Water Quality Report: 2nd 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 initiated a 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 (Ecology) 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 Washington Department of Ecology (WDOE) and the USDA Forest Service (USFS) filed study requests with FERC that identified water quality issues and related study needs (Ecology 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 Ecology and USFS comments.

This report documents results from the second year of the water quality studies, which includes the period from April 1 2005 through March 31 2006.

2.0 METHODS

Sampling methods and sampling locations are the same as reported for the first year (EES Consulting 2006). Table 2.1 provides a list of water quality parameters sampled at each site. Table 2.2 lists the site acronyms and their description. Methods are fully detailed in EES Consulting (2006).

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	Monthly1
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]

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
Aesthetics[2]	●	●	●	●	●	●		●		●	●	●	●	●				12	Monthly[1]
Biological:																			
Total Fecal Coliform (Packwood Lake only)							●											1	Monthly (June-Oct.)
Noxious/invasive Macrophytes and emergent plants							●			●								2	One time
Chlorophyll *a* (phytoplankton) (Packwood Lake only)						●	●											2	Monthly (Apr-Oct.)
Taxonomic (phytoplankton)					●	●												2	Monthly (Apr-Oct.)

[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 were monitored continuously in the tailrace for selected two week periods as well as being a parameter for monthly water quality sampling.*

[4] *Temperature was 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)
Snyder Creek upstream of ancillary water inflow (SNUP)
Snyder Creek at confluence with Hall Cr (SNMH)

2.1 Sampling Frequency

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

3.0 RESULTS

3.1 Data Quality

Water quality was sampled once per month for the period April 2005 through March 2006 except in August 2005 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.

There were only a few exceptions to the completeness of sampling. Osprey Creek was inadvertently not sampled in April 2005 and upper Lake Creek in May. Sample bottles were contaminated and not analyzed from the upper end of the tailrace in March 2005.

Table 3.1. Number of Samples and Percent of Samples Below Laboratory Detection Limits (MDL), April 2005 through March 2006

	Packwood Lake		Riverine		% Non-Detect	
Parameter	Samples	Non-Detect	Samples	Non-Detect	Lake	Riverine
Total Alkalinity	41	0	108	0	0	0
Ammonia as N	40	0	108	0	0	0
Nitrite as N	41	41	108	108	100	100
Nitrate as N	41	30	107	34	73.1	31.8
Total Kjeldahl Nitrogen	40	17	107	59	42.5	55.1
Phosphate, Ortho as P	41	41	108	100	100	92.6
Phosphorus, Total	41	27	108	49	65.9	45.4
Silica	40	0	108	0	0	0
Solids, Total Dissolved	40	0	108	0	0	0
Solids, Total Suspended	40	0	108	0	0	0
Hardness	39	0	108	0	0	0
Total Organic Carbon	39	0	108	0	0	0

Table 3.2. Laboratory Minimum Detection Limits

Parameter	Reporting Limit
Total Alkalinity	10 mg/L
Ammonia as N	0.03 mg/L
Nitrite	0.03 mg/L
Nitrate	0.02 mg/L
Kjeldahl NitrogenTKN	0.1 mg/L
Ortho phosphorus	0.1 mg/L[1]
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
Turbidity	.01 NTU

[1]*Laboratory testing of spikes and standards documented that readings as low as 0.033 mg/L are consistently measurable; however, readings below 0.1 mg/L do not meet statistical criteria for detection.*

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 the low levels contributing to uncertainty in the value.

An analysis of laboratory spikes and standards identified that orthophosphorus levels as low as 0.033 mg/L could be reliably measured even though these levels are below the reported detection limit of 0.1 mg/L. The laboratory establishes detection limits based on the level of certainty and confidence intervals. Lower readings are possible but do not meet the high standard of certainty required by the laboratory. The detection limit for total phosphorus was much lower than the one for orthophosphorus. When the orthophosphorus level was less than 0.033 mg/L, a value of 95% of the total phosphorus sample measurement was used to estimate orthophosphorus. These estimated values were used when computing seasonal means and nutrient ratios.

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. MQOs were not met for Total Kjeldahl Nitrogen (TKN). The %RSD exceeded QAQC criteria for nitrates and total organic carbon due to paired samples being very near or below detection levels. 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 2005 – March 2006

Parameter	Water Temperature	Dissolved Oxygen	pH	Turbidity	Nitrites	TKN	Ammonia
Mean %RSD	0.01	0.49	0.3	1.4	4.0	1.7	0.01
Maximum %RSD	0.05	1.3	0.8	2.6	20.2	133.8	42.0
Target Precision	0.025C	<5%RSD	<5%RSD	<10%RSD	10%RSD	10%RSD	10%RSD
	Nitrate	**Ortho phosphorus**	**Total phosphorus (ICP)**	**Total suspended solids**	**Total dissolved solids**	**Silica (ICP)**	**Total Organic Carbon**
Mean %RSD	27	0.005	0	0.5	0.1	1.3	15.8
Maximum %RSD	61	0.41	0	119	119	14	28
Target Precision	10%RSD	10%RSD	10%RSD	<10	<10	<10	<10
	Total Alkalinity	**Hardness**	**Fecal Coliform**				
Mean %RSD	4.6	7.6	<1				
Maximum %RSD	20	26	<1				
Target Precision	<10	<10	<25				

3.2 Packwood Lake

Packwood Lake was unstratified at the onset of sampling in April 2005 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 slight stratification in Packwood Lake during summer 2005. The thermocline initiated at the surface without a distinctive epilimnetic layer; i.e., a vertical temperature gradient existed but an upper layer of water with a homogeneous temperature (epilimnion) was not apparent. Figures 3-1 and 3-2 show the seasonal change in water temperature profiles for Packwood Lake at site A (deepest portion of lake) and site B (near intake canal). See Appendices A and B for detailed water temperature profile information by month. The tributary inflow to the lake is cold relative to surface waters; the inflow's density would place it at an intermediate depth.

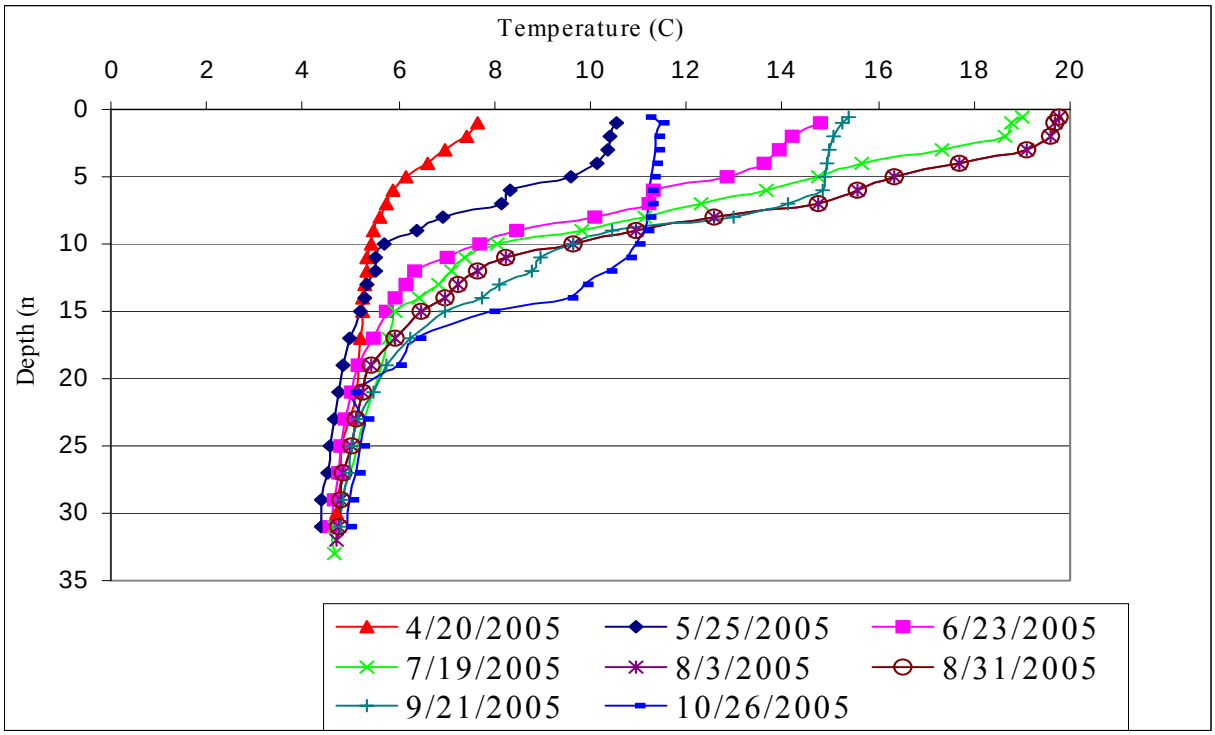

Figure 3-1. Vertical Temperature Profiles for Packwood Lake Site A (deepest area of lake)

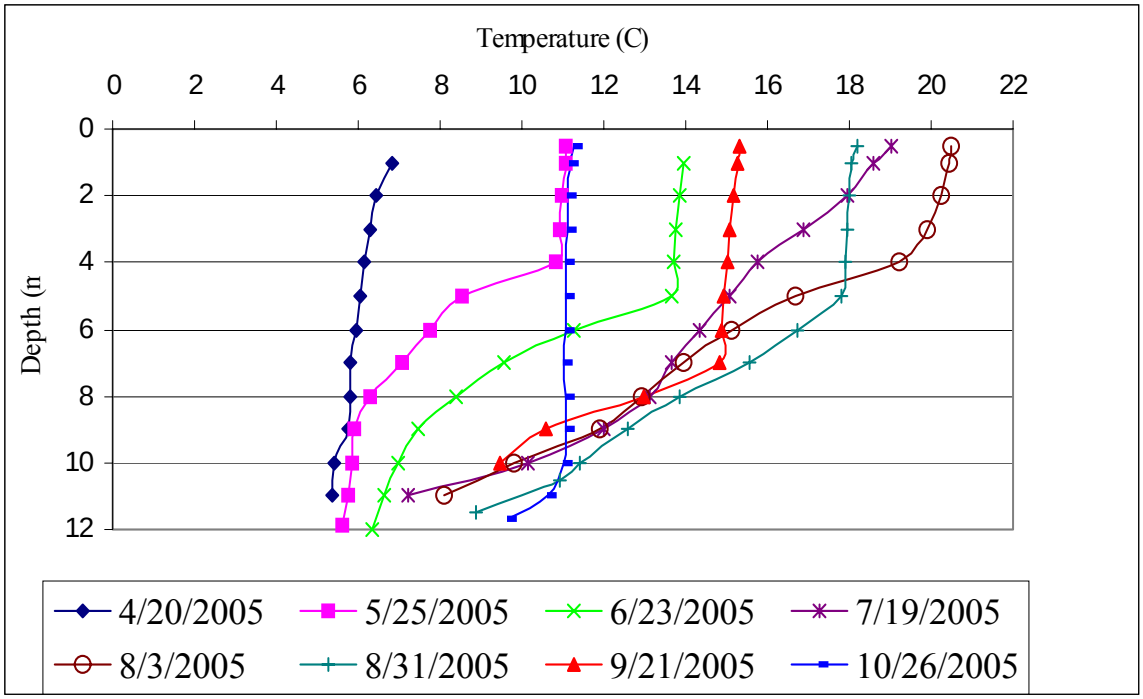

Figure 3-2. Vertical Temperature Profiles for Packwood Lake Site B (near forebay)

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 throughout the spring and summer with the exception of a minor decline in late August due to increased runoff from Upper Lake Creek associated with a rainstorm (Figure 3-3). Transparency declined in October. The maximum transparency occurred in late September (12.0 m) and the minimum Secchi depth (3.48 m) was recorded in April. Transparency was 50% greater in summer 2005 than in summer 2004. Transparency in August 2005 exceeded the bottom depth at the sample site nearest the lake outlet. The trend in Secchi depths was similar at both monitoring locations with minor differences likely attributed to travel time for a parcel of water to traverse the lake. Total dissolved solids were slightly higher in 2005 than the previous year. Tables 3.5 and 3.6 present monthly Secchi depth and turbidity data at the two lake sampling stations.

Table 3.4. Mean Annual Values for Water Quality Parameters for Packwood Lake 2005

	pH	Secchi Disk Depth (m)	Specific Conductance (uS/cm)	Alkalinity, Bicarbonate as CaCO3 (mg/L)	Total Alkalinity (mg/L)	Hardness (mg/L)
PLA(PH)[3]	7.64	7.2	0.0344	25	25	23
PLA(EP)[4]				23	23	23
PLA(ME)				25	25	22
PLA(OB)	6.95		0.0399	26	26	24
PLB(PH)[3]	7.64	7.2	0.0158	25	25	23
PLB(EP)[4]	7.83		0.0501	22	22	20
PLB(OB)	7.46		0.0367	26	26	24
Annual	7.33	7.2	0.0371	25	25	23
Spring	7.42	5.0	0.0236	25	25	
Summer	7.32	10.2	0.0430	25	25	
Fall	7.02	6.1	0.0402	27	27	
TSI						
	Silica (mg/L)	Total Dissolved (TDS) (mg/L)	Total Suspended (TSS) (mg/L)	Ammonia as N (mg/L)	Nitrite as N (mg/L)[2]	Nitrate as N (mg/L)[2]
PLA(PH)[3]	6.19	43.50	0.99	0.021	0.015	0.010
PLA(EP)[4]	5.80	46.50	0.75	0.028	0.015	0.010
PLA(ME)	5.78	43.00	0.75	0.025	0.015	0.010
PLA(OB)	6.46	45.50	1.20	0.022	0.015	0.049
PLB(PH)[3]	6.30	46.33	1.35	0.020	0.015	0.010
PLB(EP)	5.60	46.00	0.60	0.041	0.015	0.010
PLB(OB)	6.11	40.38	1.13	0.021	0.015	0.010
Annual	6.17	43.89	1.07	0.022	0.015	0.018
Spring	6.40	43.00	1.28	0.019	0.015	0.014
Summer	5.86	45.94	0.63	0.025	0.015	0.017
Fall	6.97	44.00	1.86	0.020	0.015	0.024
TSI						

Table 3.4. Mean Annual Values for Water Quality Parameters for Packwood Lake 2005 (cont'd)

	Phosphate, Ortho as P (mg/L) [1]	Phosphorus, Total (mg/L) [2]	Total Kjeldahl Nitrogen (TKN) (mg/L) [2]	Total Organic Carbon (TOC) (mg/L)	TN:TP[2]	TIN:TIP[1,2]
PLA(PH)	0.022	0.023	0.319	1.00	248.0	32.3
PLA(EP)	0.001	0.001	0.175	0.43	200.0	55.3
PLA(ME) [5]	0.023	0.024	0.190	0.96	102.6	33.1
PLA(OB) [6]	0.023	0.024	0.100	0.81	117.9	61.6
PLB(PH)	0.025	0.026	0.208	0.68	115.4	28.9
PLB(EP)	0.001	0.001	0.300	0.46	325.0	69.5
PLB(OB)	0.024	0.025	0.243	0.98	154.1	29.3
Annual	0.021	0.023	0.214	0.85	160.6	39.5
Spring	0.042	0.044	0.071	1.15	16.0	26.5
Summer	0.015	0.016	0.197	0.51	158.2	43.3
Fall	0.029	0.030	0.400	0.88	273.4	35.9
TSI		**54.780**				

Spring = April – June Summer = July – August Fall = September – October

[1] For samples that the orthophosphorus level was below detection limit, a value of 0.95 * total phosphorus was used as an estimate of orthophosphorus.

[2] For purposes of calculating a mean, non-detects were assigned a value of 0.5*detection limit

[3] The photic zone (PH) sample was collected by an integrated hose sampler that represents the water column from the surface to twice the photic depth or a maximum of 5 m, whichever is the lesser.

[4] Epilimnion (EP) samples were collected from a depth of 1- 2 m for the July and August sample trips only.

[5] Metalimnion (ME) samples were only collected from site A for June and August. Samples were collected at a depth of approximately 4 m and as deep as 10 m dependent upon the temperature profile.

[6] Off bottom (OB) samples were collected from 1 m off the lake bed at sample site.

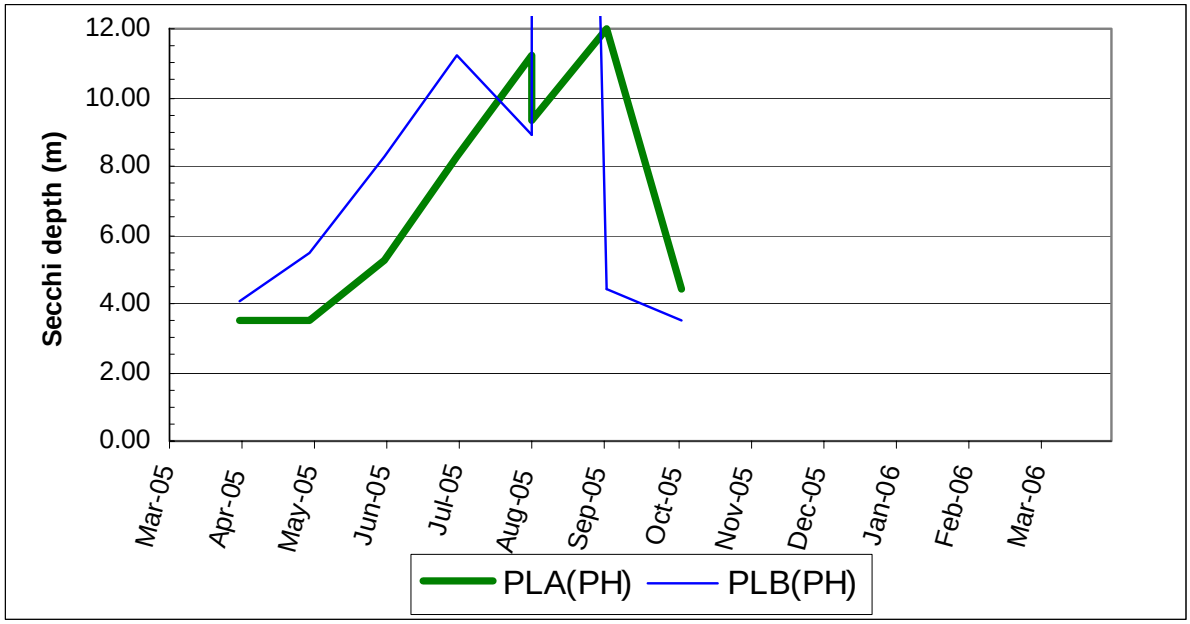

Figure 3-3. Secchi Depth (m) for Packwood Lake 2005 (Secchi depth exceeded bottom depth in August)

Table 3.5. Monthly Data for Secchi Depth (m) for Packwood Lake

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05	Oct 05
PLA(PH)	3.48	3.5	5.25	8.25	11.25	9.3	12	4.4
Photic Sample Depth (m) [1]	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5
PLB(PH)	4.1	5.5	8.25	11.2	8.9	99[2]	4.4	3.5
Photic Sample Depth (m) [1]	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5

[1] *(PH) = photic zone, which is twice Secchi depth or 5 m; whichever is less*
[2] *Exceeded bottom depth*

Table 3.6. Monthly Surface Turbidity Data (NTU) for Packwood Lake

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05	Oct 05
PLA	1.76	2.23	1.69	0.99	NA	0.18	1.3	2.48
PLB	1.85	1.86	1.01	2.4	0.44	0.46	1.99	2.01

Dissolved oxygen (D.O.) at lower depths in the lake was gradually depleted but remained well above anoxic conditions. Surface D.O. ranged from 8.3 mg/L to 10.6 mg/L while D.O. in the

deepest region of the lake ranged from a measured high of 9.1 mg/L in April 2005 to a low of 4.93 mg/L in September 2005. During summer months, maximum D.O. levels occurred at a depth of approximately 9 m to 10 m. These trends are nearly identical to patterns observed in 2004. 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. Monthly D.O. levels are reported in Table 3.7. Vertical profiles for D.O. are presented in Appendix A.

The pH showed relatively little spatial or temporal variation within Packwood Lake. The lake pH is neutral (annual mean pH 7.3). Alkalinity is a measure of a water body's 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. Monthly grab sample data for pH and total alkalinity are reported in Tables 3.8 and 3.9, respectively. Plots of vertical profiles for temperature, D.O. and pH are provided in Appendix A.

Table 3.7. Monthly Dissolved Oxygen Data for Packwood Lake

	Apr 05	**May 05**	**Jun 05**	**July** 05	**Aug 05 early**	**Aug 05 late**	**Sep 05**	**Oct 05**
	(Mg/L)							
PLA(PH)	10.64	9.83	9.83	8.35	8.42	8.98	8.30	8.80
PLA(OB)	9.1	8.52	9.3	7.74	7.33	4.98	4.93	5.49
PLB(PH)	10.49	9.50	10.04	8.6	8.65	9.12	8.8	9.94
PLB(OB)	10.65	9.48	10.02	10.37	10.88	10.92	10.67	8.37
	% Saturation							
PLA(PH)	95.7	95	115.5	107.1	93.5	103.8	89.7	85.9
PLA(OB)	77.7	70.6	86.7	72.2	58.6	42.0	41.6	46.1
PLB(PH)	92.3	93.6	117.0	112.6	98.8	104.6	95.4	96.0
PLB(OB)	92.1	81.8	97.8	123.3	94.7	102.2	100.9	77.0

(PH) = photic zone, D.O. at depth of 1 m is reported
(ME) = metalimnion, sample collected at 4 m
(OB) = 1 m off bottom

Table 3.8. Monthly pH Data for Packwood Lake

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05	Oct 05
PLA(PH)	7.48	7.53	7.86	7.9	7.5	7.7	7.8	7.34
PLA(OB)	7.37	7.03	7.24	7.2	6.79	6.6	6.64	6.75
PLB(PH)	7.64	7.69	7.93	7.81	7.34	7.39	7.65	7.42
PLB(OB)	7.66	7.26	7.56	7.73	7.34	7.39	7.47	7.23

(PH) = photic zone, reported. at depth of 1 m
(ME) = metalimnion, sample collected at 4 m
(OB) = 1 m off bottom

Table 3.9. Monthly Total Alkalinity Data (mg/L) for Packwood Lake

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05	Oct 05
PLA(PH)	25	23	22	23	24	25	27	27
PLA(EP)				23	22			
PLA(ME)			23	23	25	27		
PLA(OB)	26	26	25	25	26	26	27	28
PLB(PH)	26	23	23	23	26	25	27	
PLB(EP)				22				
PLB(OB)	25	26	26	23	25	26	26	27

(PH) = photic zone
(ME) = metalimnion, sample collected at 4 m
(OB) = 1 m off bottom

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 78% of the lake samples. The majority of nitrogen occurred as organic nitrogen, which is a portion of Kjeldahl nitrogen (TKN), and therefore was not available for immediate biological uptake. TKN levels were higher in 2005 than in 2004; a similar trend was observed in lake tributaries. Inorganic nitrogen (nitrite-nitrate + ammonia) accounted for 48 percent, on average, of total nitrogen levels. Organic nitrogen levels were elevated in October relative to other months. Figures 3-4 through 3-11 show the monthly trends in various nutrients for lake sampling locations. Table 3.10 lists monthly data for various forms of nitrogen. Table 3.11 lists monthly data for orthophosphorus and total phosphorus

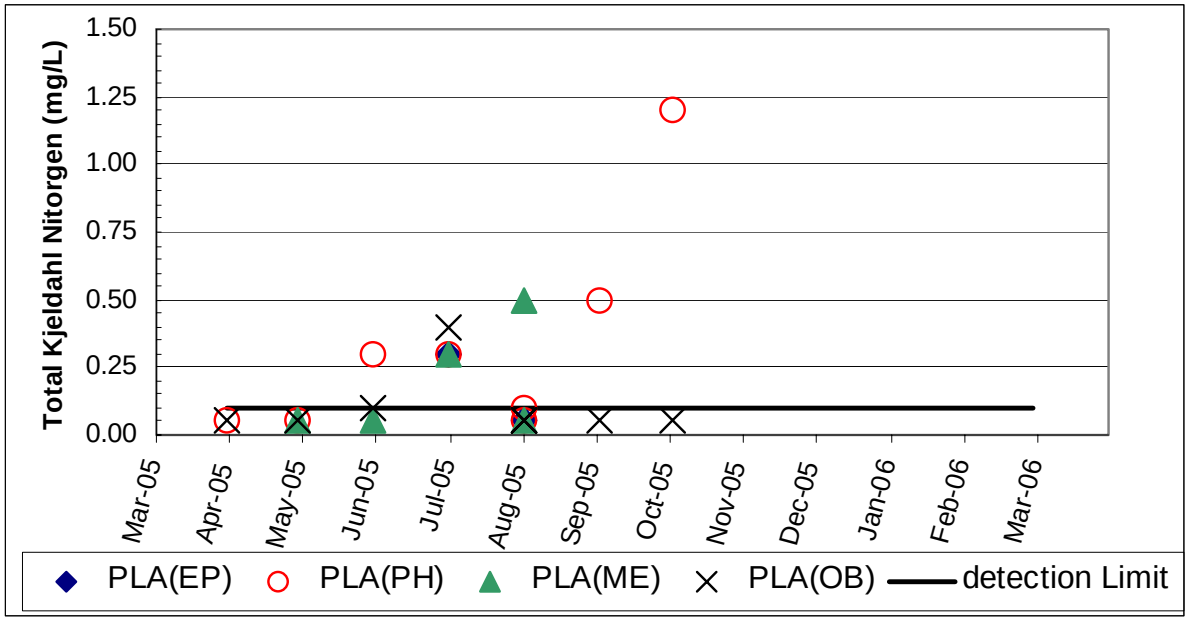

Figure 3-4. Total Kjeldahl Nitrogen for Packwood Lake Site A
Samples below detection limit of 0.1 mg/L are listed as 0.5* detection limit.

