Lacamas Lake:
Nutrient Loading and In-lake Conditions

Clark County Public Works
Water Resources Section

April 2004

Prepared by
Jeff Schnabel and Bob Hutton

Funded by the
Clark County NPDES Clean Water Program

Table of Contents

Acknowledgements
We appreciate the assistance of Water Resources staff in the completion of this project. Ron Wierenga and Jason Wolf assisted with field data collection. Peer review was provided by Bob Hutton, Kelli Frost, and Rod Swanson.

Bob Hutton constructed report graphics and performed all statistical analyses. Thanks also to Jim Sweet, Aquatic Analysts Inc., for assistance with phytoplankton data interpretation.

Introduction

Background

Lacamas Lake and Round Lake are located in Clark County, Washington, on the northern boundary of the city of Camas. In a county with few lakes, Lacamas and Round Lakes are recognized as an important recreational resource. Fishermen, swimmers, boaters, and hikers utilize the lakes and their shores year-round.

Periodic water quality monitoring by the Southwest Washington Health District (SWHD) from 1974-1980 first raised concerns about water quality in Lacamas Lake and its tributary streams. In 1983, the Clark County Intergovernmental Resource Center (IRC) received a grant from the Washington Department of Ecology (Ecology) to fund a Phase I Diagnostic and Restoration Analysis (SRI, 1985).

Based on this investigation, Lacamas and Round Lake were categorized as "eutrophic". The terms oligotrophic, mesotrophic, and eutrophic are often used to characterize lakes according to a low, medium, or high level of algae production, respectively. Over time, lakes naturally move slowly along this continuum in a direction toward eutrophic conditions (high algal production). In some cases, however, this movement can be dramatically accelerated due to human activities in a lake or watershed.

It should be noted that trophic categories are not meant to convey value judgments. Oligotrophic conditions do not necessarily imply "good" water quality or a "healthy" lake. Conversely, eutrophic conditions do not always mean a lake is impaired or has "bad" water quality. Rather, trophic categories describe the amount of nutrient enrichment and biological productivity in a lake, whereas terms like "healthy" and "impaired" refer to the condition of a lake relative to its desired uses or natural condition (Snohomish County, 2003).

In the case of Lacamas Lake, accelerated eutrophication has dramatically altered the lake from its natural historical condition and resulted in conditions that may impair current desired uses such as fishing, swimming, and aesthetic enjoyment.

Water quality problems associated with Lacamas Lake eutrophication in 1984 included severe dissolved oxygen depletion, poor water clarity, high levels of algae growth, nuisance blue-green algae blooms, and dense beds of aquatic macrophytes. These conditions are typical of a highly eutrophic lake, and were attributed primarily to excessive inputs of the nutrient phosphorus due to human activities in the Lacamas watershed.

Subsequently, the Lacamas Lake Restoration Program (LLRP), supported in part by grants from the Centennial Clean Water Fund and Section 319 Fund, implemented a program of agricultural Best Management Practice (BMP) installation, water quality monitoring, and public education in the watershed between 1987 and 2001. Those efforts were aimed at reducing the amount of phosphorus in Lacamas Lake and are summarized in the Lacamas Lake Restoration Program Final Report (Hutton, 2002), Lacamas Lake Restoration Program: WY2000 and WY 2001 Water Quality Monitoring (Schnabel, 2002), and the Lacamas Lake Watershed Restoration Project Program Review (E&S, 1998). These reports and others relating to Lacamas Lake are available from Clark County Water Resources.

The LLRP was successful in reducing the number of agricultural sources of phosphorus to the lake, establishing a greater scientific understanding of its water quality and dynamics, and raising awareness among the citizens of Clark County. However, despite the fact that annual loading and in-lake concentrations of phosphorus declined, the lake continued to exhibit the signs of eutrophication observed in the early 1980s.

Since the expiration of the Lacamas grant in December 2001, Clark County Water Resources has continued ambient monitoring activities in Lacamas Creek and Lacamas Lake under its Clean Water Program. In the absence of a coordinated lake management and monitoring approach by other local and state jurisdictions, Water Resources continues ambient monitoring of this resource to enhance future lake management decisions and improve the evaluation of potential changes in lake health.

Purpose and Scope

This report updates water quality status and trend information for Lacamas Creek and Lacamas Lake. The report describes annual loading estimates, explores possible trends in key nutrient concentrations, presents recent lake monitoring results, and defines current lake trophic status. Although comparisons are made with historical data, the report does not include a comprehensive discussion of past Lacamas Lake monitoring results.

Report Components

The report describes two separate project components:

1) Lacamas Creek (inlet/outlet): the final summary for a five-year project to estimate total phosphorus and total suspended solids loading to and from Lacamas Lake.

Annual total phosphorus (TP) and total suspended solids (TSS) loads into and out of the lake are calculated, including an estimate of annual TP and TSS retention within the lake. Average annual TP concentrations in Lacamas Creek are compared with EPA criteria. The 1999-2003 Lacamas Creek data set is analyzed for trends in TP and TSS concentration, and current TP/TSS loading rates are compared with earlier estimates.

2) Lacamas Lake: an update of lake condition and trend information based on data collected during water year (WY) 2002 and WY2003, as well as the historical dataset.

Patterns of lake stratification, dissolved oxygen, and temperature are presented for WY2003. Box-plots of summertime epilimnetic TP and total Kjeldahl nitrogen (TKN) concentrations are constructed and the 1991-2003 lake data set is analyzed for trends in epilimnetic water transparency (Secchi disk), TP, and TKN. Median epilimnetic TP concentrations are compared to EPA criteria and nitrogen concentrations are compared to expected ranges for eutrophic water bodies.

WY2003 phytoplankton population density and biovolume are compared to results from 1984 and 1995, and current population composition is discussed. Recent Washington Department of Ecology (Ecology) aquatic plant survey results are also summarized. WY2003 lake trophic status is determined through the calculation of trophic state indices (TSI) for TP, Secchi disk, chlorophyll-*a*, and phytoplankton data. Box-plots of yearly summertime TSI values are presented for the 1984-2003 dataset.

Methods

Methods and QA procedures utilized in this project are described in the Lacamas Lake Watershed Water Quality Monitoring Program QAPP (1998), Lacamas Lake Monitoring Project QAPP (2004, draft), and, where noted, the report titled Lacamas Lake Restoration Program: WY2000 and WY2001 Monitoring (2002). For a complete description of laboratory procedures, see NCA's Quality Assurance Manual (2001).

Sample station locations

Figure 1 shows sample station locations for the Lacamas project. Station LACL11 (lake samples) is located over the deepest part of Lacamas Lake, and corresponds to the location of ambient water quality monitoring in previous Lacamas Lake studies. Station LACL00 (outlet samples) is located in the narrow channel connecting Lacamas and Round Lakes, immediately east of the State Route 500 bridge. Station LAC050 (inlet samples) is located on Lacamas Creek at the Goodwin Road bridge (County bridge #172), approximately ½ mile upstream from Lacamas Lake.

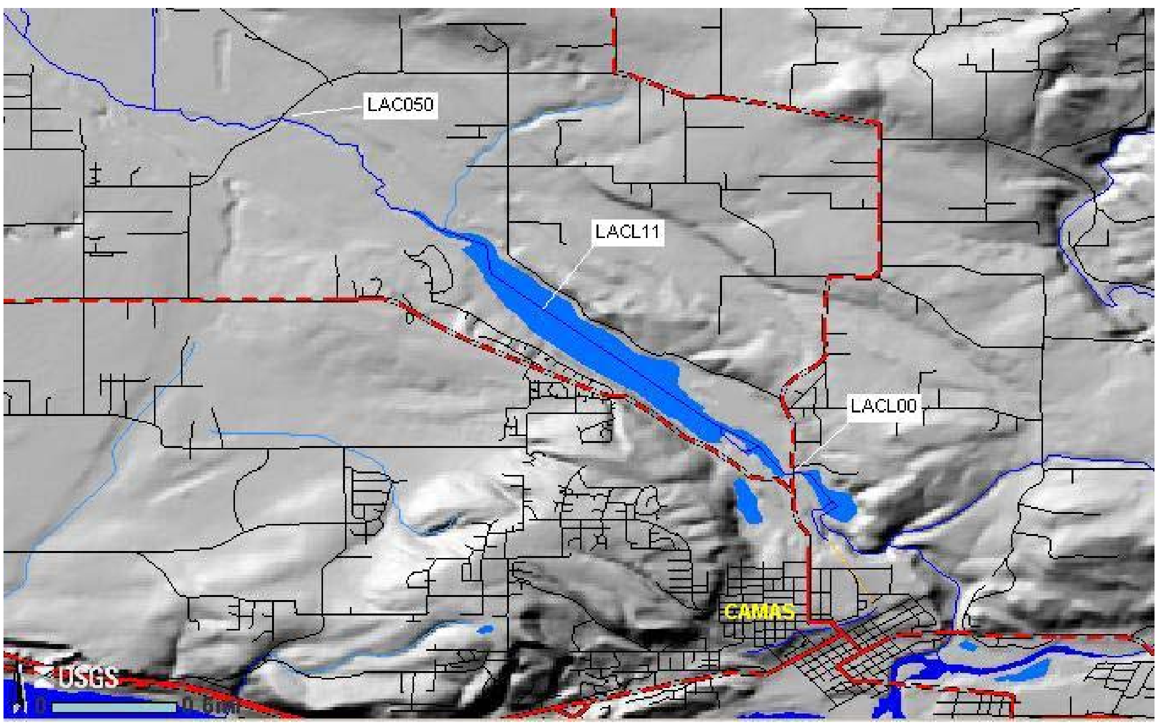


Figure 1. Location of Lacamas Lake Monitoring Program sample stations.

Sampling scheme and Parameters

The project consisted of two separate sampling components. The first component involved monitoring at the inlet and outlet of the lake to evaluate annual TP and TSS loading. The second consisted of monitoring in-lake conditions. Sampling schedules and parameters for each project component are shown in Table 1.

Field procedures

Lacamas Lake

Lake samples were collected at station LACL11. Field measurements for water temperature, dissolved oxygen, ph, and conductivity were collected at 1m intervals using a calibrated Hydrolab Datasonde 4 multi-probe and Surveyor 4 data-logger. Water samples for nutrient and suspended solids analyses were collected from the epilimnion, metalimnion, and hypolimnion using a vertical VanDorn-style sampling bottle.

Appropriate sample bottles were supplied by the analytical laboratory. Water samples were stored on ice in coolers until delivery to the lab. Secchi disk readings were taken on the shady side of the boat, with eye level just above the gunwale.

Chlorophyll *a* and phytoplankton samples were obtained by compositing three grab samples equally spaced through the photic zone. Photic zone depth was estimated as 2.5 times the measured Secchi depth. Grabs were collected using a VanDorn-style sampling bottle and composited in a nalgene carboy, from which sub-samples were drawn.

All field measurements were recorded on data sheets to provide a written backup of electronically stored data. Ancillary data pertaining to weather conditions, equipment function, and staff observations were also recorded on data sheets.

Project Component	Parameter	Schedule	Collection
Lacamas Creek:			
Inlet (LAC050)	stream flow	hourly	pressure transducer
	total phosphorus	weekly + storm events	automated grab
	total suspended solids	weekly + storm events	automated grab
Outlet (LACL00)	total phosphorus	weekly	manual grab
	total suspended solids	weekly	manual grab
Lacamas Lake:			
Lake (LACL11)	Secchi depth	monthly	visual measurement
	temperature	monthly	field meter, vertical profile
	dissolved oxygen	monthly	field meter, vertical profile
	conductivity	monthly	field meter, vertical profile
	pH	monthly	field meter, vertical profile
	total phosphorus	monthly	manual grab, 3 depths
	orthophosphorus	monthly	manual grab, 3 depths
	total suspended solids	monthly	manual grab, 3 depths
	total kjeldahl nitrogen	monthly	manual grab, 3 depths
	ammonia-nitrogen	monthly	manual grab, 3 depths
	nitrate + nitrite nitrogen	monthly	manual grab, 3 depths
	chlorophyll *a*	monthly (May-Oct 2003)	Composite, photic zone
	phytoplankton	monthly (May-Oct 2003)	Composite, photic zone

Table 1. Sampling schedule and collection methods.

Lacamas Creek (Inlet/Outlet)
Inlet samples were collected at station LAC050 using a Sigma 900MAX all-weather refrigerated sampler. In addition to providing automated sample collection, the Sigma equipment recorded hourly stream stage to calculate discharge. Water samples were collected approximately weekly and analyzed for total phosphorus and total suspended solids. In addition to this weekly base-flow sampling, selected storm events were sampled at a higher frequency to capture rapidly changing TP and TSS concentrations. A total of 125 samples were collected during WY2002 and 90 during WY2003.

Outlet samples were collected at station LACL00 using a vertical VanDorn-style sampling bottle or Sigma 900MAX portable sampler. Samples were collected from the SR500 bridge at approximately the midpoint of the channel and near the middle of the water column (approximately 2m below the water surface). Samples were collected approximately weekly and analyzed for total phosphorus and total suspended solids. A total of 53 samples were collected during WY2002 and 38 during WY 2003.

Laboratory procedures

Laboratory analyses for TP, TSS, TKN, ammonia nitrogen, nitrate + nitrite nitrogen, and chlorophyll *a* were conducted by North Creek Analytical, an Ecology-accredited facility in Beaverton, Oregon. Phytoplankton samples were analyzed by Aquatic Analysts in White Salmon, Washington. Table 2 contains analytical methods and reporting limits, in addition to precision, accuracy, and bias targets.

