

Trace metal concentrations in surface water of Lake Roosevelt.

Supplemental Report

January 1998 – March 2000

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Prepared for:
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October 2007

Abstract

As an extension of annual limnological sampling done by the Lake Roosevelt Fisheries Evaluation Program 22 water quality constituents including contaminant trace metals were collected and analyzed. Surface water was sampled at various locations across Lake Roosevelt from January 1998 to March 2000. Surface water was analyzed by inductively coupled atomic emission spectrometry, graphite furnace atomic absorption, and cold vapor atomic absorption. Mean relative percent differences for laboratory duplicates ranged from 0.6 to 22% and mean laboratory spike percent recoveries ranged from 91 to 108%. Water transparency was monitored via Secchi depth, photic zone depth, turbidity, and total suspended solids. Transparency was found to generally decrease with spring runoff and be higher at lower reservoir locations. Total recoverable concentrations of arsenic, cadmium, copper, and mercury were frequently below minimum reporting levels. Measurable percentages of those contaminants ranged from 0.2 to 2.7%. High minimum reporting levels resulting in low sample sizes coupled with variable data made identifying spatial, temporal and environmental relationships for those contaminants difficult. High minimum reporting levels made assessment of acute cadmium toxicity criteria, chronic cadmium toxicity criteria and chronic mercury toxicity criteria not possible. Measurable concentrations of total recoverable lead (66%) and zinc (15%) were more frequent. Greater sample sizes of measurable concentrations in lead and zinc allowed for some relationships to be recognized. Unfortunately, some lead samples were potentially contaminated, yet lead concentrations appeared to be higher at Gifford and possibly Evan's Landing as well as higher in the photic zone samples. Lead exceeded toxicity criteria most frequently of contaminants of concern with at least 0.5% and 56.4% exceedances of acute and chronic criteria, respectively. Zinc concentrations were higher at Porcupine Bay and were correlated to Secchi disk transparency, silica concentration, and photic zone depth. Zinc concentrations rarely exceeded acute (0.3%) and chronic (0.8%) toxicity criteria.

Acknowledgements

We would like to acknowledge all Spokane Tribal personnel who took part in the sampling and analysis especially staff with the Spokane Tribal Laboratory (Darren Lantzer and Bruce Bradburn). We would also like to thank those who reviewed the draft report and gave helpful advice. Additionally this research would not have been possible without funding provide by the Bonneville Power Administration.

Table of Contents

Abstract.....	2
Acknowledgements.....	3
Table of Contents.....	4
List of Tables.....	5
List of Figures.....	9
Introduction.....	13
Objectives.....	14
Study Area.....	14
Methods.....	17
Results.....	22
Analytical Sensitivity and Data Quality.....	22
Environmental Variables.....	24
Contaminants of Concern.....	33
Hardness.....	57
Other Elements.....	59
Water Quality Standards.....	65
Discussion.....	68
Summary.....	76
References.....	79
Appendix A.....	83
Appendix B.....	84
Appendix C.....	86

List of Tables

Table 1.	Surface water sampling dates from Lake Roosevelt.....	19
Table 2.	Complete list of sampling locations and rkm numbers.....	20
Table 3.	Complete list of methods and analytes from Lake Roosevelt surface water. ..	20
Table 4.	Mean minimum reporting level (MRL) and ranges. Mean relative percent difference (RPD) between duplicate samples where both samples were above MRL, number of RPD above or below 25%, and total number (N) of RPD calculated. Mean spike percent recovery (SPR) from all quality control samples, number of SPR above or below 25% of 100% recovery. Quality control samples systematically analyzed during processing of Lake Roosevelt surface water samples.	23
Table 5.	Inflow, outflow, water retention time (WRT) descriptive statistics during the study period in Lake Roosevelt. Includes: mean, standard deviation (SD), sample size (n), and ranges split by year.....	24
Table 6.	Mean Secchi disk depth (m), standard deviation (SD), sample size (n), and ranges from Lake Roosevelt grouped by sampling location during the entire study period.....	26
Table 7.	Mean Secchi disk depth (m), standard deviation (SD), sample size (n), and ranges from Lake Roosevelt grouped by month during the entire study period.	27
Table 8.	Correlation matrix of environmental variables from Lake Roosevelt. Italicized red values are significant at $P < 0.05$	28
Table 9.	Mean photic zone depth (m), standard deviation (SD), sample size (n), and ranges from Lake Roosevelt grouped by sampling location during the entire study period.....	29
Table 10.	Mean photic zone depth (m), standard deviation (SD), sample size (n), and ranges from Lake Roosevelt grouped by month during the entire study period.	29
Table 11.	Mean turbidity (NTU), standard deviation (SD), sample size (n), and ranges from Lake Roosevelt grouped by sampling location during the entire study period.	30
Table 12.	Mean turbidity (NTU), standard deviation (SD), sample size (n), and ranges from Lake Roosevelt grouped by month during the entire study period.	31

Table 13. Mean total suspended solids (mg l^{-1}), standard deviation (SD), sample size (n), and ranges from Lake Roosevelt grouped by sampling location during the entire study period. Data includes estimated concentrations which were calculated by dividing the minimum reporting limit (MRL) in half. 144 of 608 (23.7%) samples had total suspended solids at or above the MRL..... 31

Table 14. Mean total suspended solids (mg l^{-1}), standard deviation (SD), sample size (n), and ranges from Lake Roosevelt grouped by month during the entire study period. Data includes estimated concentrations which were calculated by dividing the minimum reporting limit (MRL) in half. 144 of 608 (23.7%) samples had total suspended solids at or above the MRL..... 32

Table 15. Mean, median, standard deviation (SD), sample size (n), ranges, and coefficients of variation (CV) for total recoverable arsenic, cadmium, copper, lead, mercury, and zinc concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water. Data includes only measurable concentrations. 33

Table 16. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable arsenic concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by sampling location. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 15 of 608 (2.5%) samples had arsenic at or above the MRL. 34

Table 17. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable arsenic concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by month. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 15 of 608 (2.5%) samples had arsenic at or above the MRL. 35

Table 18. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable cadmium concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by sampling location. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 8 of 608 (1.3%) samples had cadmium at or above the MRL..... 37

Table 19. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable cadmium concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by month. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 8 of 608 (1.3%) samples had cadmium at or above the MRL..... 38

Table 20. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable copper concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by sampling location. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 14 of 520 (2.7%) samples had copper at or above the MRL..... 40

Table 21. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable copper concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by month. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 14 of 520 (2.7%) samples had copper at or above the MRL.....	41
Table 22. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable lead concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by sampling location. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 402 of 608 (66.1%) samples had lead at or above the MRL.....	44
Table 23. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable lead concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by month. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 402 of 608 (66.1%) samples had lead at or above the MRL.	45
Table 24. Correlation matrix of total recoverable lead concentrations (measurable) from Lake Roosevelt surface water and other environmental variables. Italicized red values are significant at $P < 0.05$	47
Table 25. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable mercury concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by sampling location. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 1 of 545 (0.2%) samples had mercury at or above the MRL.	49
Table 26. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable mercury concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by month. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 1 of 545 (0.2%) samples had mercury at or above the MRL.	50
Table 27. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable zinc concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by sampling location. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 92 of 608 (15.1%) samples had zinc at or above the MRL.	53
Table 28. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable zinc concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by month. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 15 of 608 (15.1%) samples had zinc at or above the MRL.	54

Table 29. Correlation matrix of total recoverable zinc concentrations (measurable) from Lake Roosevelt surface water and other environmental variables (removed one data point with 84 $\mu\text{g l}^{-1}$ zinc because it diminished the correlation with Secchi). Italicized red correlations are significant at $P < 0.05$	56
Table 30. Mean, median, standard deviation (SD), sample size (n), and ranges of hardness concentrations (mg l^{-1}) from Lake Roosevelt surface water grouped by sampling location.	58
Table 31. Mean, median, standard deviation (SD), sample size (n), and ranges of hardness concentrations (mg l^{-1}) from Lake Roosevelt surface water grouped by month.	58
Table 32. Mean, median, standard deviation (SD), sample size (n), and ranges of various element concentrations (total recoverable, $\mu\text{g l}^{-1}$) from Lake Roosevelt surface water. Table includes all data. The last column of table lists the percent of estimated concentrations present in data. Estimated concentrations determined by dividing minimum reporting level in half.	61
Table 33. Mean concentrations (total recoverable, $\mu\text{g l}^{-1}$) of various elements from Lake Roosevelt surface water grouped by location. Table includes all data.	62
Table 34. Mean concentrations (total recoverable, $\mu\text{g l}^{-1}$) of various elements from Lake Roosevelt surface water grouped by month. Table includes all data.	62
Table 35. Mean minimum reporting level (MRL) and water quality criteria from the Spokane Tribe and Washington State (acute and chronic criteria dependent on hardness concentrations except for arsenic and mercury).....	66
Table 36. Number and percent of samples exceeding Spokane Tribe (STI) or Washington State (WA) water quality criteria (acute and chronic). Samples separated into measured (M) and estimated concentrations (E).....	67
Table 37. Mean relative percentages of contaminant element associated with dissolved and particulate portions of whole water observed in Lake Roosevelt (Bortleson et al. 1994).....	74
Table 38. Descriptive statistics including mean, standard deviation (SD), minimum (min), maximum (max), and number (n) for total recoverable and dissolved concentrations of elements of concern.	75
Table 39. Mean photic zone depths (m) during study period in Lake Roosevelt divided by location, year and month.	83

List of Figures

Figure 1. Trace element sampling locations on Lake Roosevelt.....	16
Figure 2. Components and explanation of a box plot as generated by Statistica® 7.1. ...	21
Figure 3. Inflow and outflow from Lake Roosevelt during study period (DART 2005).	25
Figure 4. Water retention time and reservoir elevation from Lake Roosevelt during study period (DART 2005).....	25
Figure 5. Photic zone and Secchi disk depths observed during the study period across all locations on Lake Roosevelt.	27
Figure 6. Turbidity and total suspended solids (TSS) observed during the study period across all locations on Lake Roosevelt. Total suspended solids were not always above MRL so estimated (TSS E) and measured (TSS M) values are noted.....	32
Figure 7. Total recoverable arsenic concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included.	34
Figure 8. Total recoverable arsenic concentrations ($\mu\text{g l}^{-1}$) from all locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included.	35
Figure 9. Total recoverable cadmium concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included (based on standard mean and hardness).	37
Figure 10. Total recoverable cadmium concentrations ($\mu\text{g l}^{-1}$) from all locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included (based on standard mean and hardness).	38
Figure 11. Total recoverable copper concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included (based on standard mean and hardness).	40

Figure 12. Total recoverable copper concentrations ($\mu\text{g l}^{-1}$) from all locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included (based on standard mean and hardness). 41

Figure 13. Total recoverable lead concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included (based on standard mean and hardness). 44

Figure 14. Total recoverable lead concentrations ($\mu\text{g l}^{-1}$) from all locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included (based on standard mean and hardness). 45

Figure 15. Box plots of total recoverable lead concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt (measurable concentrations only) with extreme values noted. 46

Figure 16. Box plots of total recoverable lead concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt (measurable concentrations only). Seven extreme values were removed (17-182 $\mu\text{g l}^{-1}$). 46

Figure 17. Total recoverable mercury concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included. 49

Figure 18. Total recoverable mercury concentrations ($\mu\text{g l}^{-1}$) from all locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included. 50

Figure 19. Total recoverable zinc concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included (based on standard mean and hardness). 53

Figure 20. Total recoverable zinc concentrations ($\mu\text{g l}^{-1}$) from all locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic

toxicity water quality standards also included (based on standard mean and hardness).	54
Figure 21. Box plots of total recoverable zinc concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt (measurable concentrations only) with extreme values noted.	55
Figure 22. Box plots of total recoverable zinc concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt (measurable concentrations only). Two extreme values were removed.....	55
Figure 23. Regression plot of total recoverable zinc concentration (measurable) and Secchi disk depth with one outlier removed (6 m Secchi, $84 \mu\text{g l}^{-1}$ Zn).....	57
Figure 24. Mean hardness on the mainstem and reservoir arms of Lake Roosevelt.	59
Figure 25. Total recoverable nickel concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included (based on standard mean and hardness).	63
Figure 26. Total recoverable nickel concentrations ($\mu\text{g l}^{-1}$) from all locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included (based on standard mean and hardness).	63
Figure 27. Total recoverable selenium concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included.	64
Figure 28. Total recoverable selenium concentrations ($\mu\text{g l}^{-1}$) from all locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included.	64
Figure 29. The high minimum reporting level (MRL) for hypothetical metal concentrations across time obscures temporal patterns and exceedances of chronic and acute toxicity criteria.	74
Figure 30. Simple linear regression of total recoverable lead and total recoverable manganese.	84
Figure 31. Simple linear regression of total recoverable lead and total recoverable iron.	84

Figure 32. Simple linear regression of total recoverable lead and total recoverable magnesium.	85
Figure 33. Simple linear regression of total recoverable lead and aluminum.	85
Figure 34. Simple linear regression of total recoverable zinc and total recoverable manganese.	86
Figure 35. Simple linear regression of total recoverable zinc and total recoverable aluminum.	86
Figure 36. Simple linear regression of total recoverable zinc and total recoverable iron.	87
Figure 37. Simple linear regression of total recoverable zinc and total recoverable magnesium.	87
Figure 38. Simple linear regression of total recoverable zinc and total recoverable lead.	88

Introduction

Previous work has identified trace metal and organic contamination in Lake Roosevelt sediment, surface water and fish (Beckman et al. 1985; Serdar 1993; Bortleson et al. 1994; Munn et al. 1995; Munn and Short 1997; Serdar et al. 1997; EVS 1998; Era and Serdar 2001; Majewski et al. 2003; Cox et al. 2005). About half of the Spokane Tribal Reservation is bordered by Lake Roosevelt (Figure 1). The waters of the Columbia and Spokane River are very important to the Spokane Tribe for cultural, recreational, and economic reasons. Recently, the U. S. Environmental Protection Agency (EPA) has initiated a remedial investigation and feasibility study (RIFS) of trace metal contamination in Lake Roosevelt under the comprehensive environmental response, compensation, and liability act (CH2M 2004).

A suite of elements from Lake Roosevelt surface water were examined in the current study. Arsenic, cadmium, copper, lead, mercury, and zinc were focused on because past work has identified these trace metals as the most concerning (Serdar 1993; Bortleson et al. 1994; Cox et al. 2005). The Spokane Tribe co-manages the Lake Roosevelt fishery and is concerned with how these contaminants may be affecting the biota as well as providing a pathway for human exposure. Since the mid-90's approximately 1 million post smolt kokanee (*Onchorhynchus nerka*) and 500,000 rainbow trout (*Onchorhynchus mykiss*) have been planted in Lake Roosevelt annually. The estimated economic value of the Lake Roosevelt fishery was 11.9 million dollars (U. S.) in 2002 with a total estimated harvest of 430,000 fish (Fields et al. 2005). Potential impacts to fish and other aquatic organisms were evaluated based upon trace metal exceedances of Spokane Tribal or Washington State water quality standards since these standards were developed in part to protect aquatic organism health (STI 2003; WDOE 1997).

