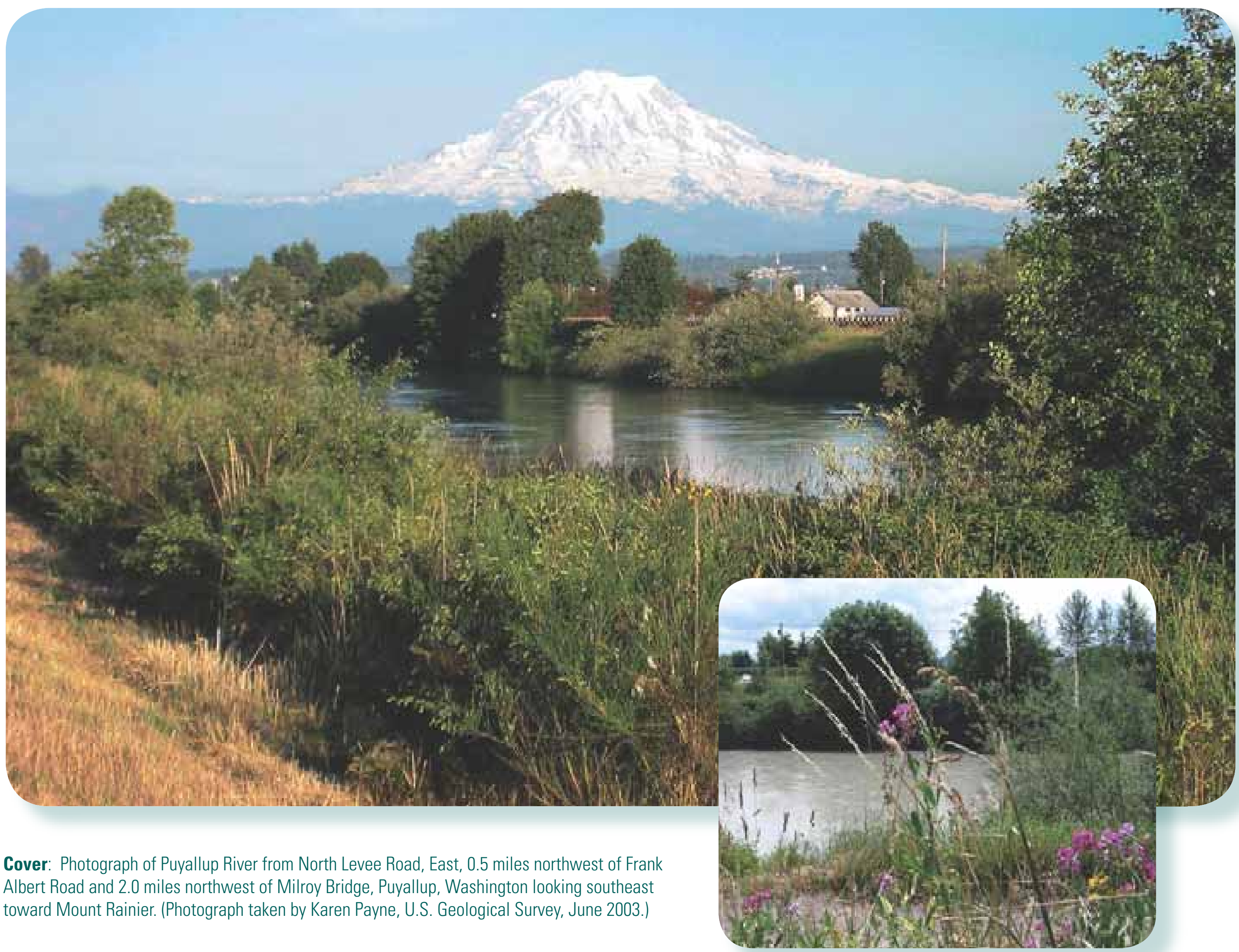
Water Temperature, Specific Conductance, pH, and Dissolved-Oxygen Concentrations in the Lower White River and the Puyallup River Estuary, Washington, August-October 2002

Water-Resources Investigations Report 03-4177

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



Cover: Photograph of Puyallup River from North Levee Road, East, 0.5 miles northwest of Frank Albert Road and 2.0 miles northwest of Milroy Bridge, Puyallup, Washington looking southeast toward Mount Rainier. (Photograph taken by Karen Payne, U.S. Geological Survey, June 2003.)

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

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Tacoma, Washington
2003

U.S. DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS AND DATUMS

CONVERSION FACTORS

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer

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

$$°F=1.8 \times °C+32.$$

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

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

DATUM

Vertical coordinate information was referenced to the National Geodetic Vertical Datum of 1929 (NGVD29), referred to in this report as "sea level."

Horizontal coordinate information was referenced to the North American Datum of 1983 (NAD83).

Water Temperature, Specific Conductance, pH, and Dissolved-Oxygen Concentrations in the Lower White River and the Puyallup River Estuary, Washington, August-October 2002

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ABSTRACT

The U.S. Geological Survey, Washington State Department of Ecology, and Puyallup Tribe of Indians monitored water temperature, specific conductance, pH, and dissolved-oxygen concentrations in the White River at river miles 4.9 and 1.8 from August until mid-October 2002. Water diverted from the White River upstream from the monitoring sites into Lake Tapps is returned to the river at river mile 3.6 between the two sites. The same characteristics were measured in a cross section of the Puyallup River estuary at river mile 1.5 during high and low tides in September 2002.

In late August, maximum daily water temperatures in the White River of 21.1 ^{o}C (degrees Celsius) at river mile 4.9 and 19.6 ^{o}C at river mile 1.8 exceeded the water-quality standard of 18 ^{o}C at both monitoring sites. In mid-September, maximum daily water temperatures at river mile 4.9 exceeded the standard on 5 days. From August 2-25, water temperatures at both monitoring sites were similar and little or no water was discharged from Lake Tapps to the White River. Increases in water temperature at river mile 1.8 in late September and early October were caused by the mixing of warmer water discharged from Lake Tapps with cooler water in the White River.

Specific conductance in the White River usually was lower at river mile 1.8 than at river mile 4.9 because of mixing with water from Lake Tapps, which has a lower specific conductance.

Maximum values of pH in the White River at river mile 4.9 often exceeded the upper limit of the water-quality standard, 8.5 pH units, from early September until mid-October, when turbidity decreased. The pH standard was not exceeded at river mile 1.8.

Dissolved-oxygen concentrations in the White River were often lower at river mile 1.8 than at river mile 4.9 because of mixing with water discharged from Lake Tapps, which has lower dissolved-oxygen concentrations. The lowest concentration of dissolved oxygen observed was 7.9 mg/L (milligrams per liter) at river mile 1.8. The lower limit allowed by the water-quality standard is 8 mg/L.

Concentrations of dissolved oxygen measured in a cross section of the Puyallup River estuary at high tide on September 12, 2002, ranged from 9.9 to 10.2 mg/L in fresh water at the surface and from 8.1 to 8.4 mg/L in salt water near the riverbed. These values were within limits set by Washington State water-quality standards for dissolved oxygen of 8 mg/L in fresh water and 6 mg/L in marine water.

INTRODUCTION

A study of Total Maximum Daily Load (TMDL) for the lower Puyallup River and the lower reaches of the tributary White River (Pelletier, 1993, 1994), conducted by the Washington State Department of Ecology (Ecology), concluded that the Puyallup River had the capacity to assimilate more ammonia and constituents causing biochemical oxygen demand than were being discharged to the river. As part of the TMDL process, Ecology determines if the additional assimilative capacity, also referred to as reserve capacity, is sufficient to permit additional discharges to the river. As part of that decision process, Ecology and other interested parties, including municipalities, industry, and Indian tribes, met in 1996 and developed a plan for managing the reserve capacity (Washington State Department of Ecology, 1998). Part of the plan called for additional monitoring to verify that concentrations of dissolved oxygen and ammonia would remain within limits set by Washington State water-quality standards.

Additional monitoring began in August 2000 when Ecology and the Puyallup Tribe of Indians installed water-quality monitors in the Puyallup River at river mile (RM) 2.9 and RM 5.8 (fig. 1) for four periods during August and September. The monitors recorded water 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 mg/L were measured on several occasions. Because Washington State water-quality standards set the lower limit for dissolved-oxygen concentrations in the Puyallup River at 8 mg/L (State of Washington, 1997), Ecology issued a moratorium on accessing the reserve capacity (Washington State Department of Ecology, 2000).

In May 2001, the U.S. Geological Survey (USGS), in a cooperative study with Ecology and the Puyallup Tribe, evaluated the data collected in August and September 2000 and collected additional data to determine if dissolved-oxygen concentrations in the Puyallup River would decrease to less than the water-quality standards again in 2001. Water-quality monitors were installed during August and September 2001 in the Puyallup River at RM 2.9 and RM 5.8 and in the White River at RM 1.8 (fig. 1). Water and bed-sediment samples also were collected and were analyzed for various constituents and properties to help interpret the dissolved-oxygen data.

The joint study concluded that inundation of the monitors with sediment, which resulted in false sensor readings, was the most likely cause of the low dissolved-oxygen concentrations measured in September 2000 (Ebbert, 2002). This conclusion was based on (1) knowledge gained when a dissolved-oxygen sensor became covered with sediment in August 2001, (2) the fact that dissolved-oxygen concentrations in the lower Puyallup and White Rivers infrequently decreased to less than 8 mg/L and never decreased to less than 7.6 mg/L in August and September 2001, and (3) an analysis of the effects of other mechanisms, such as biochemical oxygen demand that govern dissolved-oxygen concentrations in the river.

