WATER QUALITY STATUS AND TRENDS IN THE CLARK FORK-PEND OREILLE WATERSHED

Trends Analysis from 1984-2002

Prepared for:

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1.0 INTRODUCTION

1.1 Background

Historic water quality monitoring was conducted in the Clark Fork mainstem and tributaries from 1984-1994. Data collected by the Montana Department of Environmental Quality (formerly MDHES) included nutrients from approximately 63 locations, including point source discharges (MDHES 1992). A statistical study of this baseline data resulted in the design of a monitoring program implemented by the Tri-State Water Quality Council in 1998 (Land & Water 1995). Water quality and algae sampling was conducted at 27 stations located along the Clark Fork River and tributary streams in Montana and Idaho, at two stations on the Pend Oreille River in Washington and at five stations located in Pend Oreille Lake in Idaho (**Appendix A, Figures 3 and 5**). Of the 27 Clark Fork River stations, five mainstem stations were selected for more intensive summer nutrient monitoring, and seven were sampled for algae (**Appendix A, Figures 4 and 5**). The Pend Oreille Lake stations were sampled for algal constituents only. The Pend Oreille River stations were sampled for water quality constituents only.

Water chemistry constituents monitored by the Tri-State Water Quality Council included four nutrient constituents and two total recoverable metals:

- Total nitrogen (TN) (mg/L)
- Total soluble inorganic nitrogen (TSIN) (mg/L)
- Soluble reactive phosphate (SRP) (mg/L)
- Total phosphorous (TP) (mg/L)
- Copper (Cu) (mg/L)
- Zinc (Zn) (mg/L)

Clark Fork River stations were monitored for nitrate + nitrite - nitrogen (NO_2NO_3) (mg/L), ammonia - nitrogen (NH_4) (mg/L), and total Kjeldahl nitrogen (TKN) (mg/L). The total nitrogen and Total soluble inorganic nitrogen values were derived as follows:

$$\mathrm{TN} = \mathrm{NO_2NO_3} + \mathrm{TKN} \qquad \mathrm{TSIN} = \mathrm{NO_2NO_3} + \mathrm{NH_4}$$

Algal constituents included:

- Chlorophyll A (Chl A) (mg/m^2)
- Ash free dry weight (AFDW) (g/m^2)
- Secchi disk (m) (*Lake Pend Oreille only*)

In addition, the Clark Fork River stations were monitored for field constituents including:

- Water temperature (°C)
- pH (standard units)
- Dissolved oxygen (DO) (mg/L)
- Conductivity (µS/cm)
- Total dissolved solids (TDS) (mg/L)
- Turbidity (NTU)

This report provides an analysis of water quality and algae data collected during period of record from 1984 to 2002. This study includes analysis of trends in water quality, spatial differences between stations, and attainment of targets as defined in the Tri-State Water Quality Council monitoring plan.

1.2 Monitoring Objectives

Analysis of approximately 10 years of historical nutrient and periphyton data for the watershed provided statistical design criteria for the monitoring program (Land & Water 1995). Sampling frequencies and locations were optimized to maximize information for watershed management decision making while minimizing monitoring costs. The locations selected for monitoring provide distributed spatial coverage for nonpoint assessment, serve as reference points above and below major communities, and offer limited information about input from tributaries. Individual management-monitoring goals are outlined with applicable statistical criteria in the following sections.

Six priority water quality monitoring objectives were defined for the Clark Fork-Pend Oreille Watershed. These include 1) trend detection of nutrient concentrations in tributaries and mainstem of the Clark Fork River, 2) assessment of trends in periphyton in the Clark Fork mainstem, 3) assessment of compliance with mid-summer nutrient targets for the Clark Fork, 4) estimation of nutrient loads to Lake Pend Oreille, 5) assessment of trends in periphyton in the Lake Pend Oreille nearshore, and 6) trend analysis of Secchi disk transparency in Lake Pend Oreille.

1.2.1 Clark Fork and Pend Oreille Rivers, Nutrient Trend Detection

MANAGEMENT GOAL:	Improve water quality
MONITORING GOAL:	Detect significant trends in nutrient concentrations
DEFINITION OF WATER QUALITY:	TP, TN, SRP, TSIN concentrations
DEFINITION OF TREND:	50% change in 10 year period at 95% confidence level, 90% power or 40% change at 90% C.L., 80% power
STATISTICAL METHODOLOGY:	Seasonal Kendall with Sen slope estimate
STATISTICAL HYPOTHESIS:	Ho: No trend exists; Ha: Trend exists
DATA ANALYSIS RESULT:	Conclusions regarding presence of trends Provide estimate of trend magnitude
INFORMATION PRODUCT:	Management goal met when no trend exists, or indicates improvement

1.2.2 Clark Fork River, Nuisance Algae

MANAGEMENT GOAL:	Control Nuisance Algae
MONITORING GOAL:	Detect significant trends in attached algae
DEFINITION OF WATER QUALITY:	Chlorophyll A (mg/m2)/ Ash Free Dry Weight (g/m2)
DEFINITION OF TREND:	35% change in 10 years at 90% C.L., 80% Power, for annual, 50% change at 90% C.L., 80% power
STATISTICAL METHODOLOGY:	Kendall with Sen slope estimate
STATISTICAL HYPOTHESIS:	Ho: No trend exists; Ha: Trend exists
DATA ANALYSIS RESULT:	Conclusions regarding presence of trends Provide estimate of trend magnitude
INFORMATION PRODUCT:	Management goal met when slope indicates improvement

1.2.3 Clark Fork River, Instream Nutrient Targets

Management Goal:	Achieve Instream Nutrient Targets
Monitoring Goal:	Evaluate excursions of summer nutrient concentrations
Definition of Nutrient Targets:	20-39 *u*g/l TP, 300 *u*g/l TN, SRP 6 *u*g/l, TSIN 30 *u*g/l
Statistical Methodology:	Excursion Analysis, 95% below target/year, 95% C.L.
Statistical Hypothesis:	Ho: Proportion <= .05; Ha: Proportion > .05
Data Analysis Result:	Conclusions regarding achievement of targets
Information Product:	Management goal met when target achieved or exceeded

1.2.4 Lake Pend Oreille, Algal Standing Crop

Management Goal:	Maintain or reduce standing algal crop
Monitoring Goal:	Detect significant trends in attached algal biomass
Definition of Water Quality:	Chlorophyll A/Ash free dry weight on natural substrate, midsummer
Definition of Trend:	50% change in 10 year period at 90% C.L., 90% power
Statistical Methodology:	Kendall's tau with Sen slope estimate
Statistical Hypothesis:	Ho: No trend exists; Ha: Trend exists
Data Analysis Result:	Conclusions regarding presence of trends Provide estimate of trend magnitude
Information Product:	Management goal met when no trend exists, or indicates improvement

1.2.5 Lake Pend Oreille, Nutrient Loading

Management Goal:	Maintain or reduce nutrient loading to Lake P.O.
Monitoring Goal:	Detect signif. trends in nutrient loads at Cabinet Gorge
Definition of Water Quality:	TP, TN, SRP, TSIN loading
Definition of Trend:	20% change in 10 year period at 90% confidence
Statistical Methodology:	Kendall with Sen slope estimate
Statistical Hypothesis:	Ho: No trend exists; Ha: Trend Exists
Data Analysis Result:	Conclusions regarding presence of trends Provide estimate of trend magnitude
Information Product:	Management goal met when no trend exists, or indicates improvement

1.2.6 Lake Pend Oreille, Trophic Status

Management Goal:	Maintain Trophic Status
Monitoring Goal:	Detect significant trends in summer water clarity
Definition of Water Quality:	Secchi Disk transparency (depth in meters)
Definition of Trend:	30% change in 10 year period at 95% C.L., 80% Power
Statistical Methodology:	Seasonal Kendall with Sen slope estimate
Statistical Hypothesis:	Ho: No trend exists; Ha: Trend exists
Data Analysis Result:	Conclusions regarding presence of trends Provide estimate of trend magnitude
Information Product:	Management goal met when no trend exists, or indicates improvement

It should be noted that statistical criteria were defined to demonstrate the predicted statistical power of the monitoring network, but that statistical hypothesis testing generally is reported at more stringent 1% and 5% significance levels.

1.3 Sampling Methods

1.3.1 Field Constituents – Clark Fork and Pend Oreille Rivers

Field constituents on the Clark Fork and Pend Oreille Rivers, including water temperature (˚C), dissolved oxygen (mg/l), pH (standard units), redox (mv), conductivity (µs/cm), and total dissolved solids (mg/l), were collected using a hand-held water quality probe. Turbidity (NTU) data was collected using a portable turbidimeter.

1.3.2 Nutrients and Metals – Clark Fork and Pend Oreille Rivers

Water samples for total phosphorus (TP), total Kjeldahl nitrogen (TKN), nitrate plus nitrite-nitrogen (NO_2NO_3), total ammonia-nitrogen (NH_4), soluble reactive phosphorus (SRP), total recoverable copper (Cu), and total recoverable zinc (Zn) were collected using a grab sampling technique by wading in a well-mixed portion of the river. Samples were taken in the upstream direction to avoid entrainment of sediment disturbed by wading.

Water samples for TP, TKN, Cu, and Zn were collected directly in acid washed, wide-mouthed polyethylene bottles. Bottles are rinsed twice with native water (or filtered native water) prior to sampling. During sampling, the sample bottle opening should face upstream and should be drawn through the water column once, carefully avoiding disturbance of bottom sediments. Samples are acidified to a pH of less than 2 by adding concentrated sulfuric acid (H_2SO_4) for nutrient samples and concentrated nitric acid (HNO_3) for metal samples.

Water for soluble nitrogen constituents (NO_2NO_3 and NH_4) were filtered in the field through a 0.45 µm filter into acid-washed polyethylene bottles. A small volume of filtrate (30-50 ml) is discarded before the sample is collected. Nutrient samples (NO_2NO_3 and NH_4) are acidified to a pH of less than 2 with concentrated sulfuric acid. Soluble reactive phosphorus (SRP) samples were filtered into polyethylene bottles, but are not preserved. SRP samples are cooled to 4°C or less, or frozen.

Samples must be clearly labeled with a waterproof marker or pre-printed labels. Label information must include the site identification number, date and time, sample type, preservative, and sampler's initials. Each bottle must be entered onto the chain-of-custody form before leaving the site. All samples are stored in coolers and chilled to 4°C or less (or frozen for SRP) for transport to the lab. A summary of sampling protocols is provided in **Table 1**.

Table 1. ***Sampling Protocol***

Constituent	Sample Volume	Container	Preservation	Holding Time
TP and TKN	250 ml	Acid-washed polyethylene	Add H_2SO_4 to $pH<2$, cool to 4°C	28 days
Cu and Zn	250 ml	Acid-washed polyethylene	Add HNO_3 to $pH<2$	6 months
NO_2NO_3 and NH_4	250 ml	Acid-washed polyethylene	Filter, add H_2SO_4 to $pH<2$, cool to 4°C	28 days
SRP	250 ml	Acid-washed polyethylene	Filter, cool to 4°C or freeze	48 hours

Historic baseline data (1984-1997) was collected by Montana DEQ, and more recent (1998-2002) Tri-State data was collected by Land and Water Consulting. Sample locations and methodologies were consistent over the two periods. A change in protocol was initiated in October 1987 with field filtering (0.45 micron) for nutrients. Dissolved nutrient results for pre-October 1987 samples (Ortho-P, NO_2NO_3, and NH_4) were computed from raw, unfiltered samples.

1.3.3 Periphyton – Clark Fork River and Pend Oreille Lake

Two types of periphyton samples were collected: hoop samples (a bulk sampling method) and template samples (a rock scraping method). Hoop samples were collected for cladophora dominated sites (sites above Missoula) and templates were collected for diatom dominated sites (sites below Missoula). Periphyton samples on Pend Oreille Lake are taken using the template method. Both Chl A and AFDW were measured in hoop and template samples. River periphyton samples were collected on two separate sampling events in August and September to capture peak algae growth. Pend Oreille Lake periphyton samples are collected in September.

1.3.4 Secchi Disk – Pend Oreille Lake

For Secchi depth monitoring, a standard 20 cm Secchi disc was used. Secchi readings are taken on the side of the boat with the least amount of surface roughness. Water transparency is evaluated by lowering the Secchi disc over the side of a boat until the markings are no longer visible. The depth is read after the disc is lowered past the extinction point, and then raised until just visible. Depth is recorded in meters. The sampler should also note time of day, weather, water surface conditions, and any other variables that may affect the reading.

1.4 Analytical Methods

All nutrient and metals analyses are performed by a state-certified laboratory using standard methods. Periphyton analyses are performed by the University of Montana biology laboratory.

The analytical methods listed in **Table 2** represent standard accepted procedures. Details regarding these methods are not included in this document but are described in *Standard Methods for the Examination of Water and Wastewater, 20th Ed* (APHA 1999) and various EPA documents.

Table 2. *Analytical Methods and Detection Limits*

Analyte	Method	Detection Limit
Total Phosphorus (TP)	EPA 365.3	1 µg/l
Total Kjeldahl Nitrogen (TKN)	EPA 351.2	100 µg/l
Nitrate + Nitrite-Nitrogen (NO_2NO_3)	EPA 353.2	100 µg/l
Total Ammonia-Nitrogen (NH_4)	EPA 350.1	10 µg/l
Soluble Reactive Phosphorus (SRP)	EPA 365.3	1 µg/l
Total Recoverable Copper (Cu)	EPA 200.7	1 µg/l
Total Recoverable Zinc (Zn)	EPA 200.7	0.5 µg/l

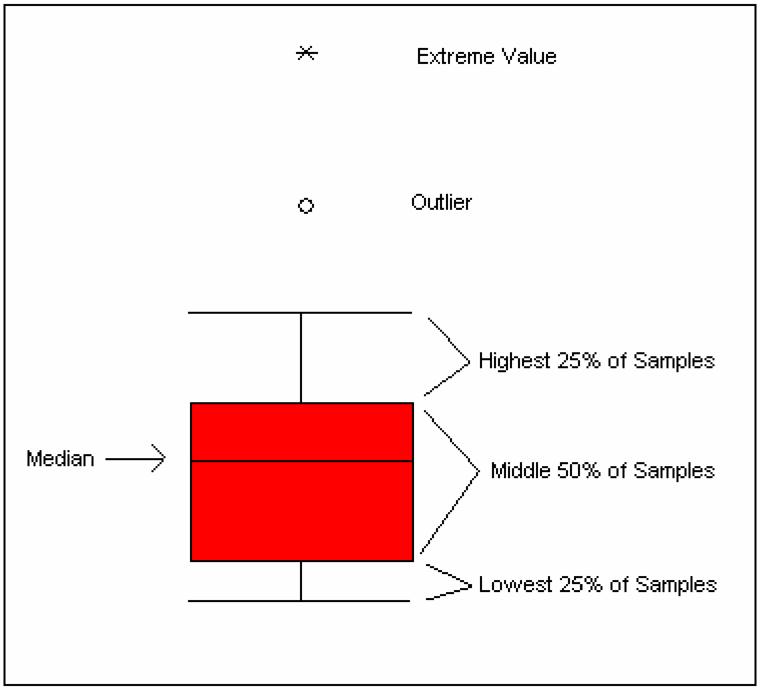
2.0 STATISTICAL METHODOLOGY

2.1 Spatial Analysis

This report includes summary statistics and boxplots for visual comparisons of water quality. Summary statistics include median, mean, minimum, maximum, standard deviation, and variance (**Appendix B**). Boxplots compare water quality and algae data from different monitoring station locations (i.e. spatial comparison) or at the same station for different sampling years (i.e. temporal comparison).

The shapes of the boxplots are based on median, quartile, and extreme values of the data. The box encloses the interquartile range, which contains 50% of the values. The median is displayed as the centerline of the box. The top and bottom whiskers display the maximum and minimum observed values, excluding outliers and extreme values. Outliers, defined as values which are 1.5 to 3 times outside of the interquartile range, are displayed as a circle (○). Extreme values, those more than 3 times outside of the interquartile range, are displayed with an asterisk (*). The boxplot is explained graphically in **Figure 1**.

Figure 1. Boxplot Construction



2.2 Temporal Analysis

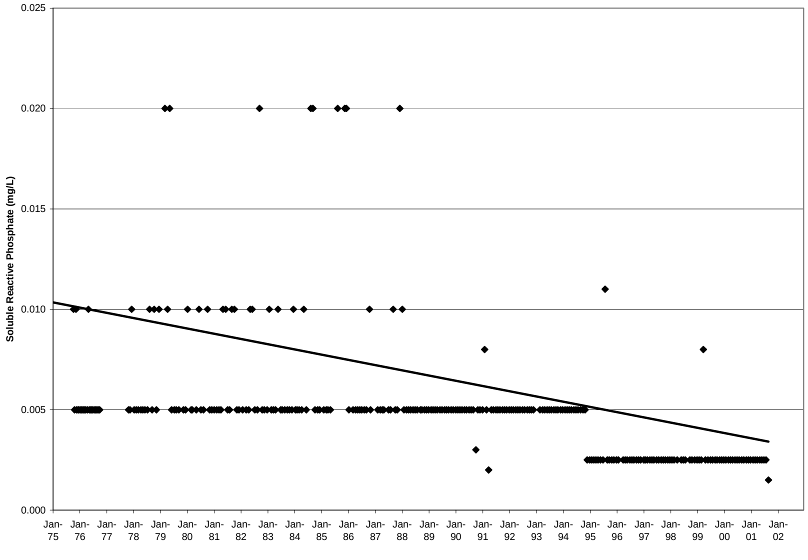
Trend evaluation was conducted on either raw or flow-adjusted/deseasonalized data as appropriate. Raw data were used when no significant flow or seasonal effects were present. Where concentrations were statistically related to discharge, interpretation of trends in water quality accounted for the effect of discharge by performing trend analysis on “flow-adjusted” concentrations. Concentration-discharge relationships were modeled with a power function $Y=aX^b$ for the majority of constituents. Flow-adjusted concentrations are derived from the unstandardized residuals of the regression of concentration on discharge, and trend analysis is performed on the residuals.

Since discharge is related to season, deseasonalizing data can be a substitute for flow adjustment. Deseasonalization can be accomplished by subtracting seasonal (quarterly or monthly) means from the concentrations. One advantage of deseasonalization is simplicity; estimation of a concentration-discharge model is unnecessary. However, significant seasonal effects unrelated to flow can remain in raw data, or on occasion, the flow adjusted data series. The seasonal Kendall test for trend was employed where seasonality was present.

A least-squares regression of concentration on time is suitable if data are normal, independent, and not autocorrelated. For non-normal, seasonal data, the Seasonal Kendall trend test with a Sen slope estimate is performed. This study relied on Kendall or seasonal Kendall tests for trend. For periphyton data that do not meet assumptions of normality but are not seasonal, Kendall's Tau-b is used. Examples and explanations of the Seasonal Kendall test and Sen slope estimate are found in Hirsch et al. 1982, Smith et al. 1982, Gilbert 1987 and Hirsch et al. 1991.

Large proportions of non-detect values make slope estimates approximate, thus if more than 25% of the values are below detection, slope should be interpreted with caution. With the exception of Washington data, detection limits were consistent over the course of the study. Laboratory detection limits were reduced in 1999 for total phosphorus and soluble reactive phosphate at the Pend Oreille River sites. Because of the high number of samples below detection, the reduction in detection limits can yield a statistically significant decreasing trend, where no true trend exists. An example is shown in **Figure 2.**

Figure 2. Pend Oreille River at Newport – Soluble Reactive Phosphate



These nutrient trend analyses are intended to detect changes in underlying watershed process and nutrient sources (exclusive of trends in flow or loading). It should be recognized that trends in flow alone can result in increasing nutrients concentrations/loads in a receiving waterbody. From a biological standpoint, particularly for a receiving waterbody such as Lake Pend Oreille, trends in watershed nutrient sources and loading are both of interest. Both trends in concentration and loading were evaluated in this case.

Autocorrelation or serial dependence is the tendency for sequential values to be related to each other (e.g. high values tend to follow high values). Some degree of autocorrelation is frequently found in water quality time series. Autocorrelation tends to occur more frequently when data are collected at higher intensities (e.g. daily or weekly) than with lower intensity sampling. The effect of autocorrelation is to inflate the reported statistical significance of trend tests, and increase the probability of falsely detecting trends when in fact no trend may exist. Autocorrelation and serial independence are challenging to address, since sequentially correlated results can be related to underlying trends, seasonality, flow effects, and other factors. Averaging values into monthly means ("collapsing" the dataset) can help reduce autocorrelation effects, though the reduction in sample size reduces statistical power of the test. Statistical tests and procedures that make corrections for autocorrelation also exist. Autocorrelation issues are not limited to time series data and can also exist spatially (e.g. replicate algae measures).

3.0 WATER QUALITY ANALYSIS

The spatial distribution of nutrient, metals, and field constituent results in the Clark Fork-Pend Oreille watershed has been extensively documented in previous Tri-State Water Quality Council reports (Land & Water 1995, 2002). The spatial distribution has been consistent for most water quality constituents over time. Spatial differences will not be addressed in detail; instead the reader is referred to previous reports.

3.1 Nutrient and Metals Spatial Comparisons

Boxplots provide a visual comparison of water quality for pooled data from 1984 through 2002 (**Appendix C**). For boxplot presentations, stations were ordered (left to right) in the downstream direction. Summary statistics are provided in **Appendix B**. The following discussion presents median values for the entire period of record (1984-2002).

Total Phosphorus

Total phosphorus (TP) generally decreases from the headwaters of the Clark Fork River to the confluence with Lake Pend Oreille. The spatial distribution of TP is controlled by three principle factors, including streamflow, point sources, and geology.

In the headwaters, nutrient loading from the Butte Wastewater Treatment Plant and natural sources (Phosphoria and other local formations) are large relative to watershed area and streamflows. These proportionately large sources result in elevated concentrations. Elevated sediment in the headwaters also influences TP concentration.

In the central portion of the watershed, point sources, including the Missoula Wastewater Treatment plant, have a notable influence on phosphorus. However, average river discharge increases in the downstream direction, and although peak flows tend to result in elevated TP, the greater average discharge tends to result in a dilution effect relative to source areas. Geological sources of phosphorus decrease because tributaries are dominantly of Belt formation meta-sediment geology which is inherently low in phosphorus.

In the lower reaches of the Clark Fork River, phosphorus concentrations are relatively low due to the large discharge, low phosphorus contribution from tributaries with forested Belt geology, and the influence of impoundments at Thompson Falls and Cabinet Gorge. Although low in phosphorus concentration, the large inflow of the Flathead River contributes a significant load of phosphorus and flow to the Clark Fork mainstem.

Soluble reactive phosphorus (SRP) concentration tends to follow the same pattern as TP, with localized increases below the cities of Deer Lodge and Missoula. Inputs from tributaries influence mainstem concentrations (e.g. Little Blackfoot River and Flint Creek). Concentrations below the detection limit (0.001 mg/L) occur in the Clark Fork River above Thompson Falls and below Cabinet Gorge Dam. Lack of contributing sources and biological uptake within the reservoirs explain these low values.

Total Nitrogen
Total nitrogen (TN) and total soluble inorganic nitrogen (TSIN) generally decrease from the headwaters of the Clark Fork River to the confluence with Lake Pend Oreille. The spatial distribution of TN is controlled by four principle factors: streamflow, nonpoint sources, point sources, and geology.

Nutrient loading from the Butte Wastewater Treatment Plant and low stream baseflows result in high concentrations of TN and TSIN in the headwaters. Nonpoint sources are also present in tributaries that drain agricultural areas (e.g. Flint Creek).

In the central portion of the watershed, point sources, including Deer Lodge and the Missoula Wastewater Treatment plant, have a notable influence on nitrogen. Nonpoint sources may also play a role in elevated nitrogen in the agricultural areas of the Deer Lodge valley.

In the lower reaches of the Clark Fork River, TN and TSIN concentrations are relatively low due to the large discharge, and low nitrogen loading from tributaries. Impoundment at Thompson Falls/Noxon appear to result in a small but consistent increase in TSIN, possibly due to nitrogen fixation. The Flathead River is low in TN and TSIN concentrations, although tributaries of the Flathead River (Little Bitterroot, Crow, Mission Creeks) have high concentrations of nitrogen.

3.2 Total Recoverable Metals Spatial Comparison

Total Recoverable Copper
Median total recoverable copper concentrations were highest in the upper watershed (Silver Bow Creek at Opportunity) and remain elevated in the Clark Fork River above the Little Blackfoot River. From this point, concentrations decrease steadily downstream. The three Clark Fork River sites below Thompson Falls had median concentrations below detection (0.001 mg/L).

