIRQAS DO model need not be extended to the reach above Salem, recognizing, however, that the initial input to operation of the model depends upon reliable measurement of residual loadings reaching Salem from upstream sources.

Potential for Algal Problems

In 1972, the Willamette River became the largest river in the United States to have all known point waste-water sources under secondary treatment. This accomplishment resulted in dramatic decreases in the carbonaceous waste loadings to the river. Nitrogen and phosphorus loads remained high, however, because secondary treatment processes were largely ineffective in removing these nutrients. Despite the high nutrient levels, the Willamette River had not experienced excessive growth of algae. The reasons for a lack of excessive algal growth were unknown at that time. The 1973-74 algal assessment involved identification of algal populations at key points in the Willamette River and an attempt to determine the environmental factors controlling algal growth and rate of production.

The study team (Rickert, Peterson, McKenzie, Hines, and Wille, 1977) determined that summer concentrations of nitrogen and phosphorus exceeded the minimum threshold levels for excessive algal growth, but that primary productivity was low and the resulting algal community was dominated by diatoms. Additional tests indicated that the Willamette River was not deficient in minor nutrients or various waste-water constituents. The healthy algal balance was thought to be maintained by short detention times of the water and possibly by low light penetration resulting from turbidity.

Purpose and Scope

The objectives of this study were to determine the effects of $CBOD_{ult}$ and ammonia loadings on DO in the upper Willamette River between Eugene and Salem (RM's 185-86.5) and to compare earlier algal populations with those of 1978 for selected reaches of the Willamette River system. Of special interest was an examination of DO problem areas in the lower reaches of the Santiam and South Santiam Rivers. The Santiam River is a tributary to the Willamette at RM 107.9, and its water quality affects DO levels in the Willamette during summer low-flow periods.

Need for the study became apparent as DEQ began using the WIRQAS DO model to predict DO concentrations between Salem and the Portland Harbor (RM's 86.5 to 5) for a variety of management options. Experience with the model, in addition to data collected in 1977, suggested the following information gaps:

1. No verified methods or data were available for flow-routing $CBOD_{ult}$ loads from upstream sources to Salem for use in the WIRQAS DO model. The accuracy of the $CBOD_{ult}$ loading at Salem is of primary importance in using the WIRQAS DO model to predict accurately the DO regimen in the Salem to Portland Harbor reach.

2. No methods or data were available for flow-routing ammonia loads from upstream sources to Salem for use in the WIRQAS DO model. An assessment of the ammonia loads from point sources upstream from Salem on the ammonia loading at Salem would give DEQ an understanding of the impact of upstream ammonia loadings on downstream river DO concentrations.

3. Knowledge of the impact of $CBOD_{ult}$ and ammonia sources upstream from Salem on downstream DO levels was needed to aid the Corps of Engineers, in cooperation with DEQ, in regulating riverflow to maintain adequate DO levels during fish runs.

4. During the 1977 summer low-flow, high-temperature period, indications were that parts of the Willamette River upstream from Salem were sufficiently stressed by the impact of certain waste-water sources to warrant further examination. Exceedance of the minimum State standard of 90 percent DO saturation occurred in the Willamette River at Independence (RM 96) (DEQ monitoring data, 1977). Preliminary analysis indicated that ammonia sources to the Willamette River at Albany and to the South Santiam River at Lebanon may have caused nitrification in the rivers and thus contributed to the DO deficit.

5. The possibility existed that changes in the river algal populations were occurring because of changes in ammonia and $CBOD_{ult}$ loadings. A new study was needed to identify algal populations and compare them with the 1973-74 algal-population data to determine if undesirable biological changes were beginning to occur.

To meet the stated objectives, the scope of this study included:

1. Defining the impact of individual $CBOD_{ult}$ and ammonia point- and nonpoint-source loads in the Willamette River above Salem and in the Santiam and South Santiam Rivers on those loads observed in Salem.

2. Determining rates of carbonaceous and nitrogenous deoxygenation so that individual source $CBOD_{ult}$ and ammonia loads could be flow-routed down the Willamette River to Salem for use in the WIRQAS DO model.

3. Collecting periphyton and phytoplankton algal samples in the Willamette River and selected tributaries for counts and identification of the algal-community structure.

Physical Setting

The Willamette River drains an area of 11,460 mi^2 in northwestern Oregon (fig. 1). The basin is roughly rectangular in shape, bounded on the north by the Columbia River, on the south by the Calapooya Mountains, on the east by the Cascade Range, and on the west by the Coast Range. The north-south length of the basin is roughly 150 mi, with an east-west width of 75 mi. Elevations range from less than 10 ft near the mouth of the Willamette River, to 450 ft at the confluence of the Coast and Middle Forks near Eugene (RM 187), and to more than 10,000 ft in the Cascade Range. The slopes and foothills of the Cascade Range occupy more than 60 percent of the basin area. Timberland, largely in the tributary basins, accounts for 62 percent of the land use (Gleeson, 1972); 33 percent of the basin is devoted to farming and the remaining 5 percent is urbanized or in other uses.

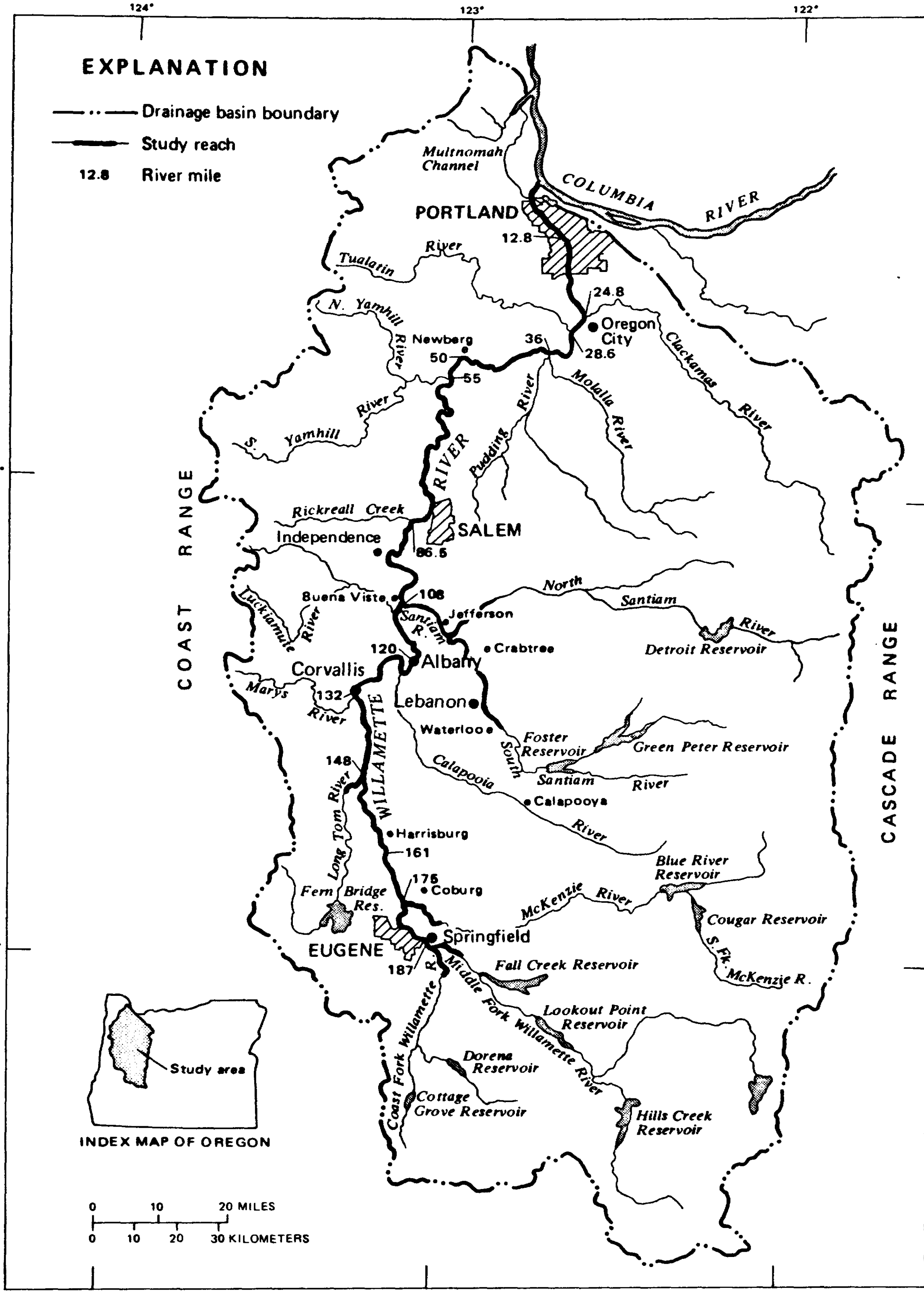

FIGURE 1. – Locations of study reaches and selected river miles, Willamette River basin, Oregon.

Within the Willamette River basin are Oregon's three largest cities, Portland, Salem, and Eugene. The basin has a population of 1.7 million people (1978 census, State of Oregon, 1979), which is approximately 70 percent of the State's population. The basin supports an economy based largely on timber, agriculture, industry, and recreation, and contains abundant fish and wildlife habitats.

Hydrologic Characteristics

Precipitation

The Willamette River basin has a modified marine climate characterized by wet, cloudy winters and dry, clear summers. Mean annual precipitation for the basin is about 63 in., with the Willamette Valley averaging less than 40 in. and several west-slope areas of the Cascade Range averaging more than 130 in. (Willamette Basin Task Force, 1969, p. II-10). Approximately 70 percent of the annual precipitation falls from November to March, 45 percent of it being divided equally among December, January, and February. Only 5 percent of the annual precipitation falls from June through August. This seasonal dry period has a significant impact on the summer-autumn streamflow and water quality of the Willamette River.

Streamflow

From November to March, most of the flow in the Willamette is derived from frequent winter rainstorms and spring snowmelt. Flows often exceed 100,000 ft^3/s during the winter. After March, snowmelt from the High Cascade Range lengthens the seasonal runoff into June or early July. The 1978 seasonal flow patterns of the upper Willamette and South Santiam Rivers, illustrated in figure 2, represent the typical post-1952 reservoir-regulated streamflow pattern (minimum flow at Salem, 6,000 ft^3/s). (See Shearman, 1976, for impact of reservoir releases on main-stem Willamette River flow during the summer-autumn period.) Figure 2 also illustrates that during the summer these streams have extended periods of stable low flow when studies ideally can be made based on assumptions of a steady-state system.

Water Temperature

In the Willamette River, the critical months for water temperature are July and August, when ambient temperature is highest and natural streamflow is lowest. In the upper reach, daily mean temperatures range from 15° to 16°C (Celsius), in the downstream reach temperatures progressively increase to 23° to 24°C in Portland Harbor. Several tributaries, such as the McKenzie, Santiam, and Clackamas Rivers, bring in cooler waters from the higher elevations.

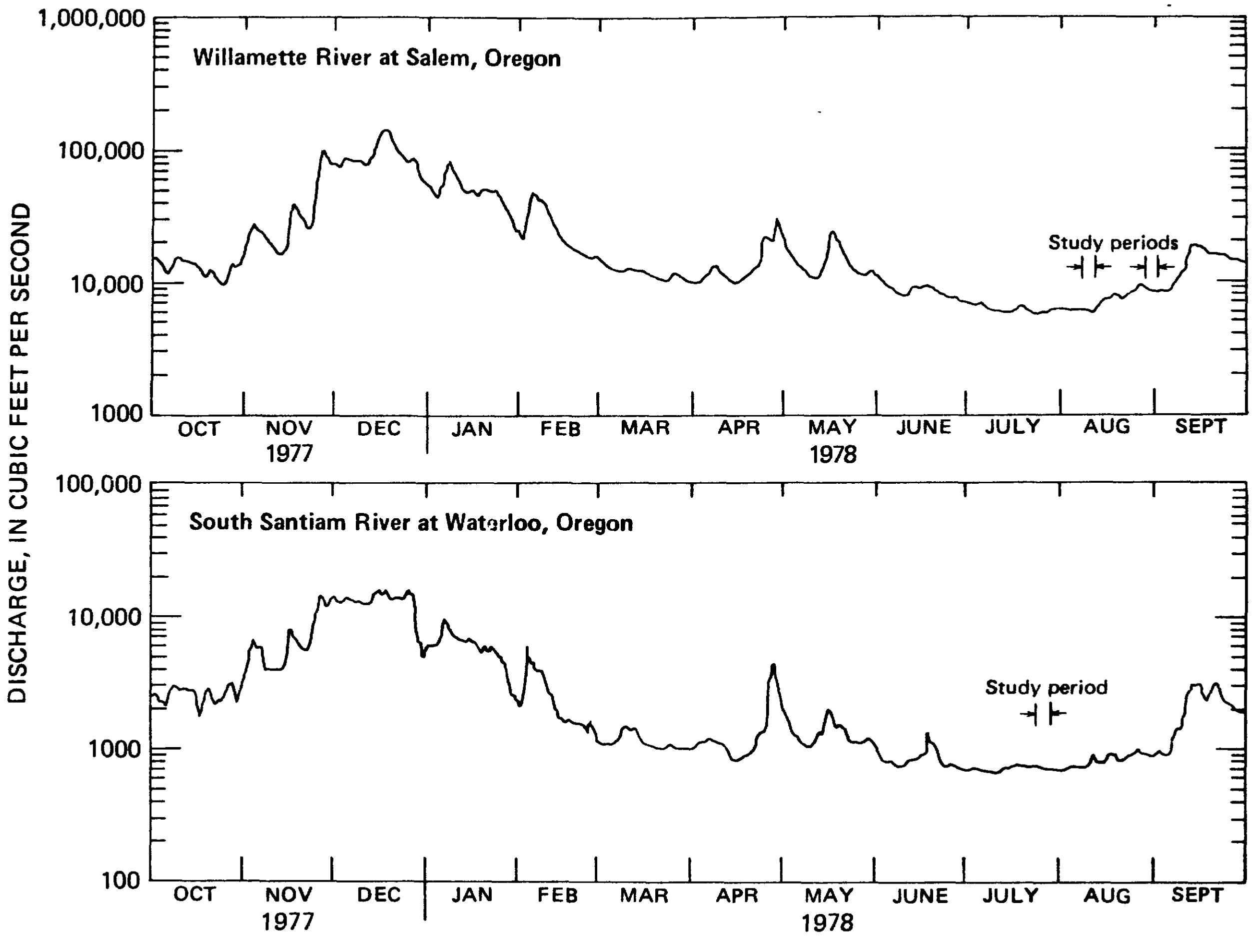

FIGURE 2. – Flow in the Willamette River basin for 1978 water year, Willamette River at Salem and South Santiam River at Waterloo.

Channel Morphology

The Coast and Middle Forks of the Willamette River join near Eugene to form the main stem of the Willamette River which flows for 187 mi to the Columbia River. The main stem consists of three distinctive reaches whose morphology influences the water's physical and biological characteristics. The Willamette's "Upstream Reach" (RM's 187-52) is characterized by shallow, fast-moving, and relatively turbulent water. The streambed consists of cobbles and gravel covered with periphyton during the summer. The "Newberg Pool" (RM's 52-26.5) is a deep, slow-moving pool with a bed surface composed of fine bottom sediments. The "Tidal Reach" (downstream from RM 26.5) is also a deep, slow-moving reach whose flow is affected by tides and backwater from the Columbia River during spring and early summer (Velz, 1961). The "Newberg Pool" and the "Tidal Reach" are separated by the 48-foot Willamette Falls.

The lower Santiam River basin is considered morphologically similar to the Willamette's "Upstream Reach."

Extensive channel cross sections were obtained for the upper reach of the Willamette above Salem to provide the data essential for time of passage and flow routing. Willamette River data are summarized in tables 18 and 19 and South Santiam data in table 20.

DISSOLVED-OXYGEN MODELING APPROACH

Design of the Study

The framework of the study program was based on the philosophy (Rickert and Hines, 1975; Hines and others, 1975) that repetitive, intensive synoptic studies will explain more fully the cause-effect relationships concerning river-water quality than will monthly monitoring.

A mathematical-modeling approach was applied to the DO regimen in the Willamette and Santiam Rivers because the technique provided the most potential for quantifying the fundamental cause-effect relationships. (See Rickert and others, 1976, for model-approach philosophy and data needs.) The approach is designed to simulate the common processes of carbonaceous and nitrogenous deoxygenation, reaeration, and benthic-oxygen demands. Photosynthesis is not directly accounted for in the approach, but can be introduced where needed to fit the measured data.

The size and complexity of most rivers limit the capability for studying all seasonal variations in the DO regimen. Therefore, it is most advantageous to conduct a DO study during the time period in which the river is under the greatest DO stress. In the Willamette, this period generally occurs during summer, when flows are low and water temperatures are high, and is the critical one for planning and management. A major advantage of examining DO levels during this critical period is that near steady-state flow conditions occur, which obviate using estimated dynamic parameters in the analysis.

Three intensive weeklong river-quality surveys were done to evaluate the significance of $CBOD_{ult}$, nitrogenous biochemical-oxygen demand (NBOD), benthic-oxygen demand, photosynthesis, and reaeration on the water quality of the Willamette and Santiam Rivers. One survey was done on the lower Santiam River during July 1978 and two surveys were done on the upper Willamette River (Eugene to Salem) during August 1978. From these surveys, $CBOD_{ult}$ and NBOD loads and rates of deoxygenation were calculated and assessments were made to determine if the rivers were experiencing DO problems. In these reaches, the rivers are considered to have DO problems if the 24-hour average DO concentration drops below the State water-quality standard of 90 percent saturation.

Sampling-Site Selection

Table 1 summarizes the times, locations, and general nature of the intensive DO studies. For those areas expected to be sufficiently DO stressed to model, extensive cross-sectional channel geometry data were collected. The cross-sectional data are used in the model to define rates of reaeration and times of travel for each river segment. Table 1 also outlines the field program of algal reassessment.

Individual sites for sampling (fig. 3) were selected based on the location of waste-water outfalls and tributaries, accessibility of boat-launching areas, and availability of bridge-measuring sites. (See Hines and others, 1977, for philosophy of site selection.)

Methods and Procedures

In general, the methods and procedures used during the 1978 Willamette-Santiam assessments were those described by Hines and others (1977). One exception is that ultimate CBOD ($CBOD_{ult}$) concentrations were calculated (using Lee's grid) from 15-day CBOD rather than 20-day CBOD tests. Review of previous work on the Willamette River indicated no significant differences in $CBOD_{ult}$ demand and k_1 rates calculated from either 15- or 20-day CBOD tests.

Sampling-site time schedules for the Willamette surveys and the Santiam survey were selected to make maximum use of equipment and manpower. The work on each Willamette DO survey involved two overlapping study areas. The first study area included all tributaries, municipal and industrial waste-water sources, and main-stem Willamette sites between RM 195 and Corvallis (RM 134.3). The second study area covered all remaining sites from Corvallis (RM 134.3) to Salem (RM 84). The Corvallis site on the Willamette River was monitored continuously during each Willamette survey and was the ending site of the first study area and the beginning site of the second study area. In each Willamette DO survey, collection on the first day consisted of sampling waste sources and tributaries in the first study area. Collection on this first day provided lead-in data to the intensive river sampling done on the second and third days from RM 195 to Corvallis. Collection on the third day provided lead-in data for the second study area (Corvallis to Salem). Intensive river sampling in the second study area was done on the fourth and fifth days.

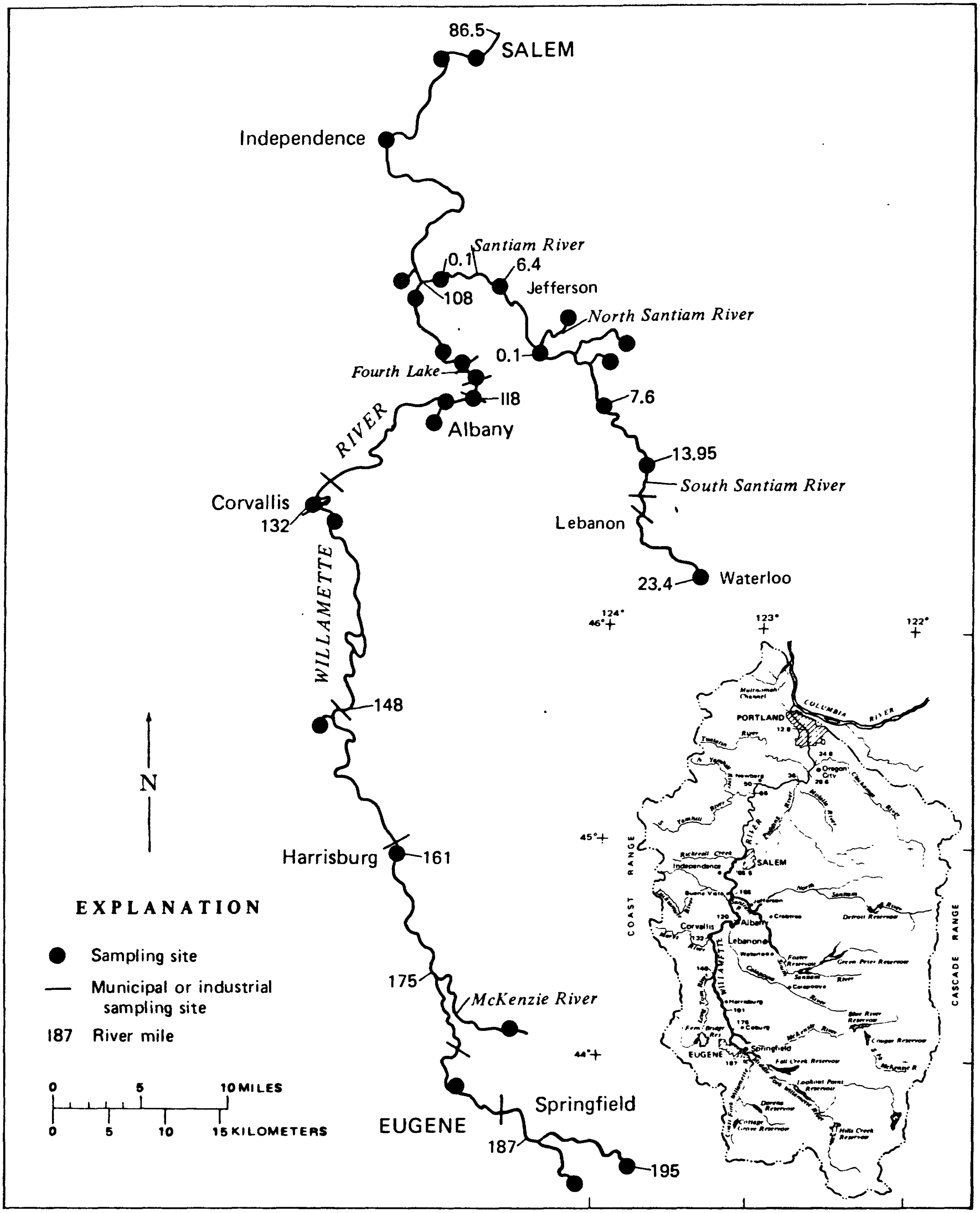

FIGURE 3. – Upper Willamette River basin, showing sampling-site locations on the Willamette and Santiam Rivers.

Table 1.--Summary of studies in the upper Willamette River basin during 1978

Description	Dates	Sampling sites
Cross-sectional geometry data.	June 5-9	Willamette River, cross-sectional depth profiles at approximately 0.2- to 0.3-mile intervals between RM's 120 and 83.8.
DO study		
South Santiam River, RM's 23.4-0.0.	July 23-28	South Santiam River, RM's 23.4, 13.95, 7.6, 0.1. Also three tributaries and two waste-water outfalls.
North Santiam River, RM's 2.9-0.0.		North Santiam River, RM 2.9
Santiam River, RM's 11.7-0.0.		Santiam River, RM's 6.4, 0.1
Collection of periphyton and phytoplankton algal samples.	August 4, 7-8, 16-17.	Willamette River, RM's 185, 176.5, 169, 161, 156, 141.7, 132, 118, 111, 107, 100, 86.5, 78, 72, 56, 50, 39, 33, 20.5, 12.8, 7.0. McKenzie River, RM 0.1 South Santiam River, RM's 23.4, 13.95, 7.6, 0.1 Santiam River, RM's 6.4, 0.1 Tualatin River, RM 0.1 Clackamas River, RM 0.1.
DO study		
Willamette River, RM's 195-85.9	August 7-11	Middle Fork Willamette River, RM 195 Coast Fork Willamette River, RM 6.4 Willamette River, RM's 180.7, 161.2, 134.3, 119.6, 118.1, 116, 115, 113.5, 108, 85.9. McKenzie River, RM 7.2 Santiam River, RM 0.1 All other major tributaries and all major waste-water outfalls.
DO study		
Willamette River, RM's 195-85.4	August 28-September 1.	Middle Fork Willamette River, RM 195 Coast Fork Willamette River, RM 6.4 Willamette River, RM's 180.7, 161.2, 134.3, 119.6, 118.1, 116, 115, 113.5, 108, 85.4. McKenzie River, RM 7.2 Santiam River, RM 0.1 All other major tributaries and all major waste-water outfalls.

In the Santiam DO survey, 4 days of lead-in data were collected at sites on tributaries and at municipal and industrial waste-water sources. These same sites were sampled on the fifth and sixth days, together with all main-stem South Santiam and Santiam River sites.

During the three surveys, more than 660 15-day CBOD tests and 285 individual nitrogen-species analyses were made on samples of river and waste waters. In addition, algal populations from 30 sites on the main stem and tributaries of the Willamette River were identified for phytoplankton; 12 of those sites were also selected for periphyton identification.