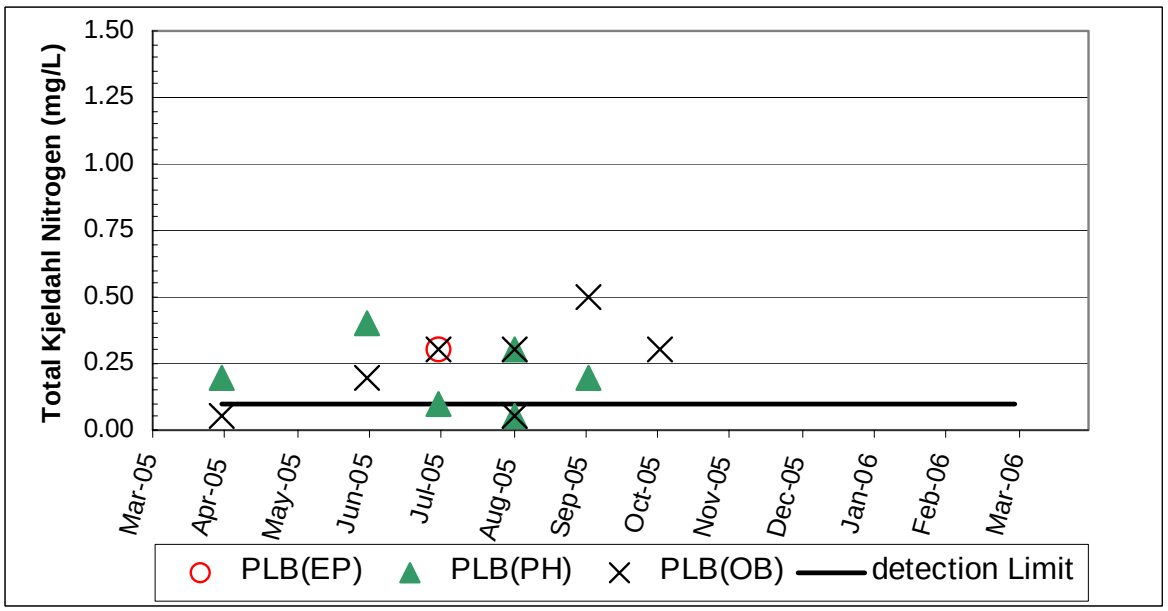

Figure 3-5. Total Kjeldahl Nitrogen for Packwood Lake Site B
Samples below detection limit of 0.1 mg/L are listed as 0.5* detection limit.

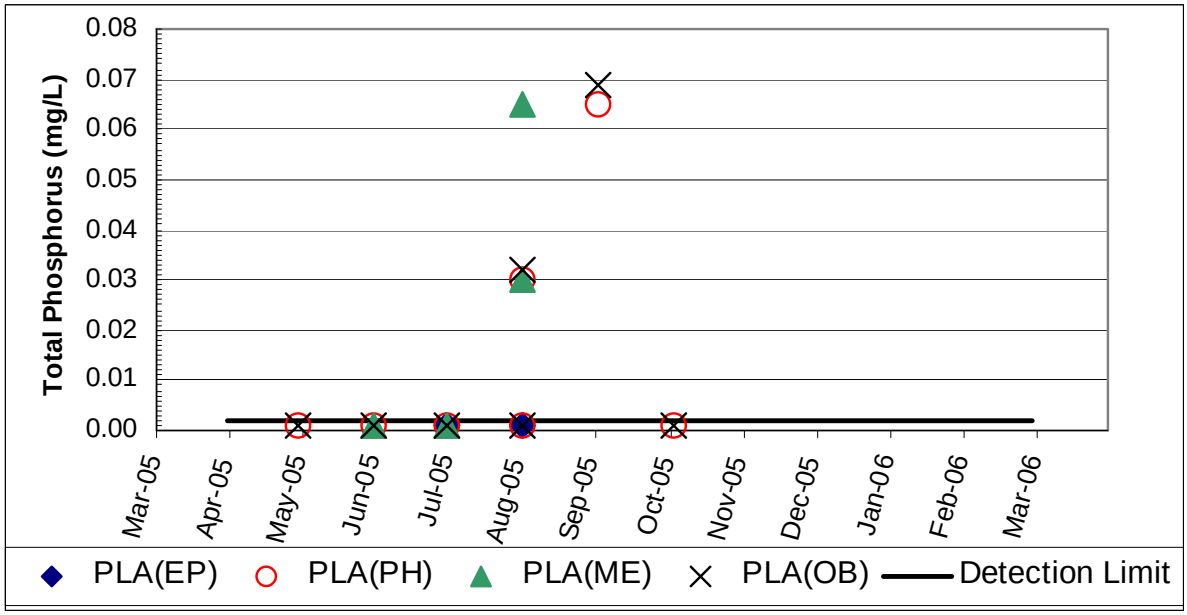

Figure 3-6. Total Phosphorus for Packwood Lake Site A
Samples below detection limit of 0.002 mg/L are listed as 0.5* detection limit.

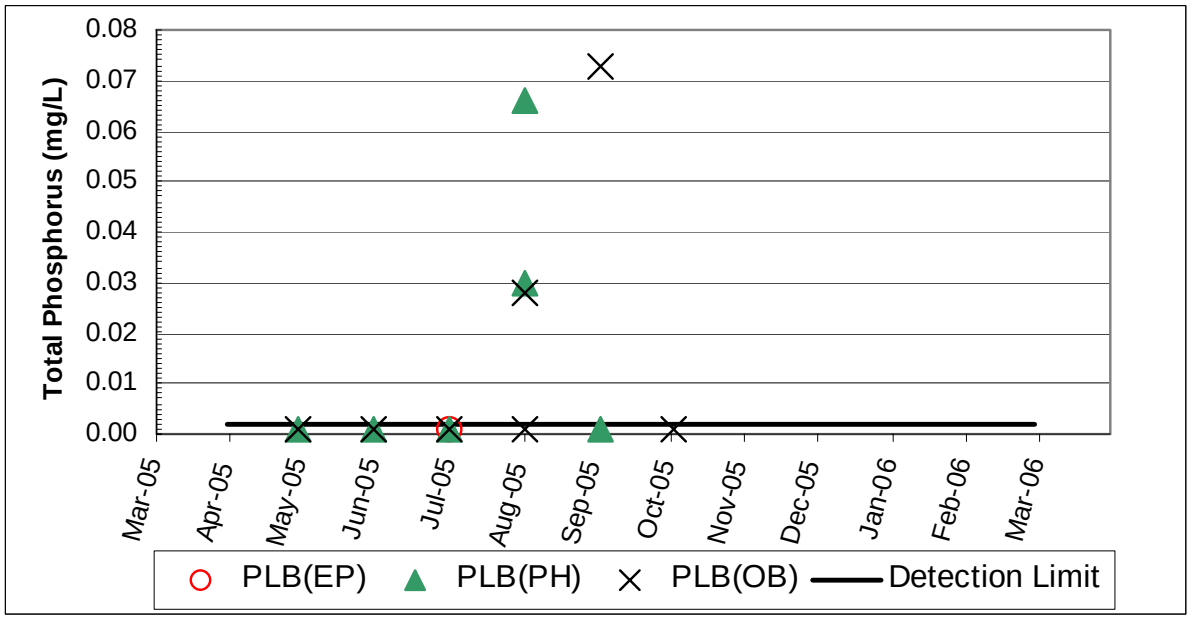

Figure 3-7. Total Phosphorus for Packwood Lake Site B
Samples below detection limit of 0.002 mg/L are listed as 0.5* detection limit.

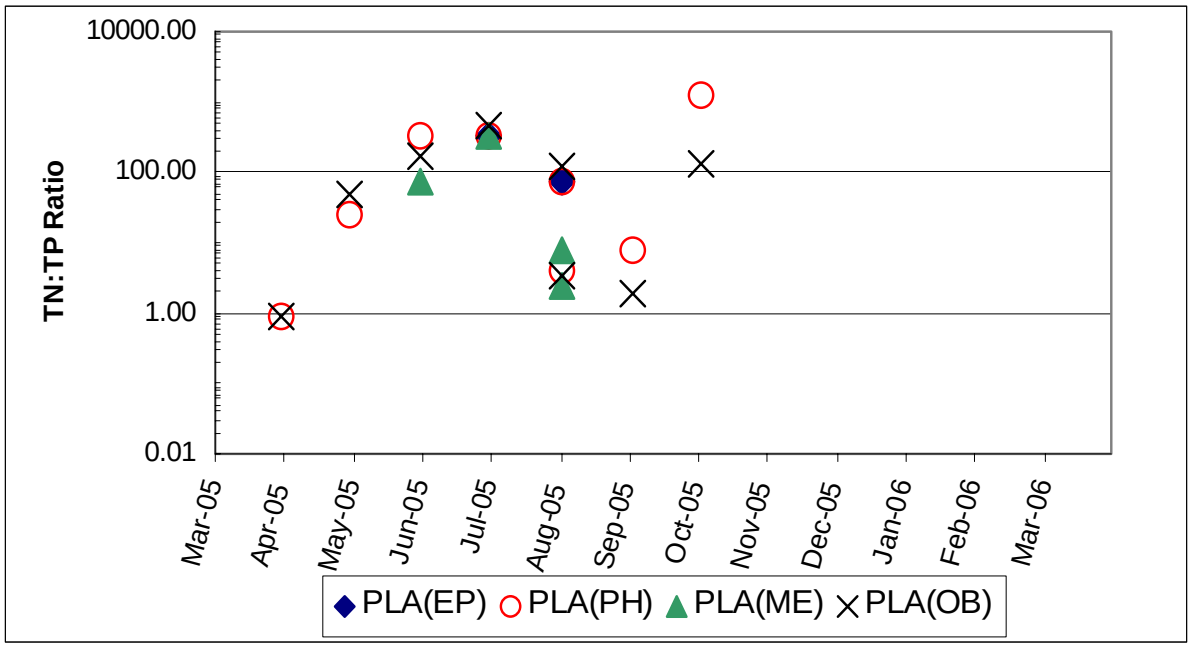

Figure 3-8. Total Nitrogen to Total Phosphorus Ratio for Packwood Lake Site A

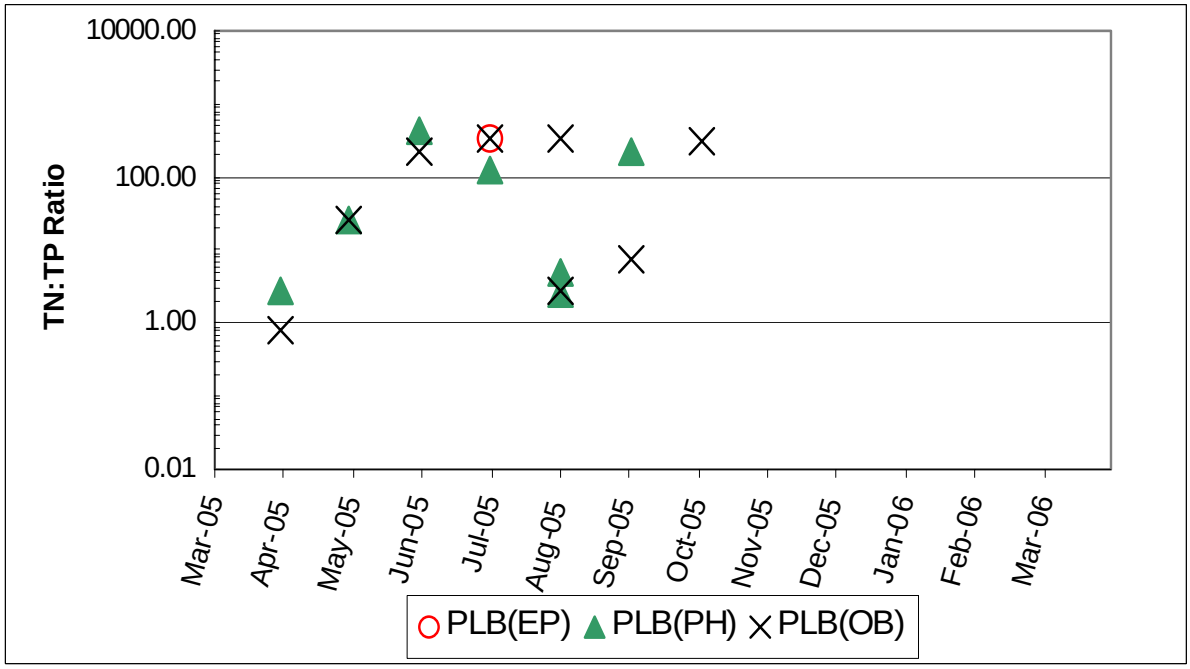

Figure 3-9. Total Nitrogen to Total Phosphorus Ratio for Packwood Lake Site B

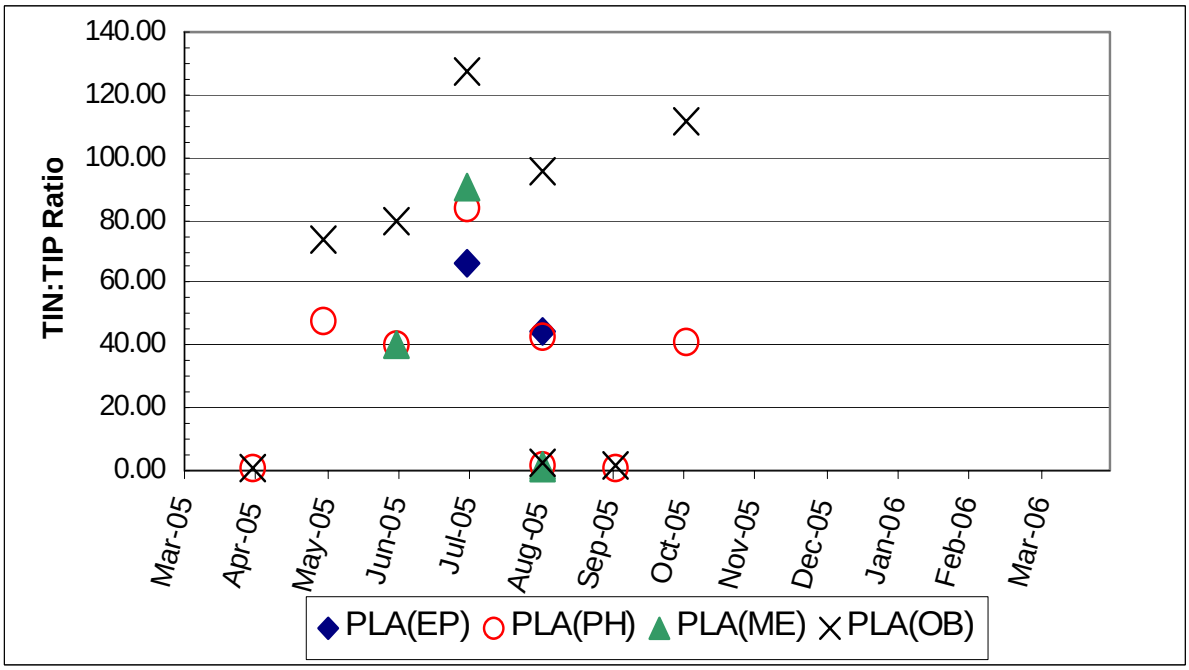

Figure 3-10. Total Inorganic Nitrogen to Total Inorganic Phosphorus Ratio for Packwood Lake Site A

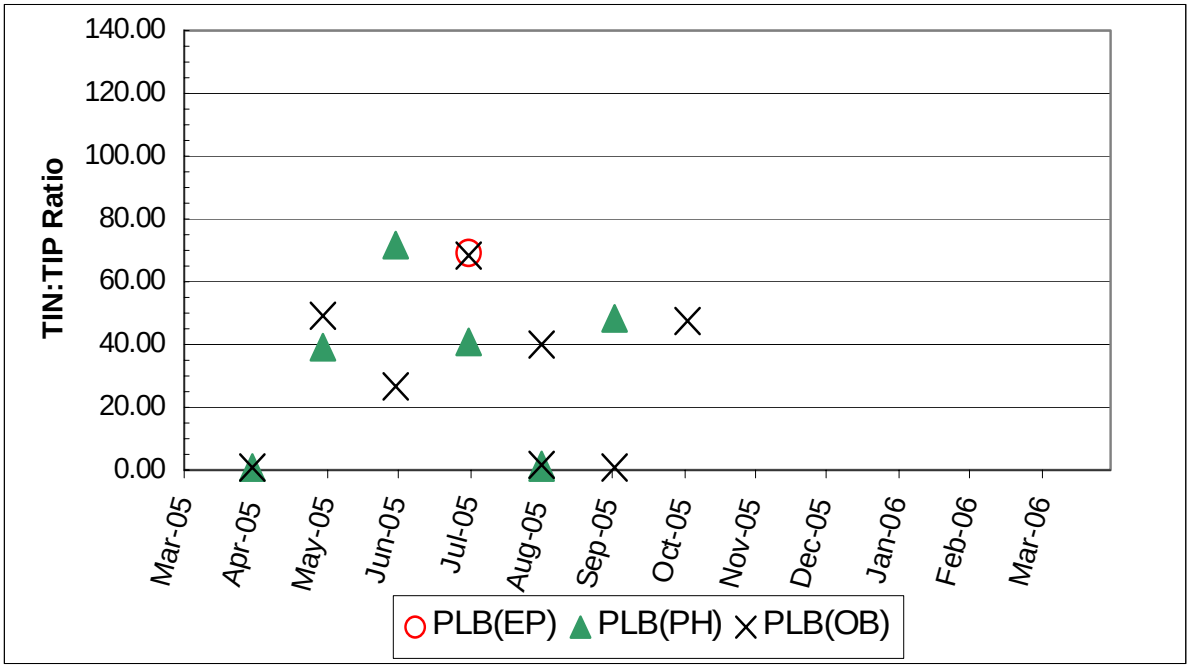

Figure 3-11. Total Inorganic Nitrogen to Total Inorganic Phosphorus Ratio for Packwood Lake Site B

Table 3.10. Nitrogen Data (mg/L) for Packwood Lake

Ammonia (mg/L)								
	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**	**Oct 05**
PLA(PH)	0.019	0.02	0.013	0.055	0.016	0.013	0.017	0.018
PLA(EP)				0.038	0.017			
PLA(ME)			0.013	0.061	0.012	0.015		
PLA(OB)	0.019	0.022	0.013	0.051	0.016	0.012	0.017	0.025
PLB(PH)	0.018	0.012	0.043	0.014	0.013	0.016	0.023	
PLB(EP)				0.041				
PLB(OB)	0.018	0.022		0.04	0.013	0.013	0.016	0.023
Nitrites (mg/L)								
	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**	**Oct 05**
PLA(PH)	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
PLA(EP)				0.015	0.015			
PLA(ME)			0.015	0.015	0.015	0.015		
PLA(OB)	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
PLB(PH)	0.015	0.015	0.015	0.015	0.015	0.015	0.015	
PLB(EP)				0.015				
PLB(OB)	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Nitrates (mg/L)								
	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**	**Oct 05**
PLA(PH)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.006
PLA(EP)				0.01	0.01			
PLA(ME)			0.01	0.01	0.01	0.01		
PLA(OB)	0.015	0.033	0.048	0.055	0.06	0.048	0.063	0.066
PLB(PH)	0.01	0.01	0.01	0.01	0.01	0.01	0.008	
PLB(EP)				0.01				
PLB(OB)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.007
Kjeldahl Nitrogen (mg/L)								
	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**	**Oct 05**
PLA(PH)	0.05	0.05	0.3	0.3	0.05	0.1	0.5	1.2
PLA(EP)				0.3	0.05			
PLA(ME)		0.05	0.05	0.3	0.05	0.5		
PLA(OB)	0.05	0.05	0.1	0.4	0.05	0.05	0.05	0.05
PLB(PH)	0.2		0.4	0.1	0.05	0.3	0.2	
PLB(EP)				0.3				
PLB(OB)	0.05		0.2	0.3	0.3	0.05	0.5	0.3

(PH) = photic zone, D.O. at depth of 1 m is reported
(ME) = metalimnion, sample collected at 4 m
(OB) = 1 m off bottom
*Shading indicates that sample was below the detection limit for that parameter and a value of 0.5 * detection limit is reported.*

Table 3.11. Phosphorus Data (mg/L) for Packwood Lake

Orthophosphorus (mg/L)								
	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**	**Oct 05**
PLA(PH)	0.078	0.001	0.001	0.001	0.001	0.029	0.062	0.001
PLA(EP)				0.001	0.001			
PLA(ME)			0.001	0.001	0.029	0.062		
PLA(OB)	0.082	0.001	0.001	0.001	0.001	0.030	0.066	0.001
PLB(PH)	0.080	0.001	0.001	0.001	0.029	0.063	0.001	
PLB(EP)				0.001				
PLB(OB)	0.090	0.001	0.001	0.001	0.001	0.027	0.069	0.001
Total Phosphorus (mg/L)								
	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**	**Oct 05**
PLA(PH)	0.082	0.001	0.001	0.001	0.001	0.030	0.065	0.001
PLA(EP)				0.001	0.001			
PLA(ME)			0.001	0.001	0.030	0.065		
PLA(OB)	0.086	0.001	0.001	0.001	0.001	0.032	0.069	0.001
PLB(PH)	0.084	0.001	0.001	0.001	0.030	0.066	0.001	
PLB(EP)				0.001				
PLB(OB)	0.095	0.001	0.001	0.001	0.001	0.028	0.073	0.001

(PH) = photic zone, D.O. at depth of 1 m is reported.
(ME) = metalimnion, sample collected at 4 m
(OB) = 1 m off bottom
*Shading indicates that sample was below the detection limit. A value of 0.5 * detection limit is reported for total phosphorus. A value of 0.95 * T-phosphorus sample measurement is used as an estimate of orthophosphorus when sample is below the detection limit.*

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 because the inflow includes glacial meltwater, which elevates turbidity and the total phosphorus load during periods of snowmelt. Ecology (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 3.12 lists TSI scores for Packwood Lake based on 2005 water quality data. Most of the chlorophyll *a* samples had TSI scores in the oligo-mesotrophic range, which best characterizes the lake's productivity. The TSI score for TP was similar for 2004 and 2005. Other TSI scores were slightly lower in 2005; however, trophic classification was the same for both years for all parameters except secchi depth, which was classified as oligotrophic in 2005 compared to mesotrophic in 2004.

Table 3.12. Trophic State Indices (TSI) for Packwood Lake 2005

	TSI Secchi	TSI TP	TSI TN	TSI Chlorophyll *a*
Trophic Status	Oligotrophic	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	28.4	54.8	34.24	31.71

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 248 for the photic zone and 160.6 averaged for samples from all depths (Table 3.13). Annual average TN:TP ratios were identical for 2004 and 2005. There was greater variability for TN:TP scores in 2005 than the previous year and TN:TP and scores were higher in summer 2005 relative to 2004. These values indicate phosphorus is limiting relative to the availability of nitrogen. The TN:TP ratios for August; however, are less than or equal to 8.0, which is indicative of a nitrogen limitation. The trend suggests that phosphorus is limiting most of the year but primary productivity during the summer exhausts nitrogen supplies. The seasonal trend was similar in 2004 although TN was exhausted earlier in 2005.

Biologically available nutrients are low for Packwood Lake. The majority of nitrogen in Packwood Lake occurred as organic nitrogen, which is TKN less ammonia; organic nitrogen is not available for immediate biological uptake. Inorganic nitrogen (nitrite-nitrate + ammonia) was 4 – 63 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 lower nitrogen to phosphorus ratios, with an annual mean of 39.5 (Table 3.14). 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. The TIN:TIP ratios also support a conclusion that phosphorus is limiting primary productivity relative to nitrogen availability.

Table 3.13. Annual and Seasonal Mean TN:TP Ratios 2005
(ratios listed are inclusive of all sampling depths, where applicable)

	Annual Mean	Seasonal Mean		
		Spring	Summer	Fall
Packwood Lake	160.6	16.0	158.2	273.4
Osprey Creek	263.8	104.0	138.9	611.0
Muller Creek	277.9	348.4	42.8	772.0
Upper Lake Creek	248.2	48.4	190.2	534.8
Crawford Creek	260.2	40.5	205.6	561.6

Table 3.14. Annual and Seasonal Mean TIN:TIP Ratios 2005
(ratios listed are inclusive of all sampling depths, where applicable)

	Annual Mean	Seasonal Mean		
		Spring	Summer	Fall
Packwood Lake	39.5	26.5	43.3	35.9
Osprey Creek	12.7	16.1	11.3	11.4
Muller Creek	43.6	50.2	26.3	75.8
Upper Lake Creek	34.6	24.3	40.3	36.3
Crawford Creek	17.0	16.0	21.3	11.8

Silica is necessary for diatom growth. Silica levels in Packwood Lake remained fairly constant throughout the growing season (Figure 3-12).

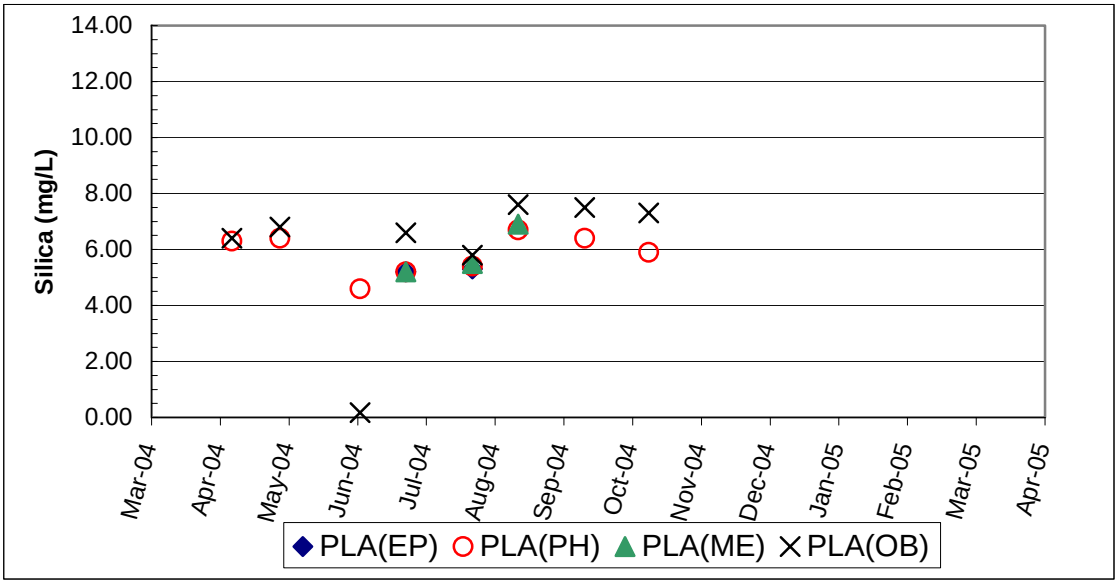

Figure 3-12. Silica Levels for Packwood Lake at Site A

Total organic carbon data for Packwood Lake are reported in Table 3.15.

