WASHINGTON STATE
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Black River Dry Season Dissolved Oxygen and Phosphorus Total Maximum Daily Load Study

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WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

Black River Dry Season Dissolved Oxygen and Phosphorus Total Maximum Daily Load Study

by
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Olympia, Washington 98504-7710

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Abstract

A Total Maximum Daily Load (TMDL) study was conducted to evaluate dry season water quality in the Black River, a tributary of the Chehalis River. Past studies have documented low dissolved oxygen (DO) levels during the summer in the mainstem Black River between Littlerock and Rochester. The Black River and tributaries were evaluated for loading sources and other physical, chemical, and biological river conditions that might contribute to the oxygen deficit.

Several surveys were conducted in the study area during the dry seasons of 1991 and 1992. Survey results showed widespread thermal stratification of the middle Black River (RM 9.6 to RM 15.3) during the summer months, with hypoxic and anoxic conditions in the hypolimnetic layer. DO below the water quality criterion of 8.0 mg/L was widespread in surface waters of the Black River. Chlorophyll *a* levels indicated conditions ranging from mesotrophic to eutrophic. Temperatures in surface waters often exceed the water quality criterion of 18.0°C.

Based on a modeling analysis using the WASP5 water quality model, DO for background conditions was found to be less than the water quality criterion of 8.0 mg/L. DO under existing conditions in some locations is degraded compared to background conditions. Also, total phosphorus (TP) is close to levels that produce eutrophic conditions, which would degrade both DO and aesthetic water quality standards.

A TMDL is recommended for TP, for oxygen-demanding materials (BOD), and for temperature. The TP loading capacity (LC) is defined as an instream criterion of 0.05 mg/L, which applies to waters of the mainstem Black River from the surface to two meters depth between RM 9.6 and RM 15.3 during the period May 1 to October 31. The BOD LC is defined as an antidegradation criterion of no significant degradation of DO due to any loading source or combination of loading sources as compared to existing or background levels. The BOD LC applies to the mainstem Black River for the period May 1 to October 31. The temperature TMDL recommends preservation and restoration of the riparian shade canopy on the mainstem Black River downstream from RM 10.0.

Wasteload Allocations (WLAs) and Load Allocations (LAs) are proposed for inclusion in the TP and BOD TMDLs. Implementation strategies are suggested that include modification of existing NPDES permits and improved Best Management Practices to control nonpoint sources. A monitoring strategy is proposed to evaluate the effectiveness of the TMDL and WLA/LAs. Additional studies are recommended to increase understanding of Black River water quality, specifically in the areas of ground water interactions, and aquatic macrophyte dynamics.

1. Introduction

1.1 Basin Description

The Black River basin covers an area of 128 square miles in Western Washington (Figure 1.1). Its drainage lies almost entirely in southwestern Thurston County, with a small portion near the mouth in southeastern Grays Harbor County. The mainstem Black River is about 24 miles long. The cities of Olympia and Tumwater are near the northern end of the basin, and the river passes near the towns of Littlerock and Rochester. The Chehalis Reservation is in the southwest end of the basin at the mouth.

The basin shows several distinct physiographic areas. The Black River itself can be divided into three stretches with different characteristics - the upper river, from the headwaters to about River Mile[1] (RM) 15.2, the middle river from RM 15.2 to RM 9.7, and the lower river from RM 9.7 to the confluence with the Chehalis River. These areas and other features of the Black River named in this report are illustrated in Figure 1.2.

Headwaters of the Black River and its tributaries lie in the eastern Black Hills and in the low-lying areas south of Olympia. The upper river drains an area of extensive freshwater wetlands, one of the largest contiguous freshwater wetlands areas in the Puget Sound region. These wetlands are most likely the source of humic acids and other materials that cause the dark color that gives the Black River its name. This area is also a residential area experiencing rapid growth.

The middle river, beginning roughly near the Department of Fish and Wildlife boat launch south of Littlerock (RM 15.3), and extending downstream to the "Big Dock" (RM 9.7), is an area of very slow flow bounded on both banks by brushy wetlands. Measurements made in previous studies have observed thermal stratification in this reach during the summer months.

From the Big Dock to the mouth, the river is relatively swift and flows through an area of mostly agricultural use. The Black River flows into the Chehalis River near Oakville.

Several creeks are tributary to the Black River. Mima Creek enters the river from the north at RM 11.8. Near Littlerock, Beaver Creek flows into the Black River

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[1] River Mile designations are based on U.S. Geological Survey Topographic Maps. River Mile values may not coincide exactly with those used in other reports.

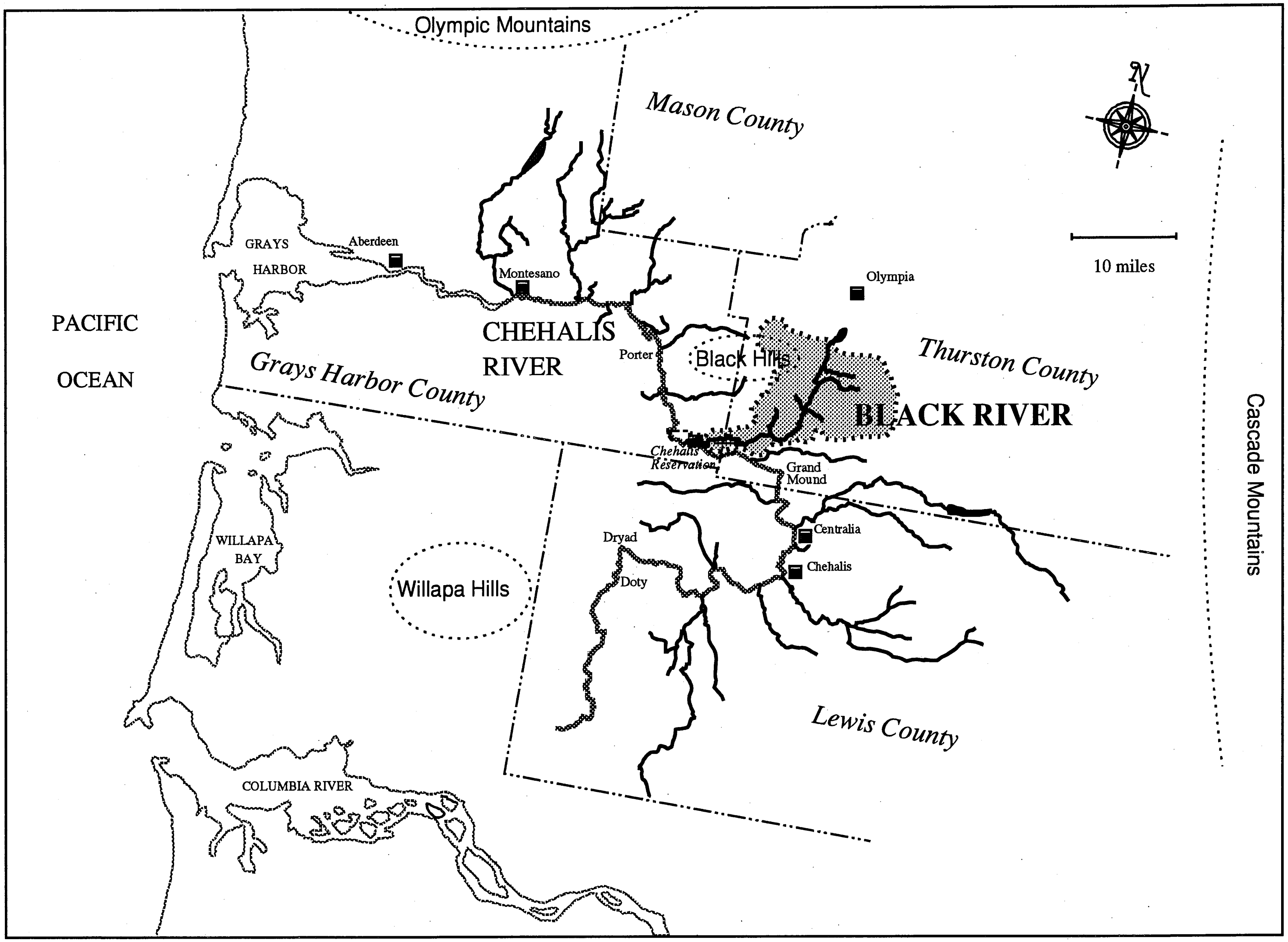


Figure 1.1 Black River System Location Map

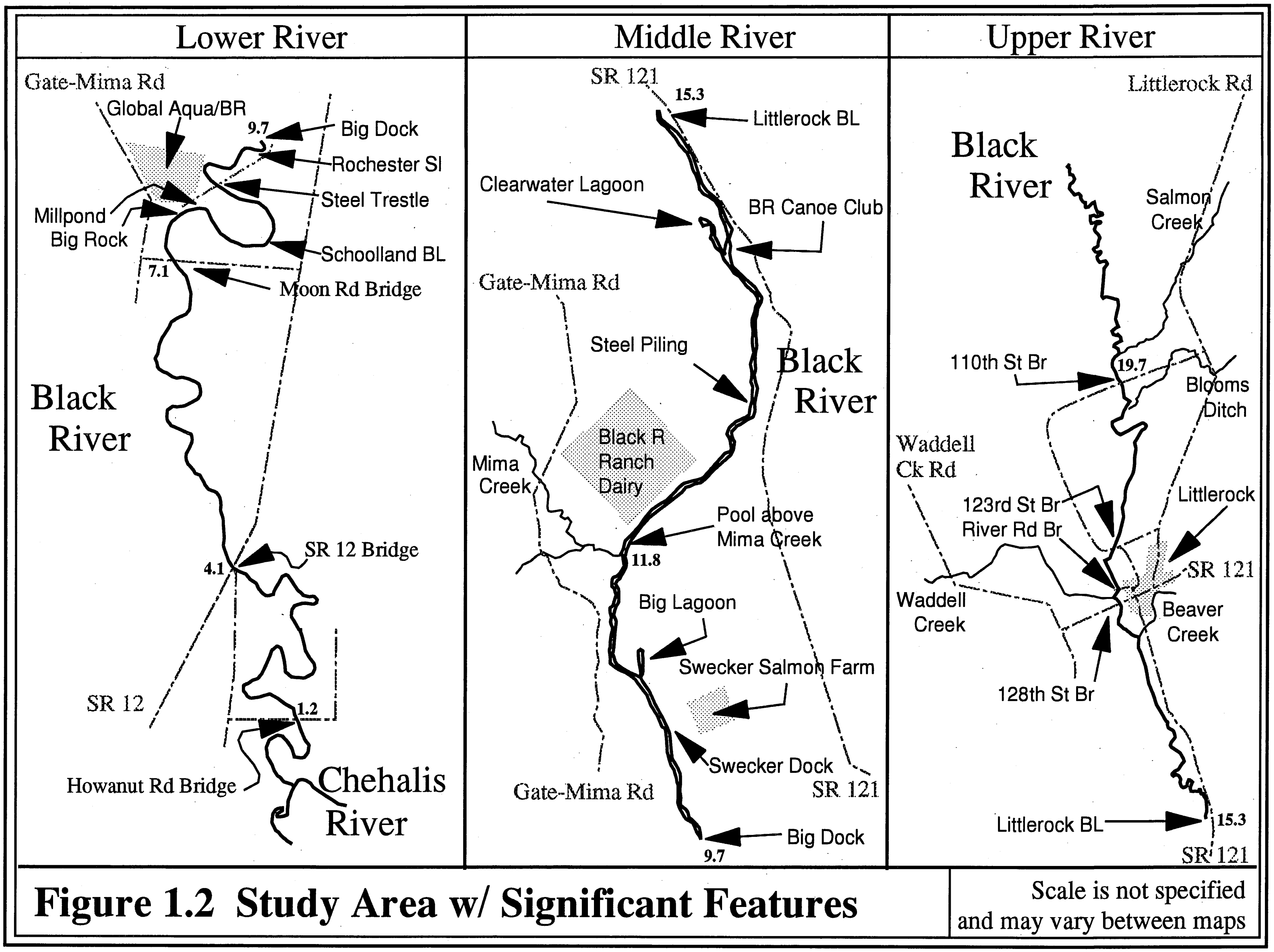


Figure 1.2 Study Area w/ Significant Features

from the east just south of town, and Waddell Creek enters from the west just north of town. Upstream of Waddell Creek are Blooms Ditch and Salmon Creek on the east, and Dempsey Creek on the west. Although Black Lake historically flowed into the Black River, recent investigations by Thurston County indicate that, at least during the dry season, the headwaters of the river near Black Lake are fed by ground water sources with no direct connection to the lake (Berg, 1993).

A major kill of fish and other aquatic life in the Black River occurred in August 1989 (Ecology, 1989). Prior to that event, the river had been little studied. The Black River fish kill sounded an alarm for a river system that was poorly understood, but appeared to be very sensitive to environmental insult and under pressure from several different land uses and from regional growth in general.

1.2 Pollutant Loading Sources

Loading sources to the Black River system consist of point and nonpoint sources. Point sources are discharges from a distinct location and are regulated under the federal and state National Pollutant Discharge Elimination System (NPDES). Nonpoint sources are diffuse discharges that include, for example, stormwater runoff, livestock access, and ground water discharge. Land use activities that generate nonpoint pollution include agriculture and livestock, urban commercial and residential development, timber harvest, and the land disposal of industrial waste, solid waste, and residential sanitary waste.

Several facilities in the Black River basin discharge as point sources under the NPDES system. Most of these are aquaculture facilities covered by the Upland Finfish Aquaculture General Permit. Permitted point sources in the Black River basin are listed in Table 1.1

None of these discharges have outfalls directly in the Black River, and all are physically distant from the mainstem river bank, with their discharges relatively indirect. Rancho Cameron and Cedar Creek Corrections Wastewater Treatment Plant (WTP) are located on tributaries, and their discharges have not been directly assessed. Similarly, Carlson Salmon Farm is relatively small and during the study discharged into the wetlands adjacent to the Black River with no defined entry to the Black River; the facility ceased discharge and cancelled its permit in 1993.

Table 1.1 Point Source Permitted Dischargers, Black River Basin.

Facility Name	RM	Type
Global Aqua/Black River	9.2	Fish Rearing
Steelhammer Salmon Farm[2]	9.6	Fish Rearing
Carlson Salmon Farm[2]	10.1	Fish Rearing
Swecker Salmon Farm	10.7	Fish Rearing
Cedar Creek Corrections WTP (Mill Cr)	11.8 (Tributary)	Sewage Treatment Plant
Rancho Cameron (Salmon Cr)[2,3]	20.1 (Tributary)	Fish Rearing

Until the spring of 1992, Steelhammer Salmon Farm discharged into a flood channel near their facility that has been dubbed "Rochester Slough." Although the discharge has existed since the mid-1970s, it has mostly percolated, and a direct discharge only reached the Black River in 1989. Due to problems attributed to the flooding of the Rochester Slough, an enforcement action by Ecology resulted in the termination of the discharge prior to the 1992 dry season sampling.

Swecker Salmon Farm and the Global Aqua/Black River facility are the two largest permitted dischargers to the Black River. These two facilities were selected for effluent monitoring and Class II inspections, discussed below.

Water for the Swecker Salmon Farm facility is pumped from wells on site, and approximately one-third of the water percolates to ground water through the bottom of the facility ponds and channels. The balance of the wastewater flows through a wetland area near the river bank, with part of the discharge reaching the river in a well-defined channel.

[2]No discharge or permit at the time of this report's completion.

[3]Rancho Cameron went into receivership during the course of this study, and the bank that took over the facility renamed it Great Fish Farms, Ltd. A new permit has not been issued for that facility as of the time of the writing of this report. This report will refer to this facility as Rancho Cameron, since the change in ownership occurred after the field work was done in this study. Permit conditions referred to in this study are those in the original permit issued to Rancho Cameron.

Global Aqua pumps their water supply from on-site wells, and wastewater discharges to a large pond near the river. The discharge apparently percolates and generates a large number of springs that can be found on the river bank just upstream of the steel trestle (RM 9.1 to 9.3), in the area of "Big Rock" between the "Millpond" (RM 7.9), and the bulkhead above Moon Road (RM 7.4). The continuity of the springs with the Global Aqua discharge was demonstrated in 1989, when the springs dried up shortly after Global Aqua shut down, and started up again shortly after Global Aqua resumed operations (Erickson, 1990a). Investigations indicate that a confining layer limits deeper percolation through otherwise highly permeable strata, creating a perched aquifer that discharges to the river (Erickson, 1993).

A number of nonpoint sources are of potential significance in the Black River basin. Stormwater runoff at commercial, light industrial areas and construction sites are potential sources of pollutants, especially in the rapidly growing upper basin. Streets, roads, and highways, including Interstate 5, could discharge pollutants in stormwater or through spills to the Black River and its tributaries. Septic systems can be a source of pollutants to the river if they are sub-standard, failing, or located adjacent to a waterbody.

A dominant activity in the Black River basin is agriculture. A number of dairies are in the basin, and many may be candidates for coverage under the Dairy General Permit that has been drafted. The largest dairies are located near the 123rd Street Bridge upstream of Littlerock, on Beaver Creek below Case Road, just east of Mima Creek and northwest of the Black River, and between Moon Road and the mouth. There are also poultry operations, a silvicultural nursery, a turf and berry farm, and hobby farms. Timber harvest and management activities occur throughout the basin, especially in the Black Hills.

1.3 Water Quality Standards

Water Quality Standards for Surface Waters for the State of Washington (Chapter 173-201A WAC) establish the water quality standards for the Black River basin. The entire Black River basin in classified as Class A waters. Beneficial uses include domestic, industrial, and agricultural water supply; stock watering; fish and shellfish migration, rearing, spawning and harvesting; wildlife habitat; primary contact recreation, sport fishing, boating, and aesthetic enjoyment; and commerce and navigation. Several parameters were of particular interest in this study - pH, temperature, dissolved oxygen (DO), fecal coliform bacteria (FC), and ammonia - because they have water quality criteria specified in the Water Quality Standards, and levels have been observed in previous studies that approach or exceed the standards. The Class A criteria for these parameters are summarized in Table 1.2.

Table 1.2 Class A Freshwater Criteria for Selected Parameters.

Parameter	Criteria
Temperature	Shall not exceed 18.0°C due to human activities. When natural conditions exceed 18.0°C, no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3°C. Incremental temperature increases resulting from point source activities shall not, at any time, exceed $t=28/(T+7)$. Incremental temperature increases resulting from nonpoint source activities shall not exceed 2.8°C. For purposes thereof, "t" represents the maximum permissible temperature increase measured at a mixing zone boundary; and "T" represents the background temperature as measured at a point or points unaffected by the discharge and representative of the highest ambient water temperature in the vicinity of the discharge.
pH	Shall be within the range of 6.5 to 8.5, with a human-caused variation within a range of less than 0.5 units.
Dissolved oxygen	Shall exceed 8.0 mg/L.
Fecal coliform	Shall both not exceed a geometric mean value of 100 colonies/100 mL, and not have more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 200 colonies/100 mL.
Ammonia	Acute and chronic toxicity criteria are defined as a function of pH and temperature. See EPA (1986).

If natural conditions in a water body result in DO less than the water quality standards, then the antidegradation policy applies (WAC 173-201A-070). Section 2 of this policy states that "whenever the natural conditions of said waters are of a lower quality than the criteria assigned, the natural conditions shall constitute the water quality criteria." Natural conditions are defined as "surface water quality that was present before any human-caused pollution" (WAC 173-201A-020).

The primary mechanism for implementing Washington's water quality standards is provided under Section 303 of the Clean Water Act. Section 303(d) requires the states and EPA to establish total maximum daily loads (TMDLs) for all water quality limited segments (*i.e.*, those waters which cannot meet water quality standards after application of technology-based source controls). After the Loading Capacity (LC) for a given pollutant in the water body is established, loading sources are apportioned between point sources (waste load allocations--WLAs) and nonpoint and natural background sources (load allocations--LAs), which forms the TMDL. The WLAs and LAs are implemented though NPDES permits, grant projects, and nonpoint source controls.

Data collected during the 1989 fish kill and in several studies following the kill (Dickes, 1990; TCEH, 1991) have shown that DO levels below the Class A criterion are widespread and common during the dry season in the Black River. Ecology ambient monitoring at Moon Road Bridge (Ecology, 1991) also found dry season DO levels that did not meet the water quality standards. These studies did not attempt to determine whether the low DO was due to natural conditions or human loading sources. A more detailed review of historical water quality data can be found in Pickett (1992).

The Southwest Regional Office Section of Ecology's Water Quality Program has requested that the Watershed Assessment Section of the Environmental Investigations and Laboratory Services Program (EILS) evaluate stream segments in the Chehalis Basin to determine if a TMDL is needed, determine the LCs for pollutants of concern, and recommend the appropriate TMDL, including WLAs and LAs (Kendra and Dickes, 1991).

The Black River was chosen for a TMDL study for a number of reasons. Foremost, although the Black River has not been formally placed on the 303(d) list as water quality-limited for DO (Ecology, 1992), the data collected since 1989 indicate that water quality standards for DO are not being met. The river has been identified as an important fisheries resource, and the 1989 kill demonstrated the sensitivity of that resource to the water quality of the river. In addition, the upper basin is located near the Olympia/Lacey/Tumwater urban area, which is experiencing rapid growth. These reasons support the development of preventative TMDLs for those pollutants that could degrade water quality and threaten beneficial uses of the Black River.

1.4 Project Goals and Objectives

The goal of the TMDL study was to assess the water quality of the Black River basin, develop LCs and recommend WLA/LAs for the appropriate parameters and reaches of the river for the protection of dissolved oxygen water quality standards. The specific objectives of the study were:

1. Assess water quality on the mainstem Black River, significant tributaries, and point sources during the dry season (late spring to early fall) to identify reaches which may be water quality-limited for dissolved oxygen, identify significant loading sources, and provide data for computer modeling.

2. Identify and evaluate significant loading sources that appear to lack "all known available and reasonable methods" of pollution control, and refer those sources to regional staff for action.

3. Evaluate the cumulative effect of pollutant loadings through data analysis and computer simulation of water quality in the Black River.

4. Evaluate sampling data and modeling results for historical conditions and estimated critical conditions.

5. Estimate natural conditions in the river system and compare the State Water Quality Standards to those conditions.

6. Establish LCs for pollutants most impacting dissolved oxygen levels.

7. Propose WLA/LA alternatives for control of point and nonpoint sources of pollution.

This study focuses on the mainstem Black River from upstream of the boat launch south of Littlerock (RM 15.3) to the confluence with the Chehalis. This includes the slowest stretches of the river, but does not directly evaluate the braided channels and wetlands in the upper basin, due to their complexity. Selective sampling was done in tributaries above the Littlerock boat launch to evaluate relative pollutant loading to the river downstream.

1.5 Other Water Quality Activities

A number of groups in the Black River basin have been engaged in water quality activities relevant to this study. Under a grant from Ecology, the Lewis County Conservation District has organized the Chehalis River Council (CRC), a citizen's committee whose goal is the protection of aquatic resources in the Chehalis basin. Under the grant, the CRC developed the Chehalis River basin Action Plan (Chehalis River Council, 1992) to address nonpoint source pollution control efforts. The CRC and its Action Plan should play a key role in the identification and implementation of nonpoint source controls.

The Thurston County Office of Water Quality received an Ecology grant to evaluate sources of pollutants in the Black River Watershed. Thurston County has coordinated closely with Ecology on Black River issues. Thurston County has also coordinated the Black River Watch, a citizens group that has for several years monitored water quality in the Black River and organized educational activities. Both Thurston County and the Black River Watch could have important roles in the implementation of the TMDL and allocations.

The US Fish and Wildlife Service (USFWS) implemented the Chehalis River basin Fishery Resources Study and Restoration Act of 1990. Under this Act, the USFWS (1993) conducted an inventory of fishery habitat degradation, which includes water quality problems and pollutant sources. Water quality was identified as one of the critical areas needing improvement to restore the Chehalis River fishery. USFWS has annually awarded grant funds for habitat improvement under the Chehalis Fisheries Restoration Program (CFRP), which has been an important source of funding for nonpoint source controls. The CFRP will continue for several more years, subject to funding by the U.S. Congress.

Also active in water quality issues in the Black River basin is the Confederated Tribes of the Chehalis Reservation (Chehalis Tribe). The Chehalis Tribe has received grant money from USFWS and EPA for fishery improvement and water quality projects, and is beginning a water quality monitoring program on the Black River as follow-up to the work done in this study. Environmental issues on the Chehalis Reservation are under the direct jurisdiction of EPA, and implementation of the TMDL on the Reservation would be conducted by the Tribe and EPA.

2. Methods

2.1 Data Collection

Two main components were included in the Black River DO TMDL study -- water quality data collection and computer modeling. The objectives of data collection were to assess the quality of the Black River and its tributaries, identify the significant sources of pollutant loading, and provide input data for a water quality model. The model was used to mathematically simulate the dynamic systems of the river which control dissolved oxygen levels. Based on the analysis of data and modeling results, LCs were determined and TMDLs were recommended for the river.

Water quality data were collected from July to October 1991, and May to September 1992. Data collected consist of hydrodynamic and channel morphology measurements (flow, gage height, channel cross-section, and velocity by drogue); physical and chemical field measurements (vertical profiles and 24-hour time series with Hydrolab® multi-parameter meters; grab measurements with meter and thermometer; Secchi depth; and vertical profiles of light intensity) and chemical and biological sampling and laboratory analysis.

Data were collected from stations in the mainstem Black River, and from tributaries, point sources, and other loading sources. The selection of sampling station locations and water quality parameters for monitoring was based on EPA guidance for waste load allocation and model development requirements (EPA, 1983a; Mills *et al.*, 1986; Ambrose *et al.*, 1993), with consideration of site access and sampling logistics. A list of the sites used for sampling and measurement (other than flow) is provided in Table 2.1. A map which shows the location of sampling stations is provided in Figure 2.1.

A detailed description of sampling and measurement methods is provided in Appendix A. Model development methods are described in Section 4 and Appendix G.

