Causes and Sources of Water Quality Impairment in the Upper Chehalis River, Washington

by

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A Research Paper

submitted to

Oregon State University

Department of Geosciences

in partial fulfillment of the requirements
for the degree of

Master of Science

April 1993

Directed by

Dr. Keith W. Muckleston

Acknowledgements

I would like to thank Eric Aroner and Paul Pickett for their technical assistance and inspiration. Eric instructed me on the statistical aspects of water quality analysis, and encouraged me to dig deeply into techniques I knew very little about. Paul explained some of the intricacies of water chemistry, and led me to many of the references used in this paper.

Dr. Keith Muckleston has shown great faith in me all these many years since I began my graduate program, and his adept suggestions helped me sharpen the focus of my research.

I would also like to thank my wife Theresa for her tremendous patience and kind encouragement. Now we can both compete for Dr. Science's job.

TABLE OF CONTENTS

FIGURES

TABLES

ABSTRACT

Water quality problems have been identified in the Chehalis River in the vicinity of Centralia and Chehalis since the 1960's. In 1992, the Washington State Department of Ecology listed four Chehalis River segments, three segments of the Newaukum River, two segments of the Wynoochee River, and three other tributaries - Salzer, Dillenbaugh, and Wildcat Creeks - as Water Quality Limited. Of these twelve waterbody segments, seven either include, or are tributary to, the 9.4 mile stretch of the Chehalis River from Scammon Creek to the Newaukum River (River Mile [RM] 65.8 to RM 75.2), referred to as the Centralia reach.

The Chehalis River displays the hydrologic characteristics typical of Western Washington rivers with minimal snowmelt input. Critical low flows occur in later summer, and high flows are almost exclusively associated with intense rainfall. Ambient water quality data show long-term and widespread problems from water quality impairment caused by low dissolved oxygen and high water temperatures during summer low flows, and elevated bacteria counts and turbidity during winter high flows.

Since the passage of the Federal Water Pollution Control Act amendments of 1972, water pollution from point source discharges has decreased. This is true in the Chehalis River Basin, yet water quality in the Centralia reach remains badly impaired. Sources of persistent water quality impairment in the Centralia reach include "natural" conditions (the Centralia reach is deep, slow, and stratified); point sources discharges (waste water treatment plants, food-processing waste); storm water runoff from a variety of nonpoint sources; and poor quality water from the Chehalis River upstream and other tributaries of the Centralia reach.

Water quality conditions in the Centralia reach resemble the nutrient-rich conditions of many eutrophic lakes in Western Washington, except that nitrogen rather than phosphorus limits algal growth. Data indicate that the Chehalis waste water treatment plant is probably the greatest contributing source of phosphorus loading to the Centralia reach.

INTRODUCTION

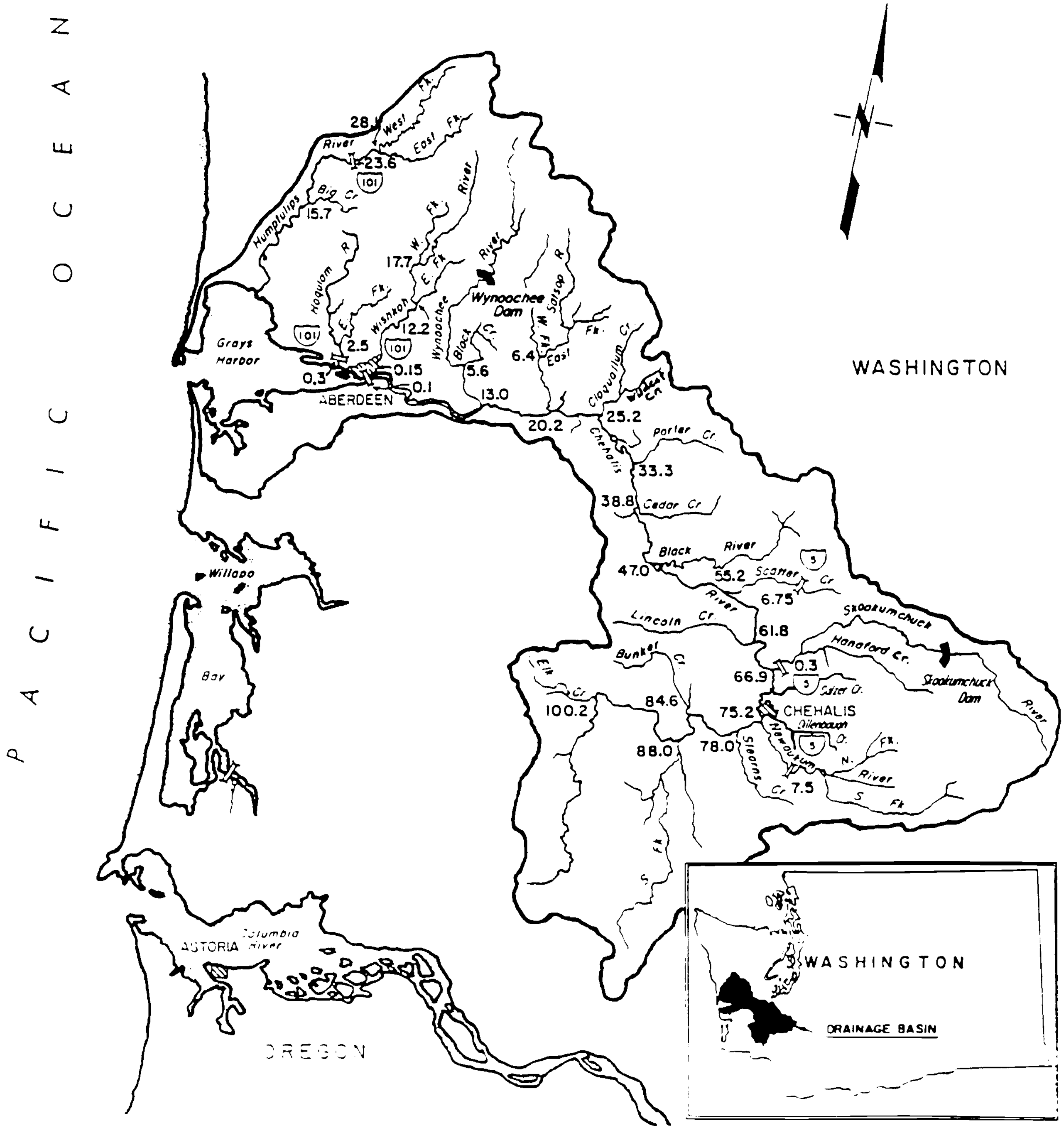
The upper Chehalis River and its tributaries (from the headwaters to Grand Mound) have experienced long-standing water quality problems and impairment of beneficial uses. Since at least the 1960's, severe water quality impairment in the stretch of the Chehalis River from Scammon Creek to the Newaukum River (Figure 1), herein referred to as the Centralia reach, has been recognized by state and federal agencies.

Water quality has been degraded by both point and nonpoint sources of pollution. In 1990, the Washington State Department of Ecology (Ecology) listed two upper Chehalis River segments, three segments of the Newaukum River, and two other tributaries - Salzer, and Dillenbaugh Creeks as water quality limited (Ecology, 1990). Waterbodies are considered to be water quality limited if they are not expected to fully support designated beneficial uses and the Clean Water Act's fishable and swimmable goals after the application of technology-based treatment requirements.

The Centralia reach has been the site of chronic low dissolved oxygen and high water temperatures in the late summer and early fall during low-flow periods (Joy, 1984). In addition to low dissolved oxygen and high water temperatures, water quality problems in the Centralia reach include bacterial contamination. Continued population growth and developmental pressures threaten to further impair beneficial uses of the Chehalis River and its tributary streams.

In the Centralia reach, the most serious oxygen-depletion events have been attributed to inadequate sewage treatment facilities at Chehalis and the accidental discharge of food-processing wastes into Salzer Creek (Devitt, 1972; Houck, 1980). The quality of water entering the Centralia reach from upstream also has a strong influence on dissolved oxygen levels. Federal and state water quality agencies have taken steps to mitigate these problems, yet the Centralia reach annually fails to meet water quality standards.

Figure 1.



LOCATION MAP

CHEHALIS RIVER BASIN
RIVER MILE INDEX

This research paper is designed to identify the causes and sources of persistent water quality impairment in the Centralia reach.

BACKGROUND

The Chehalis River Basin upstream of Grand Mound covers an area of 772 square miles in Western Washington. It includes northwestern Lewis County, southeastern Thurston County, and small portions of Pacific, Cowlitz and Wahkiakum Counties. The largest urban areas of the upper basin, Chehalis (6,000) and Centralia (12,000), are located on the south and north end of the Centralia reach, respectively (Office of Financial Management, 1992).

The upper basin is bounded on the west by the Willapa Hills, on the east by the Cascade foothills, on the north by the Black Hills, and on the south by the Cowlitz River Basin. Elevations vary from 100 feet at Grand Mound, to the 3,110 feet Boistfort Peak in the Willapa Hills.

Land use in the upper basin encompasses a wide range of activities. Forests dominate the landscape of the upper Chehalis River Basin, especially at higher elevations. Seventy-six percent of the forested land is privately owned, most of it corporate owned (U. S. Department of Agriculture, 1975). Agriculture is the principal land use in river valleys, particularly dairy, poultry, hay, row crops, and animal pasture. Several private aquaculture facilities are located in southern Thurston County, and one in Lewis County. Industrial development is mostly limited to the Chehalis/Centralia area and to the coal mine/power plant site south of Bucoda, with isolated facilities in various other locations. Rapid population growth is occurring along the entire I-5 corridor in the upper Chehalis Basin, but especially in southern Thurston County.

AMBIENT MONITORING AND ANALYSIS

Ambient monitoring stations exist at several locations in the upper Chehalis River Basin. The U. S. Geological Survey (USGS) has measured flow at 13 different locations in the upper basin since 1910. USGS currently measures flow on the upper Chehalis River at Doty (River Mile [RM] 101.8), Grand Mound (RM 59.9), and on two tributaries, the Newaukum and Skookumchuck Rivers (USGS, 1985). Flow and water quality data are published annually by USGS. Data are also available from the Environmental Protection Agency's STORET database.

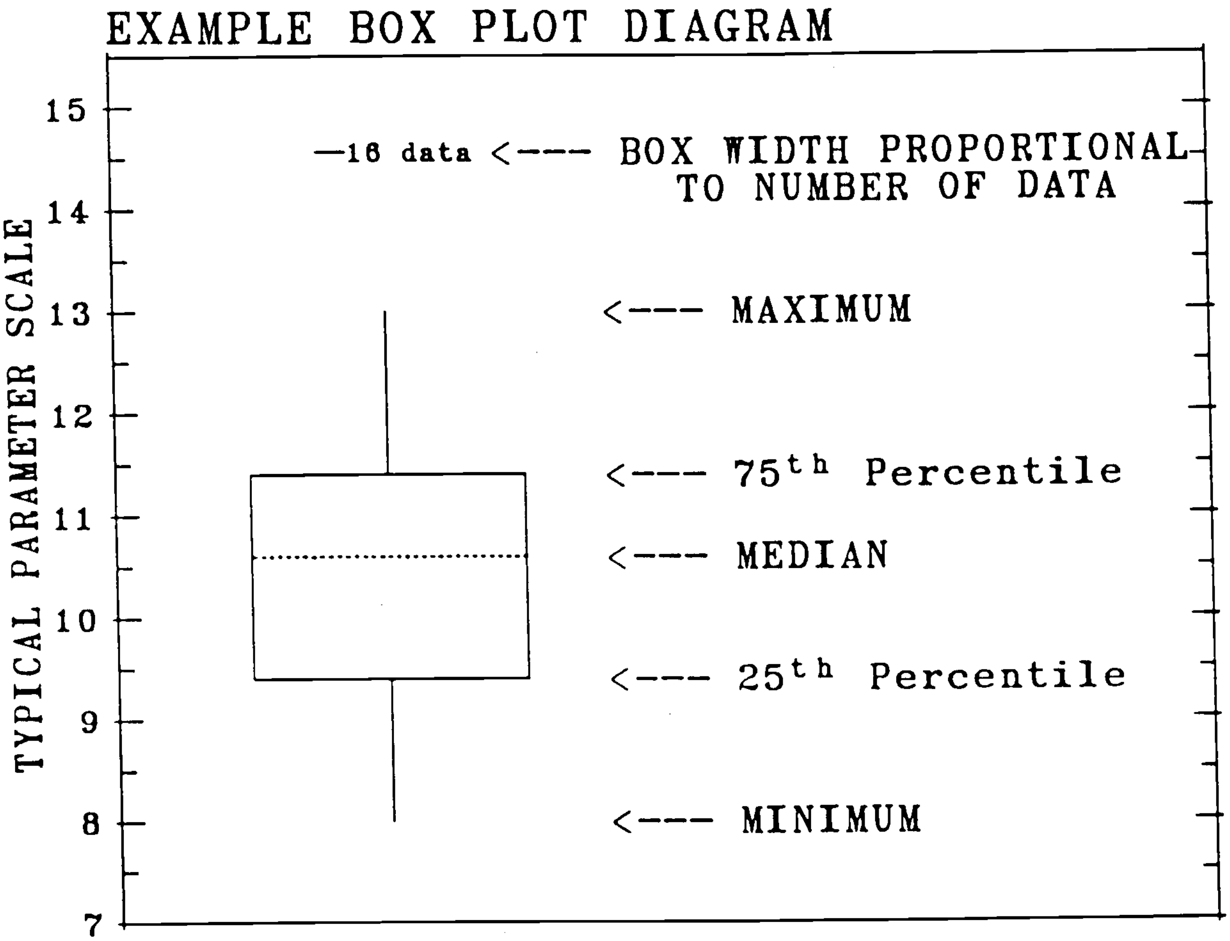
Historically, the Washington Department of Ecology Ambient Monitoring Section has collected data at several water quality stations in the Chehalis River Basin, including stations at Dryad (RM 101.3), Centralia (RM 67.5), Porter (RM 33.3), and Montesano (RM 13.2) (Ecology, 1991). Data also exist for the Newaukum, Skookumchuck, Black, and Satsop Rivers. Porter, Dryad and Centralia are currently monitored monthly. The other stations either were monitored in previous years and have been discontinued, or are currently monitored monthly one year out of three.

