Concentrations of Dissolved Oxygen in the Lower Puyallup and White Rivers, Washington, August and September 2000 and 2001

Prepared in cooperation with the
WASHINGTON STATE DEPARTMENT OF ECOLOGY
AND THE PUYALLUP TRIBE OF INDIANS

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 02-4146

Photograph of the White River looking upstream from the Tacoma Avenue Bridge in Sumner, Washington, May 2002

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GALE A. NORTON, Secretary

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Charles G. Groat, Director

CONTRIBUTING U.S. GEOLOGICAL SURVEY STAFF

Editorial, Graphics, and Text Preparation

J.A. Wayenberg, Technical Editor
C.J. Dean, Illustrator

For additional information write to:

District Chief
U.S. Geological Survey
1201 Pacific Avenue – Suite 600
Tacoma, Washington 98402

http://wa.water.usgs.gov

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Building 810
Box 25286, Federal Center
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CONVERSION FACTORS AND VERTICAL DATUM

CONVERSION FACTORS

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.2832	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	2.54	millimeter
mile (mi)	1.609	kilometer
pound	0.4536	kilogram

Temperature in degrees Celsius (^{o}C) may be converted to degrees Fahrenheit (^{o}F) as follows:

$$^{o}F=1.8\ ^{o}C+32.$$

Temperature in degrees Fahrenheit (^{o}F) may be converted to degrees Celsius (^{o}C) as follows:

$$^{o}C=(^{o}F-32)/1.8.$$

Specific conductance is given microsiemens per centimeter at 25 degrees Celsius (μS/cm at 25^{o}C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (μg/L).

VERTICAL DATUM

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

Altitude, as used in this report, refers to distance above or below sea level.

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ABSTRACT

The U.S. Geological Survey, Washington State Department of Ecology, and Puyallup Tribe of Indians conducted a study in August and September 2001 to assess factors affecting concentrations of dissolved oxygen in the lower Puyallup and White Rivers, Washington. The study was initiated because observed concentrations of dissolved oxygen in the lower Puyallup River fell to levels ranging from less than 1 milligram per liter (mg/L) to about 6 mg/L on several occasions in September 2000. The water-quality standard for the concentration of dissolved oxygen in the Puyallup River is 8 mg/L.

This study concluded that inundation of the sensors with sediment was the most likely cause of the low concentrations of dissolved oxygen observed in September 2000. The conclusion was based on (1) knowledge gained when a dissolved-oxygen sensor became covered with sediment in August 2001, (2) the fact that, with few exceptions, concentrations of dissolved oxygen in the lower Puyallup and White Rivers did not fall below 8 mg/L in August and September 2001, and (3) an analysis of other mechanisms affecting concentrations of dissolved oxygen.

The analysis of other mechanisms indicated that they are unlikely to cause steep declines in concentrations of dissolved oxygen like those observed in September 2000. Five-day biochemical oxygen demand ranged from 0.22 to 1.78 mg/L (mean of 0.55 mg/L), and river water takes only about 24 hours to flow through the study reach. Photosynthesis and respiration cause concentrations of dissolved oxygen in the lower Puyallup River to fluctuate as much as about 1 mg/L over a 24-hour period in August and September. Release of water from Lake Tapps for hydropower generation frequently lowered concentrations of dissolved oxygen downstream in the White River by about 1 mg/L. The effect was smaller farther downstream in the Puyallup River at river mile 5.8, but was still observable as a slight decrease in concentrations of dissolved oxygen caused by photosynthesis and respiration. The upper limit on oxygen demand caused by the scour of anoxic bed sediment and subsequent oxidation of reduced iron and manganese is less than 1 mg/L. The actual demand, if any, is probably negligible.

In August and September 2001, concentrations of dissolved oxygen in the lower Puyallup River did not fall below the water-quality standard of 8 mg/L, except at high tide when the saline water from Commencement Bay reached the monitor at river mile 2.9. The minimum concentration of dissolved oxygen (7.6 mg/L) observed at river mile 2.9 coincided with the maximum value of specific conductance. Because the dissolved-oxygen standard for marine water is 6.0 mg/L, the standard was not violated at river mile 2.9.

The concentration of dissolved oxygen at river mile 1.8 in the White River dropped below the water-quality standard on two occasions in August 2001. The minimum concentration of 7.8 mg/L occurred on August 23, and a concentration of 7.9 mg/L was recorded on August 13. Because there was some uncertainty in the monitoring record for those days, it cannot be stated with certainty that the actual concentration of dissolved oxygen in the river dropped below 8 mg/L. However, at other times when the quality of the monitoring record was good, concentrations as low as 8.2 mg/L were observed at river mile 1.8 in the White River.

INTRODUCTION

A Puyallup River Total Maximum Daily Load (TMDL) study prepared by the Washington State Department of Ecology (Ecology) (Pelletier, 1993, 1994) set a maximum load for 5-day biochemical oxygen demand (BOD_5) at 20,322 pounds per day (lb/d) and a maximum load for ammonia at 3,350 lb/d for the Puyallup River. The TMDL included a reserve capacity of 3,670 lb/d of BOD_5 and 1,200 lb/d of ammonia. In 1996, Ecology initiated a mediation process to establish a plan for managing the reserve capacity. This resulted in an agreement (Washington State Department of Ecology, 1998) that allocated the reserve capacity to various parties, including municipalities, industry, and Indian Tribes. The agreement also outlined a plan for additional monitoring to ensure that concentrations of dissolved oxygen and ammonia would remain within limits set by water-quality standards.

Additional monitoring started in August 2000 when Ecology and the Puyallup Tribe of Indians deployed water-quality monitors at river mile (RM) 2.9 and RM 5.8 in the lower Puyallup River (fig. 1) for four periods during August and September. The monitors recorded temperature, specific conductance, pH, dissolved-oxygen concentration, and water depth at 30-minute intervals. In September, concentrations of dissolved oxygen ranging from less than 1 to about 6 milligrams per liter (mg/L) were observed on several occasions. Because the water-quality standard for dissolved oxygen for the Puyallup River is 8 mg/L, Ecology issued a moratorium on allocating the reserve capacity of BOD_5 and ammonia (Washington State Department of Ecology, 2000).

In May 2001, the U.S. Geological Survey, in cooperation with Ecology and the Puyallup Tribe, began a study to evaluate the data collected in August and September 2000 and collect additional data to determine if concentrations of dissolved oxygen in the Puyallup River would fall below standards again in 2001. Water-quality monitors were deployed during August and September 2001 at three sites along reaches of the Puyallup and White Rivers extending from RM 2.9 on the Puyallup River to RM 1.8 on the White River (fig. 1). Water and bed-sediment samples also were collected and analyzed for various constituents and properties that might help with the interpretation of the dissolved-oxygen data.

Purpose and Scope

The purposes of this report are to (1) describe the results of monitoring dissolved-oxygen concentrations in the lower Puyallup and White Rivers during August and September 2000-2001, and (2) assess both the monitoring results and some of the factors affecting concentrations of dissolved oxygen in order to examine the probable cause of a dramatic decline in dissolved-oxygen concentration observed in September 2000. The report presents graphs of most of the dissolved-oxygen data, as well as temperature, pH, and specific conductance as needed to help interpret the dissolved-oxygen data. A table with statistical summaries of all monitoring data collected in August and September 2001 is included.

Description of the Lower Puyallup and White Rivers

The lower Puyallup River Valley is a relatively flat floodplain. Streambed altitudes in the study area range from about 9 feet below sea level at RM 2.9 on the Puyallup River to about 25 feet above sea level at RM 1.8 on the White River (Prych, 1988). The lower Puyallup River is a salt-wedge estuary with deeper marine water overlain by a layer of fresh water. The salt wedge generally extends less than 2.5 miles upstream from the river mouth (Ebbert and others, 1987); however, the monitoring data indicate it sometimes reaches RM 2.9.

Gravel, cobbles, and boulders armor the bottom of the monitored reaches of the Puyallup and White Rivers. Median particle sizes appear to decrease in the downstream direction, and material beneath the armor layer contains approximately 20 percent sand (Prych, 1988).

Mean monthly flows in the Puyallup River at the USGS streamgaging station (station 1210500 at RM 6.6) during August and September were 2,069 and 1,665 cubic feet per second (ft^3/s) for the period 1943 through 2000. Although the period of record for this station began in 1914, the record prior to 1943 does not reflect the present flow conditions because flood flows in the White River have been regulated since 1943 (Kresch and Prych, 1989).

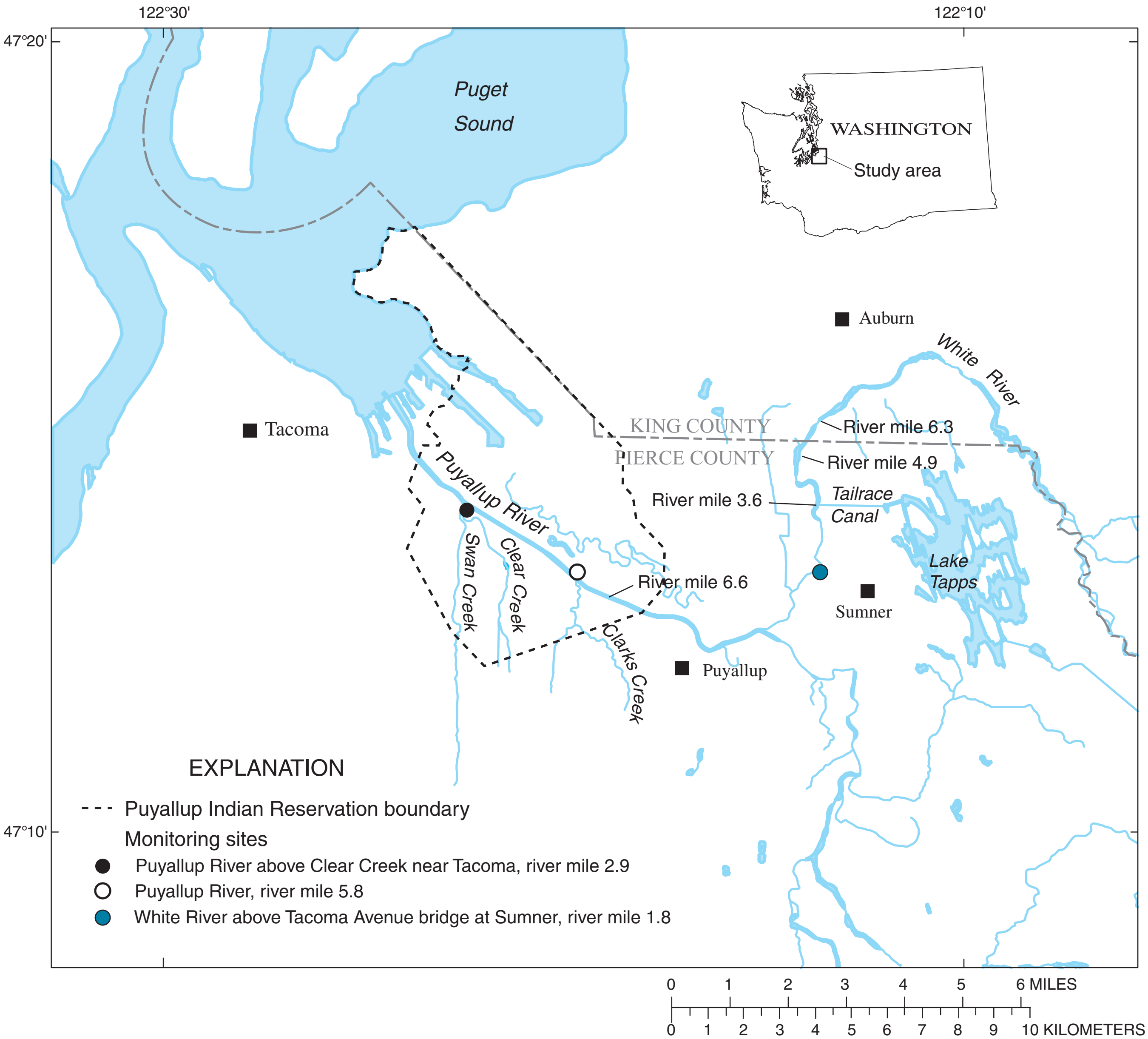

Figure 1. Location of the study area and water-quality monitoring sites on the lower Puyallup and White Rivers, Washington, August and September 2000-2001.

During summer, operation of the Lake Tapps hydropower facility by Puget Sound Energy can have a substantial effect on flows in the lower White and Puyallup Rivers. Water is diverted from the White River at RM 24.3 into Lake Tapps, and water released from the lake to produce power is returned to the White River at RM 3.6. Power is generated to meet demand during peak usage, and the cycle of releasing and then holding water often causes discharge in the Puyallup River to increase by a factor of two and then to fall back to base levels in about 12 hours. The capacities of the diversion channel and the outlet from the hydropower facility are each about 2,000 ft^3/s (Prych, 1988).