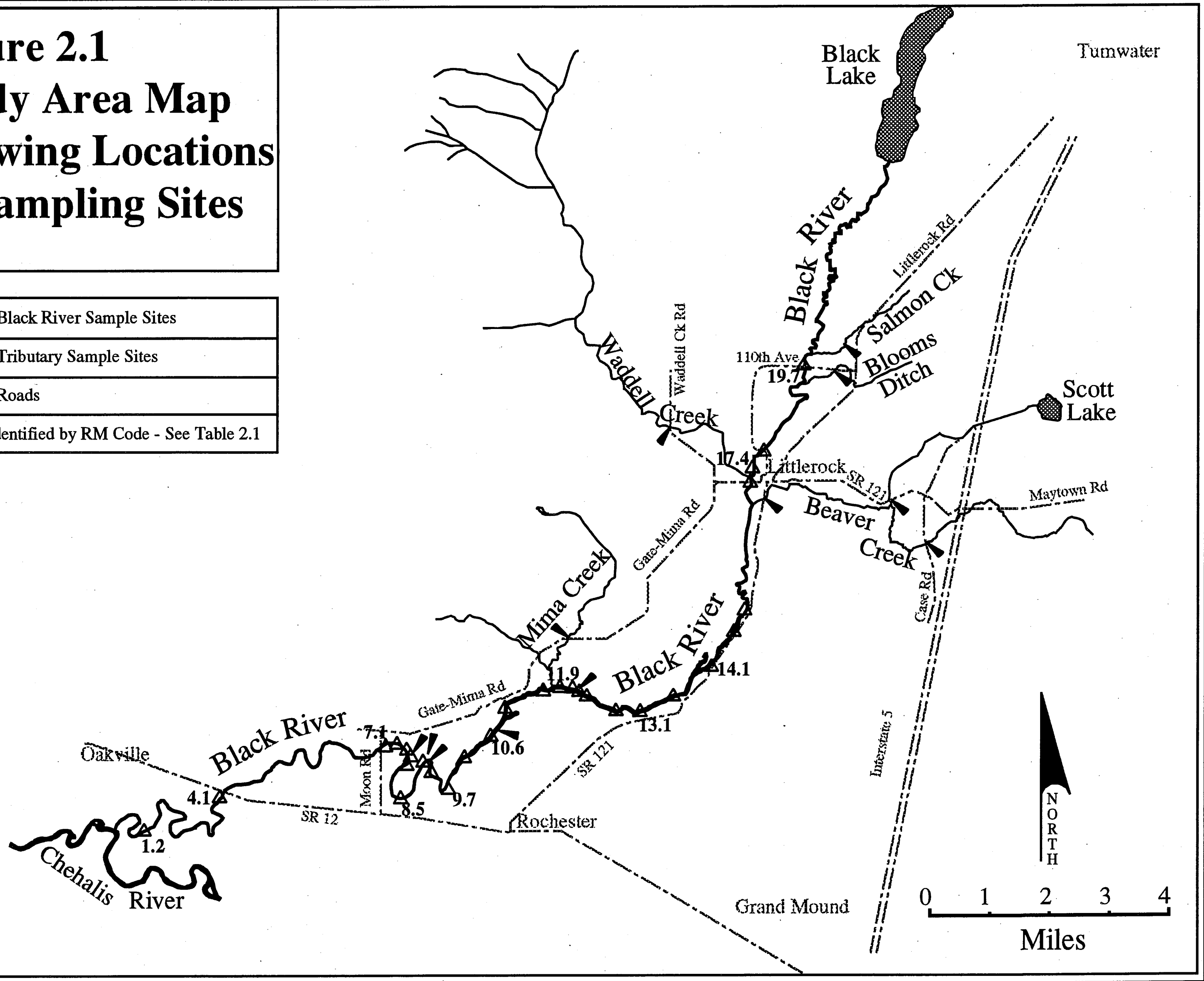
Table 2.1 Black River System Sampling Sites with RM Code

Mainstem Station Name	RM Code		Tributary Station Name
BR @ Howanut Rd Bridge	1.2		
BR @ SR 12 Bridge	4.1		
BR @ Moon Rd Bridge	7.1		
BR abv Moon Rd (Bulkhead)	7.4		
BR nr Big Rock	7.7		
		7.7001	Springs nr Big Rock
BR abv Big Rock Springs	7.8		
BR @ the Millpond	7.9		
BR abv Schoolland BL	8.5		
BR @ Steel Trestle	9.1		
		9.2001	Springs nr Global Aqua
		9.2003	Global Aqua/BR
BR abv Global Aqua	9.3		
BR blw Rochester SI	9.5		
		9.6002	Rochester SI (Steelhammer)
BR abv Big Dock	9.7		
BR nr Osprey Nest	10.1		
BR @ Swecker Dock	10.6		
		10.7001	Swecker Discharge Stream
		10.7004	Swecker Salmon Farm
		11.0001	Big Lagoon
BR abv Big Lagoon	11.1		
BR blw Mima Ck	11.8		
		11.8009	Mima Ck @ Mima-Gate Rd
BR abv Mima Ck	11.9		
BR blw Dairy Drainage	12.1		
BR nr Dairy Drainage	12.2		
BR abv Dairy Drainage	12.3		
BR blw narrows blw Steel Piling	12.6		
BR @ narrows blw Steel Piling	12.8		
BR abv Steel Piling	13.1		
BR blw Canoe Club	13.6		
BR @ Canoe Club	14.1		
		14.1001	Clearwater Lagoon
BR blw Ltlrck BL	14.7		
BR abv Littlerock BL	15.3		
		16.8002	Beaver Ck @ SR 121 nr mouth
		16.8023001	Scott Lake Ck @ SR 121
		16.8038	Beaver Ck @ Case Rd
BR @ 128th St Br	17.2		
		17.3019	Waddell Ck @ Waddell Ck Rd
BR @ River Rd	17.4		
BR blw 123d St Br	17.6		
		19.4003	Blooms Ditch @ 110th St
BR blw 110th St Br	19.6		
BR @ 110th St Br	19.7		
		20.1005	Salmon Ck @ Creekwood Dr

"RM Code" is a unique station ID code based on river or stream mile. For the mainstem, the RM Code is the approximate river mile based on USGS topographic maps. For tributaries, the first decimal place is the Black River mile where the tributary enters, the second through fourth place is the tributary stream mile, and fifth through seventh decimal place is the secondary tributary stream mile. Example: 16.8023001 = Black river mile 16.8, Tributary stream mile 2.3, secondary tributary stream mile 0.1.

Figure 2.1 Study Area Map Showing Locations of Sampling Sites

△	Black River Sample Sites
◢	Tributary Sample Sites
- - - -	Roads
Sites identified by RM Code - See Table 2.1	



3. Survey Results

3.1 Hydrodynamic and Channel Morphology Measurements

3.1.1 Flow Measurements

Flow, channel dimension, and gage height measurement results are shown in Appendix Table C.1. An estimation of the quality of the flow measurement is also indicated. Several of the unusual characteristics of the Black River that affect the quality of flow measurements are described in Appendix Section B.1.

USGS collected flow data on the Black River at Littlerock (Station Number 12029000) from 1942 to 1950 (Williams and Pearson, 1985). Otherwise, flows on the Black River have not been measured routinely. USGS measures flow at two locations on the Chehalis River upstream and downstream of the Black River. The USGS stations are Chehalis River at Porter (Station Number 12031000) and Chehalis River near Grand Mound (Station Number 12027500). The Porter station is at Chehalis RM 33.3, and the Grand Mound station at Chehalis RM 59.9. The mouth of the Black River is at Chehalis RM 47.0.

The seven-day low flow with an average return time of 10 years (7Q10) is a standard measure of critical low flow and is specified in the Water Quality Standards as the flow to be considered in the analysis of standards compliance. The 7Q10 in the Chehalis River at Porter is 198 cfs, and at Grand Mound is 114 cfs. Flows on August 31, 1992 were 182 cfs at Porter and 117 cfs at Grand Mound. In 1991, daily low flows were 337 cfs at Porter and 197 cfs at Grand Mound (on August 25). The mean monthly flow for August is 402 cfs at Porter, and 237 cfs at Grand Mound.

Based on the Chehalis River data, flows were somewhat less than average for the 1991 low flow period, and critically low in 1992. Flows at Howanut Road were in the range of 65 to 70 cubic feet per second (cfs) in the summer of 1991, while in 1992, flows were as low as 45 cfs. In late August 1992, flows in the Black River were most likely at 7Q10 levels.

To estimate the 7Q10 flow for the Black River at Howanut Road, an equation was developed to predict Black River flows from flows at the two USGS stations. Table 3.1 presents that analysis. Measured flows at Howanut Road were compared to the residual, or difference, between the flows at the Porter and Grand Mound USGS stations. Linear, semi-log, and log-log regressions were evaluated. The best fit was found for a semi-log regression, using the USGS flow residual and the $\log_{10}$ of the Howanut flows ($r^2 = 0.782$, $p<0.005$).

Based on the predictive equation shown in Table 3.1, Howanut Road flows in August 1992 were calculated (Table 3.2). The estimated 7Q10 critical low flow for the Black River of 30 cfs was likely attained near the end of August 1992.

3.1.2 Drogue Results and Time of Travel

Table 3.3 presents the results of the drogue work. The slow velocities of the middle Black River can be clearly seen. A few drogues showed no movement at all, while very low velocities were measured with others. The Black River's time of travel for this stretch based on these velocities varied from 0.6 to 1.2 days per mile.

Using the "Occupied Channel Volume" method (Velz, 1970), the time of travel for the entire river was estimated. A copy of the spreadsheet used is provided in Appendix Table C.3. The estimated time of travel from the boat launch below Littlerock (RM 15.3) to the mouth was 11.7 days for 1991 low flow conditions. The river took about 9.7 days to travel the 5.7 miles from the Littlerock boat launch to the end of the slow stretch, a rate of 1.7 days per mile. This rate compares well to the drogue study results, where travel times were often above 1 day per mile (note that river velocities too slow to measure by drogue would equate to very high travel times). The almost 10 day residence time of the middle river is slightly less than the 15 day residence time that defines a lake or reservoir in the Water Quality Standards.

Travel time for the 9.7 miles from the end of the slow stretch to the mouth is about 2 days, or about 0.2 days per mile. This illustrates the significantly different character of the middle and lower reaches of the Black River.

A time of travel estimate and channel dimensions are needed for model development. The flow balance, ground water flows, and surface withdrawals used in the time of travel estimate are only a "first-cut" estimate. To improve the estimate of inflows, outflows, and the flow balance, a dissolved conservative tracer mass balance was developed, using the WASP5 model with chloride as the tracer. The conservative tracer modeling effort is discussed in Section 4.

3.1.3 Staff Gage Measurements

Staff gage measurements were made at various locations on the Black River during this study. In addition, Thurston County collected staff gage measurements as part of their work. It was not possible to predict flows during the summer from the staff gage readings because insufficient data were collected of gage readings and flow measurements recorded at the same time.

Table 3.1 Prediction of Black River Summer Low Flow based on USGS flows in Chehalis River

All flows in cfs

	USGS			Observed		Estimated
Date	Porter	Grand Mound	Porter - GdMd	Howanut	Log(Hwnt)	Howanut
08/21/91	357	214	143	67	1.82	72
09/10/91	426	291	135	65	1.81	66
09/11/91	408	277	131	69	1.84	63
09/12/91	402	277	125	66	1.82	59
06/23/92	417	273	144	75	1.87	73
07/23/92	315	191	124	51	1.71	58
08/05/92	246	145	101	44	1.65	45

Regression Output (Semi-log):

Constant	1.1643
Std Err of Y Est	0.0409
R Squared	0.7820
No. of Observations	7
Degrees of Freedom	5
X Coefficient(s)	0.0048
Std Err of Coef.	0.0011
t	4.2355
t(.005,1,5)	4.032

Equation for Estimated Flows:

Q(H) = 10^{.0048 [Q(P)-Q(GM)]+1.1644}

where:
Q(H) = Estimated Howanut Flows
Q(P) = Gaged Flows at Porter
Q(GM) = Gaged Flows at Grand Mound

Table 3.2 Estimated Flows
for Black River @ Howanut Rd Br
August 10-31, 1992

All flows in cfs
Shaded values indicate critical low flow

	USGS			Estimated
Date	Porter	Grand Mound	Porter - GdMd	Howanut
08/10/92	344	228	116	53
08/11/92	307	196	111	50
08/12/92	280	176	104	46
08/13/92	261	162	99	44
08/14/92	247	150	97	43
08/15/92	241	141	100	44
08/16/92	235	137	98	43
08/17/92	231	137	94	42
08/18/92	226	137	89	39
08/19/92	224	134	90	40
08/20/92	217	130	87	38
08/21/92	209	128	81	36
08/22/92	208	127	81	36
08/23/92	209	131	78	35
08/24/92	207	136	71	32
08/25/92	206	137	69	31
08/26/92	203	132	71	32
08/27/92	196	127	69	31
08/28/92	191	124	67	31
08/29/92	185	120	65	30
08/30/92	183	117	66	30
08/31/92	182	117	65	30

7Q10 Low Flow at Porter =	198
7Q10 Low Flow at Grand Mound =	114
7Q10 Low Flow Estimate at Howanut Rd =	30

Table 3.3 Drogue Study Results for Black River, September 2-3, 1992				
RM	Time (min)	Dist (ft)	Speed (ft/sec)	Travel Time (days/mile)
14.9	> 10	No Movement		
14.3	22.2	100	0.075	0.8
13.7	32.0	100	0.052	1.2
12.7	30.9	100	0.054	1.1
12.0	15.9	100	0.105	0.6
11.7	> 10	No Movement		
10.1	> 10	No Movement		

Review of the combined Thurston County and Ecology gage readings showed a curious result. Heights measured at the upstream gages tended to increase as flows dropped in late August, which is counter to what one would expect. One possible explanation for this is that macrophyte beds are increasing during mid-summer, causing flow to slow through the beds' dense growth, which in turn increases the upstream head. There is an area of macrophytes downstream of Mima Creek where growth could be dense enough to produce this effect.

3.2 Water Quality Data

3.2.1 Field Measurements - Grabs and Vertical Profiles

Four parameters were measured throughout the study as field parameters - temperature, pH, specific conductance (conductivity), and dissolved oxygen. The complete results of these field measurements are presented in Appendix D.

All field monitoring meters were calibrated according to manufacturer's specifications. A bias was observed between calibrations in the field DO measurements taken with the Hydrolab® Datasonde 3 (DS3) and Surveyor 2 (S2) meters. DS3 and S2 data were corrected systematically to reduce error by subtracting a correction factor. The correction factor was the difference between a field Winkler verification sample result and a paired meter reading. All DS3 and S2 dissolved oxygen data presented in this report have been corrected.

Data collected with the S2 during August 1991 showed a large amount of bias because the meter was not properly calibrated. S2 data for pH during July and August 1991 showed unacceptable drift, and were corrected by average of the errors measured at pre- and post-calibration. Conductivity data from this period had poor precision, but were not corrected, and should be used with caution.

All other meter data can be used with confidence, taking into consideration the variability of results. A detailed description of quality assurance/quality control procedures and measures used in the TMDL study field measurements are provided in Appendix Section B.2.

3.2.1.1 Conductivity

Conductivity is a measure of how easily electricity can pass through the water. It is an indirect measure of the amount of dissolved ions, since when more ions are present, more electricity can pass. Conductivity can often be used to predict total dissolved solids (TDS), but the relationship is site-specific, because different ions conduct at different rates, and some dissolved substances are non-ionic.

Conductivity was used in this study primarily to identify suspected pollutant sources that exhibit unusually high concentrations of TDS. This situation arose during the 1991 surveys, when unusually high conductivity pointed to some input of pollutants in the area upstream of Mima Creek. The problem above Mima Creek is discussed later in the sections for other parameters, and a detailed analysis is provided in Pickett (1991). The conductivity data collected in this study are also useful for characterizing baseline water quality conditions and for comparison to other studies. There are no water quality standards for conductivity.

During the two summers of this study, conductivity measured in Black River surface waters was typically in the range of 90 to 100 μmhos/cm from the boat launch below Littlerock (RM 15.3) to the end of the slow stretch above Global Aqua (RM 9.3), and between 100 and 110 μmhos/cm downstream to the mouth, with conductivity gradually increasing in the downstream direction. Conductivities in the Black River from Littlerock upstream were typically between 80 and 90 μmhos/cm. In the Clearwater Lagoon, a large backwater area off the mainstem Black River west of the Canoe Club (RM 14.1), conductivities were between 70 and 80 μmhos/cm. Conductivities in the spring were lower than summer values.

In deeper pool areas, conductivities were typically in the range of 120 to 170 μmhos/cm. The exception to this was the deeper waters of the pool just above Mima Creek (RM 11.9), where conductivities were observed as high as 800 μmhos/cm in 1991 and close to 250 μmhos/cm in 1992.

Tributary conductivities ranged from 58 μmhos/cm in Waddell Creek and 72 μmhos/cm in Mima Creek, to 93 μmhos/cm in Beaver Creek and 98 μmhos/cm in Blooms Ditch. The springs near Global Aqua and Big Rock all had conductivities in the range of 135 to 150 μmhos/cm.

In general, conductivity measurements show that dissolved solids in the ground water were higher than values in the surface waters of the Black River. Regional ground water data are almost all in the range of 100 to 150 μmhos/cm (Sinclair and Hirschey, 1992; Erickson, 1990b; and Pearson and Higgins, 1977). Some of the deep areas showed conductivities in this range, except for the pool above Mima Creek where conductivities were notably higher.

The lowest conductivity values were found both in tributaries draining the Black Hills and in the Clearwater Lagoon. The low conductivity of the Clearwater Lagoon suggests that ground water relatively low in dissolved solids is originating in the Black Hills and surfacing in the lagoon. Field observations confirm that water in the upper end of Clearwater Lagoon is fairly clear, suggesting a source other than backwater from the Black River.

3.2.1.2 Temperature

Temperatures in the Black River were often higher than the criterion of 18°C specified in the Water Quality Standards (Table 1.2). Figure 3.1 summarizes the temperatures measured from grab and vertical profile measurement. The figure shows that the upper Black River and the deeper waters of the middle river generally had acceptable temperatures. Surface waters of the middle river frequently exceeded 18°C, and the lower river showed the highest proportion of values that exceeded the criterion. Tributaries were below 18°C, except in locations where flows were very low. Not surprisingly, the highest temperatures were found between mid-July and the end of August.

The Water Quality Standards include criteria for maximum temperature increases. An adequate understanding of the thermal balance of the Black River, and of the relative contribution of natural conditions and human impacts on temperature, is beyond the scope of this report and could only be achieved with a separate study. However, based on field observations and other studies of stream temperature, some conclusions can be drawn.

The middle river is slow, wide, and lined on both banks by brush wetlands. This area is relatively unimpacted by human activities in the riparian zone, and temperature increases in this stretch are most a likely a result of natural conditions. The lower river is swift with riffles, and some areas are quite shady. However, in many other areas the riparian shade trees are absent, most likely due to human activities associated with the agricultural and residential land uses of the lower river. Tall shade trees that allow effective shading appear to be viable from about RM 10 downstream.

The U.S Fish and Wildlife Service Habitat Degradation Survey (Wampler *et al.*, 1993) included loss of riparian canopy as part of their observations. Widespread loss of riparian canopy was documented in the stretch of the Black River from the steel trestle (RM 9.1) to the mouth. In particular, from the steel trestle to the Schoolland Road boat launch 62% of riparian canopy was reduced or absent, and from the SR 12 boat launch to the mouth 65% of riparian canopy was reduced or absent.

A study done by the Timber/Fish/Wildlife Temperature Work Group (TFW, 1990) found that "very low elevation streams (less than 100 m or 300 ft) were the most dependent on shade, requiring significant amounts to maintain temperatures." The report notes that the temperature of rivers can adjust to a new equilibrium based on downstream shading conditions.

Thus, it is reasonable to conclude that after temperatures are increased by warming in the slow middle reach of the Black River, riparian shading in the lower river could maintain or reduce river water temperatures. Any significant loss of shade on the lower river would tend to increase water temperatures over that stretch. The amount of temperature increase caused by shade tree removal cannot be quantified without further study. However, temperatures are greater than the water quality criterion, and the lack of riparian shading is contributing to that situation.

To achieve Class A standards for temperature, a strategy of best management practices is recommended. Projects that plant riparian shade trees should be encouraged, and existing riparian shade trees should be protected. As resources allow, detailed monitoring and modeling could be used to prioritize areas that would benefit the most from shade improvements. This approach would constitute a phased approach to a TMDL for temperature in the lower Black River (RM 0 to 10.0). The phased temperature TMDL should be revisited at five year cycles according to the Basin Approach of Ecology's Water Quality Program.

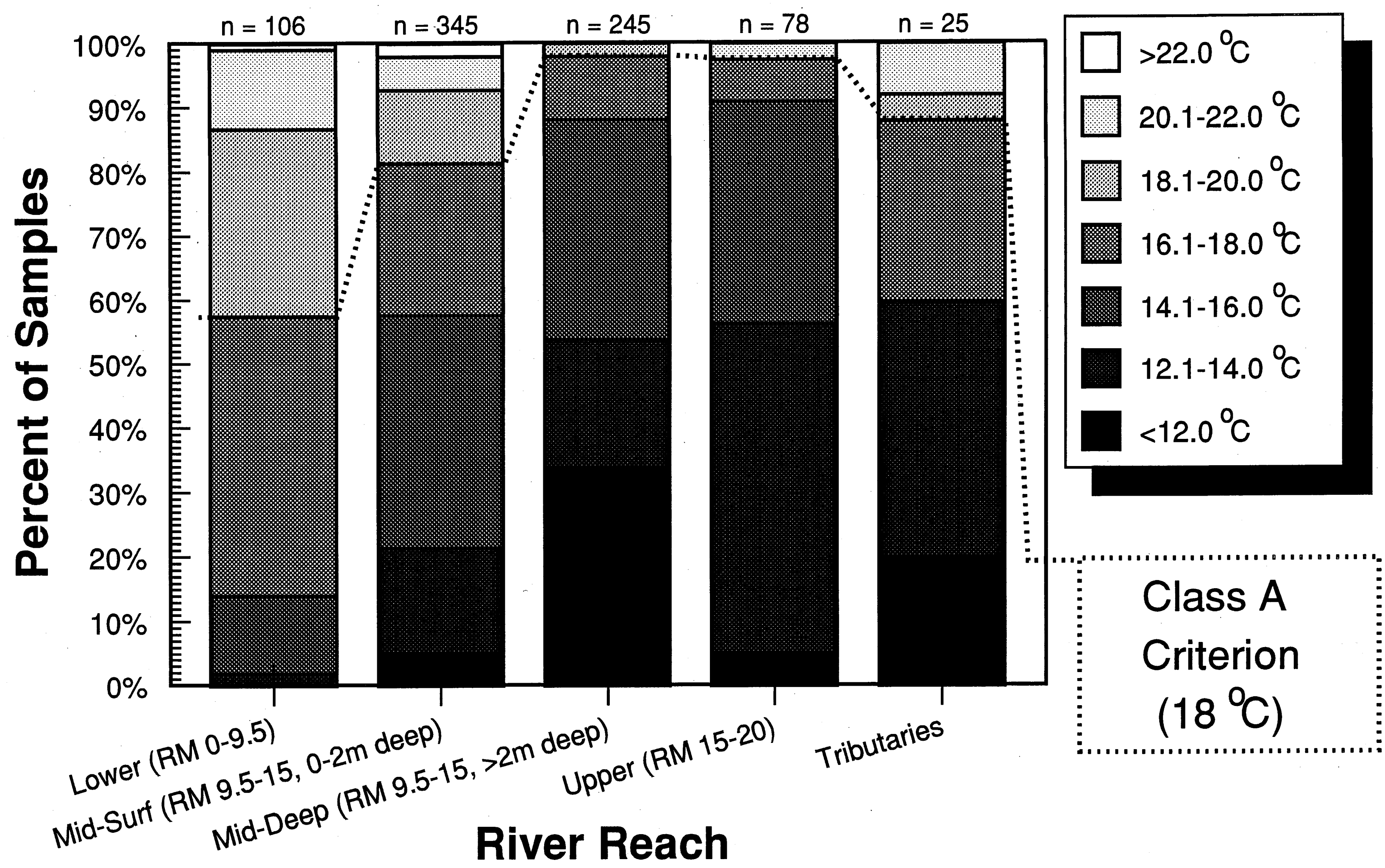


Figure 3.1 Distribution of Temperatures
Black River TMDL Survey Results

3.2.1.3 pH

Most measurements in the Black River showed pH values of 6.5 to 7.5 (Figure 3.2). However, a significant number of samples were less than pH 6.5, the water quality criterion for minimum pH (Table 1.2). Most of the samples that were less than pH 6.5 were found in bottom waters[4]. A decrease in pH of 0.3 to 0.6 units from surface to bottom was very common in the vertical profiles.

Since the Black River drains extensive wetlands, it is likely that organic acids associated with the decay of vegetation were responsible for the low pH. The dark tint of the river is evidence of the presence of organic acids. It is reasonable that organic material in the sediments reduces pH near the bottom, and algal productivity increases pH near the surface. Therefore, the low pH levels in the waters of the Black River near the river bed appear to be a natural condition, and thus not a violation of the water quality standards.

A few measurements of pH were greater than pH 8.5, the water quality criterion for maximum pH (Table 1.2). These measurements were isolated to the Clearwater Lagoon, where most likely a localized highly productive system was driving up pH. All other pH values were less than 8.0. Measurements of pH tended to increase in the downstream direction. High pH near the surface may be the result of photosynthetic productivity enhanced by human nutrient inputs and reduced shading, and where it exceeded the criteria, it would be considered a violation of the water quality standards.

3.2.1.4 Dissolved Oxygen

Dissolved oxygen varies widely throughout the Black River. Grab measurements and Winkler analysis of samples showed areas that ranged from anoxic to supersaturated. Figure 3.3 shows the distribution of DO concentrations in the different areas sampled. Figure 3.4 shows the distribution of measurements expressed as a percentage of the DO saturation concentration.

In the upper river, no samples were found above the criterion of 8.0 mg/L and all samples were below saturation. Most of the data fell between 5.0 and 7.5 mg/L, and none of the samples showed DO levels below 4.0 mg/L. The influence of the

[4] Because post-calibration showed a significant downward drift in pH, surface measurements taken on July 23, 1991 showing pH values below 6.5 can be discounted - see Appendix B and D.

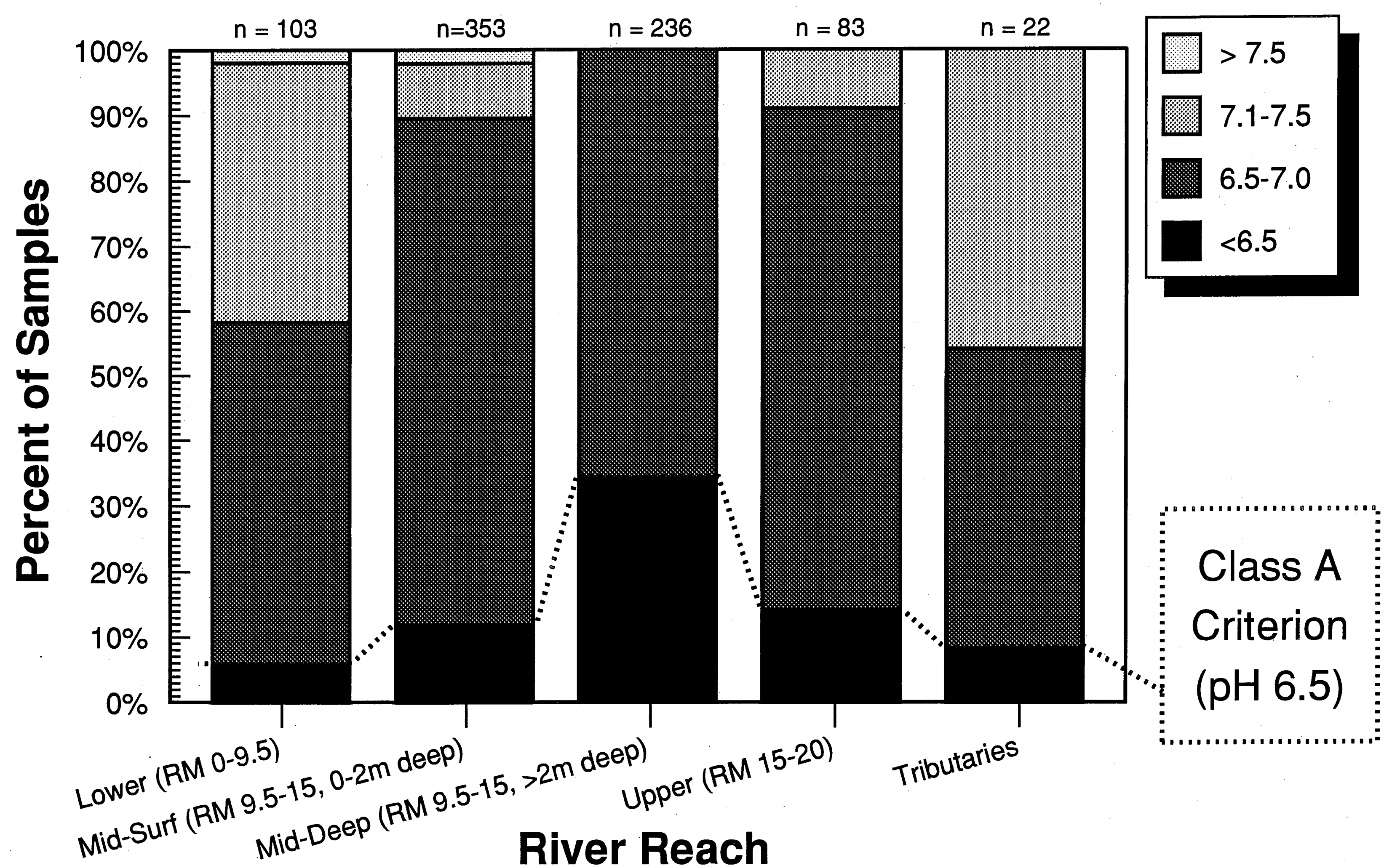


Figure 3.2 Distribution of pH
Black River TMDL Survey Results

extensive wetlands in the upper basin is a likely explanation for low DO concentrations. Researchers have noted that a high organic-matter content in the discharge from marshlands produces low DO levels and high color content (Lee *et al.*, 1975).

In the middle river, DO levels less than 8.0 mg/L were widespread. Almost one-third of surface water samples and over three-quarters of samples from deeper waters in this reach were less than the criterion. Some of the deeper areas showed extremely low DO and even anoxia. In terms of percent saturation, virtually all of the deep samples and most of the shallow samples were below saturation. However, a small percentage of shallow samples showed supersaturation, with the greatest supersaturation occurring in the Clearwater Lagoon[5].

In the lower river, as in the middle river, DO levels were still below the criterion in about one-third of the measurements and below 90% saturation in one-half of the measurements. However, supersaturated conditions were found in a greater percentage of measurements for the lower river.

About half of the measurements made on tributaries had DO levels less than the criterion, but most of these measurements were either made from springs or from locations where flow was very low. Most of the tributary streams sites with significant flow (Waddell, Beaver, and Mima Creeks) had DO levels above the criterion. One exception was a measurement made in Allen Creek (a tributary of Beaver Creek sometimes referred to as Scott Lake Creek), which had a DO of 6.0 mg/L, despite significant flow.