Table 3.15. Total Organic Carbon Data (mg/L) for Packwood Lake

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05	Oct 05
PLA(PH)	0.79	1.70	1.30		0.40	0.51	1.00	1.30
PLA(EP)				0.45	0.40			
PLA(ME)			2.20	0.49	0.50	0.65		
PLA(OB)	0.96	1.20	0.97	0.55	0.57	0.58	0.75	0.88
PLB(PH)	0.75		0.79	0.39	0.50	0.77	0.86	
PLB(EP)				0.46				
PLB(OB)	0.94	1.70	2.30	0.43	0.50	0.60	0.75	0.63

(PH) = photic zone, D.O. at depth of 1 m is reported
(ME) = metalimnion, sample collected at 4 m
(OB) = 1 m off bottom

Total dissolved solids (TDS) are a measure of the concentration of dissolved material in the water. Major cations contributing to TDS include calcium, magnesium, sodium, chlorides, carbonates, iron and manganese. Other trace materials are also dissolved in water. TDS data for Packwood Lake are reported in Table 3.16. Total suspended solids (TSS) were often below the detection limit but within a range that a reasonable measurement could still be reported by the laboratory. The only non-detect immeasurable sample for TSS was for the epilimnion in the first half of August. Monthly data for TSS are reported in Table 3.17.

Table 3.16. Total Dissolved Solids (TDS) (mg/L) for Packwood Lake

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05	Oct 05
PLA(PH)	43	39	34	43	45	51	50	43
PLA(EP)				49	44			
PLA(ME)			33	49	39	51		
PLA(OB)	50	43	36	48	48	48	47	44
PLB(PH)	45		52	45	44	45	47	
PLB(EP)				46				
PLB(OB)	43	38	33	45	43	44	37	40

(PH) = photic zone, D.O. at depth of 1 m is reported
(ME) = metalimnion, sample collected at 4 m
(OB) = 1 m off bottom

Table 3.17. Total Suspended Solids (TSS) (mg/L) for Packwood Lake

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05	Oct 05
PLA(PH)	1	2	1	1	1	0	1	2
PLA(EP)				1	1			
PLA(ME)			1	1	0	1		
PLA(OB)	2	1	1	1	1	0	1	2
PLB(PH)	1		1	1	0	0	5	
PLB(EP)				1				
PLB(OB)	2	2	1	1	1	0	2	1

(PH) = photic zone, D.O. at depth of 1 m is reported
(ME) = metalimnion, sample collected at 4 m
(OB) = 1 m off bottom

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 May 2005 (earlier than in 2004) at approximately 34,473 μm/mL and 590 units/mL, respectively. This peak was far smaller than the peak in 2004. Phytoplankton was at season minimum in late August 2005; biomass was 3,820 μm/mL and density was 73 units/mL. The time and magnitude of the minimum phytoplankton biomass were similar for both years. No cyanophyta were documented in 2005. Phytoplankton biomass and density had a secondary peak in August that is primarily attributed to Chlorophyta. Figures 3-14 through 3-21 show the seasonal trends in phytoplankton stratified by phyla. Table 3.18 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 3-13.

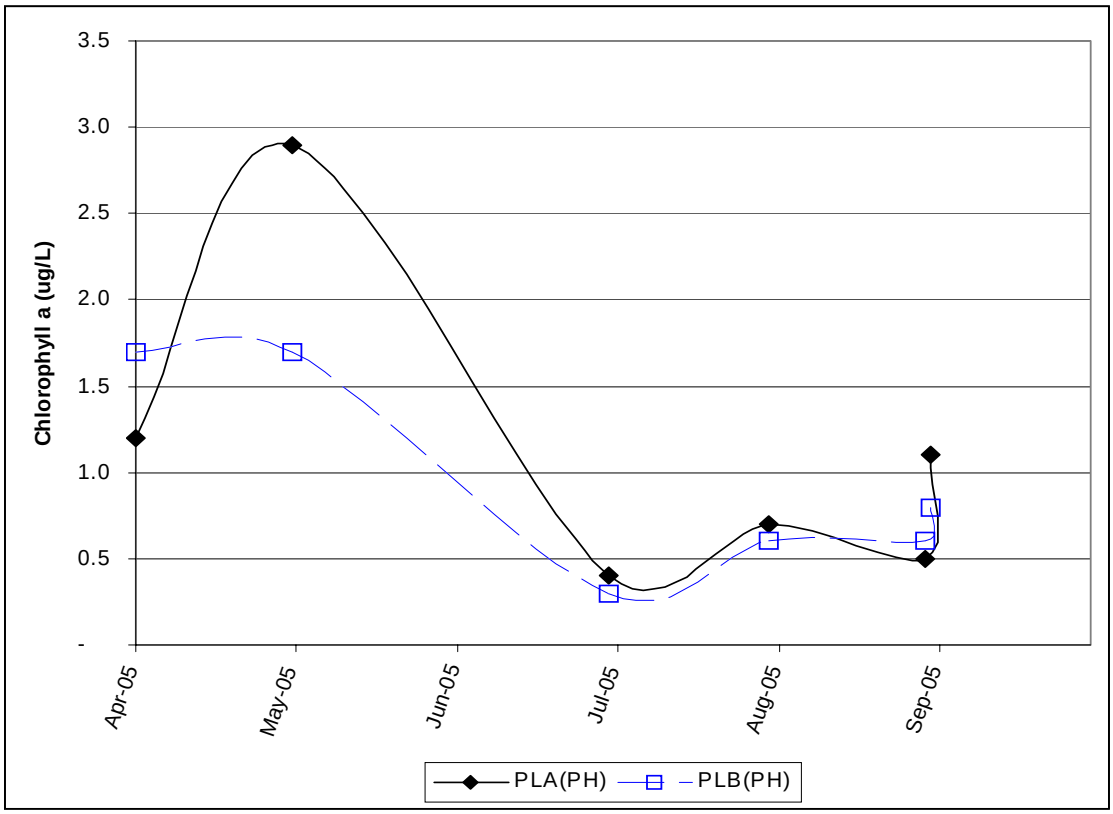

Figure 3-13. Chlorophyll *a* for Packwood Lake

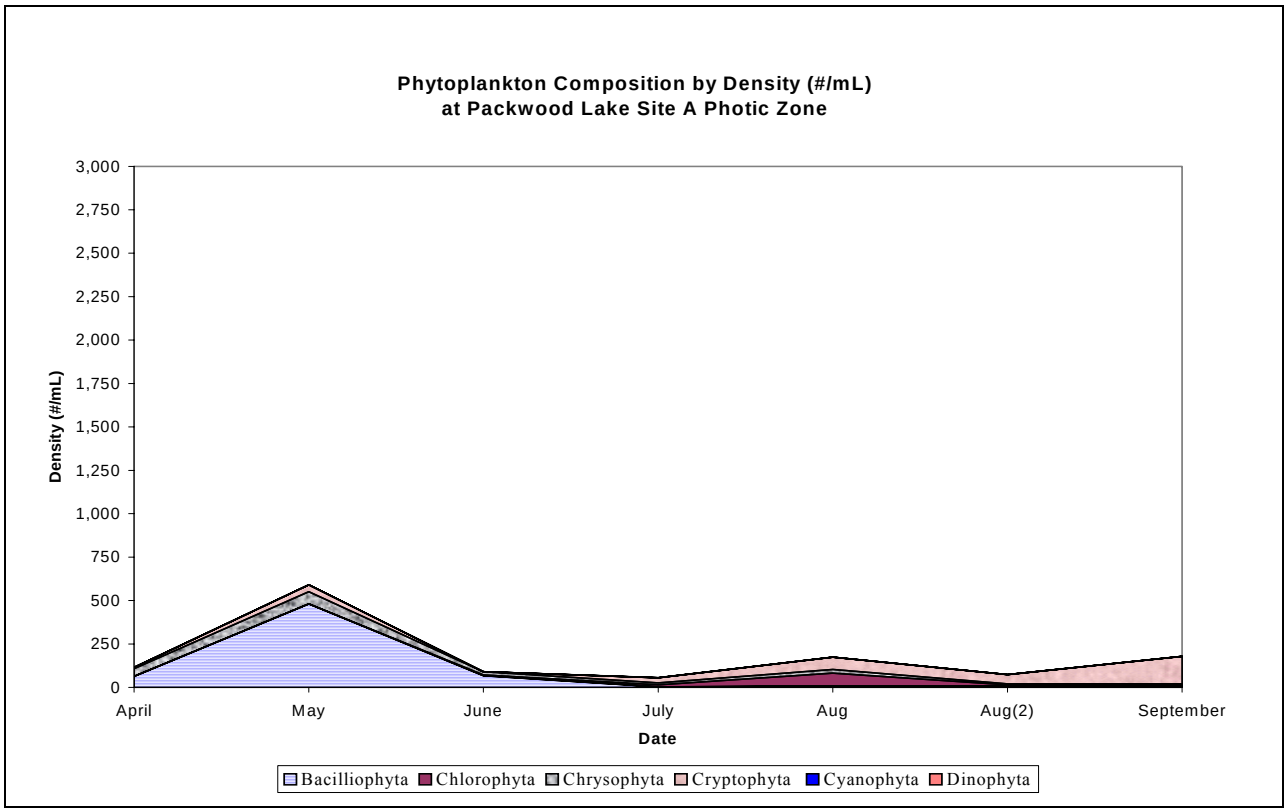

Figure 3-14. Phytoplankton Composition Density for Packwood Lake Photic Zone Site A

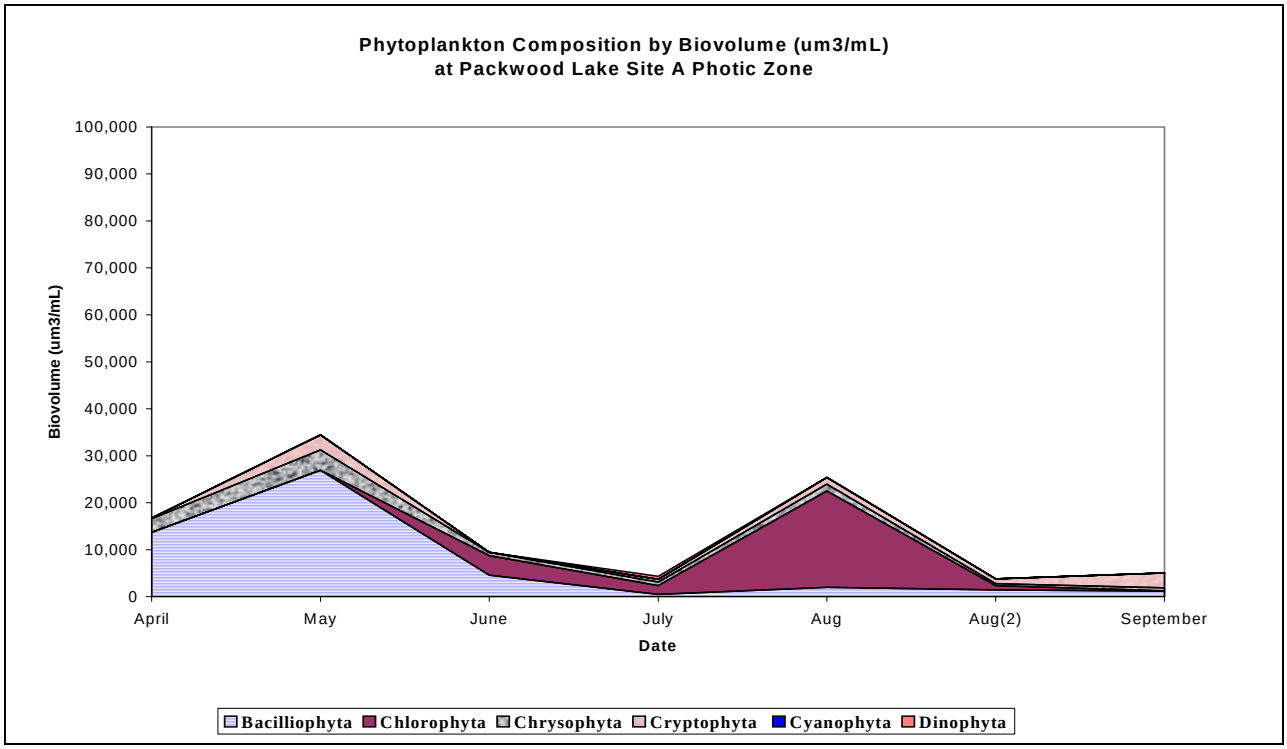

Figure 3-15. Phytoplankton Composition Biovolume for Packwood Lake Photic Zone Site A

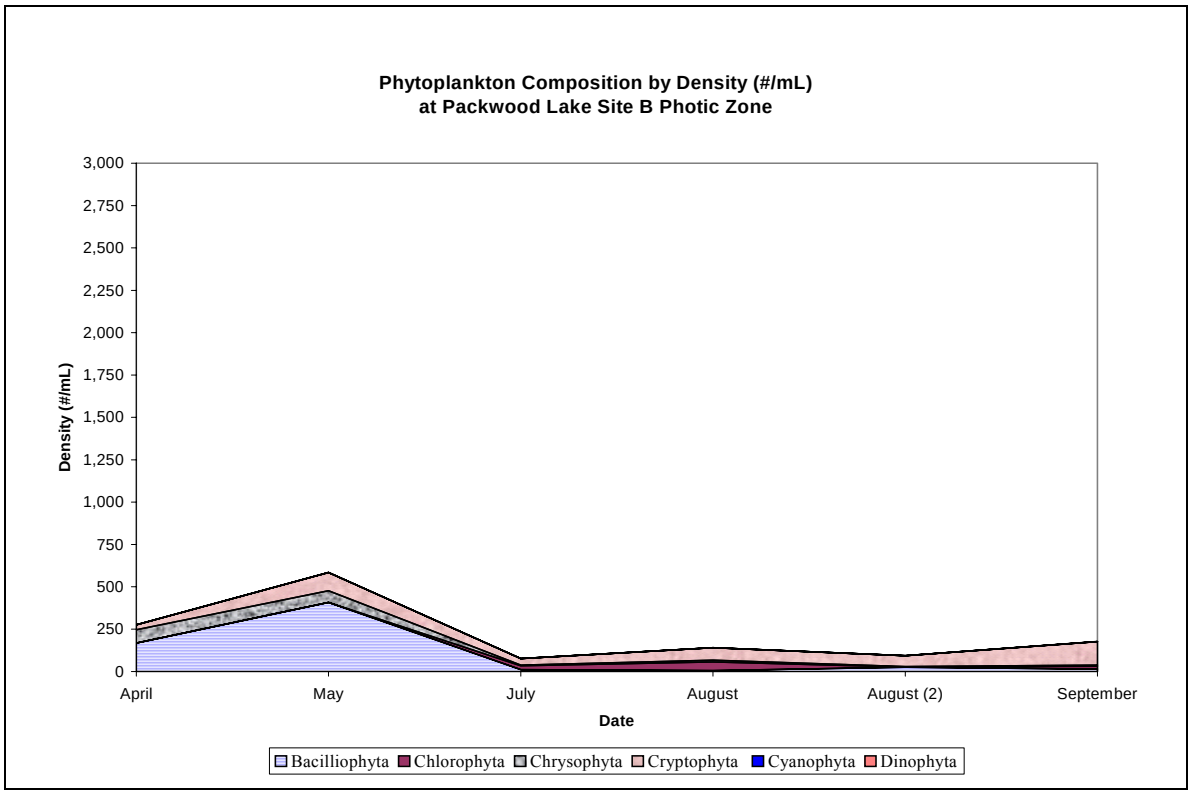

Figure 3-16. Phytoplankton Composition Density for Packwood Lake Photic Zone Site B

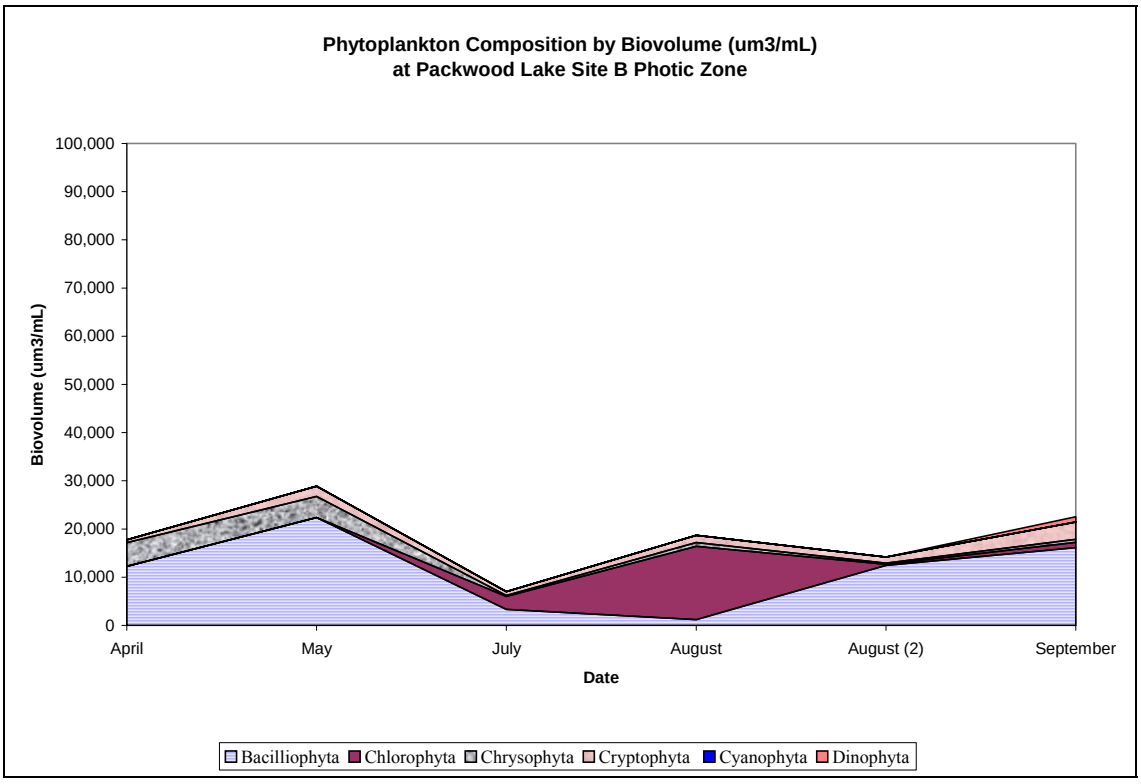

Figure 3-17. Phytoplankton Composition Biovolume for Packwood Lake Photic Zone Site B

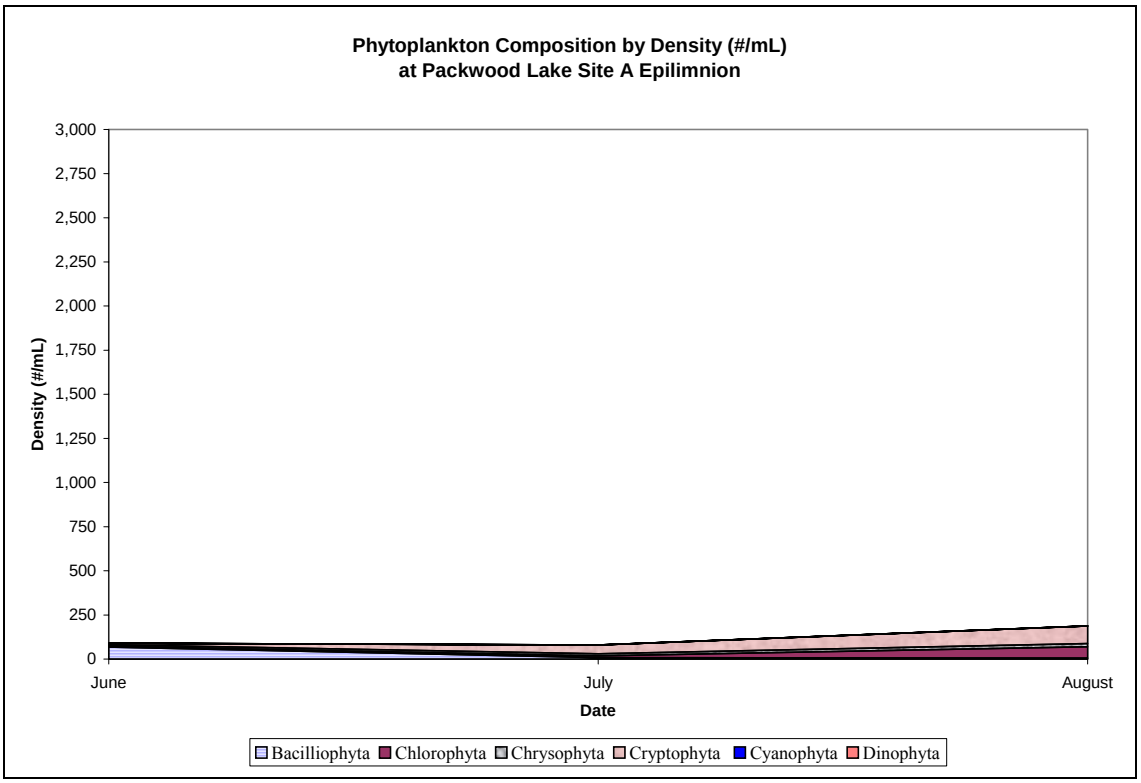

Figure 3-18. Phytoplankton Composition Density for Packwood Lake Epilimnion Site A

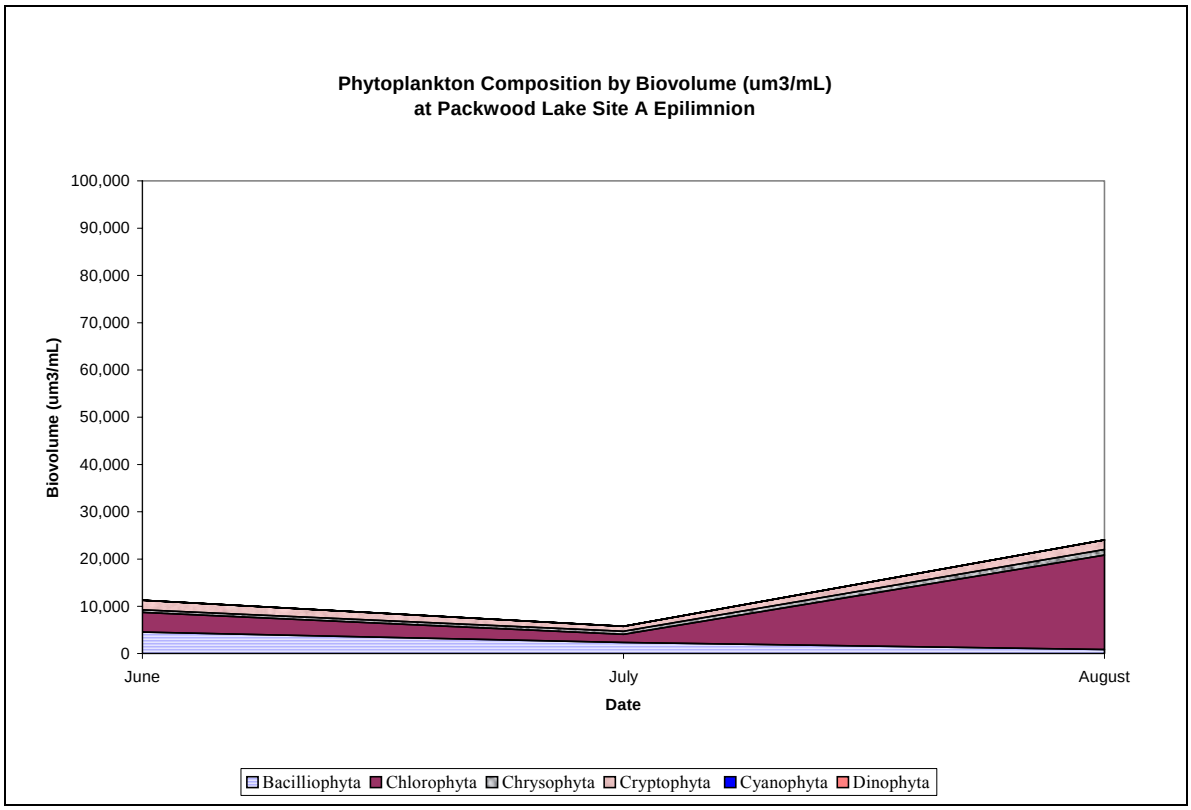

Figure 3-19. Phytoplankton Composition Biovolume for Packwood Lake Epilimnion Site A