The "WQHYDRO" environmental data presentation/analysis package (Aroner, 1991) was used for the statistical analyses and graphical displays of ambient water quality data used in this report (1978-1991). An explanatory plot (Figure 2) explains the "box and whiskers" plots shown in some of the water quality assessment figures.

Hydrologic Characteristics

The Chehalis River system is largely rain-fed with precipitation levels which range from 45 inches per year in the valley near Chehalis and Centralia, to over 80 inches per year in the Newaukum and Skookumchuck headwaters, and over 120 inches in the Willapa Hills (Figure 3, Glancy 1971). The Chehalis River displays the hydrologic characteristics typical of Western Washington rivers with minimal snowmelt input. Critical low flows

Figure 2.


EXAMPLE BOX PLOT DIAGRAM
TYPICAL PARAMETER SCALE
15
14
13
12
11
10
9
8
7
—16 data <---- BOX WIDTH PROPORTIONAL TO NUMBER OF DATA
<--- MAXIMUM
<--- 75th Percentile
<--- MEDIAN
<--- 25th Percentile
<--- MINIMUM

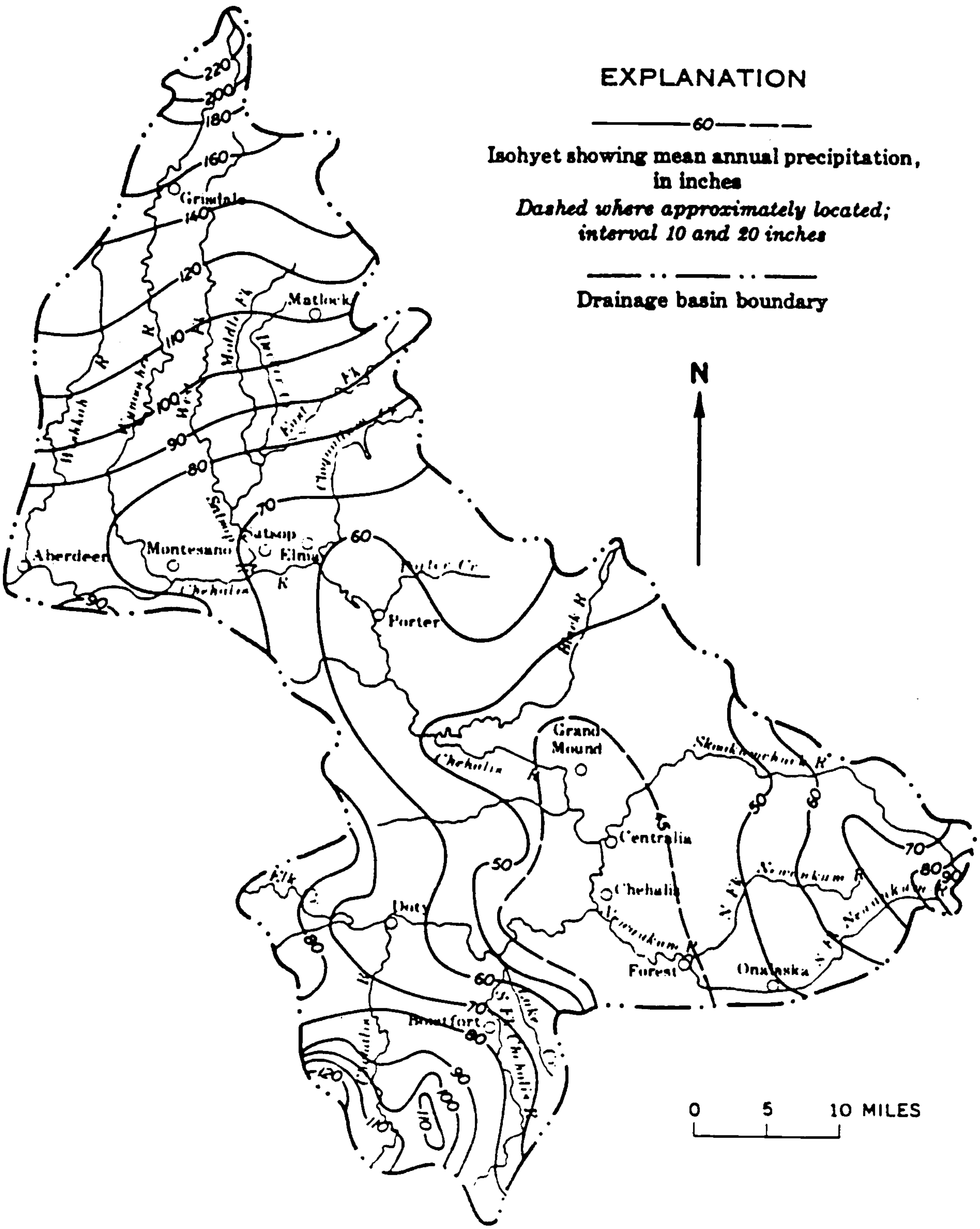


Figure 3. Areal distribution of mean annual precipitation, Chehalis River basin. Prepared by U.S. Weather Bureau, using adjusted climatological data (1930-57) and values derived by correlation with physiographic factors. Published by Glancy, 1971.

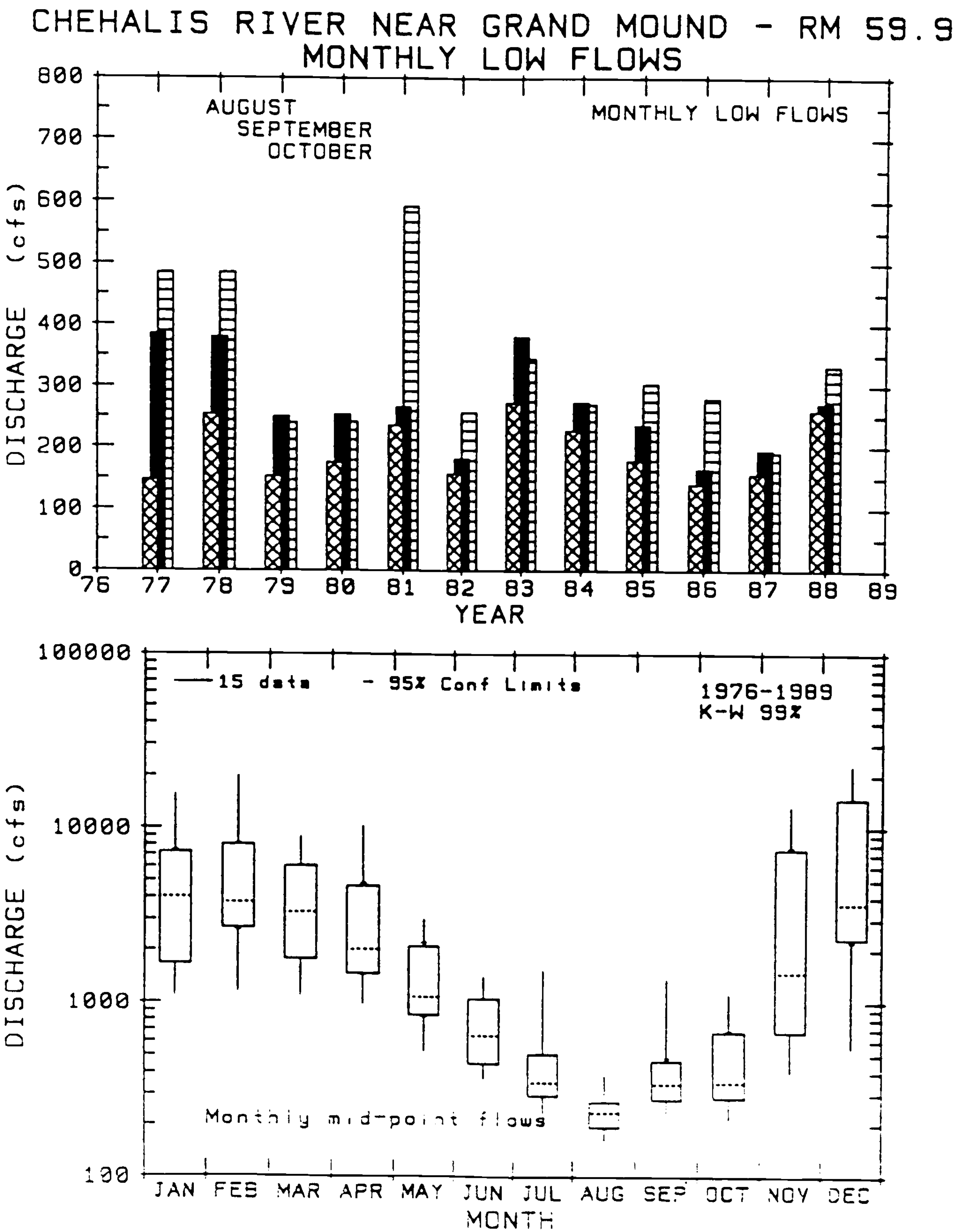
occur in later summer, and high flows are almost exclusively associated with intense rainfall.

Seasonally, rainfall follows the pattern for the maritime Northwest. Maximum monthly rainfall occurs in November through March. July and August are the months of lowest rainfall. November rainfall averages almost 8 inches, and occasionally reaches 12 inches. July rainfall averages less than 1 inch, and rarely exceeds 2 inches.

The Chehalis River Basin is not glacially fed, although snowmelt makes a minor contribution to flows in the upper Skookumchuck and Newaukum River watersheds. In general, the flow regimes follow the classic pattern of ground water recharge/release and overland flow from excess rainfall. The response of the watershed to normal rainfall is typically a function of soil saturation, land use, topography, channel characteristics, the pattern and timing of rain cells, and other factors. Intense sustained rainfall may result in flooding, as was experienced in January and November of 1990. Critical low flows occur in the summer, when flow is sustained by ground water baseflow. Typically, low rainfall years correspond to low flow years.

The seasonal pattern of Chehalis River discharge can be seen in Figure 4, which shows monthly flows recorded by the USGS from 1977 through 1988 at the Grand Mound station. Maximum flows occur in December through March, and critical low flows occur in August. Monthly low flows range from 150 cubic feet per second (cfs) to 250 cfs at Grand Mound. Monthly peak flows have been measured at over 20,000 cfs at Grand Mound. Instantaneous flows during the January 1990 flood were the highest on record - 68,700 cfs at Grand Mound on January 10.

Critical low flows are defined by the seven-day low flow which recurs once every ten years on the average (7Q10). The 7Q10 flows for the upper Chehalis River and tributaries are shown in Table 1. A low mean flow of 82 cfs occurred at the Grand Mound station in August 1967 (Hubbard, 1991). Since the Skookumchuck River flow is controlled by the Bloody Run Dam, 7Q10 flows are not specified for it. More study would be needed to



CHEHALIS RIVER NEAR GRAND MOUND - RM 59.9
MONTHLY LOW FLOWS
AUGUST
SEPTEMBER
OCTOBER
MONTHLY LOW FLOWS
DISCHARGE (cfs)
800
700
600
500
400
300
200
100
0
76 77 78 79 80 81 82 83 84 85 86 87 88 89
YEAR
100000
10000
1000
100
15 data
95% Conf Limits
1976-1989
K-W 99%
Monthly mid-point flows
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTH

Figure 4.

define critical low flow in that situation, since the 7Q10 may not be the appropriate estimation method.