Total Recoverable Zinc

Median concentrations of total recoverable zinc fluctuated significantly throughout the upper and middle watershed. Median concentrations were highest in Silver Bow Creek at Opportunity (0.302 mg/L) and remain elevated until a point above Missoula, below which the Blackfoot and Bitterroot Rivers dilute the concentration. Median concentrations at the four mainstem sites below the confluence of the Flathead River were below detection limits (0.0005 mg/L).

3.3 Field Constituents Spatial Comparison

Box plots showing the spatial distribution of field constituents are found in **Appendix C**. The spatial distribution of pH, conductivity, D.O., and turbidity has been consistent throughout the sampling period, and has been documented extensively in previous Tri-State monitoring reports (Land & Water 2002). Field constituents were not analyzed for trends.

3.4 Basin-wide Trend Analysis for Nutrients and Metals

One of the principal objectives of the Tri-State Water Quality Monitoring Program is to evaluate trends in nutrient concentration in the Clark Fork-Pend Oreille watershed. Baseline data collected by MDHES from 1984 to 1994, and Tri-State data collected from 1998-2002 provides a significant body of data to evaluate long term temporal trends.

Trend analysis was undertaken for nutrients and metals to evaluate whether statistically significant trends were present at network monitoring stations. As discussed in the statistical methodology section, concentrations for constituents were adjusted for flow effects or seasonality prior to performing trend analyses. Raw data were used when no significant flow or seasonal effects were present.

Approximately 42% to 63% of station/constituent combinations showed statistically significant correlations to flow (**Table 3**). For those constituents with statistically significant concentration/flow correlations, the raw data was adjusted for the effect of flow. In general, total phosphorus, total nitrogen, total copper, total zinc, and soluble reactive phosphorus were positively correlated to flow. Total soluble inorganic nitrogen was usually negatively correlated to flow. This result can be expected because soluble nitrogen may be more common in groundwater sources, producing higher concentrations of soluble nitrogen at low flows, and a dilution effect as flows increase.

Table 3. ***Number of Stations with Statistically Significant Constituent/Flow Correlations***

Constituent	Positive (+)	Negative (-)	% of Stations Significant
Total			
Total P	21	0	63%
Total N	13	4	52%
Total Cu	20	0	61%
Total Zn	14	0	42%
Dissolved			
TSIN	3	11	42%
SRP	14	2	48%
Flow (vs. Time)	3	9	36%

Nine stations showed statistically significant decreasing flows, and three stations showed increasing flows over the monitoring period. Stations displaying a decreasing trend in flow include Silver Bow Creek sites above Butte WWTP and at Opportunity, AMC Pond Discharge, Mission Creek, and Clark Fork River sites at Deer Lodge, above the Little Blackfoot, at Bonita, below Missoula, and at Huson. Drought conditions throughout the watershed have existed for the last several years of the sampling period. This may explain the decreasing trend in flow at these stations. Stations displaying an increasing trend in flow include Mill-Willow Bypass, Warm Springs Cr., and the Little Bitterroot River. Flow, although often thought to be an entirely natural phenomenon, has been altered by management activities within the watershed. A water lease agreement between Montana Trout Unlimited and BP/Arco has augmented flows into Warm Springs Creek in recent years, explaining the increasing trend in flow at Mill-Willow Bypass and Warm Springs Creek sites. Hydrographs (**Appendix D**) show variability of flow throughout the monitoring period. Sampling events are noted on the hydrographs.

Seasonality introduces variability that can limit the ability to detect trends in long term nutrient concentration. A large majority of total and soluble nutrient station/constituent combinations showed statistically significant seasonality (**Table 4**). Total copper and zinc showed seasonality for about one third of the sampling sites. A detailed table showing the matrix of datasets adjusted for flow, seasonality, or both is found as the first page of **Appendix E**. Deseasonalization was performed for constituents that showed seasonality but no correlation to flow. In some cases, seasonality was present in flow adjusted datasets. These datasets were also deseasonalized prior to performing trend analysis.

Table 4. ***Number of Stations with Statistically Significant Constituent/ Seasonality Correlations***

Constituent	Seasonality	% Stations Significant
Total		
Total P	27	79%
Total N	20	59%
Total Cu	12	35%
Total Zn	11	32%
Dissolved		
TSIN	31	91%
SRP	23	68%

A large number of statistically significant temporal trends were identified throughout the Clark Fork-Pend Oreille watershed. Significant temporal trends for each station/constituent combination (**Table 5**) reflect the combined results of raw, flow adjusted, and deseasonalized data series as appropriate. Plots for individual trend analyses show raw data, flow adjusted, and deseasonalized time series for all station/constituent combinations (**Appendix E**). The nonparametric Sen slope method provided a similar outcome as simple linear regression for detecting statistically significant trends, however, slope estimates would be expected to be less biased by outlier observations.

Table 5. ***Number of Statistically Significant Trends From 1984 to 2002***

	Positive (+)	**Negative (-)**	**% Total**
Total			
Total P	2	13	44%
Total N	0	15	44%
Total Cu	2	4	18%
Total Zn	1	6	21%
Dissolved			
TSIN	14	2	47%
SRP	2	17	56%

Trend analysis showed that flow tended to decrease over the monitoring period, especially at the upper river sites. Flow adjustment resulted in a net decrease in the number of statistically significant trends from those based upon raw data. Positive concentration/flow relationships and the tendency for drier years near the end of the sampling period explain this result.

Statistically significant trends included 78 station/constituent combinations for the period of record. Total phosphorus tended to show a decreasing trend at about 44% of sites, mainly in the upper river or immediately below Missoula. Total nitrogen also showed a decreasing trend at a similar number of sites distributed along the mainstem of the Clark Fork River.

SRP showed a decreasing trend at 57% of monitoring stations, and was associated with decreasing trends in total phosphorus. The only constituent which showed a tendency for increasing overall was TSIN (47% of stations).

A complete table of temporal trends is found in **Table 6**. Values in **bold** indicate a statistically significance trend. Negative slope values indicate decreasing trends, and positive slope values indicate increasing trends. The single “X” denotes that the value has been adjusted for seasonality, the effect of flow, or both.

Auto-correlation is present in the time series analyses to some degree. Tests of raw data (TN and TP) at stations up and downstream of Missoula and the subsets of summer data at the same stations were assessed for autocorrelation using simple linear regression and the Durbin Watson statistic (first order autocorrelation). These results showed minimum and maximum Durbin Watson values ranging from 1.56 to 2.29. This suggested that although some positive and (infrequent negative) autocorrelation is present, autocorrelation was not severe in the raw data sets. The effect of this tendency for positive autocorrelation is to inflate the number of statistically significant trends. It should be noted that Kendall and seasonal Kendall tests collapse the data into monthly means, and autocorrelation would be expected to be as significant an issue for monthly series.

These results suggested that overall water quality improved from 1984 to 2002 with respect to total nitrogen and phosphorus as well as total copper and zinc, but not for total soluble inorganic nitrogen, which may be the most limited constituent. Examples of such statistically significant trends, with the exception of total soluble inorganic nitrogen, is the Clark Fork at Deer Lodge station shown below (**Figures 3-8**), which illustrates a nutrient and metals time series typical of the Clark Fork River mainstem monitoring stations.

Table 6. ***Trends in Key Nutrients & Metals in the Waters of the Clark Fork/Pend Oreille Basin, from 1984 to 2002***

Sen's Slope Estimator - Slope in mg/L/Year													
Station	**Station Number**	**Total Phosphorus**		**Soluble Reactive Phosphate**		**Total Recoverable Copper**		**Total Recoverable Zinc**		**Total Nitrogen**		**Total Soluble Inorganic Nitrogen**	
SBC ab WWTP	00	**0.001**	X	**0.001**	X	**-0.007**	X	**-0.042**	X	-0.007	X	-0.003	X
SBC at Oppor	2.5	**0.007**	X	**0.007**	X	**-0.01**		**-0.028**	X	0.015	X	-0.01	X
AMC Pond	04	**-0.004**	X	**-0.001**	X	-0.001	X	**-0.004**	X	-0.004	X	-0.002	X
Mill-Willow	05	**-0.001**	X	**-0.0005**	X	0.0005	X	0.001	X	**-0.007**	X	-0.001	X
Warm Springs Cr	06	-0.0005	X	0.0005	X	0.0005	X	-0.0005	X	**-0.007**		-0.001	X
CFR bl Warm Springs	07	**-0.003**	X	**-0.001**	X	-0.001	X	**-0.003**	X	**-0.012**	X	**-0.003**	X
CFR at Deer Lodge	09	**-0.001**	X	**-0.0005**	X	**-0.002**	X	**-0.002**	X	**-0.009**	X	-0.003	X
CFR ab Ltl Blackfoot	10	**-0.002**	X	**-0.001**	X	-0.001	X	**-0.002**	X	**-0.01**	X	-0.001	X
Little Blackfoot River	10.2	-0.0005	X	-0.0005		**0.002**		0		-0.002		0.001	X
CFR at Gold Creek	11	**-0.001**	X	**-0.001**	X	**-0.001**	X	-0.001	X	**-0.008**	X	-0.001	X
Flint Creek	11.5	-0.0005	X	-0.001	X	0.003		0.004		-0.007		0.003	X
CFR at Bonita	12	-0.0005	X	**-0.001**	X	-0.0005	X	-0.0005	X	-0.003	X	0.0005	X
Rock Creek	12.5	-0.0005	X	-0.0005	X	0.0005	X	0		**-0.007**	X	0	X
CFR at Turah	13	-0.0005	X	**-0.001**	X	-0.0005	X	-0.0005	X	**-0.004**	X	0.0005	X
Blackfoot River	14	0.0005	X	-0.0005	X	0.0005	X	**0.0005**	X	-0.002	X	**0.001**	X
CFR ab Missoula	15.5	0.0005	X	-0.0005	X	0.0005	X	0.0005	X	**-0.006**	X	0.001	X
CFR bl Missoula	18	**-0.001**	X	**-0.002**	X	0.0005	X	0.0005	X	-0.002	X	**0.003**	X
Bitterroot River	19	-0.0005	X	**-0.0005**	X	0		0.0005	X	-0.002		**0.001**	X
CFR at Harper Br	20	**-0.0005**	X	**-0.001**	X	0.0005	X	0.0005	X	-0.003	X	**0.002**	X
CFR at Huson	22	**-0.001**	X	**-0.001**	X	-0.0005	X	0.0005	X	**-0.003**	X	**0.001**	X
Ninemile Creek	22.5	0.0005	X	0.0005	X	0		0		0.004	X	**0.002**	X
CFR ab Flathead	25	**-0.001**	X	**-0.0005**	X	-0.0005	X	0.0005	X	**-0.006**	X	**0.001**	X
Flathead River	26	-0.0005	X	0		-0.0005	X	0		-0.0005		**0.001**	X
Little Bitterroot Rv	26.6	0.002		**-0.003**	X	0.002		0.002		0.005	X	**0.002**	
Crow Creek	26.7	-0.001		-0.001		0.002		0		-0.002	X	0.006	X
Mission Creek	26.9	0.001		0.0005	X	**0.003**		0		0.004		0.002	X
CFR ab Thompson Falls	27	-0.0005	X	**-0.0005**	X	-0.0005	X	0.0005	X	**-0.003**	X	**0.002**	X
Thompson River	27.5	**-0.0005**	X	-0.0005	X	0		0		**-0.002**		0	
CFR bl Thompson Falls	28	-0.0005	X	**-0.0005**	X	-0.0005	X	-0.0005	X	-0.002	X	**0.001**	X
CFR at Noxon	29	**-0.0005**	X	-0.0005	X	-0.0005	X	0		-0.001		**0.002**	X
Bull River	29.5	-0.0005	X	0		0		0		0.001	X	**0.004**	X
CFR bl Cabinet Gorge	30	-0.0005	X	-0.0005	X	0		0		**-0.002**		**0.002**	X
POR at Newport	50	**-0.0005**		**-0.0005**						**-0.004**	X	**-0.002**	X
POR at Metaline Falls	55	0		0						-0.003		0	

Values in **Bold** indicate a significant temporal trend

Stations in **Bold** indicate sites with additional summer sampling

X - indicates that the value has been adjusted for seasonality, flow, or both

0 – indicates static trend or no trend

Figure 3. Clark Fork at Deer Lodge – Total Phosphorus

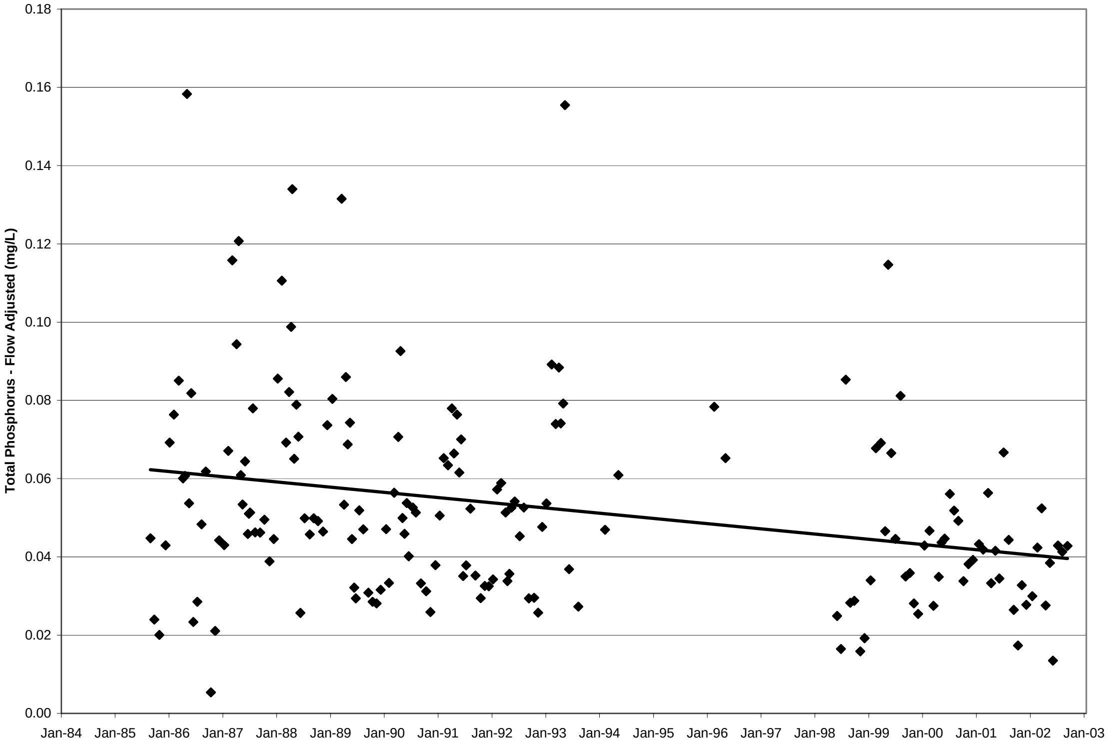


Figure 4. Clark Fork at Deer Lodge – Soluble Reactive Phosphate

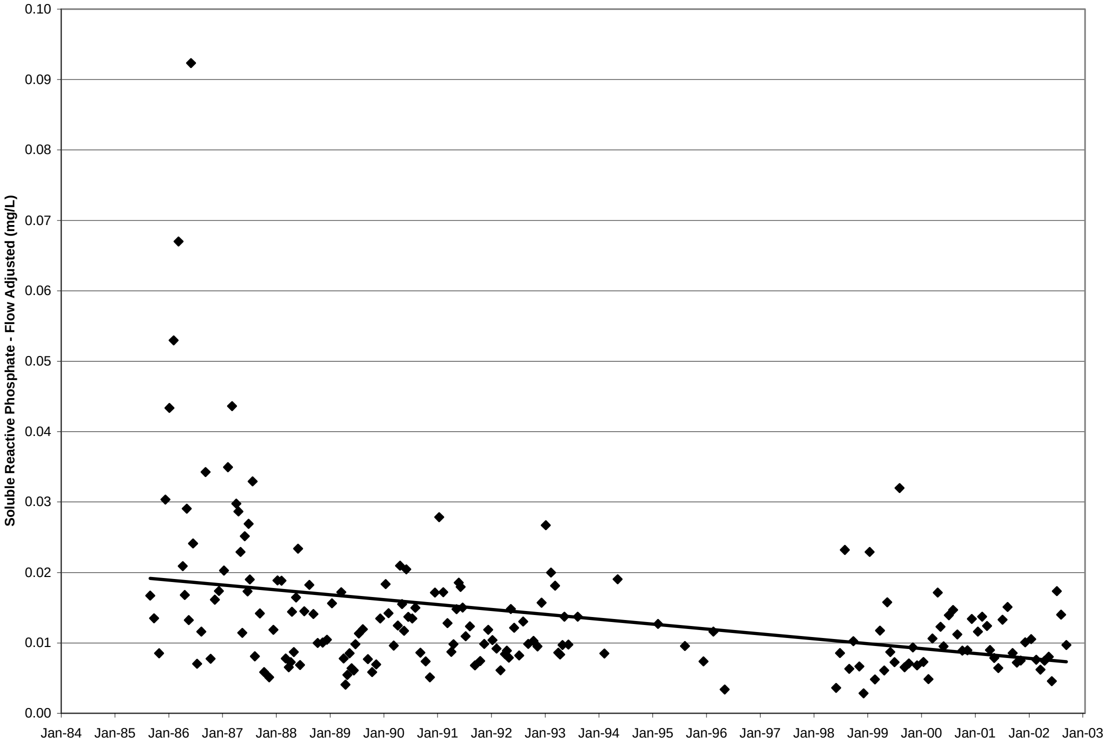


Figure 5. Clark Fork at Deer Lodge – Total Recoverable Copper

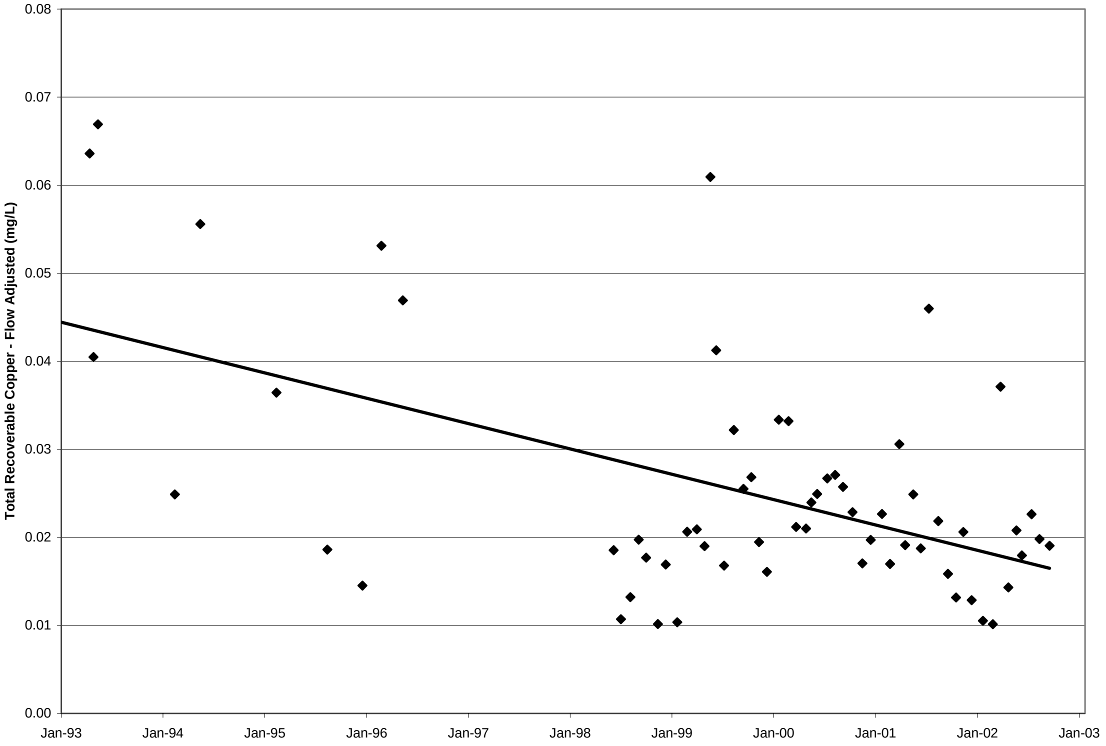


Figure 6. Clark Fork at Deer Lodge – Total Recoverable Zinc

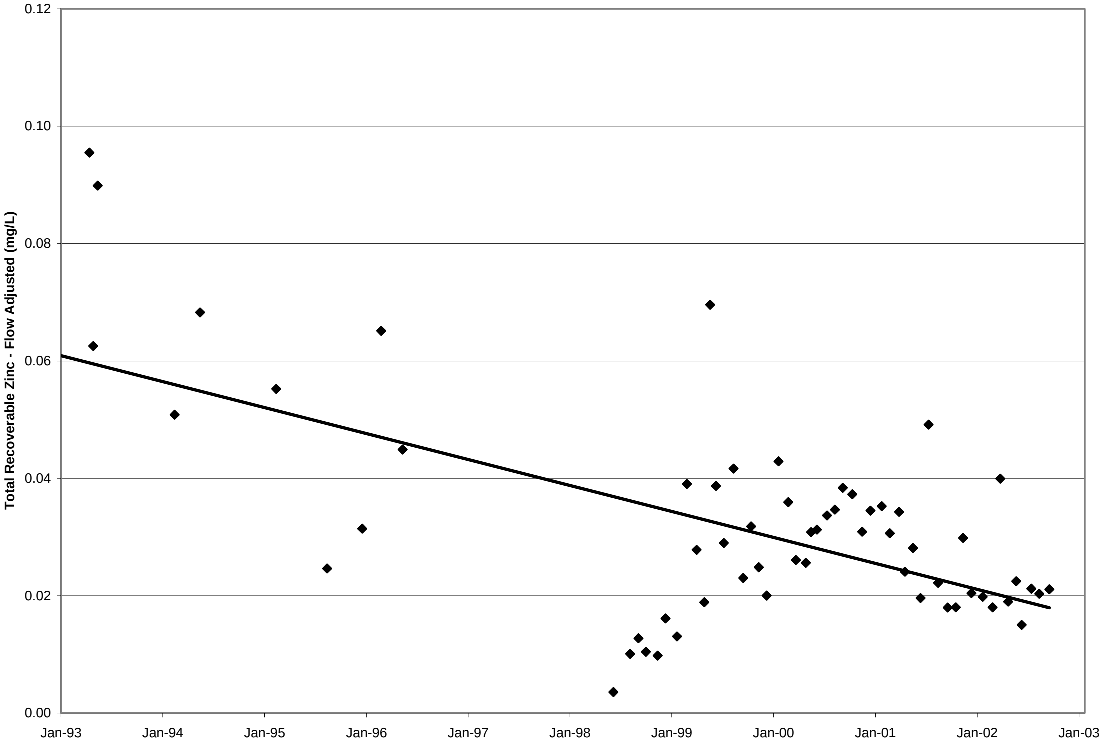


Figure 7. Clark Fork at Deer Lodge – Total Nitrogen

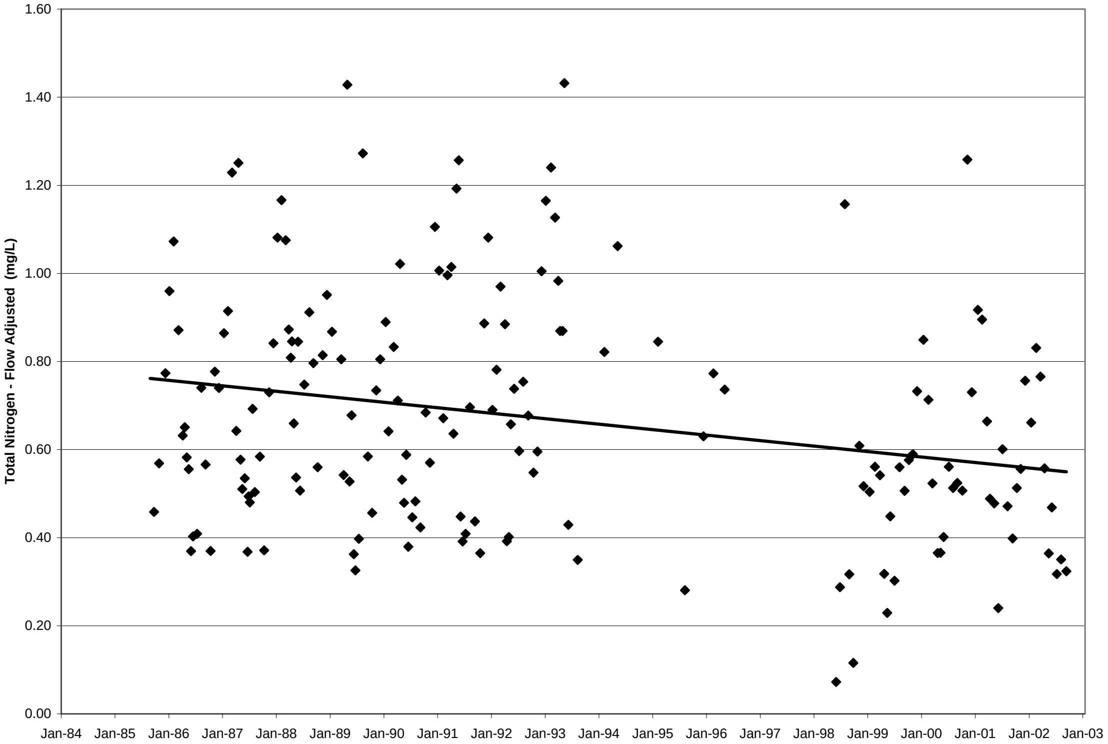
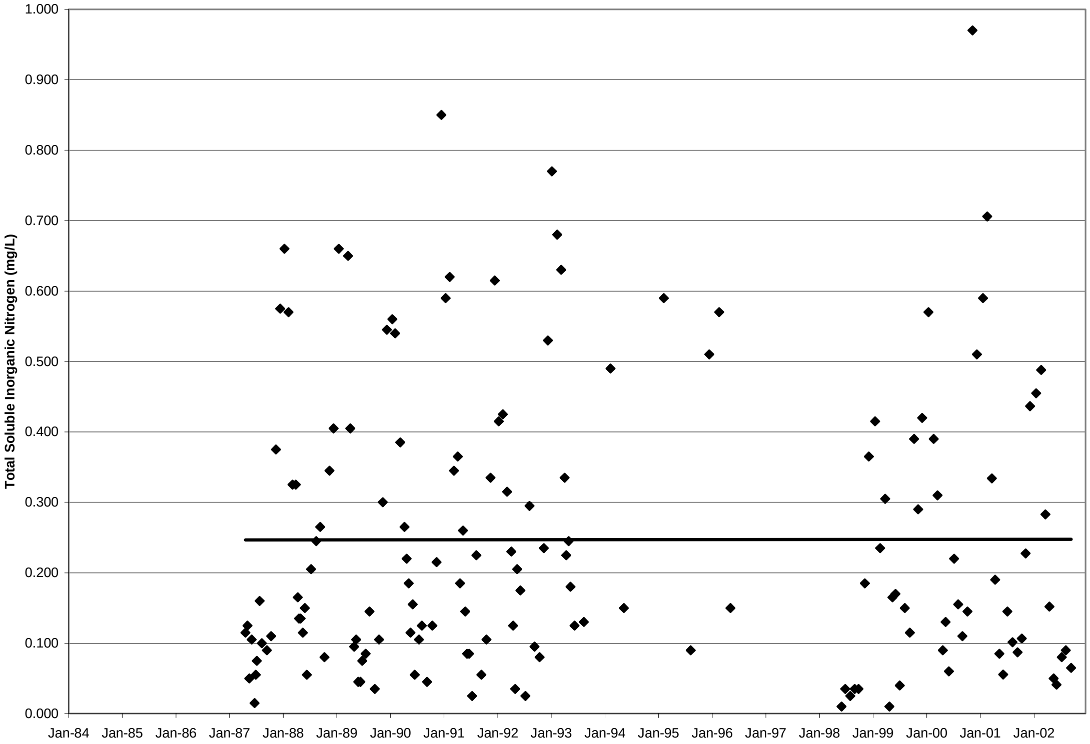