WILLAMETTE RIVER DISSOLVED-OXYGEN STUDY

$CBOD_{ult}$ Concentrations and k_1 Rates

Concentrations of $CBOD_{ult}$ in the Willamette River for both 1978 surveys are shown in table 2. Average weekly flow at the reference gage (U.S. Geological Survey Salem gage at RM 84.16) was 2,150 ft^3/s greater during the second survey (Aug. 28-Sept. 1, 1978, 8,040 ft^3/s) than during the first (Aug. 7-11, 1978, 5,890 ft^3/s). $CBOD_{ult}$ data collected during the second survey reflect the effects of river dilution. Concentrations were lower by a factor that approximates the observed increase in streamflow. Because riverflows were similar, $CBOD_{ult}$ concentrations from the first survey were compared with the 1973 WIRQAS data. For the reach from RM 195 to 85.9, 1978 river $CBOD_{ult}$ concentrations were approximately 30 percent lower than those observed during 1973. River CBOD bottle deoxygenation rates for 1978 ranged from $k_1 = 0.04$ to 0.14 d^{-1}, with most ranging from 0.06 to 0.08 d^{-1}. The 1973-74 WIRQAS bottle rates for this reach ranged from $k_1 = 0.03$ to 0.06 d^{-1}, with a mean rate near 0.04 d^{-1} (Hines and others, 1977).

The increase in CBOD bottle deoxygenation rates in 1978 is not easily explainable. Estimated accuracy of the $CBOD_{ult}$ test in the less than 4-5 mg/L range is about ± 20 percent, when sampling, handling, and analysis errors are included. Moreover, in reality, calculated values for $CBOD_{ult}$ concentrations and k_1 rates represent composite values of a variety of different biological reactions taking place in the bottle along with carbonaceous deoxygenation. If the water collected for CBOD analysis contains a low concentration of digestible carbonaceous material, other bottle biological reactions might predominate during incubation. The principal author has observed that in streams containing minimal waste discharge in Oregon, k_1 rates are much larger than can be explained by the types and amounts of organic detritus present. At low $CBOD_{ult}$ concentrations, the calculated k_1 rate seems to be affected by the bottle CBOD test. Perhaps the effects of phytoplankton decay and oxidation of the organic materials in their cells predominate over oxidation of the organic detritus.

Table 2.--$CBOD_{ult}$ concentrations and CBOD bottle deoxygenation rates (k_1) for samples of Willamette River water taken during the 1978 summer low-flow period

Sampling site (RM)	August 7-11				August 28-September 1			
	No. of samples	Mean $CBOD_{ult}$ concentration 1/ (mg/L)	$CBOD_{ult}$ concentration range (mg/L)	Average k_1 (d^{-1})	No. of samples	Mean $CBOD_{ult}$ concentration 1/ (mg/L)	$CBOD_{ult}$ concentration range (mg/L)	Average k_1 (d^{-1})
195.0	6	1.3	1.0-1.6	0.10	8	1.0	0.7-1.2	0.08
180.7	10	1.6	1.3-1.9	.10	12	1.4	1.2-1.7	.08
161.2	8	2.0	1.7-2.2	.08	8	1.9	1.7-2.4	.06
134.3	15	2.3	1.8-3.2	.08	16	1.8	1.5-2.2	.06
119.6	9	2.2	1.9-2.5	.08	9	1.6	1.4-2.0	.08
118.1	3	2.9	2.5-3.3	.06	2	1.8	1.6-2.0	.07
116.0	3	2.8	2.3-3.3	.06	4	1.9	1.8-2.0	.06
115.0	4	3.0	2.5-3.3	.06	4	2.2	1.8-2.7	.08
113.5	4	2.7	2.4-3.4	.06	2	2.1	2.1-2.1	.07
108.0	12	2.5	1.9-3.2	.06	12	1.9	1.3-2.4	.08
85.9	8	2.1	1.7-2.5	.08	2/ 10	2/ 1.7	2/ 1.3-2.2	2/ .08

1/ Mean $CBOD_{ult}$ concentration at each sampling site was calculated using the ogee summation curve method (Velz, 1970, appendix A).

2/ Farthest downstream sampling site during the August 28-September 1 Willamette River survey was at RM 85.4.

Calculated $CBOD_{ult}$ Loads

During the two surveys, total $CBOD_{ult}$ loadings to the main stem Willamette downstream to RM 86.5 were 83,000 and 88,000 lb/d, respectively (table 3). For both surveys, average contributions from point and nonpoint sources were about equal, with point sources contributing about 47 percent of the total $CBOD_{ult}$ loading and nonpoint sources contributing 53 percent. Table 4 is a summary of the major point- and nonpoint-source loadings of $CBOD_{ult}$ to this reach during the 1978 summer low-flow period. Table 4 also includes a summary of the major NBOD sources. Nonpoint-source loadings of $CBOD_{ult}$ and NBOD (table 4) represent that fraction of the tributary loads that cannot be attributed to municipal and industrial sources (point-source loadings).

Point-Source $CBOD_{ult}$ Loads

Total point-source loadings to the Willamette River during both 1978 surveys were similar, although wastes from one additional industry and from canneries were added to the river during the second survey. Point-source loads averaged about 40,000 lb/d, with about 55 percent from industrial sources and 45 percent from municipal sources.

Point-source CBOD bottle deoxygenation rates ranged from 0.02 to 0.12 d^{-1}, with about 70 percent ranging from 0.04 to 0.08 d^{-1}. These 1978 rates were approximately the same as those observed during the 1973-74 WIRQAS study, which indicates little change in the character of the treated carbonaceous waste materials over this period.

Nonpoint-Source $CBOD_{ult}$ Loads

Nonpoint-source loads to the Willamette River increased from 43,000 lb/d during the first survey to 48,000 lb/d during the second survey (table 4). Examination of the $CBOD_{ult}$ data from the Coast and Middle Forks of the Willamette River and the McKenzie and Santiam Rivers indicates no significant differences in $CBOD_{ult}$ concentrations between the two surveys. Because these rivers provide the bulk of the nonpoint-source loadings to the Willamette River, the observed increase in nonpoint-source loading to the river during the second survey was probably due to increased streamflow.

Background tributary $CBOD_{ult}$ concentrations were low, ranging from 0.7 to 2.5 mg/L. CBOD bottle deoxygenation rates ranged from 0.04 to 0.14 d^{-1}, with more than 70 percent ranging from 0.06 to 0.08 d^{-1}.

Mass Balancing and Flow Routing of $CBOD_{ult}$ Loads Downstream to Salem

A mass-balancing technique is used to determine that part of the river oxygen that is consumed by CBOD. $CBOD_{ult}$ loads, whether they represent point or nonpoint sources, are added to the existing river $CBOD_{ult}$ load at their points of entry into the river. The new in-river $CBOD_{ult}$ load (existing river plus entry $CBOD_{ult}$ loads) is flow routed downstream to where another $CBOD_{ult}$ load enters the river. The additive process is then

Table 3.--Characteristics of waste-water outfalls and tributaries to the Willamette River, August 7-11 and August 28-September 1, 1978

Location (RM)	Description	Average flow (ft^3/s)	Average temperature (°C)	Average DO (percent saturation)	Mean $CBOD_{ult}$ concentration (mg/L)	Average $CBOD_{ult}$ load (lb/d)	Average NH_4-N concentration (mg/L)	Average NBOD load (lb/d)
			August 7-11					
195	Middle Fork Willamette River near Jasper	2,370	15.7	99	1.3	16,600	0.05	2,800
187	Coast Fork Willamette River near Goshen	232	21.2	97	1.9	2,400	.06	320
184.3	Springfield STP	9.7	21.0	56	65	3,400	8.84	2,000
178	Eugene STP	29	22.0	80	80	12,500	10.5	7,100
174.8	McKenzie River near Coburg	2,130	18.2	93	1.6	18,300	.06	3,000
161	Harrisburg STP	.3	21.1	64	93	150	14.2	100
149	Long Tom River	40	24.0	80	2.8	600	.07	60
147.5	American Can Co.	25	27.8	48	27	3,600	4.73	2,800
132.2	Evans Products Co.	.5	23.3	1	260	700	.33	0
132.1	Marys River	11	23.5	85	4.2	250	.03	10
131	Corvallis STP	8.0	23.3	15	17	730	3.00	560
119.5	Calapooia River	36	18.9	100	1.8	350	.04	30
118	Albany STP	8.5	22.0	46	9.0	410	.44	90
116.5	Western Kraft Corp.	12	32.6	13	130	8,400	.32	90
115.5	Fourth Lake (including waste-water from Teledyne Wah Chang)	6.5	21.9	95	60	2,100	49.2	7,500
107.9	Santiam River	1,210	21.2	101	1.8	11,700	.06	1,700
107.5	Luckiamute River	30	22.9	101	4.2	680	.05	30
95.3	Ash Creek	.1	18.0	25	4.9	0	.36	0
88.1	Rickreall Creek	1.0	21.0	75	2.0	10	.05	0
	Total					83,000		28,000
			August 28-September 1					
195	Middle Fork Willamette River near Jasper	2,530	16.6	99	1.0	13,600	.03	1,800
187	Coast Fork Willamette River near Goshen	294	19.1	101	1.8	2,800	.03	200
184.3	Springfield STP	10	20.0	55	50	2,700	15.3	3,600
178	Eugene STP	27	21.0	79	76	11,000	8.02	5,000
174.8	McKenzie River near Coburg	2,510	15.6	98	1.5	20,300	.02	1,200
161	Harrisburg STP	.2	20.3	62	83	90	25.0	120
149	Long Tom River	36	22.2	110	4.6	890	.05	40
147.5	American Can Co.	23	27.4	16	30	3,700	1.50	800
132.2	Evans Products Co.	.4	20.9	3	300	650	1.19	10
132.1	Marys River	25	19.6	87	2.6	350	.06	30
131	Corvallis STP	6.6	22.0	63	16	570	7.12	1,100
119.5	Calapooia River	77	17.3	97	1.2	500	.04	70
118	Albany STP	7.8	21.8	33	8.7	360	.22	40
116.5	Western Kraft Corp.	11	29.5	18	160	9,500	.38	100
115.5	Fourth Lake (including waste-water from Teledyne Wah Chang)	9.6	22.1	69	20	1,000	41.0	9,200
107.9	Santiam River	2,170	16.6	100	1.7	19,900	.07	3,500
107.5	Luckiamute River	55	19.0	82	1.3	380	.05	60
95.3	Ash Creek	.5	17.6	41	3.0	10	.14	0
88.1	Rickreall Creek	16	19.0	77	1.7	150	.07	30
	Total					88,000		27,000

Table 4.--Summary of point- and nonpoint-source loadings of $CBOD_{ult}$ and NBOD to the upper Willamette River (RM's 195 to 86.5) during 1978 summer low-flow conditions

		$CBOD_{ult}$ load			NBOD load			Total BOD loading ($CBOD_{ult}$ + NBOD)	
Sampling schedule	Type of loading	lb/d	Percent load by type	Percent of total BOD load	lb/d	Percent load by type	Percent of total BOD load	lb/d	Percent load by type
Aug. 7-11	Point sources	40,000	48	36	21,000	75	19	60,000	55
	Nonpoint sources	43,000	52	39	7,000	25	6	50,000	45
Total		83,000	100	75	28,000	100	25	110,000	100
Aug. 28-Sept. 1	Point sources	40,000	45	35	21,000	78	18	61,000	53
	Nonpoint sources	48,000	55	42	6,000	22	5	54,000	47
Total		88,000	100	77	27,000	100	23	115,000	100

repeated again and again until the in-river $CBOD_{ult}$ load reaches the downstream end of the study area.

Because the $CBOD_{ult}$ load is nonconservative, the flow-routing process includes subtracting that part of the load between successive sites that is biologically satisfied. The satisfied $CBOD_{ult}$ load is equal to the initial $CBOD_{ult}$ load times the river carbonaceous deoxygenation rate (k_r) that has been adjusted for the time of travel between sites. A particular river k_r is selected that best fits a set of observed in-river $CBOD_{ult}$ data under one set of river conditions using the mass balancing-flow routing technique. This is part of the calibration process in which model parameters (in this case, k_r rate) are evaluated under one set of river conditions. Testing the reliability of the k_r rate entails using the same k_r rate under different river conditions and observing how well it predicts the new $CBOD_{ult}$ data. This reliability testing of the k_r rate is part of the verification process.

Figures 4 and 5 represent graphical summaries of the mass balancing-flow routing technique. Figure 4 shows the August 7-11, 1978, river conditions that were used for calibration, and figure 5 (Aug. 28-Sept. 1, 1978)

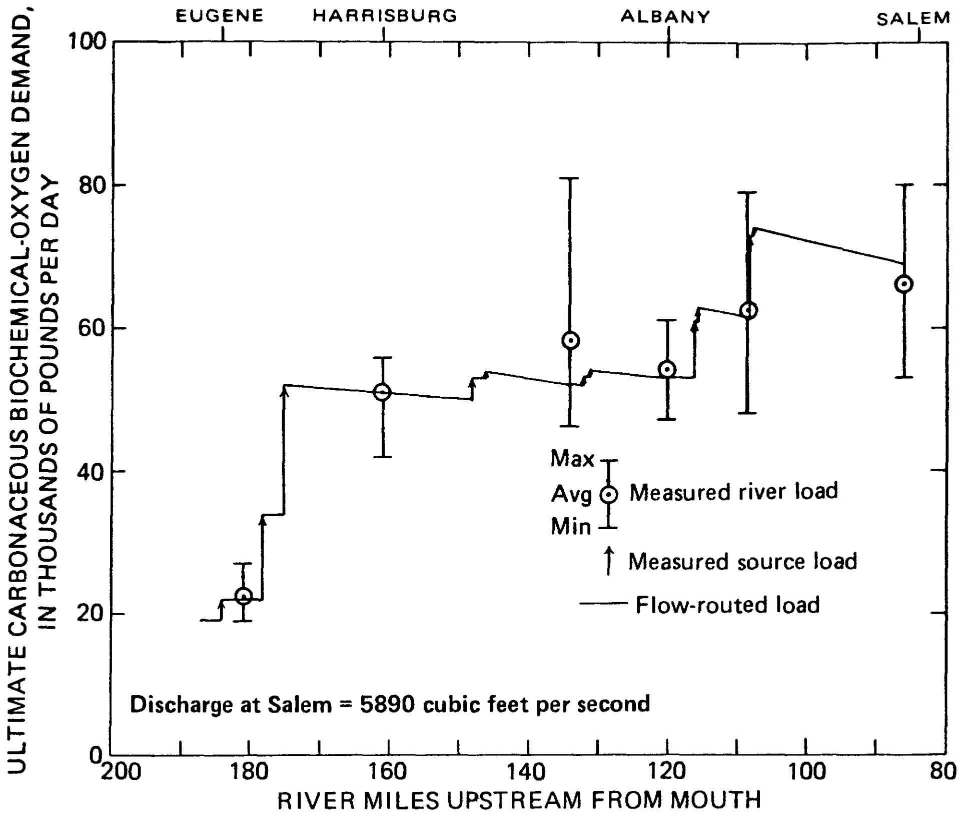

FIGURE 4. – Measured and flow-routed $CBOD_{ult}$ loads in the upper Willamette River, August 7-11, 1978. Carbonaceous deoxygenation rate (k_r) was 0.04 d^{-1} at 20°C.

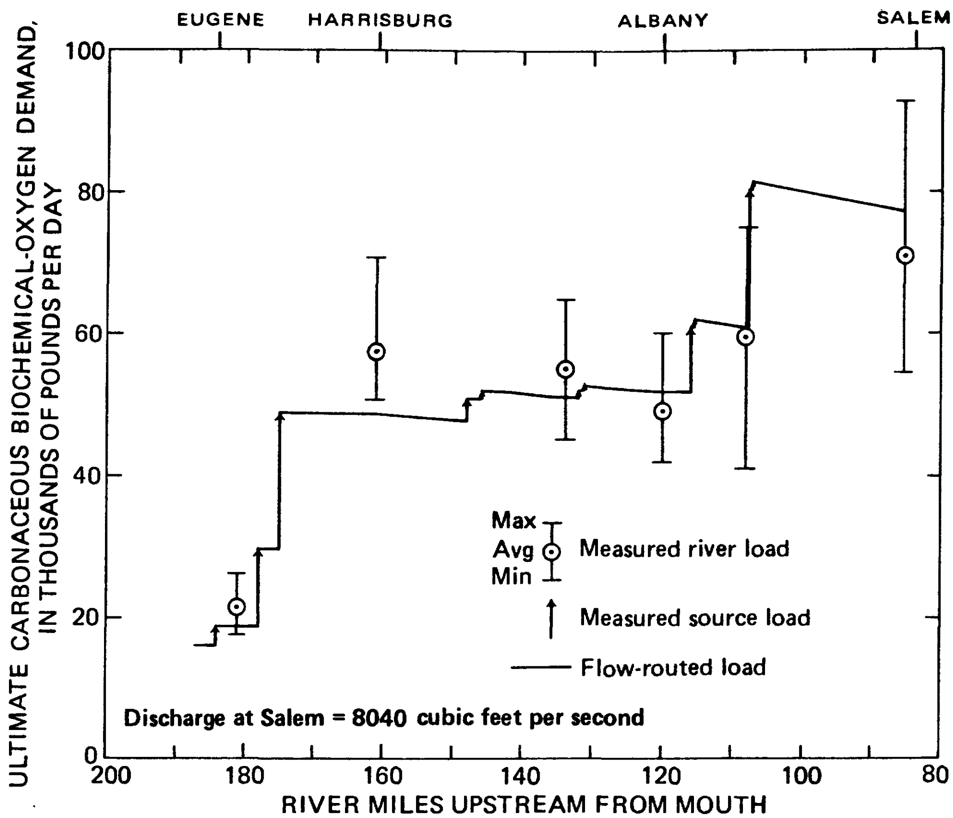

FIGURE 5. – Measured and flow-routed $CBOD_{ult}$ loads in the upper Willamette River, August 28-September 1, 1978. Carbonaceous deoxygenation rate (k_r) was 0.04 d^{-1} at 20°C, based on the August 7-11, 1978 survey.

represents the verification conditions. A river k_r rate of 0.04 d^{-1} at 20°C was determined to best fit the calibration conditions. Because k_r rates are temperature dependent, a correction of 4.7 percent was applied to the k_r rate per degree that the river temperature differed from 20°C (see supplement A).

Considering the limitations in measuring $CBOD_{ult}$ values at low concentrations, there is good to excellent agreement between measured and computed loads. The only point in the river where there is a major discrepancy is at RM 161.2 during the August 28-September 1 survey. During this period, the right bank of the channel just upstream from RM 161.2 was being extensively dredged to divert the main flow of the river away from the Harrisburg bridge pilings. Sediments, including organic materials, were being introduced into the river, and the water was visibly turbid. The actual difference in concentration between the measured $CBOD_{ult}$ (1.9 mg/L) and the computed $CBOD_{ult}$ (1.6 mg/L) was small, but because the discharge was 5,500 ft^3/s at RM 161.2, there is considerable discrepancy between measured and computed loads. The sediments resulting from dredging above RM 161.2 seemed to settle out rapidly and were not observed at the next downstream sampling site. Consistent with this observation, there was a relatively small difference between measured and computed loads at RM 134.3.

Supplement A gives a description of the calculations involved in the mass balancing-flow routing technique.

Nitrification

Nitrification is the process by which ammonia and simple amine compounds are biologically oxidized to the nitrite and then to the nitrate ion species. The nitrifying bacteria involved in this series of associated reactions are the genus *Nitrosomonas*, which oxidizes ammonia or simple amines to nitrite, and the genus *Nitrobacter*, which converts nitrite to nitrate (Velz, 1970).

Review of the 1973-74 WIRQAS work indicated that nitrification was a significant contributor to the DO deficit in the Willamette River between RM's 120 and 55.2. Because ammonia-nitrogen concentrations were low and the DO levels were near saturation, significant nitrification was considered to be absent above RM 120, despite the fact that a cobbly riverbed suitable for nitrification biofilm growth was present.

Analysis of nutrient, nitrifying bacteria, and DO data from the 1978 Willamette surveys indicates that nitrification was occurring and accounted for more than 60 percent of the DO depletion between Eugene and Albany (RM's 187 to 120) and roughly the same amount for RM 120 to Salem. (See section titled "Estimated DO-Load Losses.")

Nitrogen Concentrations

Observed average river concentrations of NH_4-N, NO_3-N, NO_2-N, and total -N for the two Willamette River surveys are shown in figures 6 and 7. Data from both figures show a slight increase in NO_3-N concentration from RM's 195 to 120 and then a rapid increase from RM 120 to the confluence of the Willamette and Santiam Rivers. Only about one-third of the total observed rise of NO_3-N concentration can be accounted for by accumulating the NO_3-N from various direct sources that enter this river segment.

The rather constant concentrations of NH_4-N in the Willamette River from RM's 195 to 120 seem to indicate that little nitrification occurs. However, if NH_4-N were treated as a conservative species and the various sources of NH_4-N were accumulated in the river segment downstream to RM 120, concentrations of NH_4-N would be between 2.4 and 1.8 times greater than observed at the Albany site (figs. 6 and 7, respectively). In reality, the observed NH_4-N profiles between RM's 195 and 120 remain relatively level because the various ammonia sources are fairly small, evenly dispersed, and approximately balance the in-river ammonia decay. Downstream from RM 120, a rapid increase in NH_4-N is observed because of a major nitrogen source entering at RM 115.5

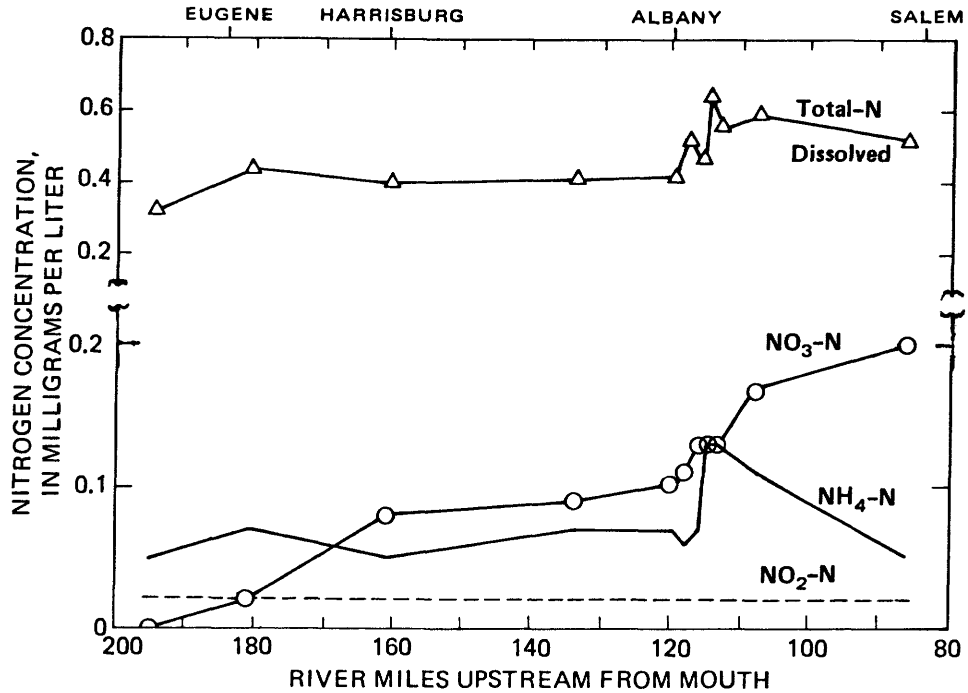

FIGURE 6. – Dissolved nitrogen-species concentrations observed in the upper Willamette River, August 7-11, 1978.

Calculated NBOD Loads

Total ammonia loadings to the main stem Willamette River, expressed as NBOD, were approximately 28,000 and 27,000 lb/d during the two 1978 surveys, respectively (table 3). As shown in table 4, more than 75 percent of the total NBOD load entering the river during the low-flow season came from discharges of municipal and industrial waste water.

Mass Balancing and Flow Routing of NBOD Loads to Salem

River nitrification generally occurs where ammonia comes in contact with the periphyton layer covering a shallow, cobbly area (Tuffy and others, 1974). Results of the 1978 study suggest that the river nitrification rate (k_n) is also dependent on the NH_4-N concentration. In 1974, with observed river NH_4-N concentrations ranging from 0.19 to 0.68 mg/L between RM's 86.5 and 55.2, the effective k_n was estimated to be 0.7 d^{-1} (at 20°C) (Hines and others, 1977). During the two 1978 upper Willamette River surveys, measured NH_4-N concentrations ranged from 0.03 to 0.13 mg/L. A k_n of 0.4 d^{-1} (adjusted to 20°C) best fit these data (see supplement A).