Table 1. Critical Low Flows for the upper Chehalis River and Tributaries.
(7Q10 using log-Pierson III analysis)

Station	ID#	Period of Record	Flow (cfs)
Chehalis at Doty	12020000	1941-1979	21.4
Chehalis near Grand Mound	12027500	1930-1979	114.4
South Fork Chehalis near Boistfort	12020900	1967-1979	0.7
Newaukum near Chehalis	12025000	1930-1979	21.5

Temperature

"Temperature shall not exceed 18.0°C (fresh water) ... by greater than 0.3° ... due to human activities." WAC 173-201-045(2)(c)(iv)

Number of observations exceeding 18.3°C / total observations:

	ANNUAL	SEASONAL
Dryad (RM 101.3)	17/163	June - September: 15/52
Centralia (RM 67.5)	32/164	June - September: 32/52
Porter (RM 33.3)	15/147	June - September: 15/44
Montesano (RM 13.2)	4/164	June - September: 14/52

Figure 5 shows the distribution of recorded temperatures from June through September at the four Chehalis River monitoring stations. The water quality criterion of 18°C is also indicated. Water temperature exceeds the criterion for more than 25% of the samples at all Chehalis River stations during this season, and for more than 50% of the samples at the Centralia station.

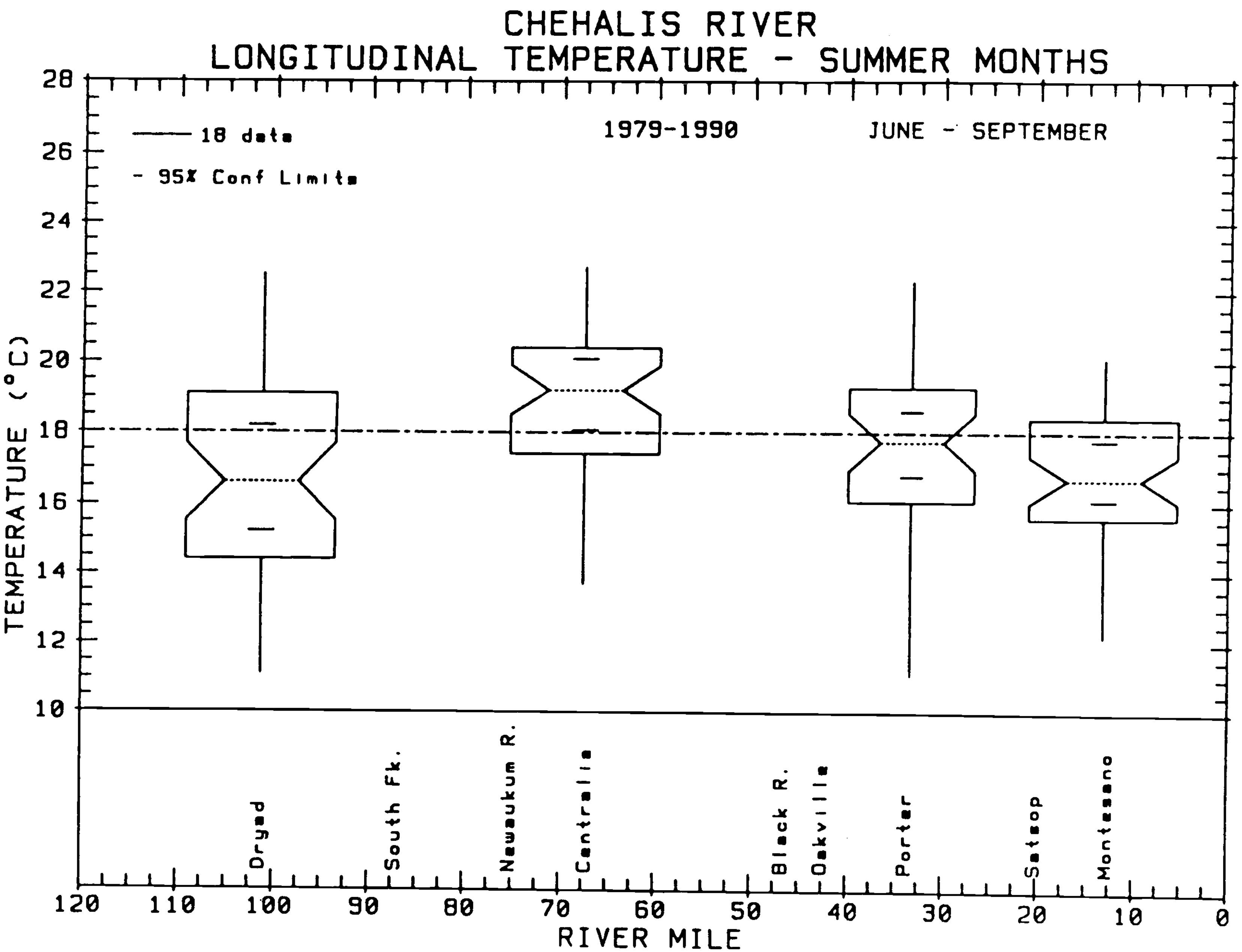

CHEHALIS RIVER
LONGITUDINAL TEMPERATURE - SUMMER MONTHS
18 data
- 95% Conf Limits
1979-1990
JUNE - SEPTEMBER
TEMPERATURE (°C)
28
26
24
22
20
18
16
14
12
10
Dryad
South Fk.
Newaukum R.
Centralia
Black R.
Oakville
Porter
Satsop
Montesano
120
110
100
90
80
70
60
50
40
30
20
10
0
RIVER MILE

Figure 5.

The seasonal pattern of temperature is illustrated in Figure 6 with data from the Centralia station. Exceedances occurred every year during the summer months, with the worst problems observed in July.

Dissolved Oxygen

"Freshwater - dissolved oxygen shall exceed 8.0 mg/L."
WAC 173-201-045(2)(c)(ii)(A)

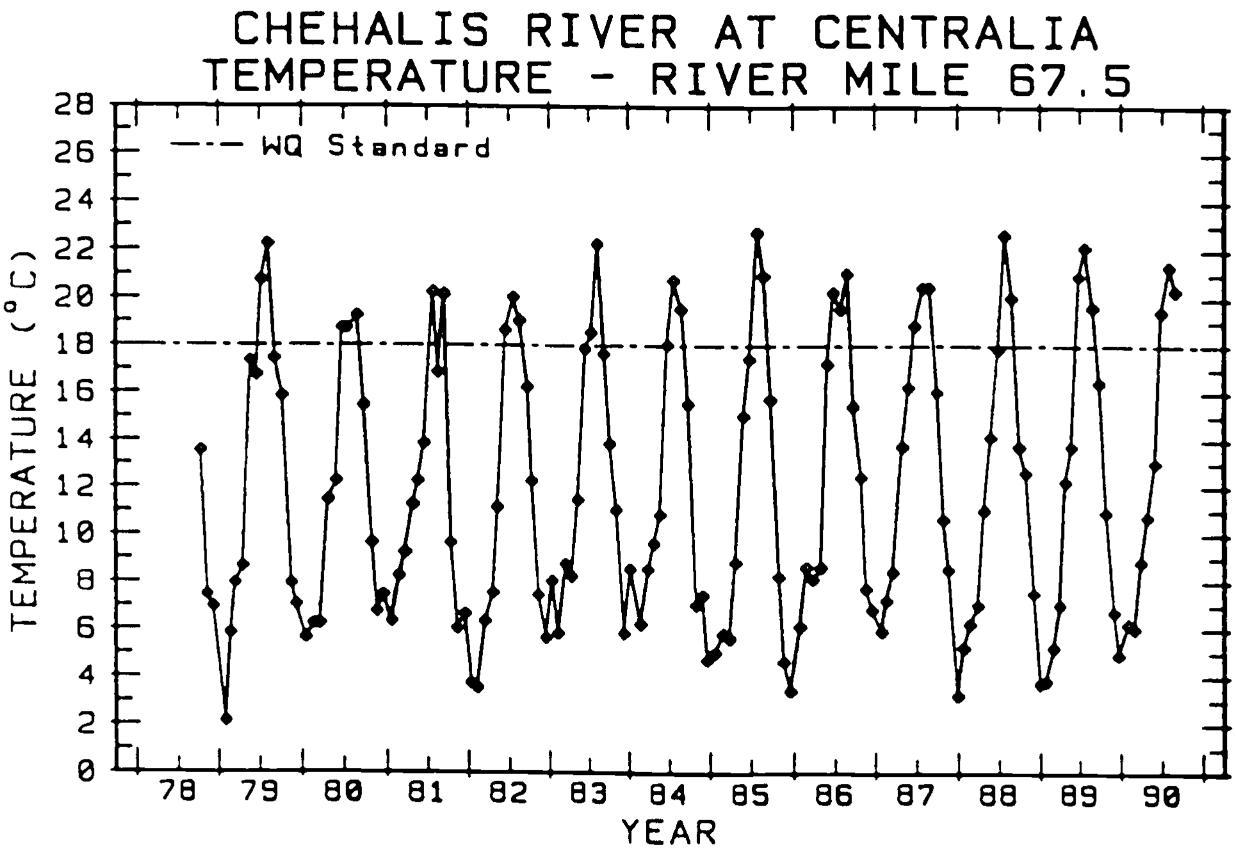
"Chehalis River from Scammon Creek (RM 65.8) to Newaukum River (RM 75.2). Special condition - dissolved oxygen shall exceed 5.0 mg/L from June 1 to September 15. For the remainder of the year, the dissolved oxygen shall meet Class A criteria."
WAC 173-201-080(8)

Number of observations less than or equal to 8.0 mg/L O_2 / total observations (also Centralia - June 1 -Sept. 15: number of observations less than or equal to 5.0 mg/L O_2 / total observations):

	ANNUAL	SEASONAL	
Dryad (RM 101.3)	0/157	---	
Centralia (RM 67.5)	10/162	June - September:	1/43
		September 16 - May:	9/119
Porter (RM 33.3)	4/137	June - September:	4/43
		October - May:	0/94
Montesano (RM 13.2)	1/159	June - September:	1/51
		October - May:	0/108

Dissolved oxygen (D.O.) measurements at the four Ecology Chehalis River ambient stations during June through September are shown in Figure 7. Dissolved oxygen levels less than criteria have been observed at Centralia and Porter. A graph of D.O. values at Centralia plotted by month (Figure 8) shows that excursions below the criteria have occurred from April through October.

Dissolved oxygen is influenced by a number of factors including temperature; the discharge of pollutants that exert Biochemical Oxygen Demand (BOD); and oxygen use by plant, animal, and microbial respiration. High temperatures in the river reduce the