Because dissolved-oxygen concentrations in the White River decreased to less than the water-quality standard of 8 mg/L on two occasions during August 2001, the joint study confirmed that there is little or no reserve capacity for biochemical oxygen demand in the lower White River. There was, however, some uncertainty in these results because on both occasions when dissolved-oxygen concentrations decreased to less than 8 mg/L, the quality of the monitoring record was rated as poor (Ebbert, 2002). A poor rating means that a correction of more than 0.8 mg/L was applied to the original record based on an evaluation of calibration data and other factors. To better quantify dissolved-oxygen concentrations in the White River, Ecology, the Puyallup Tribe, and the USGS decided to monitor again in 2002. Monitors were installed at RM 4.9 and RM 1.8, which are upstream and downstream from where water that was routed into Lake Tapps from the White River at RM 24.3 to operate a hydropower facility is discharged back into the White River through the Lake Tapps tailrace canal at RM 3.6 (fig. 1). Water temperature, specific conductance, pH, and dissolved-oxygen concentration data were recorded at 30-minute intervals from the beginning of August through mid-October 2002.

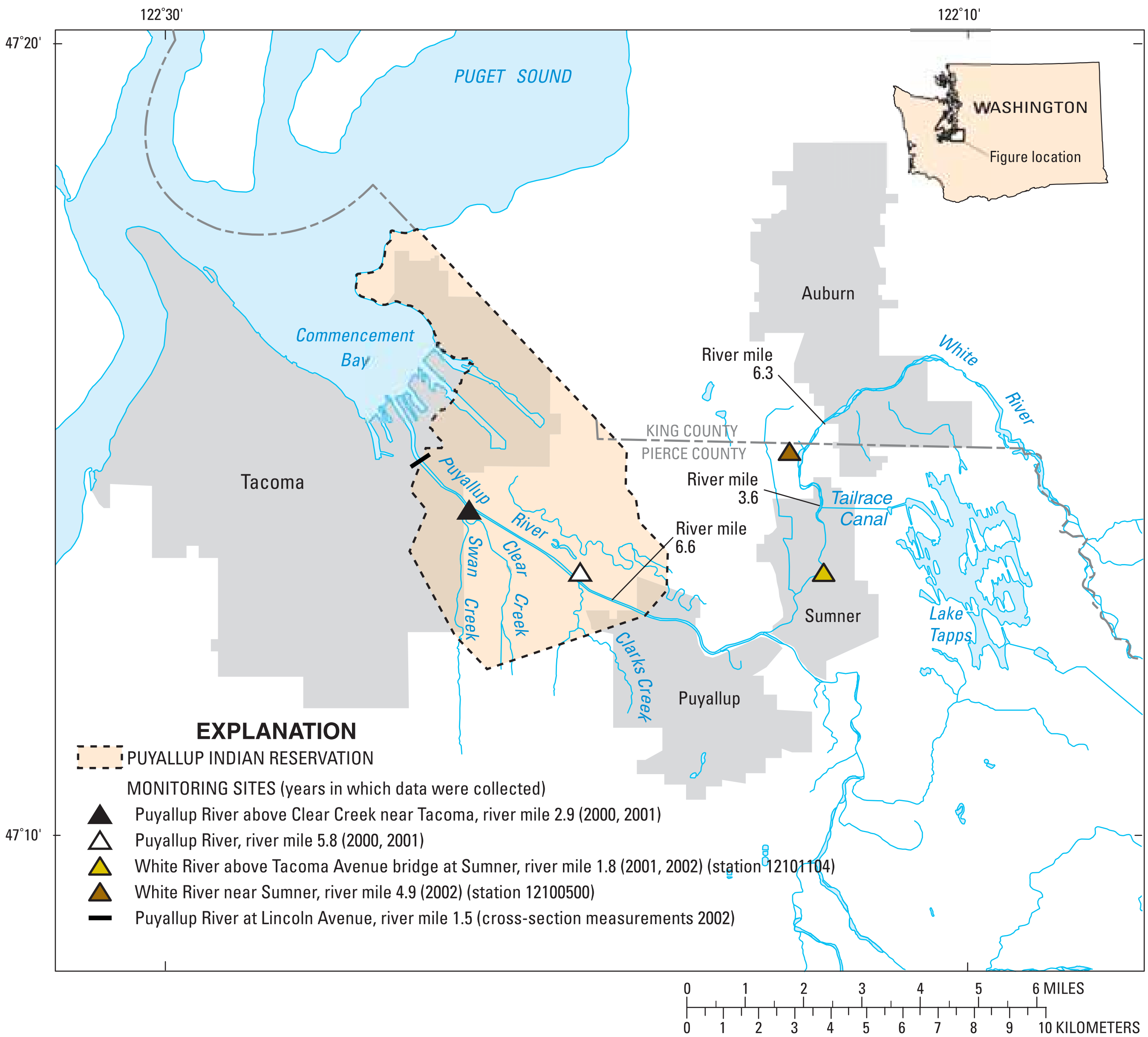


Figure 1. Location of water-quality monitoring sites on the lower Puyallup and White Rivers, Washington, for the August-October 2002 study and for previous studies in 2000 and 2001.

The 2002 study also included measuring lateral and vertical variations in water temperature, specific conductance, pH, and dissolved-oxygen concentrations in the Puyallup River estuary at RM 1.5 during high and low tides in September. The purpose of these measurements was to observe conditions downstream from RM 2.9, the location of the monitor in 2001. The Puyallup River estuary is of the salt-wedge type, which means that it contains a layer of undiluted salt water overlain by a layer of river water. It is therefore a transitional area where the water-quality standard for dissolved oxygen changes from 8 mg/L in fresh water to 6 mg/L in marine water (State of Washington, 1997). During a previous study (Ebbert and others, 1987), the USGS measured the longitudinal distribution of salinity in the Puyallup River estuary during various phases of the tidal cycle.

Purpose and Scope

The purposes of this report are to (1) summarize the water temperature, specific conductance, pH, and dissolved-oxygen concentration data collected in the lower White River; (2) compare water temperatures, dissolved-oxygen concentrations, and pH values for the lower White River to State water-quality standards; (3) discuss some of the factors affecting dissolved-oxygen concentrations and pH values in the lower White River; and (4) present and discuss the data collected in a cross section of the Puyallup River estuary at RM 1.5. The study on the lower White River included discharge data collected at two USGS streamflow-gaging stations. Results of the 2002 study are compared with those of the studies in 2000 and 2001.

Description of the Lower Puyallup and White Rivers

The Puyallup and White Rivers are located in the Puget Sound region of western Washington. The White River flows into the Puyallup River near the city of Puyallup, and the Puyallup River empties into Puget Sound at Tacoma (fig. 1). The lower Puyallup River Valley is a relatively flat floodplain. Streambed altitudes in the study area range from about 18 ft (feet) below NGVD 29 at RM 1.5 on the Puyallup River to about 50 ft above NGVD 29 at RM 4.9 on the White River (Prych, 1988). The lower-most part of the Puyallup River is a salt-wedge estuary with deeper salt water overlain by a layer of fresh water. The salt wedge generally extends less than 2.5 mi upstream from the river mouth (Ebbert and others, 1987); however, the monitoring data collected in 2001 indicate it sometimes reaches RM 2.9 (Ebbert, 2002).

During summer, operation of the Lake Tapps hydropower facility by Puget Sound Energy can have a substantial effect on discharge in the lower White and Puyallup Rivers. Water is diverted into Lake Tapps from the White River at RM 24.3, stored, and then released to produce electric power as it passes through a powerplant located on the tailrace canal that connects with 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 lower White and Puyallup Rivers to increase by a factor of two and then decrease 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 White and Puyallup Rivers is usually turbid during the summer because fine sediment derived from glacial melting on Mount Rainier is transported downstream. The turbidity limits light penetration, which reduces primary productivity and moderates 24-hour variations in pH caused by photosynthesis and respiration (Stuart, 2002).

Water in the lower White and Puyallup Rivers is classified by the State of Washington (1997) as Class A (excellent), therefore water-quality standards cited in this report are for Class A waters.

Acknowledgments

The contributions of Jeannette Barreca, Washington State Department of Ecology, and Char Naylor, Puyallup Tribe of Indians, who helped design, execute, and fund this study, are greatly appreciated. They also provided the water-quality monitors used in the White River. The USGS also thanks George Onwumere of Washington State Department of Ecology and Char Naylor and Mary Brown of the Puyallup Tribe of Indians for sharing the task of servicing and calibrating the water-quality monitors.

DATA COLLECTION AND DATA QUALITY

Water temperature, specific conductance, pH, and dissolved-oxygen concentrations were monitored from August 2 through October 16, 2002, in the White River at RM 4.9 and 1.8 and were measured in a cross section of the Puyallup River at RM 1.5 during high and low tides in September 2002 (fig.1, table 1). The White River data are available online at URL http://www.ecy.wa.gov/programs/eap/wrias/tmdl/puyallup_hydrolab/index.html.

Discharge data at RM 6.3 and RM 3.6 (the tailrace canal) that were used in this study were collected by the Hydrologic Data Program of the USGS. Discharge in the White River at RM 4.9 is based on records for the streamflow-gaging station at RM 6.3 (table 1), and there are no significant inputs or losses of water between the two locations. The sum of discharge in the White River at RM 6.3 and discharge in the Lake Tapps tailrace canal provides a rough estimate of discharge in the White River at RM 1.8. The discharge data are available online at URL http://water.usgs.gov/wa/nwis/sw. To access the online data for a particular site, use the USGS station No. listed in table 1.

