Draft

Water Quality Interim Report: 1st Year Study Results for Energy Northwest's Packwood Lake Hydroelectric Project FERC No. 2244 Lewis County, Washington

Submitted to

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1.0 INTRODUCTION

Energy Northwest, a municipal corporation and joint operating agency of the State of Washington, operates the Packwood Lake Hydroelectric Project (Project) near the town of Packwood in Lewis County, Washington. The Federal Energy Regulatory Commission (FERC) licensed the Project on July 7, 1960 (effective March 1, 1960), designated as Federal Power Commission License No. 2244. In accordance with the Integrated Licensing Process (ILP) regulations, Energy Northwest filed its Notice of Intent (NOI) to file an application for a new license on November 12, 2004. Energy Northwest also concurrently filed with the FERC and the resource agencies, a Pre-Application Document (PAD), containing existing, relevant, and reasonably available information describing the existing environment and the potential effects of the licensee's intended project proposal, including proposed project facilities and operations.

Energy Northwest has taken a proactive approach to relicensing its Project by initiating collaborative scoping of studies to develop the data and analyses that will be required for issuance of the water quality certification by the Washington Department of Ecology (WDOE) under Section 401 of the Clean Water Act. This collaborative process was initiated in March 2004 in advance of the filing of the PAD. A water quality study plan was developed in consultation with the agencies and tribes, and studies were initiated in spring 2004. The WDOE and the USDA Forest Service (USFS) filed study requests with FERC that identify water quality issues and related study needs (WDOE 2005, USDA Forest Service 2005). As a result of the agency study requests filed with FERC, the Water Quality Study Plan was modified to address WDOE and USFS comments.

This report documents results from the first year of the water quality study. The monitoring period encompassed in this report extends from study initiation in April 2004 through March 2005. Water quality monitoring will continue through March 2006. Draft and final reports that address the entire monitoring period (April 2004 through March 2006) will be prepared and distributed in fall 2006. The data collected during this study will also provide a basis for calibration of a water quality model, which will be used to evaluate project effects on water quality.

The Packwood Hydroelectric Project is located east of the community of Packwood in the Cascade Mountains. Packwood Lake lies within the Gifford Pinchot National Forest. The Project includes: an intake canal; a concrete drop structure and an intake building on Lake Creek located about 424 feet downstream from the outlet to Packwood Lake; a 21,691-foot system of concrete pipe and tunnels; a 5,621 foot-long penstock; a surge tank; a powerhouse with a 26,126 kW turbine generator; and a 6,690 foot-long lined tailrace channel. The drop structure that regulates the water level of Packwood Lake was constructed by excavating debris from a natural landslide, which occurred about 1,000 years ago and created the lake. The drop structure located adjacent to the intake structure extends 85 feet in width and is tied into impervious earth fill cutoff walls on each side extending to the natural embankment. The powerhouse is located at the base of the mountain adjacent to the community of Packwood. The powerhouse discharges into a constructed stilling basin and then travels through a lined tailrace channel about 6,690 feet to the confluence with the Cowlitz River. The tailrace includes a 200-foot highway culvert and 360-foot flume over Hall Creek.

The total area drained by Lake Creek and Packwood Lake is approximately 19.2 square miles at the drop structure. The total surface area of the lake is 452 acres. The natural lake elevation (El.) is 2,857 ft MSL, which is approximately 1,800 ft above the powerhouse. Figure 1-1 shows the lake's bathymetry. The Project seasonally regulates the lake level so that it is at El 2,857 ft ±0.5 ft in summer recreation months and drawn down to no lower than El 2,849 ft MSL during winter months. This provides 8 feet of vertical storage usable by the Project. The Project is operated to achieve a lake elevation of 2,857 ft $\pm$ 0.5 ft by May 1st of each year. This level is maintained until mid-September when draw down may begin. When lake level rises above the drop structure crest elevation (El. 2858.5 ft), the flow passes over the drop structure into Lake Creek downstream of the lake. Currently, the FERC license for the Project requires a minimum instream flow of 3 cfs at the drop structure immediately downstream of the outlet of Packwood Lake. There is also an instream flow requirement of 15 cfs at the confluence of Lake Creek with the Cowlitz River. Energy Northwest is not currently required to measure streamflow in Lake Creek at its confluence with the Cowlitz River. The Project is operated in a baseload manner depending upon water availability and power contracts. The Project has a water right for 260 cfs, but the Project does not operate at capacity at all times. Average power production is 10 MW relative to a turbine generator rated at 27,500 kVA (26.5 MW). During the summer months, Project generation flow matches lake inflow to hold the lake elevation relatively constant. During dry periods with low inflows, the Project may be shut down. Instream flow releases to Lake Creek continue regardless of Project operation.

1.1 Study Goal and Objectives

The goal of this study is to develop information to support the water quality certification issued by the WDOE, pursuant to Section 401 of the Clean Water Act, for the operation of the Project under a new FERC license. This study documents the existing water quality conditions in Packwood Lake, Lake Creek and other waters affected by the Project. This study is also investigating the effects of Project operation on water quality. Those parameters for which the WDOE has established numeric or narrative water quality standards (Chapter 173-201A WAC) are addressed in this study plan. The determination of compliance with some water quality standards requires an understanding of the natural conditions (as defined in Chapter 173-201 WAC) that would occur without the Project. Information on water quality within Project waters prior to the existence of the Packwood Lake Hydroelectric Project is very limited. Water quality modeling will be completed to better understand water quality conditions in absence of the Project.

The objectives for the water quality study are:

1. Document existing water quality conditions within the Project area, lake tributary inflows, and in the Cowlitz River (Lake Creek confluence to just below Project tailrace).

2. Document Project effects on existing water quality conditions with reference to WDOE water quality standards.

3. Model temperature, dissolved oxygen, pH, and nutrients for Packwood Lake, Lake Creek and the tailrace to characterize water quality for these waters in absence of the Project.

4. Determine Project effects relative to WDOE antidegradation policy, and determine Cowlitz River assimilative capacity.

5. Collect, analyze, and archive data in a manner that will support the identification of long-term water quality monitoring needs, if appropriate, and will ensure compatibility of data to the greatest extent feasible.

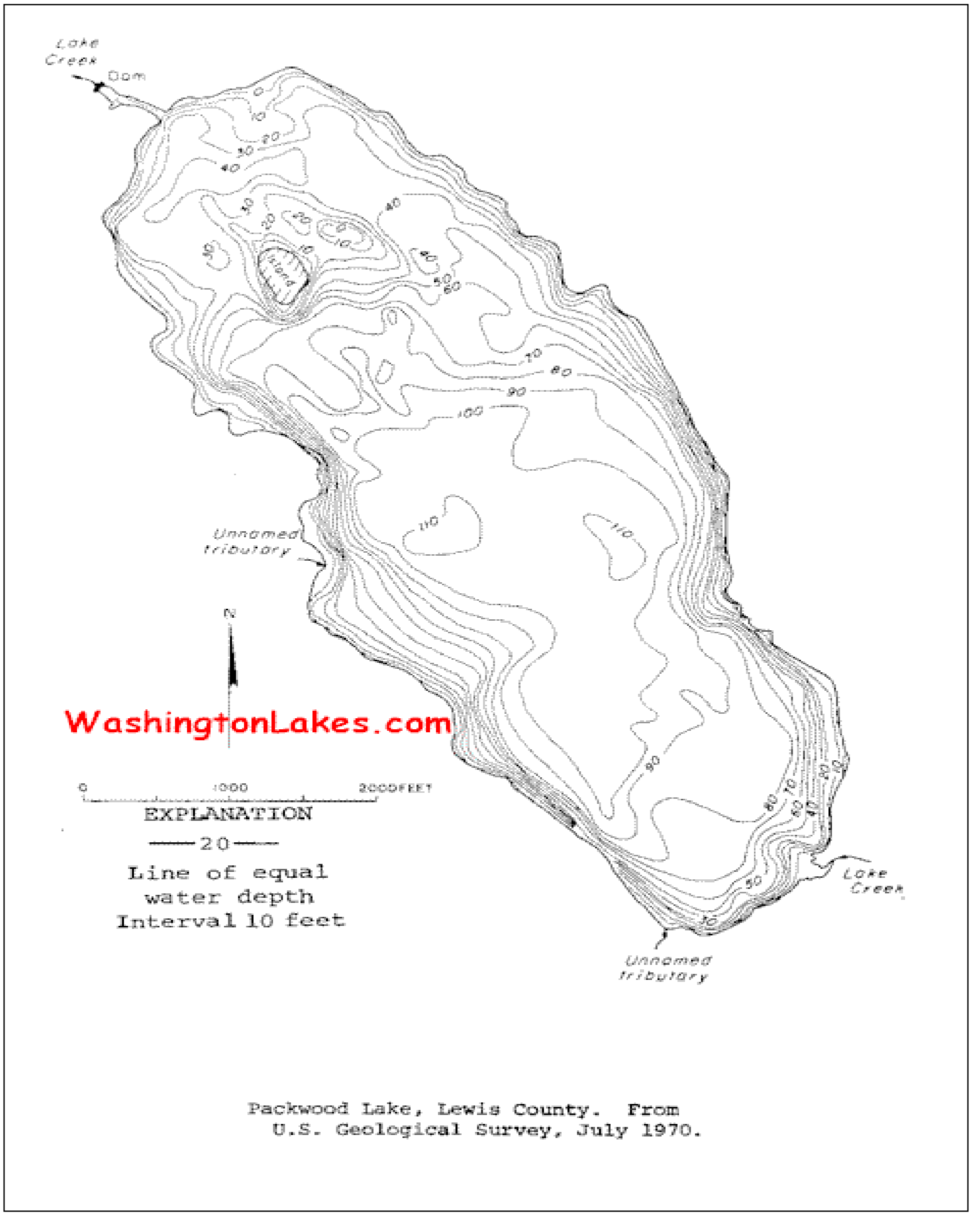

Figure 1-1. Packwood Lake Bathymetry

2.0 STUDY AREA AND METHODS

2.1 Study Area

The study area includes Packwood Lake, the Project tailrace, Lake Creek, Snyder Creek, the side channel of the Cowlitz River into which the Project tailrace flows, the tributary mouths of streams flowing into Packwood Lake, and the Cowlitz River upstream and downstream of the Project area. The study area specifically includes:

- Packwood Lake
- Tributaries into Packwood Lake including Osprey Creek, Muller Creek, Upper Lake Creek, and Crawford Creek (boundary condition at tributary mouth)
- Lake Creek from Packwood Lake outlet to mouth
- Project tailrace
- Snyder Creek
- Cowlitz River side channel at tailrace entrance
- Groundwater within Project area
- Cowlitz River from just upstream of the confluence with Lake Creek to the confluence with the tailrace side channel

Methods are presented to address each of the study objectives. The methods section is generally organized by study objective; however, many of the study objectives are interdependent.

2.2 Document Existing Water Quality Condition (Objective 1)

Document existing water quality conditions within the Project area, larger tributary inflows and immediately downstream in the Cowlitz River.

2.2.1 Variables of Interest

Sampling addresses the physical, chemical, and biological water quality characteristics as outlined in Table 2-1. A total of 25 water quality characteristics were sampled. The parameters sampled at each of the identified sampling locations vary according to the water body type.

All procedures used for the purpose of collecting, preserving, and analyzing samples follow established EPA 40 CFR Part 136 protocol. A discussion on sampling and analytical protocol for each parameter is provided.

2.2.2 Sampling Sites

Site selection is designed to evaluate longitudinal gradients in water quality for stream sections, the vertical water quality gradients in Packwood Lake, and the influence of tributaries and groundwater on Packwood Lake and Lake Creek water quality. The sampling design is structured to evaluate the effects of Project operations and structures on water quality. A description of the sampling locations is presented in Table 2-2. Sample site locations within and adjacent to Packwood Lake are shown in Figure 2-1. Sample locations in lower Lake Creek and the Cowlitz River are shown in Figure 2-2. Sample locations within the Project tailrace and Cowlitz River side channel are shown in Figure 2-3.

Sampling sites are organized by site type (riverine, tributary, lake, or other). Riverine sites are free flowing reaches. Tributary sampling sites are generally located at the mouths of inflowing surface waters. Lake sampling sites include vertical sampling, where appropriate. Other sites include the Project tailrace, and accessible groundwater sampling locations – primarily perennial springs.

Tributaries to Packwood Lake were sampled in order to estimate their influence on the water quality of Project-related waterways. Samples were collected upstream of the confluence with Packwood Lake to ensure that the sample is representative of tributary contribution. This eliminates interference from the lake.

There are two primary sampling sites within Packwood Lake. One is located over the area with the greatest water depth, as determined by available bathymetric maps with limited depth sounding verification. A second sampling site was established near the lake outlet. A secondary site within the littoral zone of the lake was established for sampling fecal coliform.

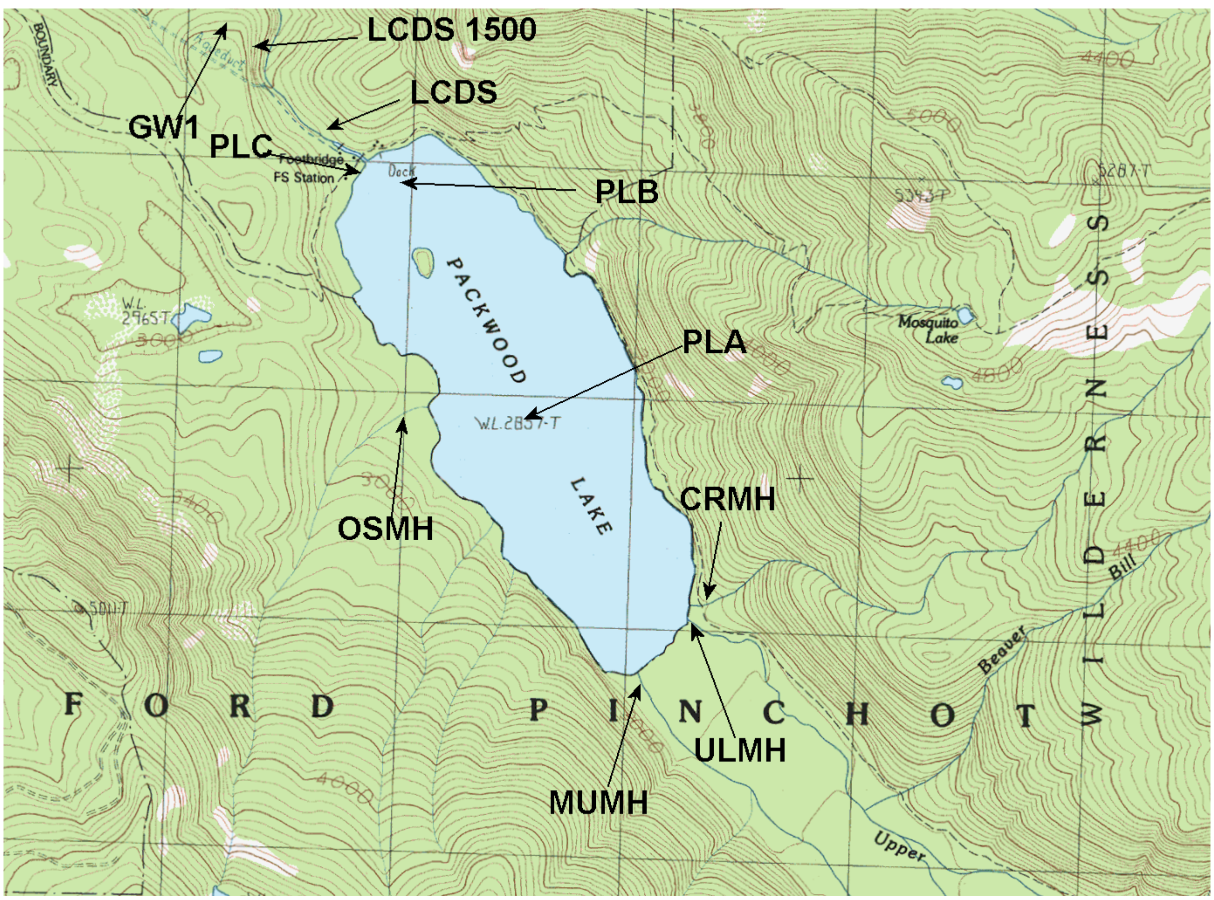

Figure 2-1. Water Quality Sample Sites Within and Adjacent to Packwood Lake.

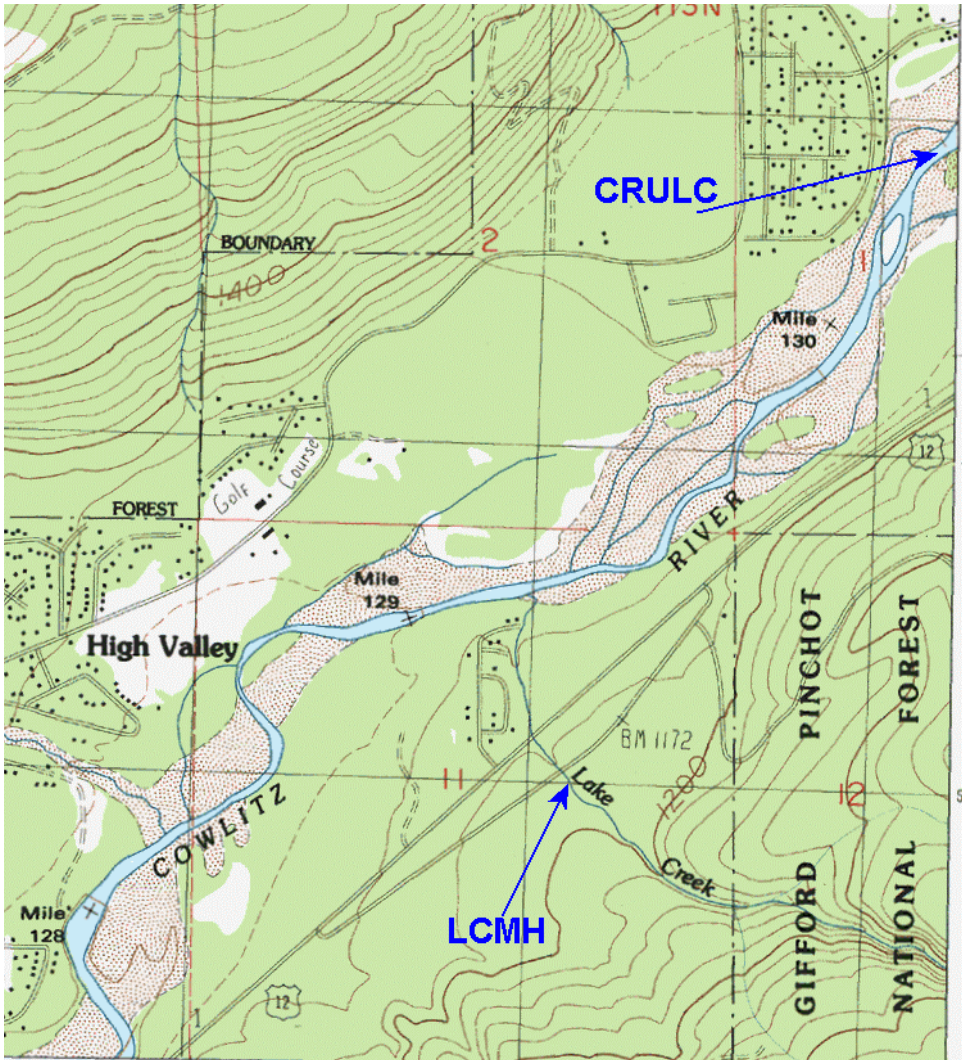

Figure 2-2. Water Quality Sampling Locations in Lower Lake Creek and Cowlitz River.

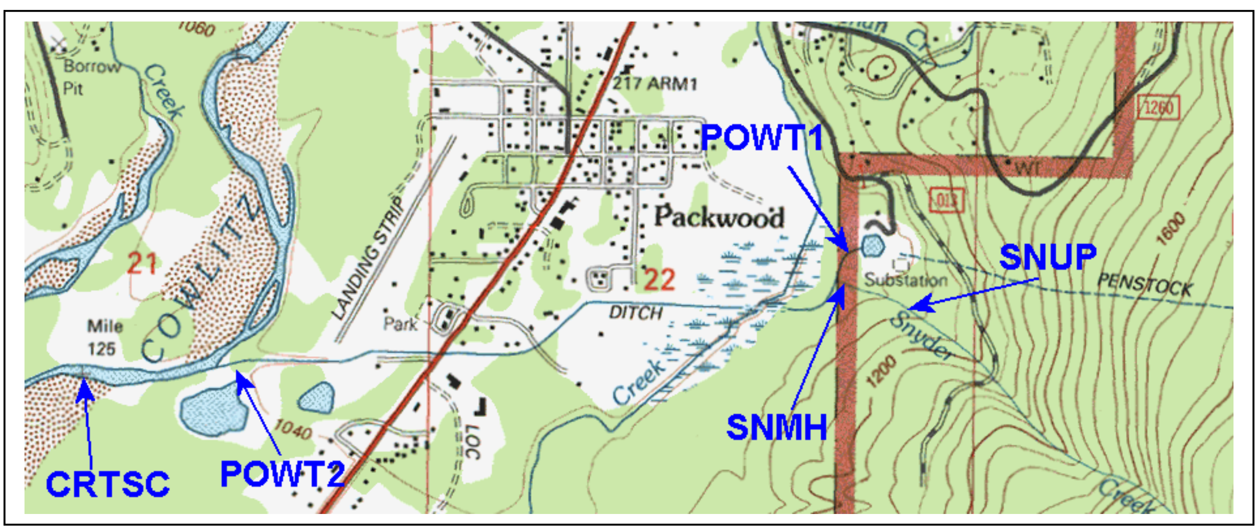

Figure 2-3. Water Quality Sampling Locations in Project Tailrace.

Table 2-1. Water Quality Parameters, Sampling Sites and Sampling

Parameter	OSMH	CRMH	MUMH	ULMH	PLA	PLB	PLC	LCDS	LCDS1500	LCMH	POWT1	POWT2	CRTSC	CRULC	GW1	SNUP	SNMH	Number of Sampling Sites	Sampling Frequency
Chemical:																			
Total Phosphorus (TP)	●	●	●	●	●	●		●		●	●	●	●	●	●			13	Monthly[1]
Ortho-phosphorus	●	●	●	●	●	●		●		●	●	●	●	●	●			13	Monthly[1]
NH_4^+-N	●	●	●	●	●	●		●		●	●	●	●	●	●			13	Monthly[1]
TKN	●	●	●	●	●	●		●		●	●	●	●	●	●			13	Monthly[1]
$NO_2^-N + NO_3^-N$	●	●	●	●	●	●		●		●	●	●	●	●	●			13	Monthly[1]
Total Alkalinity	●	●	●	●	●	●		●		●	●	●	●	●	●			13	Monthly[1]
pH	●	●	●	●	●	●		●		●	●	●	●	●	●			13	Monthly[1]
Total Suspended Solids (TSS)	●	●	●	●	●	●		●		●	●	●	●	●	●			13	Monthly[1]
Total Dissolved Solids (TDS)	●	●	●	●	●	●		●		●	●	●	●	●	●			13	Quarterly
DO (water column)	●	●	●	●	●	●		●		●	●	●	●	●	●			13	Monthly[1]
Total Dissolved Gasses											●							1	Monthly and Continuous[3]
Silica (Lake only)					●	●		●										3	Monthly[1]
Conductivity	●	●	●	●	●	●		●		●	●	●	●	●	●			13	Monthly[1]
Specific Conductance	●	●	●	●	●	●		●		●	●	●	●	●	●			13	Monthly[1]
Hardness	●	●	●	●	●	●		●		●	●	●	●	●	●			13	Monthly[1]
Carbonate	●	●	●	●	●	●		●		●	●	●	●	●	●			13	Monthly[1]
Total Organic Carbon	●	●	●	●	●	●		●		●	●	●	●	●	●			13	Monthly[1]
Petroleum NWTPH-HCID								●			●							2	Monthly[1]
Fat, Oil, and Grease								●			●							2	Monthly[1]
Physical:																			
Temperature	●	●	●	●	●	●		●	●	●	●	●	●	●		●	●	14	Continuous[4]
Turbidity	●	●	●	●	●	●		●		●	●	●	●	●	●			13	Monthly[1]
Secchi Transparency (Packwood Lake only)					●	●												2	Monthly[1]
Aesthetics[2]	●	●	●	●	●	●		●		●	●	●	●	●				12	Monthly[1]
Biological:																			
Total Fecal Coliform							●											1	Monthly (June-Oct.)

Table 2-1. Water Quality Parameters, Sampling Sites and Sampling

Parameter	OSMH	CRMH	MUMH	ULMH	PLA	PLB	PLC	LCDS	LCDS1500	LCMH	POWT1	POWT2	CRTSC	CRULC	GW1	SNUP	SNMH	Number of Sampling Sites	Sampling Frequency
(Packwood Lake only)																			
Noxious/invasive Macrophytes and emergent plants							●			●								2	One time
Chlorophyll *a* (phytoplankton) (Packwood Lake only)						●	●											2	Monthly (Apr-Oct.)
Chlorophyll *a* (periphyton)							●	●			●	●						Up to 4	Monthly as needed
Taxonomic (phytoplankton)					●	●												2	Monthly (Apr-Oct.)
Taxonomic (periphyton)							●	●			●	●						Up to 4	Monthly as needed

[1] *Monthly from April through October (2004 and 2005) for Packwood Lake and its tributaries (weather permitting); monthly April 2004 through March 2006 for all other sites. During August of each year, an additional sampling trip was scheduled for both sites within Packwood Lake and Lake Creek just downstream of the drop structure.*

[2] *Odors, fungi or other growths, sludge/deposits, discoloration, scum, oily slick, floating solids.*

[3] *TDGP and other relevant parameters was monitored continuously in the tailrace for selected two week periods as well as being a parameter for monthly water quality sampling.*

[4] *Temperature will be monitored continuously from April 2004 through October (2004 and 2005) for Packwood Lake and April 2004 through March 2006 for all other sites including tributaries to Packwood Lake.*

Table 2-2. Water Quality Sampling Sites

LOCATION AND (SITE CODE)
Tributaries to Packwood Lake
• Osprey Creek (OSMH)
• Crawford Creek (CRMH)
• Muller Creek (MUMH)
• Upper Lake Creek (ULMH)
Packwood Lake at maximum depth (PLA)
Packwood Lake near outlet (PLB)
Packwood Lake littoral site (PLC)
Lake Creek below diversion structure (LCDS)
Lake Creek 1500 ft downstream of drop structure (LCDS-1500)
Lake Creek near mouth (LCMH)
Powerhouse tailrace upper end (POWT1)
Powerhouse tailrace lower end (POWT2)
Cowlitz River tailrace side channel (CRTSC)
Cowlitz River upstream of Lake Creek (CRULC)
Groundwater spring (if available)
• groundwater runoff from tunnel 1 (GW1)
Project ancillary water outflow (P1)
Snyder Creek upstream of ancillary water inflow (SNUP)
Snyder Creek at confluence with Hall Cr (SNMH)

2.2.3 Sampling Frequency

Samples were collected monthly at all sampling sites within Packwood Lake and its tributaries from April through October for 2004. Sampling at the other stations occurred monthly from April 2004 through March 2005 and will continue through March 2006. Two sampling events occurred in August 2004 for sample sites within Packwood Lake and its tributaries, as well as Lake Creek just downstream of Packwood Lake.

