WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

Spokane River and Lake Spokane (Long Lake) Pollutant Loading Assessment for Protecting Dissolved Oxygen

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Spokane River and Lake Spokane (Long Lake) Pollutant Loading Assessment for Protecting Dissolved Oxygen

by
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Environmental Assessment Program
Olympia, Washington 98504-7710

February 2004

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Abstract

The primary goal of the Spokane River and Lake Spokane (Long Lake) study was to assess the impacts of point and nonpoint sources of pollutants on dissolved oxygen concentrations to determine if the river and lake were in compliance with Washington State water quality criteria. Another goal of the study was to evaluate the existing total phosphorus criterion and associated total daily maximum load (TMDL) for Lake Spokane.

The Spokane River exhibits diurnally low dissolved oxygen levels during the summer months mainly due to periphyton growth stimulated by nutrient loading. The dissolved oxygen concentrations in the bottom waters of Lake Spokane during the summer stratification period also have been shown to be low.

Review of the historical studies used to establish the current phosphorus criterion and TMDL for Lake Spokane indicates that the criterion and loading limits are too high to protect water quality in the lake. In addition, the historical studies reported that hypolimnetic oxygen concentrations were impaired in Lake Spokane by point and nonpoint sources of phosphorus by productivity and decomposition of organic material.

A calibrated U.S. Army Corps of Engineers dynamic 2-dimensional CE-QUAL-W2 Version 3.1 model was used to simulate the hydrodynamics and water quality of the river system and to assess the effects of pollutants from both point and nonpoint sources on dissolved oxygen concentrations. The modeling results indicate that (1) in some areas of the Spokane River and Lake Spokane, dissolved oxygen violates water quality criteria during critical conditions, and (2) current loading of organic material and nutrients from both point and nonpoint sources will need to be reduced to meet the 0.2 mg/L human-caused decrease in dissolved oxygen concentrations currently allowed.

Acknowledgements

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- Chris Berger, Rob Annear, and Scott Wells, Portland State University, School of Engineering, for developing the CE-QUAL-W2 model and providing technical assistance.

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Introduction

Background

The Washington State Department of Ecology (Ecology) is concerned about the pollutant loading capacity of the Spokane River system, including the Lake Spokane (Long Lake) impoundment which has a long history of water quality problems. The Spokane River exhibits low dissolved oxygen levels during the summer months, in violation of Washington State water quality standards. Segments of the river are included on Ecology's 1998 303(d) list of impaired waterbodies, for dissolved oxygen. The dissolved oxygen concentrations in the bottom waters of Lake Spokane during the summer stratification period have been identified as impaired (URS, 1981; Patmont et al., 1987). A total maximum daily load (TMDL) for this waterbody was identified as a high priority during the water quality scoping process for the Spokane Water Quality Management Area (Knight, 1998).

Section 303(d) of the federal Clean Water Act mandates that Washington State establish TMDLs for pollutants for surface waters that do not meet standards after application of technology-based pollution controls. The U.S. Environmental Protection Agency (EPA) has established new regulations (40 CFR 130) and developed guidance for determining TMDLs.

Under the Clean Water Act, every state has its own water quality standards designed to protect, restore, and preserve water quality. Water quality standards consist of (1) designated uses, such as cold water biota and drinking water supply, and (2) criteria, usually numeric, to achieve those uses. When a lake, river, or stream fails to meet water quality standards after application of required technology-based controls, the Clean Water Act requires the state to place the waterbody on a list of impaired waterbodies and to prepare an analysis called a *Total Maximum Daily Load (TMDL).*

The goal of a TMDL is to ensure the impaired water will attain water quality standards. A TMDL includes a written, quantitative assessment of water quality problems and of the pollutant sources that cause the problems. The TMDL determines the amount of a given pollutant that can be discharged to the waterbody and still meet water quality standards. The TMDL also determines the *loading capacity* and allocates that loading capacity among the various sources. If the pollutant comes from a discrete (*point*) source such as an industrial facility's discharge pipe, that facility's share of the loading capacity is called a *wasteload allocation*. If it comes from a diffuse (*nonpoint*) source such as agricultural land or neighborhoods, that nonpoint share is called a *load allocation.*

The TMDL must include a *margin of safety* that takes into account lack of knowledge about the causes of the water quality problem or its loading capacity. The TMDL also must account for seasonal variability and address future growth. The sum of the individual allocations and the margin of safety must be equal to or less than the loading capacity.

Ecology's Eastern Regional Office requested that Ecology's Environmental Assessment Program Watershed Studies Unit determine minimum dissolved oxygen concentrations during critical conditions in the Spokane River and Lake Spokane, and determine the potential impacts of point and nonpoint sources of oxygen-consuming substances (i.e., biochemical oxygen demand - BOD).

The Eastern Regional Office also requested that the Watershed Studies Unit reassess the nutrient loading to Lake Spokane, and if needed, update the phosphorus (P)-attenuation model developed for the river in the mid 1980s (Patmont et al., 1985). Nutrient enrichment and eutrophication of Lake Spokane has been one of the major water quality concerns for the area. In the early 1980s, Ecology established a total phosphorus TMDL for the lake. The P-attenuation model was developed to predict and allocate phosphorus loads into the lake from the Spokane River (and Little Spokane River).

The two project requests were linked because nutrient loading and BOD both affect dissolved oxygen concentrations. Eutrophication (due to excess nutrients) increases plant growth and decreases dissolved oxygen due to plant respiration and decay of the organic material produced. Direct loading of BOD from point and nonpoint sources also decreases dissolved oxygen concentrations. Both of these water quality issues can be exacerbated during periods of low river flow and warm temperatures, especially in the deep, slow-moving water segments of the river system like Lake Spokane. The results of this study will require allocations for both BOD and nutrients to mitigate the impact of these pollutants on dissolved oxygen.

The purpose of this report is to provide an assessment of pollutant loading effects on dissolved oxygen in the Spokane River and Lake Spokane. Specific pollutant TMDL(s) and allocations are not proposed. However, it is expected that the material presented in this report will be the basis for establishing pollutant loading limits for the river and lake.

Study Area

The Spokane River upstream of Lake Spokane drains over 6,000 square miles of land in Washington and Idaho (Figure 1). Most of the people in the watershed live in the Spokane metropolitan area. However, the incorporated area of Liberty Lake east of Spokane and the cities of Coeur d'Alene and Post Falls in Idaho are growing in population.

The Spokane River flows west from Lake Coeur d'Alene in Idaho, across the state line to the city of Spokane. From Spokane, the river flows northwesterly to its confluence with the Columbia River at Lake Roosevelt. The study area for this project is shown in Figure 2 and extends from the Stateline Bridge at approximately river mile[1] (RM) 96.0 to Lake Spokane Dam at RM 33.9 (i.e., the study area does not include the Idaho portion of the river).

There are four hydroelectric dams located in the study area: Upriver Dam (RM 79.9), Monroe Street Dam (RM 73.4), Nine-Mile Dam (RM 57.6), and Lake Spokane Dam (RM 33.9). There is also a dam at Post Falls, Idaho (RM 100.8) that influences the hydrodynamics of the river. All of the Washington dams are run-of-the river types except Lake Spokane Dam (Long Lake dam), which creates Lake Spokane (Long Lake), a 24-mile long reservoir.

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[1] River miles are based on those used by the U.S. Geological Survey (USGS) unless otherwise noted.

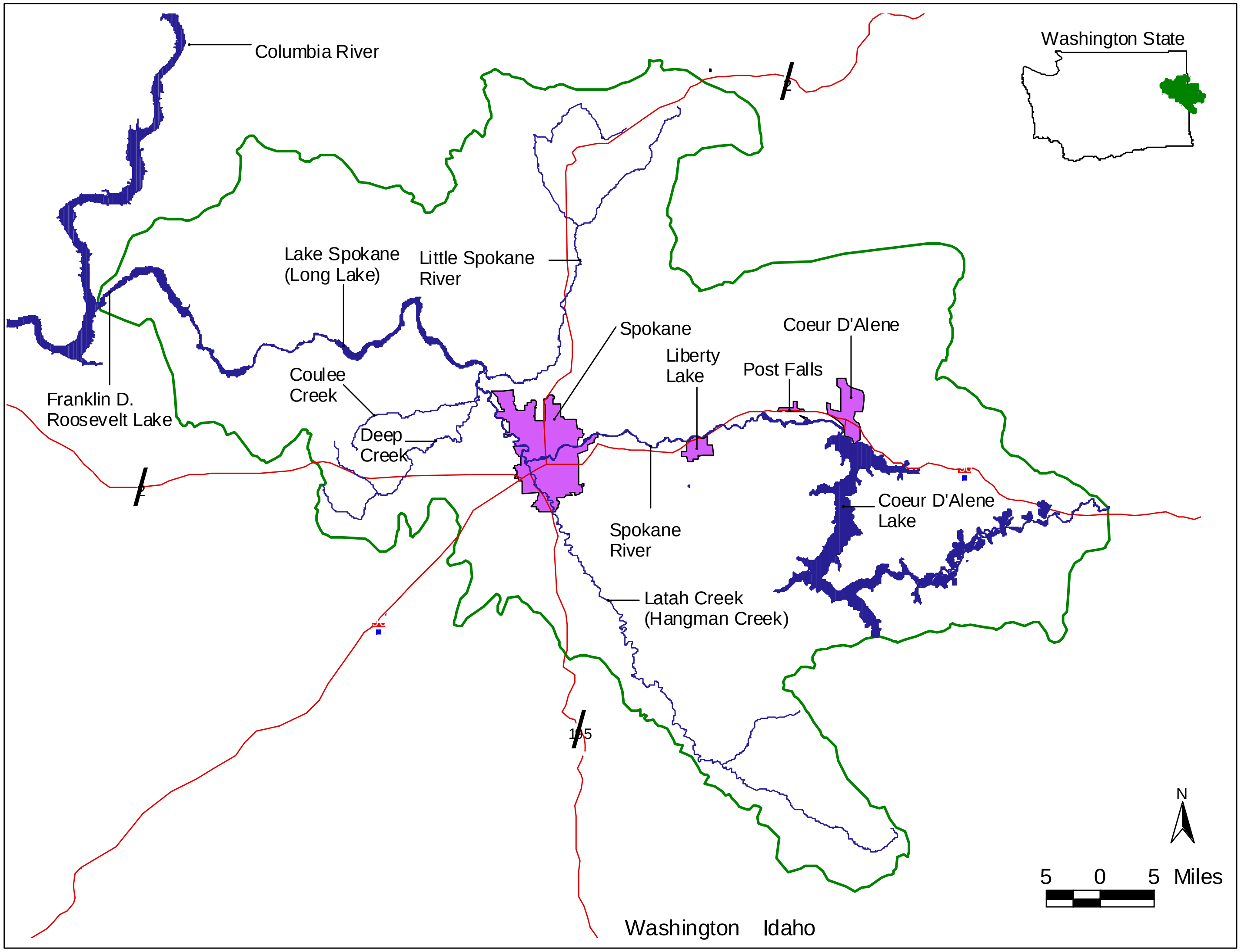

Figure 1. Spokane River watershed map. (Portions of the St. Joe River and Coeur d'Alene River, Idaho watersheds, are not included).

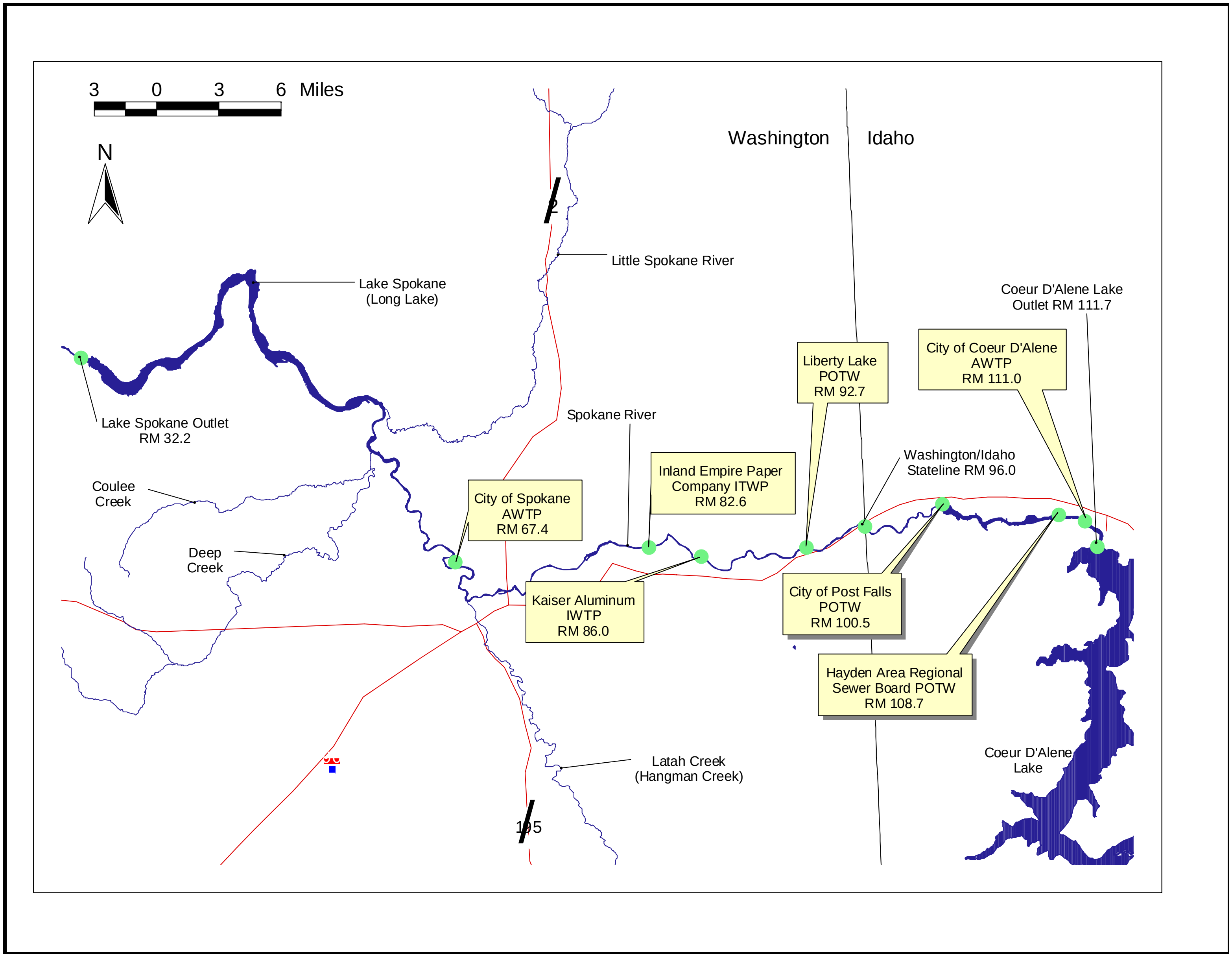

Figure 2. Spokane River and Lake Spokane study area map.

Sources of Oxygen-consuming Substances and Nutrients

The following facilities (Figure 2) have National Pollutant Discharge Elimination System (NPDES) permits for discharging biochemical oxygen demand and/or ammonia to the Spokane River study area. These are listed in order of upstream to downstream:

Idaho

- City of Coeur d'Alene Advanced Wastewater Treatment Plant (AWTP)
- Hayden Area Regional Sewer Board Publicly-owned Treatment Works (POTW)
- City of Post Falls POTW

Washington

- Liberty Lake POTW
- Kaiser Aluminum Industrial Wastewater Treatment Plant (IWTP) at Trentwood
- Inland Empire Paper Company IWTP
- City of Spokane AWTP

The following tributaries affect dissolved oxygen levels and nutrient concentrations in the Spokane River study area:

- Latah Creek (or Hangman Creek). The communities of Cheney, Spangle, Rockford, Tekoa, and Fairfield all have small seasonal POTW discharges to creeks in this watershed.
- Little Spokane River. Kaiser-Mead IWTP (currently not in operation), Washington Department of Fish and Wildlife Spokane Fish Hatchery, and Colbert Landfill Superfund Site groundwater pump and treatment system operated by Spokane County discharge to the Little Spokane River.
- Coulee/Deep Creeks. The City of Medical Lake discharges a portion of its effluent to a tributary of Deep Creek. Knight (1998) states that "At current proposed design flows, the discharge will probably not affect the Spokane River. However, as the system is expanded there may be some winter hydraulic capacity issues in Deep Creek and a potential for a new growing-season phosphorus load to the Spokane River.")

The Spokane Aquifer also affects dissolved oxygen levels and nutrient concentrations in the river. The aquifer discharges to the river in some reaches, and is recharged by the river in other reaches (see Hydrology section).

In addition, nonpoint sources along the length of the river system may be contributing BOD and nutrients. However, other than the tributary and groundwater loads, nonpoint sources along the mainstem of the river were relatively small during the period of concern because stormwater and combined sewer overflow (CSO) discharges to the river have been greatly reduced over the last 15-20 years. The contributions of BOD and nutrients from small discharges to the tributaries of the Spokane River were included as part of the tributary loading to the river, and not assessed as "discrete" loads for this study.

Classification and Water Quality Criteria

The Spokane River water quality classifications and dissolved oxygen criteria are:

Portion Of Study Area	Classification	Dissolved Oxygen Criterion
Lake Spokane or Lake Spokane (from Lake Spokane Dam to Nine Mile Bridge)	Lake Class	No measurable decrease from natural conditions.
Spokane River (from Nine Mile Bridge to the Idaho border)	Class A	Dissolved oxygen shall exceed 8.0 mg/L. If "natural conditions" are less than the criteria, the natural conditions shall constitute the water quality criteria.

In addition, the Spokane River has the following specific water quality criteria (Ch. 173-201A-130 WAC):

- Spokane River from Lake Spokane Dam (RM 33.9) to Nine Mile Bridge (RM 58.0). Special conditions:
  - (a) The average euphotic zone concentration of total phosphorus (as P) shall not exceed 25 ug/L during the period of June 1 to October 31.
  - (b) Temperature shall not exceed 20.0°C due to human activities. When natural conditions exceed 20.0°C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3°C; nor shall such temperature increases, at any time, exceed t=34/(T+9). ("t" represents the maximum permissible temperature increase measured at a mixing zone boundary; and "T" represents the background temperature as measured at a point or points unaffected by the discharge and representative of the highest ambient water temperature in the vicinity of the discharge.)

The Spokane River temperature from Nine Mile Bridge (RM 58.0) to the Idaho border (RM 96.0) shall not exceed 20.0°C due to human activities. When natural conditions exceed 20.0°C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3°C; nor shall such temperature increases, at any time, exceed t=34/(T+9).

Ecology has recently revised the surface water quality standards (effective August 1, 2003). The class-based system of organizing the standards was changed to a use-base system. However, the changes are not effective for federal Clean Water Act programs (i.e., the TMDL program) until they are approved by the U.S. Environmental Protection Agency (EPA). It is not anticipated that the new aquatic life dissolved oxygen criteria will change the discussion presented in this document. However, if site-specific criteria are developed or uses changed under a use attainability analysis (UAA) in future rule changes, then these actions may change the interpretation of the data and modeling results presented.

Project Goals

Ecology's Eastern Regional Office requested a study of the Spokane River partly because the City of Spokane is currently finalizing their 20-year facility plan, and the total assimilative capacity of the Spokane River to receive wastewater is not well understood. The major pollutants of concern that affect dissolved oxygen for NPDES permits are carbonaceous biochemical oxygen demand (CBOD) and ammonia. Nutrient loading is also of concern because of its indirect impact on dissolved oxygen through potential increased primary productivity and the resultant plant respiration and decay processes.

The primary goal of this project was to assess the assimilative capacity of the Spokane River system (including Lake Spokane) for CBOD and ammonia from point and nonpoint loading sources, and recommend pollutant limits based on the assimilative capacity of the river system.

Another goal of this study was to evaluate and update the P-attenuation model and associated Total Phosphorus Lake Spokane TMDL with respect to the original assumptions used to develop the model and its use to predict water quality responses in Lake Spokane.

Project Objectives

- Develop a hydrodynamic and water quality model (CE-QUAL-W2) that can be used to determine the capacity of the Spokane River and Lake Spokane to assimilate point and nonpoint sources of oxygen-consuming substances and meet water quality criteria.

- Gather existing and historical data, and conduct water quality sampling investigations that can be used to calibrate the CE-QUAL-W2 model.

- Use the CE-QUAL-W2 model to determine the potential to violate water quality criteria during critical conditions.

- Identify potential wasteload allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources of oxygen-consuming substances that will meet dissolved oxygen criteria.

- Assess the current conditions in the Spokane River and Lake Spokane, including the gain and loss of total phosphorus within the river system from the state line to Nine-Mile Dam.

- Evaluate and update the existing P-attenuation model used to predict water quality responses in Lake Spokane and compare prediction estimates to the CE-QUAL-W2 model developed for this project.

The original set of objectives listed in the Quality Assurance Project Plan (Cusimano, 1999) did not identify a specific model or models for simulating the Spokane River and Lake Spokane. However, after reviewing the capabilities of CE-QUAL-W2 Version 2 and its application in other reservoirs, it was selected for modeling Lake Spokane. During 2000, the model was upgraded to Version 3.0 (now 3.1). The new version includes modifications that enable simulations of river systems and a number of hydraulic structures (e.g., weirs, spillways, tainter gates, and pipes). The Version 3.0 modifications also made CE-QUAL-W2 the best choice for modeling the river portion of the study area. In the fall of 2000, Ecology contracted with the U.S. Army Corps of Engineers (through a joint cost share grant) to have Tom Cole, one of the model developers and Corps scientist, apply the model to the Spokane River and Lake Spokane. The Corps collaborated with Scott Wells, Professor of Engineering at Portland State University to apply the model to 1991 and 2000 conditions. Subsequent to the 1991 and 2000 model calibration, the NPDES permittees collected additional ambient and effluent data during 2001 and contracted directly with Scott Wells to apply the model to 2001 conditions.

Supporting Documents

This report relies on material presented in a number of other documents. Cusimano (2003) provides information on data sampling stations and locations, methods, data quality objectives and analytical procedures, sample collection and field measurement methods, sampling and quality control procedures, and data quality results for data collected by Ecology. Annear et al. (2001) and Slominski et al. (2003) provide data used to develop the CE-QUAL-W2 model, background information on the CE-QUAL-W2 model, and model boundary conditions and model setup for simulating the Spokane River system in Washington. Berger et al. (2002 and 2003) discusses the model calibration results. Wells et al. (2003) discusses the non-calibrated model set-up for simulating the Idaho portion of the Spokane River. In addition, Berger et al. (2004) discusses changes made to the Spokane River model calibration since the original calibration of the model discussed in the model development reports. The results presented in this report were based on the final calibrated model completed January 22, 2004. Although this report contains some background information for understanding the overall study, the report assumes the reader is familiar with the information presented in the referenced supporting documents.

All of the supporting documents are available on the World Wide Web at:
http://www.ecy.wa.gov/programs/wq/tmdl/watershed/spokaneriver/index.html

Hydrology

Spokane River and Major Tributaries

The Spokane River has its source in Lake Coeur d'Alene and empties into the Franklin D. Roosevelt Lake impoundment of the Columbia River (Figure 1). The river drains an area of about 6,640 square miles, with the lower 2,295 square miles in Washington State and the remainder in Idaho. Most of the basin in Idaho lies above Lake Coeur d'Alene. This drainage area (3,700 square miles) extends eastward to the crest of the Bitterroot Mountains that form the Montana-Idaho border. Two river systems feed the lake, the Coeur D'Alene River from the north and the St. Joe and St. Maries rivers from the south. Both enter the southern end of the lake. The rivers are unregulated and free discharging.

The rising terrain from Washington into Idaho faces the predominant eastward moving marine air masses, resulting in a west-to-east trend in increasing average annual precipitation. The rainfall in the Washington portion of the basin ranges from 15 inches in the west to about 25 inches at the Idaho border. From the Idaho border eastward, the annual rainfall increases from 25 inches to 50 inches at the headwaters of the Coeur D'Alene River and 70 inches at the headwaters of the St. Joe. From this, it is evident that the watershed of Coeur D'Alene Lake is the primary source of Spokane River waters.

Coeur D'Alene Lake has a general north-south orientation, with the Spokane River outlet to the north. The river length is about 112 miles from the lake's outlet to the mouth of the Spokane River, with 15 miles in Idaho and the remainder in Washington. Nine miles below the Spokane River's natural outlet from the lake is the first of the dams that regulate the flow of the Spokane River. The Post Falls Dam was constructed by Washington Water Power Company (now Avista Corporation) to regulate the lake level to optimize water power production. Avista has an additional five dams on the Spokane River, and the city of Spokane has one hydroelectric dam at Upper Falls (Table 1). With the exception of Lake Spokane, the impoundments are relatively small, and the associated hydroelectric works are operated on a run-of-the-river basis.

Table 1. Hydroelectric dams

Dam	River Mile	Year Constructed
Post Falls	102.1	1906
Spokane	80.2	1937
Upper Falls	76.2	1922
Monroe Street	74.2	1890*
Nine Mile	58.1	1908
Lake Spokane	33.9	1915
Little Falls	29.3	1911

* Replaced 1972

The Spokane River at Post Falls has been gauged since 1913 (USGS gauge 12419000 at RM 100.7), and the mean annual flow for the 1913-2001 period is 6,263 cfs. From Coeur D'Alene Lake to four or five miles into Washington, the river is perched on the permeable outwash gravels of the Rathdrum Prairie and Spokane Valley. The river is above the groundwater table and loses water over this reach. It has been estimated that the river loses an estimated 250 cfs between the lake and Post Falls and 120 cfs downstream of Post Falls into Washington (Pluhowski and Thomas, 1968). The loss is expected to be especially high during flood flows.

At RM 93.9, near Otis Orchard (Harvard Rd.), Washington, the mean annual flow declines to 6,083 cfs (USGS gauge 12419500). From the Harvard Rd. gauge to the city of Spokane at Monroe St., there is a net gain in river flow from groundwater inflow. The mean annual flow at Monroe St. (RM 72.9) is 6,765 cfs (USGS gauge 12422500: Spokane gauge).

The first major tributary, Latah Creek, joins the Spokane River at mile 72.4. Latah Creek, entering from the south, adds an annual flow of 243 cfs to the Spokane River (USGS gauge 12424000). There are no other surface water tributary streams between Post Falls and Latah Creek, nor downstream of Latah Creek to Coulee/Deep Creeks which enter the river just upstream of Nine Mile Dam at about RM 59.2. Coulee/Deep Creeks are intermittent streams that have little or no flow during the summer.

Sixteen miles downstream from the confluence of Latah Creek, the Little Spokane River enters from the north at RM 56.3. The confluence of the Little Spokane is affected by backwater from Lake Spokane on the Spokane River, and a record of streamflow is not available. The nearest USGS gage on the Little Spokane (USGS gauge 12431000) is located 10.8 miles upstream from the mouth, at Dartford, and does not measure the known groundwater inflow to the downstream reach. The mean annual flow of the Little Spokane River at Dartford is 303 cfs; the flow at the confluence with the Spokane River is greater. Patmont et al. (1985) used USGS data to estimate that about 250 cfs of groundwater enter the river between Dartford and the river's confluence with Lake Spokane. Soltero et al. (1992) suggested that during November through May the groundwater input below Dartford is greater than 250 cfs and could be more accurately estimated as the Dartford flow x 1.09 + 252 cfs.

Lake Spokane extends from the dam at RM 33.9 to just above the confluence of the Little Spokane River. Operation of the Lake Spokane powerhouse regulates the Spokane River from the dam to the river's confluence with Lake Roosevelt. The mean annual flow of the Spokane River below Lake Spokane is 7,824 cfs (USGS gauge 12433000). A few miles below Lake Spokane is the Little Falls Dam (RM 29.3). Chamokane Creek drains 176 square miles and enters the Spokane River from the north between Lake Spokane and Little Falls.

Although the Spokane River extends nearly 30 miles below Little Falls before joining the Columbia River, for most of this distance it is affected by backwater from Lake Roosevelt.

The daily average flows for the Spokane River at Post Falls, Harvard Rd., Spokane (at Monroe St.), and Lake Spokane are presented in Appendix A (Figures A1-A4). The flows for the tributaries, Latah Creek and the Little Spokane River, are also presented in Appendix A (Figures A5-A6).

The average annual hydrographs for Post Falls, Harvard Rd, and Spokane gauges are presented in Figure 3. The highest flows, resulting from snowmelt, occur from April through the beginning of June, while the lowest flows generally occur in August and early September. Avista usually increases discharge from the Post Falls Dam during the second week of September in order to begin lowering the water level in Lake Coeur d'Alene.

The average July through October hydrographs for Post Falls, Harvard Rd, and Spokane are presented in Figure 4. The decline in streamflow between Post Falls and Harvard Rd is more evident during this period of the year, as is the increased flow between Harvard Rd and Spokane. The increase in flow between the Harvard Rd and Spokane gauges represents groundwater inflow to the river.

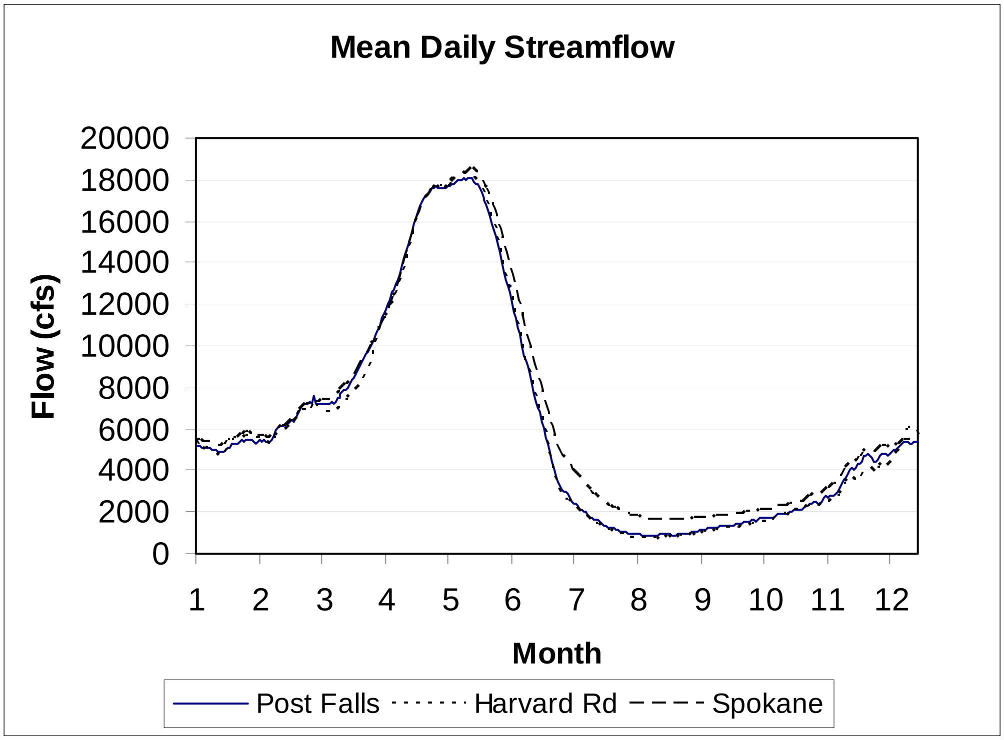

Figure 3. Average annual hydrographs for Post Falls, Harvard Rd, and Spokane USGS gauges.

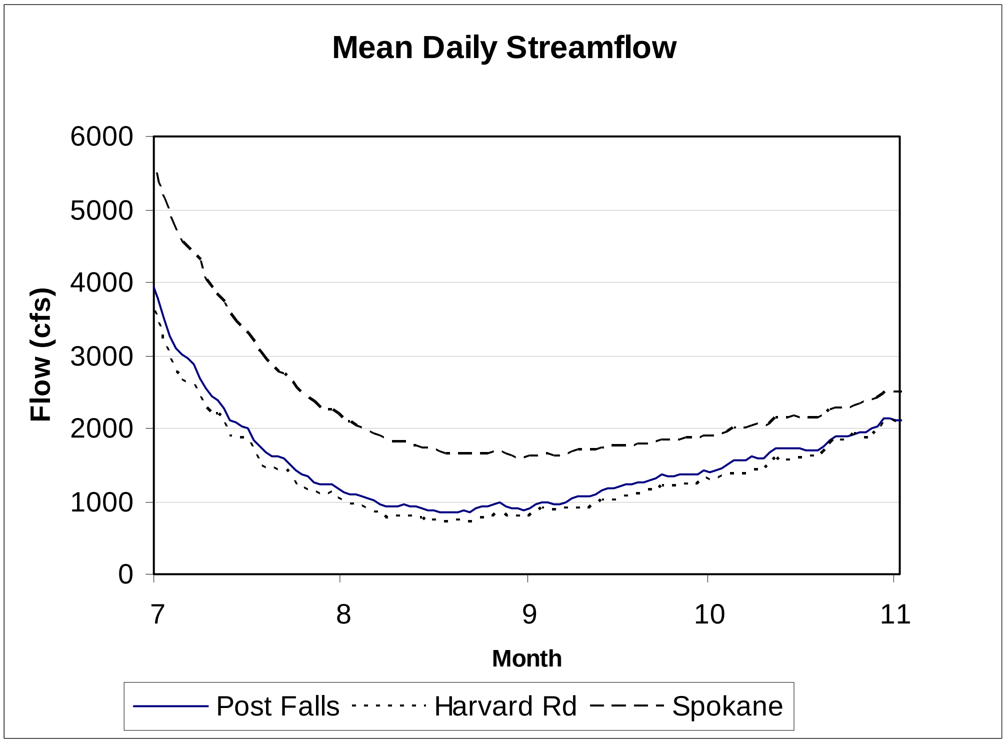

Figure 4. Average July through October hydrographs for Post Falls, Harvard Rd, and Spokane USGS gauges.

Figures 5-6 show the annual 7-day low flows for the Post Falls and Spokane gauges. The water quality/hydrology graphics/analysis system software (WQHYDRO) was used to test for significant trends (Aroner, 2001). Correlation analysis using Spearman's rho rank correlation coefficient test indicates that there is a significant decreasing trend of 7-day low flows for the period of record at the Spokane gauge (α = 0.01). Water withdrawals that occurred upstream of the Post Falls gauge before 1967 make it more difficult to determine the trend at the Post Falls gauge. It is our understanding that agricultural water withdrawals upstream of the Post Falls gauge that occurred prior to 1968 reduced the flows measured at the gauge for some unknown period in the record. Water withdrawals were discontinued in 1967. The 7-day low flows at Post Falls and Spokane also show a decreasing trend from 1968-2001 (Spearman rho, α = 0.05). The trend in 7-day low flows suggests that groundwater inflows to the surface water system in the watershed have been decreasing. However, a more comprehensive hydrologic analysis of the watershed's hydrology should be conducted to determine if the statistical trend can be supported.

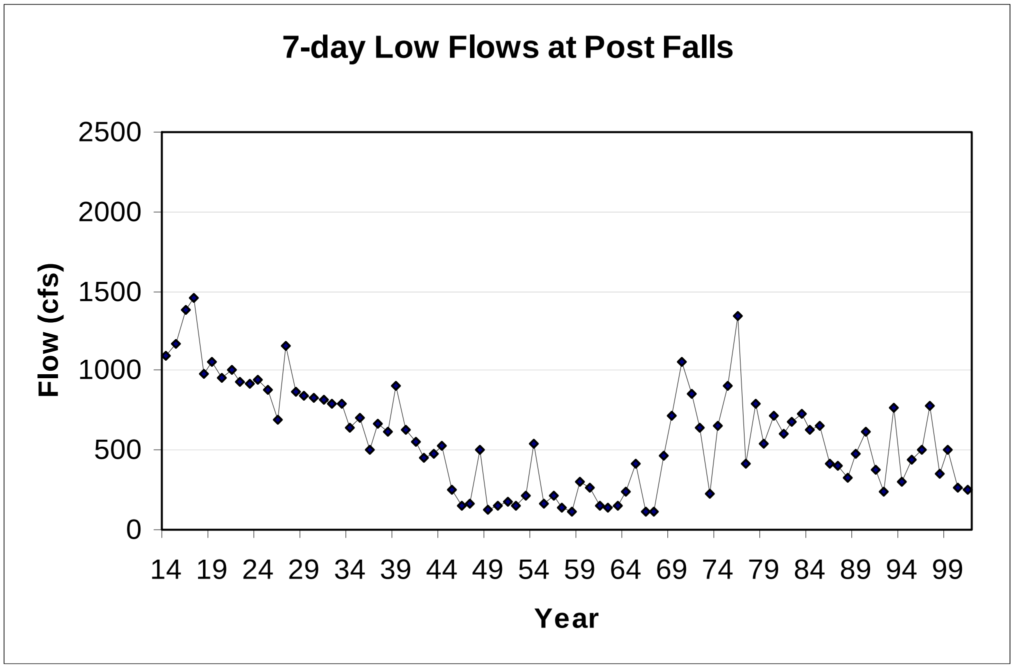

Figure 5. Annual 7-day low flows for the Spokane River at Post Falls.

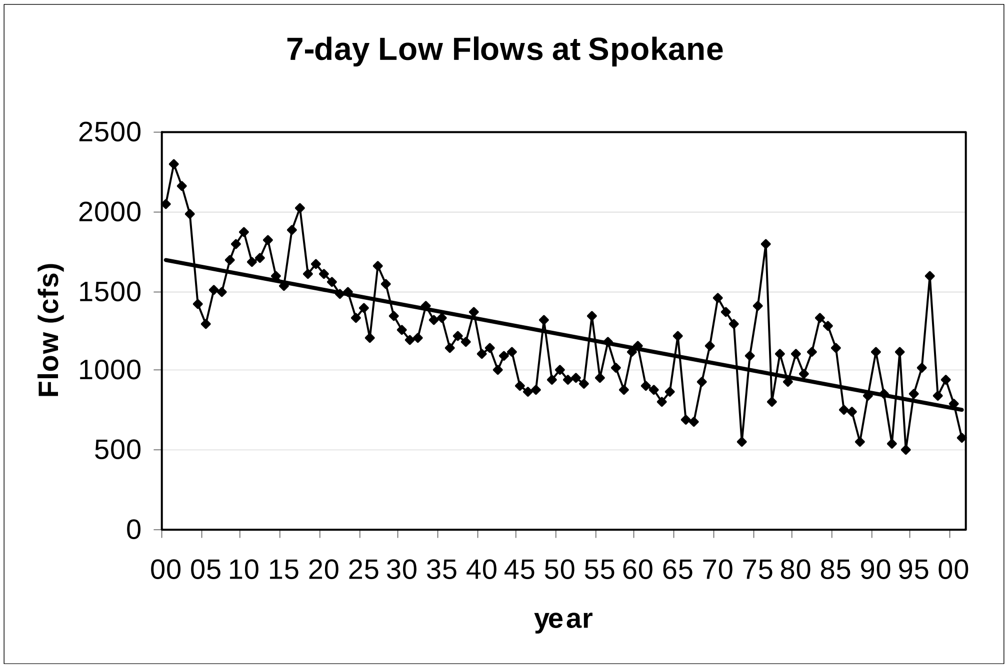

Figure 6. Annual 7-day low flows for the Spokane River at Spokane.

Spokane River and Aquifer Interactions

Areas of inflow (aquifer water inflow to the river) and outflow (river water outflow to the aquifer) complicate the river flow hydrology of the Spokane River. Historical studies documented most of the aquifer discharge zones to the river (Broom, 1951; Bolke and Vaccaro, 1981). Patmont et al. (1985) summarized estimated summer inflows and outflows from the river based on historical USGS gauge data and USGS model predictions. In addition, the report lists estimated inflows and outflows along the river based on discharge data collected during nine surveys conducted during July through September of 1984. The Patmont et al. and other historical studies reveal a complex hydrologic system with alternating inflows and outflows of water to and from the river channel (including impoundment seepage from Upriver Dam, Post St. Dam, and Nine-Mile Dam).

Table 2 lists the Patmont et al. (1985) estimated average inflows and outflows along the river based on the measured changes in flow during the July through September 1984 surveys (flow data provided by Greg Pelletier, Department of Ecology, co-author of the 1985 Patmont report). Table 2 also lists estimated inflows and outflows based on a numerical model developed by CH2M HILL for an average river flow at the state line equal to the average flow for the Patmont surveys (CH2M HILL, 1998; 2001). The CH2M HILL model was calibrated to river flow and well elevation data collected during September 1994 (a low river flow year).

Table 2. River inflows and outflows based on changes in river flow during the 1984 Patmont et al. (1985) study and CH2M HILL model estimates.

Location	RM	Average 1984 Patmont Study	CH2M HILL GW Model
Post Falls – state line	101.7-96.0	-100	
State line – Harvard Rd	96.0-93.0	-45	
State line – Barker Rd	96.0–90.4		-45
Barker Rd – Sullivan Rd	90.4-87.8		-75
Harvard Rd – Trent Rd	93.0-85.3	+404	
Sullivan – Trent Rd	87.8-85.3		+64
Trent Rd – Upriver Dam	85.3-79.8	-256	-6
Upriver Dam – Green St	79.8-78.0	+577	+174
Green St – Post St	78.0-74.1	-180	-37
Post St – Monroe St	74.1-72.9	+105	
Monroe St – Meenach Br	72.9-69.8	+47	-91
Meenach Br – Seven Mile Br	69.8-62.0	+118	+120
Seven Mile Br – Nine Mile Dam	62.0-58.0	-62	+5

Although the table results show different quantities, most of the areas that were defined as either inflow or outflow zones along the river are the same.

The aquifer interactions also were described in a graduate thesis completed in 2000 for reaches between the state line and Green St. (Gearhart, 2000). Overall, this river segment can be described based on the thesis results as follows:

- State line to Harvard Road: Outflow reach. Groundwater levels are below the river stage.
- Harvard Road to Barker Road: Outflow reach. Groundwater levels are below the river stage.
- Barker Road to Sullivan Road: Transitional reach. Groundwater levels can be above or below the river stage depending on flow. When flows are low the area is an inflow reach, but when flows rise above the groundwater table it may become an outflow reach.
- Sullivan Road to Plantes Ferry Foot Bridge: Inflow reach. Groundwater levels are above the river stage.
- Plantes Ferry Foot Bridge to Upriver Dam: Assumed outflow reach – not discussed in the thesis. Groundwater levels are below Upriver Dam pool elevations at Felts Field well.
- Upriver Dam to Greene St.: Inflow reach. Groundwater levels are above river stage.

Flow data collected by Spokane Community College during 1998 and 1999 at the Plantes Ferry Park Footbridge (RM 84.7) indicate that at low river flows the inflow zone could extend between Barker Road and the Footbridge (i.e., RM 90.4 – 84.7)

Gearhart (2000) noted seasonal and annual changes in aquifer interactions due to changes in river flow (i.e., water elevation) and corresponding changes in groundwater elevations. It was concluded that the groundwater table response to increases in river flow is on the order of a few days.

Figure 7 shows the net change (i.e., the difference) between the Monroe St and Post Falls USGS gauges for August and September 1968 through 2001. Changes in the daily and annual differences between the gauges are partly attributable to measurement variability and daily management of the flows at Post Falls Dam, but they mostly reflect fluctuations in groundwater inputs between the gauges. For example, the average net change during September 1994 (the low-flow data used to calibrate the CH2M HILL model) was +51 cfs; while the net change during the Patmont study was +436 cfs for September 1984. The net change for August 1994 and 1984 were +152 and +592 cfs, respectively.

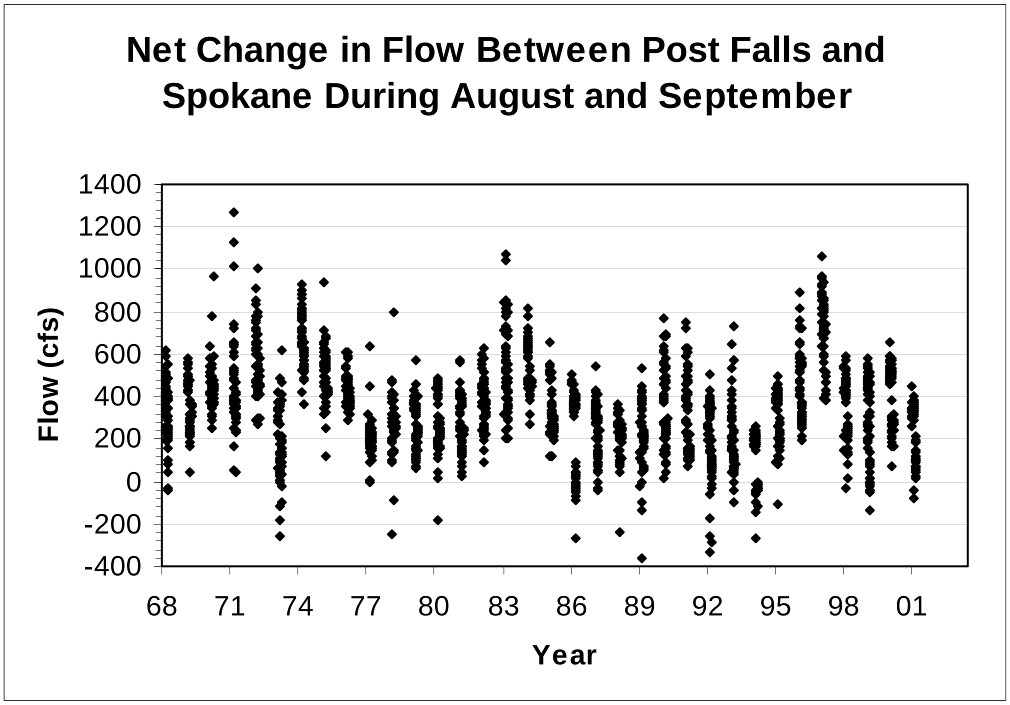

Figure 7. Net increase in river flow between Post Falls and Spokane gauges during August and September 1968-2001.

Although the absolute amount of inflows and outflows appear to depend on seasonal and annual variations in river flow and groundwater table elevations, the overall river inflow and outflow zones are fairly well defined. Table 3 lists the zones used for this study. Note that the RMs listed were somewhat different than those listed in historical documents because they were determined with ARCVIEW tools and associated waterbody coverage for this study.

Table 3. River inflow and outflow zones along the Spokane River by river mile segments.

River Mile	River Segment	Inflow or Outflow
101.7 – 93.7	Harvard Rd. USGS gauge	Outflow
93.7 – 90.4	Barker Rd. USGS gauge	Outflow
90.4 – 87.8	Sullivan Rd. Bridge	Transition
87.8 – 85.3	Trent Rd. Bridge	Inflow
85.3 – 84.2	Plantes Ferry Footbridge	Inflow
84.2 – 82.6	Argonne Rd. Bridge	No Change
82.6 – 79.8	Upriver Dam	Outflow
79.8 – 78.0	Green St. Bridge	Inflow
78.0 – 76.7	Mission St.	Outflow
76.7 – 74.1	Post St. Powerhouse	Outflow
74.1 – 72.9	Monroe St. gauge	Inflow
72.9 – 62.0	Seven Mile Bridge	Inflow
62.0 – 58.1	Nine Mile Dam	Inflow (based on dam spillway and turbine discharge data)

Lake Spokane

Whereas the river flow of the mainstem of the Spokane River is complicated by the interactions with the aquifer, the volume of water in Lake Spokane corresponds almost singularly to surface water inflows from the Spokane and Little Spokane rivers and outflows at the dam.