Data Collection

Hydrolab DatasondeTM 4 and 4a water-quality monitors were used to measure and record water temperature, specific conductance, pH, and dissolved-oxygen concentrations at 30-minute intervals in the White River at RM 4.9 and 1.8 (fig. 1, table 1). Because the monitors were usually serviced and calibrated in the field, they were almost continuously deployed. Similar to the data collection effort in 2001 (Ebbert, 2002), the monitors were installed in 20-foot-long sections of plastic pipe extending from the riverbank into the river. The submerged parts of the pipes were perforated to expose the sensors, which were placed perpendicular to the direction of flow. The sensors were 1 to 2 ft above the riverbed.

The water-quality monitors were serviced, and calibrated if needed, every 4 to 5 days during the 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). In addition, the modified Winkler method (American Public Health Association and others, 1998) was used to measure dissolved-oxygen concentrations in the White River before the monitors were removed for servicing and after they were replaced.

Table 1. Locations on the lower White River and Puyallup River estuary where water-quality and discharge data were collected by the Washington State Department of Ecology, Puyallup Tribe of Indians, and U.S. Geological Survey, August-October, 2002

[**Station No. and name:** USGS, U.S. Geological Survey; Ecology, Washington State Department of Ecology. See figure 1 for location of USGS station Nos.]

Station No.		Station name		River mile	Type of data
USGS	Ecology	USGS	Ecology		
12100496	None	White River near Auburn	None	6.3	Discharge
12100500	10C085	White River near Sumner	White River near Sumner	4.9	Water-quality monitoring
12101100	None	Lake Tapps diversion at Dieringer[1]	Lake Tapps tailrace canal	[2]3.6	Discharge
12101104	None	White River above Tacoma Avenue bridge at Sumner	White River at river mile 1.8	1.8	Water-quality monitoring
12102400	None	Puyallup River at Lincoln Avenue Bridge at Tacoma	None	1.5	Water-quality measurements in the cross section

[1]Referred to as the Lake Tapps tailrace canal in this report.
[2]Point where LakeTapps tailrace canal discharges into White River.

In the Puyallup River at RM 1.5, cross-section measurements during low tide were made at intervals about 30 ft apart in the cross section and at depths of 0.2 and 0.8 times the total depth at each interval. During high tide, the intervals ranged from about 40 to 50 ft apart, and measurements at each interval were made near the surface of the water, near the riverbed, and at the approximate interface between the salt wedge and overlying fresh water.

Data Quality

Monitoring data were corrected and rated for accuracy following the guidelines recommended by Wagner and others (2000). These guidelines for correcting the data entail an analysis to determine how sensor fouling and instrument drift affect recorded values. Error caused by sensor fouling was determined by comparing values recorded just before the monitor was removed for servicing with values obtained after cleaning the sensors and temporarily returning the monitor to the stream. Error caused by instrument drift was determined by comparing cleaned instrument readings with (1) a calibrated thermometer for water temperature, (2) standard solutions for specific conductance and pH, and (3) the partial pressure of oxygen in water-saturated air for dissolved oxygen (Radtke and others, 1998).

Corrections were applied to the monitoring data based on an analysis of how the data were affected by sensor fouling and instrument drift. In this study, dissolved-oxygen concentrations measured by the modified Winkler method also were used to help determine if corrections needed to be applied to the dissolved-oxygen data.

The accuracy of the monitoring data was determined largely by the magnitude of corrections applied. Other factors, such as instrument noise, also were considered. A fair or poor rating often underestimates the quality of the final or published data because even though the corrected data are considered to be more representative of conditions in the stream, the ratings are based on data recorded before any corrections are made. With some exceptions, the monitoring data were rated excellent or good (table 2).

Cross-section measurements made during the 2001 study (Ebbert, 2002) indicate that the White River is well mixed at RM 1.8. Good agreement between measurements made on the right and left banks of the river at RM 4.9 (table 3) was used to infer good mixing at the upstream monitoring site as well.

Because of a shift in the channel affected measurements of the stage of the White River at river mile 6.3, discharge was estimated for August 1-2 and August 25-October 14. Daily mean discharge at river mile 6.3 was estimated using data from the White River at Buckley at river mile 23.3 (USGS streamflow-gaging station No. 12100000).

Table 2. Ratings of accuracy of water temperature, specific conductance, pH, and dissolved-oxygen monitoring records for two monitoring sites in the lower White River, Washington, August-October 2002

[Rating criteria from Wagner and others (2000). Ratings do not apply to periods of missing record. ≤, less than or equal to; <, less than; >, greater than; ≥, greater than or equal to; ±, plus or minus value shown; ^{o}C, degrees Celsius; pH unit, standard pH unit; mg/L, milligram per liter]

Measured physical property and rating criteria	White River near Sumner, river mile 4.9	White River above Tacoma Avenue bridge at Sumner, river mile 1.8
Temperature (^{o}C)	Excellent	Excellent
Excellent: ≤ ±0.2		
Good: > ±0.2 to 0.5		
Fair: > ±0.5 to 0.8		
Poor: > ±0.8		
Specific conductance (percent)	Good	Excellent, except for August 21-30 and October 9-10, which are good
Excellent: ≤ ±3		
Good: > ±3 to 10		
Fair: > ±10 to 15		
Poor: > ±15		
pH (unit)	Good, except for August 8-9, which are fair	Excellent, except for September 19-23, which are good
Excellent: ≤ ±0.2		
Good: > ±0.2 to 0.5		
Fair: > ±0.5 to 0.8		
Poor: > ±0.8		
Dissolved oxygen (mg/L)	Good, except for September 23-October 16, which are poor	Good, except for August 3-9, August 13, and October 1-2, which are fair; and August 10-12 and August 14-16, which are poor
Excellent: ≤ ±0.3		
Good: > ±0.3 to 0.5		
Fair: > ±0.5 to 0.8		
Poor: > ±0.8		

Table 3. Measurements of water temperature, specific conductance, pH, and dissolved-oxygen concentrations near the right and left banks of the White River at river mile 4.9, Washington, October 2, 2002

[**Abbreviations:** ^{o}C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 ^{o}C; pH unit, standard pH unit; mg/L, milligram per liter]

Physical property	Location (time)	
	Approximately 10 feet from left bank (0910)	Approximately 2 feet from right bank beside monitor (0920)
Temperature (^{o}C)	7.6	7.6
Specific conductance (µS/cm)	91	91
pH (units)	7.1	7.2
Dissolved oxygen (mg/L)	12.1	12.2

WATER TEMPERATURE, SPECIFIC CONDUCTANCE, PH, AND DISSOLVED-OXYGEN CONCENTRATIONS IN THE LOWER WHITE RIVER AND THE PUYALLUP RIVER ESTUARY

Water temperature, specific conductance, pH, and dissolved-oxygen concentrations were monitored from August 2 until October 16, 2002, in the White River at RM 4.9 and 1.8 and were measured in a cross section of the Puyallup River at RM 1.5 during high and low tides in September 2002.

Lower White River

From August 2-25, 2002, water was not diverted from the White River into Lake Tapps, and daily mean discharge in the White River at RM 6.3 ranged from about 800 to 1,000 ft^3/s. Flow decreased at RM 6.3 when water was again diverted to Lake Tapps, and in September, daily mean discharge at RM 6.3 was relatively steady at about 400 ft^3/s (fig. 2).

Maximum daily water temperatures in the White River exceeded the water-quality standard of 18 ^{o}C (State of Washington, 1997) at both monitoring sites in mid- to late-August (table 4, fig. 3*A*). The maximum value at RM 4.9 was 21.1 ^{o}C, and at RM 1.8 was 19.6 ^{o}C. In mid-September, maximum daily water temperatures at RM 4.9 exceeded the standard on 5 days. Minimum temperatures were in mid-October at the end of the measurement period (table 4, fig. 3*A*).