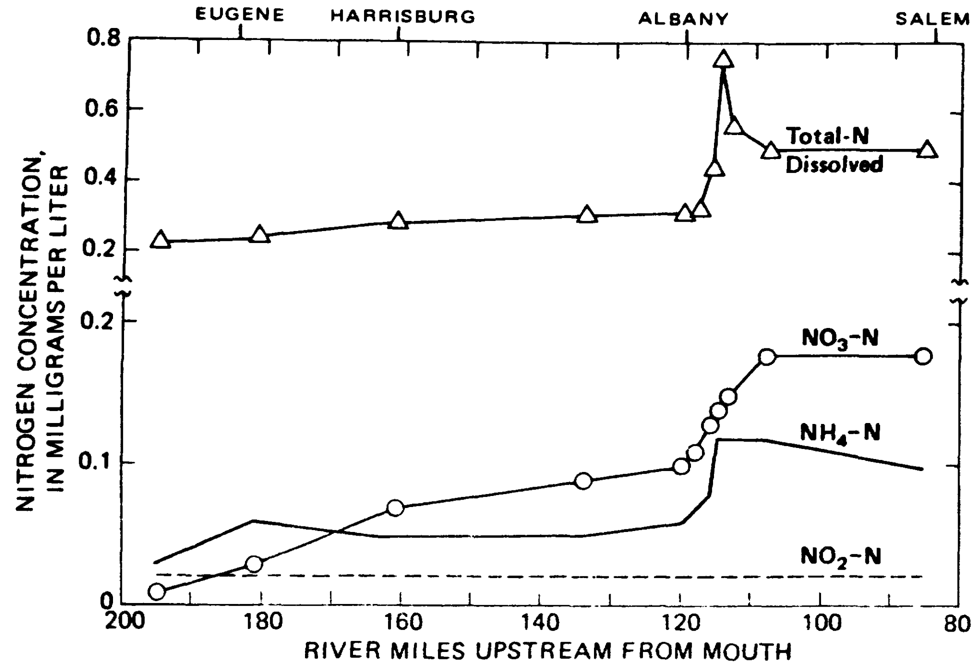

FIGURE 7. – Dissolved nitrogen-species concentrations observed in the upper Willamette River, August 28-September 1, 1978.

Figures 8 and 9 are graphical summaries of the upper Willamette River mass balance-flow routing technique for nitrification during 1978. A k_n of 0.4 d^{-1} was estimated based on the August 7-11, 1978, river conditions. A temperature-dependent correction of 4.7 percent was applied to the k_n per degree the river temperature differed from 20°C. Figure 8 shows excellent agreement between the flow-routed and measured NBOD loads, except at RM 161.2. At RM 178, the Eugene STP contributes a relatively large amount of NH_4-N to the river. This source, alone, accounted for about 50 percent of the total NH_4-N load at RM 178. The source had the potential to raise the in-river level of NH_4-N to more than 2.5 times the observed average concentration upstream from RM 161.2 at RM 180.7. If the k_n is dependent on the magnitude of the in-river NH_4-N concentration, a doubling or a tripling of the k_n in this river segment (RM's 178 to 161.2) would not be unreasonable and would account for the difference between the flow-routed and measured NBOD loads.

The analytical accuracy and precision of the NH_4-N chemical test is another factor that could easily account for the discrepancy. When analyzing NH_4-N concentration in the 0.04 to 0.07 mg/L range observed at RM 161.2 (calculated flow-routed NH_4-N concentration was 0.10 mg/L at the same site), analytical errors of as much as $\pm$50 percent can occur. With this magnitude

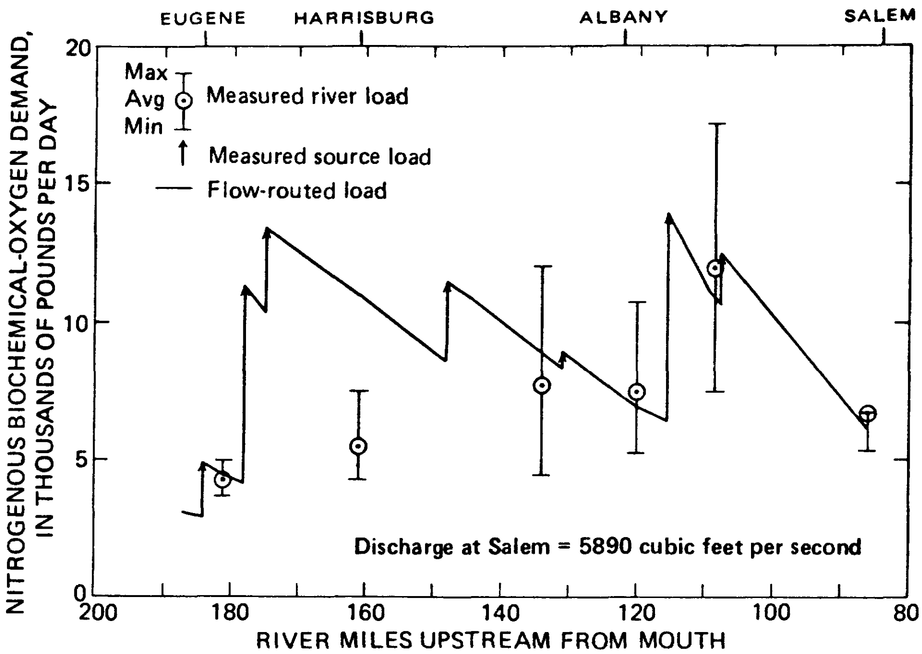

FIGURE 8. – Measured and flow-routed NBOD loads in the upper Willamette River, August 7-11, 1978. Nitrogenous deoxygenation rate (k_n) was 0.4 d^{-1} at 20°C.

of analytical error, it would be reasonable to predict that the calculated flow-routed and measured NH_4-N values are statistically part of the same population.

Figure 9 shows fair to good agreement between the mass balanced-flow routed calculations and measured NBOD loads during the second Willamette survey, except at the most downstream site at RM 85.4. Calculated NBOD loads for three of the six river stations illustrated in figure 9 are within the range of observed values. The remaining three compuated NBOD loads are within 30 percent of the measured range of values.

Because of the apparent discrepancy between the mass balanced-flow routed calculations and measured NBOD loads at RM 85.4 during the second Willamette survey, a closer inspection was made of the nitrogen cycle for this river segment. Table 5 shows two categories of NH_4-N plus NO_3-N concentration data. The first category is a cumulative concentration of NH_4-N plus NO_3-N from all point and nonpoint sources mass balanced to each river-sampling location. This category indicates the total concentration of NH_4-N and NO_3-N that would have been present if the sum of these nitrogen species were assumed to be conservative. Because ammonia is converted to nitrate in this segment, river concentration of NH_4-N will decrease downstream, with a

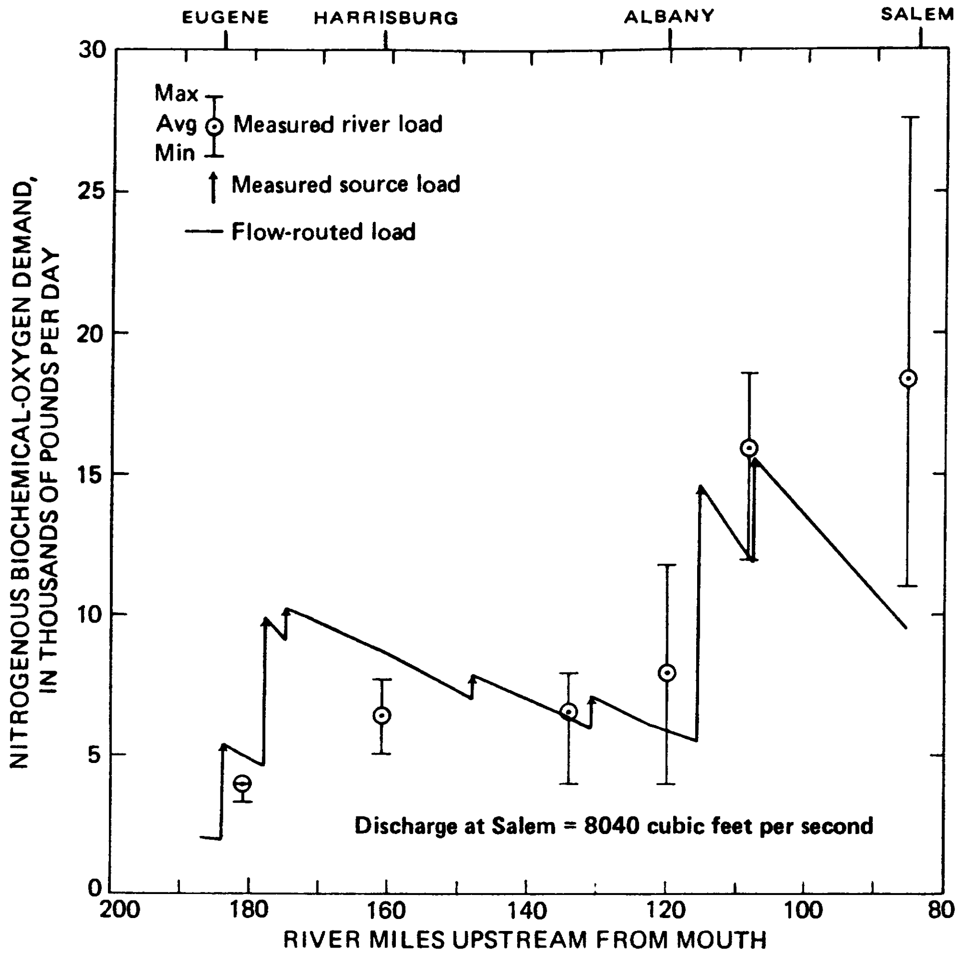

FIGURE 9. – Measured and flow-routed NBOD loads in the upper Willamette River, August 28–September 1, 1978. Nitrogenous deoxygenation rate (k_n) was 0.4 d^{-1} at 20°C, based on the August 7-11, 1978 survey.

proportional increase in NO_3-N concentration. The second category is the sum of the actually measured river concentration of NH_4-N and NO_3-N. During the August 7-11 Willamette survey, changes did occur in the concentration ratio of NH_4-N:NO_3-N, but the actual sum used to compare the cumulative concentrations to the measured concentrations did not change significantly upstream from RM 85.9. Differences in concentrations between calculated and measured NH_4 plus NO_3 sums during the first survey can be attributed to analytical accuracies of the two tests, and possibly some biological assimilation occurring at the most downstream site (RM 85.9). During the first survey, all measured NH_4 plus NO_3 sums are less than or equal to that which can be theoretically calculated.

Table 5.--Cumulative ammonia and nitrate concentrations from known point and nonpoint sources to the Willamette River as compared to measured in-river concentrations, summer 1978

[Constituents in milligrams per liter; n.s., not sampled]

Sampling location (RM)	August 7-11		August 28-September 1	
	Cumulative NH_4-N + NO_3-N concentrations assuming conservation of sum 1/	Measured in-river concentration of NH_4-N + NO_3-N	Cumulative NH_4-N + NO_3-N concentrations assuming conservation of sum 1/	Measured in-river concentration of NH_4-N + NO_3-N
187	0.06	n.s.	0.04	n.s.
180.7	.09	0.09	.10	0.09
161.2	.15	.13	.11	.12
134.3	.18	.16	.12	.14
119.6	.19	.17	.13	.16
118.1	.22	.17	.13	.18
116	.22	.20	.13	.21
115	.29	.26	.23	.26
113.5	.29	.26	.23	.27
108	.29	.28	.23	.30
85.9	.31	.25	2/ .21	2/ .28

1/ Total theoretical in-river concentrations of NH_4-N and NO_3-N were computed by summing their cumulative loads down to each sampling location and converting the resulting value to an equivalent total concentration. For these computations, the sum of NH_4-N and NO_3-N was assumed to be conservative. Input data at each location are given in table 3.

2/ Sampling site during the August 28-September 1 survey was at RM 85.4.

During the August 28-September 1 Willamette survey, the sum of the measured NH_4-N and NO_3-N concentrations below RM 119.6 were larger than can be computed, assuming conservative constituents (table 5). This could occur only if other sources of nitrogen were being added to the system. Moreover, examination of organic-N data (not shown in table 5) indicated that there was an additional unmeasured source of nitrogen to the river.

Figure 10 shows comparisons of the observed August 28-September 1 concentrations of NH_4-N, NO_3-N, and organic-N with those generated by summing all point and nonpoint sources down to each river-sampling location from RM's 119.6 to 85.4. The following can be observed:

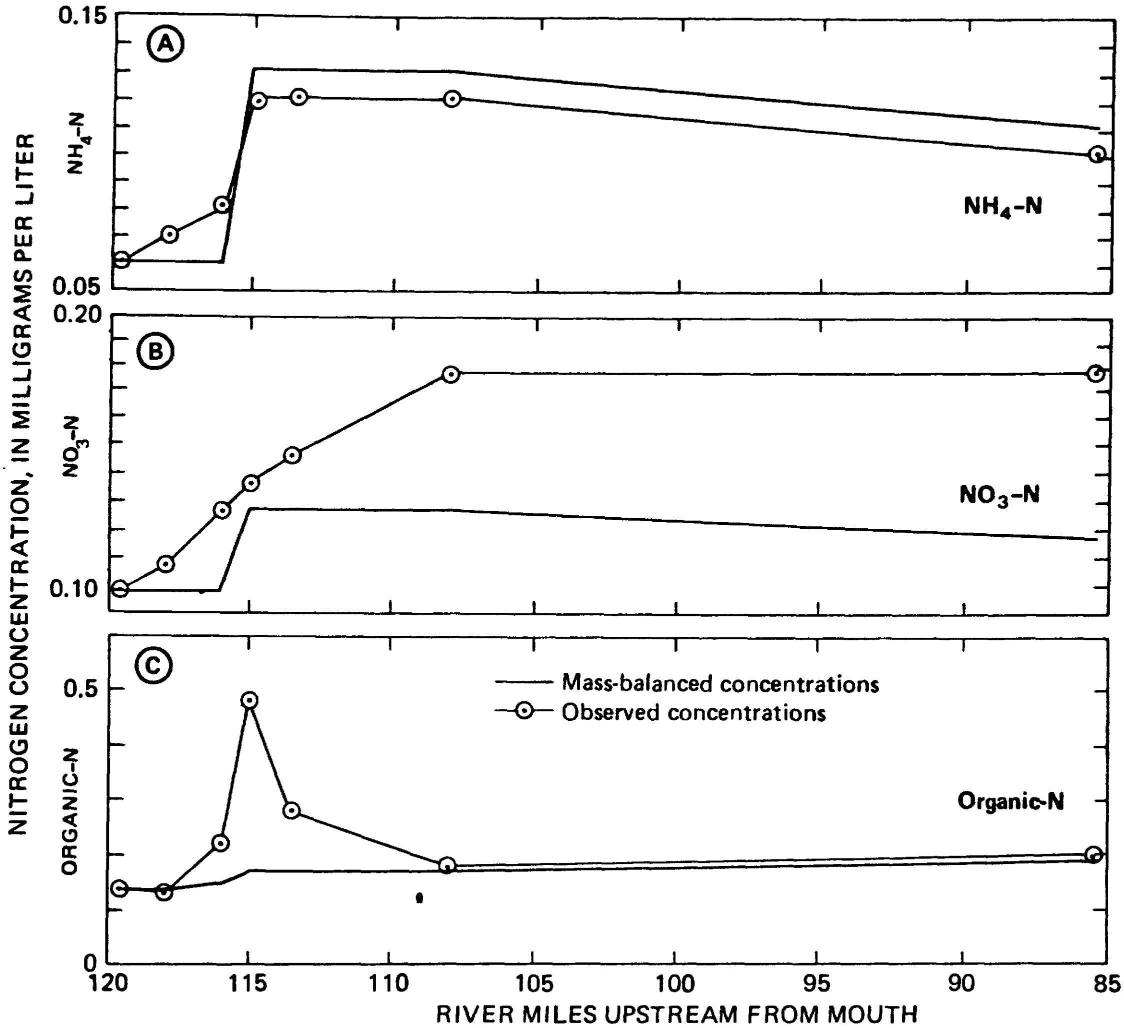

FIGURE 10. – Observed and mass-balanced dissolved nitrogen-species concentrations between river miles 119.6 – 85.4, Willamette River, August 28-September 1, 1978.

1. Downstream from RM 118, a rapid increase occurs in the observed concentration of organic-N over that which can be conservatively calculated from mass balancing the measured effluent and tributary loadings. A 2.8-fold increase in concentration occurs at RM 115. The observed organic-N concentration rapidly decreases and merges with the conservative organic-N curve near RM 108 (fig. 10c).

2. Downstream from RM 118, a rapid increase also occurs in the observed NO_3-N concentration over theoretical, with a 0.06 mg/L maximum difference occurring near RM 85.4 (fig. 10b).

3. Downstream from RM 118, essentially no difference occurs between the observed and mass-balanced NH_4-N concentrations when typical analytical accuracy and precision at the 0.10-mg/L detection level are considered (fig. 10a).

The trends observed in figure 10 are not conclusive, but do suggest that there were unmeasured sources of nitrogen to the Willamette River during the second survey. The same type of unmeasured source of nitrogen was also observed during the 1974 WIRQAS field program.

The largest measured increase of organic-N occurred between RM's 116 and 115 (fig. 10). At RM 115.5, a major industrial source of NH_4-N enters the river via a series of four lakes at the confluence with the Willamette. Fourth Lake, at the confluence with the Willamette, is a natural depositional area for the lake system. At times, a thick bed slurry of black, odoriferous, oily-looking material has been found in Fourth Lake. Particle-size analysis of the slurry materials indicates that 100 percent is <50 μm in diameter, with about 70 percent of the total <20 μm in diameter (Rickert, Kennedy, McKenzie, and Hines, 1977). Analysis of the bottom slurry material (Larson, 1974) reveals high concentrations of both NH_4-N and organic-N relative to concentrations in the water column above. Areal photographs of Fourth Lake reveal that its water and bottom-slurry materials slowly discharge out and along the right bank of the Willamette River.

On the basis of these observations, it seems likely that the increased concentrations of organic-N observed during the second survey between RM's 116 and 115 resulted from (1) eddy currents within Fourth Lake which caused an increased flow of slurry into the Willamette at the higher flow and (2) resuspension of previously settled slurry materials from along the right bank of the Willamette just downstream from the slough.

The reason the sampling system in Fourth Lake did not measure the increased flow of the slurry materials to the Willamette River during the second survey was that the station used to collect the composited 24-hour nitrogen samples was located between Third and Fourth Lakes. At this station, not in backwater, the calculated nitrogen load to the Willamette was much lower than actually occurred. Logistically, data collected at this site could not account for the increased discharge of the resuspended nitrogen-laden bottom materials from Fourth Lake at the higher Willamette flow.

Measured concentrations of NO_3-N in the Willamette increased between RM's 119.6 and 108 without an accompanying decrease in NH_4-N river concentrations (fig. 10). Assuming that all sources contributing nitrogen to the river have been accounted for, the increase in NO_3-N probably resulted from the nitrification process. If so, that process would need to occur simultaneously with hydrolysis of organic-N (from the Fourth Lake slurry) to maintain the observed constant concentration of NH_4-N. Hydrolysis would probably convert only a small part of the organic-N rich slurry from Fourth Lake or scoured from the river bottom. Thus, the unhydrolyzed organic-N would probably settle in pooled areas farther downstream.

Nitrifying Bacteria

During August 1978, river-water column and river-bottom rock-scraping samples were collected and analyzed for Nitrosomonas and Nitrobacter bacteria. The sampling scheme included five sites on the main stem Willamette between Corvallis and Salem and one site on the Santiam River near its confluence with the Willamette (table 6). Rock-scraping samples were collected at all sites and water-column samples at two sites.

Table 6.--River-water column and river-bottom rock-scraping counts of Nitrosomonas and Nitrobacter bacteria, Willamette River, August 7-8, 1978

[n.s., not sampled]

Sampling site (RM)	Location	Water column 1/ Nitrosomonas (MPN/mL)	Water column 1/ Nitrobacter (MPN/mL)	Rock scraping 2/ Nitrosomonas (MPN/in²)	Rock scraping 2/ Nitrobacter (MPN/in²)
134.3	Corvallis 3/	n.s.	n.s.	8,800	30,000
119.6	Albany	n.s.	n.s.	2,100	<25
107.9	Santiam River, 0.1 mi upstream	2	<2	6,100	<25
106.4	Buena Vista	2	2	290	25
85.9	Just upstream from Salem	n.s.	n.s.	3,900	25

1/ Most probable number (MPN) values were obtained using the 5-tube dilution method (Greeson and others, 1977) and "Standard Methods" (American Public Health Association and others, 1975, p. 924-925).

2/ Rock-scraping material was obtained by randomly selecting and scraping a 1-square-inch section from each of 10 bottom rocks in a sampling-site cross section. The scraped material was diluted to 125-mL volume with filtered (0.45 μm) river water from above Albany, subsampled, and incubated using the 5-tube method.

3/ Sample collected 1 week later.

Water-column Nitrosomonas and Nitrobacter concentrations were low (table 6), ranging from an MPN of <2 to 2 bacteria per milliliter. These data are consistent with findings in the same reach by Hines and others (1977). River-bottom rock-scraping Nitrosomonas concentrations ranged from an MPN of 290 to 8,800 bacteria per square inch, whereas Nitrobacter ranged from an MPN of <25 to 30,000 bacteria per square inch. Because of differences in methods of reporting concentrations (number/unit area versus number/unit weight), no direct comparisons of river-bottom rock-scraping data collected in 1978 and 1974 can be made.

The nitrifier data presented in table 6 give further evidence that nitrification was occurring in the sampled river segment. (See Tuffy and others, 1974, on the predominant occurrence of attached nitrifiers and nitrification in shallow, swift-flowing reaches versus the lack of occurrence of suspended nitrifiers and nitrification in deep, slow-moving river segments.)

Photosynthesis and Respiration

The 24-hour DO fluctuation caused by an aquatic community can be used as a measure of the community's metabolism or diel net oxygen production (Odum, 1956 and 1957). Stream DO fluctuations are a function of community photosynthesis and respiration, diffusion, and inflowing surface and ground water (Greeson and others, 1977). By knowing how these factors affect DO in a study area, an estimate of community metabolism can be computed. The computed community metabolism values represent the numerical differences between daytime net production (P) and nighttime respiration (R) after correcting for diffusion (Stephens and Jennings, 1976). Inability to separate plant respiration from total community respiration causes the computed community metabolism (P-R) to reflect both natural and man-induced oxygen-demanding processes.

Tables 7 and 8 show the effects of solar radiation and various oxygen-demanding processes on community metabolism. Also listed in the tables is a community trophic indicator (P/R). A P/R ratio of less than 1 implies that organic compounds are being degraded through oxygen metabolism faster than carbon is being fixed through photosynthesis (Greeson and others, 1977). Therefore, a P/R ratio of less than 1 indicates a net loss of oxygen at a river site. A P/R greater than 1 indicates that oxygen production through photosynthesis is going at a faster rate than oxygen losses by respiration.

The community metabolism data summarized in tables 7 and 8 have nominal interpretive value because of assumptions made in computation; therefore, only data trends are analyzed in the following discussion.

River P-R (tables 7, 8) shows that 24-hour oxygen deficits (negative values) occur at most sampling sites. Mass balancing and flow routing of $CBOD_{ult}$ and NBOD loads suggest that most of the 24-hour oxygen deficit is due to bacterial oxidation of point-source waste materials. The pattern of variation in P-R along the length of the Willamette River leads to the same conclusion. P-R values between RM 161.2 and 119.6 decrease, whereas P-R values at RM 108 increased and in one case was positive. P-R values at the

Table 7.--Daily solar radiation, community metabolism, and trophic indicator of the aquatic community in the Willamette River, August 7-11, 1978

Sampling site (RM)	Date[1/]	Daily solar radiation[2/] [(calories/cm^2)/d]	Community metabolism (P-R)[3/] [(g-O_2/m^2)/d]	Community trophic indicator (P/R)[3/]
161.2	8/7-8	588	-0.92	0.73
	8/8-9	618	-.93	.73
134.3	8/7-8	588	-.42	.80
	8/8-9	618	-.38	.80
	8/9-10	593	-.72	.56
	8/10-11	532	-1.51	.28
119.6	8/9-10	593	-1.27	.12
	8/10-11	532	-1.31	.13
108.0	8/9-10	593	-1.01	.18
	8/10-11	532	-.89	.06
85.9	8/9-10	593	+.30	1.20
	8/10-11	532	-.40	.76

1/ An 1800-1800 diel time period (overlapping days) was selected to calculate daily solar radiation and community metabolism values.

2/ Daily solar radiation values were obtained by summarizing average hourly Elnick strip-chart recorder readings of an R413 Star Pyranometer attached to a Martek Mark II multiparameter water-quality monitor. Solar-radiation data were collected only at the Corvallis site (RM 134.3) and were considered representative of sunlight intensity for the study area.

3/ Daytime net oxygen production (P), nighttime oxygen respiration (R), 24-hour community metabolism (P-R), and community trophic indicator (P/R) were computed using the Fortran program developed by Stephens and Jennings (1976).

Table 8.--Daily solar radiation, community metabolism, and trophic indicator of the aquatic community in the Willamette River, August 28-September 1, 1978

Sampling site (RM)	Date 1/	Daily solar radiation 2/ [(calories/cm^2)/d]	Community metabolism (P-R) 3/ [(g-O_2/m^2)/d]	Community trophic indicator (P/R) 3/
161.2	8/28-29	549	-1.00	0.61
	8/29-30	270	-1.89	.41
134.3	8/28-29	549	-1.03	.37
	8/29-30	270	-1.52	.13
	8/30-31	192	-2.04	4/ -.13
	8/31-9/1	415	-1.01	.30
119.6	8/30-31	192	-1.43	4/ -.26
	8/31-9/1	415	-.57	.09
108.0	8/30-31	192	-.35	.48
	8/31-9/1	415	1.17	4.52
85.4	8/30-31	192	-1.71	4/ -.20
	8/31-9/1	415	-.52	.17

1/ An 1800-1800 diel time period (overlapping days) was selected to calculate daily solar radiation and community metabolism values.

2/ Daily solar radiation values were obtained by summarizing average hourly Elnick strip chart recorder readings of an R413 Star Pyranometer attached to a Martek Mark II multiparameter water-quality monitor. Solar-radiation data were collected only at the Corvallis site (RM 134.3) and were considered representative of sunlight intensity for the study area.