As this data summary shows, DO concentrations below the water quality criterion were widespread in the mainstem Black River. Unlike pH, for which natural causes appear to reduce levels and pollutant sources would tend to increase them, DO levels in the Black River may be reduced by both natural causes and pollutant sources. Natural processes include the influence of the upper and middle basin riparian

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[5]Certain characteristics of the Clearwater Lagoon are of tangential interest. Productivity in the Lagoon was very high, as indicated by DO supersaturation and high pH levels. The Lagoon had a thick growth of periphytic green algae, and an unusual photosynthetic bacteria was also observed, tentatively identified as belonging to the genus Thiopedia (Brock, 1979). This bacteria grows in brilliant purple colonies, and uses reduced sulfur as an electron donor in photosynthesis. It is generally found at the anoxic interface where both large amounts of sulfides and ample sunlight are available, and is potentially capable of high productivity. This unusual organism and the ecology of the Clearwater Lagoon may be worthy of future research.

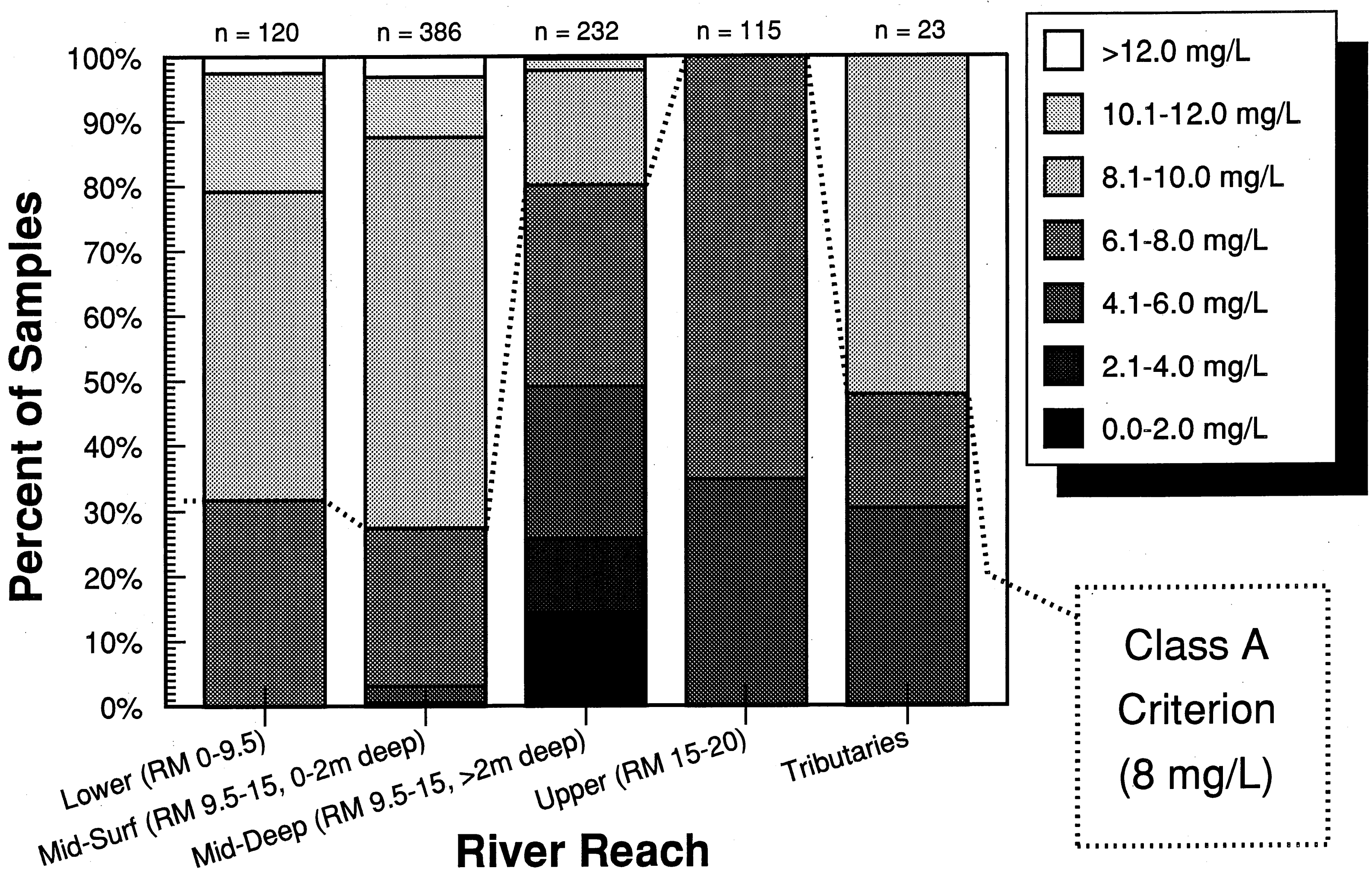

Figure 3.3 Distribution of Dissolved Oxygen

Black River TMDL Survey Results

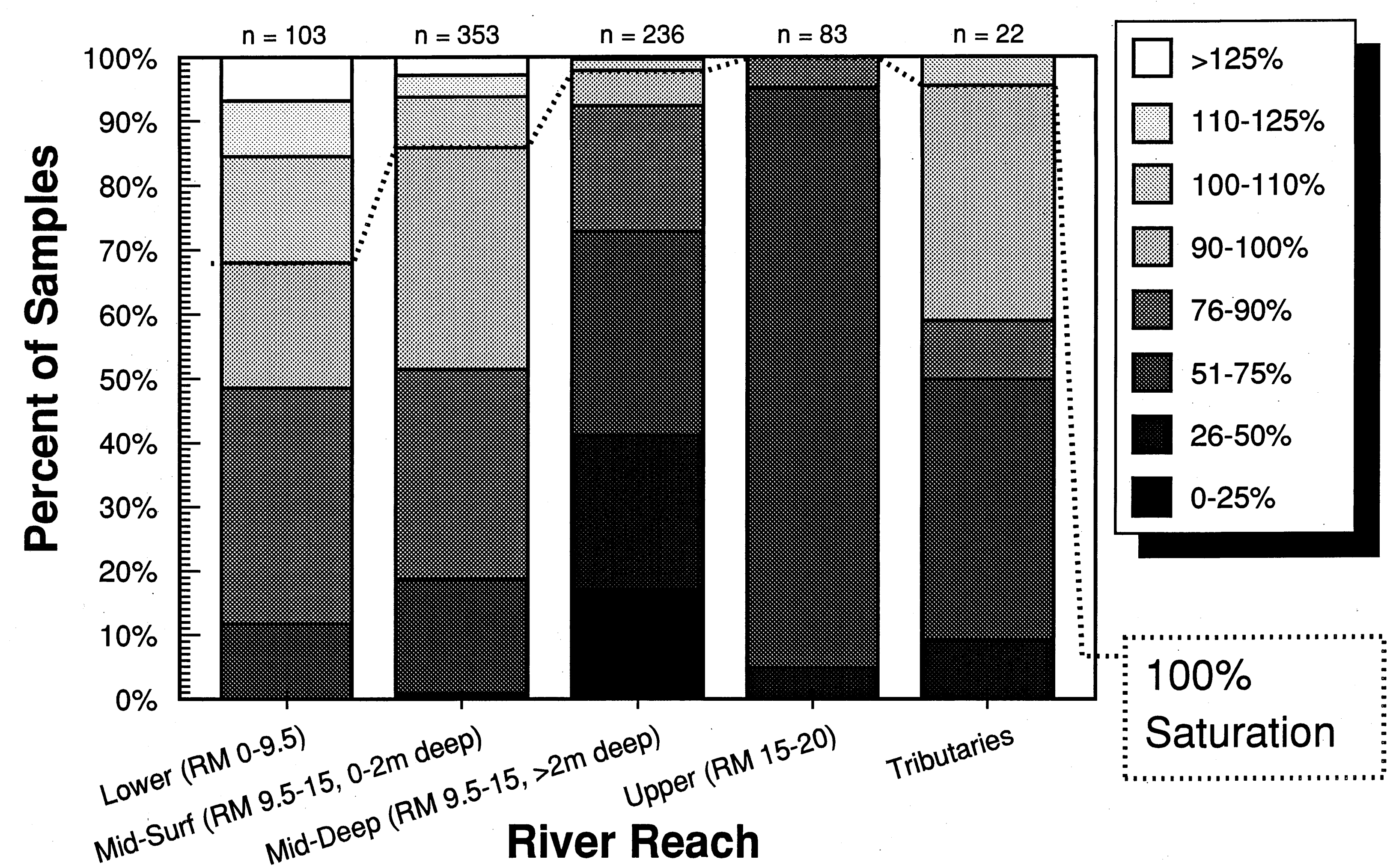

Figure 3.4 Distribution of DO Percent Saturation

Black River TMDL Survey Results

wetlands as well as other physical processes such as reaeration, stratification and temperature. Both point and nonpoint pollutant sources exist in the Black River basin that may reduce DO levels below already naturally low levels. The many processes influencing DO will be discussed throughout the rest of this report.

3.2.1.5 Stratification

One of the significant characteristics of the Black River is stratification of the water column in the middle reach. Most rivers and streams, including the upper and lower Black River, are isothermal -- the temperature is essentially the same at all depths. The turbulence of the flowing water keeps the water column fully mixed. However, during this study thermal gradients were found in the middle Black River (surface waters were warmer than bottom waters). Differences between surface and bottom temperatures as high as 12°C were found at some sites. Thermal stratification was found in some locations at all the times sampled (May through October), although stratification was strongest and most widespread in mid-August.

The significance of the vertical temperature gradients is that warmer, less dense surface water overlaying colder, denser bottom water creates a very stable formation. The density gradient is more stable with greater temperature differences and with warmer water. The water column stability resists mixing and dispersion of dissolved materials. Oxygen entering the water column from the surface moves towards the bottom very slowly, and materials released by the sediments do not mix into the upper waters. The result is that the bottom waters are often low in oxygen and high in other constituents compared to surface waters.

Figures 3.5 and 3.6 demonstrate this phenomenon in the Black River. In Figure 3.5, vertical temperature profiles are shown at three locations in the middle Black River on six different dates in 1992. The pattern at these three sites was similar. Gradients of 1 to 3°C in June increased to a maximum gradient of between 6 and 11°C in mid August, and then returned in September to a gradient similar to what was observed in June.

Figure 3.6 shows vertical DO profiles at the same sites and dates. DO levels in June were higher than later in the summer, and generally the same from top to bottom. The exception was the site above Mima Creek, where very low oxygen was measured in the deepest waters in June.

As the temperature gradients increased, DO in the deeper waters decreased. Generally, DO in deeper waters reached its lowest level in late July to late August. As the temperature gradient decayed in September, DO levels near the bottom at the Mima Creek and Big Dock sites had recovered somewhat, although not to the levels

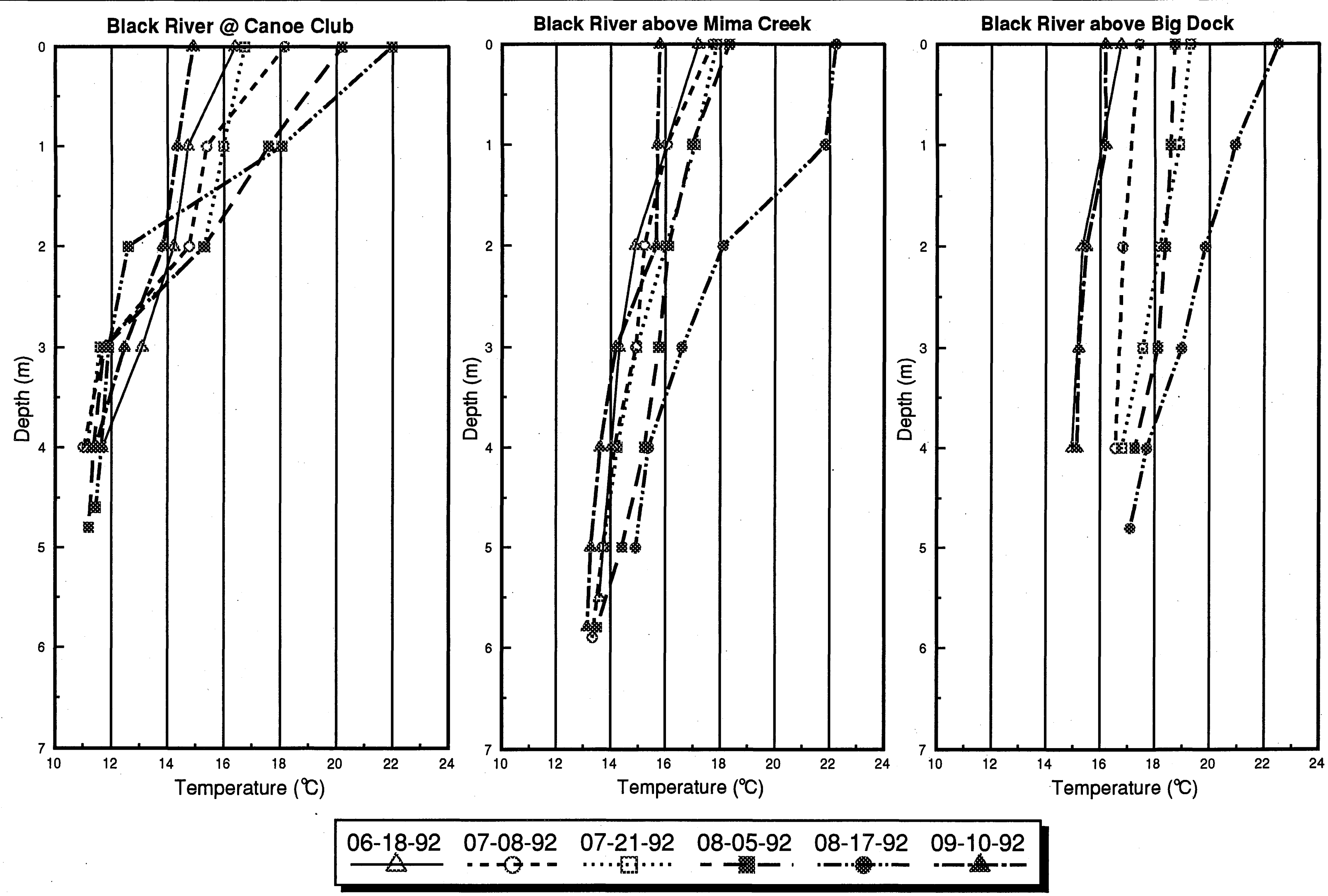

Figure 3.5 Vertical Temperature Profiles

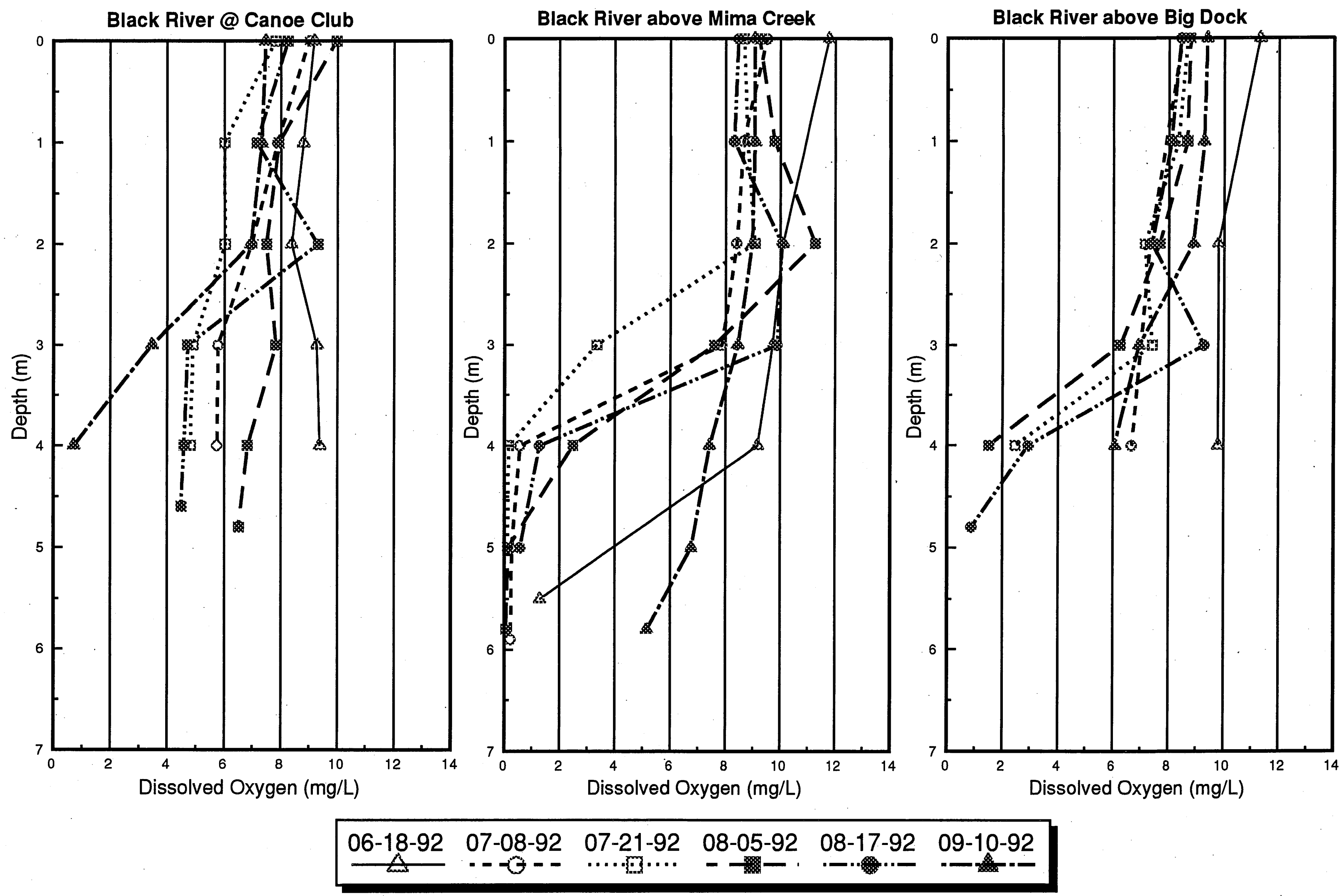

Figure 3.6 Vertical Dissolved Oxygen Profiles

observed in June. At the Canoe Club site, the lowest DO levels in deep waters were found in September, which may be explained by a temperature gradient that was greater at this site in September than at the other sites.

Other constituents show vertical differences associated with the observed stratification. Conductivity tends to increase with depth, and pH tends to decrease. The vertical pattern of chemical concentrations are discussed in Section 3.2.3, and the modeling of stratified areas are discussed in Section 4.

The extremely low DO levels in the deep waters above Mima Creek indicate a source of pollution near this location. It is believed that the discharge of pollutants from the Black River Ranch, a dairy farm located north of the river near this site, through a drainage ditch just upstream of Mima Creek (RM 12.2) was the principal factor of the water quality degradation at this location (Pickett, 1991). The Black River Ranch came under enforcement for poor waste handling practices between the 1991 and 1992 sampling season. Anoxic conditions were found as shallow as 3 meters in August 1991, but in 1992, despite much lower flows, the anoxia was found at 4 meters in July and 5 meters in August. This suggests that some improvement in water quality from 1991 to 1992 may have resulted from improvements in waste management at the Black River Ranch. Additional evidence of pollutant loading above Mima Creek will be presented later in the discussions of other parameters.

In general, stratification appears to be a natural phenomenon of the middle Black River during the low flow season, due to its low gradient and velocity. However, the existence of stratification increases the river's sensitivity to pollutants, by providing a mechanism to trap pollutants in deeper layers and release them as the stratification erodes. Depressed DO and moderate pH and conductivity gradients appear likely to occur in the middle Black River under pristine conditions. However, anoxic conditions and extreme pH or conductivity measurements would likely indicate impacts from pollutant loading.

3.2.2 Productivity and Diurnal Variation Field Measurements

3.2.2.1 Datasonde Measurements

DS3 measurements provide a measure of productivity through the diurnal variation in DO and pH. Diurnal temperature and conductivity readings are also collected. Appendix Table E.1 presents a summary of the DS3 results, with maximum, minimum and average values and the range from maximum to minimum. Complete results of the DS3 deployments are also provided in Appendix E.

Temperatures at each site showed diurnal variation of from 0.5°C up to 3.7°C. The maximum diurnal range coincided with the highest maximum temperature measured by the Datasondes in the river. Maximum temperatures were observed during the period of lowest flow in late August 1992, when average water temperature was between 19 and 22°C at all stations except above the boat launch below Littlerock (RM 15.3). The cooler temperatures at the Littlerock boat launch can be attributed to its location at the end of a shady stretch and below the cooler inflows of Waddell and Beaver Creeks. These observations lend support to the recommendation for a phased TMDL for temperature (Section 3.2.1.2).

The daily range for pH tended to be fairly steady, with a maximum range of only 0.6 units. This suggests that the water is reasonably well buffered with productivity causing only a small effect. Conductivity also showed little variation, which is not surprising.

Percent DO saturation had diurnal variations as high as 45 percentage points, although typically the range was between 10 and 20. The highest variations were observed from the Big Dock site (RM 9.7) downstream in 1991. Supersaturation was present from the site above Mima Creek (RM 11.9) downstream during the entire season, with the highest values in June 1992.

The diurnal range of DO concentrations varied from a low value of 0.4 mg/L to a maximum of 4.1 mg/L, which was measured at the Millpond site (RM 7.7) in 1991. DO ranges of greater than 2.0 mg/L were observed from the Big Dock site downstream in 1991, and DO ranges of 1.0 to 1.5 mg/L were common elsewhere. The highest DO levels (over 12 mg/L) were observed at the site above Mima Creek and the Big Dock site in June 1992. At the Littlerock boat launch site, the DO concentrations and ranges varied very little between sampling periods, and little difference was observed between that site and the two sites located farther upstream.

3.2.2.2 Other Measurements

In addition to the diurnal DS3 measurements, morning and evening DO samples were collected at several mainstem Black River stations and analyzed using the Winkler method. The results are shown in Table 3.4. Howanut Road (RM 1.2) showed the largest range in DO found in the Black River, 3.0 and 4.4 mg/L in August 1992. DO at Moon Road (RM 7.1) also showed relatively high diurnal ranges in September 1991, averaging 2.7 mg/L. The eight largest diurnal DO ranges in the mainstem Black River, including both Datasonde and Winkler measurements, were all found at the three sampling sites farthest downstream.

Light/dark bottle measurements were made at two locations, and the results are shown in Table 3.5. At the Littlerock boat launch site (RM 15.3), very little productivity was observed. This is consistent with the Datasonde observations that showed little seasonal variation in diurnal DO ranges. At Howanut Road (RM 1.2) the bottles also

Table 3.4 AM/PM Dissolved Oxygen Sampling Results

(All DO results in mg/L, using Winkler method)

Station	RM Code	AM Sampling Date	AM Sampling Time	AM Sampling DO	PM Sampling Date	PM Sampling Time	PM Sampling DO	Range
BR @ Howanut Rd Br	1.2	09/10/91	825	8.2	09/10/91	1330	9.7	1.6
		09/11/91	755	7.9	09/11/91	1350	9.2	1.3
		09/12/91	805	7.9	09/12/91	1325	9.1	1.2
		07/21/92	820	7.2	07/21/92	1445	7.8	0.6
		08/05/92	815	7.5	08/05/92	1710	10.5	3.0
		08/25/92	748	8.0	08/24/92	1900	12.4	4.4
BR @ SR 12 Br	4.1	08/25/92	738	9.1	08/24/92	1845	9.2	0.1
BR @ Moon Rd Br	7.1	09/10/91	755	7.0	09/10/91	1400	9.7	2.7
		09/11/91	740	7.0	09/11/91	1300	9.6	2.6
		09/12/91	745	7.2	09/12/91	1350	10.1	2.8
		08/25/92	730	8.2	08/24/92	1833	9.8	1.6
BR abv Littlerock BL	15.3	07/21/92	915	5.8	07/21/92	1800	6.6	0.8
		08/05/92	859	6.2	08/05/92	1641	6.9	0.8

Table 3.5 Light/Dark Bottle Experiment Results

RM		15.3	15.3	1.2
Depth	(m)	0.5	2.0	0.5
Date		09/05/91	09/05/91	09/12/91
Time In		955	1000	1200
Time Out		1400	1400	1530
DO-Initial	(mg/L)	6.2	6.1	8.6
DO-Light	(mg/L)	6.2	6.4	8.7
DO-Dark	(mg/L)	6.2	6.2	8.5
Respiration	(mg/L)	0.0	0.0	0.1
Net Productivity	(mg/L)	0.0	0.3	0.1
Gross Productivity	(mg/L)	0.0	0.3	0.3
Average Hourly Gross Productivity	(mg/L/hr)	0.00	0.06	0.07

showed low productivity. Since ambient DO measurements showed a diurnal range of over 2 mg/L on the same date, most of the primary productivity in the area of Howanut Road must have been benthic (*i.e.*, a result of aquatic macrophyte and periphyton photosynthesis).

The large diurnal range of DO in the lower river raises concerns, since minimum DO concentrations frequently drop below the water quality criterion. The association of benthic primary productivity with the low morning DOs points to the need for controls on macrophytes and periphyton to ensure that DO standards are met in the lower river. However, the management of macrophyte and periphyton growth is not simple and requires careful study. Benthic productivity in the lower river will be discussed later in Section 3 and also in Section 5.2.4.

Secchi depth measurements made during a few of the survey dates (Table 3.6) showed a pattern that occurred during four of five weeks: upstream stations had the highest clarity, and clarity decreased in the downstream direction. The pattern of decreasing clarity would tend to indicate increasing amounts of particulates, most likely suspended phytoplankton, in the downstream direction. This pattern was not observed for the early May observations, perhaps because it was early in the season and phytoplankton biomass had not yet developed. The relatively high clarity measured at the Millpond site (RM 7.9) in July 1991 seems to indicate that a significant amount of particulates were being removed from the water column in the stretch of the river upstream of that site.

3.2.3 Laboratory Sampling Results

Results for conventional parameters - conductivity, alkalinity, turbidity, total suspended solids (TSS), total dissolved solids (TDS), fecal coliform, and five-day biochemical oxygen demand (BOD_5) - are shown for mainstem and tributary sampling sites in Appendix Tables F.1 and F.2, respectively. Results for chlorophyll *a*, total organic carbon (TOC), ammonia nitrogen, nitrate and nitrite nitrogen, total persulfate nitrogen, total phosphorus (TP), soluble reactive phosphorus (SRP), and chlorides are presented for mainstem and tributary sampling sites in Appendix Tables F.3 and F.4, respectively. Ultimate carbonaceous biochemical oxygen demand (UBOD) and five day carbonaceous biochemical oxygen demand ($CBOD_5$) results and related parameters are summarized in Appendix Table F.5.

All laboratory analyses were performed within specified holding times. Certain data were qualified, as indicated in the data summary tables, and should be used with caution. A full discussion of data quality assurance and quality control can be found in Appendix Section B.3.

Table 3.6 Secchi Depth Measurements

(All Measurements in meters)

RM Code	Site Description	Date	Time	Secchi
14.1	BR @ Canoe Club	23-Jul-91	1119	2.8
13.1	BR abv Old Trestle	23-Jul-91	1140	2.5
11.9	BR abv Mima Ck	23-Jul-91	1200	1.7
11.1	BR abv Big Lagoon	23-Jul-91	1226	1.7
10.6	BR @ Swecker Dock	23-Jul-91	1245	1.5
9.7	BR abv Big Dock	23-Jul-91	1306	1.5
7.9	BR @ the Millpond	23-Jul-91	1420	2.4
14.1	BR @ Canoe Club	15-Aug-91	1055	2.3
13.1	BR abv Old Trestle	15-Aug-91	1135	1.9
11.1	BR abv Big Lagoon	15-Aug-91	1305	1.9
10.6	BR @ Swecker Dock	15-Aug-91	1325	1.9
9.7	BR abv Big Dock	15-Aug-91	1355	1.6
15.3	BR abv Littlerock BL	05-May-92	1240	1.6
14.7	BR blw Littlerock BL	05-May-92	1305	1.6
14.1	BR @ Canoe Club	05-May-92	1320	1.8
13.6	BR blw Canoe Club	05-May-92	1335	1.9
13.1	BR abv Old Trestle	05-May-92	1355	2.1
12.3	BR abv Dairy Drainage	05-May-92	1422	1.9
10.6	BR @ Swecker Dock	05-May-92	1630	1.8
9.7	BR abv Big Dock	05-May-92	1600	1.6
15.3	BR abv Littlerock BL	27-May-92	1320	2.3
14.1	BR @ Canoe Club	27-May-92	950	2.4
13.1	BR abv Old Trestle	27-May-92	1010	2.1
11.9	BR abv Mima Ck	27-May-92	1030	2.3
11.1	BR abv Big Lagoon	27-May-92	1100	2.0
9.7	BR abv Big Dock	27-May-92	1200	2.0
14.1	BR @ Canoe Club	18-Jun-92	1221	2.5
13.1	BR abv Old Trestle	18-Jun-92	1136	2.5
11.9	BR abv Mima Ck	18-Jun-92	1052	1.3
11.1	BR abv Big Lagoon	18-Jun-92	1025	1.5
10.6	BR @ Swecker Dock	18-Jun-92	1010	1.4
9.7	BR abv Big Dock	18-Jun-92	925	1.6

3.2.3.1 Conventional Parameters

Laboratory conductivities generally followed the same trend described for the field data -- gradually increasing downstream, higher in deeper areas, and particularly high in the deep waters above Mima Creek in 1991. TDS levels were generally in the range expected for the conductivities observed. However, a statistically significant relationship between TDS and conductivity, such that TDS can be predicted from conductivity with some accuracy, could not be established. This could be the result of the high variability of the TDS measurements and a varying chemical make-up of the dissolved solids.