Characteristic	Method	Reference	Reporting Limit	Precision	Accuracy	Bias
		lab	conc/units	%RSD	units/% error	%REC
stream flow		na				
temperature	thermistor	na	0.01 C	10%	±0.15 C	na
dissolved oxygen	membrane electrode	na	0.01 mg/L	10%	±0.2 mg/L	na
conductivity	electrode	na	4 digits	10%	±0.5% of reading	na
pH	glass electrode	na	0.01 units	10%	±0.2 units	na
total phosphorus	colorimetric	EPA 365.1	0.02 mg/L	10%	25%	5%
orthophosphorus	colorimetric	EPA 365.2	0.01 mg/L	10%	25%	5%
total kjeldahl nitrogen	colorimetric	EPA 351.2	0.5 mg/L	10%	25%	5%
ammonia-nitrogen	colorimetric	EPA 350.1	0.05 mg/L	10%	25%	5%
nitrate+nitrite nitrogen	colorimetric	EPA 353.2	0.05 mg/L	10%	25%	5%
chlorophyll *a*	spectrophotometric	SM 10200H	0.2 ug/L	20%	45%	5%
phytoplankton	slide transect	na	na	na	na	na

Table 2. Analytical methods and measurement quality objectives.

QA/QC

Field QA

The Quality Assurance program for field sampling consisted of several components: 1) sample collection according to standard procedures as described in the previous section and in Standard Procedures for Monitoring Activities, Clark County Water Resources Section (June 2002), 2) field staff training, 3) documented instrument calibration, and 4) the collection of field Quality Control (QC) samples.

Four types of field QC samples or measurements were collected.

- Duplicate field samples and duplicate field measurements- these consisted of an additional sample collection or measurement made a few minutes after the initial sample or measurement. These samples are also referred to as "sequential" duplicates and represent the variability due to short-term in-stream or in-lake processes, sample collection and processing, and laboratory analysis.
- Split field samples- these consisted of a single composite sample split into two containers that were processed as individual samples. This eliminated the in-lake variability and isolated the variability to that due to field processing and analysis.
- Transfer blanks- these consisted of the submission and analysis of de-ionized water samples exposed to sampling equipment and procedures in the field.
- Transport blanks- these consisted of the submission and analysis of de-ionized water samples prepared in the office and carried through the field trip.

QC collection targets were modified during late 2002 as part of a Water Resources QA review and update. QC sample schedules below reflect the updated targets used during WY 2003. At the lake station (LACL11), duplicate field samples and duplicate field measurements were collected every other month for all characteristics except chlorophyll-*a*. One split field sample was collected for chlorophyll-*a* analysis. Transfer blanks were collected during lake trips semi-annually and a transport blank was collected annually. QC samples were submitted semi-blind to the laboratory. They were identified as QC samples from a particular station, but sample type (duplicate, transfer blank, or transport blank) was not identified.

Field meters were calibrated and maintained in accordance with manufacturer's instructions. Conductivity check standards and a NIST-certified thermometer were used to verify field meter accuracy. Calibration logs were completed during each calibration and are archived in Water Resources Section files. Calibration drift in pH meters was checked against pH buffer solutions, and dissolved oxygen measurements were verified using a modified Winkler titration.

Duplicate field samples from the inlet/outlet stations (LAC050 and LACL00) were collected every other month beginning in late WY2002. Stage measurements recorded with the Sigma 900MAX at station LAC050 were checked for consistency against staff gage readings and a backup stage recorder at the same location. The accuracy of the stage-discharge relationship used for calculating stream discharge was verified through comparison with instantaneous discharge measurements collected during WY2003.

Laboratory QA

Laboratory check standards, matrix spikes, analytical duplicates, and blanks were analyzed in accordance with the NCA Quality Assurance Manual (2001). QC results were reported to Water Resources along with sample data. Laboratory data reduction, review, assessment, and reporting were performed according to the NCA Quality Assurance Manual.

Data Analysis Procedures

Data analysis included the calculation of annual loading estimates, construction of box-and-whisker plots, trend analysis, trend power and the calculation of trophic state index values. Analyses were performed using Microsoft Excel, Minitab, and WQStat Plus software. Data analysis procedures are included in the Appendix.

Results and Discussion

Quality Assurance
QA/QC results and discussion are included in the Appendix.

Lacamas Creek (inlet/outlet)
TP and TSS loading
Table 3 and Figure 2 summarize available TP loading, TSS loading, and streamflow estimates for Lacamas Creek since 1984.

During WY 2003, TP loading was estimated at 5000 kg (~5.5 tons) and TP export from the lake was ~4400 kg. This amounts to a net annual TP retention of 600 kg (12%) within the lake. Between WY1999 and WY2003, mean annual TP loading was 6000 kg, which compares favorably to the estimate of 14,000 kg in 1984. However, differences in annual stream discharge can greatly affect annual loads. To compensate for these differences, loading was also calculated per unit of stream discharge (kilograms/acre-ft). Since 1999, estimated TP loading has remained consistently between 0.06 and 0.07 kilograms per acre-foot of stream discharge. Again, this compares favorably to the earlier estimate of 0.11 kg/acre-ft in 1984 (Figure 2).

	~WY 1984	WY 1999	WY 2000	WY 2001	WY 2002	WY 2003
Total Stream Discharge (ac-ft/yr):	128,237	127,098	96,265	48,778	102,471	81,151
Mean Discharge (cfs)	178	176	133	67	141	112
TP In-load (kg):	14,387	7,560	6,414	3,061	7,632	5,001
TP load per discharge (kg/ac-ft):	0.11	0.06	0.07	0.06	0.07	0.06
TP Out-load (kg):	12,161	n/a	5,065	1,785	6,650	4,390
% Retained in lake:	15	n/a	21	42	13	12
TSS In-load (kg):	1,820,000	812,094	1,238,691	719,246	615,291	523,891
TSS load per discharge (kg/ac-ft):	14.2	6.4	12.9	14.8	6.0	6.5
TSS Out-load (kg):	n/a	n/a	543,242	464,888	417,687	204,967
% Retained in lake:	n/a	n/a	56	35	32	61

Table 3. Streamflow and loading estimates since 1984.

There has been a net retention of TP in the lake each year that loading estimates have been calculated. The retention rate has ranged from 12% to 42% of the estimated in-load, with the highest annual retention rate corresponding to a water year with exceptionally low annual discharge (WY2001).

TSS loading for WY 2003 was estimated at slightly more than 500,000 kg (~550 tons, or about 55 dump-truck loads). TSS export was estimated at ~200,000 kg, leaving a net annual TSS retention of ~300,000 kg (61%) during WY 2003. The mean annual TSS load between WY1999 and WY2003 was just under 800,000 kg, compared to 1,820,000 kg in 1984. However, TSS loading per unit of stream discharge has ranged from 6 to 15 kg/ac-ft over the past five years, compared to 14 kg/ac-ft in 1984 (Figure 2).

As with TP, there has been a net retention of TSS in the lake during each year monitored. Retention rate estimates have ranged from 32% to 61% of the estimated in-load, indicating consistent deposition of sediment within Lacamas Lake.

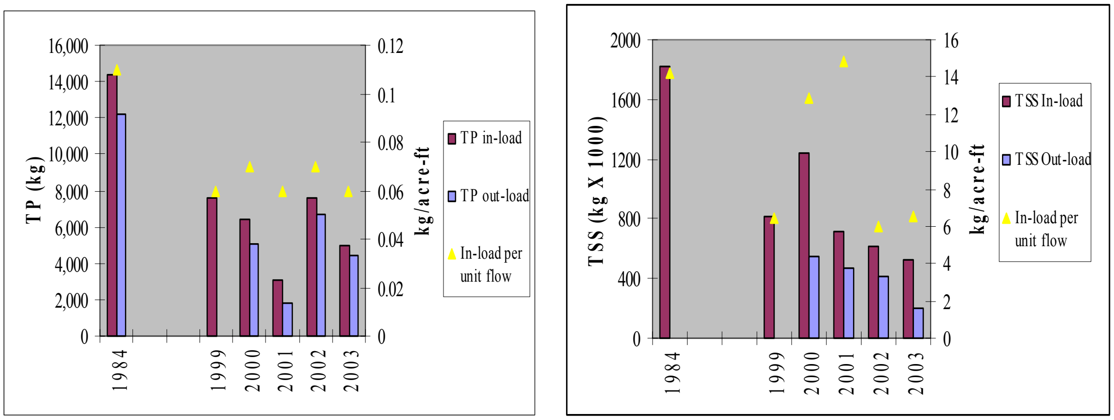


Figure 2. Annual TP and TSS in-load, out-load, and in-load per unit flow.

TP and TSS concentrations

Table 4 shows the time-weighted mean TP and TSS concentrations at the inlet and outlet of Lacamas Lake. Time-weighted means were calculated by taking the mean of the entire hourly dataset, so that individual measurements were weighted according to the length of time they were used to represent stream concentration. The time-weighted mean is an estimate, but should be a more accurate representation of annual stream conditions than the mean of the individual samples because it compensates for the effect of high concentrations in storm samples which only persist for a short time.

	~WY 1984	WY 1999	WY 2000	WY 2001	WY 2002	WY 2003
Mean In-flow TP (mg/L):*	0.089	0.050	0.061	0.046	0.052	0.038
Mean Out-flow TP (mg/L):*	n/a	n/a	0.039	0.034	0.034	0.030
Mean In-flow TSS (mg/L):*	11.5	6.3	12.5	9.6	5.3	4.1
Mean Out-flow TSS (mg/L):*	n/a	n/a	6.2	8.4	3.0	2.0
*Time-weighted						

Table 4. Time-weighted mean TP and TSS concentrations at Lacamas Lake inlet and outlet.

The usual EPA criterion for TP in streams is 0.100 mg/L. However, EPA established a more stringent criterion of 0.050 mg/L for streams that enter lakes. The EPA in-lake criterion for avoiding eutrophication is 0.025 mg/L. Since 1999, the mean inflow TP has remained near the 0.050 mg/L criterion, with the lowest concentration occurring during WY 2003. This represents a considerable decrease when compared to the annual mean of 0.089 mg/L TP in 1984. Mean outflow TP slightly exceeded the in-lake criteria of 0.025 mg/L, but has remained well below stream criteria as it enters Round Lake and, presumably, Lacamas Creek downstream of the lakes.

Figure 3 shows the results of a Seasonal Kendall test for trend on flow-adjusted monthly TP data collected at station LAC050 for WY1999-2003. For months with multiple samples, the sample collected closest to the middle of each month was used in the analysis. See the trend analysis section in the Appendix for a complete explanation of the data set and procedures used for trend analysis.

The trend analysis indicates a slight downward slope in concentration. However, the trend is not statistically significant at the 80%, 90%, or 95% confidence levels.

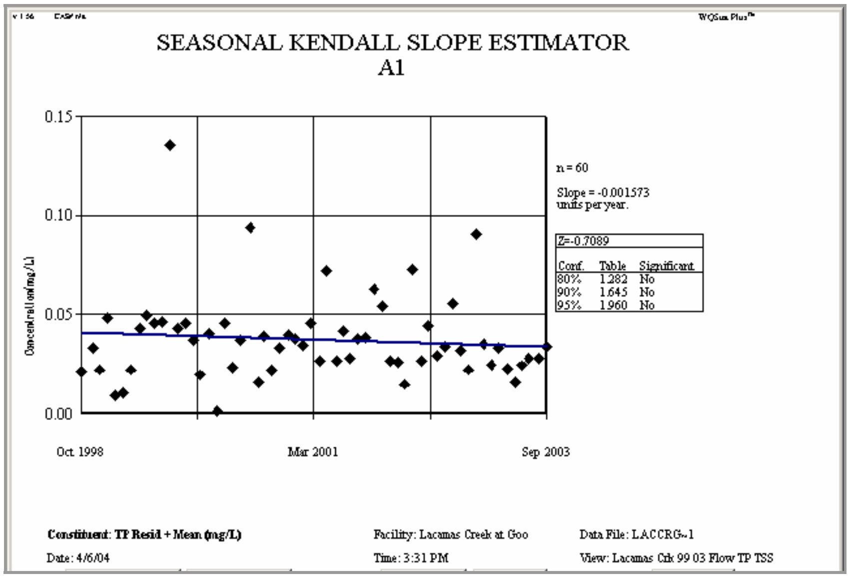


Figure 3. Seasonal Kendall test for trend in flow-adjusted total phosphorus concentrations, Lacamas Creek station LAC050, WY1999-2003.

Time-weighted mean TSS concentrations at station LAC050 from 1999-2003 ranged from 4.1 to 12.5 mg/L. Numeric criteria for TSS in streams have not been established.

Figure 4 shows the results of a Seasonal Kendall test for trend on monthly TSS data collected at station LAC050 for WY1999-2003. Again, for months with multiple samples the sample collected closest to the middle of each month was used in the analysis. TSS values were not flow-adjusted because a large number of censored data points (below laboratory reporting limits) precluded the use of the flow-adjustment procedure. The test indicates a decreasing trend in TSS concentration between 1999 and 2003. The trend is statistically significant at the 95% confidence level. However, a reliable estimate of the *slope* of the trend cannot be calculated due to the large proportion of censored data.