Water in the Puyallup and White Rivers is usually turbid during summer because fine sediment derived from glacial melting on Mount Rainier is transported downstream. Visibility during this study was always less than about 4 inches below the water surface, and it was often less than 1 inch. Poor light penetration reduces biological productivity (Welch, 1992), which probably moderates 24-hour variations in concentrations of dissolved oxygen in the lower Puyallup and White Rivers caused by photosynthesis and respiration. Diel variations of about 1 mg/L in the Puyallup River were measured by Ecology (values ranged from 10.1 to 11.2 mg/L) in the Puyallup River at RM 5.7 during various times of the day from September 18 through October 5, 1990 (Pelletier, 1993).

Acknowledgments

This study was conducted in close cooperation with individuals from the Washington State Department of Ecology and the Puyallup Tribe of Indians, and the author gratefully acknowledges their assistance. Jeannette Barreca, Ecology, and Char Naylor, Puyallup Tribe, were partners in designing and executing the study. Robert Plotnikoff, Ecology, coordinated schedules and laboratory support for water-quality sampling conducted by Ecology and the USGS. Bill Ward, Ecology, provided training, technical advice, and assistance with sampling and servicing the water-quality monitors. Anise Ahmed, Ecology, provided technical advice and assisted with sampling and servicing of the monitors. Assistance with servicing the monitors also was provided by Mary Brown and Elsie Raymond, Puyallup Tribe, and Christina Ricci and Chad Wiseman, Ecology. Jory Oppenheimer, HDR Engineering, Inc., provided data and other technical information used in this report. Richard Wagner, USGS, provided technical advice and helped process the monitoring data. Karen Payne and Greg Justin, USGS, provided assistance with sampling and servicing the monitors. Finally, the author would like to thank Ecology and the Puyallup Tribe for the use of their water-quality monitors for this study.

DATA COLLECTION

The assessment of dissolved-oxygen concentrations in the lower Puyallup and White Rivers used (1) data collected by Ecology and the Puyallup Tribe during August and September 2000, (2) data collected by the USGS, Ecology, and the Puyallup Tribe during August and September 2001, and (3) data collected by HDR Engineering, Inc., for Puget Sound Energy during August, September, and October 2001 (HDR Engineering Inc., 2002), which are briefly summarized here. Streamflow data used in this report are from USGS streamgaging stations on the Puyallup and White Rivers and on the tailrace canal from Lake Tapps (Kimbrough and others, 2001; U.S. Geological Survey, 2001).

Locations where water-quality and streamflow data were collected are listed in table 1, and the data are available online at URL, http://www.ecy.wa.gov/programs/eap/wrias/tmdl/puyallup_hydrolab/index.html. The streamflow data and the water-quality monitoring data for August and September 2001 also are stored in the USGS National Water Information System (NWIS) database. Daily streamflow data are available online at URL, http://water.usgs.gov/wa/nwis/sw.

August and September 2000

Ecology and the Puyallup Tribe used Hydrolab Datasonde™ 4a water-quality monitors to measure and record water temperature, specific conductance, pH, and dissolved-oxygen concentration, and water depth at 30-minute intervals in the Puyallup River at RM 2.9 and RM 5.8 (fig. 1, table 1). A single monitor was deployed four times (August 8-10, August 18-24, September 11-22, and September 22-28) at each location (Washington State Department of Ecology, 2001a). Each monitor was deployed on the riverbed near the center of the channel by placing it inside a plastic pipe attached to a concrete anchor. The pipe and the enclosed monitor were placed parallel to the direction of flow with the sensors, which were approximately 6 inches above the riverbed, facing downstream (fig. 2).

Table 1. Locations on the lower Puyallup and White Rivers where water-quality and streamflow data were collected during August and September, 2000-2001

[**Abbreviations:** USGS, U.S. Geological Survey, Ecology, Washington State Department of Ecology; Puy Tribe, Puyallup Tribe of Indians; HDR, HDR Engineering, Inc.; WA, Washington; NWIS, National Water Information System]

USGS station identification No.	Ecology station identification No.	USGS station name	Ecology station name	River mile	Data collected		
					Type	Years	By whom
none	10C095	none	White River at R. Street	8.0	water chemistry	2000, 01	Ecology
12100496	none	White River near Auburn, WA	none	6.3	streamflow	2000, 01	USGS
none	10C085	none	White River near Sumner	4.9	water-quality monitoring	2001	HDR
					water chemistry	2001	HDR
12101100	none	Lake Tapps Diversion at Dieringer, WA[1]	Lake Tapps Tailrace Canal	discharges to White River at river mile 3.6	streamflow, monitoring, and water chemistry	2001 (streamflow also 2000)	USGS, HDR
12101104	none	White River above Tacoma Avenue Bridge at Sumner, WA	White River at River Mile 1.8	1.8	water-quality monitoring and water chemistry	2001	Ecology, Puy Tribe, USGS
none	10A070	none	Puyallup River at Meridian Street	8.3	water chemistry	2000, 01	Ecology
12101500		Puyallup River at Puyallup, WA		6.6	streamflow	2000, 01	USGS
none	10A050	Puyallup River at River Mile 5.8[2]	Puyallup River at Puyallup	5.8	water-quality monitoring	2000, 01	Ecology, Puy Tribe, USGS[3]
					water chemistry	2001	
12102102	none	Puyallup River above Clear Creek near Tacoma, WA	Puyallup River at River Mile 2.9	2.9	water-quality monitoring	2000, 01	Ecology, Puy Tribe, USGS[3]
					water chemistry	2001	

[1] Referred to as the Lake Tapps tailrace canal in this report.

[2] Monitoring data collected in August and September 2001 are stored under Station 12101500 in USGS NWIS data base.

[3] USGS 2001 only.

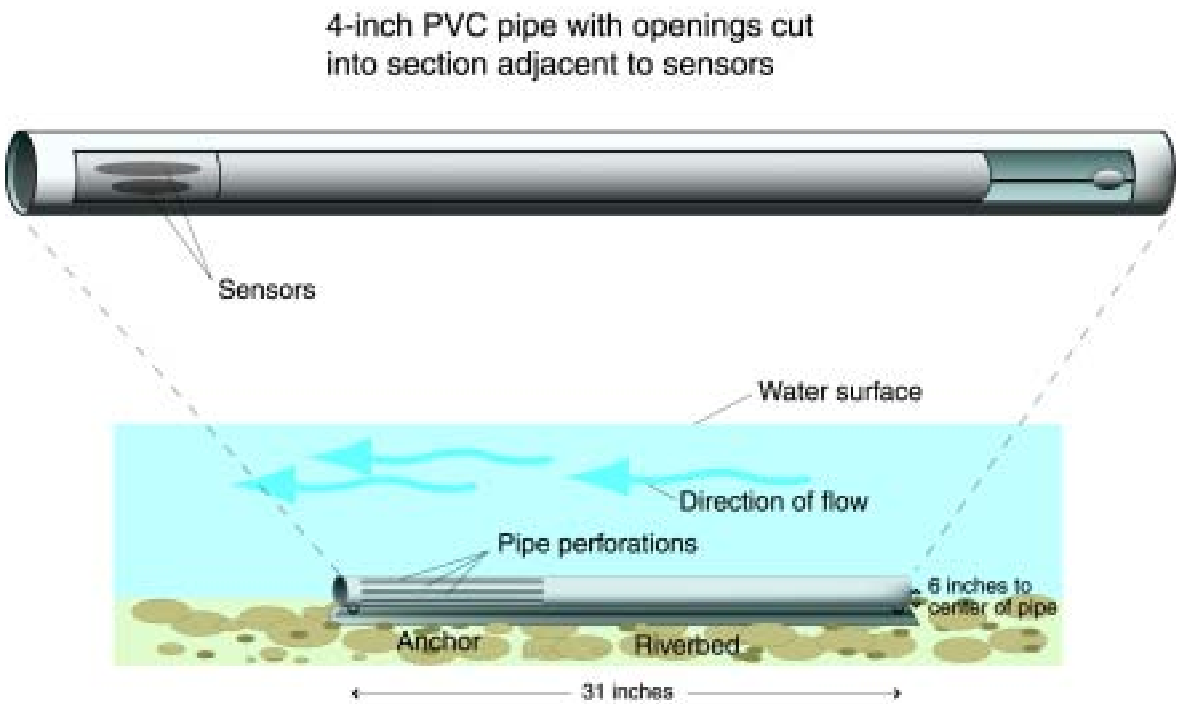

Figure 2. Placement of water-quality monitors in the lower Puyallup River, Washington, August and September 2000.

The monitors were serviced and calibrated according to the manufacturer's specifications prior to each deployment, and duplicate measurements of water temperature, specific conductance, pH, and dissolved-oxygen concentration were made at the beginning and end of each deployment. Duplicate measurements were made with separate instruments, except for the concentration of dissolved oxygen, which was determined using the modified Winkler method (American Public Health Association and others, 1998). The results of the duplicate measurements were published online along with the monitoring data (Washington State Department of Ecology, 2001a).

August and September 2001

The USGS used Hydrolab Datasonde™ 4 and 4a water-quality monitors to measure and record water temperature, specific conductance, pH, and dissolved-oxygen concentration at 30-minute intervals in the Puyallup River at RM 2.9 and 5.8 and in the White River at RM 1.8 (fig. 1, table 1). Two monitors, approximately 20 feet apart, were installed in the Puyallup River at RM 5.8 to provide a duplicate record to help with data validation. For continuity with past practices, data from the monitors located in the Puyallup River at RM 5.8 are stored in the USGS NWIS database under USGS streamgaging station 12101500, Puyallup River at Puyallup, which is the USGS streamgaging station located at RM 6.6. There are no tributaries to the Puyallup River between RM 6.6 and RM 5.8. Clarks Creek, which discharges to the Puyallup River at RM 5.8 on the opposite side of the river from the monitors, did not affect their readings.

Because the monitors were serviced and calibrated in the field, they were deployed almost continuously during August and September. Monitors were deployed in 20-foot-long sections of plastic pipe attached to either trees or boulders on the riverbank (fig. 3). The submerged parts of the pipes were perforated to expose the sensors, which were perpendicular to the direction of flow. The oxygen sensors were 1 to 2 feet above the riverbed.

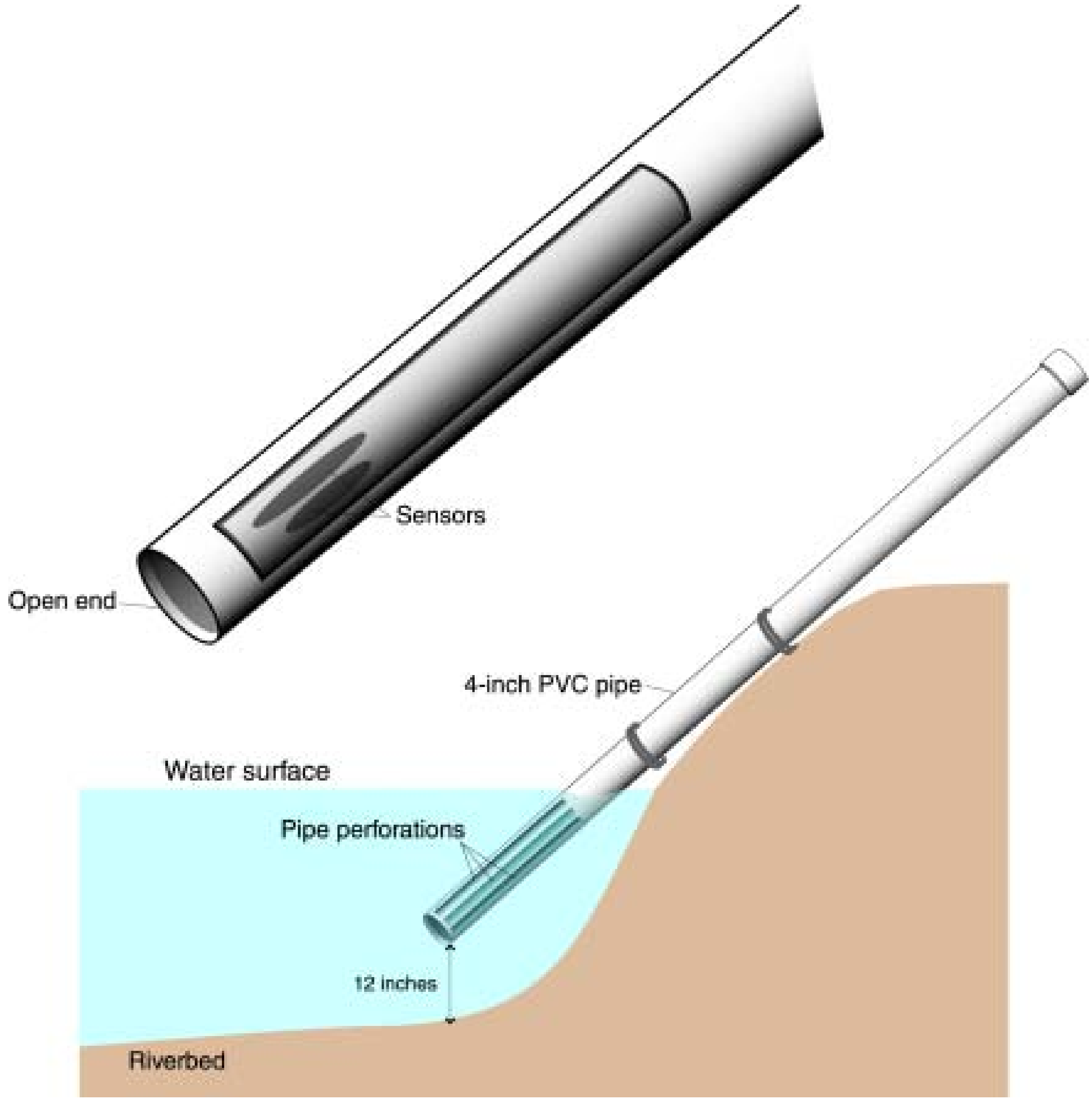

Figure 3. Placement of water-quality monitors in the lower Puyallup and White Rivers, Washington, August and September 2001.