Alkalinities were mostly just above 40 mg/L as $CaCO_3$. Alkalinity in combination with pH indicates the availability of carbon dioxide for photosynthetic uptake. Water bodies with low alkalinity may be carbon limited, as well as poorly buffered. High alkalinities are the product of the particular geology of the watershed, and generally indicate a large buffering capacity. Cole (1979) points out that alkalinities above 40 mg/L as $CaCO_3$ indicate an adequate supply of CO_2 for primary productivity, especially if phosphorus is limiting. Thus it appears that the alkalinity found in the Black River is at a moderate level, neither low enough to indicate a carbon-limited system or poor buffering, nor high enough to indicate extremely high buffering.

Turbidity and TSS results were generally quite low, both in the mainstem and tributaries. One exception was that turbidity in the deep waters above Mima Creek in 1991 was an order of magnitude higher than the rest of the river. This result is consistent with other evidence of a discharge of pollutants from the Black River Ranch, discussed earlier in Section 3.2.1.5. Results in the deep waters above Mima Creek in 1992 were much lower than 1991 levels, but still slightly higher than the rest of the river.

Turbidity and TSS at sites below the steel trestle (RM 9.1) showed a noticeable decrease from upstream levels. This pattern is consistent with the changes in Secchi readings measured along this reach. Field observations indicated an extremely lush growth of rooted aquatic macrophytes in the stretch downstream of the steel trestle and above the Schoolland Road boat launch sampling site (RM 8.5). The macrophytes may be serving as a natural filter, inducing a rapid settling of solids.

3.2.3.2 Fecal Coliform Bacteria

With only the exceptions noted here, all fecal coliform sampling results were less than the 100 cfu/100 mL criteria in the Black River mainstem and tributaries. One sample taken in July 1992 at the site above the Littlerock boat launch (RM 15.3) was above 100 cfu/100 mL. Two field replicate samples taken in August 1992 at State Route 121 near the mouth of Beaver Creek were above 200 cfu/100 mL. Samples taken on the same date higher in the Beaver Creek basin, from Allen Creek and from Beaver Creek at Case Road, were well below this level, indicating that the loading source causing the fecal coliform criteria violations at the mouth of Beaver Creek is located on Beaver Creek between Case Road and the mouth.

These results are consistent with the elevated bacteria loading observed at these two sites during the winter study (Coots, 1994). It is particularly unusual to find bacteria levels over 200 cfu/100 mL during a late summer dry spell. This suggests a source that is active even in the summer months, and raises concerns for public health, since recreational swimming in the creek is most likely at this season. Also, as noted by Coots, the exceedance at the Littlerock boat launch was likely the result of high bacteria levels in Beaver Creek.

The U.S. Fish and Wildlife Service Habitat Degradation Survey (Wampler *et al.*, 1993) documented several areas of livestock access on Beaver Creek: a small area one-half mile above the Route 121 bridge near the mouth; a stretch of almost a mile from 1.6 to 2.6 miles above the mouth; and a stretch of almost one-half mile downstream of Case Road. In particular, the USFWS survey noted three locations of "livestock waste input" in the one mile stretch of Beaver Creek upstream of Allen Creek. This identified waste input location should be the first priority for investigation in the Beaver Creek drainage.

3.2.3.3 Chlorophyll *a*

Chlorophyll *a* is one of the pigments used by algae and plants for photosynthesis, and its concentration in the water column is an indicator of the biomass of photosynthetic algae. A water body that is suffering from severe eutrophication, or the overabundance of nutrients that causes a bloom of photosynthetic algae, typically exhibits a pea-green color from high levels of chlorophyll *a*. Lower levels may not be visible, except as turbidity, but may still be measurable. Chlorophyll *a* may also be present from sources other than algae, such as detritus sloughed from rooted or floating macrophytes.

Since it is an indicator of photosynthetic algae, chlorophyll *a* can be used to define the trophic state of a lake. A lake in an oligotrophic state, such as a high alpine lake, will exhibit great clarity and will have very low levels of chlorophyll *a*. A eutrophic lake will have very high levels of chlorophyll *a*, and a mesotrophic lake is at the transition from oligotrophy to eutrophy. The implications of the trophic state to a river system may be different than for a lake, but the lake-like characteristics of the middle reach of the Black River make the comparison appropriate.

The levels of chlorophyll *a* that define different trophic states have been evaluated by a number of sources (Carlson, 1977; Welch, 1980; Schlorff, 1992; Oregon

Administrative Rule 340-41-150), and there appears to be general agreement that chlorophyll *a* concentrations below 4 μg/L indicate oligotrophic conditions and concentrations above 15 μg/L indicate eutrophic conditions.[6]

Levels of chlorophyll *a* measured in the Black River during this study ranged from not detected to around 12 μg/L. Table 3.7 shows chlorophyll *a* data between RM 11.9 and RM 9.3. The values observed in the middle Black River generally fell in the mesotrophic range during the summer, and maximum chlorophyll *a* values approached eutrophic levels. This indicates that the Black River is in a transition state between high clarity oligotrophic conditions and nutrient-enriched eutrophic conditions.

In the lower Black River below the steel trestle (RM 9.1), chlorophyll *a* levels were all below 3 μg/L, which was characteristic of oligotrophy. However, the heavy growths of periphyton and macrophytes and the large diurnal swings in DO indicated that the lower river was still fairly productive and some of the chlorophyll *a* may have been sloughed from attached growth.

Commonly, mesotrophic water bodies can easily be pushed into eutrophy by increases in nutrient loading or other changes that enhance productivity. Eutrophic conditions are characterized by wide daily changes in DO, with supersaturated conditions during the day and very low DO in the early morning. Generally pH also increases and decreases with the DO levels, due to the uptake of dissolved inorganic carbon. A high level of productivity is also usually perceived as aesthetic degradation of water quality, due to poor clarity and green coloration of the water. Seasonal die-off of algal blooms may cause offensive odors and extremely low DO concentrations. Nutrient enrichment may also cause the nuisance growth of periphyton and macrophytes, which may become objectionable.

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[6]Welch (1980) proposed an index of the trophic state of a lake based on the seasonal average of epilimnetic water samples: levels of 0 to 4 μg/L indicate oligotrophy, and levels above 10 μg/L indicate eutrophic waters. Carlson (1977) defined a lake trophic state index, in which a chlorophyll *a* value of 6.4 μg/L corresponds to mesotrophic conditions and a chlorophyll *a* value of 20 μg/L corresponds to eutrophic conditions; concentrations between these values are undefined. A literature review done as part of the development of water quality criteria for nutrients for the state of Washington (Schlorff, 1993) found that eutrophic conditions in North American and European lakes were associated with chlorophyll *a* levels above 8 μg/L. The State of Oregon Nuisance Phytoplankton Growth Rule (OAR 340-41-150) sets an action level of 15 μg/L for chlorophyll *a* in rivers.

Table 3.7 Total Phosphorus to Chlorophyll a Relationship

	RM 11.9 - 9.3	Replicates averaged	Phosphorus in mg/L
	0 - 2 m depth	Below detection set to 1/2 detection limit	Chlorophyll a in µg/L

Date	Total Phosphorus	Chlorophyll a Observed	Chlorophyll a Predicted	Error	(Error)2
09/10/91	0.059	9.9	11.8	1.8	3.32
09/11/91	0.056	11.6	11.3	-0.3	0.10
07/21/92	0.005	1.2	3.9	2.7	7.50
07/21/92	0.005	4.0	3.9	-0.1	0.01
08/05/92	0.026	9.9	7.0	-2.9	8.52
07/21/92	0.01	5.6	4.7	-1.0	0.94
08/05/92	0.022	4.0	6.4	2.4	5.53
09/10/91	0.037	6.8	8.6	1.7	3.05
09/11/91	0.048	12.3	10.2	-2.1	4.41
09/12/91	0.033	10.3	8.0	-2.3	5.49
07/21/92	0.005	5.3	3.9	-1.3	1.77
08/05/92	0.016	3.0	5.5	2.6	6.51
07/21/92	0.005	6.0	3.9	-2.1	4.44
08/05/92	0.0215	5.4	6.3	1.0	0.91
MAX	0.059	12.3		RMSE	1.9
AVG	0.025	6.8		(Root Mean	
MIN	0.005	1.2		Square Error)	

Regression Output:

Constant	3.203
Std Err of Y Est	2.092
R Squared	0.657
No. of Observations	14
Degrees of Freedom	12
X Coefficient(s)	144.944
Std Err of Coef.	30.246
t	4.79
t(1,12,.001)	3.93

Chlorophyll-a levels projected from total phosphorus

Total Phosphorus	Chlorophyll a Projected	Chlorophyll a - RMSE	Chlorophyll a + RMSE
0.01	4.7	2.7	6.6
0.02	6.1	4.2	8.0
0.03	7.6	5.6	9.5
0.04	9.0	7.1	10.9
0.05	10.5	8.5	12.4
0.06	11.9	10.0	13.8
0.07	13.3	11.4	15.3
0.08	14.8	12.9	16.7
0.09	16.2	14.3	18.2
0.1	17.7	15.8	19.6

Complaints have been voiced about the lush growth of macrophytes in the lower river (Sharer, 1992). Concerns have also been raised by the owner of the Black River Canoe Club about the protection of recreational resources of the Black River (Dahl, 1992). The Black River Watch was formed not only as a result of the 1989 fish kill, but also because long-time shoreline residents have reported a decline in the water quality of the Black River, based on their observations of increased turbidity and aquatic vegetation (TCEH, 1991). The mesotrophic conditions indicated by the chlorophyll *a* in the Black River should be viewed as a warning that the river is threatened by further degradation from eutrophication.

3.2.3.4 Phytoplankton Identification

While chlorophyll *a* is an indirect assessment of phytoplankton biomass, phytoplankton can also be directly assessed. In the Black River, samples were collected and the algal units in the sample were counted, measured, and identified (Sweet, 1992). Biovolume and algal density for the whole sample and for the most common species were reported.

The algal species found in the Black River were somewhat variable. Diatoms were common (*Cymbella minuta, Achnanthes minutissima, Cocconeis placentula, Achnanthes lanceolata*, and *Synedra ulna*). These species are typical of low to moderate nutrient waters and can be periphytic. Cryptophytes were also common at times (*Cryptomonas erosa* and *Rhodomonas minuta*). Cryptophytes are flagellate, facultative heterotrophs. They are found in a wide range of conditions, but are generally associated with slow-moving waters which are nutrient or organic-enriched. In June 1992 at the Big Dock site (RM 9.7), a particularly strong bloom of algae was observed, dominated by *Chlamydomonas*-like flagellate green algae. This coincided with high DO concentrations and saturation levels, as discussed above.

Table 3.8 summarizes total algal biovolume and density, and dominant species at sites and times sampled. Algal species composition and abundance changing seasonally, and were also markedly different between the upstream end of the middle reach (RM 15.3), the downstream end of the middle reach (RM 9.5 and 9.7) and the lower river (RM 7.1).

The relationship between chlorophyll *a* measurements and algal biovolume and density was very poor. Possible explanations for the lack of a good correlation are the large amounts of non-algal chlorophyll-containing debris of unknown origin found in some samples, and the poor analytical precision indicated by the high replicate variability of the chlorophyll *a* analyses.

Table 3.8 Summary of Phytoplankton Identification Results

ALGAL DENSITIES (#/mL)

RM	09/10/91	06/18/92	07/21/92	08/05/92	10/01/92
1.2	525				
7.1	333	678	99	67	699
9.5			80	203	
9.7		6884			612
11.1	1597				
15.3		292	50	27	135

ALGAL BIOVOLUMES (um3 x 1000 per mL)

RM	09/10/91	06/18/92	07/21/92	08/05/92	10/01/92
1.2	166				
7.1	85	235	38	25	197
9.5			21	69	
9.7		2067			132
11.1	605				
15.3		128	26	16	39

DOMINANT SPECIES

RM	09/10/91	06/18/92	07/21/92	08/05/92	10/01/92
1.2	D				
7.1	D	C	D	D	C
9.5			D	D	
9.7		G			C
11.1	C				
15.3		C	D	D	C

D = Diatoms
C = Cryptophytes
G = Green algae

Sweet (1986) summarized the algal biovolume and density levels associated with lake trophic states. Taking the average of values from RM 11.1 to RM 9.5, the mean algal density of 1875 #/mL found in the Black River exceeded the value of 1066 #/mL associated with eutrophic conditions. The mean algal biovolume of 579 um^3x1000/mL fell between the level associated with mesotrophy (329 μm^3x1000/mL) and the level indicating eutrophic conditions (1056 μm^3x1000/mL). These results support the determination from chlorophyll *a* data that conditions in the middle Black River during the summer months were commonly mesotrophic but sometimes approached eutrophy.

3.2.3.5 Biochemical Oxygen Demand

BOD measures the presence of organic pollutants that consume DO as they degrade. The BOD_5 method measures the amount of oxygen consumed over five days. BOD is made up of carbonaceous biochemical oxygen demand (CBOD) and nitrogenous biochemical oxygen demand (NBOD). NBOD is mostly caused by ammonia (and organic nitrogen that converts to ammonia) being oxidized to nitrate, through the process termed "nitrification."

BOD_5 values of less than 2 mg/L would be typical of relatively unimpacted stream, while values over 3 mg/L would suggest that some source of pollutant loading exists. BOD_5 values in the mainstem were mostly less than 2 mg/L, with a few values between 2 and 3 mg/L. The highest value of 4.5 mg/L was found in the deep waters above Mima Creek. Values in the tributaries were 3 mg/L or less.

UBOD represents the theoretical "total" amount of CBOD that would occur if the oxygen use of a sample were monitored for an indefinite amount of time. UBOD and $CBOD_5$ values in the mainstem indicated the same pattern observed with the standard BOD_5 values: low UBOD levels in the mainstem and tributary waters, except for a relatively high UBOD found in the deep waters above Mima Creek. Again, the relatively high CBOD levels found above Mima Creek provide additional evidence of a discharge from the Black River Ranch (see Section 3.2.1.5).

UBOD values in the point source effluents were generally higher than ambient levels. However, the data suggest that some reduction in CBOD occurred in the Swecker discharge stream between rearing ponds and the river. Data for Global Aqua indicated that the levels of CBOD found in the Global Aqua effluent were not seen in the Big Rock springs, which had negligible CBOD levels.

3.2.3.6 TOC and Chloride

TOC measures the organic carbon concentration in the water column, and is usually from biological or human sources. Since some portion of the TOC in the water will contribute to CBOD, TOC can be an indirect measure of CBOD and an indicator of pollutant sources. Some elevation of TOC may also occur from natural sources, such as from wetlands or autumn leaf fall.

TOC levels in the mainstem ranged from 1.5 to 4.6 mg/L. The lowest values, below 2 mg/L, were observed on August 5, 1992 throughout the mainstem. The highest values, above 4 mg/L, were either observed in the deep waters above Mima Creek or at all the middle reach stations on September 10, 1991.

Tributary TOC values were generally in the same range as the mainstem values. The extremes were high values of 4.5 and 4.9 mg/L in Salmon Creek and Allen Creek respectively, and low values of 1 mg/L or less in Waddell Creek. The Swecker discharge stream and the Big Rock springs had low TOC levels relative to those found farther upstream in the respective facility effluents.

None of the TOC values observed were unusual or extreme, with one exception. A TOC value of 10.5 mg/L was found at RM 12.2 on the north bank, where a drainage ditch was suspected to be the source of a discharge from the Black River Ranch (Pickett, 1991). This was the only value above 5 mg/L observed in the Black River basin, and adds to the evidence of an active pollutant discharge occurring in 1991.

Chloride is an ion that is typically conservative in natural waters (*i.e.*, it does not react, degrade, or adsorb). This allows it to be used as a tracer. Chloride sources include sea salt or common table salt, geologic sources, and also animal waste. Modeling of chloride is discussed in Section 4.

Chloride levels in shallow Black River waters generally increased from upstream to downstream. The lowest concentration, at the 110th Street bridge, was 3.2 mg/L, and the highest concentration of 5.7 mg/L was found at the Howanut Road site. Deep areas tended to be slightly higher than surface, up to a maximum of 6.4 mg/L. The exception, again, was the deep site above Mima Creek, where chloride values were in the range of 23.8 to 25.6 mg/L in 1991, further evidence of pollutant loading at this location. Chloride levels in 1992 were similar to levels at other deep locations.

Lowest values of chloride in the tributaries were 2.6 mg/L in Waddell Creek and 3.4 mg/L in Mima Creek. In Beaver Creek, high values of 9.3 mg/L were found near the mouth in 1991 and 16.3 mg/L at Case Road in 1992. Other samples in natural tributaries were between 4 and 6 mg/L. The Swecker Salmon Farm effluent and discharge stream had similar values of 5.7 to 6.1 mg/L, while the Global Aqua effluent and associated springs were all in the range of 7.6 to 8.4 mg/L.

3.2.3.7 Nitrate/nitrite, Ammonia, and Organic Nitrogen

Ammonia nitrogen in the mainstem Black River, except for the deep waters above Mima Creek, was less than 0.1 mg/L at all times and locations. This was well below the toxicity criteria under any pH or temperature conditions likely to be found in the Black River. Tributary ammonia nitrogen levels were mostly below 0.05 mg/L, with many samples below the 0.01 mg/L detection level. The Global Aqua and Swecker effluent values were somewhat higher than other tributary flows, but levels appeared to drop in the Swecker discharge stream near the river, and were below detection in the Big Rock springs.

Nitrate/nitrite nitrogen levels in shallow waters of the mainstem Black River appeared to increase gradually downstream. Concentrations in the upper river downstream to the Canoe Club (RM 14.1) were less than 0.5 mg/L, increased to a little over 1 mg/L above Mima Creek, dropped to between 0.5 and 0.7 mg/L below Mima Creek, and gradually increased to almost 1 mg/L near the mouth.

Deeper waters showed much higher nitrate/nitrite levels than shallow waters. Deep samples from sites at the Canoe Club and above the steel piling (RM 14.1 and 13.1) had concentrations of 2 to 5 mg/L. Downstream of Mima Creek, deeper waters were slightly elevated compared to shallow waters, but in the range of 0.6 to 1.1 mg/L. Again, the deep waters just above Mima Creek were exceptional, showing relatively low nitrate/nitrite levels of between 0.01 and 0.02 mg/L in 1991, and between 0.29 and 0.3 mg/L in 1992.

Tributary nitrate/nitrite concentrations ranged from 0.1 to almost 3 mg/L. The lowest levels, between 0.1 and 0.3 mg/L, were found in Waddell and Mima Creeks. Beaver Creek showed higher levels of between 0.68 and 1.82 mg/L. Effluent at Swecker Salmon Farm was near 2.6 mg/L, and Global Aqua effluent was near 1.3 mg/L. Nitrate/nitrite in the Swecker discharge stream and in the Big Rock springs were about the same as the effluents they are associated with, reflecting the high mobility of this form of nitrogen.

Comparing total nitrogen to ammonia and nitrate/nitrite nitrogen sheds some light on the proportions of the various fractions of nitrogen in the river. At all locations except the deep waters above Mima Creek, the largest fraction of nitrogen was nitrate/nitrite. A significant fraction of nitrogen in the river was in an organic form, typically in a range of roughly 0.1 to 0.3 mg/L[7]. Ammonia made up a small fraction of the nitrogen, and the fraction that is ammonia decreased in the downstream direction.

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[7]Organic nitrogen is calculated as: total persulfate nitrogen - (ammonia nitrogen + nitrate/nitrite nitrogen).

In the deep waters above Mima Creek, ammonia nitrogen levels were between 28.3 and 31.1 mg/L in 1991. These were extremely high concentrations for ambient waters, and exceeded both the acute and chronic water quality criteria for ammonia. Levels at this location were about 0.64 mg/L in July 1992, and between 0.35 and 0.37 mg/L in August 1992, reduced from 1991 but still much higher than anywhere else in the mainstem Black River. The amount of organic nitrogen at this location was also remarkably higher than elsewhere in the Black River: between 7 and 10 mg/L in 1991.

As a fraction of total nitrogen, ammonia nitrogen at this location made up the largest fraction while nitrate/nitrite made up a relatively low fraction. This was most likely due to the extended anoxic conditions at that site creating a reducing environment that allowed the conversion of organic nitrogen to ammonia, but suppressed nitrification, and may also have promoted denitrification.

The extremely high ammonia and organic nitrogen levels found in the deep waters above Mima Creek again point to a discharge of pollutants near this location, most likely from the Black River Ranch dairy (see section 3.2.1.5). The reduction in organic and ammonia nitrogen that occurred from 1991 to 1992 may have been the result of reduced pollutant loading from waste management practices at the Black River Ranch that improved between the two sampling seasons.

Tributary total nitrogen levels indicated a large fraction of organic nitrogen in tributary flows - generally from 25 to 75 percent. Total nitrogen in Beaver Creek near the mouth ranged from 1 to over 2 mg/L, with concentrations in 1992 almost twice those at locations upstream on Beaver Creek. This suggests a significant source of nitrogen entering Beaver Creek between Case Road and the Route 121 bridge, which follows the pattern of the observed fecal coliform levels discussed earlier in Section 3.2.3.2.

For the aquaculture facilities, a reduction in total nitrogen was observed between the Swecker effluent and the discharge stream near the river, and between the Global Aqua effluent and the springs discharging to the river. This pattern reflected both a reduction in organic and ammonia nitrogen, and an overall loss of nitrogen between the respective effluents and the points where they enter the river. This was most likely the result of vegetative uptake by wetlands and riparian plants and settling of particulate nitrogen.

3.2.3.8 Total and Soluble Reactive Phosphorus

Total phosphorus (TP) in shallow waters of the mainstem Black River was generally within the range of 0.01 to 0.05 mg/L. A few higher values, between 0.06 and 0.09 mg/L, were found in deeper waters. In the deep waters above Mima Creek, TP was between 8 and 9 mg/L in 1991, most likely reflecting the pollutant loading to this site in combination with increased solubility due to anoxic conditions. TP levels in surface waters tend to be slightly lower in the middle river above Mima Creek (RM 15.3 to 11.9) than in the upper river or from Mima Creek to the mouth.

In the tributaries, TP was lowest in Waddell and Mima Creeks, where levels ranged from less than 0.01 to just above 0.02 mg/L. Other tributaries ranged from 0.03 to 0.06 mg/L, except for Salmon Creek with a TP of 0.121 mg/L. Effluent from the Swecker facility had TP concentrations of 0.364 and 0.490 mg/L, but the discharge stream near the river showed levels between 0.15 and 0.19 mg/L. The Global Aqua effluent had TP levels that ranged from 0.088 to 0.128 mg/L. TP in the springs near Global Aqua was only slightly lower, ranging from 0.066 to 0.084 mg/L.

Soluble reactive phosphorus (SRP) is the active form of dissolved inorganic phosphorus (mostly orthophosphate) that is available for photosynthetic uptake. The fraction of TP that is not SRP is usually almost entirely in the organic form. SRP was less than 0.02 mg/L in the middle Black River, with many samples less than the detection level of 0.01 mg/L. In the lower river, SRP was somewhat higher, ranging as high as 0.036 mg/L in 1991, but only up to 0.022 in 1992. As a fraction of TP in surface waters, SRP generally ranged from a negligible fraction to about half of TP. SRP in the aquaculture effluents made up about one-half to three-quarters of TP, but in the Swecker discharge stream and the springs near Global Aqua virtually all of the TP was SRP.

3.2.4 Analysis of Upper Black River Loading

Data from August 18-19, 1992 were analyzed to evaluate the relative contribution of constituent loading from Waddell Creek, Beaver Creek, the Black River above Waddell Creek, and inputs or losses between Beaver Creek and the Littlerock boat launch. Table 3.9 shows the outcome of this analysis.

Several patterns are of interest. Most of the loading of TOC, organic nitrogen, and total phosphorus was coming from upstream of Waddell Creek. This organic loading is consistent with naturally high levels that would be expected in drainage from the wetlands in the upper basin. The high proportion of fecal coliform loading coming from the upper basin may be from wildlife, but pollutant inputs from human activities must also be suspected.

A comparison of the combined loading of several parameters in the upper river and two tributaries to loading at the Littlerock boat launch shows that loading increased in this stretch of the Black River. Increases in conductivity, chloride, and nitrate/nitrite nitrogen would have been consistent with ground water inflows. However, increases in turbidity, fecal coliform, and ammonia nitrogen loading were more likely from

Table 3.9 Upper Black River Load Analysis, August 18-19, 1992

RM Code	Station Name	Flow (cfs)	Loading: Turb (cfs-NTU)	Fec Coli (million cfu/day)	BOD-5 (lbs/day)	TOC (lbs/day)
17.4	BR @ River Rd Br	8.3	6.6	11385.50	107.4	166
17.3019	Waddell Ck @ Waddell Ck Rd	3.0	1.4	2001.56	20.4	12
16.8002	Beaver Ck @ SR 121 nr mouth	1.1	1.7	7112.27	9.5	23
	Upper Black+Waddell+Beaver	12.5	9.7	20499.33	137.3	201
15.3	BR abv Littlerock BL	17.0	34.0	33312.91	91.6	211

RM Code	Station Name	Flow (cfs)	N H3-N (lbs/day)	NO2/3-N (lbs/day)	Org-N (lbs/day)	TN (lbs/day)
17.4	BR @ River Rd Br	8.3	0.5	0.2	12.1	12.8
17.3019	Waddell Ck @ Waddell Ck Rd	3.0	0.1	5.0	1.3	6.4
16.8002	Beaver Ck @ SR 121 nr mouth	1.1	0.0	4.2	2.0	6.2
	Upper Black+Waddell+Beaver	12.5	0.6	9.4	15.5	25.5
15.3	BR abv Littlerock BL	17.0	1.2	38.4	13.6	53.2

RM Code	Station Name	Flow (cfs)	Temp (cfs-˚C)	Cond (cfs-μmho/cm)	TP (lbs/day)	Chloride (lbs/day)
17.4	BR @ River Rd Br					
17.3019	Waddell Ck @ Waddell Ck Rd	8.3	172	731	1.7	161
16.8002	Beaver Ck @ SR 121 nr mouth	3.0	54	176	0.2	42
	Upper Black+Waddell+Beaver	1.1	19	106	0.3	33
15.3	BR abv Littlerock BL	12.5	244	1013	2.2	236
		17.0	257	1579	2.3	394

Units for turbidity, temperature, and conductivity are in flow weighted relative units (measurement x flow).
All other parameters are in pounds per day, except fecal coliform in cfu/day.

surface sources. Possible sources included an area of cattle access below Beaver Creek, and the residences near the river between Waddell Creek and the Littlerock boat launch.

BOD_5 and organic nitrogen loading decreased from the tributaries and headwaters to the Littlerock boat launch. Even with loading entering the river in this stretch, this is not unexpected, since BOD_5 would be degraded by natural processes, and organic nitrogen would be transforming to ammonia and then nitrate. The decrease in organic nitrogen loading is accompanied by a doubling of ammonia loading and a four-fold increase in nitrate loading, consistent with nitrogen transformations in an oxygenated aquatic environment.

Although temperature "loading" (total heat content) stayed the same between Beaver Creek and the boat launch, this actually represents a loss of heat in this stretch. Because flows increased and temperatures were not likely to be less than 10°C from any sources in the summer (including ground water), a heat loss must have been occurring. This suggests that the shady stretch above the Littlerock boat launch was reducing water temperatures.