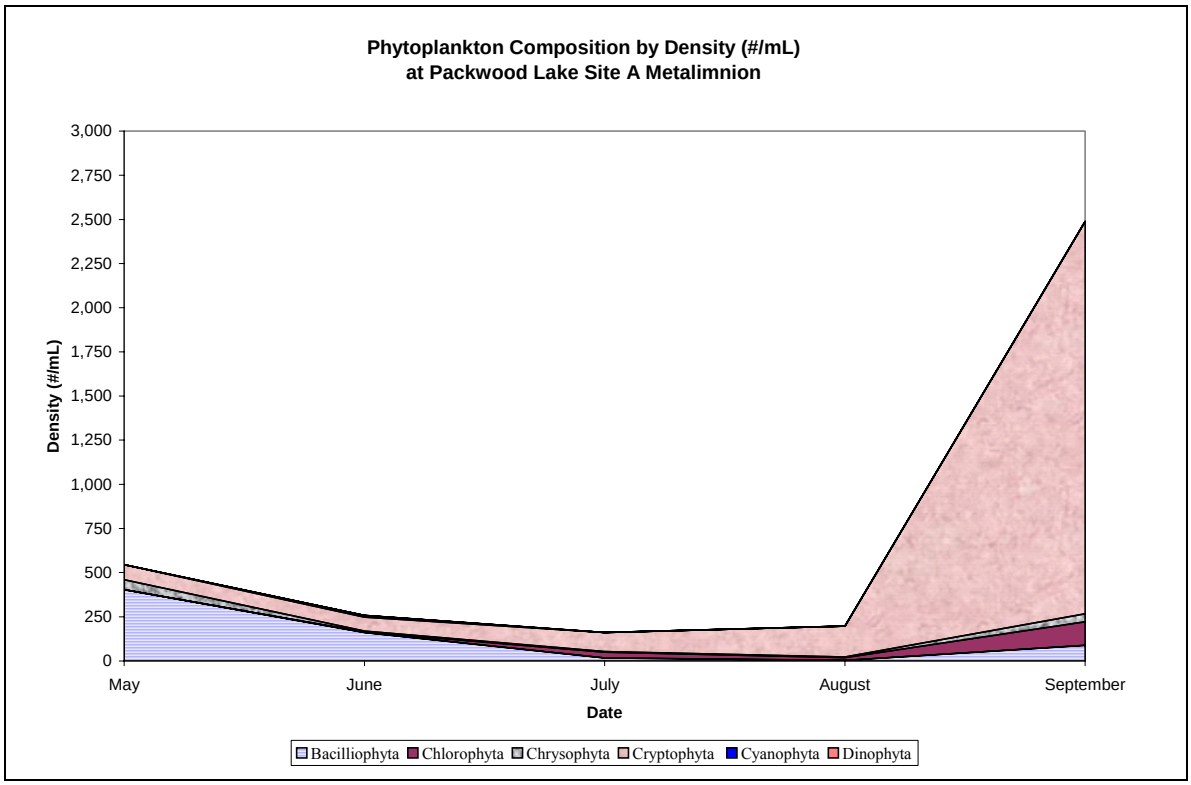

Figure 3-20. Phytoplankton Composition Density for Packwood Lake Metalimnion Site A

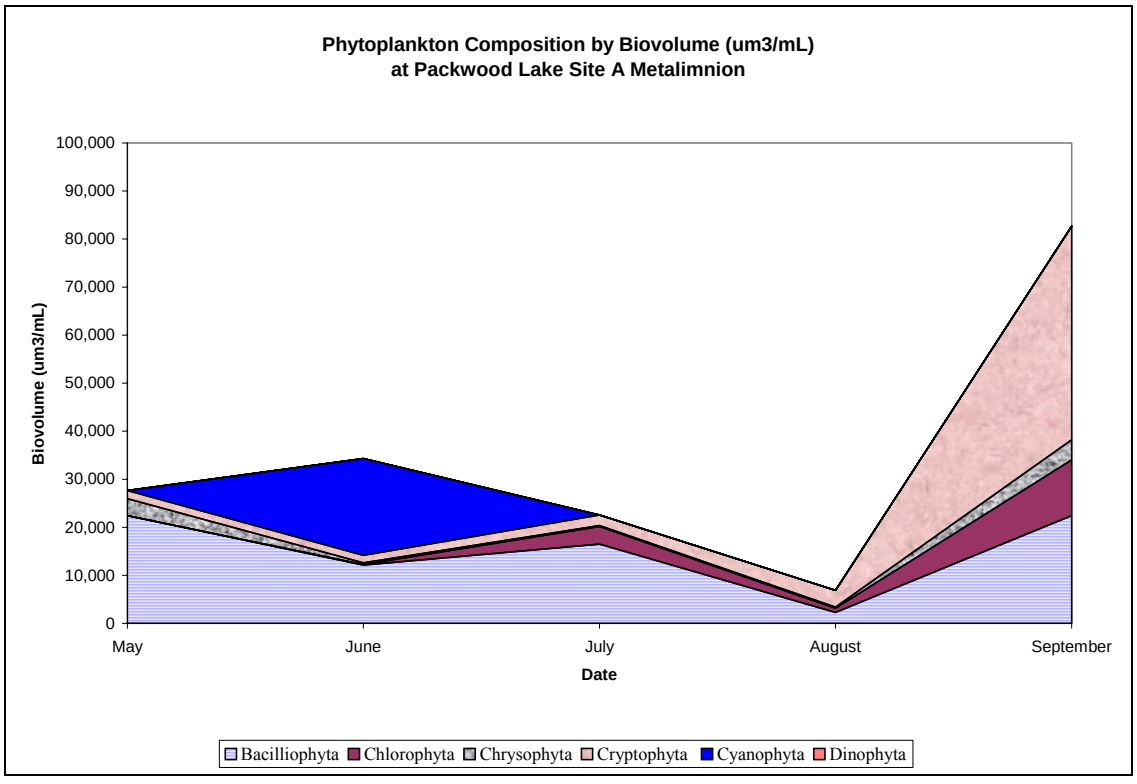

Figure 3-21. Phytoplankton Composition Biovolume for Packwood Lake Metalimnion Site A

Table 3.18. Dominant Phytoplankton Species Based on Biovolume

Packwood Lake site A (Photic zone)				
Date	20-Apr-05	25-May-06	19-Jul-05	3-Aug-05
Depth (m)				
Bacilliophyta	*Stephanodiscus astraea minutula*	*Cyclotella stelligera*	*Cocconeis placentula*	*Stephanodiscus astraea minutula*
	Melosira italica	*Synedra rumpens*	*Cyclotella stelligera*	*Gomphonema sp.*
	Cyclotella stelligera			*Gomphonema angustatum*
Chlorophyta			*Oocystis pusilla*	*Oocystis pusilla*
			Crucigenia quadrata	*Sphaerocystis schroeteri*
			Sphaerocystis schroeteri	*Ankistrodesmus falcatus*
Chrysophyta	*Kephyrion sp.*	*Kephyrion sp.*	*Kephyrion sp.*	*Kephyrion sp.*
			Kephyrion littorale	*Kephyrion littorale*
Cryptophyta	*Rhodomonas minuta*	*Cryptomonas erosa*	*Rhodomonas minuta*	*Rhodomonas minuta*
		Rhodomonas minuta		
Cyanophyta				
Dinophyta			*Glenodinium sp.*	
Date	31-Aug-05	21-Sep-05		
Depth (m)				
Bacilliophyta	*Cocconeis placentula*	*Gomphonema angustatum*		
	Stephanodiscus astraea minutula	*Navicula pseudoscutiformis*		
	Rhoicosphenia curvata	*Synedra rumpens*		
Chlorophyta	*Chlamydomonas sp.*	*Ankistrodesmus falcatus*		
	Oocystis pusilla			
	Crucigenia quadrata			
Chrysophyta	*Kephyrion littorale*	*Kephyrion littorale*		
	Kephyrion sp.			
Cryptophyta	*Rhodomonas minuta*	*Rhodomonas minuta*		
Cyanophyta				
Dinophyta				

Up to three most dominant species with each taxa are listed.

Table 3.18. Dominant Phytoplankton Species Based on Biovolume (cont'd)				
Packwood Lake site B (Photic Zone)				
Date	20-Apr-05	19-May-04	19-Jul-05	3-Aug-05
Depth (m)				
Bacilliophyta	*Cyclotella stelligera*	*Cyclotella stelligera*	*Stephanodiscus astraea minutula*	*Cocconeis placentula*
	Stephanodiscus astraea minutula	*Achnanthes minutissima*	*Cocconeis placentula*	*Gomphonema angustatum*
	Navicula cryptocephala veneta		*Cymbella minuta*	*Synedra rumpens*
Chlorophyta			*Crucigenia quadrata*	*Oocystis pusilla*
			Oocystis pusilla	*Crucigenia quadrata*
			Sphaerocystis schroeteri	*Ankistrodesmus falcatus*
Chrysophyta	*Kephyrion sp.*	*Kephyrion sp.*	*Kephyrion sp.*	*Kephyrion littorale*
				Kephyrion sp.
Cryptophyta	*Rhodomonas minuta*	*Rhodomonas minuta*	*Rhodomonas minuta*	*Rhodomonas minuta*
Cyanophyta				
Dinophyta				
Date	31-Aug-05	21-Sep-05		
Depth (m)				
Bacilliophyta	*Synedra ulna*	*Fragilaria crotonensis*		
	Cymbella minuta	*Synedra radians*		
	Melosira varians	*Cocconeis placentula*		
Chlorophyta	*Oocystis pusilla*	*Gloeocystis ampla*		
	Ankistrodesmus falcatus	*Oocystis pusilla*		
		Ankistrodesmus falcatus		
Chrysophyta	*Kephyrion littorale*	*Kephyrion littorale*		
	Kephyrion sp.			
Cryptophyta	*Rhodomonas minuta*	*Rhodomonas minuta*		
		Cryptomonas erosa		
Cyanophyta				
Dinophyta		*Glenodinium sp.*		

Up to three most dominant species with each taxa are listed

3.3 Tributaries to Packwood Lake

Water quality was monitored at the mouth of four tributaries flowing into Packwood Lake. The tributaries monitored include Osprey (OSMH), Muller (MUMH), Upper Lake (ULMH), and Crawford (CRMH) creeks (See Figure 2.1 for tributary sample locations). 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. Discussion of the results for the groundwater monitoring site (GW1) are included in this section as groundwater inflow is a boundary condition when modeling water quality.

Mean annual values for measured water quality parameters for tributaries to Packwood Lake are reported in Table 3.19. Monthly data for various water quality parameters are reported in Tables 3.20 through 3.28. Figures 3-22 through 3-31 show the seasonal trend in water quality for these tributaries. All water quality standards were met in the four tributaries to Packwood Lake for all months sampled. The tributaries are characterized as cold water streams, low in nutrients. They are phosphorus limited relative to nitrogen 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 and total phosphorus were below detection limits for the majority of samples. Total phosphorus levels were slightly above detection limits in late August and September 2005 compared to an earlier timed peak in 2004 (July and early August).

Table 3.19. Mean Annual Values for Water Quality Parameters for Tributaries to Packwood Lake, 2005-2006

	pH	Turbidity (NTU)	Specific Conductance (uS/cm)	Alkalinity, Bicarbonate as CaCO3 (mg/L)	Total Alkalinity (mg/L)	Hardness (mg/L)
Crawford	7.45	2.28	0.0348	25.3	25.3	
Osprey	7.21	1.08	0.0244	18.0	18.0	
Upper Lake	7.23	2.02	0.0422	26.7	26.7	
Muller	7.18	2.01	0.0401	25.4	25.4	
GW1	7.01	0.12	0.0253	18.6	18.6	
	Silica (mg/L)	Total Dissolved Solids (TDS) (mg/L)	Total Suspended Solids (TSS) (mg/L)	Ammonia as N (mg/L) [2]	Nitrite as N (mg/L) [2]	Nitrate as N (mg/L) [2]
Crawford	5.6	38.7	1.2	0.023	0.016	0.014
Osprey	13.3	50.7	1.9	0.022	0.016	0.013
Upper Lake	6.6	46.6	1.4	0.022	0.016	0.047
Muller	9.1	49.1	1.9	0.018	0.015	0.062
GW1	10.5	37.6	0.3	0.020	0.015	0.097
	Phosphate, Ortho as P (mg/L) [1]	Phosphorus, Total (mg/L) [2]	Total Kjeldahl Nitrogen (TKN) (mg/L) [2]	Total Organic Carbon (TOC) (mg/L)	TN:TP	TIN:TIP
Crawford	0.027	0.026	0.286	0.76	260.2	17.1
Osprey	0.028	0.018	0.279	2.00	263.8	12.7
Upper Lake	0.025	0.026	0.257	0.30	248.2	34.6
Muller	0.029	0.031	0.286	0.94	277.9	43.6
GW1	0.036	0.025	0.288	0.35	336.2	50.7

[1] For samples that the orthophosphorus level was below detection limit, a value of 0.95 * total phosphorus was used as an estimate of orthophosphorus.

[2] For purposes of calculating a mean, non-detects were assigned a value of 0.5*detection limit

Shaded values include non-detect data in average

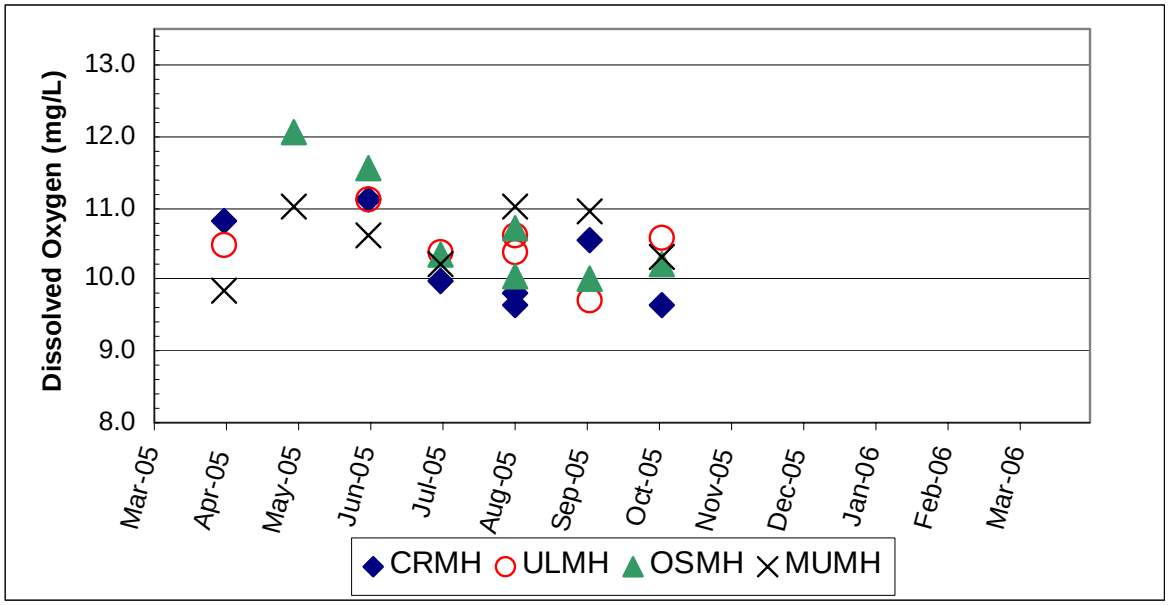

Figure 3-22. Dissolved Oxygen for Tributaries to Packwood Lake

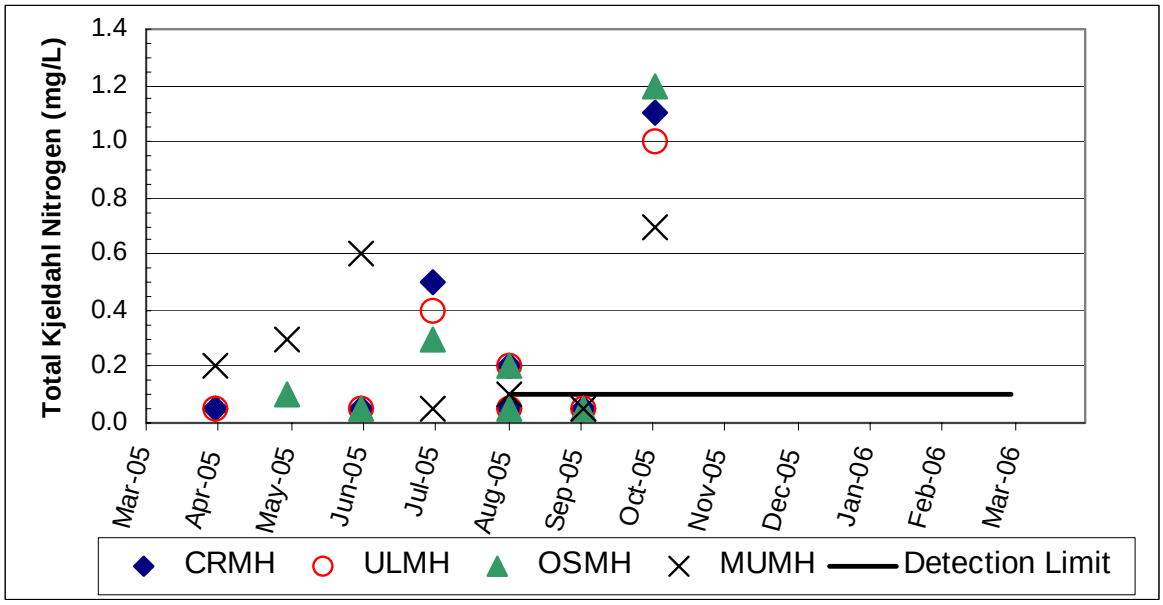

Figure 3-23. Total Kjeldahl Nitrogen TKN for Tributaries to Packwood Lake

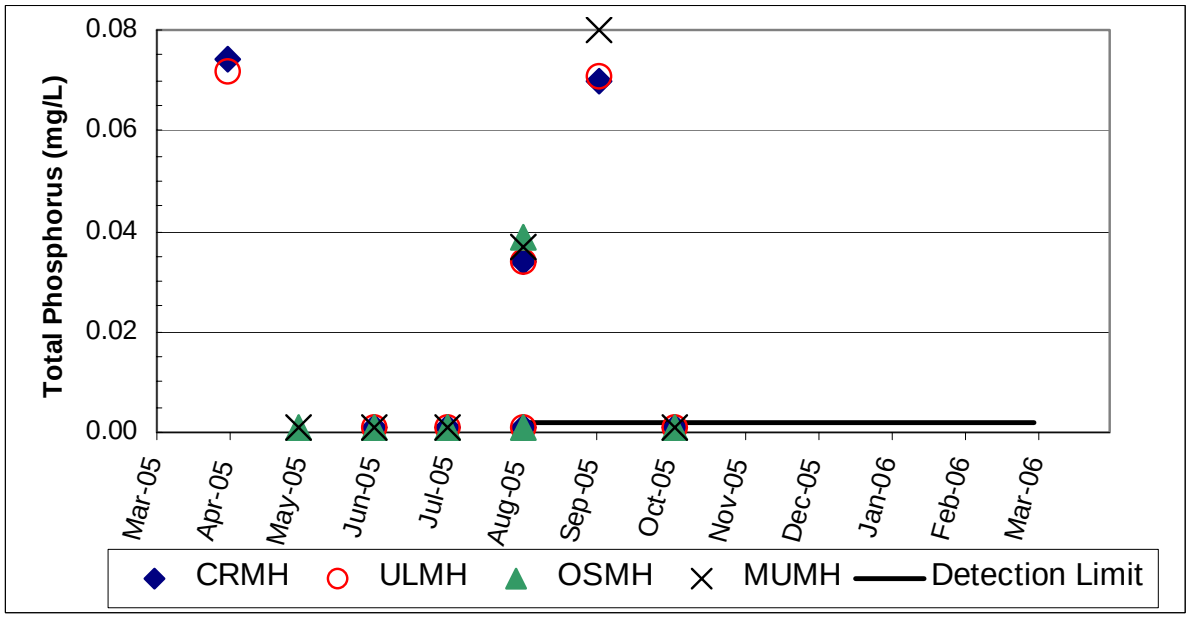

Figure 3-24. Total Phosphorus for Tributaries to Packwood Lake

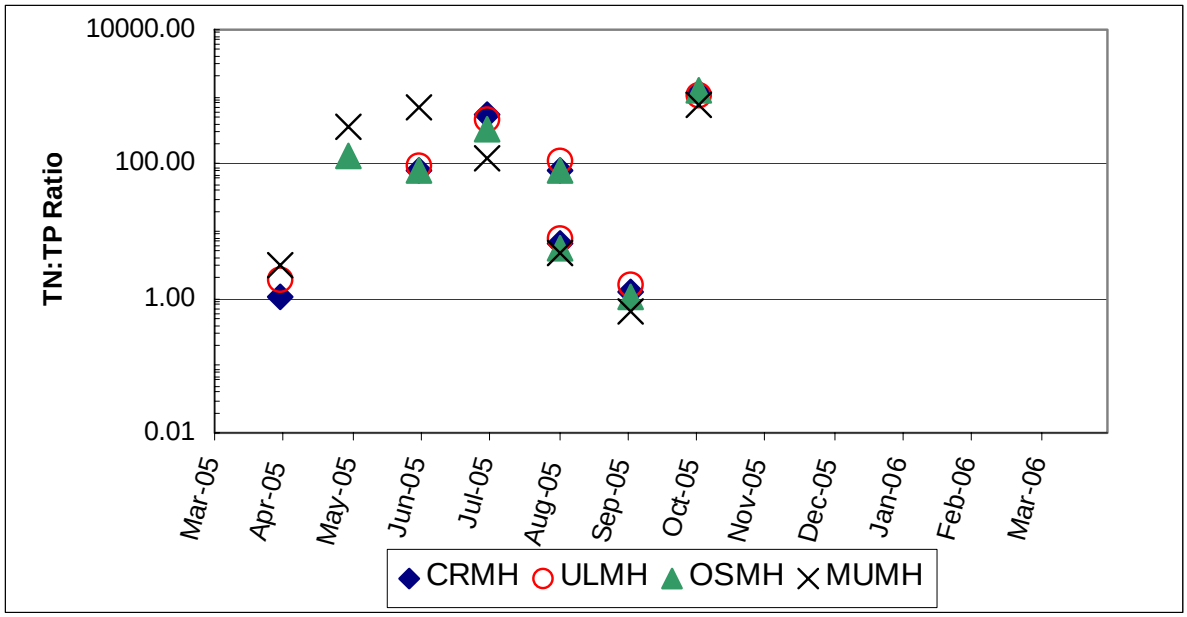

Figure 3-25. Total Nitrogen to Total Phosphorus Ratios for Tributaries to Packwood Lake

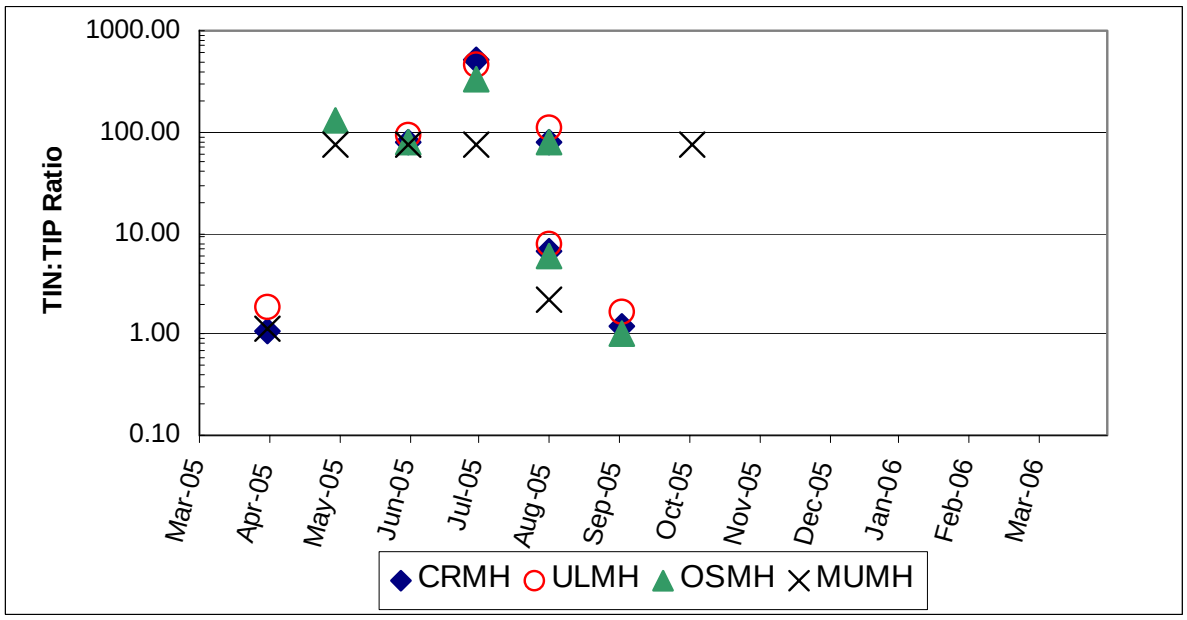

Figure 3-26. Total Inorganic Nitrogen to Total Inorganic Phosphorus Ratios for Tributaries to Packwood Lake