The water-quality monitors were serviced and calibrated, if needed, two times per week during most of the 2-month deployment period. The protocol used for servicing and calibration (Appendix A) generally took about 1 hour and was based on the guidelines specified by Wagner and others (2000). The only modifications of their guidelines were the calibration of the dissolved-oxygen sensor in a water bath, instead of in water-saturated air, and use of the modified Winkler method, instead of another instrument, for making duplicate measurements of dissolved-oxygen concentrations during servicing.

Monitoring data for August and September 2001 were corrected and rated using methods based on guidelines recommended by Wagner and others (2000). Their guidelines for correcting and rating dissolved-oxygen data entail an analysis to determine how sensor fouling and instrument drift affect differences between concentrations of dissolved oxygen in the stream and recorded concentrations. In this study, corrections applied to the dissolved-oxygen monitoring data, and the subsequent rating of those data, were determined by differences between recorded concentrations and concentrations determined by Winkler. If, for example, there was a constant difference between the Winkler titration data and the monitoring data, a uniform correction equal to that difference was applied to the monitoring data. Although the ratings (fig. 4) are based largely on the amount of correction applied to the data, additional consideration was given to factors such as instrument noise. Even though the corrected record is considered to be more representative of concentrations in the stream, the rating for that record was downgraded according to the amount of correction applied (fig. 4).

Water samples were collected in August and September to provide data that might be needed to help interpret the dissolved-oxygen data. Ecology added chlorophyll A, biochemical oxygen demand, and total iron and manganese concentration to the list of constituents and properties (Appendix B) that they analyze for in ambient monitoring samples collected from the Puyallup River at RM 8.3 (Washington State Department of Ecology, 2001b). Ecology also increased the frequency of sampling and collected samples at RM 5.8 in addition to those collected at RM 8.3. Samples were collected four times (August 22, August 27, September 10, and September 19) at both sites. Water samples also were collected from the Puyallup River at RM 2.9 and 5.8 and from the White River at RM 1.8 by the USGS with help from the Puyallup Tribe and Ecology. These samples, which were collected September 4-5 and September 17-18, were analyzed for the constituents and properties listed in Appendix B. The Washington State Department of Ecology Manchester Environmental Laboratory (Manchester Laboratory) in Port Orchard, Wash., analyzed all samples. Information about laboratory performance and quality can be obtained online (Washington State Department of Ecology, 2001c).

Bed-sediment samples were collected on August 22 by the USGS and the Puyallup Tribe at six locations extending from RM 5.8 in the Puyallup River to about RM 1 in the White River. The Manchester Laboratory analyzed these samples for total iron and manganese concentrations. During bed-sediment sampling, cross sections were probed with a rod to make a rough determination of the composition of the riverbed. Except for near-bank areas, the bed was armored with boulders and cobbles, a finding that agrees with Prych (1988).

To assess variability laterally and with depth at the monitoring sites, cross-section measurements of temperature, specific conductance, pH, and concentration of dissolved oxygen were made in the Puyallup River at RM 2.9 (on August 22, September 4, and September 17) and at RM 5.8 (on September 4), and in the White River at RM 1.8 (on September 5). The results of these measurements are presented in tables 3, 4, and 5 (at back of report).

HDR Engineering, Inc., monitored temperature, specific conductance, pH, and concentrations of dissolved oxygen in the Lake Tapps tailrace canal and in the White River at RM 4.9 (fig. 1, table 1). They also collected water samples at those locations and recorded vertical profiles of temperature, specific conductance, pH, and concentrations of dissolved oxygen in the powerhouse intake canal of Lake Tapps. See Appendix C for a complete listing of data collected by HDR Engineering Inc.

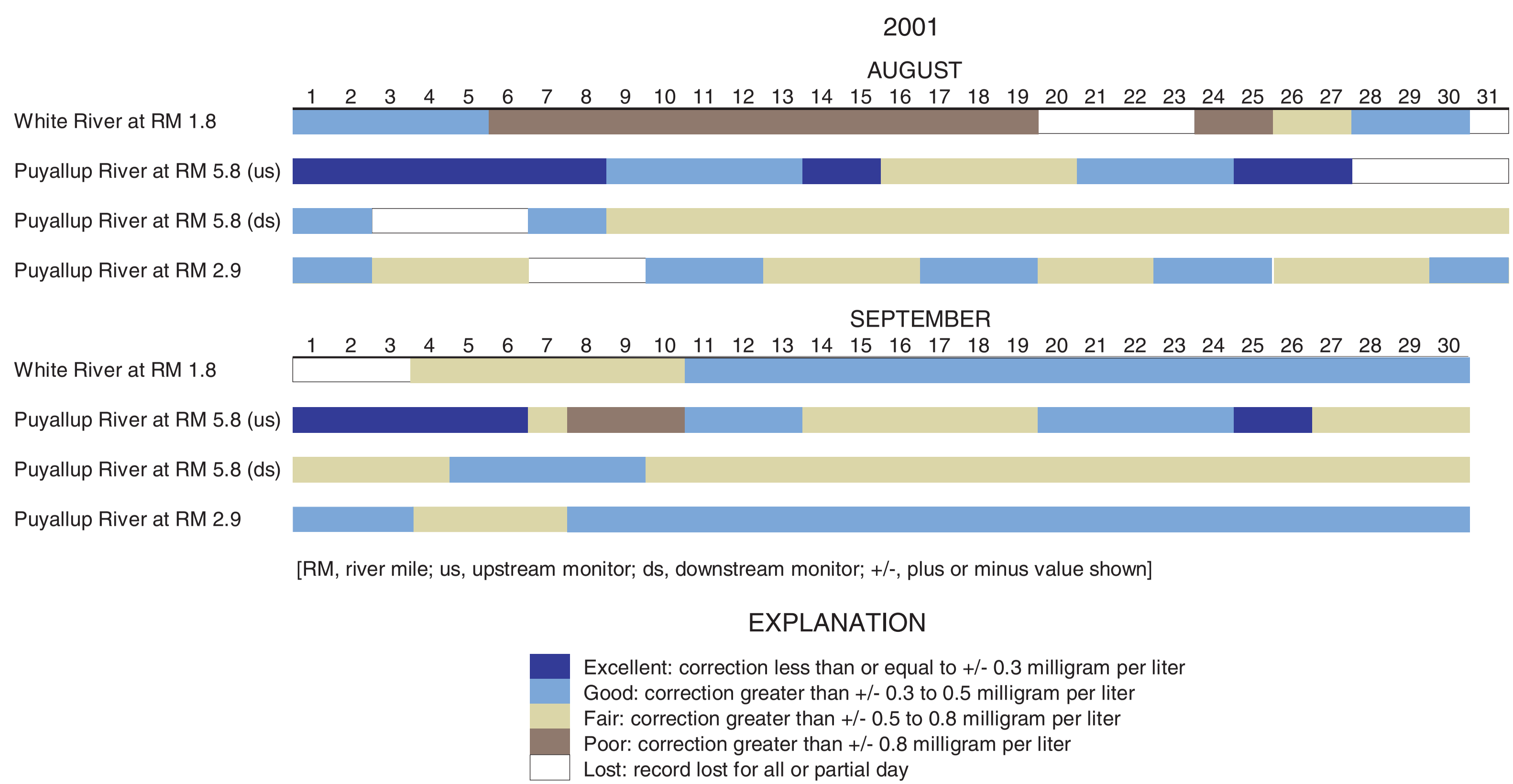

Figure 4. Ratings of dissolved-oxygen monitoring records for the Puyallup and White Rivers, August and September 2001.

CONCENTRATIONS OF DISSOLVED OXYGEN, AUGUST AND SEPTEMBER 2000, 2001

Dissolved-oxygen concentrations were monitored by Ecology and the Puyallup Tribe in 2000 as part of a water-quality monitoring program. The USGS, along with Ecology and the Tribe, monitored concentrations in 2001 after concentrations in September 2000 dropped several times below the limit set by water-quality standards.

August and September 2000

In August 2000, concentrations of dissolved oxygen in the Puyallup River at RM 5.8 ranged from 8.7 to 10.6 mg/L. This concentration range was consistent with expectations, based on concentrations ranging from 9.6 to 11.4 mg/L in samples collected during the months of August and September 1995-2000 by Ecology's ambient monitoring program at RM 8.3 (Washington State Department of Ecology, 2001b). Variations in concentrations at RM 2.9 were similar to those at RM 5.8, except for occasional downward spikes in concentration (fig. 5), some of which occurred when the tide was high enough to force saline water upstream to RM 2.9. For a given temperature and barometric pressure, saturated concentrations of dissolved oxygen are lower in saline water because the solubility of oxygen in water decreases with increasing salinity. Variations in discharge from a base level of about 1,700 ft^3/s to about 4,000 ft^3/s (fig. 5) were caused by releases of water from Lake Tapps.

In September 2000, observed concentrations of dissolved oxygen fell far below the water-quality standard of 8 mg/L on several occasions at both RM 5.8 and RM 2.9 (figs. 6 and 7). In a preliminary analysis of the data collected September 11-22 (Jeannette Barreca, Washington State Department of Ecology, written commun., May 2001), inundation of the dissolved-oxygen sensor with sediment was listed as one of several possible causes of the extremely low concentrations of dissolved oxygen observed at RM 2.9 (fig. 6), but environmental factors were not ruled out.

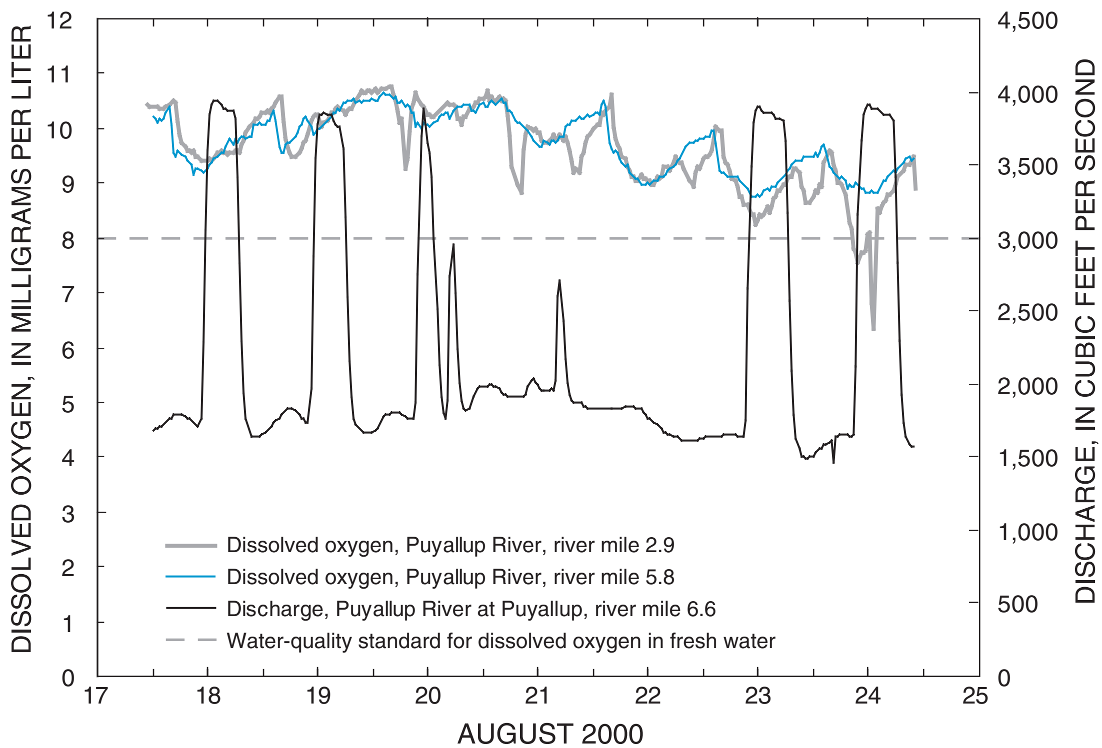

Figure 5. Concentrations of dissolved oxygen and discharge in the Puyallup River, Washington, August 17-25, 2000.