3.3 Comparison to Historical Data

Comparison of the data collected in this study to earlier data reveals some interesting differences. Data were collected from the Black River on August 17 and 18, 1989 at nine different stations as part of the Black River fish kill investigation (Ecology, 1989); monthly from November 1989 to June 1990 at three stations as a cooperative effort with the Chehalis Tribe (Dickes, 1990); monthly from July 1990 to September 1991 at Moon Road as part of the Ecology ambient monitoring program (Ecology, 1991); and weekly from July through October 1990 and monthly from November 1990 through April 1991 at six sites by the Black River Watch citizens group (TCEH, 1991).

Patterns of DO, temperature, pH, and conductivity were similar in the earlier data sets to those found in this study, with the exception of a few outliers. However, laboratory data from dry season monitoring in past studies show higher levels for some parameters.

Although only one fecal coliform sample was above 100 cfu/100 mL in the TMDL study, values well over 100 cfu/100 mL were seen in the other studies in June through October 1990 and in August 1991. The pattern of high values observed in the Black River Watch data suggests a source between the Canoe Club (RM 14.1) and Swecker's Dock (RM 10.6), which was traced to the area above Mima Creek. The Black River Watch data suggested a second source between Moon Road (RM 7.1) and Howanut Road (RM 1.2).

Black River surface ammonia nitrogen levels did not exceed 0.06 mg/L in the TMDL study, and levels are mostly similar in earlier studies. However, the significant exceptions were samples that had concentrations of between 0.08 and 0.11 mg/L: August 1989 above Global Aqua (RM 9.3); June 1990 at Moon Road (RM 7.1); and August 1990 above the steel trestle (RM 9.2).

Total phosphorus concentrations in surface waters were all below 0.06 in the TMDL study. In August 1989, total phosphorus exceeded 0.08 from RM 11.0 downstream, with a maximum of 0.19 at RM 9.3. Total phosphorus values above 0.08 mg/L were also observed at RM 1.2 and 7.1 in June 1990. Excluding a single extreme outlier, the Black River Watch found concentrations above 0.08 mg/L at Swecker's Dock (RM 10.6) in July and September 1990; at Johnson's Dock (RM 9.2) in July and September 1990; and at Moon Road in September 1990.

This evaluation of historical data identified substantially higher levels of fecal coliform bacteria, ammonia, and total phosphorus in the Black River from Mima Creek downstream as compared to upstream values, and also as compared with the results of the TMDL study. In light of the discharge found above Mima Creek in August 1991, and since no other sources have been identified on the stretch of the river downstream of the Canoe Club, uncontrolled waste discharges from the Black River Ranch were likely the source of the higher pollutant levels observed in the historical record.

It appears that the discharge was no longer active in 1992, since the quality of the Black River improved for many parameters in the Black River from Mima Creek downstream. In the deep pool just above Mima Creek, values were lower in 1992 than in 1991 for conductivity, turbidity, ammonia nitrogen, organic nitrogen, total phosphorus, and chloride. As a result of the formal Ecology enforcement action, the Black River Ranch changed a number of waste management practices between the summers of 1991 and 1992 (Harvester, 1993). It is likely that these waste management improvements have had a beneficial effect on the river.

4. Modeling Results

4.1 Modeling Methods

The Black River system was modeled using the WASP5 model, with its eutrophication kinetic subroutine EUTRO5 (Ambrose *et al.*, 1993). This model is supported by EPA, and was adapted for 486 32-bit personal computer application by AScI Corporation of Athens, Georgia. WASP5 allows time-dependent three-dimensional modeling of oxygen, nutrients, BOD, phytoplankton, and conservative parameters.

A schematic of the segment network used for the model is provided in Figure 4.1. The model was used in a steady-state mode, with multiple vertical elements. A single-layer segmentation with only surface water elements was used in the upper and lower ends of the river (segments 1-5 and 19). A two-layer segmentation with both surface and subsurface elements was used in the stratified reach of the river (segments 6-18 and 29-32). Elements were bounded on the bottom by benthic segments that routed deep ground water movements and settled phytoplankton (segment 33-38). "Dummy" elements were provided on the side to route surface water withdrawals (segment 40), and shallow ground water inputs (segment 39).

The section of the Black River selected for modeling begins just above the boat launch south of Littlerock (RM 15.3) and extends downstream to the confluence with the Chehalis River. The upper Black River was not modeled because of the inaccessible area of braided channels above the boat launch, and because of the extensive wetlands upstream of Littlerock. Because of these features, the upper Black River was judged to be too difficult to model as part of the scope of this study.

The overall water flow balance for the Black River was estimated with a spreadsheet. For each segment, a mass balance was calculated that included vertical and horizontal inflows and outflows; pumping withdrawals; and ground water, point source and tributary flows. The segments' flows were then balanced for the whole river, and all flows were specified in the "Flows" data group of the input file.

Tributaries were not directly modeled, but instead were treated as inputs to the mainstem. Where tributary temperatures were less than the temperature of the river in areas of stratification, tributary flows and loads were routed into the subsurface layers. Ground water was routed through the benthic segments into the water column segment above, unless data indicated a shallow source.

WASP5 allows pollutants to be input to the system either as boundary conditions or as waste loads. Boundary conditions are concentrations which are multiplied by the flow

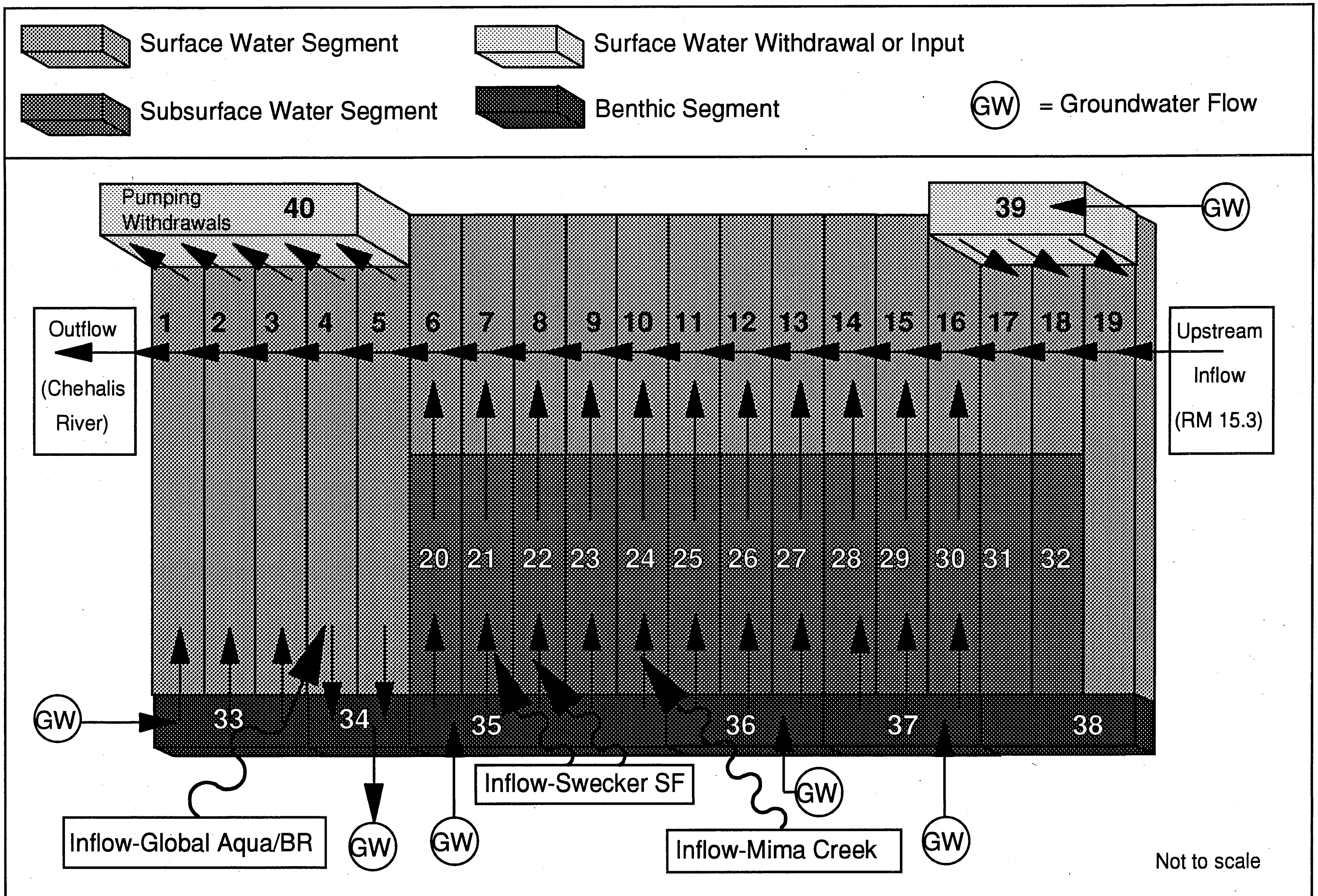

Figure 4.1 WASP5 Model Schematic, Black River Segment Layout
(Showing Water Flow Paths)

across the boundary to determine the load to the segment. Waste loads are input specifically as a loading rate (pounds per day, or equivalent), and need not be associated with an inflow. Loading sources, tributaries, and headwaters were input in the "Wasteload" data group, and background ground water quality was input in the "Boundary Condition" data group.

In order to calibrate the dispersion coefficients, refine the water flow balance, and estimate unknown loading sources, WASP5 was first run in a conservative mass-balance mode using chloride as a tracer. The ground water flow patterns illustrated in Figure 4.1 are based on the results of the conservative tracer modeling. After the chloride and flow mass balance was evaluated, the full eutrophication model was run. July 1992 and August 1992 conditions were modeled independently to calibrate the model. September 1991 conditions were then simulated to verify the modeling approach. Critical flow conditions were then estimated and the model applied to evaluation of the Black River LC.

A number of challenges present themselves in modeling the Black River. Segmentation and hydrodynamics for the model must be established that reflect the true characteristics of the physical system. Because of the stratification of the middle river, a model with both horizontal and vertical dimensions is more appropriate than a one-dimensional model. However, use of a two-dimensional model increases the complexity of the model and the data that are required.

The WASP5 system allows for time-variable dynamic modeling. However, for simplicity the Black River was simulated in a steady-state mode. This is a reasonable assumption for summertime low flow, although like all assumptions, it must be examined against the real system for validity. All input parameters were treated as 24-hour average values for the conditions observed at the time of sampling or for design conditions.

Previous studies have shown that the Black River is characterized by significant ground water inputs. Sinclair and Hirschey (1992) found the average seepage gain based on measured surface flows in late August 1987 to be 2.8 cfs/mile in the middle Black River, and 1.8 cfs/mile in the lower Black River. This estimate suggests that at low flows, as much as one-half of the river flow enters the Black River as ground water.

The quantification of ground water inflows in detail adequate for modeling is therefore clearly necessary, but also difficult. Also, the springs near Global Aqua provide an input to the river that appears to be significant, but is difficult to quantify. Riparian wetland inputs may also exist that are distributed over a wide area when they enter the river, that may be indistinguishable from ground water inputs. In addition to the flow rate of ground water and other diffuse inputs, the quality of these inputs may significantly affect the water quality of the river. Another complication to modeling the Black River are the presence of pumping withdrawals from the river. An overall flow balance for the Black river may underestimate ground water and other diffuse inputs if pumping withdrawals are not accounted for.

In general, the stratified areas in the Black River are separated from each other by shallower, fully mixed areas. This was observed in the field and confirmed with field and laboratory data. In addition, the observed characteristics of the stratified areas indicate that the surface waters are relatively well-mixed, while the hypolimnetic areas differ substantially from the surface waters. To simulate these characteristics of the river, the model was structured so that downstream flow occurs in the surface segments, but subsurface segments are not connected to each other. Each subsurface segment mixes by dispersion with the surface segment above, and any ground water or tributary inputs that are routed through the subsurface segments cause advective flow into the surface segment above.

Each subsurface segment in stratified areas and surface segment in unstratified areas is bounded below by a benthic segment that routes ground water into or out of the water column segment. In the upper end of the network, for reasons discussed later, ground water enters the surface segments directly through a bordering dummy segment. Mima Creek and Swecker Salmon Farm discharge flows enter the system in subsurface segments, because they are significantly cooler than the river and likely hug the bottom upon entering the river. A dummy segment borders the entire network to route water withdrawals out of the system. Figure 4.1 illustrates the segmentation described here.

To estimate inputs to the Black River from ground water and other nonpoint sources, the WASP5 model was run with a conservative tracer. Chloride data were used for this purpose. Chloride is useful as a tracer since it is highly soluble, non-adsorbing, chemically conservative, and easily measurable. A number of other studies have used this ion as a tracer to estimate flows where direct measurement was difficult or impossible (e.g., Walker *et al.*, 1991). EUTRO5, the WASP5 eutrophication model, allows conservative tracers to be run by using the ammonia system alone with all kinetics set to zero.

Using the chloride tracer model, a refined flow balance was developed for observed conditions. From changes in chloride loading, input loads were estimated for sources not directly measured. The flow balance thus developed was applied to the full EUTRO5 simulation. EUTRO5 input loads were estimated for unmeasured sources as a proportion of chloride loads.

EUTRO5 simulates eight different systems in combination: ammonia nitrogen, nitrate nitrogen, inorganic phosphorus (orthophosphate), phytoplankton carbon, biochemical oxygen demand, dissolved oxygen, organic nitrogen, and organic phosphorus. If the model simulates the physical system correctly, each of the state variables for the eight systems ought to match observed data.

Because the Black River model simulates steady-state, daily-averaged conditions, the diurnal variation of DO due to productivity must be separately accounted for. Model DO results were projected to the maximum and minimum daily DO by subtracting or adding a diurnal range factor. The diurnal range factor for calibration or verification is calculated as one-half of the maximum observed diurnal range during the sampling period, with interpolated values assigned to segments between sample sites. A list of the diurnal range factors used in calibration and verification are provided in Table 4.1. The figures that present the DO modeling results in the following sections show the maximum and minimum DO levels calculated using the diurnal range factors.

The overall strategy employed in modeling the Black River was to use the chloride tracer to establish the flow balance, dispersion coefficients, and distribution of loads. The full EUTRO5 was then calibrated using the two sets of data collected in July and August 1992. The model was verified with the September 1991 data set. The flow balance for verification was established using a mass balance of 1991 chloride data and simple systematic adjustments to the calibrated model. Similarly, model input data files for critical conditions were developed from the calibration flow balance adjusted to fit critical low flow estimates.

4.2 Calibration Modeling

4.2.1 Chloride Tracer Modeling

For chloride tracer modeling in the Black River, ground water chloride sources were input as boundary concentrations. Boundary concentrations for ground water were set to levels that appeared to be typical for the region. Tributary, point source, and headwater chloride sources were input as waste loads. Loading was calculated from measured or estimated flows and from chloride concentrations measured during the surveys. Where necessary to meet the chloride mass balance, additional loading was input as a waste load to benthic segments, under the assumption that unknown sources were reaching the river through ground water.

Table 4.1 Diurnal Range Factors					
					Values added to or subtracted from model results to estimate maximum and minimum daily DO. All values in mg/L.
RM Code	Seg No	Early Sept 1991	Late July 1992	Early August 1992	Critical Conditions
0.0	1	1.1	0.3	1.5	2.2
1.2	2	1.1	0.3	1.5	2.2
4.1	3	1.2	0.55	1.15	2.2
7.1	4	1.3	0.8	0.8	2.2
9.3	5	1.0	0.4	0.6	1.0
9.7	6	1.0	0.4	0.6	1.0
10.1	7	1.0	0.4	0.6	1.0
10.6	8	1.0	0.4	0.6	1.0
11.1	9	0.8	0.5	0.5	1.0
11.5	10	0.8	0.5	0.5	1.0
11.9	11	0.8	0.5	0.5	1.0
12.2	12	0.8	0.5	0.5	1.0
12.6	13	0.7	0.5	0.5	1.0
13.1	14	0.7	0.5	0.5	1.0
13.4	15	0.6	0.5	0.5	1.0
13.8	16	0.6	0.5	0.5	1.0
14.1	17	0.5	0.5	0.5	1.0
14.5	18	0.5	0.5	0.5	1.0
14.9	19	0.4	0.5	0.5	1.0

A detailed description of the development of the model input data set is provided in Appendix G. The chloride boundary concentrations and waste loads used in the July and August 1992 calibration modeling are shown in Appendix Tables G.1 and G.2.

The calibration of the Black River model to a chloride tracer was an iterative process. Different flow and chloride mass balances were modeled until a best fit was found for both the July and August 1992 survey data. Best fit was evaluated by calculating the root mean square error (RMSE) of the residuals between the modeled and observed data. Mass balances were adjusted by varying pumping withdrawals as a percentage of the water right, by varying the Global Aqua springs as a percentage of the effluent flow, and by varying ground water flows and chloride levels within a reasonable range suggested by other studies. Appendix Table G.3 shows both the final modeling results compared to observed data, and the RMSE analysis results. Figure 4.2 shows the chloride and flow calibration results for July 1992 conditions, and Figure 4.3 shows August 1992 results.

Through the simultaneous evaluation of flow and chloride mass balances for the two data sets, a number of significant features of Black River water quality were identified and quantified:

- The chloride mass balance indicated that a significant source of relatively pure water was entering the river between the boat launch below Littlerock (RM 15.3) and the Canoe Club (RM 14.1). However, ambient data from deeper areas did not indicate such a source at that depth. The evidence of high quality ground water in Clearwater Lagoon was discussed earlier. In addition, a local resident has noted the presence of springs along the banks above the Canoe Club (Dahl, 1992).

  Because of these considerations, a segment was added to this section of the river that routes ground water into surface water segments. A review of data suggests that the quality of the relatively pure water entering the river here is comparable to the quality of streams draining the Black Hills, such as Waddell Creek, and ground water from wells near the Black Hills. A boundary concentration was selected that represents the lowest chloride concentrations found in Black Hills drainage.

- Relatively high chloride loads appear to be entering the Black River between the Canoe Club (RM 14.1) and Mima Creek (RM 11.9). A chloride waste load was introduced to the benthic segments in these reaches in addition to the background boundary concentration.

- A chloride loading source appears to exist below the Swecker Dock (RM 10.6) and above the Big Dock site (RM 9.7). Although the Swecker Salmon Farm discharge enters the river at an identifiable location, only a fraction of the water pumped into the facility reaches the river in this stream. As much as one-third of the facility's

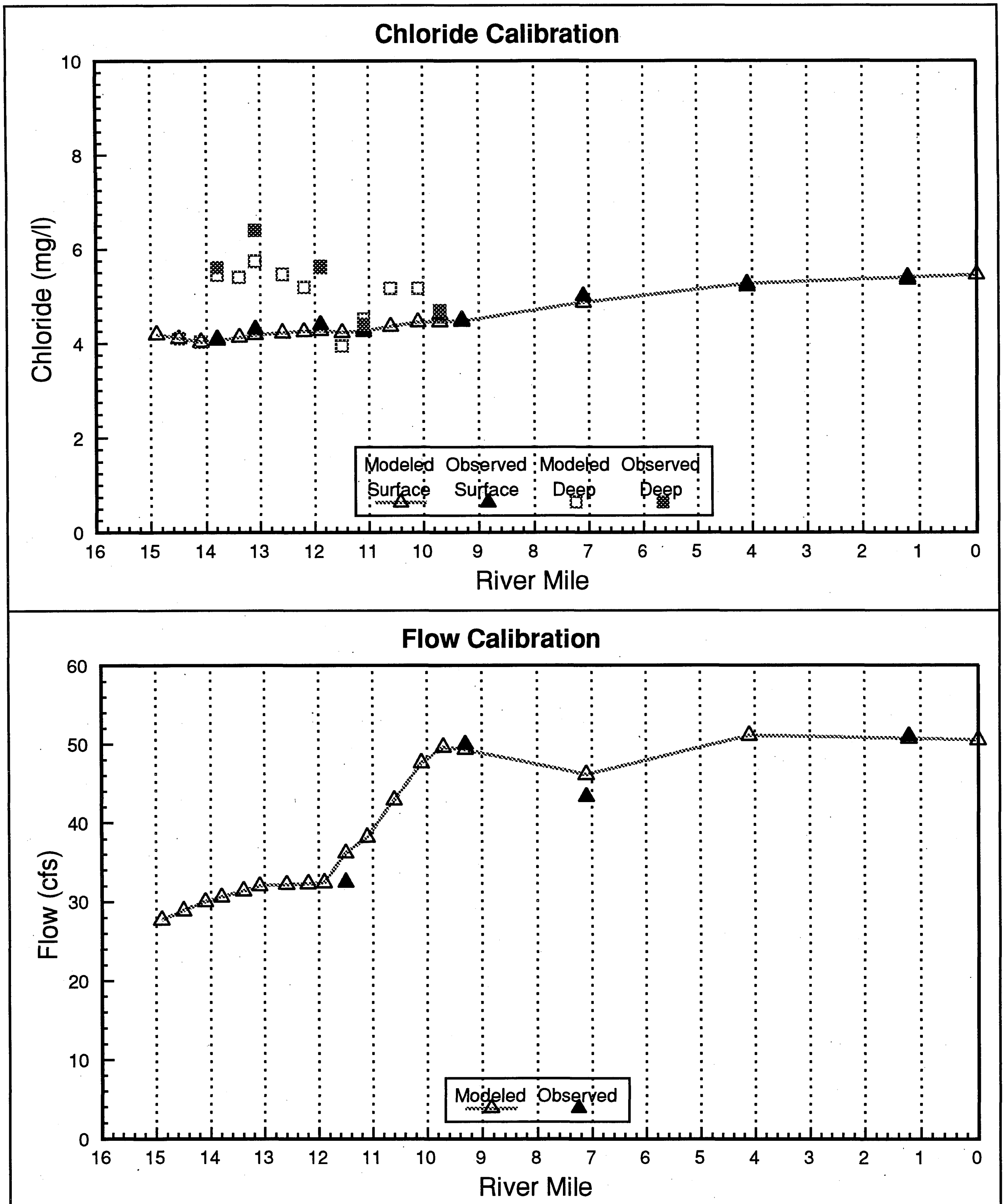

Figure 4.2 Chloride and Flow Calibration - July 1992

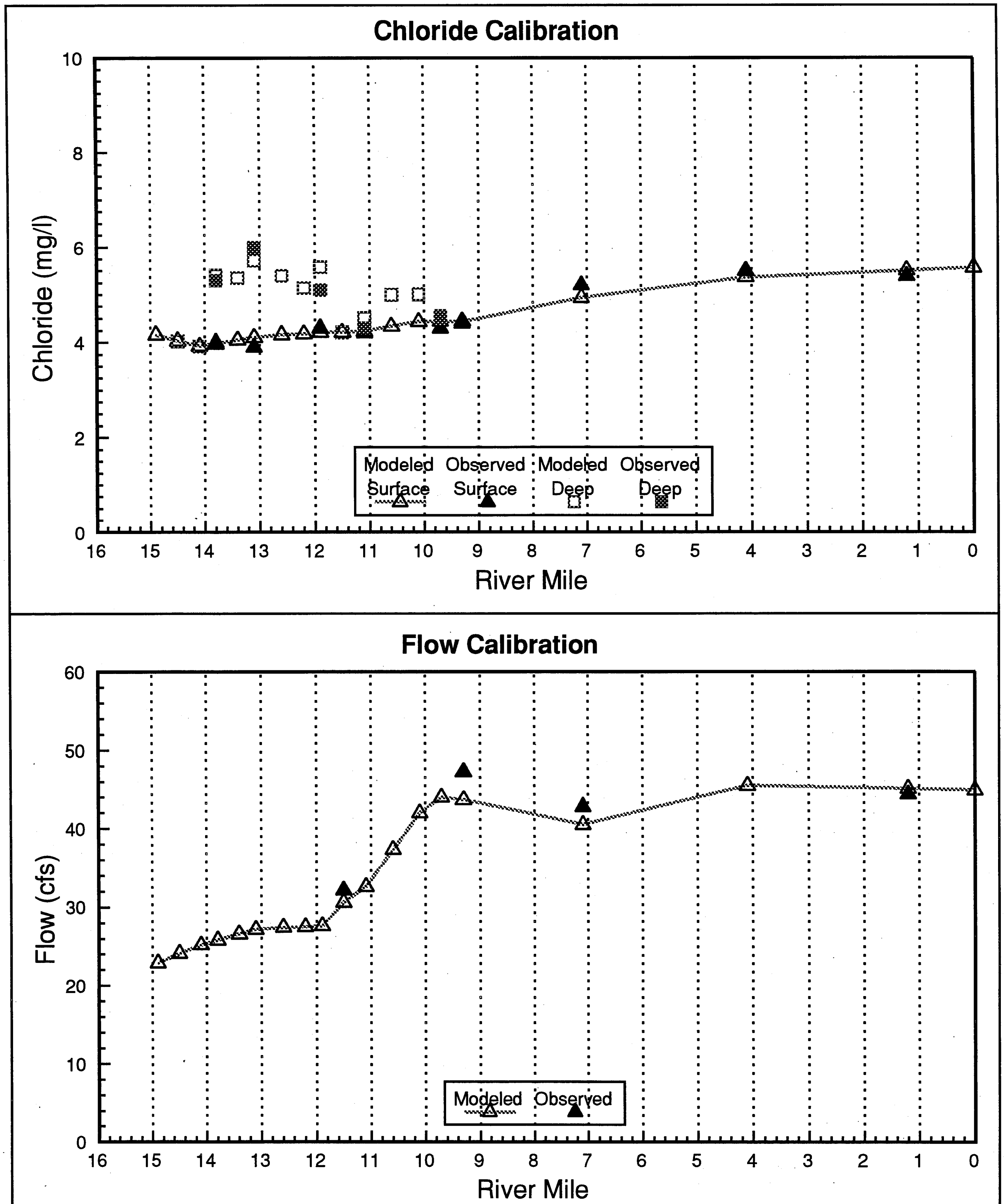

Figure 4.3 Chloride and Flow Calibration - Aug 1992

intake flow percolates, and many small streams outside the main discharge channel can be observed near the river. Therefore, the effluent flow reported on the Swecker DMRs was divided evenly into the two segments above and below the Swecker Dock. This fits the observed chloride levels better, and accounts for some of the Swecker effluent and perhaps the Carlson Salmon Farm effluent as well. The upper segment flows are considered the identifiable surface flow, and the lower segment flow a ground water flow.

- From RM 9.3 above Global Aqua to RM 7.2 above Moon Road, Black River flows drop while chloride concentrations rise. The springs along the bank in this stretch of the river have much higher chloride than the river, and the chloride calibration allowed these flows to be estimated. At the same time, a significant outflow of river water must be occurring. Permitted water withdrawals were accounted for, but a ground water outflow is necessary to maintain the flow balance. Therefore, although the Global Aqua discharge has created springs that add flow to the river, a net loss of water from the river occurs in this stretch. Although a quirk of the regional topography and ground water flow patterns may cause this effect, surface withdrawals and ground water pumping in the vicinity of this reach are a likely contributing factor.

- Calibration of the model to flow and chloride mass balances improved the estimate of surface water withdrawals. No pumps were observed above the Schoolland boat launch at RM 8.4. Pumping rates below that location were estimated to range from 20% to 80% of the permitted rights.

- A loading source appears to exist between Moon Road (RM 7.1) and the mouth of the Black River. Since no surface discharges have been observed, a chloride load has been applied to the benthic segment for this reach. This approach represents a land use that is increasing pollutant loading through the ground water to the river, in contrast to the concentrations typical of the region.

  Although a few riverfront residences exist on this stretch of the river, the primary land use is agricultural. A turf and berry farm is on the left bank upstream and downstream of Moon Road, and three dairy farms are in this reach - one between the Moon Road and Route 12 bridges, and two between the Route 12 and Howanut Road bridges. The U.S Fish and Wildlife Survey Habitat Degradation Survey (Wampler *et al.*, 1993) identified several areas of livestock bank impacts along the Black River, mostly below the Route 12 bridge.

- Calibration of chloride levels in the subsurface segments to observed chloride in deeper waters was more difficult than for surface waters, as indicated by the poorer RMSE. This is probably a result both of the spatial variability of the water quality data in the deeper waters, and of the limited capacity of a "generic" model such as WASP5 to model the unusual and unique conditions occurring in the Black River. Despite the relatively poor performance in deeper waters, the fit is still reasonably good and the overall characteristics of the river flow and chemistry are reproduced.