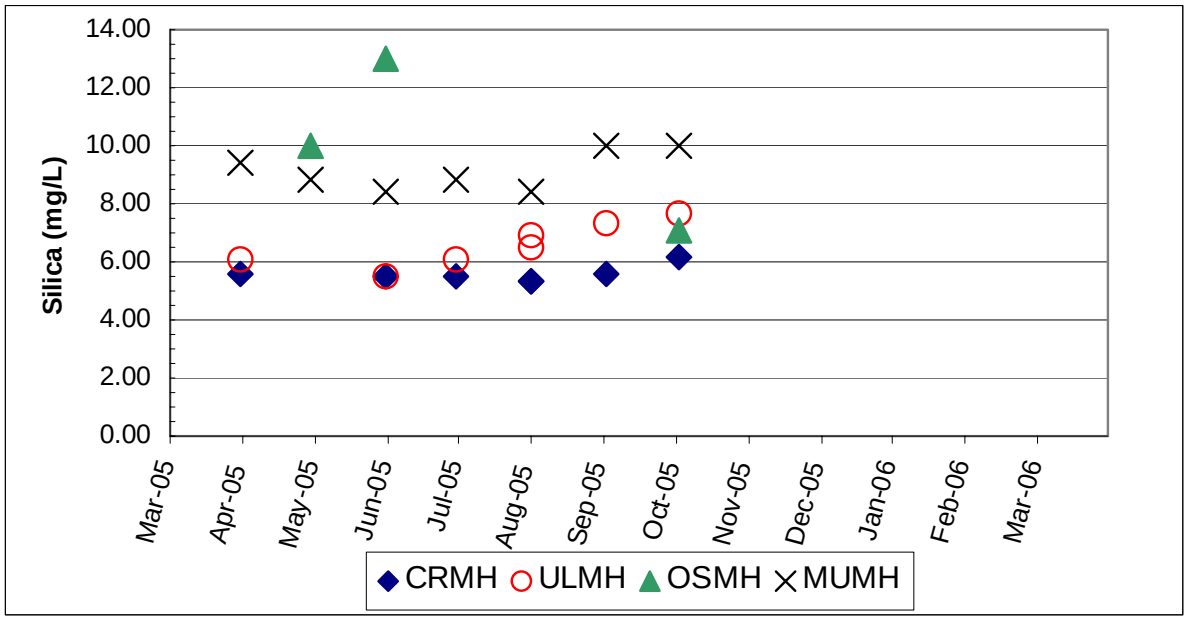

Figure 3-27. Silica for Tributaries to Packwood Lake

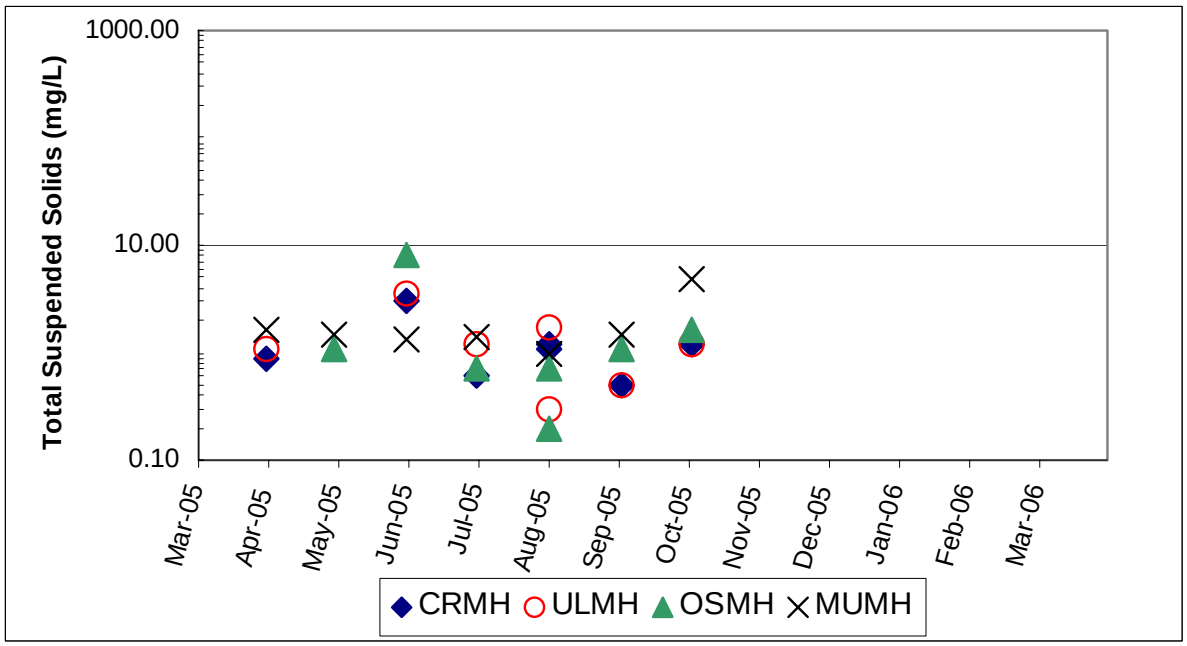

Figure 3-28. Total Suspended Solids for Tributaries to Packwood Lake

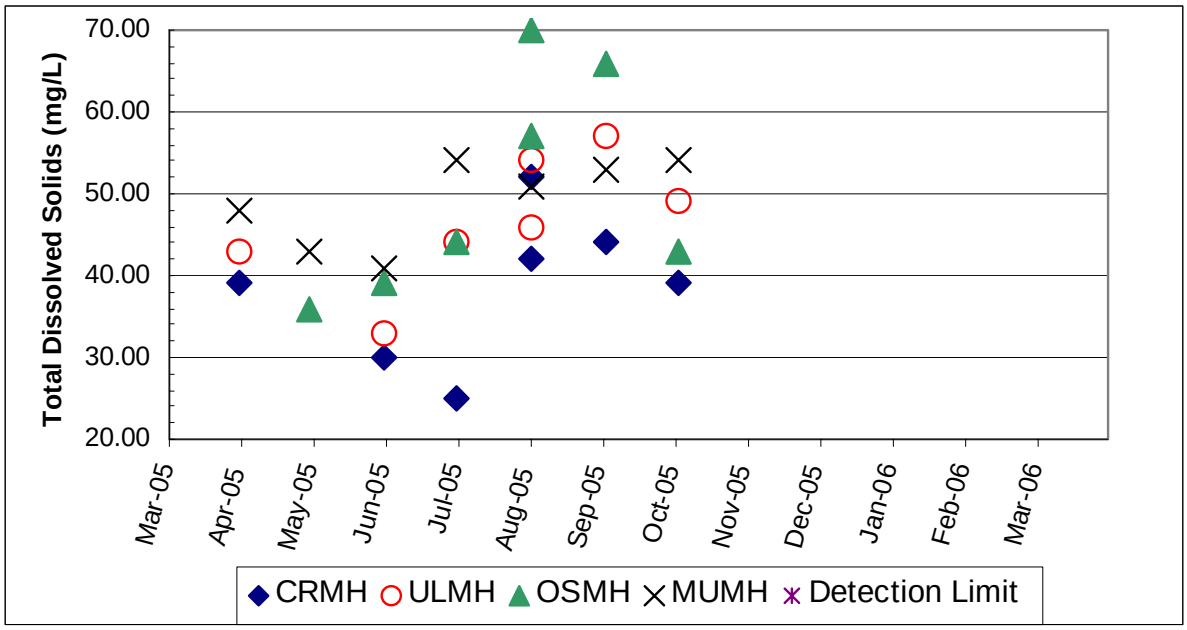

Figure 3-29. Total Dissolved Solids for Tributaries to Packwood Lake

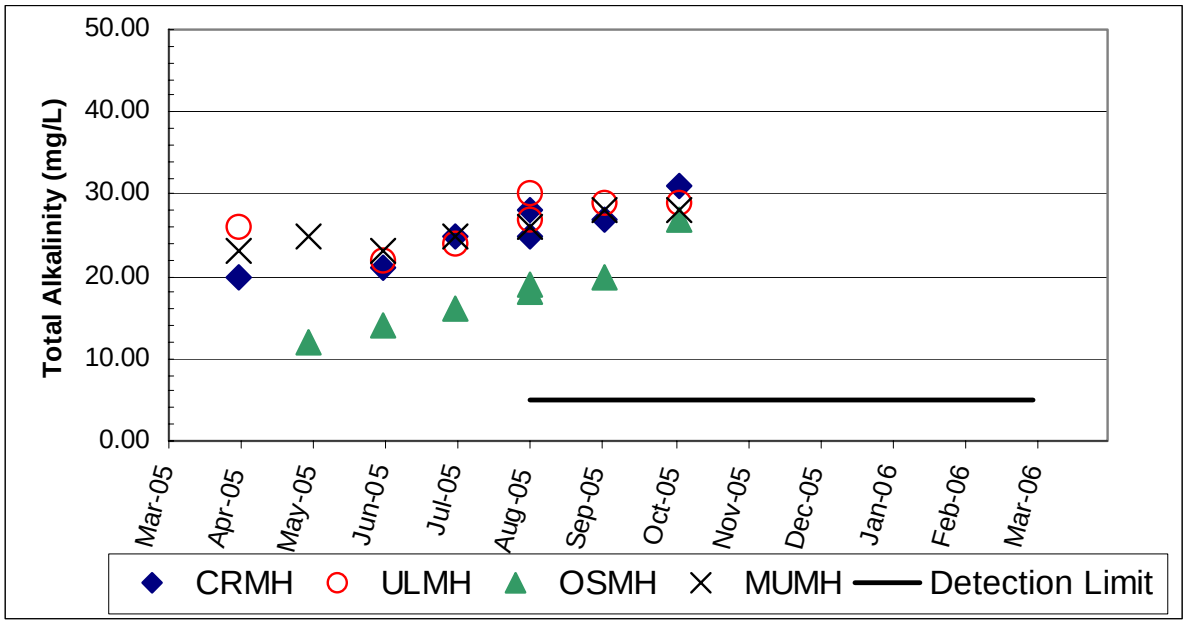

Figure 3-30. Total Alkalinity for Tributaries to Packwood Lake

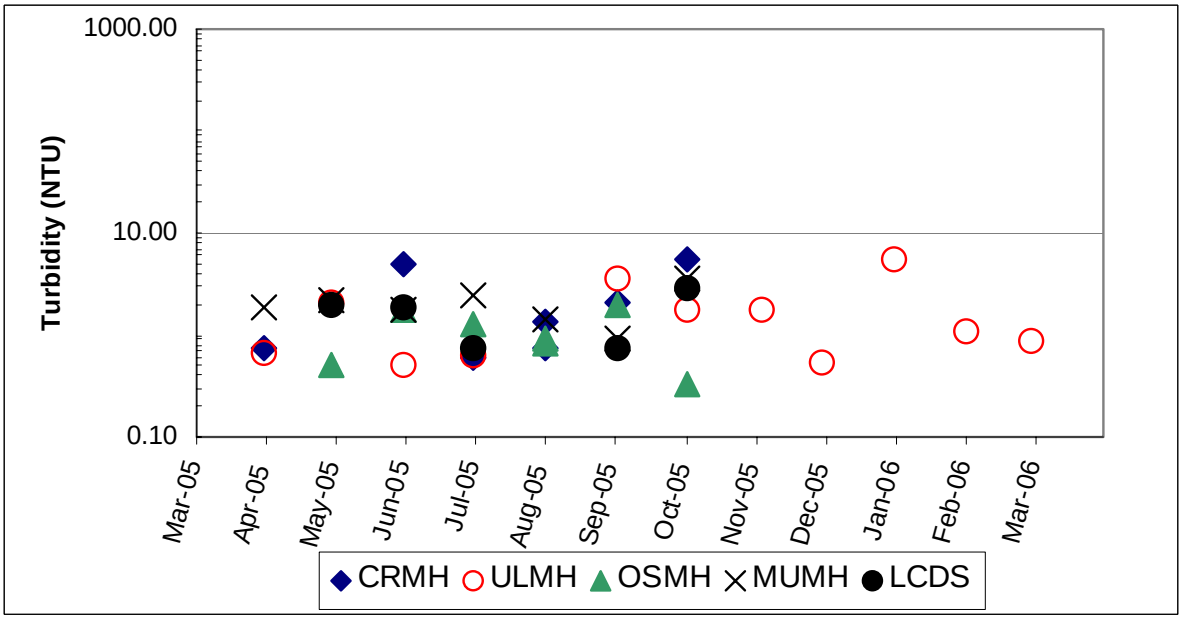

Figure 3-31. Turbidity for Tributaries to Packwood Lake Compared to Lake Outlet (LCDS)

Table 3.20. Turbidity Data for Tributaries to Packwood Lake

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05	Oct 05
Crawford	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Osprey	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Upper Lake	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Muller	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9

Table 3.21. Dissolved Oxygen Data for Tributaries to Packwood Lake

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05	Oct 05
	(mg/L)							
Crawford	10.8	NA	11.1	10.0	9.8	9.7	10.6	9.6
Osprey	NA	12.1	11.6	10.4	10.7	10.0	10.0	10.2
Upper Lake	10.5	NA	11.1	10.4	10.6	10.4	9.7	10.6
Muller	9.8	11.0	10.6	10.2	11.0	NA	11.0	10.3
GW1	10.0	11.1	10.0	10.9	11.3	9.9	10.6	10.5
	% Saturation							
Crawford	93.3	NA	116.1	106.3	88.9	92.1	91.2	82.3
Osprey	NA	105.6	115.5	107.1	94.3	92.6	86.0	82.8
Upper Lake	94.8		113.7	104.3	98.20	95.6	84.7	90.5
Muller	91.9	114.9	107.4	87.9	99.3	NA	93.4	88.1
GW1	77.0	93.5	108.0	105.5	90.7	79.5	84.6	87.6

Table 3.22. pH Data for Tributaries to Packwood Lake

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05	Oct 05
Crawford	7.4		7.6	7.6	7.2	7.5	7.5	7.5
Osprey	0.0	7.0	7.1	7.4	6.9	7.4	7.6	7.1
Upper Lake	7.3		7.3	7.4	7.1	7.0	7.3	7.2
Muller	7.3	7.4	7.1	6.8	7.2		7.3	7.2
GW1	7.1	7.0	7.4	7.4	6.3	7.1	7.1	6.9

Table 3.23. Total Alkalinity Data for Tributaries to Packwood Lake

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05	Oct 05
Crawford	20.0	0.0	21.0	25.0	25.0	28.0	27.0	31.0
Osprey	0.0	12.0	14.0	16.0	18.0	19.0	20.0	27.0
Upper Lake	26.0	0.0	22.0	24.0	30.0	27.0	29.0	29.0
Muller	23.0	25.0	23.0	25.0	26.0	0.0	28.0	28.0
GW1	18.0	18.0	19.0	18.0	19.0	19.0	19.0	19.0

Table 3.24. Nitrogen Data (mg/L) for Tributaries to Packwood Lake

Ammonia (mg/L)								
	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**	**Oct 05**
Crawford	0.019		0.014	0.062	0.024	0.012	0.015	0.013
Osprey	0.000	0.022	0.014	0.053	0.020	0.010	0.016	0.018
Upper Lake	0.019	0.000	0.012	0.062	0.013	0.021	0.016	0.012
Muller	0.019	0.011	0.043	0.014	0.010	0.000	0.015	0.013
GW1	0.019	0.026	0.012	0.044	0.015	0.010	0.021	0.010
Nitrites (mg/L)								
	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**	**Oct 05**
Crawford	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Osprey	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Upper Lake	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Muller	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
GW1	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Nitrates (mg/L)								
	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**	**Oct 05**
Crawford	0.015	0.000	0.015	0.015	0.015	0.015	0.015	0.007
Osprey	0.000	0.015	0.013	0.016	0.015	0.010	0.014	0.006
Upper Lake	0.071	0.000	0.030	0.038	0.044	0.045	0.048	0.053
Muller	0.084	0.055	0.057	0.058	0.061	0.000	0.000	0.057
GW1	0.110	0.015	0.110	0.110	0.110	0.110	0.100	0.110
Kjeldahl Nitrogen (mg/L)								
	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**	**Oct 05**
Crawford	0.050		0.050	0.500	0.050	0.200	0.050	0.050
Osprey		0.100	0.050	0.300	0.050	0.200	0.050	0.050
Upper Lake	0.050		0.050	0.400	0.200	0.050	0.050	0.050
Muller	0.200	0.300	0.600	0.050	0.100	0.000	0.050	0.200
GW1	0.050	0.200	0.300	0.500	0.050	0.050	0.050	0.050

*Shading indicates that sample was below the detection limit and a value of 0.5 * detection limit is reported.*

Table 3.25. Phosphorus Data (mg/L) for Tributaries to Packwood Lake

Orthophosphorus (mg/L)								
	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05	Oct 05
Crawford	0.070	0.000	0.001	0.001	0.001	0.045	0.067	0.001
Osprey	0.000	0.001	0.048	0.001	0.044	0.051	0.049	0.001
Upper Lake	0.068	0.000	0.001	0.001	0.032	0.001	0.067	0.001
Muller	0.089	0.001	0.001	0.001	0.035	0.000	0.076	0.001
GW1	0.076	0.055	0.001	0.001	0.042	0.033	0.075	0.001
Total Phosphorus (mg/L)								
	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05	Oct 05
Crawford	0.074		0.001	0.001	0.001	0.034	0.070	0.001
Osprey		0.001	0.001	0.001	0.001	0.039	0.081	0.001
Upper Lake	0.072	0.000	0.001	0.001	0.034	0.001	0.071	0.001
Muller	0.094	0.001	0.001	0.001	0.037	0.000	0.080	0.001
GW1	0.080	0.001	0.001	0.001	0.001	0.035	0.079	0.001

Shading indicates that sample was below the detection limit. Detection limit is reported for total phosphorus. T-phosphorus sample measurement is used as an estimate of orthophosphorus when sample is below the ortho phosphorous detection limit.

Table 3.26. Total Organic Carbon Data (mg/L) for Tributaries to Packwood Lake

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05	Oct 05
Crawford	1.100		0.810	0.640	0.480	0.520	0.770	1.000
Osprey		0.910	9.500	0.620	0.520	0.490	0.660	1.300
Upper Lake	0.460	0.000	0.320	0.270	0.240	0.150	0.260	0.380
Muller	1.000	2.800	0.400	0.290	0.400		0.660	1.000
GW1	0.260	1.000	0.900	0.130	0.080	0.130	0.190	0.070

*Shading indicates that sample was below the detection limit and a value of 0.5 * detection limit is reported*

Table 3.27. Total Dissolved Solids Data (mg/L) for Tributaries to Packwood Lake

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05	Oct 05
Crawford	39	0	30	25	52	42	44	39
Osprey	0	36	39	44	57	70	66	43
Upper Lake	43	0	33	44	54	46	57	49
Muller	48	43	41	54	51	0	53	54
GW1	40	41	40	40	48	3	48	41

*Shading indicates that sample was below the detection limit. A value of 0.5 * detection limit is reported*

Table 3.28. Total Suspended Solids Data (mg/L) for Tributaries to Packwood Lake

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05	Oct 05
Crawford	0.9	0.0	3.0	0.6	1.1	1.2	0.5	1.2
Osprey	0.0	1.1	8.0	0.7	0.7	0.2	1.1	1.6
Upper Lake	1.1	0.0	3.5	1.2	0.3	1.7	0.5	1.2
Muller	1.6	1.5	1.3	1.4	1.0	0.0	1.5	4.9
GW1	0.1	0.3	0.1	0.7	0.4	0.1	0.4	0.3

*Shading indicates that sample was below the detection limit. A value of 0.5 * detection limit is reported*

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 flow release from Packwood Lake. 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 3-29. Monthly data for lower Lake Creek and the Cowlitz River are reported in Tables 3.30 through Table 3.37.

Dissolved oxygen (DO) downstream of the drop structure was the only water quality criteria exceeded in lower Lake Creek (see Table 3.31). The DO for July 2005 near the mouth was 7.8 mg/L relative to the water quality criteria of 8.5 mg/L. the DO was well above the criteria in all other months. There was one measured exceedence of dissolved oxygen for Cowlitz River upstream of Lake Creek; however, this datapoint is suspect. 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. Dissolved oxygen levels quickly increase downstream of the drop structure due to turbulent flow.

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.

Nutrients are relatively low and phosphorus is limiting relative to nitrogen. Orthophosphorus was relatively lower in summer 2005 than the previous year; however, levels were low in both years. Figures 3-32 through 3-41 show seasonal trends for water quality constituents. Turbidity was consistently lower in Lake Creek than in the Cowlitz River. Turbidity at the mouth of Lake Creek was typically similar or lower than just below the drop structure except in July and August when turbidity was low at both stations.

Table 3.29. Mean Annual Values for Water Quality Parameters for Lower Lake Creek 2005-2006

	pH	Turbidity (NTU)	Specific Conductance (uS/cm)	Alkalinity, Bicarbonate as CaCO3 (mg/L)	Total Alkalinity (mg/L)	Hardness (mg/L)
LCDS	7.58	1.38	0.0316	24.6	24.3	22
LCMH	7.30	1.74	0.0361	22.0	22.0	27
CRULC	7.36	13.78	0.0940	29.8	29.8	22
	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 as N (mg/L)
LCDS	6.3	43.8	2.1	0.021	0.016	0.014
LCMH	7.2	49.8	15.1	0.036	0.016	0.021
CRULC	8.0	52.8	2.7	0.021	0.016	0.052
	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	0.020	0.021	0.238	1.03	237.3	19.1
LCMH	0.040	0.042	0.446	0.61	91.4	21.0
CRULC	0.039	0.041	0.212	0.72	114.3	24.8

[1] For samples that the orthophosphorus level was below detection limit, a value of 0.95 * total phosphorus was used as an estimate of orthophosphorus.
[2] For purposes of calculating a mean, non-detects were assigned a value of 0.5*detection limit. Shading indicates that samples used to calculate the mean include non-detects.

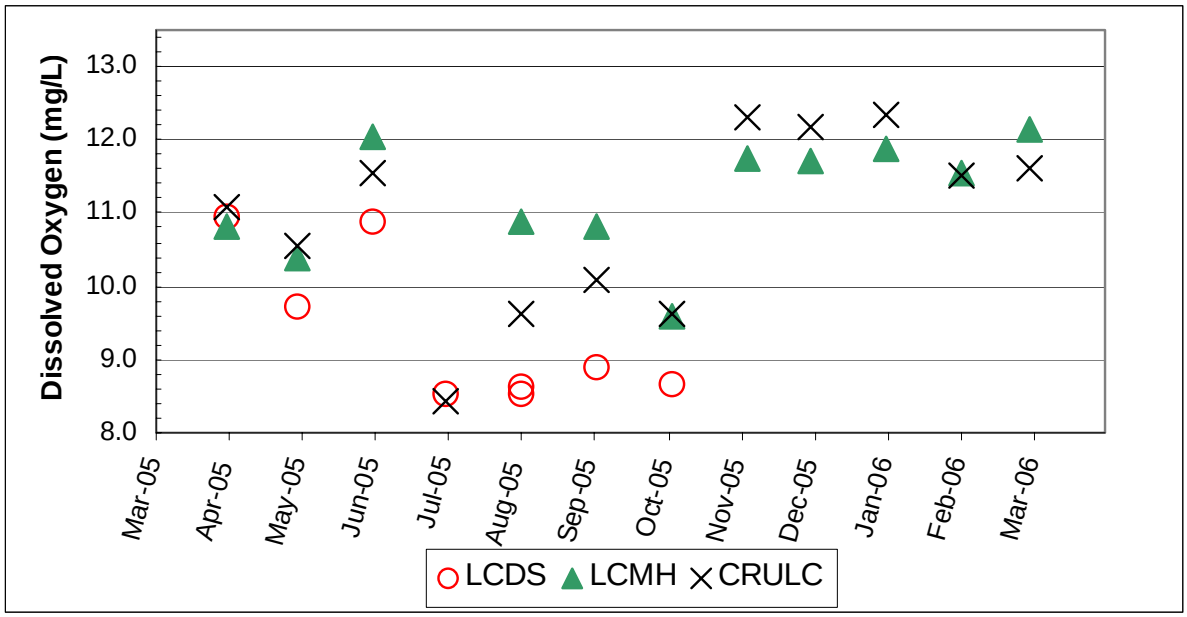

Figure 3-32. Dissolved Oxygen for Lower Lake Creek and Cowlitz River Upstream of Lake Creek

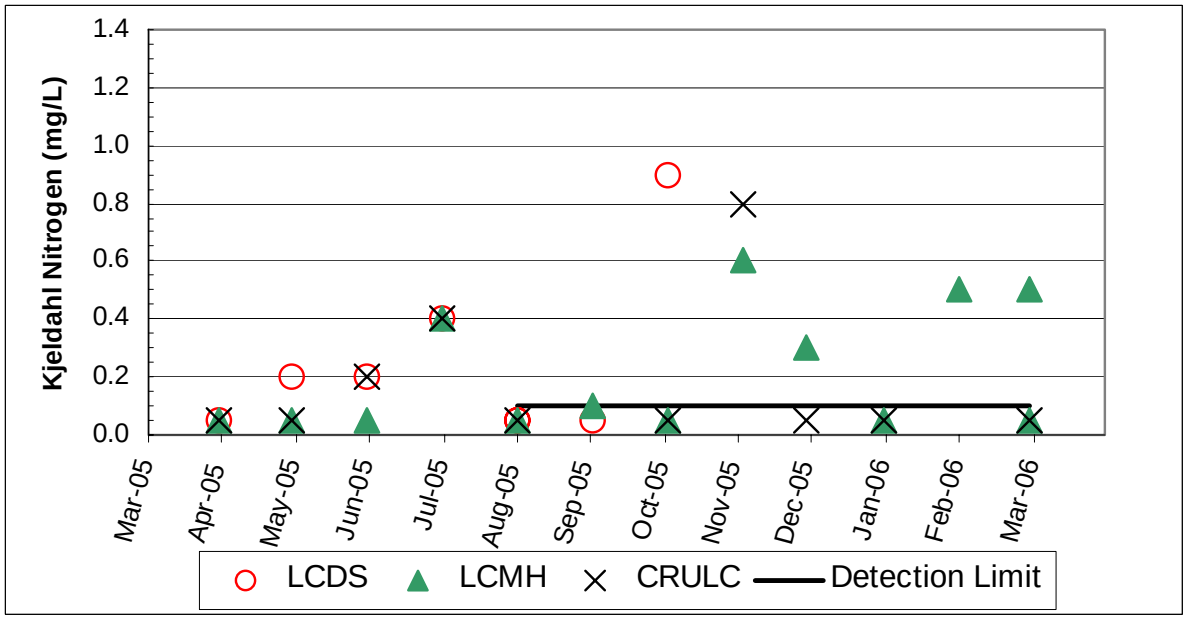

Figure 3-33. Total Kjeldahl Nitrogen TKN for Lower Lake Creek and Cowlitz River Upstream of Lake Creek