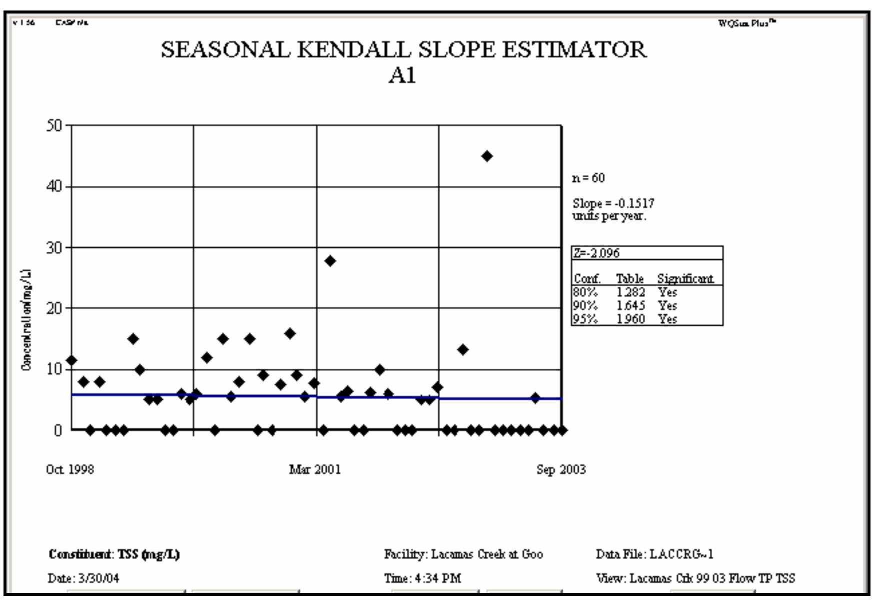


Figure 4. Seasonal Kendall test for trend in total suspended solids concentrations, Lacamas Creek station LAC050, WY1999-2003.

Lacamas Lake

Thermal stratification

In lake ecology, thermal stratification refers to the separation of the water column into distinct, non-mixing layers. Stratification occurs when solar energy warms the surface water, or epilimnion. The deeper water (hypolimnion) tends to remain colder because the sun's rays only penetrate a short distance. In a sense, the warm upper water "floats" on the cold deeper water, separated by a layer of rapidly decreasing temperature called the thermocline.

This temperature gradient is often strong enough to confine water, nutrients, dissolved oxygen, and suspended materials to a discrete layer, playing a key role in the movement of materials within lakes. Stratification generally occurs during summer, with fully-mixed periods occurring during fall through spring when solar warming is less pronounced. During mixed periods, the temperature gradient is weak or non-existent, allowing water and materials to circulate throughout the water column.

Lacamas Lake typically displays strong thermal stratification from approximately May through October. The progression of thermal stratification during WY 2003 (Figure 5) followed a similar pattern to previous years. Note the fully mixed conditions during January through March, followed by increasing stratification through spring and a strong thermocline developing between three and six meters during June through September.

Temperature

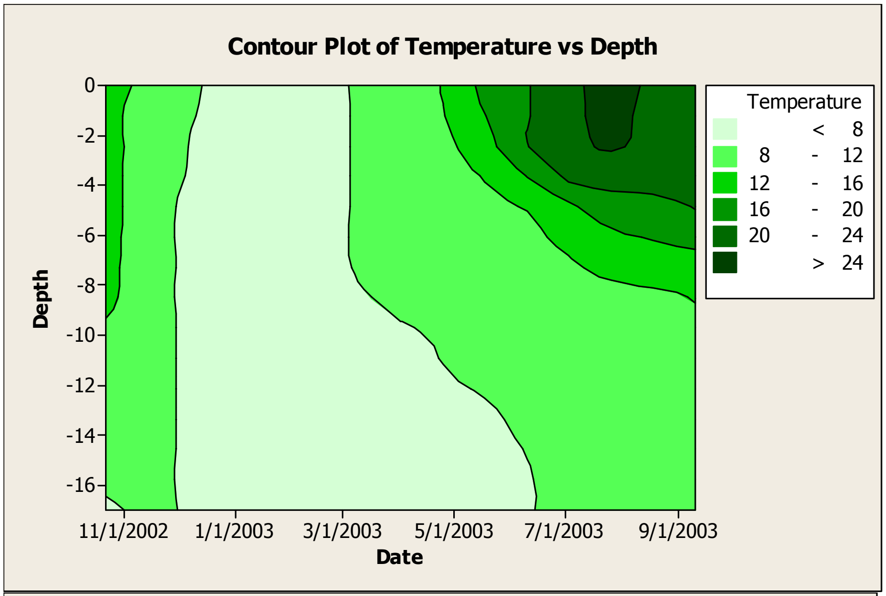
Water temperature is a key element controlling biological processes in lakes, and has a direct impact on the health of aquatic organisms. Washington State water quality criteria require that "all lakes and all feeder streams to lakes (reservoirs with a mean detention time greater than fifteen days are to be treated as a lake for use designation) … be protected for the designated uses of salmon and trout spawning, core rearing, and migration; and extraordinary primary contact recreation" (Washington Administrative Code 173-201A-600). The mean detention time calculated for Lacamas Lake (1984) is approximately 22 days. This criterion specifies that lake water temperature should not exceed 16° C (60.8° F).

Lacamas Lake temperature data from WY 2003 is summarized in Figure 5. Epilimnetic water temperatures exceeded the state criterion from June through September during both WY2002 and WY2003, reaching a maximum of approximately 23° C and 25° C during July of each year, respectively. Temperatures in this range are sufficient to promote algal growth throughout the summer, and are considerably above the acceptable temperature range for cold-water fish species such as trout. Water temperatures below 16° C were present throughout the summer at depths greater than 4-6 meters. However, as shown in the next section, these cold-water areas were often uninhabitable by fish due to extremely low dissolved oxygen concentrations.

Dissolved Oxygen

The state criterion for dissolved oxygen in lakes is 9.5 mg/L (WAC 173-201A-200). Figure 5 shows Lacamas Lake dissolved oxygen concentrations during WY2003. Dissolved oxygen concentrations have followed a similar pattern since at least 1984, decreasing dramatically with increasing depth during the summer months.

There is generally insufficient oxygen for most aquatic life uses (<5 mg/L) at depths greater than 4-5 meters from June through October, with essentially no oxygen at all below 6 meters from July through September (see lighter shades in lower section of Figure 5). Only from January through March does the entire water column meet the state criterion.



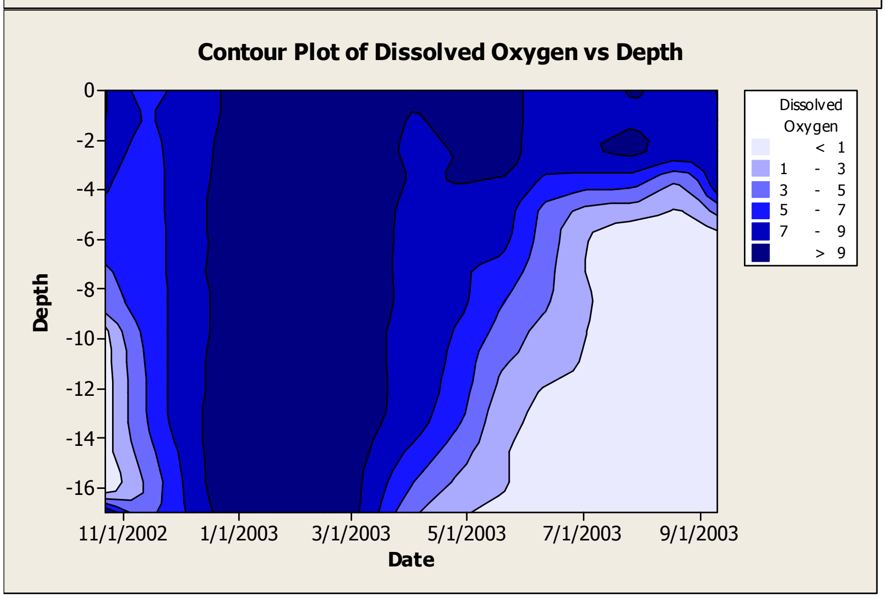


Figure 5. Water temperature and dissolved oxygen contours in Lacamas Lake, WY 2003.

Oxygen in the deeper waters is consumed as microorganisms decompose settled algae and larger plant material. Thermal stratification does not allow fresh oxygen from the atmosphere to reach the deeper layers and the hypolimnion eventually becomes anoxic. The oxygen is only replenished when the thermocline breaks down and vertical mixing of the water column occurs during fall.

During May to October of most years, the combination of hypolimnetic dissolved oxygen depletion and elevated epilimnetic temperatures in Lacamas Lake forces fish and other aquatic life to survive in a very restricted, and sometimes non-existent, band of suitable habitat.

Water transparency

Transparency represents light penetration in a lake. It is measured with a standard Secchi disk, a 20-cm white and black disk that is lowered into the water to the point it is no longer visible. Transparency can be affected by suspended sediment as well as algal growth and other organic material in the water. The Secchi disk is widely used as a general indicator of lake condition. Measurements <2.0 m often coincide with eutrophic conditions.

During WY2003, summer season (May-October) transparency in Lacamas Lake ranged from 1.2 m to 2.8 m, with a median of 1.6 m. Between 1984 and 2003, for years having at least three summer season readings, median Secchi depth has ranged from 1.2 m to 1.9 m. Figure 6 shows the results of a Seasonal Kendall test for trend on the 1991-2003 monthly Secchi disk dataset. Measurements ranged from approximately 0.5 m to 3.0 m during this time period, reflecting seasonal changes in weather, turbidity, and biological growth. The results do not indicate a statistically significant trend in water transparency since 1991.

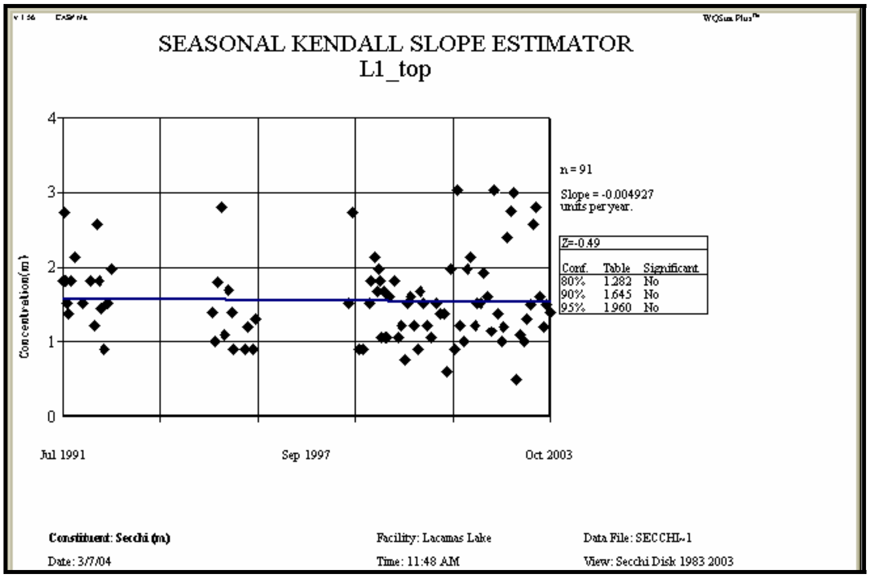


Figure 6. Seasonal Kendall test for trend in water transparency (Secchi disk), Lacamas Lake 1991-2003.

Total Phosphorus

High levels of phosphorus in Lacamas Lake were well-documented in 1984 (Beak and SRI, 1985). Phosphorus is an essential nutrient for the metabolism of all living organisms. Plant and algal growth are normally limited by phosphorus availability. Consequently, a scarcity of phosphorus will limit algal growth, while the addition of more phosphorus may produce excessive algae. Decreased dissolved oxygen concentrations often follow when the dead plant matter is broken down by oxygen-consuming bacteria. Based on the results of 1984 sampling, phosphorus reduction became the central goal of the Lacamas Lake Restoration Program.

The EPA has established TP criteria for lakes at a level of 0.025 mg/L to minimize eutrophication. Additionally, the State of Washington uses nutrient criteria to assess lakes and determine whether action needs to be taken to reduce nutrient loading (Section 173-201A-230 WAC). Washington State TP criteria are assigned by ecoregion but have not been determined for the Willamette Valley Foothills Ecoregion, where Lacamas Lake is located. However, an “action level” from the near-by Coast Range, Puget Lowlands, and Northern Rockies Ecoregions has been set at 20 μg/L (WAC Section 173-201A-230).

Based on total phosphorus samples collected by Water Resources during WY1999-WY2001, Ecology has listed Lacamas Lake as impaired in the draft 2002/2004 303(d) list, requiring that a TMDL (Total Maximum Daily Load) be developed to further reduce phosphorus loading to the lake.

Figure 7 contains annual box plots of epilimnetic (surface) TP concentrations during the summer growing season (May-October). A visual inspection of the plots suggests significant differences in the following cases where confidence intervals (darker internal boxes) do not overlap: 1984 vs. 1994, 1984 vs. 2002, 1984 vs. 2003, and 1994 vs. 1995. Overall, data from the more recent years indicates a significant decrease from the concentrations observed in 1984.