4.2.2 Eutrophication Modeling

For full eutrophication modeling, boundary conditions and waste loads must be specified for the state variables of eight systems. The method to set the inputs for the eight parameters was similar to the way chloride inputs were set. Boundary conditions were set to background levels for regional ground water quality. Tributaries and point sources were given loadings for the eight systems calculated from measured flows and concentrations. Pollutant sources identified by the chloride mass balance were assigned loading using several different approaches depending on the probable source and pathway to the river (see Appendix Section G.3). Appendix Tables G.4 and G.5 show the waste loads and boundary conditions for July and August 1992 conditions, respectively. The parameters, constants, and time functions required by the eutrophication model are described in Appendix G.4.

Appendix Tables G.6 and G.7 compare modeled to observed results for the July and August 1992 simulation. These tables also show the RMSE analysis for the eight water quality systems, separated into the lower river (segments 1 through 5), the middle river surface segments (6 through 19) and the middle river subsurface segments (20 through 32). The observed results were selected from either: the 24-hour average of DS3 data, if available; an average of vertical profile values taken from 0 to 2 meters at the surface sampling locations without DS3 data but with multiple data points; an average of vertical profile values taken from 4 meters and deeper at the deep sampling locations.

As was noted for the chloride calibration, modeled and observed results for the deep subsurface segments agreed less well than for surface segments. There are several probable explanations for this. Stratified waters in some areas were in strongly stratified "pockets" that are of a scale smaller than the model segments. In other areas, the stratification is more gradual, but more widespread. In all cases, monitoring results for deeper waters were more variable than for shallow, depending in part on the data collection depth and the particular location. In general, the model, with the scale of segmentation used in this study, was unable to completely reproduce the variability of the Black River's natural environment.

To calibrate the Black River model, various modeling parameters were adjusted to achieve the best fit, as measured by the RMSE between the modeled and observed results. Minimization of the RMSE was a time-consuming iterative process that involved numerous model runs with various input parameters. In consideration of the variability inherent to the model, and to environmental data and ecological systems in general, no calibration could ever exactly predict observed conditions. Nonetheless, the model was adapted to describe the physical, chemical, and biological systems as well as was possible.

Figure 4.4 shows the calibration results for DO, which is the target parameter for the TMDL. Close agreement between modeled and observed oxygen concentrations was not expected, since the field data for DO showed a great deal of diurnal and vertical variability, while the model simulates conditions that were averaged over 24-hours and vertically over the segment. The variation in the model results with respect to the observed data will be taken into consideration in the evaluation of simulation results.

Chlorophyll *a* model results were found to be very sensitive to certain model parameters -- in particular, the maximum growth rate and the settling rate. Without settling, modeled chlorophyll *a* levels were an order of magnitude too high. Therefore, after reasonable values were selected for all inputs affecting phytoplankton biomass, the settling rate was increased to produce the best fit. Since observed results for chlorophyll *a* had high variability, the large RMSE between modeled and observed was deemed acceptable.

With respect to nutrients, a significant feature was that observed orthophosphate was near or less than detection in both the surface and subsurface waters of the middle river, but was found at higher levels in the lower river. Adjustments were made to photosynthetic model parameters to reduce light limitation and increase productivity so that phosphorus levels were better reproduced.

Modeled and observed levels of ammonia nitrogen matched reasonably well. Nitrate nitrogen fit less well, but the overall pattern of concentrations was preserved, and the results were thus considered acceptable. Ultimate CBOD and the organic nutrients were of lesser concern due to the high variability of observed results at instream concentrations. In the course of calibration, the RMSE for each of these parameters was kept as low as possible, and the fit of the model to observed values for these parameters was also deemed acceptable.

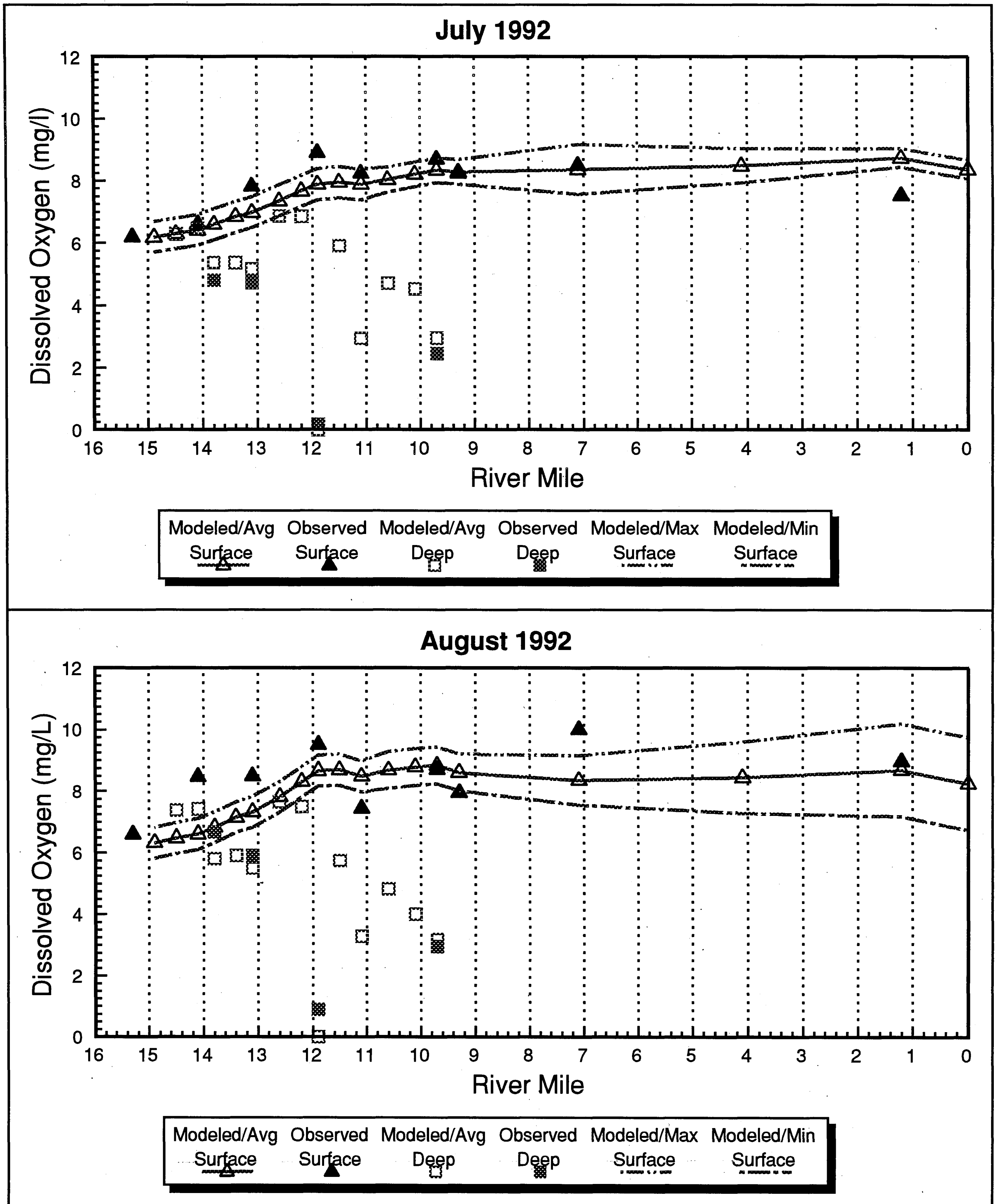

Figure 4.4 Dissolved Oxygen Calibration Results

4.3 Verification Modeling

4.3.1 Chloride and Flow Analysis

In the Black River model verification, unknown flows and loads were estimated by conservative tracer modeling with chlorides. Starting with the calibration data set, ground water flows were adjusted upward or downward globally by reach until the RMSE was minimized between the observed and modeled flows. Then additional chloride loading was added to minimize the RMSE of observed versus modeled chloride concentrations in the river.

Results from the September 1991 intensive survey were used for verification. The flow balance and chloride waste loads and boundary conditions are presented in Appendix Table H.1. The best fits for the flow and chloride load balances were achieved with slightly higher flows in the Global Aqua Springs and the same ground water flows as the model calibration input. Appendix Table H.2 compares the observed to modeled results for the chloride and flow analysis, and Figure 4.5 illustrates those results. The RMSE for the flow modeling was less than 15% of observed flows, which is similar to the variability of the flow measurements themselves.

For the chloride modeling, ground water boundary conditions were kept the same as for the calibration modeling. Waste loads were either those measured during the intensive survey, or were the loads developed in the calibration modeling. Additional chloride loading was added to the subsurface segment above Mima Creek (segment 25) to account for the higher concentrations measured in the deep waters at that location in 1991 compared to 1992. The RMSE for chloride was about the same as for calibration, and only slightly higher in deeper waters, due mostly to the high chloride values measured above Mima Creek.

4.3.2 Eutrophication Modeling

Setup of the verification run of the Black River eutrophication model was done in the same fashion as the calibration model. Beginning with the calibration input file, flows were changed to those derived from the verification chloride/flow analysis. Loads were then determined either by using sampling results or by using the load-to-chloride ratios, as described above for calibration. Boundary conditions were the same as for calibration. The waste load and boundary conditions for the verification modeling are presented in Appendix Table H.3. Water and air temperatures were set to conditions observed at the time of the 1991 survey, and the time functions for light were seasonally adjusted.

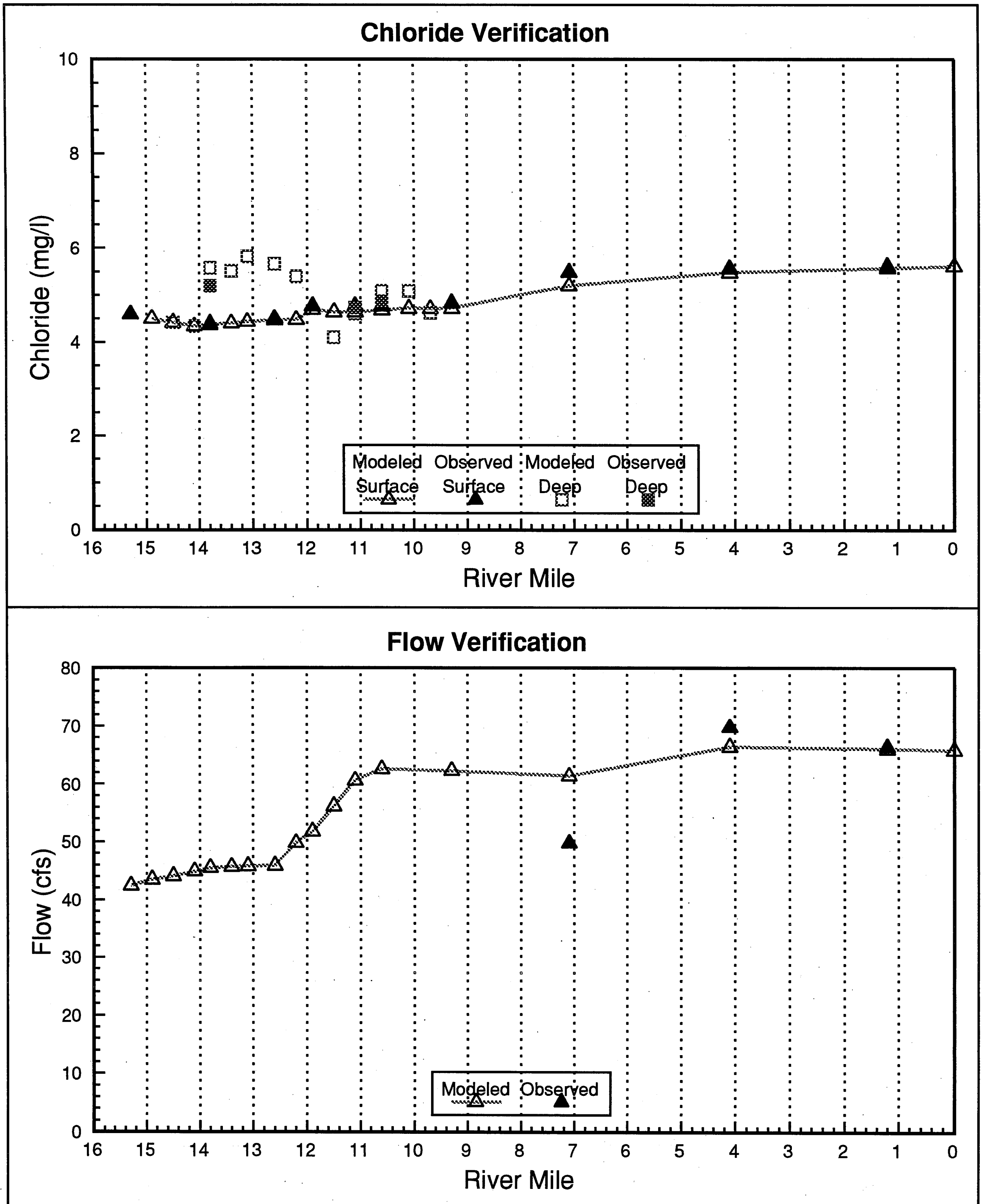

Figure 4.5 Chloride and Flow Verification - Sept 1991

Verification modeling results, along with observed data, are shown in Figure 4.6, with the output data in Appendix Table H.4. The RMSEs between modeled and observed for the eight system variables were comparable to the calibration results in the surface segments. The fit for the subsurface segments was poorer than the fit for the calibration results, and that error will be taken into account when interpreting model results. However, it is encouraging that the observed DO values fall closer within the modeled diurnal DO range.

Overall, the spatial trends and significant features of the Black River system were reproduced fairly well by the model. Taking into consideration the model assumptions and the variability of model results (as indicated by the RMSE), the Black River eutrophication model can be used with confidence to evaluate alternative loading scenarios, determine the loading capacity of the Black River, and evaluate WLAs and LAs for a proposed TMDL.

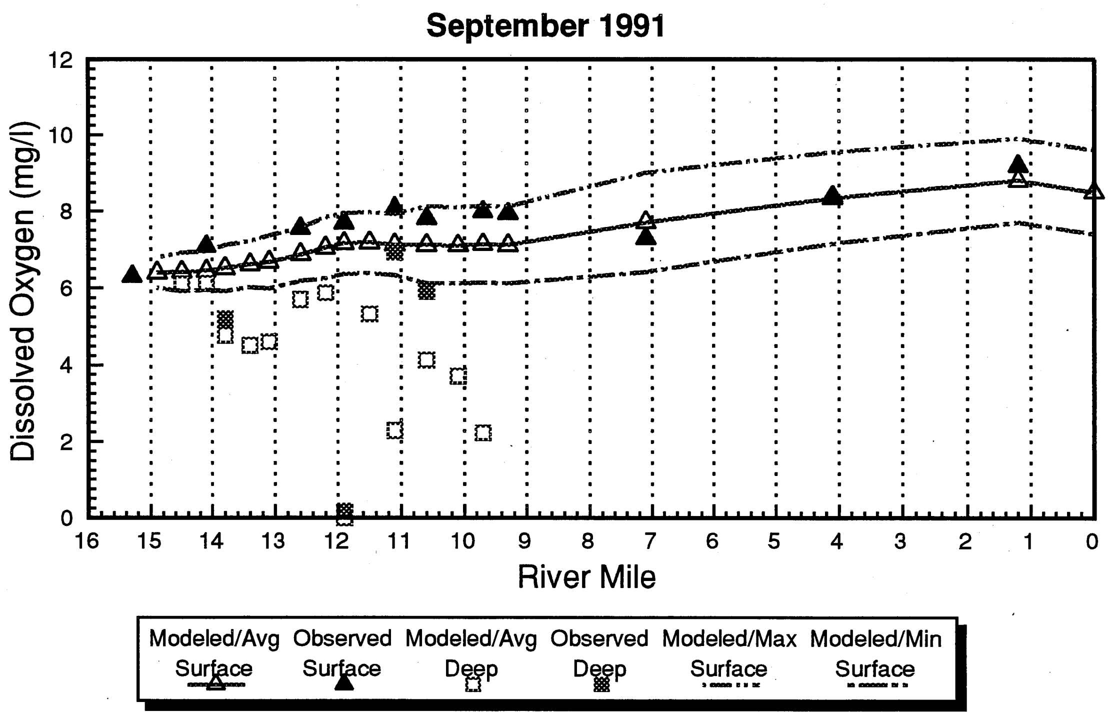

Figure 4.6 Dissolved Oxygen Verification Results

5. Loading Capacity Analysis

5.1 Regulatory Issues

Ecology uses two approaches to control the discharge of pollutants to surface waters: the technology-based approach and the water quality-based approach. The technology-based approach requires that potential sources of pollutants be provided with a minimum level of treatment or control, regardless of whether any impacts may occur to the receiving water. State law states that potential sources be provided with "all known available and reasonable methods . . . to prevent and control the pollution of the waters of the state" (RCW 90.48.010), otherwise known at the AKART requirement.

For point sources, the AKART requirement may be specified under federal regulation (such as secondary treatment, or BPT/BAT/BCT), or under state regulations or guidelines, or may be determined on a case-by-case basis through the submittal and review of an engineering report. The technology-based AKART requirement for nonpoint sources consists of the application of enforceable Best Management Practices (BMPs). BMPs usually must be selected individually for each situation. However, many efforts have been made to define a variety of possible BMP methods for categories of sources, including Section 6217 of Coastal Zone Act Reauthorization Amendments (CZARA), the Timber/Fish/Wildlife process, the Puget Sound Stormwater Manual, and development of farm plans by the US Soil Conservation Service.

The water quality-based approach aims to limit the discharge of pollutants based on their impacts on receiving water quality. As described earlier, the Clean Water Act requires that water bodies that do not meet water quality standards, even after the full application of technology-based pollution controls, must be placed on the state's Section 303(d) list. All water bodies on the Section 303(d) list must undergo an analysis for the maximum pollutant loading capacity (LC) of the water body that will allow the water quality standards to be met.

Once the LC is established, the total loading is allocated to different areas or sources. Load Allocations (LAs) are set for background/natural sources and scientific uncertainty. If capacity remains, LAs may be set for nonpoint sources and Waste Load Allocations (WLAs) for permitted point sources. The sum of LAs and WLAs that will stay within the LC and allow the water quality standards to be met, and that have been determined through a public process, is termed the "Total Maximum Daily Load," or TMDL. The Black River model provides the tool to analyze the LC and possible TMDL alternatives.

Because of the nature of ecological systems and the parameters that describe them, a TMDL need not always be in terms of daily loading *per se*, but for some parameters (temperature or turbidity, for example) and for certain site-specific situations, the TMDL may be defined in terms of criteria or indicators other than daily loading. In addition, if information is limited and future activities are dependent on the outcome of initial efforts, the TMDL may be defined as a "phased TMDL." Phased TMDLs are typically applied to situations dominated by nonpoint sources, where the results of BMPs may be uncertain and more detailed study may be needed.

5.2 Background Conditions and Scientific Uncertainty

5.2.1 Background Conditions Analysis

As was discussed above, dissolved oxygen was frequently below criteria at almost every station sampled. It is clear that the Black River did not meet water quality standards. It is also likely that natural conditions were less than water quality standards. If natural conditions did not meet criterion of the water quality standards, then those conditions constitute the new criterion [WAC 173-201A-070(2)]. Therefore, the strategy used for application of the Black River model was to model natural conditions by removing known anthropogenic loading under critical low flow conditions.

Modeling of the natural conditions that were present "before any human-caused pollution" is highly uncertain because the multitude of human impacts cannot be fully discounted in any analysis. However, the Clean Water Act requires the TMDL analysis to be conducted with the best available scientific evidence, and to proceed despite the lack of complete information. To provide the best reasonable approximation of natural conditions, background conditions were modeled by removing identified loading sources and surface withdrawals.

The modeling results for background critical conditions were compared to the results for existing critical conditions to determine the course to take for the TMDL analysis and allocation strategy. If the model, when run under background critical conditions, shows DO to be above the water quality standards, then the TMDL must be set to the total loading capacity of the river (background plus additional human inputs) that just meets the standards. If the model, when run under background critical conditions, does not meet DO standards, then the TMDL will be the sum of the background loading and any additional human-caused loading that the river can assimilate with no degradation of DO levels below background conditions.

5.2.2 Uncertainty and Diurnal Variation

Before analyzing background conditions and alternative loading scenarios, the element of scientific uncertainty must be considered. The target for any TMDL analysis is the water quality standards. However, to account for the uncertainty of modeling results, the results may need to be adjusted before comparison to target values. Uncertainty in the Black River model comes from many sources which include several key areas: the inability of the model to capture temporal variability, especially diurnal; the inability of the model to capture spatial variability, especially on a scale smaller than the segments; and the quality of the observed data to which the model is compared.

To partially account for scientific uncertainty, conservative assumptions have been made for modeling critical conditions. Maximum temperatures, 7Q10 low flows, and conservative reductions in nonpoint loading and SOD all help to reduce the possibility of underestimating the impact of pollutants on the Black River.

To account for the uncertainty introduced by the diurnal variation of DO, diurnal range factors were added to or subtracted from the model results (see Section 5.1). The diurnal range factors used in the TMDL analysis were calculated as one-half the maximum observed diurnal range found during the TMDL study. Factors of 2.2 and 1.0 mg/L were applied to the lower and middle surface segments, respectively (Table 4.1). The diurnal range factor accounts for difference between the average DO simulated by the model and the minimum DO which is the critical condition of interest.

In the middle river, no data were available on diurnal variations in the deep waters. Since light penetration is poor to the lower layers and DO levels low, the diurnal range in the subsurface segments was considered negligible. Average model results were used for the TMDL analysis and no diurnal range factor was applied.

5.2.3 Sediment Oxygen Demand

SOD is entered into the model as a fixed parameter, but in reality it is typically a function of loading sources and instream biomass. Although review of the literature indicates that several attempts have been made at modeling SOD as a function of sediment and water column physical and chemical characteristics, there are no models of SOD widely accepted or available. Therefore, changes to SOD, either due to changes in external loading of oxygen-demanding particulates, or due to changes in phytoplankton biomass caused by nutrient loading changes, cannot be easily estimated or modeled.

As a conservative assumption for evaluating the effects of load reductions, model input values for SOD were not changed from the calibration values for any of the model simulations in the TMDL study. The one exception was a very high level of SOD in the segment above Mima Creek (RM 11.9), which was most likely the result of discharges of oxygen-demanding wastes, and probably can be treated as a local anomaly. The SOD for this location (segment 25) was reduced to 0.8 mg/L for the background critical conditions simulation, the same value applied to segments farther downstream in the middle river.

5.2.4 Macrophyte Productivity

The lower Black River is dominated by macrophytes and periphyton, as anyone who has tried to travel by boat from the steel trestle downstream during the summer can attest to. The effect of reductions in nutrient loading on the growth of these benthic aquatic plants and algae, and the effect of those changes on oxygen demand, productivity and diurnal DO variation, could not be assessed with WASP5. The scope of the current study did not include the data collection necessary to gain a full understanding of the ecosystem dynamics of this benthic productivity.

However, based on the literature, some observations can be made. Recent research has found that sediments can provide a significant portion of the nutrient supply for submerged macrophytes (Barko, 1985). Hill (1986) found that sediments provided three-quarters or more of the nutrient supply for species of *Elodea* and *Potomogeton* (these genera can be found in the Black River). Hill found that macrophytes transferred a large amount of nutrients to the sediments, and at times macrophytes could also release sediment nutrients to the water column.

These observations are consistent with the evidence of phytoplankton removal in the macrophyte beds. As macrophytes pull particulate and dissolved nutrients from the water column, nutrients are cycled between the living tissue and the sediment, thus creating a self-sustaining system.

The consequence of this is that even if nutrient levels and phytoplankton in the water column are reduced, the plants would have a source of nutrients in the sediments, and a reduction of macrophyte biomass would only occur very slowly, if at all. Whether the macrophyte beds existed as a "background condition" is therefore impossible to assess at this time, and the assumption must be made that changes in water column nutrients will not have an effect on diurnal oxygen or SOD for the immediate future. This study also will not make the determination on whether the macrophyte beds constitute a "nuisance growth." Additional study would be necessary to better understand the interactions of macrophytes, sediment, and water column, and this may be an useful area for future research.

5.2.5 Background Condition Model Inputs

Flows were estimated for background critical conditions by modifying the flow balance for August 1992. Inflows to the Black River were proportionately reduced until the flows at Howanut Road met the 7Q10 critical low flow of 30 cfs (see Section 3.1.1). Point source discharges and consumptive use pumping were then removed. The resulting critical flow for background conditions at Howanut Road was estimated to be about 34 cfs. Appendix Table I.1 shows the flow balance used for this analysis of background critical conditions.

Critical conditions appear to be most common in August, when flows are lowest, temperatures highest, and stratification still strong. Maximum water temperatures in late August were used for the model input, with the maximum August air temperature from either 1991 or 1992 (34°C). Light levels were also set to August conditions.

The only waste loads applied were for the model upstream boundary condition at the Littlerock boat launch and for Mima Creek. Waste loads at the upstream boundary were set at levels reduced from the August 1992 data proportional to flow, with the exception of ammonia, nitrate, and organic nitrogen, which were reduced based on an estimate of load reductions from nonpoint sources in the upper basin. This approach to background conditions at the upstream boundary was based on the analysis of upper Black River loading (Section 3.2.4), and on the comparison of flow and concentration data between the 1991 and 1992 intensive surveys.

To account for source load reductions in the Mima Creek basin, loads from Mima Creek were calculated from the critical low flow and the concentrations in Waddell Creek. Waddell Creek sampling was done at the edge of the Black Hills above most nonpoint sources, while the Mima Creek sampling station was downstream of a point source discharge and several likely sources of nonpoint pollution that were identified by USFWS. Since both creeks drain the Black Hills, concentrations would likely be similar if pollutant sources from human activities were not present.

Boundary conditions for background conditions were held the same as in the calibration and verification runs. A review of historical ground water data dating from 1960 suggests that this is a reasonable assumption, since the concentrations of parameters found in 1960 were at roughly the same level as the concentrations found in more recent studies, despite changes in land use over the years. A summary of waste load and boundary conditions is presented in Appendix Table I.2.

5.2.6 Background Conditions Model Results

Appendix Table I.3 shows the complete results of the Black River model simulation for background critical conditions, and Figure 5.1 shows the DO modeling results. These background conditions are based on critical flow and temperature conditions. The maximum and minimum diurnal DO level are shown that were calculated from the model results as described earlier (Section 5.2.2).

This analysis shows that the background condition of the Black River is of a lower quality than the assigned criterion of 8.0 mg/L dissolved oxygen. Therefore, the DO levels derived in this analysis constitute site-specific water quality criteria for the Black River, and no degradation below these levels can be allowed. The analysis for the total maximum daily load will focus on determining the amount of loading which the river can assimilate, without degradation of DO levels.

The term "no degradation" must be evaluated in consideration of the variability of model results. The model is capable of calculating answers to an enormous number of decimal places, but that level of accuracy has no significance. A model output value slightly lower than the value for background conditions cannot immediately be considered a problem, since the value may only be lower due to modeling or measurement error. Therefore, for the purposes of modeling, a level of degradation that is significant must be defined.

Examining the accuracy of DO measurements (Appendix Section B.2), the Winkler method has a resolution of about 0.1 mg/L, and the Hydrolab meters are $\pm$ 0.2 mg/L. The RMSE for paired field verification after data correction was between 0.1 and 0.2 mg/L. Therefore, for the purposes of this TMDL modeling analysis, a reduction of greater than 0.2 mg/L below background levels will be considered a significant degradation.

5.3 Existing Critical Conditions

To determine whether existing point and nonpoint sources under critical conditions have the potential to cause degradation relative to background critical conditions, maximum design loading for existing point sources and loading from existing nonpoint sources were evaluated for critical low flow conditions. The flow balance for critical flows under existing conditions is presented in Appendix Table I.4. Loading and boundary conditions used in this analysis are presented in Appendix Table I.5.