CHEHALIS RIVER AT CENTRALIA
TEMPERATURE - RIVER MILE 67.5
WQ Standard
TEMPERATURE (°C)
YEAR

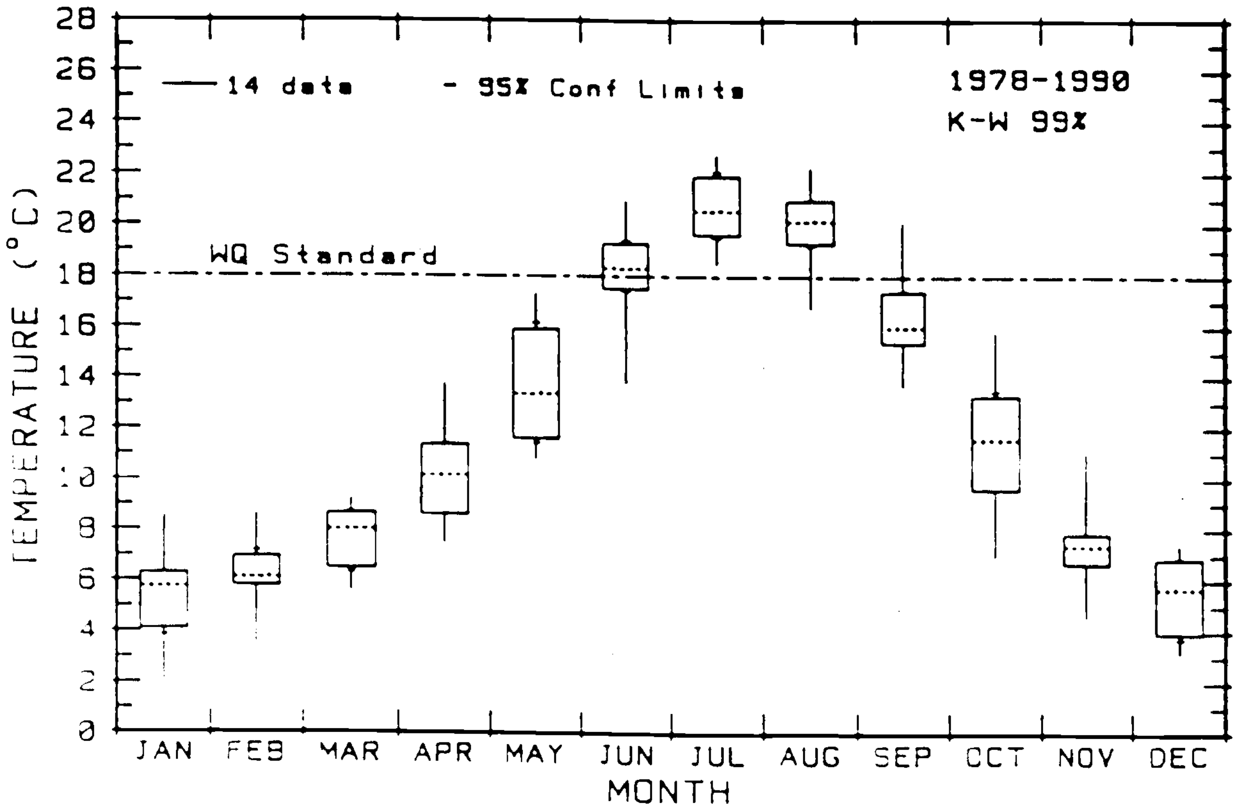
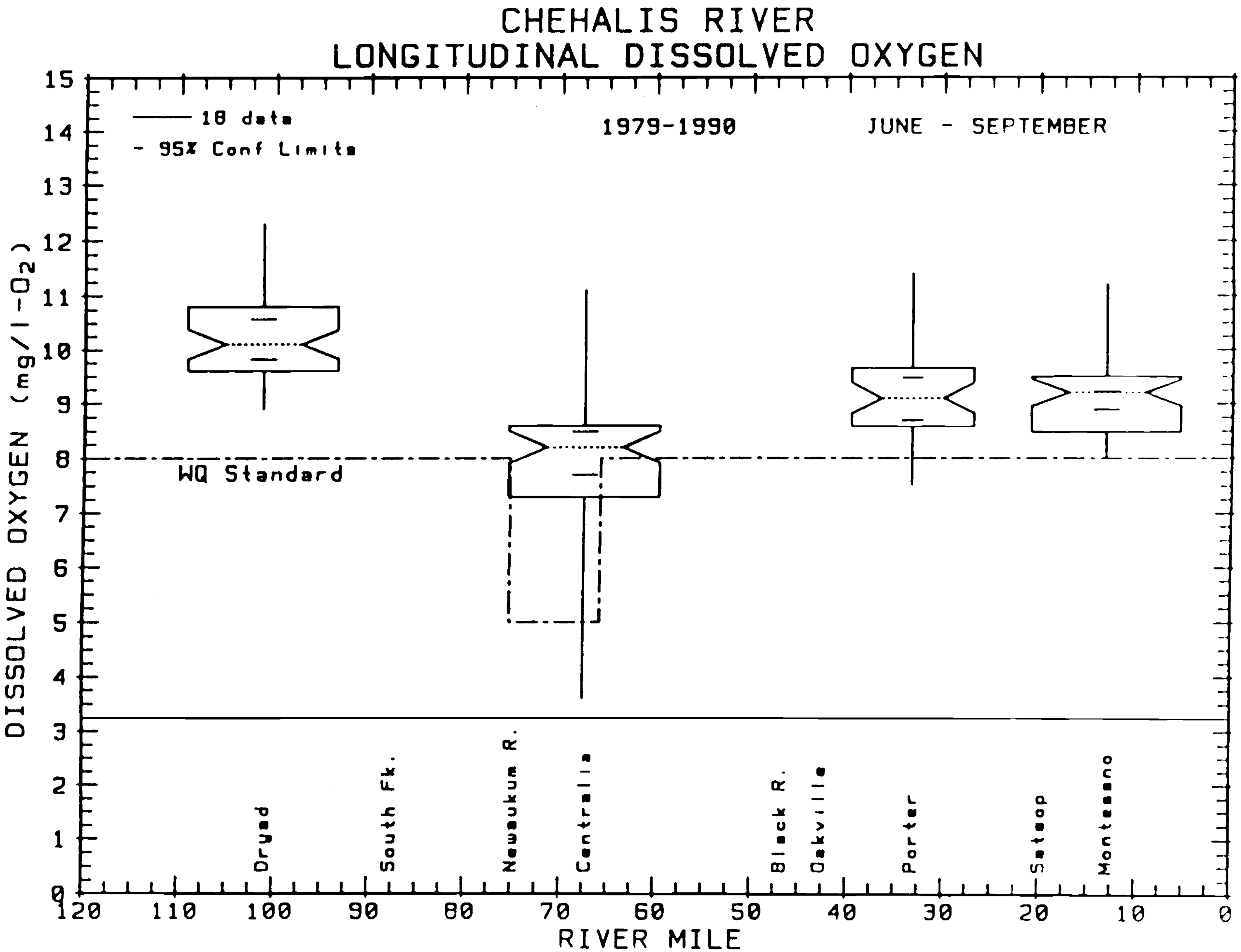

14 data
95% Conf Limits
1978-1990
K-W 99%
WQ Standard
TEMPERATURE (°C)
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTH

Figure 6.



CHEHALIS RIVER
LONGITUDINAL DISSOLVED OXYGEN
18 data
- 95% Conf Limits
1979-1990
JUNE - SEPTEMBER
WQ Standard
DISSOLVED OXYGEN (mg/l-O_2)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Dryad
South Fk.
Newaukum R.
Centralia
Black R.
Oakville
Porter
Satsop
Montesano
120
110
100
90
80
70
60
50
40
30
20
10
0
RIVER MILE

Figure 7.

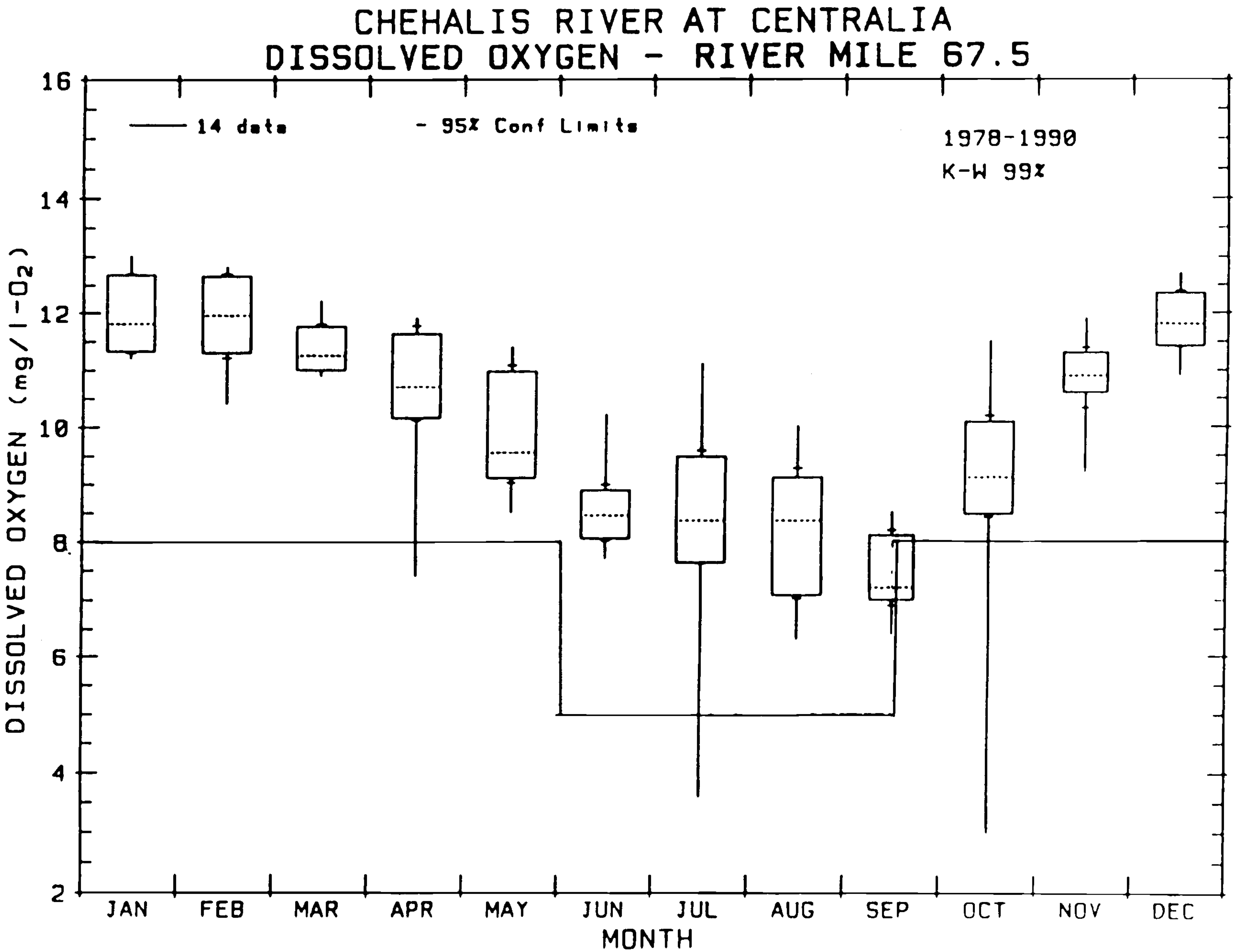

CHEHALIS RIVER AT CENTRALIA
DISSOLVED OXYGEN - RIVER MILE 67.5
14 data
- 95% Conf Limits
1978-1990
K-W 99%
DISSOLVED OXYGEN (mg/l-O2)
16
14
12
10
8
6
4
2
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTH

Figure 8.

saturated dissolved oxygen concentration. In addition, numerous studies have identified BOD loading and "eutrophication," or enhanced plant and algae growth, as probable causes of D.O. problems in the Chehalis River. These studies are described in a separate section of this paper.

pH

"pH shall be within the range of 6.5 to 8.5 (freshwater) ... "
WAC 173-201-045(2)(c)(v)

number of observations less than 6.5 / number greater than 8.5 / total observations:

	ANNUAL	SEASONAL
Dryad (RM 101.3)	1/2/163	2 summer; 1 winter
Centralia (RM 67.5)	1/1/164	1 summer, 1989; 1 winter, 1990
Porter (RM 33.3)	1/0/149	November, 1977
Montesano (RM 13.2)	1/0/164	December, 1977

Figure 9 shows pH for all months at the four Chehalis stations monitored by Ecology. Over a 13 year period, Dryad and Centralia have experienced excursions outside the criteria once and twice, respectively. The seasonal pattern of pH is consistent, with high values in the summer and low values in the winter.

High and low pH values in the upper Chehalis system, if not caused by natural processes, are likely associated with other pollution problems, such as nonpoint organic sources in the winter and eutrophication in the summer. Control of those sources through other indicators (turbidity, bacteria, D.O.) would probably reduce pH excursions. Also, the excursions are rare, and other studies have not revealed a widespread problem.

Fecal Coliform Bacteria

"Freshwater - fecal coliform organisms shall not exceed a geometric mean value of 100 organisms/100 mL, with not more than 10 percent of samples exceeding 200 organisms/100 mL." WAC 173-201-045(2)(c)(i)(A)