2.2.4 Sampling Protocol

Grab samples from riverine sites were collected in Nalgene containers provided by the laboratory. Samples for total organic carbon were collected in baked glass jars for laboratory processing. All samples were placed immediately in the dark on ice and shipped to the laboratory within 48 hours.

Lake water samples for laboratory processing were collected from a boat. When Packwood Lake was not temperature stratified, water chemistry sampling consisted of one depth-integrated hose grab sample (2.5-liter sample) collected over a depth range of 5 m and one grab sample from 1 m above the bottom; maximum sampling depth is 1 m above the bottom to avoid contamination.

At any lake sample station where thermal stratification was detected, four samples were collected. Thermal stratification is generally defined as temperature changes in the region of the thermocline (metalimnion) greater than 1.0^{o}C per 1.0 m depth (Horne and Goldman 1994). Weak stratification may not meet this guideline; however, the sampling strategy for stratification was also applied when only weak stratification was suspected. Samples were taken as follows: one grab sample from the midpoint of the epilimnion, one grab sample from the midpoint of the metalimnion, and one grab sample at 1.0 m off the bottom. In addition, one sample was collected by and integrated over the upper 5 m or the epilimnion (whichever is lesser) using a depth-integrated hose sampler.

<u>Physical and Water Chemistry</u>

Water depth was measured with the Hydrolab with confirmation from the line attached to the Vandorn sampler, which was marked in 1 m increments.

Temperature, dissolved oxygen (DO), specific conductance, conductivity and pH profiles were measured using a Hydrolab DataSonde 4a or YSI 610 at each site. Instruments were calibrated prior to each field visit according to the manufacturer's specifications. Instrument calibration procedures are summarized in Appendix B. Modified Winkler titrations were performed at the start of each day to ensure the dissolved oxygen probe was properly functioning. Modified Winkler titrations were also completed for 10% of the grab samples as further verification of dissolved oxygen probe readings. The probe was re-calibrated if the result of the Winkler titration and probe reading differed by more than 0.3 mg/L. For Packwood Lake, measurements were taken at vertical increments of 1 m (3.3 ft) in water less than 15 m (49 ft), 2 m (6.6 ft) in water 15 - 30 m (49 - 98 ft) deep, and 3 m (10 ft) intervals in water 30 - 50 m deep (98 - 164 ft). In riverine reaches, a single measurement at 0.5 m depth was made where turbulent flow ensures a fully mixed water column.

Dissolved gasses sampling was confined to the Project tailrace stilling basin and at the intake in Packwood Lake. Water depths in the tailrace stilling basin and at the intake are less than the minimum compensation depth (typically 15 ft). The probe was placed at the maximum depth available while maintaining the probe at least 0.5 m off the bottom. Total dissolved gas pressure (TDGP) data has been labeled suspect since sampling was at depths less than the compensation depth. Instantaneous TDGP readings were recorded after the instrument has had sufficient time to equilibrate in situ (approximately 15 minutes). A Hydrolab minisonde was used to measure TDGP; a two-point calibration process was applied before and after each sampling event.

In addition to monthly grab sampling, a hydrolab was deployed for approximately two-week periods in the tailrace stilling basin. TDGP, total gas saturation, water temperature, dissolved oxygen, dissolved oxygen saturation, pH and depth were recorded at 15-minute intervals. The hydrolab was deployed at a location of maximum depth in the stilling basin directly out from the powerhouse outflow with the probe positioned 0.5 m to 1 m off the bottom.

Total Alkalinity was analyzed in the laboratory.

Turbidity was measured monthly in the field using a HACH 2100P Portable Turbidometer. Measurements were made at all riverine sites including the tailrace and the surface waters of Packwood Lake.

Transparency was measured in Packwood Lake with a standard 20 cm (7.9 in) Secchi disk; resolution is 0.2 m. Two observers independently measured Secchi depth. Measurements were repeated until the difference between paired measurements was no more than 0.5 m.

Nutrients for water samples were analyzed in the laboratory using methods appropriate for low productivity waters.

Total suspended solids were analyzed by laboratory filtering of a one-liter sample and then oven drying the filter for weighing.

Total dissolved solids (composite sample) were sampled monthly. *Hardness* was also analyzed in the laboratory.

Fats, Oils and Grease (FOG) were analyzed for a composite analysis for samples from two sites; the sites are the upper end of the tailrace and just downstream of the drop structure. A 1 L water sample was collected in a clean amber glass container for transport to the laboratory for analysis. Laboratory methods for analysis (Method 1664) are fully described in EPA (1999). EPA Method 1664 is a performance-based method applicable to aqueous matrices that requires the use of n-hexane as the extraction solvent and gravimetry as the determinative technique. Alternative extraction and concentration techniques are allowed, provided that all performance specifications are met. In addition, QC procedures designed to monitor precision and accuracy have been incorporated into Method 1664.

Petroleum and Fuels were analyzed using NWTPH-HCID by GC/FIS (8015 modified) laboratory method. A 1 L sample was collected monthly in a glass amber bottle for analysis. Samples were collected from Lake Creek below the drop structure (LCDS) and at the upper end of the powerhouse tailrace (POWT1).

Biological Water Quality Parameters

Phytoplankton samples were collected at two locations in Packwood Lake. A water sample representative of the photic zone was collected with an integrated hose sampler (Straskraba and Javornicky 1973). A Van Dorn Sampler was used to collect phytoplankton samples from specific depths. One composite sample, consisting of three replicates, was collected for each sample. Two distinct subsamples from each composite sample were then processed separately for chlorophyll *a* (corrected for pheophytin) and taxonomic biovolume evaluations. One unfiltered subsample for taxonomic analysis was stored in a labeled amber Nalgene bottle and preserved with a 1% Lugol's solution. A second 250 ml subsample was collected for chlorophyll *a* analysis. All samples were temporarily stored in the dark on ice until delivery to the laboratory for analysis.

Once at the laboratory, the chlorophyll *a* samples were filtered on Whatman GF/C filters at the laboratory (APHA 1992a and 1992b). The filters were then frozen for later processing of chlorophyll *a.* Homogenized filtered samples were put through a blender or grinder, pigments extracted with an acetone solution, followed by analysis with a fluorometer (APHA 1989). Pheophytin-corrected chlorophyll *a* are reported as mg/m^3 for phytoplankton.

Samples preserved with Lugol's iodine were homogenized, and aliquots placed in a plankton sedimentation chamber such as a Palmer-Maloney counting chamber. Identification, to at least genus, and counts of natural units (may be a unit with multiple cells) was made with a microscope equipped with least-phase contrast optics at a magnification of 1000x. Only algae that were live at the time of preservation, based on cell contents, were enumerated. Algae were identified to the lowest practical taxonomic level and enumerated in sequentially viewed fields along transects of the counting chamber. Counting was continued until at least 100 units were counted and no new taxa were observed. A unit is defined as a discrete algal particle (cell, filament or colony). A subsample was processed with fuming concentrated nitric acid to generate a permanent diatom Naphrax-mounted slide. Phytoplankton samples were measured for both density and biovolume. Densities (units/ml for phytoplankton) were determined for each taxon for community composition analysis. An estimate of algal biomass was determined by converting unit densities to biovolumes (*u*m^3/ml for phytoplankton) based on average unit areas of 20 specimens for each taxon (APHA 1989).

A Shannon-Weaver diversity index was calculated for each phytoplankton sample. This index is calculated as the sum of percents for each species, times the log (base 2) of the percent for each species.

Coliform

Monthly water samples for coliform analysis were collected from June through September. Two 125 mL samples were collected from a near-shore site. Samples were collected from the lake surface directly into sterilized and sealed polyethylene sample bottles provided by the laboratory for coliform analysis. Ideally, fecal coliform samples are delivered to the laboratory within 12 hours; however, the remote location of Packwood Lake necessitated a transport time of up to 24 hours for fecal coliform samples.

2.2.5 Diurnal Monitoring

A hydrolab was used to continuously monitor dissolved oxygen, pH and temperature for a 48-hour period in August, 2004 at each of the following sites:

- Packwood Lake near forebay at 2 m depth,
- Lake Creek downstream of drop structure, and
- Lake Creek near mouth.

3.0 RESULTS

3.1 Data Quality

Water quality was sampled once per month for the period April 2004 through March 2005 except in August 2004 when two sampling events occurred. Table 3-1 lists the number of samples stratified by water type analyzed for each parameter. Table 3-1 also shows the proportion of samples that had results that were below the laboratory detection limit. The laboratory detection limits are reported in Table 3-2.

Table 3-1. Number of samples and percent of samples below laboratory detection limits (MDL), April 2004 through March 2005

Parameter	Packwood Lake		Riverine		% Non-Detect	
	Samples	Non-Detect	Samples	Non-Detect	Lake	Riverine
Total Alkalinity	37	37	102	0	100%	0%
Ammonia as N	37	0	103	0	0%	0%
Nitrite as N	38	38	103	103	100%	100%
Nitrate + Nitrite as N	37	15	103	25	41%	24%
Total Kjeldahl Nitrogen	37	25	102	61	68%	60%
Phosphate, Ortho as P	37	37	103	102	100%	99%
Phosphorus, Total	37	19	103	54	51%	52%
Silica	37	0	103	0	0%	0%
Solids, Total Dissolved	37	0	103	0	0%	0%
Solids, Total Suspended	37	1	101	3	3%	3%
Hardness	37	0	102	0	0%	0%
Total Organic Carbon	36	0	94	11	0%	12%
Phytoplankton Identification	29	0	NA		0%	
Phytoplankton Chlorophyll a	29	0	NA		0%	

Table 3-2. Laboratory Minimum Detection Limits

Parameter	Reporting Limit
Total Alkalinity	10 mg/L
NH4	0.03 mg/L
Nitrite	0.03 mg/L
Nitrate	0.02 mg/L
TKN	0.05 mg/L
Ortho phosphorus	0.1 mg/L
Total phosphorus (ICP)	0.002 mg/L
Total dissolved solids	5 mg/L
Total suspended solids	1 mg/L
Silica (ICP)	0.002 mg/L
Hardness	1 mg/L
Total Organic Carbon	0.5 mg/L
Phytoplankton (taxonomic units)	NA
Chlorophyll a (phytoplankton)	0.1 µg/L

When computing statistics and plotting data, a value of one half the detection limit was used when the laboratory results reported non-detection. Laboratory values that were at or slightly below the reporting limits are still reported in the database with data qualifiers, which document that low levels contribute to uncertainty in the value.

The management quality objectives (MQOs) as defined in the study plan were met with few exceptions for all parameters. Field instrumentation accuracy complied with criteria established in the study plan. The analysis of field blanks indicated that sampling methods did not result in any consistent bias and contamination was not evident for any of the samples. Table 3-3 summarizes the results for Relative Standard Deviation (%RSD), which is the MQO for precision.

The MQOs for %RSD were not met in the following situations. MQO's were met for Total Kjeldahl Nitrogen (TKN) with the exception of the October 27, 2004 sample for upper Lake Creek when TKN values for the two duplicate samples were at non-detect and 0.2 mg/L, respectively. The %RSD exceeded QAQC criteria for total Alkalinity (29 mg/L vs. 24 mg/L), ammonia (0.021 mg/L vs. 0.018 mg/L) and Total Organic Carbon (ND vs. 0.5 mg/L) for the September 29, 2004 sample. Silica values for the September 29, 2004 sample for Cowlitz River upstream of Lake Creek were 8.9 mg/L and 7.4 mg/L, which resulted in a %RSD above the MQO criteria. The criteria for %RSD for total suspended solids was exceeded for several samples; however, values were near the detection limits. In all cases where the %RSD criteria was exceeded, the parameter values were near or below the detection limits for the duplicate samples. Therefore, the data were not eliminated.

Table 3-3. Relative Standard Deviation (%RSD) for duplicate water quality samples: April 2004 – March 2005

Parameter	**Water Temperature**	**Dissolved Oxygen**	**pH**	**Turbidity**	**Nitrites**	**TKN**	**NH4**
Mean %RSD	0.01	0.54	0.39	1.55	ND	0.01	2.61
Maximum %RSD	0.06	1.16	3.52	7.29	ND	84.85	10.88
	Nitrate	**Ortho phosphorus**	**Total phosphorus (ICP)**	**Total suspended solids**	**Total dissolved solids**	**Silica (ICP)**	**Total Organic Carbon**
Mean %RSD	0.001	ND	4.18	49.7	4.0	3.93	27.3
Maximum %RSD	4.88	ND	39.6	64.28	1.52	13.01	141.42
	Total Alkalinity	**Hardness**	**Fecal Coliform**				
Mean %RSD	1.6	2.73	<1				
Maximum %RSD	13.34	7.07	<1				

3.2 Packwood Lake

Packwood Lake was unstratified at the onset of sampling in April 2004 although a thermocline existed. Surface waters of the lake continued to warm as the season progressed. The criteria for stratification was, at most, marginally met during summer months. Stratification is defined by Horne and Goldman (1994) as a temperature change in the region of the thermocline (metalimnion) greater than 1.0^{o}C per 1.0 m depth. Temperature profile data indicates weak stratification in Packwood Lake during summer 2004. The thermocline initiated at the surface without a distinctive epelimnetic layer; i.e., a vertical temperature gradient existed but an upper layer of water with a homogeneous temperature (epilimnion) was not apparent. The tributary inflow to the lake is cold relative to surface waters; the inflow's density would place it at an intermediate depth. Field crews noted that drift of the temperature probe at intermediate depths was likely attributed to density currents as inflow traveled across the lake at depth.

The reservoir exhibited moderate to low nutrient conditions, was only weakly stratified in the summer and turbidity varied seasonally depending upon runoff from the upper watershed. Mean values for various parameters are reported in Table 3-4 for the lake sampling locations.

Water transparency as measured by Secchi depths was primarily a function of runoff and suspended sediment load in upper Lake Creek. Water transparency showed an increasing trend during the spring until the peak of the snowmelt from the upper watershed occurred in early June (Figure 3-1), which reduced water transparency in the lake. As snowmelt and glacial runoff from the upper Lake Creek watershed decreased through the summer, water transparency again showed an increasing trend interrupted by a storm event in late August, which caused high runoff of turbid water from upper Lake Creek. The maximum transparency occurred in early August (8.0 m) and the minimum Secchi depth (0.8m) was recorded at the end of August. The trend in Secchi depths was similar at both monitoring locations with minor differences likely attributed to travel time of inflow with varying transparency to move through the lake.

Table 3-4. Mean annual values for water quality parameters for Packwood Lake 2004

	pH	Secchi Disk Depth (m)	Sp. Conductance (uS/cm)	Alkalinity, Bicarbonate as CaCO3 (mg/L)	Total Alkalinity (mg/L)	Hardness (mg/L)
PLA(PH)	7.5	3.6	0.0372	24	23	21.9
PLA(EP)				20		20.0
PLA(ME)	7.3		0.0293	22	25	21.3
PLA(OB)	6.9		0.0444	27	29	24.5
PLB(PH)	7.5	3.6	0.0382	25	33	22.2
PLB(EP)	7.2		0.0209	22		21.5
PLB(OB)	7.1		0.0397	25	24	22.9
Annual and Seasonal Mean Values averaged for all lake sites						
Annual	7.25					
Spring	7.33		0.0501	25	25	22.6
Summer	7.44		0.0324	24	24	21.9
Fall	7.13		0.0318	25	25	23.7
TSI						
	Silica (mg/L)	Total Dissolved (TDS) (mg/L)	Total Suspended (TSS) (mg/L)	Ammonia as N (mg/L)	Nitrite as N (mg/L)	Nitrate + Nitrite as N (mg/L)
PLA(PH)	5.86	40.13	1.46	0.021	0.015	0.013
PLA(EP)	5.25	36.50	0.70	0.020	0.015	0.010
PLA(ME)	5.87	39.67	3.13	0.023	0.015	0.010
PLA(OB)	6.02	44.13	2.36	0.023	0.015	0.058
PLB(PH)	5.77	39.33	4.72	0.022	0.015	0.011
PLB(EP)	5.35	38.50	0.55	0.016	0.015	0.013
PLB(OB)	6.05	42.13	3.89	0.023	0.015	0.022
Annual and Seasonal Mean Values averaged for all lake sites						
Annual						
Spring	5.17	43.09	1.39	0.020	0.015	0.023
Summer	5.94	39.35	3.84	0.023	0.015	0.018
Fall	6.56	41.44	2.37	0.021	0.015	0.033
TSI						

Table 3-4 Mean annual values for water quality parameters for Packwood Lake 2004 (cont.)

	Phosphate, Ortho as P (mg/L)	Phosphorus, Total (mg/L)	Total Kjeldahl Nitrogen (TKN) (mg/L)	Total Organic Carbon (TOC) (mg/L)	TN:TP	TIN:TIP
PLA(PH)	0.050	0.022	0.238	0.89	5.00	0.97
PLA(EP)	0.050	0.053	0.050	0.90	0.93	0.89
PLA(ME)	0.050	0.036	0.050	0.75	0.77	0.57
PLA(OB)	0.050	0.021	0.188	0.84	4.81	1.91
PLB(PH)	0.050	0.008	0.317	0.95	6.97	0.96
PLB(EP)	0.050	0.022	0.050	0.75	1.42	0.86
PLB(OB)	0.050	0.020	0.169	0.85	3.94	1.20
Annual and Seasonal Mean Values averaged for all lake sites						
Annual		0.022			4.13	1.148
Spring	0.050	0.015	0.200	0.85	4.26	1.16
Summer	0.050	0.037	0.053	0.91	1.43	1.12
Fall	0.050	0.001	0.433	0.80	8.11	1.17
TSI		54.87			4.14	
Spring =April – June Summer = July – August Fall = September – October						

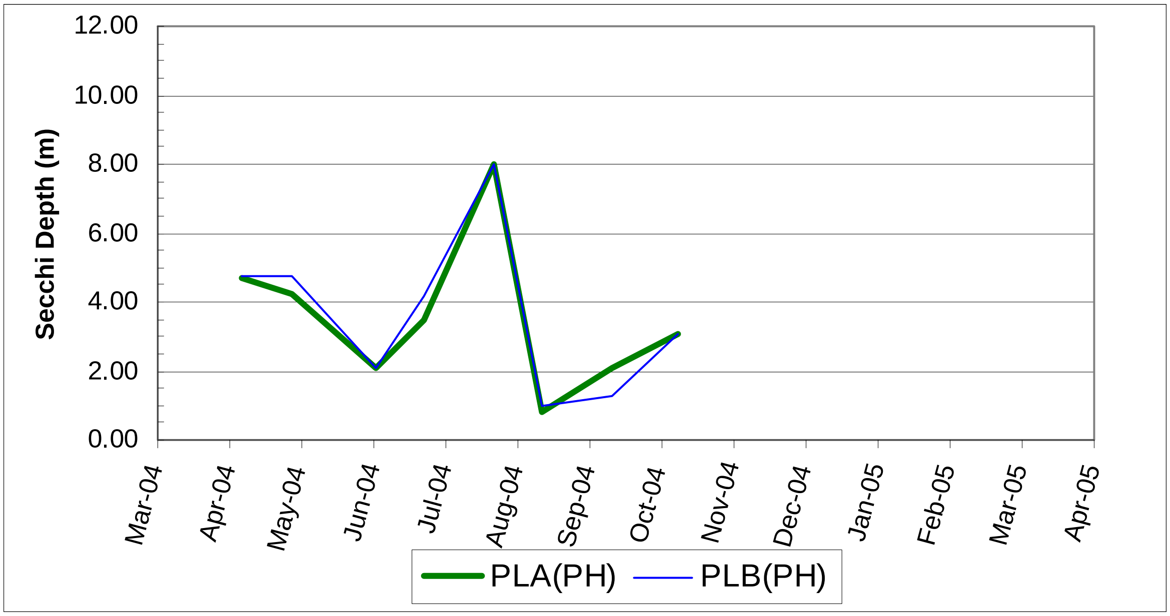

Figure 3-1. Secchi depth (m) for Packwood Lake 2004

Dissolved oxygen (D.O.) at lower depths in the lake was gradually depleted but remained well above anoxic conditions. Surface D.O. ranged from 8 mg/L to 10.5 mg/L while D.O. in the deepest region of the lake ranged from a measured high of 10.19 mg/L in April 2004 to a low of 5.09 mg/L in October 2004. During summer months, maximum D.O. levels occurred at a depth of approximately 11 m to 12 m. The cooler water at this depth is capable of holding more dissolved oxygen without depletion occurring due to respiration. Primary productivity may also contribute to this D.O. bulge.

The pH showed relatively little spatial or temporal variation within Packwood Lake. The lake pH is neutral (annual mean pH 7.3). Diurnal variability in pH as measured by continuous monitoring at the Project intake for August 31 through September 1, 2004 was negligible. Alkalinity is a measure of a water bodies buffering capacity to resist change in pH. Packwood Lake has a moderately low alkalinity so it is potentially sensitive to events that could alter its pH. Plots of vertical profiles for temperature, D.O. and pH are provided in Appendix A.

Lake nutrients varied temporally but there were minimal vertical and horizontal differences in nutrient levels as measured at the two lake monitoring sites. Ammonia levels were at the lower range of detectable laboratory limits for all months. Nitrites were consistently below detection levels for all sampling points and nitrates were below minimum detection limits for approximately 40% of the lake samples. The majority of nitrogen occurred as organic nitrogen (TKN), and therefore was not available for immediate biological uptake. Inorganic nitrogen (nitrite-nitrate + ammonia) accounted for 36.5 percent, on average, of total nitrogen levels. Organic nitrogen levels were elevated in October relative to other months. Figures 3-2 through 3-9 show the monthly trends in various nutrients for lake sampling locations.