3/ Daytime net oxygen production (P), nighttime oxygen respiration (R), 24-hour community metabolism (P-R), and community trophic indicator (P/R) were computed using the Fortran program developed by Stephens and Jennings (1976).

4/ A negative P/R ratio indicates that a negative daytime oxygen production (P) occurred.

Salem site showed mixed results. In general, the larger negative P-R values are indicative of those river segments receiving greater oxygen-demanding wastes. The smaller negative or positive P-R values represent those river segments receiving lesser amounts of the oxygen-demanding wastes or represent recovery zones. This same trend can be seen in the P/R ratios and in figures 11 and 12, where DO concentrations for the two 1978 Willamette surveys are plotted. (See section titled "Dissolved-Oxygen Profiles," p. 31.)

An attempt was also made to examine the effects of daily solar radiation on P-R. Several observations were made, as follows:

1. At each sampling site there seems to be a direct relationship between daily solar radiation and the P-R and P/R values. In general, increasing daily solar radiation increased the photosynthesis rate which, in turn, affected the river community metabolism.

2. Data for both Willamette surveys were grouped together according to sampling sites, and correlations between daily solar radiation and P/R values were computed. Excellent correlation coefficients of 0.97, 0.89, 0.95, and 0.95 were obtained, respectively, for RM's 161.2, 134.3, 119.6, and Salem. Data from RM 108 showed direct trends during each survey, but gave a poor correlation when both surveys were combined.

Dissolved-Oxygen Profiles

Figures 11 and 12 show average DO concentrations and ranges for each sampling site during the two 1978 Willamette surveys. Average values represent mean 24-hour DO concentrations as measured during each survey at midflow and 0.6 of maximum depth.

Between RM's 195 and 120, average DO concentrations were lower during the second survey than during the first. This observation seems to be contrary to the following information; namely, that (1) during the two surveys, $CBOD_{ult}$ and NBOD loadings were not significantly different and (2) during the second survey there was (a) shorter detention time, (b) lower water temperatures, and (c) greater atmospheric reaeration. By examining the maximum-minimum DO concentrations during both surveys, it was determined that during the first survey (fig. 11), (1) maximum DO concentrations between RM's 195 and 120 were 4 percent higher and minimum concentrations were 2 percent lower than comparable sampling-site values in the later survey (fig. 12), and (2) daily solar radiation was considerably higher. This suggests that photosynthesis was the driving force causing greater diel DO fluctuations and also higher average DO concentrations during the first Willamette survey. A comparison of P-R data from both surveys (tables 7, 8) further substantiates this conclusion. During the first survey, P-R data were more positive (lower negative numbers) than during the second survey, indicating less oxygen loss through community metabolism.

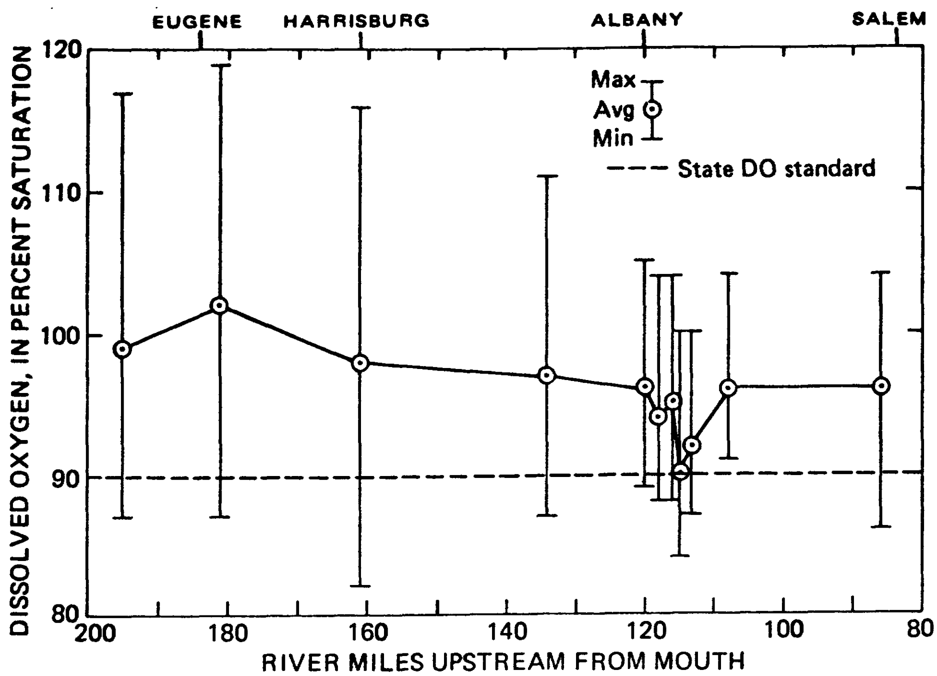

FIGURE 11. – Observed dissolved-oxygen concentration in the upper Willamette River, August 7-11, 1978.

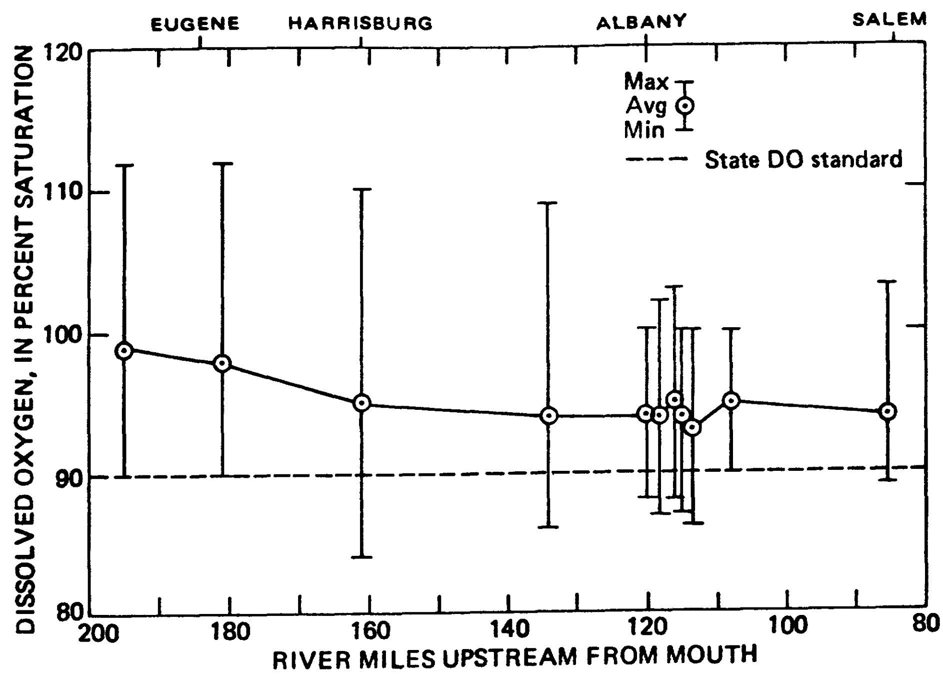

FIGURE 12. – Observed dissolved-oxygen concentration in the upper Willamette River, August 28-September 1, 1978.

Between RM's 120 and 108, different forces seem to be driving the DO regimen. Both figures 11 and 12 show DO sags occurring in this river segment. A greater DO sag occurs during the first survey under conditions of lower riverflow and higher temperature (fig. 11). The predominant influence causing the observed DO sag in this reach is bacterial oxidation of wastes from point sources. It should also be noted that the river makes a quick recovery by RM 108, where DO levels are equivalent to those at the upper end of the reach.

Average DO levels in both surveys showed little change between RM 108 and the site above Salem, indicating that community metabolism and reaeration balanced each other.

Estimated DO-Load Losses

The $CBOD_{ult}$ and NBOD materials in the water serve as a food supply for a complex chain of biological life. These materials are biologically oxidized, providing food energy, but in the process consume DO from the water column. Because the quantity of these materials and the rates at which they are biologically oxidized have been determined for the Willamette River between RM's 195 and 85.4, an estimate of the DO load loss from the river can be made (table 9).

As shown in table 9, NBOD was by far the largest cause of DO loss to the upper Willamette River. Nitrification contributed to more than 60 percent of the observed DO sag during both surveys. Also, for the two surveys, point-source $CBOD_{ult}$ and NBOD loads accounted for approximately 64 percent of the total oxygen demand, whereas nonpoint $CBOD_{ult}$ and NBOD loads accounted for the remaining 36 percent.

Summary and Conclusions

1. Willamette River 1978 $CBOD_{ult}$ concentrations were compared with those of the 1973-74 survey. In 1978, concentrations of $CBOD_{ult}$ averaged 30 percent lower than those observed in 1973-74. However, 1978 CBOD bottle deoxygenation rates averaged from 50 to 100 percent higher than those observed in 1973-74. The higher k_1 bottle rates are probably the result of other biological processes in the bottle rather than normal carbonaceous deoxygenation.

2. During the 1978 studies, $CBOD_{ult}$ loading to the river was 83 percent of that measured during the 1974 studies. Point-source $CBOD_{ult}$ loadings in 1978 averaged 39,000 lb/d, whereas in 1974 they averaged 36,800 lb/d. Overall, point-source $CBOD_{ult}$ loadings and bottle deoxygenation rates seemed to have changed little since 1974. However, there was a decrease in nonpoint-source loading of $CBOD_{ult}$ from 65,600 lb/d to about 46,000 lb/d.

3. The mass balancing and flow routing of $CBOD_{ult}$ loads from the confluence of the Middle and Coast Fork Willamette Rivers to Salem have shown good to excellent agreement between computed and observed river $CBOD_{ult}$

Table 9.--Summary of point and nonpoint DO losses to the upper Willamette River (Eugene to Salem) during 1978 summer low-flow conditions

[DO losses rounded to the nearest 100 lb/d]

Sampling schedule	Cause of oxygen demand	CBOD		NBOD		Total oxygen demand	
		(lb/d O_2)	Percent of O_2 consumed	(lb/d O_2)	Percent of O_2 consumed	(lb/d O_2)	Percent of O_2 consumed
Aug. 7-11	Point sources	5,800	17	16,200	46	22,000	63
	Nonpoint sources	7,300	21	5,600	16	12,900	37
	Total	13,100	38	21,800	62	34,900	100
Aug. 28-Sept. 1	Point sources	4,400	16	13,900	50	18,300	66
	Nonpoint sources	6,100	22	3,500	12	9,600	34
	Total	10,500	38	17,400	62	27,900	100

concentrations. A k_r rate of 0.04 d^{-1} ($\log_{10}$, adjusted to 20°C) fit the August 7-11, 1978, survey data best, and was determined to be quite reliable in predicting river $CBOD_{ult}$ concentrations under the different river conditions observed during August 28-September 1, 1978.

4. Nitrification occurred between RM 187 and Salem during the 1978 low-flow period and contributed significantly to the observed DO deficit (table 9). More than 60 percent of the DO sag measured in the river originated from NBOD sources.

5. A nitrification rate (k_n) of 0.4 d^{-1} ($\log_{10}$, adjusted to 20°C) provided the best fit to the 1978 nitrogen data. Using the computed k_n of 0.4 d^{-1}, excellent agreement resulted between calculated and measured NBOD loads during the August 7-11 survey. Except at the most downstream river site, application of the same k_n rate to the second survey showed a good comparison.

6. The DO regimens between RM 195 and Salem (figs. 11, 12) indicate that photosynthesis and the atmospheric reaeration rate do not counter-balance carbonaceous and nitrogenous deoxygenation in parts of this reach. Although mean 24-hour DO levels were above the State standard of 90 percent of saturation, all but one sampling site were at or below the standard for some part of a day (generally the early morning hours).

7. Although DO modeling was not considered (average 24-hour DO concentrations were above the 90 percent of saturation), the mass balancing-flow routing of $CBOD_{ult}$ and NBOD downstream provided an estimate of the point- and nonpoint-source oxygen demands (table 9). For the two surveys, point-source $CBOD_{ult}$ and NBOD loads accounted for about 64 percent of the oxygen demand, whereas nonpoint $CBOD_{ult}$ and NBOD loads accounted for the remaining 36 percent.

SOUTH SANTIAM AND SANTIAM RIVER DISSOLVED-OXYGEN STUDY

An intensive sampling of the lower Santiam River basin was done during July 23-28, 1978. (See section titled "Methods and Procedures" for description of sampling-site schedule and locations for the Santiam survey.) Unfortunately, between July 25-27, the Corps of Engineers abruptly increased the flow of the North Santiam River by 1,100 ft^3/s by releasing water from Big Cliff, a reregulating reservoir. (Augmentation was done to promote fish migration in downstream areas.) As a result, the Santiam River flow increased by nearly 50 percent and exceeded our criteria for steady-state conditions, which require that flow should not fluctuate by more than 10 percent just prior to and during data collection. Because intensive data collection at all main-stem South Santiam and Santiam River sites was done on July 27 and 28, data from the North Santiam River and at RM's 6.4 and 0.1 on the Santiam River were affected by the increase in flow and were therefore not interpreted.

The following results and discussion center mainly on data collected in the South Santiam River (RM's 23.4 to 0.1), where steady-state conditions prevailed.

$CBOD_{ult}$ Concentrations and k_1 Rates

Table 10 shows the in-river $CBOD_{ult}$ concentrations measured during the July 23-28, 1978, survey for the three systems, the Santiam, North Santiam, and South Santiam Rivers. During that survey, average flow at the reference gage (Waterloo, RM 23.3) for the South Santiam was 710 ft^3/s. Measured $CBOD_{ult}$ and k_1 values were similar to those measured during the two 1978 Willamette River surveys. $CBOD_{ult}$ concentrations in the South Santiam River ranged from 1.2 to 2.7 mg/L, and k_1 rates ranged from 0.04 to 0.12 d^{-1}, with more than 75 percent between 0.06 and 0.08 d^{-1}.

Calculated $CBOD_{ult}$ Loads

South Santiam River $CBOD_{ult}$ loading during the July 23-28, 1978, summer low-flow period averaged 9,000 lb/d (table 11). Point sources contributed approximately 22 percent of the total $CBOD_{ult}$ loading and nonpoint sources the remaining 78 percent. Table 12 summarizes $CBOD_{ult}$ and NBOD loading to the South Santiam River during the sampling period.

Table 10.--$CBOD_{ult}$ concentrations and CBOD bottle deoxygenation rates (k_1) for Santiam River basin water, July 23-28, 1978

Sampling site (stream and RM)	Number of samples	Mean $CBOD_{ult}$ concentration[1/] (mg/L)	$CBOD_{ult}$ concentration range (mg/L)	Average k_1 (d^{-1})
South Santiam River				
23.4	11	1.6	1.2-2.0	0.08
13.95	8	2.4	2.0-2.7	.06
7.6	8	2.2	1.9-2.4	.06
0.1	7	2.3	2.1-2.6	.06
North Santiam River				
2.9	3	1.7	1.4-1.8	.08
Santiam River				
6.4	4	2.4	2.2-2.7	.10
0.1	4	2.2	2.0-2.5	.10

1/ Mean $CBOD_{ult}$ concentration at each sampling site was calculated using the ogee summation curve method (Velz, 1970, Appendix A).

Table 11.--Summary of the characteristics of waste-water outfalls and tributaries to the South Santiam River, July 23-28, 1978

Location (RM)	Description	Average flow (ft^3/s)	Average temperature (°C)	Average DO (percent saturation)	Mean $CBOD_{ult}$ concentration (mg/L)	Average $CBOD_{ult}$ load (lb/d)	Average NH_4-N concentration (mg/L)	Average NBOD load (lb/d)
23.4	South Santiam River near Waterloo	710	14.8	101	1.6	6,100	0.07	1,200
17.4	Lebanon STP	2.0	18.4	35	48	520	9.87	460
16.5	Mark Slough	6.4	24.3	37	44	1,500	67.1	10,000
4.3	Crabtree Creek	41	22.0	100	2.2	480	.07	70
3.0	Thomas Creek	28	21.5	102	2.6	390	.20	130
					Total	9,000		12,000

Table 12.--Summary of point- and nonpoint-source loadings of $CBOD_{ult}$ and NBOD to the South Santiam River, July 23-28, 1978

Type of loading	$CBOD_{ult}$ load			NBOD load			Total BOD loading ($CBOD_{ult}$ + NBOD)	
	lb/d	Percent load by type	Percent of total BOD load	lb/d	Percent load by type	Percent of total BOD load	lb/d	Percent load by type
Point sources	2,000	22	10	10,500	88	50	12,500	60
Nonpoint sources	7,000	78	33	1,500	12	7	8,500	40
Total	9,000	100	43	12,000	100	57	21,000	100

Point-Source $CBOD_{ult}$ Loads

South Santiam River point-source $CBOD_{ult}$ loading during summer 1978 averaged 2,000 lb/d. Two major waste-water sources are located along the South Santiam River; namely, (1) Lebanon STP at RM 17.4 and (2) Crown Zellerbach Corporation at RM 16.5. Crown Zellerbach, which was not in full operation during sampling (oral communs., Larry Patterson, Oregon Department of Environmental Quality, 1979), accounted for 74 percent of this load, whereas the remaining 26 percent came from the municipal outfall.

Point-source $CBOD_{ult}$ bottle deoxygenation rates (k_1) ranged from 0.04 to 0.10 d^{-1}, with more than 80 percent at 0.06 d^{-1}. These k_1 rates are typical of those that have been measured previously for other point sources in the Willamette River basin.

Nonpoint-Source $CBOD_{ult}$ Loads

Nonpoint-source loads to the South Santiam River amounted to 7,000 lb/d during the 1978 survey. More than 87 percent of the total nonpoint-source load is attributed to background $CBOD_{ult}$ materials entering the river above Waterloo.

Background $CBOD_{ult}$ concentrations at the Waterloo site were low, ranging from 1.2 to 2.0 mg/L. South Santiam River background $CBOD_{ult}$ concentrations were comparable to background $CBOD_{ult}$ values measured during the two 1978 Willamette surveys. Carbonaceous BOD bottle deoxygenation rates from nonpoint sources ranged from 0.04 to 0.10 d^{-1}, with more than 70 percent ranging from 0.06 to 0.08 d^{-1}.

Mass Balancing and Flow Routing of $CBOD_{ult}$ Loads

Figure 13 graphically summarizes the mass balance-flow routing of $CBOD_{ult}$ loads on the South Santiam River at the prevailing time of passage and temperature. (See supplement A for details on the technique.) Figure 13 illustrates the calibration conditions used to define the in-river k_r rate. Because only one set of data was collected, an independent verification by a second set has not been possible. However, the in-river k_r calibration rate of 0.04 d^{-1} (log_{10}, adjusted to 20°C) was identical to that developed for the Willamette.

At RM 20.8 above Lebanon on the South Santiam, river water is diverted through a canal for hydroelectric generation and municipal water use for the city of Albany (personal commun., Gene McKinnis, Oregon Watermaster, Eugene District, 1980). Part of the water diverted for Albany flows back into the South Santiam River via Marks Slough (RM 16.5). The diversion is ungaged, so only estimates of the volume of water actually diverted were made. During the Santiam survey, an estimated 100 ft^3/s, or about 14 percent, of the South Santiam River flow was diverted. This means that along with the water, about 14 percent of the $CBOD_{ult}$, NBOD, and DO loads at RM 20.8 were also diverted from the river. The potential error in estimating the volume of water removed by the ungaged diversion makes accuracy of downstream $CBOD_{ult}$

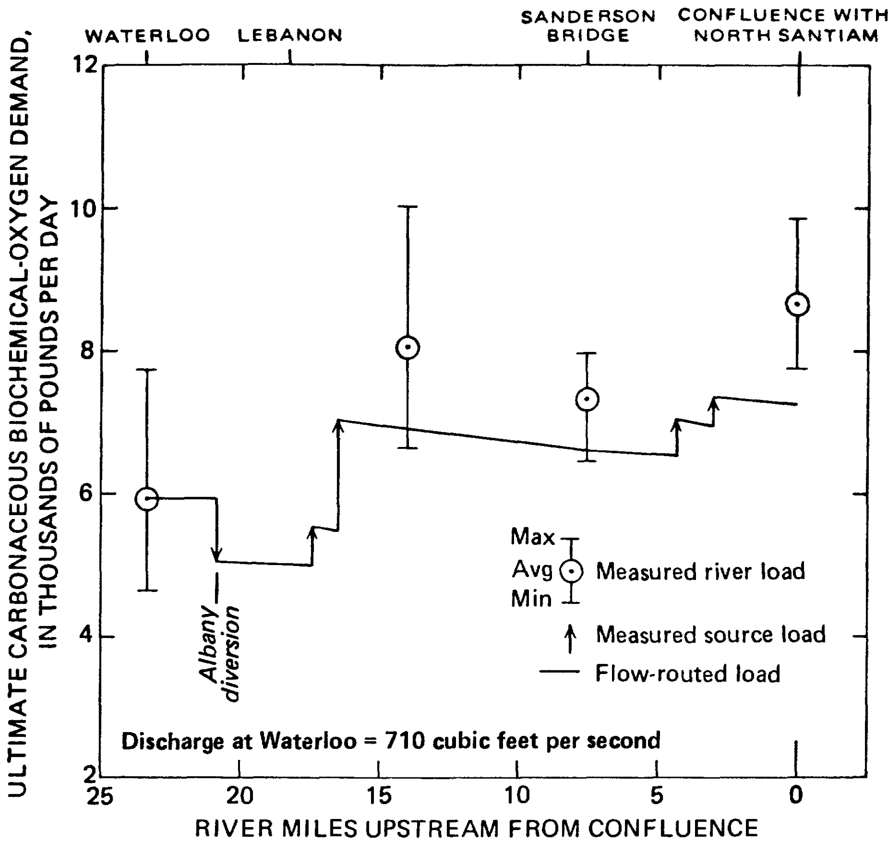

FIGURE 13. – Measured and flow-routed $CBOD_{ult}$ loads in the South Santiam River, July 23-28, 1978. Carbonaceous deoxygenation rate (k_r) was 0.04 d^{-1} at 20°C.

loads uncertain. Therefore, considering this uncertainty in streamflow and analytical measurement of $CBOD_{ult}$ values ($\pm$20 percent error at a concentration less than 4 to 5 mg/L), there is fair agreement between the computed and observed river $CBOD_{ult}$ loads (fig. 13).

Nitrification

Analysis of nutrient, nitrifying bacteria, and DO data from the 1978 Santiam survey show that nitrification was occurring in the South Santiam River below Waterloo. In fact, calculations indicate that nitrification in the South Santiam River accounted for about 60 percent of the total DO-load loss from the river. (See table 15 in section titled "Summary and Conclusions," p. 47.)

Nitrogen Concentrations

Average concentrations of NH_4-N, NO_3-N, NO_2-N, and total-N for the 1978 Santiam survey are shown in figure 14. The two major sources of NH_4-N to the Santiam River are the Lebanon STP at RM 17.4 and Mark Slough (containing Crown Zellerbach effluent) at RM 16.5. The increases in concentration of all nitrogen species between RM's 23.4 and 13.95 are consistent with the locations

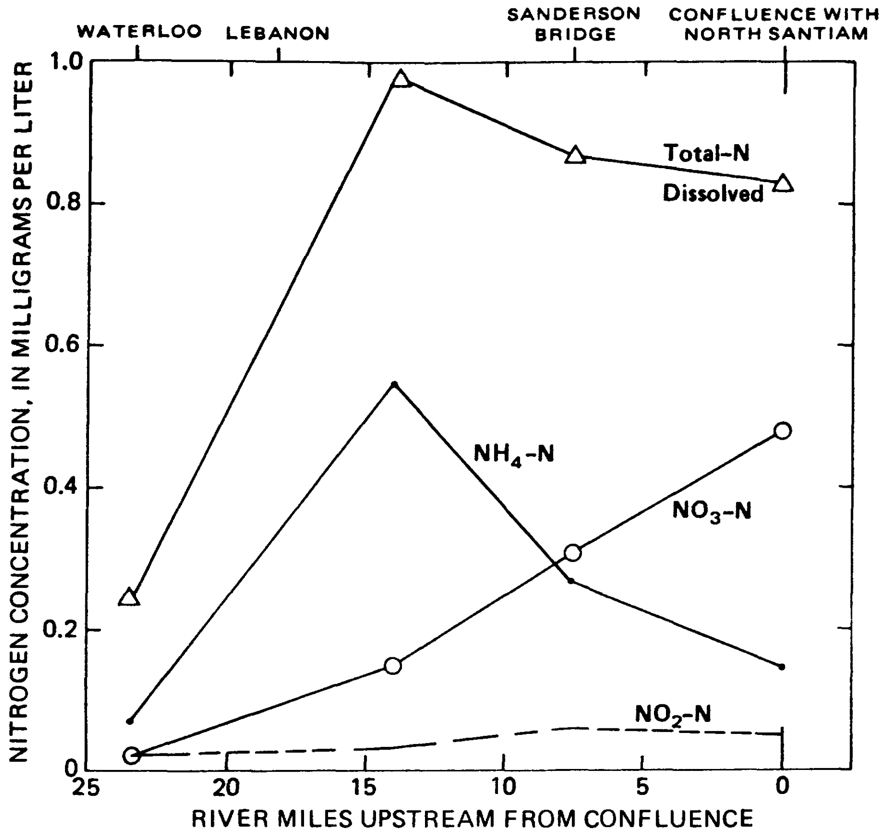

FIGURE 14. – Dissolved nitrogen-species concentrations observed in the South Santiam River, July 27-28, 1978.

of the two point sources. The two sources directly account for the increase of NH_4-N and total-N at RM 13.95. The increased levels of NO_3-N and possibly NO_2-N at RM 13.95 were the result of nitrification. Nitrification also accounts for the increased levels of NO_3-N and NO_2-N downstream to RM 0.1.