Trace metal sampling from surface water in the past has been limited likely due to expense, lack of sensitivity in analysis, and distribution of contaminants. Serdar (1993) implied that resources would be better spent looking directly at contaminant effluents and benthos condition rather than trace metals in the water column. Trace metals are often associated with sediments either suspended or deposited. Yet, Bortleson et al. (1994) reported that since suspended sediment loads in Lake Roosevelt are relatively small, trace

metal concentrations were generally higher in the dissolved phase of whole water samples. As an extension of the annual limnological sampling by the Lake Roosevelt Fisheries Evaluation Program (LRFEP), surface water trace metal sampling was undertaken in an attempt to further contaminant understanding and to supplement the more general fisheries / limnological annual reports (Shields et al. 2002, McLellan et al. 2003, Lee et al. 2003; Scofield et al. 2004). Unfortunately, the trace element data has become dated but in the interest of data sharing this report was undertaken. Defined objectives are listed below.

Objectives

- Report observed element concentrations in surface water of Lake Roosevelt and any distinguishable spatial or temporal trends.
- Relate contaminants of concern with environmental variables.
- Compare trace metal concentrations to Spokane Tribal and Washington State water quality standards.

Study Area

Lake Roosevelt was created by the impoundment of the Columbia River at Grand Coulee Dam in eastern Washington (Figure 1). The reservoir stretches approximately 243 km nearly reaching the Canadian border. The reservoir is relatively deep with a mean and max depth of 36 m and 122 m, respectively at full pool (393 m above mean sea-level). Limnologic conditions vary widely in the reservoir, with dominant lotic processes in the upper reaches, to more lentic characteristics in the lower reaches. The Spokane and Sanpoil Arms are markedly more productive than the mainstem (Columbia) of the reservoir (McLellan et al. 2003; Lee et al. 2003). Overall trophic status in Lake Roosevelt has been classified as meso-oligotrophic (Scofield et al. 2004).

The reservoir has a relatively short water retention time of 40 d and passes large volumes of water (mean annual Columbia River inflow at the Canadian border = 3,116 m³/s). The reservoir is largely operated for flood control, power generation, and recreation. The annual drawdown accommodating spring runoff averages about 15 m and lasts 2 to 3 months. Littoral benthic production is reduced in the drawdown zone because of annual desiccation and the delayed / shortened growing season. Subsequently in areas most

affected by the drawdown, many organisms rely on pelagic production (Black et al. 2003; Scofield et al. 2004). However, in the transitional areas of the upper reservoir where water elevation does not fluctuate as drastically, benthic production is likely of much greater importance as suggested by a preliminary food habits study of juvenile sturgeon (Howell and McLellan 2006).

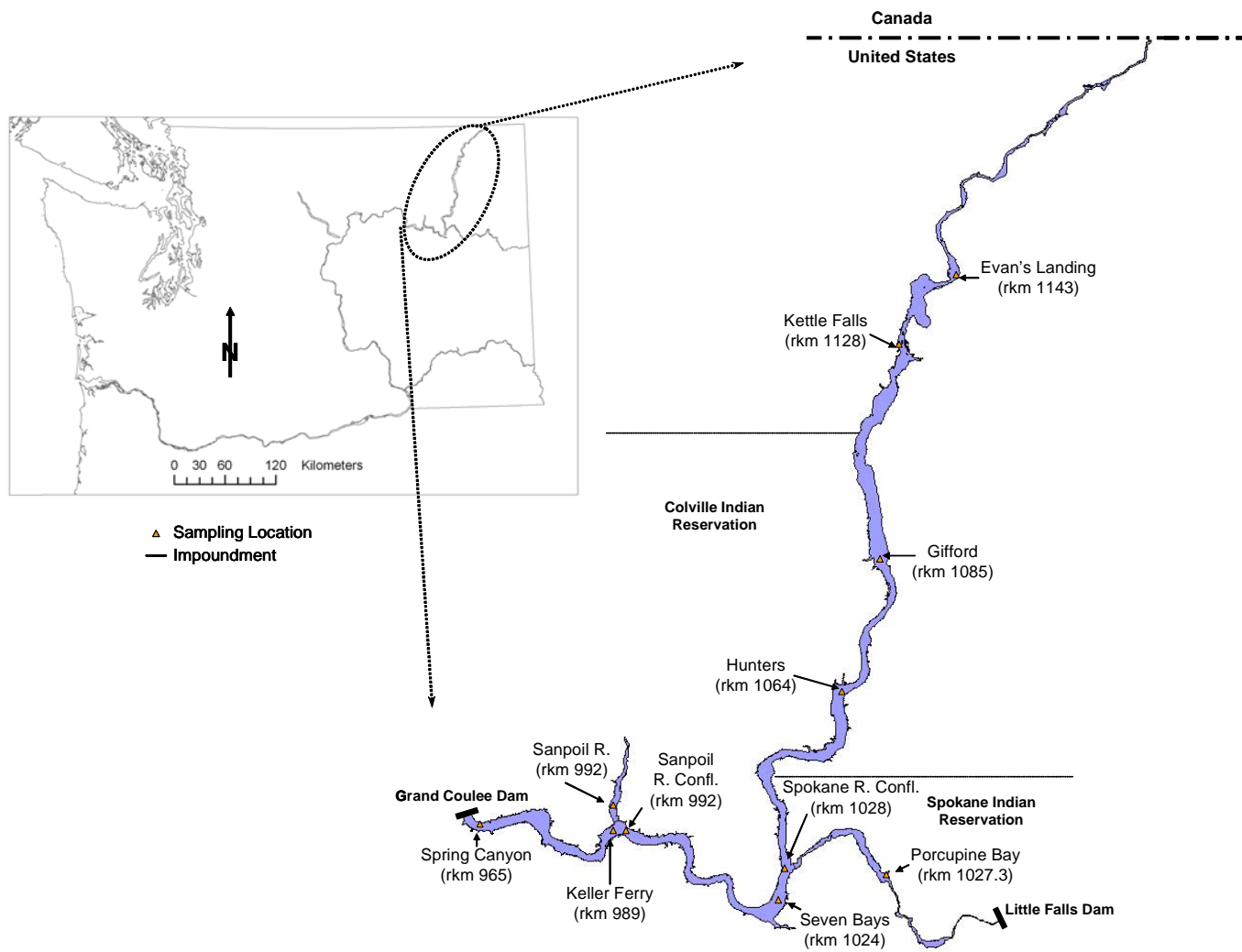


Figure 1. Trace element sampling locations on Lake Roosevelt.

Methods

Various elements were analyzed from surface water collected during 1998, 1999, and 2000 from various locations on Lake Roosevelt (Table 1; Figure 1). Water sampling locations overlap with long term limnologic sampling locations used by the LRFEP. Sampling locations are denoted by name and river km as described in Table 2. Surface water was collected with a Van Dorn bottle (1998) and depth integrated water sampler (1999-2000). Van Dorn samples were taken from mid photic zone depth and 1 m below the photic zone. Van Dorn bottle was weighted with lead cord (lead weighting will be discussed in results section). Van Dorn samples were poured directly into 500 ml polypropylene bottles for each depth. Sample bottles were rinsed once with sample water, emptied and then completely filled with sample water. A Kahl Scientific Instruments[®] irradiator (model 268WD305) was used to estimate photic zone depth or where 1% of ambient irradiance penetrates. Photic zone depths are summarized in the results section and in Appendix A. Transparency was also measured with a standard Secchi disk (20 cm diameter).

The integrated sampler consisted of a 19.5 m × 1.9 cm (inside diameter) clear vinyl tube with a valve at one end for creating a vacuum and 28.8 cm × 1.9 cm (inside diameter) galvanized pipe for weight with a plastic hose coupler attached to the other end. The integrated sampler was additionally weighted with a lead downrigger ball (lead weighting will be discussed in results section). The weighted end of the integrated sampler was lowered to the bottom of the photic zone and valved end was closed. The weighted end was then quickly lifted to the water surface and the sample was poured into an acid washed 10 l low density polyethylene carboy for homogenization. The initial integrated sample was used to rinse the carboy and then another sample was collected, homogenized and poured into a sample rinsed, 500 ml polypropylene bottle. All samples were stored in a cooler and transported to the analytical lab within 24 h of sampling. After collection water samples were preserved with nitric acid. Chain of custody records were generated during all sampling.

All water samples were processed in Spokane, WA at the certified Spokane Tribal Laboratory for total recoverable trace element concentration. Arsenic, cadmium, copper, and zinc were analyzed by inductively coupled atomic emission spectrometry (ICAES, method 200.7; NEMI 2005a). Arsenic and lead were analyzed by graphite furnace atomic absorption (GFAA, method 200.9; NEMI 2005b). Mercury was analyzed by cold vapor atomic absorption spectrometry (CVAAS, method 245.1; NEMI 2005c). Table 3 has a complete list of analytes and analytical methods used. For detail on laboratory quality control procedures see NEMI (2005a-c) and STL (2005). Hardness was estimated from calcium and magnesium concentrations. (method 2340 B; APHA 1995).

Minimum reporting levels (MRL) were defined as the smallest measured concentration of a substance that can be reliably measured by a given analytical method (USGS 1999). Relative percent difference (RPD) was calculated as follows, where S was first sample value and D was second sample value (duplicate):

$$RPD = \frac{|S - D|}{((S + D) \div 2)} \times 100$$

Matrix spike percent recovery (SPR) was calculated as follows, where SSR was spiked sample result, SR was sample result, and SA was spike added:

$$SPR = \frac{(SSR - SR)}{SA} \times 100$$

When trace element concentration was below the MRL an estimated value was substituted. Estimated values were calculated by dividing the MRL in half (USGS 1999). Water quality standards were calculated using equations or values from STI (2003) and WDOE (1997).

Descriptive statistics such as arithmetic mean, median, standard deviation (SD), sample size (N or n), minimum (min), maximum (max), and coefficient of variation (SD/mean ×

100) were used to summarize data. When sample sizes permitted ($n > 50$) analysis of variance (ANOVA) were performed to assess differences between mean groupings (measurable concentrations only) using Fisher's protected least squared distance statistic as calculated by Statview[®] 5.0.1. Data transformations were noted in results when performed to better meet ANOVA normality assumptions. Creation of box plots using Statistica[®] 7.1 assisted in determination of dataset outliers (Figure 2). Outliers were noted when removed for mean comparisons.

In an attempt to relate ecological variables with some metal constituents (lead and zinc), correlations (Pearson's standard r) and simple linear regression (coefficient of determination or r^2) were utilized. Pairwise deletion was used for missing data which was important for retaining as much data as possible for analytes without many measurable concentrations. Ecologic variables such as inflow, outflow, water retention time, reservoir elevation, Secchi disk depth, photic zone depth, total suspended solids, turbidity, hardness, and silica concentrations were related to given metal analytes.

Table 1. Surface water sampling dates from Lake Roosevelt.

1998	1999	2000
1/9, 1/12	3/22-3/24	1/18-1/20
2/3-2/5, 2/9-2/10	4/20	2/14-2/15
3/10-3/12	5/3-5/5	3/20, 3/22, 3/23
3/24-3/26	5/17-5/19	
5/06-5/07	6/7-6/9	
5/19-5/21	6/30-7/1	
6/02-6/04	7/12-7/13	
6/15-6/17	7/26-7/27	
6/30-7/02	8/9-8/10	
7/13-7/15	8/24-8/26	
7/27, 7/29, 7/30	9/8-9/9	
8/10-8/12	9/21-9/23	
8/24-8/26	10/12-10/14	
9/9-9/11	10/25-10/27	
9/22-9/24	11/15-11/17	
10/6-10/8	12/13-12/15	
11/16-11/18		
10/26-10/28		
12/14-12/16		

Table 2. Complete list of sampling locations and rkm numbers.

Location Name	rkm
Evan's Landing	1143.0
Kettle Falls	1128.0
Gifford	1085.0
Hunters	1064.0
Spokane R. Confluence	1028.0
Seven Bays	1024.0
Sanpoil R. Confluence	992.0
Keller Ferry	989.0
Spring Canyon	965.0
Porcupine Bay	1027.3
Sanpoil R.	992.6

Table 3. Complete list of methods and analytes from Lake Roosevelt surface water.

Analyte	Abbreviation	1998	1999	2000
Aluminum	Al	200.7	200.7	200.7
Antimony	Sb	200.9, 200.7	200.7	200.7
Arsenic	As	200.9, 200.7	200.7	200.7
Barium	Ba	200.7	200.7	200.7
Beryllium	Be	200.7	200.7	200.7
Cadmium	Cd	200.7	200.7	200.7
Calcium	Ca	200.7	200.7	200.7
Chromium	Cr	200.7	200.7	200.7
Cobalt	Co	200.7	200.7	200.7
Copper	Cu	200.7	200.7	200.7
Iron	Fe	200.7	200.7	200.7
Lead	Pb	200.9	200.9	200.9
Magnesium	Mg	200.7	200.7	200.7
Manganese	Mn	200.7	200.7	200.7
Mercury	Hg	245.1	245.1	245.1
Nickel	Ni	200.7	200.7	200.7
Potassium	K	200.7	200.7	200.7
Selenium	Se	200.9, 200.7	200.7	200.7
Silica	SiO ₂	200.7	200.7	200.7
Silver	Ag	200.7	200.7	200.7
Sodium	Na	200.7	200.7	200.7
Total Suspended Solids	TSS	160.2	160.2	160.2
Turbidity	Turb	180.1	180.1	180.1
Zinc	Zn	200.7	200.7	200.7

160.2 non-filterable residue by drying oven

180.1 turbidimeter

200.7 inductively coupled atomic emission spectrometry

200.9 graphite furnace atomic absorption

245.1 cold vapor atomic absorption spectrometry

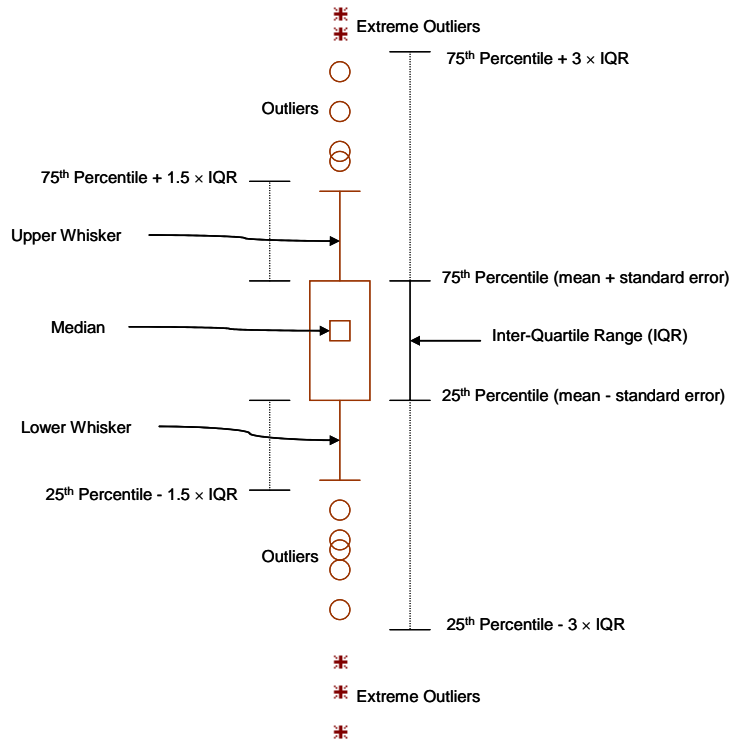


Figure 2. Components and explanation of a box plot as generated by Statistica[®] 7.1.