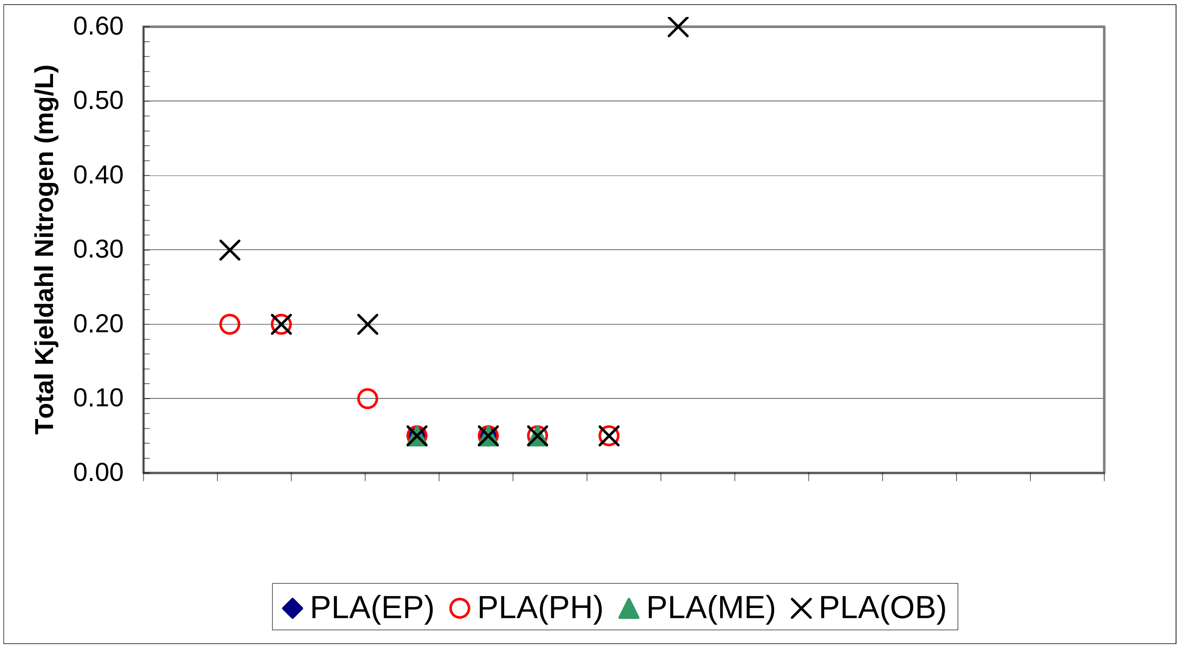

Figure 3-2. Total Kjeldahl Nitrogen for Packwood Lake Site A

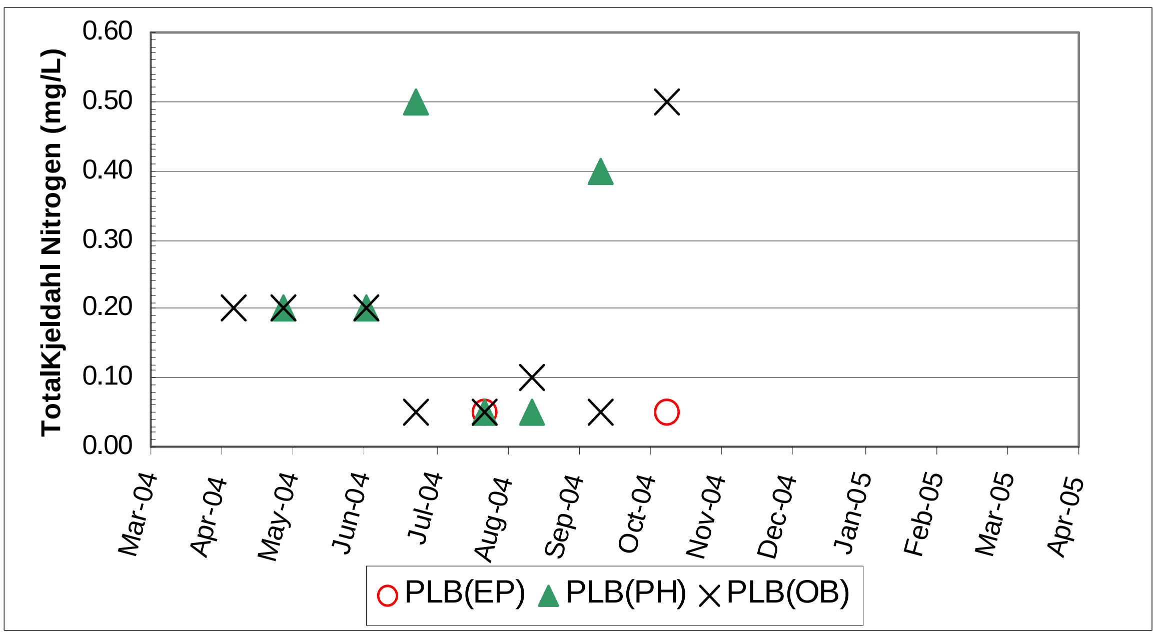

Figure 3-3. Total Kjeldahl Nitrogen for Packwood Lake Site B

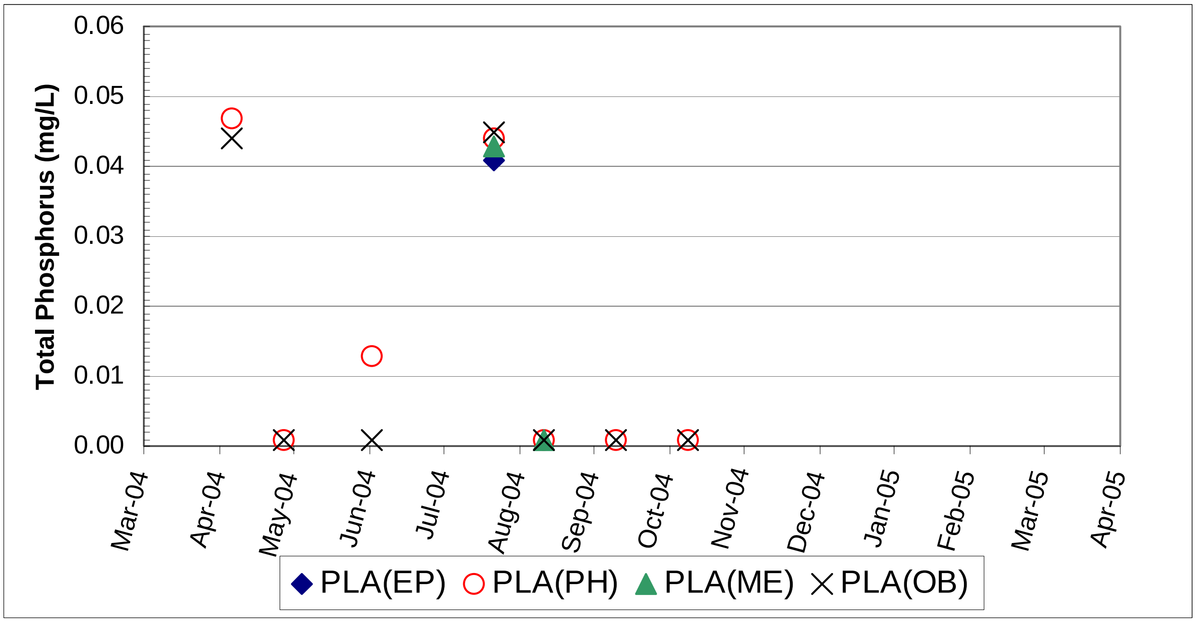

Figure 3-4. Total Phosphorus for Packwood Lake Site A

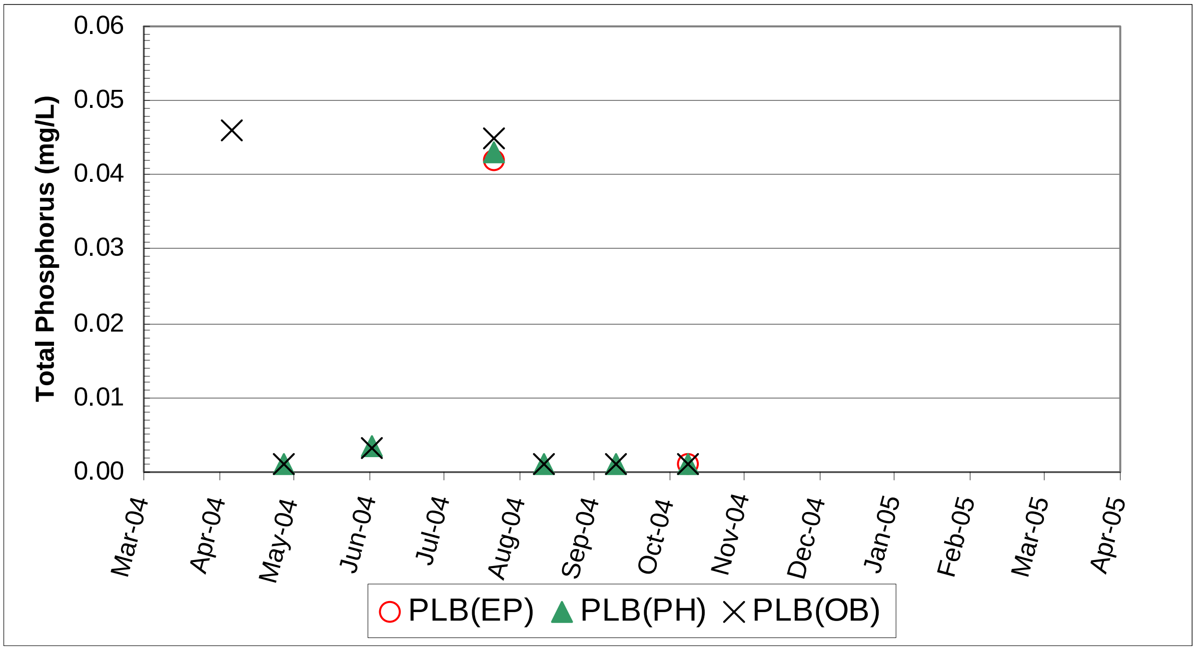

Figure 3-5. Total Phosphorus for Packwood Lake Site B

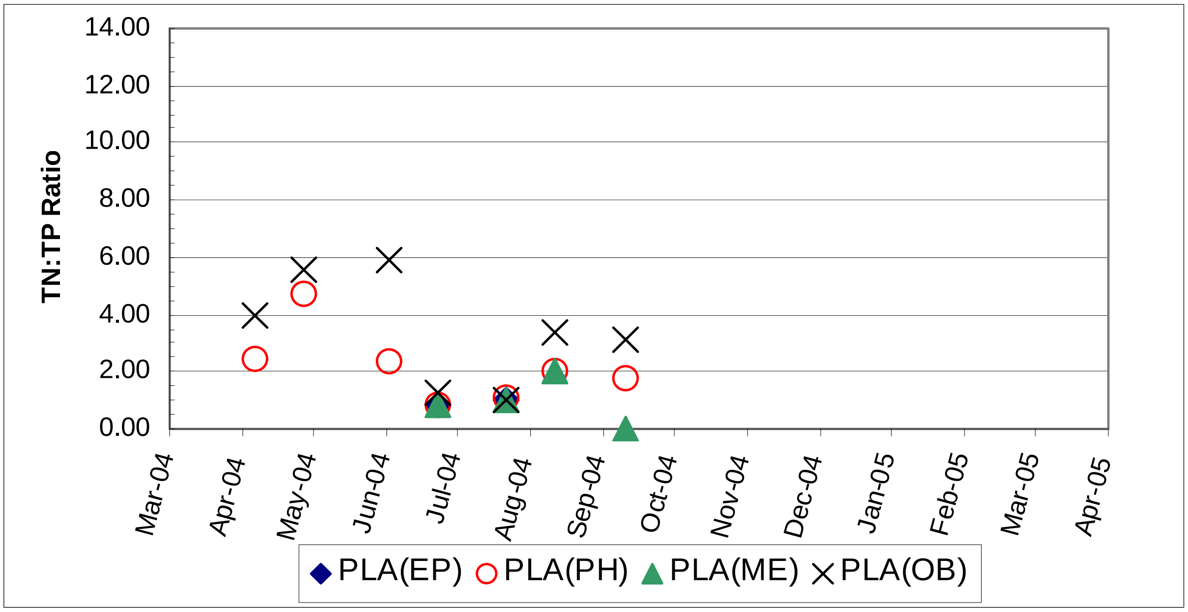

Figure 3-6. Total Nitrogen to total Phosphorus ratio for Packwood Lake Site A

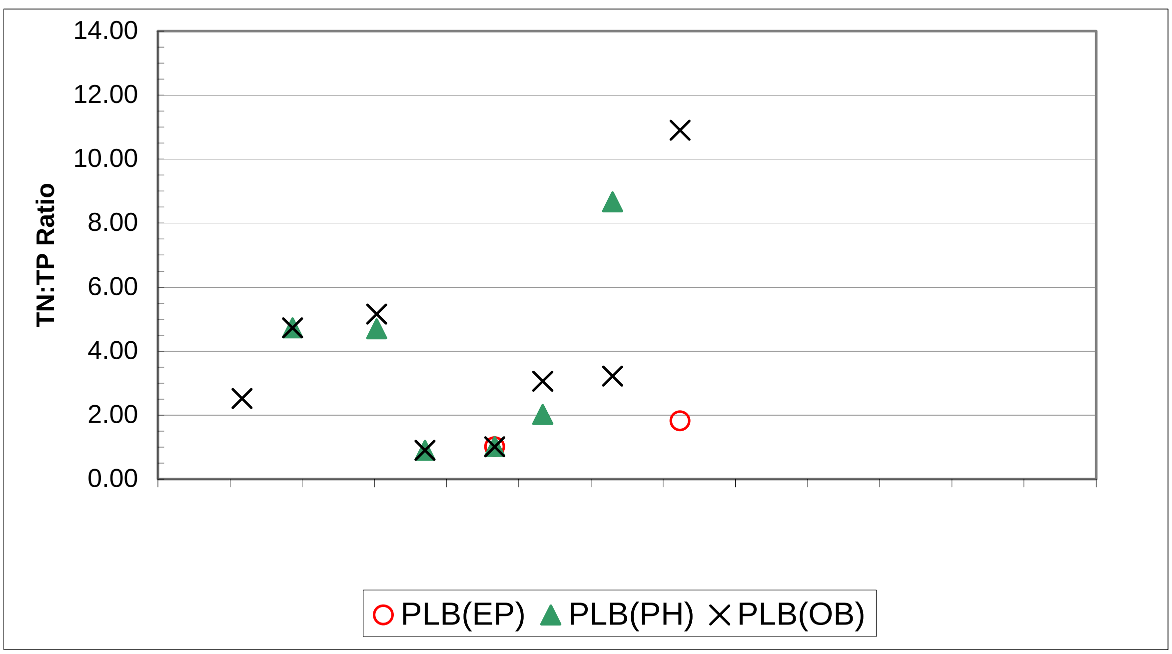

Figure 3-7. Total Nitrogen to total Phosphorus ratio for Packwood Lake Site B

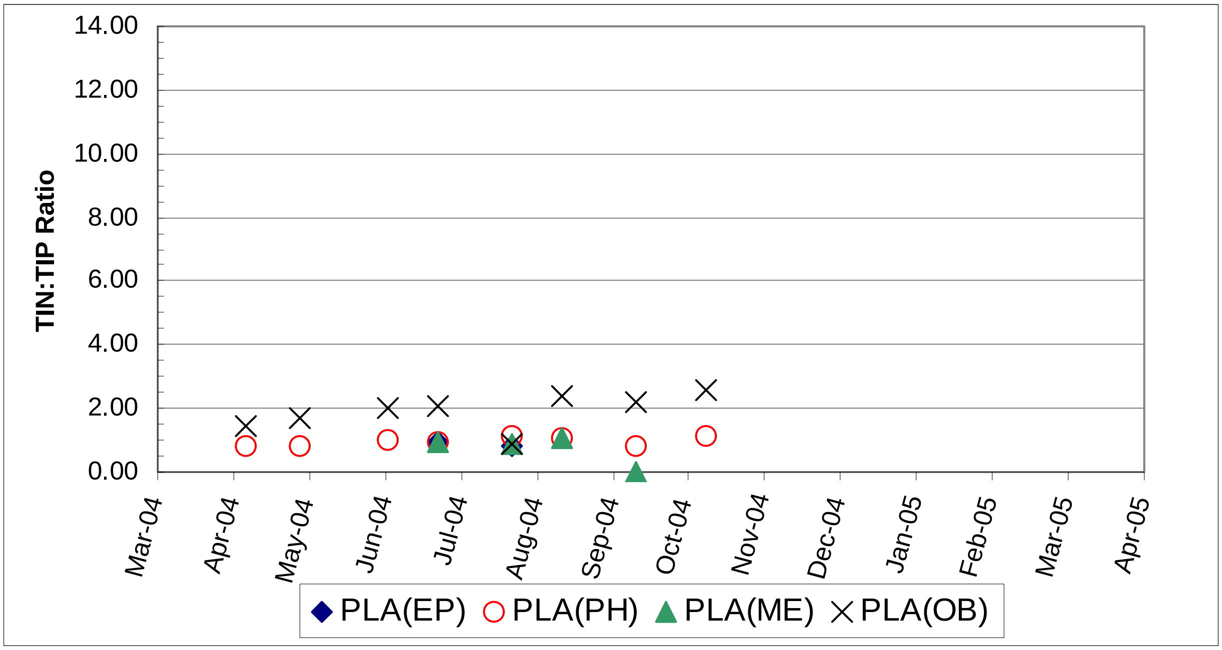

Figure 3-8. Total Inorganic Nitrogen to total Inorganic Phosphorus ratio for Packwood Lake Site A

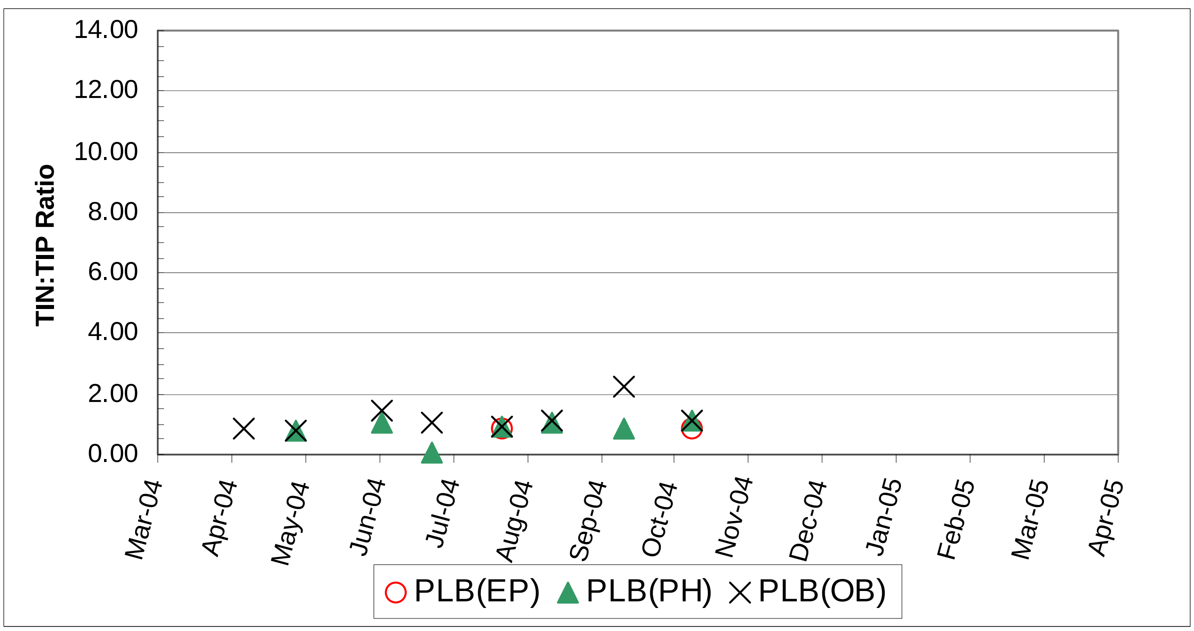

Figure 3-9. Total Inorganic Nitrogen to total Inorganic Phosphorus ratio for Packwood Lake Site B

Trophic Status Index (TSI) developed by Carlson (1977, 1996) and modified for nitrogen by (Kratzer and Brezonik 1981) revealed that Packwood Lake is generally classified as mesotrophic (moderate primary productive). Carlson (1996) suggests that the TSI for Chlorophyll *a* be the primary determinant of trophic status with the other TSI values qualifying the index status. Application of Carlson's (1977) trophic index is problematic for Packwood Lake since the inflow includes glacial meltwater, which elevates turbidity and the total phosphorus load during periods of snowmelt. WDOE (1991) previously characterized the lake as oligotrophic based on Secchi disk transparency and epilimnetic concentrations of total phosphorus and chlorophyll *a*. Although the TSI (total phosphorus) would classify the lake as eutrophic, the biologically available phosphorus is below detection levels. Therefore, the trophic status is better viewed as mesotrophic. Table 3-5 lists TSI scores for Packwood Lake based on 2004 water quality data.

Table 3-5. Trophic State Indices (TSI) for Packwood Lake 2004

	TSI Secchi	**TSI TP**	**TSI TN**	**TSI Chlorophyll *a***
Trophic Status	Mesotrophic	Eutrophic	Mesotrophic	Mesotrophic
TSI Formula	TSI= 60-14.41*ln(SD)	TSI= 14.42*ln(TP)+4.15	TSI= 54.45+14.43ln(TN)	TSI= 9.81*ln(Chl)+30.6
TSI Score	41.7	54.5	50.3	41.8

TN:TP ratios, the ratio of total nitrogen to total phosphorus by mass, are an indicator of nutrient conditions that define factors potentially limiting lake productivity. Lower TN:TP ratios indicate possible nitrogen limitation relative to available phosphorus. Current literature suggests that nitrogen limitation in terms of TN:TP ratios vary, but generally TN:TP ratios less than 10:1 can indicate nitrogen limitation (Horne and Goldman 1994). Smith (1983) found that non-nitrogen fixing algae tended to be dominant at TN:TP ratios that were greater than 29:1. Hillebrand and Sommer (1999) found nitrogen to be limiting at ratios less than 13:1 along with Downing and McCauley (1992) who determined nitrogen-fixing alga were favored at TN:TP ratios of 14:1. Barica, 1990 determined that spring-minima TN:TP ratios of 6:1 or less were the best indicator of nitrogen limitation despite seasonal TN:TP means as high as 20:1 and 30:1. In comparison, the annual mean TN:TP ratios in Packwood Lake was 6.0 for the photic zone and 4.22 averaged for samples from all depths (Table 3-6). These values are within the suggested literature ranges for nitrogen limitation. Nitrogen limitations were most pronounced during the summer months. The TN:TP ratios in September and October were notably higher but still within a range for nitrogen to be limiting relative to total phosphorus.

Biologically available nutrients are low for Packwood Lake. The majority of nitrogen in Packwood Lake occurred as organic nitrogen (TKN), which is not available for immediate biological uptake. Inorganic nitrogen (nitrite-nitrate + ammonia) was 4.4 - 70.5 percent of total nitrogen levels. Available phosphorus (measured as ortho-phosphorus) was below detection limits for all lake samples.

The TIN:TIP ratios were analyzed (where TIN = sum of all inorganic nitrogen: ammonia+nitrite+nitrate and TIP = ortho-phosphorus), resulting in much lower nitrogen to phosphorus ratios, with an annual mean of 1.18 (Table 3-7). Although Barica (1990) determined that inorganic nitrogen to phosphorus ratios tended to fluctuate more widely than TN:TP ratios between sampling periods in hypereutrophic and eutrophic lakes, Packwood Lake TIN:TIP ratios tended to be more stable between sampling periods and were lower than TN:TP ratios.

Table 3-6. Annual and Seasonal Mean TN:TP ratios 2004
(ratios listed are inclusive of all sampling depths, where applicable)

	Annual Mean	Seasonal Mean		
		Spring	Summer	Fall
Packwood Lake	4.2	4.2	1.4	8.1
Osprey Creek	3.8	5.4	1.2	4.7
Muller Creek	3.5	5.7	1.1	3.7
Upper Lake Creek	3.3	5.4	1.1	4.3
Crawford Creek	3.6	4.8	1.0	3.7

Table 3-7. Annual and Seasonal Mean TIN:TIP ratios 2004
(ratios listed are inclusive of all sampling depths, where applicable)

	Annual Mean	Seasonal Mean		
		Spring	Summer	Fall
Packwood Lake	1.2	1.2	1.1	1.2
Osprey Creek	3.8	1.1	1.1	1.3
Muller Creek	3.5	2.1	1.5	2.2
Upper Lake Creek	3.3	1.3	1.4	1.9
Crawford Creek	3.6	1.1	0.9	2.3

Silica is necessary for diatom growth. Silica levels in Packwood Lake remained fairly constant throughout the growing season (Figure 3-10).

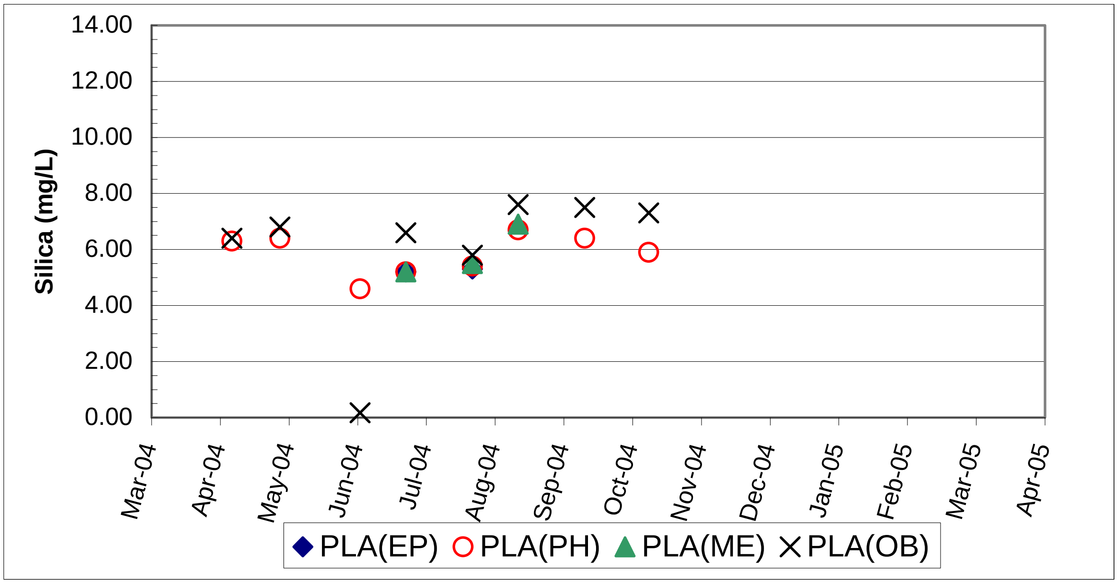

Figure 3-10. Silica levels for Packwood Lake at Site A

Fecal coliform levels were very low throughout the sample period for Packwood Lake with less than 1 colony/100 mL sample. The highest fecal coliform count was sampled on September 1, 2004 following a storm event; the fecal coliform count averaged 27 colonies per 100 mL sample, which is still well below the compliance criteria.

The phytoplankton species community and total phytoplankton biomass are characteristic of an oligotrophic (low primary productivity) lake (Wetzel 1983). Diatoms (bacilliophyta) dominated the algae community throughout the growing season. Phytoplankton biomass and density within the photic zone both peaked in June at approximately 90,000 µm/mL and 2,090 units/mL, respectively. Phytoplankton was at season minimum in late August; biomass was 4,375 µm/mL and density was 18 units/mL. A single, large blue-green algae unit (*Anabaena circinalis*) occurred in one of two samples for the photic zone at site A on August 31, 2004. No blue-green algae were observed in the duplicate sample or at any other location or time in Packwood Lake in 2004. The presence of this single unit of blue-green algae is, therefore, considered an anomaly and is not represented on the charts. Phytoplankton biomass and density had a secondary peak in September that is primarily attributed to Cryptophyta. Figures 3-12 through 3-19 show the seasonal trends in phytoplankton stratified by phyla. Table 3-8 lists the three dominant species (based on biovolume) for each sampling period.

A multiple regression analysis did not show any significant relationships between photic zone Chlorophyll *a* (dependent variable) and other water quality parameters including Secchi depth, Silica, total nitrogen, and total phosphorus. The lack of relationship suggests that different factors may regulate algae growth at different times during the year. Chlorophyll *a* seasonal trends are shown in Figure 3-11.

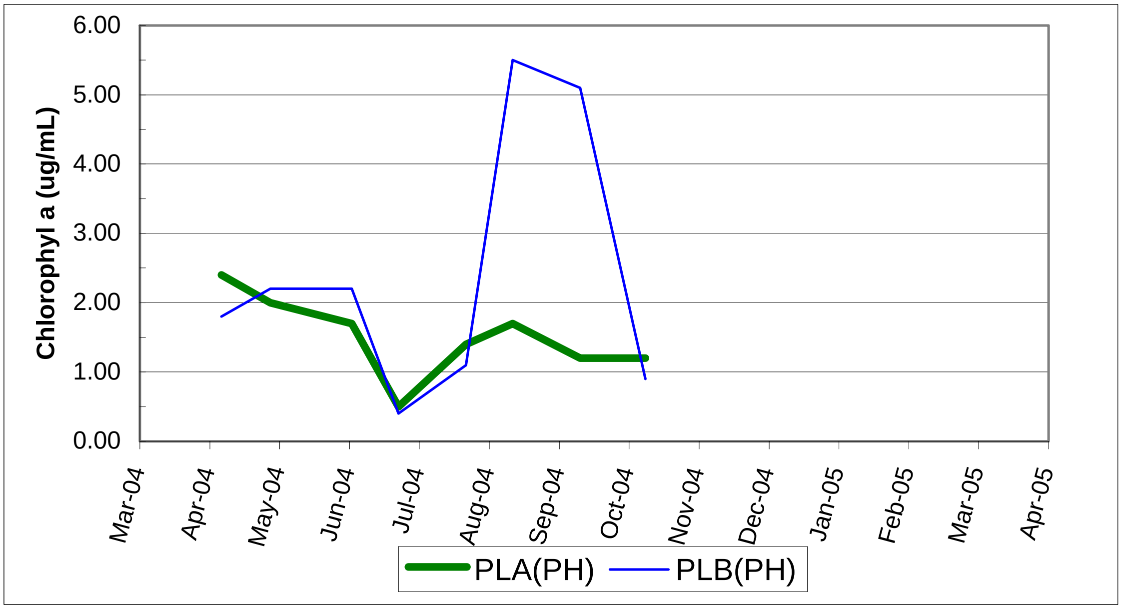

Figure 3-11. Chlorophyll *a* for Packwood Lake

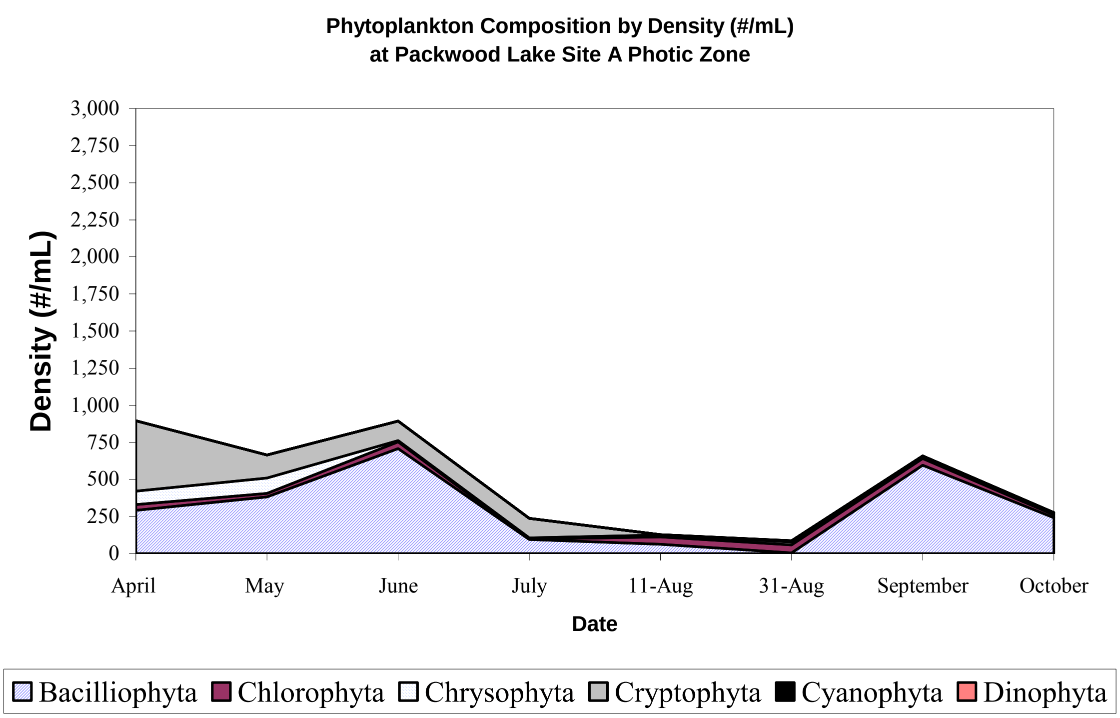

Figure 3-12. Phytoplankton composition density for Packwood Lake photic Zone Site A