Calculated NBOD Loads

Total ammonia loading to the South Santiam River, expressed as NBOD, was approximately 12,000 lb/d (table 11). As shown in table 12, about 88 percent of the total NBOD load entering the river during the low-flow season came from municipal and industrial waste-water discharges, with the remaining 12 percent from nonpoint sources.

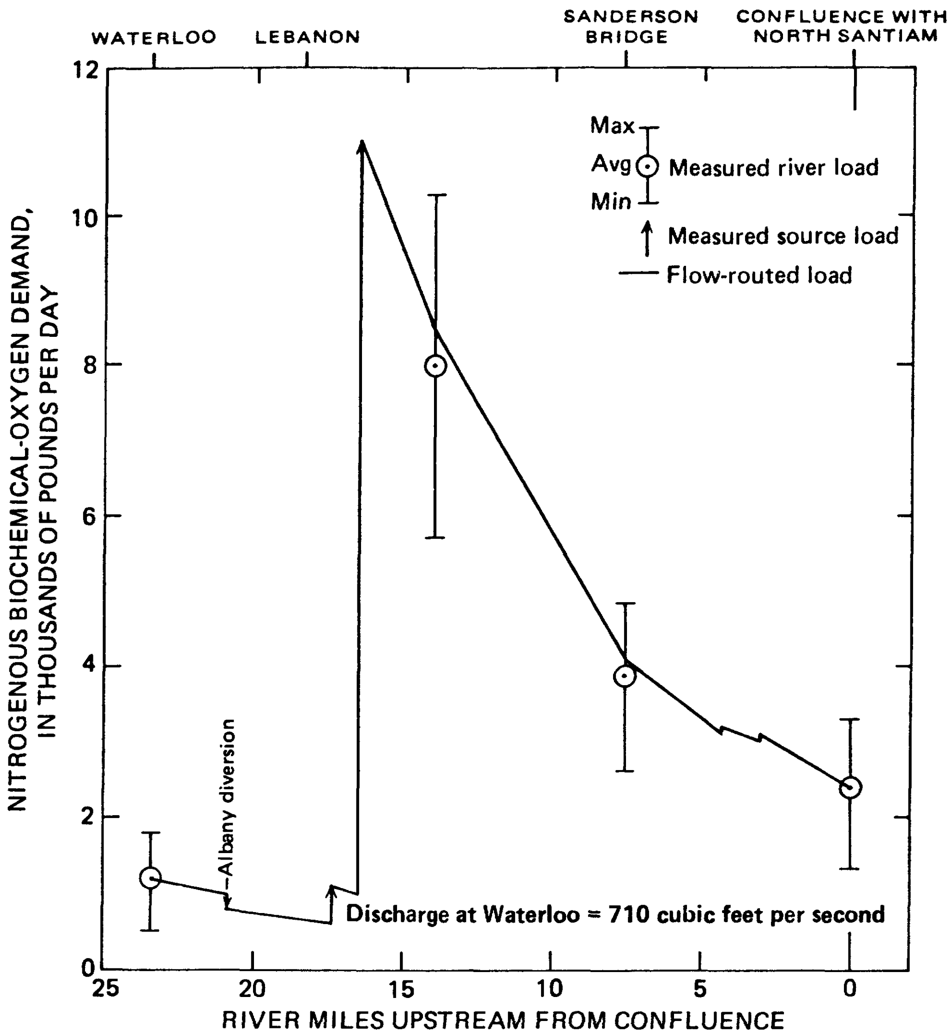

FIGURE 15. – Measured and flow-routed NBOD loads in the South Santiam River, July 23-28, 1978. Nitrogenous deoxygenation rate (k_n) was 0.7 d^{-1} at 20°C.

Mass Balancing and Flow Routing of NBOD Loads

On the basis of 1978 measured point- and nonpoint-source NBOD loads and river concentrations of NH_4-N (ranging from 0.03 to 0.71 mg/L), a k_n rate of 0.7 d^{-1} (adjusted to 20°C) was adopted. Application of this rate (adjusted by 4.7 percent per degree, the river temperature differed from 20°C) discloses a remarkable agreement between the computed NBOD profile and the observed profile based on the measured in-river NBOD loads (fig. 15). This k_n rate (0.7 d^{-1}) is associated with the introduction of a large ammonia load at RM 16.5. Similar conditions were experienced during 1973-74 on the Willamette below Salem, which also resulted in a high k_n rate of 0.7 d^{-1}.

Nitrifying Bacteria

River-water column and river-bottom rock-scraping samples were collected and analyzed for Nitrosomonas and Nitrobacter bacteria during the Santiam River survey (table 13). Four sampling sites were selected on the South Santiam River and one on the main stem Santiam. Rock-scraping samples were collected at all sites, and water-column samples were collected at two sites.

Water-column Nitrosomonas and Nitrobacter concentrations in the flowing stream ranged from an MPN of 1.7 to 200 bacteria per milliliter. These concentrations were higher than those observed during the 1978 upper Willamette survey. Rock-scraping Nitrosomonas concentrations ranged from an MPN of 4,400 to 31,000 bacteria per square inch, whereas Nitrobacter concentrations ranged from 5,800 to 2,000,000. These rock-scraping bacteria levels are also much higher than those observed in the Willamette. At RM 23.4, an anomalously high rock-scraping Nitrobacter concentration was observed, although no significant river concentrations of ammonia were measured. The cause of this anomaly is unknown at this time.

Table 13.--River-water column and river-bottom rock-scraping counts of Nitrosomonas and Nitrobacter bacteria, Santiam River basin, July 24-26, 1978

[n.s., not sampled]

Sampling site (stream and RM)	Water column 1/		Rock scraping 2/	
	Nitrosomonas (MPN/mL)	Nitrobacter (MPN/mL	Nitrosomonas (MPN/in^2)	Nitrobacter (MPN/in^2)
South Santiam River				
23.4	n.s.	n.s.	8,800	2,000,000
13.95	200	9.4	31,000	680,000
7.6	1.7	9.4	4,400	≥30,000
0.1	n.s.	n.s.	21,000	5,800
Santiam River				
6.4	n.s.	n.s.	9,900	12,500

1/ Most probable number (MPN) values were obtained using the 5-tube dilution method (Greeson and others, 1977) and "Standard Methods" (American Public Health Association and others, 1975, p. 924-925).

2/ Rock-scraping materials were obtained by randomly selecting and scraping a 1-square-inch section from each of 10 bottom rocks in a sampling-site cross section. The scraped material was diluted to 125-mL volume with filtered (0.45 μm) river water from Waterloo (RM 23.4), subsampled, and incubated using the 5-tube method.

Higher NH_4-N concentrations were observed during the Santiam survey (0.03 to 0.71 mg/L) than during the Willamette River surveys (0.03-0.13 mg/L). Higher nitrifier populations in the South Santiam are consistent with a larger energy source (NH_4-N for growth and reproduction).

The presence and quantity of these nitrifiers give further evidence that nitrification was occurring during the South Santiam River low-flow survey. Further, these findings and those of the 1973-74 lower Willamette survey support the concept that bed-contact opportunity and concentration of NH_4-N are controlling factors involved in nitrification.

Photosynthesis and Respiration

Table 14 summarizes the community metabolism data obtained from the South Santiam survey. At RM 23.4, the two P-R values were positive, indicating that O_2 production was occurring more rapidly than respiration. At RM 13.95,

Table 14.--Daily solar radiation, community metabolism, and trophic indicator of the aquatic community in the South Santiam River, July 27-28, 1978

Sampling site (RM)	Date[1/] (July 1978)	Daily solar radiation[2/] [(calories/cm^2)/d]	Community metabolism (P-R)[3/] [(g/O_2/m^2)/d]	Community trophic indicator (P/R)[3/]
23.4	27	424	+0.60	9.00
	28	401	+.40	4.20
13.95	27	424	+.87	1.60
	28	401	-.79	.77
7.6	27	424	-1.25	.63
	28	401	-1.59	.37
0.1	27	424	-.77	.66
	28	401	-.69	.63

1/ A 2400-2400 diel time period was used to calculate daily solar radiation and community metabolism values.

2/ Daily solar radiation values were obtained by summarizing average hourly Elnick strip-chart recorder readings of an R413 Star Pyranometer attached to a Martek Mark II multiparameter water-quality monitor. Solar-radiation data were collected only at RM 7.6 and were considered representative of sunlight intensity for the study area.

3/ Daytime net oxygen production (P), nighttime oxygen respiration (R), 24-hour community metabolism (P-R), and community trophic indicator (P/R) were computed using the Fortran program developed by Stephens and Jennings (1976).

the two P-R values averaged about zero. At RM 7.6, the P-R values were quite negative, whereas at RM 0.1, the values were negative but less negative than at RM 7.6.

Results of the mass balancing-flow routing of $CBOD_{ult}$ and NBOD loads down the South Santiam River suggest that the negative P-R values were due to bacterial oxidation of point-source materials. Point-source $CBOD_{ult}$ and NBOD loads between RM's 23.4 and 13.95 depressed the P-R values observed at RM 13.95, and continued exertion of point-source loads caused the negative P-R values at RM 7.6. By RM 0.1, a major part of the point-source oxygen-demanding materials had been oxidized, and the river was showing signs of a DO recovery (P-R values less negative than at RM 7.6). This same trend can be noted by examining P/R ratios in table 14 and the river DO plot in figure 16.

The effect of daily solar radiation on P/R ratios in the South Santiam was similar to that observed for the Willamette River. As daily solar radiation increased, there was a corresponding increase in the P-R and P/R levels. This indicated that an increase in daily solar radiation increased photosynthesis, which in turn increased river community metabolism.

Dissolved-Oxygen Profile

Because it was not the intention at the time of the study to develop a DO model for the South Santiam River, reliance is placed on the 24-hour daily average observed DO profile (RM's 23.4 to 0.1) for the July 27-28, 1978, river survey (fig. 16). The river water arrived at the head of the reach (RM 23.4) fully saturated with DO. After receiving the major loadings of CBOD and NBOD between RM's 23.4 and 13.95, DO declined to 90 percent of saturation (the State standard) at RM 7.6 and remained at about 90 percent to RM 0.1. The 10-percent drop in percent saturation is equivalent to a 1.6-mg/L DO loss at the observed water temperatures.

As expected, photosynthesis and respiration caused variations in DO, as shown in figure 16. During daylight, DO at river-sampling locations attained saturation and supersaturation; during night hours, DO declined below the 24-hour average with minimum values of 85, 75, and 72 percent of saturation at RM's 13.95, 7.6, and 0.1, respectively. At RM 13.95, DO levels were below State standard for about one-fourth of the day (0300-0900), whereas at RM's 7.6 and 0.1, DO levels were below State standard for about half of the day (2300-1000).

Estimated DO-Load Losses

As pointed out earlier in this report, an estimate can be made of the DO loss to a water supply, if the quantity of $CBOD_{ult}$ and NBOD materials are known and the rates of biological oxidation have been determined. For the South Santiam River, this estimate is summarized in table 15. The format for table 15 differs slightly from that for table 9 (summary of DO losses to the upper Willamette River) in that table 15 contains an additional column showing DO removal by the Albany diversion. DO removed by the diversion represents an oxygen load removed from the river when the water was diverted.

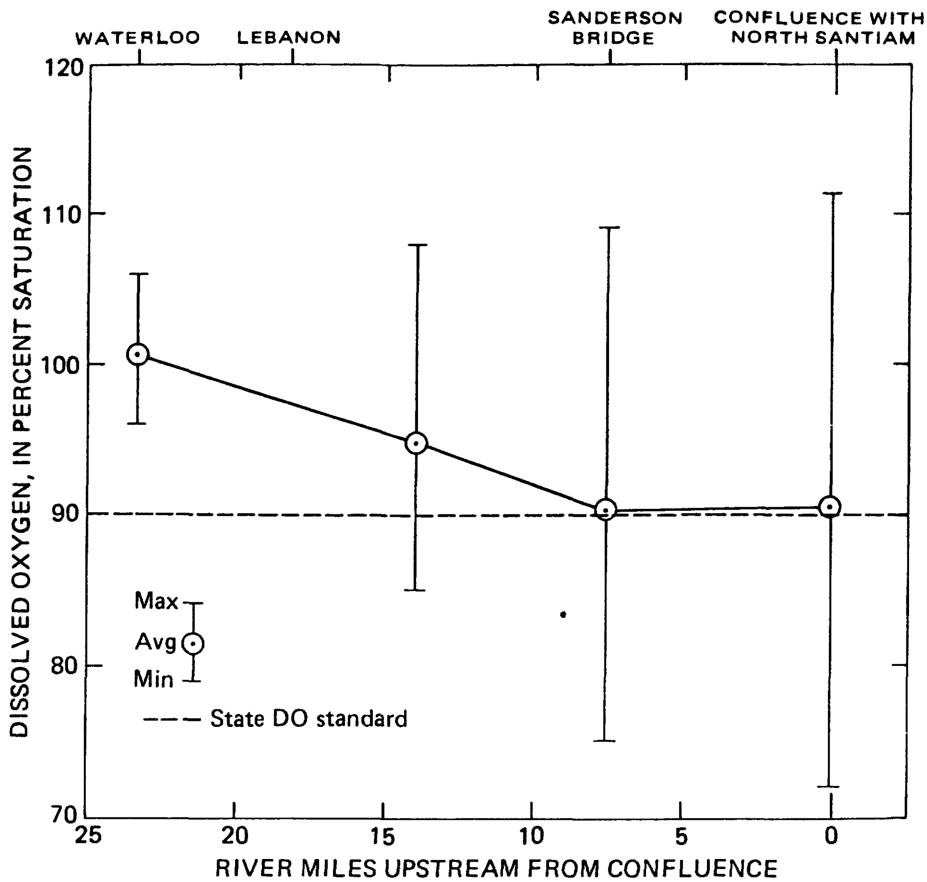

FIGURE 16. – Observed dissolved-oxygen concentrations in the South Santiam River, July 27-28, 1978.

This diverted water contains a quantity of oxygen potentially available for cleansing the river or further promoting biological life. If not diverted, this water would normally decrease water-detention time and increase atmospheric reaeration to the river.

As shown in table 15, NBOD was by far the largest cause of DO loss or removal from the river (60 percent). When considering only the total oxygen demand exerted in the river (ignoring DO load losses by the diversion), NBOD accounted for more than 92 percent of the DO losses. Approximately 35 percent of the oxygen loss or removal from the river was the Albany diversion.

Table 15.--Summary of point- and nonpoint-DO losses and DO removal by Albany water diversion to the South Santiam River, July 23-28, 1978

[DO losses rounded to the nearest 100 lb/d]

Cause of oxygen demand or loss	$CBOD_{ult}$		NBOD		Diversion		Total oxygen loss	
	lb/d O_2	Percent of O_2 consumed	lb/d O_2	Percent of O_2 consumed	lb/d O_2	Percent O_2 loss	lb/d O_2	Percent
Point sources	200	1	8,400	54	--	--	8,600	55
Nonpoint sources	600	4	900	6	--	--	1,500	10
Diversion	--	--	--	--	5,400	35	5,400	35
Total	800	5	9,300	60	5,400	35	15,500	100

Summary and Conclusions

Within the scope of the defined purposes of this study, the following conclusions are supported by the findings of the 1978 study of the South Santiam River below Waterloo.

1. The $CBOD_{ult}$ loading to the South Santiam is relatively low, totaling 9,000 lb/d, of which 6,100 lb/d is from nonpoint sources upstream from Waterloo. The rate of in-river satisfaction of $CBOD_{ult}$ load is also low, at k_r of 0.04 d^{-1}, identical with that for the upper Willamette River surveys.

2. NBOD is the dominant loading, totaling 12,000 lb/d, of which background upstream from Waterloo is only 1,200 lb/d. This dominant load is from one source, Mark Slough, which contributes 10,000 lb/d.

   The rate of satisfaction of the NBOD load is relatively high at k_n of 0.7 d^{-1} (20°C), which is equivalent to that of the lower Willamette River below Salem in the 1973-74 survey. The high k_n on the South Santiam is supported by extremely high concentrations of nitrifying organisms in the streambed. Mass balance-flow routing of the NBOD loads down the river at the prevailing streamflow and temperature disclosed a remarkably close agreement between the computed NBOD profile and that observed, based on river sampling.

   Application of the mass balance-flow routing technique to NBOD loads provides a reliable basis for determining three significant impacts: (a) the expected in-river NBOD along the river course at any location, (b) the residual unsatisfied NBOD loading at RM 0.1, and (c) the amount of DO loss to the river from nitrification.

3. Because it was not the intention during this study to develop a DO model for computation of reaeration and DO balance, emphasis was placed on the daily average DO observed during the July 27-28, 1978, survey. Daily average DO data disclose that the South Santiam arrives at Waterloo completely saturated with DO. The CBOD demand, and principally the NBOD demand, exerted along the river course reduces the daily average DO to 90 percent of saturation (the State standard) at RM 7.6, and remains at that level to RM 0.1.

4. Because of variations in streamflow in the North Santiam and the main stem of the Santiam, it is not possible to use the procedure employed on the South Santiam to determine the residual $CBOD_{ult}$ and NBOD contributions from the Santiam system to the Willamette (RM 107.9) at the confluence. However, the two 1978 surveys of the upper Willamette (table 3) disclose that at the normal expected summer low flow, such as that of the August 7-11 survey period, the streamflow from the Santiam system at the confluence with the Willamette was measured as 1,210 ft^3/s, with $CBOD_{ult}$ residual of 11,700 lb/d and NBOD residual of only 1,700 lb/d.

During the second Willamette survey, August 28-September 1, when streamflow was above normal, the Santiam system flow was 2,170 ft^3/s, and the residual load increased $CBOD_{ult}$ load to 19,900 lb/d and NBOD load to 3,500 lb/d.

Because under July 27-28 conditions, computed residual from the South Santiam at RM 0.1 was about 8,200 lb/d of $CBOD_{ult}$ and about 2,700 lb/d of NBOD, it is reasoned that little or no NBOD originates in either the North Santiam or in the main stem Santiam. Also, it would seem that $CBOD_{ult}$ from the entire Santiam system is derived primarily from nonpoint sources.

5. As this study represented reconnaissance work to define the relative impact of individual $CBOD_{ult}$ and NBOD loads on river DO, no mass balancing of river DO was attempted. Therefore, the impact on river DO of variable point-source $CBOD_{ult}$ and NBOD loads, possible extremes in summer low flow, and high river temperatures cannot be predicted at this time. Steady-state summer DO modeling of the South Santiam River is needed to define the impact of each of these stresses on the river's DO regimen. Results of the model would provide a predictive tool for use by decisionmakers in examining the impacts of proposed planned alternatives.

ALGAL POPULATIONS IN THE WILLAMETTE RIVER AND SELECTED TRIBUTARIES

During August 1978, periphyton and phytoplankton samples were collected in a downstream traverse of the main stem Willamette River and selected tributaries. (See table 1 for site locations and tables 21-26 in supplement B for analyses of the algal populations.) Phytoplankton algal populations from 30 sampling sites in the Willamette River basin were analyzed for species identification and abundance; 12 of these sites were also selected for periphyton sampling. As defined in this report, phytoplankton are those algae that were suspended in the water column at the time of sampling. These algae include the true planktonic forms (organisms that drift passively with water currents) and those that were attached to or lived upon submerged surfaces and have sloughed off (true periphytes). Periphyton include those algae attached to or those on submerged surfaces at the time of sampling. These algae consist of the true periphytic organisms and those planktonic forms that have settled out.

The results of the algal analyses were used to assess biological water-quality conditions in the river at time of sampling and to compare phytoplankton types and concentrations with those collected in previous years (1963, 1973-74, 1976, and 1977). Because, for the most part, the periphyton data reflected the same results as the phytoplankton data, mainly phytoplankton data results are discussed in the following sections.

Species Identification and River Concentrations

Diatoms were observed to be the dominant group, in both numbers and types, with the most common genera being Melosira, Stephanodiscus, Cymbella, Achnanthes, and Nitzschia. The green alga, Ankistrodesmus, and blue-green alga, Oscillatoria, occurred in the main stem Willamette River, but were much less abundant than the diatoms. The highest concentrations of the green and blue-green algae were observed in the Santiam and McKenzie Rivers, respectively.

The number of periphyton genera and frequency of occurrence increased from the uppermost sampling site at Eugene (RM 185) to the most downstream sampling site at Salem (RM 86.5). Phytoplankton concentrations and diversity also generally increased downstream. Total suspended algal counts during the downstream traverse in the main stem Willamette River increased gradually from slightly less than 1,000 cells/mL at RM 185 to about 4,800 cells/mL at RM 78. Total suspended algal counts below RM 78 typically ranged from 3,000 to 4,000 cells/mL, but occasionally dropped below 3,000 cells/mL. Even when the greens and blue-greens were at their respective peaks on the main stems of the Willamette and Santiam Rivers, phytoplankton diatom populations persisted in appreciable numbers, normally comprising from 83 to 99 percent of the algal mass.

Eighty-six species of suspended algae were identified for the main stem Willamette River, whereas only 54 algal species were identified for the Santiam River. Forty-five algal species were determined to be common to both systems. Figures 17 and 18 provide summaries of the predominant suspended algal populations in the main stems of the Willamette and Santiam Rivers. Figure 17 presents selected algal data from 21 sites on the main stem Willamette, with additional data from sites on the McKenzie, Santiam, Tualatin, and Clackamas Rivers. Algal data presented in figure 18 include samples from four sites on the South Santiam River and two sites on the main stem Santiam. Algal-population data for RM 0.1 on the Santiam River are plotted on both figures because of sampling-site location overlap. During August 1978, the seven species in figure 17 represented between 24 to 60 percent of the total Willamette algal population observed, whereas the three species shown in figure 18 accounted for between 29 to 68 percent of the Santiam algal population.

Intensive longitudinal sampling in August 1978 (fig. 17) showed the true planktonic diatom Stephanodiscus hantzschii to be the predominant algae in the Willamette River tidal reach (downstream from RM 26.5). Swale (1964) described conditions resulting in a similar dominance in the phytoplankton of the English river, Lee. In Hertfordshire, the abundance of Stephanodiscus hantzschii showed a relationship with rainfall, riverflow, and length of day. Periods of low rainfall in the spring and autumn were important in enabling large populations to develop in slow-flowing, undisturbed water. Because Stephanodiscus hantzschii was not observed above RM 78, and only intermittently above RM 50, its appearance as more than 30 percent (1,200 cells/mL) of the total species counted in the lower harbor (RM's 12.8 and 7.0) was, at first, not anticipated. The increased abundance of this species in the lower, slower

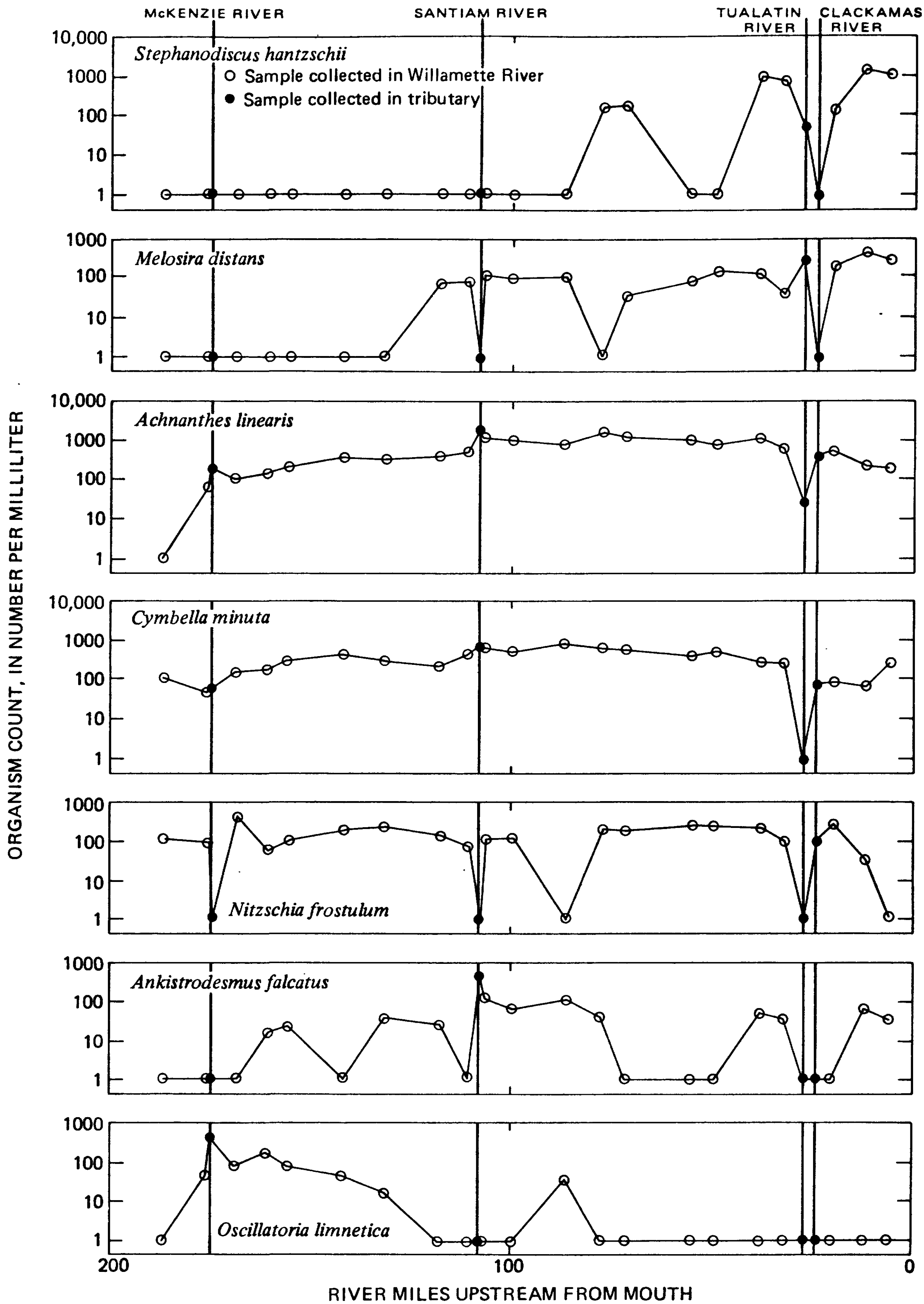

FIGURE 17. – Predominant phytoplanktonic diatoms, green alga, and blue-green alga in the Willamette River and selected tributaries, August 7-8 and 16-17, 1978.