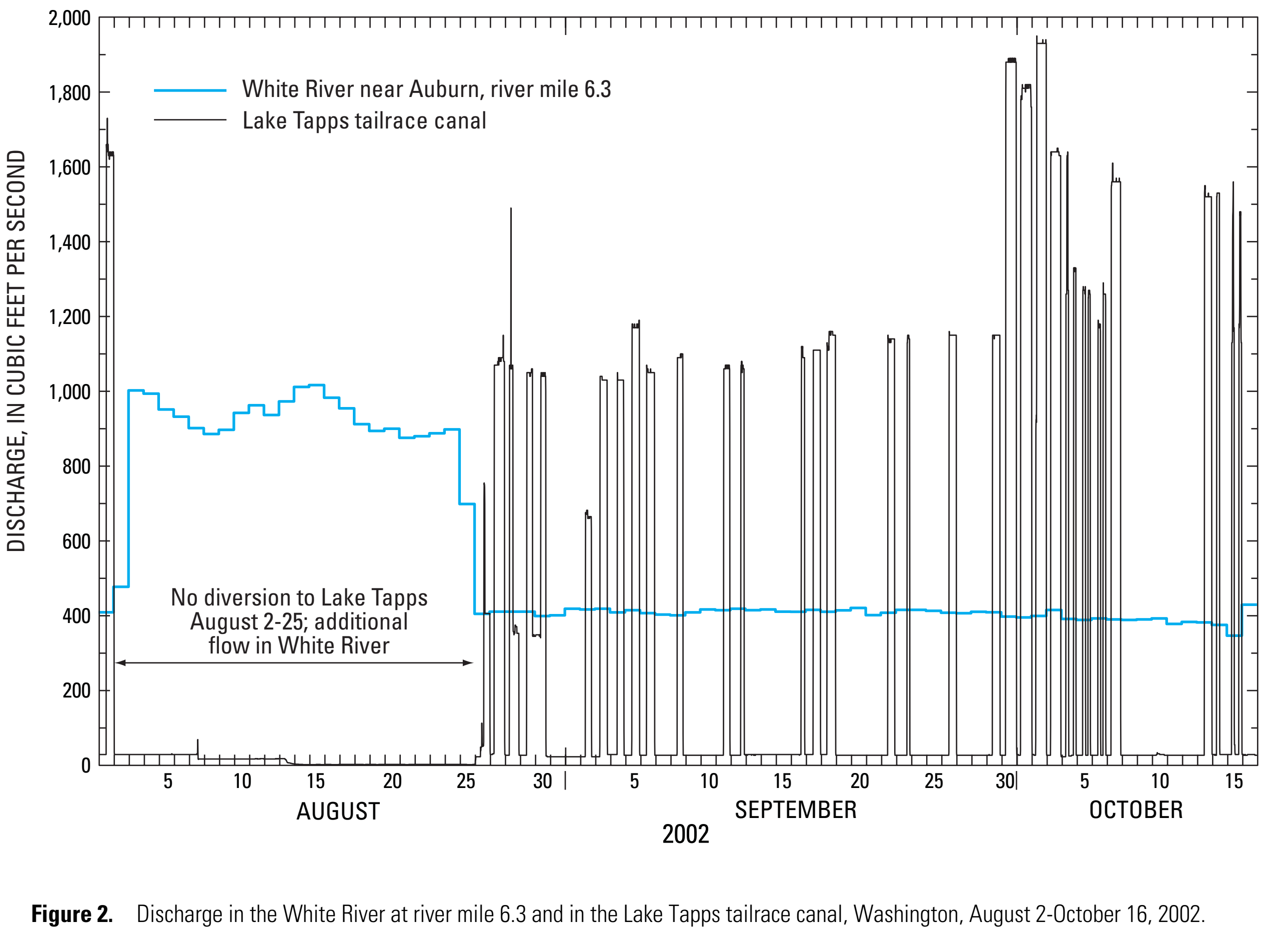


Figure 2. Discharge in the White River at river mile 6.3 and in the Lake Tapps tailrace canal, Washington, August 2-October 16, 2002. Discharge data for the White River are daily mean values and were estimated for August 1-2 and August 25-October 14.

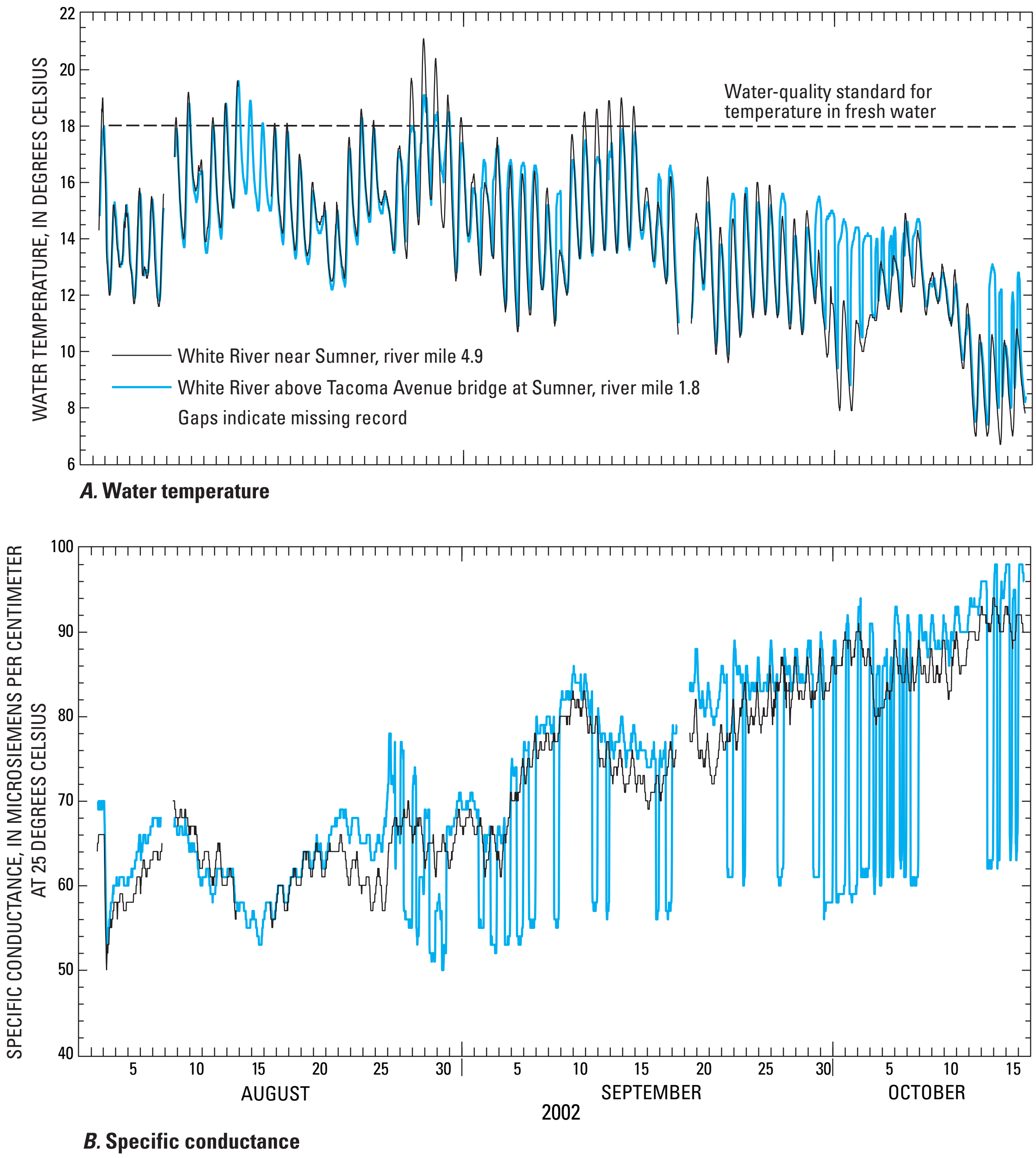
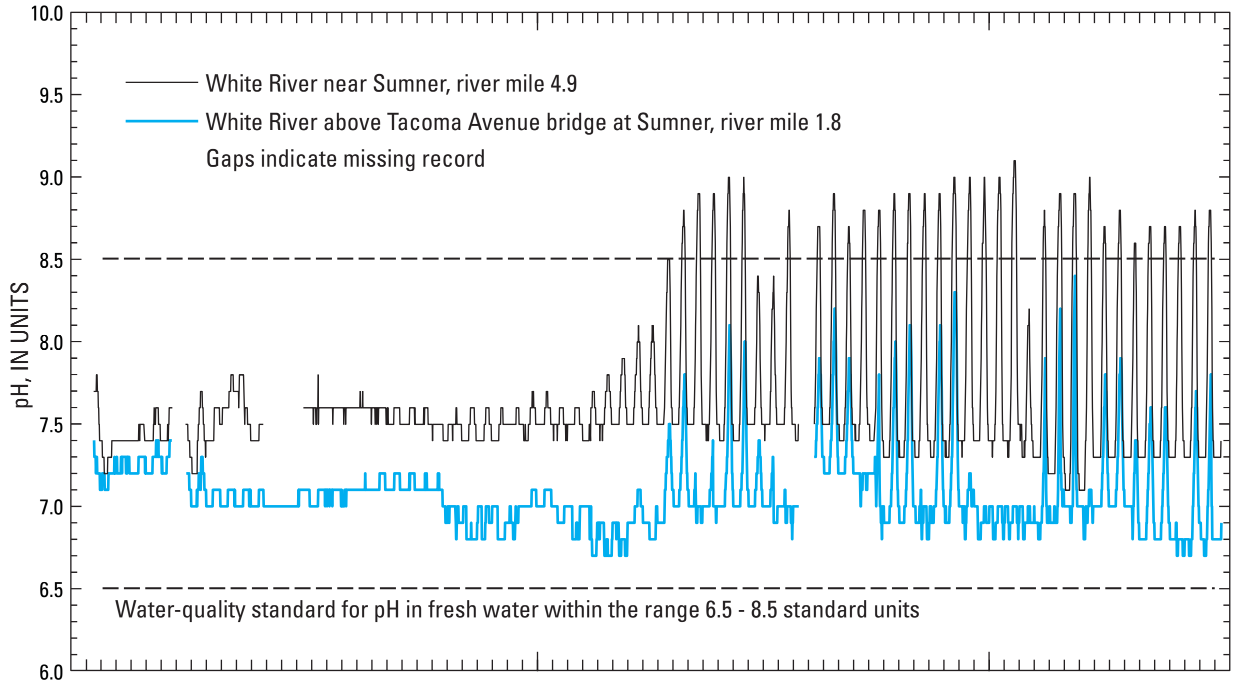
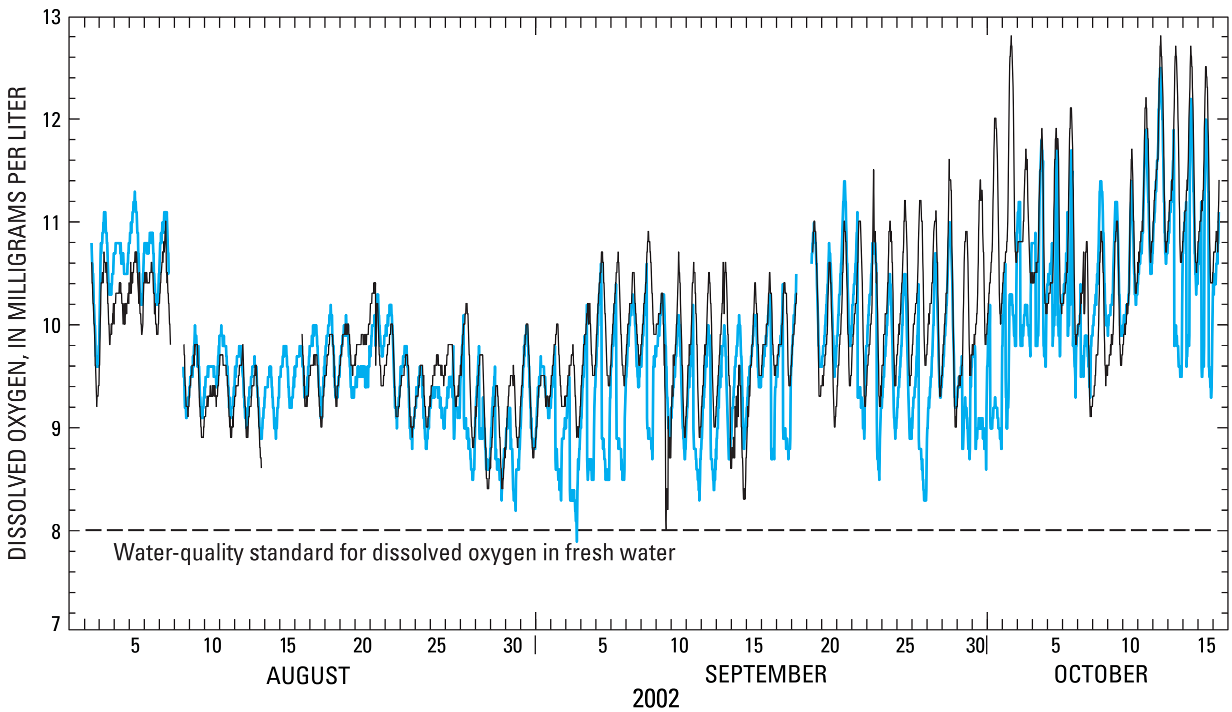