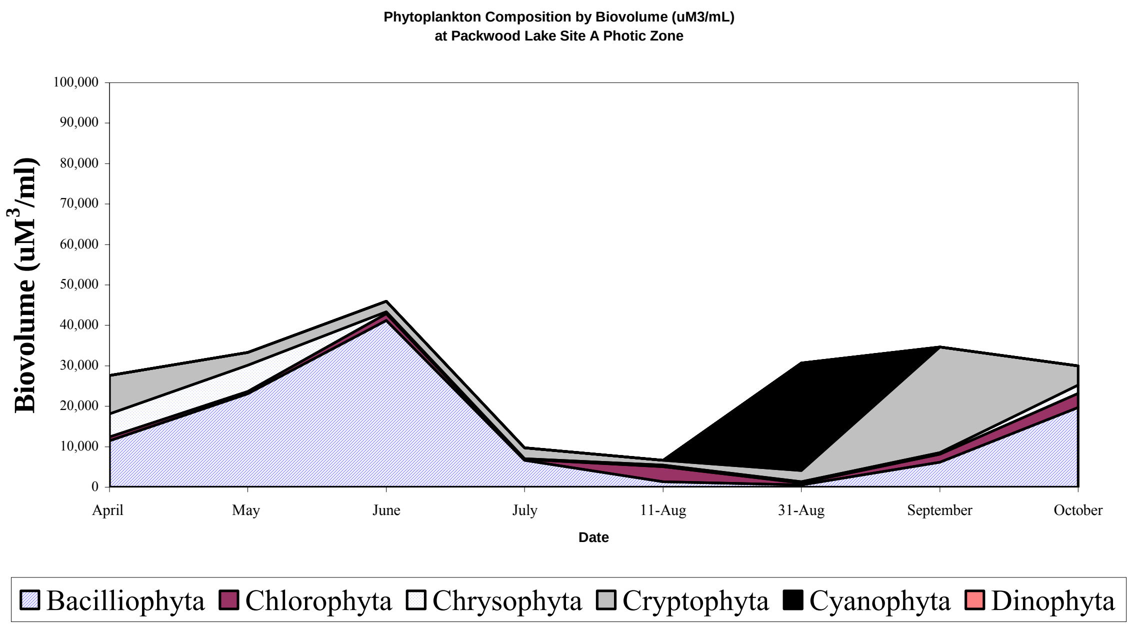

Figure 3-13. Phytoplankton composition biovolume for Packwood Lake photic Zone Site A

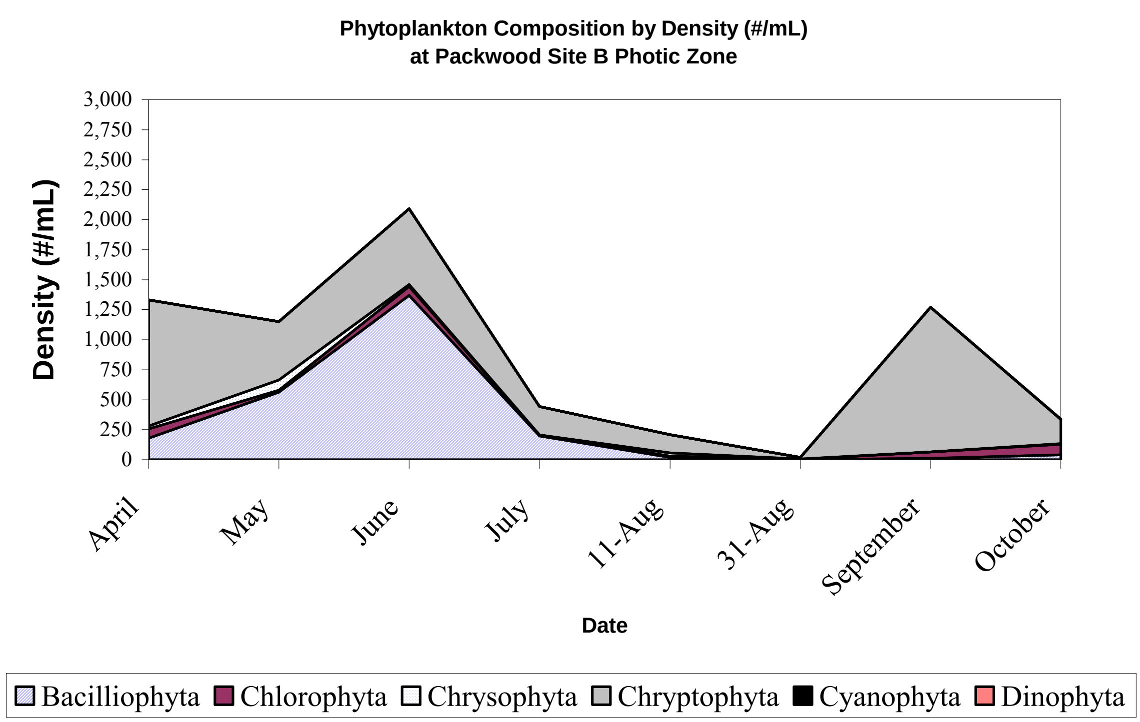

Figure 3-14. Phytoplankton composition density for Packwood Lake photic Zone Site B

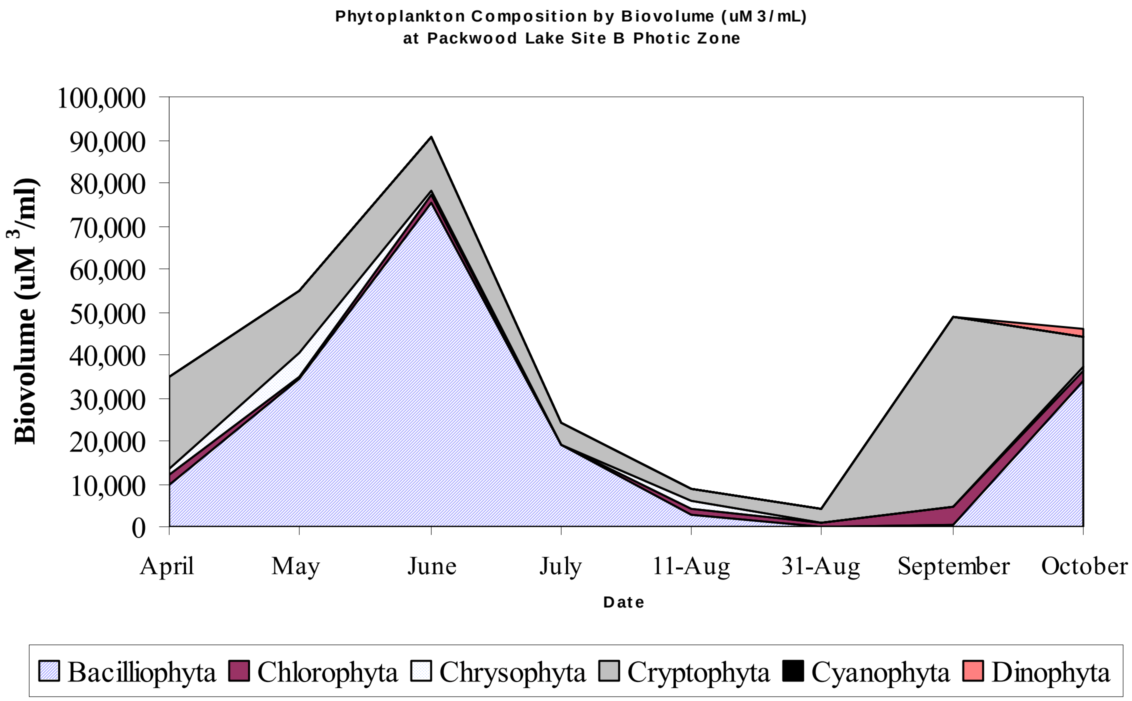

Figure 3-15. Phytoplankton composition biovolume for Packwood Lake photic Zone Site B

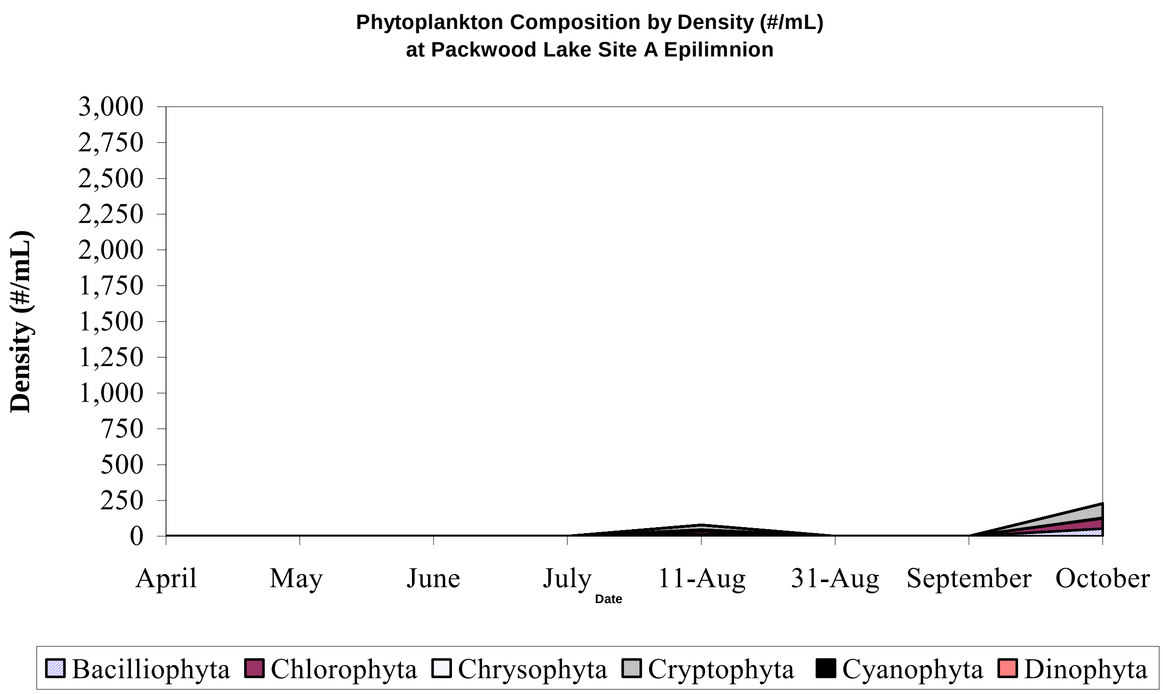

Figure 3-16. Phytoplankton composition density for Packwood Lake epilimnion Site A

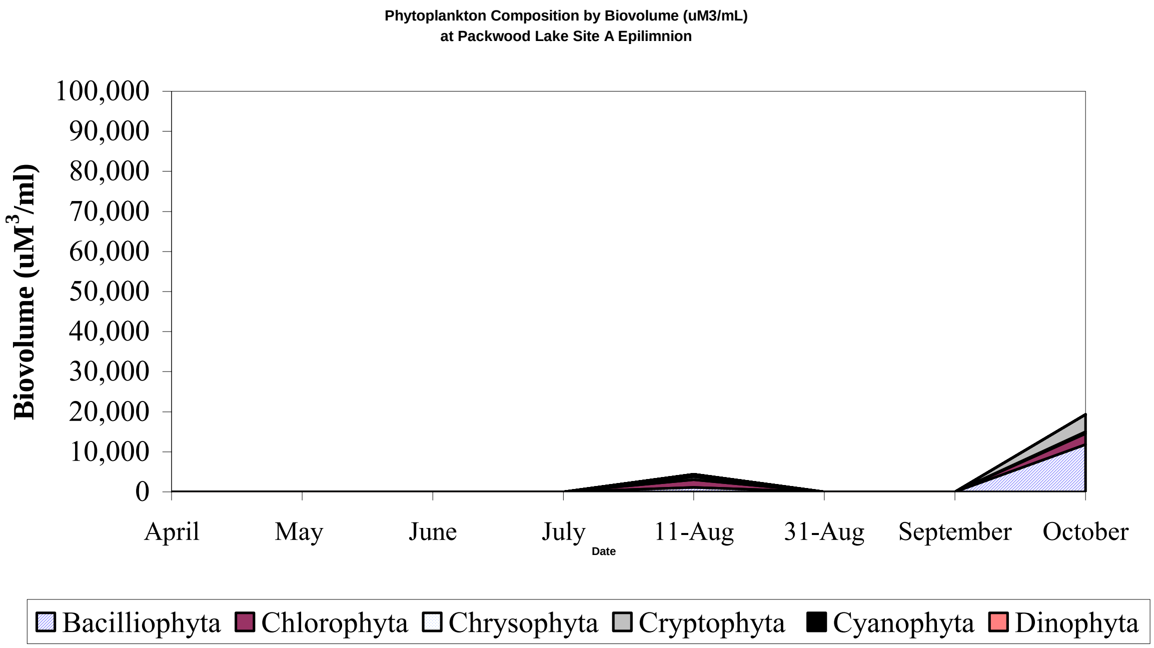

Figure 3-17. Phytoplankton composition biovolume for Packwood Lake epilimnion Site A

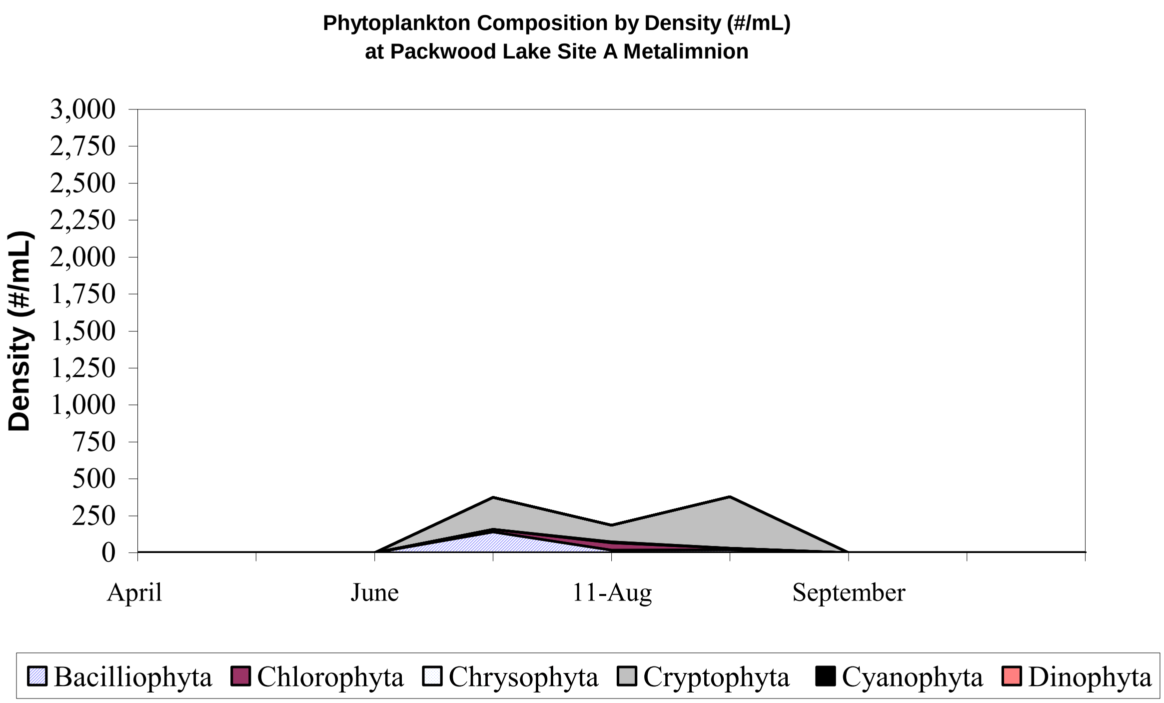

Figure 3-18. Phytoplankton composition density for Packwood Lake metalimnion Site A

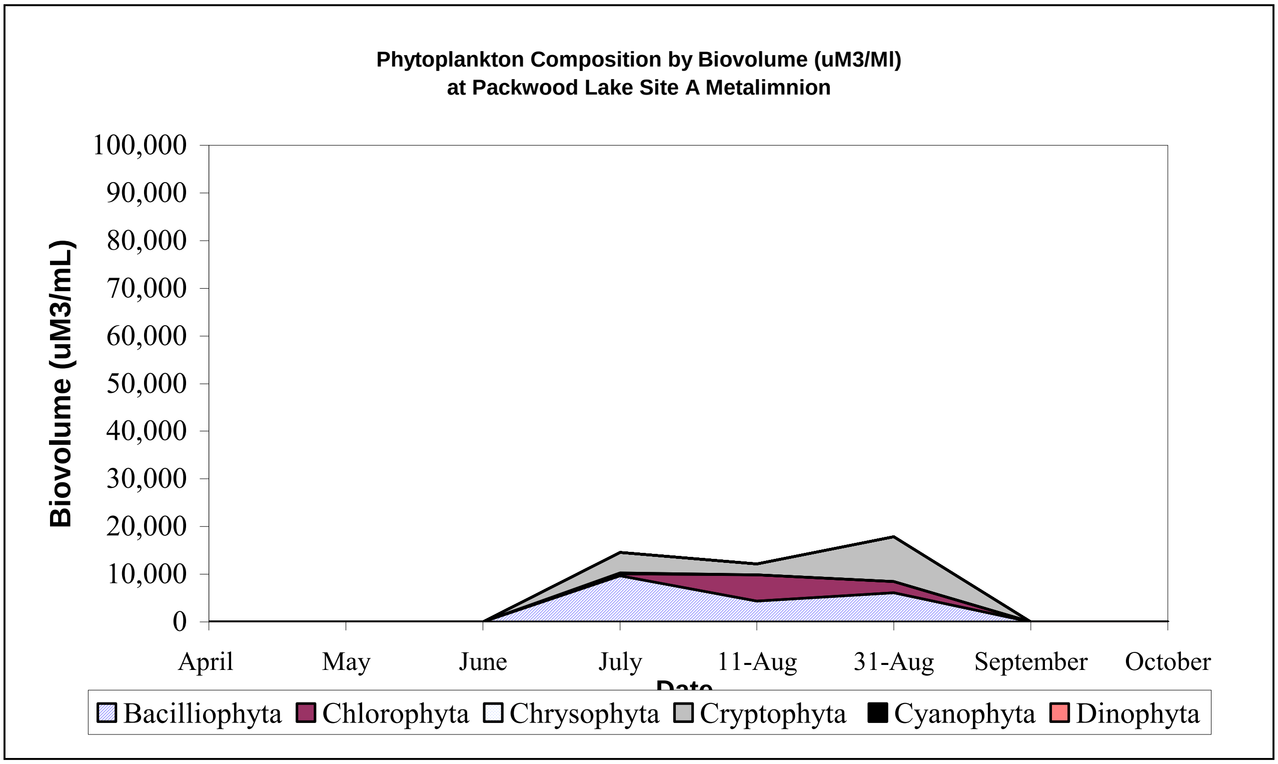

Figure 3-19. Phytoplankton composition biovolume for Packwood Lake metalimnion Site A

Table 3-8. Three dominant phytoplankton species based on biovolume

Packwood Lake site A (Photic zone)				
Date	28-Apr-04	19-May-04	23-Jun-04	13-Jul-04
Bacilliophyta	Cyclotella stelligera	Cyclotella stelligera	Cyclotella stelligera	Cyclotella stelligera
	Diatoma hiemale mesodon	Neidium sp.	Stephanodiscus astraea minutula	Achnanthes minutissima
	Eunotia pectinalis			Synedra rumpens
Chlorophyta	Ankistrodesmus falcatus			Achnanthes minutissima
		Ankistrodesmus falcatus	Ankistrodesmus falcatus	Oocystis pusilla
			Crucigenia quadrata	
Chrysophyta				
	Kephyrion sp.	Kephyrion sp.	Kephyrion spirale	Chromulina sp.
	Kephyrion spirale			
Cryptophyta	Rhodomonas minuta	Rhodomonas minuta	Rhodomonas minuta	Rhodomonas minuta
Cyanophyta				
Dinophyta				
*** Note: Duplicate samples at site.**				
Date	11-Aug-04	31-Aug-04	29-Sep-04	27-Oct-04
Bacilliophyta	Cyclotella stelligera	Navicula contenta biceps	Navicula capitata	Cyclotella stelligera
	Gomphonema angustatum	Cocconeis placentula	Stephanodiscus astraea minutula	Nitzschia frustulum
	Fragilaria construens venter		Achnanthes lanceolata	Stephanodiscus astraea minutula
Chlorophyta	Fragilaria construens venter		Ankistrodesmus falcatus	Oocystis pusilla
	Ankistrodesmus falcatus	Ankistrodesmus falcatus	Crucigenia quadrata	Ankistrodesmus falcatus
	Oocystis pusilla	Chlamydomonas sp.		
Chrysophyta	Crucigenia quadrata		Kephyrion spirale	Dinobryon sertularia
	Kephyrion spirale	Kephyrion sp.		
	Chromulina sp.	Kephyrion littorale		
Cryptophyta		Rhodomonas minuta	Cryptomonas erosa	Cryptomonas erosa
		Cryptomonas erosa	Rhodomonas minuta	Rhodomonas minuta
Cyanophyta		Anabaena circinalis		
Dinophyta				
Euglenaphyta				

Table 3-8. Three dominant phytoplankton species based on biovolume				
Packwood Lake site B (Ph)				
Date	28-Apr-04	19-May-04	23-Jun-04	13-Jul-04
Bacilliophyta	Cyclotella stelligera	Cyclotella stelligera	Cyclotella stelligera	Cyclotella stelligera
		Cocconeis placentula		Eunotia pectinalis
		Achnanthes minutissima		Gomphonema subclavatum
Chlorophyta	Ankistrodesmus falcatus	Ankistrodesmus falcatus	Ankistrodesmus falcatus	Ankistrodesmus falcatus
Chrysophyta	Kephyrion sp.	Kephyrion sp.	Kephyrion sp.	
	Kephyrion littorale	Kephyrion littorale		
Cryptophyta	Rhodomonas minuta	Rhodomonas minuta	Rhodomonas minuta	Rhodomonas minuta
		Cryptomonas erosa		
Cyanophyta				
Dinophyta				
Euglenaphyta				
Date	11-Aug-04	31-Aug-04	29-Sep-04	27-Oct-04
Bacilliophyta	Stephanodiscus astraea minutula	Gomphonema sp.	Cyclotella stelligera	Stephanodiscus niagarae
	Navicula rhynchocephala	Cyclotella stelligera		Stephanodiscus astraea minutula
	Cyclotella stelligera			Nitzschia palea
Chlorophyta	Sphaerocystis schroeteri	Oocystis sp.	Ankistrodesmus falcatus	Ankistrodesmus falcatus
	Oocystis pusilla	Sphaerocystis schroeteri	Sphaerocystis schroeteri	Crucigenia quadrata
	Crucigenia quadrata			
		Oocystis pusilla	Crucigenia quadrata	
Chrysophyta	Kephyrion sp.	Kephyrion littorale		Dinobryon sertularia
	Kephyrion spirale			
Cryptophyta	Rhodomonas minuta	Cryptomonas erosa	Rhodomonas minuta	Rhodomonas minuta
		Cryptomonas sp.	Cryptomonas erosa	Cryptomonas erosa
		Rhodomonas minuta		
Cyanophyta				
Dinophyta				Glenodinium sp.

3.3 Tributaries to Packwood Lake

Water quality was monitored at the mouth of four tributaries flowing into Packwood Lake. Discharge measurements were made at each of the monthly monitoring trips; however, accurate flow measurements for Upper Lake Creek were hindered by the multiple-braided channel pattern of this tributary. The tributaries monitored include Osprey, Muller, upper Lake, and Crawford creeks (Figure 2-1). Upper Lake Creek is considerably larger than any of the other tributaries and provides the majority of inflow into Packwood Lake. Upper Lake Creek drains glaciers at its headwater so it carries a high suspended sediment load causing high turbidity during the spring snowmelt and early summer.

Mean annual values for measured water quality parameters for tributaries to Packwood Lake are reported in Table 3-9. Figures 3-20 through 3-29 show the seasonal trend in water quality for these tributaries. Dissolved oxygen was the only water quality criteria exceeded for the tributaries during the period monitored. Upper Lake Creek was the only one of the four monitored tributaries to the lake that dissolved oxygen readings remained above the criteria of 9.5 mg/L. All dissolved oxygen measurements in the tributaries exceeded 9.0 mg/L. The tributaries are characterized as cold water streams and low in nutrients. They are nitrogen limited relative to phosphorus as indicated by low TN:TP ratios. Nearly all of the nitrogen is in the organic form (TKN) and is not available for biological uptake. Inorganic nitrogen was at or below detection limits for all samples. Orthophosphorus was also below detection limits for all samples.