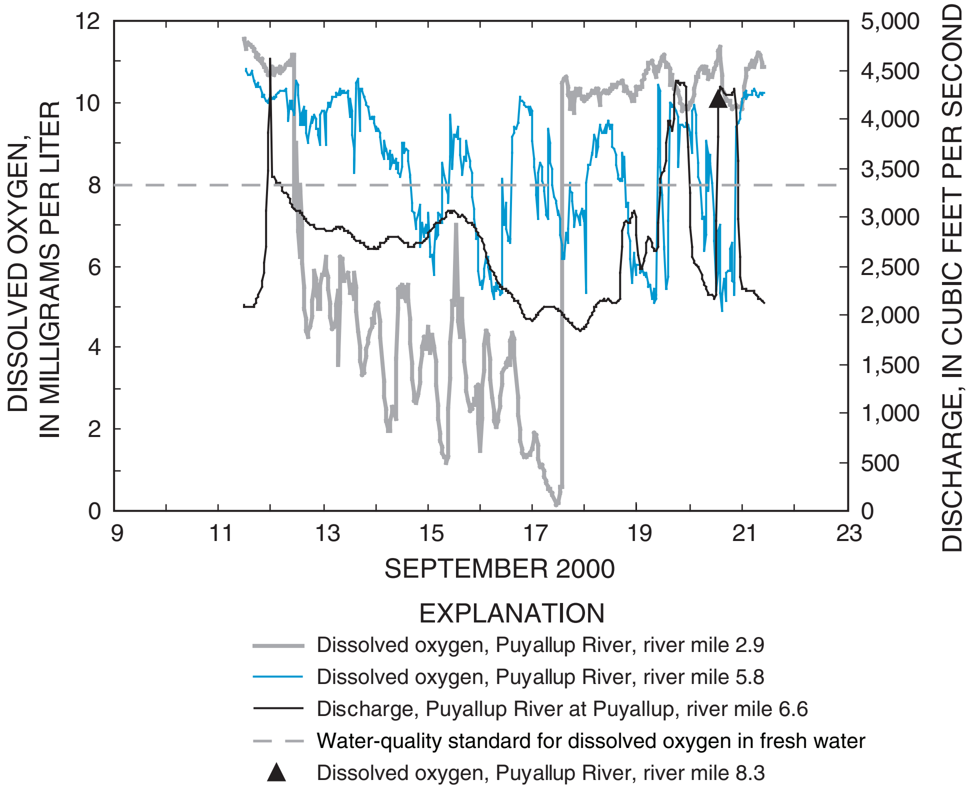

Figure 6. Concentrations of dissolved oxygen and discharge in the Puyallup River, Washington, September 11-22, 2000.

Data collected September 22-28 (fig. 7) suggested that large fluctuations in observed concentrations of dissolved oxygen might be linked to variations in streamflow caused by release of water from Lake Tapps. From September 22 until mid-day September 25, little water was released from Lake Tapps, flow in the Puyallup River was relatively steady, and concentrations of dissolved oxygen ranged from about 10 to 11.5 mg/L at RM 5.8. Steep declines in concentrations of dissolved oxygen did not occur until September 25 (fig. 7), with the resumption of routine releases of water from Lake Tapps. Upstream movement of the saline water to the monitor caused the three downward spikes in concentration occurring on September 24 and before noon on September 25 at RM 2.9 (fig. 7).

August and September 2001

Because two monitors were installed in the Puyallup River at RM 5.8, additional information was available to assess the quality of the dissolved-oxygen record, and gaps in the record of one instrument were filled by record from the other (fig. 8). Overall, the record produced by the upstream monitor was rated higher than that of the downstream monitor (fig. 4). Minimum concentrations of dissolved oxygen of 8.4 mg/L for the upstream monitor and 8.5 mg/L for the downstream monitor were in close agreement (table 2). Agreement between maximum concentrations, which were 10.7 mg/L and 11.2 mg/L for the upstream and downstream monitors, was not as good.

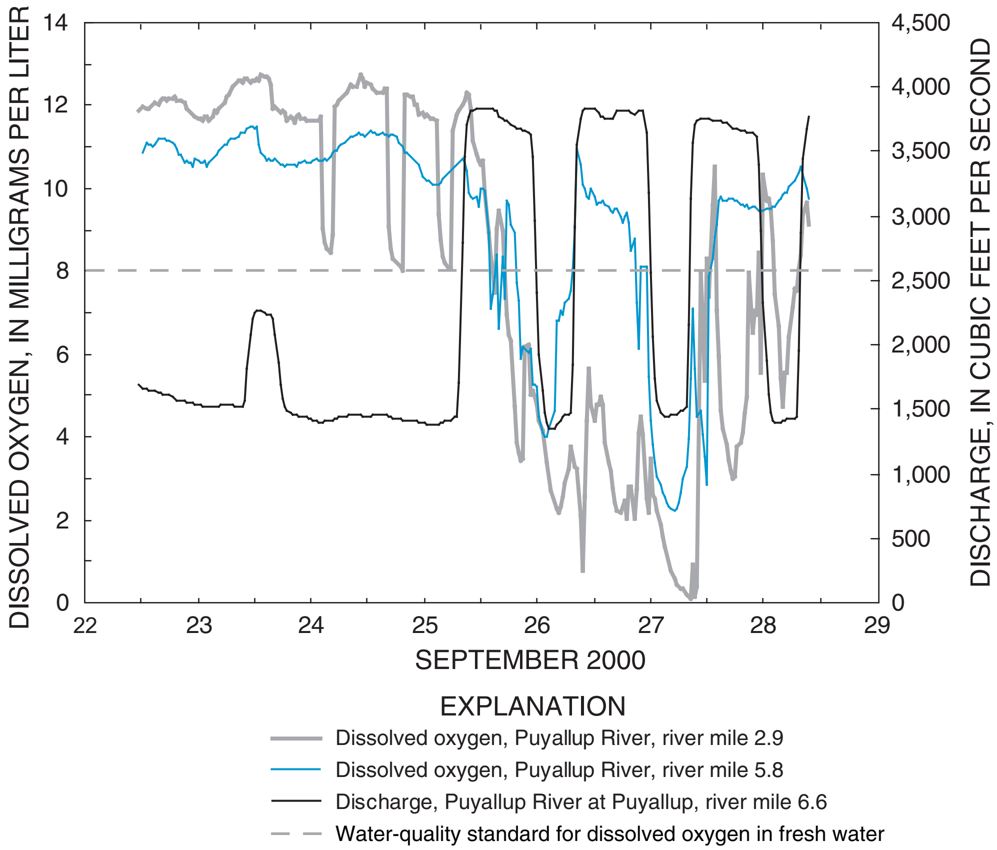

Figure 7. Concentrations of dissolved oxygen and discharge in the Puyallup River, Washington, September 22-28, 2000.

Table 2. Maximum and minimum concentrations of dissolved oxygen and values of specific conductance, temperature and pH in the lower White and Puyallup Rivers, August and September 2001

[**Abbreviations:** us, upstream monitor; ds, downstream monitor; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 ºC; ºC, degrees Celsius]

		White River at river mile 1.8	Puyallup River at river mile 5.8 (us)	Puyallup River at river mile 5.8 (ds)	Puyallup River at river mile 2.9
Dissolved oxygen (mg/L)	Maximum	11.2	10.7	11.2	10.5
	Minimum	7.8	8.4	8.5	7.6
Specific conductance (µS/cm)	Maximum	98	100	102	36,500
	Minimum	59	45	47	57
Temperature (ºC)	Maximum	20.4	17.1	17.8	17.4
	Minimum	9.7	9.6	10.0	10.1
pH (units)	Maximum	7.6	7.3	7.4	7.8
	Minimum	6.8	6.9	7.0	7.1

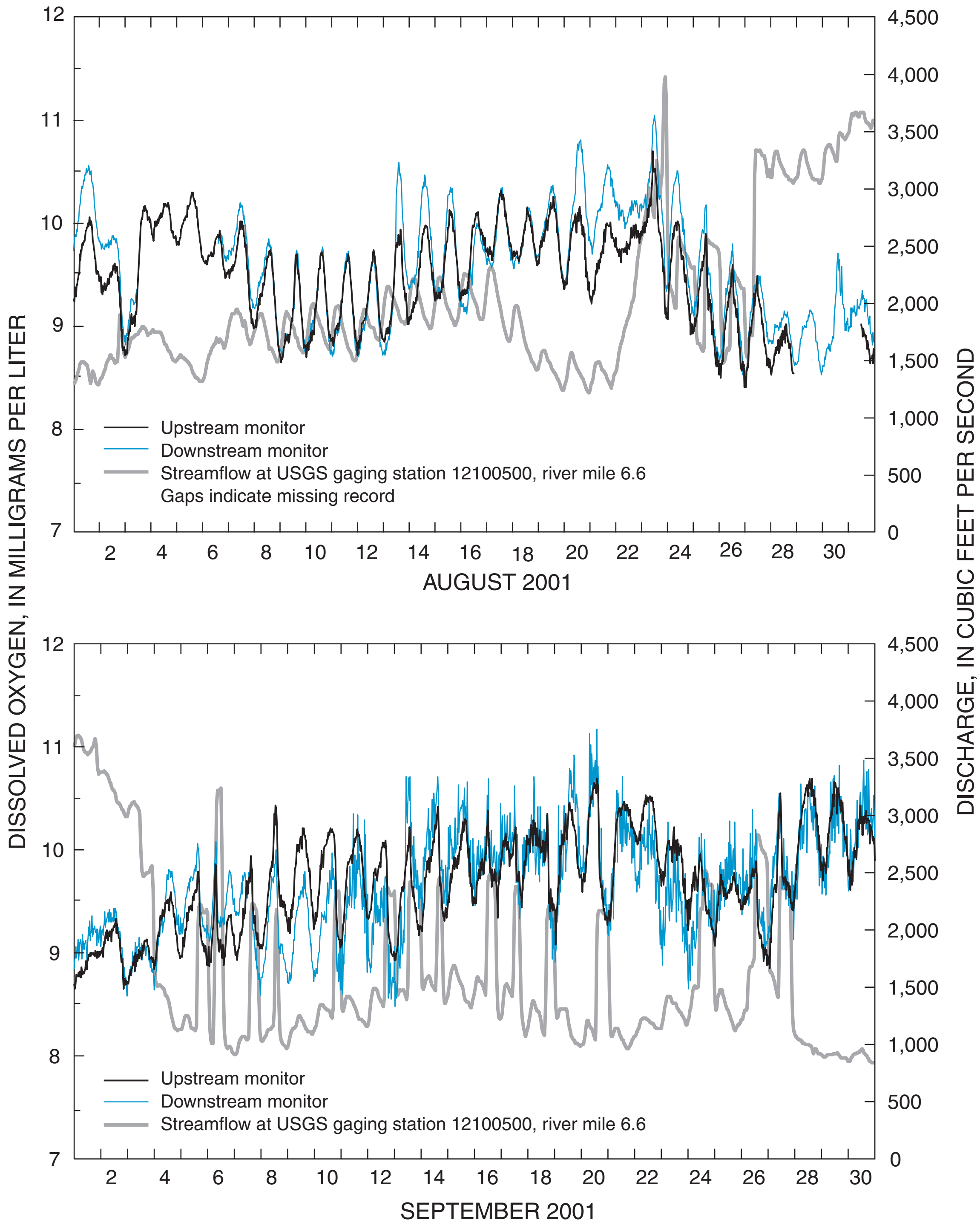

Figure 8. Concentrations of dissolved oxygen and discharge in the Puyallup River at river mile 5.8, August and September 2001.

As mentioned in the discussion of the August and September 2000 data, the upstream movement of saline water during high tide affects the concentration of dissolved oxygen in the Puyallup River at RM 2.9. Because of this effect, the minimum concentration of dissolved oxygen (7.6 mg/L) coincided with the maximum value of specific conductance (fig. 9). Because the dissolved-oxygen standard for marine water is 6.0 mg/L (Washington State Administrative Code, 1997), the standard was not violated at RM 2.9. When saline water was not present at RM 2.9, concentrations of dissolved oxygen ranged from about 8.5 to 10.5 mg/L (fig. 9).

The concentration of dissolved oxygen in the White River at RM 1.8 dropped below the water-quality standard of 8 mg/L on two occasions in August 2001 (fig. 10). The minimum concentration of 7.8 mg/L occurred on August 23rd, and a concentration of 7.9 mg/L was recorded on August 13th. Because the record for both of these days was rated as poor (fig. 4), it cannot be stated with certainty that the actual concentration of dissolved oxygen in the river dropped below 8 mg/L. It can, however, be said with confidence that the concentration of dissolved oxygen in the White River at RM 1.8 approaches 8 mg/L because a value of 8.2 mg/L was recorded on September 23rd (fig. 10), which is a day that the record was rated as good (fig. 4).