A diagnostic study of Lake Spokane (Soltero, 1992) found that surface water inflows and outflows to the lake accounted for approximately 98.5% of the hydrologic input/output during their study year. This diagnostic study included a detailed groundwater characterization using residuals from water budgets, as well as piezometers (used to measure hydraulic gradients and conductivity of the aquifers surrounding Lake Spokane), to determine the groundwater influence on the lake. The results amounted to minor, hydrologic contributions of 1.4% and 1.1% for groundwater inflows and outflows, respectively, in the annual water budget. Patmont et al. (1987) determined the average water budget for Lake Spokane during the June through October periods of 1972-1985 (excluding 1976). They reported that discharge at Nine Mile Dam represented 91% of the total hydraulic input to the lake, with 8.6% contributed by the Little Spokane River (i.e., 99.6% of the surface water inflows to the lake were from the Spokane and Little Spokane rivers.)

The volume of Lake Spokane averages about 10.5 billion cubic feet. This amounts to a little over 4% of the annual flow of the Spokane River measured at the USGS gauge just downstream of the Lake Spokane Dam. Thus the average residence time of waters within Lake Spokane is about 16 days. This declines to less than five days during the peak of the snowmelt when discharge at Lake Spokane Dam often exceeds 20,000 cfs. From July through September, when inflow to the lake can be less than 2,000 cfs, the residence time increases accordingly. During this time the lake is not well mixed, and pockets of water probably remain in the lake for several months. Thermal stratification within Lake Spokane usually begins in June and ends in October.

Soltero et al. (1992) calculated a relatively rapid annual hydraulic retention time in Lake Spokane of 0.04 years (14.6 days) during their 1991 study year, corresponding to a flushing rate of approximately 25 lake volumes per year. Monthly retention time variability ranged from 7 days in May 1991, during the highest inflows, to 56 days in August 1991, during the lowest inflows, emphasizing the flow-through response of the reservoir in connection to the magnitude of inflows. The retention time for June was estimated to be 10 days, and the average retention time for July-October was 44 days.

Nuisance algae populations and hypolimnetic oxygen depletions within Lake Spokane have occurred during the summer growing season when inflows and corresponding flushing rates are low (Patmont, 1987; Soltero, 1992). In addition to the reduced flow-through characteristic of Lake Spokane during this time, lake stratification during the growing season creates a complex mixing regime in which inflows are partially separated from the lake surface and bottom waters. This is due to an apparent interflow of incoming waters through the metalimnion to the penstock tube openings in Lake Spokane Dam. The compartmentalization due to these complex hydrodynamics results in non-steady-state relationships between nutrient loading and in-lake water quality conditions (Patmont, 1987).

Patmont et al. (1987) analyzed the average June-October specific conductance lake profile values as a “conservative tracer” to show the physical structure of the lake and define the internal hydraulics. They showed that a high conductance “tongue” of water with a conductivity level similar to the summer groundwater-dominated inflow centered at a depth of about 10-15 meters. This “interflow” zone corresponds to the location of the dam penstocks, such that much of the metalimnetic higher density interflow may short-circuit surface and deeper waters of the lake and flow directly to the penstocks. Metalimnetic interflows are found in other reservoirs. Figure A-7 (Appendix A) is a copy of the conductivity contour graph presented in the Patmont et al. (1987) report showing the interflow zone.

Patmont et al. (1987) reported that the conductivity mass balance calculations showed that the euphotic zone was flushed on average every 40 days during the June-October period. Most of the calculations ranged from 20-80 days. Their calculations indicated that the median hypolimnion residence time was approximately 60 days, with estimates ranging from 30-150 days, which indicates that the hypolimnion is slow to flush.

Point Source Discharges

See the Water Quality section of this report for specific NPDES permit discharge characteristics including, if applicable, design plant flows. Monthly average discharge flows from the facilities during the October 1994 – December 2001period are presented in Figure 8 (trend lines were not tested for significance). Facility discharges from Inland Empire Paper Company and Liberty Lake wastewater facilities appear to have increased over the time period graphed. The increased discharges are most likely due to increased production at Inland Empire and residential growth in the Liberty Lake area. The City of Spokane treatment plant peak flows appear to be decreasing, due to eliminating infiltration and inflow to the system and management changes at the facility. Kaiser Aluminum effluent flows were increasing until early 2001 when the plant cut back or stopped some of its production processes.

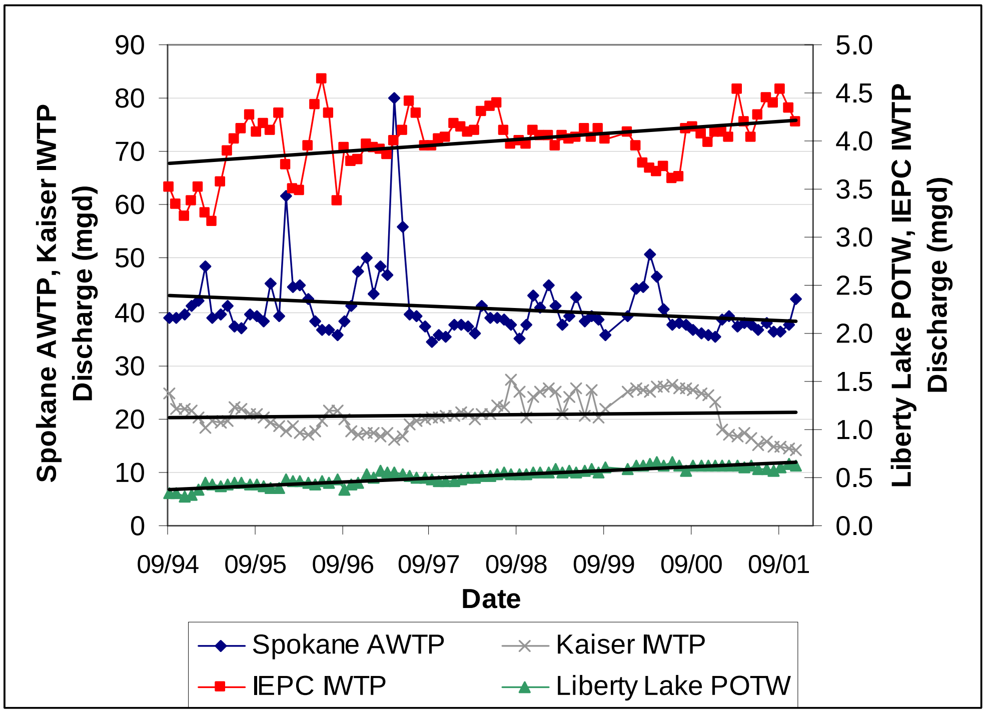

Figure 8. Effluent discharges (mgd) for the City of Spokane, Kaiser Aluminum, Liberty Lake, and Inland Empire wastewater treatment facilities during October 1994 – December 2001.

Combined Sewer Overflows

Since the 1980s, the City of Spokane constructed separate stormwater systems and eliminated the combined sewers in most of the northern part of Spokane. The City has been developing controls to reduce stormwater runoff, limit CSO overflows, and improve water quality related to the overflows and stormwater runoff. Patmont et al (1987) reported estimated CSO flows for the June-October period of about 1.4 cfs. In 2001 the measured value for this time period was 0.14 cfs or about 10% of the historical estimate (2001 estimate based on overflow event data provided by the City of Spokane). On an annual basis for 2001 there was only 29.3 million gallons discharged due to CSO events or about 0.05 cfs over the year. The CSO contributions were considered too small to contribute a significant impact on the river and lake system and were not included in the CE-QUAL-W2 model.

River Flow During CE-QUAL-W2 Model Calibration Years

The CE-QUAL-W2 model developed for this project was calibrated to water quality and hydrology data collected during 1991, 2000, and 2001. The daily average flows for these years at the USGS gauge at Spokane are plotted in Figure 9. Figures A8-A10 show these years plotted with the daily minimum, maximum, median, and estimated lower 10th percentile flows to show their relative relationship with historical flows (1968-2001). 1991 and 2000 daily flows were similar to median flows, and 2001 daily flows were low flows for most of the year. The June through October daily flows during 2001 were very close to the lower 10th percentile flows (see Design Conditions section).

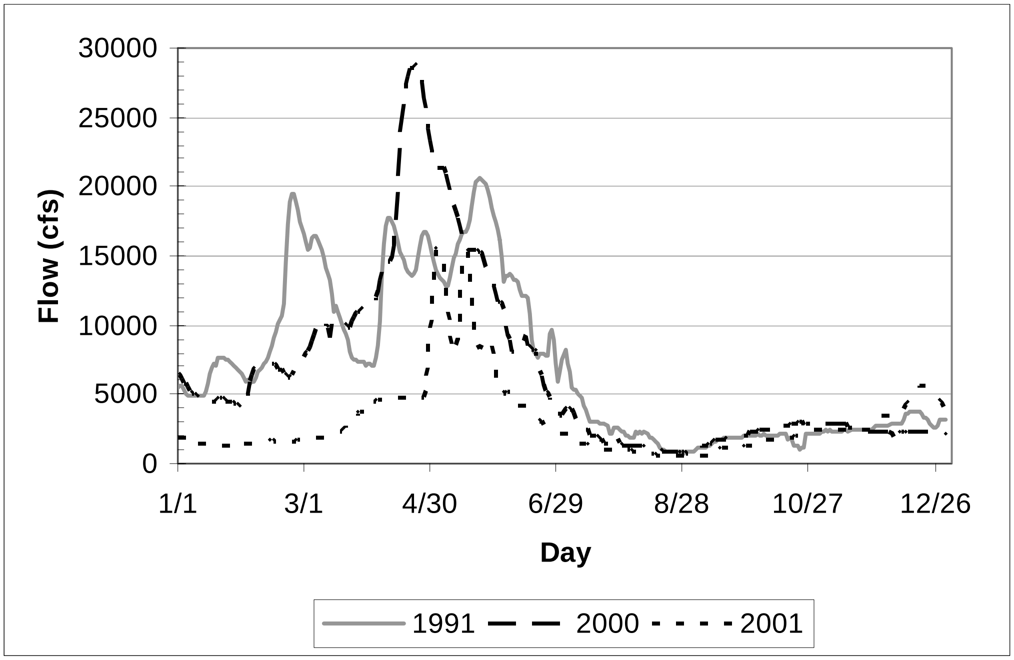

Figure 9. Daily flows for the CE-QUAL-W2 model calibration years of 1991, 2000, and 2001.

Water Quality

Spokane River, Latah Creek, and Little Spokane River

Historical and current water quality data collected for this project are presented in the Data Summary (Cusimano, 2003), and the model boundary conditions and model setup reports cited in the Supporting Documents section of this report. These documents should be referenced for detailed information on the water quality data used, including lists of all sampling stations and their river mile (RM) locations along the river and lake.

As discussed in the Hydrology section of this report, the major source of water for the Spokane River is Lake Coeur d'Alene (and groundwater inflow during the late summer). The northern part of Lake Coeur d'Alene, including the outlet to the Spokane River, has been classified as oligotrophic (i.e., low in nutrients with low organic production) and the southern shallower part as mesotrophic (i.e., moderate nutrients and organic production) (USGS, 1989). Even though the southern part of Lake Coeur d'Alene has been called mesotrophic, the bottom water dissolved oxygen concentrations were found to exceed 6 mg/L (USGS, 1989). Nutrient concentrations at the outlet to the Spokane River have been found to be near or less than analytical instrument reporting limits. For example, ammonia nitrogen (NH3), nitrite-nitrate nitrogen (NO2NO3), and soluble reactive phosphorus (SRP) concentrations have been reported during the summer (June – September) to be <0.005 mg/L – and total phosphorus (TP) concentrations of between 0.005-0.013 mg/L (Patmont, 1985, Cusimano, 2003). However, higher measurable concentrations of these variables are present by the time the river reaches the Washington/Idaho state line.

There are Ecology ambient monitoring stations located on the Spokane River at the Stateline Bridge (station 57A150 at RM 96.0) and at Riverside State Park (station 54A120 at RM 66.0, about 1.4 miles downstream of the City of Spokane's AWTP), and near the mouth of Latah Creek (station 56A070: creek enters the river at RM 72.4) and the Little Spokane River (station 55B070: river enters Lake Spokane at RM 56.4). The data from these stations provide information on the overall water quality of the river and major tributaries for the major variables measured. Figures A11-A18 present box plots of the monthly water quality data reported for the ambient stations from January 1990 through October 2002. Values below the reporting limit were plotted as the reporting limit.

Annual TP concentrations at the state line ranged from 0.010 to 0.126 mg/L, SRP ranged from 0.003 to 0.016 mg/L, and NH3 ranged from 0.010 to 0.137 mg/L. However, the reporting limit for the TP data was 0.010 ug/L, and 33% of the data were reported at or near the limit. The reporting limit for SRP changed in 1994 from 10 to 5 ug/L, and the limit for data reported in 2001 was 0.003 mg/L. The reporting limit for NH3 was 0.010 mg/L. Sixty-six percent of the SRP and 53% of the NH3 values were reported at or near the limit.

Nutrient concentrations were significantly higher in Latah Creek and the Little Spokane River compared to those measured in the Spokane River at the state line, reflecting poorer water quality conditions in these drainages. For example, annual TP values ranged from 0.010-0.253 and 0.010-1.740 mg/L, respectively; with the highest values occurring during January-April. High total suspended solids (TSS) and turbidity values were also recorded for these waters during January-March.

Table 4 lists the mean and standard deviations for some of the parameters measured at the ambient stations for June-October.

Other studies have reported high concentrations of nutrients and organic material in Latah Creek (Soltero et al., 1992; Patmont et al., 1985). Total organic carbon (TOC) and ultimate carbonaceous oxygen demand (CBODU) measured at the long-term ambient stations during 2000 and 2001 are listed in Table 5. The TOC and CBODU show that Latah Creek has higher concentrations of organic material than the Spokane or Little Spokane Rivers. The loading of nutrients and organic material to the Spokane River from Latah Creek mainly occurs during the late winter to the end of May, then discharge from the creek drops rapidly and averages <20 cfs during July-October (see Figure A5). Loading to the Spokane River from the creek during this period is minimal. Although loading to the river system from the Little Spokane River (confluence in the upstream part of Lake Spokane) also declines in the summer, it is high relative to Latah Creek because significant groundwater contributions augment the river flow such that the July-October period averages about 400 cfs (see Figure A6).

Table 4. June-October mean and standard deviations (in parentheses) for parameters measured at Ecology ambient monitoring stations located on the Spokane River at Stateline Bridge (57A150), Riverside State Park (54A120), Latah Creek (56A070), and the Little Spokane River (55B070).

Station	n	57A150	n	54A120
Conductivity umhos/cm	60	49.1 (7.1)	64	163.6 (62.8)
NH3 mg/L	60	0.017 (0.018)	66	0.071 (0.147)
NO2-NO3 mg/L	60	0.050 (0.051)	66	0.760 (0.407)
SRP mg/L	60	0.007 (0.003)	66	0.010 (0.004)
TP mg/L	60	0.015 (0.007)	66	0.026 (0.025)
TPN mg/L	46	0.149 (0.079)	47	0.916 (0.406)

Station	n	56A070	n	55B070
Conductivity umhos/cm	56	343.1 (67.6)	54	254.0 (40.5)
NH3 mg/L	56	0.024 (0.023)	56	0.017 (0.018)
NO2-NO3 mg/L	56	0.870 (0.329)	56	1.110 (0.210)
SRP mg/L	56	0.023 (0.018)	56	0.011 (0.006)
TP mg/L	56	0.060 (0.046)	56	0.027 (0.015)
TPN mg/L	43	1.218 (0.353)	47	1.247 (0.141)

Table 5. Mean and standard deviations (in parentheses) for TOC and CBODU data (mg/L) collected from Spokane River and tributary stations.

Station	2000		2001	
	TOC	CBODU	TOC	CBODU
State line	1.5 (0.30)	2.0 (.65)	1.8 (0.7)	2.4 (0.59)
Riverside State Park	1.1 (0.42)	-	2.0 (1.2)	2.5 (0.71)
Below Nine Mile Dam	1.1 (0.29)	1.7 (0.53)	3.5 (1.3)	2.7 (0.75)
Latah Creek	3.4 (1.9)	2.8 (0.72)	4.1 (2.4)	3.0 (0.42)
Little Spokane River	1.2 (0.54)	1.2 (0.17)	2.0 (1.4)	1.6 (0.53)

Soltero et al. (1992) summarized estimated percent contributions of TP to Lake Spokane during June – October from the Spokane River just upstream of Latah Creek, Latah Creek, the City of Spokane's wastewater effluent, and the Little Spokane River. The results were presented for the period before (1972-1977) and after (1978-1985 and 1991) the City of Spokane initiated advanced wastewater treatment (see Water Quality Lake Spokane section). Table 6 lists estimated percent and metric ton contributions of phosphorus for the different periods.

The estimates in Table 6 show that the City's treatment plant has significantly reduced TP loading to the system. The table also shows that the loading (metric tons) from upstream sources (i.e., upstream of Latah Creek) was significantly reduced, possibly reflecting efforts to reduce TP loading from other point and nonpoint sources. To date, CSO and stormwater discharge to the river and TP loading from the city of Lake Coeur d'Alene have been reduced. In addition, discharge from the Spokane Industrial Park and Millwood treatment plant has been eliminated. However, Liberty Lake Sewer District and Hayden treatment plants have been brought on line which offset some of the reductions. The ambient data presented in Appendix A for Riverside State Park (Figures A13-14) located about 1.4 miles downstream of the city's effluent discharge point show increases in concentrations for nutrients and other parameters from upstream conditions consistent with historical study results conducted after 1978 (Patmont et al., 1985; Soltero et al., 1992).

Table 6. Mean monthly percent contributions of total phosphorus and metric tons (in parentheses) to Lake Spokane for June - October from the Spokane River just upstream of Latah Creek (SR), Latah Creek (LC), the City of Spokane's wastewater effluent (SE), and the Little Spokane River (LSR) (Soltero et al., 1992).

Years	SR	LC	SE	LSR	Undetermined
1972-1977	29.3 (8.7)	0.3 (0.1)	54.2 (16.1)	3.6 (1.1)	12.6 (3.8)
1978-1985	49.5 (3.8)	3.8 (0.3)	27.4 (2.1)	11.9 (0.9)	7.3 (0.6)
1991	66.0 (3.5)	1.9 (0.1)	30.2 (1.6)	13.2 (0.7)	-11.3 (-0.6)

Figures 10-13 show the average in river TP and total persulfate nitrogen (TPN) concentrations and estimated loads for data collected by Ecology at stations along the river from the state line (RM 96.0) to below Nine Mile Dam (RM 58.1) during August 15-16 and September 26-27, 2000. The 2000 survey data show that most of the phosphorus and nitrogen enter the river in Washington. The loads increase in the river from the state line to Nine Mile Dam (e.g., the estimated average flow at the state line during the August 15-16 survey was about 580 cfs and increased to about 1400 cfs at Nine Mile Dam). The concentration changes were similar to those reported by others (Patmont et al., 1985: Soltero et al., 1992). Phosphorus concentrations have been found to increase below the City of Spokane's AWTP (and the City of Coeur d'Alene WTP) (Patmont et al., 1985). For example, Patmont et al. (1985) reported that during the summer of 1984, TP concentrations near the Stateline Bridge were 0.0118-0.0285 mg/L and below the Spokane treatment plant were 0.023.0-0.058 mg/L.

The TP concentration increase at Barker Road Bridge (RM 90.4) during the August survey can be attributed to the loading of phosphorus from the Liberty Lake POTW, which discharged an effluent flow of about one cfs and TP concentration of 5.5 mg/L at RM 92.7 (river flow was estimated to be about 540 cfs at Barker Road Bridge). The resultant mass balance indicates that Liberty Lake could increase the TP concentration in the river by 0.009-0.010 mg/L. The actual observed average increase for the two-day survey was about 0.007 mg/L (n=4). The corresponding mass balance estimated concentration contribution for the September survey was only 0.002 mg/L, and the observed increase was also about 0.002 mg/L (i.e., 0.0017 mg/L). Uptake of TP by periphyton and groundwater inflow dilution reduce the concentrations downstream of Barker Road Bridge even though there are additional loading sources. High groundwater concentrations of total nitrogen (measured as TPN) and nitrogen loading from the City of Spokane AWTP probably account for most of the increase in nitrogen to the river (see Groundwater section).

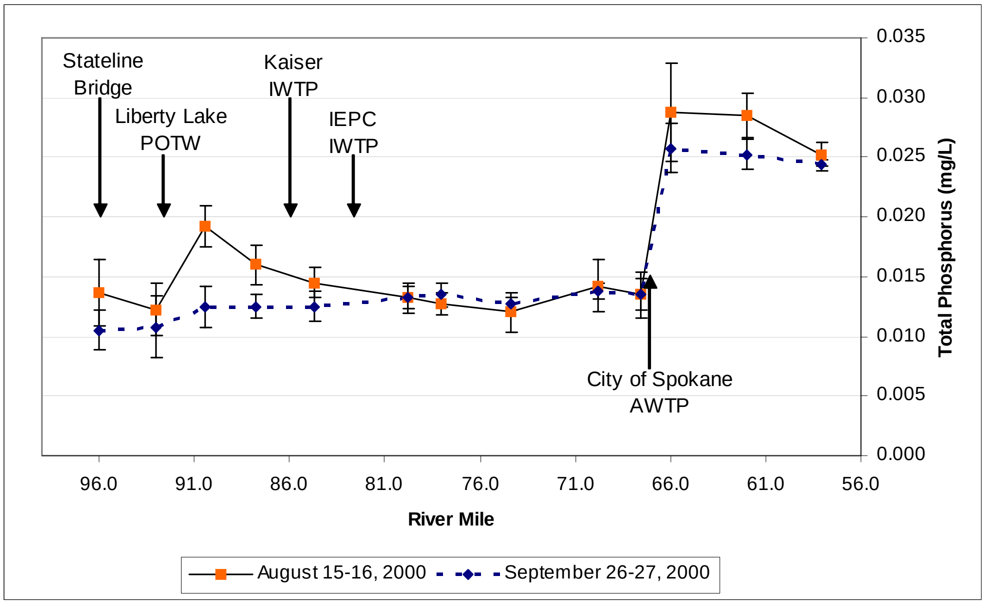

Figure 10. Average total phosphorus concentrations data (n = 4) ± standard deviation by RM for Ecology river surveys conducted on August 15-16 and September 26-27, 2000.

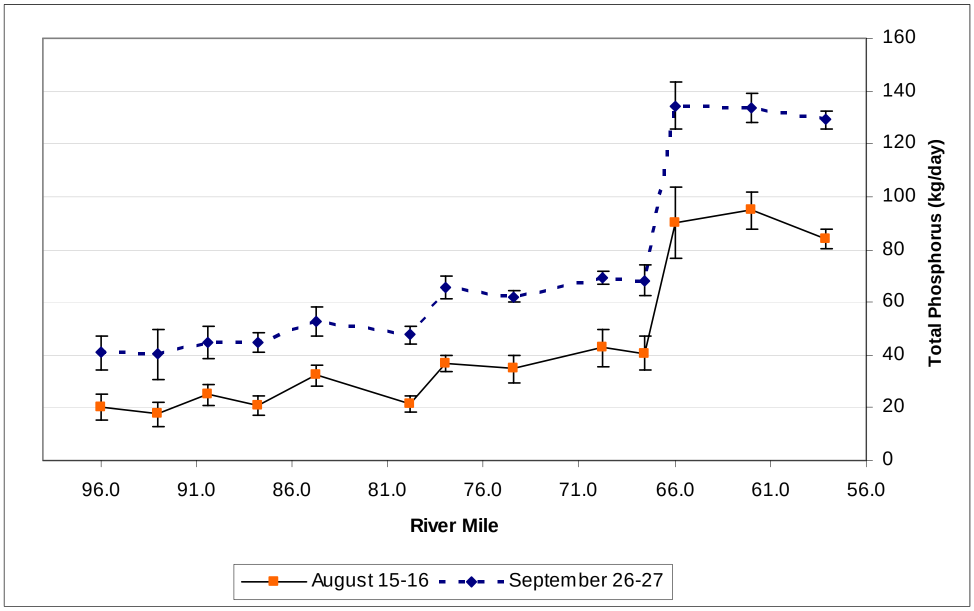

Figure 11. Average total phosphorus loading estimates (n = 4) ± standard deviation by RM for Ecology river surveys conducted on August 15-16 and September 26-27, 2000.

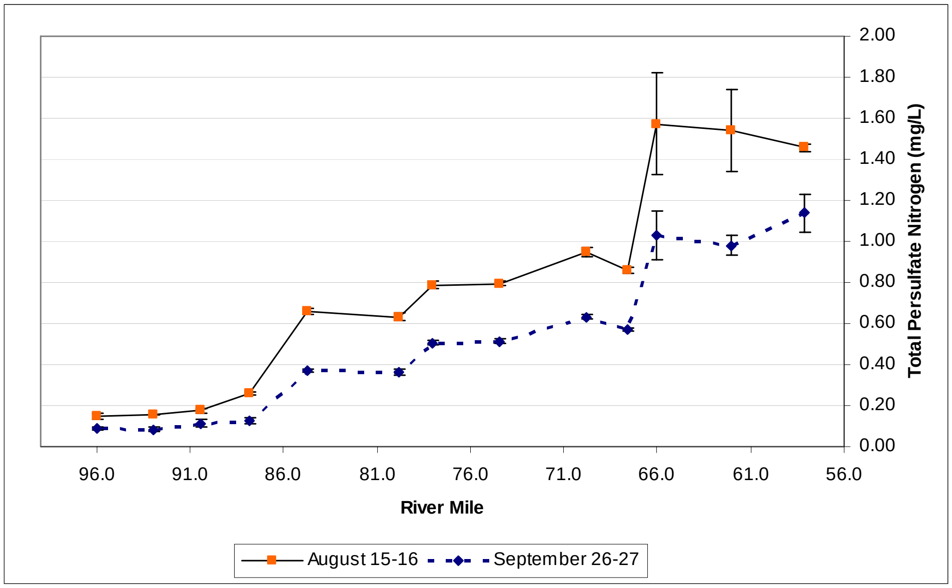

Figure 12. Average total persulfate nitrogen concentration data (n = 4) ± standard deviation by RM for Ecology river surveys conducted on August 15-16 and September 26-27, 2000.

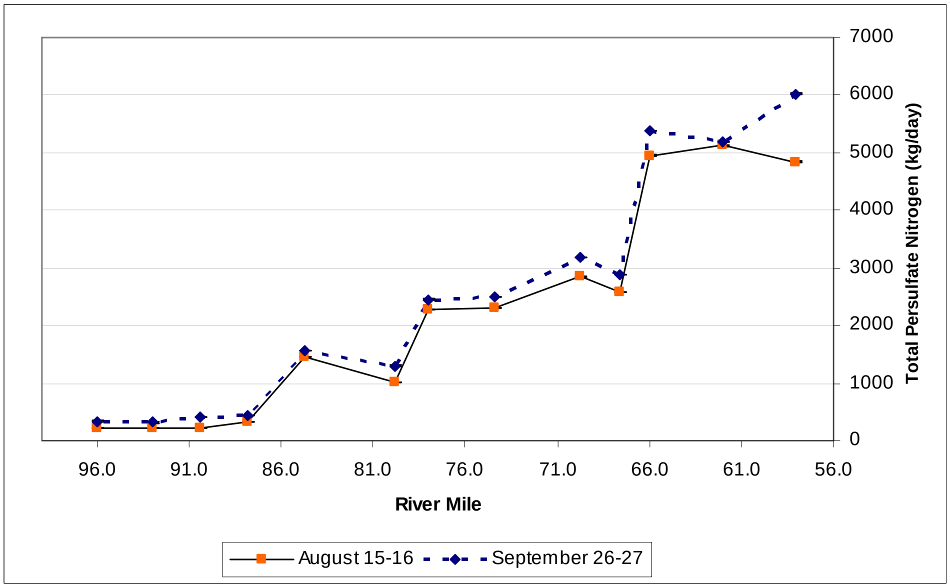

Figure 13. Average total persulfate nitrogen loading estimates (n = 4) ± standard deviation by RM for Ecology river surveys conducted on August 15-16 and September 26-27, 2000.

Ambient data at the state line show that the river and tributaries during the summer period can exceed the special temperature criterion of 20° C. Figure 14 shows that temperatures in the river can be greater than the criterion from the state line downstream to near the Sullivan Road Bridge based on longitudinal river survey data collected during August 2000 and 2001. Cooler groundwater starts to enter the river downstream of Sullivan Road Bridge, and river temperatures stay below the criterion from that point to Lake Spokane, except for the Upriver Dam pool that exceeds the criterion during the low river flow year of 2001. The range of temperatures measured during the 2000 survey represent morning and afternoon temperatures. However, sampling times were not recorded for the 2001 data.

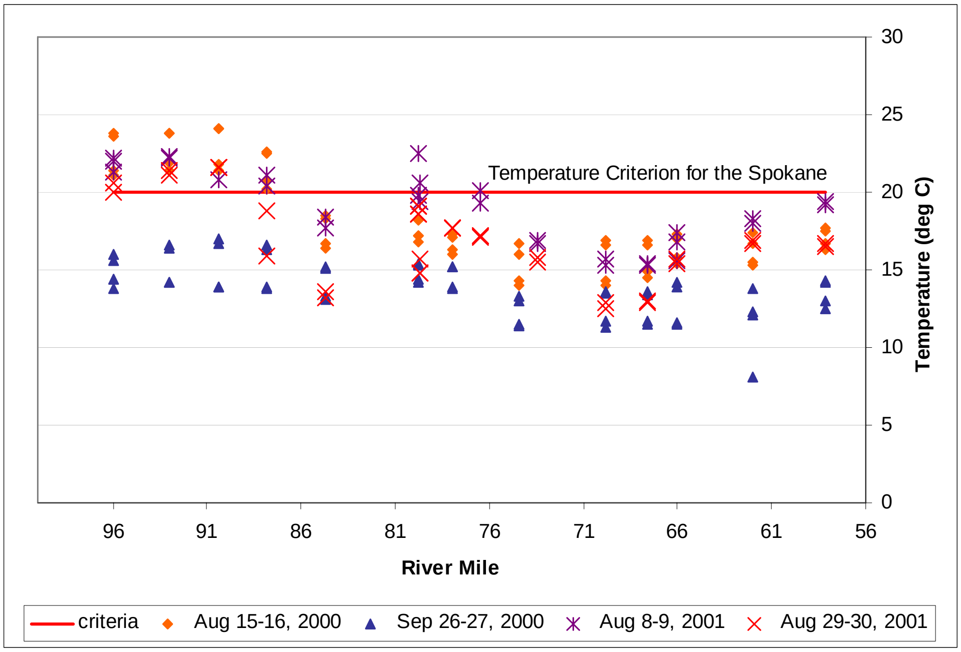

Figure 14. Temperature data by RM for Ecology river surveys conducted on August 15-16 and September 26-27, 2000; and August 8-9 and 29-30, 2001 temperature data collected by Spokane County and the City of Spokane.

Only 15 of the 150 ambient dissolved oxygen values measured at the state line monitoring station from 1990-2001 were lower than the criterion (i.e., 8.0 mg/L). However, the dissolved oxygen data only represent day-time values that do not reflect the daily minimum concentrations that apply to the standard. Figure 15 shows an example of *in situ* diurnal data collected at the state line during August 2001. The diurnal changes in dissolved oxygen concentrations (and pH) in the river were mainly caused by photosynthesis and respiration of attached algae (periphyton). (The August diurnal data in Figure 15 also show that temperatures were higher than the criterion at the state line.) The sampling elevation at the state line was 2000 feet for the diurnal data. The associated percent saturation of dissolved oxygen for this elevation and measured temperatures ranged from 88-122% (e.g., 100% saturation of dissolved oxygen at 22 ºC is 8.1 mg/L).

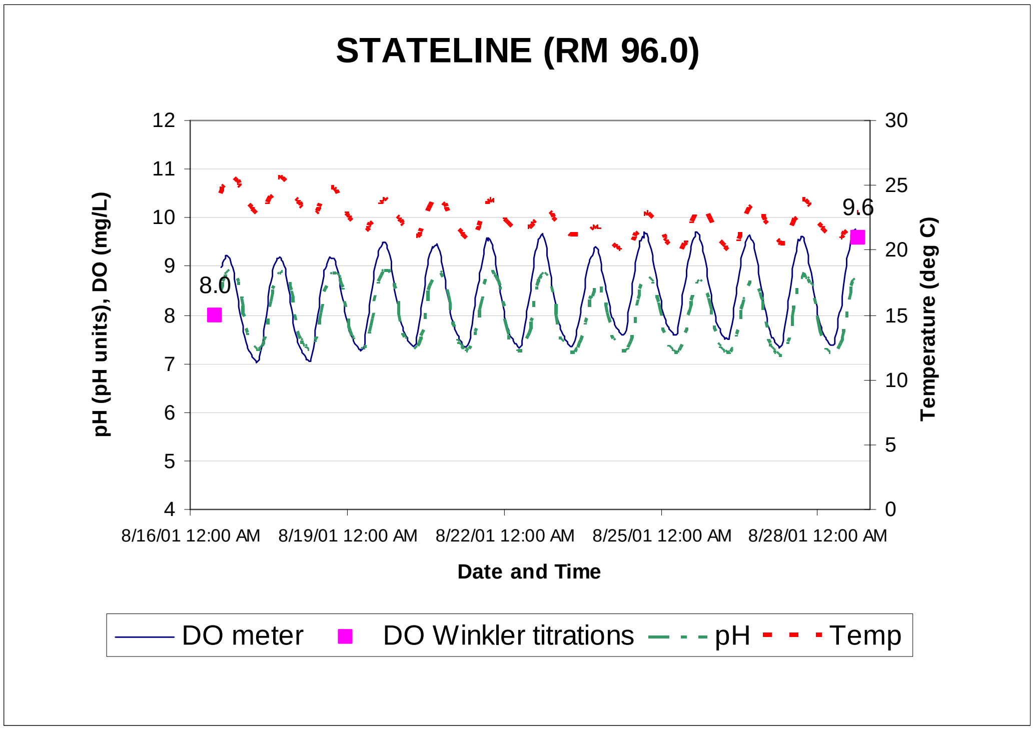

Figure 15. Diurnal data collected at the Washington/Idaho state line during August 2001.

Historical studies showed that periphyton standing crop (expressed as chlorophyll *a*) in the river can exceed "nuisance levels" (i.e., greater than 100-150 mg chl *a*/m^2) (Patmont et al., 1987). Periphyton growth was found to reduce phosphorus concentrations in the Spokane River. Conversely, the addition of phosphorus was found to increase periphyton growth (i.e., phosphorus availability limits algal growth), which can increase diurnal changes in dissolved oxygen and pH. The main sources of phosphorus loading to the river during the summer growing season were found to be the point source discharges (Patmont et al., 1985, 1987).

The upper river reach (RM 90-94) was reported to have less biomass of periphyton than downstream reaches, and were limited or co-limited by nitrogen in this reach (Patmont et al., 1985). Periphyton chlorophyll *a* values were found to range between 3-34 mg chl *a*/m^2 in the upper reach and values between 61-600 mg chl *a*/m^2 were found in the downstream reaches (RM 62-87), with the highest values downstream of the City of Spokane AWTP. Periphyton data collected during August and September 2001 indicate that biomass concentration ranges were similar to those reported by Patmont et al. (1987), with a range of 4.2-28.0 mg chl *a*/m^2 in the reach between RM 85-90, and 6.0-570 mg chl *a*/m^2 between RM 58-78 (Cusimano, 2003). The highest mean concentrations in 2001 were also measured downstream of the City of Spokane AWTP, but the highest single concentration was measured about RM 78 (near the Green St. Bridge).

Additional diurnal data were collected during 1998 just upstream of the City of Spokane AWTP, and in 2000 and 2001 diurnal data were collected at the state line, in Upriver Dam pool, in

Upper Falls Dam pool, and in the Nine Mile Dam pool (Cusimano, 2003). The maximum diurnal dissolved oxygen changes for these areas ranged between 1.0 to 2.8 mg/L with the lowest concentrations occurring just before sunrise and the highest concentrations in the mid to late afternoon. The diurnal data indicate that the minimum dissolved oxygen concentrations caused by periphyton respiration during the late summer were lower than the dissolved oxygen criterion at some locations. It should be noted that low river flows can exacerbate the diurnal changes because the standing crop of periphyton has a greater effect on dissolved oxygen and pH (i.e., less amount of overlying water per unit of biomass and longer residence time because of lower velocities). For example, the diurnal data collected at the state line show that the dissolved oxygen and pH diurnal changes were greatest during 2001, which was a lower river flow year than 2000.

Dissolved oxygen levels downstream of the Inland Empire Paper Company were analyzed as part of a wasteload allocation study for that company (study area from RM 83.5 to 72.8). Summary data are presented in Pelletier (1994 and 1997). Background dissolved oxygen levels were found to be less than 8.0 mg/L for critical conditions, and attributed to groundwater inflows with dissolved oxygen less than 8.0 mg/L and high summer river temperatures. TP values were reported to be 0.010 - 0.015 mg/L in the study area (0.010 mg/L was the laboratory reporting limit). The values reported by Patmont (1985) for the same general area ranged between 0.0106 - 0.0259 mg/L.

Groundwater

The glacial outwash deposits overlying the Spokane Valley-Rathdrum Prairie Aquifer (aquifer) is extremely permeable (Molenaar, 1988). As a transmissive, unconfined aquifer, surface water from different sources (e.g., irrigation, on-site waste disposal, and stormwater) and its associated chemical constituents may affect the aquifer water quality. As discussed in the Groundwater Hydrology section, substantial aquifer/river interactions occur along the river.

Groundwater quality near the river around Barker Road Bridge was found to be strongly influenced by the river (Marti and Garrigues, 2001). As discussed previously, the river reacharges the aquifer in this area and the groundwater quality is similar to the river water. Table 7 summarizes some of the more recent groundwater data collected from wells near the river at known inflow areas.

Table 7. Groundwater quality data (mg/L) collected from wells near the Spokane River in known inflow areas.

	TP		SRP		NO2-NO3	
	Mean	Range	Mean	Range	Mean	Range
Sullivan Rd well data 1999[a]	0.015	0.004-0.026	0.006	0.005-0.007	1.00	0.733-3.78
Sullivan Rd. well data 2001[b]	0.014	0.005-0.033	0.009	0.002-0.033	1.33	0.843-1.67
Downstream to Upper Falls Dam well data 2001[b]	0.014	0.005-0.061	0.009	0.003-0.032	1.08	0.618-1.57

[a] Data collected by Ecology (Marti and Garrigues, 2001)
[b] Data collected and provided by Spokane County

Phosphorus data from one well at Felts Field had mean TP and SRP concentrations of 0.025 and 0.026 mg/L, respectively (i.e., higher than the other wells near the river). However, the Felts Field well is located adjacent to the Upriver Dam pool which has been identified as an outflow reach of the river. Dissolved oxygen measured in the wells during 2001 from Sullivan Road to Upper Falls ranged between 3.6 - 9.3 mg/L. Dissolved oxygen concentrations measured in 1999 at the Sullivan Road wells ranged between 5.9 - 9.4 mg/L. It should be noted that no quality assurance data were reported for the Spokane County well data.

Patmont et al (1985) reported similar means and ranges to the concentrations found in 1999 and 2001 for most of the wells they sampled from RM 87.8 - 64.6. They estimated flow-weighted input concentrations of TP and total soluble phosphorus (TSP) in groundwater discharges to the river to be 0.0086 ± 0.0016 mg/L.

Point Source Discharges

The discharge locations and specific NPDES waste discharge permit conditions and limits (flows listed represent design flows and are not permit limits) that are related to oxygen-consuming substances for the Washington dischargers are as follows:

- Liberty Lake Publicly Owned Treatment Works (POTW)
    - Permit No: WA-004514-4
    - Location: N. 1926 Harvard Road, Liberty Lake, WA.
    - Receiving Water: Spokane River at RM 92.3
    - Average flow for maximum month: 1.0 mgd
    - BOD_5:
      Average Monthly: 30 mg/L, 200 lbs/day
      Average Weekly: 45 mg/L, 300 lbs/day
    - Total Ammonia: None specified
    - Total Phosphorus:
      (a) The average monthly effluent concentration for total phosphorus shall not exceed 15% of the respective monthly average influent concentration during removal season.
      (b) Phosphorus removal must be met at the time the average monthly flow for the maximum month reaches 0.895 mgd or by the date prescribed in the Spokane River Phosphorus Management Plan, whichever occurs first. When required, spring initiation and fall termination of phosphorus removal will commence according to approved methodology used by the City of Spokane, but shall not begin later than June 1st or terminate before October 15th.

- Kaiser Aluminum Industrial Wastewater Treatment Plant (IWTP) Outfall #001
    - Permit No: WA-000089-2
    - Location: E. 15000 Euclid Ave, Spokane, WA.
    - Receiving Water: Spokane River at RM 86.0
    - Average flow for maximum month: None specified
    - BOD_5: None specified
    - Total Ammonia: None specified
    - Total Phosphorus:
        (a) The daily average aggregate discharge for total phosphorus (as P) shall not exceed 16.5 kg/day (36.4 lbs/day) during the time period from June 1 to October 31 for Inland Empire Paper Company and Kaiser Aluminum & Chemical Corporation at Trentwood.

        (b) The daily average discharge for total phosphorus (as P) shall not exceed 5.35 kg/day (11.8 lbs/day) during the time period from June 1 to October 31 for Inland Empire Paper Company.

        (c) The Permittee will not be considered in violation of the daily average discharge limit contained in “b” unless the daily average aggregate discharge limit contained in “a” is also exceeded for the same reporting period.

- Inland Empire Paper Company IWTP Outfall #001
    - Permit No: WA-000082-5
    - Location: N. 3320 Argonne Road, Spokane, WA.
    - Receiving Water: Spokane River at RM 82.6
    - Average flow for maximum month: None specified
    - BOD_5:

        Average Monthly: 2,374 lbs/day
        Average Weekly: 4,536 lbs/day
    - Total Ammonia: None specified
    - Total Phosphorus:
        (a) The daily average aggregate discharge for total phosphorus (as P) shall not exceed 16.5 kg/day (36.4 lbs/day) during the time period from June 1 to October 31 for Inland Empire Paper Company and Kaiser Aluminum & Chemical Corporation at Trentwood.

        (b) The daily average discharge for total phosphorus (as P) shall not exceed 11.2 kg/day (24.7 lbs/day) during the time period from June 1 to October 31 for Inland Empire Paper Company

        (c) The Permittee will not be considered in violation of the daily average discharge limit contained in “b” unless the daily average aggregate discharge limit contained in “a” is also exceeded for the same reporting period.

- City of Spokane Advanced Wastewater Treatment Plant (AWTP)
  - Permit No: WA-002447-3
  - Location: N. 4401 A.L. White Parkway, Spokane, WA.
  - Receiving Water: Spokane River at RM 67.4
  - Average dry weather flow for maximum month: 44 mgd
  - BOD_5 and Total Ammonia: shown in Table 8.
  - Total Phosphorus:
    - (a) Monthly average: 85% minimum removal during the removal season.
    - (b) Seasonal chemical phosphorus removal must be initiated by no later than June 1, or terminate no earlier than October 15. The determination of variable spring initiation or fall termination of phosphorus removal outside the June 1- October 15 time period shall be made in accordance with approved methodology and procedural guidelines. The monthly average shall be calculated using only the days when chemical removal is required.

Table 8. City of Spokane AWTP BOD5 and ammonia effluent permit limits.

	July-October		November-June	
Average Weekly BOD5	45 mg/L	18,900 lbs/day	45 mg/L	18,900 lbs/day
Average Monthly BOD5	30 mg/L	12,600 lbs/day	30 mg/L	12,600 lbs/day
Average Weekly Total Ammonia	6.33 mg/L	2,323 lbs/day	13.4 mg/L	13,522 lbs/day
Average Monthly Total Ammonia	1.61 mg/L	591 lbs/day	5.30 mg/L	2,323 lbs/day

The October 1994 – December 2001 average monthly BOD5 discharge characteristics reported by the City of Spokane AWTP, Inland Empire Paper Company IWTP, and Liberty Lake POTW are presented in Appendix A, Figures A19-A21. Kaiser Aluminum is not required to report BOD5 data. The data indicate that the facilities were operating well below their BOD permitted limits, especially during the summer low-flow period. Table 9 presents the June-October 15, 2001 discharger effluent characteristics for BOD5 and TP (i.e., current effluent quality).

Table 9. The June-October 15, 2001 effluent concentrations and loads for BOD5 and total phosphorus for the Washington dischargers to the Spokane River (mean ± stdev).

Point Source Discharge	Discharge (mgd)	BOD5 (mg/L)	BOD5 (lbs/day)	Total P (mg/L)	Total P (lbs/day)
City of Spokane AWTP	36.9 ± 1.48	5.9 ± 1.35	1786 ± 437	0.48 ± 0.110	147 ± 34.0
Inland Empire Paper Co.	4.32 ± 0.449	6.6 ± 5.37	243 ± 203	0.45 ± 0.346	16.5 ± 12.4
Kaiser Aluminum*	15.2 ± 0.680	3.4 ± 1.03	428 ± 130	0.02 ± 0.007	2.51 ± 1.00
Liberty Lake POTW	0.623 ± 0.084	5.2 ± 2.05	27 ± 11	4.12 ± 0.708	21.3 ± 4.03

* Estimated from seven samples collected during the summer of 2001 and the daily average discharge for the June-October 15 period.

Comparing the 2001 June-October average effluent characteristics to the permitted concentrations and loads for BOD5 show that the permittees discharged <15% of their allowable monthly average loading limit. Only Liberty Lake in 2001 exceeded the amount of phosphorus loading to the river that they discharged in 1985 (see Lake Spokane Phosphorus TMDL and Total Phosphorus TMDL Evaluation sections in this report).