Figure 3. Water temperatures, specific conductance, pH, and dissolved-oxygen concentrations at two monitoring sites in the lower White River, Washington, August 2-October 16, 2002.



C. **pH**



D. **Dissolved oxygen**

Figure 3.—*Continued.*

Table 4. Maximum and minimum recorded values of water temperature, specific conductance, pH, and dissolved-oxygen concentrations at two monitoring sites in the lower White River, Washington, August 2-October 16, 2002

[**Abbreviations:** °C, degrees Celsius; µS/cm, microsiemen per centimeter at 25 °C; pH unit, standard pH unit; mg/L, milligram per liter]

Physical property		Maximum and minimum recorded value	
		White River near Sumner, river mile 4.9	White River above Tacoma Avenue bridge at Sumner, river mile 1.8
Temperature (°C)	Maximum	21.1	19.6
	Minimum	6.7	7.4
Specific conductance (µS/cm)	Maximum	94	98
	Minimum	50	50
pH (units)	Maximum	9.1	8.4
	Minimum	7.1	6.7
Dissolved oxygen (mg/L)	Maximum	12.8	12.5
	Minimum	8.0	7.9

From August 2-25, when little or no water was discharged from Lake Tapps to the White River, water temperatures at both monitoring sites were similar (fig. 3*A*). In late September and early October, water temperatures at RM 1.8 were often higher than those at RM 4.9 because of the mixing of warmer water discharged from Lake Tapps with cooler water in the White River (fig. 3*A*; see fig. 2 for discharges).

Because specific conductance in the White River increases in a downstream direction as a result of natural and anthropogenic sources of dissolved minerals and other ionic species (Stuart, 2002), water diverted from the White River at RM 24.3 into Lake Tapps has a lower specific conductance than water in the lower White River. When water released from Lake Tapps mixes with water in the White River, specific conductance decreases, as illustrated by comparing specific conductance values at RM 1.8 with those at RM 4.9 (fig. 3*B*; see fig. 2 for discharges).

Maximum values of pH in the White River at RM 4.9 often exceeded 8.5 units (fig. 3*C*), the upper limit of the water-quality standard (State of Washington, 1997), from mid-September until the end of data collection in mid-October. Some of the difference between daily minimum values of pH at RM 4.9 and those at RM 1.8 (fig. 3*C*) is caused by the error inherent in comparing data from instruments each with an accuracy of ±0.2 pH units. Other factors affecting pH in the lower White River are discussed in section "Factors Affecting Dissolved-Oxygen Concentrations and pH in the Lower White River."

Dissolved-oxygen concentrations in the lower White River remained above the water-quality standard of 8.0 mg/L (State of Washington, 1997) except for a concentration of 7.9 mg/L in the White River at RM 1.8 and a concentration of 8.0 mg/L at RM 4.9 (fig. 3*D*, table 4). The minimum concentration of 7.9 mg/L was similar to the minimum concentration of 7.8 mg/L measured at RM 1.8 in 2001 (Ebbert, 2002). As mentioned previously, an objective of monitoring in 2002 was to verify that the minimum dissolved-oxygen concentrations measured in 2001 were not the result of measurement errors. At the time, the minimum concentration of 7.9 mg/L was recorded on September 3, 2002, the accuracy of the data was considered to be good (table 2), therefore, the 2002 data help to verify that minimum dissolved-oxygen concentrations at RM 1.8 decrease to less than 8 mg/L. Other factors affecting dissolved-oxygen concentrations in the lower White River are discussed in the next section, "Factors Affecting Dissolved-Oxygen Concentrations and pH in the Lower White River."

Factors Affecting Dissolved-Oxygen Concentrations and pH in the Lower White River

Dissolved-oxygen concentrations at RM 4.9 were affected very little by the additional flow in the White River from August 2-25 (fig. 4*A*). Water temperature, however, did influence dissolved-oxygen concentrations in the lower White River, as illustrated using data for RM 4.9 that show the increase in water temperature and corresponding decrease in dissolved-oxygen concentrations after August 6, and the slow increase in average dissolved-oxygen concentrations as water temperatures began to decrease in late September and early October (fig. 4*B*).

During the 2001 study, water discharging from Lake Tapps tailrace canal into the White River at RM 3.6 usually decreased dissolved-oxygen concentrations downstream at RM 1.8 (Ebbert, 2002). Because data collected in 2002 provide a direct comparison between dissolved-oxygen concentrations in theWhite River upstream and downstream of the tailrace canal, they illustrate the decrease in dissolved-oxygen concentrations at RM 1.8 associated with discharge from Lake Tapps (fig. 5).

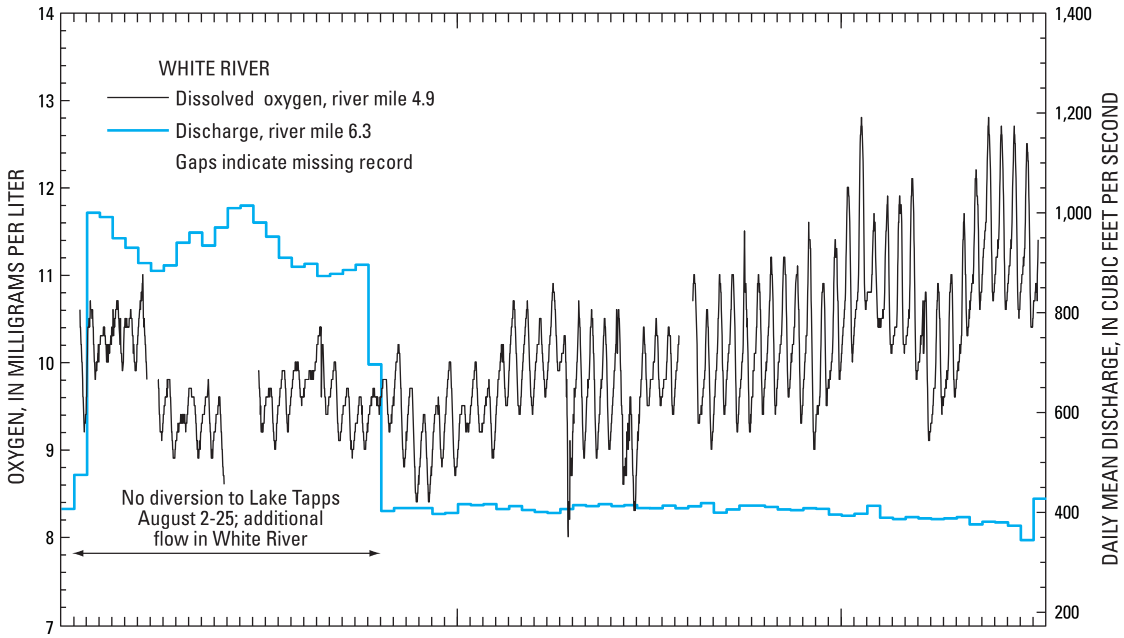
Stuart (2002) described the inverse relation between the magnitude of 24-hour variations in pH in the White River and concentrations of suspended solids. Suspended solids limit light penetration into the water column, which in turn limits primary productivity, photosynthesis, and corresponding 24-hour variations in pH and dissolved-oxygen concentrations. During summer, most of the suspended solids in the White River consist of fine-grained sediment derived from glacial melting in its headwaters on Mount Rainier.