Results

Analytical Sensitivity and Data Quality

Analyte MRLs varied with time and generally were refined as sampling progressed (Table 4). Arsenic MRLs ranged from 1 to 50 $\mu\text{g l}^{-1}$ and were lower initially because arsenic was analyzed by GFAA and later by ICAES. The cadmium MRL began at 7 $\mu\text{g l}^{-1}$ and was refined to 4 $\mu\text{g l}^{-1}$. The copper MRL was also refined from 7 to 4 $\mu\text{g l}^{-1}$. The lead and mercury MRLs were constant at 1 $\mu\text{g l}^{-1}$ and 0.2 $\mu\text{g l}^{-1}$, respectively. The zinc MRL was refined from 35 to 5 $\mu\text{g l}^{-1}$.

Generally RPDs $\leq 25\%$ are considered acceptable. Mean RPDs for all analytes ranged from 0.6 to 22.4% (Table 4). RPD $> 25\%$ resulted in part to analyte concentrations near the MRL. For some analytes the quality control samples used to determine the RPD were always below the MRL. In those cases the RPD could not be determined. Mean RPDs for arsenic, lead, and zinc were 0.6, 14.8, and 14.7%, respectively. Mean RPD for cadmium, copper, and mercury were not determinable because analyte concentrations were near or below the analyte MRL.

Spike percent recoveries were generally considered acceptable when they deviated no more than 25% from 100% recovery. Mean SPR ranged from 76.7 to 107.5% for all analytes (Table 4). Mean SPRs for everything other than silver (76.7%) and mercury (107.5%) were in the 90% recovery range. Recovery of silver was likely lowered because chloride was present in samples and complexes with silver (NEMI 2005a). Mean SPR for arsenic, cadmium, copper, lead, mercury, and zinc were 98.1, 97.3, 96.9, 91.4, 107.5, and 98.8%, respectively.

Table 4. Mean minimum reporting level (MRL) and ranges. Mean relative percent difference (RPD) between duplicate samples where both samples were above MRL, number of RPD above or below 25%, and total number (N) of RPD calculated. Mean spike percent recovery (SPR) from all quality control samples, number of SPR above or below 25% of 100% recovery. Quality control samples systematically analyzed during processing of Lake Roosevelt surface water samples.

Analyte	Symbol	MRL ($\mu\text{g l}^{-1}$)			RPD				SPR			
		Mean	Min	Max	Mean	n \leq 25%	n > 25%	N	Mean	75% \leq n \leq 125%	75% > n > 125%	N
Aluminum	Al	57.4	10.0	60.0	22.4	6	5	11	97.9	33	0	33
Antimony	Sb	46.9	20.0	50.0	.	.	.	.	98.4	29	0	29
Arsenic	As	42.3	1.0	50.0	0.6	1	0	1	98.1	27	0	27
Barium	Ba	2.3 ^a	.	.	2.1	27	0	27	98.0	27	0	27
Beryllium	Be	1.0	1.0	1.0	.	.	.	.	98.0	26	0	26
Cadmium	Cd	5.2	4.0	10.0	.	.	.	.	97.3	33	0	33
Calcium	Ca	30.0 ^a	.	.	1.6	33	0	33	88.5	27	6	33
Chromium	Cr	6.6	4.0	7.0	.	.	.	.	96.2	26	1	27
Cobalt	Co	6.6	4.0	7.0	.	.	.	.	97.8	25	1	26
Copper	Cu	6.7	4.0	7.0	.	.	.	.	96.9	27	0	27
Iron	Fe	11.6	10.0	20.0	17.6	21	9	30	97.8	33	0	33
Lead	Pb	1.0	1.0	1.0	14.8	11	3	14	91.4	21	1	22
Magnesium	Mg	30.0 ^a	.	.	1.4	33	0	33	95.1	30	2	32
Manganese	Mn	3.0	1.0	5.0	14.2	21	4	25	98.9	33	0	33
Mercury	Hg	0.2	0.2	0.2	.	.	.	.	107.5	11	3	14
Nickel	Ni	14.4	10.0	15.0	.	.	.	.	97.1	27	0	27
Potassium	K	897.9	850.0	900.0	5.7	4	0	4	97.7	33	0	33
Selenium	Se	76.7	50.0	80.0	.	.	.	.	97.7	27	0	27
Silica	SiO ₂	26.0 ^a	.	.	1.9	33	0	33	92.2	30	3	33
Silver	Ag	9.4	5.0	10.0	.	.	.	.	76.7	16	11	27
Sodium	Na	29.0 ^a	.	.	2.2	33	0	33	95.3	33	0	33
Zinc	Zn	10.5	5.0	35.0	14.7	9	0	9	98.8	33	0	33

^aMRL estimate taken from NEMI (2005a) method 200.7.

Environmental Variables

Reservoir Hydrology

Considerably more water moved through the reservoir in 1999 compared to 1998. Mean annual inflow in 1998 ($2982 \text{ m}^3 \text{ s}^{-1}$) was 19% less than mean annual inflow in 1999 ($3704 \text{ m}^3 \text{ s}^{-1}$; Table 5; Figure 3; DART 2005). Likewise, mean annual outflow in 1998 ($2882 \text{ m}^3 \text{ s}^{-1}$) was 20% less than mean annual outflow in 1999 ($3608 \text{ m}^3 \text{ s}^{-1}$; Table 5; Figure 3; DART 2005). As a consequence of more water in the drainage during 1999, water retention times were reduced and the drawdown elevation was greater than that observed in 1998. Mean annual water retention time in 1998 (46 d) was 14 d greater than the 1999 (32 d) annual mean (Figure 4; Table 5; DART 2005). Minimum reservoir elevation in 1998 (381.7 m AMSL) was 11.9 m less than the minimum reservoir elevation observed in 1999 (369.8 m AMSL; Figure 4; DART 2005). Relative to mean summer full pool elevation drawdown in 1998 and 1999 were respectively, 9.5 m and 22.6 m.

Table 5. Inflow, outflow, water retention time (WRT) descriptive statistics during the study period in Lake Roosevelt. Includes: mean, standard deviation (SD), sample size (n), and ranges split by year.

Parameter	Year	Mean	SD	n	Min	Max
Inflow ($\text{m}^3 \text{ s}^{-1}$)	1998	2982	788	365	1603	5734
	1999	3704	1001	364	1770	6366
	2000	3209	447	90	2234	4224
Outflow ($\text{m}^3 \text{ s}^{-1}$)	1998	2882	937	365	799	5805
	1999	3608	773	365	1249	5233
	2000	3302	805	91	1523	4752
WRT (d)	1998	46	18	365	22	148
	1999	32	12	364	14	102
	2000	33	10	91	22	69

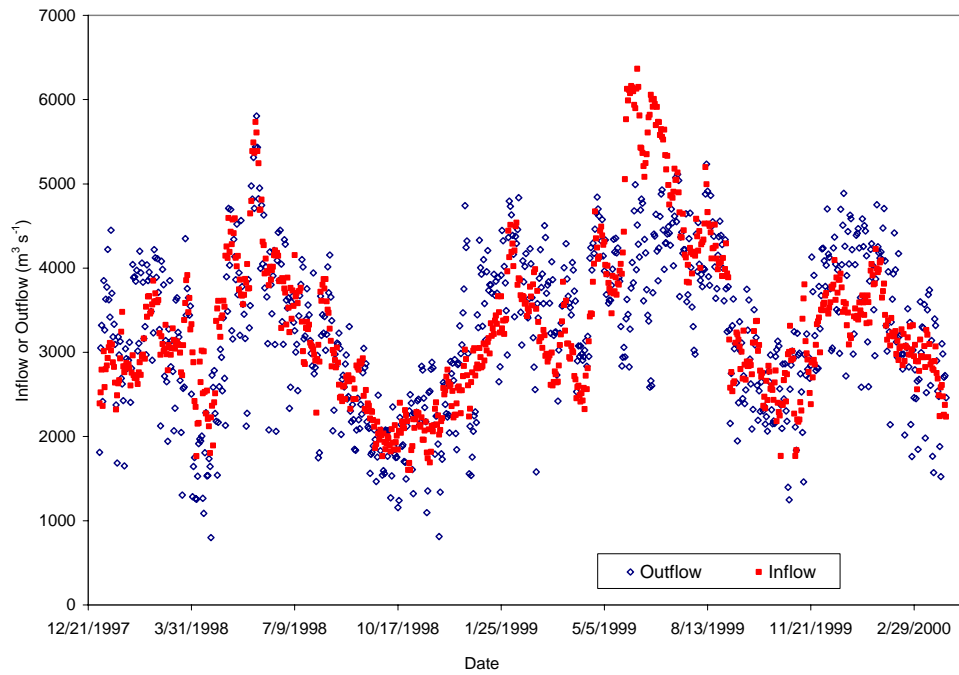


Figure 3. Inflow and outflow from Lake Roosevelt during study period (DART 2005).

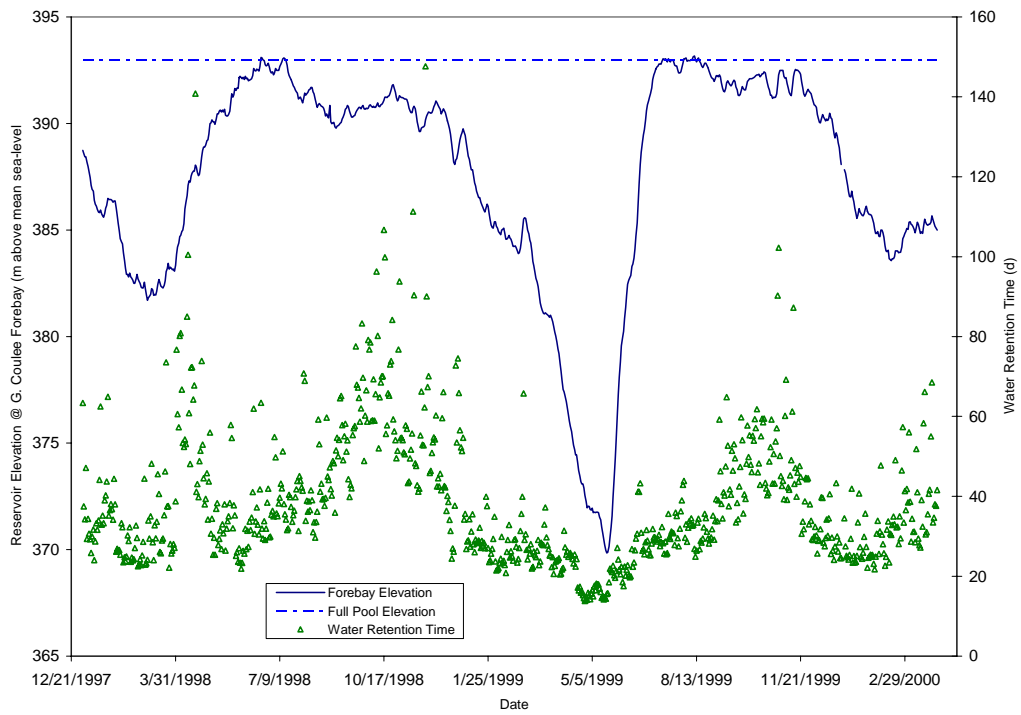


Figure 4. Water retention time and reservoir elevation from Lake Roosevelt during study period (DART 2005).

Transparency

Secchi disk depths showed distinct differences spatially and temporally. Mean Secchi depth during the study period generally increased with distance downstream. Mean Secchi depth increased from 5.4 m at Evan's Landing to 7.1 m at Spring Canyon during the entire study period (Table 6). Porcupine Bay had the lowest mean at 4.9 m. Seasonally, Secchi disk depth decreased with spring runoff and increased in late summer across all locations (Table 7; Figure 5). Mean Secchi depth across all locations was lowest in April at 2.9 m and greatest in October at 8.4 m (Table 7).

Photic zone depths generally followed the same pattern seen in Secchi disk depths. Across all locations and sampling events photic depth was strongly correlated to Secchi depth ($r = 0.80$; $P < 0.0001$; Table 8). Spatially, mean photic depth across the entire study period increased while moving from the upper reservoir to the lower reservoir. Over the entire study period mean photic depth increased from 11.2 m at Evan's Landing to 12.7 m at Spring Canyon (Table 9). Seasonally, photic depth was least during spring runoff (6.8 m in April) and highest in fall (15.6 m in November) across all locations (Table 10; Figure 5).

Table 6. Mean Secchi disk depth (m), standard deviation (SD), sample size (n), and ranges from Lake Roosevelt grouped by sampling location during the entire study period.

Secchi	Mean	SD	n	Min	Max
Evan's Landing	5.4	1.8	37	1.5	8.3
Kettle Falls	5.4	1.9	38	1.5	8.0
Gifford	5.8	2.6	39	0.5	13.0
Hunters	5.3	1.9	39	2.0	10.0
Spokane R. Confluence	5.6	2.0	35	3.0	11.0
Seven Bays	6.0	2.1	36	2.5	9.5
Sanpoil R. Confluence	6.8	2.6	37	2.0	12.5
Keller Ferry	6.7	2.6	36	1.5	11.5
Spring Canyon	7.1	2.3	37	3.0	12.0
Porcupine Bay	4.9	3.1	34	0.5	11.0
Sanpoil R.	5.9	2.4	33	1.0	11.0
Overall	5.9	2.4	402	0.5	13.0

Table 7. Mean Secchi disk depth (m), standard deviation (SD), sample size (n), and ranges from Lake Roosevelt grouped by month during the entire study period.

Secchi	Mean	SD	n	Min	Max
Jan	5.5	2.2	30	0.5	13.0
Feb	6.3	1.7	31	0.5	8.5
Mar	4.6	1.5	38	1.0	7.0
Apr	2.9	1.3	11	1.5	6.0
May	3.0	0.9	42	1.0	4.5
Jun	3.4	1.0	31	2.0	6.0
Jul	5.4	1.5	50	3.0	8.5
Aug	6.8	1.8	41	3.5	11.5
Sep	8.3	1.5	43	5.5	12.5
Oct	8.4	1.5	40	6.0	11.5
Nov	8.2	1.8	22	5.0	11.0
Dec	6.6	1.3	23	4.0	9.0
Overall	5.9	2.4	402	0.5	13.0

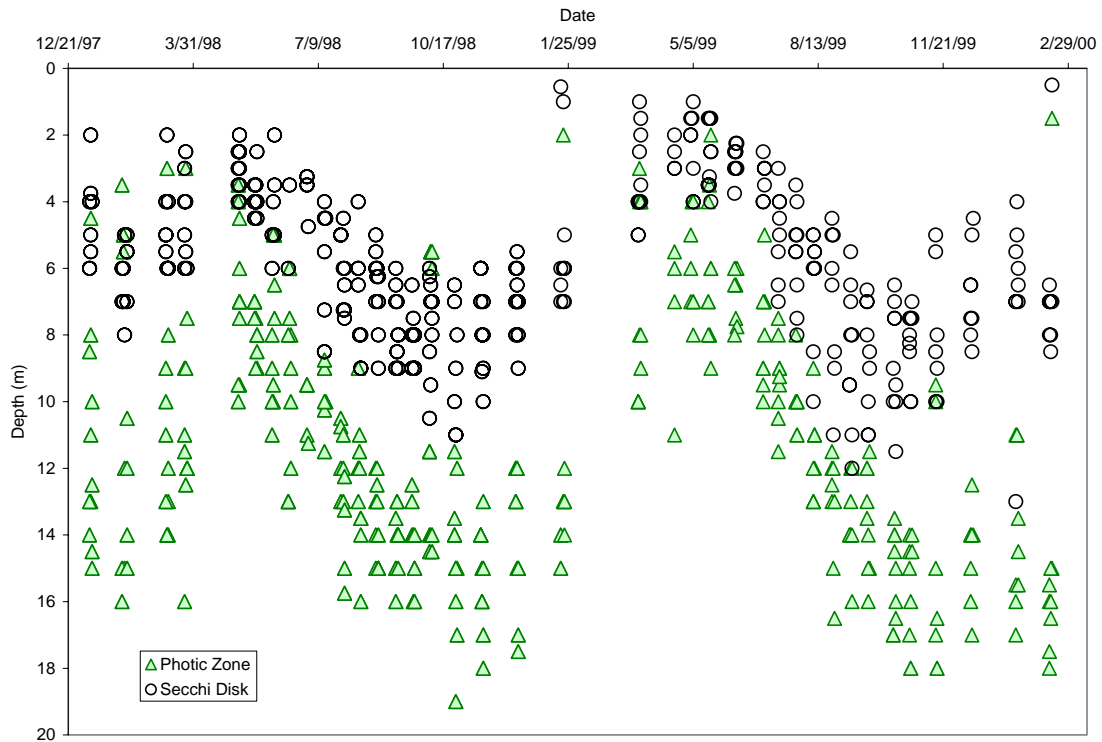


Figure 5. Photic zone and Secchi disk depths observed during the study period across all locations on Lake Roosevelt.