Lake Spokane

Water quality in Lake Spokane has been affected over the last 45 years as a result of the following major events:

- 1958: The City of Spokane built the first wastewater treatment facility for primary treatment only. Prior to 1958, the city discharged raw sewage into the river.
- 1976-78: Large blue-green blooms in the reservoir during late summer and early fall led to homeowners living near the reservoir to file a lawsuit against the Liberty Lake Sewer District No. 1 and Ecology. Concern over the water quality in the reservoir, continued discharge from the City of Spokane's treatment plant, and construction of additional treatment plants (i.e., Post Falls and Liberty Lake) that would discharge pollutants to the river led to the lawsuit.
- 1977: The City of Spokane completed construction of a new advanced wastewater treatment plant in December 1977. (The advanced treatment consisted of secondary treatment with 85% phosphorus removal.) The plant was designed to remove phosphorus from the effluent.
- 1979: A Spokane Superior Court decision entered on July 24, 1979 charged Ecology and the U.S. Environmental Protection Agency (EPA) with the task of completing a wasteload allocation for all sources discharging phosphorus into the river to slow the eutrophication process within Lake Spokane (Singleton, 1981). The Spokane River Wasteload Allocation study was initiated as a result of the Spokane Superior Court decision.
- 1987: Based on studies of the Spokane River and Lake Spokane, Ecology recommended a June through October phosphorus TMDL for the lake of 259 kg/day. The TMDL was based on setting a maximum lake euphotic zone TP concentration of 25 ug/L. The goal of the TMDL was to maintain the lake at a mesotrophic condition or better during the high use summer period.
- 1989: A Memorandum of Agreement (MOA) for the Spokane River Phosphorus Management Plan was endorsed and signed by the regulatory agencies (Ecology and EPA) and representatives of the point source dischargers to the Spokane River. The MOA specified that the point-source dischargers agreed to implement its control measures.
- 1989: A Technical Advisory Committee was established to manage phosphorus concentrations discharged by the following facilities: wastewater treatment facilities in Coeur d'Alene, Hayden, Rathdrum, Post Falls, Liberty Lake, and Spokane; Spokane Industrial Park, Inc.; Kaiser Aluminum & Chemical Corporation at Trentwood; and the Inland Empire Paper Company.
- 1990: Regional phosphate bans went into effect in Idaho and Washington in Spokane and Kootenai counties.
- 1992: Ecology submitted the proposed 25 ug/L TP TMDL for Lake Spokane to EPA on March 9. EPA approved the TMDL on November 10.

Lake Spokane is usually completely mixed or unstratified until the beginning to the middle of June because of the large amount of inflow and outflow water due to spring snowmelt conditions that significantly increase flows in the Spokane River. Figures 16 and 17 present an example of June and August temperature and conductivity profiles for Lake Spokane that represent the stratification and high conductivity interflow in the lake. (Station LL1 is located about 5.3 miles upstream of the dam.) The graphs illustrate the onset of temperature stratification in June and the fully developed stratification and interflow that occurs by the middle of July and extends to mid-September. Starting in September, temperatures in the river decrease because of cooler air temperatures. The river still has high salinities such that the inflowing water to the reservoir follows along the bottom of the reservoir (i.e., interflow turns into bottom flow). The bottom flow through the reservoir accelerates the beginning of fall turnover that begins in October (Soltero, 1992).

Nuisance algae populations and hypolimnetic oxygen depletions within Lake Spokane have been reported to occur during the summer growing season between June and October when inflows and corresponding flushing rates are low (Patmont, 1987; Soltero, 1992 and 1993). In addition to the reduced flow-through characteristic of Lake Spokane during this time, lake stratification during the growing season creates a complex mixing regime in which inflows are partially separated from the lake surface and bottom waters. This is due to the interflow of incoming waters through the metalimnion to the penstock tube openings in the Lake Spokane Dam. The compartmentalization due to these complex hydrodynamics results in non-steady-state relationships between nutrient loading and in-lake water quality conditions (Patmont, 1987).

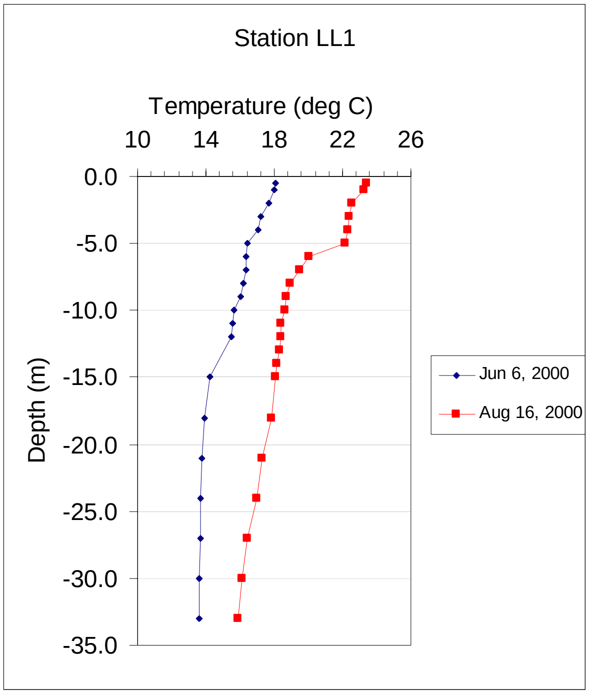

Figure 16. Lake Spokane temperature profiles for June 6 and August 16, 2000.

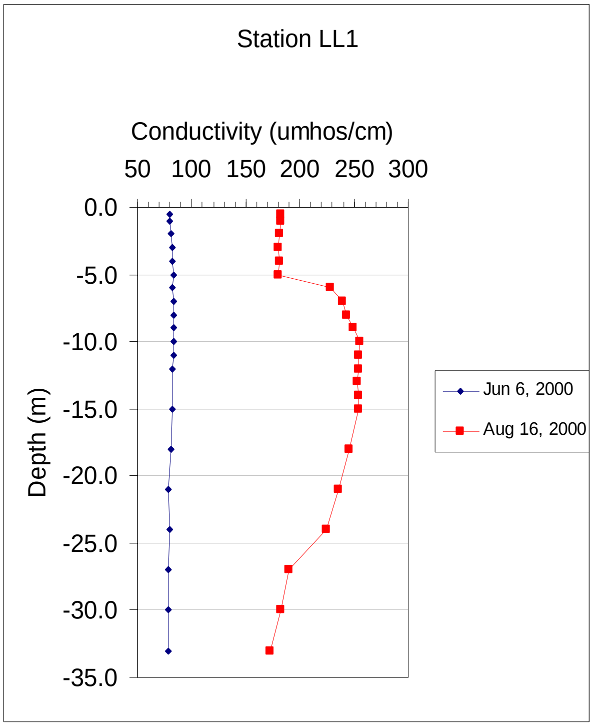

Figure 17. Lake Spokane conductivity profiles for June 6 and August 16, 2000.

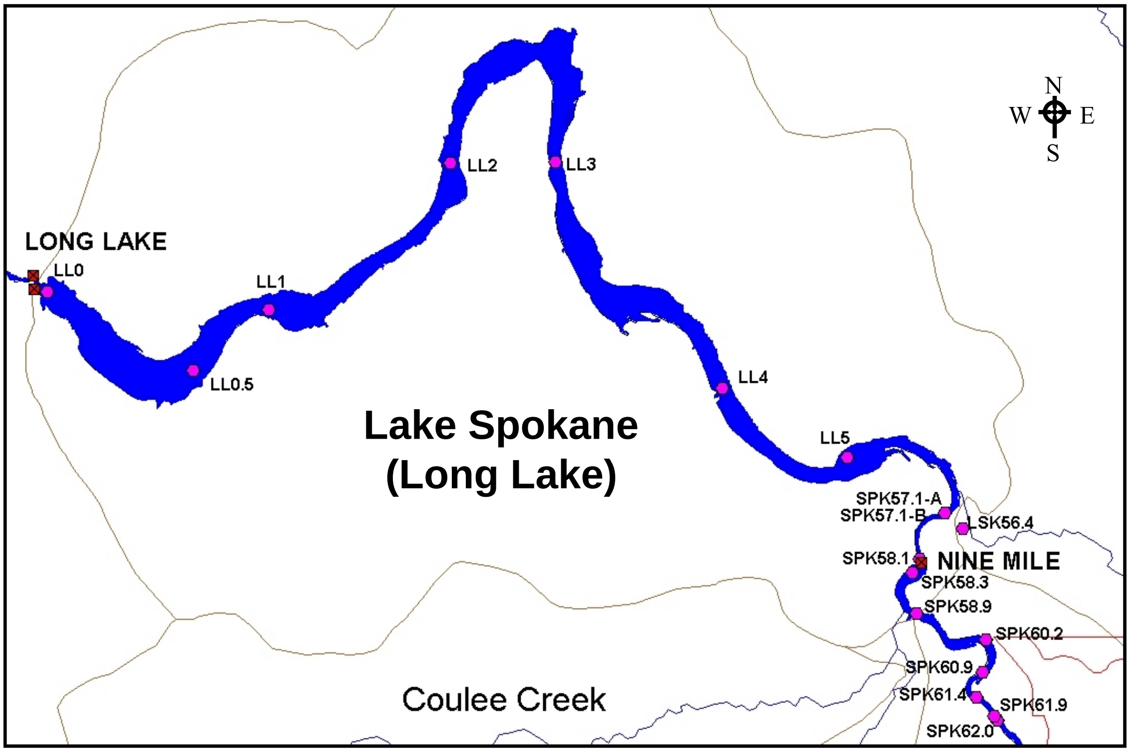

Figure 18. Lake Spokane sampling station locations.

Numerous historical studies have identified that phosphorus loading and BOD loading to Lake Spokane was directly responsible for low dissolved oxygen, excessive phytoplankton populations, and overall poor water quality during the summer period (June – October), and that lake water quality can be directly related to upstream sources (Cunningham and Pine, 1969; Soltero et al. 1973-76, 1978-85; and 1992). It was also reported that the standing crop of phytoplankton affects the oxygen demand in both the water column and the sediment water interface (Wagstaff and Soltero, 1982). In addition, the primary cause of summer declines of hypolimnetic oxygen concentrations in the lake were caused by phytoplankton that add to the internal lake BOD load (Wagstaff and Soltero, 1982). Reservoir BOD loads in 1981 were 20 to 100 times greater than influent BOD, and the maximum BOD in the reservoir occurred in late September (Wagstaff and Soltero, 1982).

When the City of Spokane's AWTP, including phosphorus removal, came on-line in 1978, the phosphorus loading to Lake Spokane decreased (Soltero et al., 1979-85). A corresponding decrease in chlorophyll *a* concentrations, primary productivity, orthophosphate concentrations, and hypolimnetic anoxia were also reported (Soltero et al., 1979-85). The major conclusion of the early studies following 1978 was that Lake Spokane had improved water quality with respect to algal biomass, transparency, and hypolimnetic anoxia such that the lake changed from eutrophic conditions during the pre-AWTP period to mesotrophic to meso-eutrophic conditions (depending on the flushing rate during the growing season) during the post-AWTP period of 1978-1985 (Soltero et al., 1979-86). However, most of the trophic values were meso-eutrophic during 1978-1985 (Soltero et al., 1992). Lake data collected during 1991 indicated that most trophic parameters were representative of mesotrophic conditions, except for summer mean biovolume which reached meso-eutrophic levels.

Figures 19-21 show examples of mid- to late August dissolved oxygen profiles for Lake Spokane found before (1977 only) and after 1978 that represent approximately the downstream 14 miles of the lake (i.e., area from the dam to station LL3). Before 1978 anoxia was found to be both temporally and spatially pervasive (e.g., in 1977 hypolimnetic anoxia occurred June-September at stations LL0 to LL2 and in August extended from the dam upstream to LL3). The degree of hypolimnetic anoxia in 1978-79 was similar but improved from 1977, with dissolved oxygen concentrations of <1.0 mg/L found at LL1 and LL2 only below 21 meter depths during August and September, and at LL0 and LL2 below 18 meter depths for about one month (Soltero et al., 1980). Again during 1981, dissolved oxygen declined throughout the summer, and minimum values occurred by the end of August. However, the extent and duration of anoxia was much less than that found during other post-AWTP years. (Note that historical profile data before this study were not collected at depths below 33 meters.)

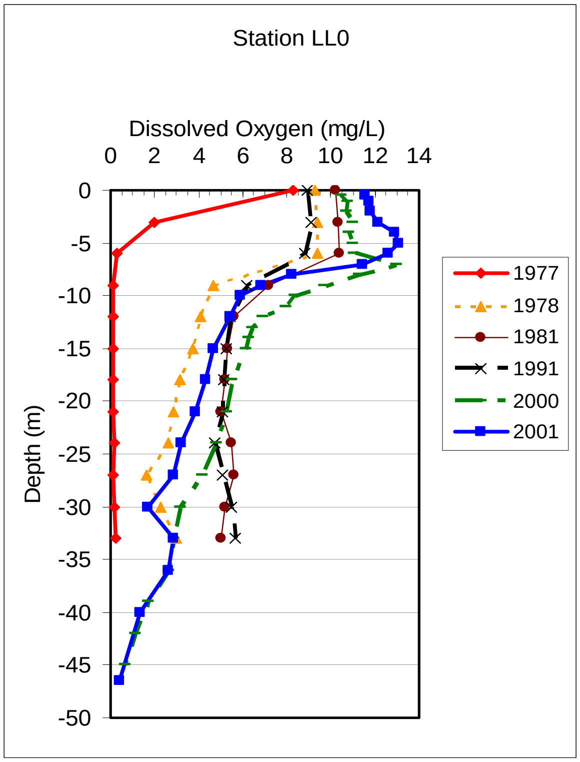

Figure 19. Lake Spokane mid to late August dissolved oxygen profile data collected at station LL0 located near the dam.

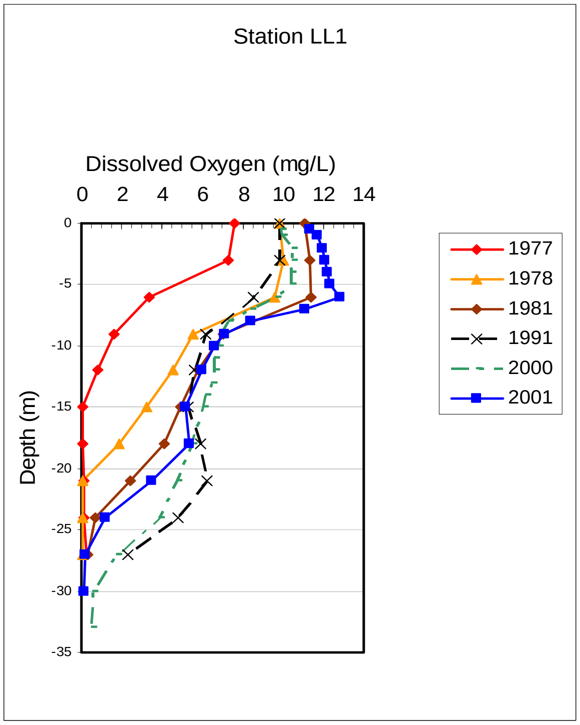

Figure 20. Lake Spokane mid to late August dissolved oxygen profile data collected at station LL1 located about 4 miles upstream of the dam.

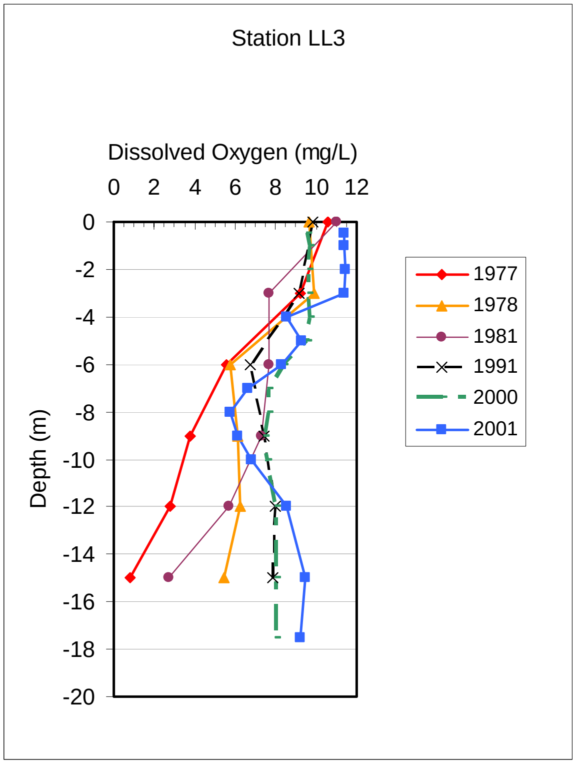

Figure 21. Lake Spokane mid to late August dissolved oxygen profile data collected at station LL3 located about 14 miles upstream of the dam.

The profile data show that the reservoir dissolved oxygen concentrations improved dramatically after the AWTP initiated operations. It was reported that hypolimnetic dissolved oxygen concentrations in 1981 and 1990-91 were very much improved and that the annual mean values could be representative of an oligotrophic range (Soltero et al., 1992). During 1990 and 1991 anoxic conditions in the hypolimnion were not observed during the study years at depths above 33 meters – again, indicating improvements in dissolved oxygen as a result of the AWTP at the City of Spokane and possibly efforts to reduce all TP sources to the river. However, annual summer variations in flow were cited as the possible cause of water quality improvements because post-AWTP year flows were higher than some of the worst water quality years during the pre-AWTP years. For example, 1977 was a low-flow year, and the post-AWTP years including 1991 were close to median-flow conditions. The June-September daily average flow in 1977 was 1,768 cfs, but in 1981 and 1991 they were 4,157 and 4,364 cfs, respectively. The seasonal daily average flow in 2001 of 1,674 cfs was similar to 1977 and indicates lake water quality (as represented by dissolved oxygen) has improved in Lake Spokane even during low river flow conditions.

A diagnostic study of Lake Spokane was completed in 1992 as part of the Lake Spokane Phase I Restoration Project. The study, *Assessment of Nutrient Loading Sources & Macrophyte Growth in Long Lake (Lake Spokane), WA and the Feasibility of Various Control Measures* (Soltero et al., 1992), provides a limnological assessment of Lake Spokane while focusing on the major water quality concerns of algae blooms and increasing large stands of aquatic macrophytes in the lake. Annual water and phosphorus budgets were completed, the aquatic macrophyte community was assessed, and restoration control measures were evaluated. They found that the Spokane and Little Spokane rivers contributed about 94% of the phosphorus load to the reservoir. Groundwater was estimated to be contributing approximately 5% of the phosphorus load while the standing crop of macrophytes during senescence and sediment release were estimated to be contributing less than 1% of the phosphorus load. A 90% sedimentation loss was used in the macrophyte phosphorus release estimate, but the contribution would still have been less than 1% of the TP load even if a 50% sedimentation loss value was used in the estimate.

A shift in the make-up of the phytoplankton community from diatom domination in earlier studies to blue-green domination in 1990, 1991, and 1992 was identified (Soltero et al., 1992, 1993). It was also reported in earlier studies that blue-green algae grow better under conditions of low free metals, and that prior to 1976 zinc levels entering Lake Spokane were high (Yake, 1979; Soltero and Nichols, 1981). (Note: The blue-green blooms that occurred in late summer to early fall during 1976-1978 led to the citizen lawsuit.) Soltero et al. (1992) reported that there was a decreasing trend in zinc levels entering Lake Spokane and zinc levels were lowest in August and September when blue-green blooms occur.

Lake Spokane Phosphorus TMDL

The phosphorus concentration criterion for Lake Spokane and the associated phosphorus TMDL was mainly based on analyses presented in four documents: URS (1981), Singleton (1981), and Patmont et al. (1985 and 1987).

The Spokane Superior Court's 1979 decision required that Ecology and EPA complete a water quality study on the Spokane River system. As summarized in Singleton (1981), the court stated that Ecology and EPA:

1. Quantify the levels of phosphorus and related parameters in the river system,
2. Identify the sources of phosphorus contributing to the system,
3. Identify the deleterious effects of the high levels of phosphorus and,
4. Publish conclusions that would recommend a method or methods of slowing the eutrophication process within Lake Spokane.

The URS (1981) report identified the major beneficial uses of the Spokane River and Lake Spokane as sole source water supply for the aquifer, fish and wildlife habitat, recreation, and aesthetic enjoyment. The river upstream of Greene Street was identified as supporting a trout fishery, and downstream of Greene Street the major beneficial use was identified as aesthetics, because the river was deemed not conducive to water contact recreation. Fishing (trout, perch, bass, and crappie) also occurred between the Upriver Dam and Lake Spokane (planted with rainbow and German brown trout). The beneficial uses of Lake Spokane were identified as primary contact recreation (swimming and water skiing) and fishing (bass, yellow perch, and crappie). Trout were present in the section between the mouth of the Little Spokane River and Nine Mile Dam considered to be in the Spokane River, not the lake. (This section was planted with eastern brook trout and German brown trout.)

The URS report did not identify any water quality problems for the Spokane Aquifer. Dissolved oxygen concentrations below Lake Spokane and at the Washington/Idaho Stateline Bridge were reported as dropping below the criterion for the river system of 8 mg/L. In addition, high metal concentrations were also noted as a water quality problem for the river.

Water quality problems for Lake Spokane were identified as blue-green algal blooms that occurred in late summer and early fall (August-October), algal growth during the summer (June-September), and macrophyte growth. The report also stated:

> "In contrast (to the algae blooms and macrophytes) no adverse effects of the low dissolved oxygen levels in the hypolimnion of Lake Spokane on the resident fish population have been reported. Thus, comparison of beneficial uses and water quality conditions suggest that the major existing problems in Lake Spokane are algal blooms and macrophyte growth."

Although the authors recognized that low hypolimnetic dissolved oxygen levels still occurred after phosphorus removal began, the URS report and subsequent reports focused only on developing phosphorus loading limits for the lake and corresponding wasteloads to protect the aesthetic quality of the water, i.e., they did not address hypolimnetic oxygen deficits and dissolved oxygen criteria.

The URS report presented some examples of total phosphorus (TP) TMDLs based on meeting chlorophyll *a* mean seasonal (June-November) criteria of 8, 10, 12 or 15 ug/L assuming different design inflows for the Spokane River. The TP loading to reach these levels was based on the relationship between total aerial phosphorus loading and the euphotic zone chlorophyll *a* concentration. Aerial loading was established by using a phosphorus budget model. The report also provided an example wasteload allocation scenario using the chlorophyll *a* criterion of 10 ug/L and a June-November average design river flow with a 1 in 20 year return period. The example scenario was determined for existing conditions and estimated 1990 loads (assuming secondary treatment for all wastewater treatment plants). The seasonal TMDL for the lake using this example was 211 kg/day. Loading estimates for then-current conditions show that the background and nonpoint phosphorus loads alone would be greater than the load that would be needed to reach a chlorophyll *a* criterion of 8 ug/L (i.e., it would be impossible to achieve because it would not allow any point source loading to the system).

The authors of the URS report noted that a chlorophyll *a* criterion of 10 ug/L is regarded by other limnologists as the demarcation between eutrophic and mesotrophic lakes, and that the water clarity associated with this chlorophyll *a* concentration was both aesthetically enjoyable and afforded sufficient safety for swimming. They also stated that the choice of a chlorophyll *a* criterion was subject to judgment as to what is a "reasonable value" with respect to maintaining acceptable water quality and the costs for controlling phosphorus discharges to the Spokane River. They identified public input as "vital" to development of an acceptable allocation plan and also very important for selection of the criteria and definition of time periods to protect the lake.

Phosphorus retention coefficients (i.e., fraction of phosphorus retained in the lake = R) used by URS in the phosphorus budget model had a significant influence on the permissible load. Based on historical data, URS estimated that R could range between 0.23 and 0.44. Retention values of 0.2 and 0.4 were used in the budget model. The results indicated that the allowable loading could be 33% greater if an R value of 0.4 was used instead of 0.2 (e.g., 211 kg/day discussed above was based on R = 0.2, but would be 282 kg/day if R = 0.4).

The URS report also assessed the feasibility of allowing seasonal phosphorus removal as opposed to year-round removal. They estimated that phosphorus removal in the winter and early spring would not affect algal growth during the critical summer season, because algal production is limited by phosphorus levels only during April-October. They concluded that a finite period of time would be needed between the start of phosphorus removal and reduction of phosphorus concentrations to a given target level in the lake. However, they also concluded that the period of time that phosphorus removal was required depended on river flow. For example, if river flow is high, then phosphorus removal would not need to start until June 1, but at low flow it may need to be initiated by April 1.

Ecology (Singleton, 1981) reviewed the URS report and accepted the mean chlorophyll *a* criterion of 10 ug/L based on the reasons specified in the report, but revised the allowable loading to 230 kg/day. The change was based on meeting the chlorophyll *a* criterion of 10 ug/L, but using a revised loading estimate for the Little Spokane River and a revised R value of 0.25 in the phosphorus budget model. The R value was revised based on recommended changes to the loading data used to establish the range of R values reported by URS. The current existing load estimated for a 1-in-20 year flow was 229 kg/day. Ecology concluded that the Spokane River was currently at complete allocation.

In 1984 a study was conducted during the July-September summer period to determine if significant losses of phosphorus occurred along the river from Lake Coeur d'Alene, Idaho to Nine Mile Dam, Washington (Patmont et al., 1985). The study finding was that more than 40% of the TP load to the river was lost (or removed) during transport either by seepage to the aquifer or by "in-river removal processes." In-river removal processes were identified as periphyton growth (i.e., algal uptake). The investigators referred to phosphorus removal as "phosphorus attenuation." Patmont et al. (1985*)* found that about two-thirds of the phosphorus attenuation was due to in-river uptake by periphyton and the remainder due to hydraulic attenuation (i.e., leaves the river via seepage to the aquifer).

Patmont et al. (1985) also discussed the development of a predictive phosphorus transport model for the river that could be used to assign wasteload allocations. The model included the uncertainties associated with groundwater interactions, phosphorus loading, and attenuation processes. Using their model, the estimated design loading to Lake Spokane was 21% lower than the allowable 248 kg/day load established by Ecology. [Although they reported the Ecology TMDL value as 248 kg/day, it appears that the actual value was 230 kg/day (Singleton, 1981).]

Given the findings of the Patmont et al. (1985) report, Ecology contracted with Harper Owes to review and revise the Spokane River/Lake Spokane database and water quality models, and develop appropriate allocation strategies for determining phosphorus wasteload allocations.

Harper Owes completed a report summarizing this work in 1987 (Patmont et al., 1987). The report provided an evaluation of the data available on the Spokane River and Lake Spokane through 1985. They identified laboratory bias in some of the chlorophyll *a* and TP data and corrected the data. The corrected data were used to update the lake database.

The Patmont et al. (1987) report concluded that only the lower flow months of June-October needed to be considered when assessing lake trophic response to nutrient loading. The authors also concluded that the complex hydrodynamics and flushing rate of the lake during the low-flow period results in "varying or non-steady-state relationships between nutrient loading and in-lake water quality conditions." They stated that generalized steady-state models that predict retention were not appropriate for Lake Spokane (i.e., models previously applied to predict lake phosphorus concentrations).

Patmont et al. (1987) developed regression models based on the relationships of flow-weighted seasonal (June-October) influent TP concentrations and average seasonal area-weighted lake TP and chlorophyll *a* concentrations, as well as median biovolume, median Secchi disc depth, and minimum mean hypolimnetic dissolved oxygen concentrations. They found that seasonal mean TP concentrations could be predicted directly from the flow-weighted influent concentration (i.e., 1.005 x influent concentration). Because euphotic zone TP concentration data were limited and the flow weighted average seasonal influent TP concentrations were nearly identical to average eutrophic zone concentrations, the latter was used as the independent variable in the regression analyses. The regressions were used to evaluate the significance of trophic responses (as reflected by the lake variables, e.g., chlorophyll *a*, secchi depth, and phytoplankton biovolume).

Patmont et al. (1987) noted that the TP-chlorophyll *a* regression relationship for Lake Spokane was non-linear. Increases in TP concentrations do not lead to proportional increases in chlorophyll *a*, especially at higher concentrations. They contrasted this against the reported nearly linear relationships for these variables in most temperate lakes. The authors state that the probable cause for the non-linear relationship was a potential nitrogen limitation at higher TP levels based on algal assay results. They also note that the TP-phytoplankton biovolume regression relationship was nearly linear, and that euphotic zone biovolume may be more closely controlled by (related to) phosphorus than chlorophyll *a*. Regression analysis showed that influent TP was a significant determinant of the minimum mean hypolimnetic dissolved oxygen level. However, river flow was also found to be an equally significant determinant. The authors presented a stepwise multiple regression model for predicting minimum mean hypolimnetic dissolved oxygen concentrations from influent TP and river flow. Based on all of the regression relationships, the authors concluded that phosphorus was the limiting nutrient for Lake Spokane.

[Comment: the non-linear TP-chlorophyll *a* relationship may have been because the interflow zone mitigates the higher summer influent TP concentrations by reducing the mixing with the euphotic zone.]

The report also discussed internal and external loading of organic material to the lake with respect to hypolimnetic oxygen deficits and presented a total organic carbon (TOC) budget for the lake. Their conclusions were similar to those presented in an earlier BOD study of the lake (Soltero et al., 1982). They determined:

1. Phytoplankton production within the reservoir was the greatest source of TOC.
2. The City of Spokane AWTP was a minor direct loading TOC source.
3. Only about 10-20% of the TOC input to the reservoir was estimated to have decomposed in the hypolimnion, possibly due to the complex hydrodynamics.
4. It would be reasonable to expect that the extent of dissolved oxygen depletion in the reservoir was related to phosphorus supplies.

The biomass of periphyton in the river and response to nutrient loading was also reported based on data collected from 1984 to 1986 and growth experiments (Patmont et al., 1987). A nuisance growth of periphyton was identified in the middle and lower reaches of the river due to phosphorus loading (i.e., phosphorus concentrations limit growth). Patmont et al. (1987) noted that critical concentrations of phosphorus (mainly SRP) that lead to excessive periphyton growth could be very low (2-5 ug/L).

The management goal of the TMDL was identified in the Patmont et al. (1987) report as developing wasteload allocations to slow the eutrophication process within Lake Spokane per the 1979 court order. The impairment was identified as the "undesirable eutrophic character of Lake Spokane prior to and shortly after the implementation of advanced wastewater treatment at Spokane… (e.g., *Anabaena* and *Microcystis* blooms)." The primary objective was identified as "….achievement of a more desirable mesotrophic condition in Lake Spokane." The URS (1981) and Singleton (1981) documents were cited as support for the impairment and primary objective for establishing wasteload allocations.

Patmont et al. (1987) discussed possible water quality criteria for Lake Spokane relative to trophic status (i.e., trophic classification and values for annual or summer mean TP, chlorophyll *a*, algal biovolume, secchi, and dissolved oxygen). They pointed out that the state water quality standards applicable to "Lake Class" did not have any numeric criteria for trophic category to prevent eutrophication. The authors also noted that the lake dissolved oxygen standard of "no change from natural conditions" would be difficult to define in a regulated system like Lake Spokane. (The stepwise regression to predict mean minimum hypolimnetic dissolved oxygen concentrations does show that changes in TP and river flow change dissolved oxygen levels, e.g., June-October median river flow and influent TP concentrations of 25 ug/L would yield a mean minimum hypolimnetic dissolved oxygen of 3.3 mg/L and an influent TP value of 20 ug/L would yield 4.7 mg/L or a 1.4 mg/L increase.) However, they stated that "an enforceable eutrophication-related water quality standard(s) for Lake Spokane was desirable if future wasteload allocation efforts throughout the project area were to be implemented."

Patmont et al. (1987) concluded that the June-October euphotic zone average TP concentration can be the best predictor of trophic status variables like chlorophyll *a*, and recommend that a value of 25 ug/L would be a reasonable goal for Lake Spokane. A euphotic zone TP value of 25 ug/L was cited as a concentration that would lead to "mid-mesotrophic delineation." The authors went on to present predicted June-October trophic parameter concentrations based on the TP 25 ug/L target [i.e., mean chlorophyll *a*, peak chlorophyll a, median algal biovolume, median secchi, and minimum mean hypolimnetic dissolved oxygen]. They pointed out that euphotic zone June-October mean and peak chlorophyll *a* concentrations were predicted to exceed the mesotrophic boundary values using a TP value of 25 ug/L, but biovolume and secchi disc (measures of algal biomass) were predicted to be within the mesotrophic range.

Patmont et al. (1987) qualified the recommendation to adopt a lake criterion for the euphotic zone of TP of 25 ug/L by stating that the value does not include a "safety factor" based on the uncertainty associated with the trophic delineations. They stated that there was nearly a 20% probability that the lake could have eutrophic characteristics, indicating that low hypolimnetic dissolved oxygen levels, especially during low-flow years, could lead to some aquatic life impacts. Furthermore, they said that a nuisance bloom of *Microsystis* occurred during 1978 (September) with a predicted euphotic zone concentration of 28 ± 6 ug/L TP. The authors stated that the 25 ug/L value represents an "approximate" threshold level where the risk of adverse water quality conditions is "unreasonable" above this level. It was cited that Ecology determined that the 25 ug/L afforded an "acceptable" level of protection for Lake Spokane.

The phosphorus attenuation model developed earlier (Patmont et al., 1985) was modified based on a re-evaluation of river flows and some TP loading sources. The river model was then used with the lake regression models to recommend a TP TMDL for Lake Spokane and to propose wasteload allocations based on the lake TP criterion of 25 ug/L (Patmont et al., 1987). As directed by Ecology, Harper Owes evaluated TP loading for the June-October season, median and 1-in-10-year low river flow conditions for managing Lake Spokane (URS proposed using a 1-in-20-year low flow). The TMDL for Lake Spokane using a 1-in-10-year low (1,537 cfs) and median (2,970 cfs) river flow at the outlet of Lake Coeur d'Alene were estimated to be 163 and 259 kg/day, respectively. However, the total allowable loading to the river using 1985 conditions, including the phosphorus load that would be "attenuated" in the river, was estimated to be 330 kg/day. The authors explained that the risk of the lake exhibiting eutrophy would only increase by 6% (i.e., 17% increased to 23%) using the median flow, but the median flow would allow considerably greater allowable point source loadings:

> "In consideration of the potential environmental benefits and additional treatment costs associated with alternative design flow conditions, Ecology determined that the proposed 25 ug/L euphotic zone TP standard should be applied to the median flow event…."

The report goes on to present an allocation example based on the allowable June-October average loading of 259 kg/day to Lake Spokane (i.e., 330 kg/day total loading to the river), and reviews methods for determining initiation/termination dates for point source phosphorus removal. The industrial and municipal facilities, CSOs, and stormwater were assigned 57% of the total load to the river. They reported that 1985 phosphorus loading to the lake using the median design river flow would result in 255 ± 23 kg P/day, and concluded that existing phosphorus levels in the Spokane River basin were meeting the TMDL. The 1985 loads were predicted to result in a Lake Spokane eutrophic zone TP concentration of 24.8 ± 4.3 ug/L with the median design flow, but with the 1-in-10-year flow the value would be 30.5 ± 5.5 ug/L. Observed June-October TP loading to the lake in 1985 was 193 ± 19 kg P/day, and the attenuation model prediction was 196 ± 19 kg P/day. The euphotic zone average aerial-weighted chlorophyll *a* concentration measured in 1985 was reported as 7.9 ug/L.

In the spring of 1989, the municipal and industrial point-source dischargers to the Spokane River in Washington and Idaho agreed to the TMDL limits by signing a memorandum of agreement (MOA) for managing the point-source phosphorus loading to the river system. Under the Lake Spokane TMDL and MOA, phosphorus point source loads to the lake are controlled by specifying 85% phosphorus removal. However, the management scheme only requires 85% removal for the largest contributors first, and then as the in-lake criterion is approached, the next largest contributor would need to begin phosphorus removal. Currently, only the City of Spokane AWTP and the City of Lake Coeur d'Alene are required to have seasonal 85% removal. Given the current growth in the area, it is expected that the City of Post Falls would be the next facility required to upgrade to seasonal removal of phosphorus for the river to stay below the TMDL.

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Total Phosphorus TMDL Evaluation

An assessment of the Spokane River phosphorus attenuation model using 1990 through 1992 Lake Spokane data was reported in *Verification of Lake Spokane Water Quality as Predicted by the Spokane River Phosphorus Attenuation Model* (Soltero et al., 1993). The report documents the statistical verification of the river model. Model predictions of key water quality variables in Lake Spokane did not differ significantly from actual water quality measurements, which substantiated the use of the model. The report listed recommendations that included a review of source loadings for the model input because of the lapse of time and change of conditions since the model was developed.

Even though the data collected during the early 1990s verified the accuracy of the river model, the same data were used to report that "The present total maximum daily phosphorus load allowed to enter the reservoir during the growing season (259 ± 43 kg/day) via the surface tributaries is too high" (Soltero et al., 1992). It was also reported that the reservoir's retention time is greatest during the late summer through early fall which allows for greater phosphorus assimilation from algal growth. It was noted that "senescing macrophytes" in the upper end of the lake could have contributed to the phosphorus concentrations in 1991 because the large algal blooms occurred in late September through October. However, equally large blooms during 1990 and 1992 began in August which indicates that senescing macrophytes may contribute to blooms in the early fall but are not the major cause.

Although the total phosphorus (TP) growing season loads in 1990 and 1991 were 229 and 191 kg/day, respectively, the upper end of the reservoir had large blue-green blooms during the late summer to early fall, even though the summer river flows were equal to about median flows (Soltero et al., 1992 and 1993). Blue-green algal blooms also occurred in the upper end of the reservoir during the low-flow year of 1992, with growing season loads of 198 kg/day. Chlorophyll *a* concentrations >20 ug/L were reported for stations in the upper end of the reservoir starting as early as mid-August in 1992 which indicates that senescing macrophytes were not the cause of the blooms.

The phosphorus loading to Lake Spokane in 2000 (also about a median flow year) was also less than the recommended seasonal loading allocation for the Spokane and Little Spokane Rivers. Yet during 2000, the portion of the lake upstream of station LL3 had late summer and early fall phytoplankton blooms that produced chlorophyll *a* concentrations that were higher than 10 ug/L. Euphotic zone average chlorophyll *a* concentrations at LL4 in September-October 1991 ranged from 16 to 53 ug/L (high concentration was 74 ug/L on October 7). During 2000 the maximum chlorophyll *a* concentrations were only about 20 ug/L during the August and September surveys at LL4 or LL5. However, a significant bloom was observed in the upper end of the lake during early September (no samples were collected). In addition, chlorophyll *a* samples collected by Ecology at LL4 on August 29-30, 2001 were 70 ug/L at the surface (0.5-meter depth) and 22 ug/L at 6 meters depth. Secchi disc readings ranged from 4.75 meters at LL0 to 1.25 meters at LL4 during the August 29-30 lake survey. During early September 2001 a dense unsightly blue-green bloom was observed in the upper end of the lake. As discussed previously, a "nuisance" bloom of *Microsystis* occurred during September 1978. The euphotic zone chlorophyll *a* concentration at LL4 was 154 ug/L that year.

The chlorophyll *a* data and observations of dense algal blooms during late August through early October since 1978 show that the upstream end (about 9-10 miles) of the lake will often exceed 10 ug/L and exhibit other eutrophic conditions. The upstream part of the lake has a period of poor water quality because of greater retention (poor flushing) and warm surface temperatures during the late summer through early fall. The morphology of the reservoir (long, narrow, and shallow in the upper end of the lake), poor flushing during the late summer and early fall period, and changing hydodynamics through the growing season (see Lake Spokane Hydrology section) suggest that the upstream end of the lake is not protected under the current TP TMDL.

Figures 22 and 23 show the 1991 TP and chlorophyll *a* data for Lake Spokane reported in Soltero et al. (1993). Figure 24 shows the 1990-92 chlorophyll *a* data. Figure 25 and 26 present the chlorophyll *a* and phytoplankton biovolume data for 1985, one of the years used to establish the TP TMDL. Again, the graphs demonstrate that the reservoir experiences longitudinal changes in water quality over the June-October period. The graphs also show that the upper end of the lake as represented by LL3 and LL4 can have higher concentrations of chlorophyll *a* (and phytoplankton biovolume). As noted earlier, Patmont et al. (1987) reported a June-October mean euphotic zone chlorophyll *a* concentration for 1985 of 7.9 ug/L and the corresponding seasonal mean TP load at Nine Mile as 193 ± 19 kg/day, which was under the TP TMDL allocation for the Spokane River of 221 kg/day. The 1985 station data show that the lake upstream of LL3 experienced eutrophic conditions during August-October, even though the TP TMDL criterion for the growing season was not exceeded.

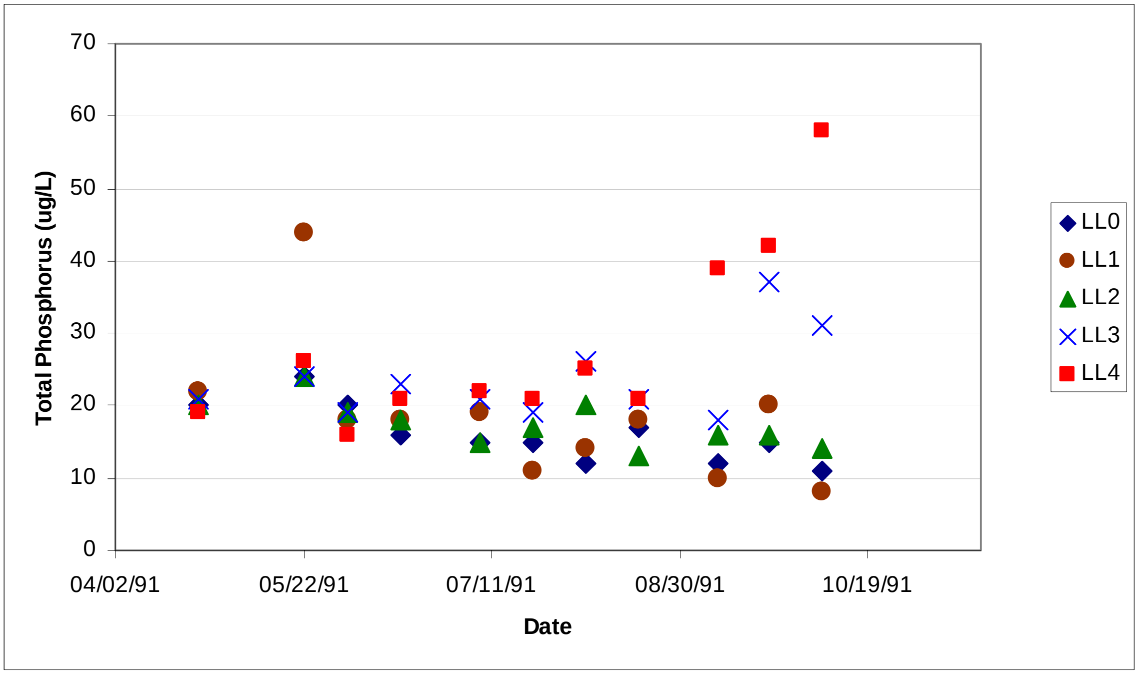

Figure 22. 1991 euphotic zone total phosphorus concentration data for Lake Spokane sampling stations LL0-LL4.

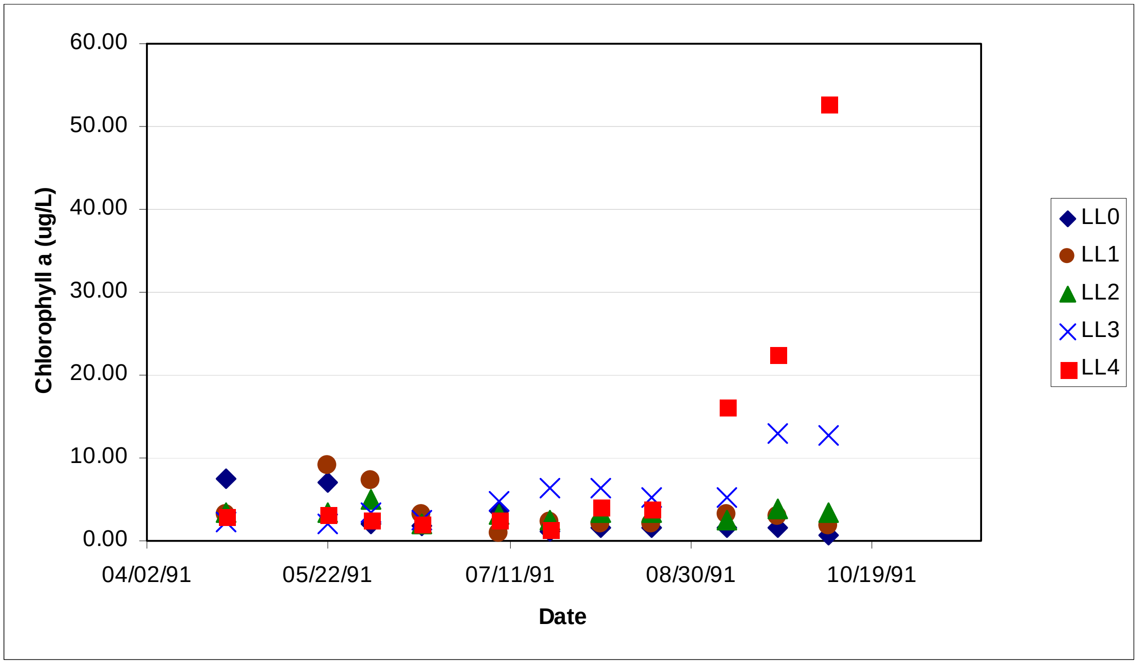

Figure 23. 1991 euphotic zone chlorophyll *a* concentration data for Lake Spokane sampling stations LL0-LL4.

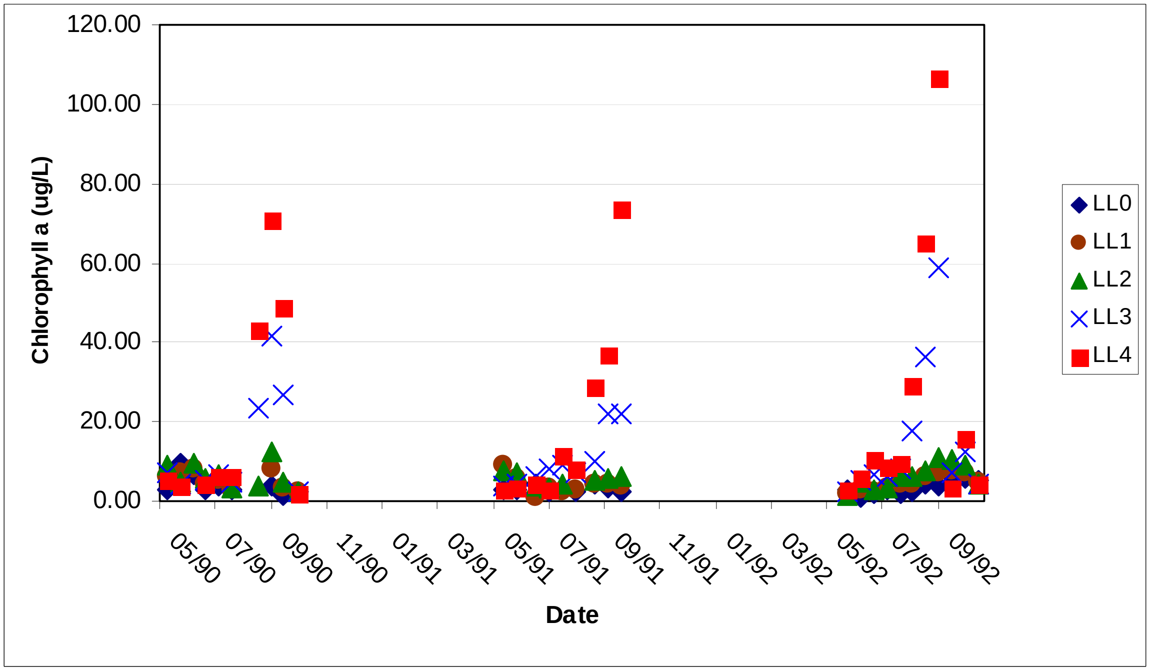

Figure 24. 1990-92 June-October euphotic zone chlorophyll *a* concentration data for Lake Spokane sampling stations LL0-LL4.