ANALYSIS OF FACTORS AFFECTING CONCENTRATIONS OF DISSOLVED OXYGEN

In addition to monitoring, the types of samples collected in August and September 2001 were based largely on the need for data to help determine the cause of the low concentrations of dissolved oxygen observed in September 2000. Three mechanisms (not including sensor fouling) were considered as possible causes of the low concentrations of dissolved oxygen (Washington State Department of Ecology, 2001d), and all three were related to the schedule of retention and release of water from Lake Tapps. The first mechanism was biochemical oxygen demand in the White and Puyallup Rivers caused by the release of water that may have accumulated algal biomass and organic carbon during routine maintenance of the discharge flume September 8-14, 2000. Water was not released from the lake during flume maintenance, and release of water was infrequent until September 25 (figs. 6 and 7). Algal biomass and organic carbon may have accumulated because there was less flushing of lake water while it was impounded. The second mechanism was the mixing of released lake water, which may have become depleted in dissolved oxygen because of increased stratification of the lake during flume maintenance, with river water. The third mechanism was demand for oxygen caused by the scour of anoxic bed sediments containing reduced iron and manganese. Scour of bed sediments might occur when water released from Lake Tapps increases discharges and flow velocities in the White and Puyallup Rivers. Because water is not released during the maintenance period, bed sediments would remain undisturbed, allowing the thickness of the anoxic layer to increase. Scour of anoxic bed sediments during releases after the maintenance period would expose large amounts of reduced iron and manganese compounds, and their rapid oxidation would exert an unusually high demand for oxygen.

Because any changes in concentrations of dissolved oxygen in the Puyallup River caused by retention and release of water from Lake Tapps would be superimposed on 24-hour variations in concentrations caused by photosynthesis and respiration, the effects of photosynthesis and respiration are described first.

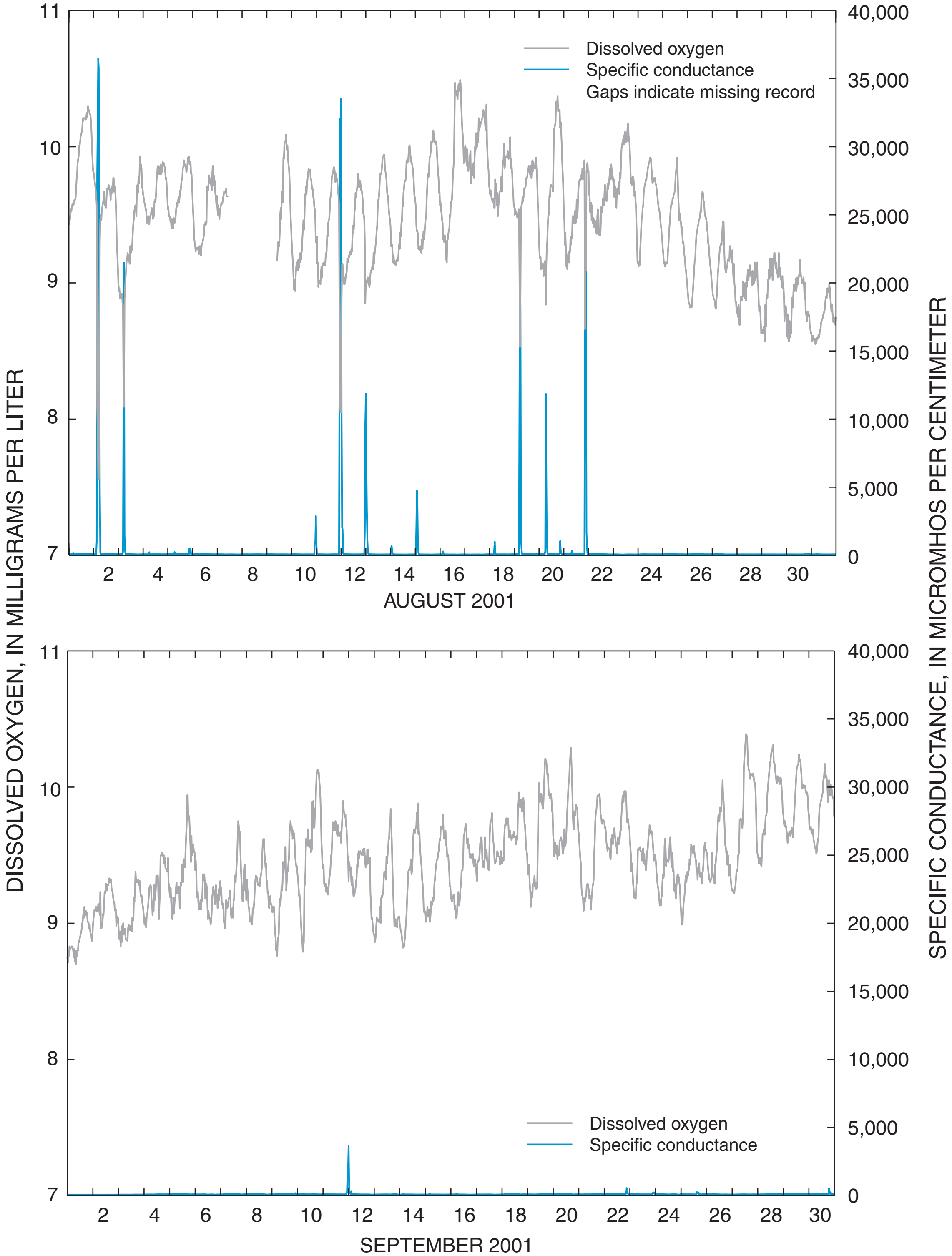

Figure 9. Concentrations of dissolved oxygen and specific conductance in the Puyallup River at river mile 2.9, August and September 2001.

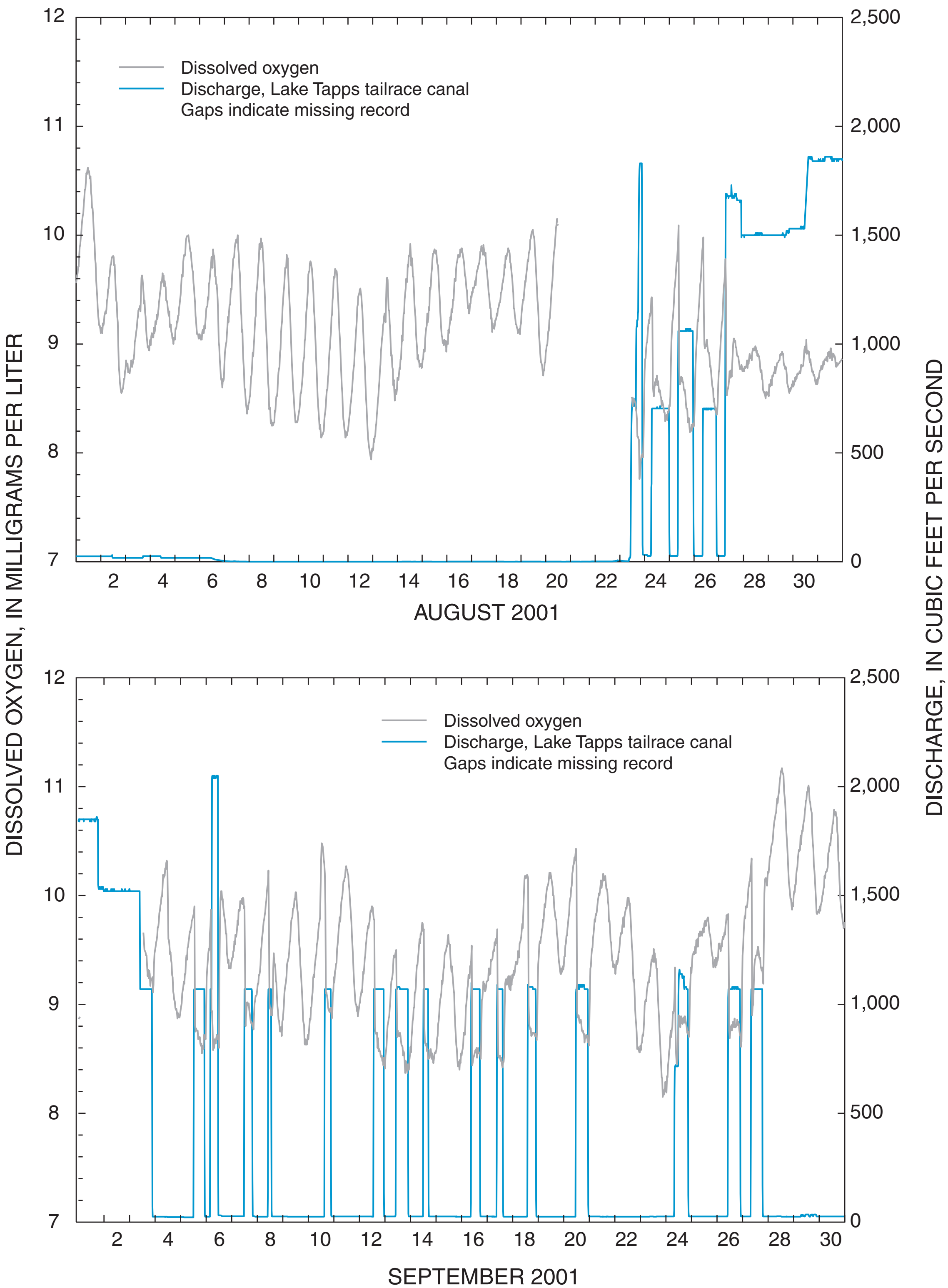

Figure 10. Concentrations of dissolved oxygen in the White River at river mile 1.8 and discharge in the Lake Tapps tailrace canal, August and September 2001.

Photosynthesis and Respiration

From August 1-23, 2001, 24-hour variations in concentrations of dissolved oxygen in the Puyallup and White Rivers (figs. 8, 9, and 10) were largely in response to photosynthesis and respiration, because no water was released from Lake Tapps during that time. Although variations in discharge in the Puyallup River caused by changes in the rate of glacial melting over a 24-hour cycle may have some influence on concentrations of dissolved oxygen (fig. 8), the simultaneous variations in pH and concentrations of dissolved oxygen (fig. 11) are indicative of the photosynthetic activity of aquatic biota (Pogue and Anderson, 1995).

From August 1-23, 2001, concentrations of dissolved oxygen in the White River at RM 1.8 varied over a range of about 1 to 2 mg/L in 24 hours (fig. 10). During the same period, concentrations of dissolved oxygen in the lower Puyallup River varied over a range of about 1 mg/L in 24 hours (figs. 8 and 9). Variations in concentrations of about 1 mg/L over a 24-hour period are in general agreement with the concentration range of 10.1 to 11.2 mg/L measured by Ecology in the Puyallup River at RM 5.7 during various times of the day from September 18 through October 5, 1990 (Pelletier, 1993).

Biochemical Oxygen Demand

Five-day biochemical oxygen demand (BOD_5) in 10 water samples collected from the lower Puyallup and White Rivers during August and September 2001 ranged from 0.22 to 1.78 mg/L; the mean value was 0.55 mg/L. Samples were collected over a range of flow regimes including rising stage caused by release of water from Lake Tapps. The maximum BOD_5 of 1.78 mg/L was in a sample collected when river discharge was increasing rapidly during a rainstorm on August 22nd. The range of BOD_5 in all other samples was from 0.22 to 0.59 mg/L, indicating that release of water from Lake Tapps had little effect on biochemical oxygen demand in the lower White and Puyallup Rivers. Even if release of water from Lake Tapps were to cause a slight increase in biochemical oxygen demand, time is short for it to exert much effect because water released from the lake reaches the mouth of the Puyallup River in about 24 hours (Pelletier, 1993).

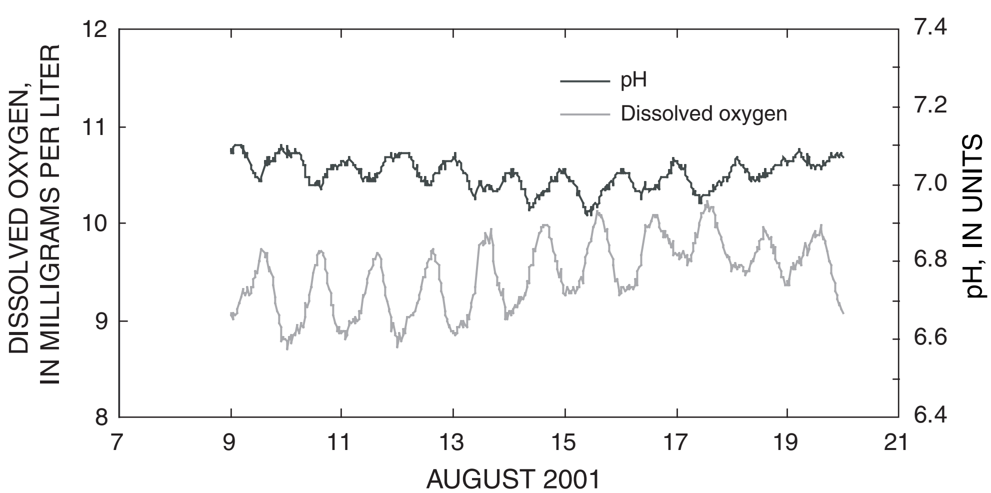

Figure 11. Variations in pH and concentrations of dissolved oxygen in the Puyallup River at river mile 5.8, August 9-19, 2001.