Table 3-9. Mean annual values for water quality parameters for tributaries to Packwood Lake, 2004

	pH	Turbidity (NTU)	Sp. Conductance (uS/cm)	Alkalinity, Bicarbonate as CaCO3 (mg/L)	Total Alkalinity (mg/L)	Hardness (mg/L)
Crawford	7.55	0.92	0.0262	21.8	21.8	17.6
Osprey	7.14	1.01	0.0108	18.0	18.0	8.7
Upper Lake	7.31	14.11	0.0290	22.4	22.4	21.8
Muller	7.22	2.50	0.0322	24.7	24.7	21.3
	Silica (mg/L)	Total Dissolved Solids (TDS) (mg/L)	Total Suspended Solids (TSS) (mg/L)	Ammonia as N (mg/L)	Nitrite as N (mg/L)	Nitrate + Nitrite as N (mg/L)
Crawford	5.18	32.40	1.40	0.023	0.02	0.042
Osprey	11.81	42.25	1.56	0.020	0.02	0.021
Upper Lake	4.92	35.40	15.90	0.020	0.02	0.045
Muller	7.63	41.17	5.20	0.019	0.02	0.063
	Phosphate, Ortho as P (mg/L)	Phosphorus, Total (mg/L)	Total Kjeldahl Nitrogen (TKN) (mg/L)	Total Organic Carbon (TOC) (mg/L)	TN:TP	TIN:TIP
Crawford	0.050	0.015	0.083	0.960	3.593	1.508
Osprey	0.050	0.023	0.125	1.117	3.762	1.163
Upper Lake	0.050	0.027	0.075	0.333	3.278	1.600
Muller	0.050	0.030	0.120	0.883	3.473	1.929

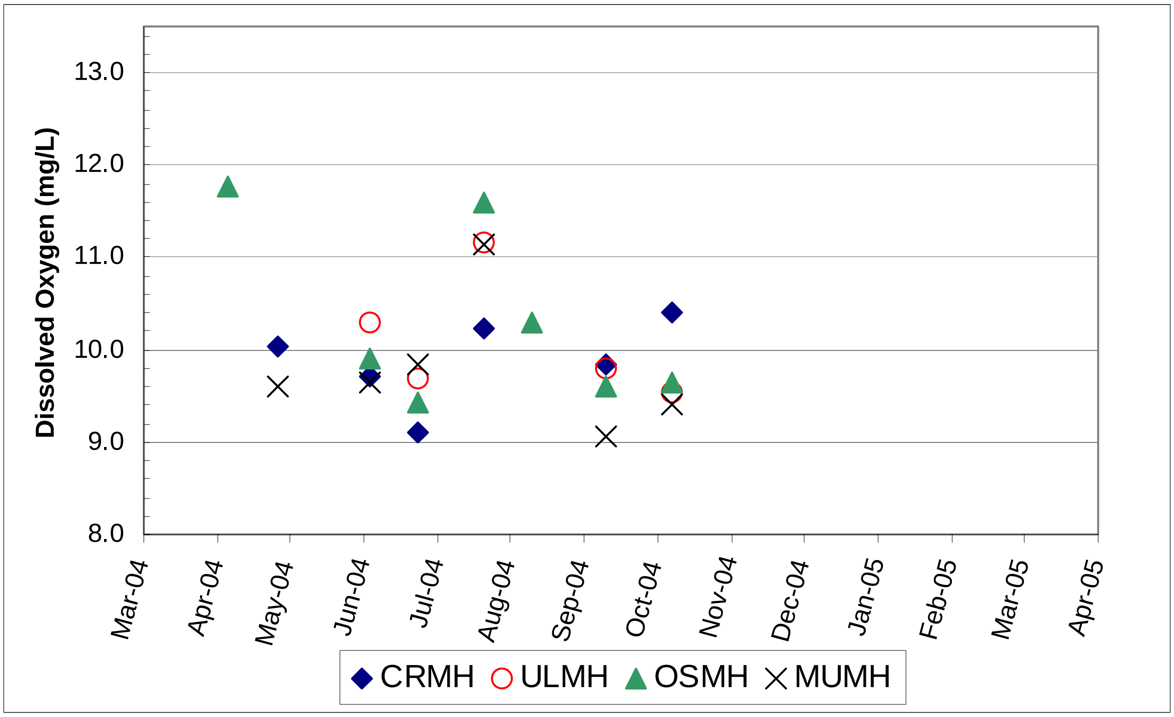

Figure 3-20. Dissolved oxygen for tributaries to Packwood Lake

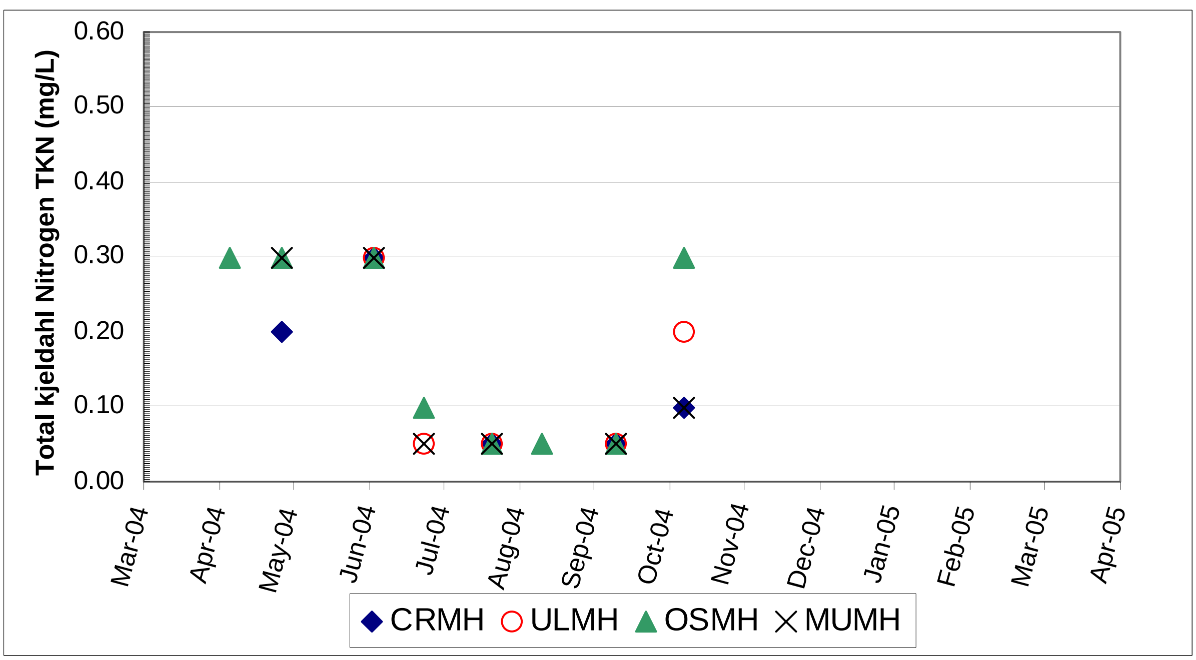

Figure 3-21. Total Kjeldahl nitrogen TKN for tributaries to Packwood Lake

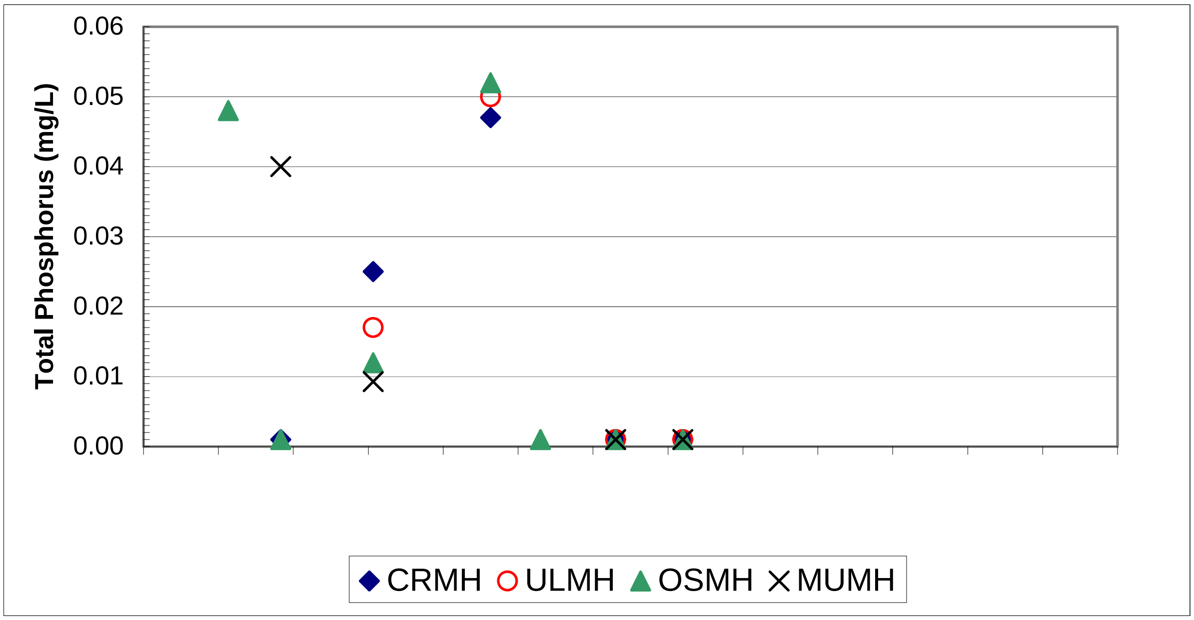

Figure 3-22. Total phosphorus for tributaries to Packwood Lake

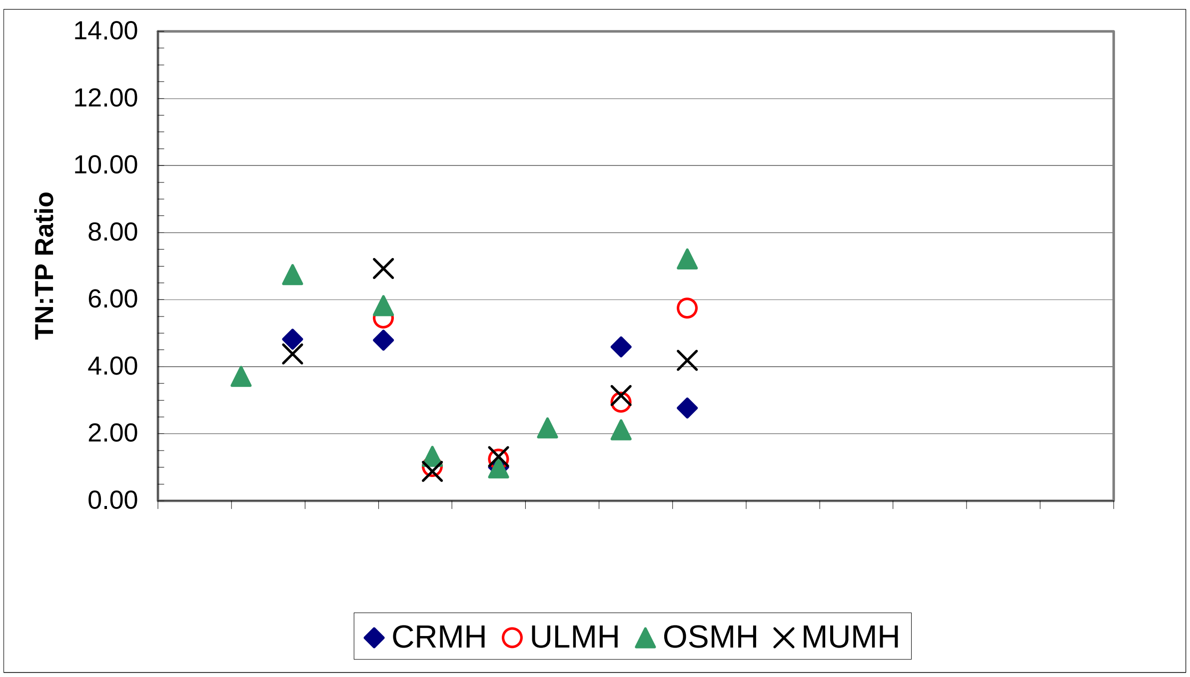

Figure 3-23. Total nitrogen to total phosphorus ratios for tributaries to Packwood Lake

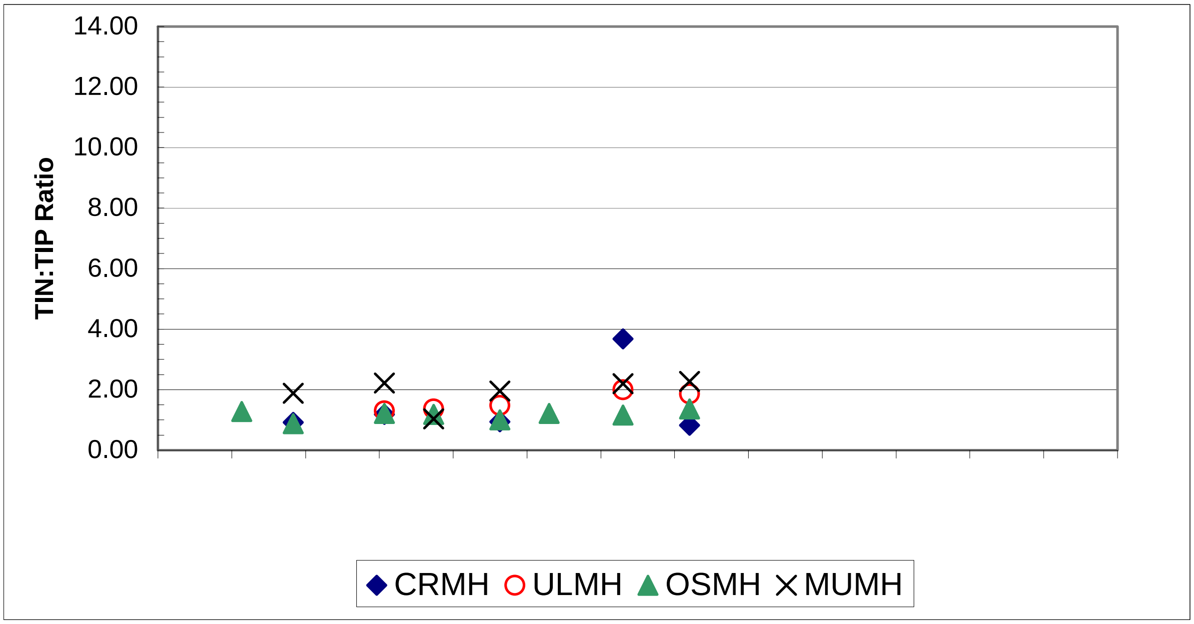

Figure 3-24. Total inorganic nitrogen to total inorganic phosphorus ratios for tributaries to Packwood Lake

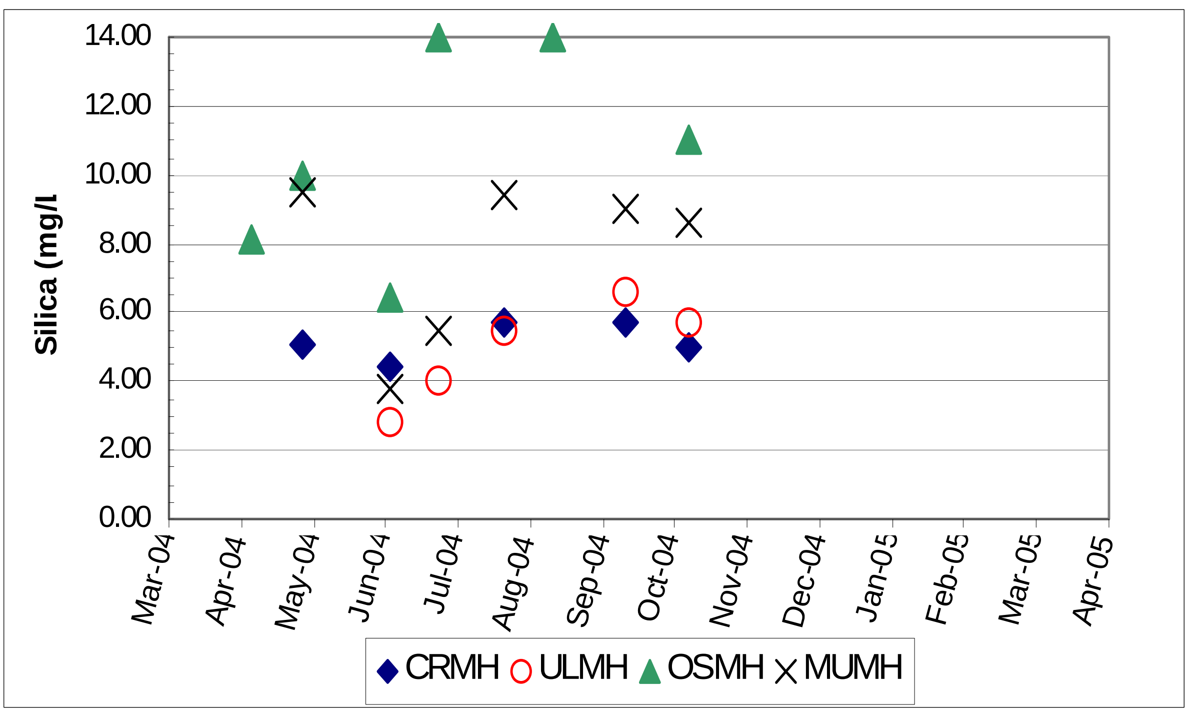

Figure 3-25. Silica for tributaries to Packwood Lake

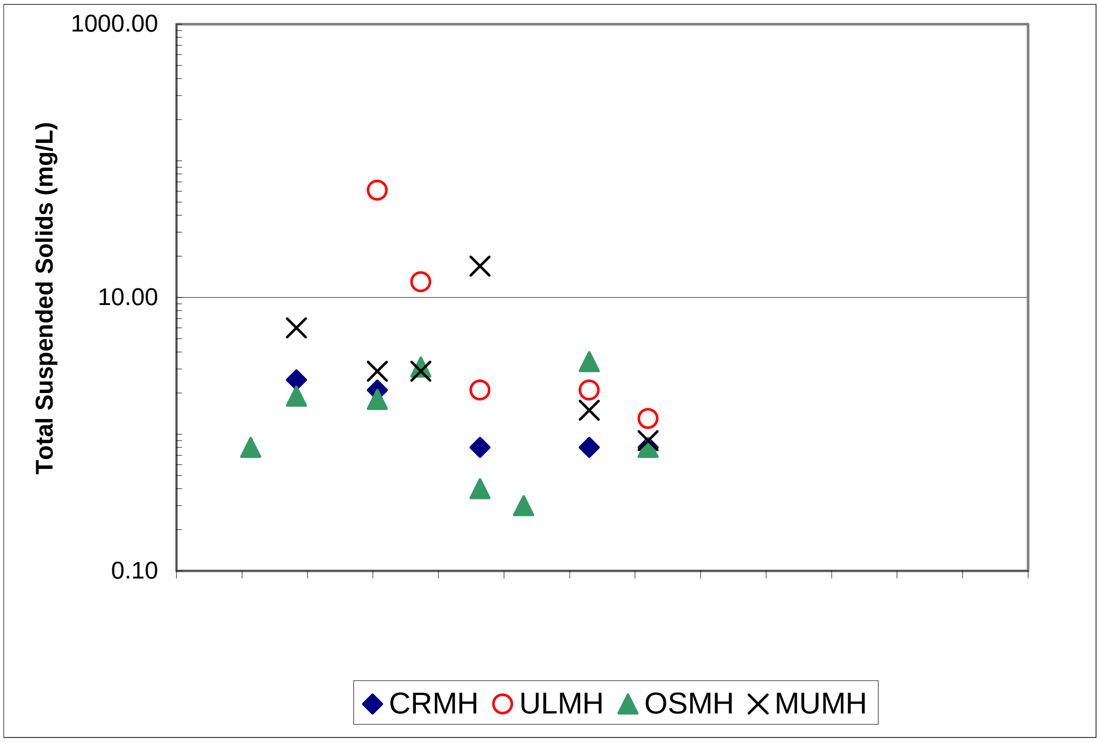

Figure 3-26. Total suspended solids for tributaries to Packwood Lake

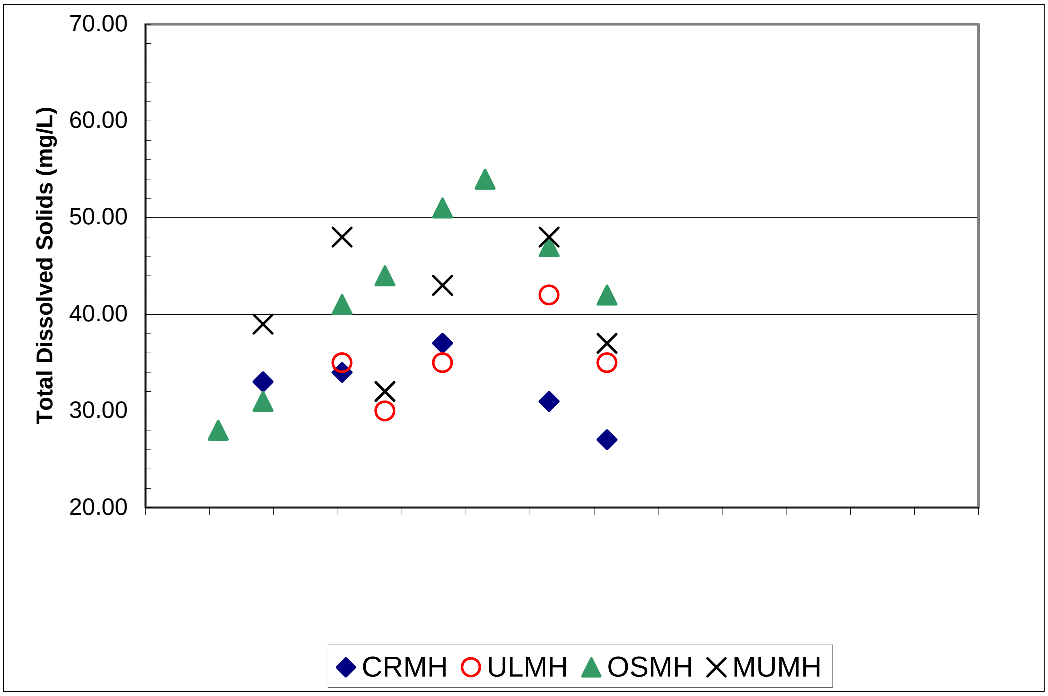

Figure 3-27. Total dissolved solids for tributaries to Packwood Lake

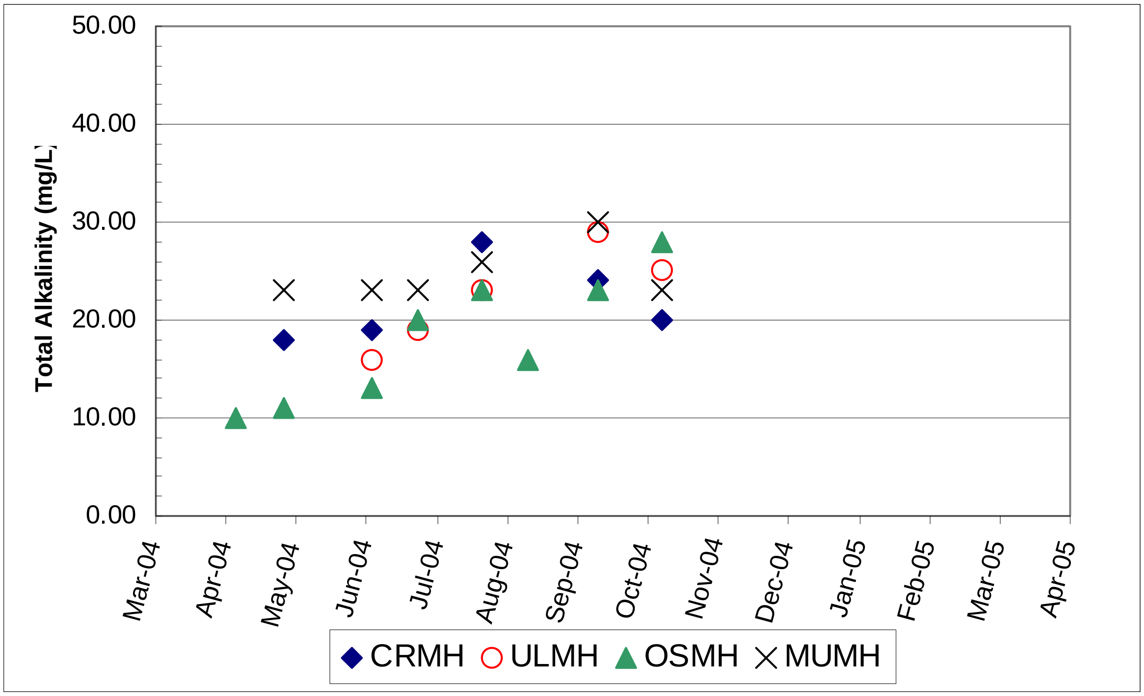

Figure 3-28. Total Alkalinity for tributaries to Packwood Lake

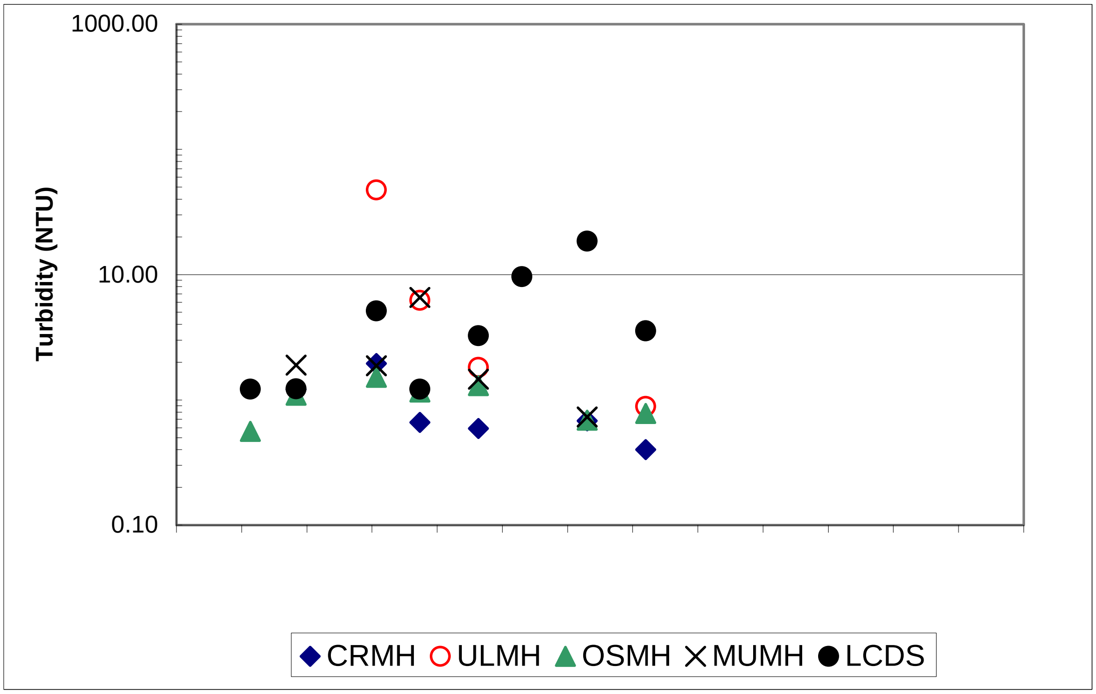

Figure 3-29. Turbidity for tributaries to Packwood Lake compared to lake outlet (LCDS)

3.4 Lake Creek and Cowlitz River Upstream of Lake Creek

Water quality was monitored at two locations downstream of Packwood Lake; station LCDS is immediately downstream of the drop structure and station LCMH is at the mouth of Lake Creek. Water quality was also monitored in the Cowlitz River just upstream of the confluence with Lake Creek. When no spill over the drop structure occurs, the flow in lower Lake Creek is from accretion except for the minimum 3 cfs fish flow release from Packwood Lake. The sampling event at the end of August 2004 coincided with the release flow of approximately 30 cfs for the instream flow study. Water quality downstream of the drop structure was not monitored during winter months due to access limitations. Mean annual values for water quality parameters in lower Lake Creek are listed in Table 3-10.

Dissolved oxygen was the only water quality criteria exceeded in lower Lake Creek; exceedences occurred at all sites. Dissolved oxygen was consistently higher at the mouth of Lake Creek relative to just downstream of the drop structure, which is consistent with colder water temperatures near the mouth. Continuous monitoring of dissolved oxygen for the period August 31 through September 2, 2004 showed little diurnal variability. Weather during this period was cool with rain so diurnal patterns may have been muted. Essentially no diurnal variation was observed for dissolved oxygen at the mouth of Lake Creek. A minor decline in dissolved oxygen levels was recorded during the night for Lake Creek below the drop structure (Figure 3-31).

Water depth is insufficient to reliably measure total dissolved gas (TDG) in Lake Creek downstream of the drop structure. Although data should be considered suspect, all readings for monthly sampling were 100% saturation or less. Measurements in the lake in front of the intake where depth was sufficient to measure TDG,also indicated saturation was 100% or less.

Water pH in Lake Creek is neutral to very slightly basic (range 6.87 – 7.89). No diurnal variability in pH was observed in Lake Creek during the continuous monitoring at the end of August 2004.

Nutrients are relatively low and nitrogen is limiting relative to phosphorus. Figures 3-30 through 3-40 show seasonal trends for water quality constituents. Turbidity was consistently lower at the mouth than just below the drop structure except in July when the turbidity at the mouth (4.76 NTU) was elevated due to release of the mid flow (16 cfs release) for the instream flow study.

Water samples from Lake Creek just downstream of the drop structure (LCDS) were also analyzed for fats, oils and grease (FOG) as well as petroleum and fuel products (NWTPH-HCID). All samples were below detection limits for these parameters.