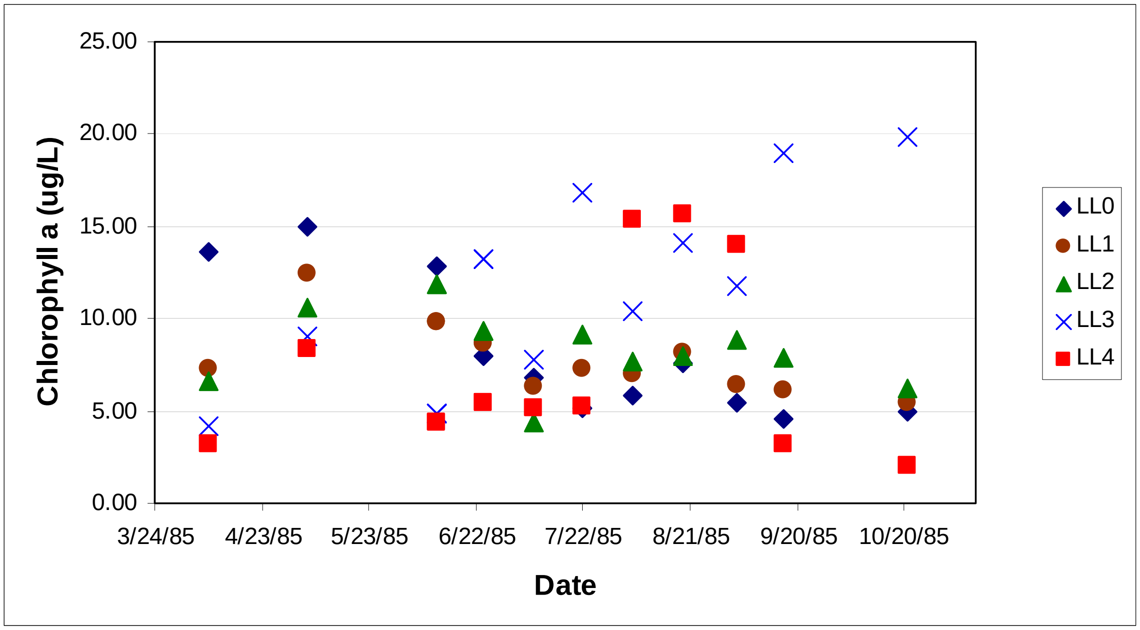

Figure 25. 1985 euphotic zone chlorophyll *a* concentration data for Lake Spokane sampling stations LL0-LL4.

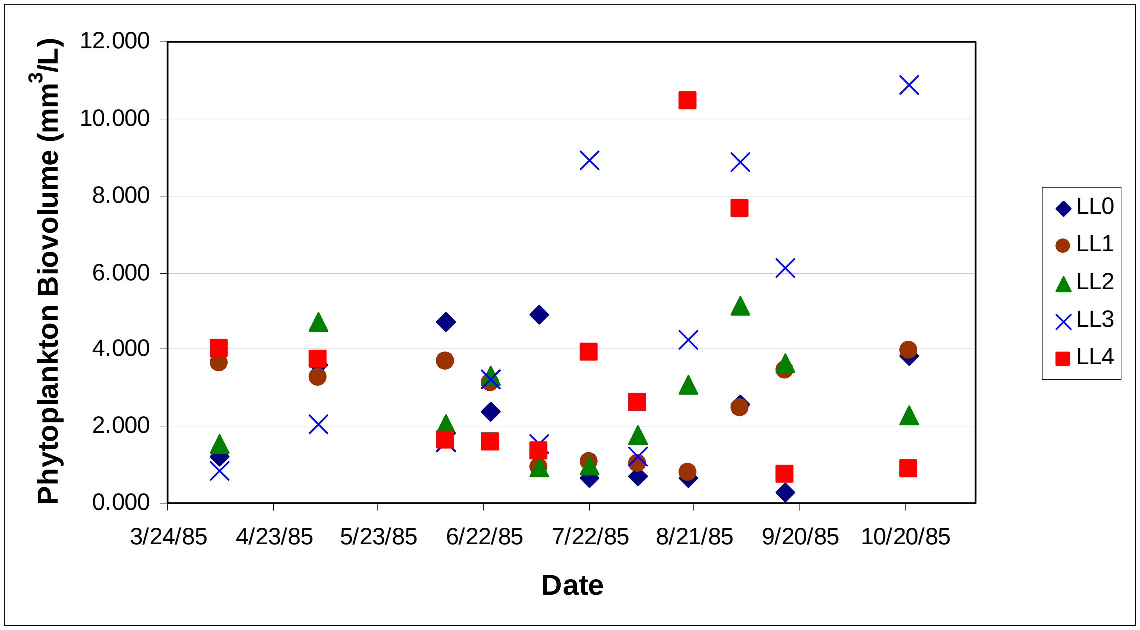

Figure 26. 1985 euphotic zone phytoplankton biovolume concentration data for Lake Spokane sampling stations LL0-LL4.

Table 10 summarizes the 1978-1985 mean, median, and range of chlorophyll *a* (geometric mean) for each lake station during August-October. The table values show that there is a longitudinal gradient of chlorophyll *a* in the reservoir and that the upper end of the lake can have average and median concentrations that exceed the proposed criterion. (Pre-1978 chlorophyll *a* data do not show a longitudinal gradient of values in the lake.) Table 11 summarizes the data for the same period of record, but during April-June. The April-June data shows that the opposite condition exists during spring, but again demonstrates a longitudinal gradient of chlorophyll *a*. The same information for phytoplankton biovolume is summarized in Tables 12 and 13.

Table 10. Mean, median, and range of chlorophyll *a* data reported for August-October 1978-1985.

Lake Station	Mean Chl *a* (ug/L)	Median Chl *a* (ug/L)	Range Chl *a* (ug/L)
LL0	7.6	6.7	4.2-26.2
LL1	8.4	7.6	4.5-23.2
LL2	10.1	8.9	4.3-26.4
LL3	13.6	10.7	4.7-28.2
LL4	13.0	14.3	2.0-154.3

Table 11. Mean, median, and range of chlorophyll *a* data reported for April-June 1978-1985.

Lake Station	Mean Chl *a* (ug/L)	Median Chl *a* (ug/L)	Range Chl *a* (ug/L)
LL0	15.9	16.0	7.8-31.4
LL1	15.7	14.4	7.3-32.1
LL2	14.5	13.2	6.6-34.0
LL3	9.5	10.2	3.8-21.4
LL4	7.7	6.7	3.2-20.8

Table 12. Mean, median, and range of phytoplankton biovolume data reported for August-October 1978-1985.

Lake Station	Mean Biovolume (mm^3/L)	Median Biovolume (mm^3/L)	Range Biovolume (mm^3/L)
LL0	2.0	2.0	0.3-9.7
LL1	2.1	2.1	0.6-14.3
LL2	2.8	2.5	0.7-11.6
LL3	3.9	2.9	0.7-228.7
LL4	3.7	3.5	0.4-1552.0

Table 13. Mean, median, and range of phytoplankton biovolume data reported for April-June 1978-1985.

Lake Station	Mean Biovolume (mm^3/L)	Median Biovolume (mm^3/L)	Range Biovolume (mm^3/L)
LL0	5.1	4.5	1.2-11.2
LL1	4.7	3.7	1.6-13.0
LL2	4.4	4.3	1.2-11.9
LL3	2.9	2.8	0.7-6.7
LL4	2.5	2.2	0.3-5.9

The chlorophyll *a* and phytoplankton biovolume data presented in the graphs and tables show that the lake is both spatially and temporally dynamic with respect to phytoplankton blooms. The major factors affecting the concentration of algal biomass and chlorophyll *a* during and between each growing season appear to be the phosphorus concentration in the influent and the associated volume of inflow from the Spokane River (and the Little Spokane River). The influent phosphorus concentration determines the reservoir euphotic zone phosphorus concentration, but the hydrodynamics appear to determine when and where the peak blooms will occur. In general, during the spring to early summer the lake is mostly mixed because of high river flows. At this time of year, peak diatom dominated blooms occur in the downstream end of the reservoir because the residence time in the upper end of the lake is too short to facilitate algal blooms, i.e., the epilimnion in the downstream end of the reservoir is the only area of the lake with sufficient residence time to allow algal blooms (interflow caused by the penstock outflow allows longer residence time for the surface waters). However, blue-green dominated blooms that begin in late August or early September occur in the upstream end of the lake when residence time is longer.

The major phosphorus sources in the spring that fuel blooms in the downstream end of the reservoir are likely from Little Spokane River and Latah Creek (i.e., nonpoint sources). During the late summer and early fall, the major sources of phosphorus that fuel blue-green blooms in the upper end of the reservoir are likely the municipal and industrial effluent dischargers (i.e., point sources). Macrophyte senescence probably also contributes to the phytoplankton peak blooms.

Comments on Total Phosphorus TMDL

Overall, the data that were used and the work that was accomplished to establish the TP TMDL were extensive. The limnological characteristics of the reservoir have been well studied. However, there were a number of major decisions and assumptions that appear to have led to over-estimating the amount of phosphorus that can be assimilated in the Spokane River and Lake Spokane. The major decisions and assumptions that formed the basis of the TP TMDL were as follows:

1. Even though the URS (1981) report highlighted the need for public input as "essential" for selecting an appropriate water quality criterion for protecting beneficial uses, there does not appear to have been much public involvement or intergovernmental coordination (e.g., Fish and Wildlife) in determining the beneficial uses of Lake Spokane, or in determining the lake criterion (time- and area-weighted average euphotic zone TP concentration of 25 ug/L).

   Initially, Ecology recommended managing Lake Spokane as an upper mesotrophic system by identifying a mean euphotic zone chlorophyll *a* criterion for the June-October period of 10 ug/L (a value that represents the threshold between mesotrophic and eutrophic conditions). This criterion did not lead directly to the site-specific TP criterion that was ultimately approved by EPA. The TP criterion was adopted because predicted phytoplankton biovolume and secchi disc fell within an approximate mesotrophic criteria range. However, it was acknowledged that the predicted trophic characteristics for mean and peak chlorophyll *a* and mean hypolimnetic minimum dissolved oxygen may exceed the upper mesotrophic target boundary values (i.e., eutrophic characteristics). Data collected since 1978 show that the chlorophyll *a* variables regularly exceed the mesotrophic target boundary values of 10 ug/L in the upper end of the lake.

2. Although it is important to acknowledge that the Lake Spokane TMDL was one of the first established in Washington State and that little guidance was available for how to determine site-specific nutrient criteria, it is also important to understand that today Ecology and EPA would have more stringent requirements for establishing a site-specific criterion. The most significant difference would be that an assessment of the potential water quality in the lake minus human impacts would be required (i.e., natural conditions). Today, the result of the natural conditions analysis would be the yardstick for determining how much "degradation" of water quality due to human impacts should be allowed. For example, "natural" levels of phosphorus could have been estimated for the headwaters of the Spokane River (i.e., Lake Coeur d'Alene) and the tributaries, and then the combined loading to the lake would lead to a predicted trophic condition in Lake Spokane. Given that the source water for the Spokane River from Lake Coeur d'Alene should have oligotrophic characteristics, it is unlikely that the outcome of this analysis, even for the June-October median flow event, would lead to the conclusion that the lake should be managed as an upper mesotrophic or meso-eutrophic waterbody.

   About 187 of the 330 kg/day TP loading to the Spokane River in the example provided by Patmont et al. (1987) for 1985 conditions was from identified human sources (nonpoint sources in Latah Creek and the Little Spokane River were not identified). The resultant predicted load to the lake was 255.3 kg/day which was estimated to provide a seasonal euphotic zone average TP concentration of 24.8 ± 4.3 ug/L. As an example, if the Spokane River P-attenuation model is run without point source dischargers and 91% TP removal is from CSOs and stormwater (one of the choices listed for model input), the model yields an estimated TP load of about 119 kg/day (i.e., no assumed reduction in tributary loading). Under this scenario, the water quality predictions from the model output for Lake Spokane are listed in Table 14 below:

Table 14. P-attenuation model results without point source dischargers and 91% total phosphorus removal from CSOs and stormwater.

Parameter	Prediction	Standard Error	Target Criteria
EZ mean TP	11.8	2.4	25 ug/L
EZ Chl *a* - upper 95%tile	14.2	3.1	<16 ug/L
EZ Chl *a* – mean	7.3	1.6	10 ug/L
EZ Phyto. Biovolume	1.4	0.4	5 mm^3/L
Secchi Disk Depth	4.2	0.6	3 meters
Extinction Coefficient	0.56	0.008	0.5/m
Minimum Hypolimnetic DO	9.8	3.5	>4 mg/L

EZ = euphotic zone
DO = dissolved oxygen

Although it is unlikely that the minimum hypolimnetic dissolved oxygen would improve to an average of 9.8 mg/L (more likely 6-8 mg/L), the model predictions overall suggest that the lake could have lower mesotrophic (oligo-mesothrophic) characteristics for the parameters listed in the table, even without reducing nonpoint loading associated with Latah Creek and the Little Spokane River.

3. The median river flow design condition used to establish allocations will not minimize the frequency of water quality violations in Lake Spokane. As noted by URS (1981), "To minimize the frequency of water quality violations, a critical or worst-case condition is usually selected as the design condition for the allocation calculations." Ecology initially recommended using the seasonal 1-in-10-year low flow to calculate the load associated with meeting the lake criterion. Ecology later approved increasing the seasonal flow used in the loading calculation to a 1-in-2 year or median flow based on the analysis that the median flow event would only increase the likelihood of eutrophic conditions by about 6%. However, this decision shifted the probability associated with each potential classification such that it also reduced the likelihood that the lake would exhibit oligotrophic conditions by 9%, i.e., using a seasonal median flow did not "minimize" but rather "increased" the likelihood that if the criterion and associated load was reached it would lead to more exceedances of the trophic objective.

4. The post-1977 chlorophyll *a*, phytoplankton biovolume, and hypolimnetic dissolved oxygen data indicate that the lake is both temporally and spatially dynamic with respect to these trophic parameters. The assumption that temporally and aerial-weighted average trophic parameters for the June-October period can be used to represent Lake Spokane are not well founded. Lake Spokane is a long, narrow reservoir with internal hydrodynamics that change as the river inflows and dam outflows change.

5. The citizen's lawsuit was filed in response to unsightly blue-green algal blooms that can occur during late summer through early fall in the upper end of the lake. Controlling blue-green blooms was identified as a major objective for establishing an appropriate phosphorus TMDL. However, the TMDL was based on relationships of June-October average or area-weighted average parameters such that the analysis was not sensitive to the blue-green blooms that occur later in the growing season. Blue-green algal blooms still occur in the upper end of the lake during the low river flow period.

6. Trophic targets should have been set based on minimizing peak phytoplankton concentrations, not area-weighted values, because in addition to phosphorus availability the lake hydraulics determine when and where blooms will occur. It should be noted that the daily average June river flow at Spokane (using 1968-2001 data) is approximately 7400 cfs, and for July-October it is about 1400 cfs. June flows are significantly greater than the later growing season months that determine the hydrologic conditions that lead to algal blooms. In establishing the TMDL, the June lake hydraulics and associated trophic conditions should not have been included with the lower flow months of July-October.

7. The phosphorus attenuation model assumes that phosphorus is "lost" in the river and that there would be no impact on water quality in the river as a result of changes in phosphorus loading. However, "nuisance" levels of periphyton were identified in the river that affect water quality (i.e., dissolved oxygen concentrations and pH). It was also determined that periphyton growth was limited by the availability of phosphorus. It was not determined whether the allowable TMDL would protect the minimum dissolved oxygen levels in the river with respect to the Class A water quality criterion of 8 mg/L. Data from different locations along the river (e.g., the state line) show that diurnal minimums have been found that were lower than the criterion, due to periphyton growth.

8. Minimum mean hypolimnetic dissolved oxygen concentrations were shown to be related to influent TP concentration and dam outflow (dam outflow was related to inflow), such that lower influent TP would lead to higher hypolimnetic dissolved oxygen concentrations with the same outflow. The hypolimnetic dissolved oxygen analysis presented in Patmont et al. (1987) showed that dissolved oxygen was impaired with respect to the lake criterion of "no change from natural conditions" by showing that human loading of phosphorus was the cause of low hypolimnetic dissolved oxygen concentrations. In addition, the analysis results predicted that the site-specific lake TP criterion would not meet the associated dissolved oxygen criterion for a lake with mesotrophic characteristics, much less if the target was a lower mesotrophic condition.

9. No margin of safety (MOS) was included in setting the criterion and associated allowable loading to Lake Spokane. As established, the criterion would have an exceedance probability of 50% when the TMDL is reached. Currently, EPA requires either an implicit or explicit MOS for all TMDLs. The uncertainty associated with the TMDL of 259 kg/day is ± 43 kg/day (i.e., value appears to be a combination of uncertainty in flows and predicted euphotic zone TP concentration). The uncertainty should have been applied to the TMDL value such that there would only be a 5 or 10% probability of exceeding the TMDL. For example, since the uncertainty appears to represent a standard deviation, the TMDL could have been corrected to 188 or 204 kg/day to provide 95 or 90% confidence that the TMDL and TP criterion would not be exceeded (applying Z distribution statistics to establish the lower 5th or 10th percentile). The adjusted TMDL would then be allocated to point and nonpoint sources of phosphorus.

In summary, the current Lake Spokane criterion of an average euphotic zone concentration of 25 ug/L and corresponding TMDL are too high, even to protect the upstream portion of the lake to a degraded mesotrophic level. However, before establishing any modified phosphorus TMDL for the lake, the beneficial uses and an appropriate criterion to protect the uses, including the time period(s) to protect, need to be determined.

If the TMDL was originally set to protect the July-October period instead of June-October using all the same assumptions and averaging, the resultant TMDL would be lower because the seasonal median flow at the outlet to Lake Coeur d'Alene would have been about 1119 cfs versus the 2970 cfs used to establish the current loading (based on the 1968-2001 daily average flows at the Post Falls gauge plus 11 cfs estimated outflow in the Post Falls Dam pool). (The 1-in-10-year daily average flow for the July-October period is only about 700 cfs at

Post Falls.) The TMDL would be even more restrictive if the analysis was conducted to protect the upstream part of the lake from experiencing large blue-green algal blooms. For example, Figure 27 shows the 1978-1985 average August-October station LL3 and LL4 chlorophyll *a* concentrations versus the average July-October seasonal Spokane River influent TP concentration measured at Seven Mile Bridge.

In order to get an average chlorophyll *a* concentration of 10 ug/L in the euphotic zone for these two stations (i.e., protect the upper end of the lake during the blue-green algal bloom period), the Spokane River influent would need to be about 19 ug/L. The load associated with the July-October median river flow would only be about 111 kg/day or only 50% of the current allowable loading (calculations based on the same assumed median flow inflow/outflow conditions from Patmont et al., 1987, Table 9). Achieving this level of seasonal phosphorus loading without a MOS would not leave any assimilative capacity for the point source discharges to the river system and require some reduction in nonpoint sources.

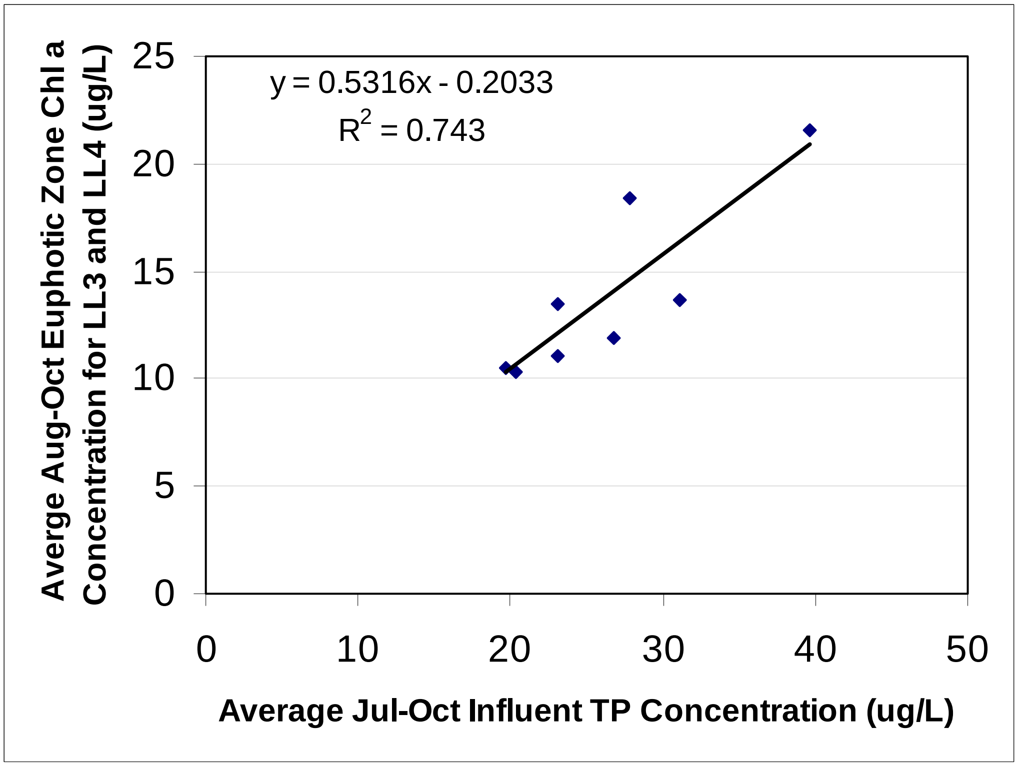

Figure 27. 1978-1985 average July-October Spokane River influent total phosphorus concentration (at Seven Mile Bridge) versus the average August-October euphotic zone chlorophyll *a* concentration for Lake Spokane stations LL3 and LL4.

CE-QUAL-W2 Model Selection, Calibration, and Uncertainty

The companion documents cited at the beginning of this report should be referenced for detailed information on the model set-up and boundary conditions, and the model calibration results, for 1991, 2000, and 2001. The following is a general discussion of the model selection, calibration, and uncertainty with respect to its use for assessing the effects of point and nonpoint sources of pollutants on dissolved oxygen in the Spokane River and Lake Spokane, and as a tool for establishing pollutant loading allocations.

Model Selection

In selecting the 2-D dynamic CE-QUAL-W2 model, Ecology recognized that the Spokane River and Lake Spokane system have specific physical features that require a complex model to simulate water movement through the system. Specifically, the river has a number of dams with turbines and spillways that affect river flow and residence time. In addition, Lake Spokane has pronounced metalimnetic interflows and other hydrodynamic features that need to be considered when assessing water quality.

In the TMDL process, the model was selected to help determine the wasteload (WLAs) and load allocations (LAs) necessary to restore and protect water quality. Achieving the assigned WLAs and LAs may require increased levels of treatment to control the point sources and best management practices (BMPs) to control the nonpoint sources of pollution. Ecology is aware of the implications of additional treatment to the dischargers and has selected the best water quality management tool available given the requirements listed above.

Model Calibration

Ecology's dynamic modeling effort should not be viewed as a "research" project requiring scientific understanding of all the physical, chemical, and biological features of the Spokane system, but rather as applying a model to manage pollutants using the best available information. As such, the "best" available information for calibrating the CE-QUAL-W2 model ranges from historical and newly collected field and laboratory data to the selection of literature values to define specific model parameters, rates, and constants. Ecology believes the CE-QUAL-W2 model has been calibrated with the best available information and represents a level-of-effort seldom achieved in conducting water quality studies for managing pollutants.

While no numerical model can recreate perfectly the complex, time-varying interactions of every physical, chemical, and biological process, Ecology's goal was to have the CE-QUAL-W2 model represent the primary and even some of the secondary processes that control dissolved oxygen in the Spokane River and Lake Spokane. Although Ecology recognizes the need to apply good scientific principles, we also recognize that determining a level of treatment for a point source discharge or recommending BMPs in a watershed to mitigate nonpoint sources should not require an exhaustive scientific data collection and model parameterization process. Rather, the objective was to collect enough data to develop a scientifically based model application that provides a *good approximation* of the system. We believe the Spokane CE-QUAL-W2 model was appropriately developed and calibrated. We also believe the model provides a good approximation of the major forcing processes and features of the system that affect water quality such as the hydrodynamics of Lake Spokane, pools associated with the dams, periphyton growth, and pollutant loading. Finally, we believe the model will be an effective tool for recommending WLAs and LAs.

The major input or calibration values that represent the physical, chemical, and biological processes being simulated by the CE-QUAL-W2 model include the following:

1. Lake and river bathymetry, including channel elevations and slope
2. Lake and river hydrology
3. Lake and river surface water elevations (i.e., water levels)
4. Boundary conditions, including upstream, tributary, and point source boundaries
5. Groundwater
6. Meteorological data
7. Hydraulic structures
8. Heat exchange
9. Water quality for the lake and river including phytoplankton and periphyton growth
10. Rate coefficients and reaction rates

Ecology believes that input values for items 1-4 have been well developed such that the CE-QUAL-W2 model provides an excellent representation of these features of the system. Although groundwater (item 5) should be included with the model boundary conditions, it was listed separately for this discussion. Overall, we believe that groundwater quantity and quality was adequately simulated. However, historical and current information on groundwater contributions included in the model were more uncertain than the other boundary conditions. Groundwater quantity was partly developed for the model based on the historical data discussed in the Hydrology section of this report and as the residual from water balances calculated for the river and lake based on flow and water surface elevation data collected from USGS gauging stations and dam turbine and spillways operations. With the exception of dissolved oxygen concentrations, groundwater quality values used in the CE-QUAL-W2 model were representative of current and historical average data, and ambient variation in these values were not expected to significantly impact model predictions. However, groundwater dissolved oxygen average concentration values used in the original calibration of the model represented only the average values measured near the known aquifer inflow area to the river at Sullivan Road. Dissolved oxygen concentrations for wells near the river have been reported to range from about 2-10 mg/L. Inputting lower dissolved oxygen concentrations in the model were found to improve the model calibration (Berger et al., 2004).

Accounting for the “uncertainty” in groundwater dissolved oxygen concentrations was accomplished by using a lower percentile estimate from the data distribution (rather than the mean) that better matched the river dissolved oxygen calibration data (i.e., the groundwater dissolved oxygen model input concentrations were set such that the model better reproduced river concentrations).

Meteorological conditions were established based on the best available data. With the exception of the effect of wind speed and direction on the temperature profiles in Lake Spokane, spatial variation in meteorological data for the area have little effect on the calibration of the model. Wind speed and direction are highly variable in the study area, and wind sheltering coefficients were used as a calibration "knob" for simulating temperature profiles in the lake. As calibrated, the model accurately predicts temperature profiles.

Hydraulic structures were built into the model to provide appropriate hydraulic characteristics of the river and lake with respect to changes in water flow and constituent transport. Simulating the turbine and spillways also helped in the development of more accurate water balance calculations.

Heat exchange was "hard wired" in the model such that calibration can only be accomplished by developing accurate bathymetry and hydrology and using the wind sheltering coefficients to adjust for changes in wind throughout the modeled area. Ideally, site-specific meteorological wind data would be collected at numerous locations and not altered. The major goal of colleting site-specific wind data with enough spatial coverage to actually simulate the natural conditions on Lake Spokane would be the same as using the wind sheltering coefficients, i.e., reproduce ambient temperature profiles. Given the excellent temperature calibration results for the lake, it is unlikely that collecting more site-specific wind data would have improved the model temperature predictions. Plus, wind has little effect on river temperature predictions. However, it was found that wind direction was important for predicting algal blooms in the upper end of the lake because upstream wind-driven surface currents may hold algae in the upper end of the lake (Berger et al., 2004). On-site wind data could help explain wind-driven surface currents and their effects on algal distributions. However, the total algal productivity in the lake estimated by the model is not affected by wind direction.

Historical and current ambient water quality data were collected and used to calibrate the model. In general, the water quality variables were calibrated to represent the system within ranges reported by other investigators. However, the original model calibration underestimated algal productivity in Lake Spokane, which affected the model estimates for dissolved oxygen in the lake. Underestimating the lake algal productivity suggested that the model estimates of the effects of point and nonpoint sources on dissolved oxygen concentrations in the lake were also underestimated. The possible causes for underestimating water column nutrient concentrations were identified as

1. Assumed model stoichiometry for nutrients in CBOD and organic matter at the boundaries are not representative of the total concentrations measured.
2. Additional loadings exist that are not captured in the monitoring data used to establish the model boundary conditions.
3. Additional unknown sources exist that are contributing to the concentration.

Portland State University and Ecology made some changes to the model to improve the 2001 model calibration (Berger et al., 2004). The modifications included adjusting the phosphorus stoichiometry associated with the boundary CBOD concentrations and wind direction. Overall, the changes to the model improved dissolved oxygen predictions in Lake Spokane and showed that algal blooms could be accounted for by the current known pollutant loading used in the model (Berger et al., 2004).

The selection of model rates and constants were discussed in the model calibration reports. The rates and constants act collectively and were set to provide the best calibration of the model. As such, rates and constants should not be altered “individually” to modify the calibration or make statements about their effect on model predictions unless the total calibration of the model is improved.

Model Uncertainty

Model uncertainty analysis is the examination of how the lack of knowledge or possible variation in model input values, including the physical, chemical, and biological processes described in the model, propagate through the model leading to errors in the model output parameters. Currently, there are no methods available for conducting uncertainty analyses using first order error analysis or monte carlo simulations with dynamic models like CE-QUAL-W2. In addition, the U.S. Environmental Protection Agency (EPA) has not provided specific guidance on model uncertainty analysis or guidance on “acceptable” variances for determining when a water quality model is adequately “calibrated” to a specific variable so it can be used for establishing WLAs and LAs.

The goal of model calibration was to minimize the differences between model predictions and measured values and reproduce major physical and chemical processes (e.g., metalimnetic interflow in Lake Spokane, temperature stratification, and major variable concentrations). As part of the reporting documentation for the development of the CE-QUAL-W2 model, commonly used error statistics and sensitivity analyses for the major variables and kinetics were provided. EPA will also provide a technical review and assessment of the model as an appropriate tool for establishing WLAs and LAs. Although these procedures do not constitute uncertainty analysis, they are currently the acceptable methods for determining “acceptable” uncertainty associated with using model output for assessing water quality and developing loading allocations.

Even though model sensitivity for some parameters was evaluated, due to resource and time limitations an exhaustive assessment of each variable and parameter sensitivity has not been conducted. However, all interested parties have been provided the study reports and models and can conduct their own analysis of model uncertainty or sensitivity for variables or parameters of specific interest. The results of these analysis can be submitted to Ecology for consideration during the public review process scheduled to begin during the summer of 2004.

Ecology recognizes that there will be data and model uncertainty associated with recommending WLAs and LAs to meet any TMDL. The federal Clean Water Act requires that any lack of knowledge about the system must be accounted for by establishing a margin of safety (MOS) in developing a TMDL. The implicit (conservative assumptions) or explicit (reserving a portion of the loading capacity) MOS must be identified as part of the TMDL as it undergoes public review. Ecology believes that current water quality regulations require that pollutant loading sources bear the burden of that uncertainty and not the environment. In support of this position, we cite the following documents:

> Clean Water Act Section 303(d) (1) (C)
>
> (C) Each State shall establish for the waters identified in paragraph (1)(A) of this subsection, and in accordance with the priority ranking, the total maximum daily load, for those pollutants which the Administrator identifies under section 1314(a)(2) of this title as suitable for such calculation. Such load shall be established at a level necessary to implement the applicable water quality standards with seasonal variations and a margin of safety which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality.
>
> Code of Federal Regulations Section 40 130.7(c) (1)
>
> (1) Each State shall establish TMDLs for the water quality limited segments identified in paragraph (b) (1) of this section, and in accordance with the priority ranking. For pollutants other than heat, TMDLs shall be established at levels necessary to attain and maintain the applicable narrative and numerical WQS with seasonal variations and a margin of safety which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality. Determinations of TMDLs shall take into account critical conditions for stream flow, loading, and water quality parameters.

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Application of Water Quality Criteria

The dissolved oxygen criterion for Lake Spokane is “no measurable change from natural conditions.” The criterion for the river is “dissolved oxygen shall exceed 8.0 mg/L,” which is to apply at all times; therefore, the minimum dissolved oxygen concentrations shall exceed 8.0 mg/L. However, in other TMDLs for oxygen-consuming substances, Ecology has allowed a 0.2 mg/L degradation in dissolved oxygen concentration due to human impacts when the dissolved oxygen concentration is below (or near) the criteria. We are proposing to apply this allowable change in dissolved oxygen for the Spokane River and Lake Spokane TMDL study as discussed in the following paragraphs. Any additional decrease in dissolved oxygen would require formally changing the water quality criteria for the river and lake (i.e., developing site-specific criteria) or conducting a Use Attainability Analysis (UAA) to reduce the level of beneficial use protection. No discussion about developing site-specific dissolved oxygen criteria or conducting a UAA is presented in this document.

In general, it is not possible to precisely define natural conditions that existed before human impacts. Any analysis can only approximate natural conditions given the physical changes that may have altered the waterbody and its watershed (including groundwater). For example, Lake Spokane is a man-made reservoir that is formed by a hydroelectric dam and is classified as a lake in the state standards. Physical, chemical, and biological processes in the reservoir, even without additional human impacts due to pollution, are different than what they would be if the river were free flowing, and any attempt to compare the two states directly would be inappropriate unless there is likelihood that the dam will be removed. In general, impoundments have less assimilative capacity for oxygen-consuming substances than free-lowing rivers, because organic substances can accumulate and degrade in the bottom waters and cause large oxygen deficits unlike a well-aerated, free-flowing river. At this time, Ecology does not foresee the dams being removed on the Spokane River and we will not attempt to define water quality conditions with and without the dams. However, because there may be some benefit to water quality by examining the effects of changing their operation or water withdrawal points, modeling scenarios could be conducted to examine management options for the dams that might provide more assimilative capacity for the river system.

Even if “natural” conditions cannot be fully determined, Ecology believes that water quality in Lake Spokane (and the Spokane River) does have a reference water quality condition that would exist if there were little or no pollutant effects. Once defined, this reference condition can be used to compare against current and possible future water quality conditions. We are proposing to apply the Lake Class dissolved oxygen criteria to Lake Spokane as follows:

> Under critical year conditions, allow no more than a 0.2 mg/L deficit in dissolved oxygen from "natural conditions" (i.e., reference conditions) at any point in the water column due to identified point and nonpoint pollutants. Reference conditions for Lake Spokane will be defined as the water quality conditions estimated by the calibrated CE-QUAL-W2 model that would occur with no point source discharges and tributary pollutant (nonpoint source) concentrations set to estimated background conditions. Critical year conditions will be a

hydrologic year that provides critical low-flow conditions equal to approximately a 10% recurrence frequency (see Design Conditions section).

The Class A water quality criterion for dissolved oxygen will be applied to the Spokane River as follows:

Under critical year conditions, the dissolved oxygen criterion will be assumed to be met:

(1) When the CE-QUAL-W2 model predicts dissolved oxygen greater than 8.0 mg/L; or

(2) When the CE-QUAL-W2 model predicts natural background dissolved oxygen to be less than 8.0 mg/L and the combined impact of identified point and nonpoint sources of oxygen-consuming substances causes less than a 0.2 mg/L deficit in dissolved oxygen.

Impacts from future changes to standards and criteria are currently outside the scope of this document, but evaluations may be made using the calibrated model predictions in comparison to any new criteria.

Design Conditions

Design conditions are the receiving water flows, temperature, background, and nonpoint source loading conditions upon which the TMDL and allocations are based. In order to minimize the frequency of water quality violations, critical conditions or worst-case conditions are usually selected as the design conditions for a TMDL.

Historically, Ecology has used steady-state water quality models under "critical conditions" to establish pollutant allocations to protect water quality relative to a specific water quality criterion. In WAC 173-201A a critical condition is defined as:

> Critical condition is when physical, chemical, and biological characteristics of the receiving water environment interact with the effluent to produce the greatest potential adverse impact on aquatic biota and existing or characteristic water uses. For steady-state discharges to riverine systems, the critical condition may be assumed to be equal to the 7Q10 flow event unless determined otherwise by the department.

Pollutant allocations are usually established by introducing different pollutant loading into the model under critical conditions (including low river flow, high temperatures, and estimated nonpoint source loading) then, by a trial-and-error procedure, the model is used to find allocations that just satisfy the water quality criterion. However, the Spokane River system CE-QUAL-W2 model application is dynamic (i.e., simulates real-time changes in water quantity and water quality), and applying a "steady-state" modeling solution for establishing pollutant allocations would not make use of the model's capabilities to predict water quality under changing conditions. Therefore, a "critical year" was used for establishing pollutant allocations.

The critical year should provide low river flows during periods of the year that most influence water quality in Lake Spokane and the Spokane River. We determined that 2001 would best represent a critical year for establishing pollutant allocations based on the following analysis of flow data from the USGS gauge near Monroe Street:

- The water year daily average and 7-day low flows for flow years 1968-2001 were ranked from lowest to highest, and the seven years with the lowest flows were selected for further assessment. The years selected were 1973, 1977, 1987, 1988, 1992, 1994, and 2001. (The years 1986 and 2000 had lower 7-day low flows than 1977; however, they had water year daily average flows close to median conditions. 1977 had the lowest water year daily average flow and the ninth lowest 7-day low flow.)
- The exceedance probabilities for the algal growing season (June-October), individual summer months, and the spring snowmelt period were determined. These periods were considered "critical" for assessing the impact of pollutants that affect dissolved oxygen concentrations. The periods and results are listed in Table 15. Exceedance probabilities were determined by fitting a theoretical "best fit" distribution (e.g., Normal, log-Pearson type III, Weibull) to the 34-year data record and for the different periods using WQHYDRO (Aroner, 2001).

- The mean exceedance probabilities for all of the critical periods during 1992 and 2001 were close to 90% (i.e., 92.4 and 92.2, respectively), and had low variability. During late August 1992, average flows increased at Spokane for one week to about 1400 cfs, which interrupted late summer low flows such that 1992 does not represent late August low-flow conditions.
- Water quality data were collected during 2001, and the CE-QUAL-W2 model was set up to simulate 2001 conditions, which reduces the uncertainty associated with projecting water quality conditions to low-flow conditions.
- 2001 may best represent current low river flow conditions because there does appear to be a downward trend in 7-day low flows that represent baseflows in the river.

Table 15. Daily average river flow for various periods and calculated exceedance probabilities for selected years that have river flow conditions during the algal growing season with exceedance probabilities close to 90%.

Critical Period		Year						
		1973	1977	1987	1988	1992	1994	2001
Jun-Oct	(cfs)	1513	1621	1404	1404	1387	1144	1431
	(%) EXP[a]	89.8	87.2	92.0	92.0	92.4	95.9	91.5
Jul	(cfs)	1167	1233	1371	1481	1318	998	1348
	(%) EXP	90.7	89.7	87.3	85.1	88.3	93.0	87.7
Aug	(cfs)	739	912	828	646	793	530	715
	(%) EXP	91.2	83.3	87.5	94.1	89.1	96.6	92.4
Sep	(cfs)	1517	1576	1341	988	1085	963	916
	(%) EXP	65.3	59.2	80.8	96.6	94.1	97.1	97.9
Apr-May	(cfs)	5759	4681	8614	9961	5571	6827	7221
	(%) EXP	93.6	95.8	83.7	76.7	94.1	90.7	89.4
7-day low flow	(cfs)	556	800	550	743	545	502	578
	(%) EXP	95.8	73.3	96.1	81.2	96.4	98.3	94.4
Average	(%) EXP	87.7	81.4	87.9	87.6	92.4	95.3	92.2
Std deviation		11.2	13.2	5.5	7.9	3.1	2.9	3.6

[a] = Percent exceedance probability.

In general, spring and early summer river flows likely influence late-summer water quality of Lake Spokane because the magnitude of the spring snowmelt and summer baseflows determine pollutant residence time in Lake Spokane (i.e., high spring and summer flows provide more flushing than low flows). In addition, flows in August determine the magnitude of the annual low-flow period for the river. The low river flow period is expected to be the most critical period for pollutant loading effects in the river and Lake Spokane (i.e., less dilution and longer residence time). By using a critical year like 2001 that has seasonal and August low flows that correspond to about a 0.10 exceedance probability to establish pollutant allocations, the water quality in Lake Spokane and the Spokane River should be adequately protected. These actual flow conditions would be expected to be lower only about 10 times every 100 years.

Another important variable when considering critical conditions is water temperature. There are no long-term temperature data that represent the whole waterbody. However, air temperature is probably a good indicator of annual variation in water temperature. The average air temperatures recorded at the Spokane International Airport for June-October and August for the low-flow years are listed in Table 16. The estimated June-October daily average temperature air temperature with a 90% exceedance probability was 63.7º F for the June-October period and 72.1º F for August. The daily average air temperature data show that 2001 and 1977 were the only low-flow years that approached critical air temperature conditions. The sensitivity of the model results to air temperature are presented in the Model Results section.

Table 16. Daily average air temperature for different periods.

Critical Period		Year						
		1973	1977	1987	1988	1992	1994	2001
Jun-Oct	(deg F)	61.8	61.0	62.0	62.1	62.4	62.7	61.5
	(%) EXP	51.2	31.0	56.4	59.0	66.5	73.3	43.4
Aug	(deg F)	69.0	71.1	66.2	68.4	69.5	69.4	71.1
	(%) EXP	56.4	81.6	20.6	48.0	63.2	61.9	81.6

All other critical conditions for the model boundaries (i.e., headwater, tributaries, and point source discharges) were defined as those conditions that occurred during 2001. The 2001 conditions were called “current conditions” when presenting modeling results from different scenarios.

To estimate the current and potential future impacts of point and nonpoint sources of oxygen-consuming substances, the CE-QUAL-W2 model was run under the following scenarios:

1. **CURRENT**: A base case defined as 2001 conditions for the study area from the state line through Lake Spokane.

2. **NO-POINT**: The CURRENT case without point source loads. The associated point source flow was kept in the model, but the loads were reduced to reflect groundwater constituent concentrations. The state line boundary conditions were set at those found in 2001, which were affected by Idaho point source dischargers, i.e., the effects of the Idaho point sources were not removed for the NO-POINT scenario. (See Spokane River Model: Boundary Conditions and Model Setup 2001, Annear et al., 2001.)

3. **NO-SOURCE**: The NO-POINT case with tributary and upstream river boundary concentrations set at estimated natural or natural background conditions. Tributaries and upstream river nutrient (nitrate, phosphorus, ammonia) concentrations were set to background conditions based on data collected by Soltero et al. (1988) at the inlet to Eloika Lake in the Little Spokane and/or data from the outlet of Lake Coeur D’Alene collected as part of this study. The average Lake Coeur D'Alene ultimate CBOD as measured by the dischargers in 2001 of 1.4 mg/L was used to set the maximum CBOD at Latah Creek and the Little Spokane River. All other constituents were the same as 2001 conditions. The non-calibrated 2001 CE-QUAL-W2 model of the Idaho portion of the river from the outlet of Lake Coeur D’Alene to the state line was used to estimate upstream boundary conditions for the No_Source scenario (i.e., Idaho point and nonpoint sources were removed).

Tables B1-B6 list the 2001 and estimated natural background conditions that were used for the CURRENT and NO-SOURCE scenarios. Coulee Creek water quality constituents were the same as those used for Latah Creek.

4. **SOD**: The NO-SOURCE case with the maximum sediment oxygen demand set 0.25 g O_2 m^{-2} per day, which is a value that has been historically used to define an oligotrophic system (Welch, 1980).

5. **PERMIT**: The CURRENT case with point source daily concentrations increased to provide a monthly average value equal to the monthly average BOD5 permit limits (e.g., The City of Spokane AWTP 2001 monthly average BOD5 calculated from the daily record provided by the City was 5.6 mg/L, and the monthly average permit limit for BOD5 was 30 mg/L. Each 2001 daily model input file value was increased from the reported value plus the difference between the monthly average permit value and the actual monthly average value). Concentrations of soluble reactive phosphorus, ammonia, and nitrate were set at estimated upper 10th percentile effluent values based on the 2001 measured values (i.e., adding the difference between the monthly average and estimated upper 10th percentile value to the data record listed in the model input files). Kaiser Aluminum does not have a BOD5 permit limit, and daily values were set at estimated upper 10th percentile effluent concentrations for BOD5, soluble reactive phosphorus, ammonia, and nitrate.

   In addition, the phosphorus loading for the PERMIT scenario was limited such that the total loading would not exceed the target total phosphorus concentration for Lake Spokane used to establish the original TMDL (i.e., an average euphotic zone total phosphorus concentration of 25 ug/L). The target phosphorus concentration was estimated by a series of trial-and-error model runs based on adjusting the phosphorus stoichiometry associated with the point sources CBOD values and averaging the total predicted phosphorus concentration in the upper 10 meters of the lake for the June-October period. The upper 10 meters of the lake was assumed to approximate the maximum euphotic zone.

Margin of Safety

When using a steady-state modeling approach to establish pollutant loading limits, Ecology has not historically identified an explicit margin of safety (MOS) to meet a TMDL because the “conservative assumptions” incorporated in the critical conditions not only considered low flow but other conditions like high temperatures, lower groundwater dissolved oxygen concentrations, and point sources continuously discharging at their maximum permitted level. For the Spokane TMDL study, an explicit MOS may need to be identified because the model uses ambient conditions for 2001 that may or may not be exceeded during other low years (e.g., air temperature), and the daily or weekly point source discharge data records. In addition, the apparent decreasing trend in low river flows (i.e., low 7Q10 flows) indicates that the system may provide less dilution for pollutants in the future. Other lack of knowledge about the system or possible variation in model input values should also be considered when establishing a final MOS.

Model Results

The following is a discussion and presentation of model-predicted dissolved oxygen concentrations for the scenarios listed in the Design Conditions section of this report for selected model segments (i.e., 2001 conditions with different pollutant loading scenarios). Segments were chosen to represent different reaches of the lake and river and are presented from downstream to upstream of the study area. Note that all model segments were predicted to have somewhat different water quality conditions.