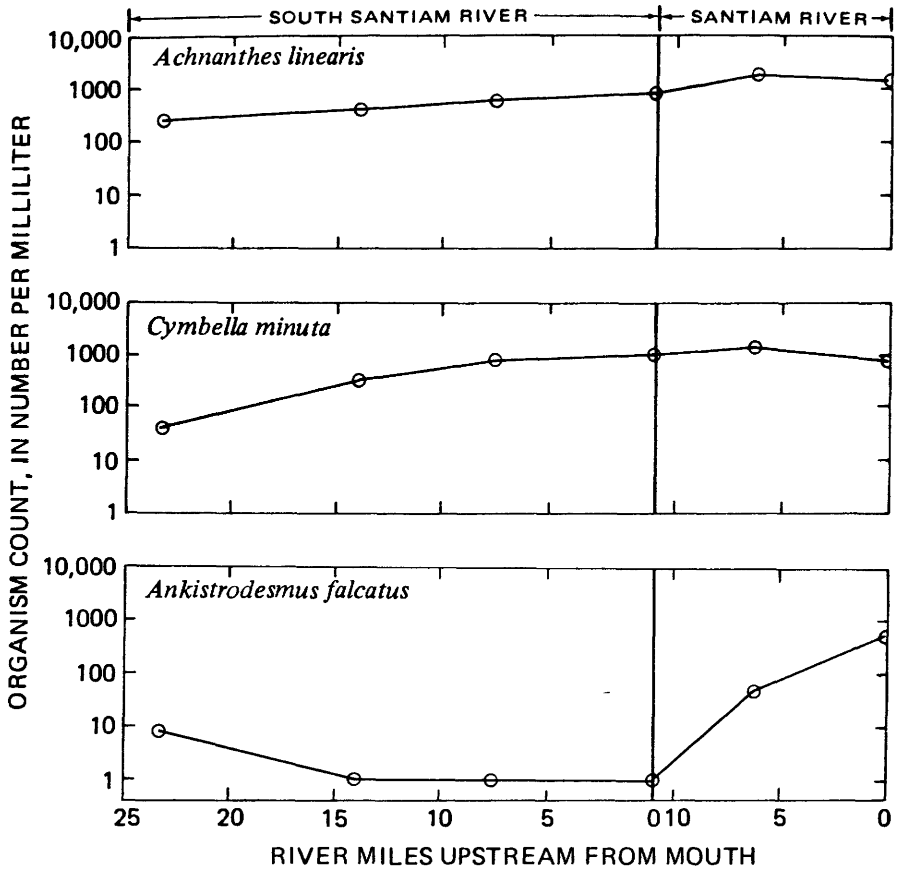

FIGURE 18. – Predominant phytoplanktonic diatoms and green alga in the South Santiam and Santiam Rivers, August 4, 1978.

moving reaches is, however, in character with its planktonic nature. The slowing of the current apparently provides lakelike conditions that are more conducive to algal reproduction and growth while effectively removing other more heavily frustulated species through settling. Stephanodiscus hantzschii was not observed in the periphyton samples.

Melosira distans was not observed above RM 118 in 1978, but maintained a stable enough population below this station to increase gradually to a maximum abundance in the tidal reach. This species is also planktonic in nature. Records for 1978 indicate that this species also enters the Willamette River from the Tualatin River (240 cells/mL). The presence of Melosira distans was not observed in the periphyton.

Only a few of the species observed in the lower reaches of the river can be regarded as true planktonic forms. These include Stephanodiscus hantzschii Melosira distans, and also Melosira granulata angustissima. Furthermore, the spatial distribution of these algae suggests that they were actively growing in the lower harbor rather than merely being derived from growth in the upstream reaches or reservoirs.

The periphytic alga Cymbella minuta (reported as Cymbella ventricosa by Rickert, Petersen, McKenzie, Hines, and Wille, 1977) maintained populations that accounted for more than 13 percent of the suspended plankton at the 16 upstream stations (RM's 185 to 50). Its presence, associated with Cymbella affinis, also accounted for high counts in the periphyton sampling of the upper river stations. Upon entering the Newberg Pool, the Cymbella minuta population decreased to only 5 percent of the total suspended algal community. Other commonly occurring periphytic diatom species that behaved similarly upon reaching the slower flowing waters of the Tidal Reach were Rhoicosphenia curvata, Achnanthes linearis, Cymbella affinis, and Cocconeis placentula. In general there was a greater abundance of periphytic algae in the suspended algal samples from above RM 50. This finding is consistent with the presence of extensive beds of periphyton attached to bottom rocks in the Willamette above RM 52.

Miscellaneous green and blue-green algae were observed to be sporadic along the entire length of the Willamette. The occurrence of the green alga, Ankistrodesmus falcatus, was notable, first appearing in small numbers at RM 161, disappearing below RM 78, and then reappearing farther downstream at RM 39. The patchy occurrence suggests algal sources from outside the main stem Willamette. Such an occurrence is consistent with the large numbers of the species counted in the Santiam River (RM 108). Downstream occurrence of these algae also may result from inflow from another tributary. The Yamhill (RM 55, not shown in fig. 17) and Tualatin Rivers have low flows, long detention times, and high temperatures, and are likely sources of this algae. It is also possible that algae such as Ankistrodesmus falcatus might enter the lower Willamette from adjacent oxbow lakes. The blue-green Oscillatoria probably is carried into the upstream reach of the Willamette River from tributary sources, as this species occurs consistently, but in small quantities, from RM's 169 to 132. A relatively large number of blue-green filaments were observed at the mouth of the McKenzie River (RM 175), and simple dilution would have reduced its abundance upon entering the Willamette.

Figures 17 and 18 also show comparisons of algal populations in the McKenzie, Santiam, Tualatin, and Clackamas Rivers to those observed in the main stem Willamette River. In the McKenzie River, the predominant diatom genera were Achnanthes, Nitzschia, and Fragilaria, with the associated species Achnanthes minutissima and Cocconeis placentula. Neither of the two latter species is uncommon to the Willamette, although Achnanthes minutissima occurs more sporadically. In the McKenzie River, the blue-green algae Oscillatoria was predominant over the plankton diatom species and constituted about 27 percent of the counted species. Blue-greens are generally considered to be indicative of eutrophic (highly enriched) waters. Because the McKenzie River is a relatively clean river, the introduction of blue-greens into the river is undoubtedly from the upstream reservoir system.

In the Santiam River survey, both the suspended and periphytic algal determinations indicated an overwhelming abundance of the periphytic species Achnanthes linearis and Cymbella minuta (fig. 18). The large number of Achnanthes linearis produced in the lower Santiam River probably accounts for its increased occurrence in the Willamette (fig. 17), where the number of algae increased from 480 to 1,050 cells/mL between RM's 111 and 107.

The Achnanthes linearis and Cymbella minuta species consistently accounted for more than 50 percent of the diatom frustules counted at the four downstream sampling locations in the Santiam River basin. Samples collected above and below the confluence of the South and North Santiam Rivers (RM 11.7) showed an increase in the green alga Ankistrodesmus downstream (fig. 18), which suggests that the North Santiam is the primary source of that alga. A yellow-brown algae, Dinobryon sertularia, was observed only at several sites of the South Santiam River (RM's 23.4, 7.6, and 0.1). Because of its delicate morphology, this colonial, flagellated planktonic form is normally associated with standing waters of lakes and ponds. Its presence in the South Santiam may reflect its existence in upstream reservoirs or, alternately, in sluggish stretches within this reach. Stephanodiscus hantzschii and Melosira distans, both commonly occurring in the Willamette River, were not observed in the Santiam River.

The Tualatin River at RM 28.4 was sampled in 1978 for phytoplankton only. A variety of green algae comprised about 44 percent of the total algal population. The planktonic species, Melosira distans, was the predominant diatom observed (9 percent). An increase in the concentration of Melosira distans (fig. 17) and total green algae (table 23) was noted in the Willamette River at RM 20.8; this increase was most likely due to the high concentration in the Tualatin River.

Compared to the other tributaries sampled, the Clackamas River contributed a relatively small amount to the total number of phytoplankton in the Willamette. The most abundant species observed were the periphytic Achnanthes linearis (27.3 percent), followed by Cymbella affinis and Cymbella minuta (8.4 and 6.3 percent, respectively).

Comparison with Historical Data

Table 16 shows a comparison of the abundance of diatoms, green algae, and blue-green algae in the lower Willamette River for the months of August in 1963, 1973, 1974, 1976 (U.S. Geological Survey Oregon District files), 1977 (personal communs., James Sweet, Portland State University, 1979), and 1978. The species data indicate no major differences between the planktonic assemblages in the Willamette River in 1978 and those from earlier years. (Differences in sampling and identification techniques could easily explain the lower numbers observed in 1963.) Algal analyses for all samples show that diatoms were the major component of the suspended algal population in the lower river. A Public Health Service report (U.S. Public Health Service, 1964) also noted that Stephanodiscus hantzschii was among the dominant spring and autumn diatoms. The 1973 and 1974 data show that Stephanodiscus hantzschii was among the dominant late spring and summer species in the lower Willamette (Rickert, Petersen, McKenzie, Hines, and Wille, 1977), as it was from 1976 to 1978.

Figure 19 shows the predominant abundance of diatoms, green algae, and blue-green algae in the Willamette River during 1974 (Rickert, Petersen, McKenzie, Hines, and Wille, 1977). Comparison of figure 17 with figure 19 indicates that the algal genera Stephanodiscus, Melosira, Achnanthes, and Cymbella were common to both surveys. Although not shown in figure 19, the algal genera Nitzschia was also present during the 1974 Willamette River survey in counts ranging from 10 to 1,000 cells/mL. During the 1978 survey, the diatom genera Asterionella, reported in figure 19 as an abundant alga, was observed only at Willamette RM 12.8.

In 1974, the green-algae group (fig. 19) was dominated by a colonial form, but also included unidentified single-cell and filamentous forms and a small number of Scenedesmus and Pediastrum (Rickert, Petersen, McKenzie, Hines, and Wille, 1977). Also, no green algae were observed during 1974 above RM 78. In 1978, the group was dominated by the species Ankistrodesmus falcatus. Green algae were also observed in counts ranging from 10 to 100 cells/mL upstream to Harrisburg (RM 161), and occurred sporadically thereafter to Eugene (RM 187). Anabaena spp. was the predominant blue-green alga

Table 16.--Abundance of phytoplankton algae, grouped by type and total, in the lower Willamette River at RM 7.0, August 1963, 1973-74, 1976, 1977, and 1978

[Counts, in number per milliliter]

Algal types	Date					
	1/ 8-21-63	8-21-73	8-20-74	8-11-76	8-16-77	8-17-78
Diatoms	290	2,625	2,650	2,692	1,307	2,990
Greens	60	225	120	142	20	405
Blue-greens	20	0	50	0	0	0
Total	370	2,850	2,820	2,834	1,327	3,395
Discharge at Portland (ft^3/s)	2/ 7,100	6,290	7,950	9,190	7,740	9,400

1/ Sampling location for the August 21, 1963, algal identification was at RM 8.1 (U.S. Public Health Service, 1964).

2/ Accuracy of the 1963 estimated mean daily flow is ±10 percent.

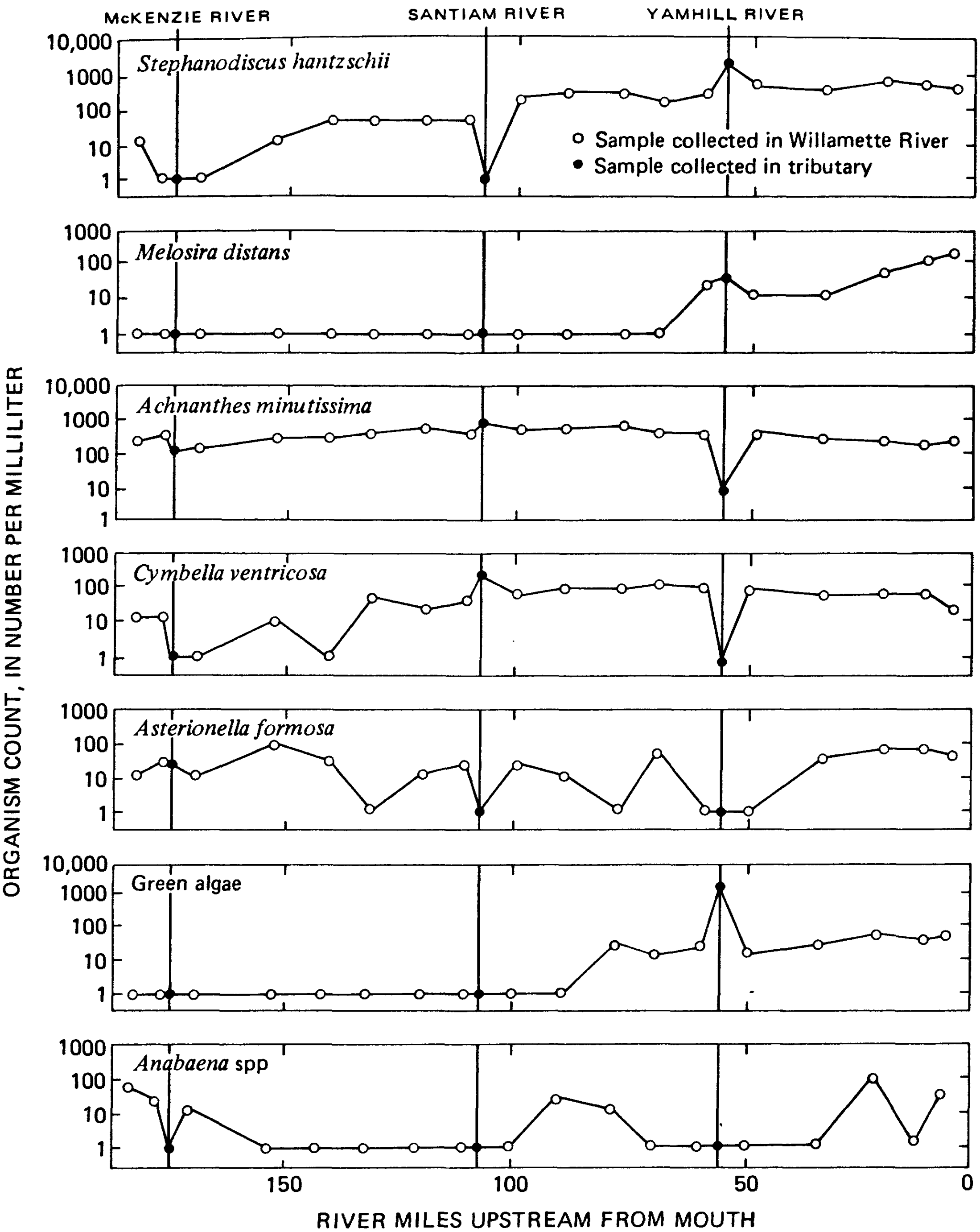

FIGURE 19. – Abundance of selected phytoplanktonic algae in the Willamette River and certain tributaries, August 5-7, 1974 (adopted from Rickert and others, 1977). Values at RM 35.0 are from July 23, 1974.

observed in 1974, whereas Oscillatoria limnetica was most frequently observed in 1978.

In summary, little change has occurred in the present algal populations (1978) of the Willamette River over that observed during the last 5 years. Diatoms still comprise more than 80 percent of the total number of algae in the water column. No major shifts have occurred in the predominant diatom species. Sporadic occurrences of patches of green and blue-green algae are still observed along almost the entire length of the river (RM's 185 to 7). Although these algae can tolerate more nutrient-enriched waters, their populations do not seem to be either dramatically increasing or decreasing.

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Appreciation is also extended to James Sweet, a graduate student at Portland State University, who sampled and identified the 1978 algal populations in the Willamette River basin to species level.

REFERENCES CITED

American Public Health Association and others, 1975, Standard methods for the examination of water and wastewater [14th ed.]: Washington, D.C., American Public Health Association, 1193 p.

Gleeson, G. W., 1972, The return of a river, the Willamette River, Oregon: Advisory Committee on Environmental Science and Technology and Water Resources Institute, Oregon State University, Corvallis, 103 p.

Greeson, P. E., Ehlke, T. A., Irwin, G. A., Lium, B. W., and Slack, K. V., 1977, Methods for collection and analysis of aquatic biological and microbiological samples: U.S. Geological Survey Techniques of Water Resources Investigations, book 5, chap. A4, 332 p.

Harris, D. D., 1968, Travel rates of water from selected streams in the Willamette River basin: U.S. Geological Survey Hydrologic Investigations Atlas HA-273, 2 sheets.

Hines, W. G., McKenzie, S. W., Rickert, D. A., and Rinella, F. A., 1977, Dissolved-oxygen regimen of the Willamette River, Oregon, under conditions of basinwide secondary treatment: U.S. Geological Survey Circular 715-I, 51 p.

Hines, W. G., Rickert, D. A., McKenzie, S. W., and Bennett, J. P., 1975, Formulation and use of practical models for river-quality assessment: U.S. Geological Survey Circular 715-B, 13 p.

Larson, D. W., 1974, Ecological fate and effects of ammonia in industrial waste discharges in the Willamette and South Santiam Rivers, Oregon: Oregon Department of Environmental Quality, 78 p.

McKenzie, S. W., Hines, W. G., Rickert, D. A., and Rinella, F. A., 1979, Steady-state dissolved oxygen model of the Willamette River, Oregon: U.S. Geological Survey Circular 715-J, 28 p.

Odum, H. T., 1956, Primary production in flowing waters: Limnology and Oceanography, v. 1, no. 2, p. 102-117.

________1957, Trophic structure and productivity of Silver Springs, Florida: Ecological Monographs, v. 27, p. 51-112.

Oregon Department of Environmental Quality, 1975, Water quality control in Oregon: A status report: An updated revision of: Water quality control in Oregon, December 1970, 68 p.

Phelps, E. G., 1944, Stream sanitation: New York, John Wiley, 209 p.

Rickert, D. A., and Hines, W. G., 1975, A practical framework for river-quality assessment: U.S. Geological Survey Circular 715-A, 17 p.

Rickert, D. A., Hines, W. G., and McKenzie, S. W., 1976, Project development and data programs for assessing the quality of the Willamette River, Oregon: U.S. Geological Survey Circular 715-C, 31 p.

Rickert, D. A., Kennedy, V. C., McKenzie, S. W., and Hines, W. G., 1977, A synoptic survey of trace metals in bottom sediments of the Willamette River, Oregon: U.S. Geological Survey Circular 715-F, 27 p.

Rickert, D. A., Petersen, R. R., McKenzie, S. W., Hines, W. G., and Wille, S. A., 1977, Algal conditions and the potential for future algal problems in the Willamette River, Oregon: U.S. Geological Survey Circular 715-G, 39 p.

Shearman, J. O., 1976, Reservoir-system model for the Willamette River basin, Oregon: U.S. Geological Survey Circular 715-H, 22 p.

State of Oregon, 1979, Oregon blue book, 1979-1980: Secretary of State, State of Oregon, 380 p.

Stephens, D. W., and Jennings, M. E., 1976, Determination of primary productivity and community metabolism in streams and lakes using diel oxygen measurements: Computer program documentation: U.S. Geological Survey, Bay St. Louis, Miss., 100 p.

Swale, E. M. F., 1964, A study of the phytoplankton of a calcareous river: Journal of Ecology, v. 52, p. 433-446.

Tuffy, T. J., Hunter, J. V., and Matulewich, V. A., 1974, Zones of nitrification: Water Resources Bulletin, v. 10, no. 3, p. 555-563.

U.S. Public Health Service, 1964, Water pollution surveillance system: Annual compilation of data for October 1, 1962-September 30, 1963, v. 10, 179 p.

Velz, C. J., 1961, Supplementary report on lower Willamette River waste assimilation capacity: National Council for Stream Improvement of the Pulp, Paper, and Paperboard Industries, Incorporated: School of Public Health, Michigan Univ., Ann Arbor, 28 p.

________1970, Applied stream sanitation: New York, John Wiley, 619 p.

Willamette Basin Task Force, 1969, Hydrology, Willamette Basin comprehensive study, Appendix B: Pacific Northwest River Basins Commission report, 163 p.

SUPPLEMENT A

THE MASS BALANCING-FLOW ROUTING TECHNIQUE

The technique of mass balancing and flow routing was used to decay $CBOD_{ult}$ and NBOD loads down the Willamette and South Santiam Rivers. The calculations involved can be computed by hand or by using a programable calculator. The assumptions made when using this technique are: (1) the river is in a steady-state condition, which means that no significant variations are occurring in the physical, chemical, or biological nature of the system; (2) the oxidizable materials obey simple first-order decay kinetics (Phelps, 1944); (3) there are no unaccounted for significant sources or sinks that alter greatly the mass-balancing computations; (4) the calculated deoxygenation rate is a composite rate that incorporates the different oxidizability potentials of the point and nonpoint materials; and (5) the deoxygenation rate is temperature dependent and is subject to a 4.7 percent change per degree Celsius that the river temperature differs from 20°C.

The following basic equations are used for the mass balancing-flow routing computation technique.

1. The equation that describes the decay of the oxidizable load ($CBOD_{ult}$ or NBOD) is:

$$\frac{L_t}{L} = 10^{-k_T t} \qquad (1)$$

where

L = the ultimate oxidizable load at time = 0, in lb-O_2/d,

L_t = the remaining oxidizable load at time = t, in lb-O_2/d,

$\frac{L_t}{L}$ = the fraction of oxidizable load remaining at time = t,

t = time period, in days. In decaying oxidizable matter as it trails downstream, t is equivalent to the time of travel between two points in the river, and

k_T = river deoxygenation rate ($\log_{10}$), adjusted to river temperature T.

2. The equation used to adjust the river deoxygenation rate for temperature is:

$$k_T = k_{20°C} \times 1.047^{(T-20.)} \qquad (2)$$

where

$k_{20°C}$ = river deoxygenation rate at 20°C, and

T = average river-segment temperature, in °C.

3. The equation for converting $CBOD_{ult}$ concentration to pounds per day of oxidizable matter is:

$$[CBOD_{ult}\ (mg/L)] \times Q \times 5.39 = CBOD_{ult}\ \text{load}\ (lb\text{-}O_2/d) \qquad (3)$$

where

Q = flow of waste source or tributary, in cubic feet per second, and

5.39 = unit conversion factor.

4. The equation for converting ammonia concentration to pounds per day of oxidizable matter is:

$$[NH_4\text{-}N\ (mg/L)] \times Q \times 5.39 \times 4.33 = NBOD\ \text{load}\ (lb\text{-}O_2/d) \qquad (4)$$

where

$[NH_4\text{-}N]$ = ammonia concentration, in milligrams per liter, as N,

Q = flow of input, in cubic feet per second, and

4.33 = factor that indicates the oxygen oxidizability potential per milligrams per liter NH_4-N.

To illustrate the mass balancing-flow routing technique, an example calculation is given below using data from the August 7-11, 1978, Willamette River survey. Table 17 summarizes the calculations made for flow-routing $CBOD_{ult}$ loads from the confluence of the Middle and Coast Forks of the Willamette River (RM 187) down to RM 178. Also, table 17 illustrates the introduction and decay of a municipal waste-water load from RM 184.3 to RM 178, where additional municipal effluent enters the river.

Tables 18-20 present cumulative times of travel, in hours, and average daily river temperature calculated for the Willamette and South Santiam River studies during the 1978 summer low-flow period.

Table 17.--Sample calculations illustrating the mass balancing-flow routing technique, Willamette River, August 7-11, 1978

River mile	(ft^3/s)	[$CBOD_{ult}$] (mg/L)	Time of travel (d)	k_{r_T} 1/ (d^{-1})	Input $CBOD_{ult}$ load (lb/d)	Cumulative flow-routed $CBOD_{ult}$ load (lb/d)
187	2,600	1.4	0.0	0	2/ 19,600	19,600
187-184.3	--	--	.08	.034 (16.6°C)	--	19,500
184.3	9.7	65	--	--	3,400	22,900
184.3-178	--	--	.18	.036 (17.9°C)	--	22,600

1/ River carbonaceous deoxygenation rate for this river segment, adjusted to 20°C, was 0.040 d^{-1} ($k_{r_{20°C}}$). Column number in parentheses represents average river-segment temperature, T.

2/ Initial background $CBOD_{ult}$ load at RM 187 was measured to be 19,600 lb/d.

Table 18.--Cumulative time of travel and average daily river temperature, Willamette River, August 7-11, 1978

Willamette river mile location (RM)	Cumulative time of travel to river mile[1,2] (hours)	Average daily river temperature at river mile[3] (°C)
187	0.0	16.2
184.3	1.9	16.9
178	6.2	18.9
174.8	8.3	19.3
161	13.4	19.9
149	19.1	20.3
147.5	19.7	20.4
132.2	27.1	21.0
132.1	27.2	21.0
131	27.8	21.0
119.6	33.7	21.3
119.5	33.7	21.3
118	35.3	21.3
116.5	36.2	21.3
115.5	36.8	21.3
107.9	43.0	21.6
107.5	43.3	21.6
95.3	52.0	22.2
88.1	57.5	22.6
85.9	59.4	22.8

1/ Average weekly flow at U.S. Geological Survey gage: Harrisburg, 4,630 ft^3/s; Albany, 4,600 ft^3/s; Salem, 5,890 ft^3/s. Measured average weekly flow at Albany was slightly lower than that observed at Harrisburg due to evaporation and irrigation losses.