Table 8. Correlation matrix of environmental variables from Lake Roosevelt. Italicized red values are significant at $P < 0.05$.

	Reservoir Elevation	Water Retention Time	Inflow (5 d mean)	Outflow (5 d mean)	Inflow (15 d mean)	Outflow (15 d mean)	Photic Depth	Secchi Depth	Turbidity	Total SiO ₂	Hardness	Total Suspended Solids
Reservoir Elevation	1.00	<i>0.45</i>	0.00	<i>-0.15</i>	0.04	<i>-0.16</i>	<i>0.30</i>	<i>0.44</i>	<i>-0.28</i>	<i>-0.28</i>	<i>-0.25</i>	0.07
Water Retention Time	<i>0.45</i>	1.00	<i>-0.61</i>	<i>-0.75</i>	<i>-0.55</i>	<i>-0.66</i>	<i>0.45</i>	<i>0.51</i>	<i>-0.24</i>	<i>-0.33</i>	<i>0.16</i>	-0.01
Inflow (5 d mean)	0.00	<i>-0.61</i>	1.00	<i>0.87</i>	<i>0.89</i>	<i>0.73</i>	<i>-0.50</i>	<i>-0.52</i>	<i>0.19</i>	<i>0.24</i>	<i>-0.50</i>	0.00
Outflow (5 d mean)	<i>-0.15</i>	<i>-0.75</i>	<i>0.87</i>	1.00	<i>0.81</i>	<i>0.85</i>	<i>-0.46</i>	<i>-0.53</i>	<i>0.23</i>	<i>0.24</i>	<i>-0.41</i>	0.12
Inflow (15 d mean)	0.04	<i>-0.55</i>	<i>0.89</i>	<i>0.81</i>	1.00	<i>0.87</i>	<i>-0.44</i>	<i>-0.47</i>	<i>0.13</i>	<i>0.18</i>	<i>-0.52</i>	-0.01
Outflow (15 d mean)	<i>-0.16</i>	<i>-0.66</i>	<i>0.73</i>	<i>0.85</i>	<i>0.87</i>	1.00	<i>-0.38</i>	<i>-0.46</i>	<i>0.20</i>	<i>0.20</i>	<i>-0.38</i>	0.11
Photic Depth	<i>0.30</i>	<i>0.45</i>	<i>-0.50</i>	<i>-0.46</i>	<i>-0.44</i>	<i>-0.38</i>	1.00	<i>0.80</i>	<i>-0.47</i>	<i>-0.51</i>	<i>0.28</i>	0.05
Secchi Depth	<i>0.44</i>	<i>0.51</i>	<i>-0.52</i>	<i>-0.53</i>	<i>-0.47</i>	<i>-0.46</i>	<i>0.80</i>	1.00	<i>-0.39</i>	<i>-0.45</i>	<i>0.19</i>	0.04
Turbidity	<i>-0.28</i>	<i>-0.24</i>	<i>0.19</i>	<i>0.23</i>	<i>0.13</i>	<i>0.20</i>	<i>-0.47</i>	<i>-0.39</i>	1.00	<i>0.56</i>	<i>-0.14</i>	<i>0.17</i>
Total SiO ₂	<i>-0.28</i>	<i>-0.33</i>	<i>0.24</i>	<i>0.24</i>	<i>0.18</i>	<i>0.20</i>	<i>-0.51</i>	<i>-0.45</i>	<i>0.56</i>	1.00	0.04	0.00
Hardness	<i>-0.25</i>	<i>0.16</i>	<i>-0.50</i>	<i>-0.41</i>	<i>-0.52</i>	<i>-0.38</i>	<i>0.28</i>	<i>0.19</i>	<i>-0.14</i>	0.04	1.00	-0.07
Total Suspended Solids	0.07	-0.01	0.00	0.12	-0.01	0.11	0.05	0.04	<i>0.17</i>	0.00	-0.07	1.00

Table 9. Mean photic zone depth (m), standard deviation (SD), sample size (n), and ranges from Lake Roosevelt grouped by sampling location during the entire study period.

Photic Zone Depth	Mean	SD	n	Min	Max
Evan's Landing	11.2	3.5	39	4.5	18.0
Kettle Falls	10.9	3.6	39	2.0	17.5
Gifford	11.6	3.2	40	5.0	16.0
Hunters	11.2	3.1	40	5.0	17.0
Spokane R. Confluence	11.2	3.2	39	5.5	18.0
Seven Bays	11.2	3.4	40	4.0	18.5
Sanpoil R. Confluence	12.4	3.4	39	4.0	18.0
Keller Ferry	12.0	3.9	40	4.0	18.0
Spring Canyon	12.7	3.5	40	6.0	19.0
Porcupine Bay	9.3	4.7	41	1.5	17.0
Sanpoil R.	11.3	3.7	40	3.0	16.5
Overall	11.4	3.7	438	1.5	19.0

Table 10. Mean photic zone depth (m), standard deviation (SD), sample size (n), and ranges from Lake Roosevelt grouped by month during the entire study period.

Photic Zone Depth	Mean	SD	n	Min	Max
Jan	12.5	3.2	33	2.0	17.0
Feb	12.3	4.2	33	1.5	18.0
Mar	9.9	3.5	43	3.0	16.0
Apr	6.8	2.0	11	3.0	11.0
May	6.8	1.8	44	2.0	10.0
Jun	8.3	2.1	48	5.0	13.0
Jul	10.3	1.7	50	7.5	15.8
Aug	12.7	1.7	44	9.0	16.5
Sep	14.0	1.3	44	11.5	16.0
Oct	14.1	3.2	44	5.5	19.0
Nov	15.6	2.5	21	9.5	18.5
Dec	13.8	2.1	23	8.5	17.5
Overall	11.4	3.7	438	1.5	19.0

As would be expected, turbidity showed a reverse spatial and temporal pattern compared to Secchi and photic depths. Turbidity was negatively correlated with Secchi ($r = -0.391$) and photic depths ($r = -0.466$; $P < 0.0001$; Table 8). Mean turbidity was slightly higher at upper reservoir locations and in reservoir arms, compared to lower reservoir locations

(Table 11). Mean turbidity during the entire study period was highest at Porcupine Bay (2.63 NTU) and lowest at Spring Canyon (0.96 NTU). Seasonally, across all locations mean turbidity was greatest in April (3.53 NTU) and least in September (0.63 NTU; Table 12). Opposite to Secchi and photic depths, turbidity was greatest following the spring runoff and least in the fall (Figure 6).

Spatial and temporal patterns in total suspended solids (TSS) were not as readily discernable as Secchi, photic depth and turbidity. Of 608 total samples only 144 (23.7%) had concentrations at or above the MRL. However, TSS showed similar patterns compared with turbidity. Total suspended solids was weakly correlated with turbidity and was the only significant correlation observed with other environmental variables ($r = 0.17$; $P = 0.0386$; Table 8). Mean TSS and measurable TSS were higher at upper reservoir locations and in reservoir arms. Mean TSS was highest at Evan’s Landing (3.70 mg l^{-1}) and least at Keller Ferry (2.05 mg l^{-1} ; Table 13). Seasonally, mean TSS was highest in January (5.33 mg l^{-1}) but measurable TSS was most often observed in the spring where estimated TSS ranged from 0 to 55% of measurements (Table 14). Mean TSS was highest in April (4.98 mg l^{-1}) and lowest in December (1.87 mg l^{-1}). Estimated TSS concentrations ranged from 92 to 98% in August to December. Most measurable TSS appeared in late winter and spring (Figure 6).

Table 11. Mean turbidity (NTU), standard deviation (SD), sample size (n), and ranges from Lake Roosevelt grouped by sampling location during the entire study period.

Turbidity	Mean	SD	n	Min	Max
Evan's Landing	1.19	0.70	58	0.40	4.00
Kettle Falls	1.25	1.22	58	0.35	7.95
Gifford	1.20	1.48	58	0.35	11.10
Hunters	1.26	1.31	58	0.18	8.90
Spokane R. Confluence	0.98	0.60	43	0.27	2.70
Seven Bays	1.21	0.93	56	0.33	4.67
Sanpoil R. Confluence	1.07	0.88	43	0.23	4.92
Keller Ferry	1.10	1.08	58	0.24	5.93
Spring Canyon	0.96	0.76	58	0.25	3.46
Porcupine Bay	2.63	3.68	60	0.12	20.00
Sanpoil R.	2.17	4.31	58	0.36	29.80
Overall	1.39	2.05	608	0.12	29.80

Table 12. Mean turbidity (NTU), standard deviation (SD), sample size (n), and ranges from Lake Roosevelt grouped by month during the entire study period.

Turbidity	Mean	SD	n	Min	Max
Jan	1.41	2.33	42	0.14	15.40
Feb	1.79	3.66	31	0.27	20.00
Mar	1.87	2.19	64	0.39	13.00
Apr	3.53	1.36	11	2.21	6.86
May	2.40	1.79	66	0.56	8.89
Jun	2.44	3.95	66	0.37	29.80
Jul	0.71	0.41	80	0.12	2.46
Aug	0.92	0.43	62	0.18	2.07
Sep	0.63	0.28	62	0.24	2.11
Oct	0.68	0.23	62	0.32	1.79
Nov	0.73	0.36	31	0.37	2.05
Dec	1.06	0.36	31	0.58	2.19
Overall	1.39	2.05	608	0.12	29.80

Table 13. Mean total suspended solids (mg l⁻¹), standard deviation (SD), sample size (n), and ranges from Lake Roosevelt grouped by sampling location during the entire study period. Data includes estimated concentrations which were calculated by dividing the minimum reporting limit (MRL) in half. 144 of 608 (23.7%) samples had total suspended solids at or above the MRL.

Total Suspended Solids	Mean	SD	n	Min	Max	% E
Evan's Landing	3.70	8.58	58	1.00	67.00	63.8
Kettle Falls	2.91	3.89	58	1.00	24.50	74.1
Gifford	3.01	5.10	58	1.00	38.50	75.9
Hunters	2.50	2.09	58	1.00	13.50	77.6
Spokane R. Confluence	2.25	1.32	43	1.00	8.25	83.7
Seven Bays	2.71	4.73	56	1.00	37.00	80.4
Sanpoil R. Confluence	2.41	2.00	43	1.00	14.00	83.7
Keller Ferry	2.05	0.75	58	1.00	5.00	81.0
Spring Canyon	2.31	2.53	58	1.00	20.50	84.5
Porcupine Bay	3.54	3.54	60	1.00	23.30	61.7
Sanpoil R.	2.50	2.29	58	1.00	16.50	81.0
Overall	2.74	4.03	608	1.00	67.00	76.3

Table 14. Mean total suspended solids (mg l^{-1}), standard deviation (SD), sample size (n), and ranges from Lake Roosevelt grouped by month during the entire study period. Data includes estimated concentrations which were calculated by dividing the minimum reporting limit (MRL) in half. 144 of 608 (23.7%) samples had total suspended solids at or above the MRL.

Total Suspended Solids	Mean	SD	n	Min	Max	% E
Jan	5.33	12.53	42	1.00	67.00	61.9
Feb	2.31	2.41	31	1.00	13.50	51.6
Mar	1.90	1.24	64	1.00	8.00	54.7
Apr	4.98	2.32	11	2.00	8.50	0.0
May	4.16	3.75	66	1.00	24.50	47.0
Jun	3.11	3.37	66	2.00	20.50	75.8
Jul	2.55	2.96	80	1.00	23.30	87.5
Aug	2.04	0.43	62	1.00	4.00	91.9
Sep	2.03	0.25	62	2.00	4.00	98.4
Oct	2.11	0.47	62	2.00	4.50	95.2
Nov	2.20	1.12	31	2.00	8.25	96.8
Dec	1.87	0.85	31	1.00	5.00	93.5
Overall	2.74	4.03	608	1.00	67.00	76.3

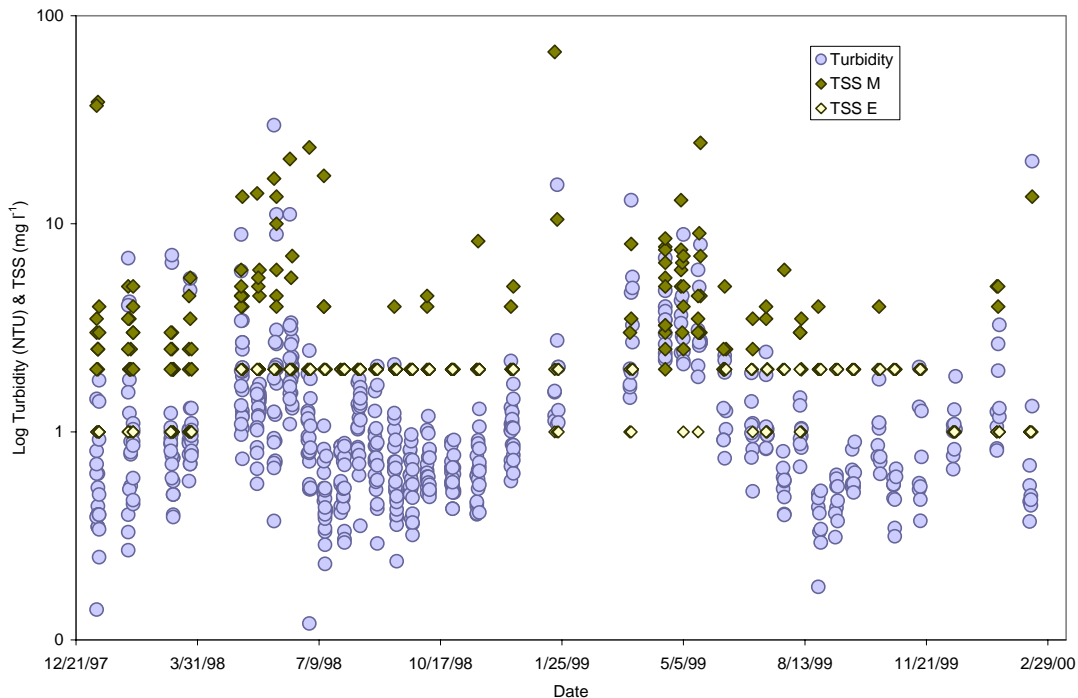


Figure 6. Turbidity and total suspended solids (TSS) observed during the study period across all locations on Lake Roosevelt. Total suspended solids were not always above MRL so estimated (TSS E) and measured (TSS M) values are noted.