Lake Results

Figure 28 shows the difference between the CURRENT and NO-POINT scenario results for model segments 188, 181, and 178 on Julian day 243.25 (September 1). The locations of these model segments, representing sections of Lake Spokane, are shown in Figure 29. In general, these segments and the model results presented in the graphs represent the downstream 8-9 miles of the lake (from model segment 188 to 176). The average difference in dissolved oxygen between the CURRENT and NO-POINT scenario at segment 188 below a depth of 7 meters was 0.56 mg/L (i.e., the dissolved oxygen concentration profile was predicted to increase by an average of 0.56 mg/L below 7 meters from the CURRENT scenario). A maximum difference of 2.28 mg/L was predicted to occur at a depth of about 8 meters and the minimum difference of 0.22 mg/L about 43 meters. The maximum differences between the scenarios at segment 181 and 178 were 1.94 and 1.47 mg/L, respectively at about 8 meters. The graphs show that the summer interflow zone was predicted to be the area of the lake most affected by pollutants from the point sources (i.e., dissolved oxygen differences due to internal and external BOD loading).

Figure 30 shows the difference between the CURRENT and NO-SOURCE scenario results for the same model segments and day (September 1). The average difference between the scenarios at segment 188 below 7 meters was 1.9 mg/L with the maximum difference of 2.90 mg/L occurring near the bottom. The maximum differences at segment 181 and 178 were 2.40 and 2.53 mg/L, respectively, and were predicted to occur between 25-28 meters.

Figure 31 shows the difference between the CURRENT and PERMIT scenario results for the same model segments and day. The average difference between the scenarios at segment 188 below 7 meters was 2.93 mg/L with the maximum difference of 3.62 mg/L occurring about 10 meters. The maximum differences at segment 181 and 178 were 3.65 and 3.24 mg/L, respectively, and were predicted to occur at about 14 meters.

Figure 32 shows the difference between the CURRENT and SOD scenario results for the same model segments and day. As expected, the dissolved oxygen profiles were predicted to significantly increase under oligotrophic SOD conditions. Although it is probably not possible to determine exactly what level of sediment oxygen demand would be in the system without point and nonpoint sources of pollution, the predicted profile probably represents the "best possible" dissolved oxygen profile that could be attained over time given the time of year, location, and flushing rate.

Although the Spokane River system would be expected to have oligotrophic or lower mesotrophic water quality characteristics without human sources of nutrients and oxygen-consuming substances, the CE-QUAL-W2 model cannot be used to forecast changes in sediment oxygen demand due to changes in pollutant loading. Therefore, the SOD scenario results can only be used as a possible best-case condition for the lake and should not be used as the reference condition for establishing pollutant loading allocations relative to an allowable change. Pollutant allocations should be established using the NO-SOURCE scenario as the reference condition to determine allowable dissolved oxygen deficits, because the pollutant loads that cause dissolved oxygen deficits of 0.2 mg/L should be the same for either scenario.

Figures C1-C3 in Appendix C shows the scenario results that are presented above for June 15, September 1, and October 1. The model segments show varying degrees of dissolved oxygen concentration changes greater than 0.20 mg/L due to point and nonpoint sources (i.e., CURRENT versus NO-SOURCE scenarios) that extend from the middle of June until the middle of October. However, the dates graphed do not represent the greatest differences in predicted dissolved oxygen concentrations (e.g., on Julian Day 227.25 or August 16 the maximum difference between the CURRENT and NO-SOURCE scenarios was 3.48 mg/L).

One additional model run was conducted to determine the change in dissolved oxygen in Lake Spokane associated with the state line boundary conditions and Washington point source discharges to the river. Figure 33 shows the results for the CURRENT, NO-SOURCE, and NO-SOURCE-IDAHO scenarios. The NO-SOURCE-IDAHO scenario is the NO-POINT scenario with the upstream model boundary set at estimated natural background conditions listed in Table B-6, and Latah Creek and the Little Spokane River set at 2001 conditions listed in Table B-1 and B-3, respectively. The results indicate that the Washington point sources and upstream model boundary account for most of the estimated change in dissolved oxygen concentrations in the lake below 15 meter depth. However, although the state line boundary appears to have a greater effect on hypolimnetic dissolved oxygen concentrations in Lake Spokane than either Latah Creek or the Little Spokane River, the effects of the individual sources and boundary conditions are not independent (additive), such that conducting similar scenarios by setting the concentrations in the Little Spokane River and Latah Creek to natural conditions separately would not provide an estimate of their individual contributions to the change in dissolved oxygen concentrations.

Residence time profile plots for segments 188 and 161 are presented in Figures 34 and 35. The epilimnetic waters from segments 188 to 161 represent the euphotic zone of the lake. Maximum euphotic zone residence time is predicted to occur about September 17 which corresponds to the period when the large blue-green algal blooms occurred during 2001. Patmont et al. (1987) calculated euphotic residence times for the lake during the June-October period that ranged from 20-80 days. The residence time predictions suggest that loading that occurs no earlier than the middle of June causes the onset (August) to peak algal blooms (middle September to beginning of October) that occur in the upper end of the lake that produce internal loading of BOD. In addition, the loading from the state line that affects bottom water dissolved oxygen concentrations in August and September probably enters the lake during the May-June period.

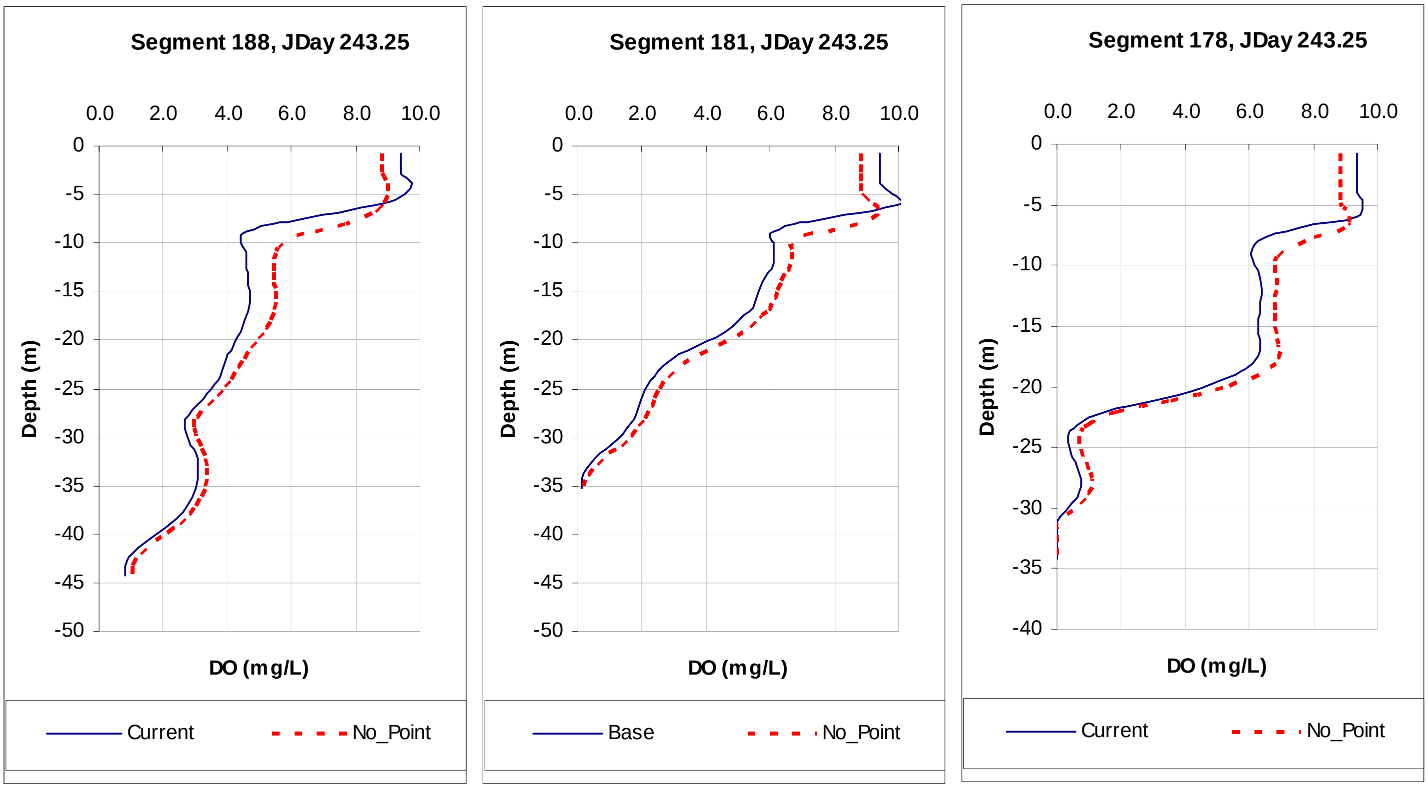

Figure 28. Model-predicted dissolved oxygen profiles for Lake Spokane at model segments 188, 181, and 178 for the CURRENT and NO-POINT scenarios for Julian Day 243.25 (September 1).

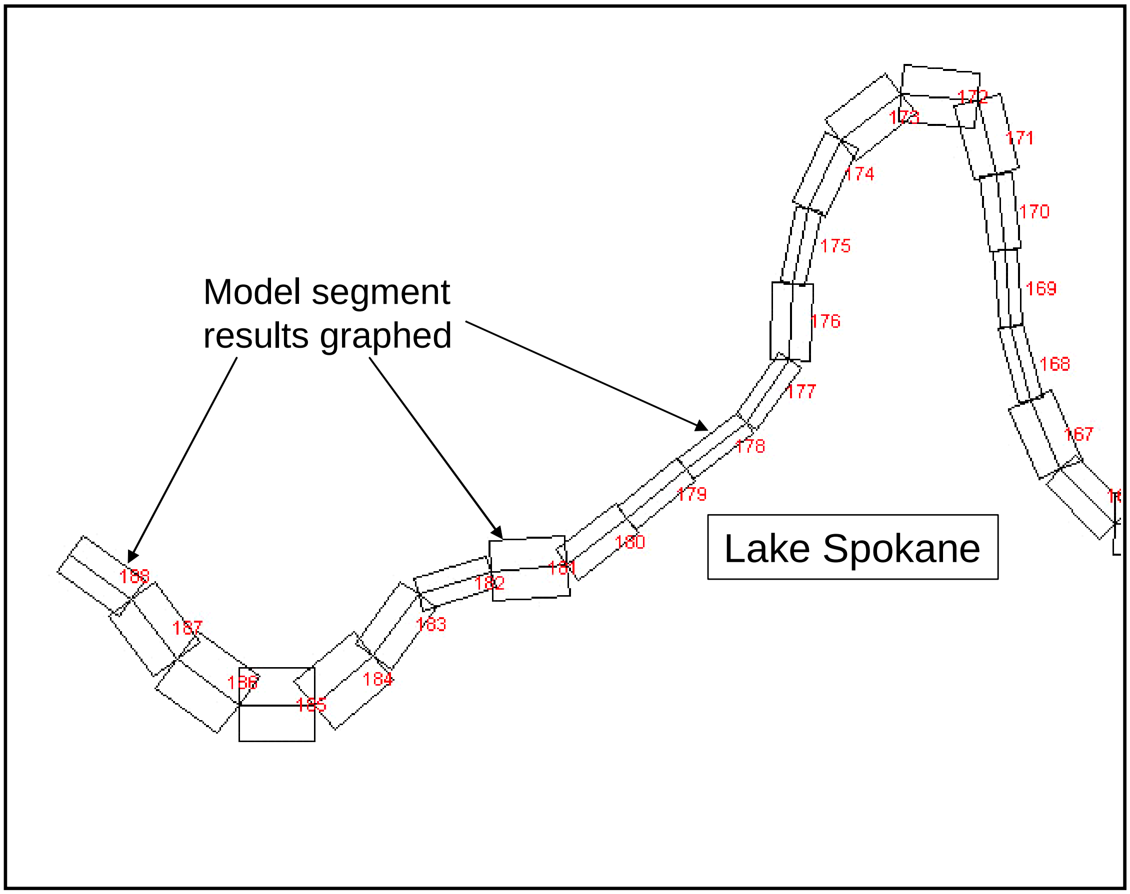

Figure 29. Model segments that represent the downstream portion of Lake Spokane.

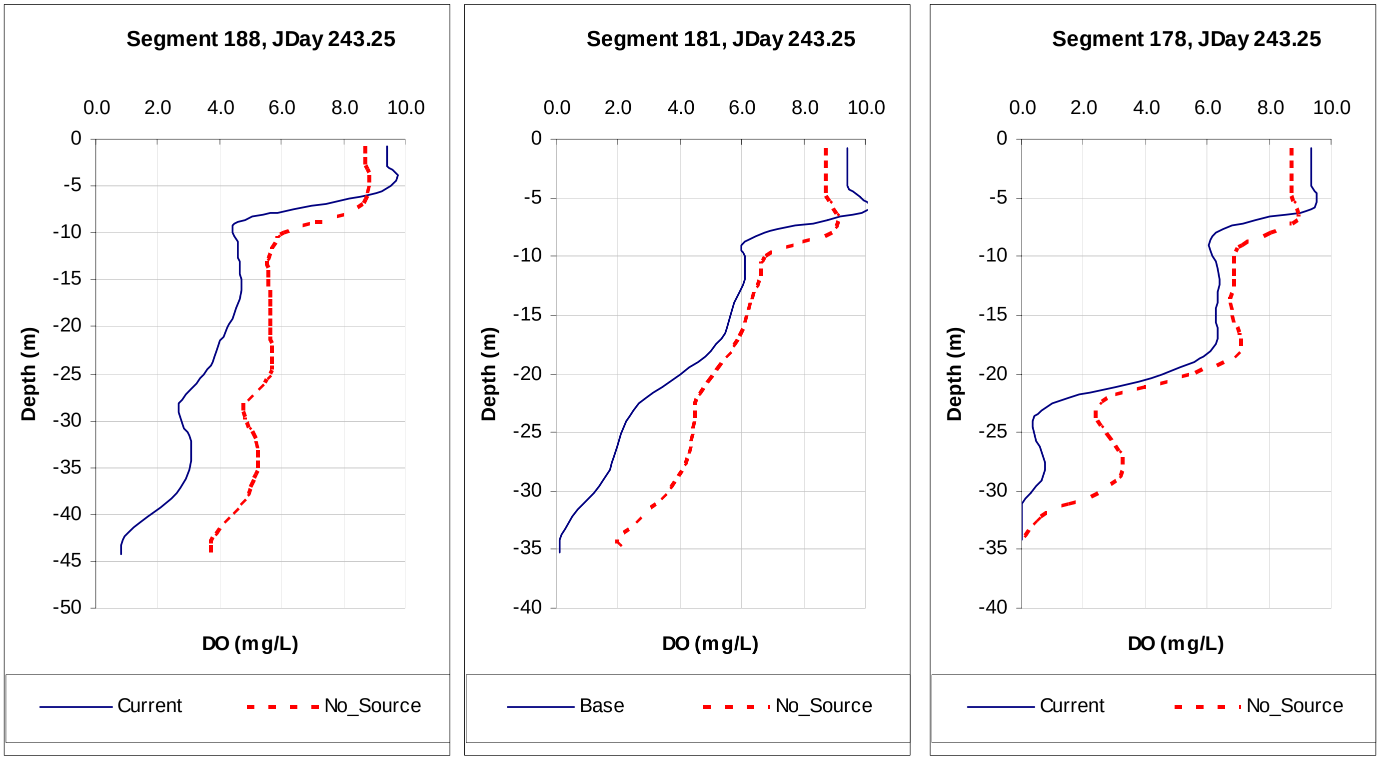

Figure 30. Model-predicted dissolved oxygen profiles for Lake Spokane at model segments 188, 181, and 178 for the CURRENT and NO-SOURCE scenarios for Julian Day 243.25 (September 1).

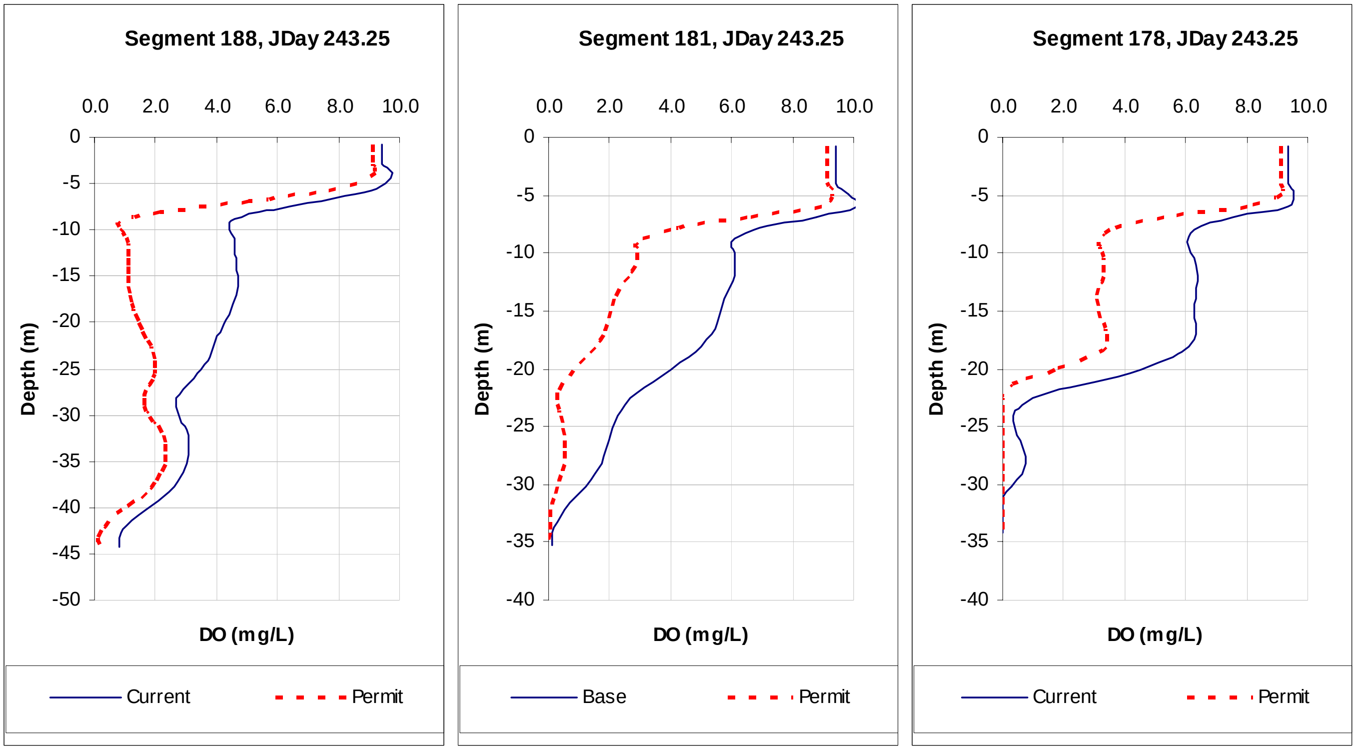

Figure 31. Model-predicted dissolved oxygen profiles for Lake Spokane at model segments 188, 181, and 178 for the CURRENT and PERMIT scenarios for Julian Day 243.25 (September 1).

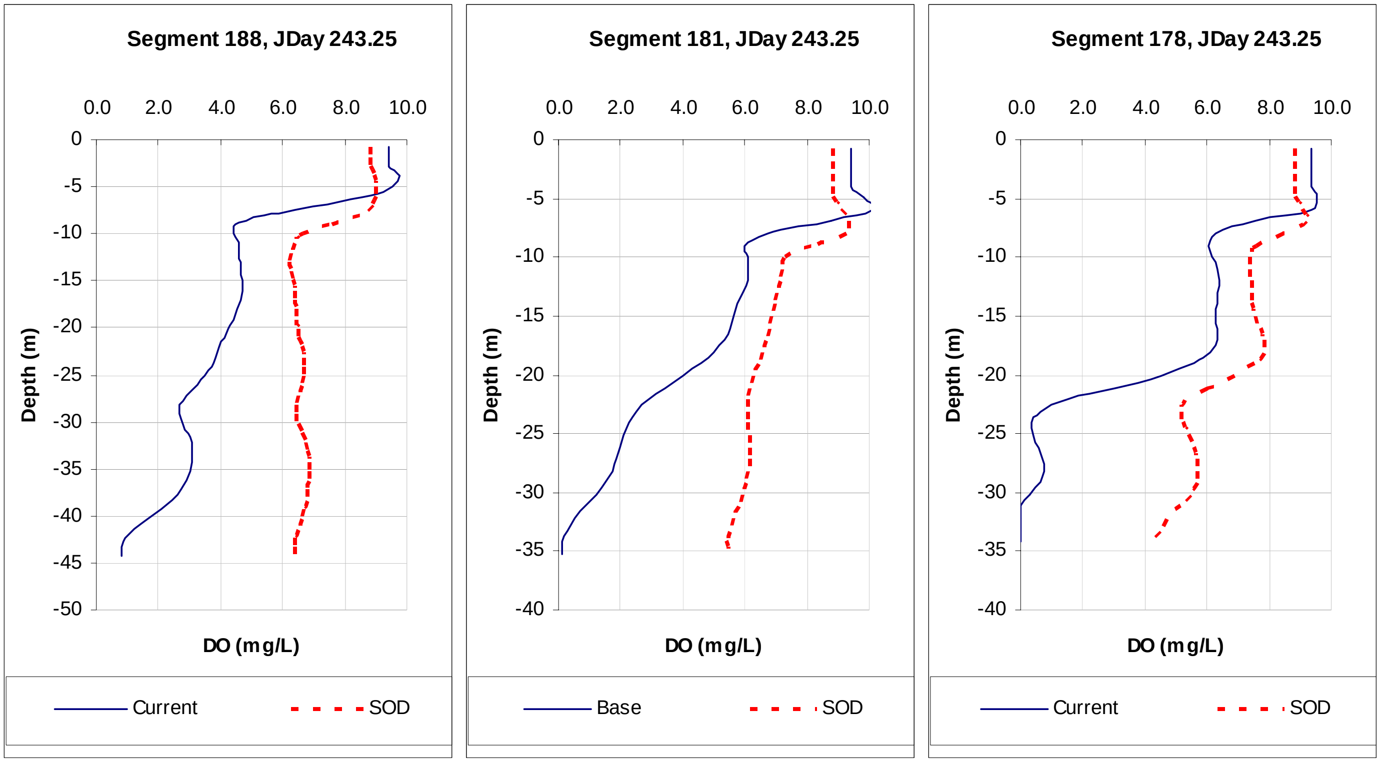

Figure 32. Model-predicted dissolved oxygen profiles for Lake Spokane at model segments 188, 181, and 178 for the CURRENT and SOD scenarios for Julian Day 243.25 (September 1).

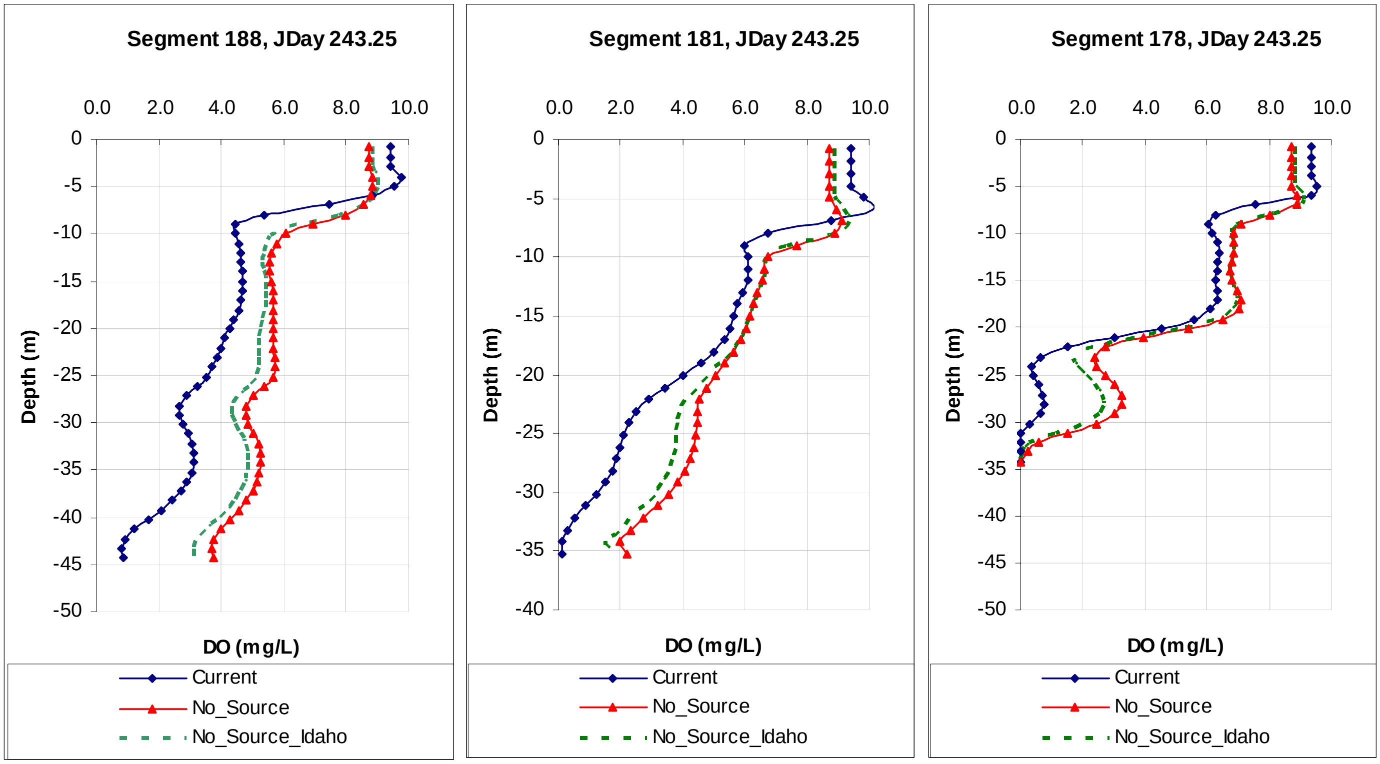

Figure 33. Model-predicted dissolved oxygen profiles for Lake Spokane at model segments 188, 181, and 178 for the CURRENT, NO-SOURCE and NO_SOURCE_IDAHO scenarios for Julian Day 243.25 (September 1).

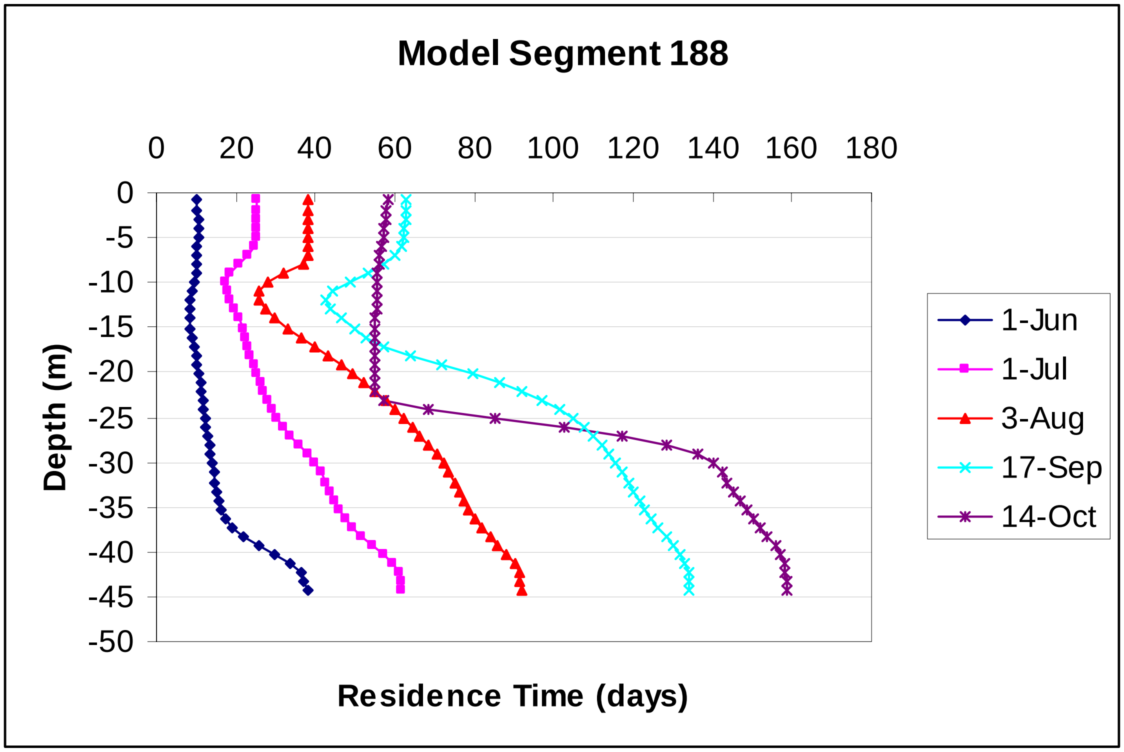

Figure 34. Lake Spokane model-predicted residence time for segment 188.

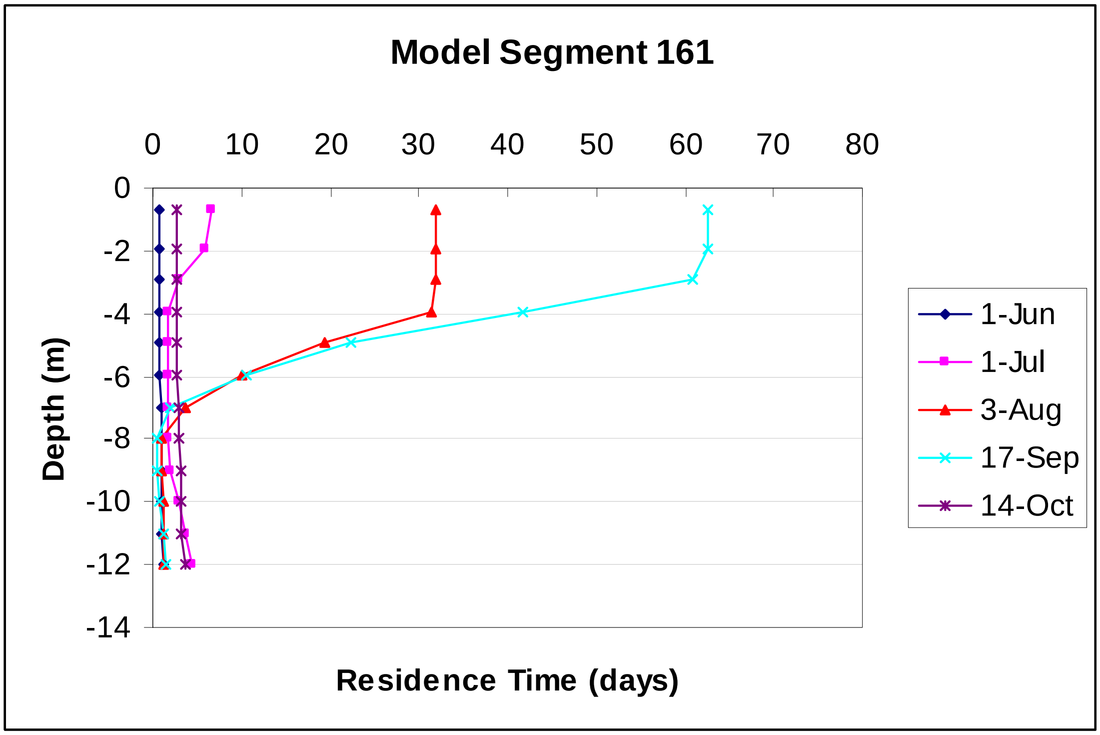

Figure 35. Lake Spokane model-predicted residence time for segment 161.

River Results

Figures 36 and 37 show continuous plots of the model-predicted dissolved oxygen concentration results for model segment 142 and 135 which are representative of the model segments in the Nine Mile Dam pool (model segments 131-151) under CURRENT and NO-SOURCE conditions. (The NO-POINT scenario predicted almost identical results as the NO-SOURCE condition and was not included in the graphs.)

Figures 38 and 39 show model segment 135 model-predicted dissolved oxygen concentrations under the CURRENT and PERMIT scenarios. These model segment locations are shown in Figure 40. Segment 135 is predicted to have only a few diurnal minimum dissolved oxygen concentrations less than 8 mg/L under the CURRENT loading scenario. The NO-POINT and NO-SOURCE scenarios predicted minimum dissolved oxygen concentrations to be above 8 mg/L. The minimum dissolved oxygen concentrations predicted at segment 135 were 7.97, 8.21, and 8.21 mg/L for the CURRENT, NO-POINT, and NO-SOURCE scenarios. The magnitude of the diurnal changes are due to differences in predicted periphyton growth and associated effects under the different scenarios caused mainly by point source loading of nutrients, i.e., little difference was predicted to occur between the NO-POINT and NO-SOURCE scenario results. The PERMIT scenario shows small increases in the diurnal range (minimum dissolved oxygen of 7.70 mg/L) which indicate that additional loading from CURRENT conditions may not significantly increase periphyton growth and its effects on dissolved oxygen concentrations, i.e., CURRENT phosphorus loading is not limiting to periphyton growth. (Other river segments were not presented because they showed similar results.)

Figure 41 shows the scenario results for model segment 112 that represents model segments 97-112 upstream of the City of Spokane AWTP effluent discharge point in model segment 114 (i.e., from just downstream of the Upper Falls to the AWTP). The segments in this reach are not predicted to drop below the criteria with current loading, and only show a small change with and without the point and nonpoint sources.

Figure 42 shows scenario results for model segment 82 that represents model segments in Upper Falls Dam pool (segments 76-86). Minimum dissolved oxygen concentrations during the last two weeks of August 2001 were measured to be below 8 mg/L in the Upper Falls pool (minimum measured was about 7.3 mg/L), the CE-QUAL-W2 model predicts minimum dissolved oxygen concentrations of about 7.5 mg/L during this time period. Model segments 112 and 82 locations are shown on Figure 43.

Figures 44 and 45 show the model results for segments 57 and 54. These segments represent the Upriver Dam pool reach just downstream and upstream of the Inland Empire Paper Company discharge point at model segment 55 as shown in Figure 46. Diurnal dissolved oxygen concentrations were predicted to be below 8 mg/L for most of the summer/fall except for the very low river flow period during late August and early September. Minimum dissolved oxygen concentration differences between the CURRENT and NO-SOURCE scenarios were <0.2 mg/L until mid to late September when daily differences were predicted to be >0.2 mg/L, with a maximum difference of 0.41 mg/L.

During 2001, a very low-flow period occurred from late August until more water was released at Post Falls on September 10. The Upriver Dam pool was predicted by the model to have higher dissolved oxygen concentrations during this time period because of increased algal productivity and thermal stratification (i.e., the pool exhibits characteristics of a lake during this period). When flows are higher, the pool is well mixed, and diurnal changes due to periphyton growth and respiration influence the dissolved oxygen in the pool. Although some of the model segments in the pool have profile dissolved oxygen concentrations near the bottom sediments that are <8.0 mg/L, dissolved oxygen concentrations throughout the profile were predicted to slightly decrease under the NO-SOURCE scenario during the late August through early September period (i.e., dissolved oxygen concentrations were predicted to be less without pollutant sources).

Figures 47 and 48 show model-predicted results for segments 20 and 10 that represent segments of the Spokane River upstream and downstream (to Barker Road Bridge at segment 24) of the Liberty Lake POTW discharge point into segment 15 as shown in Figure 49. The results presented for segment 10 indicate that the state line boundary conditions has a significant effect on predicted dissolved oxygen concentrations in this reach of the river. As discussed in the Hydrology and Water Quality sections, this is an outflow reach that has high temperatures and relatively low river flows that during 2001 were <200 cfs. The large predicted diurnal changes may partly be due to the very shallow depth and longer predicted residence time of water in the segments. Periphyton growth (biomass) was predicted to be in the range of values measured between the state line and Barker Road Bridge. Ecology collected *in situ* dissolved oxygen data near Myers Road (i.e., approximately model segment 20) during August 7-27, 2003 to verify the model predictions. Although river flows were a little higher in 2003 than 2001, the diurnal ranges measured during this period were similar to those estimated by the model for 2001 with the measured maximum range of 6.1 to 11.7 mg/L (i.e., 5.6 mg/L range) on August 26-27, 2003.

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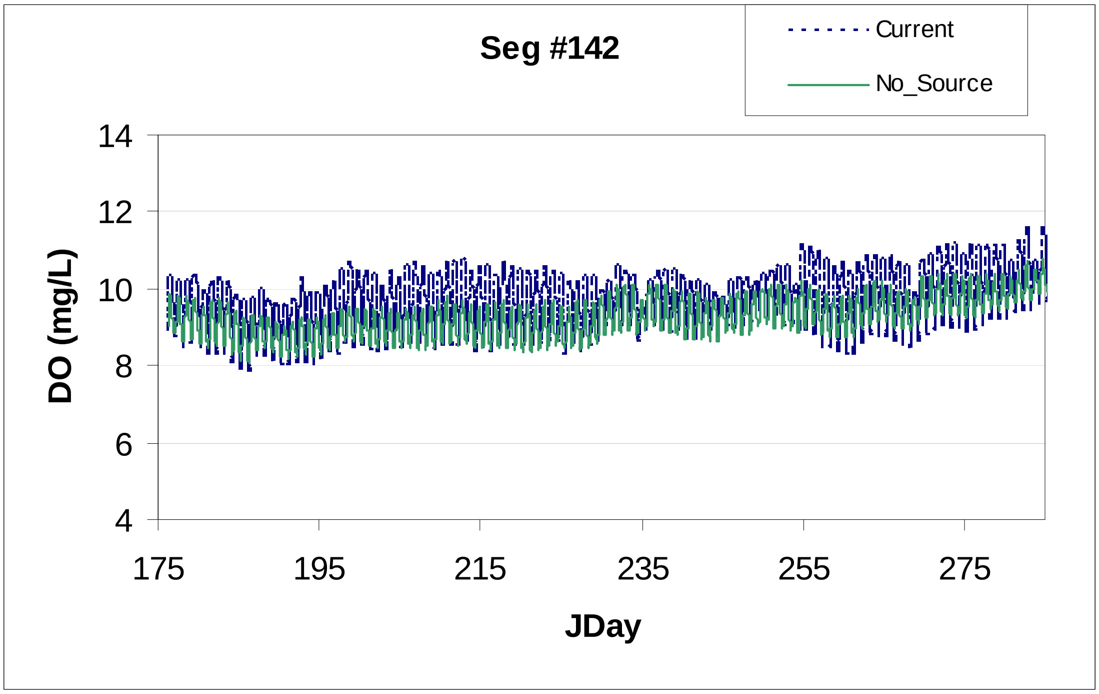

Figure 36. Model-predicted diurnal dissolved oxygen concentrations for model segment 142 located about 2.6 miles upstream of Nine Mile Dam for Julian Days 176-284 (June 25-October 10).

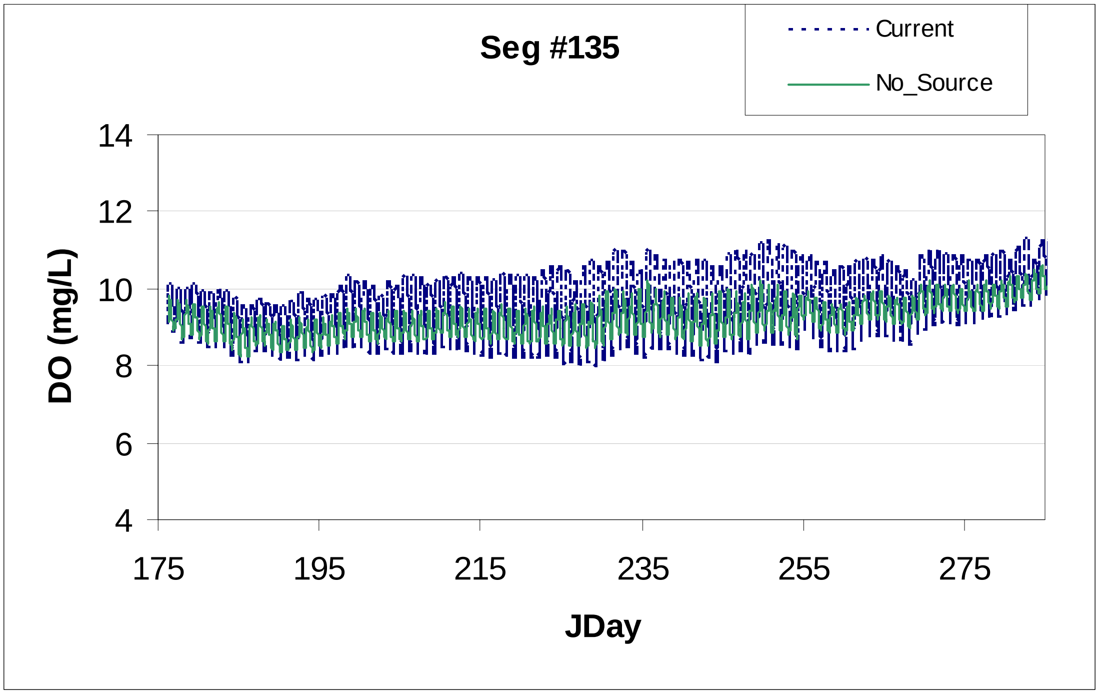

Figure 37. Model-predicted diurnal dissolved oxygen concentrations for model segment 135 located about 4.1 miles upstream of Nine Mile Dam for Julian Days 176-284 (June 25-October 10).

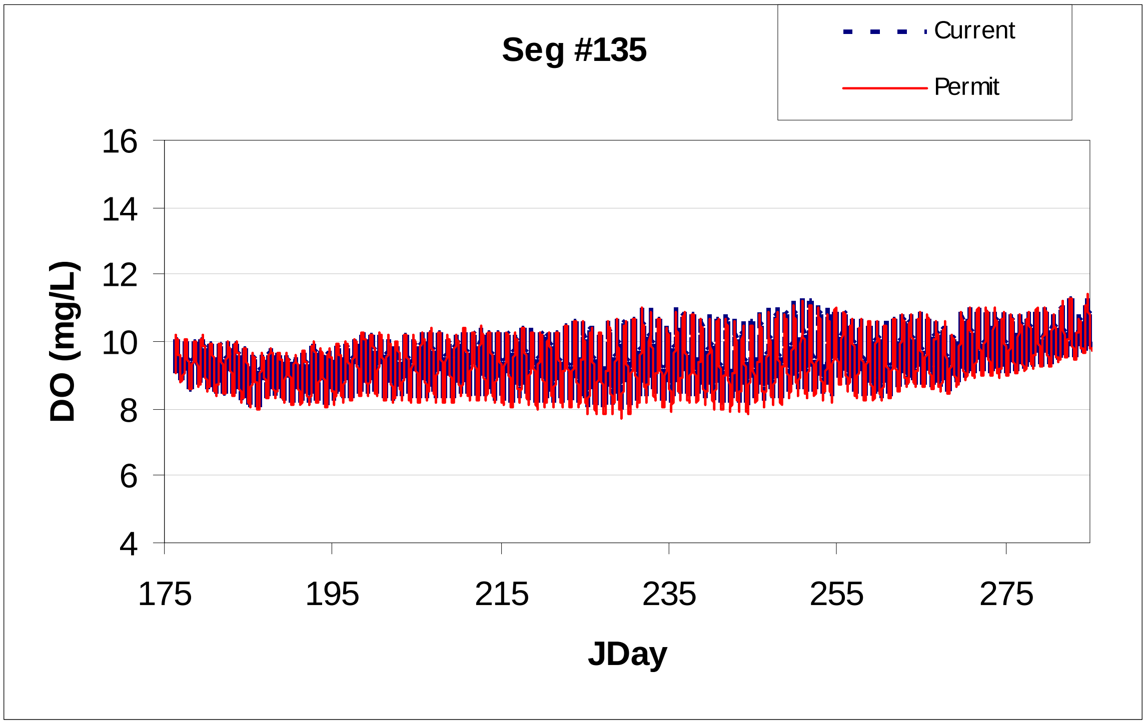

Figure 38. Model-predicted diurnal dissolved oxygen concentrations for model segment 135 located about 4.1 miles upstream of Nine Mile Dam for Julian Days 176-284 (June 25-October 10).

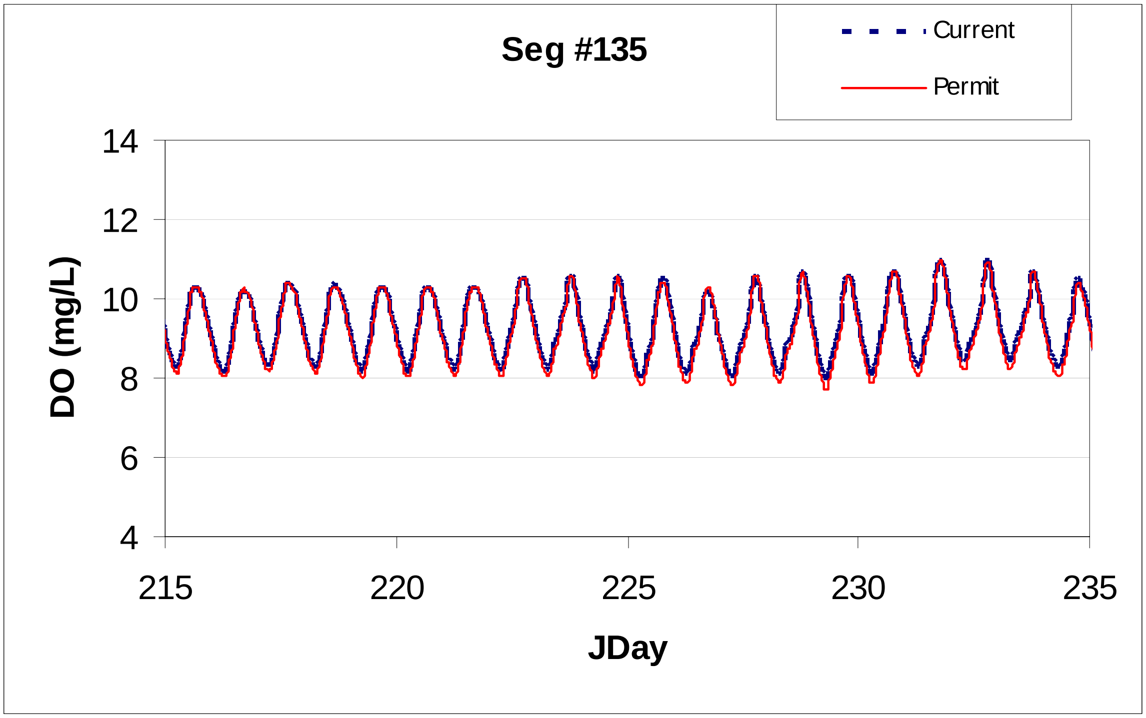

Figure 39. Model-predicted diurnal dissolved oxygen concentrations for model segment 135 located about 4.1 miles upstream of Nine Mile Dam for Julian Days 215-235 (August 4-24).