Mixing of River Water With Water Released From Lake Tapps

In August and September 2001, sags in concentrations of dissolved oxygen in the White River coinciding with release of water from Lake Tapps (fig. 10) occurred when concentrations of dissolved oxygen in water released from Lake Tapps were lower than concentrations in the White River. On average, concentrations of dissolved oxygen in the Lake Tapps tailrace canal, which discharges to the White River at RM 3.6, were less than concentrations in the White River at RM 4.9 (HDR Engineering Inc., 2002). HDR data indicate that from August 22 to October 16, 2001, concentrations of dissolved oxygen in the tailrace canal ranged from 6.2 to 13.4 mg/L (mean 9.4 mg/L), compared with concentrations ranging from 8.6 to 12.3 mg/L (mean 10.1 mg/L) in the White River at RM 4.9.

Release of water from Lake Tapps frequently lowered concentrations of dissolved oxygen in the White River at RM 1.8 by about 1 mg/L (fig. 12). Although smaller, sags in concentrations of dissolved oxygen associated with release of water from Lake Tapps also were observed farther downstream in the Puyallup River at RM 5.8 (fig. 12).

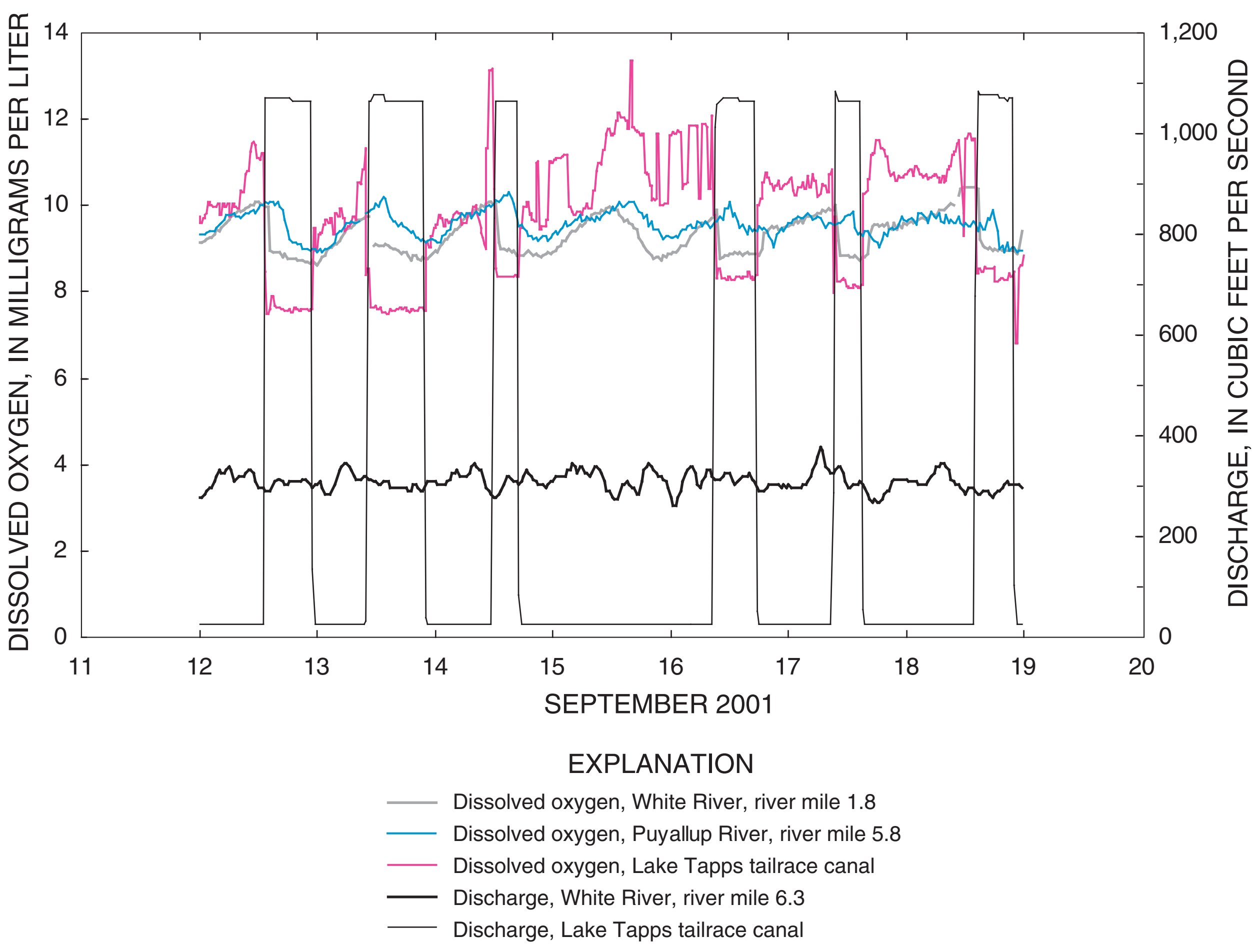

Figure 12. Discharges in the Lake Tapps tailrace canal and in the White River at river mile 6.3, with corresponding concentrations of dissolved oxygen in the Lake Tapps tailrace canal, the White River at river mile 1.8, and the Puyallup River at river mile 5.8, September 12-18, 2001.

Scour of Bed Sediment and Oxidation of Reduced Iron and Manganese

Two methods, both of which are based on highly simplified representations of sediment transport in the lower Puyallup River, were used to compute an upper limit for oxygen demand caused by the scour of anoxic bed sediment and the oxidation of associated reduced iron and manganese. In the first method, demand for oxygen was computed by assuming that all iron and manganese dissolved and suspended in water had been converted from reduced to oxidized forms within the study reach (table 6, at back of report). In the second method, oxygen demand was computed by assuming that anoxic bed sediment was the sole source of suspended solids in the river and that all iron in the bed sediment was oxidized upon suspension (table 7, at back of report). For both sets of computations, it was assumed that iron is oxidized from the +2 to the +3 oxidation state, and for the first set of computations, it was assumed that manganese is oxidized from the +2 to the +4 oxidation state. Manganese was not used in the second set of computations (table 7) because its concentrations were small compared with those of iron. Also, the assumption that manganese is oxidized from the +2 to the +4 oxidation state is not entirely correct because it has three possible valence states (+2, +3, and +4) in aquatic systems and can form a wide variety of mixed-valence states (Hem, 1985).

The results from both computational methods were similar, in that they indicated an upper limit for oxygen demand of less than 1 mg/L. This represents an extreme upper limit because the highly simplified representation of sediment transport does not agree with data (Ebbert and others, 1987) and a modeling study (Sikonia, 1990) showing that most of the fine suspended sediment in the lower White and Puyallup Rivers is transported from upstream and not derived solely within the study reach. Data were not available to do a more comprehensive evaluation of this mechanism.

PROBABLE CAUSE OF LOW CONCENTRATIONS OF DISSOLVED OXYGEN OBSERVED SEPTEMBER 2000

An initial examination of data collected in August and September 2001 and observations made while collecting those data were helpful in determining that inundation of the sensors with sediment was the most likely cause of the steep declines in concentrations of dissolved oxygen observed in September 2000. Initial examination of the 2001 data indicated that variations in concentrations of dissolved oxygen were consistent with most available data, excluding those collected in September 2000, and with a general understanding of controlling processes, as previously described. Concentrations in the Puyallup River at RM 5.8 did not drop below 8 mg/L, and they usually remained above 8 mg/L in the Puyallup River at RM 2.9.

Field observations became important when the monitor at RM 2.9, which had been set too far into the pipe (fig. 3), became buried with sediment. This was discovered when the sensors were found caked with sediment when the monitor was retrieved for servicing on August 9, 2001. The recovered data indicated that as the sensor became buried on August 7, the recorded concentration of dissolved oxygen dropped from 9.6 to less than 1 mg/L in 3.5 hours and remained below 1 mg/L until the monitor was retrieved. The rapid decline in concentrations was similar to those observed in September 2000.

More complete analyses of the 2001 data, as presented in the previous sections of this report, indicate that natural processes cannot explain the extreme variations in concentrations of dissolved oxygen observed in September 2000. For example, the monitored concentration of dissolved oxygen at RM 2.9 increased from 0.6 to 10.5 mg/L in 30 minutes on September 17, 2000, and it remained above the monitored concentration at RM 5.8 by as much as 6 mg/L until September 21 (fig. 6). On September 20, when monitored concentrations of dissolved oxygen were 11.1 and 5.8 mg/L at RM 2.9 and 5.8, respectively, the concentration at Ecology's ambient monitoring site at RM 8.3 was 10.1 mg/L (fig. 6) (Washington State Department of Ecology, 2001b). Because the time of travel from RM 8.3 to RM 2.9 is only about 3 hours, such a rapid and large decrease in concentration between RM 8.3 and 5.8, followed by an even larger increase in concentration between RM 5.8 and 2.9, simply is not consistent with a natural process controlling concentrations of dissolved oxygen in the lower Puyallup River.

Placement of the monitors with the sensors facing downstream in August and September 2000 (fig. 2) probably facilitated sediment buildup around the dissolved-oxygen sensors. Similar to the drag that causes dust to accumulate on the back of a car or truck, the negative pressure differential at the downstream end of the monitor housing would cause sediment to accumulate around the sensors.

SUMMARY AND CONCLUSIONS

The purpose of this study, which was conducted during August and September 2001, was to monitor concentrations of dissolved oxygen in the lower Puyallup and White Rivers and analyze some of the factors affecting concentrations. This study was initiated because observed concentrations of dissolved oxygen in the lower Puyallup River fell to levels ranging from less than 1 to about 6 mg/L on several occasions in September 2000.

This study concluded that inundation of the sensors with sediment was the most likely cause of the low concentrations of dissolved oxygen observed in September 2000. The conclusion was based on (1) knowledge gained when a dissolved-oxygen sensor became covered with sediment in August 2001, (2) the fact that, with few exceptions, concentrations of dissolved oxygen in the lower Puyallup and White Rivers did not fall below the water-quality standard of 8 mg/L in August and September 2001, and (3) an analysis of other mechanisms affecting concentrations of dissolved oxygen.

The analysis of other mechanisms indicated that they are unlikely to cause steep declines in concentrations of dissolved oxygen like those observed in September 2000. Five-day biochemical oxygen demand ranged from 0.22 to 1.78 mg/L (mean of 0.55 mg/L), and river water takes only about 24 hours to flow through the study reach. Photosynthesis and respiration cause concentrations of dissolved oxygen in the lower Puyallup River to fluctuate as much as about 1 mg/L over a 24-hour period in August and September. Release of water from Lake Tapps often lowered concentrations of dissolved oxygen downstream in the White River by about 1 mg/L. The effect was smaller farther downstream in the Puyallup River at river mile 5.8, but was still observable as a slight decrease in concentrations of dissolved oxygen caused by photosynthesis and respiration. The upper limit on oxygen demand caused by the scour of anoxic bed sediment and subsequent oxidation of reduced iron and manganese is less than 1 mg/L. The actual demand is probably negligible.

In August and September 2001, concentrations of dissolved oxygen in the lower Puyallup River did not fall below the water-quality standard of 8 mg/L, except at high tide when the saline water from Commencement Bay reached the monitor at river mile 2.9. The minimum concentration of dissolved oxygen (7.6 mg/L) observed at river mile 2.9 coincided with the maximum value of specific conductance. Because the dissolved-oxygen standard for marine water is 6.0 mg/L, the standard was not violated at river mile 2.9.

The concentration of dissolved oxygen at river mile 1.8 in the White River dropped below the water-quality standard on two occasions in August 2001. The minimum concentration of 7.8 mg/L occurred on August 23, and a concentration of 7.9 mg/L was recorded on August 13. Because there was some uncertainty in the monitoring record for those days, it cannot be stated with certainty that the actual concentration of dissolved oxygen in the river dropped below 8 mg/L. However, at other times when the quality of the monitoring record was good, concentrations as low as 8.2 mg/L were observed at river mile 1.8 in the White River.

REFERENCES CITED

American Public Health Association, American Water Works Association, and Water Environment Federation, 1998, Standard methods for the examination of water and wastewater, 20th Edition: Washington, D.C., American Public Health Association, p. 4-129.