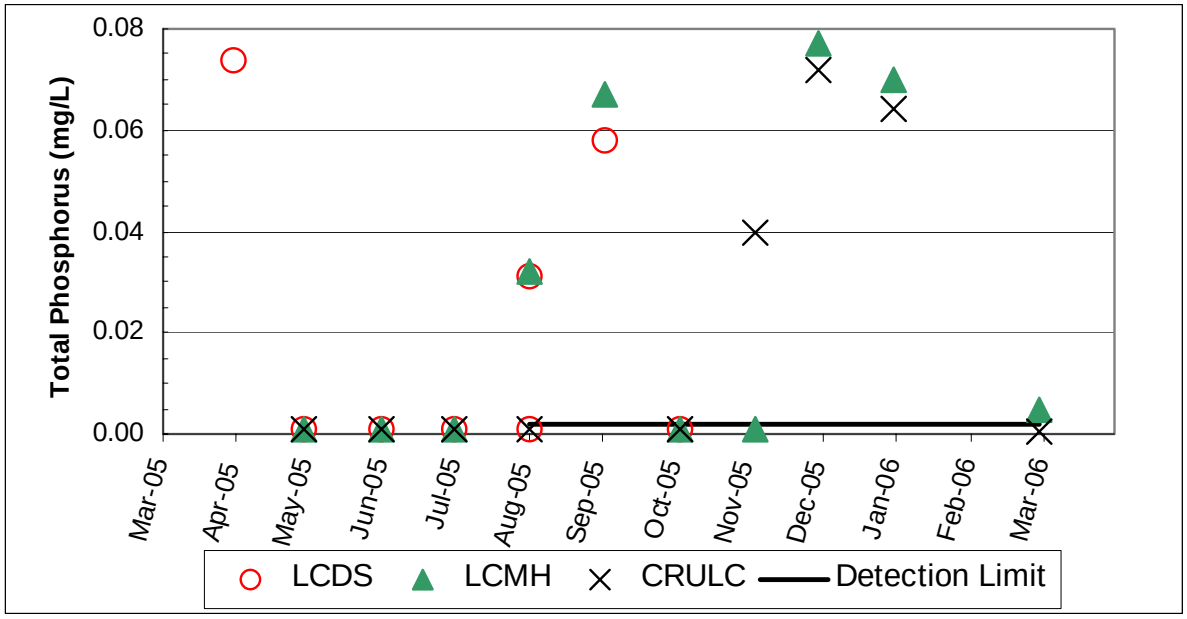

Figure 3-34. Total Phosphorus for Lower Lake Creek and Cowlitz River Upstream from Lake Creek

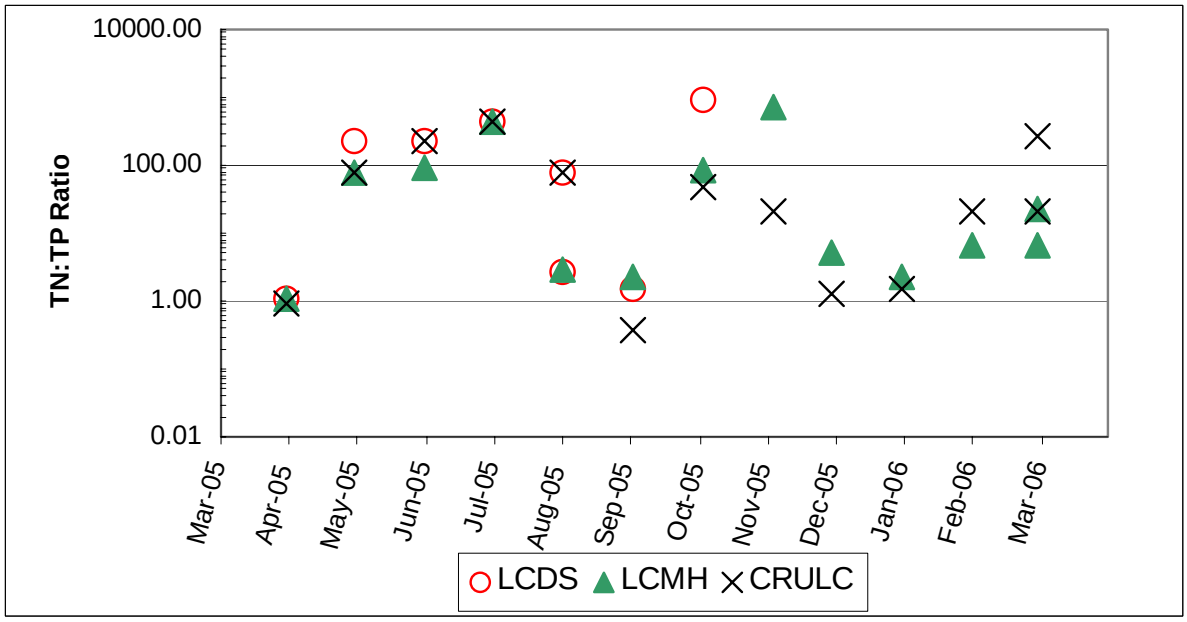

Figure 3-35. Total Nitrogen to Total Phosphorus Ratios for Lower Lake Creek and Cowlitz River Upstream from Lake Creek

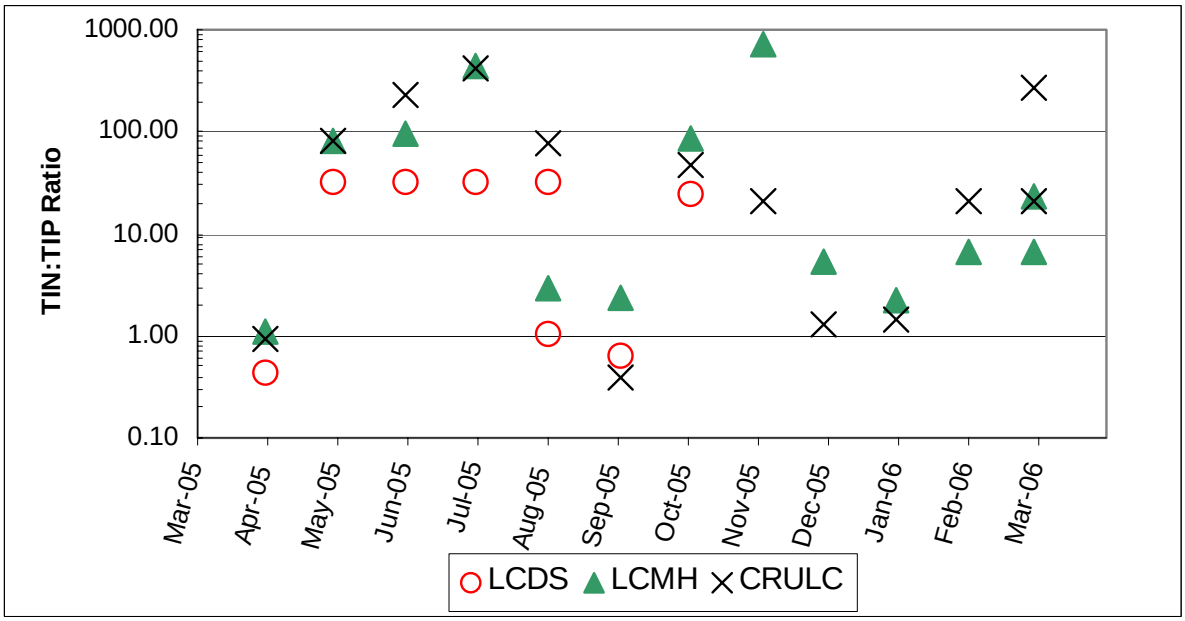

Figure 3-36. Total Inorganic Nitrogen to Total Inorganic Phosphorus Ratios for Lower Lake Creek and Cowlitz River Upstream from Lake Creek

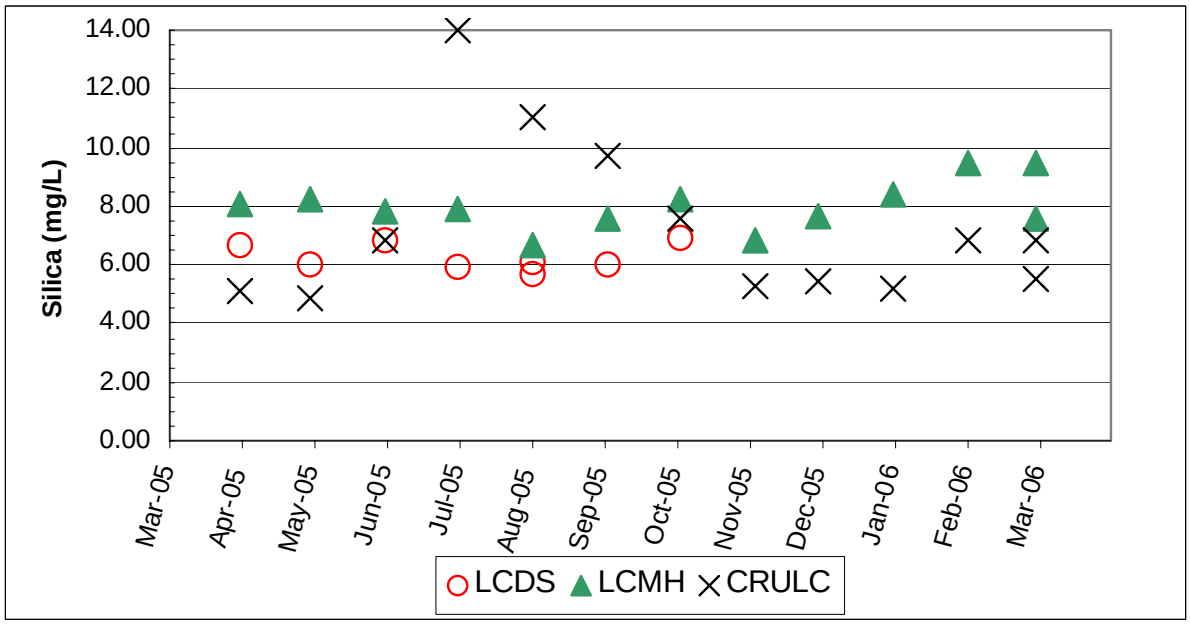

Figure 3-37. Silica for Lower Lake Creek and Cowlitz River Upstream from Lake Creek

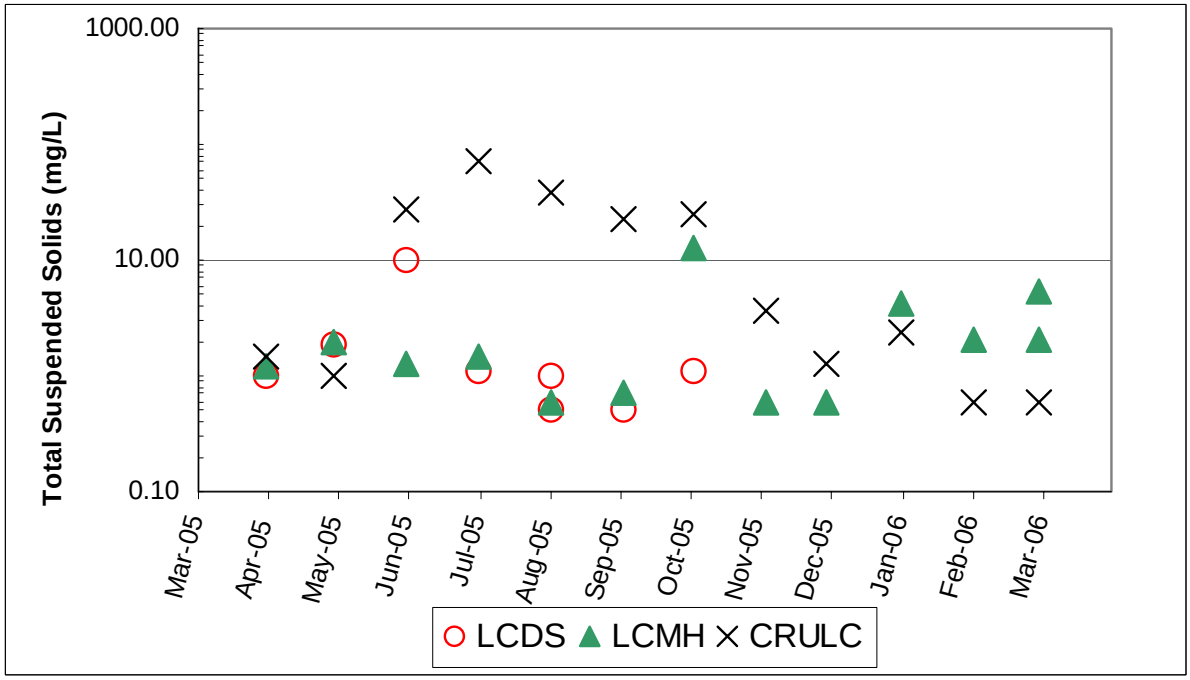

Figure 3-38. Total Suspended Solids for Lower Lake Creek and Cowlitz River Upstream from Lake Creek

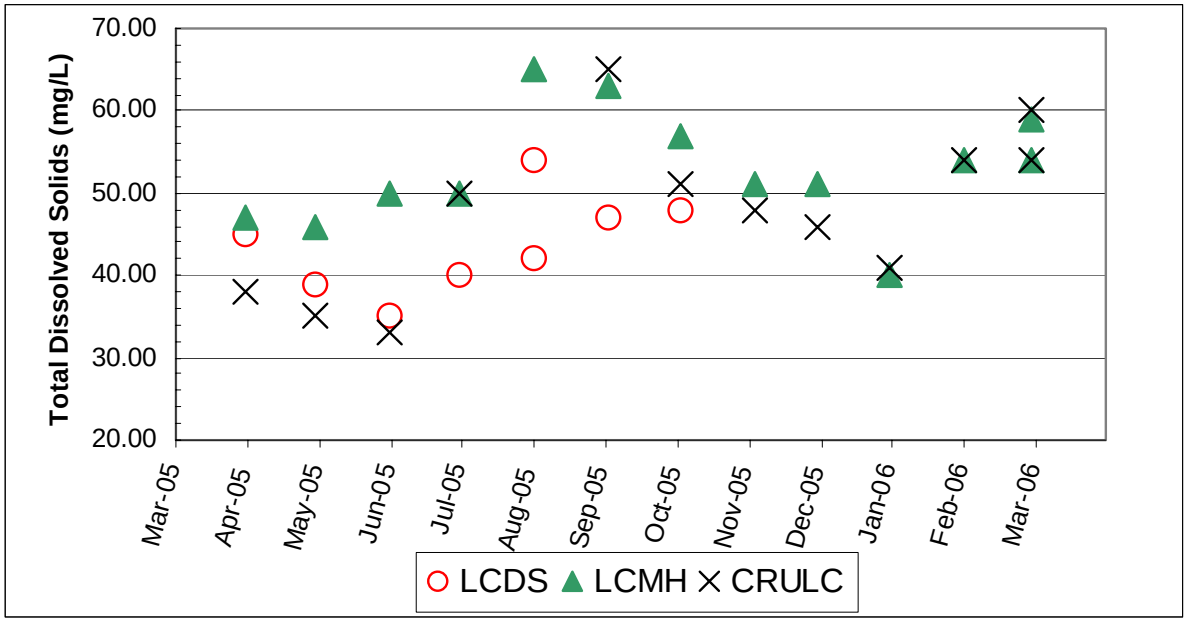

Figure 3-39. Total Dissolved Solids for Lower Lake Creek and Cowlitz River Upstream from Lake Creek

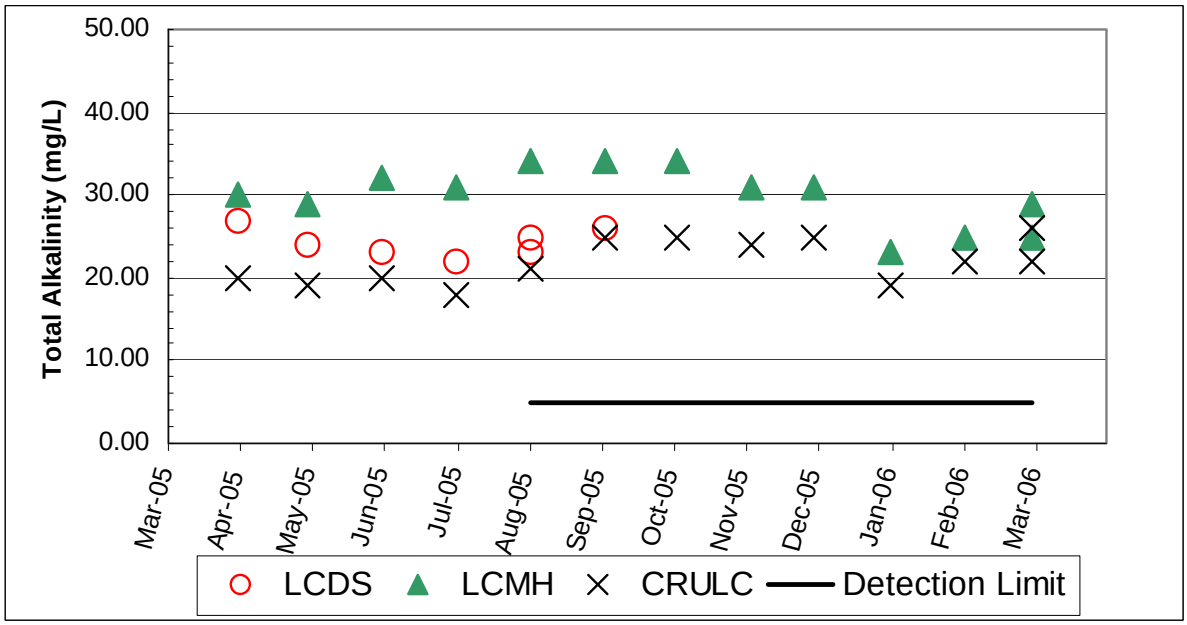

Figure 3-40. Total Alkalinity for Lower Lake Creek and Cowlitz River Upstream from Lake Creek

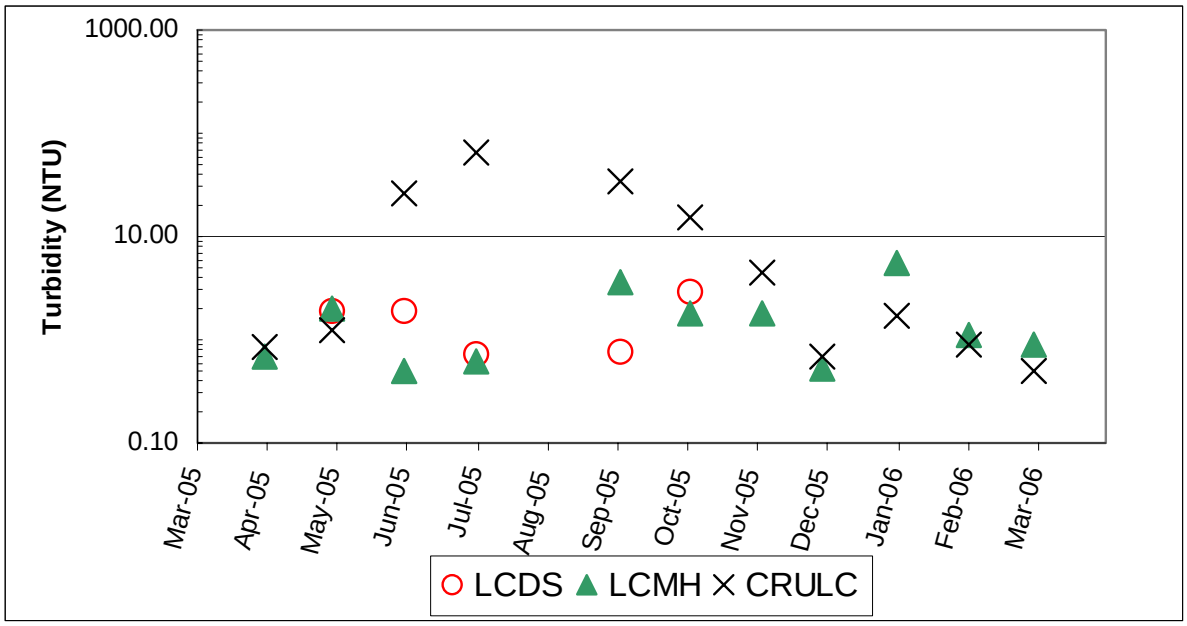

Figure 3-41. Turbidity for Lower Lake Creek and Cowlitz River Upstream from Lake Creek

Table 3.30. Monthly Turbidity Data (NTU) for Lake Creek and Cowlitz River Upstream of Lake Creek

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05
LCDS		1.9	1.9	0.7	0.1		0.8
LCMH	0.7	0.7	0.7	0.7	0.7	0.7	0.7
CRULC	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
LCDS	2.9						
LCMH	0.7	0.7	0.7	0.7	0.7	0.7	
CRULC	0.9	0.9	0.9	0.9	0.9	0.9	

Table 3.31. Monthly Dissolved Oxygen Data for Lake Creek and Cowlitz River Upstream of Lake Creek

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05
	(mg/L)						
LCDS	11.0	9.7	10.9	8.5	8.5	8.6	8.9
LCMH	10.8	10.4	12.0	7.8	10.9		10.8
CRULC	11.1	10.5	11.6	8.4	9.6		10.1
	% Saturation						
LCDS	86.00	94.5	125.0	106.5	93.2	98.0	94.9
LCMH	89.0	111.0	128.0	92.1	95.9		99.4
CRULC	90.9	116.0	125.0	105.2	95.7		99.5
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
	(mg/L)						
LCDS	8.7						
LCMH	9.6	11.8	11.7	11.9	11.6	12.1	
CRULC	9.6	12.3	12.2	12.3	11.5	11.6	
	% Saturation						
LCDS	87.2						
LCMH	89.2	101.3	96.4	97.9	94.4	98.5	
CRULC	90.1	110.2	97.1	99.1	91.1	96.0	

Table 3.32. Monthly pH Data for Lake Creek and Cowlitz River Upstream of Lake Creek

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05
LCDS	7.6	7.5	7.9	7.6	7.4	7.6	7.7
LCMH	7.6	7.6	7.8	7.8	7.5		7.2
CRULC	7.4	7.9	7.6	7.6	7.3		7.2
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
LCDS	7.4						
LCMH	7.4	7.4	6.9	7.0	7.3	7.0	
CRULC	7.2	7.3	7.1	7.0	7.2	7.0	

Table 3.33. Monthly Total Alkalinity Data (mg/L) for Lake Creek and Cowlitz River Upstream of Lake Creek

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05
LCDS	27.0	24.0	23.0	22.0	23.0	25.0	26.0
LCMH	30.0	29.0	32.0	31.0	34.0		34.0
CRULC	20.0	19.0	20.0	18.0	21.0		25.0
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
LCDS							
LCMH	34.0	31.0	31.0	23.0	25.0	25.0	
CRULC	25.0	24.0	25.0	19.0	22.0	22.0	

Table 3.34. Monthly Nitrogen Data (mg/L) for Lake Creek and Cowlitz River Upstream of Lake Creek

Ammonia (mg/L)							
	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**
LCDS	0.019	0.025	0.012	0.052	0.020	0.011	0.015
LCMH	0.016	0.022	0.010	0.045	0.010	0.000	0.014
CRULC	0.017	0.023	0.011	0.044	0.190	0.000	0.018
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
LCDS	0.013						
LCMH	0.021	0.028	0.032	0.022	0.023	0.023	
CRULC	0.021	0.028	0.030	0.021	0.024	0.024	
Nitrites (mg/L)							
	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**
LCDS	0.015	0.015	0.015	0.015	0.015	0.015	0.020
LCMH	0.015	0.015	0.015	0.015	0.015		0.020
CRULC	0.015	0.015	0.015	0.015	0.015		0.020
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
LCDS	0.015						
LCMH	0.015	0.015	0.015	0.015	0.020	0.015	
CRULC	0.015	0.015	0.015	0.015	0.020	0.015	
Nitrates (mg/L)							
	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**
LCDS	0.015	0.015	0.015	0.015	0.015	0.015	0.015
LCMH	0.043	0.015	0.030	0.037	0.029		0.035
CRULC	0.025	0.015	0.015	0.010	0.011		0.015
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
LCDS	0.008						
LCMH	0.019	0.110	0.088	0.093	0.068	0.068	
CRULC	0.033	0.040	0.027	0.030	0.020	0.020	
Kjeldahl Nitrogen (mg/L)							
	Apr 05	**May 05**	**Jun 05**	**Jly 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**
LCDS	0.050	0.200	0.200	0.400	0.050	0.050	0.050
LCMH	0.050	0.050	0.050	0.400	0.050		0.100
CRULC	0.050	0.050	0.200	0.400	0.050		0.050
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
LCDS	0.900						
LCMH	0.050	0.600	0.300	0.050	0.500	0.500	
CRULC	0.050	0.800	0.050	0.050	1.800	1.800	

*Shading indicates that sample was below the detection limit. A value of 0.5 * detection limit is reported .*

Table 3.35. Monthly Phosphorus Data (mg/L) for Lake Creek and Cowlitz River Upstream of Lake Creek

Orthophosphorus (mg/L)							
	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**
LCDS	0.070	0.001	0.001	0.001	0.001	0.029	0.055
LCMH	0.095	0.001	0.001	0.001	0.030		0.064
CRULC	0.091	0.001	0.001	0.001	0.001		0.086
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
LCDS	0.001						
LCMH	0.001	0.001	0.073	0.067	0.086	0.086	
CRULC	0.001	0.038	0.068	0.061	0.086	0.086	
Total Phosphorus (mg/L)							
	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**
LCDS	0.074	0.001	0.001	0.001	0.001	0.031	0.058
LCMH	0.100	0.001	0.001	0.001	0.032		0.067
CRULC	0.096	0.001	0.001	0.001	0.001		0.091
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
LCDS	0.001						
LCMH	0.001	0.001	0.077	0.070	0.090	0.090	
CRULC	0.001	0.040	0.072	0.064	0.090	0.090	

*Shading indicates that sample was below the detection limit. A detection limit is reported for total phosphorus. A value of 0.95 * T-phosphorus is used as an estimate of orthophosphorus when sample is below the detection limit*

Table 3.36. Total Organic Carbon (mg/L) for Lake Creek and Cowlitz River Upstream of Lake Creek

	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**
LCDS	0.680	3.900	1.000	0.510	0.420	0.480	0.750
LCMH	1.100	1.200	0.600	0.230	0.290		0.230
CRULC	0.890	0.970	1.200	0.150	0.190		0.510
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
LCDS	0.530						
LCMH	0.820	0.810	0.760	0.980	0.810	0.810	
CRULC	0.380	0.630	0.590	0.870	0.610	0.610	

*Shading indicates that sample was below the detection limit. A value of 0.5 * detection limit is reported.*

Table 3.37. Total Dissolved Solids (mg/L) for Lake Creek and Cowlitz River Upstream of Lake Creek

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05
LCDS	45	39	35	40	42	54	47
LCMH	47	46	50	50	65		63
CRULC	38	35	33	50	72		65
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
LCDS	48						
LCMH	57	51	51	40	54	54	
CRULC	51	48	46	41	54	54	

Table 3.38. Total Suspended Solids (mg/L) for Lake Creek and Cowlitz River Upstream of Lake Creek

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05
LCDS	1.0	1.9	10.0	1.1	1.0	0.5	0.5
LCMH	1.2	2.0	1.3	1.5	0.6		0.7
CRULC	1.5	1.0	28.0	71.0	38.0		23.0
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
LCDS	1.1						
LCMH	13.0	0.6	0.6	4.2	2.1	2.1	
CRULC	25.0	3.7	1.3	2.4	0.6	0.6	

Shading indicates that sample was below the detection limit.
*A value of 0.5 * detection limit is reported when sample is below detection limit.*

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.