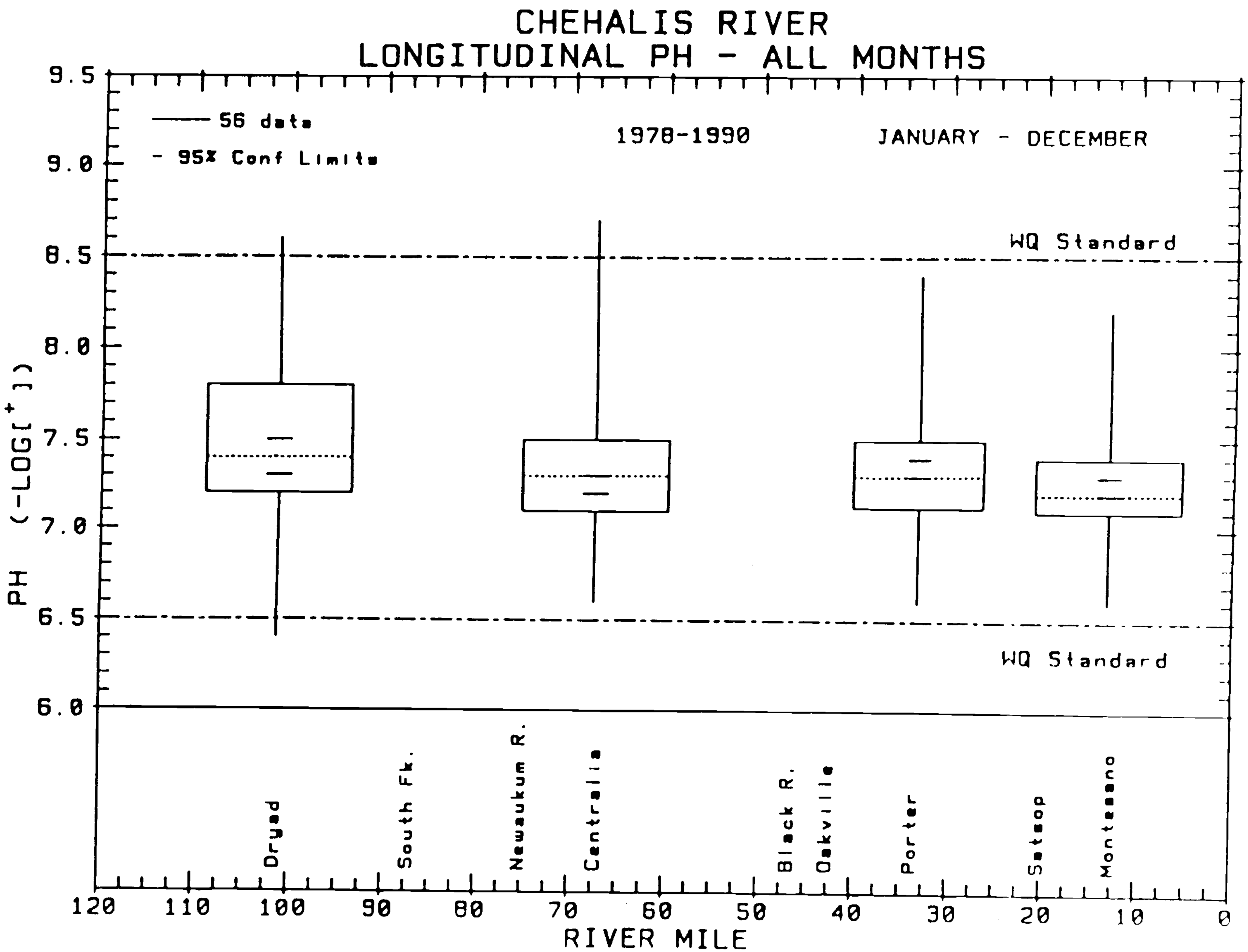

CHEHALIS RIVER
LONGITUDINAL PH - ALL MONTHS
— 56 data
- 95% Conf Limits
1978-1990
JANUARY - DECEMBER
WQ Standard
WQ Standard
PH (-LOG[+])
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
Dryad
South Fk.
Newaukum R.
Centralia
Black R.
Oakville
Porter
Satsop
Montesano
120
110
100
90
80
70
60
50
40
30
20
10
0
RIVER MILE

Figure 9.

number of observations greater than 200 mg/L / total observations:

	ANNUAL	SEASONAL
Dryad (RM 101.3)	7/158	June - September: 3/51 October - May: 4/107
Centralia (RM 67.5)	35/161	June - September: 2/52 October - May: 33/109
Porter (RM 33.3)	12/99	June - September: 0/32 October - May: 12/67
Montesano (RM 13.2)	31/159	June - September: 4/51 October - May: 27/108

Fecal coliform levels at the four Chehalis River ambient monitoring stations are shown in Figure 10. Comparison of the two seasons show that median and upper quartile values are higher in the wet season at the stations downstream of Dryad.

Figures 11 and 12 demonstrate bacteria standard compliance using a calendar year time frame for two mainstem sites. If the figure indicates that the 90th percentile for a particular year exceeds the criterion of 200 organisms/100mL, then more than 10% of the samples exceeded the criterion, which violates the water quality standard. For Centralia, the 10-year percentile standard was violated almost every year. Dryad also has several years with exceedances, although fewer than Centralia. The calendar year geometric mean, shown in the bottom plots, was exceeded in one year at Centralia.

This analysis indicated that violations of fecal coliform standards are a significant problem in the upper Chehalis Basin. The highest values are observed in the wet season, which would indicate contaminated storm water runoff as a probable source.

Turbidity

> "Turbidity shall not exceed 5 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 10 percent increase in turbidity when the background turbidity is more than 50 NTU." WAC 173-201-045(2)(c)(vi)

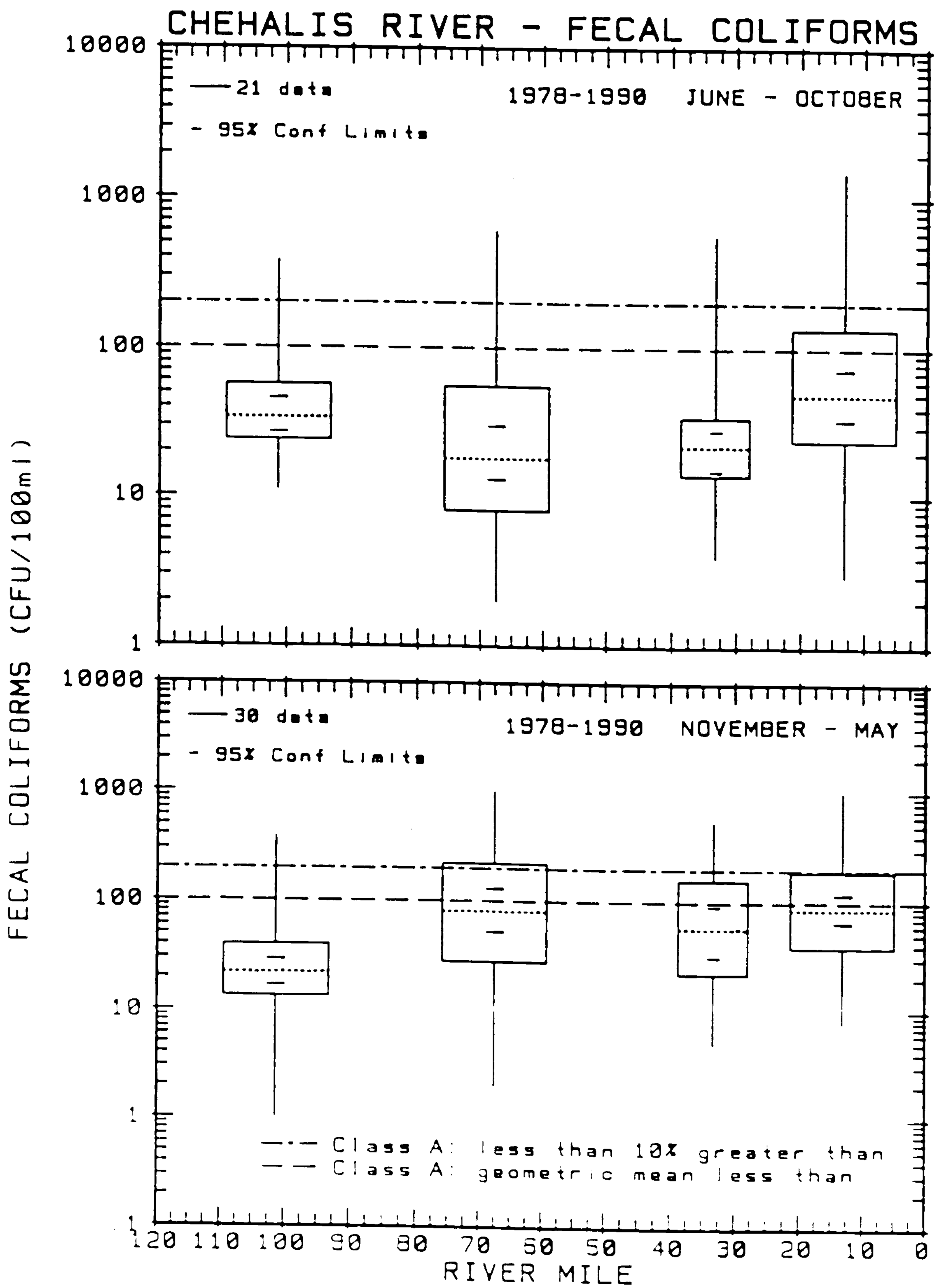
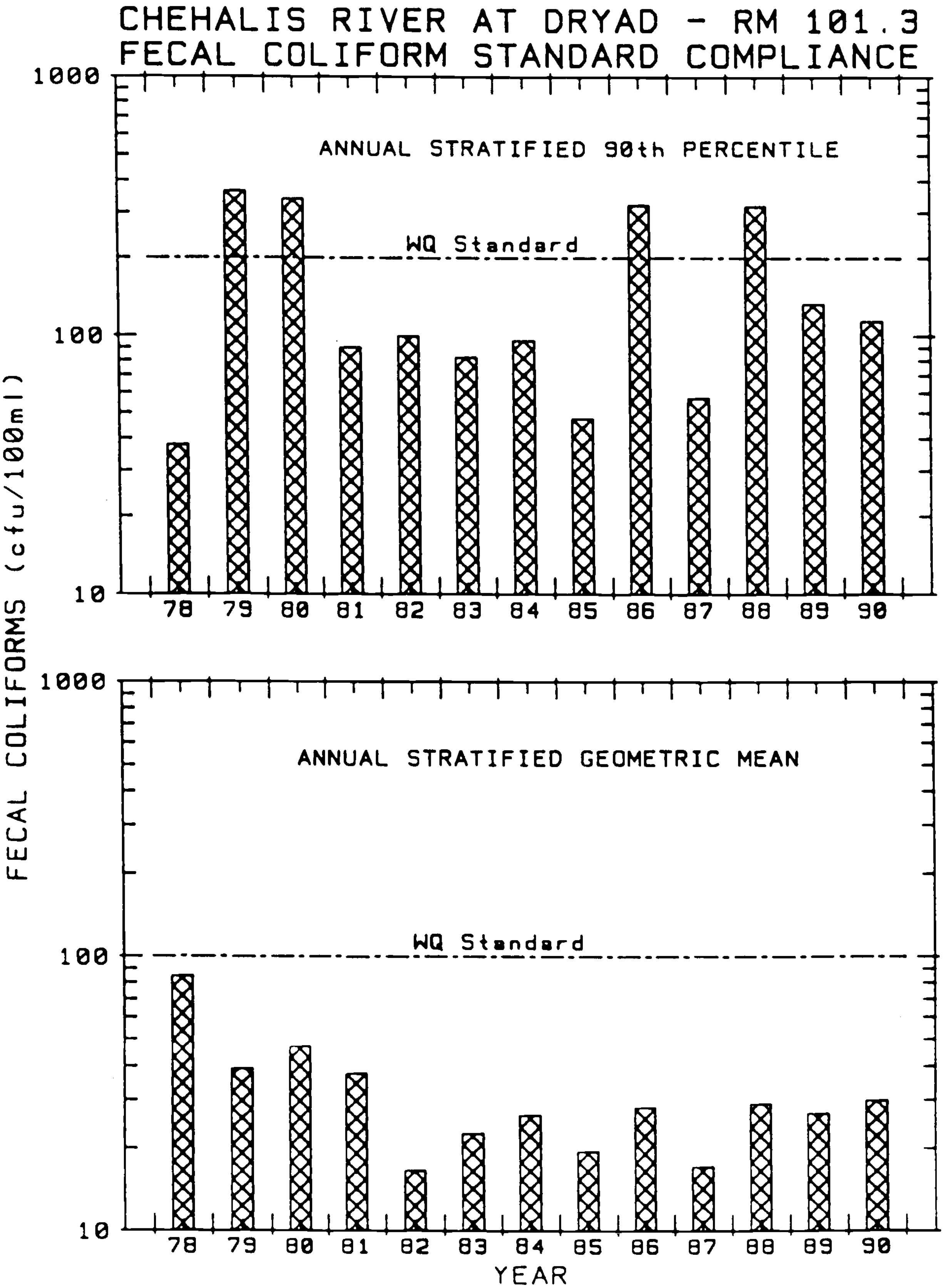
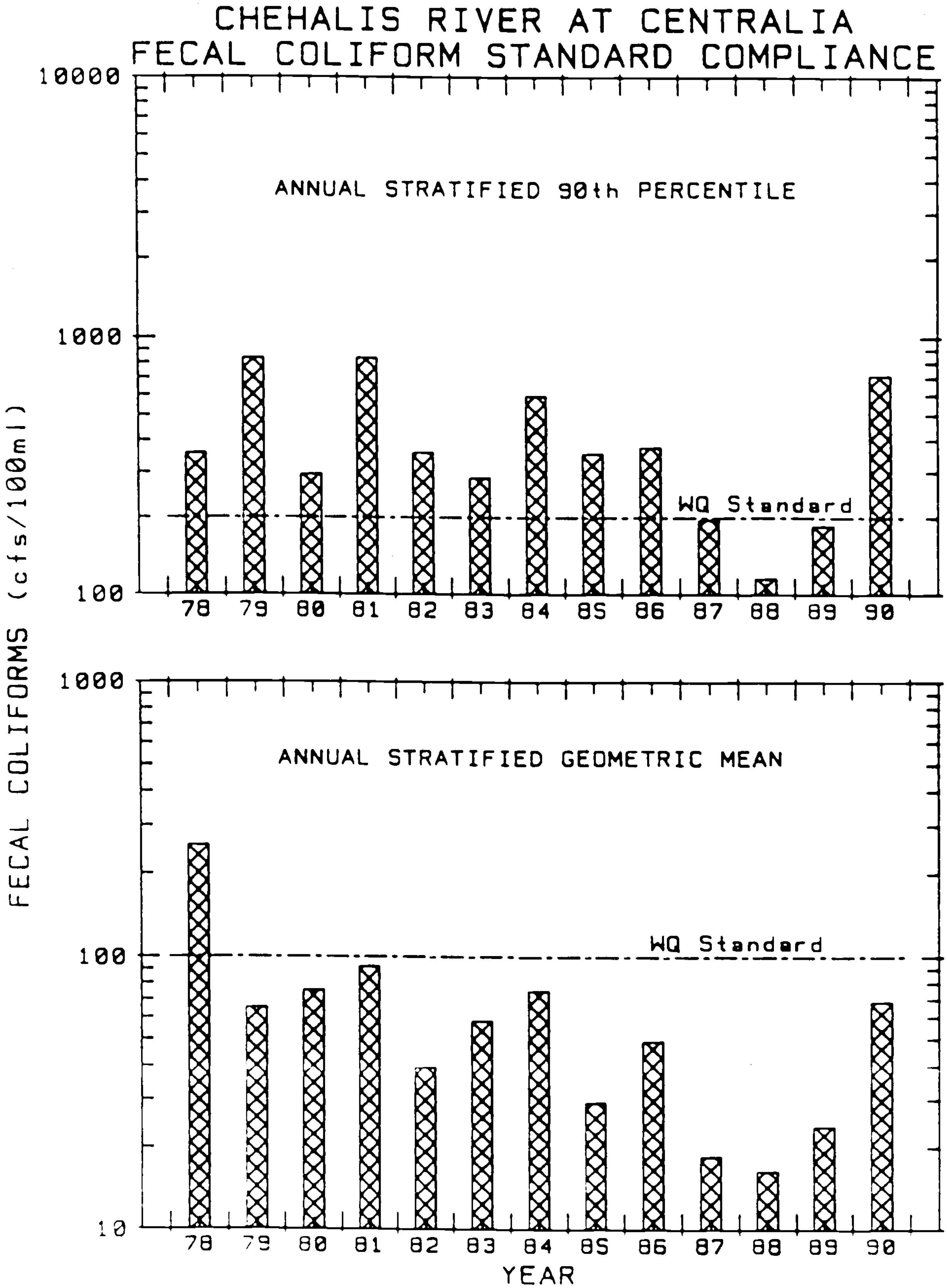