Ebbert, J.C., Bortleson, G.C., Fusté, L.A., and Prych, E.A., 1987, Water quality in the lower Puyallup River Valley and adjacent uplands, Pierce County, Washington: U.S. Geological Survey Water-Resources Investigations Report 86-4154, 199 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

HDR Engineering, Inc., 2002, Water quality monitoring results: Lake Tapps Reservoir Water Right Technical Memorandum No. 19 dated March 19, 2002, 19 p. plus appendices.

Kimbrough, R.A., Smith, R.R., Ruppert, G.P., Wiggins, W.D., Knowles, S.M., and Renslow, V.F., 2001, Water resources data for Washington water year 2000: U.S. Geological Survey Water-Data Report WA-00-1, 541 p.

Kresch, D.L., and Prych, E.A., 1989, Streamflow statistics for streams on the Puyallup Indian Reservation, Washington: U.S. Geological Survey Water-Resources Investigations Report 87-4228, 43 p.

Pelletier, G.J., 1993, Puyallup River total maximum daily load for biochemical oxygen demand, ammonia, and residual chlorine: Washington State Department of Ecology Publication Number 96-326, 105 p.

Pelletier, G.J., 1994, Addendum to the 1993 Puyallup River TMDL Report: Washington State Department of Ecology Memorandum dated July 22, 1994.

Pogue, T.R., Jr., and Anderson, C.W., 1995, Processes controlling dissolved oxygen in the Upper Willamette River Basin, Oregon, 1994: U.S. Geological Survey Water-Resources Investigations Report 95-4205, 71 p.

Prych, E.A., 1988, Flood-carrying capacities and changes in channels of the lower Puyallup, White, and Carbon Rivers in Western Washington: U.S. Geological Survey Water-Resources Investigations Report 87-4129, 69 p.

Sikonia, W.G., 1990, Sediment transport in the lower Puyallup, White, and Carbon Rivers of Western Washington: U.S. Geological Survey Water-Resources Investigations Report 89-4112, 204 p.

U.S. Geological Survey, 2001, Water resources data for Washington, surface water, accessed October 2001, at URL http://wa.water.usgs.gov/realtime/waterdata.sw.html.

Washington State Administrative Code, 1997, Water quality standards for surface waters of the State of Washington, November 18, 1997, chapters 173-201A, 18 p.

Washington State Department of Ecology, 1998, Agreement on the allocation of the Puyallup River TMDL reserve capacity of biochemical oxygen demand (BOD_5) and ammonia, accessed October 2001, at URL http://www.ecy.wa.gov/programs/wq/tmdl/watershed/puyallup/index.html.

———2000, Letter dated December 1, 2000 to Citizens for a Healthy Bay describing the moratorium on allocating reserve capacity of BOD_5 and ammonia, accessed October 2001, at URL http://www.ecy.wa.gov/programs/wq/tmdl/watershed/puyallup/index.html.

———2001a, Puyallup River TMDL Hydrolab data, accessed October 2001, at URL http://www.ecy.wa.gov/programs/eap/wrias/tmdl/puyallup_hydrolab/index.html.

——— 2001b, Six-year water quality data summary for station 10A070, accessed October 2001, at URL http://www.ecy.wa.gov/programs/eap/fw_riv/data/rv10a070.html.

———2001c, Manchester Laboratory quality and performance, accessed October 2001, at URL http://www.ecy.wa.gov/programs/eap/manchester/melqual.htm.

———2001d, Summer 2001 sampling plan, accessed October 2001, at URL http://www.ecy.wa.gov/programs/wq/tmdl/watershed/puyallup/index.html.

Wagner, R.J., Mattraw, H.C., Ritz, G.F., and Smith, B.A., 2000, Guidelines and standard procedures for continuous water-quality monitors: Site selection, field operation, calibration, record computation, and reporting: U.S. Geological Survey Water-Resources Investigations Report 00-4252, 53 p. This report is available online at http://water.usgs.gov/owq/pubs.html.

Welch, E.B., 1992, Ecological effects of wastewater-Applied limnology and pollutant effects: London, Chapman and Hall, 425 p.

Tables 3 through 7

Table 3. Cross-section measurements of water temperature, specific conductance, pH, and concentrations of dissolved oxygen in the Puyallup River at river mile 2.9

[Data collected at USGS station 12102102—Puyallup River above Clear Creek near Tacoma; parameter codes are indicated; **Abbreviations:** LB, left bank; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 °C; DO, dissolved oxygen; mg/L, milligrams per liter; mm Hg, millimeters of mercury; --, no data]

Date	Time	Distance from LB (feet) 00009	Depth to bottom (feet) 81903	Depth of sample (feet) 00003	Water temper-ature (°C) 00010	Specific Conduct-ance (µS/cm) 00095	pH (standard units) 00400	DO (mg/L) 00300	Remarks
8/22/01	12:25	5	5.4	1.1	12.8	106	7.3	10.6	
8/22/01	12:26	5	5.4	3.8	12.8	104	7.2	10.3	
8/22/01	12:27	33	5	1	12.7	100	7.2	10.7	
8/22/01	12:28	33	5	3.5	12.7	97	7.2	10.4	
8/22/01	12:29	49	4.8	1	12.7	97	7.2	10.6	
8/22/01	12:30	49	4.8	3.5	12.7	99	7.2	10.4	
8/22/01	12:31	66	4.8	1	12.8	89	7.2	10.7	
8/22/01	12:32	66	4.8	3.5	12.7	91	7.2	10.4	
8/22/01	12:33	82	4.5	1	12.8	87	7.2	10.6	
8/22/01	12:34	82	4.5	3.5	12.7	87	7.2	10.6	
8/22/01	12:35	118	4	1	12.8	86	7.2	10.6	
8/22/01	12:36	118	4	2.8	12.7	86	7.2	10.3	
8/22/01	12:37	148	3.5	0.7	13	86	7.2	10.7	
8/22/01	12:38	148	3.5	2.5	12.8	86	7.2	10.6	
8/22/01	12:39	164	3	0.6	12.9	87	7.2	10.5	
8/22/01	12:40	164	3	2.1	12.8	86	7.2	10.4	
8/22/01	12:45	1	1	0.5	12.8	108	7.2	10.7	adjacent to monitor
Barometric pressure 755 mm Hg									
high tide	7:56								
low tide	14:06								
9/4/01	13:00	10	4	0.8	14.1	111	7.1	10.2	
9/4/01	13:01	10	4	3.2	14	110	7.1	10.4	
9/4/01	13:02	26	3.7	0.7	14.1	85	7.1	10.5	
9/4/01	13:03	26	3.7	3	14.1	87	7.1	10.2	
9/4/01	13:04	39	3.8	0.8	14.1	89	7.1	10.3	
9/4/01	13:05	39	3.8	3	14.1	88	7.1	9.9	
9/4/01	13:06	59	3.7	0.7	14.1	73	7.1	10.3	
9/4/01	13:07	59	3.7	3	14.1	70	7.1	10.1	
9/4/01	13:08	75	3.2	0.6	14.1	--	7.1	10.1	Specific conductance reading erratic
9/4/01	13:09	75	3.2	2.6	14.1	--	7.1	10.1	Specific conductance reading erratic
9/4/01	13:10	98	2.8	0.6	14.2	--	7.1	10.2	Specific conductance reading erratic

Table 3. Cross-section measurements of water temperature, specific conductance, pH, and concentrations of dissolved oxygen in the Puyallup River at river mile 2.9—*Continued*

Date	Time	Distance from LB (feet) 00009	Depth to bottom (feet) 81903	Depth of sample (feet) 00003	Water temper-ature (^oC) 00010	Specific Conduct-ance (µS/cm) 00095	pH (standard units) 00400	DO (mg/L) 00300	Remarks
9/4/01	13:11	98	2.8	2.2	14.2	--	7.1	10.2	Specific conductance reading erratic
9/4/01	13:12	114	2.3	0.5	14.3	70	7.1	10.2	
9/4/01	13:13	114	2.3	1.8	14.3	66	7.1	10.6	
9/4/01	13:14	137	2	0.4	14.3	71	7.1	10.2	
9/4/01	13:15	137	2	1.6	14.3	77	7.1	10.2	
9/4/01	13:16	157	1.7	1	14.3	73	7.1	9.9	
9/4/01	13:17	173	1.8	1	14.4	72	7.1	9.8	
Barometric pressure 762 mm Hg									
high tide	6:18								
low tide	12:44								
9/17/01	12:09	2	4.2	0.8	12.7	89	7.3	10.5	
9/17/01	12:10	2	4.2	3.4	12.6	89	7.2	10.2	
9/17/01	12:12	10	4.6	0.9	12.6	86	7.2	10.4	
9/17/01	12:13	10	4.6	3.7	12.6	86	7.2	10.3	
9/17/01	12:15	20	4.4	0.9	12.6	82	7.2	10.4	
9/17/01	12:16	20	4.4	3.5	12.6	81	7.1	10.4	
9/17/01	12:18	35	4.4	0.9	12.6	77	7.1	10.4	
9/17/01	12:19	35	4.4	3.5	12.7	78	7.1	10.3	
9/17/01	12:20	55	4.5	0.9	12.7	75	7.1	10.4	
9/17/01	12:21	55	4.5	3.6	12.7	75	7.1	10.3	
9/17/01	12:22	68	4.4	0.9	12.7	74	7.1	10.4	
9/17/01	12:23	68	4.4	3.5	12.7	74	7.1	10.4	
9/17/01	12:25	94	4.1	0.8	12.7	73	7	10.5	
9/17/01	12:26	94	4.1	3.3	12.7	73	7	10.5	
9/17/01	12:27	120	3.6	0.7	12.7	73	7.1	10.6	
9/17/01	12:28	120	3.6	2.9	12.7	73	7	10.4	
9/17/01	12:29	140	3	0.6	12.7	73	7.1	10.5	
9/17/01	12:30	140	3	2.4	12.8	73	7	10.4	
9/17/01	12:31	163	2.8	0.6	12.8	73	7	10.6	
9/17/01	12:32	163	2.8	2.2	12.8	74	7	10.4	
Barometric pressure 766 mm Hg									
high tide	4:59								
low tide	11:30								

Table 4. Cross-section measurements of water temperature, specific conductance, pH, and concentrations of dissolved oxygen in the Puyallup River at river mile 5.8

[For historical reasons, the data are stored with USGS station 12101500—Puyallup River at Puyallup, which is at mile 6.6; measurements were made upstream from Milroy Bridge to avoid inflow from Clarks Creek; parameter codes are indicated; **Specific conductance:** much of the variation in specific conductance is likely due to instrument noise; **Abbreviations:** LB, left bank; ^{o}C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 ^{o}C; DO, dissolved oxygen; mg/L, milligrams per liter; mm Hg, millimeters of mercury]

Date	Time	Distance from LB (feet) 00009	Depth to bottom (feet) 81903	Depth of sample (feet) 00003	Water temperature (^{o}C) 00010	Specific Conduct-ance (µS/cm) 00095	pH (standard units) 00400	DO (mg/L) 00300
9/4/01	10:00	148	6	1.2	13.4	72	6.9	10.8
9/4/01	10:01	148	6	4.2	13.3	74	7	10.9
9/4/01	10:02	112	5.5	1.1	13.3	77	7.1	10.3
9/4/01	10:03	112	5.5	3.9	13.3	76	7.1	10.3
9/4/01	10:04	99	4	0.8	13.3	89	7.1	10.8
9/4/01	10:05	99	4	2.8	13.3	90	7.1	10.7
9/4/01	10:06	85	4.5	0.9	13.4	89	7.1	10.8
9/4/01	10:07	85	4.5	3.2	13.3	89	7.1	10.7
9/4/01	10:08	59	3.8	0.8	13.3	73	7.1	10.8
9/4/01	10:09	59	3.8	2.7	13.3	73	7.1	10.4
9/4/01	10:10	43	4	0.8	13.3	73	7.1	10.6
9/4/01	10:11	43	4	2.8	13.3	73	7.1	10.2
9/4/01	10:12	30	3	0.6	13.3	85	7.1	10.2
9/4/01	10:13	30	3	2.1	13.3	85	7.1	10.3
9/4/01	10:14	13	2.5	0.5	13.4	81	7.1	10.4
9/4/01	10:15	13	2.5	1.8	13.3	81	7.1	10.3
9/4/01	10:16	10	2.4	0.5	13.4	80	7.1	10.2
9/4/01	10:17	10	2.4	1.7	13.4	81	7.1	10.1
Barometric pressure 761 mm Hg								

Table 5. Cross-section measurements of water temperature, specific conductance, pH, and concentrations of dissolved oxygen in the White River at river mile 1.8