Contaminants of Concern

Arsenic

Of the 608 samples analyzed only 15 had arsenic concentrations above the MRL. Measurable arsenic concentrations ranged from 1.0 to 98 $\mu\text{g l}^{-1}$ (Table 15). The coefficient of variation for measurable arsenic concentrations was 74. Mean arsenic concentrations including estimates across locations ranged from 20.4 to 23.1 $\mu\text{g l}^{-1}$ (Table 16). Spatial and temporal trends were not distinct in part because arsenic was detected so few times. However, most (6 of 15) of the measurable arsenic samples were from Porcupine Bay (Figure 7). Differences between aphotic and photic sample depths were not distinct (Figure 7). Mean monthly arsenic concentrations including estimates ranged from 6.3 to 28.8 $\mu\text{g l}^{-1}$ (Table 17). Lower arsenic concentrations in January, February, and March of 1998 resulted from the lower MRL capability given by the initial analytical technique of GFAA (Table 17; Figure 8).

Table 15. Mean, median, standard deviation (SD), sample size (n), ranges, and coefficients of variation (CV) for total recoverable arsenic, cadmium, copper, lead, mercury, and zinc concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water. Data includes only measurable concentrations.

Analyte	Mean	Median	SD	n	Min	Max	CV
Arsenic	44.7	57.0	33.2	15	1.0	98.0	74
Cadmium	5.9	5.5	1.0	8	5.0	7.0	17
Copper	9.1	8.0	6.2	14	4.0	28.0	68
Lead	5.6	4.0	10.5	402	1.0	182.0	188
Mercury	1.2	1.2	.	1	1.2	1.2	
Zinc	22.5	14.5	16.1	92	5.0	84.0	72

Table 16. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable arsenic concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by sampling location. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 15 of 608 (2.5%) samples had arsenic at or above the MRL.

Location	Mean	Median	SD	n	Min	Max	% E
Evan's Landing	21.9	25.0	7.5	58	0.5	25.0	100.0
Kettle Falls	21.7	25.0	10.0	58	0.5	62.0	98.3
Gifford	21.0	25.0	8.4	58	0.5	25.0	100.0
Hunters	21.0	25.0	8.4	58	0.5	25.0	100.0
Spokane R. Confluence	21.2	25.0	11.1	43	0.5	57.0	97.7
Seven Bays	21.4	25.0	9.5	56	0.5	52.0	98.2
Sanpoil R. Confluence	20.4	25.0	9.6	43	0.5	25.0	100.0
Keller Ferry	21.0	25.0	8.4	58	0.5	25.0	100.0
Spring Canyon	22.8	25.0	11.4	58	0.5	68.0	94.8
Porcupine Bay	23.1	25.0	13.9	60	0.5	98.0	90.0
Sanpoil R.	23.1	25.0	13.2	58	0.5	71.0	94.8
Overall	21.7	25.0	10.3	608	0.5	98.0	97.5

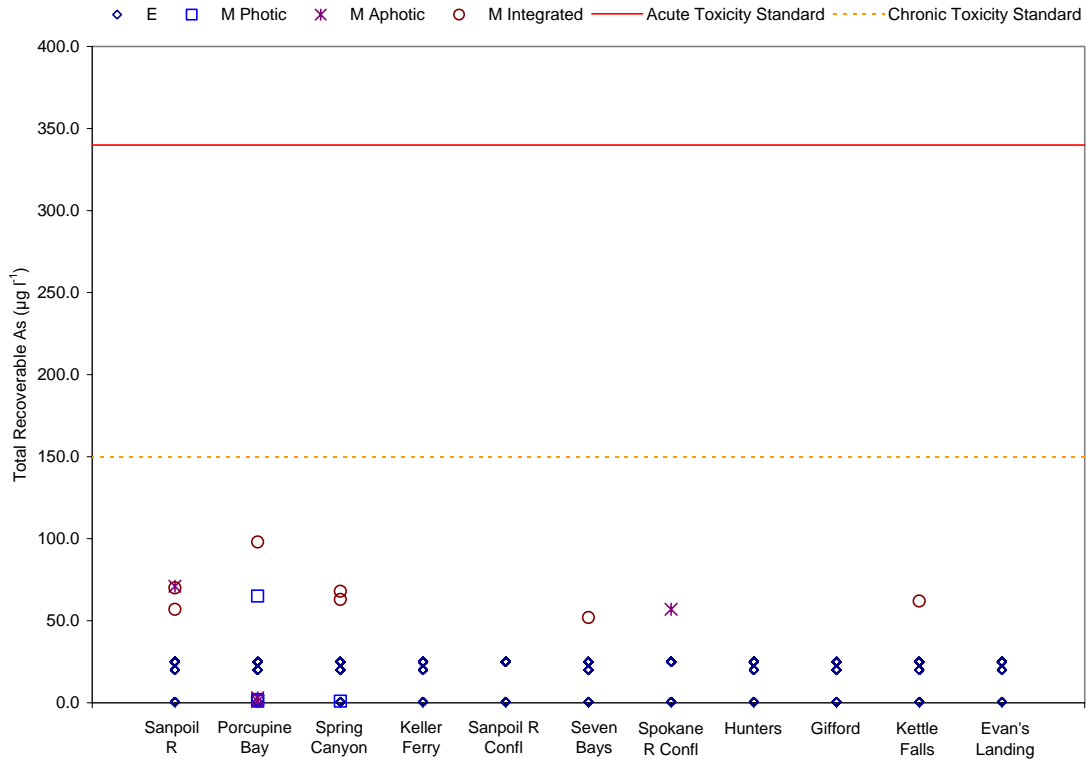


Figure 7. Total recoverable arsenic concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included.

Table 17. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable arsenic concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by month. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 15 of 608 (2.5%) samples had arsenic at or above the MRL.

Month	Mean	Median	SD	n	Min	Max	% E
Jan	11.1	1.0	11.3	42	0.5	25.0	92.9
Feb	6.3	0.5	8.9	31	0.5	20.0	93.5
Mar	8.6	0.5	11.0	64	0.5	25.0	100.0
Apr	25.0	25.0	0.0	11	25.0	25.0	100.0
May	25.0	25.0	0.0	66	25.0	25.0	100.0
Jun	28.8	25.0	12.9	66	25.0	98.0	90.9
Jul	26.0	25.0	6.1	80	25.0	70.0	97.5
Aug	25.6	25.0	5.1	62	25.0	65.0	98.4
Sep	25.0	25.0	0.0	62	25.0	25.0	100.0
Oct	23.5	25.0	2.3	62	20.0	25.0	100.0
Nov	25.0	25.0	8.8	31	20.0	71.0	96.8
Dec	23.5	25.0	2.3	31	20.0	25.0	100.0
Overall	21.7	25.0	10.3	608	0.5	98.0	97.5

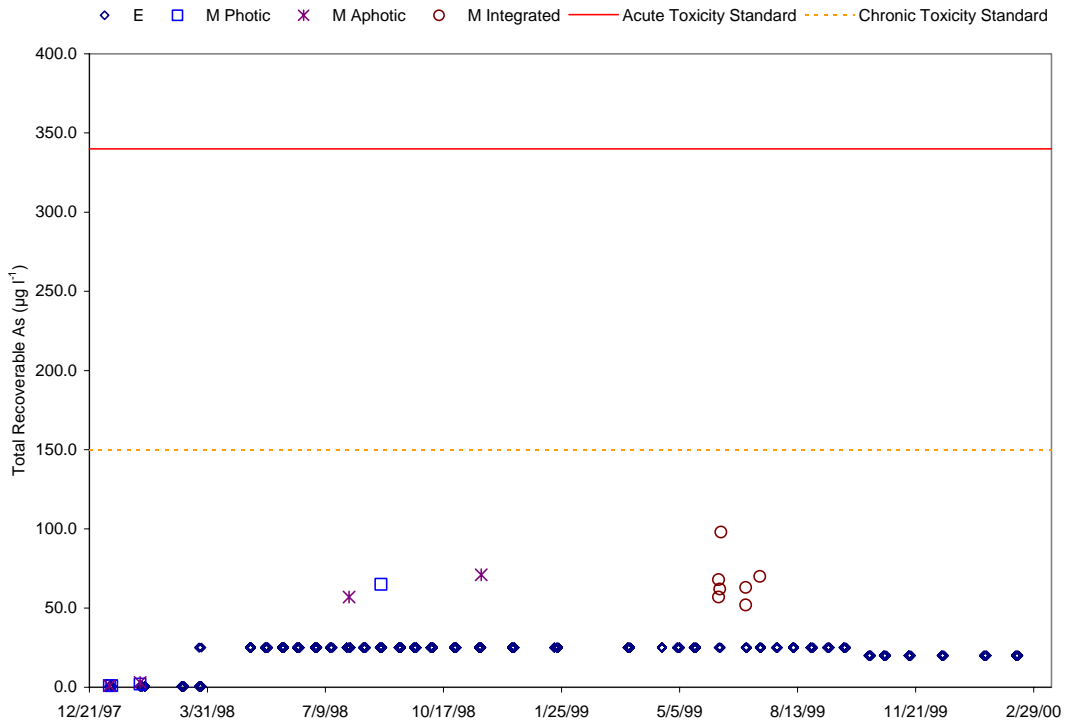


Figure 8. Total recoverable arsenic concentrations ($\mu\text{g l}^{-1}$) from all locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included.

Cadmium

Similar to arsenic, cadmium was rarely above the MRL. Of 608 samples analyzed for total recoverable cadmium only 8 (1.3%) samples had concentrations at or above the MRL. Measurable cadmium concentrations originated from samples taken at or upstream of Seven Bays in September 1998 (Figure 9; Figure 10). Measurable values ranged from 5.0 to 7.0 $\mu\text{g l}^{-1}$ and 5 of the 8 samples originated from aphotic samples (Table 15; Figure 10). The coefficient of variation for measurable cadmium concentrations was 17. Again spatial and temporal patterns were not readily recognized because the analytical method was not sensitive enough. Mean cadmium concentrations including estimated values across locations and months ranged from 2.6 to 2.7 $\mu\text{g l}^{-1}$ and 2.4 to 3.7 $\mu\text{g l}^{-1}$, respectively (Table 18; Table 19). Estimated cadmium concentrations in January 1998 were higher than other months because the MRL was refined in subsequent months (Table 19; Figure 10).

Table 18. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable cadmium concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by sampling location. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 8 of 608 (1.3%) samples had cadmium at or above the MRL.

Location	Mean	Median	SD	n	Min	Max	% E
Evan's Landing	2.7	2.5	0.8	58	2.0	7.0	96.6
Kettle Falls	2.6	2.5	0.5	58	2.0	5.0	100.0
Gifford	2.7	2.5	0.9	58	2.0	7.0	96.6
Hunters	2.6	2.5	0.6	58	2.0	5.0	98.3
Spokane R. Confluence	2.7	2.5	0.6	43	2.5	5.0	97.7
Seven Bays	2.6	2.5	0.6	56	2.0	5.0	98.2
Sanpoil R. Confluence	2.7	2.5	0.5	43	2.5	5.0	100.0
Keller Ferry	2.6	2.5	0.5	58	2.0	5.0	100.0
Spring Canyon	2.6	2.5	0.5	58	2.0	5.0	100.0
Porcupine Bay	2.7	2.5	0.8	60	2.0	7.0	98.3
Sanpoil R.	2.6	2.5	0.5	58	2.0	5.0	100.0
Overall	2.6	2.5	0.6	608	2.0	7.0	98.7

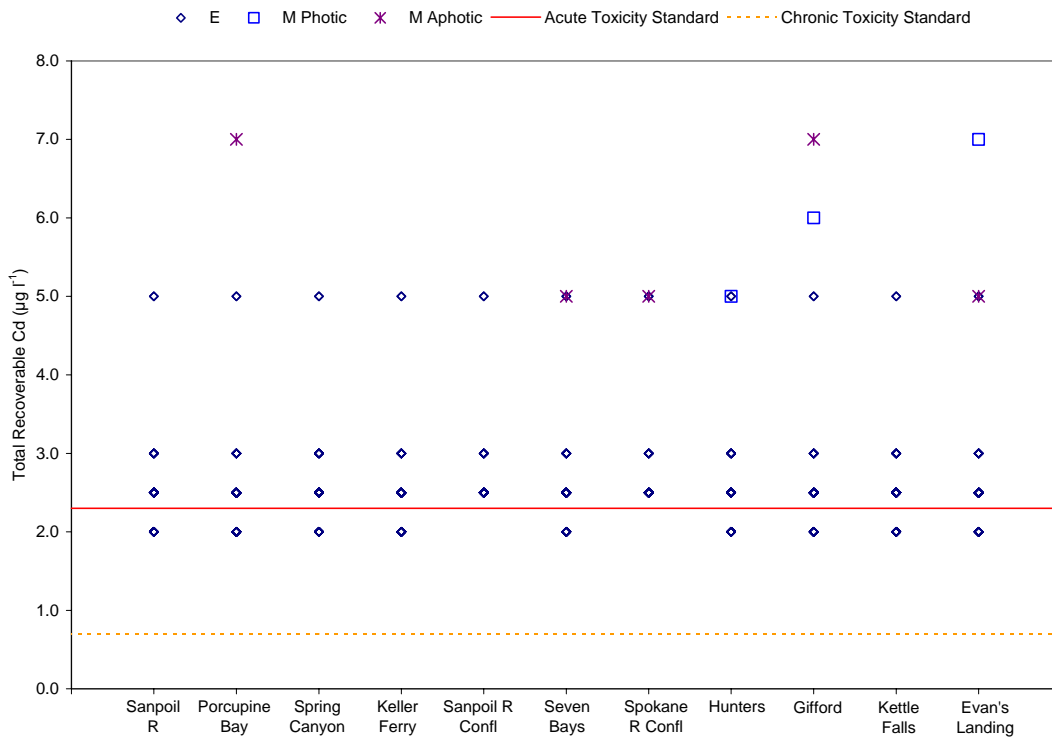


Figure 9. Total recoverable cadmium concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included (based on standard mean and hardness).

Table 19. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable cadmium concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by month. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 8 of 608 (1.3%) samples had cadmium at or above the MRL.