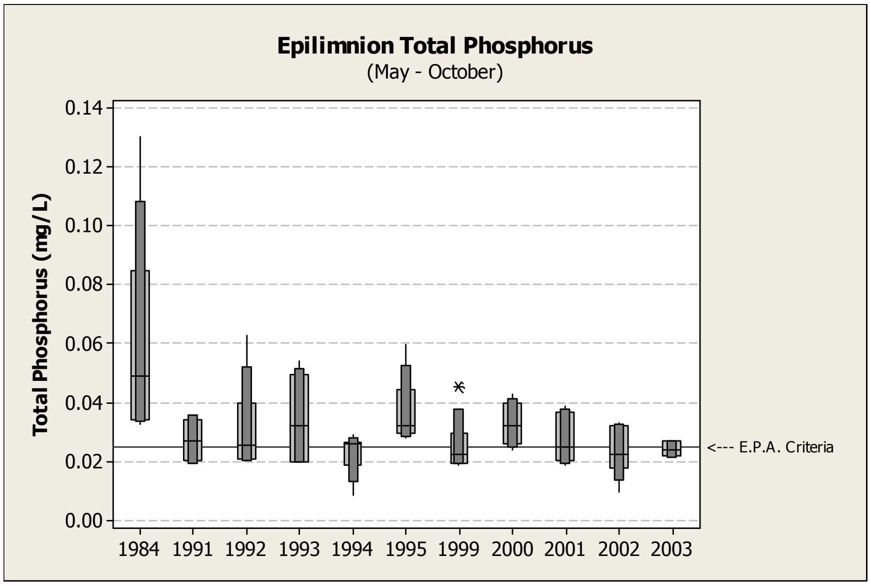


Figure 7. Median and interquartile range of May-October epilimnetic total phosphorus concentrations, Lacamas Lake, 1984-2003.

Despite this improvement, median summertime concentrations (indicated by horizontal line in each box) since 1984 have generally remained above the EPA lake criterion, indicating sufficient TP to facilitate eutrophic conditions. Small variations between years are likely due to fluctuating weather patterns and biological activity.

The Seasonal Kendall test for trend does not indicate a statistically significant trend in epilimnetic TP between 1991 and 2003 (Figure 8).

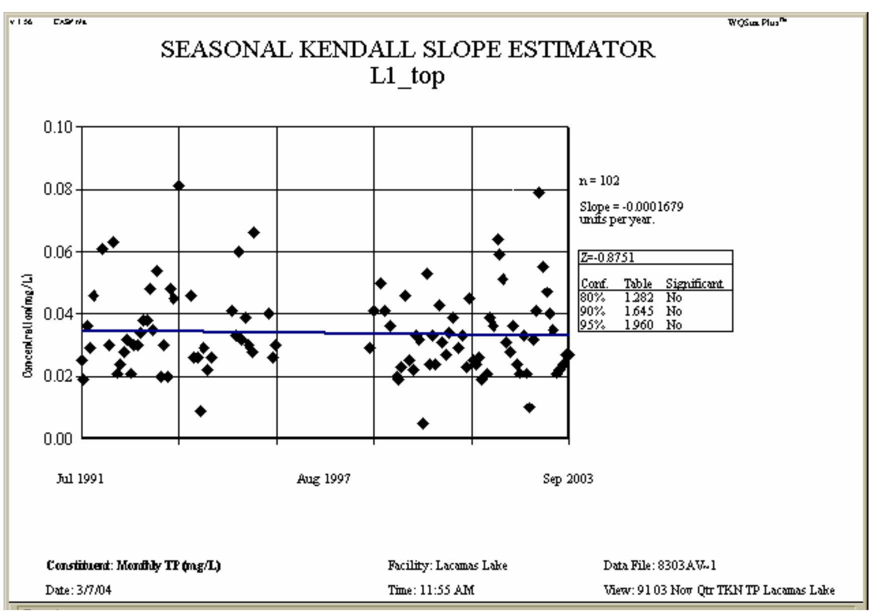


Figure 8. Seasonal Kendall trend test, Lacamas Lake epilimnion total phosphorus, 1991-2003.

Nitrogen
Nitrogen is the second major plant nutrient of interest in lakes. In the presence of sufficient phosphorus, elevated nitrogen levels may also cause excess algal and plant growth. Inorganic nitrogen forms are the most readily available for uptake by algae and plants, while total Kjeldahl nitrogen primarily reflects nitrogen already captured in organic material. Total Kjeldahl Nitrogen is the sum of organic + ammonia nitrogen, while inorganic nitrogen consists of nitrite + nitrate-N and ammonia.

Inorganic-N concentrations are highly variable seasonally. In general, springtime inorganic-N concentrations >0.3 mg/L are sufficient to facilitate summer algal blooms, and average concentrations 0.5 to 1.5 mg/L are often associated with eutrophic conditions (Wetzel, 1983). Springtime inorganic-N concentrations in Lacamas Lake routinely range from 0.5 – 1.2 mg/L, and annual average concentrations in WY2002 and WY2003 were 0.65 mg/L and 0.56 mg/L, respectively.

Wetzel (1983) suggests that average epilimnetic organic nitrogen concentrations of 0.4 to 0.7 mg/L generally correspond to meso-eutrophic conditions while average concentrations >0.7 mg/L correspond to eutrophic conditions. Annual average concentrations in WY2002 and WY2003 were 0.72 mg/L and 0.55 mg/L, respectively, placing Lacamas Lake in the meso-eutrophic to eutrophic categories. Additionally, Figure 9 contains annual box plots of epilimnetic TKN during the growing season (May-October). The plots suggest significant differences in the following cases where confidence intervals do not overlap: 1991 vs. 2000, 1991 vs. 2001, 1991 vs. 2002, and 1993 vs. 2000.

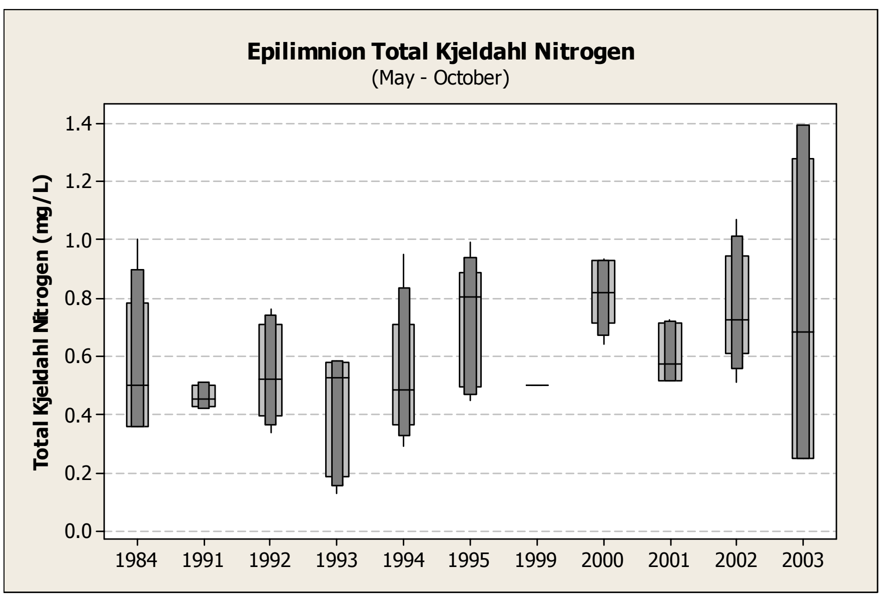


Figure 9. Median and interquartile range of epilimnetic total Kjeldahl nitrogen concentrations, Lacamas Lake, 1984-2003.

Figure 10 shows the results of the seasonal Kendall test for trend in epilimnetic TKN from 1991-2003. The test indicates an increasing trend in TKN concentrations of approximately 0.020 mg/L per year and is significant at the 95% confidence level. The trend suggests an overall increase in the amount of nitrogen being captured in organic material in Lacamas Lake.

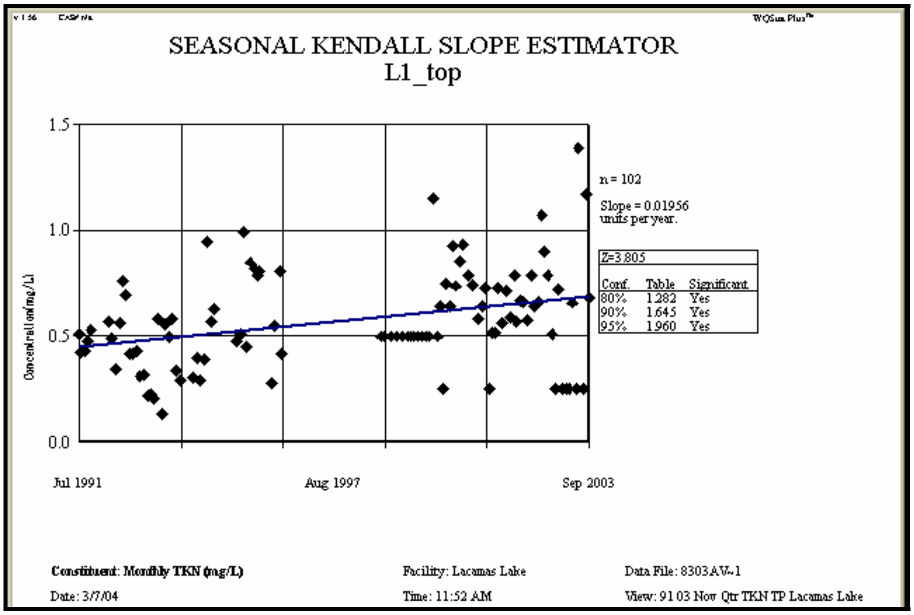


Figure 10. Seasonal Kendall test for trend, Lacamas Lake epilimnetic total Kjeldahl nitrogen, 1991-2003.

TIN:TP ratio
The ratio of Total Inorganic Nitrogen (TIN) to TP provides an indication of lake nutrient dynamics and the likelihood of blue-green algae blooms. TIN includes nitrate-nitrite N and ammonia-N. As noted above, phosphorus is often the limiting factor for algal growth in lakes.

However, in some lakes with plentiful phosphorus, nitrogen may become the limiting factor during certain periods, especially summer and fall. In a nitrogen-limited system, blue-green algae species have a competitive advantage due to their ability to utilize atmospheric nitrogen. Under these circumstances, large blooms of blue-green species may occur.

Monitoring during 1995 by E&S Environmental Chemistry, Inc. suggested that Lacamas Lake may be nitrogen limited during parts of the summer and fall. A TIN:TP ratio >20 suggests phosphorus limitation, while a ratio <15 often indicates limitation by nitrogen. Figure 11 shows the monthly TIN:TP ratios for Lacamas Lake during WY2003, following the same procedure used in 1995. Although P was limiting during much of the winter, spring, and early summer, the lake was N-limited from mid- summer through fall. The switch from P to N limitation during July coincides with the onset of dominance by blue-green algal species.

On a practical level, the N-limitation during summer and fall indicates that the P concentration would need to be further reduced in order for phosphorus to be limiting during this time period. Consistent limitation by phosphorus could be a positive change in the lake, possibly leading to lower overall algal biomass and a decreased competitive advantage for blue-greens.

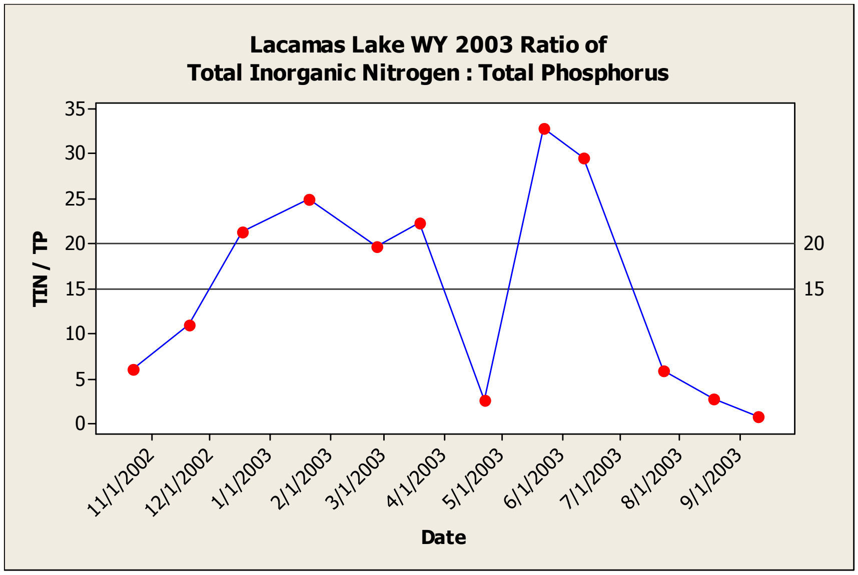


Figure 11. TIN:TP ratio in the eplimnion of Lacamas Lake, WY2003.

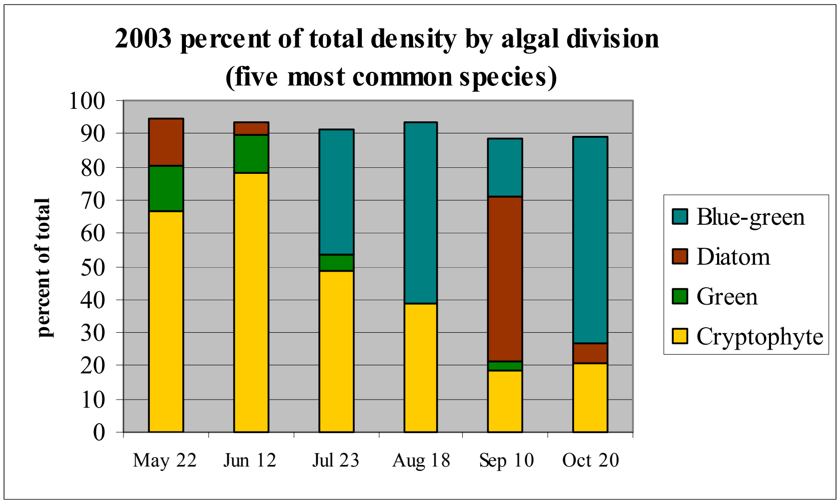
Phytoplankton
Phytoplankton, or algae, are microscopic plant-like organisms that capture solar energy through photosynthesis. They are the source of primary production that forms the base of the aquatic food web. The type and amount of algae affects water chemistry, transparency, food availability, and the composition of the higher food web.