CHEHALIS RIVER - FECAL COLIFORMS
21 data
95% Conf Limits
1978-1990 JUNE - OCTOBER
30 data
95% Conf Limits
1978-1990 NOVEMBER - MAY
Class A: less than 10% greater than
Class A: geometric mean less than
FECAL COLIFORMS (CFU/100ml)
RIVER MILE

Figure 10.



CHEHALIS RIVER AT DRYAD - RM 101.3
FECAL COLIFORM STANDARD COMPLIANCE
ANNUAL STRATIFIED 90th PERCENTILE
WQ Standard
1000
100
10
78 79 80 81 82 83 84 85 86 87 88 89 90
FECAL COLIFORMS (cfu/100ml)
ANNUAL STRATIFIED GEOMETRIC MEAN
WQ Standard
1000
100
10
78 79 80 81 82 83 84 85 86 87 88 89 90
YEAR

Figure 11.



CHEHALIS RIVER AT CENTRALIA
FECAL COLIFORM STANDARD COMPLIANCE
ANNUAL STRATIFIED 90th PERCENTILE
WQ Standard
ANNUAL STRATIFIED GEOMETRIC MEAN
WQ Standard
FECAL COLIFORMS (cfs/100ml)
10000
1000
100
10
78
79
80
81
82
83
84
85
86
87
88
89
90
YEAR

Figure 12.

Figure 13 shows seasonal turbidity at the four Chehalis River ambient monitoring stations. The line marked "WQ Standard" indicates the 50 NTU level. Although it is difficult to interpret the regulations in the context of these graphs, one can observe that the range of turbidity spans several orders of magnitude. Since the vertical scale is logarithmic, the magnitude of the peak values at all stations as compared to the upper range of the quartiles would indicate extremely elevated turbidity values. In addition, turbidity during the November through April period in comparison to the May through October period has a higher median value at stations downstream of Dryad, and a higher peak value at all stations.

This analysis indicates that elevated turbidity is occurring in the wet season. The magnitude of some turbidity values may indicate that land uses are causing violations of water quality standards. However, more study is needed to determine background levels for the Chehalis system, the conditions that result in turbidity exceedances, and the locations where exceedances are a chronic problem.

Conductivity

Conductivity, also called specific conductance, is an indirect measure of the amount of dissolved solids in the water. Conductivity at the four ambient monitoring stations in the Chehalis River is shown in Figure 14.

On the average, conductivity is highest at Centralia, and lowest in the headwaters near Dryad. Conductivity decreases downstream of Centralia and is lower in winter, probably as a result of dilution at higher flows. The data indicate that the highest concentration of dissolved constituents observed in the river are found in the summer at the Centralia station.

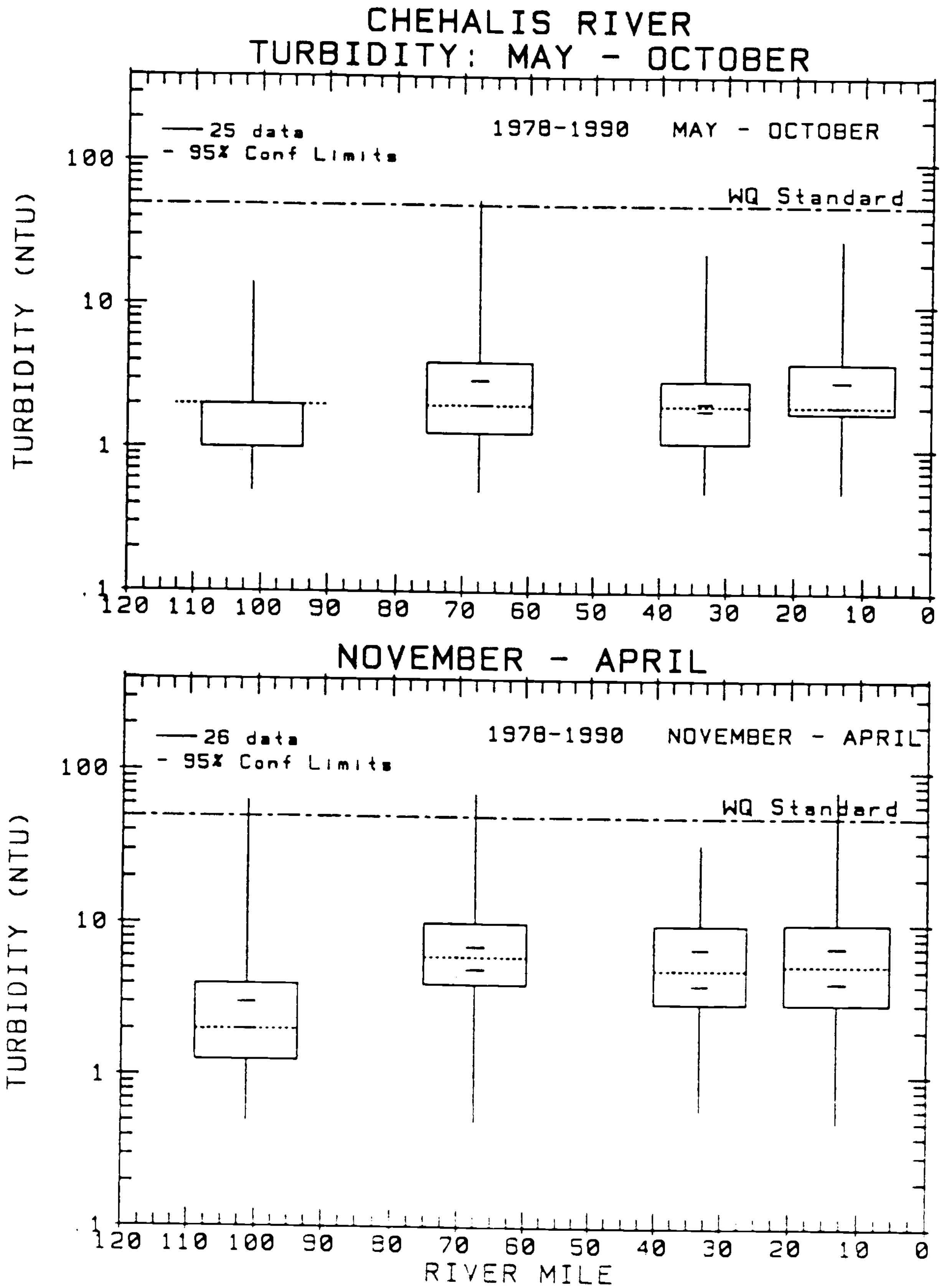
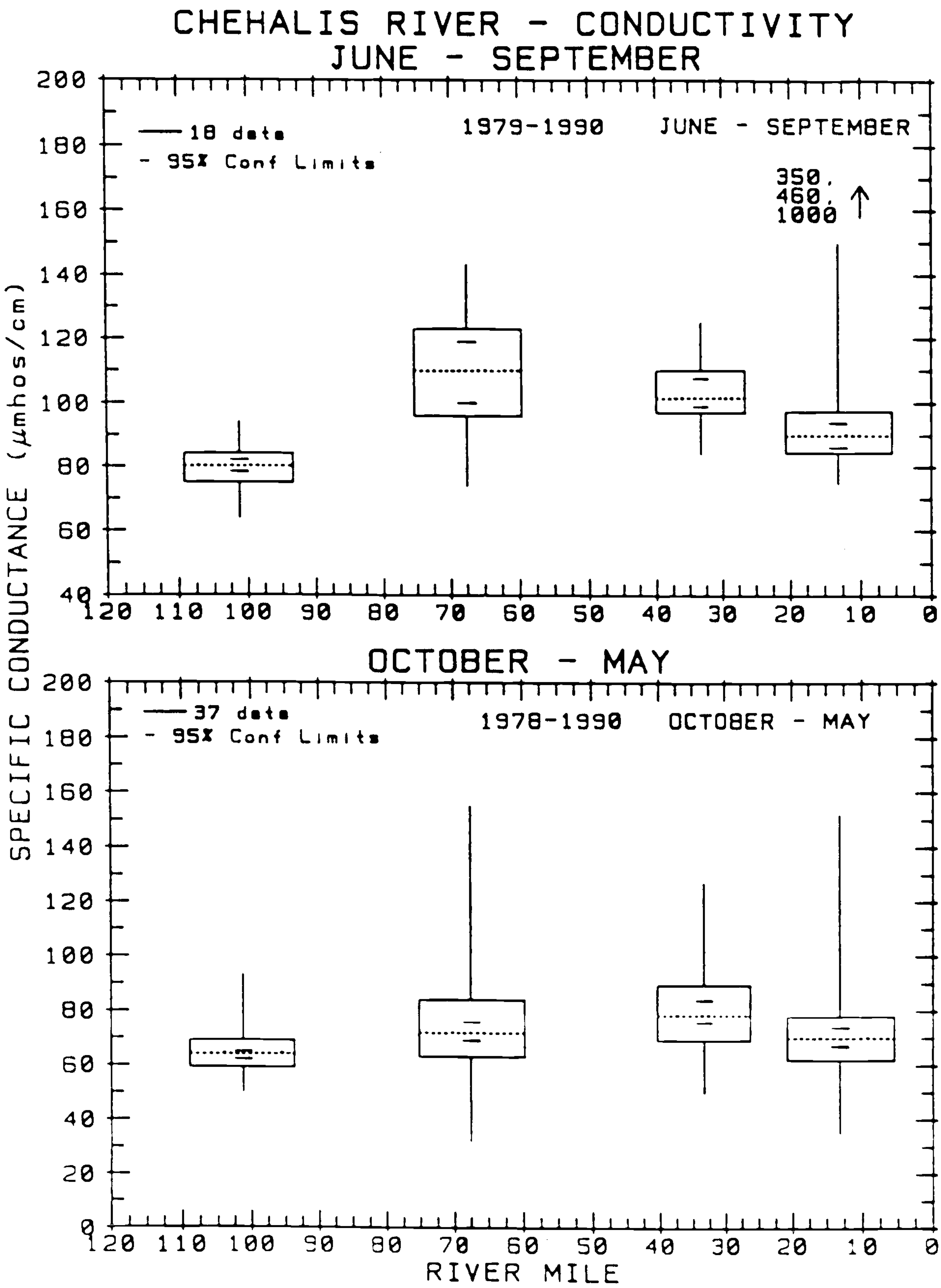

CHEHALIS RIVER
TURBIDITY: MAY - OCTOBER
25 data
- 95% Conf Limits
1978-1990 MAY - OCTOBER
WQ Standard
TURBIDITY (NTU)
100
10
1
.1
120 110 100 90 80 70 60 50 40 30 20 10 0
NOVEMBER - APRIL
26 data
- 95% Conf Limits
1978-1990 NOVEMBER - APRIL
WQ Standard
TURBIDITY (NTU)
100
10
1
.1
120 110 100 90 80 70 60 50 40 30 20 10 0
RIVER MILE

Figure 13.