Outflow from a drain that collects groundwater from along the flowline was sampled as a surrogate for groundwater (GW1). There was very little seasonal variation for water quality parameters analyzed for GW1. Mean annual values for water quality parameters analyzed for GW1 are reported in Table 3-10. Data for GW1 are not shown in charts since there was very little monthly variability.

Table 3-10. Mean annual values for water quality parameters for lower Lake Creek 2004

	pH	Turbidity (NTU)	Sp. Conductance (uS/cm)	Alkalinity, Bicarbonate as CaCO3 (mg/L)	Total Alkalinity (mg/L)	Hardness (mg/L)
LCDS	7.52	5.46	0.0273	23.3	23.3	22.0
LCMH	7.44	3.12	0.0371	30.6	30.6	27.0
CRULC	7.12	25.94	0.0207	20.2	20.2	19.2
GW1	6.67	NA	0.0091	19.5	19.5	14
	Silica (mg/L)	Total Dissolved Solids (TDS) (mg/L)	Total Suspended Solids (TSS) (mg/L)	Ammonia as N (mg/L)	Nitrite as N (mg/L)	Nitrate + Nitrite as N (mg/L)
LCDS	5.71	39.38	4.15	0.021	0.02	0.015
LCMH	7.42	47.50	4.18	0.019	0.02	0.060
CRULC	5.60	36.83	45.71	0.023	0.02	0.029
GW1	10.48	40.75	0.70	0.022	0.02	0.11
	Phosphate, Ortho as P (mg/L)	Phosphorus, Total (mg/L)	Total Kjeldahl Nitrogen (TKN) (mg/L)	Total Organic Carbon (TOC) (mg/L)	TN:TP	TIN:TIP
LCDS	0.050	0.014	0.163	0.814	12.394	1.040
LCMH	0.050	0.017	0.083	0.995	5.110	1.933
CRULC	0.050	0.019	0.091	0.883	3.354	1.340
GW1	0.050	0.029	0.10	0.25	2.898	0.7

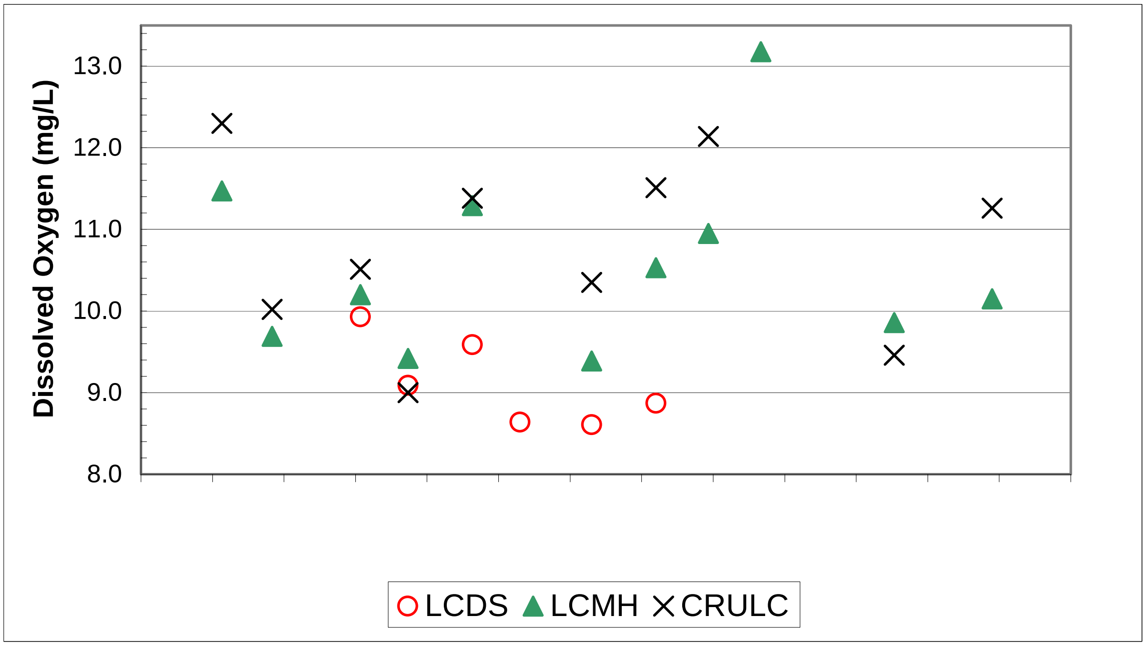

Figure 3-30. Dissolved oxygen for lower Lake Creek

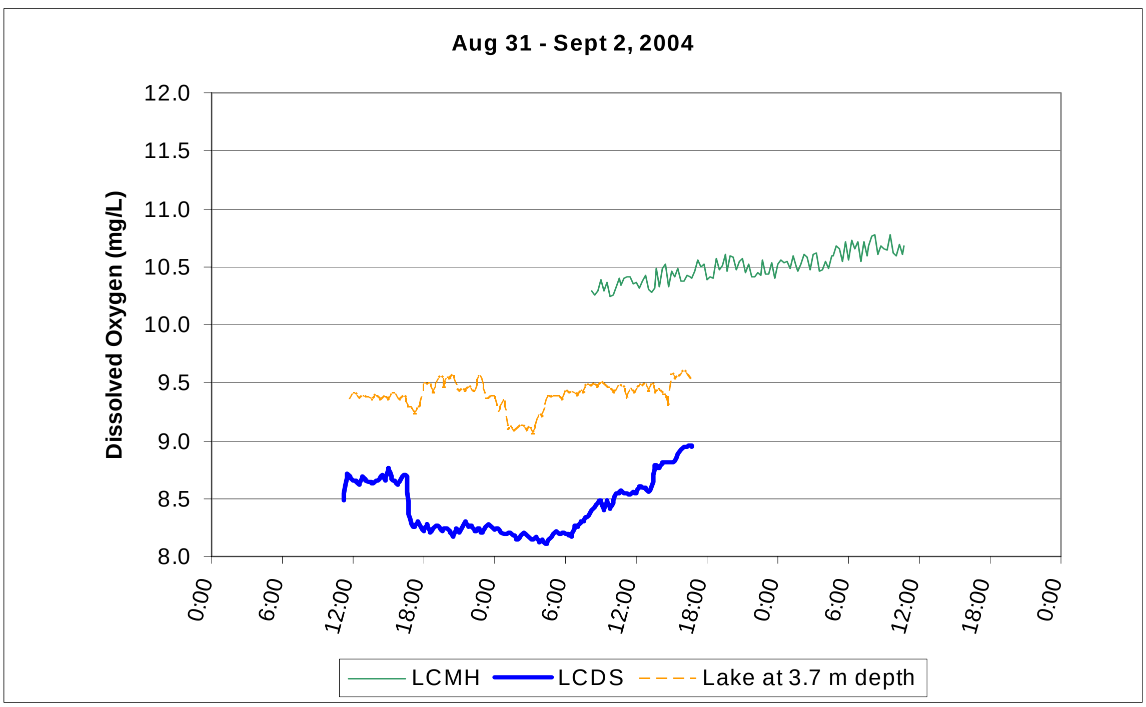

Figure 3-31. Diurnal dissolved oxygen patterns for August 31 through September 2, 2004. (Data are 15-minute interval Hydrolab data.)

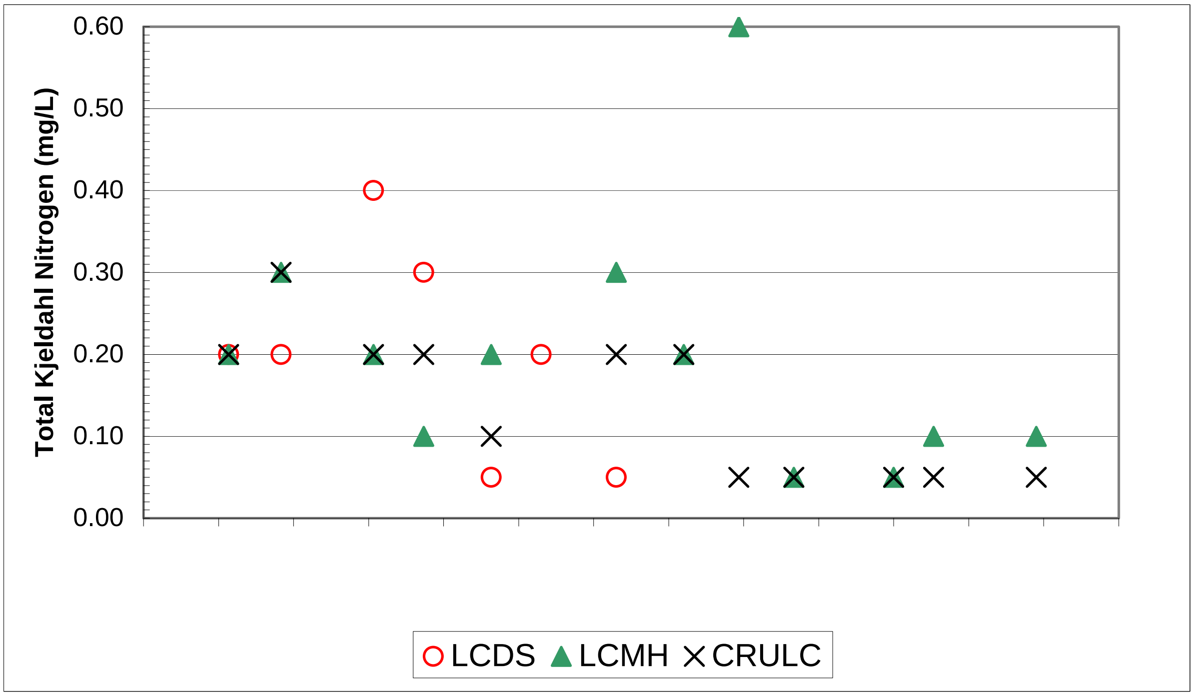

Figure 3-32. Total Kjeldahl nitrogen TKN for lower Lake Creek

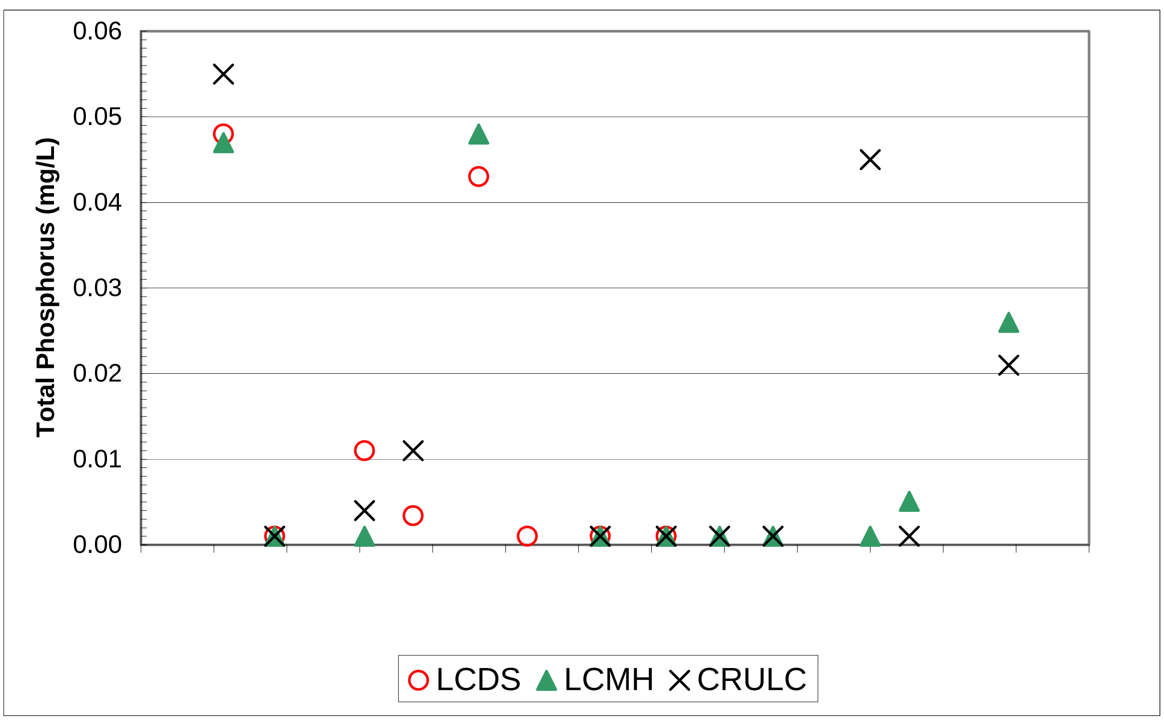

Figure 3-33. Total phosphorus for lower Lake Creek

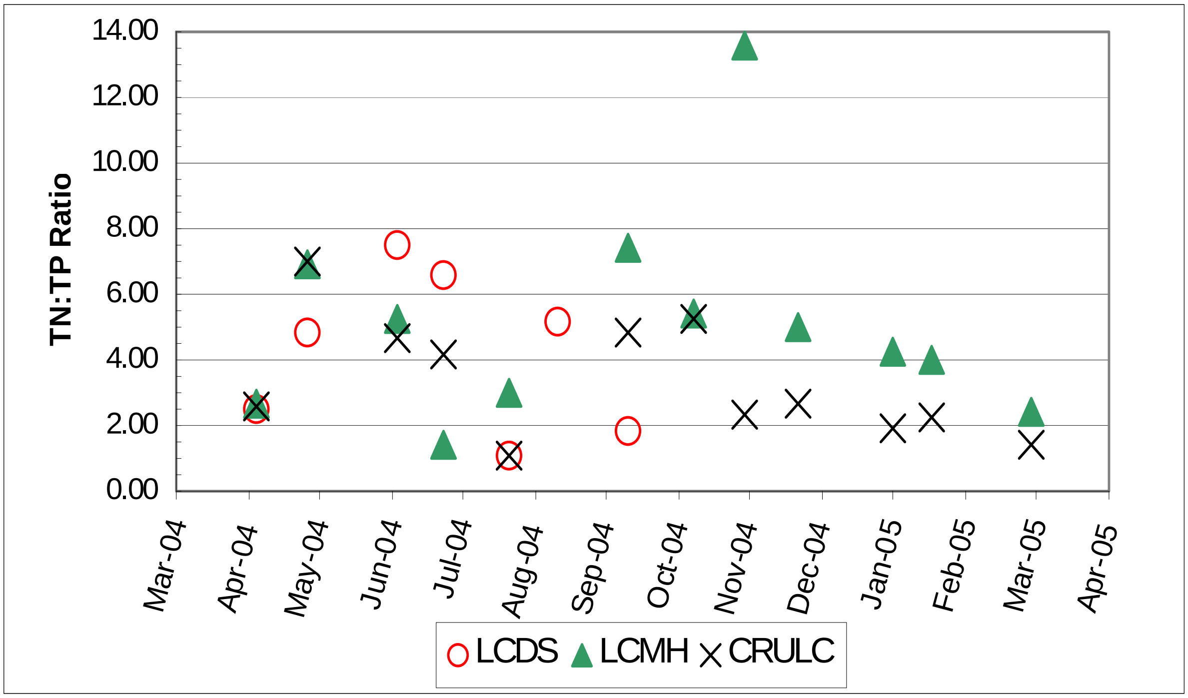

Figure 3-34. Total nitrogen to total phosphorus ratios for lower Lake Creek

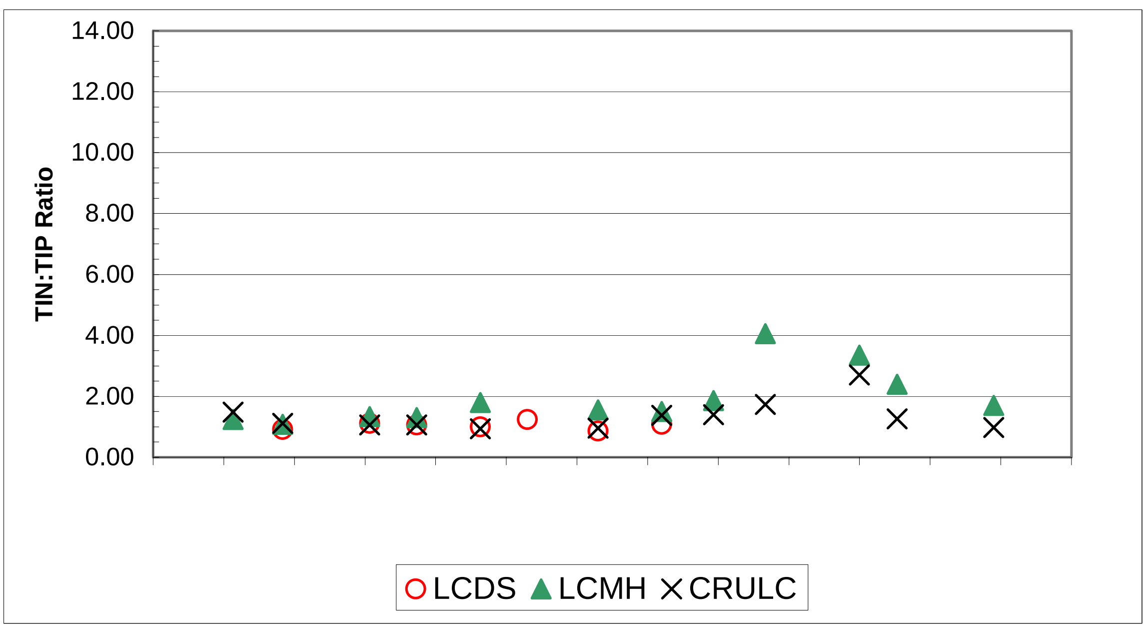

Figure 3-35. Total inorganic nitrogen to total inorganic phosphorus ratios for lower Lake Creek

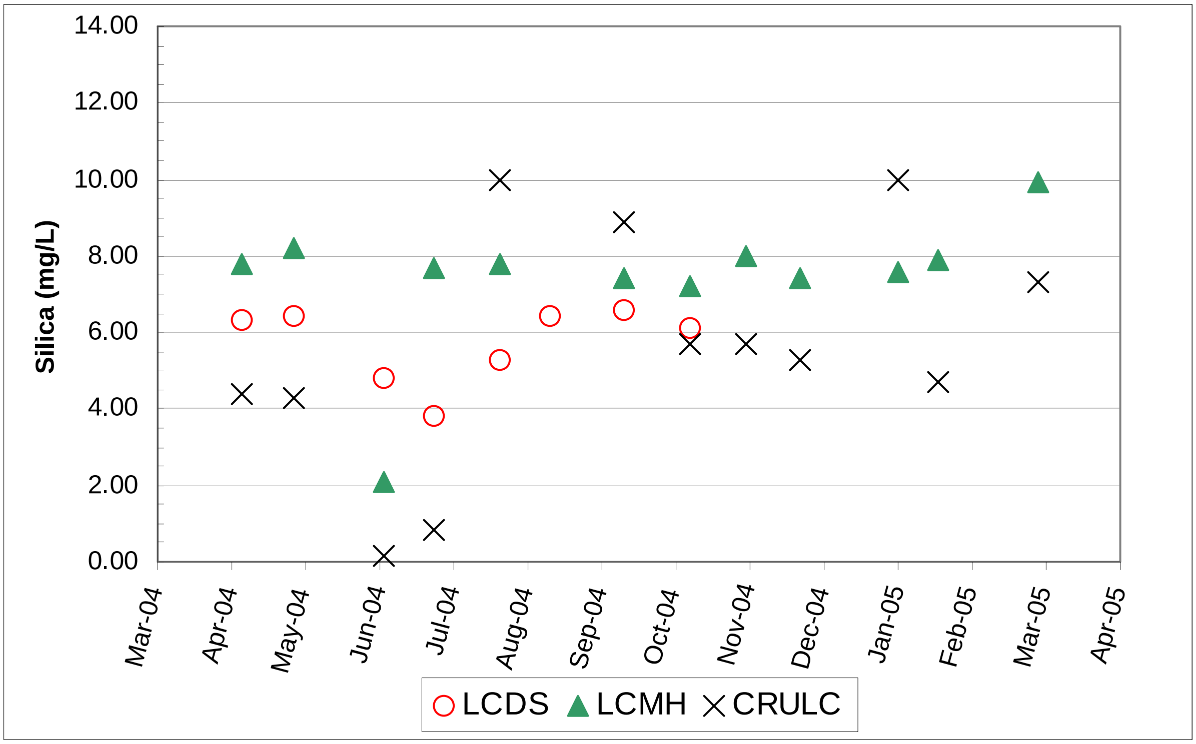

Figure 3-36. Silica for lower Lake Creek

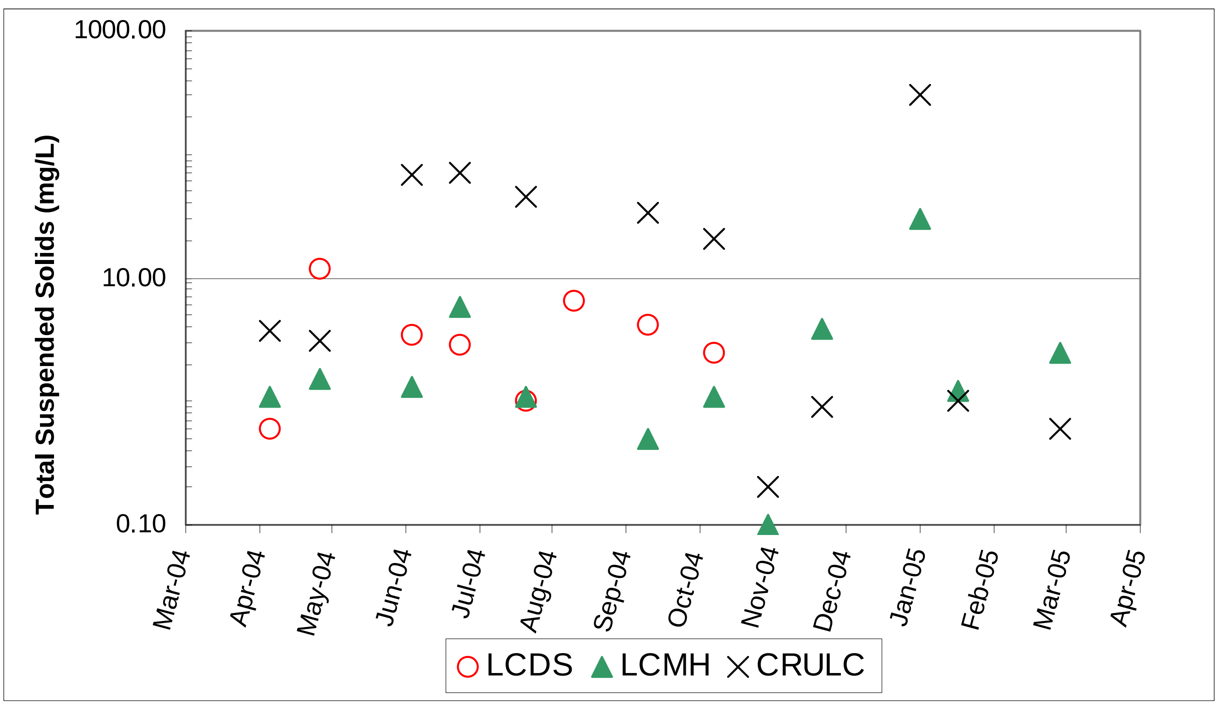

Figure 3-37. Total suspended solids for lower Lake Creek

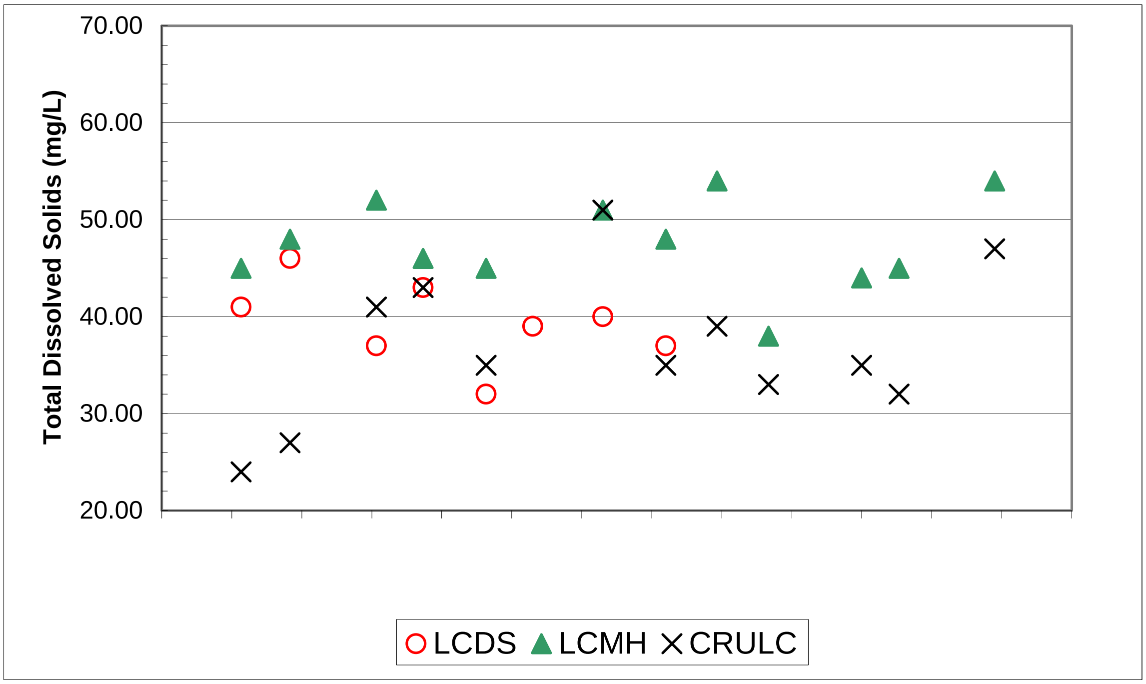

Figure 3-38. Total dissolved solids for lower Lake Creek

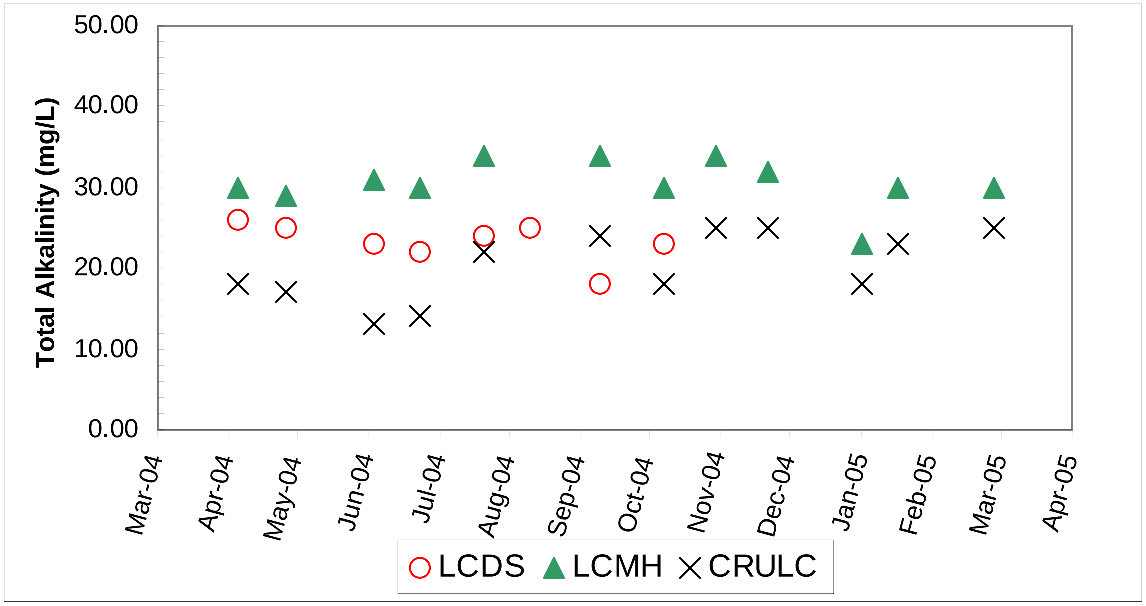

Figure 3-39. Total Alkalinity for lower Lake Creek

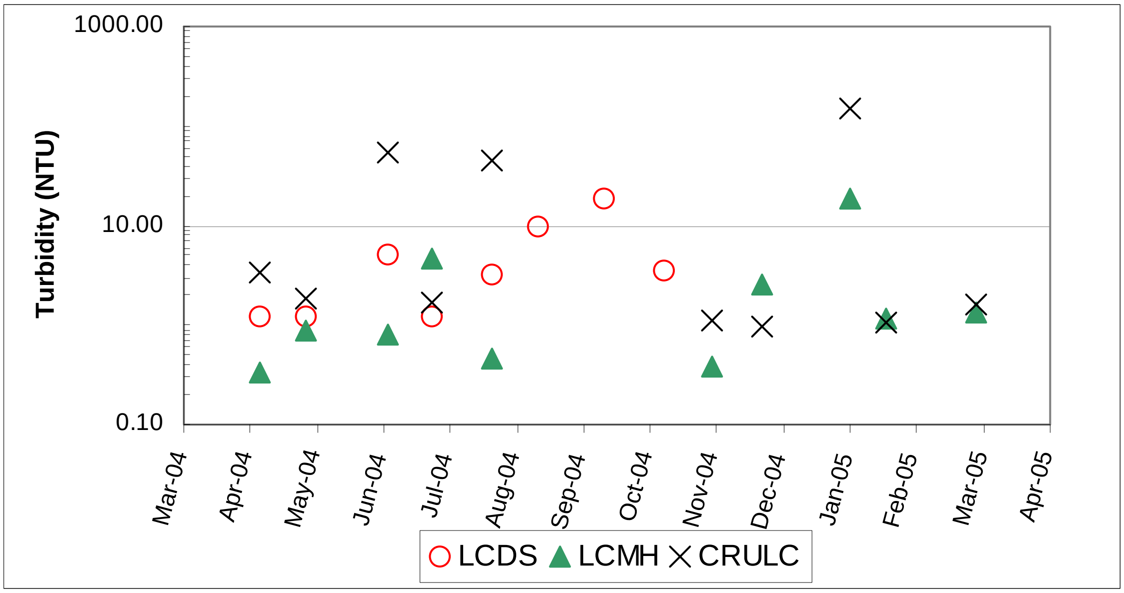

Figure 3-40. Turbidity for lower Lake Creek

3.5 Tailrace and Cowlitz River Downstream of Tailrace

Water quality in the tailrace was monitored at the lower end of the lined tailrace (POWT2) and at the outflow of the stilling basin (POWT1), which is immediately downstream of the powerhouse. Water quality was also monitored in the side channel of the Cowlitz River into which the tailrace discharges. Data are not available for the lower end of the tailrace for October since no flow occurred in the tailrace during this month due to Project shutdown. Flow in the side channel is partially from the Cowlitz River and partially from the Project tailrace when the Project is operating.