Cell density was enumerated and biovolume calculated for each algal species in each sample. Density is simply the number of algal units/mL of sample, while biovolume is a measure of the total volume of the algal cells. Because algal cells of different species vary widely in size, biovolume provides a convenient way to measure the total amount, or volume, of algal production. Diatom species are often the most desirable food for grazers (zooplankton), though green algae and cryptophytes are also grazed. Blue-green species are considered a poor food source.

Figure 12 shows the percentage of total 2003 density and biovolume by algal division. The figures are based on the five most dominant species in each sample (either by density or biovolume), which in most cases accounted for over 90% of the total.

The small, flagellated cryptophytes *Rhodomonas minuta* and *Cryptomonas erosa* comprised the majority of the algal density from May through July and were present in significant numbers throughout the sampling period. Rhodomonas is among the most common planktonic algae nationwide and is common in all types of lakes, whereas Cryptomonas tends to be more abundant in mesotrophic to eutrophic conditions. Rhodomonas was generally more common than Cryptomonas until late summer. Due to their small size, the cryptophytes comprised only a small percentage of the total biovolume.

During May, June, and September, diatom blooms consisting primarily of *Fragilaria crotonensis* dominated the biovolume. Fragilaria is a large, colonial, planktonic species and usually indicates eutrophic conditions. It rarely occurs in oligotrophic lakes. Although it can thrive in cool water and low-light conditions, Fragilaria is more typical of warmer surface waters.



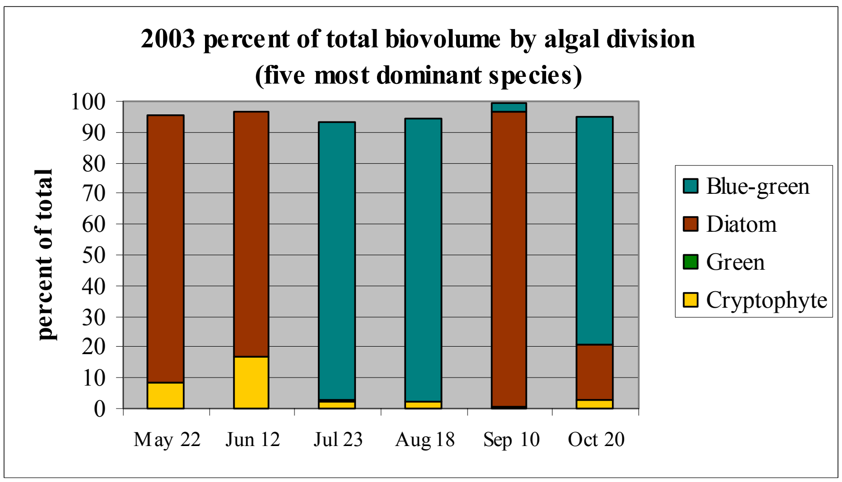


Figure 12. 2003 summer Lacamas Lake algal density and biovolume, by algal division.

During July, August, and October, algal biovolume was dominated by blooms of blue-green algae species. During July and August, both density and biovolume were dominated by *Anabaena planctonica*. In September, *Anabaena planctonica* declined sharply while *Aphanizomenon flos-aquae* increased. By October, *Aphanizomenon flos-aquae* dominated in terms of density while the larger *Anabaena planctonica* had a smaller population but represented most of the biovolume.

Anabaena species tend toward eutrophic lakes and often form blooms that may be unaesthetic, smell badly, and deplete hypolimnetic oxygen after decomposing. *Aphanizomenon flos-aquae* is a very good indicator of eutrophic and hyper-eutrophic lakes. An increase in either of these two species over time is a good indicator of advancing eutrophication (Jim Sweet, personal comm.).

The dominance of blue-green species can be problematic in several ways. Blue-green algae are highly specialized and often have a competitive advantage over more desirable algae species. In addition to being a poor food source for zooplankton, some species produce toxins that may be harmful to aquatic biota, terrestrial animals, or humans in significant amounts.

All Anabaena species are potentially toxin-producing, although *Anabaena flos-aquae* is usually more related to harmful toxin levels than is *Anabaena planctonica*. *Anabaena flos-aquae* was present in very low numbers in Lacamas Lake during 2003. *Microcystis aeruginosa*, a highly toxic species, was also present in low numbers in 2003. *Aphanizomenon flos-aquae* is generally not particularly toxic, but it too has the potential to produce toxins under certain conditions.

Lacamas Lake phytoplankton were sampled in 1984 and 1995 in addition to 2003. This phytoplankton dataset is not sufficient to perform statistical comparisons between sampling periods, and extensive comparative analysis of algal populations is beyond the scope of this report. However, a limited examination of growing season (May-October) algal density and biovolume during these years reveals several notable differences.

Overall, the relative densities of dominant species for May-October of 1984, 1995, and 2003 were:

1984		**1995**		**2003**	
Fragilaria crotonensis	44.0 %	Fragilaria crotonensis	19.6%	Rhodomonas minuta	25.8%
Rhodomonas minuta	9.8	Anabaena planctonica	19.0	Cryptomonas erosa	19.4
Schroederia judayi	7.4	Rhodomonas minuta	17.6	Anabaena planctonica	17.6
Ochromonas sp.	3.2	Cryptomonas erosa	14.1	Fragilaria crotonensis	11.6
Chrysophyte sp.	3.2	Asterionella Formosa	7.6	Aphanizomenon f.-aquae	10.4

Among individual species, several possible shifts are apparent. The dominance of *Fragilaria crotonensis* in 1984 was reduced in 1995, and by 2003 Fragilaria comprised only 12% of the population density. As noted above, Fragilaria remains a dominant species in terms of biovolume due to its large colonial structure. It is also noteworthy that the most common 5 species in 1984 composed 67% of the total phytoplankton population. By 1995, this percentage increased to 78%, and by 2003 the most common 5 species comprised 85% of the total algal density.

The most notable shift may be the advance of *Aphanizomenon flos-aquae.* As noted above, an increase in this species over time is a good indication of advancing eutrophication. In 2003, *Aphanizomenon flos-aquae* comprised 10% of the algal density during the May-October period. During the same period in 1995 it represented 1%, and in 1984 only 0.1%. Also, the highly toxic blue-green alga *Microcystis aeruginosa*, though still not common, increased from 0.1% in 1995 to 0.6% in 2003. This species was not found in 1984.

Although toxic algal blooms have not been a historical problem in Lacamas Lake, the dominance of blue-green species during mid-late summer, and particularly the increasing presence of *Microcystis aeruginosa*, is a potential area of concern for future recreational use.

Mean summer biovolume was similar in May-October of 1984, 1995, and 2003. Figure 13 shows the average monthly biovolume by algal division in the summer of 1984. A somewhat similar pattern of biovolume dominance among algal divisions is apparent when compared with the 2003 results shown in Figure 12, although the dominance by diatoms and blue-green algae evident in 2003 was not as pronounced in 1984. In particular, during 1984 the cryptophytes represented a much greater percentage of early summer biovolume, and green algae were present in measurable amounts throughout much of the summer.

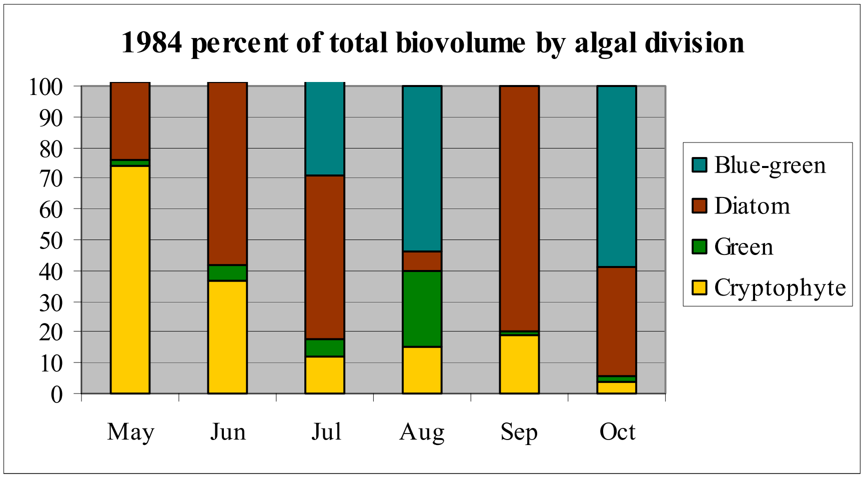


Figure 13. 1984 summer Lacamas Lake algal biovolume, by division.

Aquatic plants

Lacamas Lake is characterized by extensive aquatic plant (macrophyte) growth. Based on surface and scuba surveys, as well as Secchi disk readings and lake bathymetry, scientists in 1984 concluded that at least 97% of the potential colonizable area in Lacamas Lake was already being used by macrophytes.

An aggressive exotic species called *Egeria densa* (Brazilian elodea) was common in Lacamas Lake by 1984, although it was generally found on the outer (deeper) edges of plant beds and was interspersed with several other species. The native *Elodea canadensis* (Common elodea) dominated shallower depths. In Round Lake, *Egeria densa* was already dominant by 1984, to the almost complete exclusion of other submersed macrophytes (Beak and SRI, 1985).

The most recent Ecology aquatic plant survey performed in Lacamas Lake took place in June, 1999. Plant species and distribution data are summarized in Table 5. Of particular interest is the continued expansion of *Egeria densa*. In many areas, *Egeria densa* has displaced more desirable species such as the native *Elodea canadensis* and some pondweed species.

Trophic state index

Monthly TSI values for Lacamas Lake during May-October 2003 are shown in Figure 14. Values are generally in the mid to upper mesotrophic range (45-50) during late May and June, increasing to the eutrophic range (50-70) from July-October.

The seasonal pattern of results is generally consistent between parameters, although some variability is normal. 2003 phytoplankton results consistently indicate a higher trophic status than the other variables, while chlorophyll-*a*, Secchi disk, and total phosphorus results generally agree more closely.

In some cases, variability between parameters may be caused by non-random variability such as errors in sample collection or analysis. The exceptionally low TSI value for chlorophyll-a during August 2003 is probably an example of this type of error. It is likely that the low value (40, or oligo-mesotrophic) is erroneous when compared to the results from the other three parameters (52-63, or eutrophic). See the QA discussion in the Appendix for a description of chlorophyll-*a* analysis issues.

Date **17-Jun-99**

Scientific name	Common name	Distribution Value	Comments
Callitriche stagnalis	pond water-starwort	1	only in north end of lake near river
Ceratophyllum demersum	Coontail; hornwort	2	
Egeria densa	Brazilian elodea	4	dominant or co-dominant throughout most of shoreline
Elodea canadensis	common elodea	2	some dense areas in north end
Lemna minor	duckweed	1	only in north end of lake near river
Nitella sp.	stonewort	1	
Nuphar polysepala	spatter-dock, yellow water-lily	2	most in north end
Phalaris arundinacia	reed canarygrass	3	dense in north end
Potamogeton amplifolius	large-leaf pondweed	3	co-dominant with Egeria
Potamogeton epihydrus	ribbonleaf pondweed	1	only in north end of lake near river
Potamogeton illinoensis	Illinois pondweed	2	
Potamogeton robbinsii	fern leaf pondweed	2	
Scirpus sp.	bulrush	1	one patch seen on E shore
Sparganium sp.	bur-reed	1	only in north end of lake near river
Typha sp.	cat-tail	1	

Comments: Overcast, cool. Egeria very dense in many areas, at the surface and blooming. Grows densely to 3 m deep. More diverse in the river north of the lake. Lots of water skiers. Made a map with plant locations.

Distribution Value Definitions:

0 the value was not recorded (plant may not be submersed)
1 few plants in only 1 or a few locations
2 few plants, but with a wide patchy distribution
3 plants growing in large patches, co-dominant with other plants
4 plants in nearly mono-specific patches, dominant
5 thick growth covering the substrate at the exclusion of other species

Table 5. 1999 Lacamas Lake aquatic plant summary (Washington State Dept of Ecology).

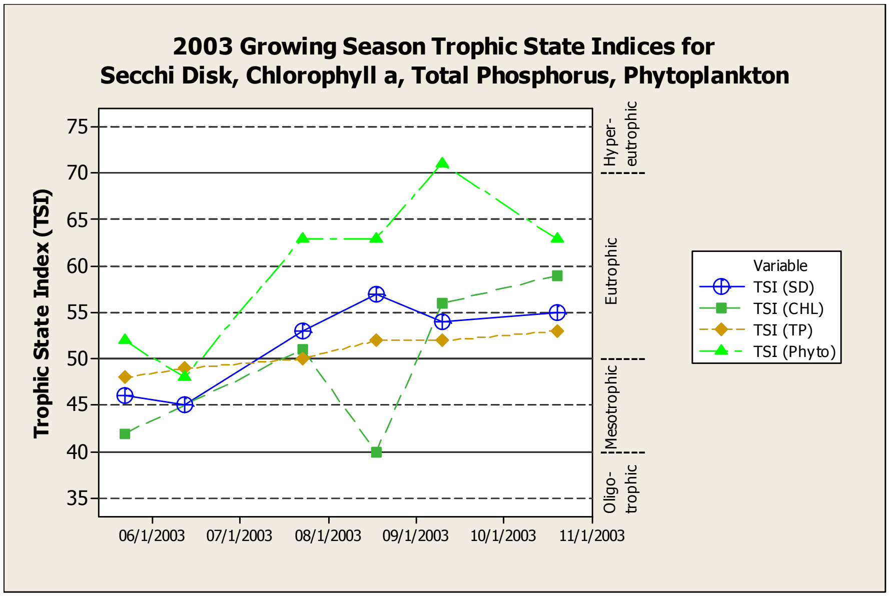


Figure 14. Monthly TSI values for Lacamas Lake, May-October 2003.