CHEHALIS RIVER - CONDUCTIVITY
JUNE - SEPTEMBER
18 data
- 95% Conf Limits
1979-1990 JUNE - SEPTEMBER
350, 460, 1000
OCTOBER - MAY
37 data
- 95% Conf Limits
1978-1990 OCTOBER - MAY
SPECIFIC CONDUCTANCE (µmhos/cm)
RIVER MILE
200
180
160
140
120
100
80
60
40
20
0
120 110 100 90 80 70 60 50 40 30 20 10 0

Figure 14.

Streamflow-Water Quality Relationships

Table 2 lists the results of a Kendall correlation analysis for most ambient monitoring parameters versus river discharge for five sampling sites. Kendall's coefficient of concordance (tau) is a nonparametric alternative to the parametric Pearson product correlation coefficient. The test is based on the relative rank of the data, so that extreme values and non-normal distributions of data have little effect on the test outcome.

The correlations found in the data and discussed in this section do not necessarily result from cause-effect relationships. Two parameters may correlate because they correlate to a third parameter, such as seasonal meteorological conditions. The correlations should be taken as indicators or clues of relationships, but not as absolute proof.

Table 2. Kendall tau correlation between daily river discharge and ambient water quality parameters. Chehalis ambient monitoring stations, 1978-1990.

Parameter	Water Quality Station			
	Dryad (RM 101.3)	Centralia (RM 67.5)	Porter (RM 33.3)	Montesano (RM 13.2)
Temperature	(-)	(-)	(-)	(-)
Conductance	(-)	(-)	(-)	(-)
pH	(-)	(-)	(-)	(-)
TSS	(+)	(+)	(+)	(+)
Turbidity	(+)	(+)	(+)	(+)
Fecal Coliforms	o	(+)	(+)	(+)
Dissolved Oxygen	(+)	(+)	(+)	(+)
NO_2NO_3	(+)	(+)	(+)	(+)
NH_3-N	o	(-)	(+)	(+)
TP	o	(-)	-	+
OP-Dissolved	o	(-)	(-)	o

(+) 99% significant positive correlation
(-) 99% significant negative correlation
\+ 90% significant positive correlation
\- 90% significant negative correlation
o Not significant (less than 90%)

Temperature, conductance, and pH show a negative correlation with discharge at all stations at the 99% significance level. The negative correlation implies that the higher the discharge, the lower the value of the parameter. The temperature correlation reflects the typical inverse relationships of high summer temperatures associated with low flows and low winter temperatures associated with higher winter streamflows. Conductance may reflect a dilution relationship between concentration and discharge. If ionic constituents are primarily contributed by point sources and ground water, higher flows mean greater dilution. A lower pH associated with high flows may reflect a number of conditions, including the leaching of organic acids or aquatic plant respiration in the absence of photosynthesis or reduced dilution during summer low flows.

Turbidity and suspended solids show a 99% significant positive correlation with flow at all stations. This generally suggests erosion and scouring. Higher flows are associated with higher erosion rates and overland transport of particulates. In addition, higher flows may result in the resuspension and transport of streambed sediments.

Centralia, Porter, and Montesano all show positive correlations between fecal coliforms and discharge, significant at the 99% level. This may indicate that nonpoint sources associated with rainfall events dominate instream bacteria concentrations.

Dissolved oxygen shows a significant positive correlation with discharge. High discharge occurs in winter months when water temperatures are low and the saturation concentration of oxygen is high. Conversely, high summer water temperatures result in lower saturation concentrations. Also, low oxygen levels at low flows may reflect less dilution of oxygen-demanding substances, lower reaeration rates, and greater rates of respiration at higher temperatures by the ambient biota.

Nutrients show a mixed pattern of both positive and negative correlations. Nitrate/nitrite concentrations increase significantly with increasing flow at the 99% level. At Centralia, ammonia, total phosphorus, and ortho-phosphorus all show a negative correlation to discharge, significant at the 99% level. This may be a result of point source discharges providing most of the loading of those parameters on this stretch of the river, and concentrations decreasing with increasing flow due to dilution.

Water Quality Trend Analysis

Ambient monitoring data for the upper mainstem Chehalis River stations were analyzed for trends over time. A Seasonal Kendall Test was used for the trend analysis, and the data set was adjusted to remove variation due to flow and time of sampling (Aroner, 1991).

No significant trends emerged for most parameters at most stations. Flow showed a downward trend at Centralia (Grand Mound minus Skookumchuck flows). An upward trend in total phosphorus and conductivity was also observed at the Centralia station. Ammonia and fecal coliform showed a downward trend at the Centralia station.

The downward trend in flow could be a reflection of either short-term climatic trends, or of increased consumptive use of the water resource. The downward trend in ammonia and fecal coliform reflects a statewide trend, which may represent improvements in pollutant treatment and control. The conductivity trend shows a very small increase over time, and is probably not worthy of any concern. The upward trend in phosphorus goes against a statewide downward trend. This trend shows a steady increase in phosphorus in the Chehalis River system of about 2 ppb per year. Increased phosphorus loading to the Chehalis River system from municipal, industrial, and agricultural sources is a distinct possibility. The upward trend in conductivity and phosphorus may also be affected by the downward trend in flow through decreased dilution.

Trends are difficult to interpret. The cause of a trend, as with the cause of a correlation or regression, cannot always be determined, and the true cause of the trend may be an unknown factor such as a change in sampling method. Also, ammonia and phosphorus levels are often close to or less than the level of detection, which decreases the certainty that a trend truly exists.

SPECIAL STUDIES

Sediment Loading

Sediment loading in the Chehalis River during water years 1962-65 was studied by Glancy (1971). The focus of that study was the sediment yield of the basin and the sources of sediments. The study found that almost three-quarters of the sediment load in the basin came from the Satsop and Wynoochee Rivers (43.8% and 30.6% respectively). Only one-quarter of the sediment load originated above Porter.

Of the tributaries above Porter, the Chehalis River above Doty, the South Fork Chehalis River, and Newaukum River had the highest sediment yields. In general, subbasins with high rainfall and steep slopes had the greatest sediment yield. Changes in subbasin sediment transport were largely attributed to changes in channel characteristics and land use due to human activities.

Water Quality Basin Planning

R. W. Beck and Associates (1975) completed the Sewage Drainage Basin Plan for the upper Chehalis River Basin. This report is a comprehensive study of water quality problems in the basin, their sources, and potential solutions.

Problems with turbidity, dissolved oxygen, and temperature were observed at that time in roughly the same magnitude as observed in the most recent ambient data. The probable sources of turbidity, color, bacteria, and nutrients were identified as storm and farm run-off sources. Low D.O. was attributed to nutrient enrichment problems and to treatment plant effluent. Solar heating was suggested as the cause of temperature violations.

The Sewage Drainage Basin Plan identifies a number of suspected causes of water quality problems. The main purpose of the study was to identify future needs for sewer and treatment plant development. However, other pollution sources were identified, including areas with failing septic systems, historical landfills, poor animal waste management, forest practices, and specific permitted and non-permitted industrial facilities, including wood products, meat packing, and food processing.

The Washington Department of Ecology (1975) issued the 303(e) report for the Chehalis River Basin as a addendum to the Sewage Drainage Basin Plan (SDBP). The report repeats material from the SDBP and summarizes basin-wide ambient monitoring and studies for 1971 through 1973. A graphical synopsis of water quality problems in the Chehalis Basin is provided in the report.

In the 303(e) report, high temperatures and bacteria problems were documented on the Newaukum River and mainstem Chehalis River. High turbidities were observed in the Newaukum and mainstem Chehalis Rivers during the wet season. Conditions conducive to algal blooms in the mainstem Chehalis River were identified.

Dillenbaugh Creek

Dillenbaugh Creek was the subject of a intensive survey by Ecology in 1986 (Crawford, 1987a). Earlier surveys had observed D.O. levels below water quality criteria (Johnson and Prescott, 1982; Joy, 1984). The object of the 1986 survey was to investigate point and nonpoint sources of pollution, including NPDES permitted dischargers.

A wide variety of sources were found to be causing violations of fecal coliform, dissolved oxygen, and temperature water quality criteria in Dillenbaugh Creek. Farming activity, including a dairy feedlot, was considered the primary cause of low oxygen. Failing septic systems were identified as the major sources of bacterial contamination. Industries in the Chehalis Industrial Park were contributing to violations of temperature standards. An urban storm sewer was found to be the source of several contaminated discharges. A 10-acre woodwaste landfill was also suspected of impacting the creek. The Southwest Regional Office of Ecology (SWRO) took follow-up action on a number of the documented sources (Pickett, 1992). The American Crossarm and Conduit Company, whose now-defunct operations led to pentachlorophenol contamination of Dillenbaugh Creek, the factory site, and the surrounding wetlands, is undergoing corrective clean-up action as a federal Superfund site.

Salzer Creek

Salzer Creek has been the object of several water quality investigations. In October 1979, low oxygen was observed in the Chehalis River at the Mellen Street Bridge in Centralia, which prompted an investigation of the cause (Houck, 1980). The source of the problem was identified as a ruptured food processing waste water pipe, which caused a spill to Salzer Creek. The waste water from the National Fruit Canning Company was being applied to fields bordering Salzer Creek. Follow-up by SWRO resulted in the installation of an alarm system to provide notification of pipeline failure. National Frozen Foods, the successor company, currently holds a Washington State Discharge Permit to apply food processing waste to fields near Salzer Creek.

Surveys after the spill continued to document low dissolved oxygen in Salzer Creek (Johnson and Prescott, 1982; Joy, 1984). In 1986, Ecology conducted a survey of Salzer Creek to identify point and nonpoint sources in the drainage and their impacts on water quality in the creek (Crawford, 1987b). Very low dissolved oxygen and high fecal coliform levels were discovered. Farm animal management practices were identified as the predominant cause of these problems. The Southwest Washington Fairgrounds were also considered a potential threat to degrade the creek with contaminated storm water runoff. SWRO took action to correct some of the identified problems (Pickett, 1992).

Mainstem Near Chehalis/Centralia

The Centralia reach of the Chehalis River [from the Newaukum River downstream to the Skookumchuck River (RM 75.2 to RM 66.9)] is probably the most heavily studied area in the upper Chehalis Basin. Problems with low dissolved oxygen in the river have been identified for at least 25 years.

McCall (1970) reported on sampling of the Centralia reach in 1969, where he observed extremely low oxygen and high bacteria levels. He mentioned that stratification and low oxygen problems were observed in 1967. In 1970, improvements to the Chehalis Waste Water Treatment Plant (WWTP) resulted in higher surface oxygen levels and relatively low bacteria counts. However, the deepest points sampled in three different areas in August 1970 were devoid of oxygen.

In September 1972, Devitt (1972) repeated sampling at the same stations in the Centralia reach as in 1970. Oxygen levels were between 5 and 7.5 mg/L at all depths and stations, which meets the standard for that stretch. However, river temperatures were relatively cool, and no stratification was observed. Devitt commented that stratification and algal activity were factors that complicated the interpretation of D.O. data on this stretch of the river. However, the conclusion was reached that changes in the municipal treatment plants had improved the river, although problems still remained.

In addition, Devitt made the following observation regarding the aesthetics of the Centralia reach:

> "Automobiles which have been used to rip rap the river banks to retard erosion are unsightly, but they are obvious mostly to the limited numbers of boaters who use this section of river. Garbage has been dumped at some areas. Cows still have free access to the river. The improved water quality, of course, improved the general aesthetics of the river, but the general area is still somewhat of an eyesore."

Pickett (1992) noted that automobile rip-rap and cattle with free access to the river could still be observed in 1991.

In his report on the Salzer Creek spill investigation, Houck (1980) noted several points regarding conditions in the river itself. For river conditions at the time of the spill, a travel time of 6.4 days was estimated from the Chehalis WWTP to the Mellen Street bridge. Decreases in oxygen between Salzer Creek and the Mellen Street bridge were attributed to "a large bacterial bloom and/or sediment oxygen demand." Houck recommended further study of the relative importance of BOD, nutrients, and sediment oxygen demand (SOD).