[This is USGS station 12101104—White River above Tacoma Avenue Bridge at Sumner; cross-section measurements were made from Tacoma Avenue Bridge; parameter codes are indicated; **Distance from LB**: 64 feet = right edge of water. Stopped at 55 to avoid seepage from storm drain; **Specific conductance:** Specific conductance readings were erratic during cross-section measurements. Specific conductance values shown represent readings from a troll of probe from left to right banks at a depth of 1 foot after completion of cross-sectional measurements; **Abbreviations**: LB, left bank; °C, degrees Celsius;µS/cm, microsiemens per centimeter at 25 °C; DO, dissolved oxygen; mg/L, milligrams per liter; mm Hg, millimeters of mercury;]

Date	Time	Distance from LB (feet) 00009	Depth to bottom (feet) 81903	Depth of sample (feet) 00003	Water temperature (°C) 00010	Specific conduct-ance (µS/cm) 00095	pH (standard units) 00400	DO (mg/L) 00300
9/5/01	9:55	5	2.9	1.8	13.1	92	7.3	10.1
9/5/01	9:54	10	3.7	0.7	13.1	92	7.3	10.1
9/5/01	9:53	10	3.7	3.0	13.1		7.3	10.1
9/5/01	9:52	15	4.3	0.9	13	92	7.3	10.1
9/5/01	9:51	15	4.3	3.4	13		7.3	10.1
9/5/01	9:50	20	4.4	0.9	13	92	7.3	10.1
9/5/01	9:49	20	4.4	3.5	13		7.3	10.1
9/5/01	9:48	25	4.6	0.9	13	92	7.3	10.1
9/5/01	9:47	25	4.6	3.7	13		7.3	10.1
9/5/01	9:46	30	5	1.0	13	92	7.3	10.2
9/5/01	9:45	30	5	4.0	13		7.3	10.1
9/5/01	9:44	35	5.3	1.1	13	92	7.3	10.1
9/5/01	9:43	35	5.3	4.2	13.1		7.3	10.2
9/5/01	9:42	40	5.9	1.2	13	92	7.3	10.2
9/5/01	9:41	40	5.9	4.7	13		7.3	10.1
9/5/01	9:40	45	6	1.2	13.1	92	7.3	10.2
9/5/01	9:39	45	6	4.8	13.1		7.3	10.2
9/5/01	9:38	50	5.9	1.2	13.1	92	7.3	10.4
9/5/01	9:37	50	5.9	4.7	13.1		7.3	10.3
9/5/01	9:36	55	6	1.2	13.1	92	7.3	10.4
9/5/01	9:35	55	6	4.8	13.1		7.2	10.4
Barometric pressure 762 mm Hg								

Table 6. Hypothetical oxygen demand caused by instantaneous oxidation of all suspended and dissolved iron and manganese in water samples from the lower Puyallup River

[**Iron**: Concentrations in samples collected August and September 2001 (Washington State Department of Ecology, 2001a); **Oxygen demand**: Oxidation of one mole of iron from the +2 to +3 oxidation state requires 0.25 mole of oxygen (Hem, 1985); oxidation of one mole of manganese from the +2 to the +4 oxidation state requires 0.5 mole of oxygen (Hem, 1985); **Abbreviations:** µg/L, micrograms per liter; L, liter; µmole/L, micromoles per liter; mg/L, milligrams per liter;]

Iron, total recoverable in water		Oxygen demand	
(µg/L)	(µmole/L)	(µmole/L)	(mg/L)
5,490	98.3	24.6	0.79
1,570	28.1	7.0	0.22
6,520	116.7	29.2	0.93
5,470	97.9	24.5	0.78
4,360	78.1	19.5	0.62
4,060	72.7	18.2	0.58
6,220	111.4	27.8	0.89
2,430	43.5	10.9	0.35
3,130	56.0	14.0	0.45
		Minimum	0.22
		Mean	0.62
		Maximum	0.93

Manganese, total recoverable in water		Oxygen demand	
(µg/L)	(µmole/L)	(µmole/L)	(mg/L)
121	2.20	1.10	0.035
63.9	1.16	0.58	0.019
127	2.31	1.16	0.037
107	1.95	0.97	0.031
81.9	1.49	0.75	0.024
82.4	1.50	0.75	0.024
110	2.00	1.00	0.032
110	2.00	1.00	0.032
52.2	0.95	0.48	0.015
69.1	1.26	0.63	0.020
		Minimum	0.015
		Mean	0.026
		Maximum	0.037

Table 7. Hypothetical oxygen demand caused by oxidation of anoxic bed sediment

[It is assumed that anoxic bed sediment is the sole source of suspended solids and that all iron associated with the suspended solids is oxidized; **Total suspended solids**: Concentrations in samples collected August and September 2001 (Washington State Department of Ecology, 2001a); **Iron, total recoverable**: Concentration groups represent minimum, mean, and maximum concentrations of iron in 10 bed sediment samples collected during August 2001 (Washington State Department of Ecology, 2001a); **Iron, total suspended**: Assuming that the concentration of iron associated with suspended solids equals the concentration in bed sediment; **Oxygen demand**: Oxidation of one mole of iron from the +2 to +3 oxidation state requires 0.25 mole of oxygen (Hem, 1985); **Abbreviations:** mg/kg, milligrams per kilogram dry weight; mg/L, milligrams per liter; mmole/L, millimole per liter]

Total suspended solids, in mg/L		Iron, total recoverable in bed sediment, in mg/kg	Iron, total suspended, in mg/L	Iron, total suspended, in mmole/L	Oxygen demand, in mmole/L	Oxygen demand, in mg/L
Minimum	207	5,830	1.21	0.022	0.005	0.17
Mean	359	5,830	2.09	0.037	0.009	0.30
Maximum	565	5,830	3.29	0.059	0.015	0.47
Minimum	207	7,480	1.55	0.028	0.007	0.22
Mean	359	7,480	2.69	0.048	0.012	0.38
Maximum	565	7,480	4.23	0.076	0.019	0.61
Minimum	207	8,940	1.85	0.033	0.008	0.27
Mean	359	8,940	3.21	0.057	0.014	0.46
Maximum	565	8,940	5.05	0.090	0.023	0.72
					Mimimum	0.17
					Mean	0.40
					Maximum	0.72

Appendixes

APPENDIX A. MONITOR INSPECTION AND CALIBRATION SHEET

Station No. _____________________ Location____________________________________ Date_________________

Barometric pressure_________ Turbidity (visibility limit)_____________ Inspected by___________________

Step 1: Before retrieving the monitor, take readings with field meter & collect sample for Winkler DO titration on the hour or half-hour. The corresponding readings from the Hydrolab monitor will be added to the table after the data are downloaded.

Parameter	Time of Measurement	Hydrolab Monitor	Field Meter	Winkler DO
Temperature				
Specific conductance				
pH				
Dissolved oxygen				

Step 2: Retrieve the monitor, clean and inspect probes, re-deploy monitor for “after-cleaning” measurements. Take a series of these measurements until stable (T +/- 0.2 deg C; SC the greater of 5 uS/cm or 3% of measured value; DO +/- 0.3 mg/L; pH +/- 0.2 units)

<u>Important</u>: Record time that monitor was retrieved ____________ Condition of probes____

	Monitor	Field Meter	Monitor	Field Meter	Monitor	Field Meter	Monitor	Field Meter
Time								
Temp								
SC								
pH								
DO								

Step 3: Retrieve the monitor and download data from the previous collection period. Inspect the data. The decision to recalibrate the monitor is somewhat subjective and is based on 1) how its readings compared with the field meter & Winkler, 2) its stability as observed in step 2, and 3) the data from the previous collection period (In general, DO in the Puyallup and White Rivers does not vary widely.) If in doubt, perform a calibration check. **Name of file downloaded**__________________________________

Step 4: Calibration check (perform if indicated by Step 3).

Parameter	Standard or Winkler DO	Monitor Reading	@ temperature, deg C
Specific conductance			
Specific conductance			
pH			
pH			
Dissolved oxygen			

Step 5: Recalibrate if calibration check limits fall outside stability limits in Step 2. **Always calibrate Specific Conductance first.**

DO membrane replaced? ________, If yes, DO must be calibrated 24 hours from time of replacement. Time of replacement ________

Parameter	Standard or Winkler	Reading	@ temp, deg C	Monitor set to:	Calibrated reading
Specific cond.					
Specific cond.					
pH					
pH					
Dissolved Oxy					

Step 6: Create a new logging file and <u>check file status to make sure it was created</u>, re-deploy the monitor, and take instream readings with field meter & collect sample for Winkler DO titration on the hour or half-hour. The readings from the Hydrolab will be added to the table after the data are downloaded next visit.

Parameter	Time of Measurement	Hydrolab Monitor	Field Meter	Winkler DO
Temperature				
Specific conductance				
pH				
Dissolved oxygen				

<u>Important</u>: Record time that monitor was deployed here: ____________ Name of new logging file _____________________

APPENDIX B. METHODS USED TO ANALYZE WATER AND SEDIMENT SAMPLES

[**Abbreviations and symbols:** mL, milliliter; NA, not applicable; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; ^{o}C, degrees Celsius; EPA, Environmental Protection Agency; APHA, American Public Health Association; poly, polyethylene; HDPE, high-density polyethylene; mg/kg, milligrams per kilogram; H_2SO_4, sulfuric acid; HNO_3, nitric acid; <, less than]

Parameter	Container type	Sample volume (mL)	Preservation	Holding time	Analytical/field method	Detection limit/resolution
Specific conductance	NA	NA	NA	NA	Electrode	1 µS/cm
Dissolved oxygen	NA	NA	NA	NA	Titration	0.1 mg/L
pH	NA	NA	NA	NA	Glass electrode	0.1 unit
Temperature	NA	NA	NA	NA	Thermistor	0.1^{o}C
Suspended solids	poly	1,000	cool to <4^{o}C	7 days	Gravimetric (EPA 160.2)	1 mg/L
Total phosphorus	poly	125	adjust pH<2 w H_2SO_4 and cool to <4^{o}C	28 days	Persulfate digestion, ascorbic acid (EPA 365.3/APHA 4500-PF)	10 µg/L
Soluble reactive phosphorus	brown poly	125	filter in field and cool to <4^{o}C	48 hours	Ascorbic acid (EPA 365.3/APHA 4500-PF)	10 µg/L
Nitrate+nitrite-N	poly	125	adjust pH<2 w H_2SO_4 and cool to <4^{o}C	28 days	Automated cadmium reduction (EPA 353.2/APHA 4500-NO_3F	10 µg/L
Ammonia-N	poly	125	adjust pH<2 w H_2SO_4 and cool to <4^{o}C	28 days	Automated phenate (EPA 350.1/APHA 4500-NH_3D	10 µg/L
Total nitrogen	poly	125	adjust pH<2 w H_2SO_4 and cool to <4^{o}C	28 days	Persulfate digestion, cadmium reduction	25 µg/L
Biochemical oxygen demand	poly	2-L	cool <4^{o}C	48 hours	EPA 405.1, APHA 5210B	2 mg/L
Total organic carbon	poly	50	cool <4^{o}C	30 hours	EPA 415.1	1 mg/L
Chlorophyll A	amber poly	500	cool <4^{o}C	30 hours	Standard methods 10200H(3)	0.5 µg/L
Iron, water	HDPE	1,000	HNO_3 to pH <2	28 days	EPA 200.7	20 µg/L
Manganese, water	HDPE	1,000	HNO_3 to pH <2	28 days	EPA 200.7	1 µg/L
Iron, sediment	glass	50 grams	cool <4^{o}C	28 days	EPA 200.7	2 mg/kg
Manganese, sediment	glass	50 grams	cool <4^{o}C	28 days	EPA 200.7	0.1 mg/kg

APPENDIX C. SUMMARY OF DATA COLLECTED FOR THE PUGET SOUND ENERGY 2001 WATER QUALITY MONITORING PROGRAM. (DATA COLLECTED BY HDR ENGINEERING, INC.)

Monitoring element	Sample dates	Parameters	Stations
1. Continuous monitoring	August 22nd through October 16th	Temperature, pH, dissolved oxygen, conductivity	1. Tailrace canal 2. White River (river mile 4.9)
2. Sample collection	1. August 23 2. August 28 3. September 4 4. September 10 5. September 17 6. September 24 7. October 2 8. October 9 9. October 16	Dissolved oxygen, temperature, ammonia-N, nitrate+nitrite-N, total kjeldahl nitrogen, total phosphorus, soluble reactive phosphorus, total organic carbon, dissolved organic carbon total biochemical oxygen demand (5-day) dissolved biochemical oxygen demand (5-day) chlorophyll *a*, turbidity, fecal coliform, total suspended solids	1. Tailrace canal 2. White River (river mile 4.9)
3. Lake Tapps intake canal profiling	1. August 28 2. September 4 3. September 10 4. October 2	Temperature, pH, dissolved oxygen, conductivity	Sumner—Lake Tapps Highway East Bridge

J.C. Ebbert

Concentrations of Dissolved Oxygen in the Lower Puyallup and White Rivers, Washington, August and September 2000 and 2001

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