Annual box plots of May-October TSI values, based on the historical Lacamas Lake dataset (1984-2003), are shown in Figures 15, 16, 17, and 18. Note that phytoplankton and chlorophyll-*a* data are somewhat limited for the period of record.

Despite some variation in median TSI values for each parameter, most of the annual confidence intervals overlap indicating that statistically significant differences in medians between years are unlikely.

Median TSI values for Secchi depth and total phosphorus tend to be in the low to mid-eutrophic range (50-60), occasionally dropping into the upper mesotrophic category (45-50) for TP. No significant differences are indicated for Secchi depth TSI. However, a significant difference is indicated between the total phosphorus median values in 1984 versus 1994, 2002, and 2003. In 1984, median total phosphorus TSI was in the mid-eutrophic range (60), with values ranging upwards into the hyper-eutrophic range (>70). Since that time, medians have not exceeded 55 and individual values have generally remained below 60.

Most of the available chlorophyll-*a* and phytoplankton data consistently indicate eutrophic status, with median values tending to fall in the mid to upper-eutrophic range. The exception is the median of the 2003 chlorophyll-a data. However, as discussed in the QA section in the Appendix, the low chlorophyll-*a* TSI values for 2003 may be due to problems with the laboratory analysis. Despite the questionable low values, the median value for 2003 still falls in the lower eutrophic range.

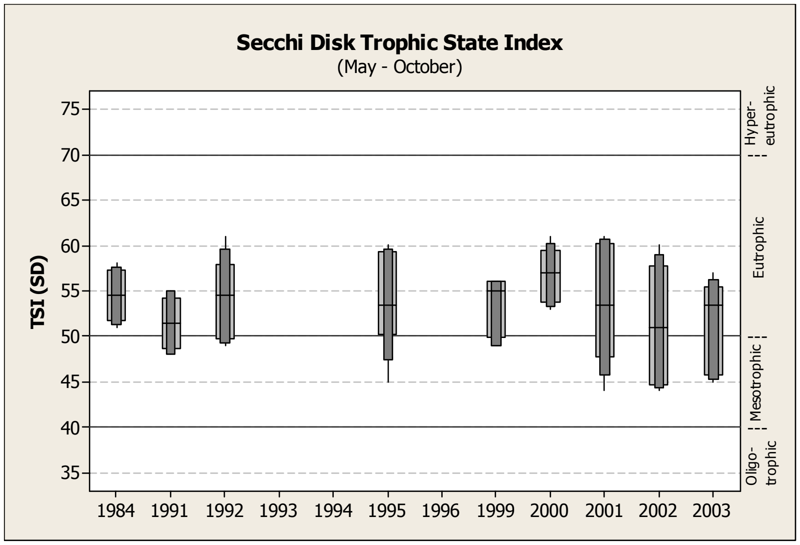


Figure 15. Median and interquartile range for May-October Secchi depth TSI, `
Lacamas Lake 1984-2003.

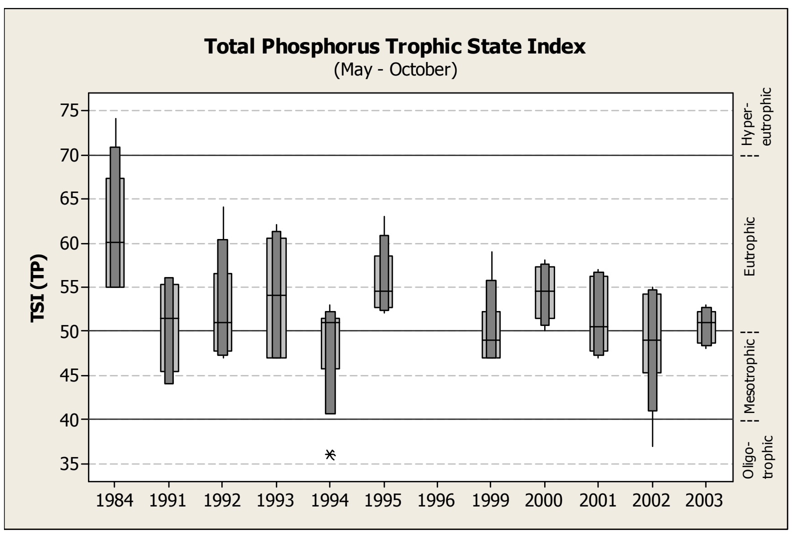


Figure 16. Median and interquartile range of May-October total phosphorus TSI, Lacamas Lake 1984-2003.

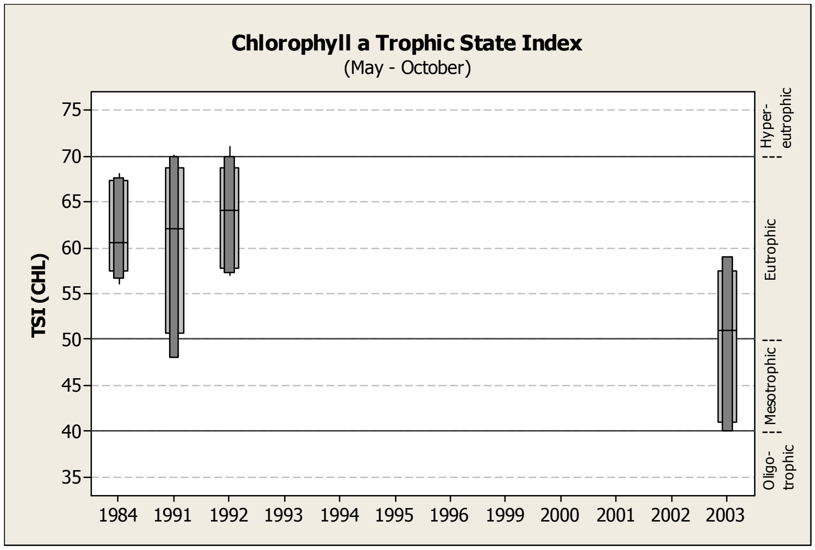


Figure 17. Median and interquartile range of May-October chlorophyll-*a* TSI, Lacamas Lake 1984-2003.

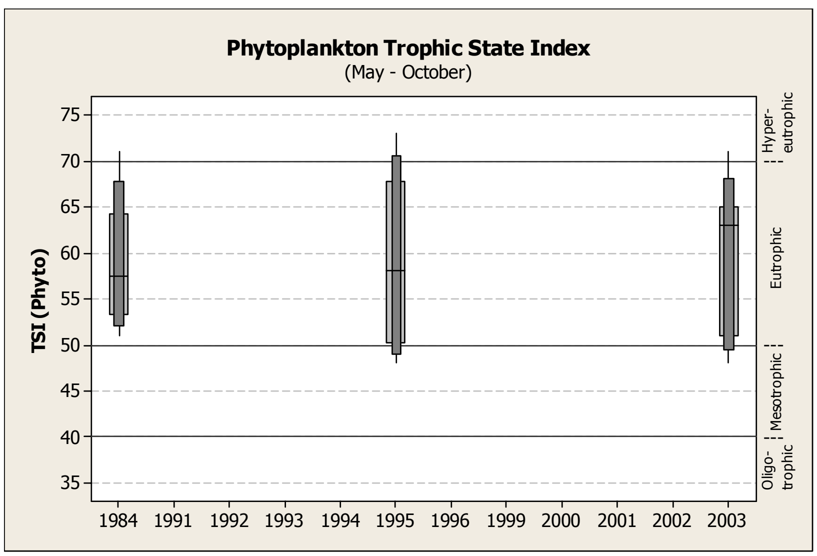


Figure 18. Median and interquartile range of May-October phytoplankton TSI, Lacamas Lake 1984-2003

<u>Trend Power</u>

The trend power analysis and results are described in more detail in the Appendix. The power of a trend test is the probability that the test will actually detect a trend when one is present. Therefore, an evaluation of the trend power provides insights into the limitations of conclusions reached using statistical tests. A failure to *detect* a trend is often used to improperly conclude that there *was no trend*, when in reality there may have simply been insufficient data or too much variance in the data to allow trend detection at the specified level of confidence (Hallock, 2003).

Predicted minimum detectable trends (as a percentage change in the mean) for the Lacamas Creek data were 37% and 93% for TP and TSS data, respectively. In effect, this means we would only expect to be able to detect trends in excess of these magnitudes. For example, the calculated change in the mean for Lacamas Creek TP over the 5-year monitoring period was 21%, and no significant trend was detected. A trend was detected in TSS data, even though the calculated change in mean was only 13%. This significant trend was probably influenced by the presence of a large number of censored data points in the TSS data set. Although a significant TSS trend does exist, it was not possible to reliably assign a magnitude to that trend.

Predicted minimum detectable trends (as a percentage change in the mean) for the Lacamas Lake data were 20%, 29%, and 20% for TKN, TP, and Secchi disk data, respectively. Therefore, we would only expect to be able to detect trends in excess of these magnitudes. The calculated changes in the means were 34% for TKN, 5% for TP, and 3% for Secchi disk. TKN was the only parameter having a calculated trend larger than the predicted minimum detectable trend, and was also the only parameter where a significant trend was detected.

Summary

The information summarized below is addressed in greater detail in the Results and Discussion section. For additional information from historical monitoring in Lacamas Creek and Lacamas Lake, see the documents listed in the Background section of this report.

<u>Creek</u>
Loading:
In 2003, annual loading was estimated at 5000 kg of total phosphorus (TP) and 500,000 kg of total suspended solids (TSS). Since 1999, annual TP loading has averaged 6000 kg and TSS has averaged 800,000 kg. During this time, the in-lake retention rate for TP ranged from 12-42% of the annual load. TSS retention in the lake ranged from 32-61%. This indicates a considerable annual accumulation of nutrients and settled material in Lacamas Lake.

Current loading rates compare favorably with annual estimates from 1984, when TP load was estimated at 14,000 kg and TSS load was estimated at 1,800,000 kg. On the basis of kilograms/acre-ft of annual discharge, TP loading since 1999 has remained consistently between 0.06 and 0.07 kg/acre-ft, compared to 0.11 kg/acre-ft in 1984. TSS has not followed a similar pattern: loading since 1999 has ranged from 6-15 kg/acre-ft, compared to 14 kg/acre-ft in 1984.

Total phosphorus concentration:
The EPA criterion for TP in streams that enter lakes is a maximum of 0.050 mg/L. For the five-year period beginning in 1999, the annual mean TP concentration in Lacamas Creek has ranged from 0.038 to 0.061 mg/L, meeting the EPA criterion in 3 years and narrowly exceeding the criterion (0.052 mg/L) in another year. These values compare favorably to an annual mean of 0.089 mg/L estimated in 1984. Despite the apparent reduction compared to 1984 estimates, no trend is apparent in recent Lacamas Creek TP concentration (1999-2003). Outflow TP concentration ranged from 0.030 to 0.039 mg/L during 1999-2003. If concentrations remain fairly constant as the water travels through Round Lake, then water discharged to Lacamas Creek downstream of the lakes is well within the EPA criterion of 0.1 mg/L for streams not flowing into lakes.

Total suspended solids concentration:
For the five-year period beginning in 1999, the annual mean TSS concentration in Lacamas Creek has ranged from 4.1 to 12.5 mg/L. An annual mean of 11.5 mg/L was calculated in 1984. Since 1999, trend analysis indicates a decrease in TSS concentration in Lacamas Creek at the 95% confidence level. However, due to limitations in the dataset, it is not possible to reliably calculate the slope, or magnitude, of the apparent trend. Overall, baseflow TSS concentrations in Lacamas Creek tended to remain quite low, with somewhat higher concentrations occurring during storm events.

Lake

Secchi transparency:
Secchi measurements <2.0 m are often associated with eutrophic conditions. Median secchi depth during 1984 and 1991-2003 ranged from 1.2-1.9 m. No trend is apparent in the 1991-2003 dataset.

Temperature:
The Washington State temperature criterion for lakes is <16 degrees C. In 2002 and 2003, Lacamas Lake failed to meet the criterion from June-September. Annual maximums were 22 C and 25 C, respectively. The dataset since 1984 indicates that summer cold-water habitat beneficial uses are consistently impaired.

Dissolved Oxygen(DO):
The Washington State dissolved oxygen criterion for lakes is >9.5 mg/L. In 2002 and 2003, Lacamas Lake had severe DO depletion below 4m depth from June-October. Severe summertime DO depletion below 4-5 meters depth has been a consistent issue since 1984. Habitat for aquatic biota is severely limited during summer due to a combination of elevated water temperatures in the epilimnion and dissolved oxygen depletion in the hypolimnion.

Total Phosphorus(TP):
The EPA criteria for TP in lakes is <0.025 mg/L. The State of Washington has set an “action level” of TP in nearby ecoregions at <0.020 mg/L. In 2002 and 2003, median TP concentrations met the EPA lake criterion, but still exceeded the state action level for nearby ecoregions. Summer TP concentrations are significantly lower today than in 1984, but since 1991 have continued to exceed state action levels and EPA criteria on a regular basis. No statistically significant trend in TP is apparent in the 1991 to 2003 dataset. Based on data collected by Water Resources between 1999 and 2001, Ecology has listed Lacamas Lake as impaired in the draft 2002/2004 303(d) list, requiring that a TMDL (Total Maximum Daily Load) be developed under the Clean Water Act to further reduce phosphorus loading to the lake.