Month	Mean	Median	SD	n	Min	Max	% E
Jan	3.7	5.0	1.4	42	2.0	5.0	100.0
Feb	2.7	3.0	0.5	31	2.0	3.0	100.0
Mar	2.8	3.0	0.4	64	2.0	3.0	100.0
Apr	2.5	2.5	0.0	11	2.5	2.5	100.0
May	2.5	2.5	0.0	66	2.5	2.5	100.0
Jun	2.5	2.5	0.0	66	2.5	2.5	100.0
Jul	2.5	2.5	0.0	80	2.5	2.5	100.0
Aug	2.5	2.5	0.0	62	2.5	2.5	100.0
Sep	2.9	2.5	1.2	62	2.5	7.0	87.1
Oct	2.4	2.5	0.2	62	2.0	2.5	100.0
Nov	2.4	2.5	0.2	31	2.0	2.5	100.0
Dec	2.4	2.5	0.2	31	2.0	2.5	100.0
Overall	2.6	2.5	0.6	608	2.0	7.0	98.7

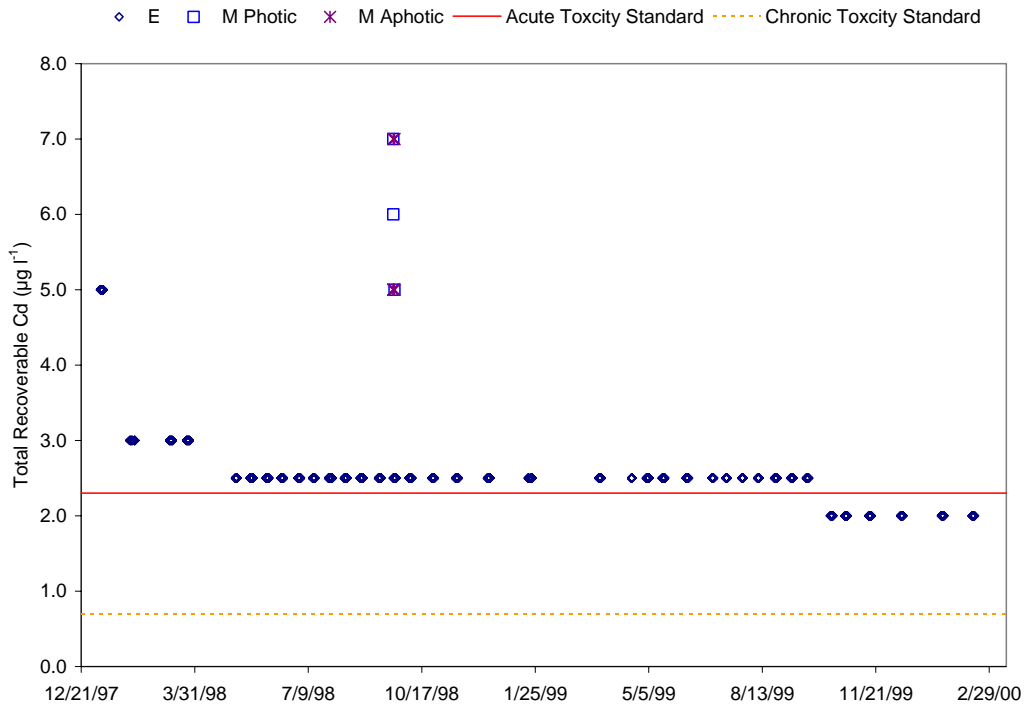


Figure 10. Total recoverable cadmium concentrations ($\mu\text{g l}^{-1}$) from all locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included (based on standard mean and hardness).

Copper

Temporal and spatial patterns were not distinct in total recoverable copper concentrations in part because of low sample size for measurable copper. Only 2.7% (14 of 520) of all copper concentrations were above the MRL. Measurable copper concentrations ranged from 4.0 to 28.0 $\mu\text{g l}^{-1}$ and 5 of the 14 measurable copper concentrations originated from Keller Ferry (Table 15; Figure 11; Figure 12). Differences between measurable copper from aphotic and photic zone samples were not readily apparent (Figure 12). The coefficient of variation for measurable copper concentrations was 68. Mean copper concentrations including estimates across locations and months ranged from 3.3 to 3.9 and 2.8 to 4.2 $\mu\text{g l}^{-1}$, respectively (Table 20; Table 21).

Table 20. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable copper concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by sampling location. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 14 of 520 (2.7%) samples had copper at or above the MRL.

Location	Mean	Median	SD	n	Min	Max	% E
Evan's Landing	3.4	3.5	0.9	50	2.0	8.0	96.0
Kettle Falls	3.3	3.5	0.5	50	2.0	3.5	100.0
Gifford	3.5	3.5	1.1	50	2.0	10.0	96.0
Hunters	3.3	3.5	0.5	50	2.0	3.5	100.0
Spokane R. Confluence	3.7	3.5	1.1	35	3.5	10.0	97.1
Seven Bays	3.3	3.5	0.5	48	2.0	3.5	100.0
Sanpoil R. Confluence	3.5	3.5	0.0	35	3.5	3.5	100.0
Keller Ferry	3.9	3.5	2.1	50	2.0	15.0	90.0
Spring Canyon	3.8	3.5	3.5	50	2.0	28.0	98.0
Porcupine Bay	3.4	3.5	0.8	52	2.0	8.0	96.2
Sanpoil R.	3.3	3.5	0.5	50	2.0	4.0	98.0
Overall	3.5	3.5	1.4	520	2.0	28.0	97.3

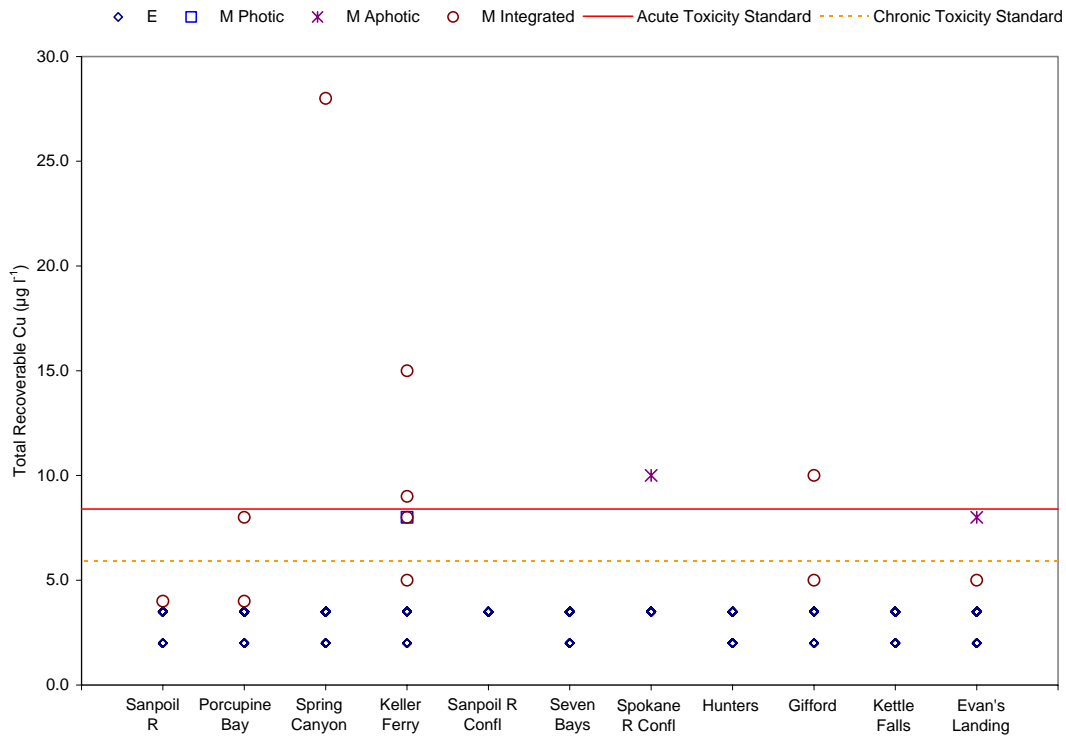


Figure 11. Total recoverable copper concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included (based on standard mean and hardness).

Table 21. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable copper concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by month. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 14 of 520 (2.7%) samples had copper at or above the MRL.

Month	Mean	Median	SD	n	Min	Max	% E
Jan	2.8	3.5	0.8	20	2.0	3.5	100.0
Feb	3.4	4.0	1.4	9	2.0	5.0	44.4
Mar	2.8	3.5	0.8	20	2.0	3.5	100.0
Apr	3.9	3.5	1.4	11	3.5	8.0	90.9
May	3.5	3.5	0.0	66	3.5	3.5	100.0
Jun	3.5	3.5	0.0	66	3.5	3.5	100.0
Jul	4.2	3.5	3.2	80	3.5	28.0	93.8
Aug	3.7	3.5	1.0	62	3.5	10.0	96.8
Sep	3.6	3.5	0.6	62	3.5	8.0	98.4
Oct	3.1	3.5	0.7	62	2.0	3.5	100.0
Nov	3.1	3.5	0.7	31	2.0	3.5	100.0
Dec	3.1	3.5	0.7	31	2.0	3.5	100.0
Overall	3.5	3.5	1.4	520	2.0	28.0	97.3

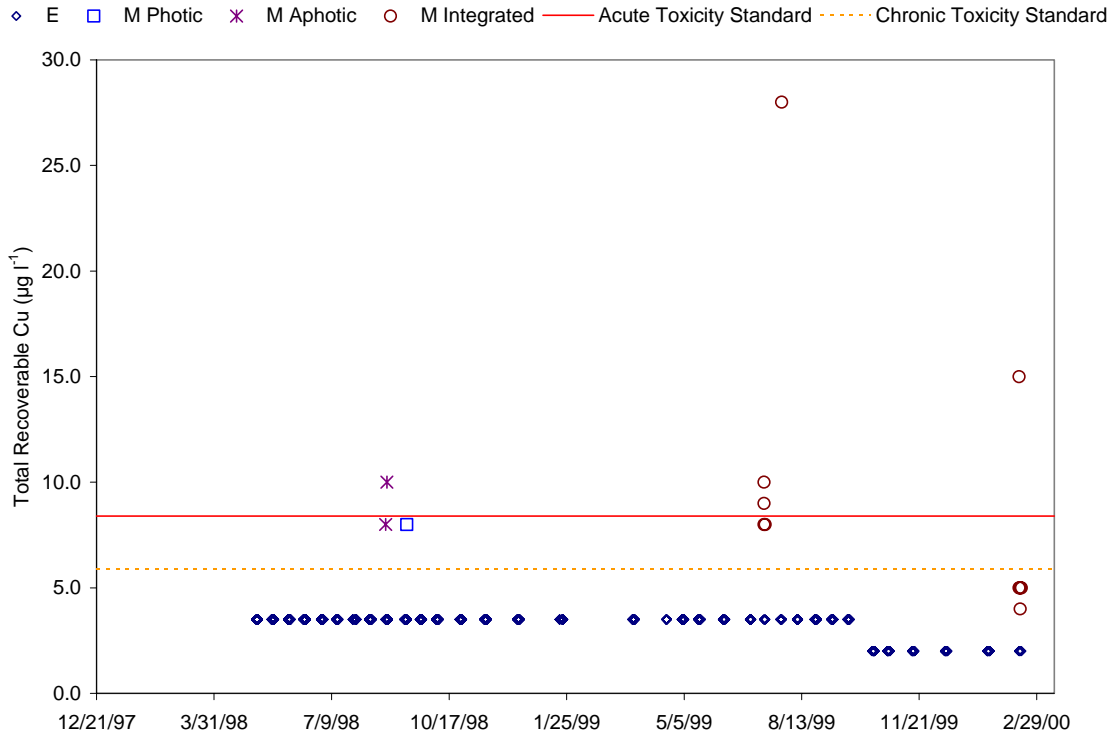


Figure 12. Total recoverable copper concentrations ($\mu\text{g l}^{-1}$) from all locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included (based on standard mean and hardness).

Lead

Of all the contaminants of concern lead was most frequently at measurable concentrations. Of the 608 samples analyzed for total recoverable lead, 402 had detectable concentrations (66.1%). Unfortunately due to the method of field collection (lead weight used to hold water sampler vertically in water column) some percentage of the samples were likely contaminated. Despite this we attempted to find meaningful patterns in the lead concentrations observed. However, lead results are questionable because every sample taken had the potential to be contaminated by the lead weighted water sampler.

Measurable lead concentrations ranged from 1 to 182 $\mu\text{g l}^{-1}$ (Table 15). Measurable lead coefficient of variation was the highest (188) of any contaminant of concern and may indicate sporadic contamination by lead weighted water sampler (Table 15). Measurable lead concentrations were observed across all sampling locations and months (Figure 13; Figure 14). Extreme outliers that could have complicated interpretation of differences between location means and depth zone means were identified before analysis (Figure 15). Seven extreme outliers were found and removed (lead concentrations $\geq 17 \mu\text{g l}^{-1}$) before making location mean and depth zone mean comparisons (Figure 16). Differences between location means in log transformed lead concentrations (measurable) with the outliers removed were insignificant at the 0.05 alpha level ($P \geq 0.0852$). At a higher alpha level (0.10) Gifford ($4.8 \mu\text{g l}^{-1}$) had a higher mean lead concentration (measurable) than at Spring Canyon ($3.8 \mu\text{g l}^{-1}$; $P = 0.0852$) and Porcupine Bay ($3.8 \mu\text{g l}^{-1}$; $P = 0.0945$). Mean measurable lead at Seven Bays ($5.1 \mu\text{g l}^{-1}$) was significantly greater than concentrations at Spring Canyon ($3.8 \mu\text{g l}^{-1}$; $P = 0.0951$) by this same criteria.

Evan's Landing another upper reservoir location had the highest percentage of measurements above the MRL (Table 22). Mean measurable lead at Evan's Landing ($4.9 \mu\text{g l}^{-1}$) was nearly significantly greater than some other locations where the smallest P value was with the Spring Canyon ($3.8 \mu\text{g l}^{-1}$; $P = 0.1498$) comparison. Median lead concentrations generally decreased from upstream to downstream (Table 22). Upper reservoir location median concentrations ranged from 3.0 to 2.0 $\mu\text{g l}^{-1}$ whereas, lower

reservoir median concentrations ranged from 2.0 to 1.0 $\mu\text{g l}^{-1}$. Log transformed mean measurable lead concentrations taken from the aphotic zone (mean depth = 12.4 m) at 2.1 $\mu\text{g l}^{-1}$ and photic zone (mean depth = 5.8 m) at 4.5 $\mu\text{g l}^{-1}$ in 1998 (May-Dec) were significantly different ($P < 0.0001$).

Monthly median lead concentrations were greatest in spring and fall (Table 23). April had the highest percentage of measurable lead concentrations compared to any other month (Table 23). Measurable lead concentrations were not strongly correlated to any environmental variable tested (Table 24). The greatest correlation between a single variable and lead was that with water retention time ($r = 0.10$; $P = 0.047$). Total recoverable lead (measurable concentrations) was weakly correlated with the following other metals: manganese ($r = -0.08$; $P = 0.1670$); iron ($r = 0.05$; $P = 0.2887$); magnesium ($r = 0.05$; $P = 0.3104$); and aluminum ($r = 0.03$; $P = 0.6757$; Appendix B). In correlations between lead and other contaminants of concern (arsenic, cadmium, copper, and mercury) sample sizes were too small ($n \leq 5$) to draw meaningful conclusions.

Table 22. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable lead concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by sampling location. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 402 of 608 (66.1%) samples had lead at or above the MRL.