The side channel geometry and flow pattern was dramatically altered by flood events in December 2004 and January 2005. Flows in the upper Cowlitz River at Packwood increased by over an order of magnitude from December 9 to December 11, 2004, when river flows were increased from 1,050 cfs to 12,800 cfs. As a result of this event, the Cowlitz River changed course in the vicinity of the tailrace side channel and reconnected a previously dormant side channel below the tailrace terminus. Subsequently, another high flow event occurred in January 2005. Preliminary analysis indicates that about 20% of the upper Cowlitz River is now directed through this side channel.

Mean annual values for water quality parameters for the tailrace and tailrace slough are listed in Table 3-11.

Table 3-11. Mean annual values for water quality parameters for the tailrace

	pH	Turbidity (NTU)	Sp. Conductance (uS/cm)	Alkalinity, Bicarbonate as CaCO3 (mg/L)	Total Alkalinity (mg/L)	Hardness (mg/L)
POWT1	7.25	3.21	0.0294	26.8	27.0	23.3
POWT2	7.44	2.74	0.0272	24.8	24.8	22.6
CRTSC	7.25	26.79	0.0261	23.0	23.0	21.3
	Silica (mg/L)	Total Dissolved Solids (TDS) (mg/L)	Total Suspended Solids (TSS) (mg/L)	Ammonia as N (mg/L)	Nitrite as N (mg/L)	Nitrate + Nitrite as N (mg/L)
POWT1	5.89	44.15	1.58	0.026	0.02	0.025
POWT2	5.76	39.82	1.86	0.022	0.02	0.025
CRTSC	7.56	40.00	85.27	0.029	0.02	0.027
	Phosphate, Ortho as P (mg/L)	Phosphorus, Total (mg/L)	Total Kjeldahl Nitrogen (TKN) (mg/L)	Total Organic Carbon (TOC) (mg/L)	TN:TP	TIN:TIP
POWT1	0.050	0.015	0.082	0.948	4.724	1.154
POWT2	0.050	0.019	0.150	1.251	4.097	1.169
CRTSC	0.052	0.029	0.145	1.015	3.622	1.248

Dissolved oxygen levels were below the criteria of 9.5 mg/L in the tailrace in May, July, February, and March. Dissolved oxygen levels in the tailrace side channel were below the criteria of 9.5 mg/L in July, September, October, February, and March. The lowest dissolved oxygen levels were recorded in July 2004. Turbidity in the tailrace was equal or less than turbidity in the receiving side channel of the Cowlitz River. Charts showing water quality trends in the tailrace for various parameters are provided in Figures 3-41 through 3-53.

Organic nitrogen (TKN) was elevated in May within the tailrace (0.6 mg/L at POWT1); the cause is unknown. Phosphorus trends in the tailrace were similar to those for Packwood Lake near the intake. Nitrogen is limiting relative to phosphorus for tailrace waters. Although, periphyton growth was not quantified in the tailrace, productivity did not visually appear excessive. Growth was patchy with short, dense mats in some locations. Artificial substrates were placed in the tailrace for the purpose of collecting periphyton samples; however, recreationists removed the concrete blocks so no periphyton sampling was completed.

Water samples from the upper end of the tailrace were also analyzed for fats, oils and grease (FOG) as well as petroleum and fuel products (NWTPH-HCID). All samples were below detection limits for these parameters

Water quality in the tailrace stilling basin (upper end of the tailrace; POWT1) was also continuously monitored seasonally to assess diurnal trends. A hydrolab was deployed in the stilling basin for the periods March 17-25, July 14-27, September 29-October 12, October 27 – November 1, 2004. The latter two periods encompassed Project shutdown and startup. Water temperature data including diurnal trends are reported in EESC (2005) and are also provided as Appendix A to this report. Water temperature at the upper end of the tailrace is primarily a function of lake temperature at the intake and diurnal variation is relatively small. pH varied only minimally on a diurnal basis. The range in pH during the continuous monitoring in July was 7.38 – 7.7. The diurnal range in pH for other periods of continuous monitoring was less than 0.3 units and no exceedences of the pH water quality standard were noted. The dissolved oxygen data failed to pass QA/QC for March 2005. The diurnal dissolved oxygen patterns for the other monitoring periods are shown in Figures 3-41 through 3-44. When the Project is operating (flow through the tailrace), dissolved oxygen levels showed about 0.5mg/L or less diurnal variation. The Project was shutdown with no flow through the tailrace stilling basin for October 1 at 19:15 through October 29 (Figures 3-43 and 3-44). The diurnal range in dissolved oxygen increased to about 1 mg/L during the first days of shutdown (D.O. range 8.17 – 9.17 mg/L). The diurnal variation in dissolved oxygen within the stilling basin was less towards the end of Project shutdown due to colder temperatures and D.O. levels were above 9 mg/L. After the Project was started backup in November, there was essentially no diurnal variability in dissolved oxygen (Figure 3-44).

Total dissolved gasses (TDG) were also monitored in the tailrace. During monthly sampling, the hydrolab probe was deployed for at least 15 minutes to allow for equilibration before recording total dissolved gas pressure (TDGP). Local barometric pressure at the time of sampling was also recorded. Percent saturation for total dissolved gasses (%TDG) at monthly samplings ranged from 98% to 103%. Since water depths in the tailrace are less than the minimum compensation depth (about 3 m), all total dissolved gas data is conditional. Air bubbles trapped on the probe membrane can give erroneous data when the probe is deployed at depths less than the minimum compensation depth.

TDG was continuously monitored for the same periods as listed above for dissolved oxygen. The hydrolab was placed in the main current of the tailrace stilling basin. The hydrolab was anchored about 0.3m off the bottom at a water depth of about 2 to 2.8 m dependent upon water level in the tailrace stilling basin. The hydrolab was calibrated on site prior to and immediately after deployment.

Calculating %TDG requires knowing the barometric pressure. Local barometric pressure data was only available for instantaneous measurements at the monthly sampling events and sporadically during the hydrolab deployment period. The nearest NOAA climate station that records barometric pressure is at Toledo Winlock (WBAN station no. 727926) at elevation 113 m. Local barometric pressure at Packwood was derived by adjusting the data from the Toledo Winlock NOAA station for elevation and air temperature differences between the Toledo station and the Packwood powerhouse. An adjustment factor of 0.27% was applied. The frequency of barometric pressure data at the Toledo station is variable. Although the Toledo station records barometric pressure throughout any 24-hour day, the frequency is inconsistent with multiple hour gaps in the record. The %TDG data presented in Figures 3-54 through 3-57 are therefore not continuous since %TDG can only be calculated when the local barometric pressure is available. The figures also show TDGP, which was recorded at 15-minute intervals.

%TDG levels were generally close to 100% saturation and well below the 110% criteria. There was no evidence of TDG spikes during Project shutdown or startup. The continuous TDG data are shown in Figures 3-54 through 3-57.

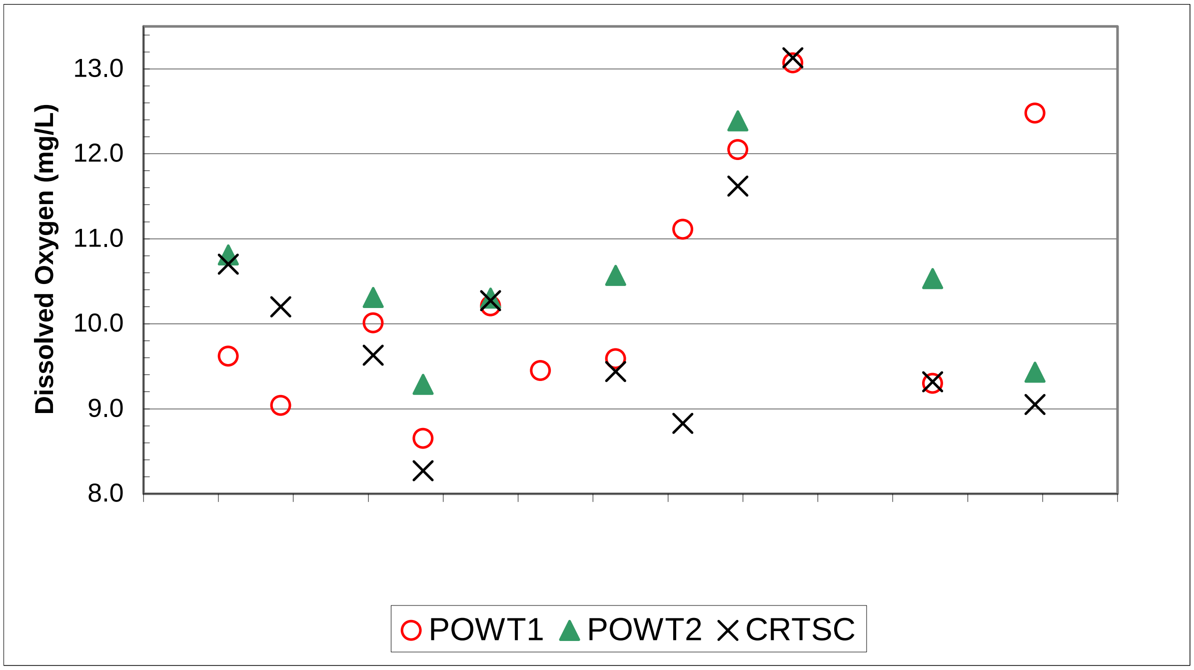

Figure 3-41. Dissolved oxygen grab samples for tailrace

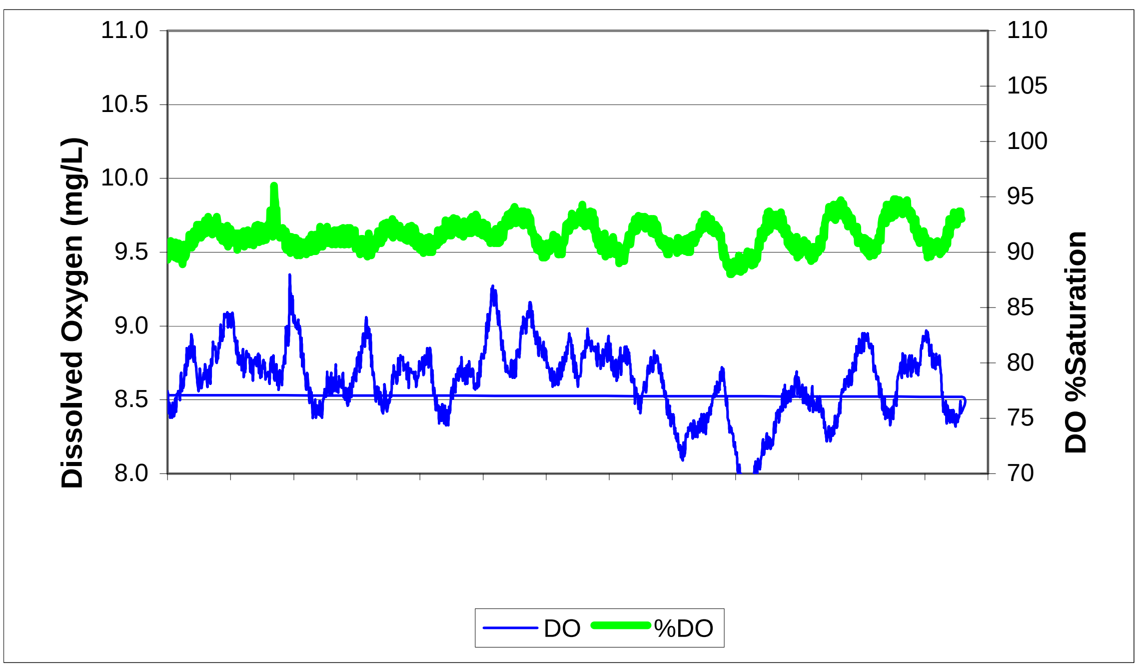

Figure 3-42. Dissolved oxygen monitoring for July 2004 in powerhouse stilling basin

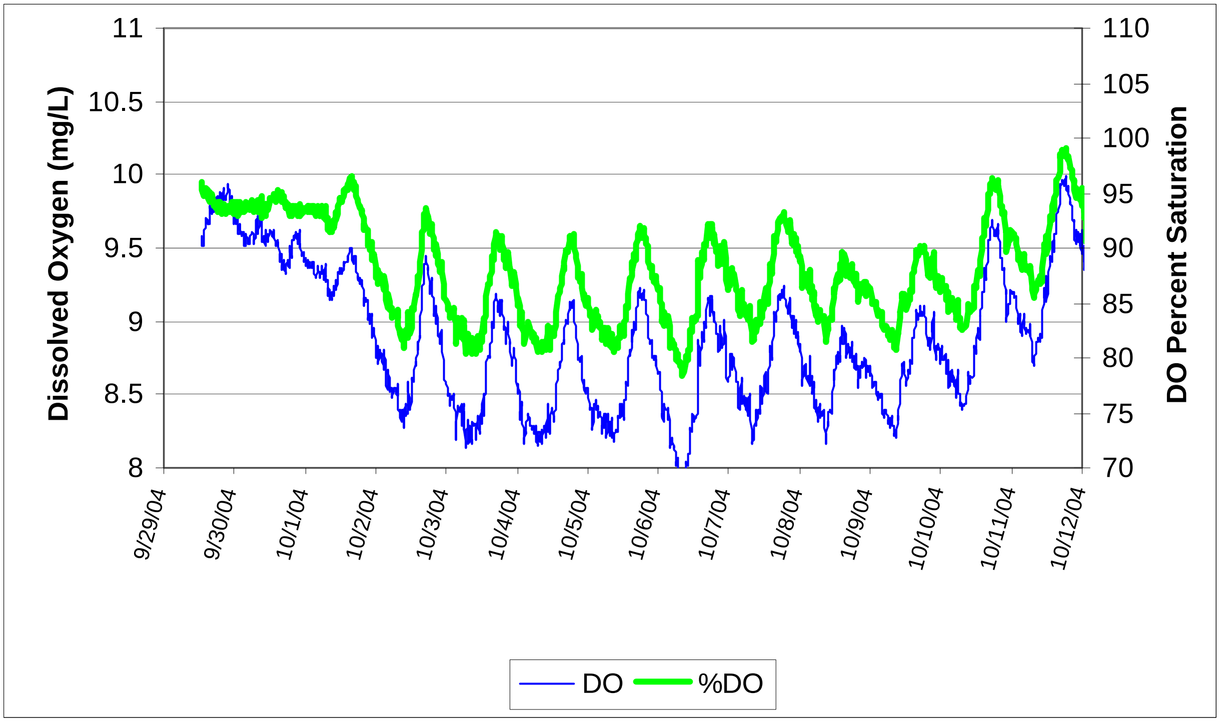

Figure 3-43. Dissolved oxygen monitoring for September– October 2004 in powerhouse stilling basin

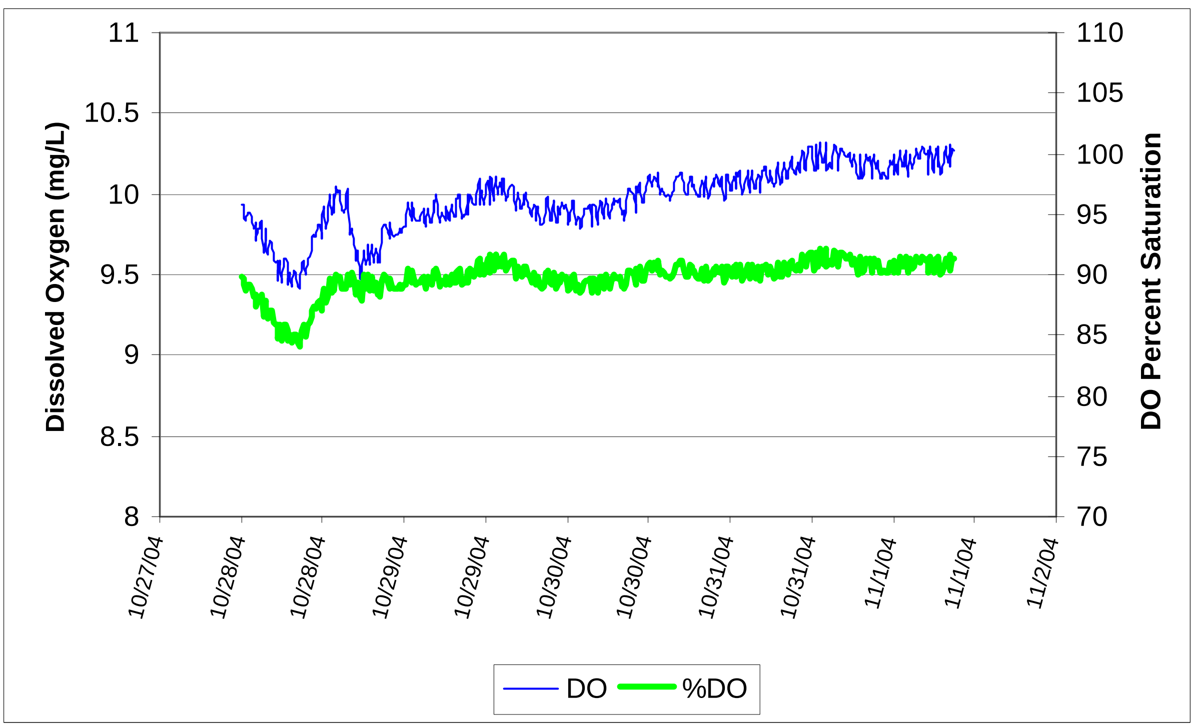

Figure 3-44. Dissolved oxygen monitoring for October – November 2004 in powerhouse stilling basin

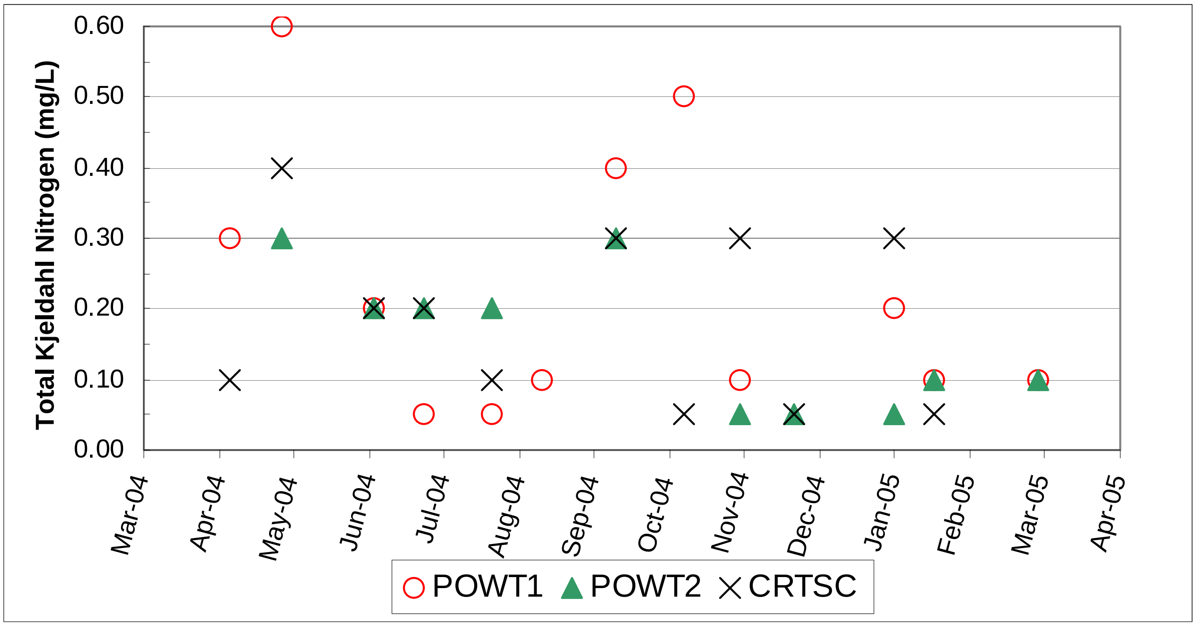

Figure 3-45. Total Kjeldahl nitrogen (TKN) for the tailrace

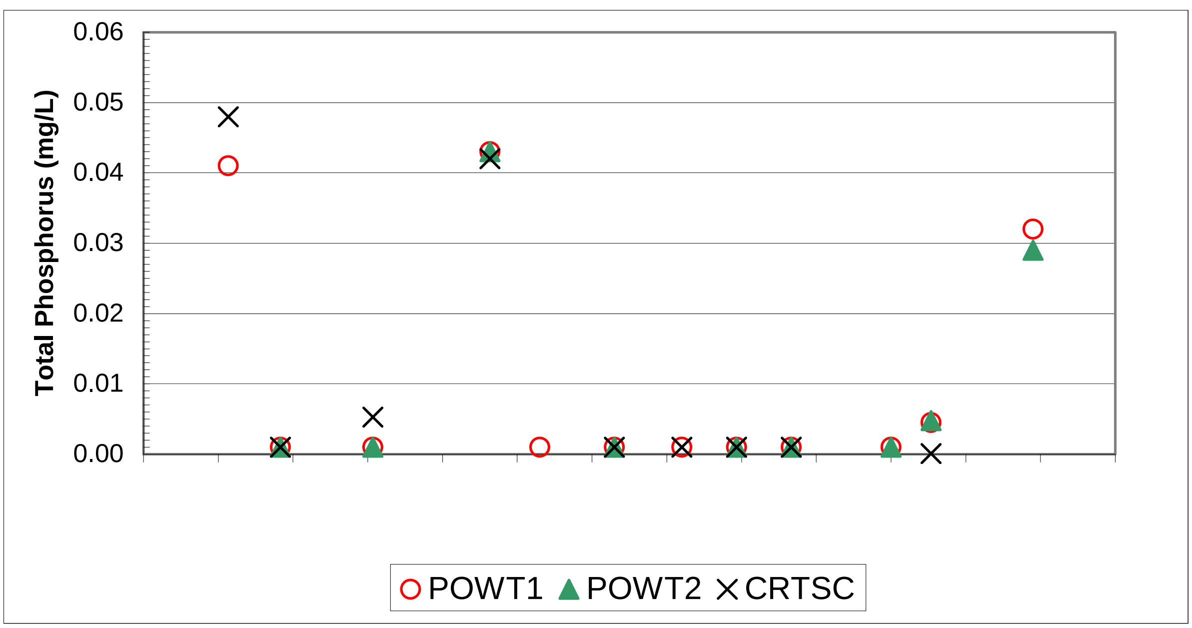

Figure 3-46. Total phosphorus for the tailrace

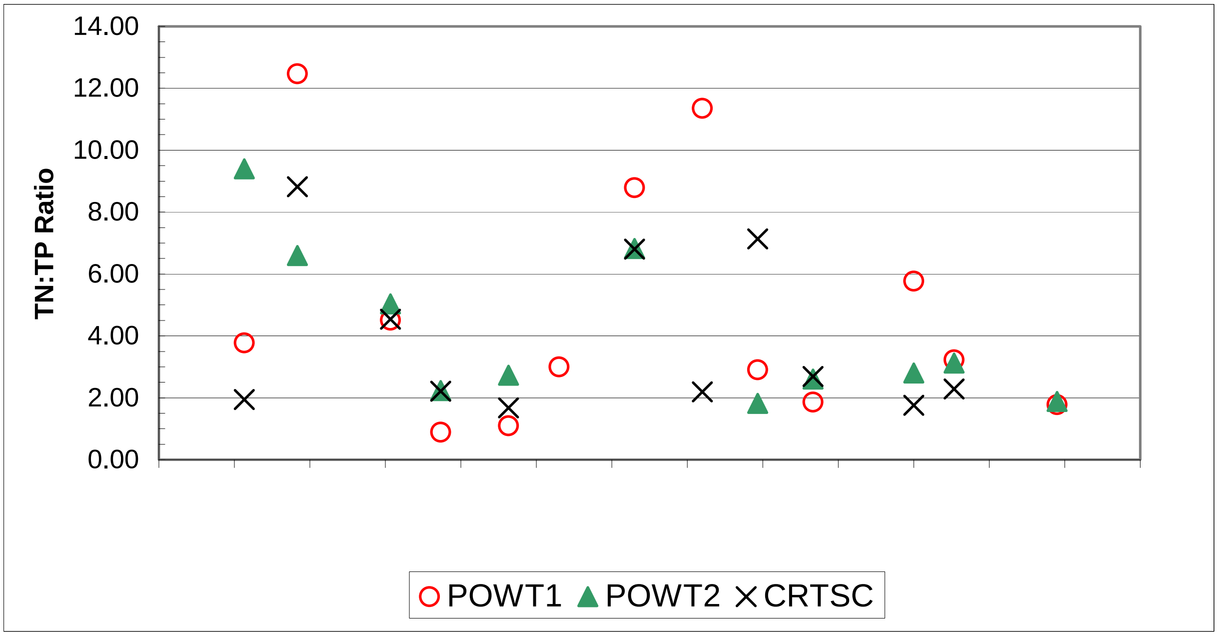

Figure 3-47. Total nitrogen to total phosphorus ratio for the tailrace

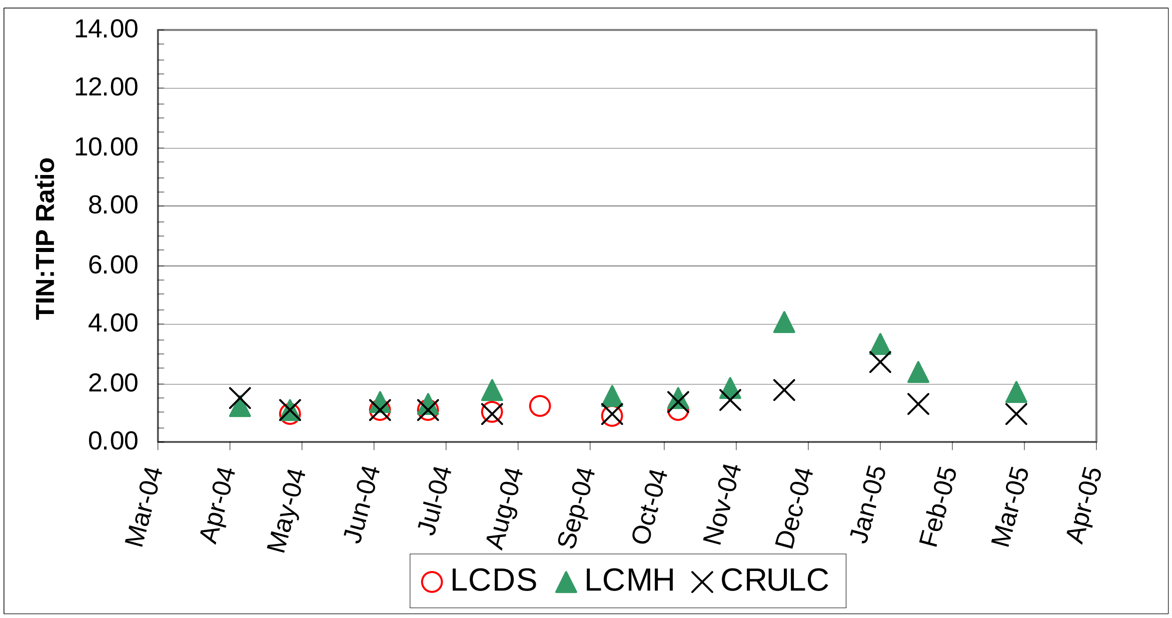

Figure 3-48. Total inorganic nitrogen to inorganic phosphorus ratio for the tailrace