Nitrogen
Inorganic nitrogen, consisting of nitrite + nitrate-N and ammonia-N, occurs in the forms most readily available for uptake by algae and plants. Springtime inorganic-N concentrations in Lacamas Lake typically range from 0.5 – 1.2 mg/L, and annual average concentrations in 2002 and 2003 were 0.65 mg/L and 0.56 mg/L. Springtime concentrations >0.3 mg/L and annual average concentrations 0.5 to 1.5 mg/L are often associated with eutrophic conditions and summer algal blooms.

Total Kjeldahl nitrogen (organic N + ammonia) is composed primarily of nitrogen that has been incorporated into biomass. In general, recent annual average TKN concentrations correspond to concentrations typically found in meso-eutrophic to eutrophic lakes. An increasing trend in TKN of ~0.020 mg/L per year is apparent in the 1991-2003 dataset. This trend is significant at the 95% confidence level (i.e. there is a 95% chance that the perceived trend actually exists). The trend suggests an overall increase in the amount of nitrogen being captured in organic material in Lacamas Lake.

TIN:TP ratio
The ratio of total inorganic nitrogen to total phosphorus gives an indication of which primary nutrient (N or P) is the limiting factor for algal growth in lakes. A ratio >20 suggests P limitation and <15 suggests N limitation. In 2003, similar to 1995 and 1984, Lacamas Lake was nitrogen limited during mid-summer through fall, probably contributing to the dominance of blue-green algae which, unlike other algae species, are able to obtain nitrogen directly from the atmosphere.

Phytoplankton (algae):
In summer 2003, the phytoplankton community biovolume was dominated by species commonly associated with eutrophic conditions. The average biovolume and a general pattern of dominance by the diatom *Fragilaria crotonensis* and blue-green algal species were consistent with results from 1984 and 1995. However, a significant increase in the blue-green algae *Aphanizomenon flos-aquae* since 1984 is a likely indication of advancing eutrophication.

Macrophytes (aquatic plants):
Results of a WA Dept of Ecology survey in 1999 indicate increasing dominance of the macrophyte community by *Egeria densa*, an aggressive exotic species. Since 1984, *Egeria densa* has largely displaced more desirable native species in the shallow-water areas.

Trophic state:
A Trophic State Index (TSI) is used to describe the level of algae production of a lake. The index uses a numbered scale to compare variables with one another, or with a reference number. Thus indices provide a "common currency" with which to describe lake conditions. A TSI value <40 = oligotrophic, 40-50 = mesotrophic, 50-70 = eutrophic, and >70 = hypereutrophic.

Median monthly TSI values (May-October 2003) for secchi transparency (53), total phosphorus (51), chlorophyll-*a* (51), and phytoplankton (63) all indicate that Lacamas Lake is eutrophic. Total phosphorus is the only TSI indicator that suggests a possible decrease in trophic status since 1984. There has been no significant change in the median value for other TSI indicators, though individual TSI values for Secchi disk and TP periodically dip into the upper-mesotrophic range.

Conclusions

All of the measurements and indicators utilized in this report suggest that Lacamas Lake remains eutrophic. A few indicators suggest that eutrophication may in fact be increasing.

Total phosphorus concentrations in the creek and lake are much lower today than when first measured in the 1970s and 1980s. Despite this improvement, Trophic State Index values for secchi disk, total phosphorus, chlorophyll-a, and phytoplankton have remained relatively constant since 1984, with annual median values falling consistently within the eutrophic range. The available data do not suggest an impending shift to a lower trophic state.

An increasing trend in total Kjeldahl nitrogen since 1991 may be an indication of continuing or accelerating eutrophication despite past reductions in phosphorus. Additionally, continued high levels of algal production and an apparent increase in the blue-green species *Aphanizomenon flos-aquae* suggest that the level of eutrophication is stable at best and possibly increasing.

The water quality issues first noted in the 1970s and 1980s continue to threaten the beneficial uses of Lacamas Lake. In particular, the combination of severe hypolimnetic dissolved oxygen depletion and high surface water temperatures during the summer, high algal productivity dominated by blue-green species during mid-late summer, and the continued expansion of the exotic macrophyte *Elodea densa* pose significant challenges to the primary beneficial uses of fishing, swimming, and boating.

In assessing the long-term information available for Lacamas Lake, it appears that early efforts in the watershed successfully decreased phosphorus inputs. Although these reductions were not sufficient to bring about an improvement in overall lake conditions, they appear to have slowed or even temporarily halted the rapid advance of eutrophication. The long-term dataset suggests that lake conditions, though still eutrophic, have remained relatively stable since the early 1990s. However, some current data raises concerns that Lacamas Lake may be sliding toward further eutrophication and increased water quality problems.

Given the already significant extent of eutrophication, further nutrient enrichment and the associated water quality degradation it causes has the potential to seriously impact future beneficial uses of Lacamas Lake.

Current monitoring results and trend analyses support the premise put forth by E&S Environmental Chemistry, Inc (1998) and Clark County Water Resources (Schnabel 2002), that future Lacamas Lake management efforts should focus not on returning the lake to a pristine state but rather on protecting and enhancing current beneficial uses and minimizing further degradation.

The Lacamas watershed has been and will continue to be impacted by human activities. Despite past progress in controlling phosphorus pollution, historical and ongoing land use changes have permanently altered the lake and watershed in ways that render a return to pristine, pre-settlement conditions infeasible. In all likelihood, Lacamas Lake and its watershed will require diligent, ongoing management simply to maintain current beneficial uses such as fishing, boating, and aesthetic enjoyment, especially given increasing impacts from a growing population.

A renewed commitment by the public and local agencies, along with prudent lake and watershed management choices, is needed if Lacamas Lake and its watershed are to remain valuable community assets for future generations.

References

APHA (1992). *Standard Methods for the Examination of Water and Wastewater*, 18th ed.

Aquatic Analysts (2001). *Algal Analytical Procedures*. White Salmon, Washington.

Beak/SRI (1985). *Lacamas-Round Lake Diagnostic and Restoration Analysis Final Report.* Beak Consultants Incorporated and Scientific Resources Incorporated, Portland, Oregon.

Clark County Public Works, Water Resources Section. (June 2002). *Standard Procedures for Monitoring Activities*, Clark County Water Resources Section.

Gilbert, R.O. (1987). *Statistical Methods For Environmental Pollution Monitoring*. Van Nostrand Reinhold, New York.

Helsel, D.R. and Hirsch, R.M. (1993). *Statistical Methods In Water Resources.* Elsevier Science B. V. Amsterdam, The Netherlands.

Hutton, R. (2002). *Lacamas Lake Restoration Program Final Report*. Clark County Public Works, Vancouver, Washington.

Kleinbaum, D.G., Kupper, L.L., and Muller, K.E. (1988). *Applied Regression Analysis and Other Multivariate Methods*. PWS-KENT Publishing Co., Boston.

North Creek Analytical, Inc., 2001. Quality Assurance Manual, Beaverton, Revision 13.0. Beaverton, Oregon.

Raymond, R.B., J.M. Eilers, J.A. Bernert, and K.B. Vache' (1998). *Lacamas Lake Watershed Restoration Project Program Review*. E&S Environmental Chemistry, Inc., Corvallis, Oregon.

Schertz, T.L., Alexander, R.B., and Ohe, D.J. (1991). *The Computer Program ESTIMATE TREND (ESTREND), A System For The Detection Of Trends In Water-Quality Data*. U.S. Geological Survey, Reston, Virginia. U.S.G.S. Water-Resources Investigations Report 91-4040.

Schnabel, J.D. (2004, Draft). *Lacamas Lake Monitoring Project Quality Assurance Project Plan*. Clark County Public Works Water Resources, Vancouver, Washington.

Schnabel, J.D. (2002). *Lacamas Lake Restoration Program: WY200 and WY2001 Water Quality Monitoring.* Clark County Public Works, Vancouver, Washington.

Schnabel, J.D. and R. Hutton (1998). *Lacamas Lake Watershed Water Quality Monitoring Program Quality Assurance Project Plan*. Clark County Public Works, Vancouver, Washington.

Snohomish County (2003). *State of the Lakes Report*. Public Works, Surface Water Management.

Sweet, J. (2003). Aquatic Analysts, Inc. Personal communication.

Wetzel, R.G. (1983). *Limnology*. 2nd ed. Saunders College Publishing.

Appendix

<u>Data Analysis Procedures</u>

Loading estimates

Annual loading estimates for TP and TSS in WY2002 and WY2003 were calculated according to the method described in Lacamas Lake Restoration Program: WY2000 and WY2001 Monitoring (Schnabel, 2002). Individual TP and TSS grab sample concentrations were combined with the hourly discharge dataset. Each grab sample result was assumed to represent the constituent concentration in the stream until the time of the next sample collection. Using hourly discharge totals and the concurrent TP or TSS concentration, individual loads (in kg) were calculated for each 1-hr period and summed to provide an estimate of annual load.

Discharge data was not available at the outlet of Lacamas Lake (station LACL00). As a result, out-load calculations were based on the discharge dataset from the lake inlet (station LAC050). However, dam operations, fluctuating lake storage, and the effect of Dwyer Creek inflow below station LAC050 all result in differences in the instantaneous discharge at the two stations. Over the course of a year the effect of these fluctuations is assumed to be negligible, but outload estimates should be interpreted with caution as the true instantaneous discharge is unknown.

Box-and-whisker plots

Box-and-whisker plots, or box-plots, allow convenient comparison of central tendency and distribution characteristics such as medians, ranges or dispersion, symmetry, and extreme values. The horizontal line within each box depicts the median value of the data set. The upper and lower edges of the outer (light gray) box depict the 75th and 25th percentiles while the distance between them is the interquartile range (IQR) or the middle 50% of values. The inner (dark gray) box that extends within and often beyond the ends of the IQR represents the 95% confidence interval around the median (e.g. there is a 95% probability that the true median lies somewhere within this range). Vertical lines or whiskers extending from the ends of the inner box include all values that are less than 1.5 times the IQR. Finally, asterisks appear for extreme values or outliers that are more than 1.5 times the IQR from the box.

Differences between medians are statistically significant at the 95% confidence level only if the inner (dark gray) boxes do not overlap. If the data are symmetrically distributed the median will lie near the center of the box-plot and the whiskers will be of similar length. High variability in the data is reflected by a large IQR. The statistical software package MINITAB (MINITAB, 2003 [Release 14]) was used to construct the box-plots.

Annual box-plots of growing season data (May-October) were constructed to highlight both inter-annual changes and potential patterns in nutrients and trophic state index values.

Trends

Both Lacamas Lake and Lacamas Creek water quality were evaluated for trends over time. Initially, exploratory data analysis was conducted using descriptive statistics, time series plots, and scatterplots to examine distributions, patterns in the data, and relationships between water quality parameters. The effects of seasonality and flow for Lacamas Creek data were addressed with the overall goal of reducing background variability and improving trend detection.

Lacamas Lake secchi disk depth, total phosphorus, and total Kjeldahl nitrogen values and Lacamas Creek total phosphorus and total suspended solids were analyzed for monotonic trends using the nonparametric Seasonal Kendall test. Statistical considerations (Helsel and Hirsch, 1993) supported the use of monotonic trend analysis (for trends are generally expected to indicate gradual and continuous changes over time). Step-trend analysis was not supported due to the relative continuity of the data and the absence of any definable event that may have dramatically changed overall water quality.

The analysis was limited to the periods of July 1991 through September 2003 for the lake data and October 1998 through September 2003 for the creek data due to the limited amount of earlier data and substantial gaps in the historical dataset.

Data transformation was not required because the nonparametric Seasonal Kendall test (used for both lake and creek trend analyses) has less restrictive distribution assumptions than comparable parametric approaches, the variability of the tested parameters was relatively constant over time, and the ratio of the smallest to largest data values was less than twenty (Gilbert, 1987).

Prior to trend analysis, censored data (values below reporting limits) were substituted with other values. Data sets containing less than 5% censored data and a single reporting limit had their censored data recoded as one-half of the reporting limit (Schertz, et al., 1991). For data sets with more than 5% censored data and multiple reporting limits, values reported as less than the most common reporting limit were entered as zero, while three censored values greater than the most common reporting limit were discarded.

Additional statistical techniques were needed to analyze Lacamas Creek data (station LAC050) for trends in TP and TSS concentrations. Natural, random fluctuations in an associated variable (X) such as flow often increase the variability of constituent concentrations due to the effects of dilution and surface wash-off or overland flow (Helsel and Hirsch, 1993). Statistical models such as regression or smoothing can help explain or account for the effects of flow, increasing the ability or power of the trend test to discern changes over time. As with the lake data, seasonal variation must also be compensated for in order to better discern trends.

Prior to testing for trends, applicable Lacamas Creek data were flow-adjusted by utilizing the smoothing technique LOWESS (Locally Weighted Scatter-plot Smoothing) to describe the relationship between Y (concentration) and X (flow). An f (fraction) value of 0.5 and two iterations for smoothing were utilized. This approach does not assume linearity or normality of residuals. Residuals, which express the differences between the fitted model $Y^{\wedge}$ and the actual Y values (concentrations), describe the variation in concentrations over and above that due to changes in X (flow). The assumption was made that there was no substantial trend or drift in flow over the monitoring period.