Figure 8: Clark Fork at Deer Lodge – Total Soluble Inorganic Nitrogen (not a significant trend)



These decreasing trends in total nitrogen, total phosphorus, and total metals were most frequently observed in the upper portion of the Clark Fork River, and less commonly in the lower portion of the Clark Fork. Tributary stations generally showed few or no trends in nutrient or metals concentrations.

The Clark Fork above Missoula showed no trend in total phosphorus from 1989-2002 (**Figure 9**). This station served as a control for the City of Missoula point and nonpoint source nutrient loading. The Clark Fork below Missoula showed a statistically significant decreasing trend in total phosphorus over the same period (**Figure 10**). This decreasing trend is probably attributable to improvements in the Missoula Wastewater Treatment Plant operations, increasing sewer hookups (decreased nonpoint), and continued water quality improvement due to the phosphate ban that went into effect in 1989.

Figure 9. Clark Fork above Missoula – Total Phosphorus

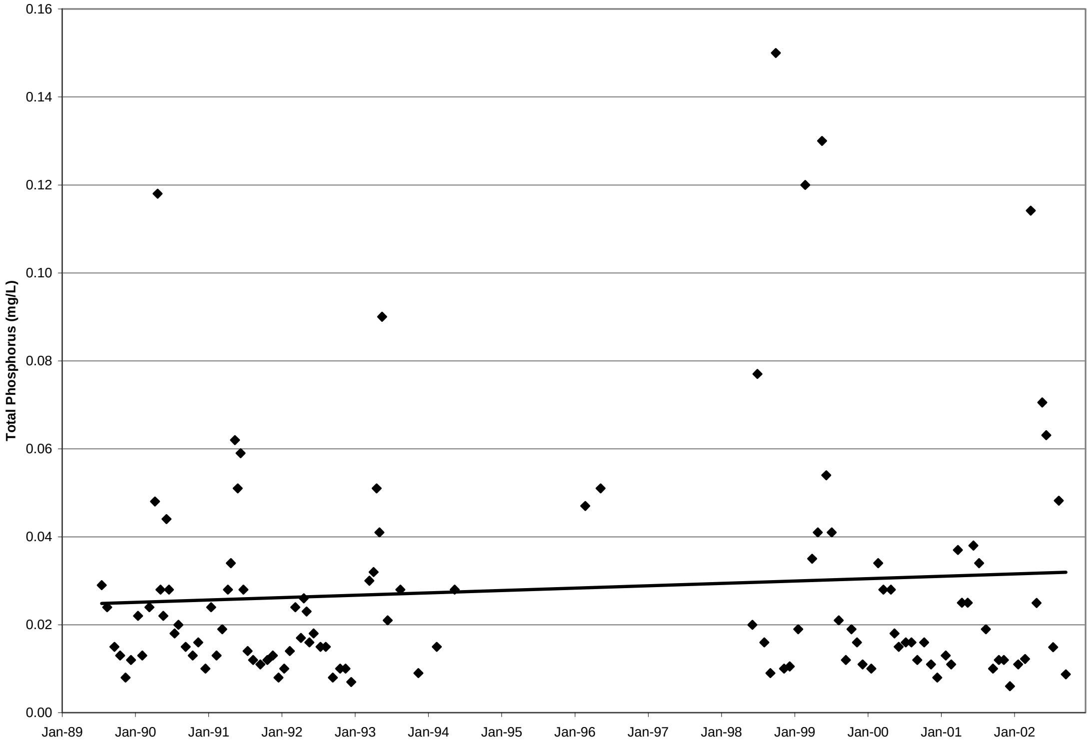
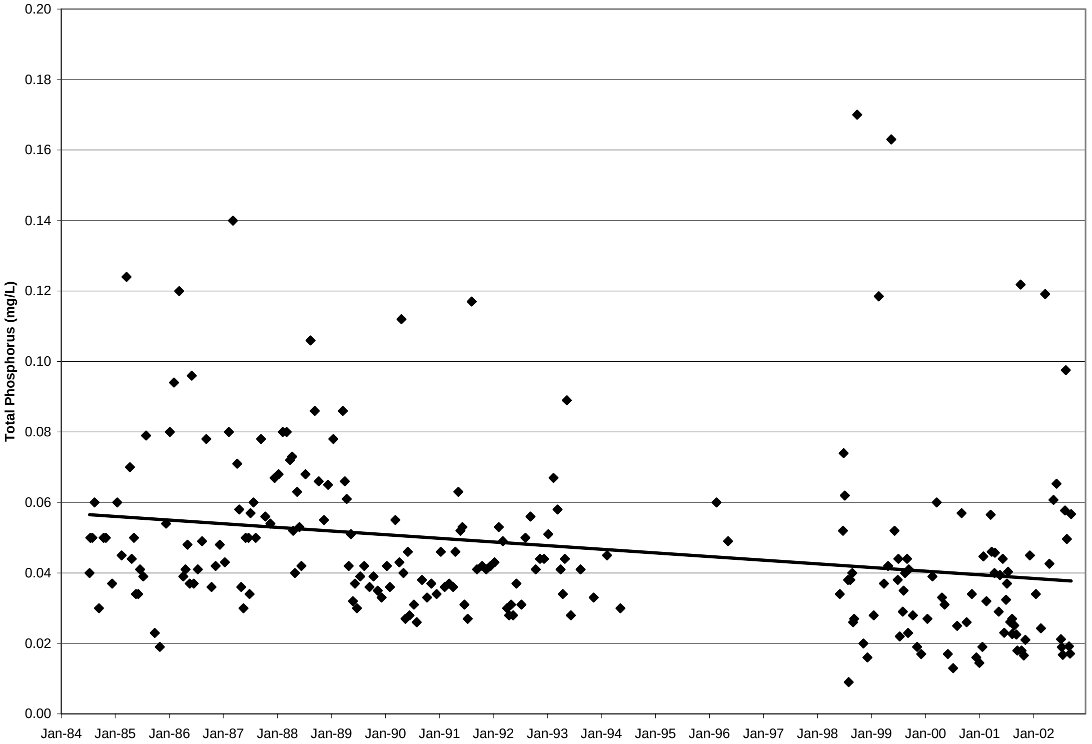


Figure 10. Clark Fork below Missoula – Total Phosphorus



The Cabinet Gorge station showed no statistically significant trend for total phosphorus (**Figure 11**) or soluble reactive phosphate from 1984 to 2002. A significant increasing trend was present at Cabinet Gorge for total soluble inorganic nitrogen, and a decreasing trend was observed for total nitrogen (**Figure 12**). The decreasing trend for TN was related to the presence of infrequent values exceeding 0.4 mg/l prior to 1993. Improved lab QA/QC or sampling technique consistency may explain less frequent high values to some extent. Although possible changes in peaking operations might have the potential to influence sample results, flow effects on constituent concentrations are generally minor at the Cabinet Gorge site. This tendency for decreasing TN, and increasing TSIN was observed at other Clark Fork stations, and these results are probably unrelated to dam operations.

The Pend Oreille River station at Newport showed statistically significant decreasing trends for total phosphorus, soluble reactive phosphorus, total nitrogen, and total soluble inorganic nitrogen. The decreasing trends in total phosphorus and soluble reactive phosphorus was due to a reduction in analytical detection limits during the monitoring period, and does not reflect a true reduction in constituent concentrations. The Pend Oreille River station at Metaline Falls did not show any statistically significant trends.

Figure 11: Clark Fork below Cabinet Gorge Dam – Total Phosphorus

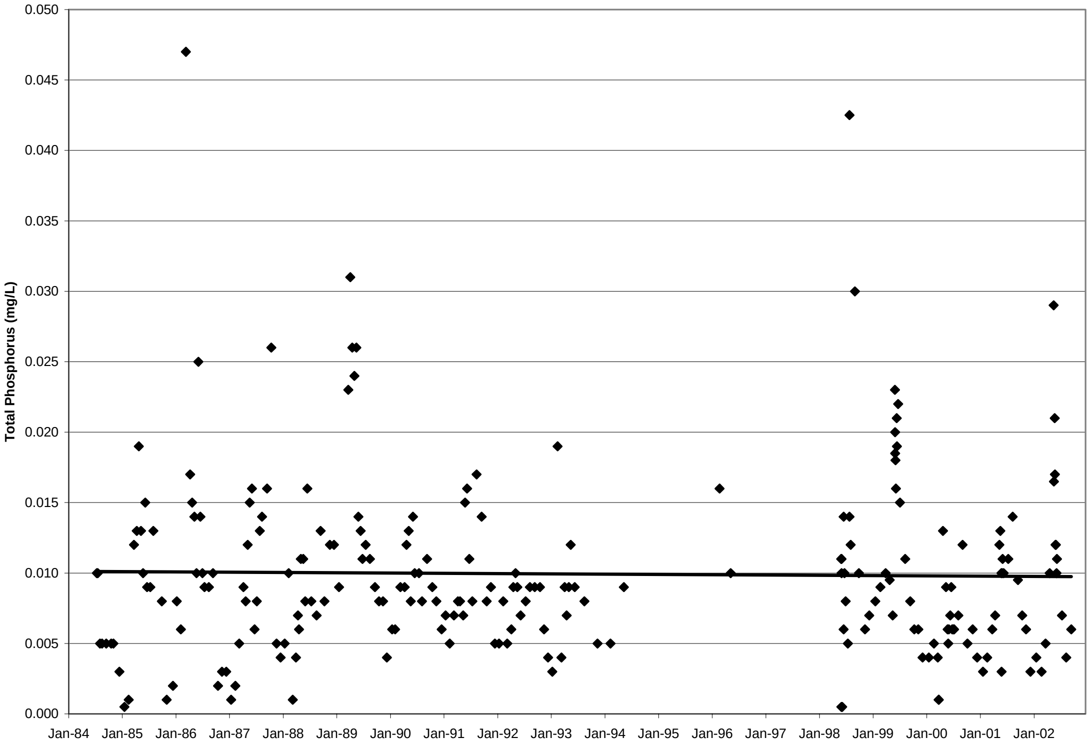
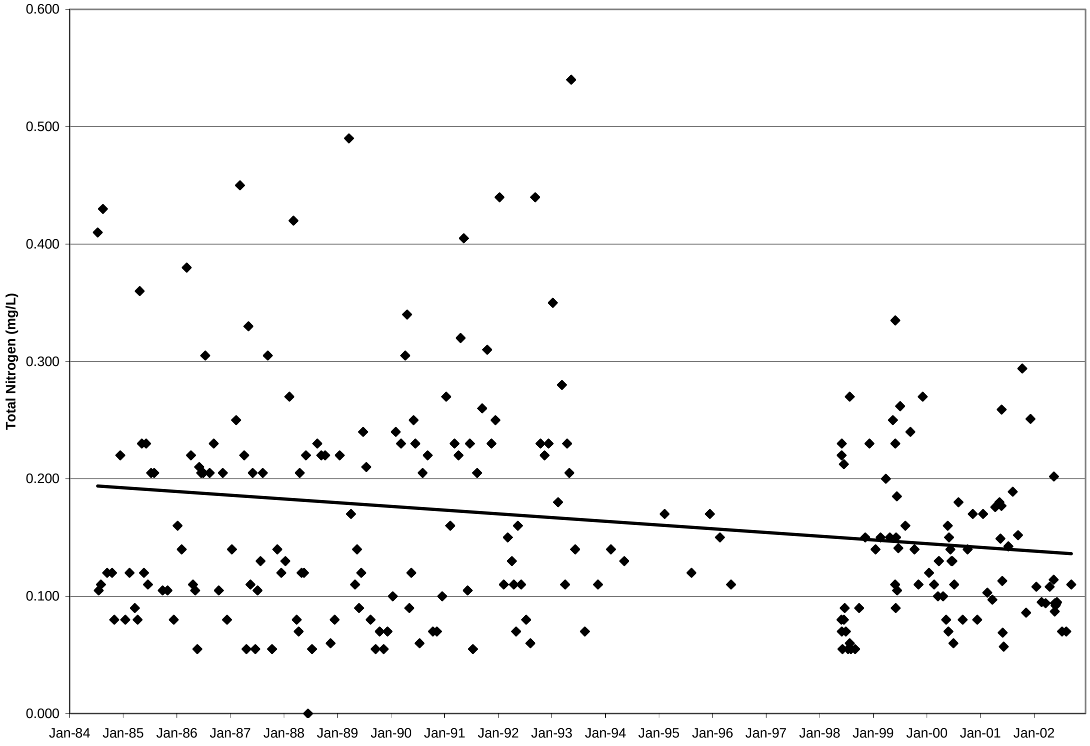


Figure 12: Clark Fork below Cabinet Gorge Dam – Total Nitrogen



3.5 Summer Nutrient Trend Analysis

Intensive summer nutrient monitoring was conducted at five stations in the upper watershed and mainstem of the Clark Fork River. In addition to monthly monitoring, the following stations were each sampled six additional times from June through August by Missoula WWTP personnel: Silver Bow Creek at Opportunity, Clark Fork River below Warm Springs, Clark Fork River above the Little Blackfoot River, Clark Fork River below Missoula, and Clark Fork River at Huson.

The summer period for nutrient trend analysis was defined as the period from July 1 to September 31. Data from five stations with higher intensity summer nutrient sampling were analyzed to determine if trends in nutrient or metals concentrations were present.

Most stations showed decreasing trends in several nutrient constituents (**Table 7**). Statistical significance was tested using Kendall's Tau-b correlation analysis with a significance level of 0.05.

Table 7. ***Stations with Statistically Significant (P<0.05) Trends based on Summer Data***

Station	TN	TP	SRP	TSIN	Cu	Zn
Silver Bow at Opportunity					Decreasing	
Clark Fork below Warm Sp.	Decreasing	Decreasing	Decreasing	Decreasing		
Clark Fork abv L. Blackfoot	Decreasing	Decreasing	Decreasing			
Clark Fork below Missoula		Decreasing	Decreasing	Decreasing		
Clark Fork at Huson		Decreasing	Decreasing	Increasing		

Silver Bow Creek at Opportunity showed a significant decrease in total recoverable copper concentration and was the only station to show a trend in metals concentrations. The Clark Fork River below Warm Springs, Clark Fork River above Little Blackfoot, Clark Fork River below Missoula, and Clark Fork River at Huson all showed decreasing trends in TP and SRP. Decreasing trends for TN were also observed in the Clark Fork River below Warm Springs and Clark Fork River above Little Blackfoot. The Clark Fork River below Warm Springs and Clark Fork River below Missoula stations showed decreasing trends for TSIN. The Clark Fork River at Huson was the only station to show deteriorating water quality for a nutrient constituent (TSIN). Significant trends for TP and TN are shown in **Figures 13-18**, and the remaining trend graphs are found in **Appendix E**.

The decreasing trend for TP and SRP at four of five summer monitoring stations indicated that water quality improved with respect to phosphorus during the monitoring period from 1986-2002. The phosphorus ban established in 1989, along with improvements at the wastewater treatments plants in Butte, Deer Lodge, and Missoula probably account for these relative improvements in summer water quality through the basin.

Figure 13. Summer Total Phosphorus in the Clark Fork below Warm Springs

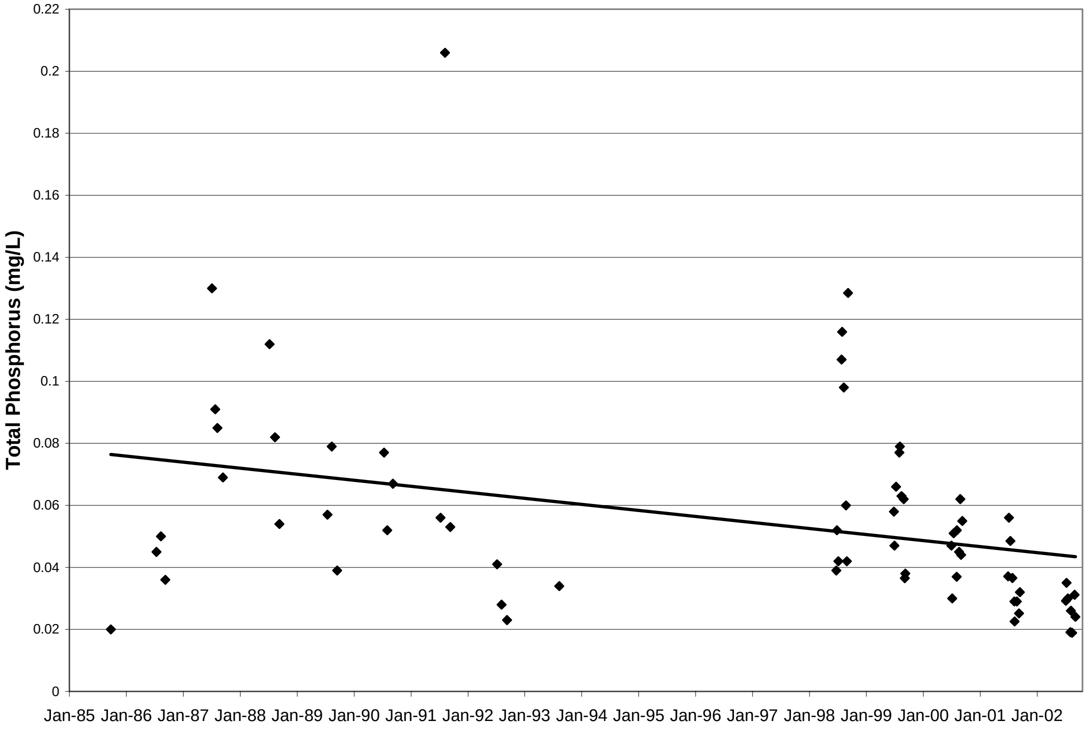


Figure 14. Summer Total Phosphorus in the Clark Fork above the Little Blackfoot River