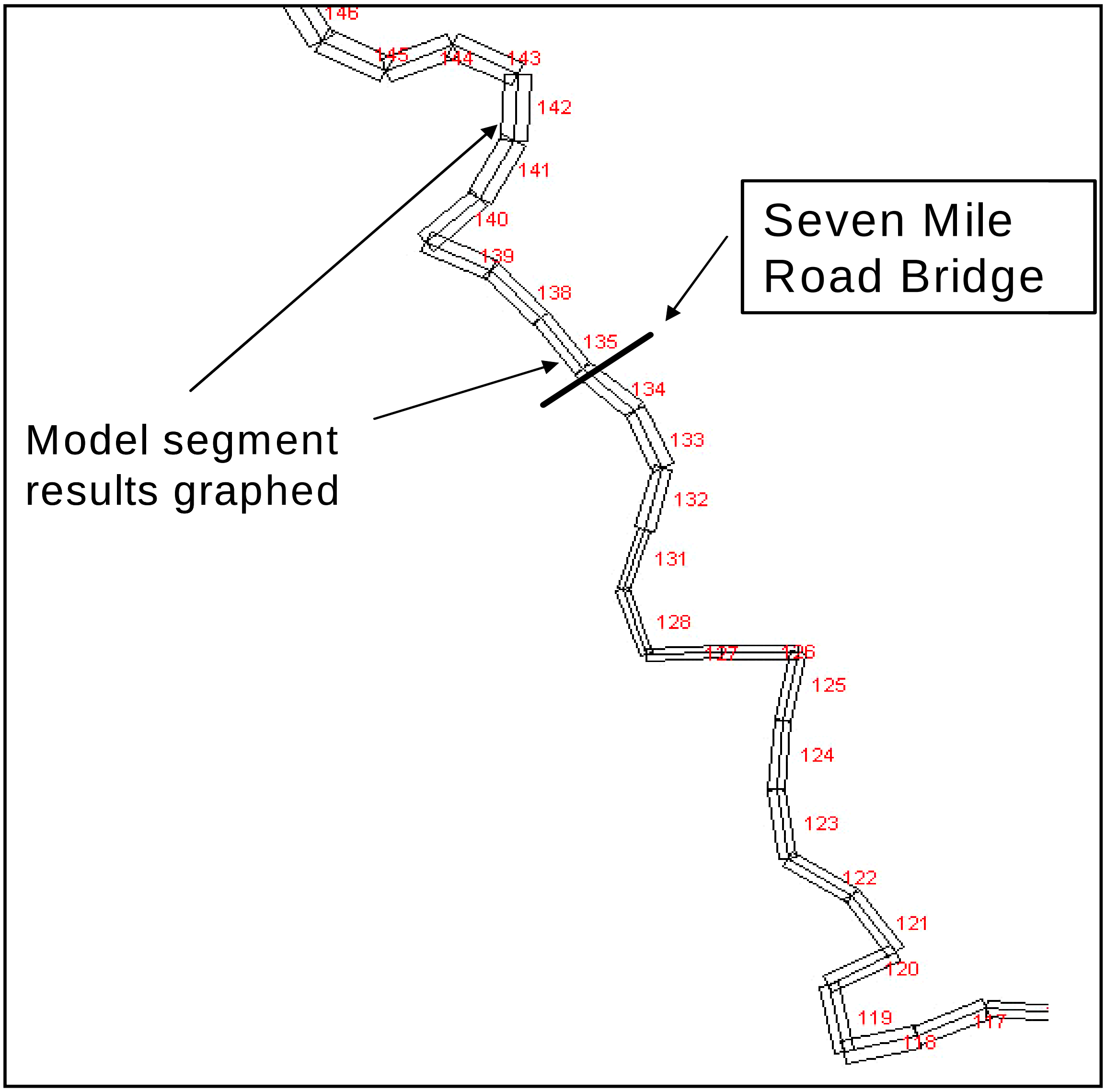

Figure 40. Model segments that represent the upstream end of the Nine Mile Dam pool.

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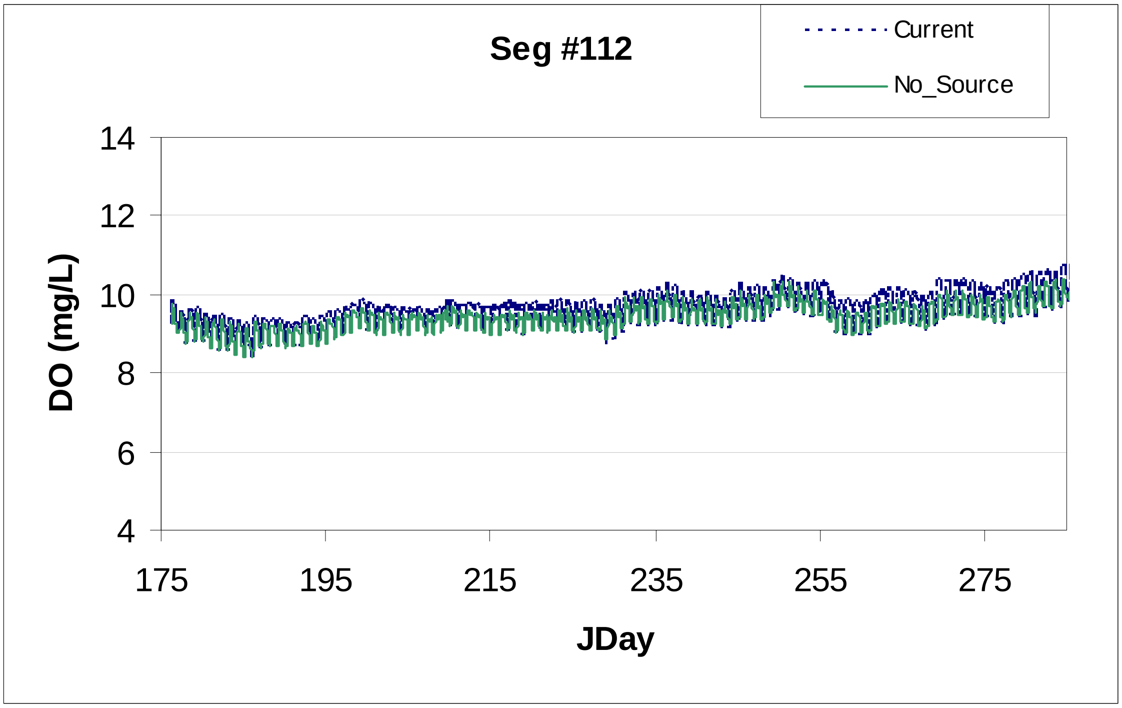

Figure 41. Model-predicted diurnal dissolved oxygen concentrations for model segment 112 located about 0.6 miles upstream of the City of Spokane AWTP for Julian Days 176-284 (June 25-October 10).

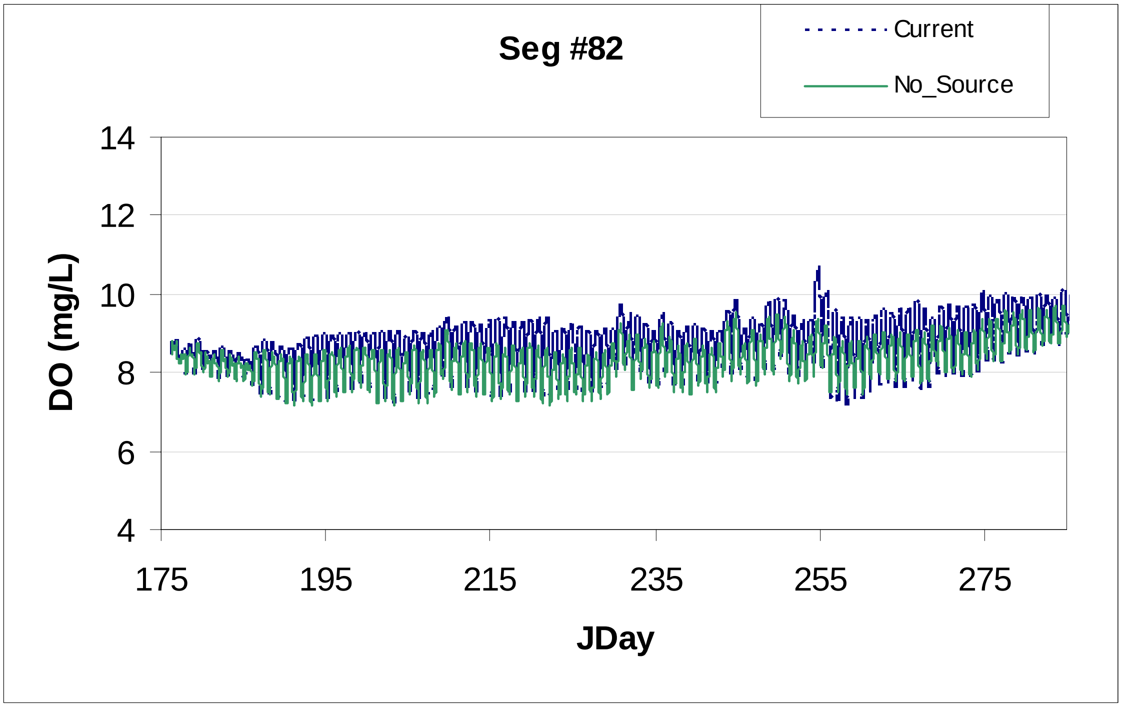

Figure 42. Model-predicted diurnal dissolved oxygen concentrations for model segment 82 located about 0.6 miles upstream of the City of Spokane AWTP for Julian Days 176-284 (June 25-October 10).

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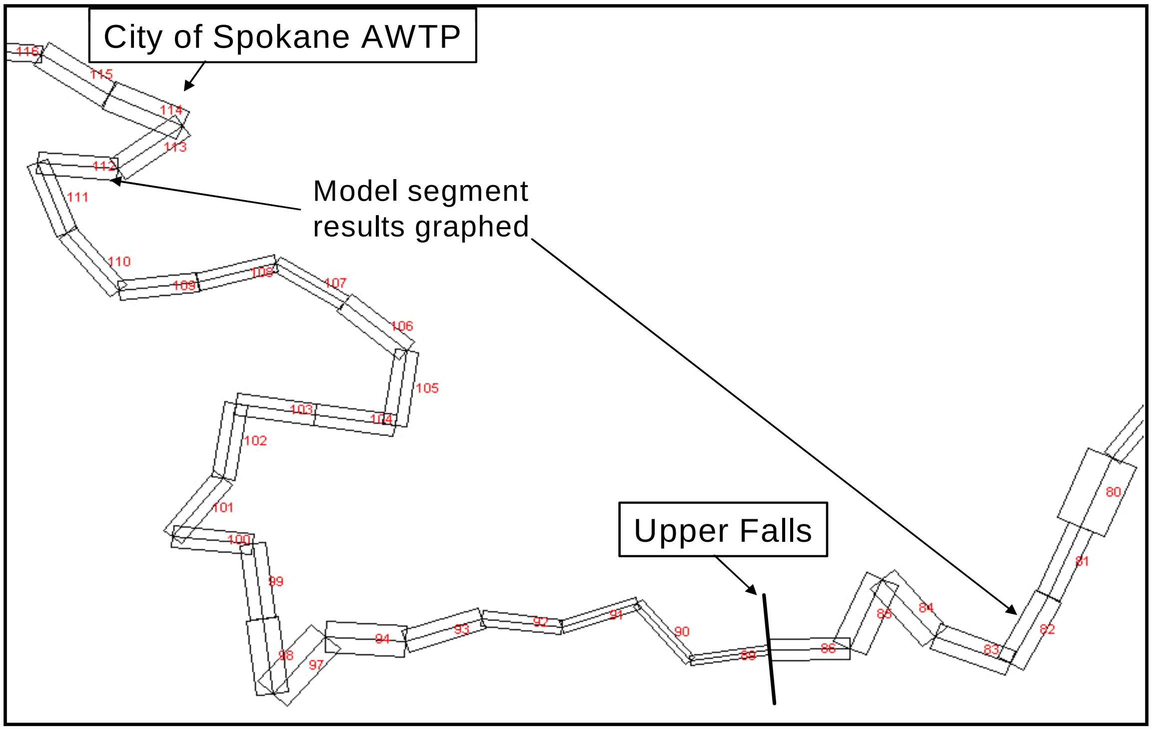

Figure 43. Model segments for the area upstream of the City of Spokane AWTP discharge point and the downstream end of Upper Falls pool.

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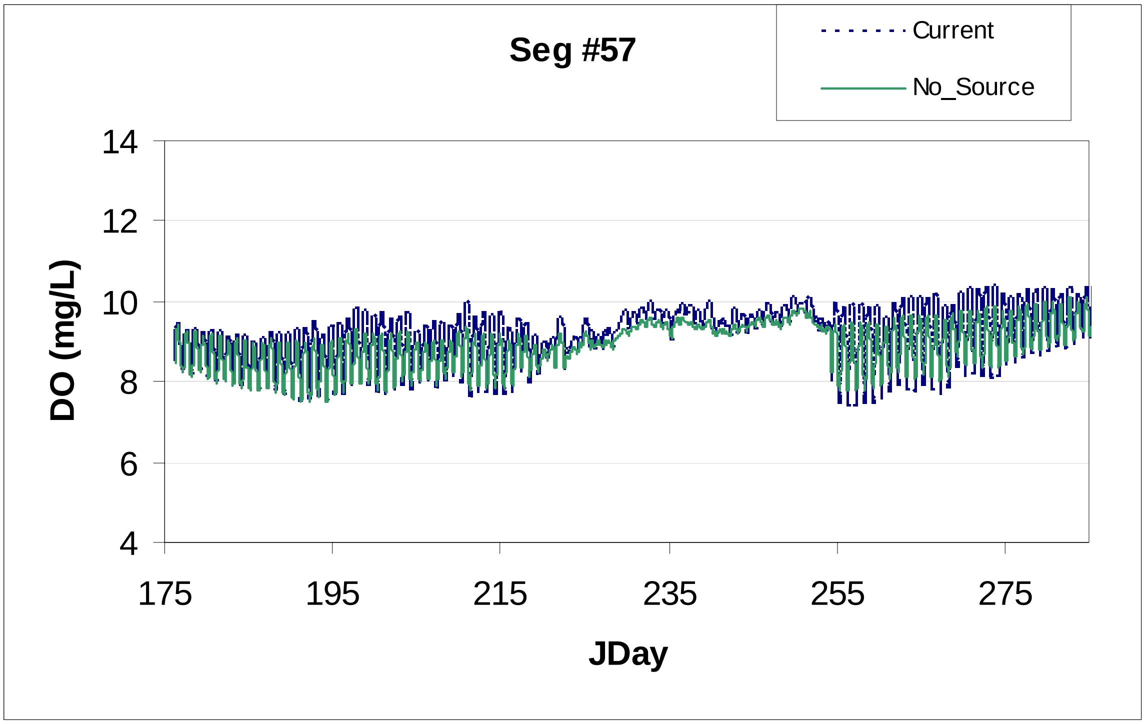

Figure 44. Model-predicted diurnal dissolved oxygen concentrations for model segment 57 located just downstream of Inland Empire Paper Co. discharge point into segment 56 for Julian Days 176-284 (June 25-October 10).

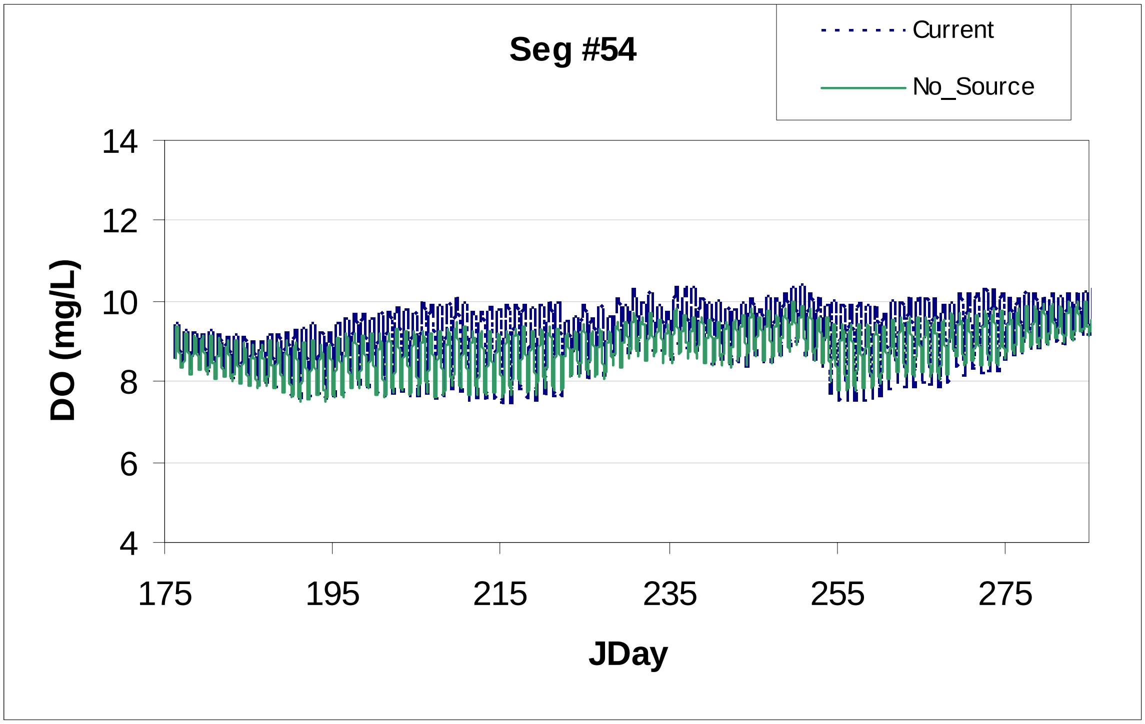

Figure 45. Model-predicted diurnal dissolved oxygen concentrations for model segment 54 located upstream of Inland Empire Paper Co. discharge point into segment 56 for Julian Days 176-284 (June 25-October 10).

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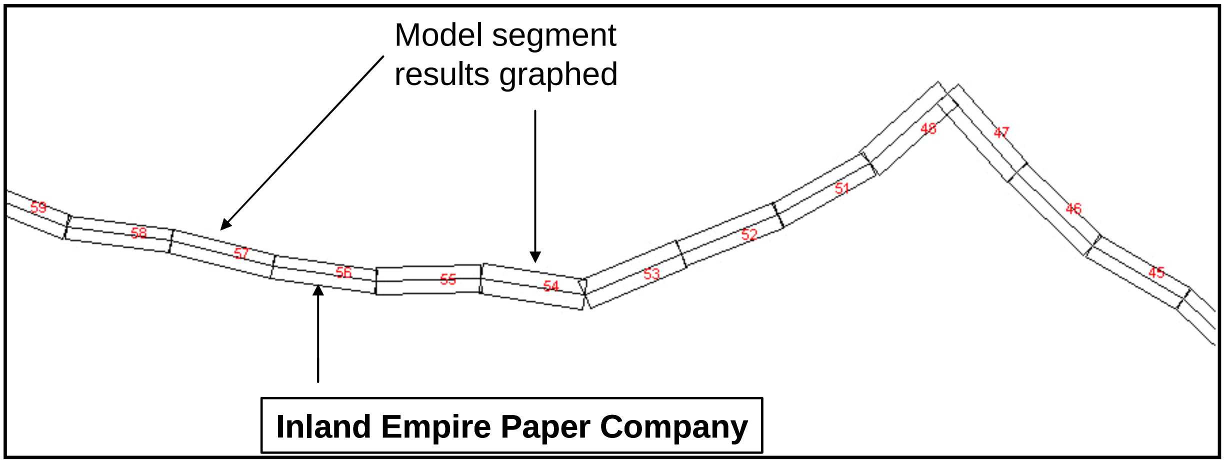

Figure 46. Model segments that represent the upstream end of the Upriver Dam pool near the Inland Empire Paper Co. discharge point.

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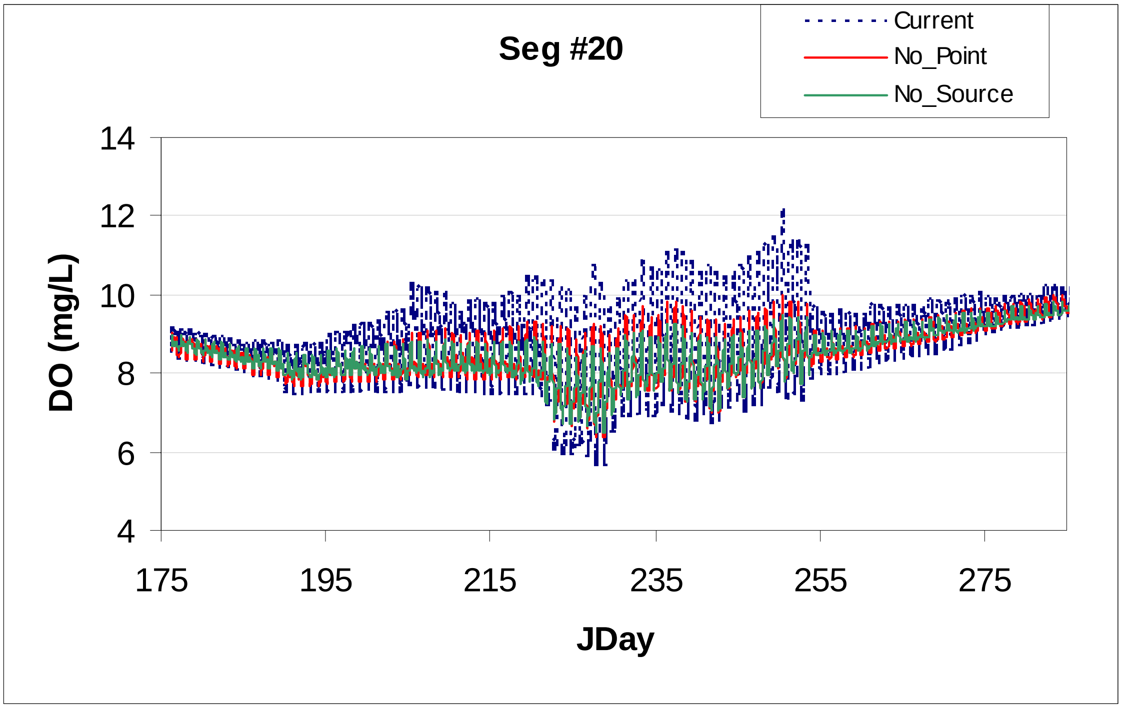

Figure 47. Model-predicted diurnal dissolved oxygen concentrations for model segment 20 located about 1.5 miles downstream of Liberty Lake POTW discharge point into segment 15 for Julian Days 176-284 (June 25-October 10).

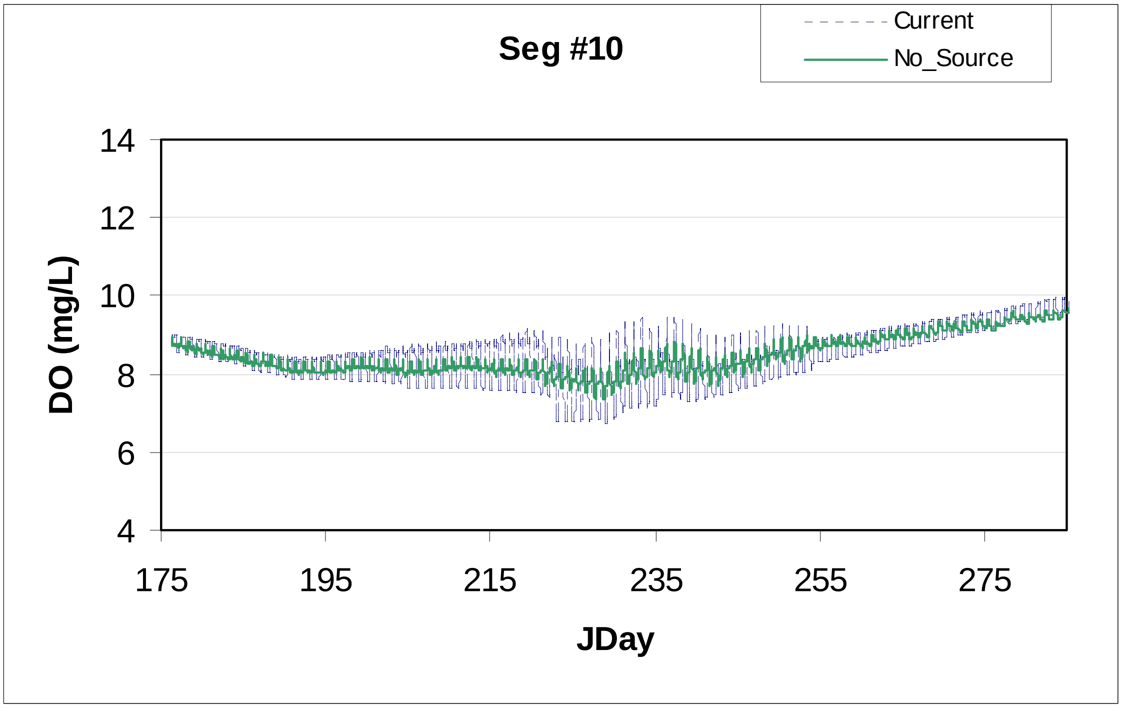

Figure 48. Model-predicted diurnal dissolved oxygen concentrations for model segment 10 located about 0.9 miles upstream of Liberty Lake POTW for Julian Days 176-284 (June 25-October 10).

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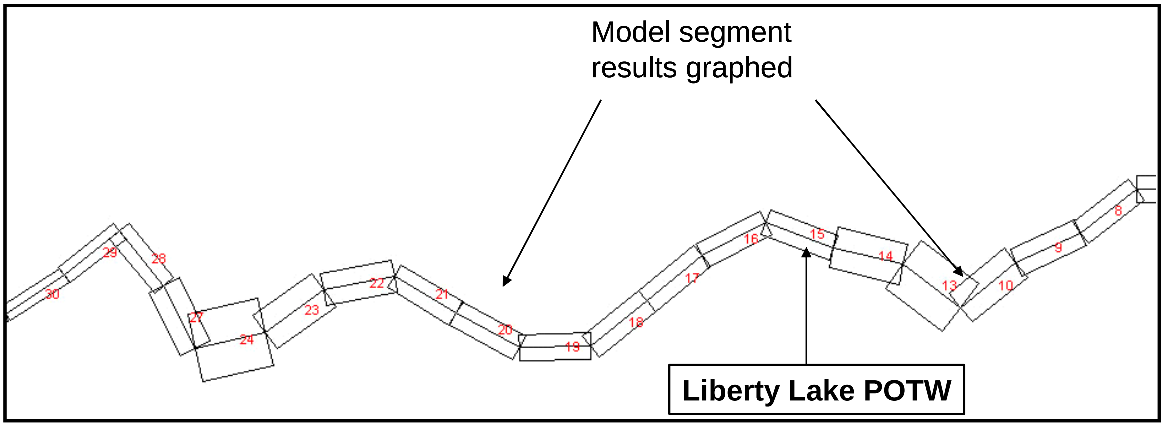

Figure 49. Model segments that represent the Spokane River near the Liberty Lake POTW discharge point.

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Conclusions and Recommendations

1. One of the major objectives of this study was to evaluate and update the existing P-attenuation model for the Spokane River used to determine phosphorus loading responses in Lake Spokane. However, the authors believe the assumptions used to develop the existing total phosphorus TMDL for Lake Spokane indicate that the current allowable phosphorus loading is too high to protect water quality in the lake per the objectives identified in URS (1981). We recommend revising the current phosphorus TMDL to protect water quality in the upper end of the lake from excessive algal growth. The historical data indicate that the current TMDL may need to be reduced by more than 50% to control late summer-fall algal blooms that occur in the upper end of the lake.

2. Based on historical studies and this current study of the Spokane River and Lake Spokane, there are three major water quality issues related to dissolved oxygen concentrations:
   - Periphyton growth causes diurnal minimum dissolved oxygen concentrations in some locations in the river to drop below 8 mg/L. The major source of phosphorus (the growth-limiting nutrient) that stimulates periphyton growth during the growing season is from the point source discharges to the river.
   - Hypolimnetic dissolved oxygen concentrations in Lake Spokane are depressed due to human-caused internal and external biological oxygen demand (BOD) loading.
   - Excessive phytoplankton growth due to human causes increases internal loading of BOD to Lake Spokane and decreases hypolimnetic dissolved oxygen concentrations.

3. Excessive algal growth in the upper end of the lake also causes aesthetic impairment that was not adequately addressed by the existing phosphorus TMDL.

4. The model results indicate that, under the 2001 critical year conditions, current levels of point and nonpoint BOD and phosphorus loading violate the dissolved oxygen criteria in Lake Spokane and parts of the Spokane River. The major conclusions that can be drawn from the model results for the critical year scenarios are as follows:
   - Dissolved oxygen depletion predicted by the model due to human causes is far in excess of the allowable 0.2 mg/L for the current and permitted loads (both point and nonpoint loading). The impacts of future population growth likely will be even greater.
   - On an annual basis, the effects of point source BOD and phosphorus loading on dissolved oxygen concentrations during the summer are predicted to be the greatest in the interflow zone or metalimnion of the lake. The greatest effects of the nonpoint sources are predicted to be in lower depths. Point sources are the major sources of pollutant loading to the Spokane River during the summer, and during the spring the major sources are nonpoint tributary loading. The summer point source and spring nonpoint source dominated pollutant loading to the lake mostly affects dissolved oxygen in different zones of the lake because the residence time is shortest in the interflow zone and longest in the lower depths.

The model-predicted euphotic zone residence time in 2001 for the upper end of the lake at the beginning of August was about 30-36 days, and increased to a maximum of about 63 days by mid September, consistent with Patmont et al. (1987) calculated residence times for June-October of 20-80 days. The residence time predictions indicate that loading that occurs from the middle of June and later causes the algal blooms that occur in the upper end of the lake in late summer and early fall that produce internal loading of BOD. In addition, loading that occurs in the late spring affects bottom water dissolved oxygen concentrations during late summer and early fall.

- Diurnal dissolved oxygen concentrations in the river are caused by photosynthesis and respiration of periphyton. Reducing phosphorus loading to the river reduces the diurnal range of dissolved oxygen.
- Although a few river model segments are predicted to have diurnal minimum dissolved oxygen concentrations that violate the criterion under 2001 loading conditions, the results indicate that Lake Spokane is the most critical area of the modeled river system for determining pollutant TMDL limits and associated allocations. Managing pollutant loads and associated oxygen deficits in the lake also will likely protect water quality in the river.
- Current monthly permitted BOD5 loading would cause significant degradation of dissolved oxygen in Lake Spokane beyond current levels.

5. If point and nonpoint sources of BOD and phosphorus are reduced, overtime sediment oxygen demand (SOD) will be reduced which will lead to higher dissolved oxygen concentrations in the lower depths of Lake Spokane.

6. During August 2003, field sampling was conducted in the Spokane River reach just downstream of the Liberty Lake POTW discharge point. The data verified the large diurnal ranges of dissolved oxygen predicted by the CE-QUAL-W2 model.

References

Annear, R.L, C.J. Berger, S.A. Wells, and T. Cole, 2001. Upper Spokane River Model: Boundary Conditions and Model Setup. (1991 and 2000) Technical Report EWR-04-01. Department of Civil Engineering, Portland State University, Portland, OR.

Aroner, E.R., 2001. WQHYDRO: Water Quality/Hydrology Graphics/Analysis System. February 2001. P.O. Box 18149, Portland, OR. 97218.

Berger, C.J., R.L. Annear, S.A. Wells, and T. Cole, 2002. Upper Spokane River Model: Model Calibration. (1991 and 2000) Technical Report EWR-01-02. Department of Civil Engineering, Portland State University, Portland, OR.

Berger, C.J., R.L. Annear, S.A. Wells, and T. Cole, 2003. Upper Spokane River Model: Model Calibration 2001. Technical Report EWR-01-03. Department of Civil Engineering, Portland State University, Portland, OR.

Berger, C.J., R.L. Annear, S.A. Wells, and T. Cole, 2004. Review of Spokane River Model for Washington Department of Ecology. Technical Report EWR-01-04. Department of Civil Engineering, Portland State University, Portland, OR.

CH2M HILL, 1998. City of Spokane Wellhead Protection Program Phase I – Technical Assessment Report. Prepared for the Spokane City Council. CH2M HILL, Bellevue, WA.

CH2M HILL, 2001. Spokane River Flow Model – Review Comments. Memorandum from C. Gruenenfeld and J. Porcello to Jim Carrell, Washington State Department of Ecology, dated February 20, 2001 with attached spreadsheet. CH2M HILL, Bellevue, WA.

Cunningham, R.K. and R.E. Pine, 1969. Preliminary Investigation of the Low Dissolved Oxygen Concentrations that Exist in Long Lake, Located near Spokane, Washington. Washington State Water Pollution Control Commission, Technical Report No. 69-1.

Cusimano R.F., 1999. Spokane River and Lake Spokane TMDL Study for Biochemical Oxygen Demand and Update of the Phosphorus Attenuation Model. Final Quality Assurance Project Plan. Washington State Department of Ecology, Environmental Assessment Program, Olympia, WA.

Cusimano R.F., 2003. Data Summary: Spokane River and Lake Spokane (Long Lake) Pollutant Loading Assessment for Protecting Dissolved Oxygen. Publication Number 03-03-023. Washington State Department of Ecology, Environmental Assessment Program, Olympia, WA. http://www.ecy.wa.gov/biblio/0303023.html

Gearhart, C. and J.P. Buchanan, 2000. The Hydraulic Connection Between the Spokane River and the Spokane Aquifer: Gaining and Losing Reaches of the Spokane River from Stateline, Idaho to Spokane, Washington. A final report prepared for the Spokane County Water Quality Management Program by Eastern Washington University, Cheney, WA.

Knight, D.T., 1998. Watershed Approach to Water Quality Management Needs Assessment for the Spokane Water Quality Management Area (WRIA 54-57). Washington State Department of Ecology, Water Quality Program, Spokane, WA.

Marti, P.B. and R. Garrigues, 2001. Spokane River/Aquifer Interaction Project Results, May-November 1999. Publication No. 01-03-024. Washington State Department of Ecology, Environmental Assessment Program, Olympia, WA. http://www.ecy.wa.gov/biblio/0103024.html

MEL, 2001. Manchester Environmental Laboratory Lab Users Manual. Fifth Edition. Washington State Department of Ecology, Manchester Environmental Laboratory, Manchester, WA.

Molenaar, D., 1988. The Spokane Aquifer, Washington: Its Geologic Origin and Water-bearing and Water-quality Characteristics: U.S. Geological Survey Water-Supply Paper 2265.

Patmont, C.R., G.J. Pelletier, and M.E. Harper, 1985. Phosphorus Attenuation in the Spokane River. Project Completion Report. Contract No. C84-076. Harper-Owes, Seattle, WA Prepared for Washington State Department of Ecology, Olympia, WA. Publication No. 85-e28. http://www.ecy.wa.gov/biblio/85e28.html

Patmont, C.R., G.J. Pelletier, L. Singleton, R. Soltero, W. Trial, and E. Welch, 1987. The Spokane River Basin: Allowable Phosphorus Loading. Final Report. Contract No. C0087074. Harper-Owes, Seattle, WA. Prepared for State of Washington State Department of Ecology, Olympia, WA. Publication No. 87-e29.

Pelletier, G.J., 1994. Dissolved Oxygen in the Spokane River Downstream from Inland Empire Paper Company with Recommendations for Waste Load Allocations for Biochemical Oxygen Demand. Publication No. 94-155. Washington State Department of Ecology, Environmental Investigations and Laboratory Services, Olympia, WA.

Pelletier, G.J., 1997. Waste Load Allocations for Biochemical Oxygen Demand for Inland Empire Paper Company. Publication No. 97-313. Washington State Department of Ecology, Environmental Investigations and Laboratory Services, Olympia, WA.

Pluhowski, E.J. and Thomas, C.A., 1968. A Water-balance Equation for the Rathdrum Prairie Groundwater Reservoir, Near Spokane, Washington. U.S. Geological Survey Professional Paper 600-D, Geological Survey Research.

Singleton, L.R., 1981. Spokane River Wasteload Allocation Study. Supplemental report for phosphorus allocation. Publication No. 81-15. Washington State Department of Ecology, Olympia, WA.

Slominski, S., Annear, R.L, C.J. Berger, and S.A. Wells, 2003. Upper Spokane River Model: Boundary Conditions and Model Setup 2001. Department of Civil Engineering, Portland State University, Portland, OR.

Smith, M.A., 1981. Pollutant Contributions of Significant Idaho Point Sources. Idaho Division of Environment; Boise, 1D.

Soltero, R.A., A.F. Gasperino, and W.G. Graham, 1973. An Investigation of the Cause and Effect of Eutrophication in Long Lake, WA. 0.W.R.R. Project 143-34-IOE-3996-5501. Completion Report. Eastern Washington State College, Cheney, WA.

Soltero, R.A., A.F. Gasperino, and W.G. Graham, 1974. Further Investigation as to the Cause and Effect of Eutrophication in Long Lake, WA. Project 74-025A. Completion Report. Eastern Washington State College, Cheney, WA.

Soltero, R.A., A.F. Gasperino, P.H. Williams, and S.R. Thomas, 1975. Response of the Spokane River Periphyton Community to Primary Sewage Effluent and Continued Investigation of Long Lake. Project 74-144. Completion Report. Eastern Washington State College, Cheney, WA.

Soltero, R.A., O.M. Kruger, A.F. Gasperino, J.P. Griffin, S.R. Thomas, and P.H. Williams, 1976. Continued Investigation of Eutrophication in Long Lake, WA: Verification Data for the Long Lake Model. WDOE Project WF-6-75- 081. Completion Report. Eastern Washington State College, Cheney, WA.

Soltero, R.A., D.G. Nichols, G.A. Pebles, and L.R. Singleton, 1978. Limnological Investigation of Eutrophic Long Lake and its Tributaries Just Prior to Advanced Wastewater Treatment with Phosphorus Removal by Spokane, WA. Project 77-108. Completion Report. Eastern Washington University, Cheney, WA.

Soltero, R.A., D.G. Nichols, G.P. Burr, and L.R. Singleton, 1979. The Effect of Continuous Advanced Wastewater Treatment by the City of Spokane on the Trophic Status of Long Lake, WA. WDOE Project 77-108. Completion Report. Eastern Washington University, Cheney, WA.

Soltero, R.A., D.G. Nichols, and J.M. Mires, 1980. The Effect of Continuous Advanced Wastewater Treatment by the City of Spokane on the Trophic Status of Long Lake, WA, During 1979. Project 80-019. Completion Report. Eastern Washington University, Cheney, WA.

Soltero, R.A. and D.G. Nichols, 1981. The Recent Blue-Green Algal Blooms of Long Lake, Washington. In: The Water Environment: Algal Toxins and Health. Plenum Pub.

Soltero, R.A., D.G. Nichols, and J.M. Mires, 1981. The Effect of Continuous Advanced Wastewater Treatment by the City of Spokane on the Trophic Status of Long Lake, WA. Contract No. WF81-001. Completion Report. Eastern Washington University, Cheney, WA.

Soltero, R.A., D.G. Nichols, and M.R. Cather, 1982. The Effect of Continuous Advanced Wastewater Treatment by the City of Spokane on the Trophic Status of Long Lake, WA. Contract No. WF81-001. Completion Report. Eastern Washington University, Cheney, WA.

Soltero, R.A., D.G. Nichols, and M.R. Cather, 1983. The Effect of Seasonal Alum Addition (chemical phosphorus removal) by the City of Spokane's Advanced Wastewater Treatment Plant on the Water Quality of Long Lake, Washington, 1982. City of Spokane Contract No. 414-430-000-534.40-3105. Completion Report. Eastern Washington University, Cheney, WA.

Soltero, R.A., D.G. Nichols, M.R. Cather, and K.O. McKee, 1984. The Effect of Seasonal Alum Addition (chemical phosphorus removal) by the City of Spokane's Advanced Wastewater Treatment Plant on the Water Quality of Long Lake, Washington, 1983. City of Spokane Contact No. 414-430-000-534.40-3105. Completion Report. Eastern Washington University, Cheney, WA.

Soltero, R.A., M.R. Cather, K.O. McKee, and B.G. Nichols, 1985. Variable Initiation and Termination of Alum Addition at Spokane's Advanced Wastewater Treatment Facility and the Effect on the Water Quality of Long Lake, Washington, 1984. City of Spokane Contract No. 414-430-000-501.34-3105. Completion Report. Eastern Washington University, Cheney, WA.

Soltero, R.A., M.R. Cather, K.O. McKee, K.R. Merrill, and D.G. Nichols, 1986. Variable Initiation and Termination of Alum Addition at Spokane's Advanced Wastewater Treatment Facility and the Effect on the Water Quality of Long Lake, Washington, 1985. City of Spokane Contract No. 414-430-000- 501.34-3105. Completion Report. Eastern Washington University, Cheney, WA.

Soltero, R.A., L.A. Campbell, K.R. Merrill, R.W. Plotnikoff, and L.M. Sexton, 1988. Water Quality Assessment and Restoration Feasibility for Eloika Lake, WA. Department of Biology, Eastern Washington University, Cheney, WA.

Soltero, R.A., L.M. Sexton, L.L. Wargo, D.D. Geiger, K.S. Roberton, K.E. Bolstad, J.P. Buchanan, and M.S. Johnson, 1992. Assessment of Nutrient Loading Sources and Macrophyte Growth in Lake Spokane (Lake Spokane), WA and the Feasibility of Various Control Measures. Departments of Biology and Geology, Eastern Washington University, Cheney, WA.

Soltero, R.A., R.J. Appel, D.D. Geiger, and L.M. Sexton, 1993. Verification of Lake Spokane Water Quality as Predicted by the Spokane River Phosphorus Attenuation Model. City of Spokane, Clerk’s No. OPR93-236, Public Works File #14099. Department of Biology, Eastern Washington University, Cheney, WA.

URS, 1981. Spokane River Wasteload Allocation Study: Phase 1. Prepared by URS Co., Seattle, WA. for Washington State Department of Ecology Publication No. 81-e27. http://www.ecy.wa.gov/biblio/81e27.html

USGS, 1989. Hypolimnetic Concentrations of Dissolved Oxygen, Nutrients, and Trace Elements in Coeur D'Alene Lake, Idaho. Water-Resources Investigations Report 89-4032. U.S. Geological Survey, Boise, ID.

Wagstaff, W.H. and R.A. Soltero, 1982. The Cause(s) of Continued Hypolimnetic Anoxia in Lake Spokane, Washington Following Advanced Wastewater Treatment by the City of Spokane. Final Progress Report, Contract No. 82-031. Report submitted by Eastern Washington University, Department of Biology, Cheney, WA. to Washington State Department of Ecology, Olympia, WA. Publication No. 82-31. http://www.ecy.wa.gov/biblio/8231.html.

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

Wells, S.A., R.L Annear, and C.J. Berger, 2003. Upper Spokane River Model in Idaho: Boundary Conditions and Model Setup for 2001. Technical Report EWR-02-03. Department of Civil Engineering, Portland State University, Portland, OR.

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Appendix A

Additional Water Quantity and Quality Graphs

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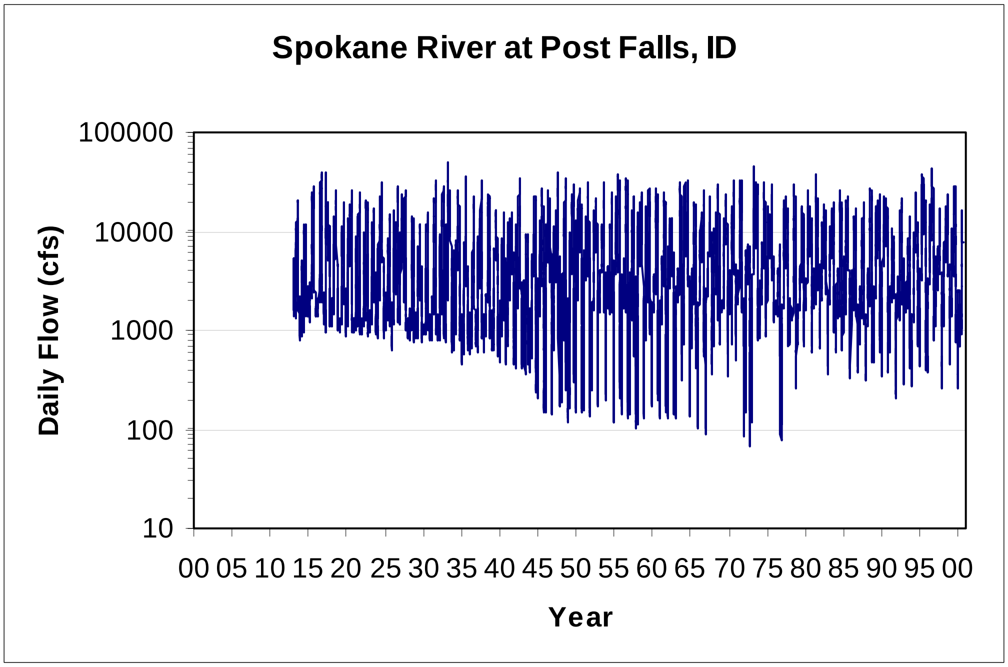

Figure A-1. Spokane River daily flow at Post Falls, Id.

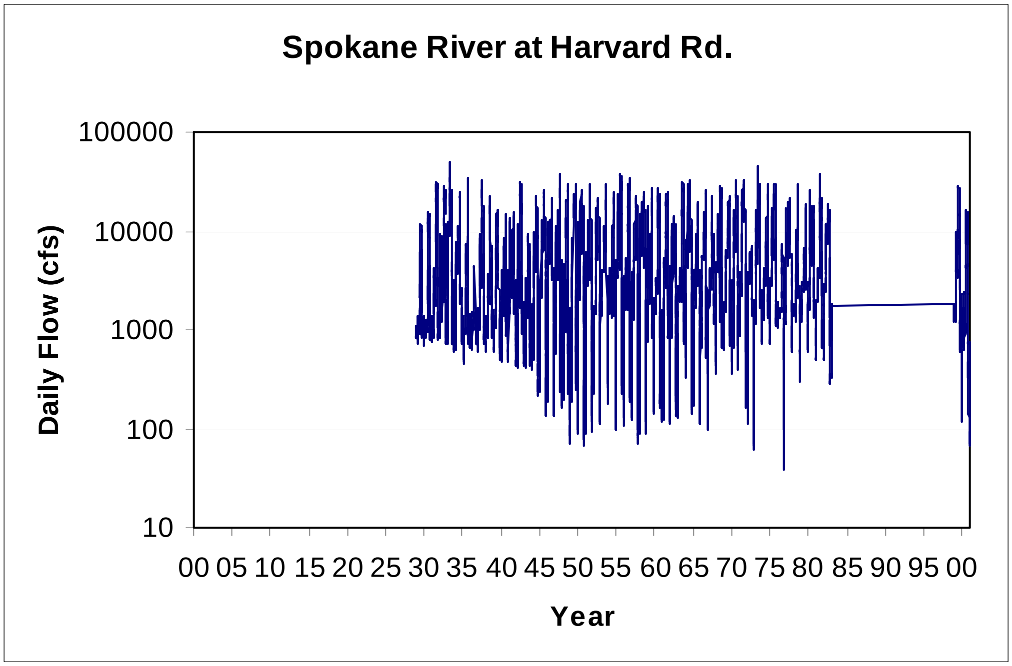

Figure A-2. Spokane River daily flow at Harvard Rd., WA.