2/ Cumulative time of travel was calculated using two methods: (a) for RM's 187 to 119.6, used dye-study data (Harris, 1968), and (b) for RM's 119.6 to 85.9, collected cross-sectional profile data and calculated passage by volume-displacement method.

3/ Average daily river temperatures were computed two ways: (a) for monitored sites, average daily values were computed, and (b) for nonmonitored sites, a plot of cumulative time of travel versus the monitored average daily values was used to extrapolate values.

Table 19.--Cumulative time of travel and average daily river temperature, Willamette River, August 28-September 1, 1978

Willamette river mile location (RM)	Cumulative time of travel to river mile[1,2] (hours)	Average daily river temperature at river mile[3] (°C)
187	0.0	16.9
184.3	1.8	17.1
178	6.0	18.4
174.8	8.0	17.8
161	13.0	17.9
149	18.4	18.0
147.5	19.1	18.0
132.2	26.2	18.0
132.1	26.2	18.0
131	26.8	18.0
119.6	32.6	17.8
119.5	32.6	17.8
118	34.0	17.8
116.5	34.9	17.8
115.5	35.3	17.8
107.9	41.1	18.0
107.5	41.3	17.7
95.3	48.8	18.1
88.1	53.4	18.4
85.4	55.1	18.5

1/ Average weekly flow at U.S. Geological Survey gage: Harrisburg, 5,530 ft^3/s; Albany, 5,660 ft^3/s; Salem, 8,040 ft^3/s.

2/ Cumulative time of travel was calculated using two methods: (a) for RM's 187 to 119.6, used dye-study data (Harris, 1968) and (b) for RM's 119.6 to 85.4 collected cross-sectional profile data and calculated passage by volume-displacement method.

3/ Average daily river temperatures were computed two ways: (a) for monitored sites, average daily values were computed, and (b) for nonmonitored sites, a plot of cumulative time of travel versus the monitored average daily values was used to extrapolate values.

Table 20.--Cumulative time of travel and average daily river temperature, South Santiam River, July 23-28, 1978

South Santiam river mile location (RM)	Cumulative time of travel to river mile[1,2] (hours)	Average daily river temperature at river mile[3] (°C)
23.4	0.0	14.8
20.8	3.8	15.4
17.4	8.7	16.0
16.5	10.3	16.3
4.3	31.4	18.4
3.0	32.7	18.5
0.0	36.8	18.9

1/ Average weekly flow at U.S. Geological Survey Waterloo gage 710 ft^3/s.

2/ Cumulative time of travel calculated from dye-study data (Harris, 1968).

3/ Average daily river temperatures were computed two ways: (a) for monitored sites, average daily values were computed, and (b) for nonmonitored sites, a plot of cumulative time of travel versus the monitored average daily values was used to extrapolate values.

SUPPLEMENT B

ANALYSIS OF ALGAL POPULATIONS IN THE MAIN STEM WILLAMETTE RIVER AND SELECTED TRIBUTARIES, AUGUST 1978

Table 21.--Phytoplankton identification and abundance, Willamette RM's 185.0 to 132.0

(Common name is indicated in parentheses after division, class, order, or family. Cell count is in organisms per milliter; percent is percent of total organisms in sample)

DIVISION / CLASS / Order / Family / Genus species — River name / Sampling site (RM) / Date	Willamette 185.0 8-7-78 Cell count	Per-cent	Willamette 176.5 8-7-78 Cell count	Per-cent	McKenzie 0.1 8-7-78 Cell count	Per-cent	Willamette 169.0 8-7-78 Cell count	Per-cent	Willamette 161.0 8-7-78 Cell count	Per-cent	Willamette 156.0 8-7-78 Cell count	Per-cent	Willamette 141.7 8-8-78 Cell count	Per-cent	Willamette 132.0 8-8-78 Cell count	Per-cent
CHLOROPHYTA (green algae)																
CHLOROPHYCEAE																
Ulotrichales																
Ulotrichaceae																
Ulothrix aequalis	--	--	--	--	20	1.1	--	--	--	--	--	--	--	--	--	--
Chlorococcales																
Oocystaceae																
Ankistrodesmus falcatus	--	--	--	--	--	--	--	--	15	1.0	25	1.2	--	--	35	1.6
Scenedesmaceae																
Scenedesmus spp.	--	--	--	--	--	--	--	--	--	--	--	--	25	0.9	--	--
Zygnematales																
Desmidiaceae (placoderm desmids)																
Cosmarium spp.	10	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Staurastrum spp.	10	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Misc. green algae	10	1.0	--	--	--	--	--	--	--	--	--	--	25	.9	--	--
CHRYSOPHYTA																
BACILLARIOPHYCEAE (diatoms)																
Centrales (centric diatoms)																
Coscinodiscaceae																
Cyclotella meneghiniana	--	--	--	--	--	--	35	2.6	--	--	--	--			--	--
Melosira granulata angustissima	--	--	--	--	20	1.1	--	--	--	--	--	--	--	--	20	.9
M. varians	25	2.6	50	5.5	35	1.9	--	--	15	1.0	--	--	--	--	20	.9
Stephanodiscus astrea minutula	--	--	--	--	--	--	--	--	--	--	--	--	25	.9	--	--
Pennales (pennate diatoms)																
Diatomaceae																
Diatoma hiemale mesodon	--	--	10	1.1	--	--	--	--	--	--	--	--	25	.9	--	--
D. vulgare	--	--	--	--	20	1.1	25	1.8	15	1.0	25	1.2	--	--	--	--
Fragilariaceae																
Fragilaria vaucheriae	--	--	--	--	55	2.9	10	.7	35	2.2	70	3.5	--	--	--	--
F. spp.	--	--	--	--	170	9.1	--	--	--	--	--	--	--	--	--	--
Hanneae arcus	10	1.0	--	--	--	--	10	.7	--	--	--	--	--	--	--	--
Synedra mazamaensis	10	1.0	35	3.8	--	--	--	--	--	--	--	--	--	--	35	1.6
S. rumpens	--	--	--	--	--	--	--	--	15	1.0	--	--	--	--	--	--
S. ulna	--	--	--	--	--	--	10	.7	15	1.0	45	2.2	--	--	55	2.6
S. ulna contracta	--	--	--	--	--	--	--	--	35	2.2	--	--	--	--	--	--
Achnanthaceae																
Achnanthes lanceolata	85	8.7	95	10.4	20	1.1	35	2.6	15	1.0	--	--	--	--	35	1.6
A. linearis	--	--	60	6.6	200	10.7	110	8.2	150	9.5	210	10.4	380	13.0	320	15.2
A. minutissima	100	10.2	25	2.7	--	--	10	.7	15	1.0	45	2.2	25	.9	35	1.6
Cocconeis placentula	85	8.7	190	21.0	90	4.8	160	11.7	150	9.5	160	8.1	380	13.0	210	9.9
Rhoicosphenia curvata	25	2.6	--	--	75	4.0	10	.7	50	3.1	45	2.2	--	--	95	4.5
Naviculaceae (naviculoid)																
Navicula capitata	--	--	--	--	--	--	--	--	--	--	--	--	--	--	20	.9
N. cryptocephala	75	7.7	35	3.8	35	1.9	10	.7	--	--	--	--	95	3.3	95	4.5
N. cryptocephala veneta	--	--	--	--	--	--	--	--	50	3.1	25	1.2	--	--	--	--
N. pupula	--	--	--	--	--	--	10	.7	--	--	--	--	--	--	--	--
N. salinarum	--	--	--	--	--	--	--	--	15	1.0	--	--	--	--	--	--
N. spp.	--	--	--	--	--	--	35	2.6	--	--	--	--	--	--	55	2.6
Comphonemataceae																
Gomphoneis herculeana	--	--	--	--	35	1.9	35	2.6	15	1.0	25	1.2	70	2.4	35	1.6
Gomphonema angustata	40	4.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--
G. parvulum	--	--	--	--	--	--	--	--	--	--	--	--	--	--	130	6.1
G. tenellum	--	--	50	5.5	35	1.9	--	--	--	--	25	1.2	70	2.4	--	--
G. spp.	10	1.0	--	--	--	--	25	1.8	15	1.0	45	2.2	25	.9	--	--
Cymbellaceae																
Amphora ovalis	10	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--
A. perpusilla	--	--	--	--	--	--	10	.7	--	--	--	--	--	--	--	--
Cymbella affinis	75	7.7	70	7.7	55	2.9	25	1.8	130	8.3	210	10.4	140	4.8	110	5.2
C. minuta	110	11.3	50	5.5	55	2.9	160	11.7	180	11.5	300	15.0	450	15.5	300	14.2
C. sinuata	--	--	--	--	--	--	10	.7	--	--	--	--	25	.9	75	3.5
C. tumida	--	--	--	--	--	--	25	1.8	--	--	25	1.2	--	--	55	2.6
Rhopalodia gibba	--	--	--	--	20	1.1	--	--	--	--	--	--	--	--	--	--
Nitzschiaceae																
Nitzschia amphibia	--	--	--	--	150	8.0	--	--	100	6.4	140	7.1	190	6.5	--	--
N. dissipata	25	2.6	10	1.1	--	--	--	--	35	2.2	--	--	120	4.1	55	2.6
N. frustulum	125	12.8	110	12.1	--	--	480	35.3	--	--	--	--	--	--	240	11.4
N. frustulum subsalina	--	--	--	--	--	--	--	--	65	4.0	110	5.6	210	7.2	--	--
N. palea	--	--	--	--	--	--	--	--	--	--	45	2.2	--	--	--	--
N. paleaceae	--	--	--	--	220	11.8	--	--	210	13.3	180	9.1	400	13.7	--	--
N. spp.	110	11.3	70	7.7	35	1.9	25	1.8	15	1.0	45	2.2	95	3.3	75	3.5
Misc. pennate diatoms	25	2.6	--	--	--	--	10	.7	35	2.2	70	3.5	45	1.5	--	--
CYANOPHYTA (blue-greens)																
CYANOPHYCEAE																
Chroococcales (coccoid blue-greens)																
Chroococcaceae																
Chroococcus spp.	--	--	--	--	--	--	--	--	--	--	23	1.2	--	--	--	--
Hormogonales (filamentous blue-greens)																
Oscillatoriaceae																
Lyngbya spp.	--	--	--	--	--	--	--	--	--	--	25	1.2	--	--	--	--
Oscillatoria limnetica	--	--	--	--	500	26.8	--	--	180	11.5	90	4.5	45	1.5	20	.9
O. spp.	--	--	50	5.5	20	1.1	90	6.7	--	--	--	--	45	1.5	--	--
Total	975	100.0	910	100.0	1,859	100.0	1,365	100.0	1,570	100.0	2,010	100.0	2,910	100.0	2,125	100.0

Table 22.--Phytoplankton identification and abundance, Willamette RM's 118.0 to 56.0

(Common name is indicated in parentheses after division, class, order, or family. Cell count is in organisms per milliter; percent is percent of total organisms in sample)

DIVISION / CLASS / Order / Family / Genus species	River name / Sampling site (RM) / Date	Willamette 118.0 8-16-78		Willamette 111.0 8-16-78		Willamette 107.0 8-16-78		Willamette 100.0 8-16-78		Willamette 86.5 8-16-78		Willamette 78.0 8-16-78		Willamette 72.0 8-16-78		Willamette 56.0 8-17-78	
		Cell Count	Per-cent	Cell Count	Per-cent	Cell Count	Per-cent	Cell Count	Per-cent	Cell Count	Per-cent	Cell Count	Per-cent	Cell Count	Per-cent	Cell Count	Per-cent
CHLOROPHYTA (green algae)																	
CHLOROPHYCEAE																	
Volvocales																	
Chlamydomonadaceae																	
Chlamydomonas spp.		--	--	--	--	40	0.9	--	--	--	--	40	0.8	--	--	--	--
Oedogoniales																	
Oedogoniaceae																	
Oedognium spp.		--	--	--	--	--	--	30	0.9	--	--	--	--	--	--	--	--
Chlorococcales																	
Oocystaceae																	
Ankistrodesmus falcatus		25	1.1	--	--	110	2.6	60	1.8	110	2.9	40	.8	--	--	--	--
Kirchneriella spp.		--	--	--	--	40	.9	--	--	--	--	--	--	--	--	--	--
Scenedesmaceae																	
Crucigenia quadrata		--	--	--	--	--	--	--	--	35	.9	--	--	--	--	--	--
C. spp.		--	--	25	0.9	--	--	30	.9	--	--	--	--	--	--	--	--
Scenedesmus quadricauda		25	1.1	--	--	--	--	30	.9	--	--	--	--	35	0.8	--	--
S. spp.		--	--	--	--	40	.9	--	--	--	--	--	--	--	--	25	0.8
Misc. green algae		--	--	25	.9	--	--	--	--	110	2.9	--	--	--	--	--	--
EUGLENOPHYTA (euglenoids)																	
EUCLENOPHYCEAE																	
Euglenales																	
Euglenaceae																	
Euglena spp.		--	--	--	--	--	--	--	--	--	--	40	.8	--	--	--	--
Misc. euglenoids		--	--	--	--	--	--	30	.9	--	--	--	--	--	--	--	--
CHYRSOPHYTA																	
BACILLARIOPHYCEAE (diatoms)																	
Centrales (centric diatoms)																	
Coscinodiscaceae																	
Cyclotella meneghiniana		--	--	25	.9	--	--	--	--	180	4.9	110	2.3	35	0.8	270	9.1
C. stelligera		75	3.4	55	2.0	75	1.8	90	2.7	--	--	--	--	35	.8	--	--
Melosira ambigua		50	2.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--
M. distans		75	3.4	80	2.9	110	2.6	90	2.7	110	2.9	--	--	35	.8	80	2.7
M. granulata angustissima		--	--	--	--	40	.9	30	.9	--	--	150	3.2	--	--	--	--
M. varians		25	1.1	25	.9	--	--	--	--	--	--	--	--	--	--	25	.8
Stephanodiscus astrea		--	--	25	.9	--	--	--	--	--	--	--	--	--	--	--	--
S. hantzschii		--	--	--	--	--	--	--	--	--	--	150	3.2	180	4.2	--	--

Table 22.--Phytoplankton identification and abundance, Willamette RM's 118.0 to 56.0--Continued

DIVISION / CLASS / Order / Family / Genus species	River name / Sampling site (RM) / Date	Willamette 118.0 8-16-78 Cell Count	Per-cent	Willamette 111.0 8-16-78 Cell Count	Per-cent	Willamette 107.0 8-16-78 Cell Count	Per-cent	Willamette 100.0 8-16-78 Cell Count	Per-cent	Willamette 86.5 8-16-78 Cell Count	Per-cent	Willamette 78.0 8-16-78 Cell Count	Per-cent	Willamette 72.0 8-16-78 Cell Count	Per-cent	Willamette 56.0 8-17-78 Cell Count	Per-cent
Pennales (pennate diatoms)																	
Diatomaceae																	
Diatoma hiemale mesodon		--	--	25	.9	40	.9	--	--	35	.9	--	--	--	--	--	--
Fragilariaceae																	
Fragilaria construens		--	--	--	--	--	--	--	--	--	--	--	--	--	--	25	.8
F. crotonensis		25	1.1	--	--	--	--	--	--	--	--	40	.8	--	--	--	--
F. vaucheriae		--	--	--	--	--	--	--	--	--	--	40	.8	35	.8	--	--
Hanneae arcus		--	--	--	--	--	--	--	--	35	.9	--	--	--	--	--	--
Synedra mazamaensis		--	--	55	2.0	--	--	--	--	--	--	--	--	--	--	--	--
S. ulna		25	1.1	55	2.0	75	1.8	30	.9	110	2.9	75	1.6	35	.8	25	.8
S. ulna contracta		--	--	--	--	--	--	60	1.8	--	--	--	--	--	--	--	--
Eunotiaceae																	
Eunotia spp.		--	--	--	--	40	.9	--	--	--	--	--	--	--	--	--	--
Achnanthaceae																	
Achnanthes lanceolata		50	2.3	80	2.9	--	--	--	--	180	4.9	40	.8	70	1.7	55	1.8
A. linearis		370	16.9	480	17.4	1,050	24.6	920	27.1	760	20.3	1,500	31.4	1,100	25.9	940	31.3
A. minutissima		100	4.5	55	2.0	150	3.5	120	3.5	--	--	--	--	250	5.9	--	--
A. spp.		--	--	--	--	--	--	--	--	35	.9	--	--	--	--	--	--
Cocconeis placentula		170	7.8	190	6.9	190	4.5	280	8.3	180	4.9	460	9.6	350	8.3	380	12.7
Rhoicosphenia curvata		50	2.3	80	2.9	110	2.6	90	2.7	70	1.9	150	3.2	180	4.2	25	.8
Naviculaceae (naviculoid)																	
Navicula captiata		--	--	--	--	--	--	30	0.9	--	--	--	--	--	--	--	--
N. cryptocephala		--	--	80	2.9	--	--	--	--	--	--	--	--	--	--	--	--
N. cryptocephala veneta		75	3.4	--	--	110	2.6	90	2.7	--	--	110	2.3	70	1.7	--	--
N. mutica		--	--	--	--	--	--	--	--	--	--	40	.8	--	--	--	--
N. salinarum		--	--	--	--	40	.9	120	3.5	--	--	40	.8	70	1.7	--	--
N. spp.		--	--	--	--	--	--	--	--	--	--	--	--	--	--	55	1.8
Neidium iridis		--	--	--	--	--	--	--	--	35	.9	--	--	--	--	--	--
Gomphonemataceae																	
Gomphoneis herculeana		--	--	55	2.0	75	1.8	--	--	70	1.9	--	--	--	--	--	--
Gomphonema angustata		--	--	--	--	--	--	--	--	--	--	190	4.0	35	.8	--	--
G. parvulum		50	2.3	--	--	--	--	--	--	110	2.9	--	--	--	--	55	1.8
G. tenellum		--	--	110	3.9	110	2.6	90	2.7	--	--	40	.8	140	3.3	--	--
G. spp.		--	--	25	.9	75	1.8	--	--	--	--	--	--	--	--	--	--
Cymbellaceae																	
Amphora perpusilla		--	--	--	--	--	--	30	.9	--	--	--	--	--	--	--	--
Cymbella affinis		220	10.0	110	3.9	230	5.4	220	6.5	110	2.9	40	.8	180	4.2	130	4.4
C. minuta		220	10.0	430	15.6	650	15.2	490	14.4	790	21.1	610	12.8	560	13.3	380	12.7
C. sinuata		100	4.5	55	2.0	75	1.8	30	.9	70	1.9	110	2.3	70	1.7	80	2.7
C. tumida		--	--	--	--	40	.9	--	--	--	--	75	1.6	--	--	55	1.8

Table 22.--Phytoplankton identification and abundance, Willamette RM's 118.0 to 56.0--Continued

DIVISION / CLASS / Order / Family / Genus species	River name / Sampling site (RM) / Date	Willamette 118.0 8-16-78 Cell Count	Per-cent	Willamette 111.0 8-16-78 Cell Count	Per-cent	Willamette 107.0 8-16-78 Cell Count	Per-cent	Willamette 100.0 8-16-78 Cell Count	Per-cent	Willamette 86.5 8-16-78 Cell Count	Per-cent	Willamette 78.0 8-16-78 Cell Count	Per-cent	Willamette 72.0 8-16-78 Cell Count	Per-cent	Willamette 56.0 8-17-78 Cell Count	Per-cent
Nitzschiaceae																	
Nitzschia acicularis		--	--	--	--	--	--	--	--	35	.9	--	--	--	--	--	--
N. acuta		--	--	--	--	40	.9	--	--	--	--	--	--	--	--	--	--
N. amphibia		75	3.4	190	6.9	110	2.6	120	3.5	--	--	420	8.9	210	5.0	--	--
N. dissipata		--	--	110	3.9	--	--	60	1.8	--	--	--	--	35	.8	25	.8
N. frustulum		--	--	--	--	--	--	--	--	--	--	--	--	--	--	240	8.1
N. frustulum subsalina		150	6.9	80	2.9	110	2.6	120	3.5	--	--	190	4.0	180	4.2	--	--
N. palea		25	1.1	--	--	--	--	--	--	--	--	--	--	35	.8	--	--
N. paleaceae		220	10.0	160	5.8	340	8.0	90	2.7	180	4.9	75	1.6	180	4.2	--	--
N. spp.		--	--	25	.9	--	--	--	--	250	6.7	--	--	35	.8	80	2.7
Misc. pennate diatoms		--	--	55	2.0	110	2.6	--	--	110	2.9	--	--	70	1.7	--	--
CYANOPHYTA (blue-green algae)																	
CYANOPHYCEAE																	
Chroococcales (coccoid blue-greens)																	
Chroococcaceae																	
Chroococcus spp.		--	--	--	--	--	--	--	--	--	--	--	--	--	--	25	.8
Hormogonales (filamentous blue-green)																	
Oscillatoriaceae																	
Oscillatoria limnetica		--	--	--	--	--	--	--	--	35	1.0	--	--	--	--	--	--
Nostocaceae																	
Anabaena spp.		--	--	--	--	--	--	--	--	--	--	--	--	--	--	25	.8
Misc. blue-green algae		--	--	--	--	40	.9	--	--	--	--	--	--	35	.8	--	--
Total		2,205	100.0	2,765	100.0	4,265	100.0	3,380	100.0	3,745	100.0	4,775	100.0	4,245	100.0	3,000	100.0

Table 23.--Phytoplankton identification and abundance, Willamette RM's 50.0 to 7.0

(Common name is indicated in parentheses after division, class, order, or family. Cell count is in organisms per milliter; percent is percent of total organisms in sample)

DIVISION / CLASS / Order / Family / Genus Species	River name / Sampling site (RM) / Date															
River name	Willamette		Willamette		Willamette		Tualatin		Clackamas		Willamette		Willamette		Willamette	
Sampling site (RM)	50.0		39.0		33.0		0.1		0.1		20.5		12.8		7.0	
Date	8-17-78		8-17-78		8-17-78		8-17-78		8-17-78		8-17-78		8-17-78		8-17-78	
	Cell count	Per-cent	Cell count	Per-cent	Cell count	Per-cent	Cell count	Per-cent	Cell count	Per-cent	Cell count	Per-cent	Cell count	Per-cent	Cell count	Per-cent
CHLOROPHYTA (green algae)																
CHLOROPHYCEAE																
Volvocales																
Chlamydomonadaceae																
Chlamydomonas spp.	--	--	--	--	--	--	430	16.1	--	--	--	--	--	--	100	2.9
Volvocaceae																
Eudorina elegans	--	--	--	--	--	--	--	--	--	--	45	1.5	--	--	--	--
Pandorina morum	--	--	--	--	--	--	110	4.1	--	--	--	--	--	--	--	--
Tetrasporales																
Palmellaceae																
Gloeocystis spp.	--	--	--	--	--	--	--	--	--	--	85	2.9	30	0.7	--	--
Chlorococcales																
Characiaceae																
Characium spp.	--	--	--	--	--	--	--	--	--	--	85	2.9	--	--	--	--
Hydrodictyaceae																
Pediastrum tetras	35	1.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Oocystaceae																
Ankistrodesmus falcatus	--	--	55	1.3	35	1.0	--	--	--	--	--	--	65	1.6	35	1.0
Chlorella spp.	--	--	--	--	--	--	--	--	15	1.2	--	--	--	--	--	--
Oocystis spp.	35	1.3	--	--	--	--	110	4.1	15	1.2	--	--	--	--	--	--
Selenastrum minutum	--	--	--	--	--	--	25	.9	--	--	--	--	--	--	--	--
Scenedesmaceae																
Crucigenia quadrata	--	--	--	--	--	--	--	--	--	--	--	--	30	.7		
C. tetrapedia	--	--	--	--	--	--	55	2.0	--	--	--	--	--	--	--	--
Scenedesmus quadricauda	--	--	--	--	70	2.0	25	.9	--	--	--	--	65	1.6	--	--
S. spp.	--	--	--	--	--	--	25	.9	--	--	--	--	--	--	--	--
Zygnematales																
Desmidiaceae (placoderm desmids)																
Cosmarium spp.	--	--	--	--	35	1.0	--	--	--	--	--	--	--	--	--	--
Misc. green algae	--	--	--	--	70	2.0	400	15.0	--	--	260	8.8	--	--	270	8.0
Misc. euglenoids	--	--	--	--	--	--	200	8.2	--	--	--	--	--	--	--	--
PYRRHOPHYTA (fire algae)																
DINOPHYCEAE (dinoflagellates)																
Gymnodiniales																
Gymnodiniaceae																
Gymnodinium spp.	--	--	--	--	35	1.0	--	--	--	--	--	--	--	--	--	--
Peridiniales																
Glenodiniaceae																
Glenodinium spp.	35	1.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CHRYSOPHYTA																
BACILLARIOPHYCEAE (diatoms)																
Centrales (centric diatoms)																
Coscinodiscaceae																
Cyclotella meneghiniana	65	2.3	--	--	--	--	--	--	25	2.1	310	10.3	95	2.3	240	7.1
C. pseudostelligera	--	--	--	--	--	--	--	--	--	--	--	--	65	1.6	--	--
C. stelligera	--	--	110	2.5	100	3.0	80	3.0	--	--	--	--	420	10.2	170	5.0
Melosira ambigua	--	--	110	2.5	--	--	25	.9	90	7.4	--	--	640	15.5	35	1.0
M. distans	130	4.6	110	2.5	35	1.0	240	9.0	--	--	180	6.0	390	9.5	240	7.1
M. granulata angustissima	35	1.3	55	1.3	70	2.0	--	--	--	--	180	6.0	30	.7	620	18.3
M. italica	--	--	--	--	--	--	--	--	--	--	--	--	--	--	35	1.0
M. varians	65	2.3	--	--	--	--	--	--	15	1.2	--	--	--	--	--	--
Stephanodiscus astrea	--	--	--	--	70	2.0	--	--	--	--	--	--	--	--	--	--
S. astrea minutula	--	--	--	--	140	4.1	110	4.1	--	--	--	--	--	--	--	--
S. hantzschii	--	--	950	21.7	730	21.3	55	2.0	--	--	130	4.4	1,350	32.7	1,000	29.6
Pennales (pennate diatoms)																
Fragilariaceae																
Asterionella formosa	--	--	--	--	--	--	--	--	--	--	--	--	30	.7	--	--
Fragilaria vaucheriae	--	--	110	2.5	--	--	--	--	--	--	--	--	30	.7	--	--
F. spp.	--	--	--	--	--	--	--	--	--	--	45	1.5	--	--	--	--
Synedra goulardi	--	--	--	--	--	--	--	--	15	1.2	--	--	--	--	--	--
S. mazamaensis	--	--	--	--	--	--	--	--	15	1.2	--	--	--	--	--	--
S. rumpens	--	--	--	--	--	--	--	--	15	1.2	--	--	--	--	--	--
S. ulna	35	1.3	--	--	70	2.0	25	.9	--	--	45	1.5	65	1.6	--	--
S. ulna contracta	--	--	--	--	--	--	--	--	15	1.2	85	2.9	--	--	--	--