Mean annual values for water quality parameters for the tailrace and Cowlitz River side channel (tailrace slough) are listed in Table 3.39.

Table 3.39. Mean Annual Values for Water Quality Parameters for the Tailrace and Tailrace Slough

	pH	Turbidity (NTU)	Specific Conductance (uS/cm)	Alkalinity, Bicarbonate as CaCO3 (mg/L)	Total Alkalinity (mg/L)	Hardness (mg/L)
POWT1	7.28	1.53	0.0381	25.5	24.5	
POWT2	7.31	1.72	0.0377	23.3	23.3	
CRTSC	7.33	5.52	0.0372	23.5	23.5	
	Silica (mg/L)	Total Dissolved Solids (TDS) (mg/L)	Total Suspended Solids (TSS) (mg/L)	Ammonia as N (mg/L) [2]	Nitrite as N (mg/L) [2]	Nitrate as N (mg/L) [2]
POWT1	6.4	49.5	0.9	0.023	0.016	0.018
POWT2	6.4	46.5	1.0	0.024	0.016	0.017
CRTSC	6.6	46.5	5.3	0.022	0.016	0.043
	Phosphate, Ortho as P (mg/L) [1]	Phosphorus, Total (mg/L) [2]	Total Kjeldahl Nitrogen (TKN) (mg/L) [2]	Total Organic Carbon (TOC) (mg/L)	TN:TP	TIN:TIP
POWT1	0.038	0.040	0.245	1.17	89.5	13.0
POWT2	0.045	0.048	0.240	0.81	84.1	9.0
CRTSC	0.044	0.046	0.200	0.72	70.5	11.4

[1] For samples that the orthophosphorus level was below detection limit, a value of 0.95 * total phosphorus was used as an estimate of orthophosphorus.
[2] For purposes of calculating a mean, non-detects were assigned a value of 0.5*detection limit

Dissolved oxygen levels were below the criteria of 9.5 mg/L (WDOE 2006) in the tailrace in July through September, which is less time than exceedences occurred in 2004. Dissolved oxygen levels in the tailrace side channel were below the criteria of 9.5 mg/L in July and August. 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 3-42 through 3-54.

Organic nitrogen (TKN less ammonia) was elevated in July within the tailrace (0.56 mg/L at POWT1); the cause is unknown. A similar outlier occurred in May 2004. Phosphorus trends in the tailrace were similar to those for Packwood Lake near the intake. Phosphorus is limiting relative to nitrogen for tailrace waters. Although periphyton growth was not quantified in the tailrace, productivity did not visually appear excessive. Previous attempts to place tiles to culture periphyton upon were vandalized. Growth was patchy with short, dense mats in some locations.

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 102%. 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.

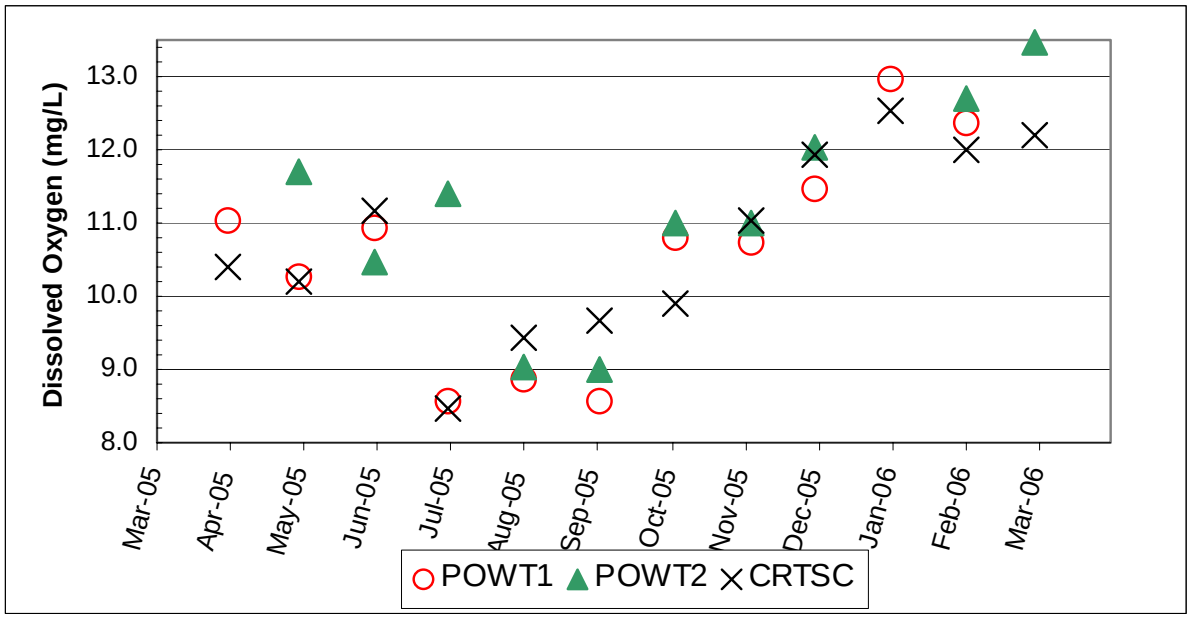

Figure 3-42. Dissolved Oxygen Grab Samples for Tailrace and Tailrace Slough

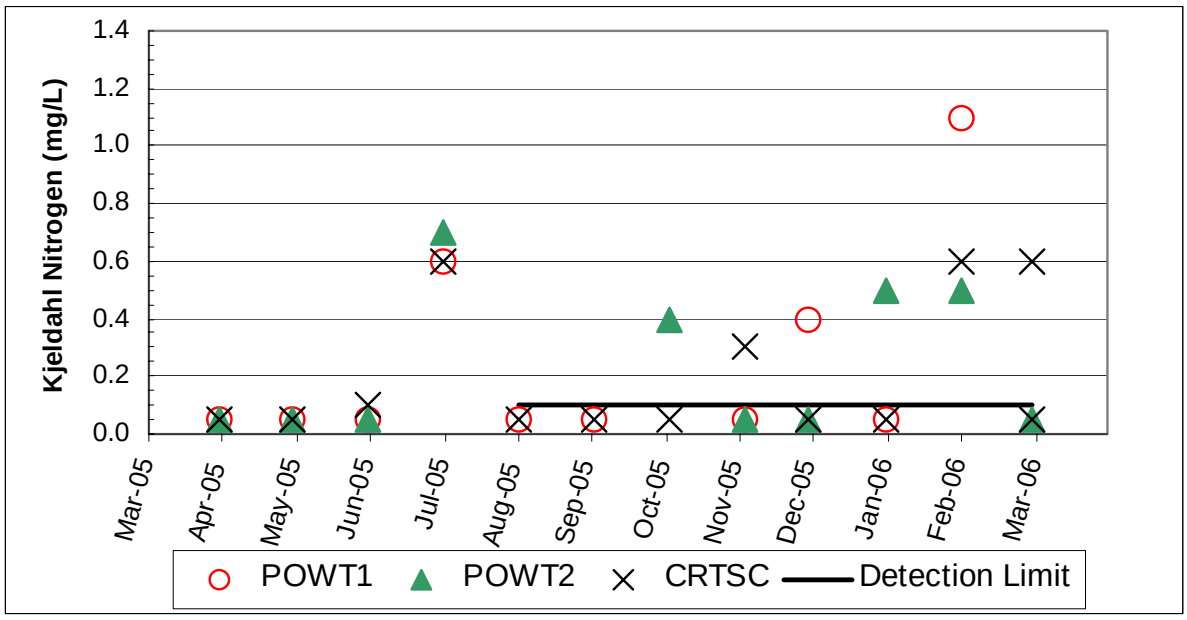

Figure 3-43. Total Kjeldahl Nitrogen (TKN) for the Tailrace and Tailrace Slough

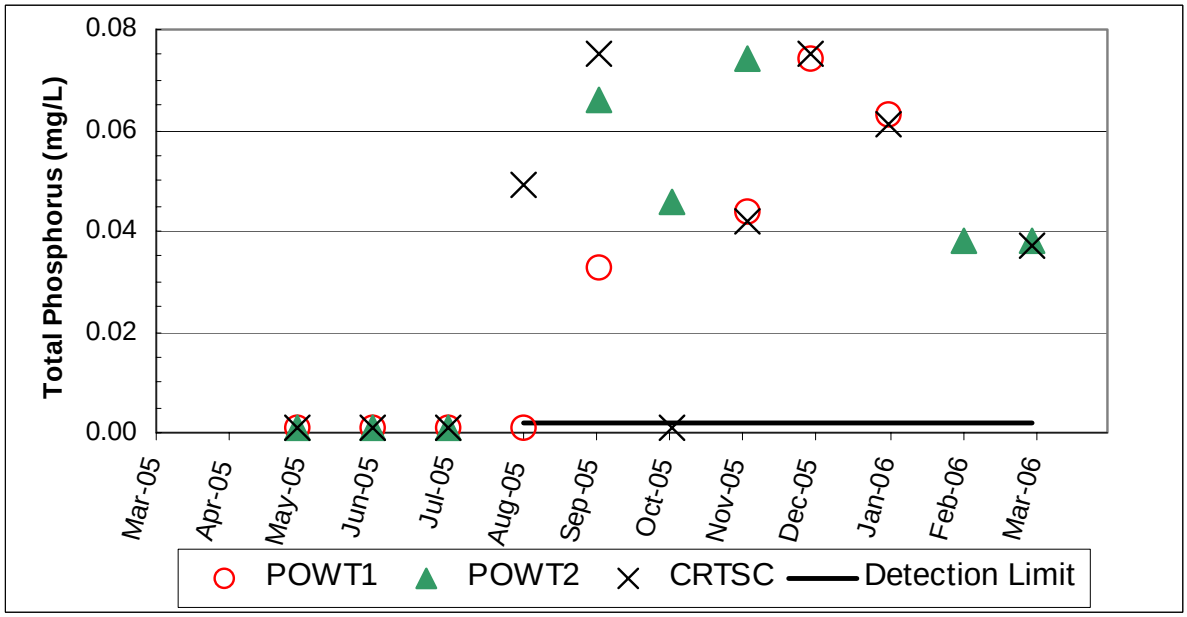

Figure 3-44. Total Phosphorus for the Tailrace and Tailrace Slough

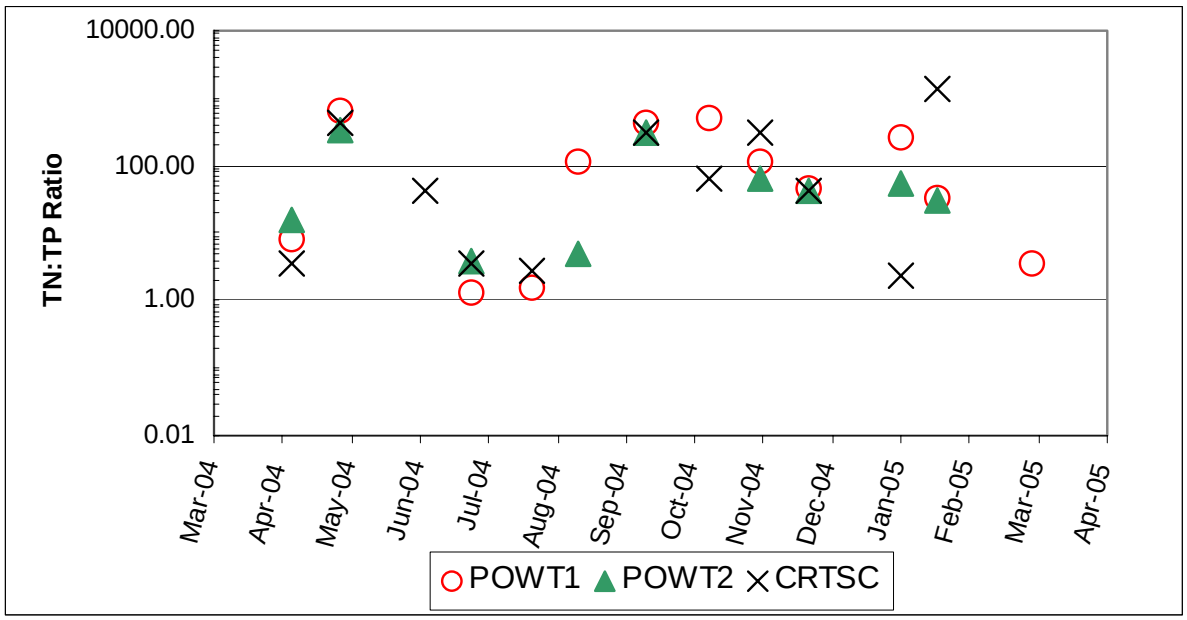

Figure 3-45. Total Nitrogen to Total Phosphorus Ratio for the Tailrace and Tailrace Slough

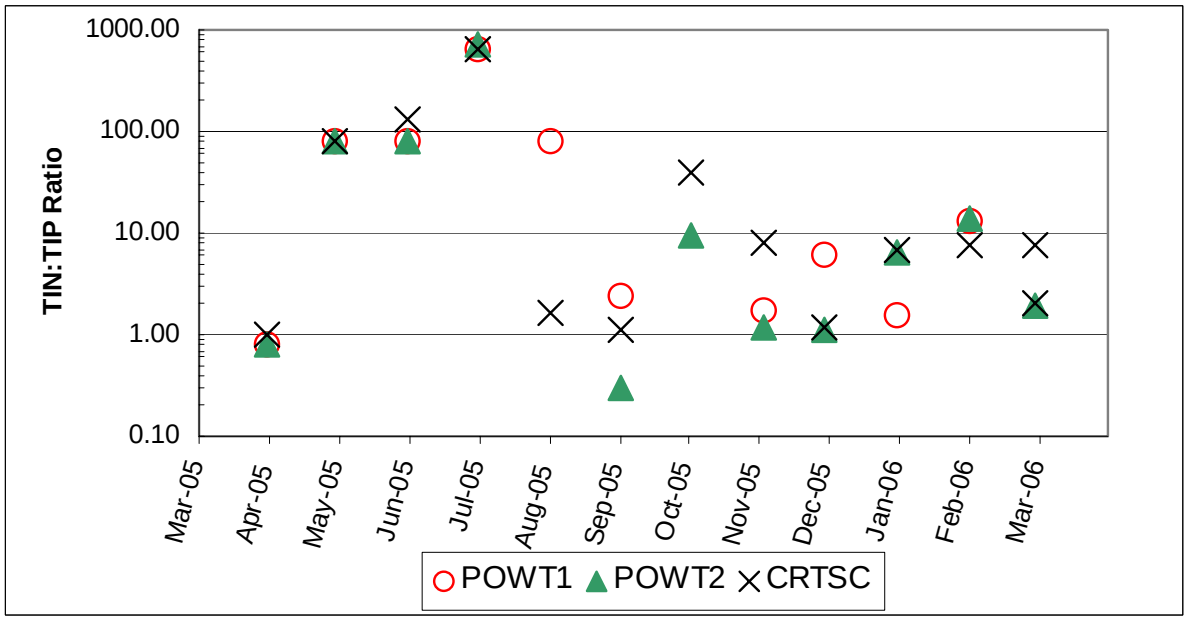

Figure 3-46. Total Inorganic Nitrogen to Inorganic Phosphorus Ratio for the Tailrace and Tailrace Slough

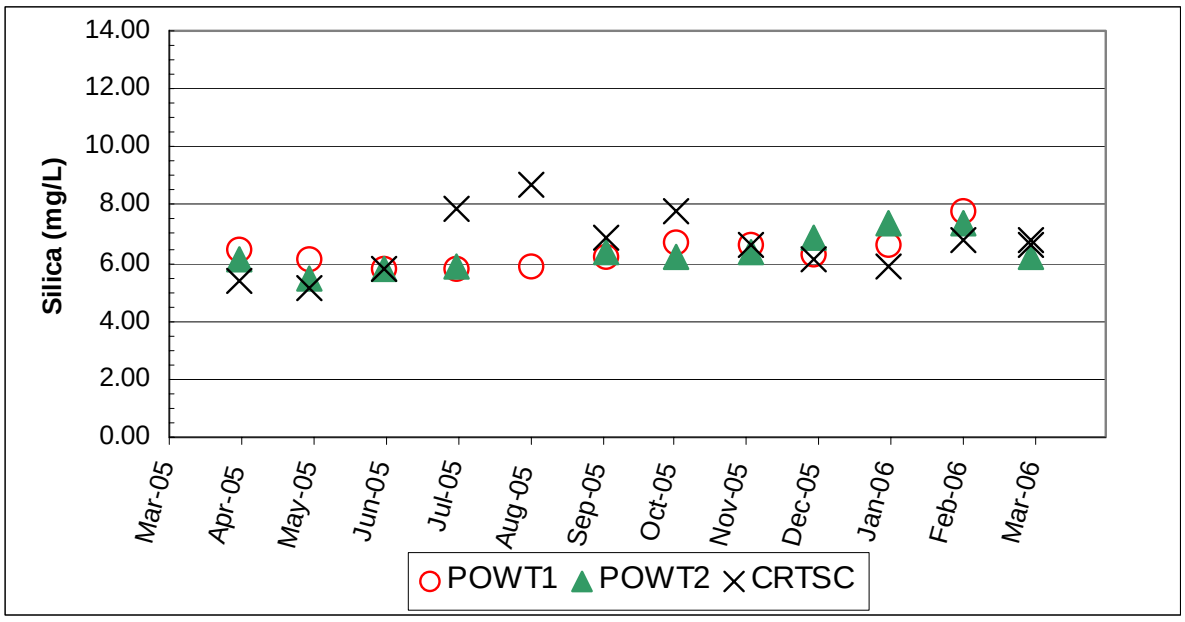

Figure 3-47. Silica for the Tailrace and Tailrace Slough

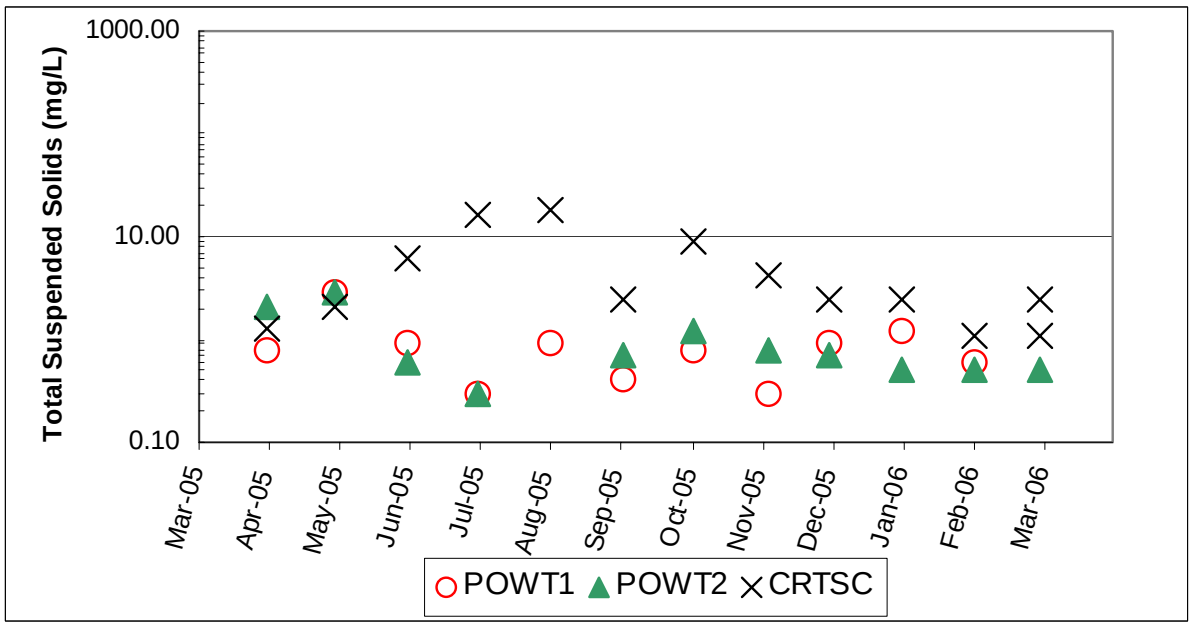

Figure 3-48. Total Suspended Solids for the Tailrace and Tailrace Slough

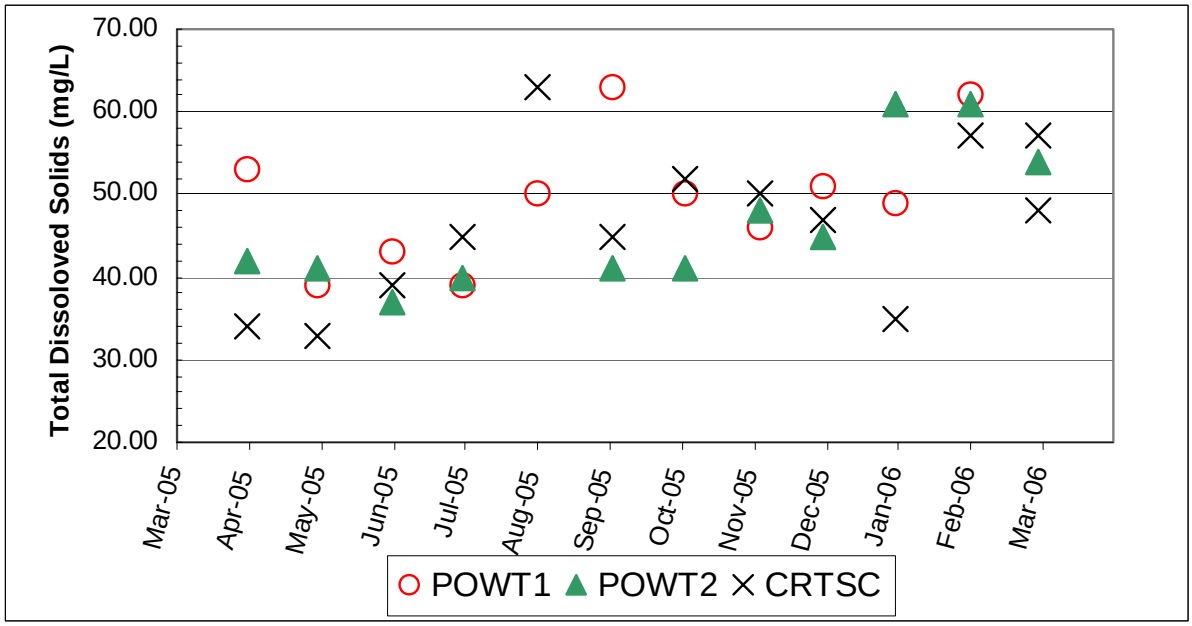

Figure 3-49. Total Dissolved Solids for the Tailrace and Tailrace Slough

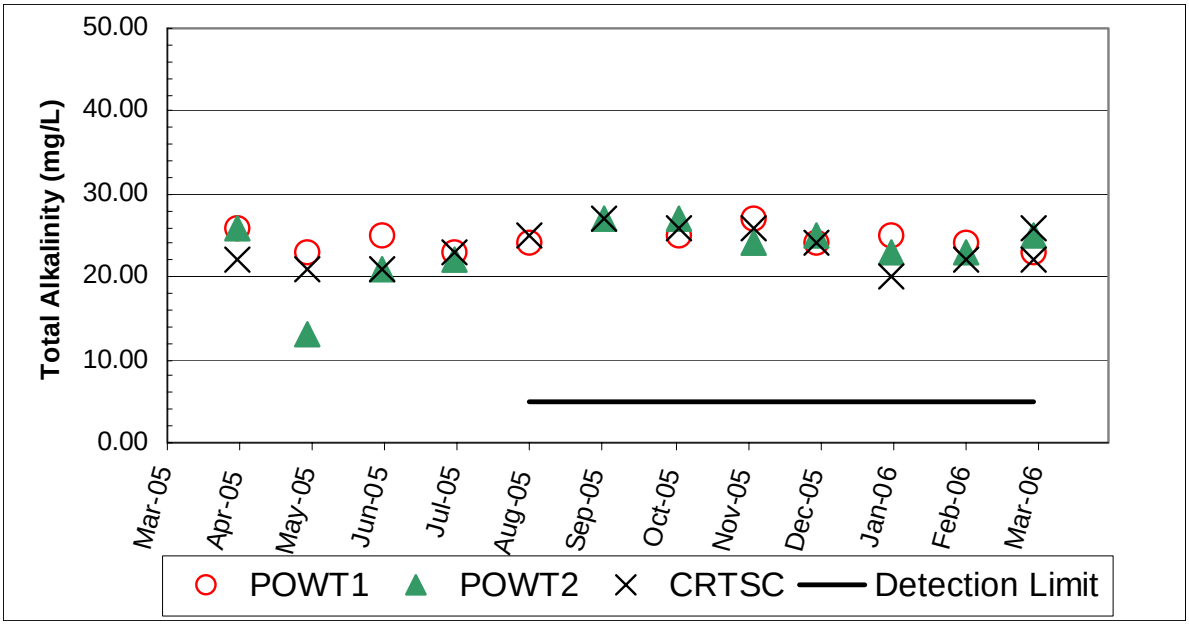

Figure 3-50. Total Alkalinity for the Tailrace and Tailrace Slough

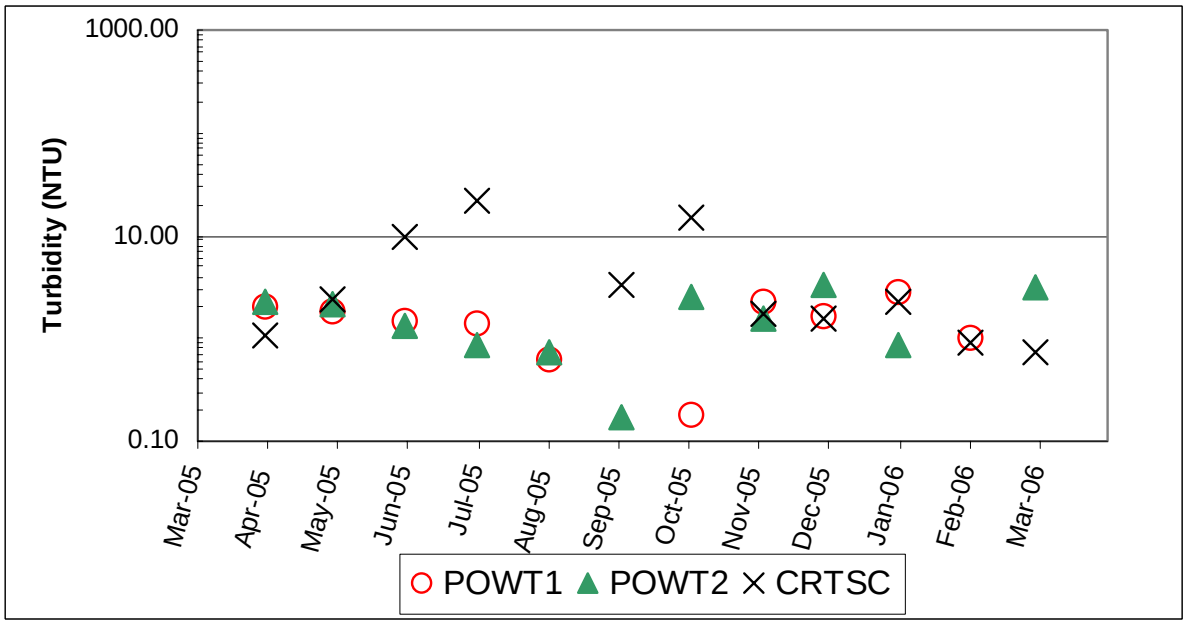

Figure 3-51. Turbidity for the Tailrace and Tailrace Slough

Table 3.40. Monthly Turbidity Data (NTU) for Tailrace and Side Channel

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05
POWT1	2.0	2.0	2.0	2.0	2.0	2.0	2.0
POWT2	2.3	2.3	2.3	2.3	2.3	2.3	2.3
CRTRSC	1.1	1.1	1.1	1.1	1.1	1.1	1.1
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
POWT1	2.0	2.0	2.0	2.0	2.0	2.0	
POWT2	2.3	2.3	2.3	2.3	2.3	2.3	
CRTRSC	1.1	1.1	1.1	1.1	1.1	1.1	