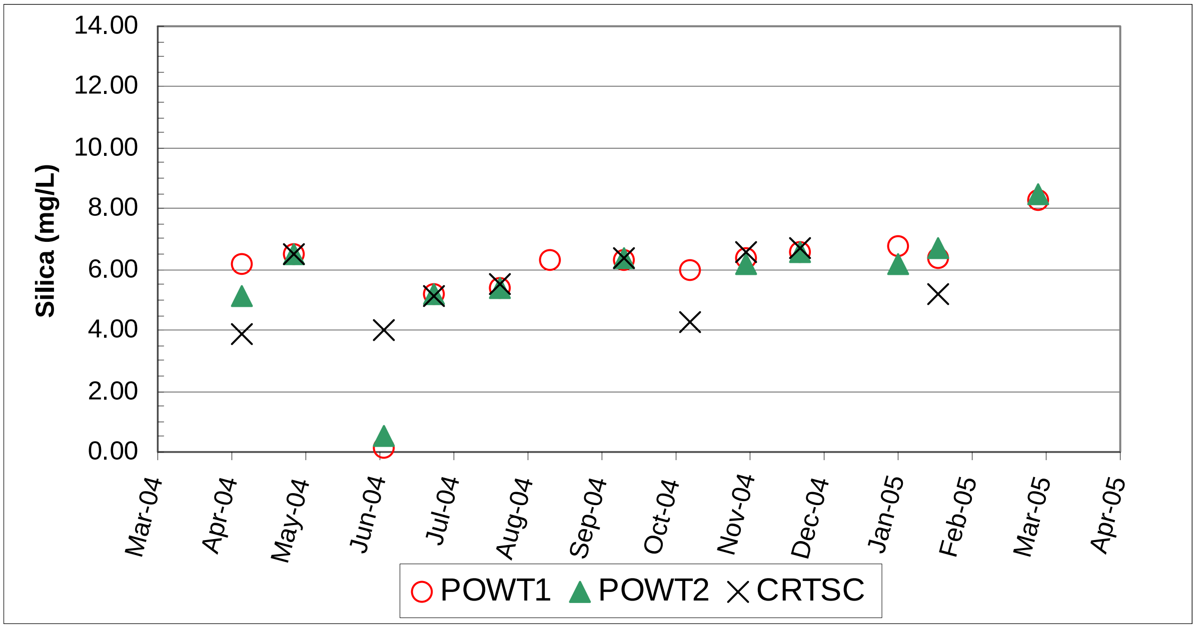

Figure 3-49. Silica for the tailrace

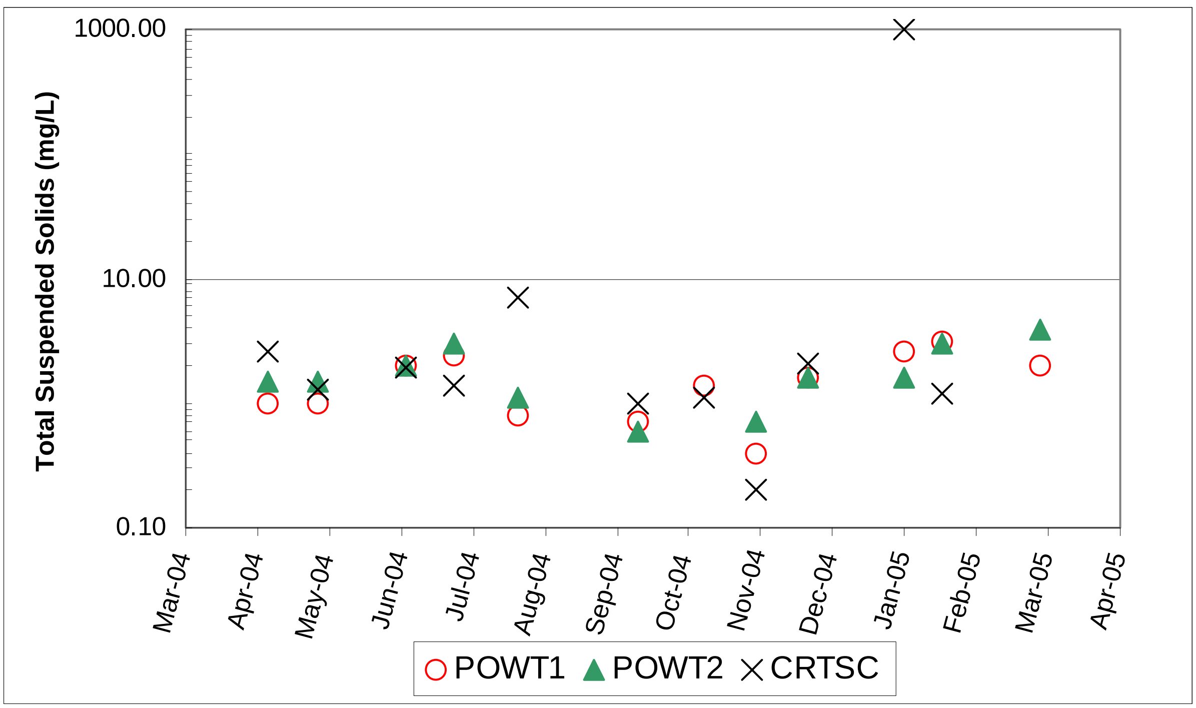

Figure 3-50. Total suspended solids for the tailrace

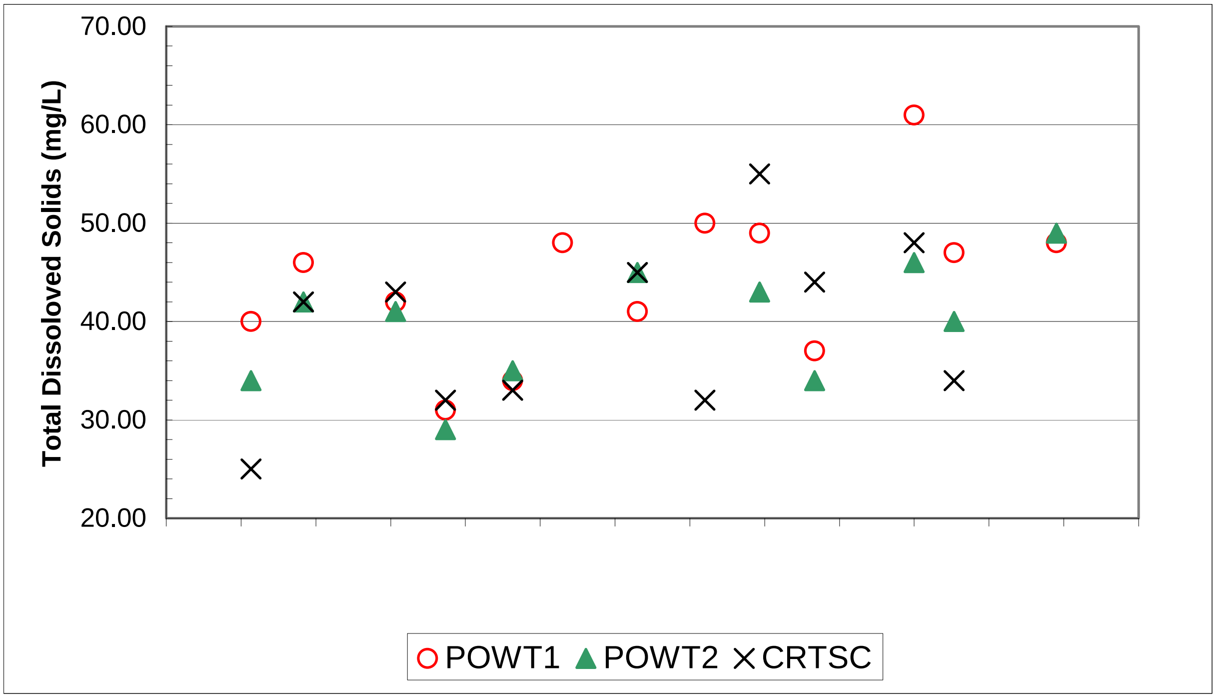

Figure 3-51. Total dissolved solids for the tailrace

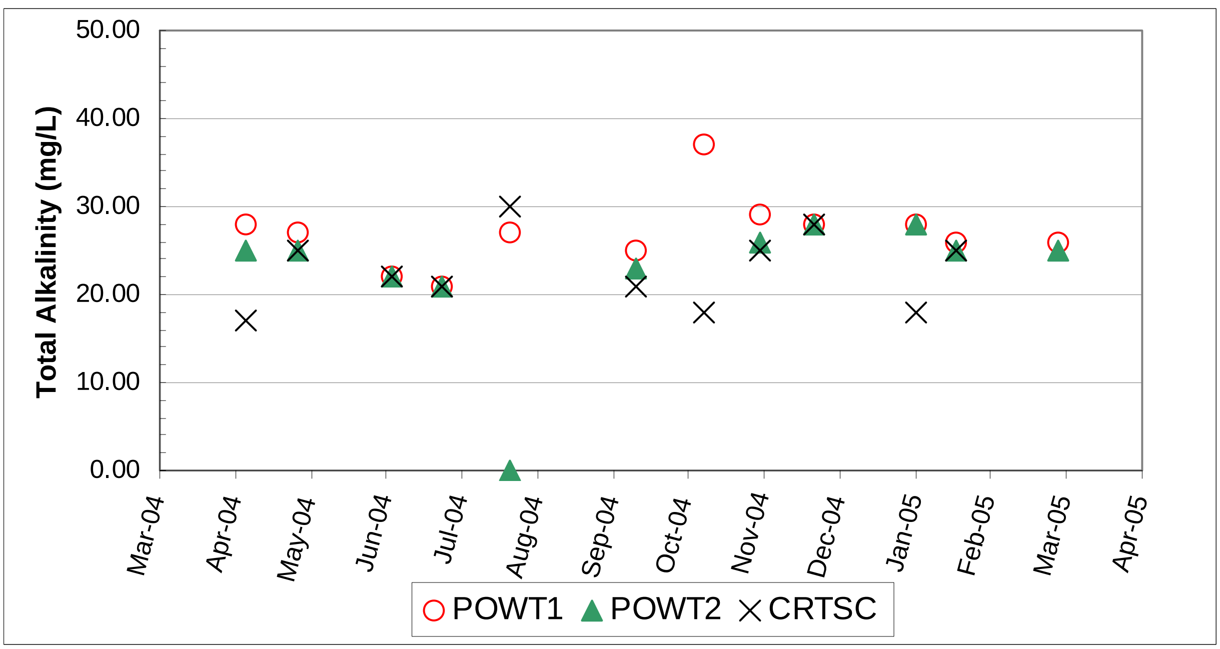

Figure 3-52. Total alkalinity for the tailrace

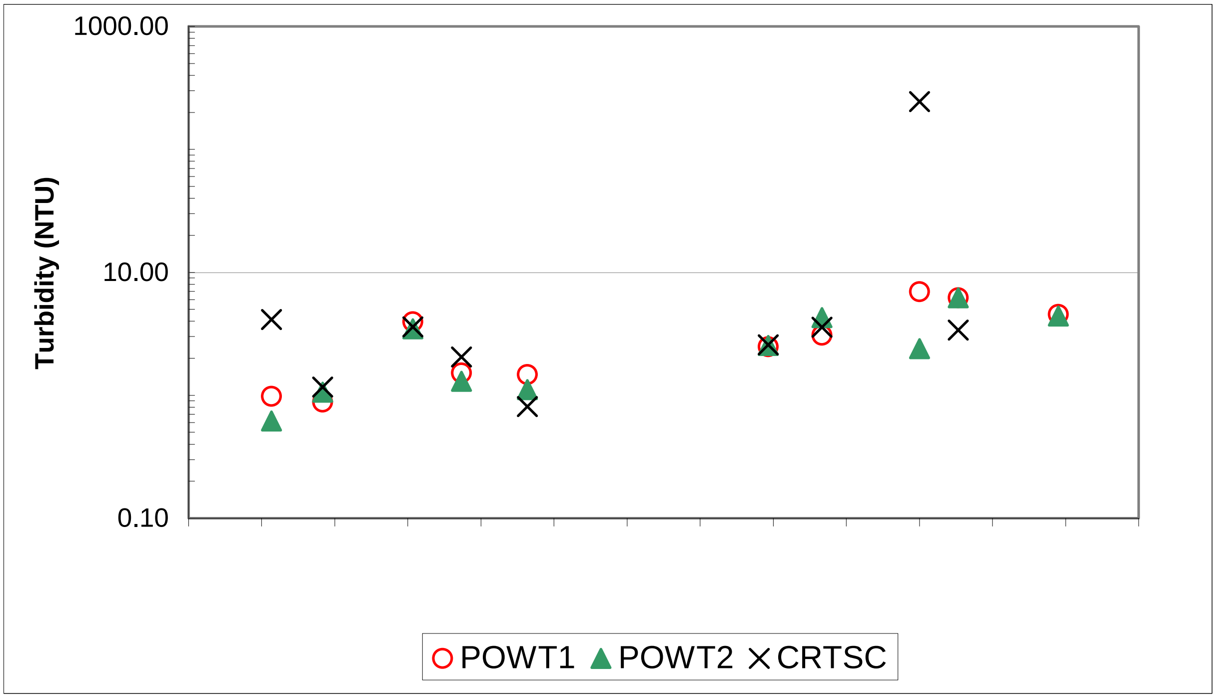

Figure 3-53. Turbidity for the tailrace

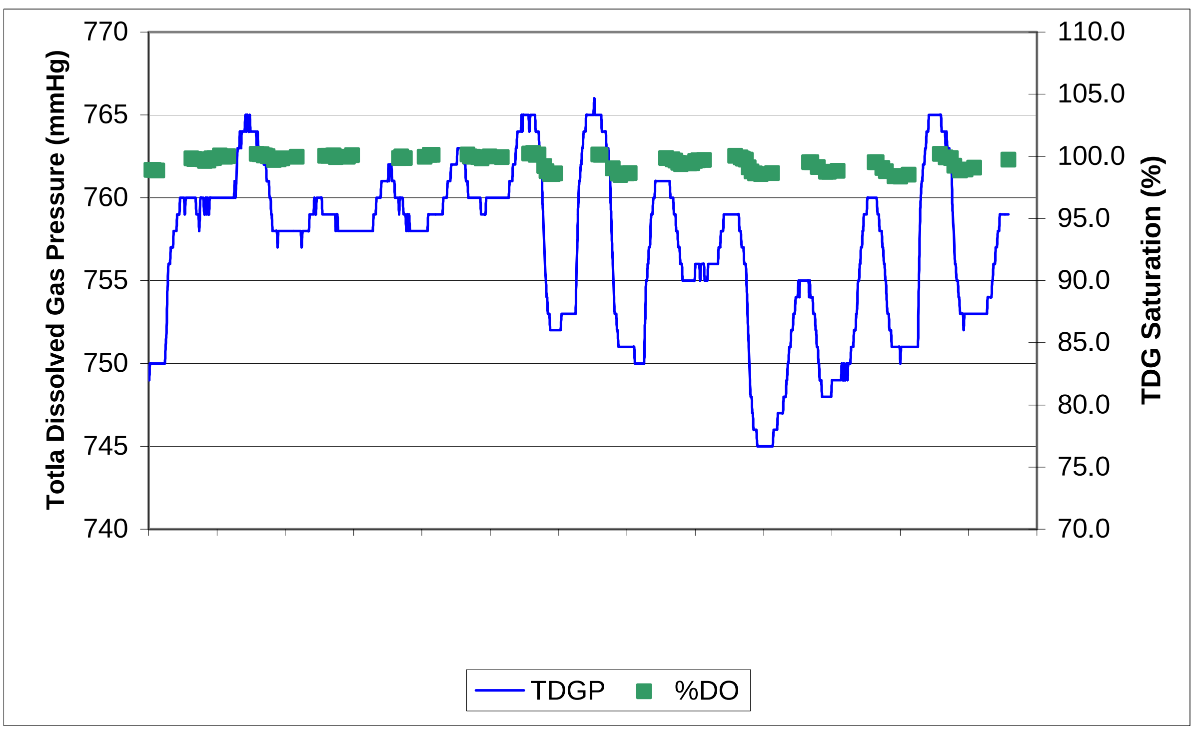

Figure 3-54. Total dissolved gas for the tailrace (POWT1) July 2004

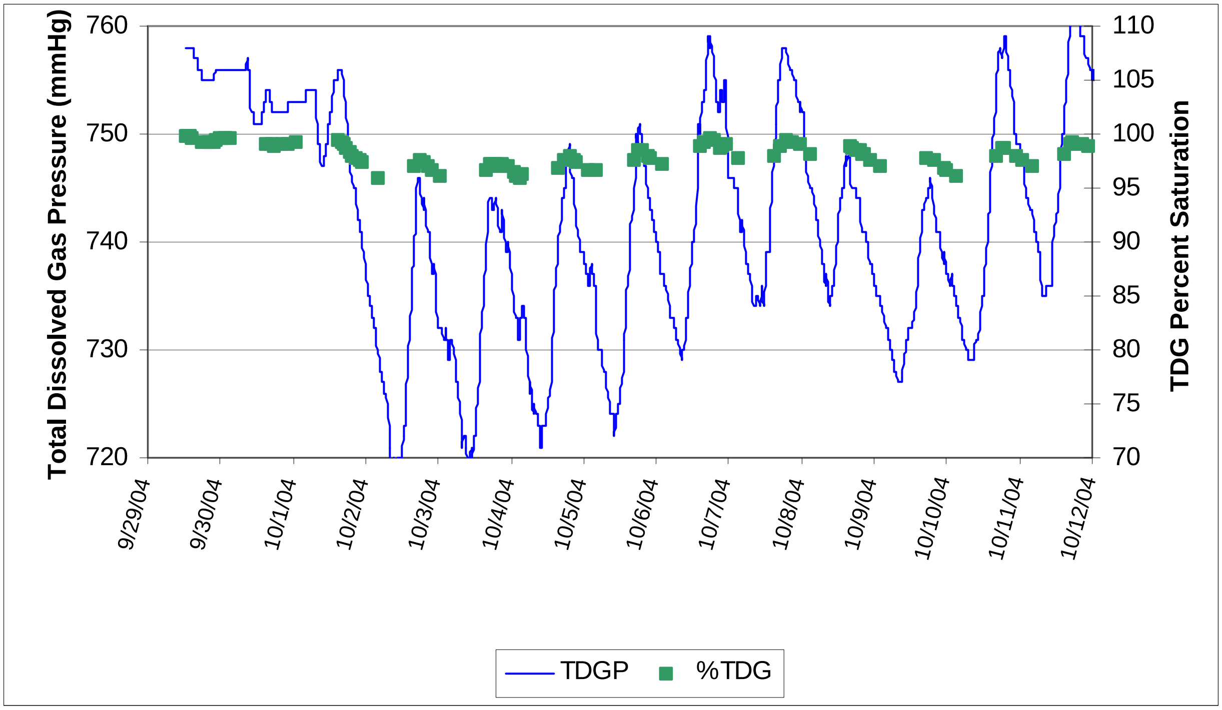

Figure 3-55. Total dissolved gas for the tailrace (POWT1) fall shutdown 2004

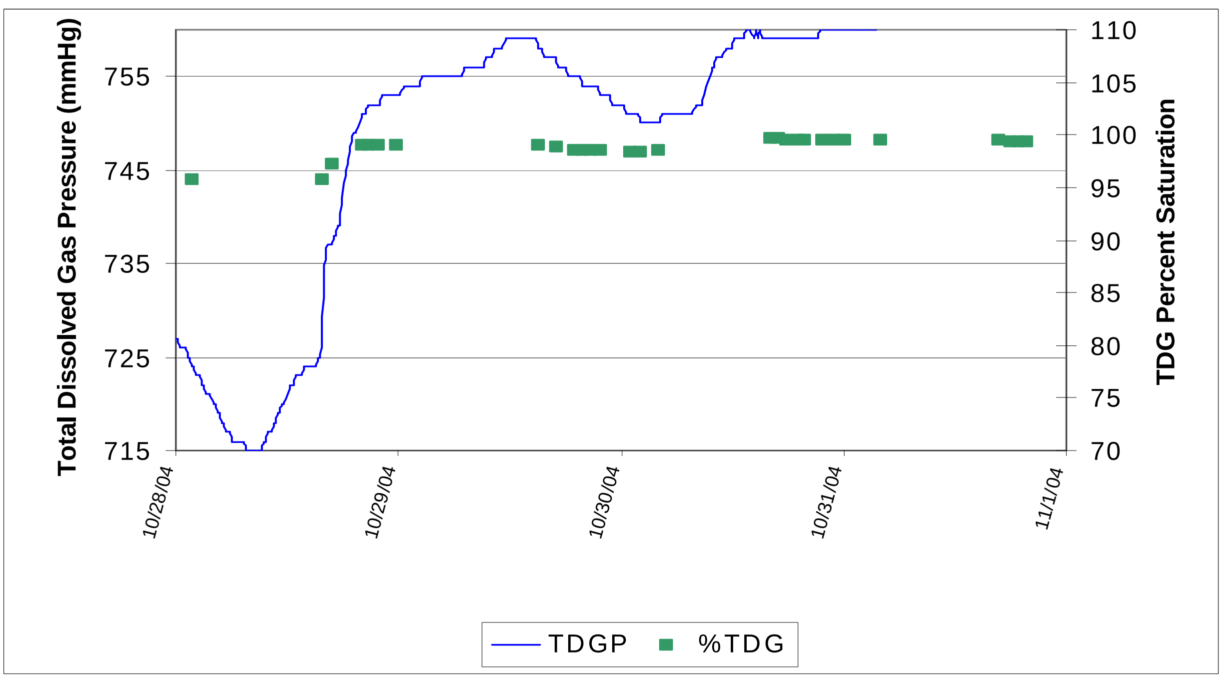

Figure 3-56. Total dissolved gas for the tailrace (POWT1) fall startup 2004

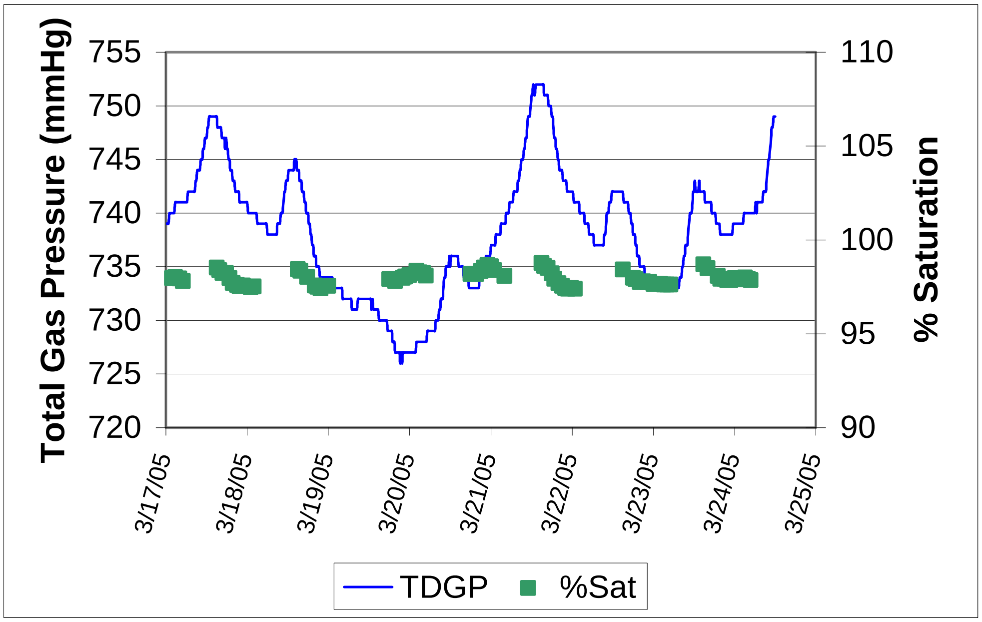

Figure 3-57. Total dissolved gas for the tailrace (POWT1) March 2005

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APPENDIX A

2004 WATER TEMPERATURE MONITORING REPORT