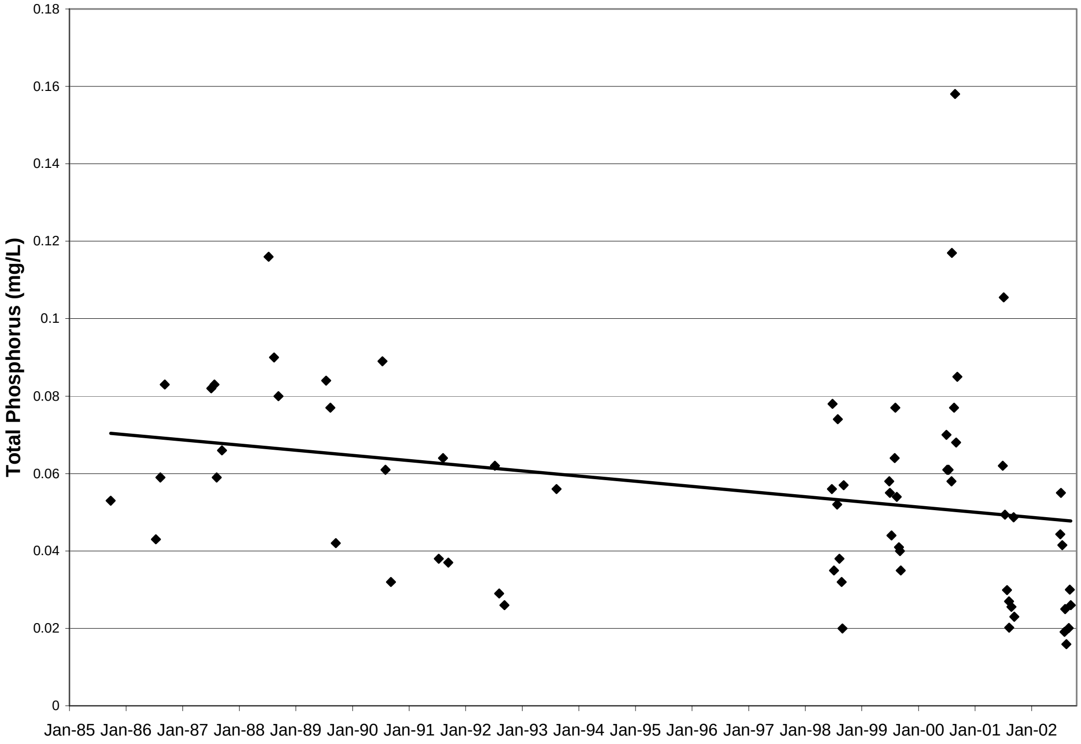


Figure 15. Summer Total Phosphorus in the Clark Fork below Missoula

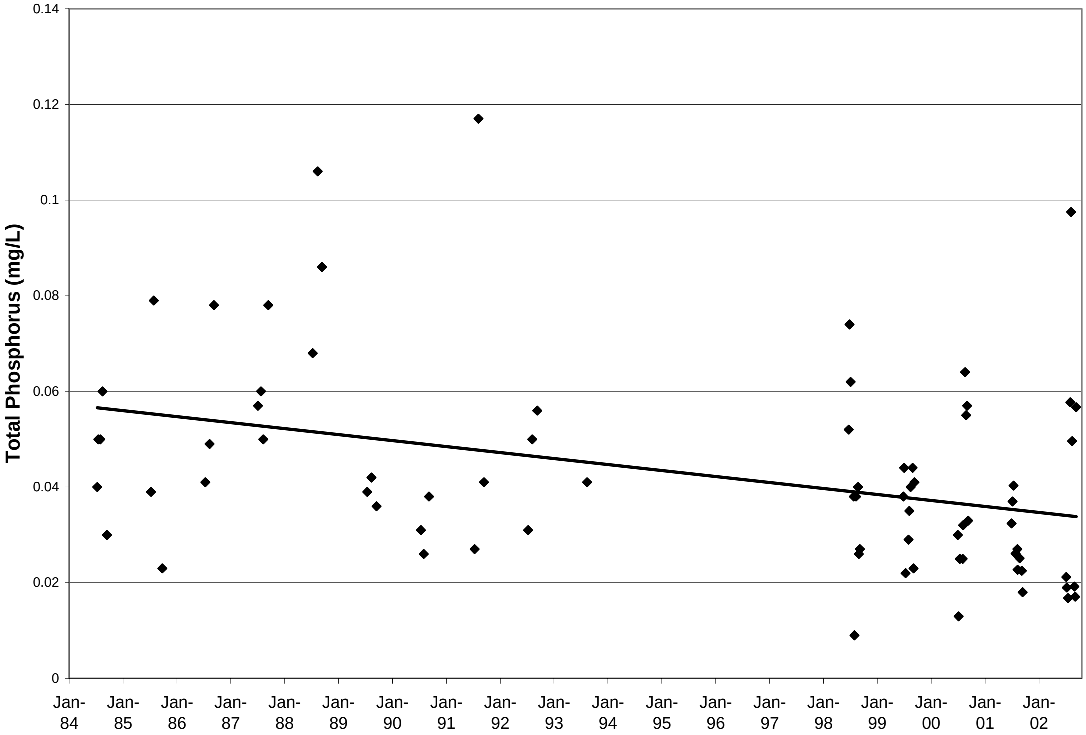


Figure 16. Summer Total Phosphorus in the Clark Fork at Huson

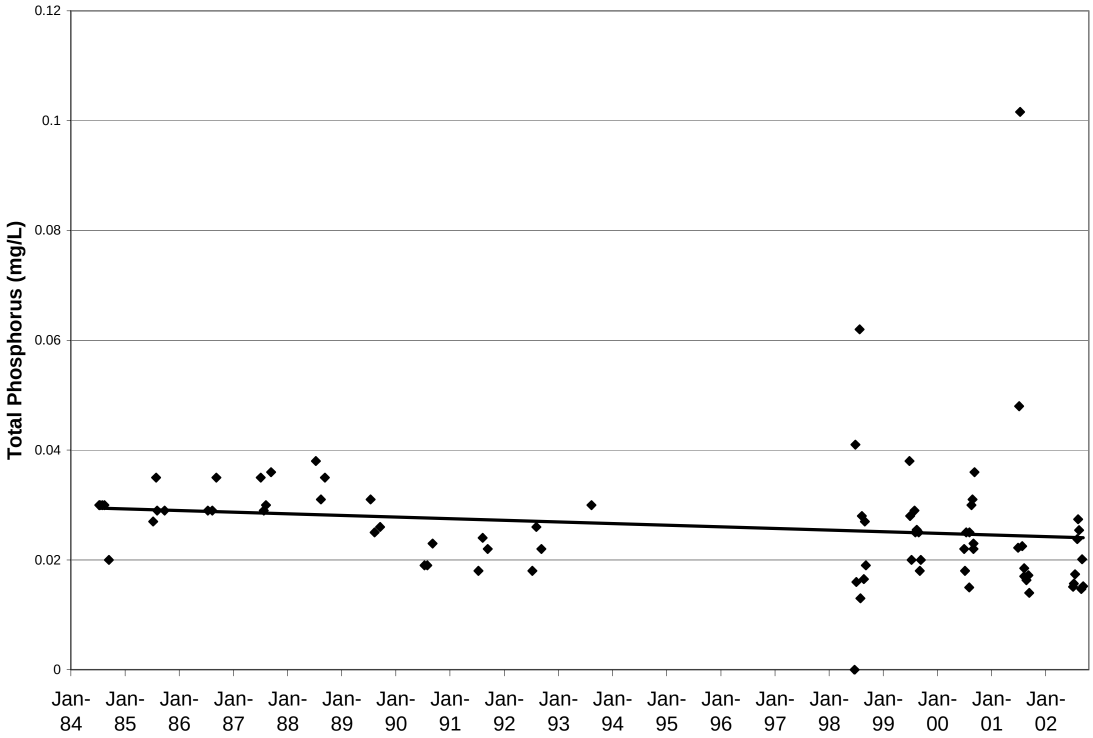


Figure 17. Summer Total Nitrogen in the Clark Fork below Warm Springs

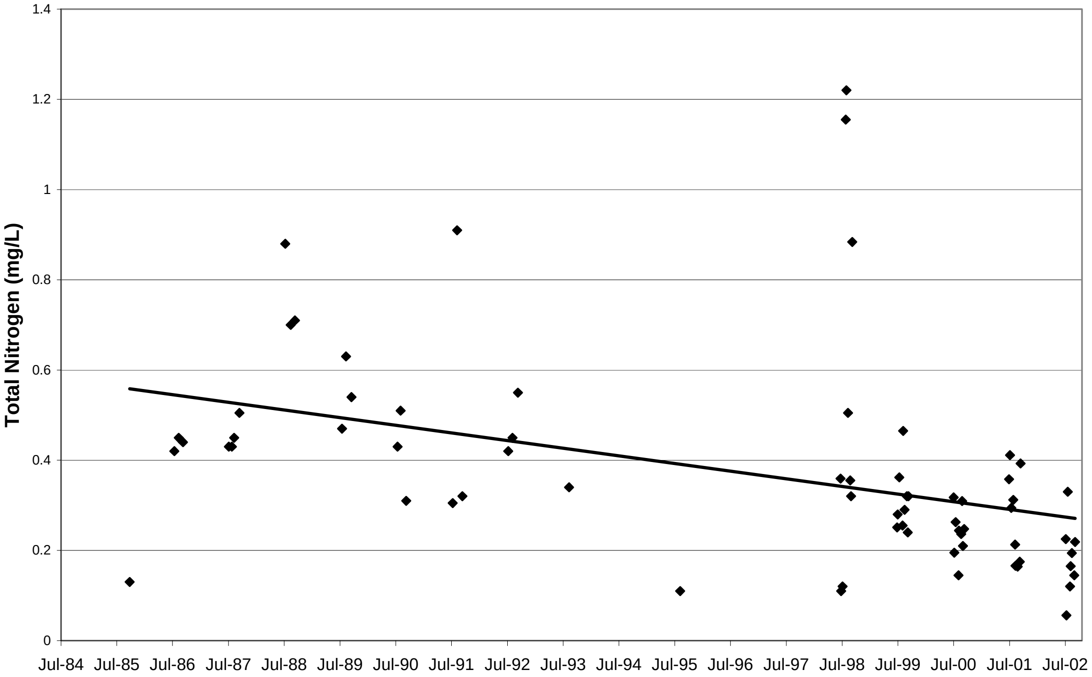
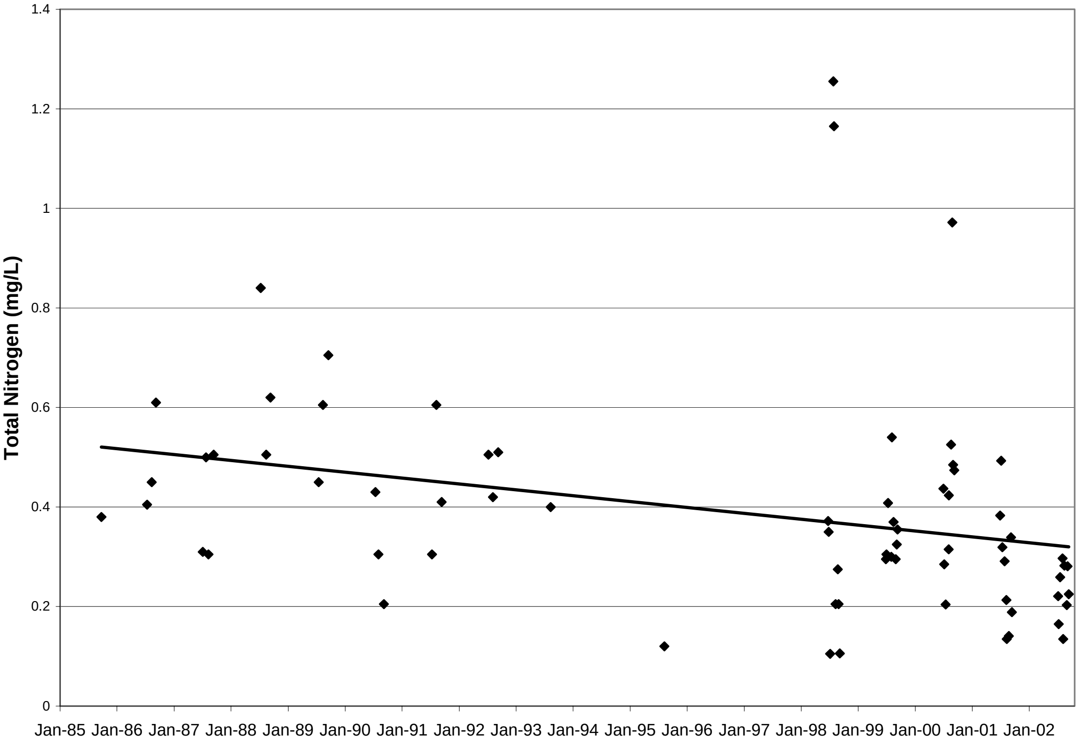


Figure 18. Summer Total Nitrogen in the Clark Fork above the Little Blackfoot River



3.6 Summer Nutrient Targets

Formal targets for the Clark Fork River have been established for TN and TP, with secondary targets for TSIN and SRP. The following nutrient targets were adopted as part of the Voluntary Nutrient Reduction Program (VNRP). The state adopted these numeric criteria as state standards in July 2002:

• Total nitrogen	All Stations	300	μg/L
• Total phosphorous	Upstream of Missoula	20	μg/L
• Total phosphorous	Downstream of Missoula	39	μg/L

Secondary target values include soluble components for nitrogen and phosphorus:

• Total soluble inorganic nitrogen	(nitrate/nitrite + ammonia)	30	μg/L
• Soluble reactive phosphate		6	μg/L

The water quality objective is to attain a statistically significant 95% attainment rate for these targets in any given summer period, defined as June 21 to September 21.

3.6.1 Summer Boxplots

Summer nutrient spatial comparisons were displayed using statistical boxplots for the period of record (**Appendix F**). For TSIN, boxplots may be displayed on two scales to better display the data.

The total nitrogen (TN) plot shows that all stations had median values exceeding the target (300 μg/L) with the exception of the Clark Fork below Huson. Silver Bow Creek had a median TN concentration of 2437 μg/L, while the Clark Fork River below Missoula station had a median concentration of 347 μg/L. Clark Fork River stations below Warm Springs, above the Little Blackfoot, and at Huson were above the target (330, 322, and 273 μg/L respectively).

Total soluble inorganic nitrogen (TSIN) median concentrations were above the target value (30 μg/L) at four stations. Silver Bow Creek at Opportunity had the highest median value (1760 μg/L). Clark Fork River stations below Warm Springs, below Missoula, and at Huson were above the target (33.8, 97.5, and 44.7 μg/L respectively).

Median total phosphorus (TP) concentrations decreased downstream from Silver Bow Creek at Opportunity, but increased slightly below Deer Lodge. All sites upstream of Missoula exceeded the target value of 20 μg/L. The Clark Fork River below Missoula (39.5 μg/L) and Clark Fork River at Huson (25 μg/L)) were above and below the target value (39 μg/L), respectively.

Median soluble reactive phosphorus (SRP) concentrations decreased downstream from Silver Bow Creek at Opportunity (46.8 μg/L) to the Clark Fork River at Huson (7.4 μg/L). All monitoring sites had median SRP concentrations above the target level (6 μg/L).

3.6.2 *Summer Target Attainment*

Intensive summer nutrient monitoring was conducted at five stations in the Clark Fork-Pend Oreille watershed. This resulted in 10 samples for the summer period defined as July-September. The stated objective of the Tri-State Water Quality Council for summer nutrient targets is to achieve a 95% compliance rate at the 95% confidence level. At a 95% confidence level, the allowable number of exceedances for 10 samples is 14.3%, or no more than 1 in 10 samples.

Target level compliance has been reported for individual years from 1998-2002 (Land & Water 2002). For the period of record, most nutrient targets have not been met (**Table 8**). Total phosphorus targets were met in one year below Missoula, and in 3 of 5 years at Huson. At the Clark Fork River above the Little Blackfoot, total nitrogen targets were met one year, and TSIN secondary values were met in 2 of 5 years. SRP secondary targets were not met at any station in any year.

Table 8. ***Summer Nutrients 1998-2002 - Number of Years below Target***

Station	TP	TN	SRP	TSIN
Silver Bow Creek above WWTP	0	0	0	0
Clark Fork below Warm Springs	0	0	0	0
Clark Fork above Little Blackfoot	0	1	0	2
Clark Fork below Missoula	1	0	0	0
Clark Fork at Huson	3	0	0	0

Although annual nutrient targets have not been met for most station/nutrient combinations, the number of samples falling below the target values suggests that water quality meets standards for at least a portion of the summer (**Table 9**). Silver Bow Creek is of poor quality with respect to nutrients, and has had no individual sample results below targets. Individual samples at the Clark Fork River stations at Warm Springs and Little Blackfoot have had relatively good compliance rates for TN and TSIN (50 and 70%), and low rates for TP and SRP (4 to 9%). The Clark Fork River station below Missoula met TP targets most frequently (65% of all samples), followed by TN (37%). Soluble components TSIN and SRP met targets infrequently. The Clark Fork below Huson had the highest percentage of samples overall that were within target values.

Table 9. ***Summer Nutrients - Percent of Samples below Target***

Station	TP	TN	SRP	TSIN
Silver Bow Creek ab WWTP	0%	0%	0%	0%
Clark Fork bl Warm Springs	6%	61%	6%	55%
Clark Fork ab Ltl Blackfoot	4%	50%	9%	70%
Clark Fork bl Missoula	65%	37%	17%	4%
Clark Fork at Huson	90%	70%	54%	19%

Although numerical targets are not yet being consistently achieved, water quality continues to improve with respect to phosphorus (and to a lesser extent nitrogen). It should be reiterated that 4 of the 5 monitoring stations showed statistically significant decreasing trends over the long term in TP and SRP concentrations (**Table 6**).

4.0 CLARK FORK RIVER PERIPHYTON

Seven Clark Fork River stations were monitored for periphyton for five years from 1998-2002 (**Appendix A, Figure 5**). Sites included Clark Fork River at Deer Lodge, Clark Fork River above the Little Blackfoot River, Clark Fork River at Bonita, Clark Fork River above Missoula, Clark Fork River below Missoula, Clark Fork River at Huson, and Clark Fork River above the Flathead River. Ten replicate samples were collected in each sampling event at each station and were analyzed for two algal constituents, 1) Chlorophyll A (Chl A) (mg/m^2) and 2) Ash free dry weight (AFDW) (g/m^2).

4.1 Temporal Trends

Periphyton results for the Clark Fork River stations were evaluated to determine if significant trends were apparent in Chl A or AFDW during the five year period. Many Clark Fork River stations showed statistically significant increasing trends ($p = 0.05$) in periphyton standing crop over the five year period from 1998-2002 (**Table 10**). This analysis included all 10 replicate values for each individual summer sampling event.

Table 10. ***Statistically Significant Trends in Chl A & AFDW at Clark Fork Mainstem Sites***

Site	Trend in Chlorophyll A	Trend in Ash Free Dry Weight
Clark Fork at Deer Lodge	None	None
Clark Fork above Little Blackfoot	None	Decreasing
Clark Fork at Bonita	Increasing	Increasing
Clark Fork above Missoula	Increasing	Increasing
Clark Fork below Missoula	Increasing	Increasing
Clark Fork at Huson	Increasing	None
Clark Fork above Flathead	None	Decreasing

This presence of increasing trends for periphyton is somewhat unusual since summer nutrient concentrations have generally shown a decreasing trend at most of these same stations. This may be a function of increased nutrient uptake by periphyton, though the reasons for this are uncertain. The tendency for lower copper concentrations did not explain increases in periphyton using multiple regression analysis. Other potential factors such as changes in ambient temperature, flow duration/timing, or scouring floods clearly have the potential to influence periphyton communities. Detailed analyses of these factors were beyond the scope of this study.

It should be noted that the reported statistical significance of these trends is influenced by including all replicates (e.g. larger sample size), and probable lack of sample independence. Although variability within a site was frequently as great as variability between sites, replicate samples are not truly independent samples either spatially or temporally. Lack of sample independence along with increased sample size using replicates inflates the statistical significance of results.

A trend analysis for periphyton was also conducted using data from the entire period of record from 1987-2002 and also included September 1987 observations by the University of Montana. Replicates were averaged which resulted in a much smaller total sample size (i.e. n=6 or 7). The results of this analysis showed that no statistically significant trends in Chl A were present at the 0.05 significance level. Small sample size limits the power of this analysis. Interestingly, using raw data (i.e. replicates not averaged, n=156 to 241) shows a tendency for statistically significant decreasing trends at 4 stations (Clark Fork at Deer Lodge, Clark Fork above Little Blackfoot, Clark Fork at Bonita, and Clark Fork above Flathead).

In summary, using annual average values suggested that no significant trend existed in Chl A from 1987-2002. This is the most conservative statistical approach, though power is low due to small sample size. If replicate values are included, a decreasing trend appeared likely from 1987-2002 and an increasing trend was present from 1998-2002. Both these analyses violate statistical assumptions of sample independence to some degree, and therefore must be viewed with caution.

4.2 Chlorophyll A Target Comparison

Periphyton data are shown in spatial boxplots for the years 1998-2002 (**Appendix G**). Clark Fork River Chl A boxplots show the targets set for mean (100 mg/m^2) and maximum (150 mg/m^2) Chl A content. Clark Fork River stations were sampled in both August and September, and Pend Oreille Lake stations were sampled only in September (see **Section 5**).

Target value attainment for the years 1998-2002 is summarized in **Table 11**. Generally, percent of samples below target mean (100 mg/m^2) and maximum (150 mg/m^2) increase in the downstream direction, associated with improving water quality. However, a marked decrease in percent target attainment occurs at Clark Fork River below Missoula. Upstream of Missoula, 70% mean and 90% maximum target attainment is achieved, compared to 40% mean and 50% maximum target attainment below Missoula. This decrease in target attainment can be attributed to effluent discharge from the City of Missoula Wastewater Treatment Plant.

Comparisons of 1998-2002 algal metrics to target values for Clark Fork River stations are shown in **Figures 19-25**. Mean values are displayed by points on the chart. The target mean Chl A content (100 mg/m^2) is displayed as a dashed line, the target maximum Chl A content (150 mg/m^2) is shown as a solid line.

Table 11. ***Chlorophyll A Target Attainment***

Station	% Sample Events below Target Mean (100 mg/m2)	% Sample Events below Target Maximum (150 mg/m2)
Clark Fork at Deer Lodge	30	30
Clark Fork ab Ltl Blackfoot	60	80
Clark Fork at Bonita	50	60
Clark Fork ab Missoula	70	90
Clark Fork bl Missoula	40	50
Clark Fork at Huson	80	90
Clark Fork ab Flathead	90	100

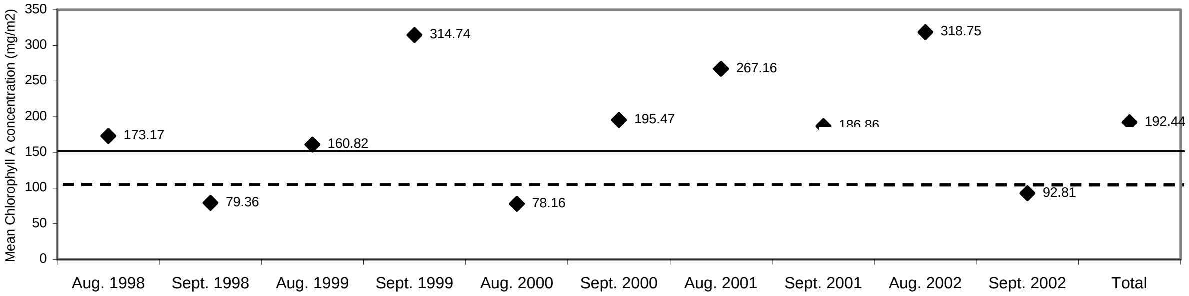


Figure 19. Clark Fork at Deer Lodge Target Chlorophyll A Comparison

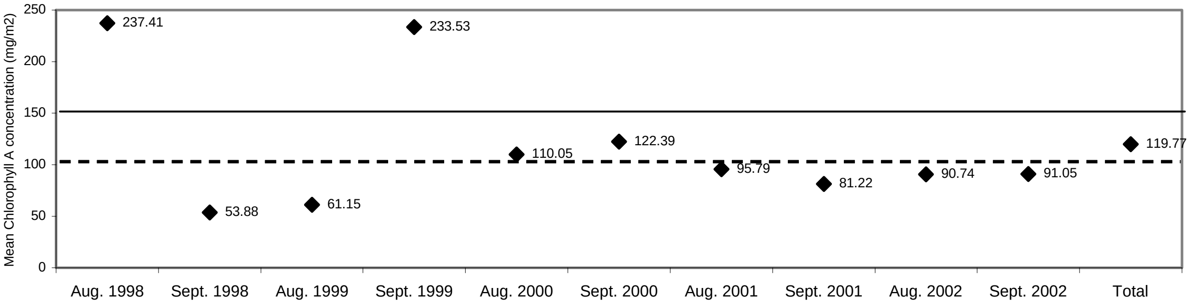


Figure 20. Clark Fork above Little Blackfoot River Target Chlorophyll A Comparison