Although the 2002 study did not sample for suspended solids or measure turbidity, the effect of suspended-solids concentrations on 24-hour variations in pH and dissolved-oxygen concentrations can be assessed using turbidity data provided by the U.S. Army Corps of Engineers for the White River at RM 23.8, upstream of the study area. The turbidity data provide a rough estimate of variations in concentrations of suspended solids in the lower White River. The data generally are consistent with Stuart's findings (Stuart, 2002) (fig. 6). Daily variations in pH at river mile 4.9 increased in mid-September when all but one turbidity value was less than 200 NTU (nephelometric unit). Turbidity values reached as high as 1,000 NTU in August. Water temperatures at river mile 4.9 indicate that decreasing water temperatures in late September and early October, which might limit primary productivity, had little effect on 24-hour variations in pH. Daily variations in dissolved-oxygen concentrations in the White River at RM 4.9, which are not affected by discharge from Lake Tapps, also increased in mid-September (fig. 4A) after turbidity decreased (fig. 6).

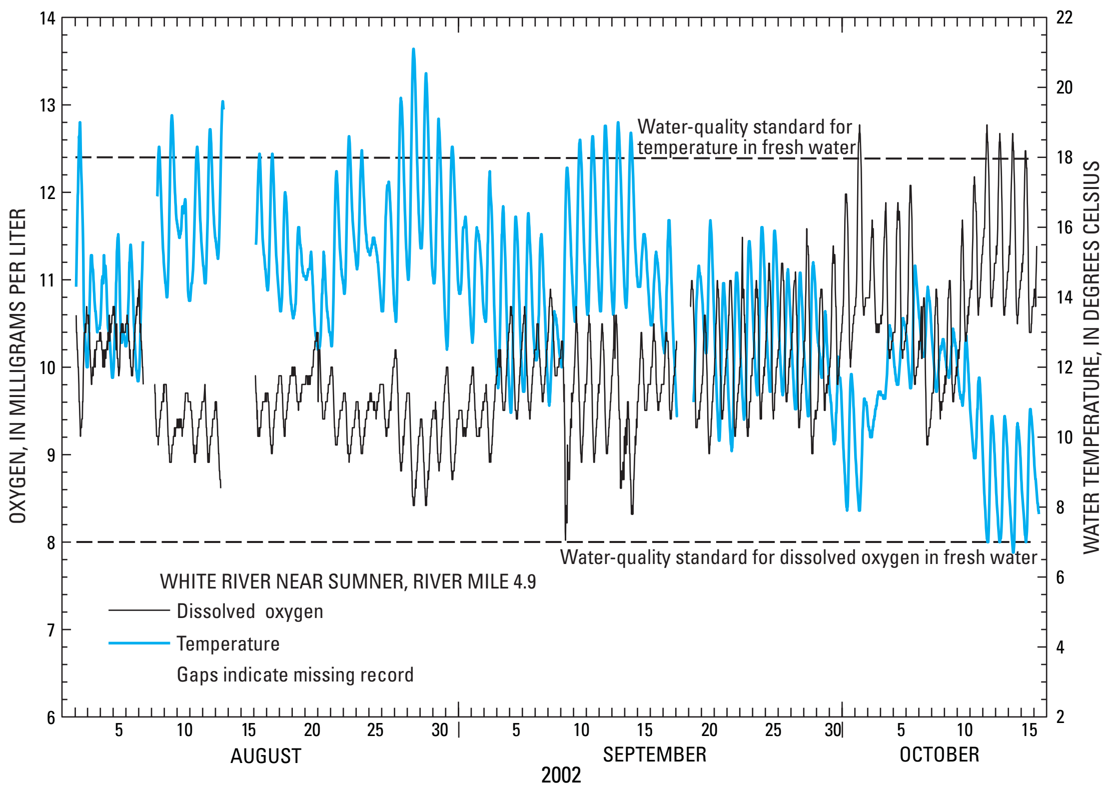
Puyallup River Estuary

In September 2002, lateral and vertical variations in water temperature, specific conductance, pH, and dissolved-oxygen concentrations were measured along a cross section at RM 1.5 in the lower Puyallup River estuary during low and high tides (table 5). At low tide, on September 5, 2002, the salt wedge did not extend to RM 1.5 and the measured concentrations were indicative of mostly unaltered Puyallup River water (table 5). During high tide on September 12, the salt wedge extended to RM 1.5, as indicated by a steep increase in specific conductance values starting at about 4 feet below the water surface (fig. 7, table 5).

At high tide, dissolved-oxygen concentrations ranged from 9.9 to 10.2 mg/L in fresh water at the surface and from 8.1 to 8.4 mg/L in salt water near the riverbed (fig. 7). These values were within lower limits set by water-quality standards for dissolved oxygen of 8 mg/L in fresh water and 6 mg/L in marine water (State of Washington, 1997). Based on a measurement made in the Puyallup River at RM 3.2, the dissolved-oxygen concentrations in water flowing into the estuary was 10.4 mg/L (table 5). The dissolved-oxygen concentrations near the surface of Commencement Bay was 8.3 mg/L, which was similar to concentrations measured in the salt wedge (table 5).



A. **Dissolved oxygen and discharge**



B. **Dissolved oxygen and temperature**

Figure 4. Relation between dissolved-oxygen concentrations at river mile 4.9 and daily mean discharge and at river mile 6.3 and relation between dissolved-oxygen concentrations and water temperature at river mile 4.9 in the White River, Washington, August 2-October 16, 2002.

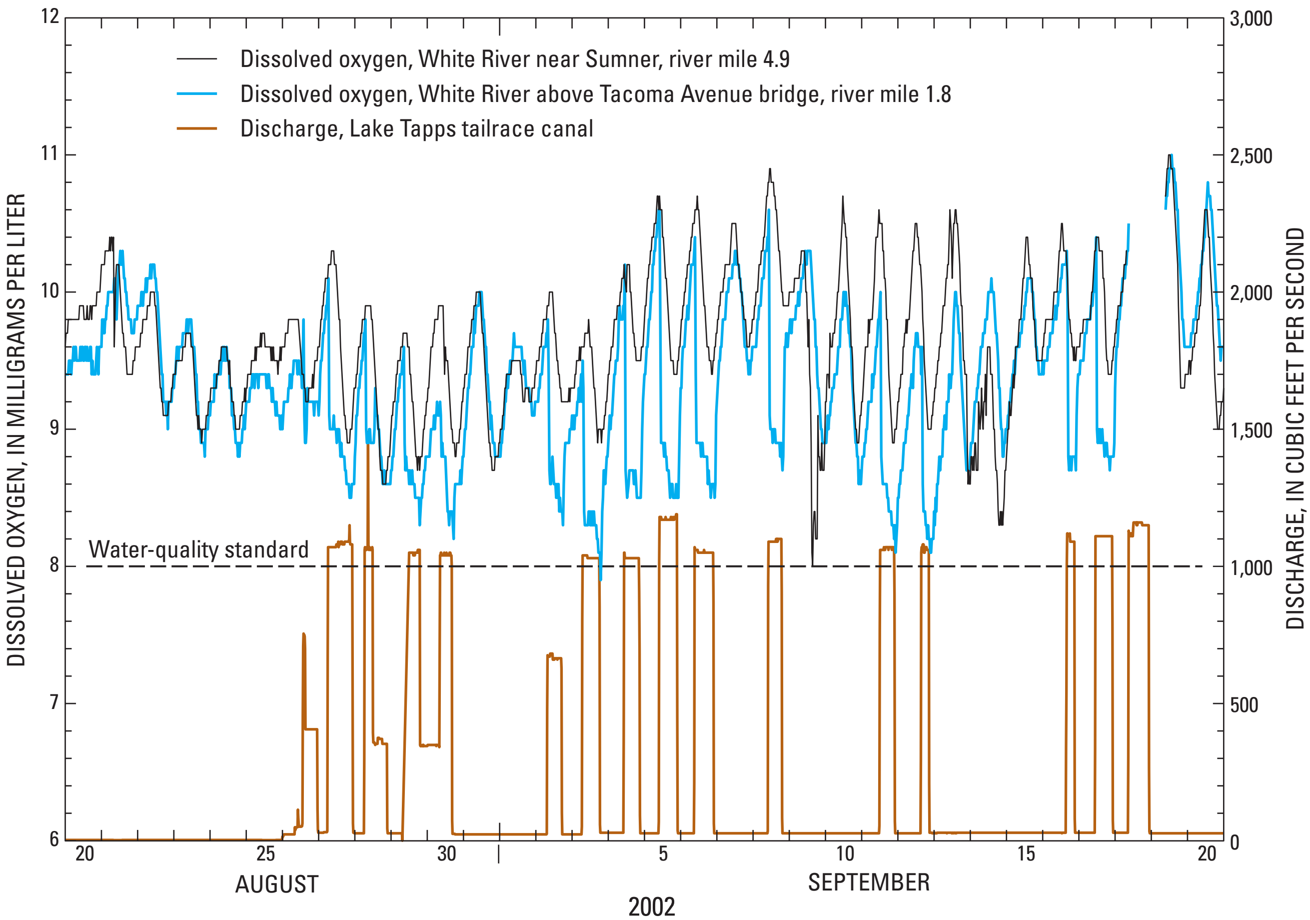


Figure 5. Effect of discharge from the Lake Tapps tailrace canal dissolved-oxygen concentrations at river mile 1.8 in the lower White River, Washington, August-October 2002.