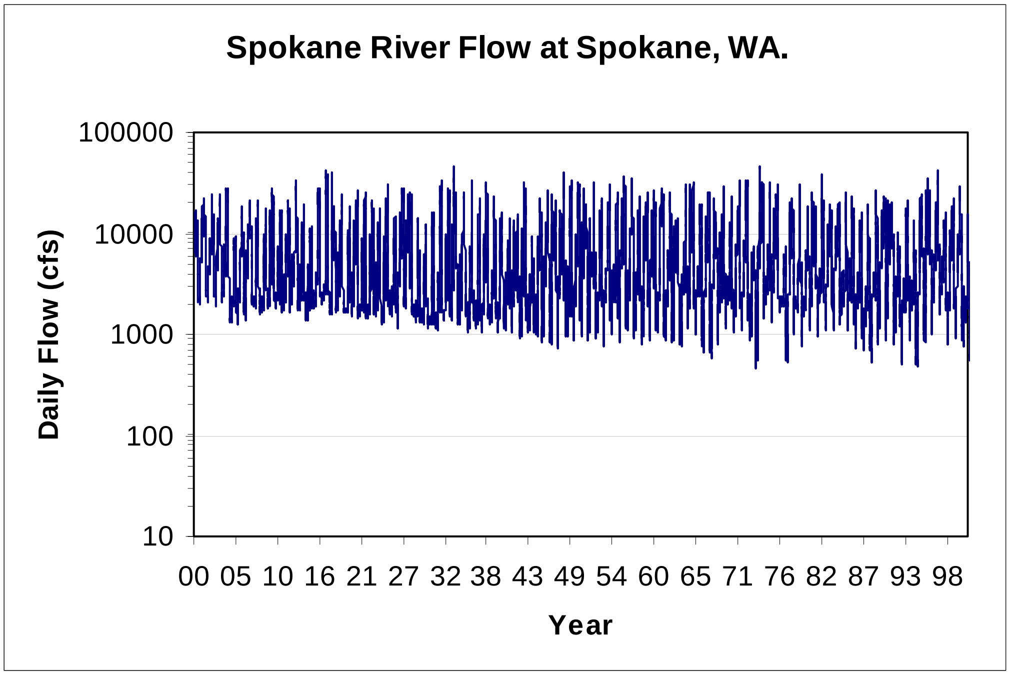

Figure A-3. Spokane River daily flow at Spokane, WA.

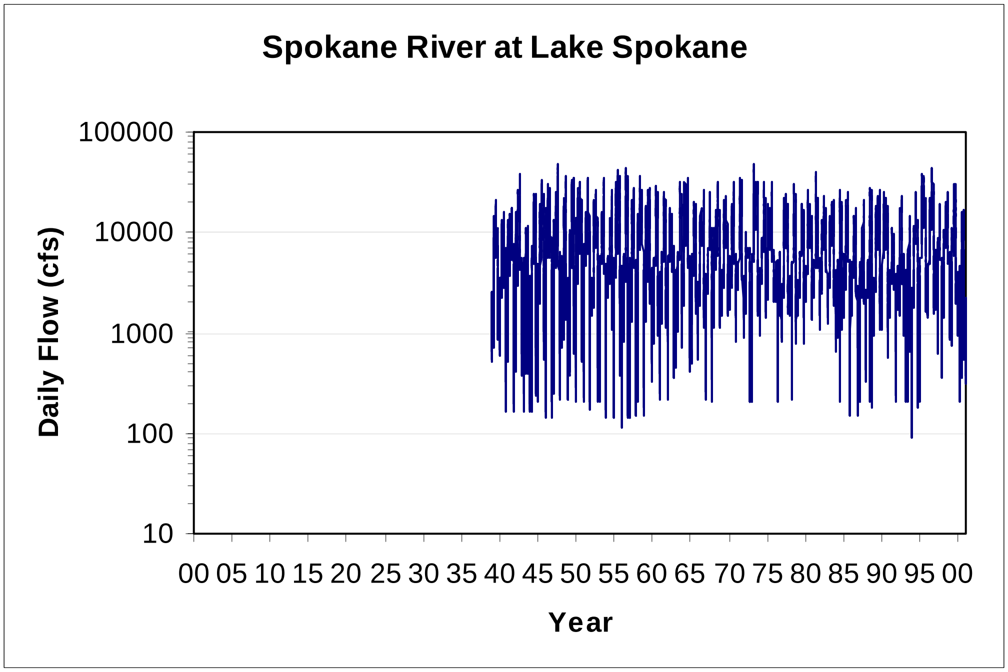

Figure A-4. Spokane River daily flow at Lake Spokane.

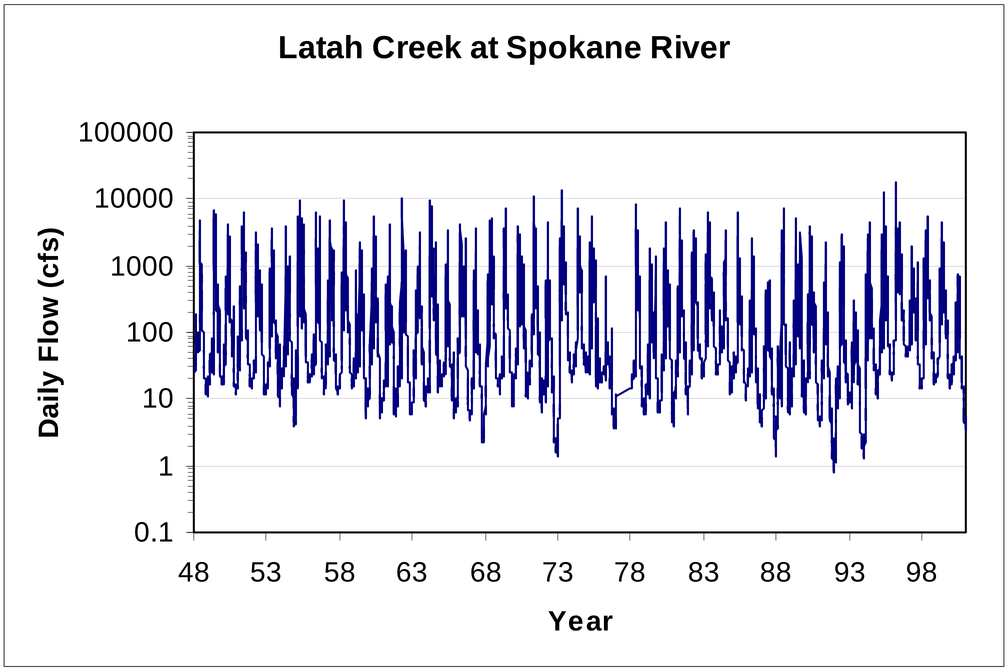

Figure A-5. Latah Creek daily flow at the Spokane River.

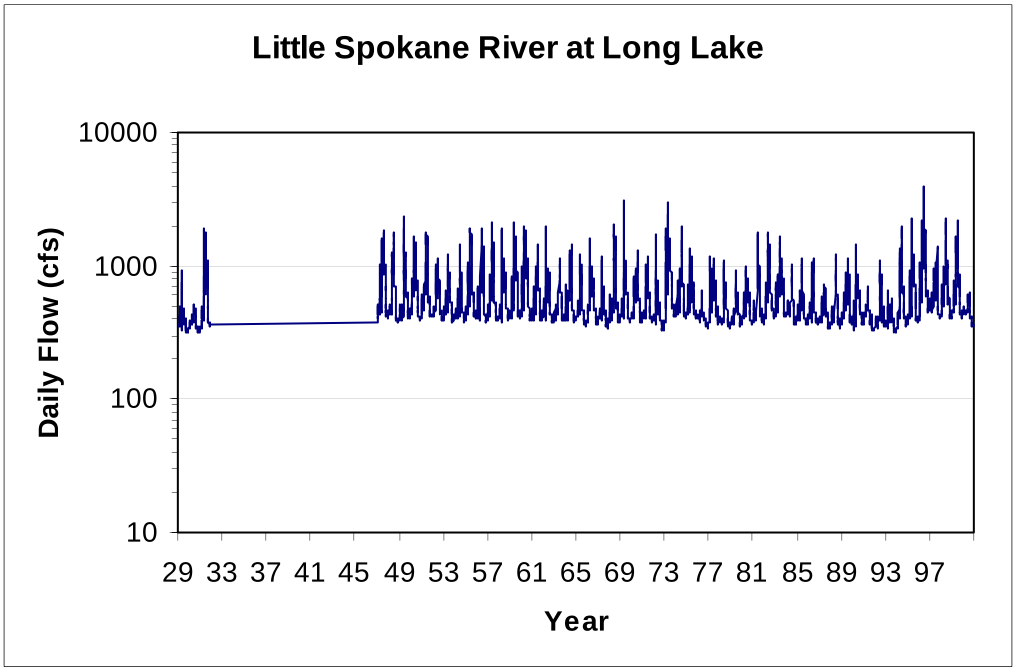

Figure A-6. Little Spokane River daily flow estimated at Long Lake.

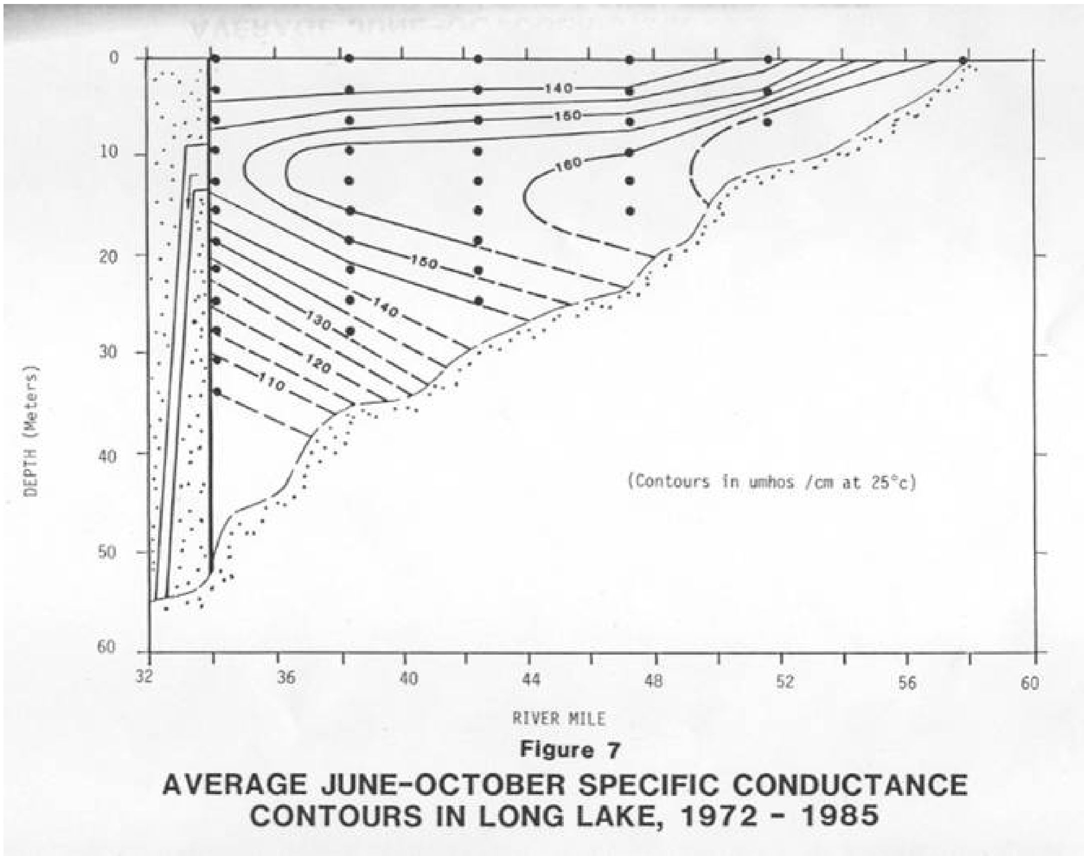

Figure 7

AVERAGE JUNE-OCTOBER SPECIFIC CONDUCTANCE CONTOURS IN LONG LAKE, 1972 - 1985

Figure A-7. Conductivity contour plot from Patmont et al. (1985) showing the Lake Spokane interflow zone.

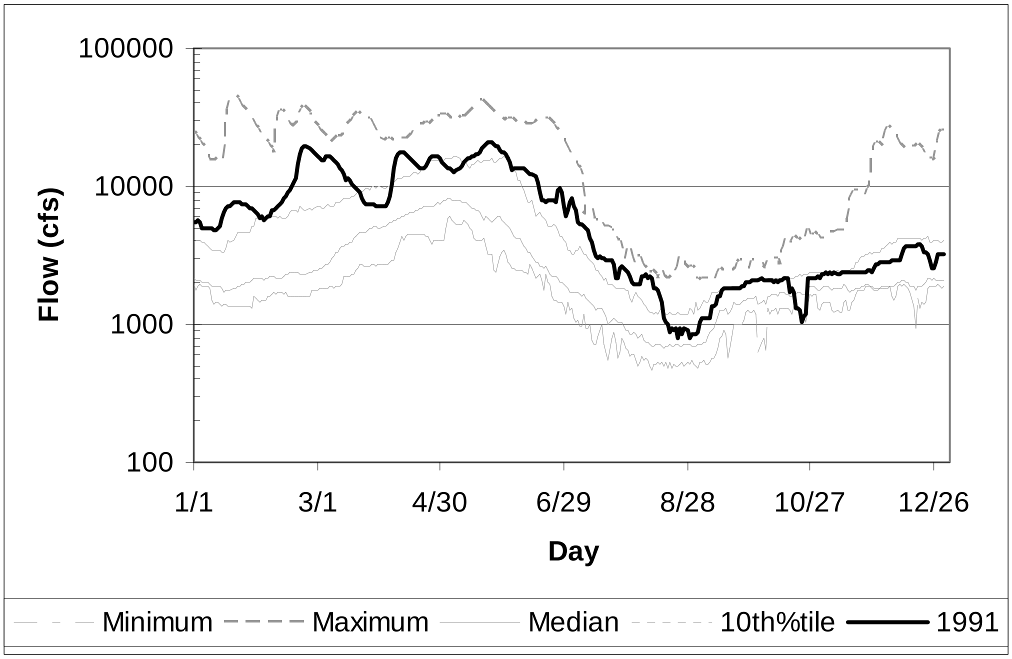

Figure A-8. 1991 daily river flow at Spokane relative to historical daily flow characteristics.

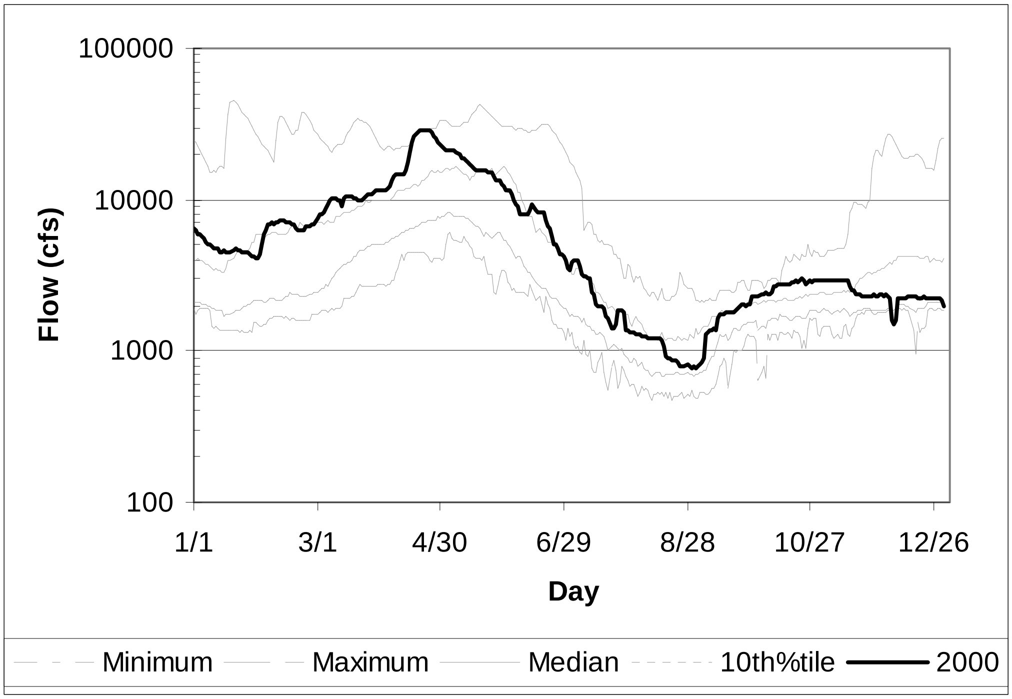

Figure A-9. 2000 daily river flow at Spokane relative to historical daily flow characteristics.

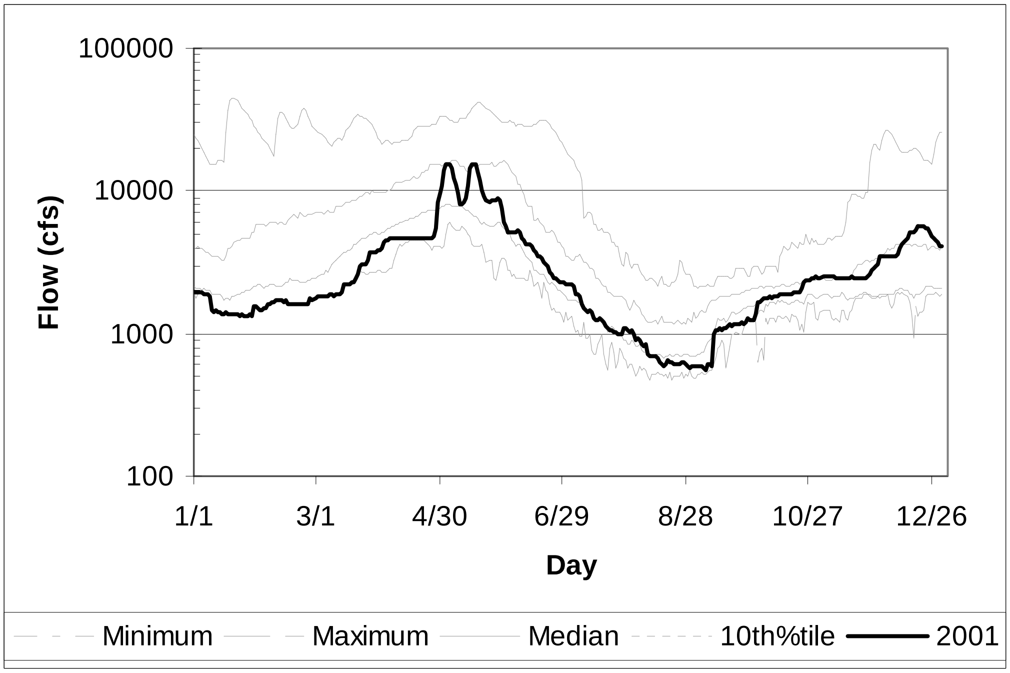

Figure A-10. 2001 daily river flow at Spokane relative to historical daily flow characteristics.

Key for acronyms in Figures A-11 through A-16.

Acronym	Definition	Units
TEMP	Temperature	Deg Celsius
COND	Conductivity	umhos/cm
OXYGEN	Dissolved Oxygen	mg/L
pH	pH	pH Units
TSS	Total Suspended Solids	mg/L
TURBIDITY	Turbidity	NTUs
TP	Total Phosphorus	mg/L
SRP	Soluble Reactive Phosphorus	mg/L
TPN	Total Persulfate Nitrogen	mg/L
NO2NO3	Nitrite-Nitrate Nitrogen	mg/L
NH3	Ammonia Nitrogen	mg/L

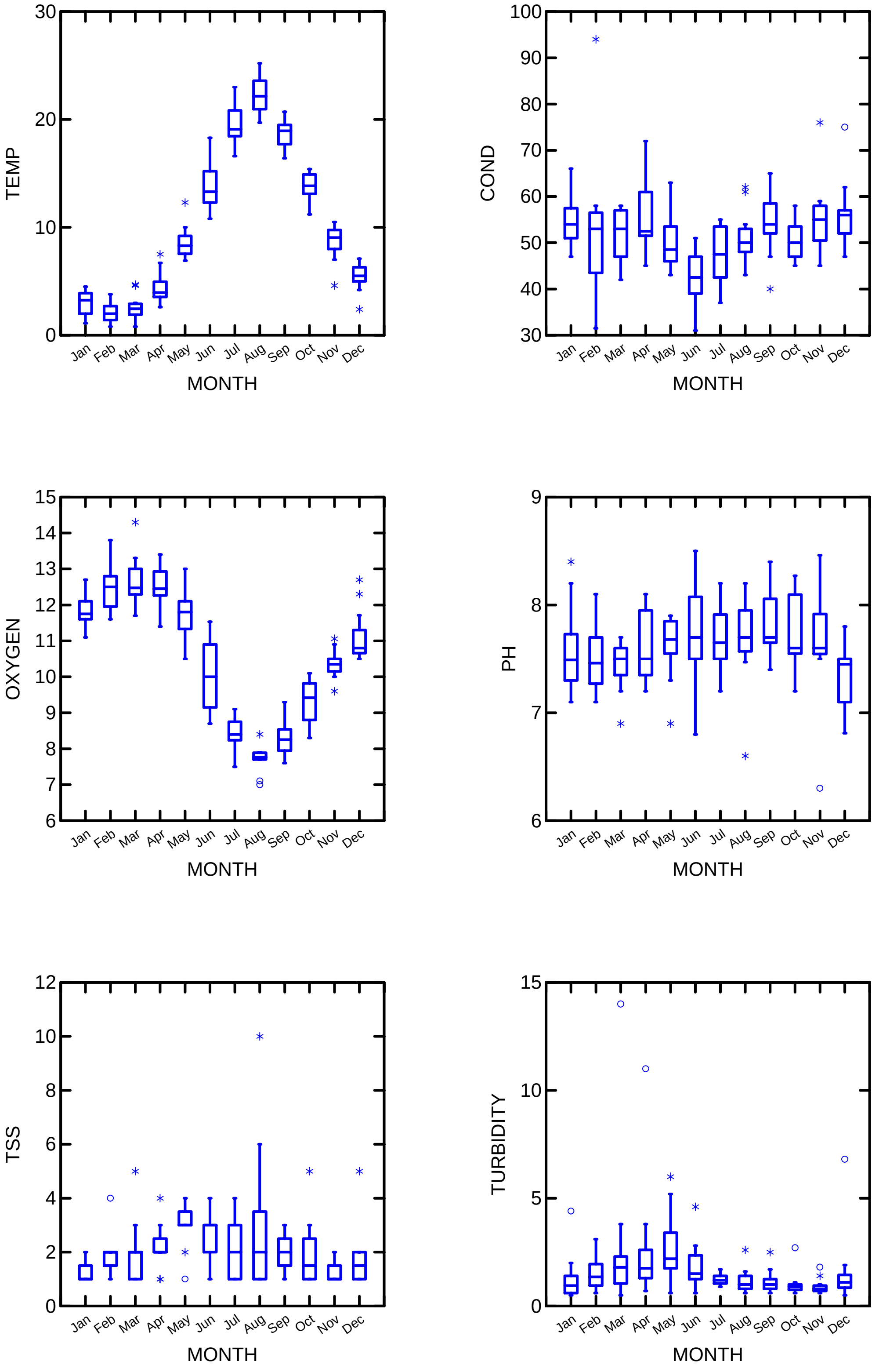

Figure A-11. Box plots showing Ecology ambient monitoring data (1990-2002) for the Spokane River at the Washington/Idaho state line (Station 57A150).

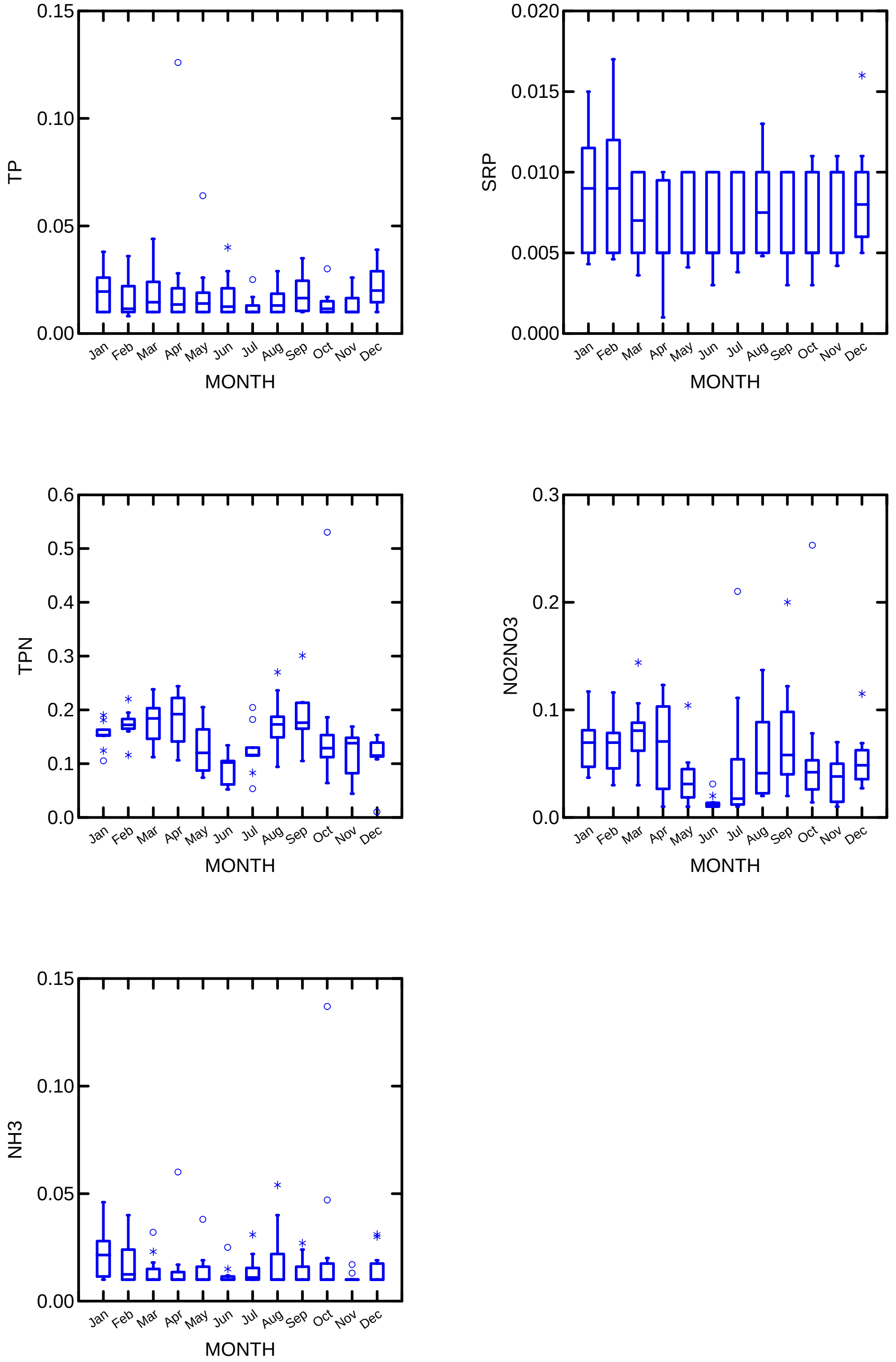

Figure A-12. Box plots showing Ecology ambient monitoring data (1990-2002) for the Spokane River at the Washington/Idaho state line (Station 57A150).

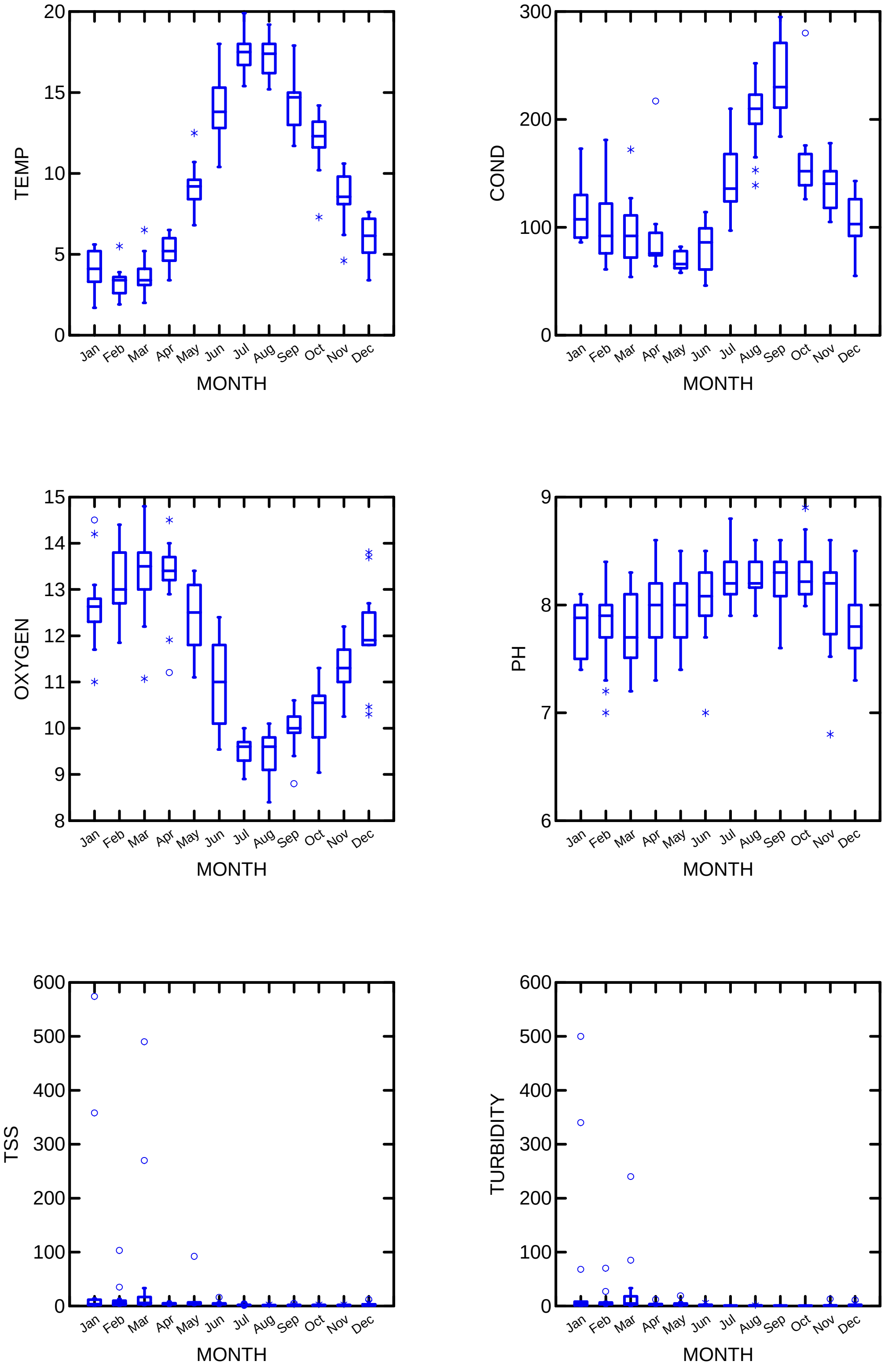

Figure A-13. Box plots showing Ecology ambient monitoring data (1990-2002) for the Spokane River at the footbridge at Riverside State Park (Station 54A120).

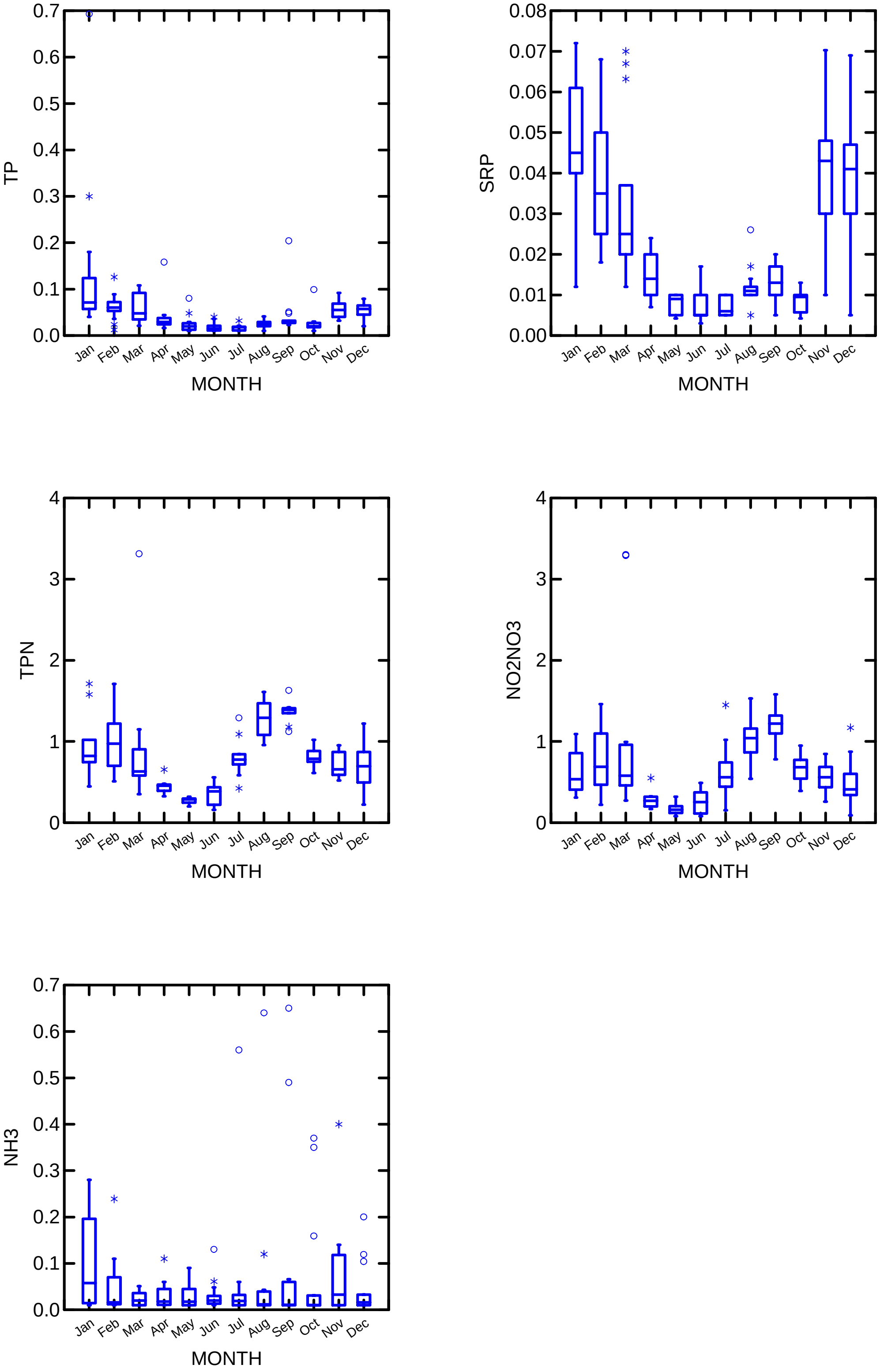

Figure A-14. Box plots showing Ecology ambient monitoring data (1990-2002) for the Spokane River at the footbridge at Riverside State Park (Station 54A120).

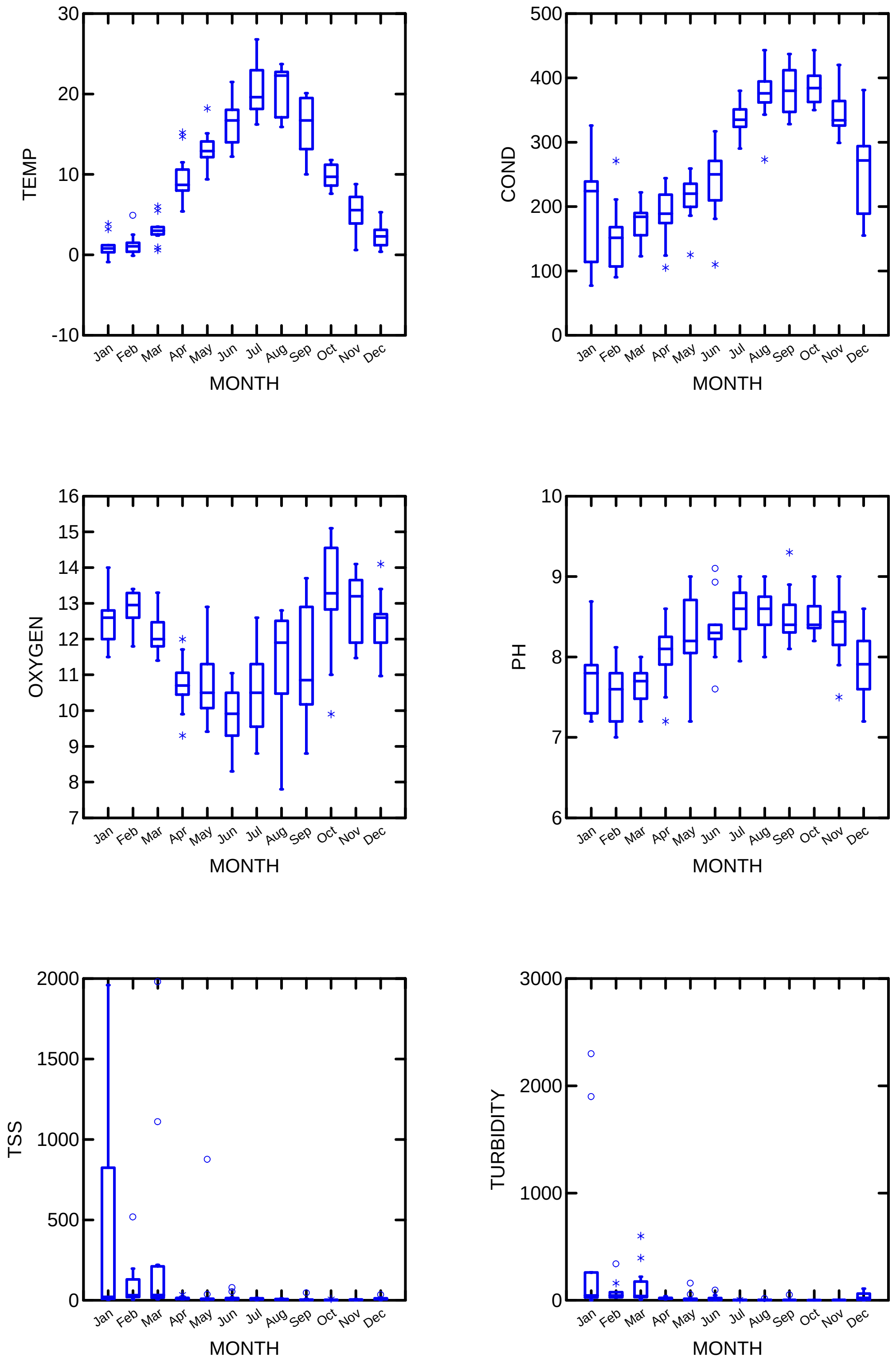

Figure A-15. Box plots showing Ecology ambient monitoring data (1990-2002) for Latah Creek at Government Rd. bridge near the confluence with the Spokane River (Station 56A070).

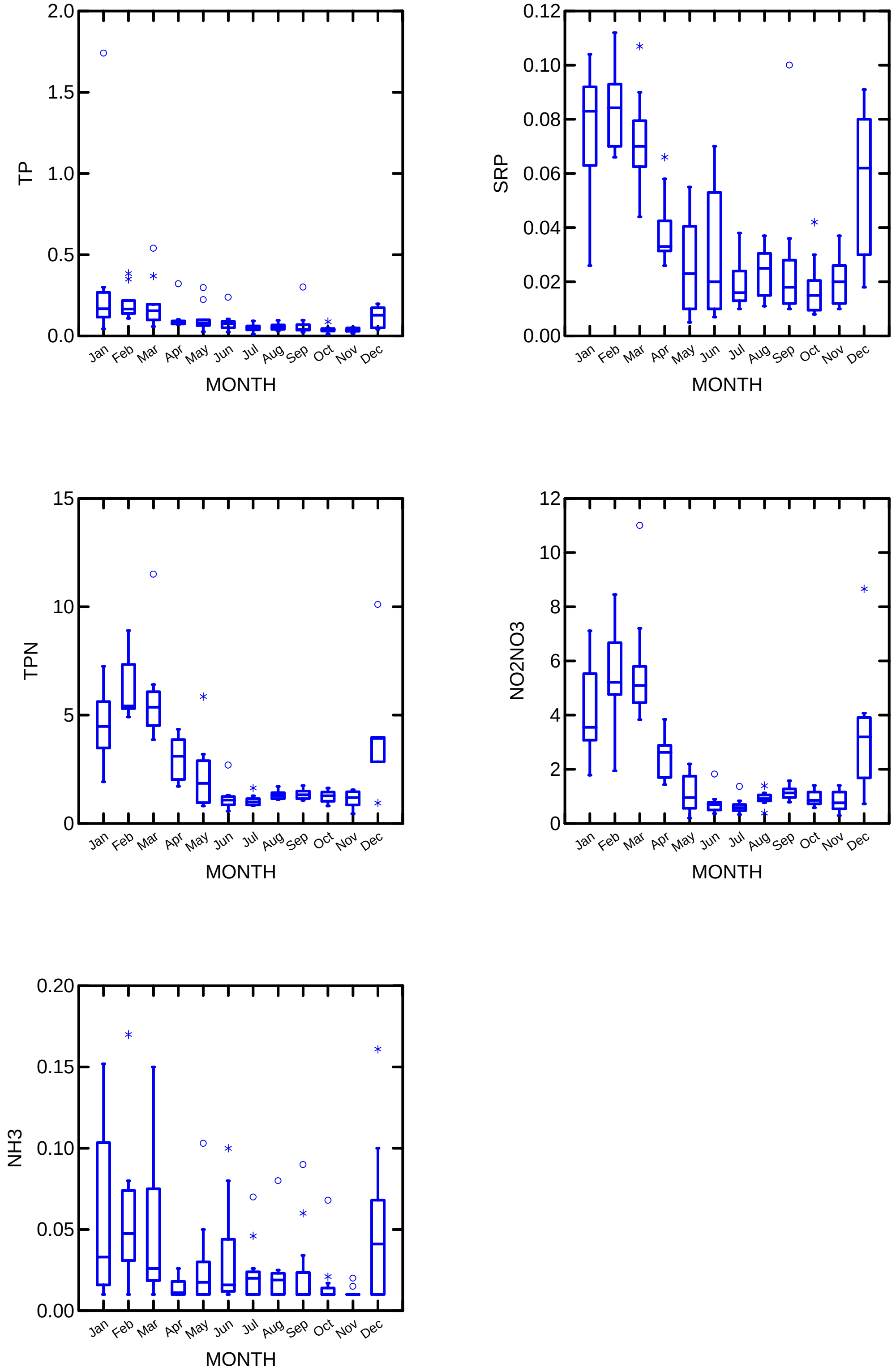

Figure A-16. Box plots showing Ecology ambient monitoring data (1990-2002) for Latah Creek at Government Rd. bridge near the confluence with the Spokane River (Station 56A070).

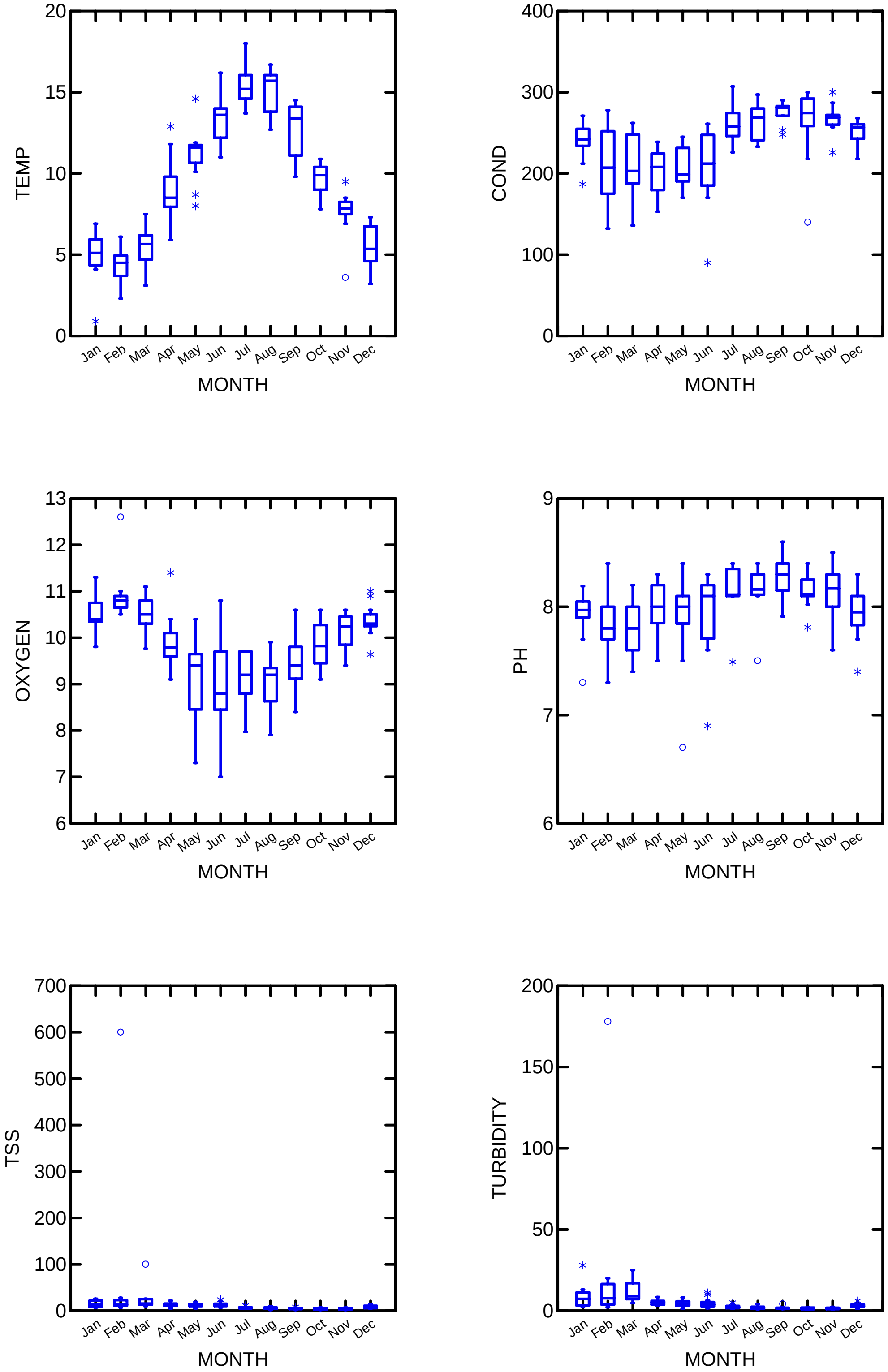

Figure A-17. Box plots showing Ecology ambient monitoring data (1990-2002) for the Little Spokane River at Highway 291 bridge near the confluence with Lake Spokane (Station 55B070).