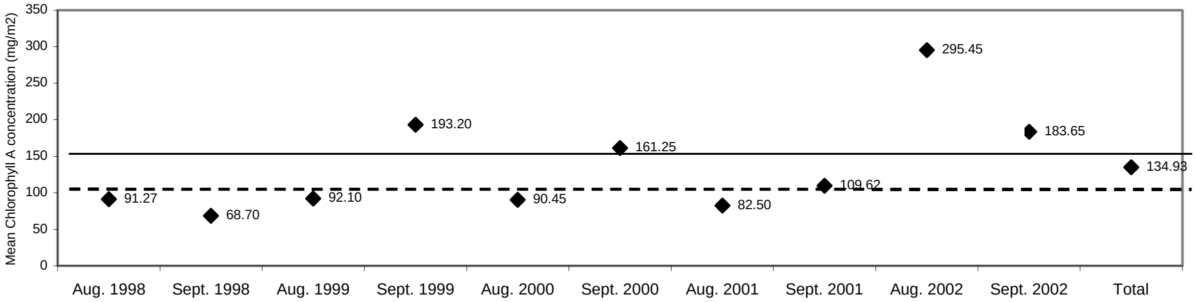


Figure 21. Clark Fork at Bonita Target Chlorophyll A Comparison

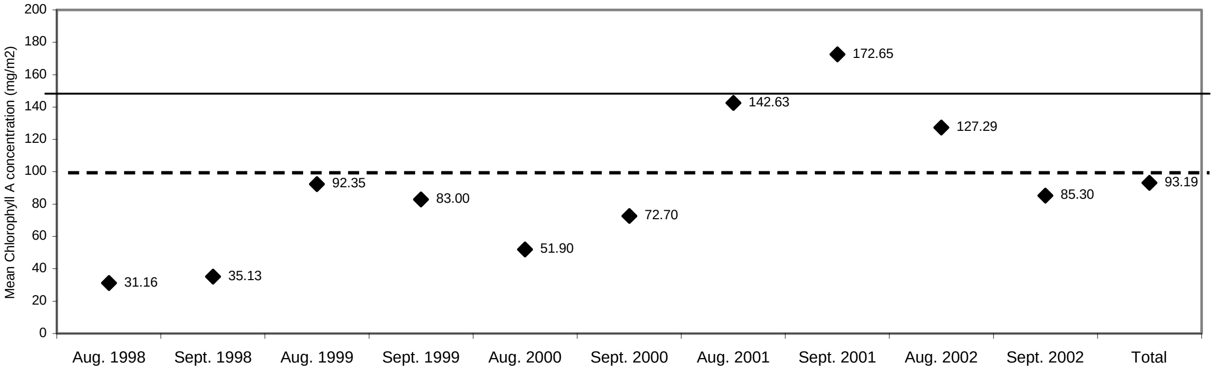


Figure 22. Clark Fork above Missoula Target Chlorophyll A Comparison

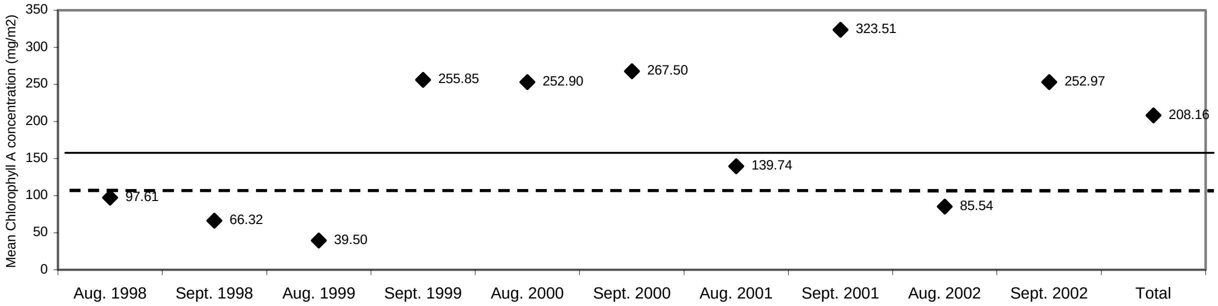


Figure 23. Clark Fork below Missoula Target Chlorophyll A Comparison

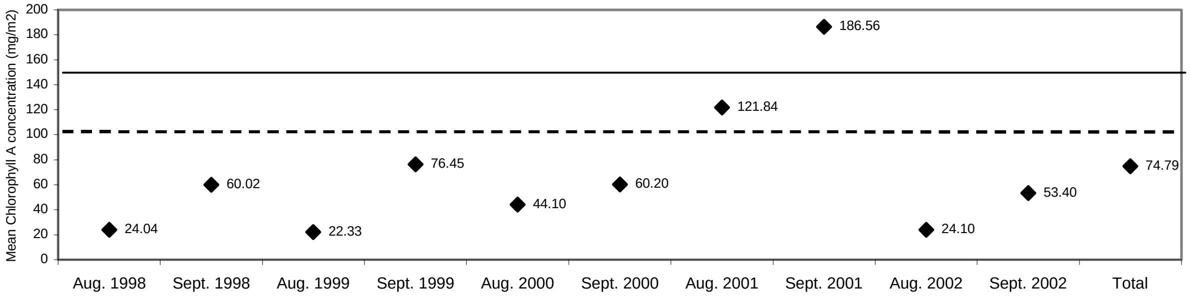


Figure 24. Clark Fork at Huson Target Chlorophyll A Comparison

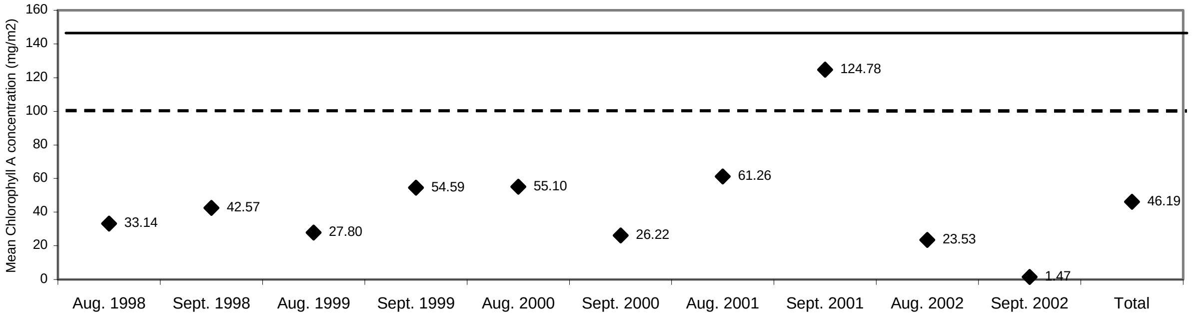


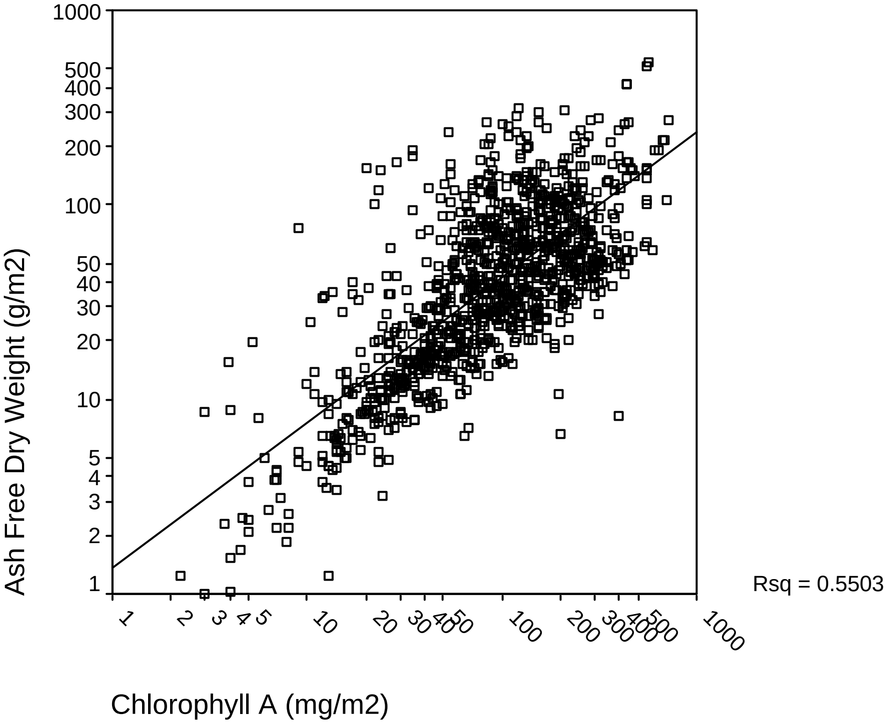
Figure 25. Clark Fork above Flathead Target Chlorophyll A Comparison

4.3 Clark Fork Chlorophyll A, Ash Free Dry Weight, & Nutrient Correlations

The relationship between Chlorophyll A (Chl A), ash free dry weight (AFDW), and nutrient concentrations at the Clark Fork River stations was investigated. A variety of correlations were examined, including the relationship between Chl A and AFDW for pooled data, and individual stations and years. Additionally, summer and winter nutrient concentrations were compared to median and maximum Chl A/AFDW concentrations for pooled data, and individual stations and years. For station/constituent combinations where effects of seasonality and flow exist, nutrient concentrations have been adjusted for flow and/or seasonality. No adjustment has been performed on periphyton data, raw values were used in these analyses.

The relationship for Chl A/AFDW for all data pooled (**Figure 26**) shows a significant correlation, and considerable variability. Using log-transformed data, Chl A explained about 55% of the variability in AFDW results. This scatter arises from numerous sources including differences between stations, annual variability, benthic community differences, lab and experimental error, and other factors.

Figure 26. Chl A and AFDW for all Clark Fork Stations/Years Pooled



The relationship between Chl A and AFDW was different for sites above and below Missoula (**Figures 27 and 28**). Sites above Missoula tended to show higher AFDW values for a given Chl A result, and Chl A/AFDW correlations were stronger in sites below Missoula. This is likely to result from the difference between cladophora populations at sites above Missoula and the diatom communities below Missoula, which contain less overall biomass than the cladophora sites. Chl A/AFDW correlations do improve when stratified by individual stations with all years pooled (**Table 12**), yet stratifying by year does not result in any significant correlations.

Figure 27. Chl A and AFDW for Stations above Missoula/Years Pooled

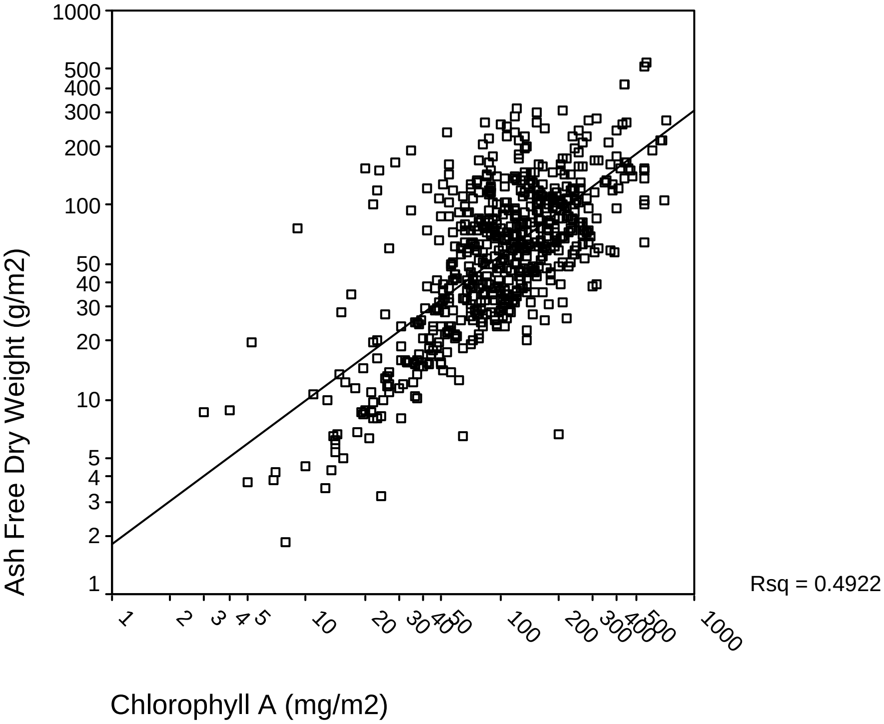


Figure 28. Chl A and AFDW for Stations below Missoula/Years Pooled

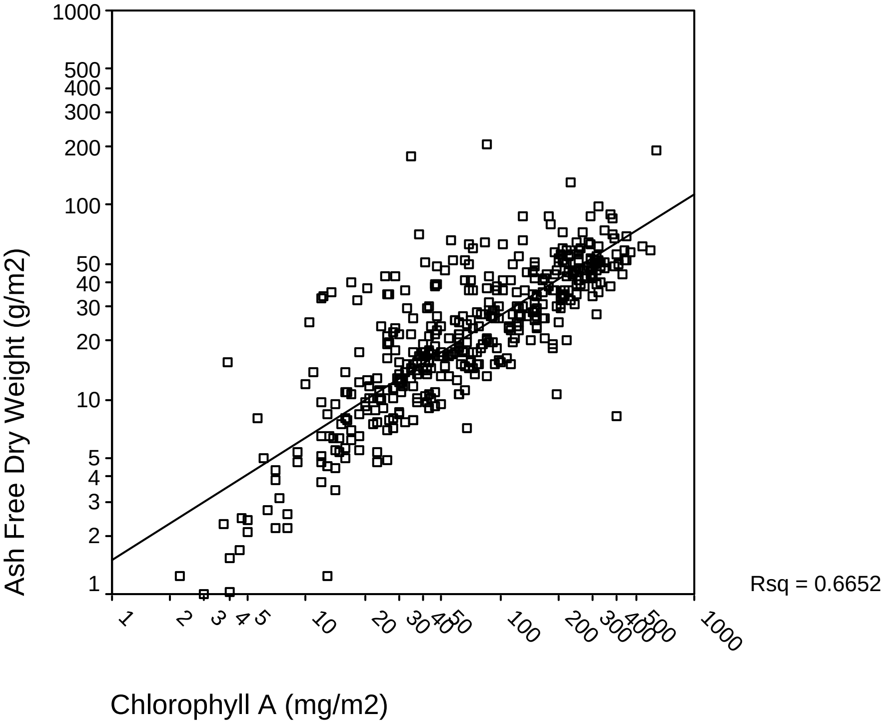


Table 12. ***Kendall-Tau Correlations for Chl A and AFDW***

Station	K-T Correlation	
CFR at Deer Lodge	0.414	**
CFR ab Ltl Blackfoot	0.373	**
CFR at Bonita	0.363	**
CFR ab Missoula	0.625	**
CFR bl Missoula	0.620	**
CFR at Huson	0.614	**
CFR ab Flathead	0.669	**
Sites above Missoula	0.459	**
Sites below Missoula	0.639	**
all river sites	0.513	**

** = significant at the 0.01 level

* = significant at the 0.05 level

The relationship between summer total nutrients and Chl A showed considerable variability. Nutrient concentrations explained only about 1% to 7% of the variability in Chl A values (**Figures 29-30**) for pooled data from all stations. The sites above Missoula showed higher concentrations of Chl A and AFDW for a given TP or TN concentration than the sites below Missoula. Stratifying the dataset by location improves correlations in the sites above Missoula, but not for sites below Missoula (**Figures 31-32**).

Figure 29. Chlorophyll A and Median Summer TP for all Clark Fork Stations/Years Pooled

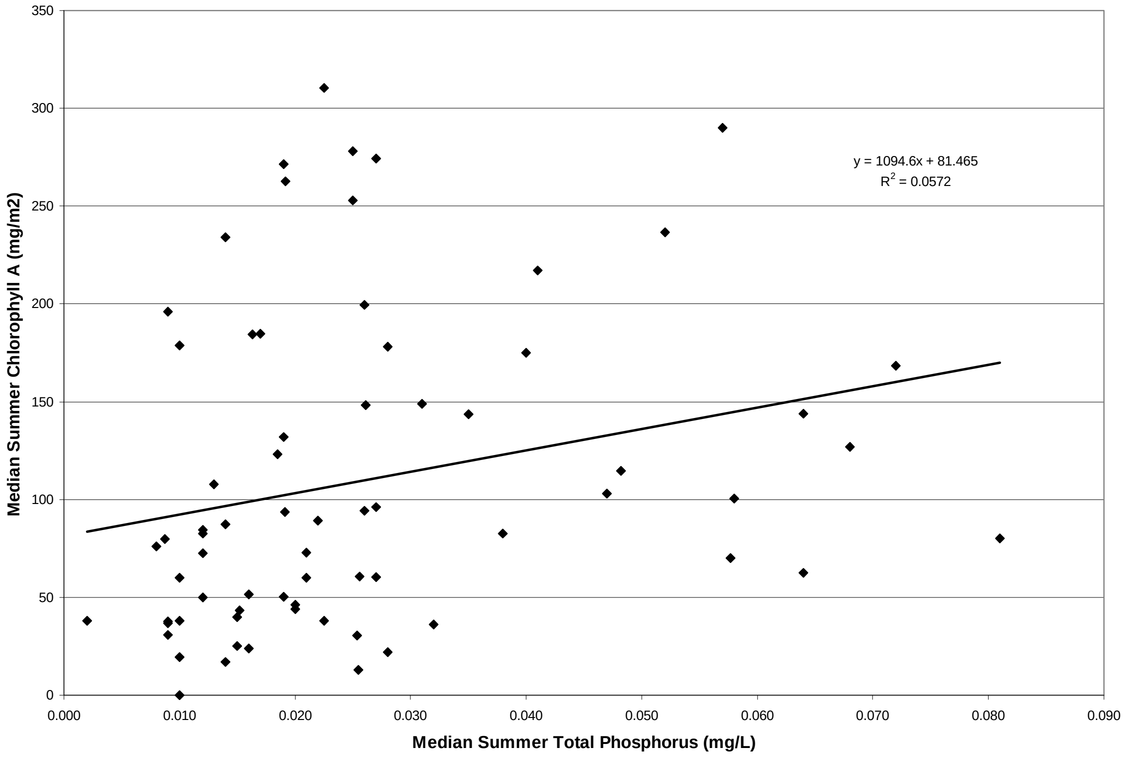


Figure 30. Chlorophyll A and Median Summer TN for all Clark Fork Stations/Years Pooled

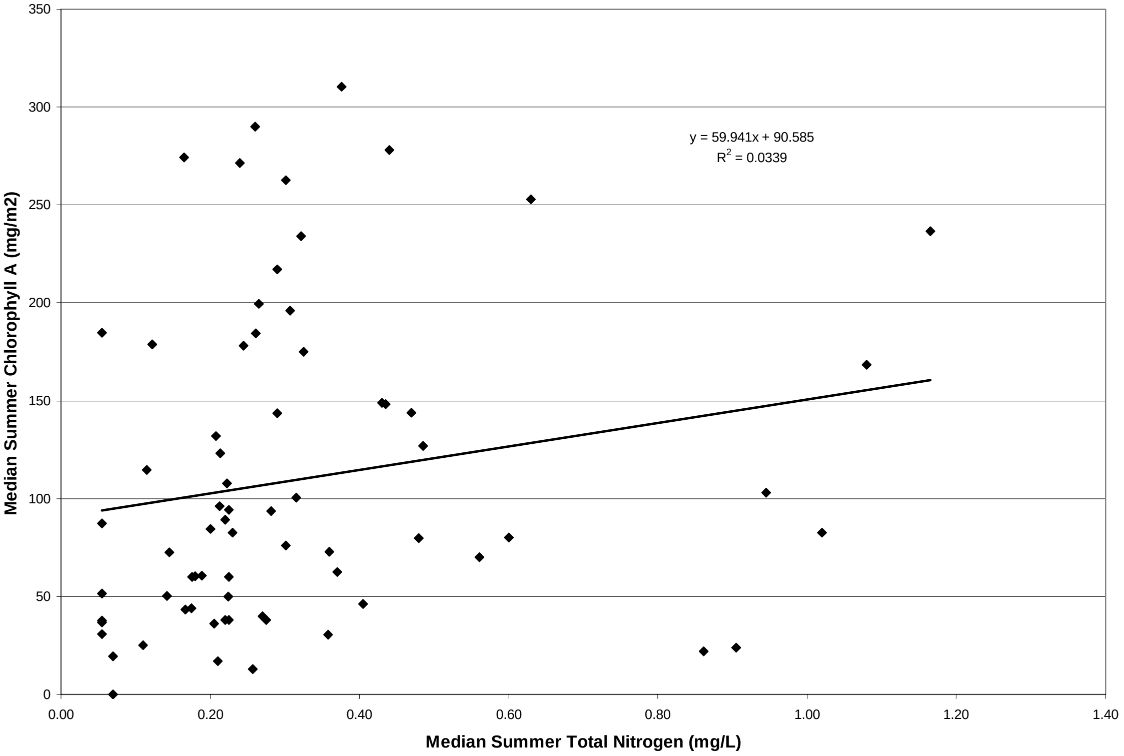


Figure 31. Chlorophyll A and Median Summer TP for Clark Fork Stations/Stratified

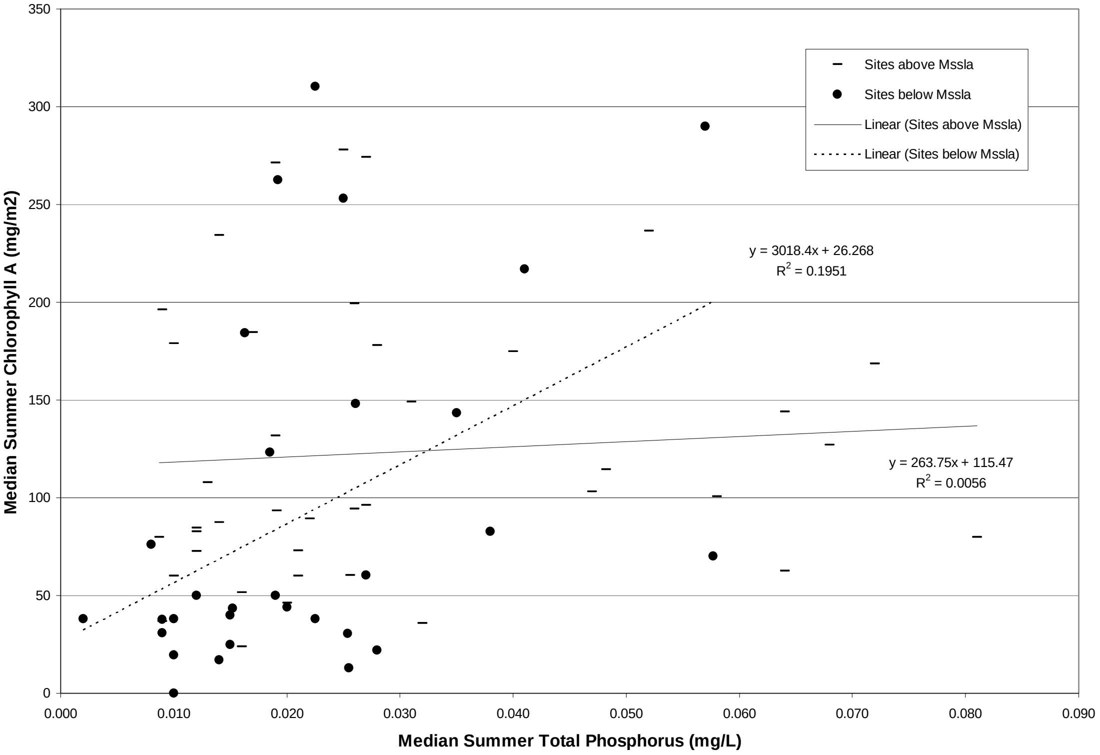
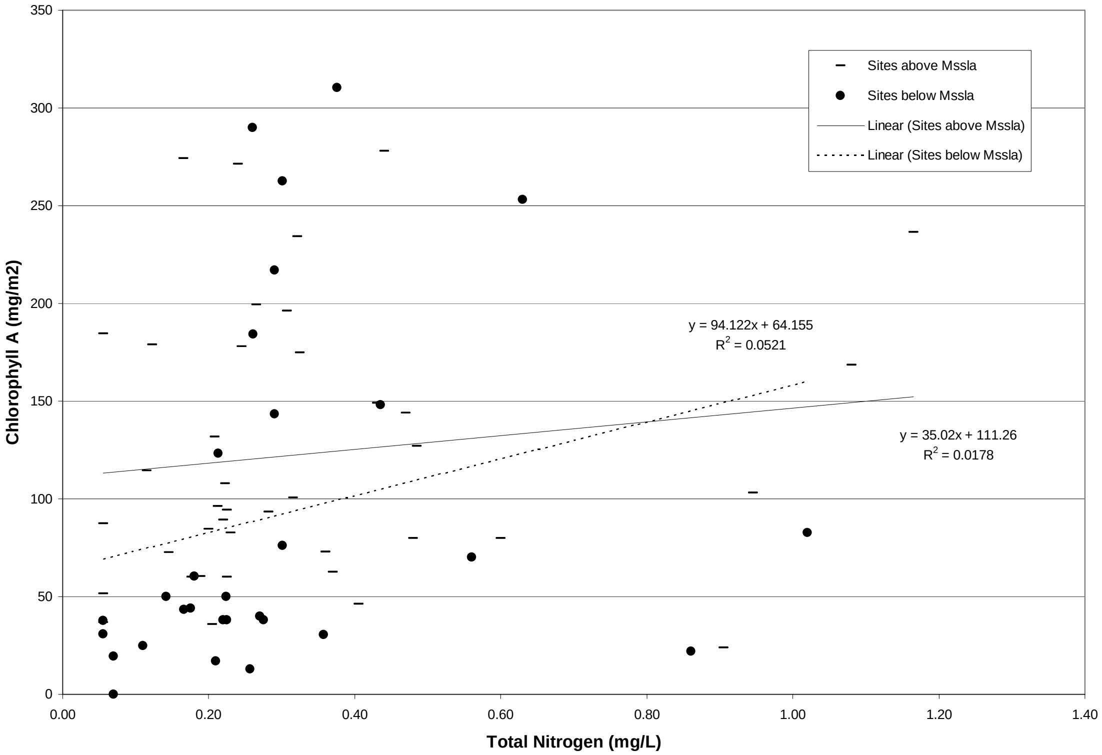


Figure 32. Chlorophyll A and Median Summer TN for all Clark Fork Stations/Stratified



The relationship between winter nutrients and Chl A also showed considerable variability, and was not as well correlated as summer nutrients. In general, nutrient concentrations from the previous winter are higher than the summer months throughout the watershed (**Figures 33-34**). Median winter total nutrient concentrations explained only about 2% to 4% of the variability in Chl A values (**Figures 35-36**) for pooled data from all stations. Stratifying the dataset by location (above and below Missoula) improves the correlations, but produces an unexpected inverse relationship for both total phosphorus and total nitrogen in the sites above Missoula (**Figures 37-38**).