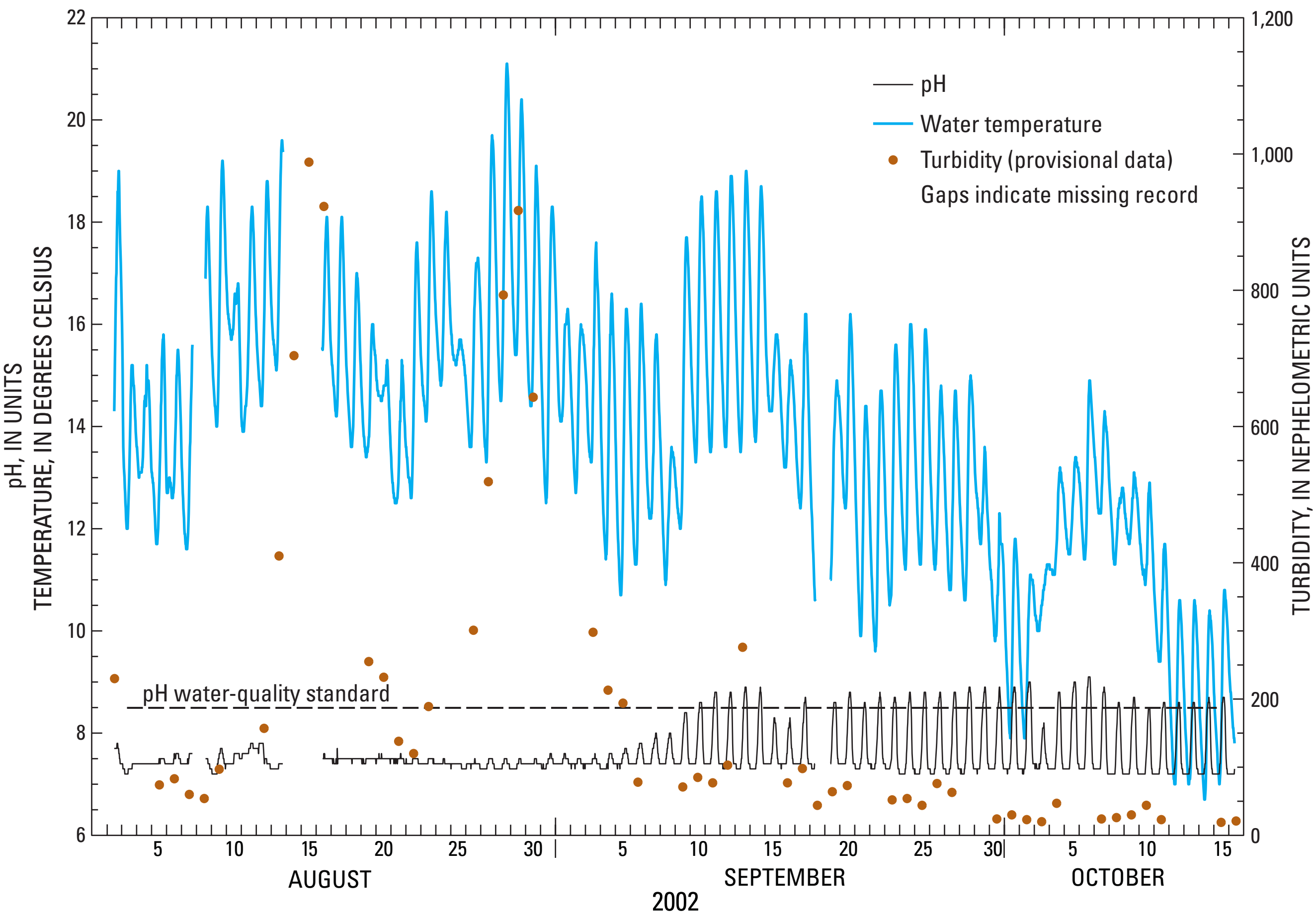


Figure 6. Relation between pH and water temperature at river mile 4.9 and turbidity upstream from the study area at river mile 23.8 in the White River, Washington, August-October 2002.

Turbidity data were provided by the U.S. Army Corps of Engineers and are provisional.

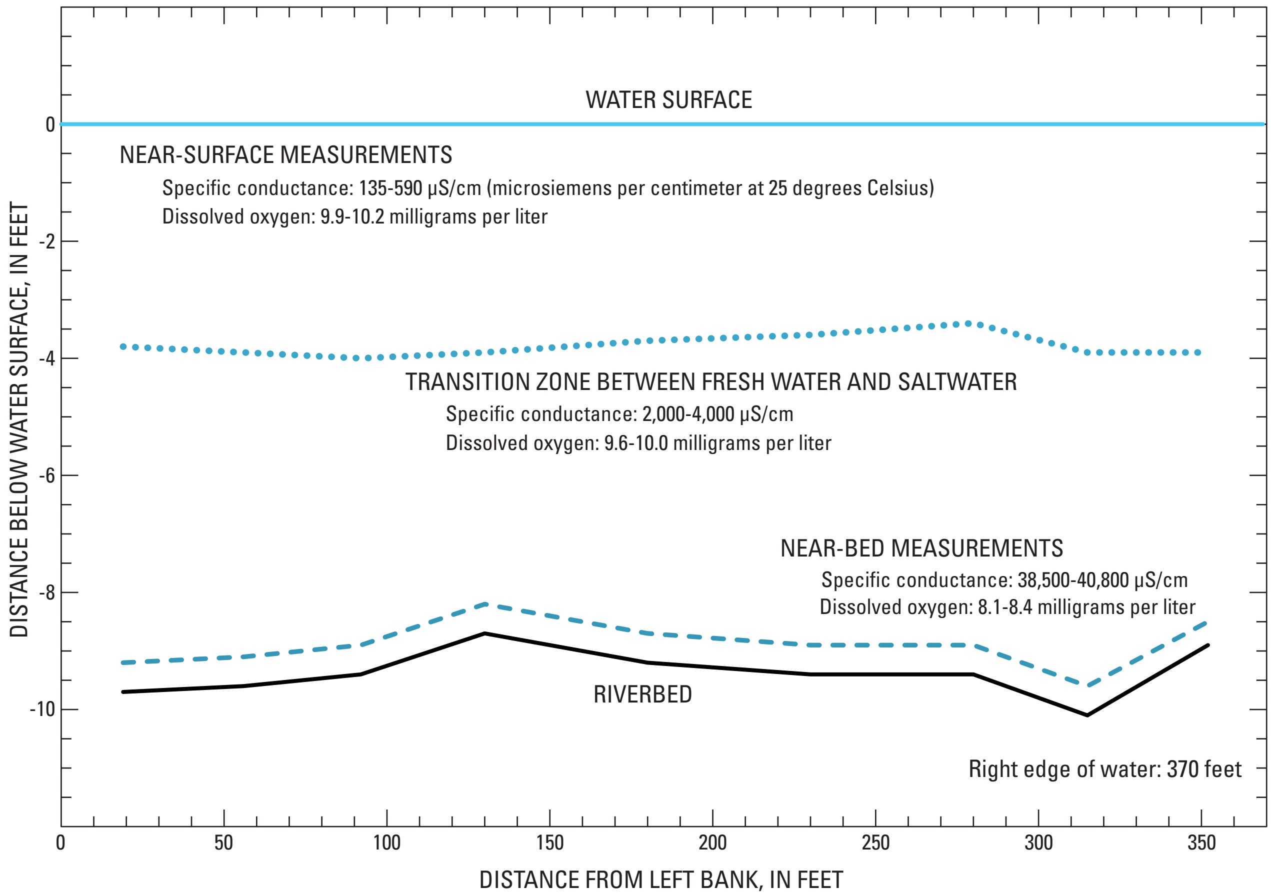


Figure 7. Lateral and vertical variations in specific conductance and dissolved-oxygen concentrations during high tide at river mile 1.5 in the Puyallup River, Washington, September 12, 2002.