Both the Lacamas Lake and Creek data sets were reduced in order to maintain representativeness and minimize bias. In the few cases where multiple Lacamas Lake values existed for any particular month, the values were averaged to obtain a single monthly value. Because Lacamas Creek was often sampled more frequently during data gathering primarily for loading estimates, its data set was reduced by selecting the data point closest to the middle of each month over the five year monitoring period (Schertz, et al., 1991).

After the data were reduced, the Seasonal Kendall trend test was applied. The statistical test was applied directly to the monthly Lacamas Lake values. However, prior to performing the trend test, the applicable flow-adjusted Lacamas Creek values [residuals of the LOWESS model of Y (concentration) versus X (flow)] were transformed by adding the mean of the reduced data set to each flow adjusted value. Statistical significance is reported for tests at the 80, 90, and 95% confidence levels while the yearly rate of change in median values is expressed as a slope (WQSTAT PLUS, 1998).

Data sets were analyzed and results graphed utilizing the spreadsheet software EXCEL (Microsoft EXCEL 2002, 2002), statistical software (MINITAB release 14 for Windows, 2003), and the water quality statistical software WQSTAT PLUS (WQSTAT PLUS, 1998).

Trend power

The power of a trend test is the probability that the test will actually detect a trend where one is present. Therefore, an evaluation of the trend power provides insights into the limitations of conclusions reached using statistical tests. A failure to *detect* a trend is often used to improperly conclude that there *was no trend*, when in reality there may have simply been insufficient data or too much variance in the data to allow trend detection at the specified level of confidence (Hallock, 2003). An understanding of the smallest practical difference (versus actual statistical difference) in the means over time is also needed (Kleinbaum, et al., 1988).

Estimates of minimum detectable trends for each parameter over the monitoring period were derived from chosen levels of acceptable errors and other calculations. First, acceptable probabilities for alpha (Type I error) and Beta (Type II error) were set at 10%. Estimates were then made of the central tendencies of the original data (mean and median). The standard deviation was calculated after de-seasonalizing (subtracting seasonal means from individual data points then adding back the overall mean) and de-trending the data (Sen's Slope estimator in WQStat Plus). A minimum *relative* detectable trend (delta value) was looked up (Hallock and Ehinger, 2003) for a given number of monthly values (sample size).

The *predicted* minimum detectable trend was then calculated from the above information and expressed as a percent of the change in the mean over the monitoring period. A correction factor (Hallock, 2003) was incorporated to address the non-normality typically found in water quality data. Finally, statistically calculated changes in the mean over the monitoring period were compared to the predicted minimum detectable trend to evaluate the reliability of the statistical test. If the absolute value of the calculated statistical trend is smaller than the predicted minimum detectable trends, the results of statistical tests may be suspect.

Trend power calculations for Lacamas Creek and Lacamas Lake are shown in the following table:

Methodology for Water Resources Trend Power Calculations

Adapted from Washington Department of Ecology's:
River and Stream Ambient Monitoring Report for Water Year 2002, Publication No. 03-03-032, June 2003,
Stream Ambient Water Quality Monitoring Quality Assurance Monitoring Plan (Draft), January 2003.

Assumptions:
Type 1 Error (alpha or significance level) = 0.1 (i.e., 10% probability of incorrectly deciding trend exists when in fact one does not.)
Type 2 Error (beta) = 0.1 (i.e., 10% probability of incorrectly deciding trend does not exists when one in fact does exist.)
Minimum Relative Detectable Trend (delta) for monthly data:
For n = 60 months or 5 years, delta = 1.33
For n = 120 months or 10 years, delta = 0.93
For n = 180 months or 15 years, delta = 0.76
For n = 240 months or 20 years, delta = 0.66

Usually preferable to use flow adjusted values for applicable data sets (if for example, less than 5% of the original data is censored).

Formulas:
Minimum change in the mean over some time period for normally distributed data:
Minimum change in the mean = total standard deviation of deseasonalized & detrended data * minimum relative detectable trend

Correction Factor (used by Washington State Department of Ecology):
CF=(1+(mean-median)/mean)**-6

Predicted Minimum Detectable Trends (MDT) for nonnormally distributed data (combination of above two formulas):
Predicted MDT expressed as a percent of change in the mean over some time period at given Type I and II Error rates.
PredMDT=(100/mean)*(Std Dev of Deseasonalized Detrended Data*Minimum Relative Detectable Trend)*(1+(mean-median)/mean)**-6

Lacamas Watershed Trend Power Calculations (Typical of Nonnormally Distributed Data):

Using **Lacamas Creek** at Goodwin Road monthly data for WY 1999 - 2003 (assuming Type 1 and 2 errors of 10%):

Parameter	Mean	Median	Standard Deviation of Deseasonalized & Detrended Data	Minimum Relative Detectable Trend (delta for 60 months)	Predicted Minimum Detectable Trend (% of change in mean over monitoring period)
Flow (cfs)	139.8	76.7	99.15	1.33	10.1
Flow Adjusted TP (mg/L)	0.038	0.034	0.019	1.33	36.5
Non-Flow-Adjusted TSS (mg/L)	5.542	5	6.78	1.33	93.0

Compared to Seasonal Kendall test and Slope Estimator for Trend calculated in WQSTAT PLUS for above parameters:

Parameter	Significant Trend (alpha=0.1)	Number Of Months (n)	Annual Trend Slope (units per year)	5 Year Change (units per 5 years)	Calculated Change in Mean Over 5 Years*
Flow (cfs)	Yes	60	-7.875	-39.375	-28.2%
Flow Adjusted TP (mg/L)	No	60	-0.0016	-0.008	-21.1%
Non-Flow-Adjusted TSS (mg/L)	Yes *	60	-0.1517	-0.7585	-13.7%

* Note:
Calculated trend for non-flow-adjusted TSS was statistically significant but was less than the predicted minimum detectable trend.
The magnitude of this trend is not reliable possibly due to highly censored and variable data and / or too short a monitoring period.

Using **Lacamas Lake** monthly data for WY 1991 - 2003 (assuming Type 1 and 2 errors of 10%):

Parameter	Mean	Median	Standard Deviation of Deseasonalized & Detrended Data	Minimum Relative Detectable Trend (delta for 120 months)	Predicted Minimum Detectable Trend (% of change in mean over monitoring period)
TKN (mg/L)	0.5694	0.5240	0.1947	0.93	20.1
TP (mg/L)	0.0367	0.0310	0.02729	0.93	29.0
Secchi (m)	1.5509	1.4440	0.5012	0.93	20.1

Compared to Seasonal Kendall test and Slope Estimator for Trend calculated in WQSTAT PLUS for above parameters:

Parameter	Significant Trend (alpha=0.1)	Number Of Months (n)	Annual Trend Slope (units per year)	Approximate 10 Year Change (units per 10 years)	Approximate Calculated Change in Mean Over 10 Years
TKN (mg/L)	Yes	102	0.0196	0.1956	34.4%
TP (mg/L)	No	102	-0.0002	-0.0017	-4.6%
Secchi (m)	No	91	-0.0049	-0.0493	-3.2%

Trophic state index
A Trophic State Index (TSI) is used to describe the level of production of a lake, or the amount of algal matter produced by photosynthesis in a lake (Carlson, 1981, Wetzel, 1983). The amount of algal matter has proven to be a reliable measure of the problems that typically plague lakes. An index generally uses a numbered scale to compare variables with one another, or with a reference number. Thus indices provide a "common currency" with which to describe lake conditions.

The terms oligotrophic, mesotrophic, and eutrophic are used to characterize lakes by a low, medium, and high amount of algae production, respectively. The TSI interprets measured indicators of algal biomass, and expresses the result on a numbered scale that is easy to understand, approximately from zero to one hundred. A single measurement of TSI does not imply whether a lake's health is deteriorating, nor does it imply where a lake *should be* in terms of the current health.

The following equations, taken from Carlson and Simpson, 1996, were used to calculate the TSI from chlorophyll-a , Secchi depth, and total phosphorus data. The equation calculating TSI from algal biovolume was provided by the consultant performing the algal counts (Jim Sweet, personal communication, December 2003):

- TSI(SD) = 60 - 14.41 ln(SD), where SD is Secchi depth in meters;
- TSI(CHL) = 9.81 ln(CHL) + 30.6, where CHL is chlorophyll-a in μg/L;
- TSI(TP) = 14.42 ln(TP) + 4.15, where TP is total phosphorus in μg/L;
- TSI (BV) = (Log-base 2 (B+1))*5, where B is the phytoplankton biovolume in cubic micrometers per milliliter, divided by 1000.

Quality Assurance/Quality Control Results

During WY2002 and WY2003, all of the scheduled lake nutrient samples, vertical lake profiles, and composite samples were collected. Inlet/outlet samples were collected at nearly the intended rates, with sampling intervals sometimes exceeding one week. A total of 215 inlet and 91 outlet samples were collected during the monitoring period, but fewer outlet samples were collected in WY2003 (38) than were anticipated (52).

Quality Control sample collection for WY2002 and WY2003 is shown in Table X. Note that QC collection targets were modified during late 2002 as part of a Water Resources QA review and update. WY2002 QC collection met targets for that time period, except for duplicate field samples at the inlet/outlet stations. During WY2003, duplicate field sample collection at the inlet/outlet stations again fell slightly short of targets, but all other QC sample collection met or exceeded targets.

Precision results for duplicate samples, duplicate measurements, and split samples are reported as pooled percent relative standard deviation (%RSD) in Table X. Target precision for each characteristic was 10% RSD, except for chlorophyll-*a* which had a target of 20% RSD.

Percent RSD calculations for chlorophyll-*a* included data from Battleground Lake and Vancouver Lake because only one duplicate pair was collected in Lacamas Lake. All other percent RSD values include only LLMP project duplicates.

Field QC sample type	WY2002 Collected	WY2003 Collected	WY2003 Target	Comment
Transfer blank	1	3	4	expanded in WY2003
Transport blank	0	1	1	added in WY2003
Duplicate field sample (lake)	12	7	6	reduced in WY2003
Duplicate field sample (inlet/outlet)	2	4	6	expanded in WY2003
Duplicate field measurement (lake)	2	6	6	expanded in WY2003
Field split sample (chlorophyll-*a*)	0	1	1	not applicable in WY2002

Table X. Field QC sample collection completeness.

Characteristic	Pooled %RSD	Characteristic	Pooled %RSD
Total Phosphorus (lake)	± 18%	Total Suspended Solids (lake)	± 8%
Total Phosphorus (inlet/outlet)	± 10%	Total Suspended Solids (inlet/outlet)	± 17%
Ortho-phosphorus	± 6%	Temperature	± 0.8%
Total Kjeldahl Nitrogen	± 21%	Dissolved Oxygen	± 12%
Nitrate/Nitrite-Nitrogen	± 8%	pH	± 5%
Ammonia-Nitrogen	± 13%	Conductivity	± 0.7%
Chlorophyll-a	± 38%		

Table X. Precision as pooled % relative standard deviation.

Six constituent categories failed to meet target criteria. However, in-lake or in-stream variability is included in the duplicate field samples and duplicate field measurements, so their variability is not solely a measure of sampling error plus analytical error. Allowing for expected natural variability, %RSD results were acceptable for all characteristics except chlorophyll-*a*.

The split field samples collected for chlorophyll-*a* measure variability from sampling error plus analytical error, and do not include in-lake variability. The 38% RSD for chlorophyll-*a* was nearly twice the target level and is addressed in the issues section below.

The expected results of the analyses of blank samples were "below reporting limit" for all measured characteristics. With one exception, all results for blank samples met expectations. The total phosphorus transport blank was reported at 0.241 mg/L and is discussed below.

Review of stage measurement comparisons and the stage-discharge relationship versus manual measurements indicated good agreement.

Laboratory staff assessed the laboratory QA program through review of laboratory quality control results including check standards, matrix spikes, and laboratory blanks. Results were within acceptable ranges as defined in NCA's quality assurance manual or were coded as necessary on laboratory reports.

Quality Assurance Issues

1) 117 of 432 lake nutrient results (27%) were below laboratory reporting limits, primarily ammonia (35 results), total suspended solids (27 results), and ortho-phosphorus (24 results).

Large numbers of results reported as non-detects can complicate data analysis and may limit the usefulness of a monitored characteristic. Ortho-phosphorus non-detects will not be addressed because results are expected to fall below reporting limits during summer. Ammonia concentrations are also expected to remain relatively low, but in response to the high rate of non-detects the laboratory reporting procedure has been modified. Ammonia results below the reporting limit but above the method detection limit (MDL) will be reported and flagged as an estimated value (J) rather than ND. Total suspended solids analysis will be replaced by turbidity measurements in future Lacamas Lake sampling. Turbidity data provide a useful measure of water clarity and will reflect the presence of suspended colloidal material (very fine sediment) more effectively than TSS.

2) Chlorophyll-a results from WY2003 did not meet measurement quality objectives for precision. Comparison with pheophytin concentrations and other results indicate that samples may have been unintentionally degraded during storage, preparation, or analysis. One clearly suspect chl-a value from 6/12/03 has been excluded from the dataset. The remaining five values from WY2003 are utilized in this report, but the reader should note the poor data precision and the probability that reported chl-a values are lower than the true value. Based on WY2003 results, Water Resources may utilize a different laboratory for future chlorophyll-*a* analyses.

3) The high transport blank TP result suggests that sample contamination occurred during field processing or during laboratory analysis. A specific cause was not apparent. Possible sources of this error could include contamination during bottle prep (e.g. phosphorus soap), sample switching at the laboratory, contamination during the analytical procedures, or data entry error at the laboratory. The abnormal result was brought to the attention of the contracted laboratory.