Figure 33. Total Phosphorus Boxplots for Winter and Summer Months

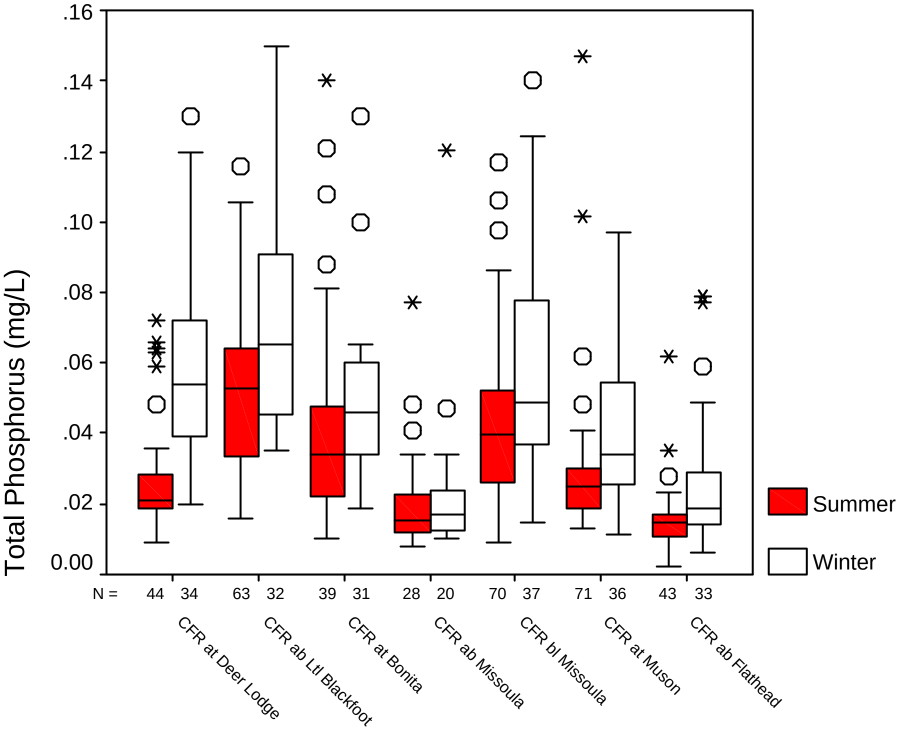


Figure 34. Total Nitrogen Boxplots for Winter and Summer Months

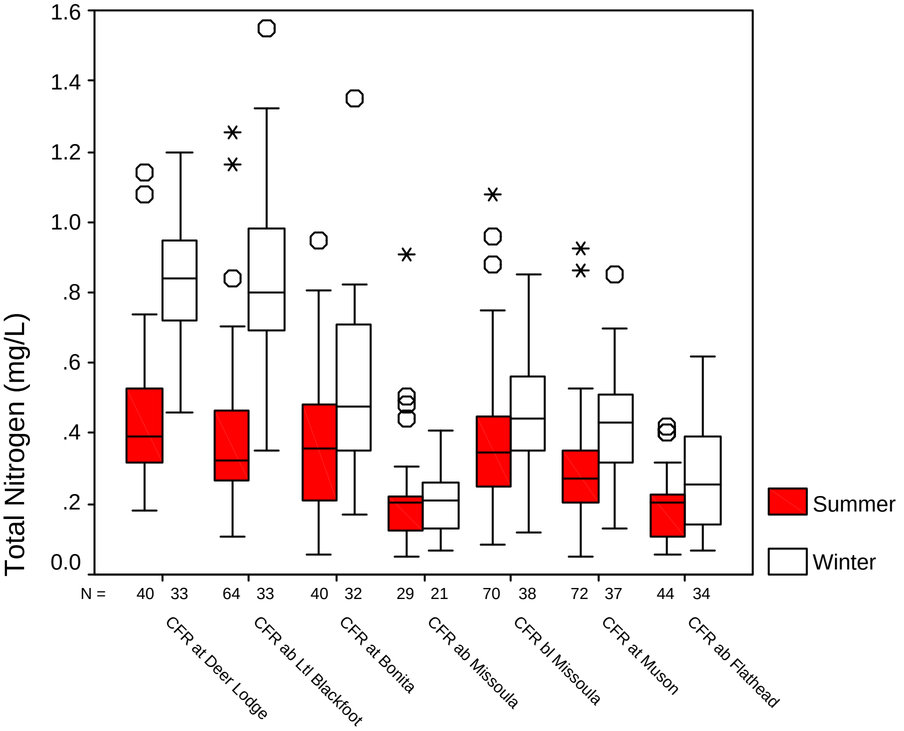


Figure 35. Chlorophyll A and Median Winter TP for all Clark Fork Stations/Years Pooled

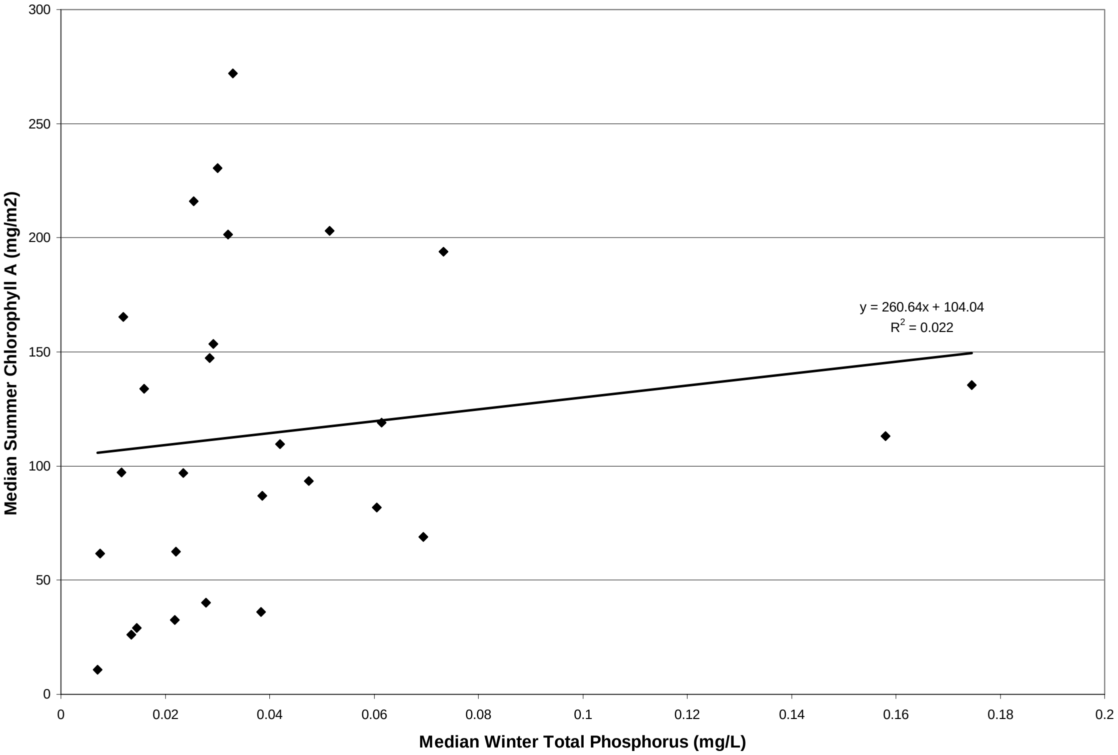


Figure 36. Chlorophyll A and Median Winter TN for all Clark Fork Stations/Years Pooled

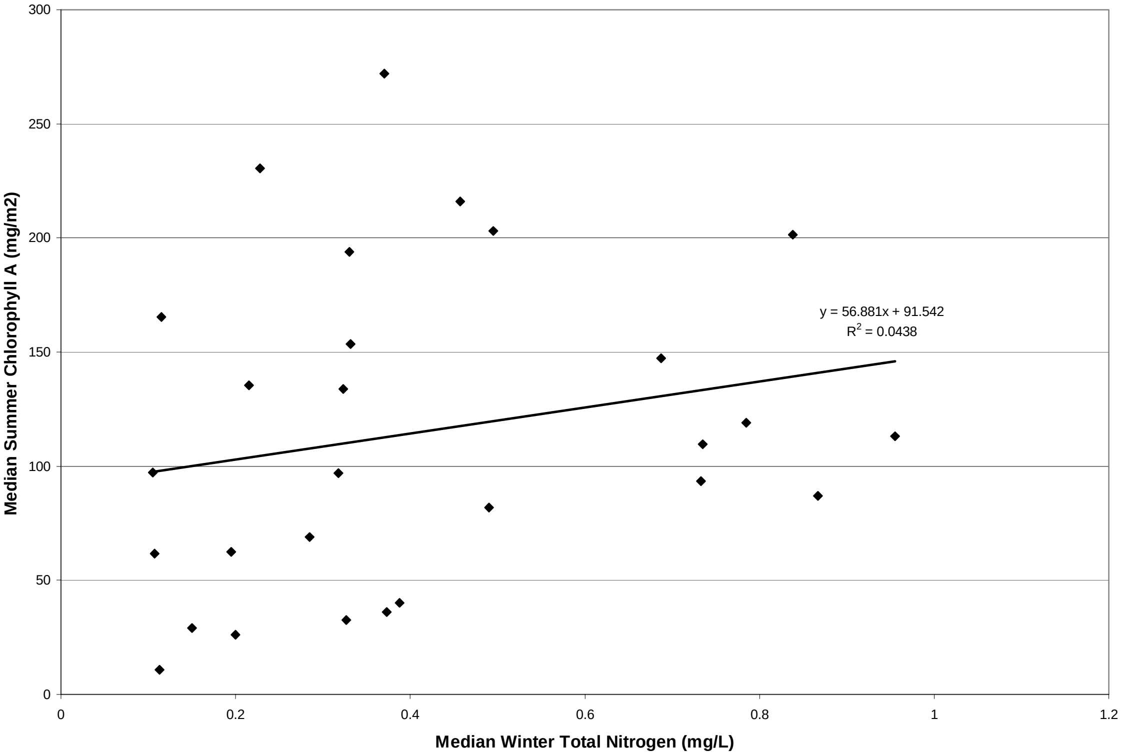


Figure 37. Chlorophyll A and Median Winter TP for all Clark Fork Stations/Stratified

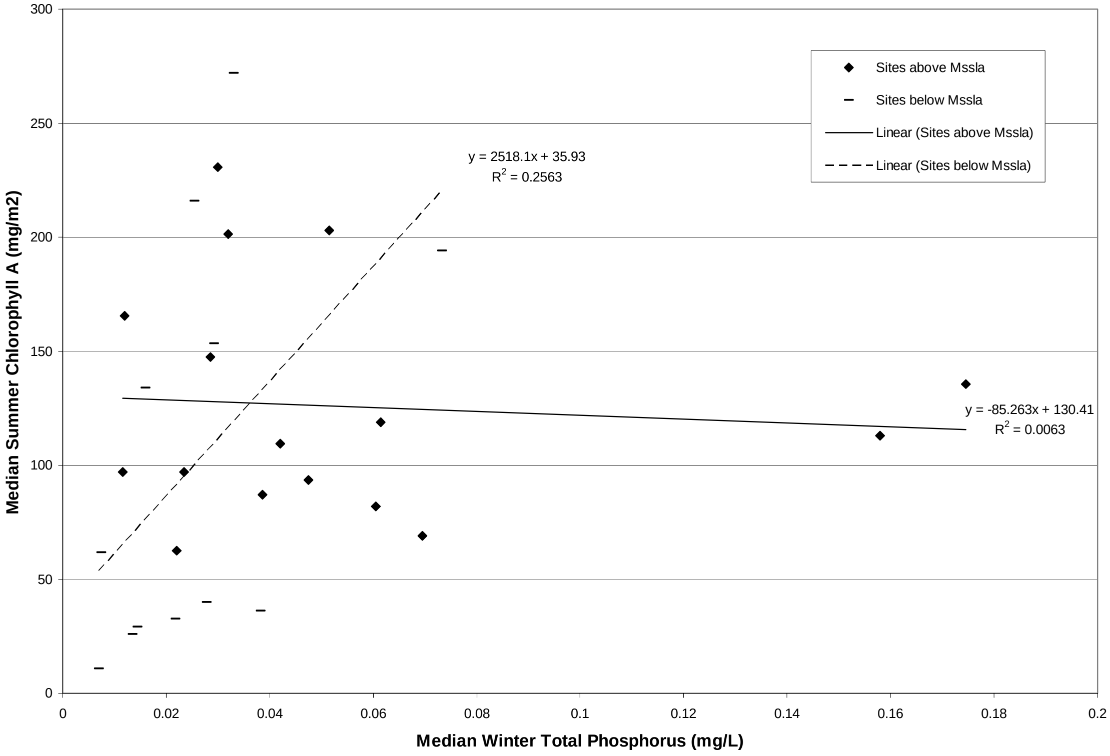
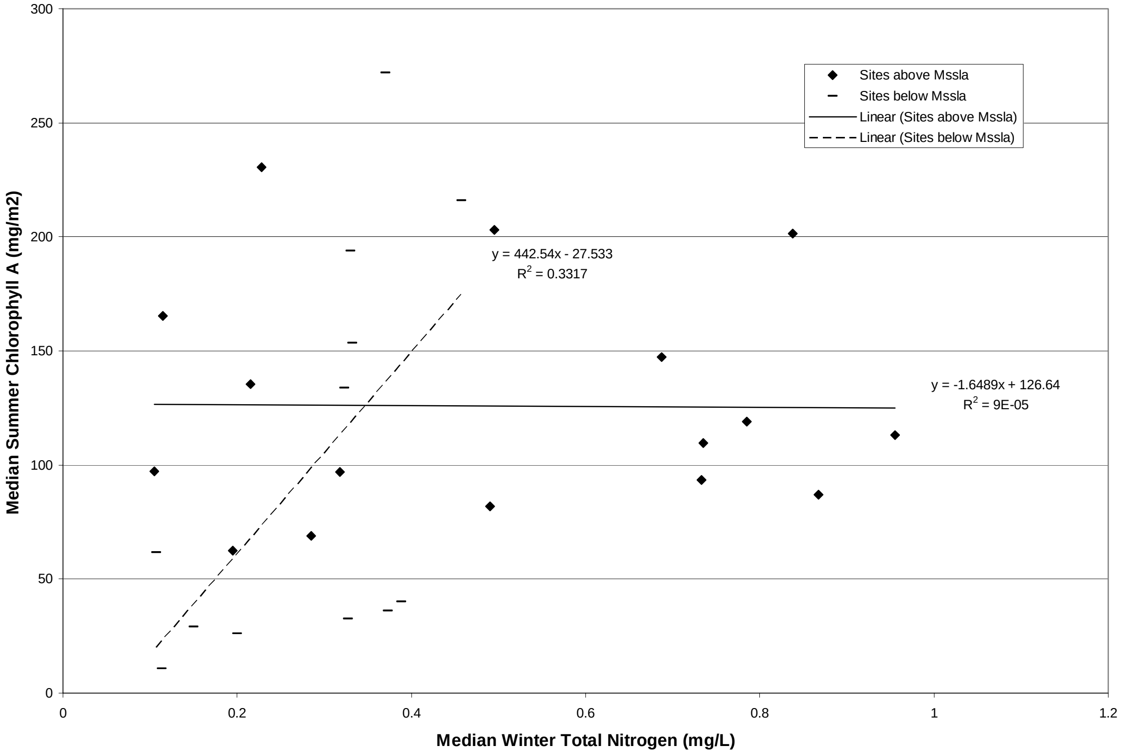


Figure 38. Chlorophyll A and Median Winter TN for all Clark Fork Stations/Stratified



We also investigated the relationship between soluble nutrients and Chl A concentrations during summer and winter months. Generally, median Chl A concentrations were more closely correlated with soluble nutrient concentrations during summer months (**Table 13**), however this relationship was not evident in the winter months. Stratifying the dataset by sites above and below Missoula improved the correlations below Missoula, but once again results in an inverse relationship in the sites above Missoula, with a few exceptions.

Table 13. ***Kendall-Tau Correlations for Median Chl A and Median Nutrient Concentrations***

Station	Summer TP	Summer TN	Summer SRP	Summer TSIN	Winter TP	Winter TN	Winter SRP	Winter TSIN
Sites above Missoula	-0.105	-0.181	-0.480	0.449 *	-0.061	-0.152	-0.046	-0.121
Sites below Missoula	0.515 **	0.364 *	0.556 **	0.391 *	0.350	0.293	0.276	0.217
All River Sites	0.306 *	0.328 **	0.359 **	0.325 **	0.265 *	0.217	0.187	0.212

** = significant at the 0.01 level
* = significant at the 0.05 level

The year-to-year variability and differences between stations preclude a simple analysis relating nutrient concentrations to algal standing crop. Although algae levels can be predicted from nutrient treatments in a controlled laboratory experiment (where all other factors influencing algae growth are held constant), a strong correlation is not expected between algae and nutrient levels in the river where many other variables confound the response. Numerous dynamic factors interact to determine biomass results, including annual runoff regime, periphyton community structure and dynamics, substrate characteristics, stressors, N:P ratio, temporal variability in algal standing crop and nutrients, and others.

In 1995, the Nutrient Target Subcommittee of the Tri-State Water Quality Council established the Voluntary Nutrient Reduction Program (VNRP) to establish in-stream nutrient targets and implement a basin-wide nutrient reduction program to meet those targets. The subcommittee agreed on setting primary targets for total nitrogen and total phosphorus, and secondary targets for soluble inorganic nitrogen and soluble reactive phosphate. Although our findings suggest that algal growth in the Clark Fork River is more closely correlated to soluble nutrients, past research (Dodds and Smith, 1995) suggests that total nutrients are a better predictor of Chl A than soluble nutrients. Based on Dodd's work, VNRP targets were established for total nutrients.

A strong correlation between nutrients and algae is challenging to demonstrate based on limited sampling at any one site or year. Nevertheless, it is apparent from reviewing plots of nutrients and periphyton that algal biomass does track with TN, TP and other nutrient components when all data are pooled. Box plots for individual stations showing summer TP and TN versus Chl A and AFDW demonstrate that algal biomass and nutrient concentrations generally correlate well in a spatial sense over the period of record.

Total phosphorus and total nitrogen tracked well with periphyton metrics (**Figures 39-42**). An exception to this was TP and Chl A at the Clark Fork River sites above Little Blackfoot and at Bonita (**Figure 39**). These sites frequently had cladophora dominated periphyton communities and tend to peak before the sampling events in August and September. The median N:P ratio at the Clark Fork River site above the Little Blackfoot River was 6.9, indicating that this site was likely approaching nitrogen-limitation. Although this site had the highest median summer TP value, nitrogen limitation may help explain the lack of correspondence between algal metrics and TP. Median values for summer N:P ratios ranged from about 7 to 14 at other summer monitoring sites. N:P ratios exceeding 15 constituted fewer than 25% of all individual observations (**Figure 43**).

Figure 39. Chlorophyll A and Median Summer TP for all Clark Fork Stations/Years Pooled

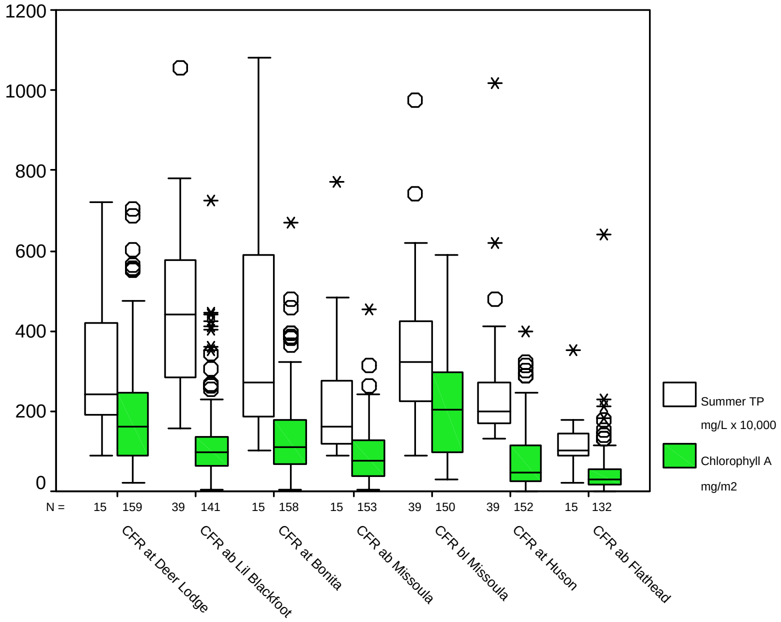


Figure 40. Chlorophyll Aand Median Summer TN for all Clark Fork Stations/Years Pooled

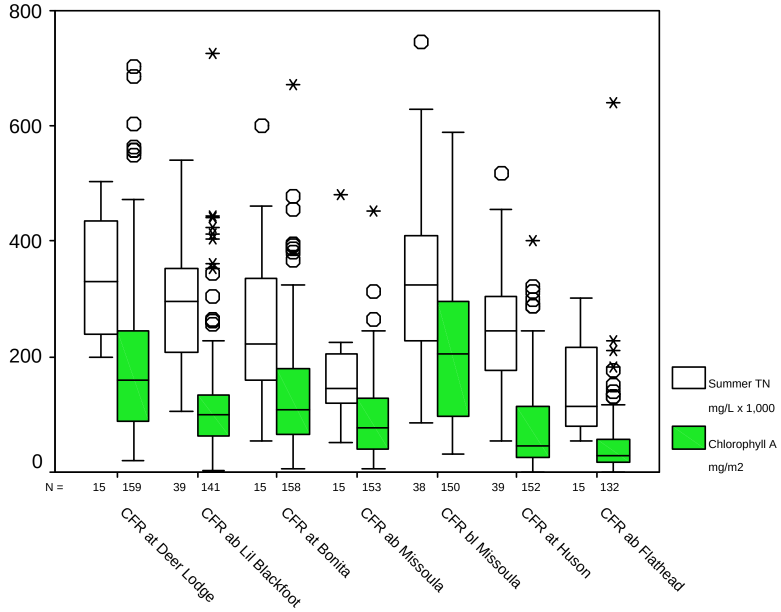


Figure 41. AFDW and Median Summer TP for all Clark Fork Stations/Years Pooled

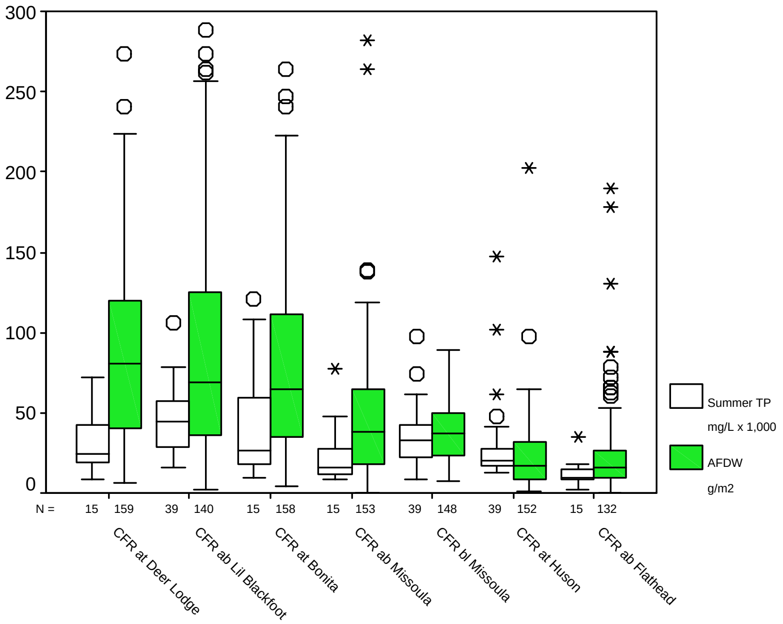


Figure 42. AFDW and Median Summer TN for all Clark Fork Stations/Years Pooled

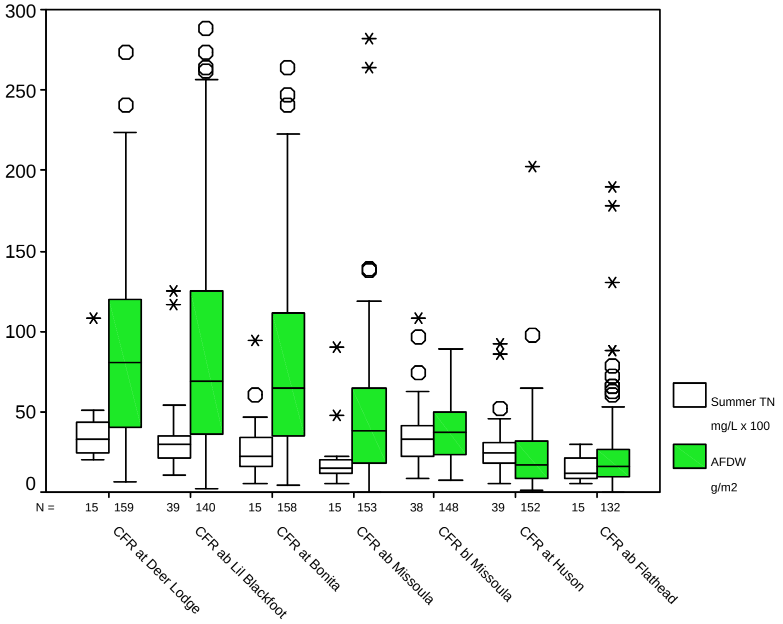
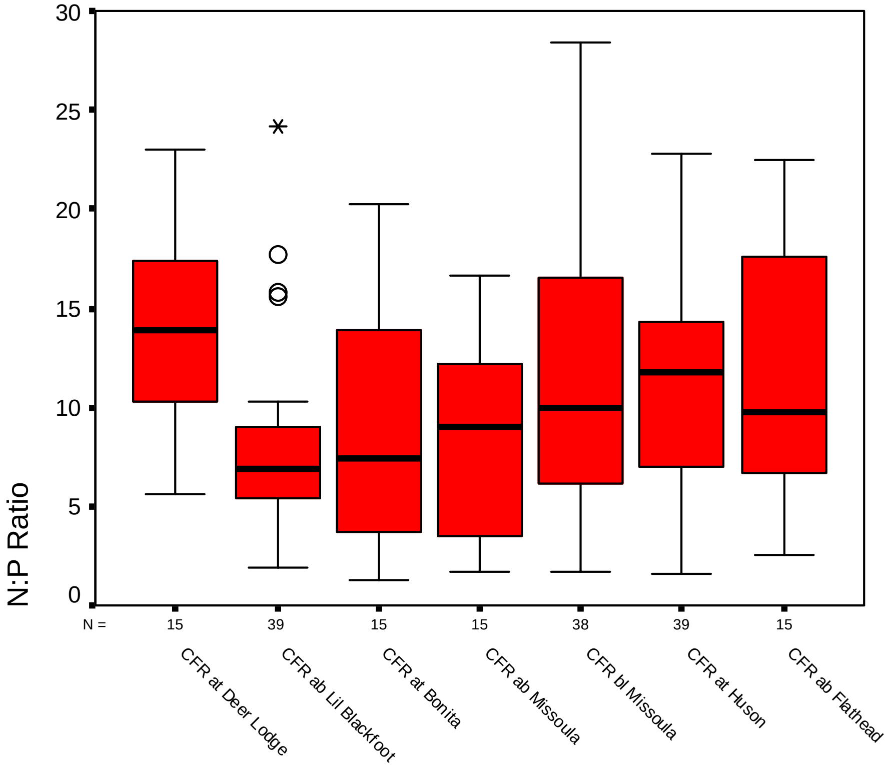


Figure 43. N:P Ratio for Summer Period



The relationship between soluble and total nutrients during summer months was also investigated. To avoid using nutrient samples that were not field filtered, we selected only data from 1987-2002 for this analysis. Although the data is quite variable throughout the watershed, there are some obvious temporal patterns with regards to the ratios of SRP:TP and TSIN:TN.