Table 5. Lateral and vertical variations in water temperature, specific conductance, pH, and concentrations of dissolved oxygen during low and high tides at river mile 1.5 in the Puyallup River estuary, Washington, September 2002

[Data collected at USGS station 12102400 – Puyallup River at Lincoln Avenue at Tacoma, WA; LB, left bank; ^{o}C, degrees Celsius; µS/cm, microsiemen per centimeter at 25 ^{o}C; mg/L, milligram per liter; mm Hg, millimeter of mercury]

Barometric pressure: 752 mm Hg
Stream width: 340 feet
Time of low tide: 1019
Date: September 5, 2002

LOW TIDE (Parameter and code)							
Time	**Distance from left bank (feet) 00009**	**Depth to bottom (feet below water surface) 81903**	**Depth of sample (feet below water surface) 00003**	**Water temperature (^{o}C) 00010**	**Specific conductance (µS/cm) 00095**	**pH (standard units) 00400**	**Dissolved oxygen (mg/L) 00300**
0925	20	2.7	.5	11.6	362	7.1	10.3
0927	20	2.7	2.1	11.6	356	7.0	10.4
0930	50	3.0	.6	11.6	284	7.0	10.4
0932	50	3.0	2.4	11.6	284	7.1	10.7
0935	85	2.4	.5	11.5	239	7.2	10.5
0937	85	2.4	1.9	11.5	236	7.1	10.7
1002	120	2.0	.4	11.6	214	7.3	10.8
1003	120	2.0	1.6	11.6	217	7.2	11.0
1005	150	2.4	.5	11.6	203	7.1	10.7
1006	150	2.4	1.9	11.6	203	7.1	10.7
1007	190	2.0	.4	11.7	201	7.1	10.7
1008	190	2.0	1.6	11.7	200	7.1	10.8
1010	220	2.1	.4	11.7	203	7.1	10.6
1011	220	2.1	1.6	11.7	203	7.1	10.7
1012	260	2.0	.4	11.7	231	7.2	10.7
1013	260	2.0	1.6	11.7	229	7.1	10.8
1014	290	2.4	.5	11.8	304	7.2	10.7
1015	290	2.4	1.9	11.8	294	7.1	10.9
1016	320	2.8	.5	11.9	523	7.2	10.6
1017	320	2.8	2.1	11.9	607	7.1	10.6
1018	335	1.6	.3	12.0	750	7.1	10.6
1019	335	1.6	1.3	12.0	738	7.1	10.8

Table 5. Lateral and vertical variations in temperature, specific conductance, pH, and concentrations of dissolved oxygen in the Puyallup River at river mile 1.5—*Continued*

[Data collected at USGS station 12102400 – Puyallup River at Lincoln Avenue at Tacoma, WA; LB, left bank; deg ^{0}C, degrees Celsius; µs/cm, microsiemens per centimeter at 25 deg ^{0}C; mg/L, milligrams per liter; mm Hg, millimeters of mercury; parameter codes are indicated]

Barometric pressure: 759 mm Hg
Stream width: 370 feet
Time of high tide: 1030
Date: September 12, 2002

HIGH TIDE							
Time	Distance from left bank (feet) 00009	Depth to bottom (feet) 81903	Depth sample (feet) 00003	Water temperature (deg ^{0}C) 00010	Specific conductance (µS/cm) 00095	pH (standard units) 00400	Dissolved oxygen (mg/L) 00300
1047	19	9.7	0.6	14.1	590	7.5	10.0
1045	19	9.7	3.8	14.2	3,300	7.5	9.7
1044	19	9.7	9.2	13.4	40,100	7.4	8.4
1050	56	9.6	0.6	14.0	408	7.4	10.1
1055	56	9.6	3.9	14.1	3,850	7.6	9.8
1053	56	9.6	9.1	13.3	40,800	7.3	8.3
1058	92	9.4	0.6	14.0	135	7.5	10.1
1102	92	9.4	4.0	13.8	4,000	7.5	9.7
1100	92	9.4	8.9	13.4	40,600	7.5	8.1
1105	130	8.7	0.6	14.1	150	7.5	10.2
1110	130	8.7	3.9	13.7	3,300	7.6	10.0
1107	130	8.7	8.2	13.4	40,600	7.5	8.1
0959	180	9.2	0.6	14.7	160	7.5	9.9
0953	180	9.2	3.7	14.3	3,200	7.7	9.7
0950	180	9.2	8.7	13.5	38,500	7.5	8.1
1009	230	9.4	0.6	14.6	146	7.4	9.9
1005	230	9.4	3.6	14.2	2,700	7.5	9.7
1001	230	9.4	8.9	13.4	39,700	7.5	8.3
1018	280	9.4	0.6	14.6	137	7.4	9.9
1013	280	9.4	3.4	14.2	670	7.8	9.7
1010	280	9.4	8.9	13.4	39,800	7.4	8.2
1030	315	10.1	0.6	14.5	135	7.5	9.9
1025	315	10.1	3.9	14.2	3,000	7.4	9.8
1021	315	10.1	9.6	13.4	40,400	7.6	8.1
1040	352	8.9	0.6	14.3	388	7.4	9.9
1037	352	8.9	3.9	14.5	2,000	7.7	9.9
1033	352	8.9	8.5	13.4	40,300	7.6	8.1
Additional data collected 9/12/02							
Puyallup River at river mile 3.2 at 1130			surface	13.8	102	7.1	10.4
Commencement Bay at 1142			surface	13.5	41,300	7.7	8.3

SUMMARY

The U.S. Geological Survey, Washington State Department of Ecology, and Puyallup Tribe of Indians monitored water temperature, specific conductance, pH, and dissolved-oxygen concentrations in the White River, a tributary of the Puyallup River, at river miles 4.9 and 1.8 from August through mid-October 2002. During the same period in a similar study in 2001, dissolved-oxygen concentrations in the lower White River decreased to less than Washington State water-quality standards on two occasions, but the results were uncertain because quality of the monitoring record for those times was rated as poor. The 2002 study reach includes the point where a tailrace canal discharges water, diverted from the White River upstream from the study area to a hydropower facility on Lake Tapps, back into the river. The 2002 study also included measuring lateral and vertical variations of the same parameters at river mile 1.5 in the Puyallup River estuary, in order to measure conditions downstream of river mile 2.9, the location of a monitor in the 2001 study.

In late August, maximum daily temperatures in the White River exceeded the water-quality standard of 18 ^{o}C at both monitoring sites. The maximum water temperature at river mile 4.9 was 21.1 ^{o}C, and at river mile 1.8, it was 19.6 ^{o}C. In mid-September, maximum daily water temperatures at river mile 4.9 exceeded the standard on 5 days. Minimum temperatures at both sites were in mid-October at the end of the installment period.

From August 2-25, little or no water was discharged from Lake Tapps to the White River at river mile 3.6, and water temperatures at both monitoring sites were similar. In late September and early October, increases in water temperature at river mile 1.8 that were not observed at river mile 4.9 were caused by the mixing of warmer water discharged from Lake Tapps with cooler water in the White River.

The mixing of water discharged from Lake Tapps with water in the White River usually lowered specific conductance in the White River at river mile 1.8 compared with values measured upstream at river mile 4.9. This is because water diverted into Lake Tapps has a lower specific conductance than water in the lower White River.

In August, turbidity caused by the presence of fine-grained sediment derived from glacial melting on Mount Rainier limited light penetration, which in turn limited primary productivity and moderated 24-hour variations in pH and dissolved-oxygen concentrations in the lower White River. Turbidity decreased in early September, and from mid-September until the end of data collection in mid-October, maximum values of pH in the White River at river mile 4.9 often exceeded 8.5 pH units, which is the upper limit of the water-quality standard. The pH standard was not exceeded at river mile 1.8.

Because dissolved-oxygen concentrations in water discharged from Lake Tapps are usually lower than concentrations in the White River, mixing of water discharged from Lake Tapps with water in the White River usually lowered dissolved-oxygen concentrations in the White River at river mile 1.8 compared with concentrations measured upstream at river mile 4.9. The lowest dissolved-oxygen concentrations observed was 7.9 mg/L at river mile 1.8. The lower limit allowed by the water-quality standard is 8 mg/L.

Dissolved-oxygen concentrations measured in a cross section of the Puyallup River estuary at high tide on September 12, 2002, ranged from 9.9 to 10.2 mg/L in fresh water at the surface and from 8.1 to 8.4 mg/L in salt water near the riverbed. These values were within lower limits set by Washington State water-quality standards for dissolved oxygen of 8 mg/L in fresh water and 6 mg/L in marine water.

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Appendix A. Protocol used for servicing and calibration of water-quality monitors on the Lower White River and Puyallup River estuary, Washington, August–October 2002

Station No. ____________________ Location__________________________________ Date________________

Barometric pressure_________ Turbidity (visibility limit)____________ Inspected by__________________

Step 1: On the hour or half hour and before retrieving the monitor, take readings with the field meter and collect enough sample water to fill three bottles for Winkler DO titration. Fix and titrate two of the three bottles. If the results agree within 0.3 mg/L, stop. If not, fix and titrate the third bottle. 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)

Important: 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: Download the data from the previous deployment period. Inspect the data to discover potential problems like sedimentation or erratic readings.

Name of file downloaded________________________________

Step 4: Calibration check. Recalibrate if difference between reading and standard are more than the limits listed in Step 2. **Always calibrate specific conductance first.** Perform calibration check for DO using zero DO solution and the water-saturated air method.

DO membrane replaced? ________, If yes, replace with back-up DO probe.

Parameter	Standard, or other check value	Reading	@ Temperature, deg Celsius	Monitor set to:	Calibrated reading
Specific cond.	Air				
Specific cond.					
Specific cond.					
pH	7				
pH	10				
Dissolved Oxy	Zero DO solution				
Dissolved Oxy	Sat. value =				

Step 5: Create a new logging file and check file status to make sure it was created. Deploy the monitor. On the hour or half-hour, take instream readings with field meter, and collect enough sample water to fill three bottles for Winkler DO titration. Fix and titrate two of the three bottles. If the results agree within 0.3 mg/L, stop. If not, fix and titrate the third bottle. The readings from the Hydrolab will be added to the table after the data are downloaded during the next visit.

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

Important: Record time that monitor was deployed here: ___________ Name of new logging file ____________________

USGS

Ebbert

Water Temperature, Specific Conductance, pH, and Dissolved-Oxygen Concentrations in the Lower White River and the Puyallup River Estuary, Washington, August-October 2002

WRIR 03–4177