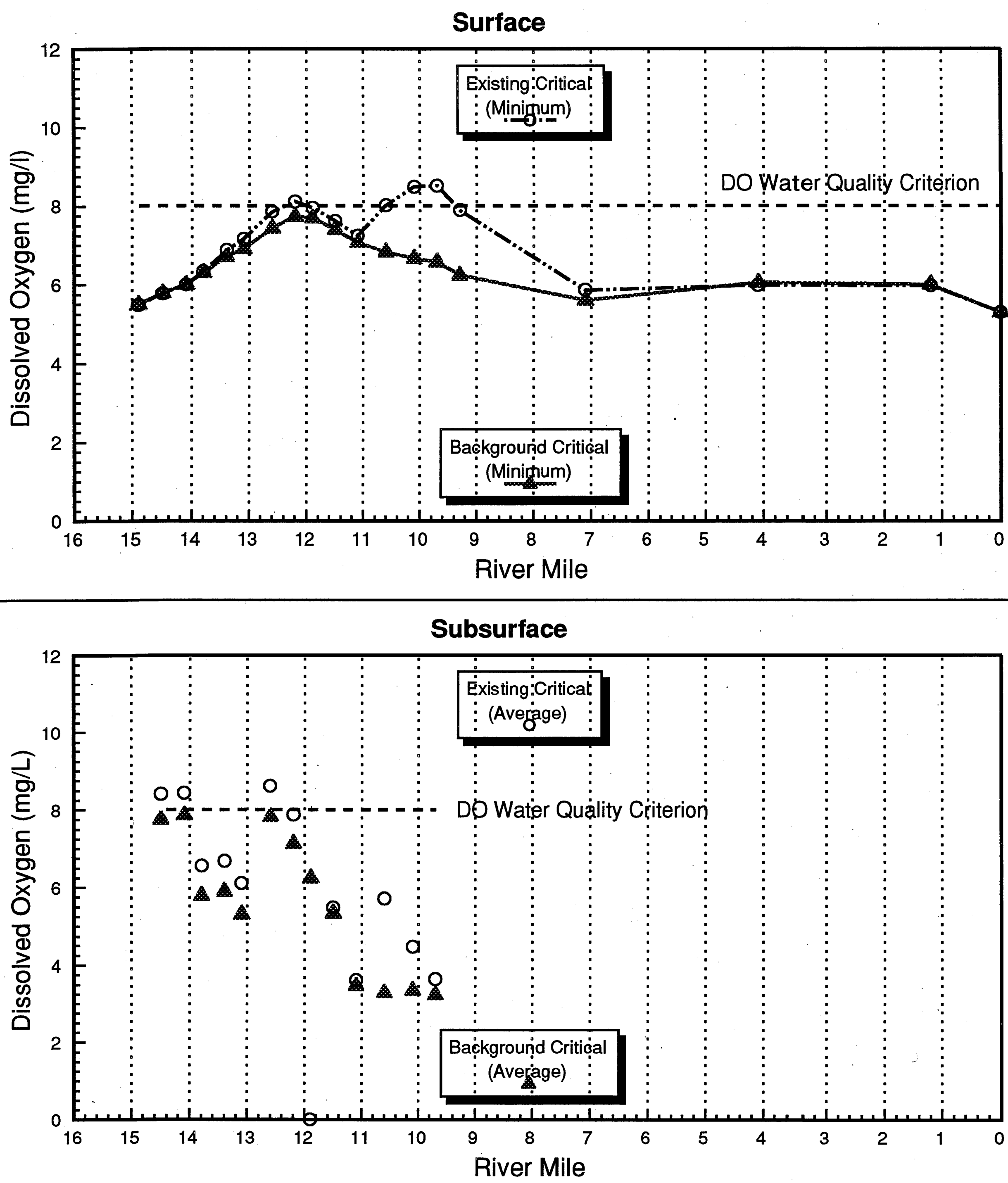

Figure 5.1 Dissolved Oxygen Model Results - Background and Existing Critical Conditions

Boundary conditions and waste loads were kept the same as for August 1992 conditions, with two exceptions: point source loading was increased to approximate design flow levels; and chlorophyll *a* and DO loading for Mima Creek and the upstream boundary were reduced proportional to flow. This approach was based on a comparison of July 1992 data to August 1992 data at these sites, which showed that as flows dropped, loading held fairly constant for BOD and nutrients, but concentrations held constant for chlorophyll *a* and DO. Temperature and light were held to the same values as used in the background conditions analysis.

The results of this modeling are presented in Appendix Table I.6. Figure 5.1 shows the DO modeling results for both background and existing critical conditions. When compared to the results for background conditions, DO showed degradation in three areas of the Black River: in the upper river (segments 17 through 19), in the lower river (segments 2 and 3), and in the pool above Mima Creek. The decrease in DO in the upper and lower river under existing conditions was less than the 0.2 mg/L guideline established for this study, and therefore was not considered significant. On the other hand, the pool above Mima Creek showed degradation of over 6 mg/L.

In almost all the segments, the minimum DO was still below the water quality criterion. Although the model results indicated more DO under existing conditions than under background conditions, this result should not be given much credence. The model predicted increased daily average DO from increased productivity when nutrient loading was higher, but a constant diurnal range was being used which did not account for lower minimum DO concentrations due to respiration of the increased biomass.

Because of the limitations of the Black River model in predicting diurnal DO variation, the model could not estimate the amount of DO degradation where it was also predicting increased photosynthetic productivity due to nutrient loading. Therefore, an alternative method was necessary to analyze the impacts of nutrient enrichment on the Black River DO.

5.4 Total Phosphorus Loading Capacity

A large body of literature exists regarding eutrophic conditions in lakes and associated impacts on the water body. In general, many studies have found that eutrophic conditions cause reduced DO levels, elevated pH, and degradation of fisheries and aesthetic values. As discussed earlier in Section 3.2.3.3, the chlorophyll *a* level where eutrophication conditions begin is between 8 and 20 μg/L. Since chlorophyll *a* and total phosphorus (TP) levels that produce eutrophication in rivers appear to be slightly higher than the levels for lakes, and also considering the Oregon standard of 15 μg/L chlorophyll *a* for rivers, a target value of 15 μg/L is recommended for maximum chlorophyll *a* levels for the Black River.

In examining the observed data and modeling results for the Black River, several observations can be made with respect to nutrients and productivity. Maximum productivity occurred at the downstream end of the middle river between Mima Creek (RM 11.9) and the beginning of the swifter lower river above Global Aqua (RM 9.3). Orthophosphate levels in this reach were negligible, which was consistent with other evidence of phosphorus-limited conditions. The analysis of TP and chlorophyll *a* presented in Table 3.7 also indicates phosphorus limitation, since chlorophyll *a* levels increased with increasing TP.

To develop a TP criterion for the Black River, the analysis presented in Table 3.7 and the results of modeling were used. The linear regression that was developed between TP and chlorophyll *a* is shown in Table 3.7 and illustrated in Figure 5.2. Taking into consideration the error in the regression, a TP concentration of 0.06 mg/L predicted a range of chlorophyll *a* of 10.0 to 13.8 μg/L. Maximum chlorophyll *a* values associated with 0.07 mg/L TP are predicted to exceed 15 μg/L.

The model results for existing critical conditions can be compared to the regression analysis for TP and chlorophyll *a*. In Appendix Table I.6, the maximum level of TP -- the sum of inorganic P (SRP) and organic P -- was 0.055 mg/L (Segment 7), and the maximum chlorophyll *a* level was 15.6 μg/L (Segment 5). Although the regression to observed data predicted that a TP below 0.7 mg/L would keep chlorophyll *a* below 15 μg/L, the model results suggest a TP criterion of 0.05 mg/L is necessary to maintain chlorophyll *a* below 15 μg/L. A criterion of 0.05 mg/L would be more conservative and provide a margin of safety to account for scientific uncertainty.

The recommended loading capacity for total phosphorus in the Black River is the load that would result in a daily average concentration of 0.05 mg/L from May 1 through October 31. The TP LC applies to all waters of the Black River from the surface to two meters depth, from RM 9.6 (the location where the Black River crosses from Range 3W into Range 4W) upstream to RM 15.1 (the location where the Black River crosses from the north half to the south half of Section 14, Range 3W, Township 16N).

The TP LC for the Black River is intended to protect the Black River from degradation with respect to the water quality criteria for aesthetic values, dissolved oxygen, and pH. The goal of the TP LC is to allow the Black River to support the beneficial uses of fisheries and recreation specified by the Class A water quality

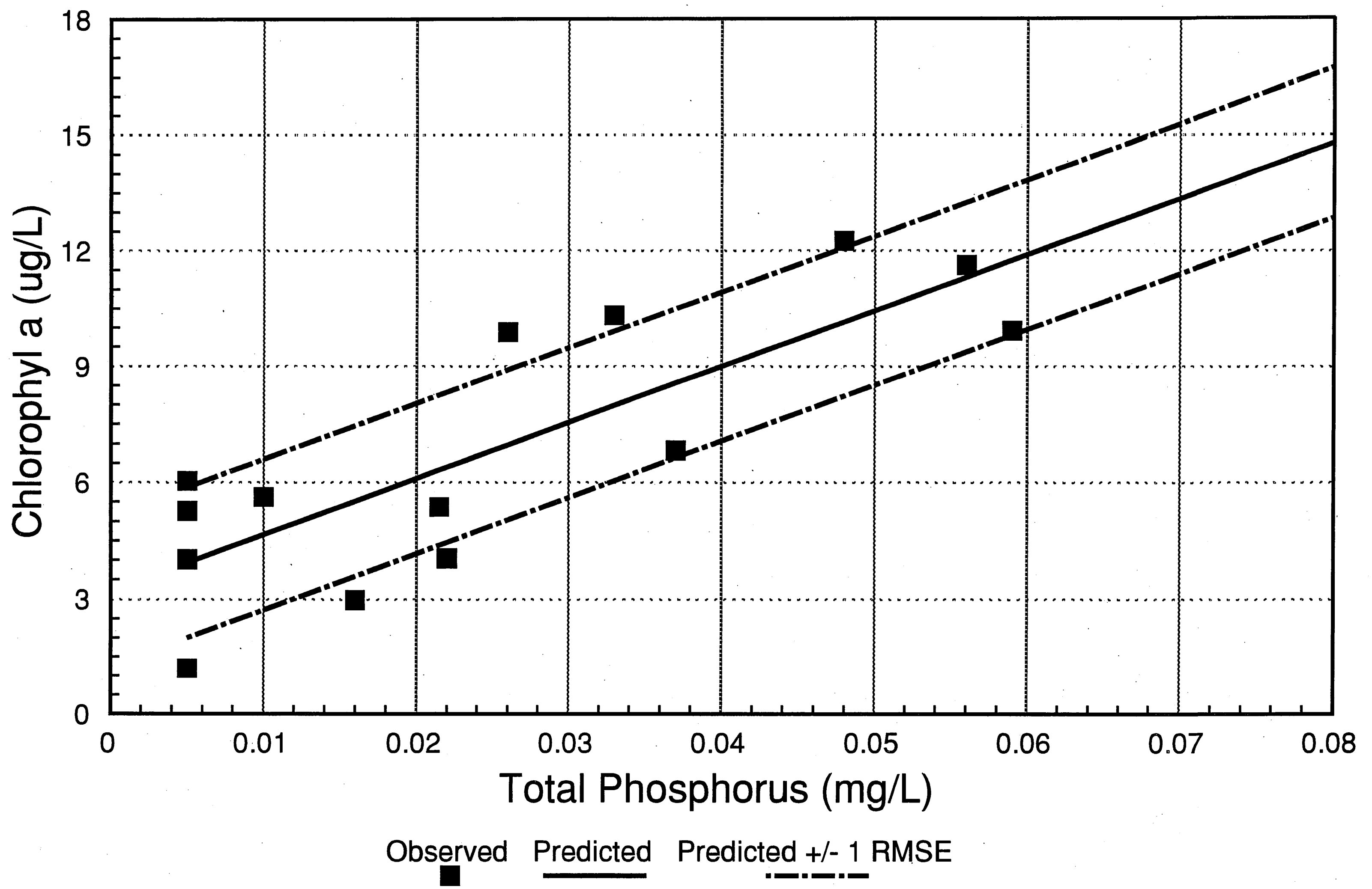

Figure 5.2 Total Phosphorus vs Chlorophyll a
Showing linear regression +/- 1 RMSE

standards to the fullest extent possible. The area is defined to coincide with the slowest reaches of the Black River where conditions support phytoplankton growth. The dates bracket the season of phytoplankton growth and river stratification.

5.5 BOD Loading Capacity

Comparison of the model runs for background and existing critical conditions showed that existing pollutant sources have produced a net increase in DO at certain locations in the river. This raises two questions: 1) should the pollutants that reduce oxygen through CBOD and NBOD be controlled separately from nutrients that influence DO levels through stimulated productivity?; and 2) should the increase in average DO above background conditions created by one discharge be interpreted as creating capacity for other discharges that may degrade water quality back to background conditions?

In answer to the first question, most pollutant wastestreams will be a chemical combination of nutrients and oxygen-demanding materials that cannot be separated without additional treatment. The pollutants should probably be considered together, unless a specific proposed waste treatment or management method may reduce various pollutants at differential rates. In other words, the net effect of the combination of pollutants in the specific source under consideration will probably need to be evaluated on a case-by-case basis. Restricting both degradation of DO and eutrophication from TP inputs in combination will control the impacts of the mixture of pollutants.

With respect to the second question, the model results that show an increase in average DO should not be interpreted as creating capacity for more pollutants. Although the model as currently applied appeared to show improvements in DO from nutrient inputs, this result is inconsistent with most observations in the literature. Typically, increased productivity increases the average DO, but reduces the minimum DO because of the respiration of the increased biomass. The model does not predict the diurnal minimum DO caused by the productivity and respiration of the river's ecological system. Also, the results of the modeling may not hold true for conditions in the Black River that lie outside the assumptions and scope of the model. This uncertainty argues against giving any credence to the apparent increase in capacity for DO demanding substances.

Due to the potential for violations of the DO water quality standards in the Black River, a TMDL is recommended for the protection of DO levels which would restrict the input of materials that exert biochemical oxygen demand (BOD), specifically carbonaceous BOD (CBOD), nitrogenous BOD (NBOD), and sediment oxygen demand (SOD). CBOD is exerted by the oxidation and microbial breakdown of the organic carbon portion of materials. NBOD is exerted by the oxidation of organic and ammonia nitrogen. SOD may be increased by external loads of solids and particulate materials that exert BOD after settling to the sediments, and by the settling of phytoplankton and decaying macrophytes whose growth is promoted by nutrient loads.

The loading capacity for BOD (CBOD, ammonia, and materials that increase SOD) is that pollutant load or combination of pollutant loads which causes no significant degradation to the dissolved oxygen levels of the Black River, both compared to natural conditions and to existing conditions. This LC will not specify a certain loading amount, since it is dependent on several factors, including the timing and location of the source. The total effect of each discharge or loading source must also be considered with respect to other existing sources.

What constitutes a "significant" degradation must be determined on a case-by-case basis. For ambient data, statistical methods may be used to determine whether significant degradation of DO has occurred. For the purposes of modeling, a target of 0.2 mg/L DO was chosen for the TMDL study, based on the accuracy of DO measurement methods. This target is recommended as a guideline for future evaluations of degradation using models or other analytical tools, although a different measure of significance may be acceptable if based on a well-supported rationale. It is also possible that an analysis of beneficial uses could provide a biologically-based definition of significant DO degradation.

The LC for BOD is intended to ensure that the Black River complies with the water quality standards, including the dissolved oxygen criteria and the antidegradation policy. The LC should allow the Black River to meet or exceed Class A requirements for the beneficial uses of fisheries and recreation to the fullest extent possible. The LC for BOD applies to the entire mainstem river from its confluence with the Chehalis River to its headwaters near Black Lake from May 1 to October 31 of every year. The entire mainstem Black River is specified because background conditions do not meet the Class A water quality criterion of 8.0 mg/L DO over this area. The recommended dates bracket the season when river stratification, low flows, high water temperatures, and low DO levels have been observed.

6. TMDL Wasteload/Load Allocations

6.1 Existing Conditions

To evaluate Wasteload Allocation and Load Allocation (WLA/LA) alternatives under a recommended TMDL, several possible changes to current loading sources were evaluated and compared to the recommended TP and BOD LCs. Beginning with the Existing Critical Conditions simulation (Appendix Tables I.4 and I.5), loading sources were categorized and removed singly to determine if the discharge caused a net degradation. Eight cases were run, which are described in Table 6.1. Results are discussed below, and copies of the full results can be found in Appendix Tables J.1 through J.8.

Table 6.1 Summary of Loading Simulation Cases

Case #	Action	Result
1	Eliminate loading from direct discharge above Mima Creek and reduce SOD.	Improves DO in subsurface segment. TP above criterion.
2	Case 1, plus reduce upstream boundary loading in upstream segment to background levels.	Improves upstream DO slightly. TP at criterion
3	Case 2, plus reduce Swecker Salmon Farm loading.	No improvement in DO. TP below criterion.
4	Case 2, plus remove Swecker Salmon Farm loading and flow entirely.	No improvement in DO. TP below criterion.
5	Case 2, plus remove Global Aqua loading and flow entirely.	DO in 3 segments improve, but not significantly. TP at criterion.
6	Case 2, plus remove ground water loading from lower river.	No improvement in DO. TP below criterion.
7	Case 2., plus reduce Mima Creek loading to background levels.	No improvement in DO. TP below criterion.
8	Case 2, plus remove ground water loading in middle river.	No improvement in DO. TP below criterion.

A significant impact to the Black River comes from the uncontrolled discharge of waste from the Black River Ranch. The pool above Mima Creek is the one area on the Black River where DO conditions are degraded from background conditions. Termination of that discharge should result in SOD returning to normal levels over time, which will allow degraded DO conditions at this location to recover. Case 1 should be adopted as a necessary condition to meet the BOD LC prior to any other load reduction options.

The point of discharge that is most sensitive to inputs is the upstream boundary of the model. Discharges here become fully mixed with the surface waters and affect downstream waters for a long distance. About one-half of the flow in the middle and lower river comes from upstream, and it is the largest single source of loading. Reductions in loading due to improved nonpoint source controls (Case 2) will help to ensure that the TP criterion is met and will improve DO in the river.

The single largest source of phosphorus to the Black River, other than uncontrolled discharges from the Black River Ranch, is the Swecker Salmon Farm discharge. This source represents about one half the phosphorus loading in the Black River in the vicinity of the discharge. The discharge appears to have a ground water component and a surface water component. Discharge through ground water, such as occurs at Global Aqua, appears to reduce TP loading to the river from the levels found in the effluent. TP loading in the surface discharge is much higher.

The estimated discharge of TP from the Swecker Salmon Farm at full capacity of the facility would result in the criterion just being met, with no further capacity for future growth. Requiring a lower TP loading than the estimated current design level is necessary to reduce Black River TP concentrations below criteria and allow capacity for growth in the basin.

Analysis of the data collected in this study indicates the loading entering the river due to the Swecker Salmon Farm discharge is greatly reduced from the loading leaving the facility at the rearing ponds. Comparison of the facility effluent data collected in 1991 to the river inputs used in the model suggests that the TP loading discharging directly to the river is about 25% of the loading at the facility outflow. This is probably due to phosphorus attenuation as effluent percolates, and to natural processes such as macrophyte and algal uptake, that provide some reduction of phosphorus in the discharge channel.

6.2 Total Phosphorus TMDL Recommendations

A total phosphorus TMDL for the Black River is recommended for the period of May 1 through October 31 to the Black River basin between RM 9.6 and RM 15.3, and to all sources tributary to the TP TMDL area that have the potential to increase TP levels. The TP TMDL was calculated as 29.26 lbs/day, plus a reserve for future growth, not to exceed the LC criterion of 0.05 mg/L TP. The TMDL should be viewed as an overall strategy to meet the LC criterion, incorporating a numeric WLA for the affected point source discharger, narrative LAs for existing nonpoint sources, and a phased approach with regard to capacity for future growth. The TMDL, LC, and allocations are summarized in Table 6.2.

The following TP WLA/LAs are recommended as part of the TMDL:

Wasteload Allocation: The Black River TP TMDL assumes that all point sources to the Black River system above RM 9.6 must meet the standard for all known available and reasonable treatment. All point source discharges currently under permit meet this requirement.

- Black River Ranch - 0.0 pounds per day TP. Proper implementation of a farm plan and associated BMPs under the coverage of an NPDES permit should eliminate any discharge during the TMDL season.

- Swecker Salmon Farm - 16.0 pounds per day TP to be measured in the facility discharge stream at the outflow of the final facility ponds. This allocation is based on a TP loading to the river of 4.0 pounds per day, assuming that TP loading at the river is 25% of TP loading at the monitoring location.

  In 1991 Swecker Salmon Farm was discharging approximately 10 pounds per day. Swecker Salmon Farm should be capable of meeting this allocation under current conditions. If the facility begins operating at a higher capacity and TP loading increases above the WLA, changes in management practices or physical improvements may be necessary to reduce TP loading. BMPs may be available that reduce TP in the effluent, such as low-phosphorus feed. If necessary, a wastewater retention pond or designed wetland could be constructed that would reduce TP loading to the Black River by sedimentation, biological uptake and solids adsorption.

  The other currently permitted facility in the Black River basin tributary to the TP TMDL area, Cedar Creek Corrections WTP, is relatively low in flow and distant from the mainstem Black River. The TP loading reaching the Black River from this facility could not be separately measured, and is likely of minor importance. Technology-based treatment under the existing permit can be

Table 6.2 BOD5, Ammonia, and TP Allocations, TMDL, and Loading Capacity

All loading in lbs/day

	BOD5	NH3-N	TP
Wasteload Allocations			
Cedar Creek WTP	25.2	0.26	Included in LA
Black River Ranch	0.0	0.00	0.00
Swecker Salmon Farm	210.3	84.13	16.00
Global Aqua/Black River	421.4	168.54	
Load Allocations			
Background-Ground water	35.7	0.36	2.85
Background-Upstream	167.1	2.22	2.15
Background-Mima Creek	16.2	0.04	0.06
Existing Nonpoint Sources	53.54 Application of BMPs to reduce BOD	7.17 Application of BMPs to reduce NH3N	8.20 Application of BMPs to reduce TP
Reserve for Future Growth	Unspecified load, not to exceed LC	Unspecified load, not to exceed LC	Unspecified load, not to exceed LC
Total Maximum Daily Load (TMDL)	929.4 + Reserve	262.72 + Reserve	29.26 + Reserve
Loading Capacity (LC)	No significant degradation of dissolved oxygen below background or existing conditions.		Shall not exceed a criterion of 0.05 mg/L.
Location	Entire mainstem Black River		Mainstem RM 9.6 to 15.3 Surface waters to 2m depth
Applicable Season	May 1 to October 31		May 1 to October 31

considered adequate for the control of TP under this TMDL. Therefore, this facility will not be specifically provided a WLA, but will be included in the LA for existing loading to Mima Creek. Cedar Creek Corrections WTP may discharge under current permit conditions with full application of all known available reasonable treatment, but if expansion of the facility is proposed, the impacts of increased TP loading on the mainstem Black River should be analyzed, and a WLA may be proposed at that time.

Load Allocation for background conditions and scientific uncertainty: The LA for background conditions is equivalent to the loading that maintains a TP concentration of no more 0.03 mg/L in the Black River. The exact amount of loading is a function of the location on the river and the flows at that location. The loading used in the background critical conditions model simulation is 2.85 lbs/day from ground water, 2.15 lbs/day from the upstream mainstem, and 0.06 lbs/day from Mima Creek (Table 6.2).

Scientific uncertainty is accounted for in the conservative assumptions used to develop the TMDL.

Load Allocation for nonpoint sources and future growth: The remaining capacity in the Black River for TP is available as an LA for nonpoint sources and/or future growth. The Black River is predicted to reach TP levels of 0.043 mg/L at existing critical conditions after the 16 lbs/day WLA for Swecker Salmon Farm is applied. Appendix Table J.9 shows the modeling results for this situation, which is based on Case 1 with Swecker Salmon Farm discharging at its WLA. This indicates that some capacity exists for an LA for current nonpoint sources and an LA for future growth.

An LA of 8.20 lbs/day is recommended for existing nonpoint sources, based on the input loading from the existing critical conditions simulation. A narrative LA is also recommended which provides that existing nonpoint sources implement all known available and reasonable BMPs that reduce or eliminate the discharge of TP during the TMDL period. A watershed action plan for the Black River or amendments to the Chehalis Basin Action Plan should be developed that would specify the schedule for implementing BMPs for existing nonpoint sources and the range of available BMPs that are reasonable for existing sources. Since the predicted TP level of 0.043 mg/L is based on current conditions, any reductions in TP loading due to improved BMPs implemented for existing nonpoint sources should result in additional capacity for future growth.

The narrative LA for existing nonpoint sources applies to all sources that may affect the Black River and its tributaries above RM 9.6 and are capable of providing BMPs to limit the amount of TP that reaches the Black River. Such BMPs would include:

limiting livestock access to the Black River and tributaries; no livestock waste discharges to the Black River or tributaries; land application of waste and fertilizers at agronomic rates for the uptake of phosphorus to harvestable crops; septic systems that meet current county standards, especially for river front residences; stormwater controls for residential and other developed areas that reduce TP loading to the maximum extent practicable; preventing the application of silvicultural, agricultural and residential phosphate fertilizers directly to surface waters; and because of the important role of wetlands in the uptake of nutrients, protection of the wetlands associated with the Black River and its tributaries to the maximum reasonable extent.

An LA is also recommended for future growth. Capacity for future growth exists to the extent that additional loading will not increase the TP concentration in the Black River above the maximum of 0.050 mg/L. The exact amount of that loading is unspecified, because it is dependent on the timing and location of the new source, and on the effectiveness of BMPs in meeting the WLA and LAs for existing sources. Any new point source discharges and any increased loading from existing point sources should be analyzed for whether the discharge will cause an exceedance the TP TMDL criterion, and whether a WLA should be provided to that discharge. New nonpoint sources should provide all known available and reasonable BMPs that reduce or eliminate the discharge of TP during the TMDL period. Revised LAs for existing nonpoint sources may be required that include the new source if the TP loading to the Black River is expected to increase despite the application of the identified BMPs. A watershed action plan for the Black River could specify the schedule for implementing BMPs for new nonpoint sources and the range of available BMPs that are reasonable for those new sources.

Continued residential and commercial growth is anticipated in the Olympia and Grand Mound areas. If point and nonpoint discharges under conditions of future growth, even with AKART and BMPs implemented, exceed the allocations available under the TMDL and cause violations of the TP criterion, point and nonpoint sources will have to be reviewed to determine what levels of advanced treatment and/or increased BMPs would bring loading allocations back within TMDL levels.

The TP TMDL is recommended as a phased TMDL. The availability of capacity for future growth is dependent on success in meeting the WLA and LAs for existing sources. The LA for future growth should be held in reserve or allocated conservatively until the effectiveness of BMPs and compliance with the WLA and LAs for existing sources can be assured.

6.2.2 BOD TMDL Allocation Recommendations

A TMDL for BOD is recommended that would apply to the entire Black River basin for the period May 1 through October 31. TMDL values were calculated as 929.4 lbs/day BOD_5 and 262.72 lbs/day ammonia nitrogen, plus a reserve for future growth, with no significant degradation of DO below background or existing conditions. The BOD TMDL should be viewed as an overall strategy to prevent the degradation of DO in the Black River from any pollutant source or combination of sources.

The following WLA/LAs for BOD are recommended:

Wasteload Allocations: The Black River BOD TMDL assumes that all point sources to the Black River system must meet the standard for all known available and reasonable treatment. The three currently permitted facilities in the Black River basin (Global Aqua/Black River, Swecker Salmon Farm, and Cedar Creek Corrections WTP) meet this requirement, which provides sufficient pollutant controls for the discharges to meet the requirements of the BOD TMDL. These permitted point source discharges may all be granted WLAs for BOD, which allow these facilities to discharge current technology-based loading with full application of all known available reasonable treatment. The specific WLAs in pounds/day have been calculated from effluent data (if not already in the permit), and are provided in Table 6.2.

In addition, the Black River Ranch, which is expected in the future to be covered by a permit, should have no discharge of CBOD or ammonia during the TMDL season after BMPs are fully implemented. Therefore, a WLA of zero is recommended for this facility.

Load Allocation for background conditions and scientific uncertainty: Background conditions are considered to be critical low instream and tributary flows, ground water baseflow, with no direct withdrawals; background ground water and tributary quality; and no point or nonpoint source loading to the Black River or its tributary ground or surface waters. The estimate of background conditions based on modeling was discussed in Section 5.2; the flows, loading, ground water concentrations and model results are shown in Appendix Tables I.1 through I.3. Table 6.2 provides a summation of background loads that are divided into three LAs for the mainstem Black River at the upstream boundary of the study area, Mima Creek, and for ground water inputs.

Scientific uncertainty includes model variability, sampling variability, and uncertainty due to the limited scope of analysis. Scientific uncertainty was included as part of the modeling analysis for the TMDL and WLA/LAs by the use of conservative assumptions. Specifying that any observed or calculated degradation must be determined to be significant, such as through the use in this study of a 0.2 mg/L criteria, also factors in scientific uncertainty. Therefore, a separate LA for scientific uncertainty is unnecessary.