Location	Mean	Median	SD	n	Min	Max	% E
Evan's Landing	4.3	3.0	3.9	58	0.5	17.0	17.2
Kettle Falls	3.3	2.0	3.6	58	0.5	16.0	27.6
Gifford	3.7	3.0	4.5	58	0.5	28.0	34.5
Hunters	3.9	2.0	4.9	58	0.5	22.0	31.0
Spokane R. Confluence	2.3	2.0	2.4	43	0.5	10.0	39.5
Seven Bays	4.5	2.0	8.9	56	0.5	65.0	37.5
Sanpoil R. Confluence	6.5	1.0	27.5	43	0.5	182.0	39.5
Keller Ferry	3.4	2.0	4.3	58	0.5	24.0	36.2
Spring Canyon	3.7	1.5	5.6	58	0.5	26.0	39.7
Porcupine Bay	4.1	2.0	6.4	60	0.5	39.0	31.7
Sanpoil R.	3.3	1.0	4.8	58	0.5	29.0	41.4
Overall	3.9	2.0	8.8	608	0.5	182.0	33.9

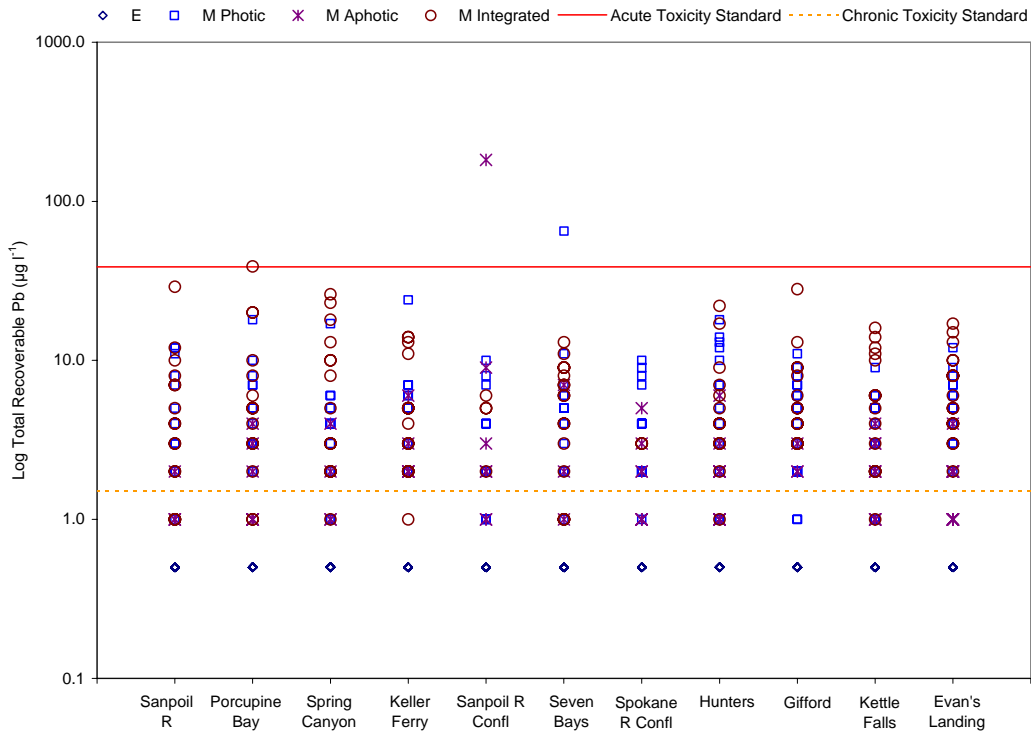


Figure 13. Total recoverable lead concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included (based on standard mean and hardness).

Table 23. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable lead concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by month. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 402 of 608 (66.1%) samples had lead at or above the MRL.

Month	Mean	Median	SD	n	Min	Max	% E
Jan	3.5	1.5	6.3	42	0.5	39.0	47.6
Feb	2.2	1.0	2.4	31	0.5	10.0	41.9
Mar	2.7	1.0	3.7	64	0.5	17.0	46.9
Apr	7.0	4.0	8.1	11	0.5	29.0	9.1
May	3.1	2.0	3.9	66	0.5	24.0	43.9
Jun	4.1	3.0	4.0	66	0.5	18.0	22.7
Jul	2.7	2.0	2.4	80	0.5	12.0	22.5
Aug	2.7	1.0	4.1	62	0.5	26.0	43.5
Sep	8.0	3.0	24.1	62	0.5	182.0	22.6
Oct	4.0	2.0	5.3	62	0.5	20.0	33.9
Nov	5.4	3.0	6.8	31	0.5	28.0	35.5
Dec	4.0	3.0	4.0	31	0.5	20.0	22.6
Overall	3.9	2.0	8.8	608	0.5	182.0	33.9

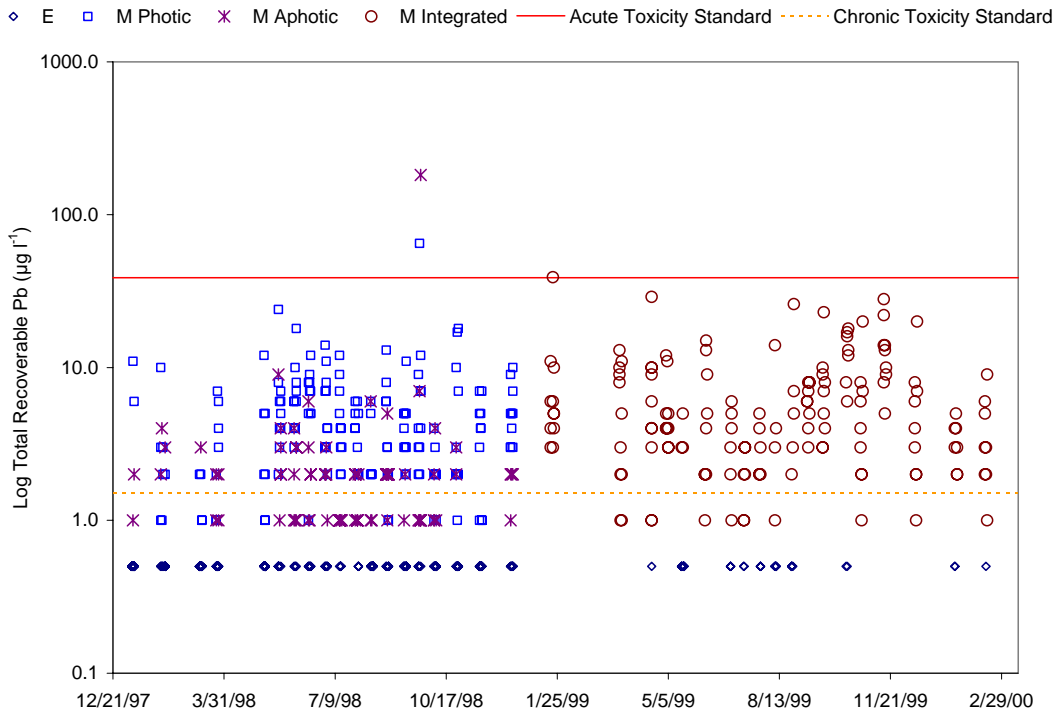


Figure 14. Total recoverable lead concentrations ($\mu\text{g l}^{-1}$) from all locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included (based on standard mean and hardness).

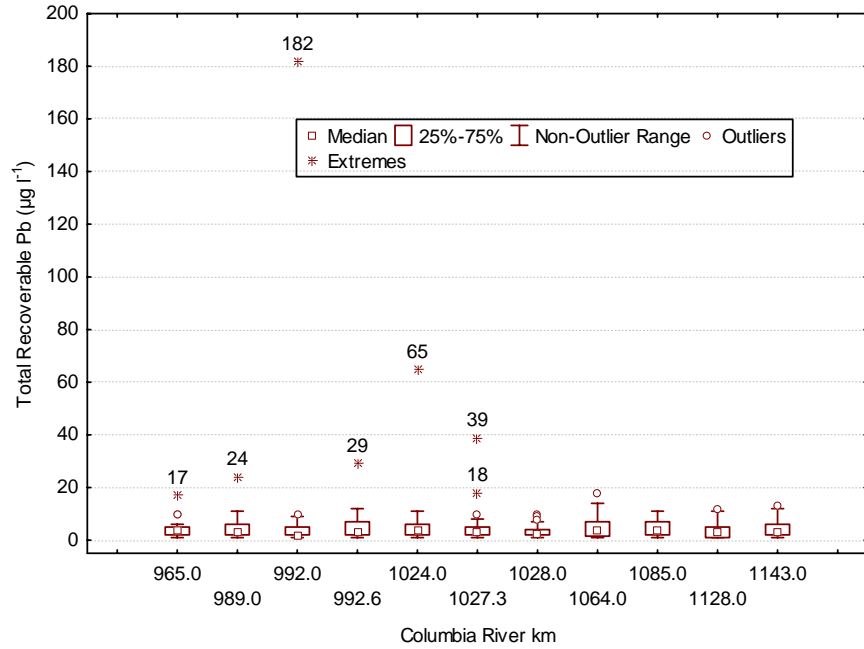


Figure 15. Box plots of total recoverable lead concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt (measurable concentrations only) with extreme values noted.

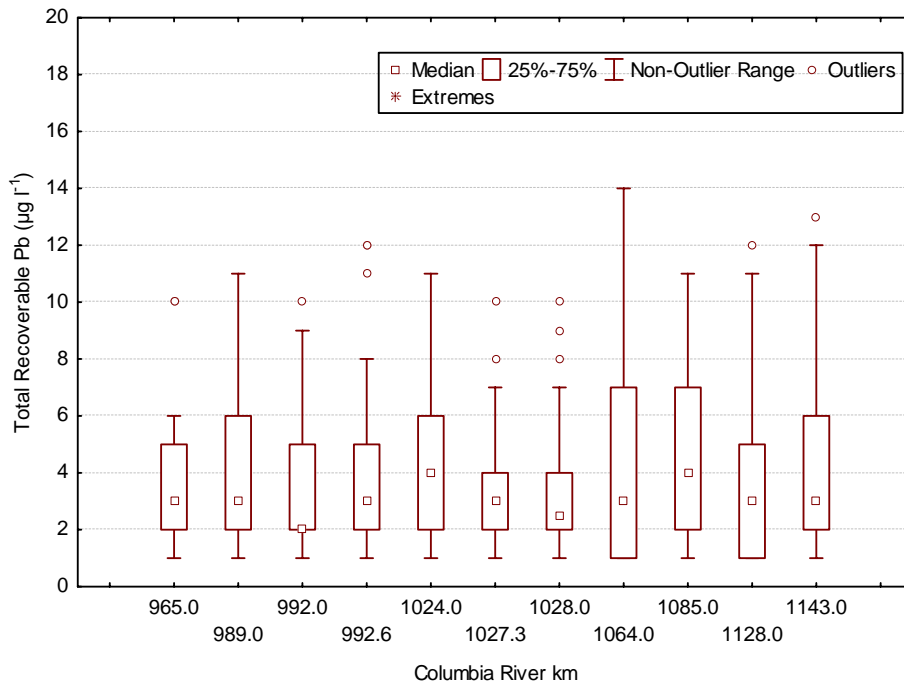


Figure 16. Box plots of total recoverable lead concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt (measurable concentrations only). Seven extreme values were removed (17-182 $\mu\text{g l}^{-1}$).

Table 24. Correlation matrix of total recoverable lead concentrations (measurable) from Lake Roosevelt surface water and other environmental variables. Italicized red values are significant at P < 0.05.

	Photic Depth	Secchi Depth	Water Retention Time	Reservoir Elevation	Inflow (5 d mean)	Outflow (5 d mean)	Inflow (15 d mean)	Outflow (15 d mean)	Total Suspended Solids	Turbidity	Hardness	Total Pb	Total SiO ₂
Photic Depth	1.00	<i>0.82</i>	<i>0.45</i>	<i>0.33</i>	<i>-0.52</i>	<i>-0.49</i>	<i>-0.46</i>	<i>-0.41</i>	0.11	<i>-0.57</i>	<i>0.29</i>	0.07	<i>-0.56</i>
Secchi Depth	<i>0.82</i>	1.00	<i>0.49</i>	<i>0.46</i>	<i>-0.52</i>	<i>-0.52</i>	<i>-0.46</i>	<i>-0.45</i>	0.08	<i>-0.50</i>	<i>0.18</i>	0.10	<i>-0.50</i>
Water Retention Time	<i>0.45</i>	<i>0.49</i>	1.00	<i>0.44</i>	<i>-0.61</i>	<i>-0.75</i>	<i>-0.55</i>	<i>-0.68</i>	0.02	<i>-0.30</i>	<i>0.22</i>	<i>0.10</i>	<i>-0.38</i>
Reservoir Elevation	<i>0.33</i>	<i>0.46</i>	<i>0.44</i>	1.00	-0.03	<i>-0.16</i>	0.07	<i>-0.14</i>	0.09	<i>-0.40</i>	<i>-0.19</i>	0.01	<i>-0.38</i>
Inflow (5 d mean)	<i>-0.52</i>	<i>-0.52</i>	<i>-0.61</i>	-0.03	1.00	<i>0.89</i>	<i>0.89</i>	<i>0.74</i>	-0.02	<i>0.15</i>	<i>-0.47</i>	-0.06	<i>0.25</i>
Outflow (5 d mean)	<i>-0.49</i>	<i>-0.52</i>	<i>-0.75</i>	<i>-0.16</i>	<i>0.89</i>	1.00	<i>0.81</i>	<i>0.85</i>	0.09	<i>0.22</i>	<i>-0.42</i>	-0.08	<i>0.28</i>
Inflow (15 d mean)	<i>-0.46</i>	<i>-0.46</i>	<i>-0.55</i>	0.07	<i>0.89</i>	<i>0.81</i>	1.00	<i>0.86</i>	-0.03	0.08	<i>-0.52</i>	-0.07	<i>0.19</i>
Outflow (15 d mean)	<i>-0.41</i>	<i>-0.45</i>	<i>-0.68</i>	<i>-0.14</i>	<i>0.74</i>	<i>0.85</i>	<i>0.86</i>	1.00	0.13	<i>0.21</i>	<i>-0.40</i>	-0.08	<i>0.24</i>
Total Suspended Solids	0.11	0.08	0.02	0.09	-0.02	0.09	-0.03	0.13	1.00	0.14	-0.07	0.03	0.02
Turbidity	<i>-0.57</i>	<i>-0.50</i>	<i>-0.30</i>	<i>-0.40</i>	<i>0.15</i>	<i>0.22</i>	0.08	<i>0.21</i>	0.14	1.00	<i>-0.13</i>	0.05	<i>0.66</i>
Hardness	<i>0.29</i>	<i>0.18</i>	<i>0.22</i>	<i>-0.19</i>	<i>-0.47</i>	<i>-0.42</i>	<i>-0.52</i>	<i>-0.40</i>	-0.07	<i>-0.13</i>	1.00	-0.01	-0.02
Total Pb	0.07	0.10	<i>0.10</i>	0.01	-0.06	-0.08	-0.07	-0.08	0.03	0.05	-0.01	1.00	0.00
Total SiO ₂	<i>-0.56</i>	<i>-0.50</i>	<i>-0.38</i>	<i>-0.38</i>	<i>0.25</i>	<i>0.28</i>	<i>0.19</i>	<i>0.24</i>	0.02	<i>0.66</i>	-0.02	0.00	1.00

Mercury

Spatial and temporal patterns were not readily distinguishable in total recoverable mercury concentrations. Only 0.2% (1 of 544) of all mercury concentrations were above the MRL. The one measurable mercury concentration ($1.2 \mu\text{g l}^{-1}$) originated from Spring Canyon in late October of 1998 and was taken in the aphotic zone (Table 15; Figure 17; Figure 18). Mean mercury concentrations including estimates across locations and months did not deviate from $0.1 \mu\text{g l}^{-1}$ when rounded (Table 25; Table 26).

Table 25. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable mercury concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by sampling location. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 1 of 545 (0.2%) samples had mercury at or above the MRL.