In the Silver Bow Creek sites, the ratio of SRP:TP has been steadily increasing throughout the study period (**Figure 44**). Both constituents exhibit statistically significant increasing trends at the Silver Bow sites, but the magnitude of increase is greater for the soluble component of phosphorus. At several middle watershed sites, the ratio decreases from 1988-1998, but increases over the final years of the study period (**Figure 45**). This increase may be a result of greater groundwater influence during low water years, yielding a rise in soluble phosphorus. Several sites in the lower watershed also exhibited this trend, notably the Clark Fork River site at Noxon (**Figure 46**).

In general, the ratio of TSIN:TN has been increasing throughout the watershed. The trend is less apparent in the upper watershed, but becomes more obvious downstream, as displayed at the Clark Fork River site above Missoula (**Figure 47**). This trend also appears in the lower watershed, notably the Clark Fork River below Cabinet Gorge Dam (**Figure 48**), and in tributary sites such as the Blackfoot River (**Figure 49**). It should be noted that fourteen sites exhibited statistically significant increasing trends for TSIN, while fifteen sites exhibited significant decreasing trends for TN.

Figure 44. Silver Bow Creek above WWTP – SRP:TP, 1988-2002

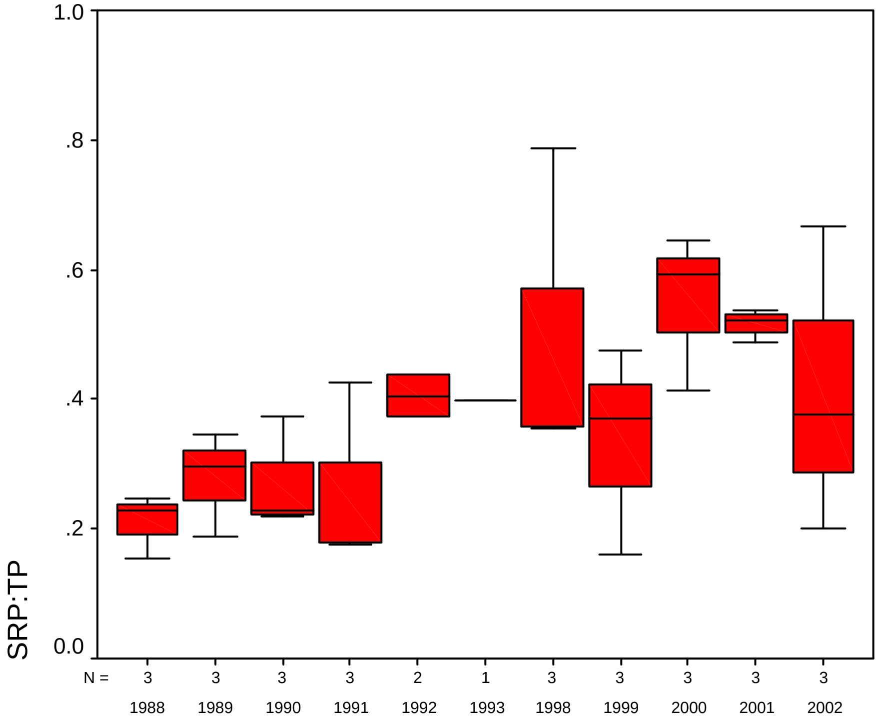


Figure 45. Clark Fork River at Gold Creek – SRP:TP, 1987-2002

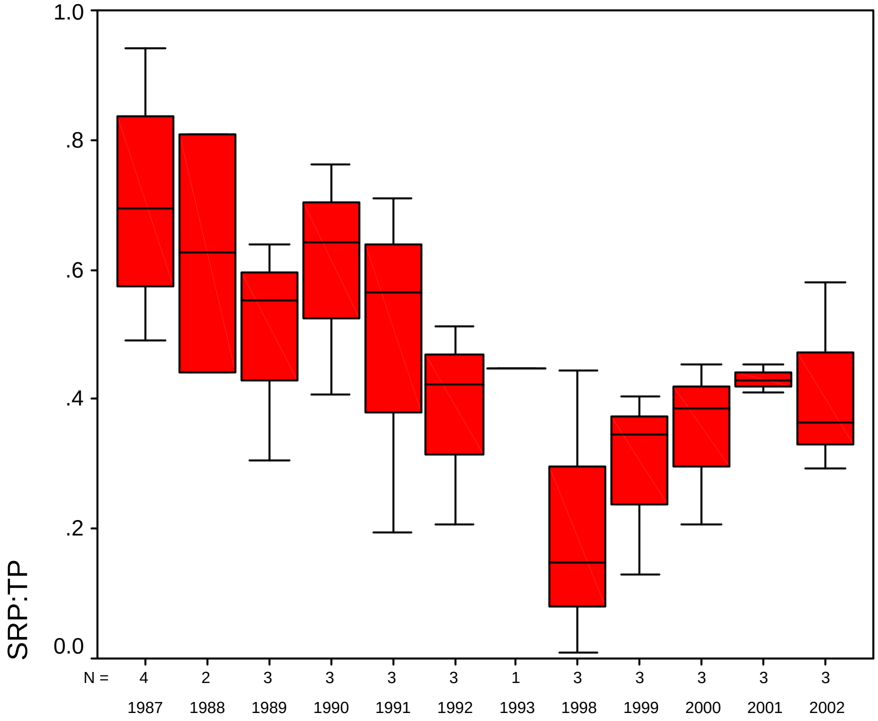


Figure 46. Clark Fork River at Noxon – SRP:TP, 1987-2002

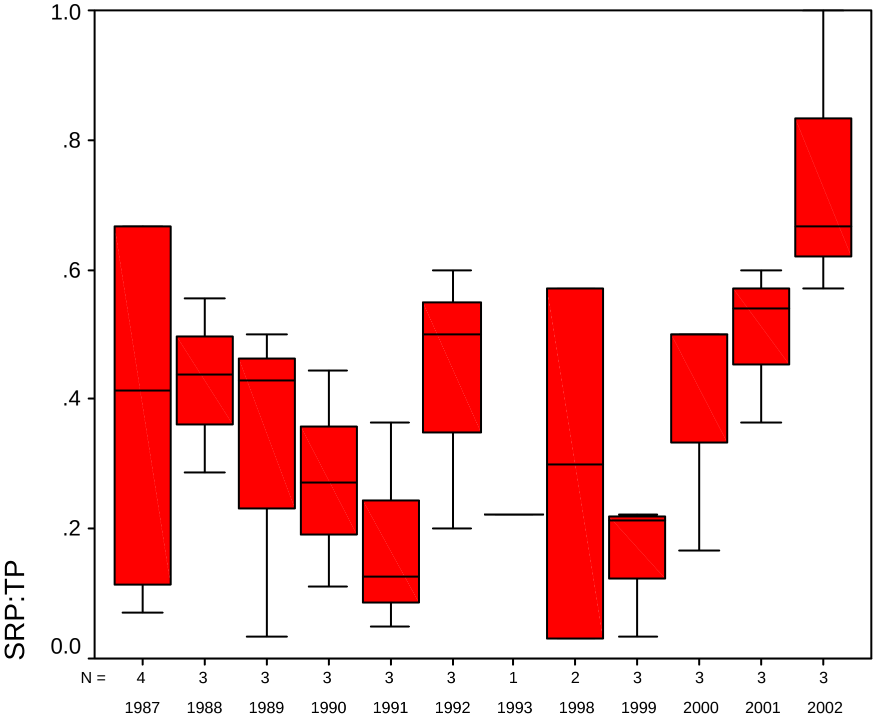


Figure 47. Clark Fork River above Missoula – TSIN:TN, 1989-2002

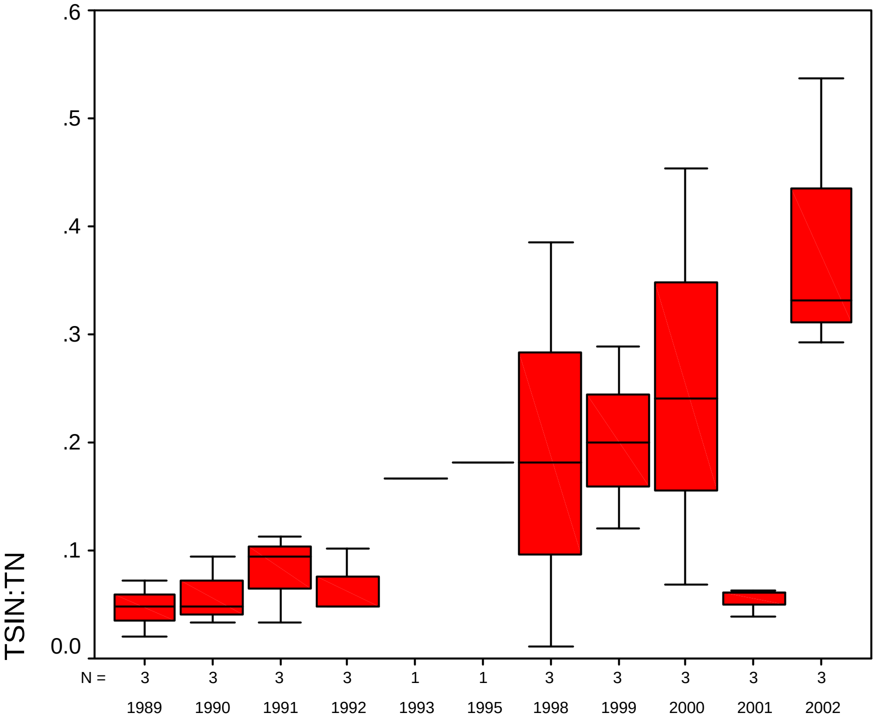


Figure 48. Clark Fork River below Cabinet Gorge Dam – TSIN:TN, 1987-2002

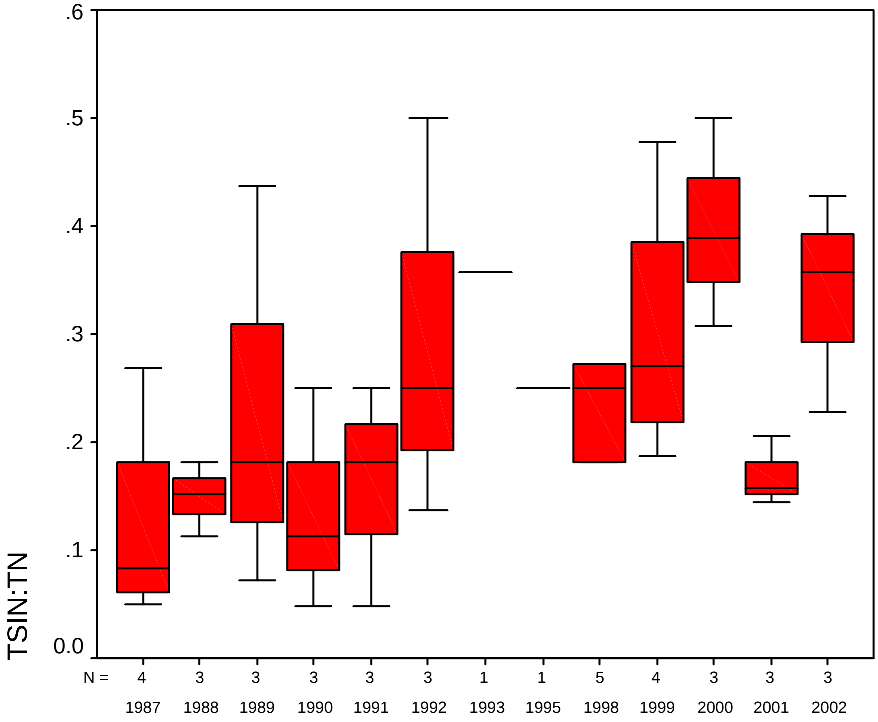
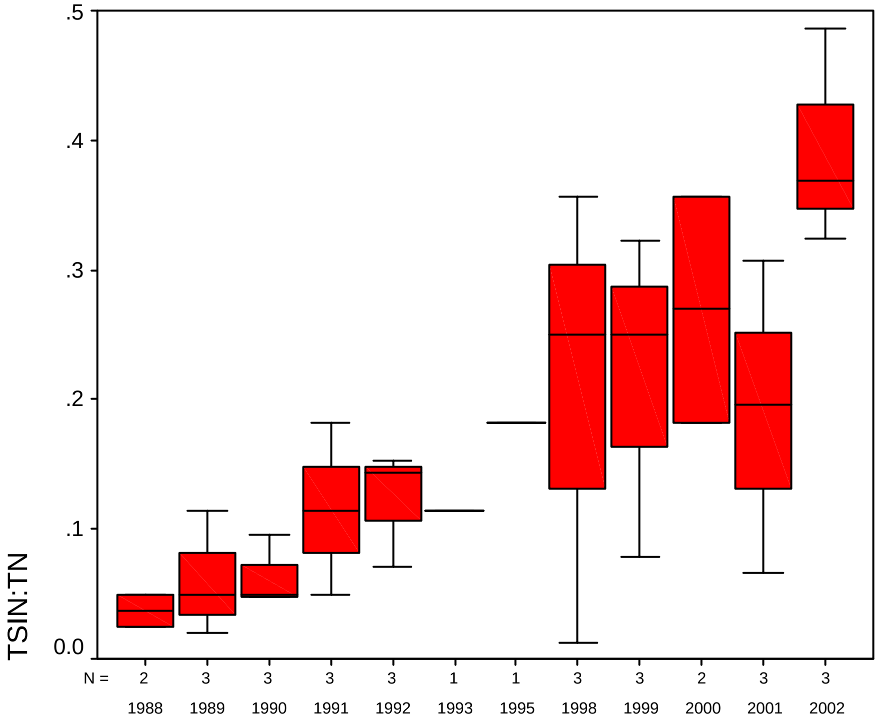


Figure 49. Blackfoot River near mouth – TSIN:TN, 1988-2002



5.0 LAKE PEND OREILLE PERIPHYTON

Five Lake Pend Oreille (LPO) stations were monitored from 1998-2002 for periphyton (**Appendix A, Figure 5**). The sites included Bayview, Kootenai, Springy Point, Sunnyside, and Trestle. Ten replicate samples were collected in each sampling event at each station and were analyzed for three algal constituents:

- Chlorophyll A (Chl A) (mg/m^2)
- Ash Free Dry Weight (AFDW) (g/m^2)
- Secchi Disk Depth (m)

Lake Pend Oreille periphyton samples were collected in September only. Secchi disk readings were taken at three locations on Lake Pend Oreille (**Appendix A, Figure 5**).

5.1 Spatial Distribution of Nearshore Periphyton

The spatial distribution of Chl A and AFDW in Lake Pend Oreille was documented in previous annual reports (e.g. Land & Water 2002). Bayview and Trestle sites have had low median values for Chl A (3 and 3.5 mg/m2) and AFDW (4.3 and 4.0 g/m2) historically (**Figures 50-51**). The Kootenai site has been generally low until recently, with median Chl A of 6.0 mg/m2 and AFDW of 6.5 g/m2 (1998-2002).

Figure 50. Spatial Distribution of Chl A in Lake Pend Oreille from 1998-2002

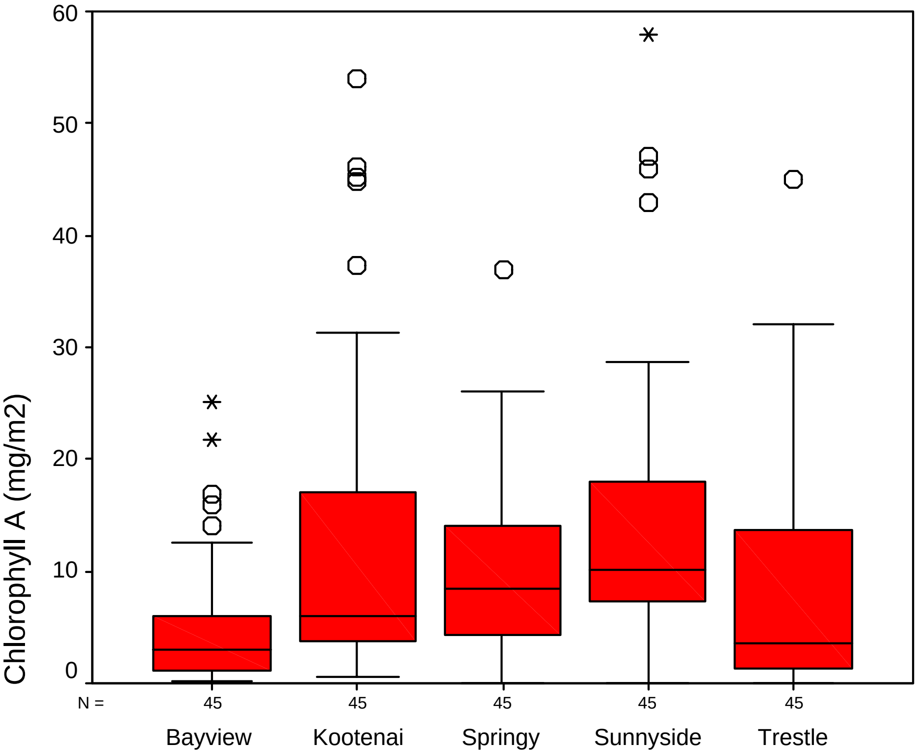
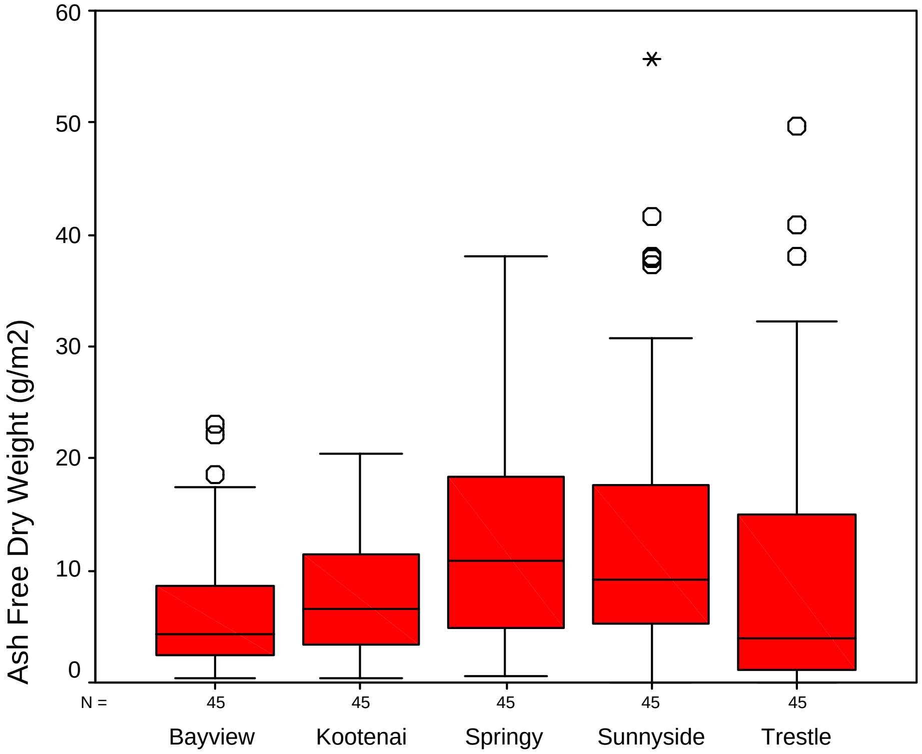


Figure 51. Spatial Distribution of AFDW in Lake Pend Oreille from 1998-2002



5.2 Temporal Trends for Nearshore Periphyton

Five stations on Lake Pend Oreille were sampled each September from 1998-2002 to document status and trends in nearshore periphyton. Ten replicate samples were collected from natural substrate during each sampling event. Temporal boxplots Lake Pend Oreille periphyton data show changes over time (**Appendix G**).

Statistically significant trends in attached algae metrics were noted at most monitoring sites with the exception of Sunnyside (**Table 14**).

Table 14. ***Statistically Significant (0.05) Trends in Chl A and AFDW at LPO Nearshore Sites***

Site	Trend in Chlorophyll A	Trend in Ash Free Dry Weight
Bayview	Decreasing	Decreasing
Kootenai	Increasing	Increasing
Springy Point	None	Decreasing
Sunnyside	None	None
Trestle	Decreasing	Decreasing

The Kootenai site showed a statistically significant increase in Chl A concentration over the five year period. The magnitude of the increase is notable, with Kootenai showing an order of magnitude change from a median value of 2.8 mg/m^2 in 2000 to a median of 34.4 mg/m^2 in 2002.

The Bayview and Trestle sites had a decreasing trend in Chl A, while Springy Point and Sunnyside showed no trend.

Trends in AFDW were detected at all sites except Sunnyside. Kootenai had an increasing trend in AFDW, while Bayview and Trestle had decreasing trends. Springy Point also displayed a decreasing trend for AFDW, although no trend was detected for Chl A.

Median values of Chl A and AFDW were at their lowest in 2002 at the Bayview and Trestle sites (**Figures 52 and 56**). Kootenai and Springy Point both had their highest median Chl A values in 2002 (**Figures 53-54**). Median Chl A values in 2002 were comparable to previous years at the Sunnyside site (**Figure 55**). For the entire period of record (1998-2002), the Sunnyside site has the highest mean Chl A value (10.2 mg/m^2), while the Springy Point site has the highest median AFDW value (10.9 g/m^2).

Overall, the Trestle and Bayview sites have shown the lowest periphyton values from 1998-2002. Periphyton either remained unchanged or decreased during the monitoring period at four of the five sites. The increasing trend in periphyton observed at the Kootenai site suggests the possibility that significant changes in water quality or other factors may be occurring. Additional investigation may be warranted, including a review of sampling methodology, site specific temporal effects, anthropogenic nutrient sources, or other factors.