As a consequence of the 1979 spill, a comprehensive study was undertaken of the Centralia reach that included evaluation of conditions in the river and compliance sampling (Class II) inspections of the Chehalis and Centralia WWTPs. Yake's (1980) inspection report on the Chehalis WWTP included an in-depth evaluation of receiving water conditions and the impact of the plant discharge. Samples were taken from the river at the Mellen Street bridge as well as from the plant effluent. A number of observations and findings were made:

1. The Centralia reach is deep, slow, and stratified, and algal photosynthesis is the process that dominates oxygen dynamics. Algal activity is indicated by elevated chlorophyll *a* levels near the surface relative to deeper samples, and by diurnal fluctuations of dissolved oxygen from supersaturated to depressed levels.
2. The growth of algae in this stretch of the river is controlled by the level of inorganic nitrogen (nitrate+nitrite+ammonia) in the water.
3. The Chehalis WWTP raises the level of nitrogen in the river by two to six times the level upstream of the plant.
4. The impact of BOD, both carbonaceous and nitrogenous, does not appear to adequately account for low oxygen levels. More likely, inorganic nitrogen inputs have a far more significant impact on D.O. through the effects of algal growth and respiration. The effect of algal decay below the eutrophic zone on D.O. levels could not be determined from the data.

5. The Chehalis WWTP appears to be capable of nitrification (ammonia to nitrate) and denitrification (nitrate to nitrogen gas). Nitrogen reduction in the treatment system was observed, but plant operators were not intentionally managing the plant for nitrogen removal, and it is not clear how the reductions could be maintained on an on-going basis. Effluent quality would be improved and impacts on the river reduced if nitrification-denitrification could be continually and effectively accomplished.

Johnson and Prescott (1982) conducted four field investigations of the Centralia reach during the summer of 1980. Seventeen stations were sampled at several depths on July 15, July 30, August 5, and September 16 of that year. Stratification was observed, which reached a maximum during the July 30 sampling. The maximum temperature gradient was 4.5°C from surface to bottom at the station upstream of the Mellen Street bridge, and the river D.O. concentration was less than 1.0 mg/L at a depth of 4 meters. On August 5, the gradients were somewhat less severe and oxygen-devoid layers were deeper, but, nonetheless, four stations showed temperature gradients of at least 2.0°C with D.O. levels of less than 2.0 mg/L near the bottom.

In summarizing their conclusions, Johnson and Prescott made a number of other observations. Surface D.O. was not a problem, and no diurnal variation was observed. Water temperatures were sometimes high enough to pose a threat to salmonids. Nitrogen was the limiting parameter for algal growth during late July and August. They close with the following observation:

> "It appears to us that the fluctuations in physical/chemical parameters we observed in this sluggish reach of the Chehalis River are typical of many eutrophic Western Washington lakes -- except that nitrogen rather than phosphorus was limiting."

In September 1981, Clark (1981) sampled oxygen and temperature at five sites in the Chehalis River, three in the Centralia reach and two downstream of the Skookumchuck. Oxygen levels were all above 8 mg/L and temperatures were 15.0°C or less. However, the percent saturation of D.O. was between 80 and 90 percent.

In the summer of 1982, the U.S. Fish and Wildlife Service conducted a survey of spring Chinook salmon habitat, which included temperature and oxygen monitoring at four sites on the Chehalis River and at the mouths of the Newaukum and Skookumchuck Rivers (Hiss, 1983). Measurements were made on six dates from July through September. Again, stratification was found in August at the two stations in the Centralia reach, with high surface temperatures and low bottom D.O.

Temperatures in the Chehalis River were between 16°C and 20°C in July and August, and as high as 16°C in the Skookumchuck River and 19°C in the Newaukum River. The report points out that the observed temperatures are higher than the safe temperature for salmonid egg development (14°C). These temperatures also approach the critical level for adult salmon survival (23°C), and since measurements were made in the morning, river temperatures may actually exceed the critical level.

The impact of logging practices on water temperature has been examined by the Timber, Fish, and Wildlife program in Washington. A study of models for predicting temperature (TFW, 1990) stated that:

> "Although many characteristics were shown to correlate with stream temperature, two factors were of such overwhelming importance that they could be used to reliably predict temperature sensitivity - shading and elevation (which probably indicates air temperature regime). A simple graphic model (the temperature "screen") based on these characteristics correctly identified the temperature category according to water quality criteria of 89% of these sites."

In July through October 1982, Ecology conducted a survey of the Centralia reach (Joy, 1984). This survey included flow measurements, an estimate of time of travel, field measurements of water quality parameters, and laboratory analysis of water samples. The survey results were used to simulate Chehalis River conditions with a one-dimensional steady-state dissolved oxygen computer model.

Several observations were made as a result of Joy's 1982 survey:

1. Estimated river velocities in the Centralia reach were between 0.04 and 0.10 feet per second (fps) at low flow. The estimated time for a volume of water to travel the 7 miles from the Chehalis WWTP to the Mellen Street bridge was 5 to 7 days at flows in the range of 73 to 112 cfs.
2. Patterns of high surface temperatures and stratified pools with extremely low oxygen at the bottom reinforced previous survey finding. Oxygen levels less than the seasonal standard of 5.0 mg/L were found in deeper layers at up to seven locations in late August. Surface oxygen was depressed below the standard of 8.0 at several locations after September 15.
3. Sediment oxygen demand (SOD) was considered to be significant in several locations, and estimates of the SOD rate were made. Suspected sources of organic sediments were the Chehalis WWTP, Salzer Creek, and settled plankton cells.
4. BOD concentrations in Salzer Creek ranged from 33 to 110 mg/L, which compares to Chehalis WWTP discharges of 40 to 70 mg/L and Centralia WWTP discharges of 16 to 30 mg/L.
5. Algal production was indicated by supersaturated D.O., elevated pH and chlorophyll *a*, and low inorganic nitrogen near the surface.
6. Nitrogen was again estimated to be the limiting nutrient in the Chehalis River as far downstream as the Independence bridge (RM 56.2). Above the Chehalis WWTP, neither phosphorus nor nitrogen could be identified as limiting. On the average, the source of

inorganic nitrogen loading in the Centralia reach was two-thirds from the Chehalis WWTP and one-third from upstream background sources.

7. In the area of the Centralia reach just below Salzer Creek, inorganic nitrogen levels were lower and organic nitrogen levels higher relative to upstream, without corresponding increases in chlorophyll *a* and oxygen. Joy suspected that, in this area, heterotrophic bacterial activity might be more prevalent than planktonic photosynthesis. This would be understandable, considering the large BOD loads discharged from Salzer Creek during this survey.

Hanaford Creek

Sampling was conducted in the Hanaford Creek watershed in 1970 and 1971 to assess baseline conditions and, based on the impacts of initial operations at the mine site, assess the potential future effects of the coal mine/power plant project (McCall, 1971). Elevated turbidity, conductivity, and iron were observed due to construction. Mercury was also detected from the coal piles, but the quality of data is suspect (Pickett, 1992). Data were reported for twice monthly sampling over a year at seven station in the Hanaford Creek system. Six of seven stations reported oxygen levels below 8.0 mg/L,. and the station at the mouth of South Hanaford creek reported oxygen at 4.0 mg/L or less from June to September 1970. Temperatures at three stations exceeded 18.0°C on at least one occasion.

Toxicity and Toxic Materials

A number of sites contaminated with toxic compounds in the upper Chehalis River Basin are known to have had negative impacts on surface waters. These include the Centralia Landfill near Salzer Creek (Springer, 1988), the Lewis County PUD/Ross Electric Coal Creek site (Norton, 1986), and the American Crossarm and Conduit site near Dillenbaugh Creek (Yake, 1987). Other sites have been investigated in the past as possible sources of contamination. The Ecology Toxic Cleanup Program maintains a list of all known contaminated sites as part of the requirements of the Model Toxics Control Act (MTCA). Site cleanups and the control of contaminants may be pursued either under the federal Superfund Program or under MTCA.

Michaud (1989) conducted a bioassay study in the mainstem Chehalis River. The study used a *Ceriodaphnia* (water flea) reproduction and survival test. From February 1987 to February 1988, samples were collected on three dates from four stations on the Chehalis River.

Significant toxicity was found in the Chehalis River at Dryad (RM 101.3) during sampling in September 1987. No chemical analysis was conducted and no source of toxicity was identified. The watershed above the Dryad station has largely agricultural and silvicultural land uses, which led Michaud to speculate that forest or farm chemicals may have been a cause. More study would be needed to confirm that a recurring toxicity problem exists and to identify the source of toxicity.

SUMMARY

Based on an analysis of the studies discussed above, a number of on-going, widespread water quality problems can be identified in the upper Chehalis River Basin. These problems are summarized below:

1. Low dissolved oxygen has been identified as a significant problem in many areas of the Chehalis system during dry weather low flows. The Centralia reach in particular exhibits characteristics more typical of a stratified eutrophic lake. Site-specific problems have been identified in Salzer and Dillenbaugh Creeks, although it is likely that some of the problems have been diminished.

Studies to date have looked at a number of causes of low D.O. in the Chehalis system. BOD loading from the Chehalis WWTP and spills of food processing waste water into Salzer Creek have historically been identified as the cause of low oxygen in the Centralia reach. The quality of the water entering the Centralia reach from upstream also has a strong influence on D.O. levels. Specific sources have not been identified above the Chehalis WWTP.

Studies of the Centralia reach have provided evidence that nutrient enrichment and SOD may also significantly contribute to D.O. problems. This stretch has exhibited significant variation between morning and midday D.O. levels, which indicates the existence of highly productive conditions. Elevated chlorophyll *a* levels in the surface waters of the Centralia reach confirm the productivity of the system. Data indicate that the Centralia reach is nitrogen limited, most likely because of the high loading of phosphorus introduced by the Chehalis WWTP.

Despite the apparent productivity, surface waters often remain depressed below saturation, and bottom waters in areas that stratify exhibit severely depressed D.O. levels and even anoxic conditions. This situation indicates that an oxygen demand is being exhibited by sediments and benthic debris.

The effects of nutrient enrichment and the influence of SOD on D.O. in the Chehalis system have not been closely examined by previous studies. Productivity enhanced by nutrient inputs could impair D.O. levels through the respiration and decay of algal and macrophyte biomass. This could occur both during the night and morning hours when respiration is not offset by photosynthesis; at the end of the growing season when the plant community dies off; and by the oxygen demand of benthic deposits of settled algal cells and macrophyte detritus. It is also possible, although doubtful, that nutrient inputs, by increasing photosynthetic algal production, are enhancing the fisheries resource through increased oxygen levels and food availability.

The source of SOD may be from instream plant production, as discussed above. It may also be caused by inputs to the river from external sources, such as pollutant sources high in settleable solids or natural vegetative detritus. The level of SOD, location of areas with significant levels of SOD, and the source of SOD have not been determined by previous studies.

2. Fecal coliform bacteria have been identified as a widespread wet weather problem. Excessive levels of bacteria associated with rainfall events regularly occur in the Chehalis River above Centralia. The highest values have been observed in the wet season, which suggests contaminated storm water runoff as the probable source. More study is required to better identify the sources of bacterial contamination. Although livestock waste has been identified as a principal source (Ecology, 1990), failing septic systems and ineffective municipal waste water treatment plants are also suspected of contributing significant bacterial loading.

3. Temperatures in excess of 18°C have been observed throughout the upper Chehalis River system in most years. Since human activities have had a significant impact on the environment of the Chehalis Basin for over a century, it is difficult to say whether the elevated temperatures that have been observed represent "natural" conditions of the river. However, studies have found that human activities, such as the removal of riparian shade

trees, can elevate river water temperatures. A study of models for predicting temperature conducted by the Timber/Fish/Wildlife Temperature Work Group stated that two factors, shading and elevation, could be used to reliably predict temperature sensitivity (TFW, 1990). Fisheries experts have identified high temperatures as one of the water quality problems restricting efforts to restore anadromous salmonid fisheries in the Chehalis Basin (Hiss, 1982; Hiss, 1983). Therefore, it is likely that human activities are impairing the beneficial uses of the Chehalis River by causing changes in the environment that result in elevated river water temperatures.

Increased riparian shading could likely lead to reductions in river water temperatures.

4. Turbidity data indicate high levels with wet season runoff. Whether the levels represent "natural" conditions or violations of criteria due to human land uses cannot be determined. It is possible that because of the association of suspended solids with phosphorus and bacteria transport, study of those issues may result in controls or improvements in turbidity problems.

5. A bioassay study of the Chehalis River Basin found toxicity in several locations. These results are troubling, since they are apparent violations of Water Quality Standards.

6. Although some permitted point source dischargers in the Chehalis River Basin have been examined for their contributions to D.O. and bacteria problems downstream in the receiving water, most dischargers have not been evaluated for "near-field" effects. This includes an analysis of mixing zone characteristics and compliance with metals, chlorine, ammonia, and whole effluent toxicity water quality standards in the vicinity of the plant discharge.

7. Several of the creeks that are tributary to the Chehalis River have been identified as having significant water quality problems of their own. Specifically, Dillenbaugh Creek, Salzer Creek, Hanaford Creek, and Wildcat Creek have been studied in the past, and other creeks may be identified during future studies.

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