Table 23.--Phytoplankton identification and abundance, Willamette RM's 50.0 to 7.0--Continued

DIVISION / CLASS / Order / Family / Genus Species	River name / Sampling site (RM) / Date	Willamette 50.0 8-17-78 Cell count	Percent	Willamette 39.0 8-17-78 Cell count	Percent	Willamette 33.0 8-17-78 Cell count	Percent	Tualatin 0.1 8-17-78 Cell count	Percent	Clackamas 0.1 8-17-78 Cell count	Percent	Willamette 20.5 8-17-78 Cell count	Percent	Willamette 12.8 8-17-78 Cell count	Percent	Willamette 7.0 8-17-78 Cell count	Percent
Achnanthaceae																	
Achnanthes lanceolata		35	1.3	--	--	--	--	55	2.0	--	--	45	1.5	--	--	35	1.0
A. linearis		690	24.6	1,000	22.9	590	17.2	25	.9	330	27.3	480	16.1	190	4.7	170	5.0
A. minutissima		35	1.3	--	--	70	2.0	--	--	25	2.1	--	--	--	--	--	--
Cocconeis placentula		170	6.0	160	3.7	35	1.0	80	3.0	130	10.7	--	--	65	1.6	--	--
Rhoicosphenia curvata		100	3.5	160	3.7	35	1.0	110	4.1	15	1.2	130	4.4	65	1.6	--	--
Naviculaceae (naviculoid)																	
Navicula cryptocephala		--	--	110	2.5	70	2.0	--	--	25	2.1	85	2.9	--	--	35	1.0
N. mutica		--	--	--	--	--	--	--	--	--	--	--	--	30	.7	--	--
Pinnularia spp.		--	--	--	--	--	--	--	--	15	1.2	--	--	--	--	--	--
Gomphonemataceae																	
Gomphoneis herculeana		--	--	--	--	35	1.0	--	--	--	--	--	--	--	--	--	--
Gomphonema parvulum		170	6.0	--	--	70	2.0	130	4.9	--	--	45	1.5	30	.7	--	--
G. subclavatum		--	--	--	--	--	--	--	--	40	3.3	--	--	--	--	--	--
G. tenellum		--	--	110	2.5	35	1.0	110	4.1	65	5.4	--	--	95	2.3	100	2.9
G. spp.		65	2.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cymbellaceae																	
Cymbella affinis		130	4.6	55	1.3	210	6.1	--	--	100	8.4	45	1.5	65	1.6	--	--
C. minuta		500	17.8	260	6.0	240	7.1	--	--	75	6.3	85	2.9	65	1.6	240	7.1
C. sinuata		35	1.3	55	1.3	70	2.0	--	--	--	--	130	4.4	--	--	--	--
C. tumida		35	1.3	--	--	--	--	25	.9		--	--	--	--	--	--	--
Nitzschiaceae																	
Nitzschia acicularis		--	--	--	--	35	1.0	--	--	--	--	--	--	--	--	--	--
N. amphibia		--	--	210	4.8	210	6.1	--	--	--	--	--	--	30	.7	35	1.0
N. dissipata		35	1.3	55	1.3	35	1.0	--	--	25	2.1	130	4.4	--	--	35	1.0
N. frustulum		230	8.2	--	--	--	--	--	--	100	8.4	260	8.8	--	--	--	--
N. frustulum subsalina		--	--	210	4.8	100	3.0	--	--	--	--	--	--	30	.7	--	--
N. linearis		--	--	--	--	--	--	--	--	15	1.2	--	--	30	.7	--	--
N. minima		--	--	--	--	--	--	25	.9	--	--	--	--	--	--	--	--
N. palea		35	1.3	--	--	--	--	--	--	15	1.2	85	2.9	--	--	--	--
N. paleaceae		--	--	420	9.6	140	4.1	80	3.0	--	--	--	--	65	1.6	--	--
N. spp.		--	--	55	1.3	--	--	--	--	--	--	--	--	30	.7	--	--
Misc. pennate diatoms		100	3.5	--	--	--	--	--	--	15	1.2	--	--	30	.7	--	--
Misc. blue-green algae		--	--	--	--	--		100	4.1	--	--	--	--	--	--	--	--
	Total	2,800	100.0	4,360	100.0	3,440	100.0	2,685	100.0	1,210	100.0	2,970	100.0	4,125	100.0	3,395	100.0

Table 24.--Phytoplankton identification and abundance, South Santiam RM's 23.4 to 0.1

(Common name is indicated in parentheses after division, class, order, or family. Cell count is in organisms per milliter; percent is percent of total organisms in sample)

DIVISION / CLASS / Order / Family / Genus species	River name	South Santiam River								Santiam River			
	Sampling site (RM)	23.4		13.95		7.6		0.1		6.4		0.1	
	Date	8-4-78		8-4-78		8-4-78		8-4-78		8-4-78		8-16-78	
		Cell count	Percent	Cell count	Percent	Cell count	Percent	Cell count	Percent	Cell count	Percent	Cell count	Percent
CHLOROPHYTA (green algae)													
CHLOROPHYCEAE													
Volvocales													
Chlamydomonadaceae													
Chlamydomonas spp.		--	--	--	--	50	2.1	--	--	45	0.9	--	--
Chlorococcales													
Oocystaceae													
Ankistrodesmus falcatus		10	1.0	--	--	--	--	--	--	45	.9	530	12.8
Scenedesmaceae													
Scenedesmus obliguus		--	--	--	--	--	--	65	2.2	--	--	--	--
Zygnematales													
Desmidiaceae (placoderm desmids)													
Cosmarium spp.		--	--	--	--	25	1.0	--	--	--	--	--	--
Misc. green algae		50	5.0	--	--	25	1.0	--	--	45	.9	--	--
EUGLENOPHYTA (euglenoids)													
EUGLENOPHYCEAE													
Euglenales													
Euglenaceae													
Trachelomonas spp.		--	--	--	--	--	--	--	--	--	--	35	.8
CHRYSOPHYTA													
CHRYSOPHYCEAE (yellow-brown algae)													
Chrysomonadales													
Ochromonadaceae													
Dinobryon sertularia		35	3.5	--	--	25	1.0	95	3.1	--	--	--	--
BACILLARIOPHYCEAE (diatoms)													
Centrales (centric diatoms)													
Coscinodiscaceae													
Cyclotella meneghiniana		--	--	20	1.2	--	--	--	--	--	--	--	--
C. stelligera		--	--	--	--	--	--	--	--	--	--	330	8.0
Melosira ambigua		35	3.5	20	1.2	--	--	--	--	--	--	--	--
M. distans		10	1.0	--	--	--	--	--	--	--	--	--	--
M. granulata angustissima		35	3.5	35	2.1	50	2.1	30	1.0	45	.9	--	--
M. varians		25	2.5	--	--	--	--	--	--	--	--	--	--
M. spp.		--	--	--	--	--	--	30	1.0	--	--	--	--
Pennales (pennate diatoms)													
Fragilariaceae													
Asterionella formosa		10	1.0	--	--	--	--	--	--	--	--	--	--
Fragilaria construens		10	1.0	--	--	--	--	--	--	--	--	--	--
F. crotonensis		50	5.0	20	1.2	--	--	--	--	45	.9	--	--
F. vaucheriae		--	--	--	--	--	--	30	1.0	--	--	--	--
Synedra rumpens		--	--	20	1.2	--	--	--	--	--	--	--	--
S. ulna		10	1.0	--	--	--	--	--	--	45	.9	35	.8
S. ulna contracta		--	--	--	--	--	--	--	--	45	.9	--	--
S. spp.		--	--	--	--	25	1.0	--	--	--	--	--	--
Achnanthaceae													
Achnanthes lanceolata		10	1.0	--	--	25	1.0	65	2.2	--	--	35	.8
A. lewisiana		15	1.5	35	2.1	--	--	--	--	--	--	--	--
A. linearis		240	24.0	400	24.1	590	24.4	780	25.7	1,900	37.9	1,500	36.0
A. minutissima		50	5.0	70	4.2	130	5.5	30	1.0	190	3.8	35	.8
Cocconeis placentula		40	4.0	120	7.2	75	3.2	65	2.2	280	5.6	200	4.8
Rhoicosphenia curvata		--	--	--	--	50	2.1	30	1.0	--	--	--	--

Table 24.--Phytoplankton identification and abundance, South Santiam RM's 23.4 to 0.1--Continued

DIVISION CLASS Order Family Genus species	River name Sampling site (RM) Date	South Santiam River 23.4 8-4-78		13.95 8-4-78		7.6 8-4-78		0.1 8-4-78		Santiam River 6.4 8-4-78		0.1 8-16-78	
		Cell count	Per-cent	Cell count	Per-cent	Cell count	Per-cent	Cell count	Per-cent	Cell count	Per-cent	Cell count	Per-cent
Naviculaceae (naviculoid)													
Navicula cryptocephala		40	4.0	55	3.3	50	2.1	--	--	45	0.9	--	--
N. decussis		--	--	20	1.2	--	--	--	--	--	--	--	--
N. pupula		--	--	--	--	--	--	--	--	45	.9	--	--
N. salinarum		--	--	--	--	25	1.0	--	--	45	.9	--	--
Stauroneis spp.		10	1.0	--	--	--	--	--	--	--	--	--	--
Gomphonemataceae													
Gomphoneis herculeana		25	2.5	--	--	25	1.0	--	--	--	--	35	0.8
Gomphonema angustata		--	--	35	2.1	50	2.1	--	--	--	--	--	--
G. parvulum		--	--	--	--	--	--	130	4.3	45	.9	--	--
G. tenellum		25	2.5	--	--	--	--	95	3.1	280	5.6	35	.8
G. spp.		--	--	--	--	--	--	--	--	95	1.9	--	--
Cymbellaceae													
Amphora perpusilla		15	1.5	--	--	25	1.0	--	--	--	--	--	--
Cymbella affinis		25	2.5	55	3.3	25	1.0	130	7.6	190	3.8	400	9.6
C. minuta		40	4.0	320	19.2	790	32.8	1,000	33.1	1,450	28.8	770	18.4
C. sinuata		--	--	20	1.2	25	1.0	--	--	--	--	--	--
C. tumida		--	--	20	1.2	25	1.0	30	1.0	45	.9	35	.8
Nitzschiaceae													
Nitzschia acicularis		--	--	--	--	--	--	--	--	--	--	35	.8
N. amphibia		50	5.0	90	5.4	50	2.1	130	4.3	45	.9	35	.8
N. dissipata		15	1.5	110	6.6	25	1.0	30	1.0	--	--	--	--
N. frustulum subsalina		--	--	--	--	25	1.0	--	--	--	--	--	--
N. palea		--	--	20	1.2	--	--	30	1.0	--	--	--	--
N. paleaceae		65	6.5	160	9.6	180	7.5	65	2.2	--	--	130	3.2
N. spp.		--	--	--	--	--	--	30	1.0	--	--	--	--
Misc. pennate diatoms		15	1.5	--	--	25	1.0	--	--	45	.9	--	--
CYANOPHYTA (blue-green algae)													
CYANOPHYCEAE													
Chroococcales (coccoid blue-greens)													
Chroococcaceae													
Microcystis spp.		15	1.5	--	--	--	--	--	--	--	--	--	--
Hormogonales (filamentous blue-greens)													
Oscillatoriaceae													
Lyngbya spp.		--	--	20	1.2	--	--	--	--	--	--	--	--
Oscillatoria spp.		--	--	--	--	--	--	32	1.1	--	--	--	--
Nostocaceae													
Anabaena spp.		15	1.5	--	--	--	--	--	--	--	--	--	--
Misc. blue-green algae		10	1.0	--	--	--	--	--	--	--	--	--	--
	Total	1,000	100.0	1,665	100.0	2,415	100.0	3,020	100.0	5,015	100.0	4,175	100.0

Table 25.--Periphyton identification and abundance, Willamette RM's 185.0 to 86.5

(Common name is indicated in parentheses after division, class, order, or family. Cell count is in thousands of organisms per square inch; percent is percent of total organisms in sample)

DIVISION / CLASS / Order / Family / Genus species	River name: Willamette; Sampling site (RM): 185.0; Date: 8-7-78		McKenzie 0.1 8-7-78		Willamette 161.0 8-7-78		Willamette 132.0 8-8-78		Willamette 118.0 8-16-78		Willamette 107.0 8-16-78		Willamette 86.5 8-16-78	
	Cell count (x10^3)	Percent	Cell count (x10^3)	Percent	Cell count (x10^3)	Percent	Cell count (x10^3)	Percent	Cell count (x10^3)	Percent	Cell count (x10^3)	Percent	Cell count (x10^3)	Percent
CHLOROPHYTA (green algae)														
CHLOROPHYCEAE														
Chlorococcales														
Oocystaceae														
Oocystis spp.	4	1.3	--	--	--	--	--	--	--	--	--	--	--	--
Scenedesmaceae														
Scenedesmus quadricauda	4	1.3	--	--	--	--	25	0.7	--	--	75	0.9	--	--
Misc. green algae	4	1.3	5	0.9	--	--	--	--	--	--	--	--	--	--
CHRYSOPHYTA														
BACILLARIOPHYCEAE (diatoms)														
Centrales (centric diatoms)														
Coscinodiscaceae														
Cyclotella meneghiniana	--	--	--	--	--	--	25	.7	--	--	--	--	--	--
C. spp.	--	--	--	--	--	--	--	--	8	0.9	150	1.7	--	--
Melosira varians	4	1.3	--	--	--	--	--	--	30	3.4	75	.9	75	0.9
M. spp.	4	1.3	--	--	--	--	--	--	--	--	--	--	--	--
Misc. centric diatoms	--	--	--	--	--	--	25	.7	--	--	--	--	150	1.9
Pennales (pennate diatoms)														
Diatomaceae														
Diatoma hiemale mesodon	--	--	--	--	--	--	--	--	8	.9	--	--	--	--
D. vulgare	7	2.4	5	.9	--	--	25	.7	8	.9	--	--	--	--
Fragilariaceae														
Fragilaria construens	--	--	40	7.5	--	--	--	--	--	--	--	--	--	--
F. vaucheriae	--	--	9	1.7	--	--	--	--	15	1.7	--	--	--	--
F. spp.	--	--	--	--	--	--	--	--	--	--	75	.9	--	--
Hanneae arcus	--	--	--	--	--	--	--	--	--	--	75	.9	--	--
Synedra mazamaensis	--	--	--	--	--	--	--	--	8	.9	--	--	--	--
S. parasitica	--	--	--	--	--	--	--	--	--	--	75	.9	--	--
S. ulna	--	--	5	.9	65	.8	230	6.7	30	3.4	75	.9	220	2.8
Achnanthaceae														
Achnanthes lanceolata	7	2.4	5	.9	65	.8	25	.7	15	1.7	230	2.6	220	2.8
A. linearis	35	11.8	30	5.6	590	7.1	280	8.1	95	10.8	680	7.7	2,650	33.0
A. minutissima	7	2.4	55	10.4	65	.8	--	--	60	6.9	75	.9	--	--
Cocconeis placentula	50	16.8	45	8.6	330	4.0	210	6.1	60	6.9	830	9.5	510	6.4
Rhoicosphenia curvata	4	1.3	15	2.8	260	3.1	100	2.9	40	4.5	230	2.6	220	2.8
Naviculaceae (naviculoid)														
Navicula cryptocephala	15	5.1	25	4.8	200	2.4	280	8.1	25	2.8	300	3.4	290	3.6
N. mutica	--	--	5	.9	--	--	--	--	--	--	2,100	24.0	75	.9
N. salinarum	4	1.3	--	--	--	--	25	.7	--	--	380	4.3	75	.9
N. spp.	--	--	5	.9	--	--	--	--	--	--	--	--	--	--
Gomphonemataceae														
Gomphoneis herculeana	7	2.4	--	--	--	--	50	1.5	--	--	--	--	--	--
Gomphonema subclavatum	--	--	--	--	--	--	--	--	8	.9	75	.9	150	1.9
G. tenellum	7	2.4	9	1.7	130	1.6	25	.7	25	2.8	75	.9	290	3.6
G. spp.	4	1.3	5	.9	200	2.4	230	6.7	15	1.7	75	.9	--	--
Cymbellaceae														
Cymbella affinis	30	10.1	5	.9	2,300	27.8	590	17.2	130	14.7	680	7.7	590	7.3
C. minuta	20	6.7	25	4.8	1,100	13.4	670	19.4	95	10.8	600	6.9	1,000	12.5
C. sinuata	--	--	--	--	--	--	50	1.5	--	--	--	--	220	2.8
C. tumida	--	--	--	--	--	--	--	--	--	--	150	1.7	--	--
Nitzschiaceae														
Nitzschia acicularis	--	--	5	.9	--	--	--	--	--	--	--	--	--	--
N. amphibia	7	2.4	35	6.6	720	8.7	280	8.1	70	7.9	75	.9	220	2.8
N. dissipata	4	1.3	20	3.8	--	--	50	1.5	25	2.8	300	3.4	150	1.9
N. frustulum	--	--	5	.9	200	2.4	--	--	--	--	--	--	--	--
N. frustulum subsalina	10	3.4	--	--	200	2.4	75	2.2	55	6.2	75	.9	150	1.9
N. palea	--	--	--	--	65	.8	--	--	--	--	150	1.7	--	--
N. paleaceae	15	5.1	40	7.5	920	11.1	100	2.9	25	2.8	150	1.7	150	1.9
N. spp.	7	2.4	15	2.8	130	1.6	50	1.5	8	.9	680	7.7	440	5.5
Misc. pennate diatoms	30	10.1	9	1.7	330	4.0	--	--	25	2.8	150	1.7	150	1.9
CYANOPHYTA (blue-green algae)														
CYANOPHYCEAE														
Hormogonales (filamentous blue-greens)														
Oscillatoriaceae														
Lyngbya spp.	7	2.4	--	--	--	--	--	--	--	--	--	--	--	--
Oscillatoria spp.	--	--	65	12.3	390	4.8	--	--	--	--	75	.9	--	--
Rivulariaceae														
Amphithrix janthina	--	--	40	7.5	--	--	--	--	--	--	--	--	--	--
Misc. blue-green algae	--	--	5	.9	--	--	25	.7	--	--	--	--	--	--
Total	297	100.0	532	100.0	8,260	100.0	3,445	100.0	883	100.0	8,735	100.0	7,995	100.0

Table 26.--Periphyton identification and abundance, South Santiam RM's 23.4 to 0.1

(Common name is indicated in parentheses after division, class, order, or family. Cell count is in thousands of organisms per square inch; percent is percent of total organisms in sample)

DIVISION / CLASS / Order / Family / Genus species	River name: South Santiam, Sampling site (RM): 23.4, Date: 8-4-78, Cell count ($x10^3$)	Percent	South Santiam, 13.95, 8-4-78, Cell count ($x10^3$)	Percent	South Santiam, 7.6, 8-4-78, Cell count ($x10^3$)	Percent	South Santiam, 0.1, 8-4-78, Cell count ($x10^3$)	Percent	Santiam, 6.4, 8-4-78, Cell count ($x10^3$)	Percent
CHLOROPHYTA										
CHLOROPHYCEAE										
Volvocales										
Chlamydomonadaceae										
Chlamydomonas spp.	--	--	200	5.2	--	--	95	1.7	--	--
Chlorococcales										
Oocystaceae										
Ankistrodesmus falcatus	--	--	--	--	70	1.6	150	2.7	20	0.9
Oocystis spp.	--	--	25	.7	--	--	--	--	--	--
Scenedesmaceae										
Scenedesmus obliquus	--	--	50	1.3	--	--	95	1.7	40	1.8
S. quadricauda	--	--	--	--	--	--	50	.9	--	--
Zygnematales										
Desmidiaceae (placoderm desmids)										
Cosmarium spp.	5	1.9	25	.7	--	--	--	--	--	--
Misc. green algae	--	--	25	.7	--	--	95	1.7	20	.9
CHRYSOPHYTA										
BACILLARIOPHYCEAE (diatoms)										
Centrales (centric diatoms)										
Coscinodiscaceae										
Cyclotella meneghiniana	--	--	--	--	35	.8	--	--	20	.9
Melosira granulata angustissima	--	--	25	.7	--	--	--	--	--	--
M. varians	5	1.9	50	1.3	35	.8	--	--	--	--
Stephanodiscus astrea minutula	--	--	25	.7	35	.8	--	--	--	--
Misc. centric diatoms	2	.8	75	1.9	--	--	--	--	--	--
Pennales (pennate diatoms)										
Fragilariaceae										
Fragilaria construens	--	--	75	1.9	35	.8	--	--	--	--
F. crotonensis	2	.8	75	1.9	--	--	50	.9	--	--
Synedra ulna	5	1.9	25	.7	35	.8	--	--	40	1.8
Achnanthaceae										
Achnanthes lanceolata	5	1.9	--	--	--	--	50	.9	--	--
A. linearis	85	32.5	750	19.6	960	22.0	1,900	34.6	790	34.5
A. minutissima	2	.8	130	3.3	170	3.9	190	3.6	--	--
Cocconeis pediculus	--	--	25	.7	--	--	--	--	--	--
C. placentula	35	13.3	75	1.9	240	5.5	50	.9	20	.9
Rhoicosphenia curvata	5	1.9	25	.7	--	--	--	--	20	.9
Naviculaceae (naviculoid)										
Navicula cryptocephala	7	2.7	100	2.6	--	--	95	1.7	--	--
N. decussis	2	.8	--	--	--	--	50	.9	--	--
N. tripunctata	2	.8	--	--	--	--	--	--	--	--
N. spp.	--	--	25	.7	--	--	--	--	--	--
Gomphonemataceae										
Gomphoneis herculeana	2	.8	25	.7	35	.8	--	--	20	.9
Gomphonema parvulum	--	--	75	1.9	35	.8	190	3.6	--	--
G. subclavatum	--	--	25	.7	--	--	--	--	--	--
G. tenellum	--	--	50	1.3	35	.8	95	1.7	20	.9
G. spp.	5	1.9	25	.7	--	--	340	6.2	--	--
Cymbellaceae										
Cymbella affinis	2	.8	150	3.9	140	3.2	490	8.9	260	11.3
C. cymbiformis	--	--	--	--	--	--	--	--	20	.9
C. minuta	20	7.7	550	14.3	1,000	22.9	1,250	22.9	690	30.3
C. sinuata	--	--	--	--	--	--	50	.9	--	--
C. tumida	--	--	--	--	35	.8	--	--	--	--
Epithemia sorex	2	.8	--	--	--	--	--	--	--	--
Nitzschiaceae										
Nitzschia acicularis	--	--	25	.7	--	--	--	--	--	--
N. acuta	--	--	--	--	35	.8	--	--	--	--
N. amphibia	2	.8	75	1.9	100	2.3	50	.9	40	1.8
N. dissipata	2	.8	75	1.9	--	--	--	--	20	.9
N. frustulum	--	--	--	--	--	--	--	--	40	1.8
N. frustulum subsalina	--	--	--	--	--	--	50	.9	--	--
N. palea	--	--	25	.7	--	--	--	--	--	--
N. paleaceae	15	5.7	250	6.5	1,200	27.5	50	.9	40	1.8
N. spp.	7	2.7	500	13.0	100	2.3	--	--	60	2.5
Misc. Pennate diatoms	15	5.7	150	3.9	35	.8	--	--	60	2.5
CYANOPHYTA (blue-green algae)										
CYANOPHYCEAE										
Hormogonales (filamentous blue-greens)										
Rivulariaceae										
Amphithrix janthina	2	.8	--	--	--	--	--	--	--	--
Colothrix spp.	15	5.7	--	--	--	--	--	--	--	--
Misc. blue-green algae	10	3.8	25	.7	--	--	50	.9	40	1.8
Total	261	100.0	3,830	100.0	4,365	100.0	5,485	100.0	2,280	100.0