Load Allocation for nonpoint sources and future growth: LAs for BOD_5 and ammonia are recommended for existing nonpoint sources, based on the input loading from the existing critical conditions simulation. These LAs are shown in Table 6.2. A narrative LA is also recommended for existing nonpoint sources, which provides that these sources implement all known available and reasonable BMPs, with the goal of eliminating the discharge of oxygen-demanding materials during the TMDL period. A watershed action plan for the Black River or amendments to the Chehalis Basin Action Plan should be developed that would specify the schedule for implementing BMPs for existing nonpoint sources and the range of available BMPs that are reasonable for existing sources.

The LA for existing nonpoint sources applies to all sources that may affect the Black River and its tributaries and are capable of providing Best Management Practices (BMPs) to limit the amount of BOD, ammonia, and oxygen-demanding solids that reach the Black River. Such BMPs would include: limiting livestock access to the Black River and tributaries; no livestock waste discharges to the Black River or tributaries; land application of waste and fertilizers at agronomic rates for the uptake of ammonia to harvestable crops; septic systems that meet current county standards, especially for river front residences; stormwater controls for residential and other developed areas that reduce the loading of BOD, ammonia, and oxygen-demanding solids to the maximum extent practicable; preventing the application of silvicultural, agricultural and residential ammonia fertilizers directly to surface waters; and because of the important role of wetlands in the uptake of oxygen-demanding materials, protection of the wetlands associated with the Black River and its tributaries to the maximum reasonable extent.

A narrative LA is also recommended for future growth. The capacity for future growth will be dependent on the timing, location and loading of that discharge. No discharges or combination of discharges that will cause a significant degradation of dissolved oxygen in the mainstem Black River should be allowed. Any facility proposing a change in an existing discharge, or any proposed facility with a new discharge in the Black River basin, must demonstrate that the discharge will cause no significant degradation of dissolved oxygen in the mainstem Black River, alone or in combination with other discharges. This analysis will determine whether a WLA should be provided to that discharge.

New nonpoint sources should provide all known available and reasonable BMPs that prevent the discharge of oxygen-demanding materials during the TMDL period. A watershed action plan for the Black River could specify the schedule for implementing

BMPs for new nonpoint sources and the range of available BMPs that are reasonable for these new sources. New nonpoint sources that do not cause degradation of DO may be considered for inclusion in the LA for existing nonpoint sources.

If point and nonpoint discharges under conditions of future growth, even with AKART treatment and BMPs implemented, exceed the allocations available under the TMDL and causes a degradation of dissolved oxygen, point and nonpoint sources would have to be reviewed to determine what levels of advanced treatment and/or increased BMPs that would bring loading allocations back within TMDL levels.

7. Implementation and Monitoring

7.1 TMDL and WLA/LA Implementation

Implementation of the TP and BOD TMDLs for the Black River must be viewed as a long-term effort that will require the support of not just the Water Quality Program at Ecology, but also other programs at Ecology; other federal, state, and local agencies; the Chehalis Tribe; dischargers; and citizens living in the drainage basin. A number of activities are recommended to help implement the Black River TMDLs and allocations:

- The TP LC criterion and the BOD LC antidegradation criterion should be reviewed for their possible inclusion as special conditions into the Specific Classifications-Freshwater section of the Water Quality Standards (WAC 173-201A-130).

- The Swecker Salmon Farm permit should be modified or other regulatory action taken to implement the WLA for TP. Monitoring of the effluent for TP loading every two weeks during the TMDL season (May through October) is recommended.

- Permits for the Swecker Salmon Farm, Global Aqua/Black River, and the Cedar Creek Corrections WTP should be modified or other regulatory action taken to implement the BOD WLAs for these facilities. Monitoring of the effluent for ammonia nitrogen and BOD_5 loading every two weeks during the TMDL season is recommended.

- Dairy farms and other livestock facilities in the Black River basin should provide Best Management Practices to control the discharge of TP and oxygen-demanding materials to the Black River. These BMPs should include: agronomic rates of land application of waste for the optimal uptake of phosphorus; restricting or eliminating the access of livestock to the Black River and tributaries; and eliminating overland flow of waste materials or leachate to the Black River and tributaries. The priority for working with facilities to improve BMPs should be: 1) Black River Ranch dairy; 2) facilities along Beaver Creek; 3) facilities on the mainstem Black River above the boat launch south of Littlerock; 4) facilities along Mima Creek; and 5) facilities downstream of RM 9.6.

  The Black River Ranch should be covered by an NPDES permit that specifies implementation through a farm plan of BMPs for sources of TP, ammonia, and BOD_5, and no discharge of TP, ammonia, and CBOD during the TMDL season.

- Septic systems should be inspected at residences that border the Black River and its tributaries, and failing or inadequate systems should be brought up to current standards. These inspections should be made by county Health Department personnel as time and resources allow. The priority for this effort should be: 1) systems on the mainstem Black River between RM 9.6 and RM 15.3; 2) systems on the mainstem Black River above RM 15.3; 3) systems on Beaver Creek below Case Road; 4) systems on Mima Creek; 5) systems on the mainstem Black River downstream of RM 9.6; and 6) systems on other tributaries of the Black River.

- Stormwater from public roads and significant development that would discharge to the Black River and its tributaries during the period May 1 to October 31 should be provided BMPs. The Puget Sound Stormwater Manual should be used as the standard for this treatment. All new development should meet this standard, and existing roads and development should phase into these standards when improvement or expansion occurs.

- Silvicultural, agricultural, and residential fertilization should be conducted with methods that prevent the application of fertilizer directly to surface waters. Fertilization should be done at agronomic rates that allow the full uptake of nutrients and minimize leaching to ground water near the Black River or its tributaries.

- Riparian wetlands along the middle and upper Black River should be protected. Natural wetlands should not be used as a substitute for proper stormwater controls.

- Best management practices are recommended to increase shading on the mainstem Black River. Projects that plant riparian shade trees should be encouraged, and existing riparian shade trees should be protected. The effectiveness of tree planting efforts should be evaluated periodically with sampling or temperature modeling, possibly at five-year intervals in accordance with the Basin Approach of Ecology's Water Quality Program.

- A new watershed nonpoint source action plan or a revision of the Chehalis Basin Action Plan should be developed to specifically address the Black River TMDL. The plan should be developed by the Chehalis River Council or by a Black River watershed committee composed of local citizens. The plan should have specific timetables and priorities, and should describe the available and reasonable BMPs for existing and new nonpoint sources. Ecology should work with local agencies and citizens to facilitate the development of a grant proposal to fund a watershed planning process consistent with, or similar to, those specified in Chapter 400-12 WAC.

- BMPs should be implemented through Shoreline Management Act permits for projects within the Act's jurisdiction. BMPs could be identified during the State Environmental Policy Act process, or in the permits themselves. To recognize the Black River TMDLs and specify the BMPs for inclusion in Shoreline permits, modification of the Shoreline Master Plans that affect the Black River should be considered.

- Flow should be monitored during the summer low flow season and appropriate actions taken if flows are less than the minimum flows specified by regulation (Chapter 173-522 WAC). Water rights and existing withdrawals should be reviewed and actions taken as appropriate to maintain minimum flows.

7.2 Monitoring and Further Study

Long-term monitoring of the Black River is necessary to assess the effectiveness of the TMDLs in protecting water quality. This monitoring could either be conducted by Ecology or by other agencies, and data quality should be assured so that all data are of a comparable good quality. The scope of monitoring is dependent on priorities and available resources. A number of strategies are suggested below:

- Annual synoptic monitoring should be conducted in the Black River twice a month in July, August, and September. If resources do not allow this intensity of monitoring, monitoring could be less frequent, although monitoring should occur at least once in mid-August. An alternative to annual monitoring would be monitoring once every five years consistent with the Basin Approach of Ecology's Water Quality Program. However, due to the importance of nonpoint sources in the Black River basin, and based on the experience of the Rural Clean Water Program (Gale *et al.*, 1992), long-term monitoring (6-10 years) twice a month is recommended to evaluate the trends in water quality and the effectiveness of BMP implementation.

  Key locations for this monitoring are Howanut Road (RM 1.2), above the Big Dock at multiple depths (RM 9.7), above Mima Creek at multiple depths (RM 11.9), above the boat launch south of Littlerock (RM 15.3), at the River Road bridge above Waddell Creek (RM 17.4), and the near the mouths of Mima, Beaver, and Waddell Creeks. Parameters should include temperature, pH, conductivity, turbidity, DO, orthophosphate, total phosphorus, ammonia nitrogen, nitrate/nitrite nitrogen, total persulfate nitrogen, BOD_5, chlorophyll *a*, and fecal coliform bacteria.

- A permanent station with monthly ambient monitoring should be established at the Moon Road bridge where monitoring has been done in the past. Parameters should include temperature, pH, conductivity, turbidity, DO, orthophosphate, total phosphorus, ammonia nitrogen, nitrate/nitrite nitrogen, total persulfate nitrogen, and fecal coliform bacteria. This monitoring would allow evaluation of long-term trends in the quality of the Black River and comparison to pre-TMDL conditions on a year-round basis.

- Flow should be monitoring on a regular basis, at least twice a month from July through September. Measurements at the Howanut Road bridge are recommended, although the SR 12 bridge is also a good location. A permanent staff gage should also be established for predictions of flows from a stage-discharge relationship. Flow data would allow calculation of loading, evaluation of low flows to identify critical low flow periods, and would help in the response to a spill or other water quality emergency.

Two complex studies are suggested below for consideration in future years. The first study would address the unresolved question of the relationship of the lower river macrophytes to nutrients and dissolved oxygen, and to the fisheries resource in general. The study would evaluate summertime macrophyte, periphyton and epiphyton growth in the Black River from RM 9.6 to the mouth by measuring the standing biomass, geographic distribution, and productivity of benthic plants and algae. Interactions between the dissolved and particulate materials in the water column and in the sediments, and the relationship of those systems to benthic productivity would be assessed.

The goals of the benthic productivity study would be: to quantify the relationship of standing biomass and productivity to upstream dissolved and particulate nutrients; to determine the effect of changes in benthic biomass and productivity on dissolved oxygen; to define the optimal benthic biomass that is beneficial to the fishery resource through the combined effect of water quality, habitat, and other considerations; and to recommend a management strategy to control macrophytes and periphyton at the optimal level. If further loading restrictions were found to be necessary to control macrophyte growth, these could be included in the TMDL at a future date.

The second study that is recommended is a study of the interactions of ground water with summertime base flow in the Black River. Over one-half of the flow in the Black River appears to come from ground water inflows. In addition, ground water inputs in some areas appear to be of high quality, and in other areas of relatively poor quality. The goal of the study would be to evaluate the extent to which ground water withdrawals are reducing baseflows, and the extent to which pollutant concentrations in ground water are affecting river water quality.

The regional growth that the Black River basin is experiencing is likely to continue to put pressure on the ground water resource, both from withdrawals and from pollutant inputs. Ground water withdrawals may be reducing summertime base flows, but whether this is occurring and to what extent is not known. Also, the effect of land use activities on ground water pollutant levels, and ultimately on pollutant loading to the Black River, is poorly understood. The long-term protection of the Black River and effectiveness of the TMDLs may depend on improved understanding of the interactions of ground water and the river, and development of effective controls on use of the ground water resource.

8. SUMMARY AND CONCLUSIONS

8.1 Summary of Survey Results

A review of the data developed as part of this study reveals a number of significant details regarding the characteristics of the Black River.

- The upper Black River (upstream of RM 15.3) is strongly influenced by extensive wetlands. During the study, most dissolved constituents were relatively low, DO was depressed, organic compounds were relatively abundant, and the river had its characteristic dark color.

- Beaver Creek appeared to have one or more pollutant loading sources in the stretch between Case Road and Route 121. This was suggested by data for fecal coliform bacteria, total nitrogen, and nitrate/nitrate nitrogen. U.S. Fish and Wildlife Service survey information has identified livestock access areas and waste inputs on Beaver Creek that are likely sources of these pollutants.

- Waddell Creek and Mima Creek had relatively high quality water. Both drain the Black Hills, a forested area with basaltic bedrock.

- Clearwater Lagoon showed evidence that it is affected by a ground water source of high quality; its quality was similar to Mima and Waddell Creeks, suggesting a common source in the Black Hills.

- The lower temperatures and higher levels of some constituents in the deeper waters of the middle Black River between RM 14.1 and 11.9 suggest ground water inputs to these areas.

- A large body of evidence suggests that just upstream of Mima Creek a discharge of dairy waste from the Black River Ranch to the Black River has occurred in the past. This discharge was probably more active in wet weather, but has also occurred in dry weather. Evidence suggests that a discharge occurred in August 1991, and probably was occurring periodically prior to that date. Improved water quality in 1992 suggests that waste management improvements at the Black River Ranch had reduced or eliminated this discharge.

- The Swecker Salmon Farm is the only permitted point source for which a distinct surface discharge location can be identified. There appeared to be a reduction in several pollutants in the Swecker effluent between the pond outflow and discharge point to the river.

- The Global Aqua discharge reaches the Black River indirectly through springs in two locations: the area immediately above the steel trestle (RM 9.1), and the area near Big Rock roughly between RM 7.9 and 7.2. Certain pollutants showed attenuation from the effluent to the springs.

- Based on chlorophyll *a* levels as an indicator of trophic state, the Black River during the study period classified as mesotrophic, bordering on eutrophic. Significant phytoplankton productivity was indicated, with diatoms and cryptophytes as the dominant species. Occasional blooms of green algae occurred. Productivity appeared to decrease from spring into summer, and increase again in the fall. A possible explanation for this pattern is that higher light and nutrient availability increased productivity in the spring; lower light and nutrient limitation reduced productivity in the summer; and productivity increased in the fall due to nutrients released from various sources, which may have included erosion of the nutrient-rich hypolimnion, fall rainfall runoff, and seasonal leaf fall.

- Chlorophyll *a*, phytoplankton ID, turbidity, and TSS data all indicated that a significant proportion of suspended phytoplankton was removed by the dense macrophyte beds below the steel trestle.

- Dissolved oxygen concentrations below the standard of 8.0 mg/L were widespread on the Black River.

8.2 Summary of TMDL Analysis Results

- Dissolved oxygen in the Black River violates the freshwater quality criterion of 8.0 mg/L throughout most of the mainstem during the summer months. An analysis of background conditions indicates that dissolved oxygen falls below this criterion even in the absence of anthropogenic pollutant loading. Because background conditions are less than the criterion, background conditions define the new standard, therefore no further degradation of dissolved oxygen can be allowed.

- The LC was established for carbonaceous biochemical oxygen demand, ammonia, and materials that can increase sediment oxygen demand. The LC is defined as no significant degradation of DO as compared to existing or background conditions in the Black River that is caused by any pollutant load or combination of pollutant loads. The BOD LC applies to all waters of the mainstem Black River from May 1 to October 31. The total effect of each discharge or loading source shall be considered both alone and in combination with other sources.

"No significant degradation" was defined in this study as less than a 0.2 mg/L reduction in DO when compared to conditions with the pollutant load absent, under either existing conditions or background conditions. Significant degradation may also be determined in future work by statistical methods, beneficial use-based methods, or other rationally justified approaches.

- WLAs and LAs are proposed to meet the BOD LC and protect water quality standards. WLAs are proposed for existing permitted dischargers based on full application of all known available reasonable treatment as currently exists at the facilities. An LA is proposed for existing nonpoint sources, in combination with a narrative LA that states that nonpoint loading sources be provided BMPs that minimize the discharge of oxygen-demanding materials. The narrative LA for future growth is that any new point or nonpoint source or changes to existing point or nonpoint sources to the mainstem or tributaries of the Black River should cause no significant degradation of dissolved oxygen in the Black River.

- Background conditions in the middle Black River are mesotrophic, and existing conditions appear to be nearing eutrophy. It is well established that eutrophication of a water body is characterized by nuisance algal growth, low dissolved oxygen, high pH, and ultimately depletion of fishery resources. Therefore, a limit on total phosphorus is necessary to protect the Black River from the deleterious effects of eutrophication.

- The LC was determined for total phosphorus in the Black River, defined as the load that would result in a daily average concentration of 0.05 mg/L from May 1 through October 31. This LC would apply to all waters of the Black River from the surface to two meters depth, from RM 9.6 (the location where the Black River crosses from Range 3W into Range 4W) upstream to RM 15.1 (the location where the Black River crosses from the north half to the south half of Section 14, Range 3W, Township 16N).

- WLAs and LAs are proposed to meet the TP LC. A WLA is proposed for Swecker Salmon Farm of 16 pounds of TP per day, to be met in the effluent stream at the outflow from the final facility ponds. The Cedar Creek Corrections WTP will be included in the LA for Mima Creek. The LA for background conditions is the loading that corresponds to a concentration of 0.03 mg/L TP. An LA is recommended for existing nonpoint sources, in combination with a narrative LA which provides that these sources implement all known available and reasonable BMPs to reduce or eliminate the discharge of TP during the TMDL period. An LA is also recommended as a reserve for future growth, subject to the future loading source not causing an exceedance of the TP LC criterion of 0.050 mg/L in the mainstem Black River. The exact amount of future allocations within the future growth LA are dependent on the timing, location, and loading of the proposed discharge.

- Temperatures in the Black River exceed the water quality criterion of 18°C during the summer months. Although much of the middle and upper river is bordered by wetlands that likely would not support significant riparian shading, the lower river from about RM 10 downstream does appear to be capable of supporting a riparian shade canopy. However, much of that canopy is absent due to human activities, which has likely resulted in an increase in water temperatures in the Black River.

- A phased TMDL for temperature is recommended for the Black River. The temperature TMDL calls for riparian shade trees to be protected and replanted to the fullest extent possible along the lower Black River, downstream of RM 10 to the mouth. The phased temperature TMDL will be revisited at five year cycles according to the Basin Approach of Ecology's Water Quality Program, when the effectiveness of tree planting efforts will be evaluated through sampling or temperature modeling.

- Implementation of the BOD and TP WLA/LAs will occur primarily through regulatory action for permitted discharges and implementation of BMPs for nonpoint sources. A new watershed action plan or amendment to the Chehalis Basin Action Plan specific to the Black River is suggested to coordinate BMP implementation. Use of Shoreline permits to implement BMPs is also a potential tool. Implementation of nonpoint source controls should be coordinated with federal, state, tribal, and local agencies, as well as with citizen's groups.

- A long-term monitoring program is proposed to evaluate the effectiveness of the TMDL and WLA/LAs. Additional studies are proposed to determine the effect of macrophyte growth on Black River water quality, and to improve our understanding of the effect of ground water resource use on Black River flow and quality.

9. References

Ambrose, R.B., T.A. Wool, and J.L. Martin, 1993. The Water Quality Analysis Simulation Program, WASP5. Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, GA.

APHA *et al.*, 1989. Standard Methods for the Examination of Water and Wastewater, 17th Edition. Clesceri, L.S., A.E. Greenberg, and R.R. Trussel (eds). American Public Health Assn., American Water Works Assn., Water Pollution Control Federation, Washington, DC.

Barko, J.W., 1985. Nutrition and Growth of Submersed Macrophytes: The Role of Bottom Sediments. Aquatic Plant Control Research Program, Information Exchange Bulletin, Vol. A-85-1, U.S. Army Corps of Engineers, Waterway Experiment Station, Vicksburg, MS.

Berg, S.H., 1993. Thurston County Environmental Health Division, Personal Communication.

Brock, T.D., 1979. Biology of Microorganisms. 3rd edition, Prentice-Hall, Inc., Englewood Cliffs, NJ.

Carlson, R.E., 1977. "A Trophic State Index for Lakes." Limnology and Oceanography 22(2):361-369.

Chehalis River Council, 1992. Chehalis River Basin Action Plan for the Identification and Control of Nonpoint Source Pollution. Chehalis, WA, December.

Cole, G.A., 1979. Textbook of Limnology. The C.V. Mosby Company, St. Louis.

Coots, R., 1994. Black River Wet Season Nonpoint Source Total Maximum Daily Load Study. Environmental Investigations and Laboratory Services Program, Washington State Department of Ecology, Olympia, WA.

Dahl, B., 1992. Personal Communication, Owner of Black River Canoe Club.

Das, T., 1993. Chehalis River Basin Class II Inspections at Eight NPDES Permitted Dischargers, August 1991-August 1992. Environmental Investigations and Laboratory Services Program, Washington State Department of Ecology, Olympia, WA.

Dickes, B., 1990. "Black River Water Quality, Winter, 1989/1990." Memorandum to G. Deschamps (Chehalis Tribe), Washington State Department of Ecology, Olympia, WA.

Ecology, 1989. The Black River Fish Kill Report. Publication No. 89-54, Washington State Department of Ecology, Olympia, WA.

------, 1991. Ambient Water Quality Monitoring Database. Environmental Investigations and Laboratory Services Program, Washington State Department of Ecology, Olympia, WA.

------, 1992a. Statewide Water Quality Assessment 305(b) Report. Publication No. 90-04, Washington State Department of Ecology, Olympia, WA.

------, 1992b. Field Sampling and Measurement Protocols for the Watershed Assessments Section. Environmental Investigations and Laboratory Services Program. Washington State Department of Ecology, Olympia, WA.

------, 1992c. 1990-1991 Quality Assurance/Quality Control Assessment, Marine Water Column Monitoring Program. Environmental Investigations and Laboratory Services Program, Washington State Department of Ecology, Olympia, WA.

EPA, 1983a. Technical Guidance Manual for Performing Waste Load Allocations, Book II-Streams and Rivers. Chapter 1 - Biochemical Oxygen Demand/Dissolved Oxygen, and Chapter 2 - Nutrient/Eutrophication Impacts. U.S. Environmental Protection Agency, Washington, DC.

------, 1983b. Methods for Chemical Analysis of Water And Wastes. EPA-600/4-79-020. U.S. Environmental Protection Agency, Washington, DC.

------, 1985. Rates, Constants, and Kinetic Formulations in Surface Water Quality Modeling (Second Edition). EPA/600/3-85/040. U.S. Environmental Protection Agency, Washington, DC.

------, 1986. Quality Criteria for Water 1986. EPA 440/5-86-001. U.S. Environmental Protection Agency, Washington, DC.

------, 1987. The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS: Documentation and User Model. EPA/600/3-87/007. U.S. Environmental Protection Agency, Washington, DC.

------, 1992. TMDL Case Study: Sycamore Creek, Michigan. EPA 841-F-92-012. Office of Water, U.S. Environmental Protection Agency, Washington, DC.

Erickson, D.E., 1990a. "Global Aqua Start Up Ground Water Monitoring Investigation, Rochester, Washington." Memorandum to John Bernhardt, Washington State Department of Ecology, Olympia, WA, January 22, 1990.

------, 1990b. Rochester Ground Water Quality Investigation. Environmental Investigations and Laboratory Services Program, Washington State Department of Ecology, Olympia, WA.

------, 1992. Ground Water Quality Assessment, Sheridan Dairy Lagoon, Adna, Washington. Environmental Investigations and Laboratory Services Program, Washington State Department of Ecology, Olympia, WA.

------, 1993. Personal Communication, Environmental Investigations and Laboratory Services Program, Washington State Department of Ecology, Olympia, WA.

Gale, J.A., D.E. Line, D.L. Osmond, S.W. Coffey, J. Spooner, and J.A. Arnold, 1992. Summary Report: Evaluation of the Experimental Rural Clean Water Program. National Water Quality Evaluation Project, NCSU Water Quality Group, Biological and Agricultural Engineering Department, North Carolina State University, Raleigh, NC.

Harvester, D.D., 1993. Personal Communication, Southwest Region Water Quality Programs, Washington State Department of Ecology, Olympia, WA.

Hill, B.H., 1986. "The Role of Aquatic Macrophytes in Nutrient Flow Regulation in Lotic Ecosystems." from *Rationale for Sampling and Interpretation of Ecological Data in the Assessment of Freshwater Ecosystems*. ASTM STP 894. B.G. Isom. Ed., American Society for Testing and Materials, Philadelphia, PA (157-167).

Huntamer, D. and J. Hyre, 1991. Manchester Environmental Laboratory, Laboratory Users Manual. Manchester Environmental Laboratory, Manchester, WA.

Kendra, W. and B. Dickes, 1991. Scope of Work for Chehalis River Basin TMDL Study. Environmental Investigations and Laboratory Services Program, Washington State Department of Ecology, Olympia, WA.

Lee, G.F., E. Bentley, and R. Amundson, 1975. "Effects of Marshes on Water Quality" from Coupling of Land and Water Systems. A.D. Hasler, ed., Springer-Verlag, New York, NY.

Liu, H., 1977. "Predicting Dispersion Coefficient of Streams." Journal of the Environmental Engineering Division, Proceedings of the American Society of Civil Engineers. Vol 103, No EE1, February, 59-69.

Mills, W.B. *et al.*, 1986. Handbook - Stream Sampling for Waste Load Allocation Applications. Publication EPA/625/6-86/013, U.S. Environmental Protection Agency, Washington, DC.

NCASI, 1987a. A Procedure for the Estimation of Ultimate Oxygen Demand (Biochemical). NCASI Special Report No. 87-06, National Council of the Paper Industry for Air and Stream Improvement, Inc., New York, NY.

NCASI, 1987b. User's Manual for Parameter Estimation for First Order Ultimate BOD Decay, BODFO. NCASI Technical Bulletin No. 529, National Council of the Paper Industry for Air and Stream Improvement, Inc., New York, NY.

NCASI, 1991. Supplemental User's Guide for Applying the WASP4 Model Program. NCASI Technical Bulletin No. 618, National Council of the Paper Industry for Air and Stream Improvement, Inc., New York, NY.

Pearson, H.E. and G.T. Higgins, 1977. Water Resources of the Chehalis Indian Reservation, Washington. Open-File Report 77-704, U.S. Geological Survey, Tacoma, WA.

Pickett, P.J., 1991. "Investigation of Water Quality Problems in the Black River Between the Black River Canoe Club and the Mouth of Mima Creek." Memorandum to Diane Harvester, Washington State Department of Ecology, Olympia, WA.

------, 1992. Historical Data Sources and Water Quality Problems in the Chehalis River Basin. Environmental Investigations and Laboratory Services Program, Washington State Department of Ecology, Olympia, WA.

Reckhow, K.H., J.T. Clements, and R. Dodd, 1986. Statistical Goodness-of-Fit Measures for Waste Load Allocation Models. Draft Report, Work Assignment No. 33, EPA Contract No. 68-01-6904, LimnoSystems, Durham, NC.

Schlorff, E.J., 1993. Personal Communication, Water Quality Program, Washington State Department of Ecology, Olympia, WA.

Sharer, E., 1992. Personal Communication, Black River Property Owner.

Sinclair, K.A. and S.J. Hirschey, 1992. A Hydrogeologic Investigation of the Scatter Creek/Black River Area, Southern Thurston County, Washington State. Master thesis, The Evergreen State College, Olympia, WA.

Sweet, J.W., 1986. A Survey and Ecological Analysis of Oregon and Idaho Phytoplankton. Aquatic Analysts, Portland, OR.

Sweet, J.W., 1992. Chehalis River Phytoplankton, 1991-1992. Report to the Washington Department of Ecology. Aquatic Analysts, Portland, OR.

TCEH, 1991. Water Quality on the Black River, Thurston County, Washington. Thurston County Environmental Health, Olympia, WA.

TFW, 1990. Evaluation of Prediction Models and Characterization of Stream Temperature Regimes in Washington. Timber/Fish/Wildlife Temperature Work Group, Publication No. TFW-WQ3-90-006, Washington State Department of Natural Resources, Olympia, WA.

Thomann, R.V. and J.A. Mueller, 1987. Principles of Surface Water Quality Modeling and Control. Harper and Row Publishers, New York, NY.

USFWS, 1993. Chehalis River Fisheries Restoration Program: Fiscal Year 1993 Program Summary. Western Washington Fishery Resource Office, U.S Fish and Wildlife Service, Olympia, WA.

Valderrama, J.C., 1981. "The Simultaneous Analysis of Total Nitrogen and Total Phosphorus in Natural Waters." Marine Chemistry 10 (1981) 109-122.

Velz, C.J., 1970. Applied Stream Sanitation. John Wiley & Sons, New York, NY.

Walker, G.R., I.D. Jolly and P.G. Cook, 1991. "A New Chloride Leaching Approach to the Estimation of Diffuse Recharge following a Change in Land Use." Journal of Hydrology 128 (1991) 49-67.

Wampler, P., E. Knudsen, M. Hudson, and T. Young, 1993. Chehalis River Basin Fishery Resources: Salmon and Steelhead Stream Habitat Degradation. U.S. Fish and Wildlife Service. Olympia, WA.

Welch, E.B., 1980. Ecological Effects of Waste Water. Cambridge University Press, New York, NY.

Williams, J.R. and H.E. Pearson, 1985. Streamflow Statistics and Drainage-basin Characteristics for the Southwestern and Eastern Regions, Washington. Open-file Report 84-145-A, U.S. Geological Survey, Tacoma, WA.