Table 3.41. Monthly Dissolved Oxygen Data for the Tailrace and Side Channel

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05
	(mg/L)						
POWT1	11.0	10.3	10.9	8.6	8.9		8.6
POWT2	11.7	10.5	11.4	9.0	9.0		11.0
CRTRSC	10.4	10.2	11.2	8.5		9.4	9.7
	% Saturation						
POWT1	89.2	10.3	127.6	110.5	100.0		93.9
POWT2	96.0	118.5	130.1	117.3	101.7		108.1
CRTRSC	87.0	115.2	128.8	108.4		99.7	98.8
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
	(mg/L)						
POWT1	10.8	10.8	11.5	13.0	12.4		
POWT2	11.0	12.0	13.7	12.7		13.5	
CRTRSC	9.9	11.0	12.0	12.5	12.0		
	% Saturation						
POWT1	110.3	99.6	97.8	100.0	97.8		
POWT2	100.1	102.5	165.9	96.1		104.1	
CRTRSC	9.5	100.6	100.6	99.3	91.2	97.0	

Table 3.42. Monthly pH Data for the Tailrace and Side Channel

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05
POWT1	7.6	7.7	7.8	7.8	5.5	0.0	7.7
POWT2	7.6	7.7	7.8	7.9	7.7	0.0	7.2
CRTRSC	7.2	7.8	7.7	7.9	7.2	7.6	7.2
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
POWT1	7.6	7.2	6.9	7.1	7.2	0.0	
POWT2	7.2	6.8	6.6	7.3	7.0	6.8	
CRTRSC	7.4	7.3	7.1	6.7	7.0	7.0	

Table 3.43. Monthly Total Alkalinity Data (mg/L) for the Tailrace and Side Channel

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05
POWT1	26.0	23.0	25.0	23.0	24.0		25.0
POWT2	26.0	13.0	21.0	22.0			27.0
CRTRSC	22.0	21.0	21.0	23.0		25.0	27.0
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
POWT1	27.0	24.0	25.0	24.0	23.0	0.0	
POWT2	27.0	24.0	25.0	23.0	23.0	25.0	
CRTRSC	26.0	26.0	24.0	20.0	22.0	22.0	

Table 3.44. Monthly Nitrogen Data (mg/L) for the Tailrace and Side Channel

Ammonia (mg/L)							
	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**
POWT1	0.033	0.022	0.008	0.041	0.016	0.000	0.008
POWT2	0.015	0.022	0.009	0.053	0.000	0.000	0.019
CRTRSC	0.015	0.022	0.010	0.047	0.000	0.011	0.017
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
POWT1	0.017	0.027	0.032	0.022	0.025	0.000	
POWT2	0.027	0.033	0.020	0.024	0.024	0.014	
CRTRSC	0.022	0.028	0.033	0.020	0.024	0.024	
Nitrites (mg/L)							
	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**
POWT1	0.015	0.015	0.015	0.015	0.015		0.015
POWT2	0.015	0.015	0.015	0.015			0.020
CRTRSC	0.015	0.015	0.015	0.015		0.015	0.020
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
POWT1	0.000	0.015	0.015	0.015	0.020		
POWT2	0.015	0.015	0.015	0.020	0.015	0.015	
CRTRSC	0.015	0.015	0.015	0.015	0.020	0.015	
Nitrates (mg/L)							
	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**
POWT1	0.012	0.015	0.015	0.015	0.015		0.015
POWT2	0.009	0.015	0.015	0.015			0.000
CRTRSC	0.022	0.015	0.015	0.015		0.015	0.015
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
POWT1	0.000	0.012	0.025	0.031	0.025	0.000	
POWT2	0.012	0.022	0.028	0.022	0.022	0.009	
CRTRSC	0.025	0.022	0.024	0.340	0.023	0.023	
Kjeldahl Nitrogen (mg/L)							
	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**
POWT1	0.05	0.05	0.05	0.60	0.05		0.05
POWT2	0.05	0.05	0.05	0.70			0.00
CRTRSC	0.05	0.05	0.10	0.60		0.05	0.05
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
POWT1		0.05	0.40	0.05	1.10		
POWT2	0.40	0.05	0.05	0.50	0.50	0.05	
CRTRSC	0.05	0.30	0.05	0.05	0.60	0.60	

*Shading indicates that sample was below the detection limit. A value of 0.5 * detection limit is reported.*

Table 3.45. Monthly Phosphorus Data (mg/L) for the Tailrace and Side Channel

Orthophosphorus (mg/L)							
	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**
POWT1	0.091	0.001	0.001	0.001	0.001		0.031
POWT2	0.089	0.001	0.001	0.001			0.063
CRTRSC	0.084	0.001	0.001	0.001		0.052	0.071
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
POWT1		0.042	0.070	0.060	0.084	0.000	
POWT2	0.044	0.070	0.079	0.079	0.036	0.036	
CRTRSC	0.001	0.040	0.071	0.058	0.081	0.081	
Total Phosphorus (mg/L)							
	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**
POWT1	0.096	0.001	0.001	0.001	0.001		0.033
POWT2	0.094	0.001	0.001	0.001			0.066
CRTRSC	0.088	0.001	0.001	0.001		0.049	0.075
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
POWT1		0.044	0.074	0.063	0.088		
POWT2	0.046	0.074	0.083	0.083	0.038	0.038	
CRTRSC	0.001	0.042	0.075	0.061	0.085	0.085	

*Shading indicates that sample was below the detection limit. A value of 0.5 * detection limit is reported for total phosphorus. A value of 0.95 * T-phosphorus sample measurement is used as an estimate of orthophosphorus when sample is below the detection limit*

Table 3.46. Total Organic Carbon (mg/L) for the Tailrace and Side Channel

	Apr 05	**May 05**	**Jun 05**	**July 05**	**Aug 05 early**	**Aug 05 late**	**Sep 05**
POWT1	0.900	4.900	2.100	0.340	0.390		0.500
POWT2	0.840	1.000	1.100	0.400	0.000		0.590
CRTRSC	0.870	1.200	1.100	0.340	0.000	0.036	0.720
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
POWT1	0.660	0.660	0.930	0.670	0.830		
POWT2	0.720	0.740	0.970	0.950	0.950	0.670	
CRTRSC	0.420	0.580	0.850	0.830	0.840	0.840	

*Shading indicates that sample was below the detection limit and a value of 0.5 * detection limit is reported.*

Table 3.47. Total Dissolved Solids (mg/L) for the Tailrace and Side Channel

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05
POWT1	53	39	43	39	50	0	63
POWT2	42	41	37	40	0	0	41
CRTRSC	34	33	39	45	0	63	45
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
POWT1	50	46	51	49	62	50	
POWT2	41	48	45	61	61	41	
CRTRSC	52	50	47	35	57	52	

*Shading indicates that sample was below the detection limit and a value of 0.5 * detection limit is reported.*

Table 3.48. Total Suspended Solids (mg/L) for the Tailrace and Side Channel

	Apr 05	May 05	Jun 05	July 05	Aug 05 early	Aug 05 late	Sep 05
POWT1	0.8	2.8	0.9	0.3	0.9		0.4
POWT2	2.1	2.8	0.6	0.3		0	0.7
CRTRSC	1.3	2.1	6.3	16.0		18.0	2.4
	Oct 05	**Nov 05**	**Dec 05**	**Jan 06**	**Feb 06**	**Mar 06**	
POWT1	0.8	0.3	0.9	1.2	0.6		
POWT2	1.2	0.8	0.7	0.5	0.5	0.5	
CRTRSC	9.1	4.2	2.4	2.4	1.1	1.1	

*Shading indicates that sample was below the detection limit and a value of 0.5 * detection limit is reported*

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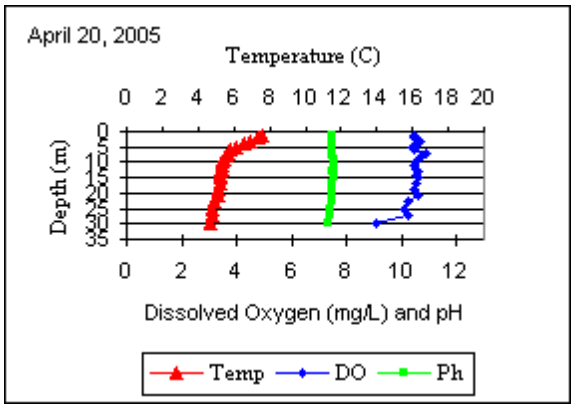
APPENDIX A

TEMPERATURE, DISSOLVED OXYGEN, and pH LAKE PROFILES

APPENDIX A

TEMPERATURE, DISSOLVED OXYGEN, and pH LAKE PROFILES

To be distributed separately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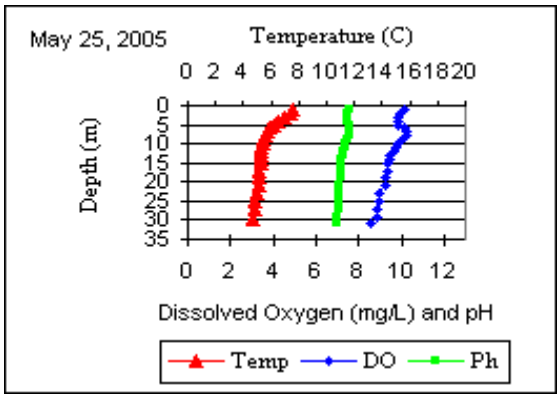
Temp
DO
Ph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Depth (m)
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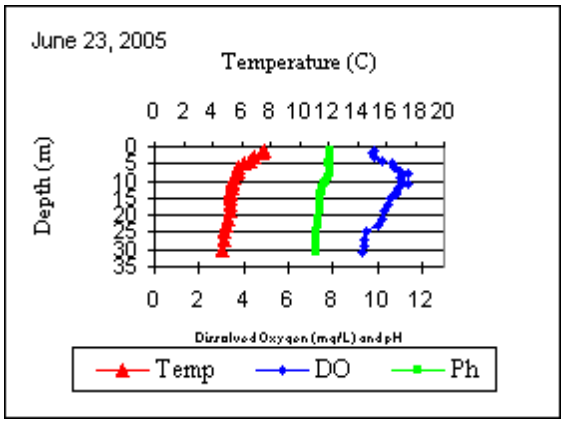
Dissolved Oxygen (mg/L) and pH
Temp
DO
Ph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Depth (m)
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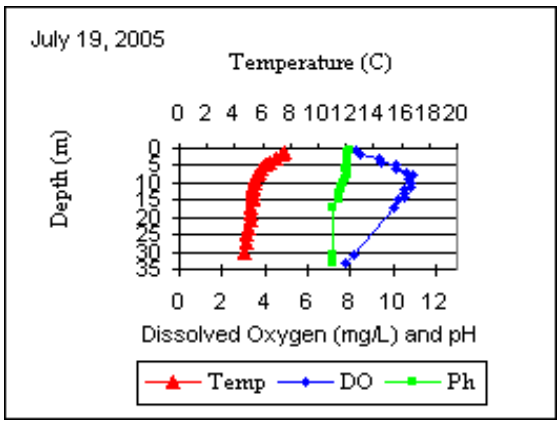
Dissolved Oxygen (mg/L) and pH
Temp
DO
Ph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Depth (m)
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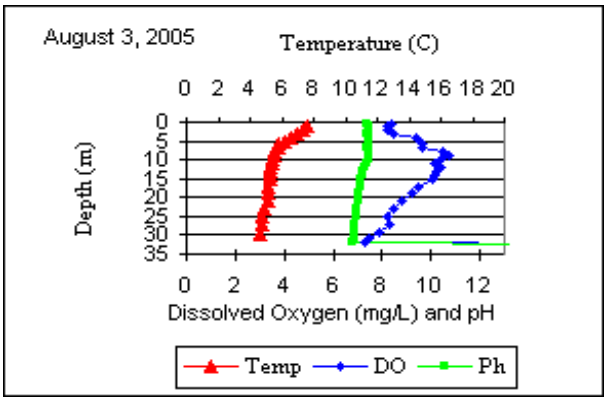
Dissolved Oxygen (mg/L) and pH
Temp
DO
Ph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Depth (m)
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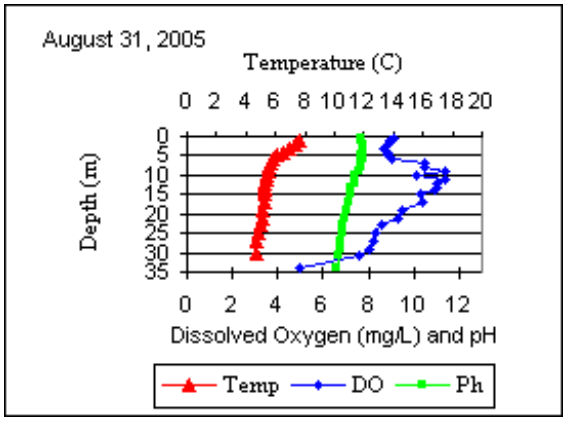
Dissolved Oxygen (mg/L) and pH
Temp
DO
Ph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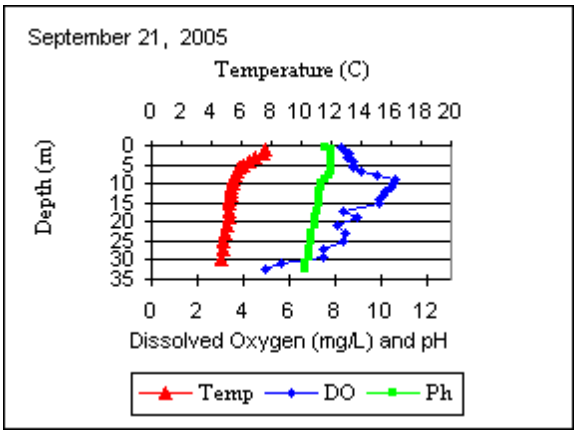
Dissolved Oxygen (mg/L) and pH
Temp
DO
Ph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Depth (m)
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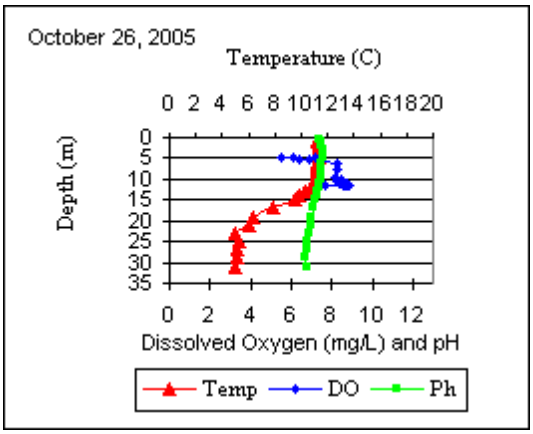
10
15
20
25
30
35
0 2 4 6 8 10 12
Dissolved Oxygen (mg/L) and pH
Temp
DO
Ph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Depth (m)
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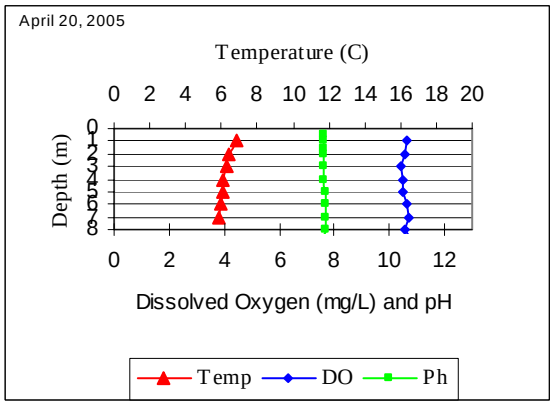
Dissolved Oxygen (mg/L) and pH
Temp
DO
Ph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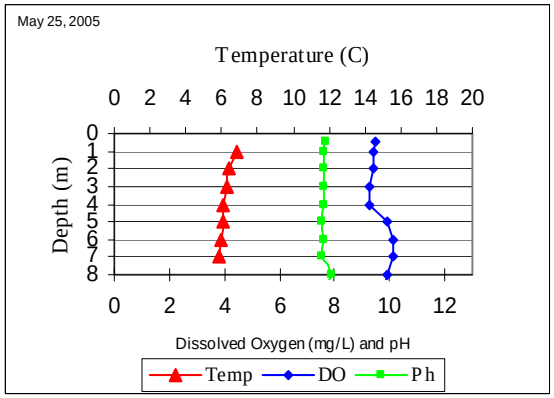
Dissolved Oxygen (mg/L) and pH
Temp
DO
Ph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Depth (m)
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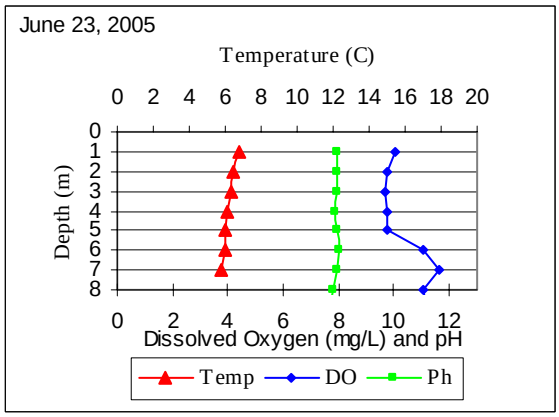
Dissolved Oxygen (mg/L) and pH
Temp
DO
Ph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Temperature (C)
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Depth (m)
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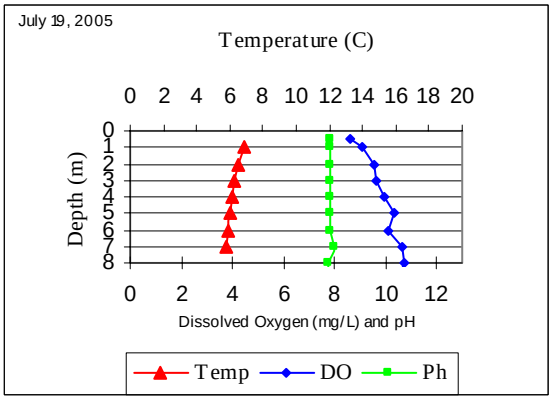
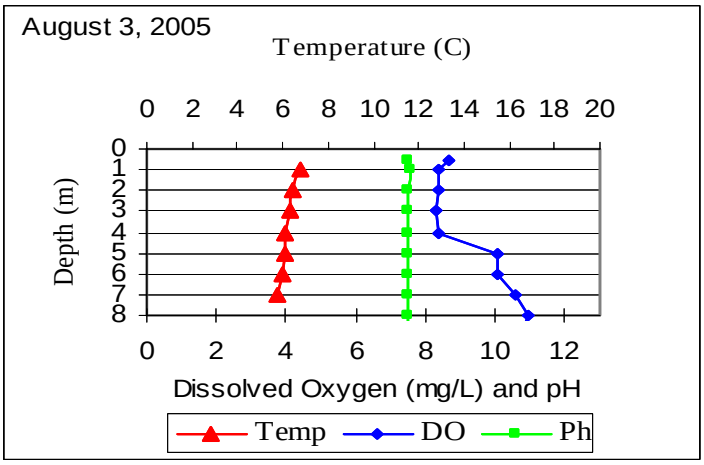
0 2 4 6 8 10 12
Dissolved Oxygen (mg/L) and pH
Temp
DO
Ph


July 19, 2005
Temperature (C)
0 2 4 6 8 10 12 14 16 18 20
Depth (m)
0 1 2 3 4 5 6 7 8
0 2 4 6 8 10 12
Dissolved Oxygen (mg/L) and pH
Temp
DO
Ph


August 3, 2005
Temperature (C)
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Depth (m)
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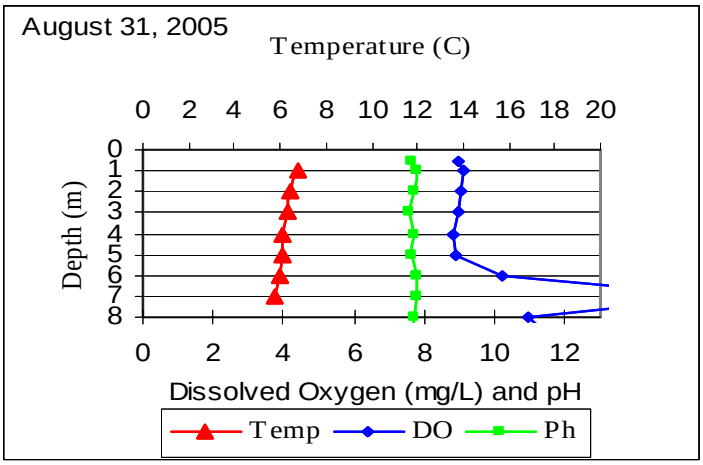
0 2 4 6 8 10 12
Dissolved Oxygen (mg/L) and pH
Temp
DO
Ph


August 31, 2005
Temperature (C)
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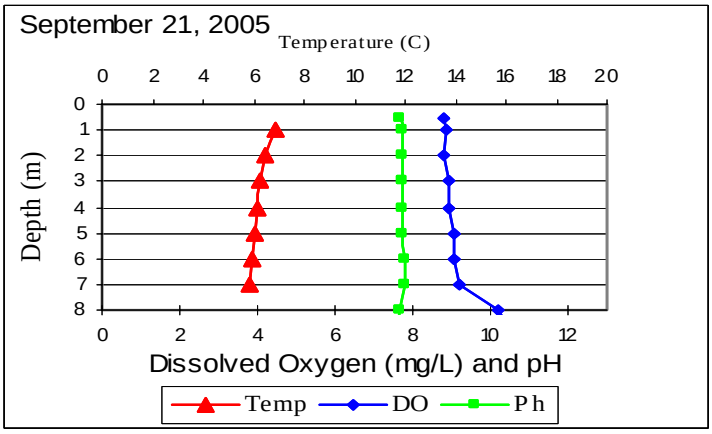
Depth (m)
0 1 2 3 4 5 6 7 8
0 2 4 6 8 10 12
Dissolved Oxygen (mg/L) and pH
Temp
DO
Ph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Temperature (C)
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Depth (m)
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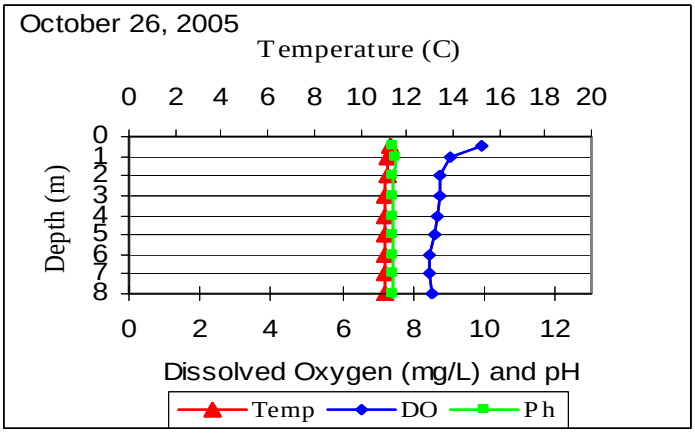
0 2 4 6 8 10 12
Dissolved Oxygen (mg/L) and pH
Temp
DO
Ph


October 26, 2005
Temperature (C)
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Depth (m)
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0 2 4 6 8 10 12
Dissolved Oxygen (mg/L) and pH
Temp
DO
Ph