Figure 52. Temporal Trend in Chlorophyll A, Bayview Site

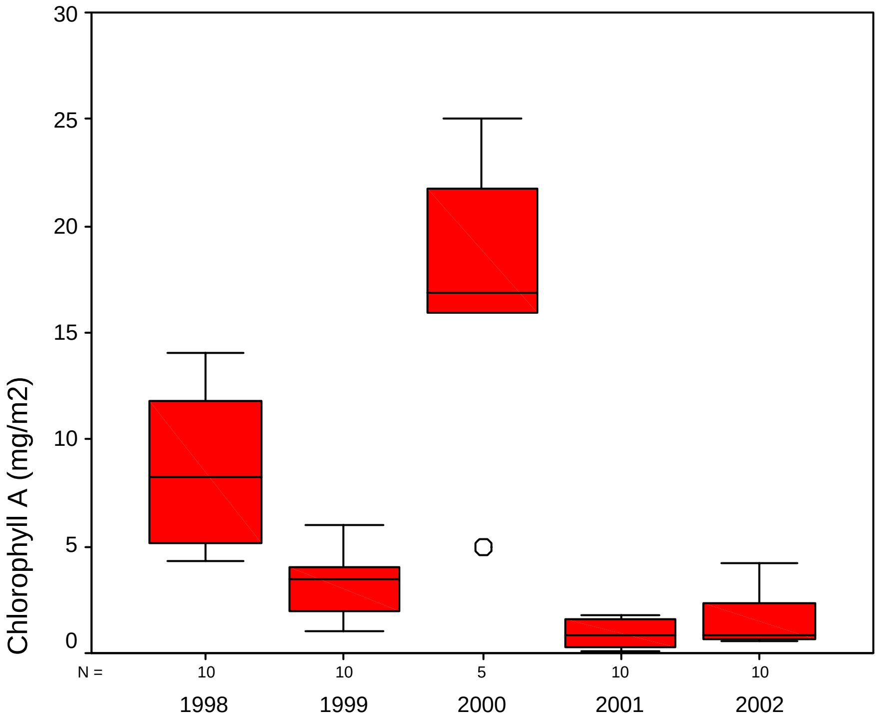


Figure 53. Temporal Trend in Chlorophyll A, Kootenai Site

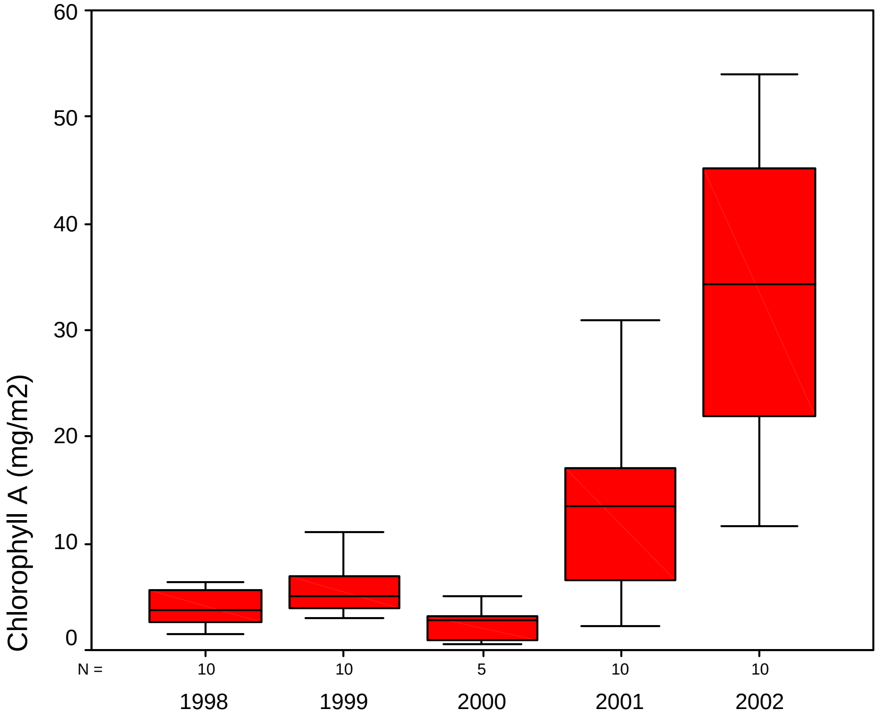


Figure 54. Temporal Trend in Chlorophyll A, Springy Point Site

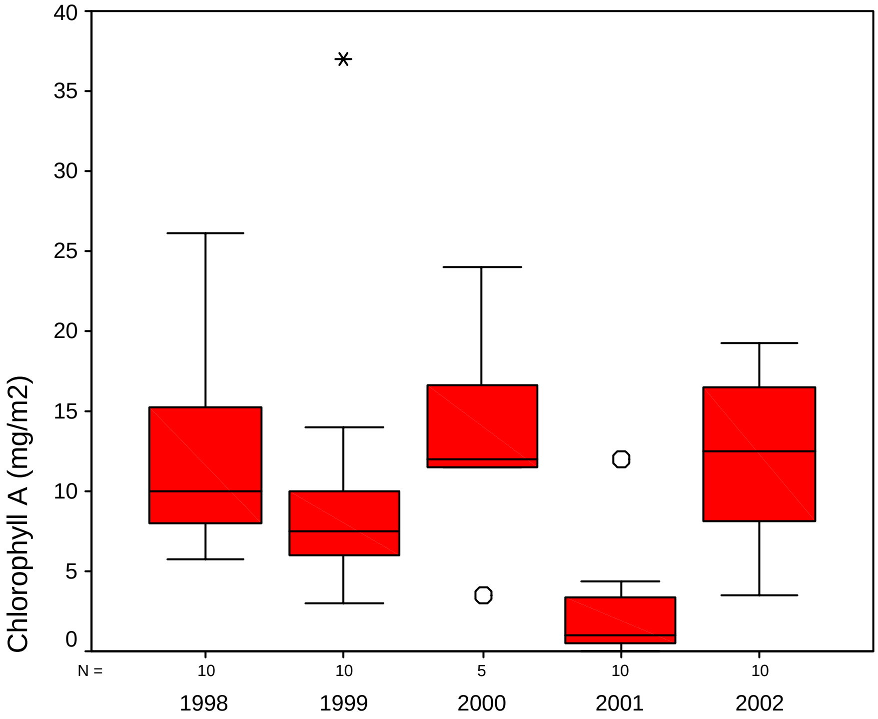


Figure 55. Temporal Trend in Chlorophyll A, Sunnyside Site

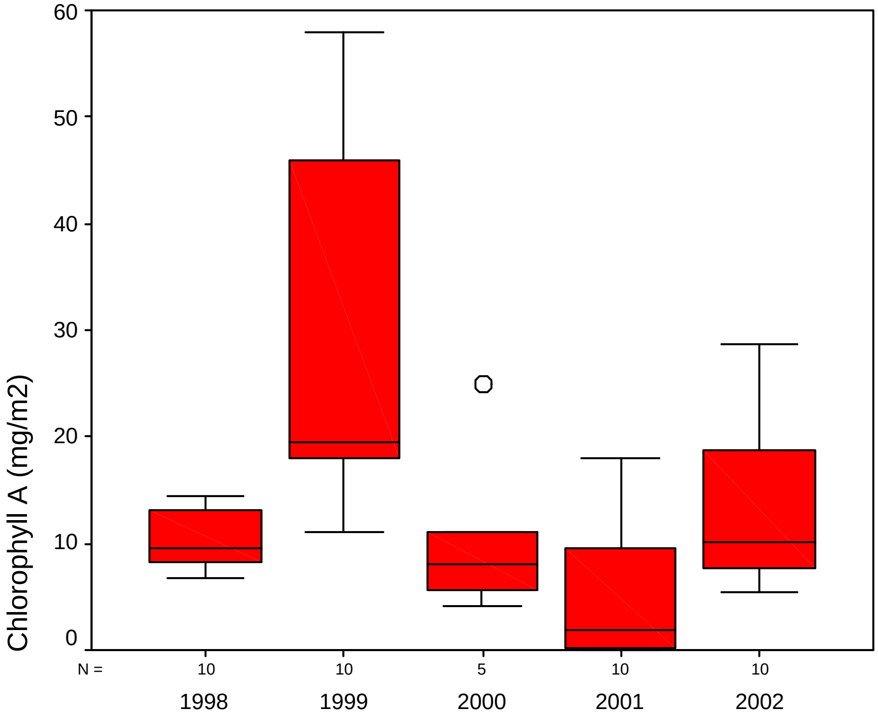
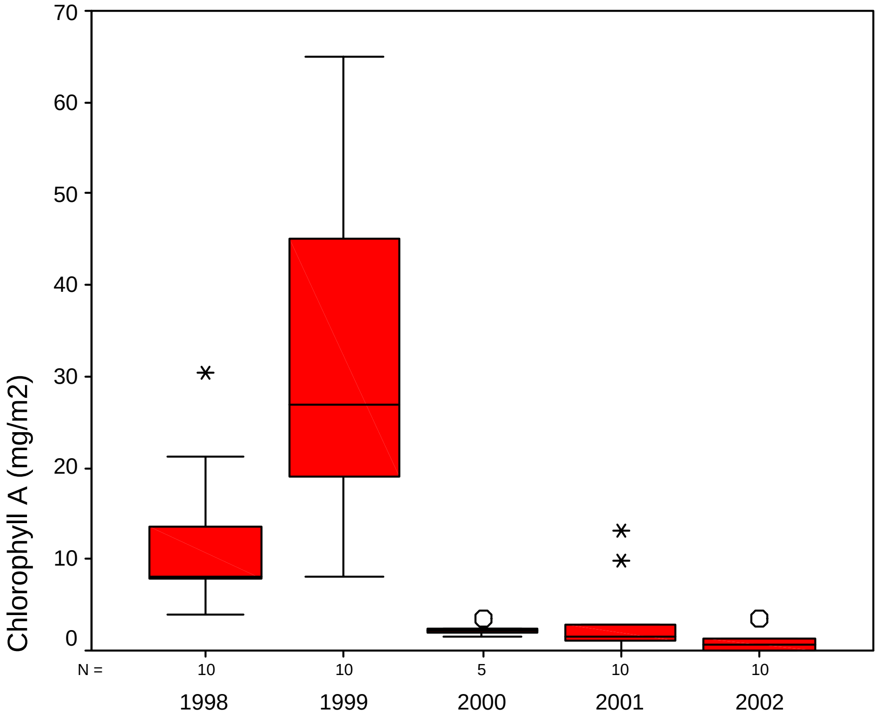


Figure 56. Temporal Trend in Chlorophyll A, Trestle Site

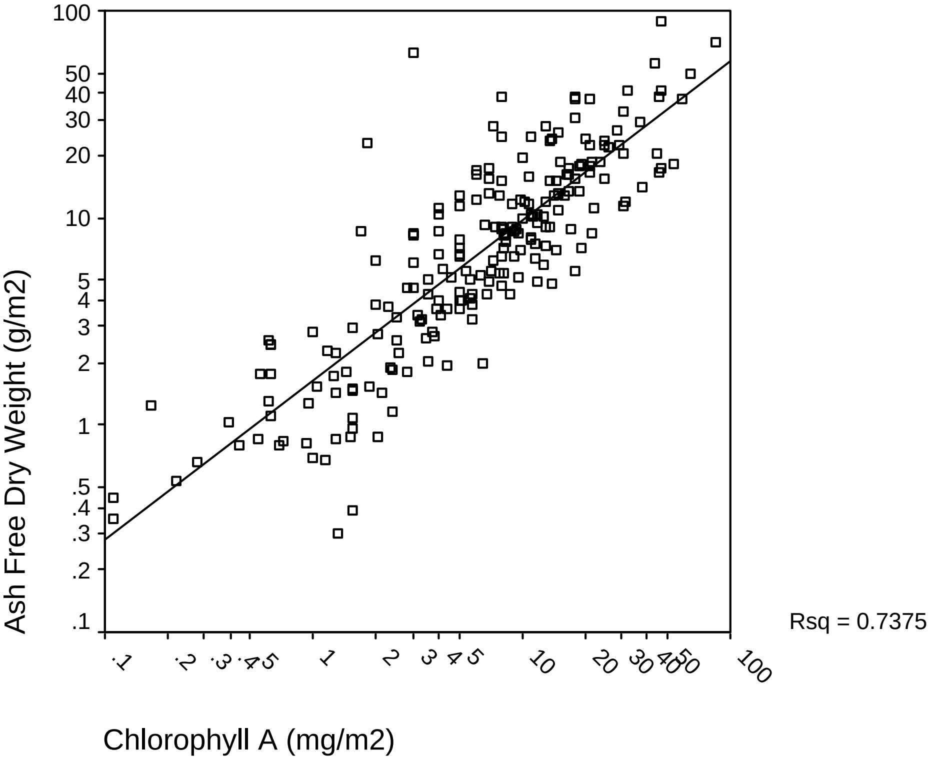


5.3 Lake Pend Oreille Chlorophyll A and Ash Free Dry Weight Correlations

The relationship between Chl A and AFDW for Lake Pend Oreille stations was investigated. The correlation between Chl A and AFDW was fairly strong for nearshore periphyton (**Figure 57**). Data are presented on a log-log scale, and the linear relationship implies a power function $Y=aX^b$, where Y is AFDW, X is Chlorophyll A, b is the slope of the log-log regression, and a is the intercept (antilog of log-log regression).

It should be noted that variability of AFDW encompasses nearly an order of magnitude for any given value of Chlorophyll A. This suggests that like the Clark Fork River periphyton metrics, Lake Pend Oreille metrics also have significant factors influencing the AFDW/Chl A correlation.

Figure 57. AFDW as a Function of Chlorophyll A at LPO Nearshore Stations



6.0 LAKE PEND OREILLE NUTRIENT LOADING

Nutrient loading into Lake Pend Oreille was evaluated using a US Army Corps of Engineers computer model (FLUX), one of three models that make up the BATHTUB Eutrophication model (Walker 1999). The Clark Fork River provides more than 90% of Lake Pend Oreille's water and 75 % of its total nutrient loading (Tri-State 1998). Daily flow values were taken at the USGS gauging station on the Clark Fork River less than one mile below Cabinet Gorge Dam, and grab samples were gathered by the State of Montana (MDHES) and the Tri-State Water Quality Council (Tri-State). Nutrients (total nitrogen, total soluble inorganic nitrogen, total phosphorus, and soluble reactive phosphate) were sampled by MDHES monthly from July 1984 through August 1993. The Tri State Water Quality Council sampled monthly at the same locations starting in June 1998. During high river flows (June and part of July) additional samples were taken by both organizations. This resulted in 18 samples annually. These data were used in the model to determine annual loading to Lake Pend Oreille from 1984 through 2002.

The model used grab-sample nutrient concentrations, corresponding flow measurements and complete flow records for the period of interest. The FLUX model uses six calculation techniques to map the flow/concentration relationship developed from the sample record onto the entire flow record. Method 2, *Flow-Weighted Concentration (Ratio Estimate)*, routinely had lower coefficients of variation than other methods and therefore was the method used in this study.

Method 2 – Flow-Weighted Concentration (Ratio Estimate)

$$W_2 = W_1 \text{ Mean}(Q_j)/\text{Mean}(q_i)$$

where $W_1 = \text{Mean}(w_i)$

w_i =measured flux during sample i = $q_i\ c_i$ (kg/year)

q_i =measured flow during sample i (hm^3/year)

c_i = measured concentration in sample i (mg/m^3)

Q_j = mean flow on day j (hm^3/year)

Sample concentrations in mg/L were converted to mg/m^3.
Flows in CFS were converted to hm^3/year (cubic hectometers per year) (Walker 1999).

Annual loadings for each constituent were calculated using monthly nutrient concentrations and daily flow volumes (**Table 15**). The FLUX model uses the average constituent concentration for those months without a sampling event. Constituents with a laboratory value below equipment detection limits were given a value of one-half the detection limit for statistical purposes. The flow data was stratified to give better estimates of loadings. These stratifications were developed by the model (separated at QMEAN) to lower the coefficient of variation (CV) for the loading calculations.

Trend analysis of nutrient load indicated that only TSIN showed a statistically significant increasing trend. Other constituents did not have significant trends. It should be noted that the

Cabinet Gorge Station did have a statistically significant increasing trend for TSIN concentration, but a decreasing trend for TN concentration (see **Figure 12**).

Table 15. ***Estimated Lake Pend Oreille Nutrient Loads via Clark Fork River***

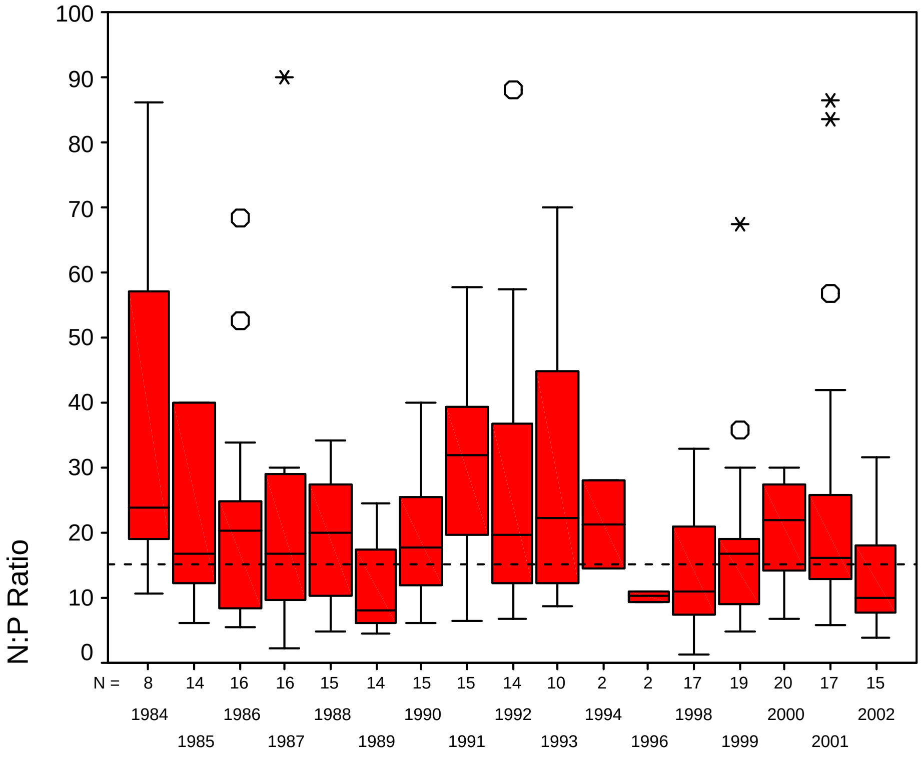
Year	Volume (hm3)	% of Avg Yr (1929-2001)	TN (kg)	TSIN (kg)	SRP (kg)	TP (kg)
1984	17757	92	3848221	398770	48558	114323
1985	17734	93	2708498	587844	44737	175517
1986	18642	97	3455848	584845	142102	279554
1987	13794	72	2683650	424370	18607	142012
1988	12951	67	1960940	353015	20760	110215
1989	18915	99	2715963	759911	49191	286132
1990	22120	115	4101743	810517	48041	213426
1991	23085	121	6672667	759218	40830	241701
1992	12177	63	2085298	529494	15140	92221
1993	16178	84	4276937	784406	23502	147237
1994	11848	62				
1995	18282	95				
1996	28219	147				
1997	30288	158				
1998	16992	89	1932514	689760	81767	203518
1999	19637	102	3355667	1275591	104406	261233
2000	16105	84	1891669	1005887	27793	103664
2001	9739	51	1484484	477131	20602	82860
2002	20115	105	2028364	1365497	34516	219493
Average	18,136		3,013,498	720,417	48,037	178,207
Median	17,757		2,708,498	689,760	40,830	175,517

In September 2001, the Tri-State Water Quality Council recommended nutrient targets and apportioning loads to Lake Pend Oreille for an agreement between the states of Montana and Idaho (Tri-State 2001). The targets were developed out of concern for maintaining the water quality of open waters of Pend Oreille Lake. To achieve this goal, an area-weighted euphotic zone concentration target of 7.3 ug/L was recommended for total phosphorus in Lake Pend Oreille. To meet this target, a total load of 328,651 kg/year total phosphorus was recommended to be allocated as follows:

- 259,500 kg/year total phosphorus from Montana (as measured at Clark Fork River below Cabinet Gorge Dam) and,
- 69,151 kg/year total phosphorus from Lake Pend Oreille watershed in Idaho.
- Greater than 15:1 total nitrogen to total phosphorus ratio

The target for total phosphorus load entering Lake Pend Oreille from Montana was exceeded three times over the study period, including 1986, 1989, and 1999. The target for N:P ratio was not met four times over the study period, including 1989, 1996, 1998, and 2002 (**Figure 58**).

Figure 58. Clark Fork River below Cabinet Gorge Dam – N:P Ratio, 1984-2002

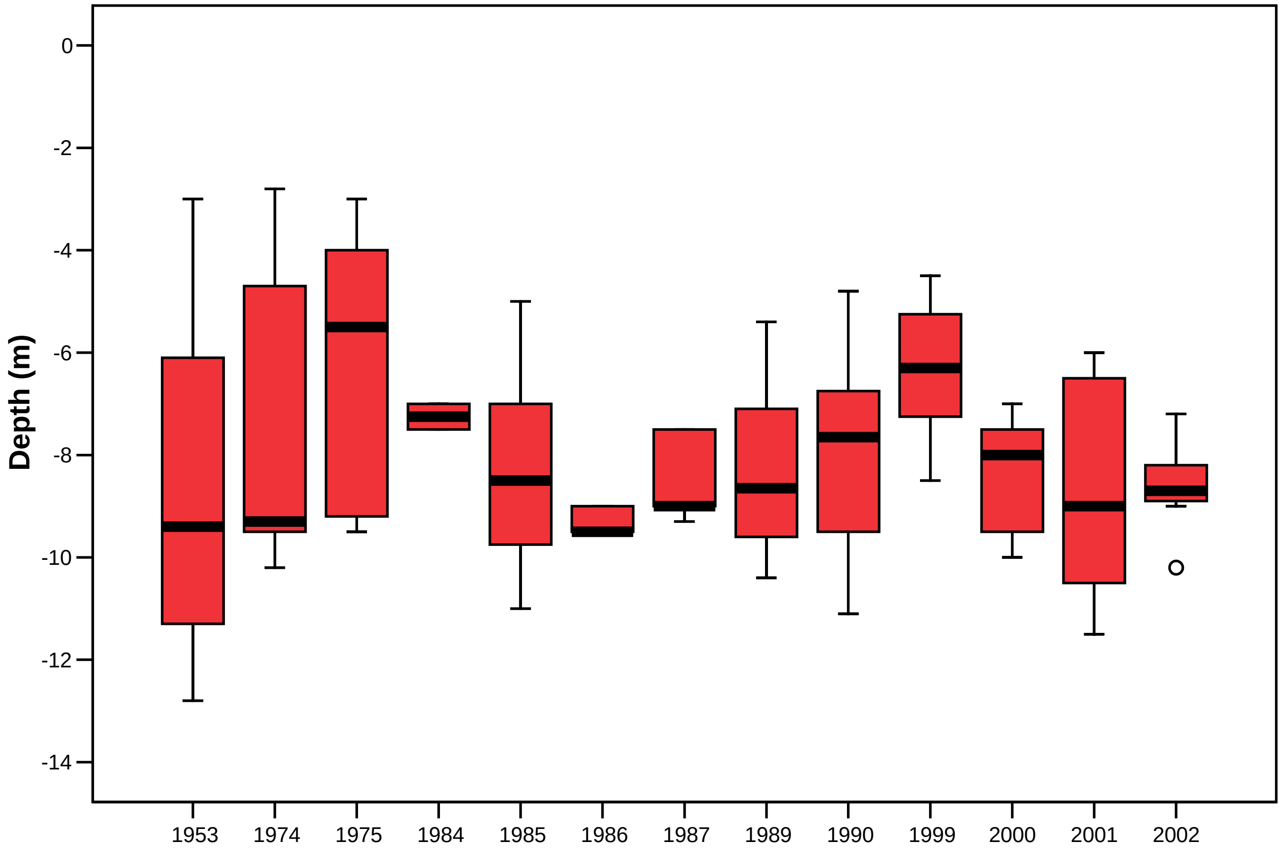


7.0 LAKE PEND OREILLE SECCHI DISK

Secchi disk measurements have been collected on Lake Pend Oreille periodically since 1953. Bayview, Hope and Granite Point stations had over 10 years of historical data, and are currently the stations monitored by the Tri-State Water Quality Council. Temporal boxplots (**Appendix H**) show a fluctuation of median summer Secchi depth with maximum depths in 1953, and minimum depths in 1975 and 1999. Maximum Secchi depths are typically in winter, with minimum depths in spring. The Bayview station has experienced the greatest summer transparency and Hope has shown the least summer transparency.

No trend in summer Secchi disk measures were apparent, either at individual stations, or for all stations pooled (**Figure 59**). No temporal trends were observed at individual stations. This suggested that pelagic water quality and trophic condition remained unchanged in Lake Pend Oreille from the period from 1952-2002.

Figure 59. Lake Pend Oreille Secchi Disk Depth – Summer Months



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