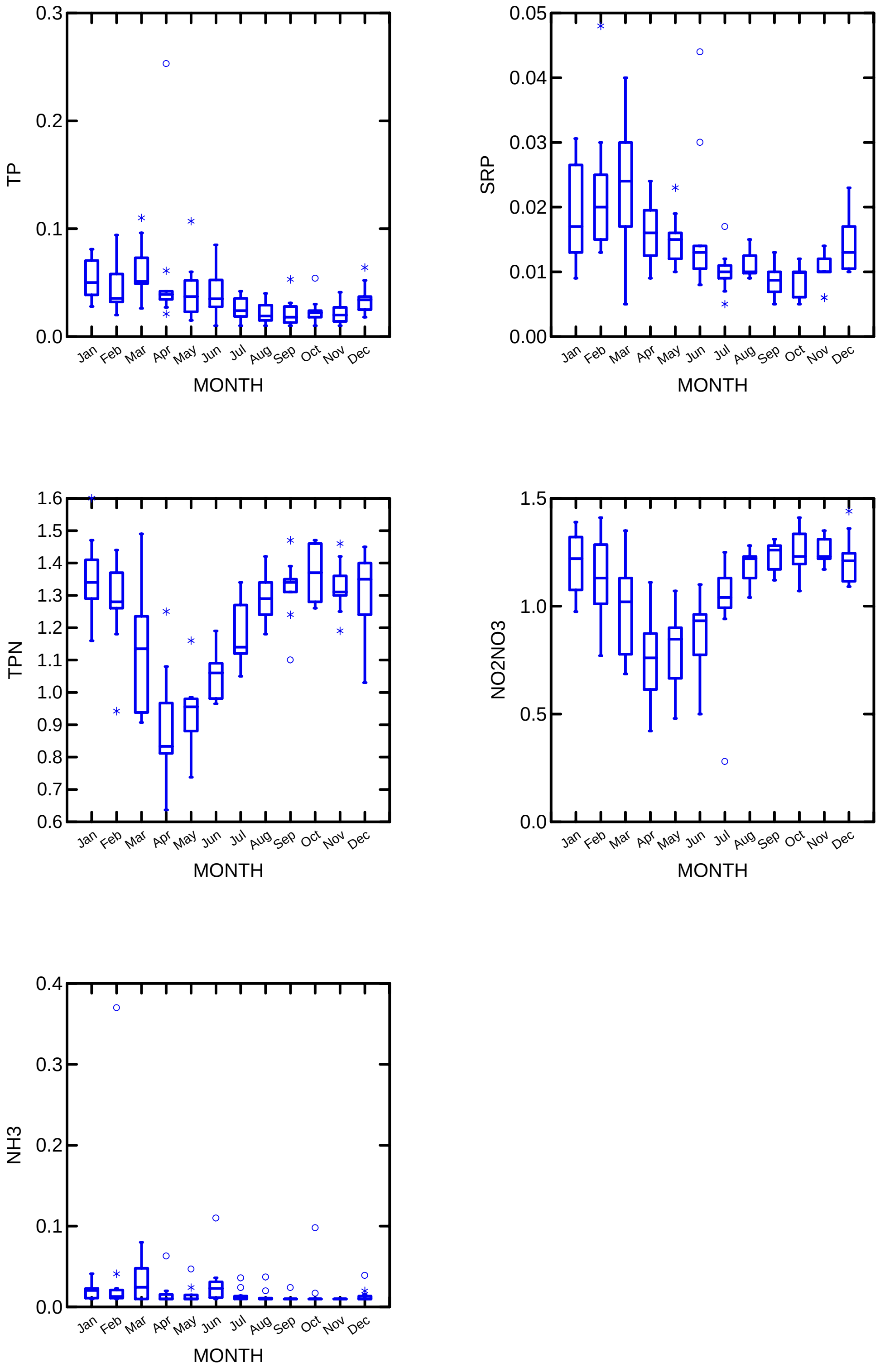

Figure A-18. Box plots showing Ecology ambient monitoring data (1990-2002) for the Little Spokane River at Highway 291 bridge near the confluence with Lake Spokane (Station 55B070).

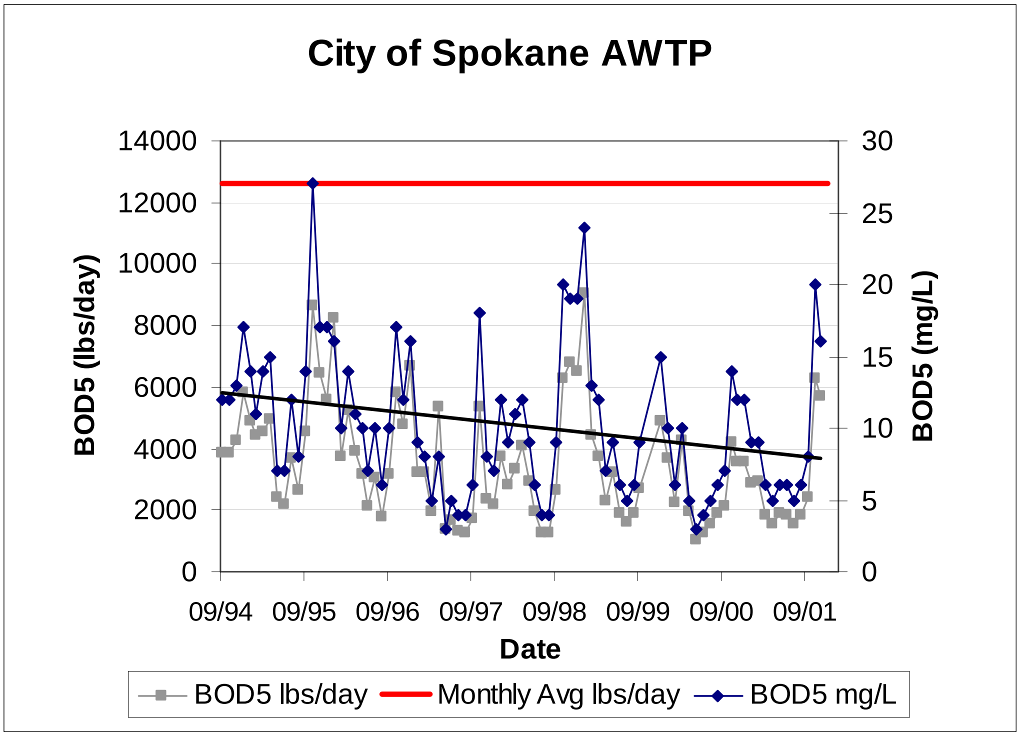

Figure A-19. City of Spokane AWTP BOD5 discharge characteristics for the period 10/94–12/01 including the current monthly average lbs/day permit limit.

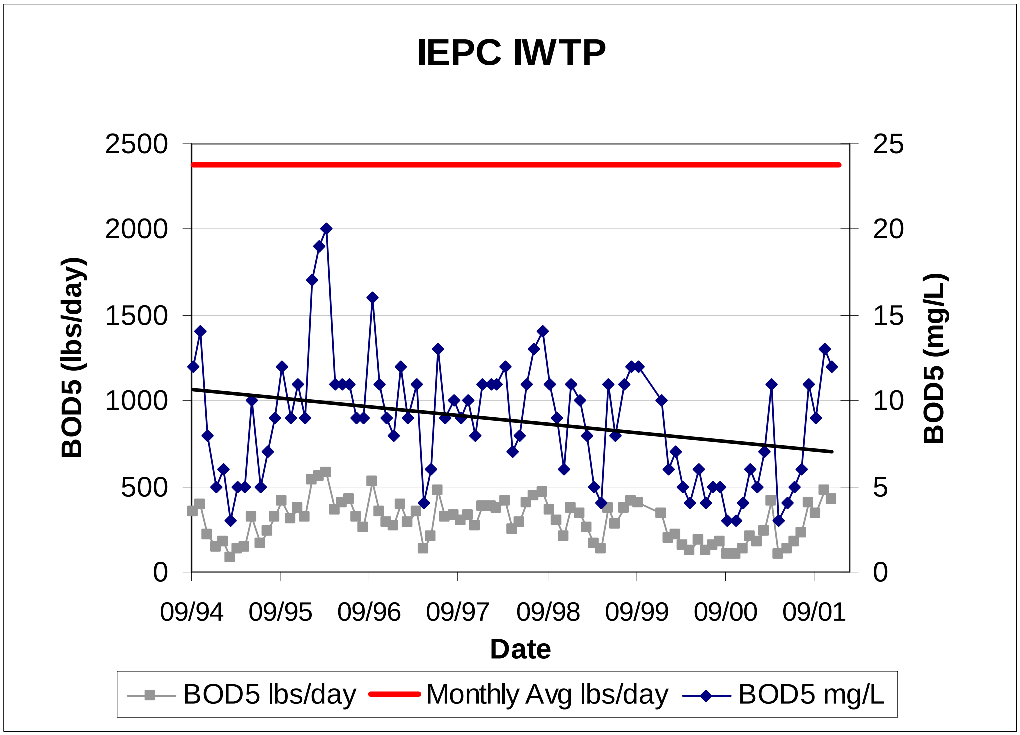

Figure A-20. Inland Empire Paper Company IWTP BOD5 discharge characteristics for the period 10/94–12/01 including the current monthly average lbs/day permit limit.

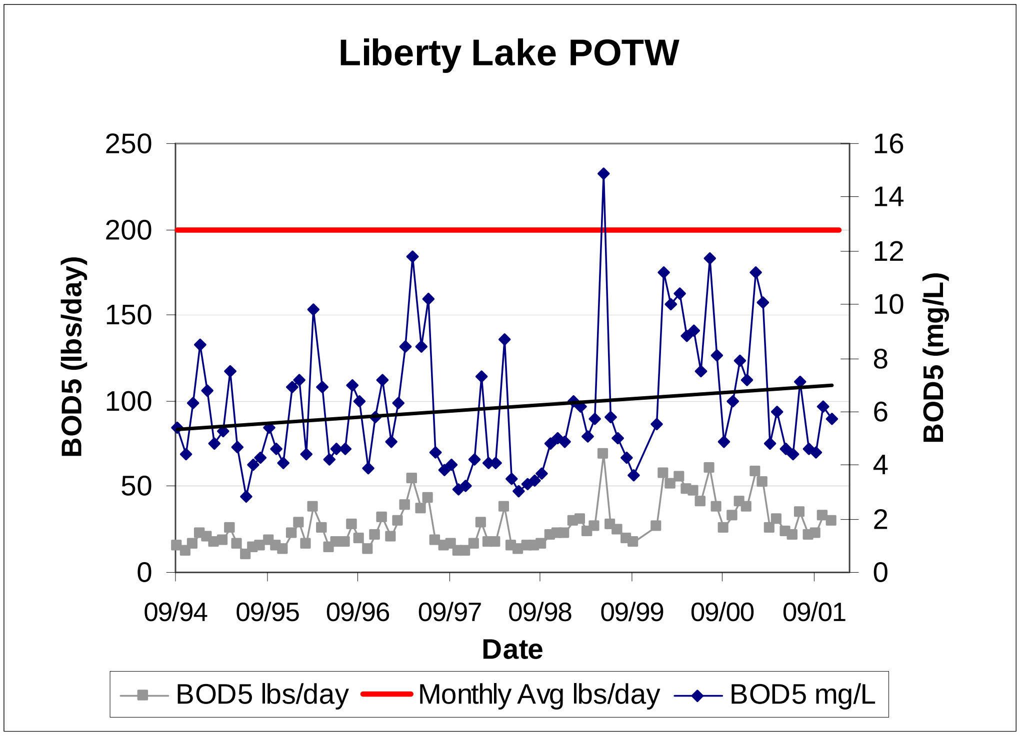

Figure A-21. Liberty Lake POTW BOD5 discharge characteristics for the period 10/94–12/01 including the current monthly average lbs/day permit limit.

Appendix B

CE-QUAL-W2 Model Input Files for Tributaries and Upstream River Boundary
CURRENT and NO-SOURCE Scenarios

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Table B1. Latah and Coulee Creek model input water quality constituents for 2001 CURRENT conditions.

JDAY	TDS	TRACER	COLFRM	COND	CHLORID	ISS	PO4	NH4	NO3	LDOM	RDOM	LPOM	RPOM	1CBOD	2CBOD	3CBOD	4CBOD	5CBOD	6CBOD	1Algae	2Algae	3Algae	DO	TIC	ALK
1.00	0	0	2	326.0	11.13	2.31	0.026	0.005	1.780	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	3.80	0.00	0.546	0.001	0.001	14.0	42.88	179.5
8.60	0	0	2	326.0	11.13	2.31	0.026	0.005	1.780	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	3.80	0.00	0.546	0.001	0.001	14.0	42.88	179.5
43.67	0	0	5	271.0	11.13	3.31	0.066	0.052	6.670	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	3.80	0.00	0.546	0.001	0.001	13.3	44.11	179.5
71.63	0	0	4	214.0	11.13	15.46	0.090	0.080	11.000	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	3.80	0.00	0.546	0.001	0.001	11.9	45.21	179.5
99.66	0	0	8	180.0	11.13	4.62	0.033	0.011	3.110	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	3.80	0.00	0.546	0.001	0.001	11.7	43.74	179.5
134.63	0	0	220	229.0	11.13	7.08	0.055	0.030	0.640	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	3.80	0.00	0.546	0.001	0.001	9.4	42.91	179.5
162.67	0	0	14	292.0	11.13	2.06	0.023	0.012	0.360	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	3.80	0.00	0.546	0.001	0.001	11.1	41.83	179.5
179.00	0	0	47	318.2	11.13	9.19	0.025	0.020	0.500	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	3.80	0.00	0.970	0.001	0.001	11.3	41.55	179.5
190.72	0	0	70	337.0	11.13	14.31	0.026	0.026	0.600	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	3.55	0.00	1.274	0.001	0.001	11.5	41.33	179.5
193.00	0	0	65	342.5	11.13	13.31	0.025	0.024	0.630	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	3.50	0.00	1.211	0.001	0.001	11.6	41.47	179.5
207.00	0	0	33	376.1	11.13	7.16	0.019	0.014	0.790	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	3.20	0.00	0.827	0.001	0.001	12.1	42.17	179.5
218.63	0	0	6	404.0	11.13	2.06	0.014	0.005	0.930	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	2.57	0.00	0.507	0.001	0.001	12.5	42.61	179.5
220.00	0	0	6	405.1	11.13	2.03	0.014	0.005	0.940	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	2.50	0.00	0.499	0.001	0.001	12.6	42.62	179.5
235.00	0	0	7	417.6	11.13	1.67	0.013	0.005	1.040	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	3.40	0.00	0.416	0.001	0.001	13.0	42.71	179.5
241.00	0	0	7	422.5	11.13	1.53	0.013	0.005	1.080	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	2.50	0.00	0.382	0.001	0.001	13.2	42.75	179.5
253.63	0	0	8	433.0	11.13	1.23	0.012	0.005	1.170	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	3.26	0.00	0.312	0.001	0.001	13.6	42.83	179.5
256.00	0	0	8	431.0	11.13	1.23	0.012	0.005	1.150	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	3.40	0.00	0.312	0.001	0.001	13.6	42.87	179.5
270.00	0	0	8	419.0	11.13	1.23	0.010	0.005	1.000	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	3.20	0.00	0.312	0.001	0.001	13.5	43.08	179.5
287.58	0	0	9	404.0	11.13	1.23	0.008	0.005	0.820	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	3.20	0.00	0.312	0.001	0.001	13.4	43.35	179.5
308.60	0	0	33	368.0	11.13	0.23	0.012	0.005	0.570	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	3.20	0.00	0.312	0.001	0.001	13.6	43.09	179.5
336.57	0	0	6	286.0	11.13	1.23	0.018	0.005	0.730	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	3.20	0.00	0.312	0.001	0.001	13.4	44.01	179.5
366.99	0	0	6	286.0	11.13	1.23	0.018	0.005	0.730	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	3.20	0.00	0.312	0.001	0.001	13.4	44.01	179.5

Table B2. Latah and Coulee Creek model input water quality constituents for 2001 NO-SOURCE conditions.

JDAY	TDS	TRACER	COLFRM	COND	CHLORID	ISS	PO4	NH4	NO3	LDOM	RDOM	LPOM	RPOM	1CBOD	2CBOD	3CBOD	4CBOD	5CBOD	6CBOD	1Algae	2Algae	3Algae	DO	TIC	ALK
1.00	0	0	2	326.0	11.13	2.31	0.004	0.011	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	14.0	42.88	179.5
8.60	0	0	2	326.0	11.13	2.31	0.004	0.011	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	14.0	42.88	179.5
43.67	0	0	5	271.0	11.13	3.31	0.004	0.023	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	13.3	44.11	179.5
71.63	0	0	4	214.0	11.13	15.46	0.007	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	11.9	45.21	179.5
99.66	0	0	8	180.0	11.13	4.62	0.005	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	11.7	43.74	179.5
134.63	0	0	220	229.0	11.13	7.08	0.003	0.012	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	9.4	42.91	179.5
162.67	0	0	14	292.0	11.13	2.06	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	11.1	41.83	179.5
179.00	0	0	47	318.2	11.13	9.19	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	11.3	41.55	179.5
190.72	0	0	70	337.0	11.13	14.31	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	11.5	41.33	179.5
193.00	0	0	65	342.5	11.13	13.31	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.200	0.001	0.001	11.6	41.47	179.5
207.00	0	0	33	376.1	11.13	7.16	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.200	0.001	0.001	12.1	42.17	179.5
218.63	0	0	6	404.0	11.13	2.06	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.200	0.001	0.001	12.5	42.61	179.5
220.00	0	0	6	405.1	11.13	2.03	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.200	0.001	0.001	12.6	42.62	179.5
235.00	0	0	7	417.6	11.13	1.67	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.200	0.001	0.001	13.0	42.71	179.5
241.00	0	0	7	422.5	11.13	1.53	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.200	0.001	0.001	13.2	42.75	179.5
253.63	0	0	8	433.0	11.13	1.23	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.200	0.001	0.001	13.6	42.83	179.5
256.00	0	0	8	431.0	11.13	1.23	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.200	0.001	0.001	13.6	42.87	179.5
270.00	0	0	8	419.0	11.13	1.23	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	13.5	43.08	179.5
287.58	0	0	9	404.0	11.13	1.23	0.004	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	13.4	43.35	179.5
308.60	0	0	33	368.0	11.13	0.23	0.004	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	13.6	43.09	179.5
336.57	0	0	6	286.0	11.13	1.23	0.004	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	13.4	44.01	179.5
366.99	0	0	6	286.0	11.13	1.23	0.004	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	13.4	44.01	179.5

Table B3. Little Spokane River model input water quality constituents for 2001 CURRENT conditions.

JDAY	TDS	TRACER	COLFRM	COND	CHLORID	ISS	PO4	NH4	NO3	LDOM	RDOM	LPOM	RPOM	1CBOD	2CBOD	3CBOD	4CBOD	5CBOD	6CBOD	1Algae	2Algae	3Algae	DO	TIC	ALK
1.00	174	0	38	268.0	4.06	9.88	0.013	0.005	1.390	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	2.50	0.00	0.897	0.001	0.001	10.3	32.20	132.0
9.32	174	0	38	268.0	4.06	9.88	0.013	0.005	1.390	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	2.50	0.00	0.897	0.001	0.001	10.3	32.20	132.0
44.30	174	0	55	276.0	4.06	12.88	0.014	0.012	1.410	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	2.50	0.00	0.897	0.001	0.001	10.7	32.21	132.0
72.31	174	0	20	262.0	4.06	14.88	0.018	0.073	1.350	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	2.50	0.00	0.897	0.001	0.001	9.8	32.14	132.0
100.32	174	0	32	239.0	4.06	13.88	0.017	0.063	1.110	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	2.50	0.00	0.897	0.001	0.001	9.8	32.11	132.0
135.32	174	0	180	245.0	4.06	17.88	0.015	0.015	1.070	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	2.50	0.00	0.897	0.001	0.001	8.4	31.87	132.0
163.30	174	0	110	261.0	4.06	8.88	0.008	0.005	1.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	2.50	0.00	0.897	0.001	0.001	8.6	31.90	132.0
179.00	174	0	98	286.8	4.06	6.96	0.009	0.005	1.150	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	2.50	0.00	0.569	0.001	0.001	8.4	32.04	132.0
191.33	174	0	88	307.0	4.06	5.46	0.010	0.005	1.190	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.27	0.00	0.312	0.001	0.001	8.2	32.17	132.0
193.00	174	0	88	306.0	4.06	5.52	0.010	0.005	1.200	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.10	0.00	0.307	0.001	0.001	8.2	32.16	132.0
207.00	174	0	90	298.0	4.06	6.06	0.011	0.005	1.240	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.50	0.00	0.268	0.001	0.001	8.2	32.12	132.0
219.29	174	0	92	291.0	4.06	6.54	0.011	0.005	1.280	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.93	0.00	0.234	0.001	0.001	8.2	32.09	132.0
220.00	174	0	91	293.1	4.06	6.43	0.011	0.007	1.280	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.90	0.00	0.212	0.001	0.001	8.2	32.08	132.0
221.00	174	0	90	296.0	4.06	6.27	0.011	0.010	1.280	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.00	0.00	0.182	0.001	0.001	8.2	32.06	132.0
235.00	182	0	74	294.7	4.06	4.06	0.010	0.010	1.290	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	2.40	0.00	0.199	0.001	0.001	8.5	31.88	132.0
241.00	185	0	67	294.1	4.06	3.11	0.010	0.010	1.290	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.20	0.00	0.207	0.001	0.001	8.6	31.80	132.0
242.00	186	0	66	294.0	4.06	2.95	0.010	0.010	1.290	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.25	0.00	0.208	0.001	0.001	8.6	31.79	132.0
254.32	186	0	52	285.0	4.06	1.00	0.008	0.005	1.310	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.82	0.00	0.221	0.001	0.001	8.8	31.65	132.0
256.00	186	0	50	285.5	4.06	0.95	0.008	0.005	1.310	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.90	0.00	0.221	0.001	0.001	8.9	31.67	132.0
270.00	186	0	34	289.2	4.06	0.53	0.008	0.005	1.320	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.70	0.00	0.221	0.001	0.001	9.5	31.89	132.0
287.65	186	0	14	294.0	4.06	0.10	0.007	0.005	1.340	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.70	0.00	0.221	0.001	0.001	10.3	32.20	132.0
308.63	186	0	13	287.0	4.06	0.10	0.011	0.005	1.310	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.70	0.00	0.221	0.001	0.001	10.2	32.21	132.0
336.60	186	0	44	253.0	4.06	3.00	0.018	0.011	1.240	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.70	0.00	0.221	0.001	0.001	10.6	33.00	132.0
365.99	186	0	44	253.0	4.06	3.00	0.018	0.011	1.240	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.70	0.00	0.221	0.001	0.001	10.6	33.00	132.0

Table B4. Little Spokane River model input water quality constituents for 2001 NO-SOURCE conditions.

JDAY	TDS	TRACER	COLFRM	COND	CHLORID	ISS	PO4	NH4	NO3	LDOM	RDOM	LPOM	RPOM	1CBOD	2CBOD	3CBOD	4CBOD	5CBOD	6CBOD	1Algae	2Algae	3Algae	DO	TIC	ALK
1.00	174	0	38	268.0	4.06	9.88	0.004	0.011	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	10.3	32.20	132.0
9.32	174	0	38	268.0	4.06	9.88	0.004	0.011	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	10.3	32.20	132.0
44.30	174	0	55	276.0	4.06	12.88	0.004	0.023	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	10.7	32.21	132.0
72.31	174	0	20	262.0	4.06	14.88	0.007	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	9.8	32.14	132.0
100.32	174	0	32	239.0	4.06	13.88	0.005	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	9.8	32.11	132.0
135.32	174	0	180	245.0	4.06	17.88	0.023	0.012	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	8.4	31.87	132.0
163.30	174	0	110	261.0	4.06	8.88	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	8.6	31.90	132.0
179.00	174	0	98	286.8	4.06	6.96	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	8.4	32.04	132.0
191.33	174	0	88	307.0	4.06	5.46	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.27	0.00	0.120	0.001	0.001	8.2	32.17	132.0
193.00	174	0	88	306.0	4.06	5.52	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.10	0.00	0.120	0.001	0.001	8.2	32.16	132.0
207.00	174	0	90	298.0	4.06	6.06	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.50	0.00	0.200	0.001	0.001	8.2	32.12	132.0
219.29	174	0	92	291.0	4.06	6.54	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.93	0.00	0.200	0.001	0.001	8.2	32.09	132.0
220.00	174	0	91	293.1	4.06	6.43	0.003	0.007	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.90	0.00	0.200	0.001	0.001	8.2	32.08	132.0
221.00	174	0	90	296.0	4.06	6.27	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.00	0.00	0.200	0.001	0.001	8.2	32.06	132.0
235.00	182	0	74	294.7	4.06	4.06	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.200	0.001	0.001	8.5	31.88	132.0
241.00	185	0	67	294.1	4.06	3.11	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.20	0.00	0.200	0.001	0.001	8.6	31.80	132.0
242.00	186	0	66	294.0	4.06	2.95	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.25	0.00	0.200	0.001	0.001	8.6	31.79	132.0
254.32	186	0	52	285.0	4.06	1.00	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.200	0.001	0.001	8.8	31.65	132.0
256.00	186	0	50	285.5	4.06	0.95	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.200	0.001	0.001	8.9	31.67	132.0
270.00	186	0	34	289.2	4.06	0.53	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	9.5	31.89	132.0
287.65	186	0	14	294.0	4.06	0.10	0.004	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	10.3	32.20	132.0
308.63	186	0	13	287.0	4.06	0.10	0.004	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	10.2	32.21	132.0
336.60	186	0	44	253.0	4.06	3.00	0.004	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	10.6	33.00	132.0
365.99	186	0	44	253.0	4.06	3.00	0.004	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	1.40	0.00	0.120	0.001	0.001	10.6	33.00	132.0

Table B5. Spokane River upstream boundary at Stateline model input water quality constituents for 2001 CURRENT conditions.

JDAY	TDS	TRACER	COLFRM	COND	CHLORID	ISS	PO4	NH4	NO3	LDOM	RDOM	LPOM	RPOM	1CBOD	2CBOD	3CBOD	4CBOD	5CBOD	6CBOD	1Algae	2Algae	3Algae	DO	TIC	ALK
1.00	0	0	4	52.0	0.86	0.23	0.015	0.010	0.120	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	1.80	0.481	0.001	0.001	12.1	5.30	19.8
9.41	0	0	4	52.0	0.86	0.23	0.015	0.010	0.120	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	1.80	0.481	0.001	0.001	12.1	5.30	19.8
44.40	0	0	8	55.0	0.86	0.10	0.017	0.018	0.120	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	1.80	0.481	0.001	0.001	12.7	5.40	19.8
72.39	0	0	2	52.0	0.86	1.17	0.010	0.011	0.090	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	1.80	0.481	0.001	0.001	12.4	5.25	19.8
100.40	0	0	1	51.0	0.86	1.15	0.003	0.005	0.050	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	1.80	0.481	0.001	0.001	12.3	5.32	19.8
135.40	0	0	3	54.0	0.86	3.11	0.003	0.005	0.030	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	1.80	0.481	0.001	0.001	11.4	5.06	19.8
163.40	0	0	3	51.0	0.86	1.09	0.003	0.005	0.030	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	1.80	0.481	0.001	0.001	9.2	4.92	19.8
179.00	0	0	11	53.2	0.86	1.17	0.003	0.009	0.040	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	1.80	0.387	0.001	0.001	8.8	4.88	19.8
191.44	0	0	17	55.0	0.86	1.23	0.003	0.013	0.050	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	2.07	0.312	0.001	0.001	8.4	4.86	19.8
193.00	0	0	28	55.4	0.86	1.69	0.003	0.013	0.060	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	2.10	0.315	0.001	0.001	8.4	4.85	19.8
207.00	0	0	130	58.9	0.86	5.86	0.006	0.011	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	1.60	0.341	0.001	0.001	8.1	4.81	19.8
219.38	0	0	220	62.0	0.86	9.54	0.008	0.010	0.130	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	1.60	0.364	0.001	0.001	7.9	4.77	19.8
220.00	0	0	218	62.1	0.86	9.40	0.008	0.010	0.130	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	1.60	0.368	0.001	0.001	7.9	4.77	19.8
235.00	0	0	171	63.3	0.86	6.14	0.006	0.008	0.120	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	3.10	0.468	0.001	0.001	8.1	4.79	19.8
241.00	0	0	152	63.9	0.86	4.84	0.005	0.007	0.120	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	2.40	0.508	0.001	0.001	8.3	4.79	19.8
254.41	0	0	110	65.0	0.86	1.92	0.003	0.005	0.120	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	2.89	0.598	0.001	0.001	8.5	4.81	19.8
256.00	0	0	105	64.7	0.86	1.81	0.003	0.005	0.110	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	2.95	0.598	0.001	0.001	8.6	4.81	19.8
270.00	0	0	62	61.8	0.86	0.79	0.003	0.005	0.100	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	2.20	0.598	0.001	0.001	9.1	4.82	19.8
288.67	0	0	3	58.0	0.86	0.10	0.003	0.005	0.080	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	2.20	0.598	0.001	0.001	9.9	4.83	19.8
309.63	0	0	4	59.0	0.86	0.10	0.004	0.005	0.070	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	2.20	0.598	0.001	0.001	10.5	4.90	19.8
337.65	0	0	5	56.0	0.86	0.10	0.006	0.016	0.070	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	2.20	0.598	0.001	0.001	10.8	5.50	19.8
366.99	0	0	5	56.0	0.86	0.10	0.006	0.016	0.070	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	2.20	0.598	0.001	0.001	10.8	5.50	19.8

Table B6. Spokane River upstream boundary at Stateline model input water quality constituents for 2001 NO-SOURCE conditions. Input values were every 0.10 days, i.e., continuous from JDAY 1 through JDAY 304. (Values from time series provided below to compare to CURRENT scenario input file.)

JDAY	TDS	TRACER	COLFRM	COND	CHLORID	ISS	PO4	NH4	NOx	LDOM	RDOM	LPOM	RPOM	1CBOD	2CBOD	3CBOD	4CBOD	5CBOD	6CBOD	1Algae	2Algae	3Algae	DO	TIC	ALK
1.00	48	0	0	50.6	0.00	0.08	0.002	0.001	0.000	0.321	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	1.06	0.101	0.001	0.001	12.3	5.09	20.4
10.00	48	0	0	50.6	0.00	0.08	0.002	0.001	0.000	0.321	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	1.06	0.101	0.001	0.001	12.3	5.09	20.4
44.40	48	0	0	50.1	0.00	0.09	0.004	0.016	0.007	0.066	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	1.10	0.107	0.001	0.001	11.6	5.13	20.3
72.40	47	0	0	49.9	0.00	0.09	0.003	0.008	0.001	0.088	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	1.12	0.109	0.001	0.001	11.1	5.06	20.2
100.40	47	0	0	49.4	0.00	0.09	0.004	0.011	0.004	0.072	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	1.16	0.115	0.001	0.001	10.3	5.01	20.1
135.40	47	0	0	49.1	0.00	0.09	0.004	0.010	0.005	0.056	0.000	0.004	0.000	0.00	0.00	0.00	0.00	0.00	1.17	0.128	0.001	0.001	9.5	4.99	20.0
163.40	47	0	0	49.5	0.00	0.09	0.003	0.005	0.000	0.115	0.000	0.007	0.000	0.00	0.00	0.00	0.00	0.00	1.15	0.137	0.001	0.001	9.3	4.97	20.1
179.00	47	0	0	49.7	0.00	0.10	0.004	0.027	0.002	0.171	0.000	0.012	0.000	0.00	0.00	0.00	0.00	0.00	1.11	0.169	0.001	0.001	8.7	5.07	20.2
191.40	48	0	0	50.1	0.00	0.10	0.003	0.003	0.000	0.248	0.000	0.019	0.000	0.00	0.00	0.00	0.00	0.00	1.06	0.159	0.001	0.001	8.5	4.99	20.3
193.00	48	0	0	50.2	0.00	0.10	0.004	0.024	0.003	0.250	0.000	0.020	0.000	0.00	0.00	0.00	0.00	0.00	1.06	0.170	0.001	0.001	8.2	5.07	20.3
207.00	48	0	0	50.8	0.00	0.10	0.004	0.023	0.005	0.316	0.000	0.030	0.000	0.00	0.00	0.00	0.00	0.00	1.00	0.191	0.001	0.001	8.2	5.10	20.5
220.00	48	0	0	50.9	0.00	0.10	0.004	0.023	0.006	0.318	0.001	0.033	0.000	0.00	0.00	0.00	0.00	0.00	0.98	0.197	0.001	0.001	8.1	5.11	20.5
235.00	42	0	0	56.2	0.00	0.10	0.004	0.025	0.008	0.397	0.001	0.045	0.000	0.00	0.00	0.00	0.00	0.00	1.06	0.204	0.001	0.001	8.4	5.51	22.1
241.00	42	0	0	57.2	0.00	0.10	0.004	0.025	0.008	0.408	0.001	0.047	0.000	0.00	0.00	0.00	0.00	0.00	1.13	0.207	0.001	0.001	8.4	5.59	22.5
254.40	75	0	0	51.6	0.00	0.10	0.002	0.008	0.001	0.299	0.000	0.025	0.000	0.00	0.00	0.00	0.00	0.00	1.33	0.153	0.001	0.001	9.1	5.28	21.5
256.00	74	0	0	50.9	0.00	0.10	0.003	0.023	0.004	0.200	0.000	0.016	0.000	0.00	0.00	0.00	0.00	0.00	1.42	0.139	0.001	0.001	8.8	5.32	21.3
270.00	74	0	0	50.8	0.00	0.10	0.003	0.024	0.004	0.191	0.000	0.016	0.000	0.00	0.00	0.00	0.00	0.00	1.42	0.143	0.001	0.001	9.2	5.32	21.3
288.70	74	0	0	50.4	0.00	0.10	0.002	0.003	0.000	0.118	0.000	0.010	0.000	0.00	0.00	0.00	0.00	0.00	1.49	0.131	0.001	0.001	9.6	5.24	21.2
300.00	74	0	0	50.3	0.00	0.10	0.003	0.022	0.007	0.084	0.000	0.009	0.000	0.00	0.00	0.00	0.00	0.00	1.51	0.128	0.001	0.001	9.8	5.32	21.2

Appendix C

Model Predicted Dissolved Oxygen Profiles for Lake Spokane

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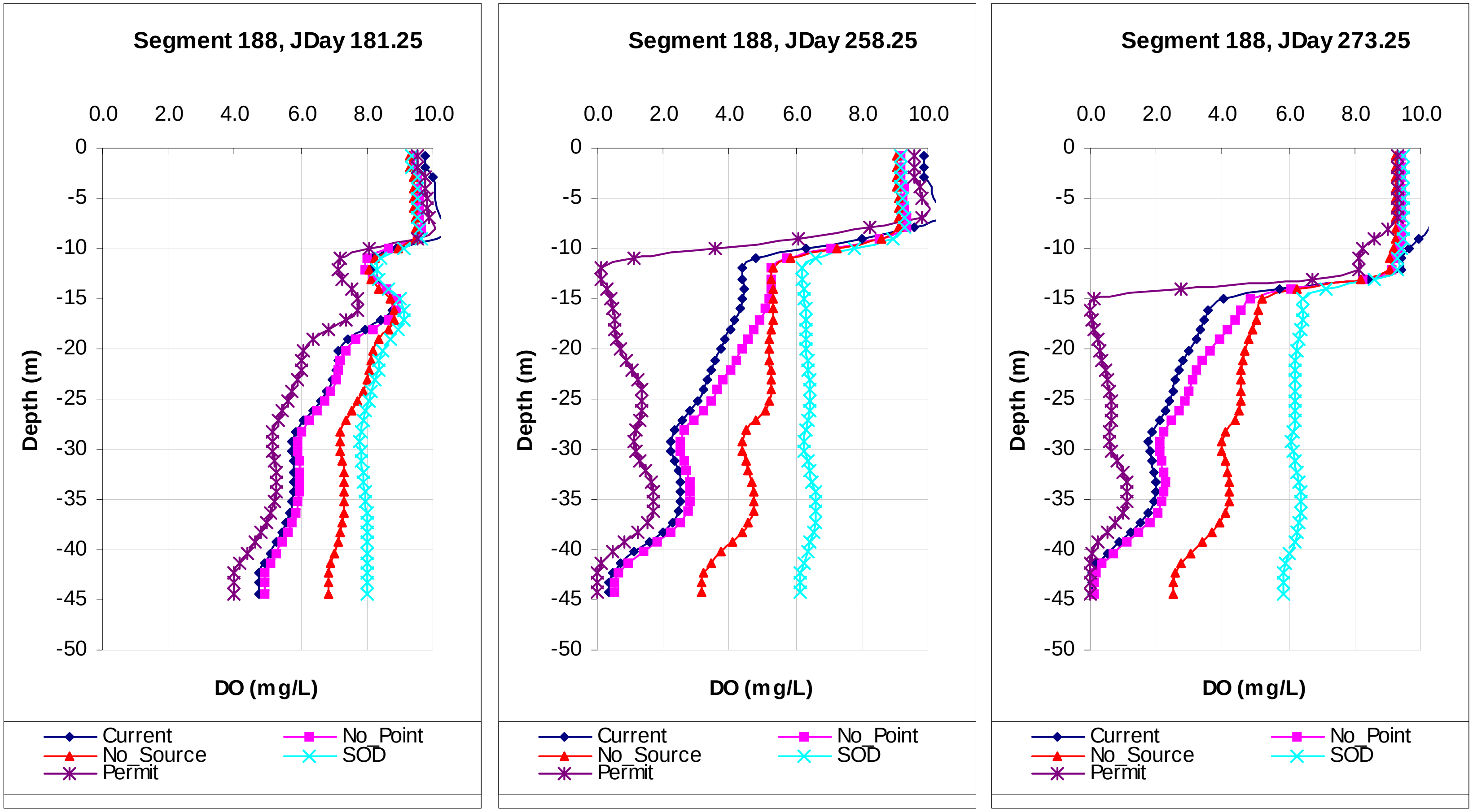

Figure C1. Model predicted dissolved oxygen profiles for Lake Spokane at model segments 188 for the CURRENT, NO-POINT, NO-SOURCE, PERMIT, and SOD scenarios on Julian days 181.25 (Jun 15), 258.25 (Sep 15), 273.25 (Oct 1).

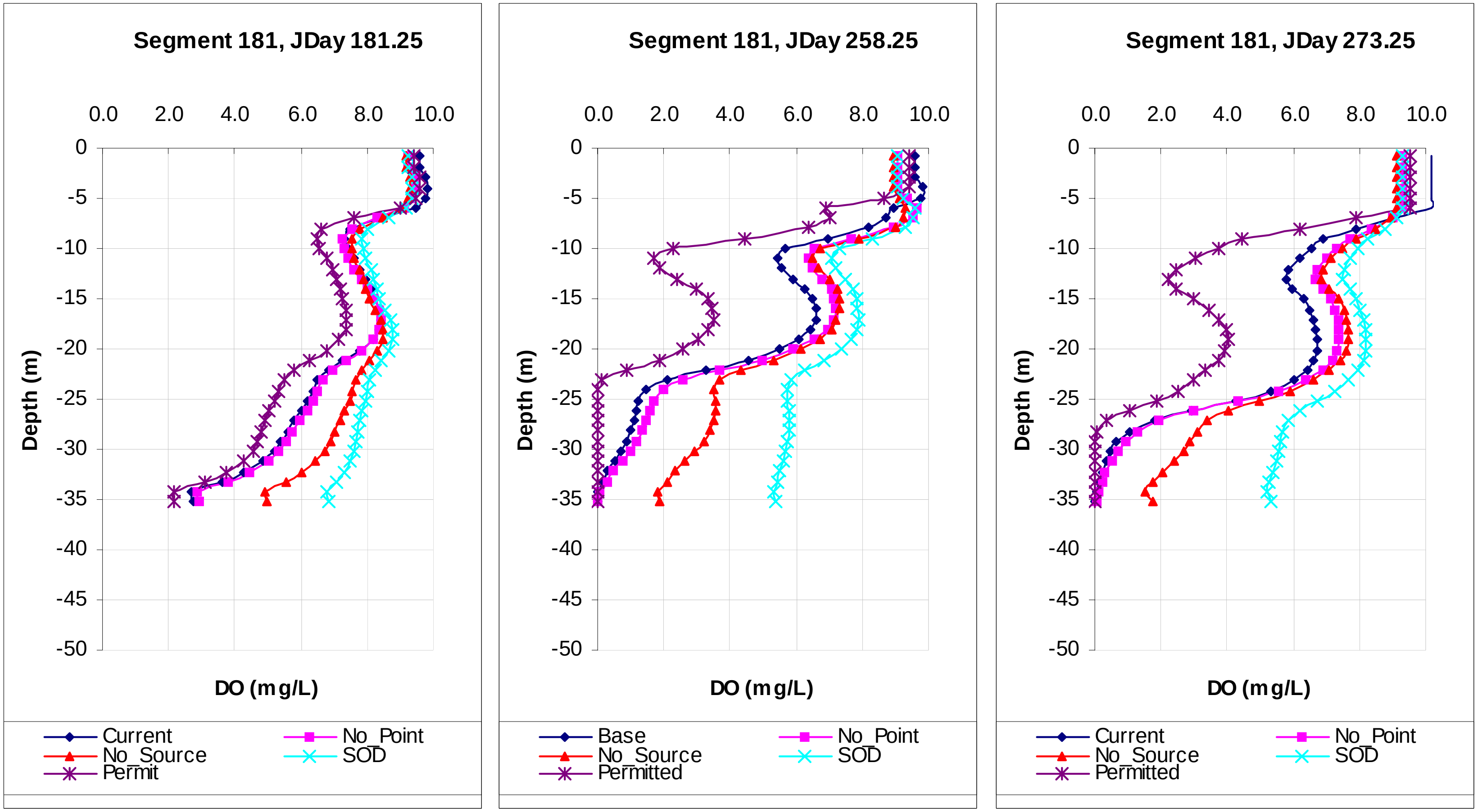

Figure C2. Model predicted dissolved oxygen profiles for Lake Spokane at model segments 181 for the CURRENT, NO-POINT, NO-SOURCE, PERMIT, and SOD scenarios on Julian days 181.25 (Jun 15), 258.25 (Sep 15), 273.25 (Oct 1).

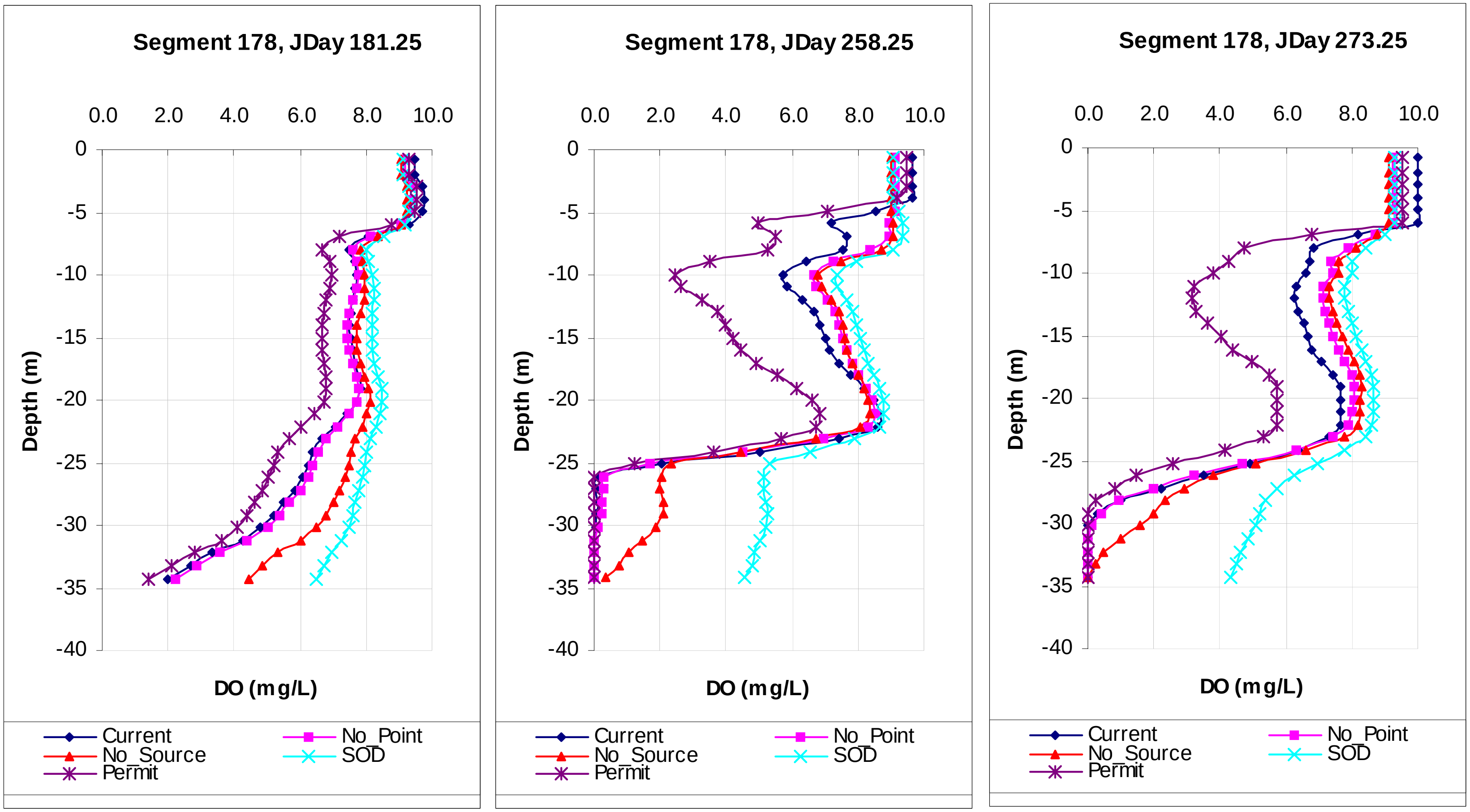

Figure C3. Model predicted dissolved oxygen profiles for Lake Spokane at model segments 178 for the CURRENT, NO-POINT, NO-SOURCE, PERMIT, and SOD scenarios on Julian days 181.25 (Jun 15), 258.25 (Sep 15), 273.25 (Oct 1).