Location	Mean	Median	SD	n	Min	Max	% E
Evan's Landing	0.1	0.1	0.0	53	0.1	0.1	100.0
Kettle Falls	0.1	0.1	0.0	53	0.1	0.1	100.0
Gifford	0.1	0.1	0.0	51	0.1	0.1	100.0
Hunters	0.1	0.1	0.0	51	0.1	0.1	100.0
Spokane R. Confluence	0.1	0.1	0.0	37	0.1	0.1	100.0
Seven Bays	0.1	0.1	0.0	51	0.1	0.1	100.0
Sanpoil R. Confluence	0.1	0.1	0.0	39	0.1	0.1	100.0
Keller Ferry	0.1	0.1	0.0	53	0.1	0.1	100.0
Spring Canyon	0.1	0.1	0.2	51	0.1	1.2	98.0
Porcupine Bay	0.1	0.1	0.0	53	0.1	0.1	100.0
Sanpoil R.	0.1	0.1	0.0	53	0.1	0.1	100.0
Overall	0.1	0.1	0.0	545	0.1	1.2	99.8

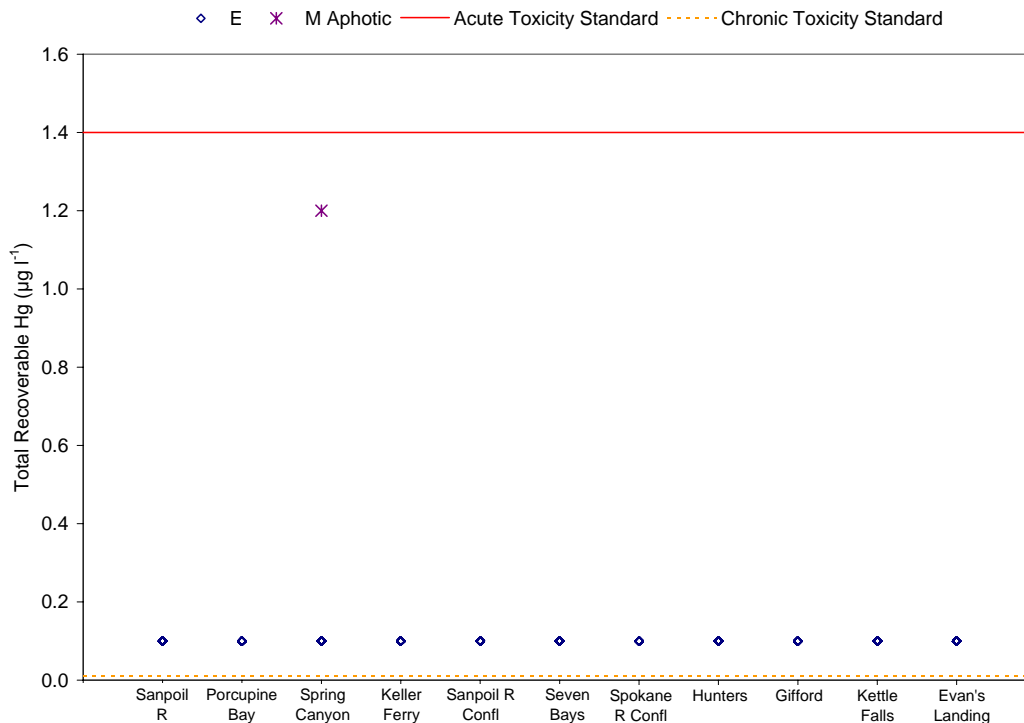


Figure 17. Total recoverable mercury concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included.

Table 26. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable mercury concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by month. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 1 of 545 (0.2%) samples had mercury at or above the MRL.

Month	Mean	Median	SD	n	Min	Max	% E
Jan	0.1	0.1	0.0	20	0.1	0.1	100.0
Feb	0.1	0.1	0.0	9	0.1	0.1	100.0
Mar	0.1	0.1	0.0	54	0.1	0.1	100.0
Apr	0.1	0.1	0.0	11	0.1	0.1	100.0
May	0.1	0.1	0.0	66	0.1	0.1	100.0
Jun	0.1	0.1	0.0	61	0.1	0.1	100.0
Jul	0.1	0.1	0.0	76	0.1	0.1	100.0
Aug	0.1	0.1	0.0	62	0.1	0.1	100.0
Sep	0.1	0.1	0.0	62	0.1	0.1	100.0
Oct	0.1	0.1	0.1	62	0.1	1.2	98.4
Nov	0.1	0.1	0.0	31	0.1	0.1	100.0
Dec	0.1	0.1	0.0	31	0.1	0.1	100.0
Overall	0.1	0.1	0.0	545	0.1	1.2	99.8

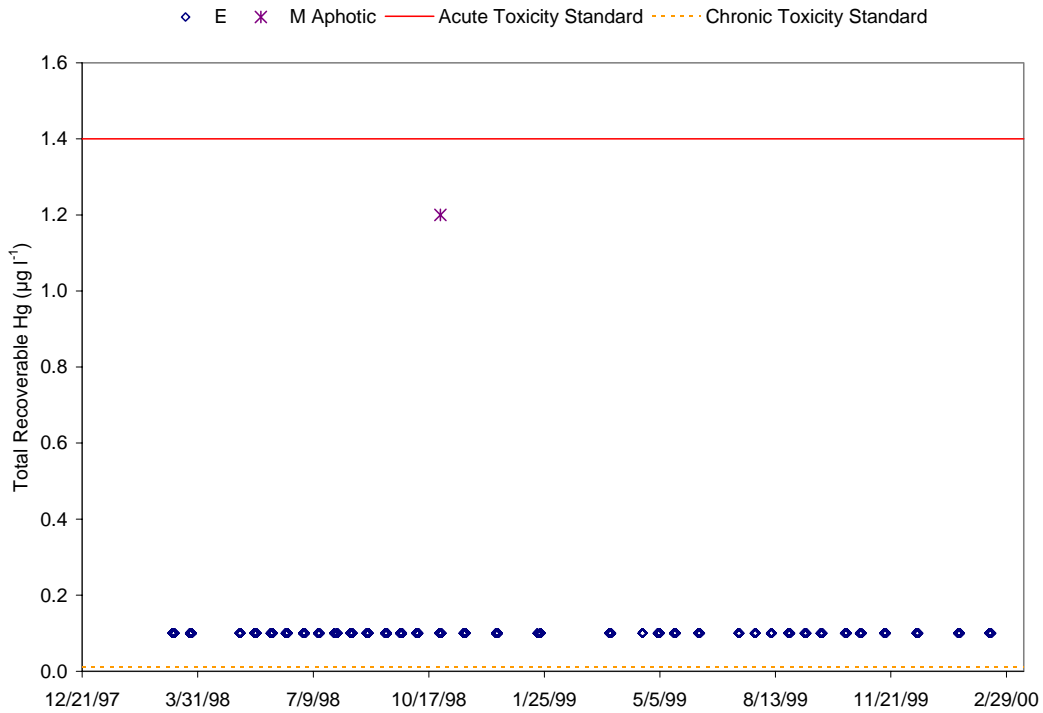


Figure 18. Total recoverable mercury concentrations ($\mu\text{g l}^{-1}$) from all locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included.

Zinc

Total recoverable zinc was the next most frequently measurable contaminant of concern behind lead. Of the 608 samples analyzed for total recoverable zinc, 92 had concentrations above or at the MRL (15.1%). Measurable zinc concentrations ranged from 5 to 84 $\mu\text{g l}^{-1}$ (Table 15). The coefficient of variation for measurable zinc concentrations was 72. Measurable zinc concentrations were observed at all sampling locations and months of the year except August (Figure 19; Figure 20). Prior to mean comparisons extreme values were identified in measurable zinc concentrations (Figure 21). Two extreme values were removed prior to mean comparisons. Both extreme values were from sampling in January 1998, with one value from the Sanpoil River Confluence (39 $\mu\text{g l}^{-1}$) and the other from Spring Canyon (60 $\mu\text{g l}^{-1}$; Figure 22).

Log transformed zinc concentration (measurable) at Porcupine Bay (33.2 $\mu\text{g l}^{-1}$) was significantly greater than concentrations at Evan's Landing (13.0 $\mu\text{g l}^{-1}$; $P < 0.0001$), Kettle Falls (8.8 $\mu\text{g l}^{-1}$; $P < 0.0001$), Gifford (17.1 $\mu\text{g l}^{-1}$; $P = 0.0079$), Hunters (17.6 $\mu\text{g l}^{-1}$; $P = 0.0018$), Seven Bays (13.0 $\mu\text{g l}^{-1}$; $P = 0.0002$), Sanpoil River (11.3 $\mu\text{g l}^{-1}$; $P < 0.0001$), and Spring Canyon (10.8 $\mu\text{g l}^{-1}$; $P = 0.0002$). Median zinc concentration at Porcupine Bay (17.5 $\mu\text{g l}^{-1}$) was 3.5 times greater than median zinc concentrations at all other locations (5.0 $\mu\text{g l}^{-1}$; Table 27). Zinc was measurable at Porcupine Bay more frequently than at all other locations (Table 27). Only 42% of all zinc samples at Porcupine Bay were below the MRL as compared to 86 to 97% of samples at all other locations. Log transformed zinc concentrations (measurable) from aphotic zone (mean depth = 9.8 m) samples at 23 $\mu\text{g l}^{-1}$ and photic zone (mean depth = 4.3 m) samples at 20 $\mu\text{g l}^{-1}$ in 1998 (May-Dec) were not significantly different ($P < 0.6393$).

Zinc had significant correlations with environmental variables including Secchi depth, total silica concentration, photic zone depth, hardness, turbidity, and water retention time (Table 29). Total recoverable zinc (measurable) was most correlated to Secchi depth ($r = -0.64$; $P < 0.0001$; Figure 23). Zinc was negatively correlated to Secchi depth, photic depth, hardness, and water retention time (Table 29). Conversely, zinc was positively correlated to silica concentration and turbidity (Table 29). Total recoverable zinc was

moderately to weakly correlated (measurable concentrations only) with the following other metals: manganese ($r = 0.51$; $P = 0.00001$), aluminum ($r = 0.50$; $P = 0.00008$), iron ($r = 0.48$; $P = 0.000003$), magnesium ($r = -0.11$; $P = 0.2834$), and lead ($r = -0.04$; $P = 0.7413$; Appendix C). In correlations between zinc and other contaminants of concern (arsenic, cadmium, copper, and mercury) sample sizes were too small ($n \leq 6$) to draw meaningful conclusions.

Table 27. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable zinc concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by sampling location. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 92 of 608 (15.1%) samples had zinc at or above the MRL.

Location	Mean	Median	SD	n	Min	Max	% E
Evan's Landing	6.4	5.0	4.3	58	2.5	27.0	86.2
Kettle Falls	5.6	5.0	2.7	58	2.5	17.5	91.4
Gifford	6.5	5.0	5.2	58	2.5	31.0	89.7
Hunters	6.3	5.0	6.0	58	2.5	43.0	91.4
Spokane R. Confluence	7.2	5.0	5.8	43	5.0	33.0	88.4
Seven Bays	6.3	5.0	3.9	56	2.5	21.0	85.7
Sanpoil R. Confluence	6.7	5.0	5.7	43	5.0	39.0	88.4
Keller Ferry	6.6	5.0	10.6	58	2.5	84.0	96.6
Spring Canyon	6.4	5.0	7.6	58	2.5	60.0	89.7
Porcupine Bay	21.4	17.5	17.7	60	2.5	59.0	41.7
Sanpoil R.	6.0	5.0	3.5	58	2.5	20.0	87.9
Overall	7.9	5.0	9.1	608	2.5	84.0	84.9

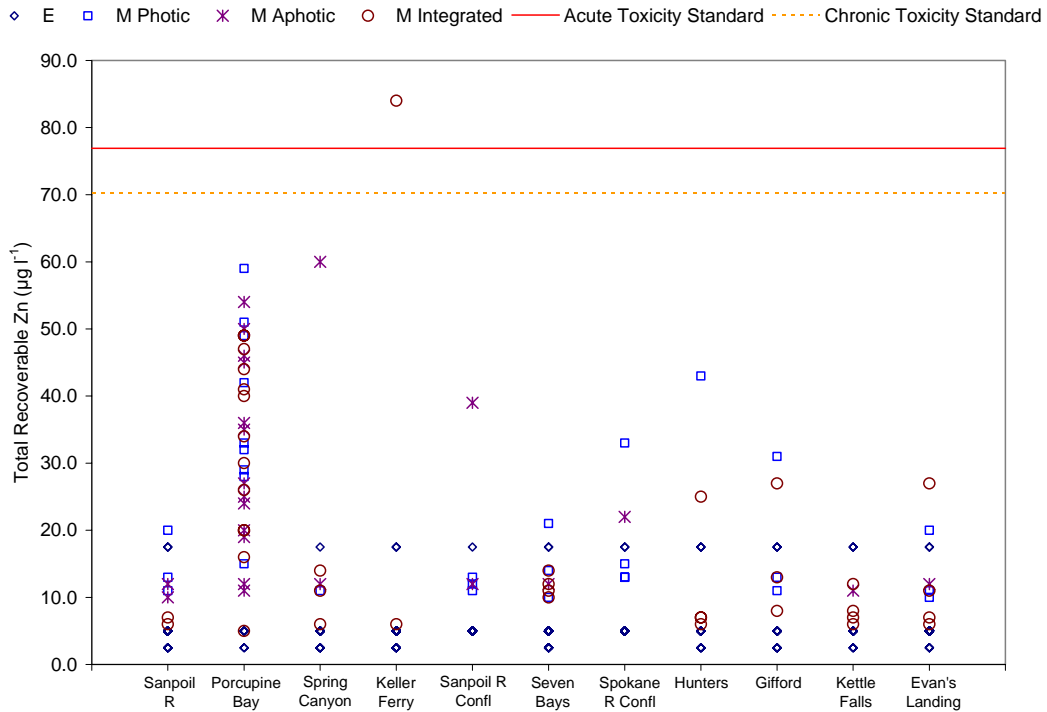


Figure 19. Total recoverable zinc concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included (based on standard mean and hardness).

Table 28. Mean, median, standard deviation (SD), sample size (n), and ranges of total recoverable zinc concentrations ($\mu\text{g l}^{-1}$) from Lake Roosevelt surface water grouped by month. Data includes estimated concentrations which were calculated by dividing the minimum reporting level (MRL) in half. 15 of 608 (15.1%) samples had zinc at or above the MRL.

Month	Mean	Median	SD	n	Min	Max	% E
Jan	18.5	17.5	18.2	42	2.5	84.0	73.8
Feb	9.7	5.0	9.4	31	2.5	33.0	64.5
Mar	10.2	5.0	11.1	64	5.0	49.0	68.8
Apr	9.1	5.0	11.7	11	5.0	44.0	81.8
May	9.8	5.0	12.0	66	5.0	54.0	77.3
Jun	7.7	5.0	7.5	66	5.0	45.0	84.8
Jul	7.3	5.0	6.4	80	5.0	43.0	83.8
Aug	5.0	5.0	0.0	62	5.0	5.0	100.0
Sep	5.2	5.0	1.2	62	5.0	12.0	96.8
Oct	4.4	5.0	1.2	62	2.5	8.0	96.8
Nov	4.8	5.0	1.5	31	2.5	10.0	87.1
Dec	5.0	5.0	3.2	31	2.5	20.0	93.5
Overall	7.9	5.0	9.1	608	2.5	84.0	84.9

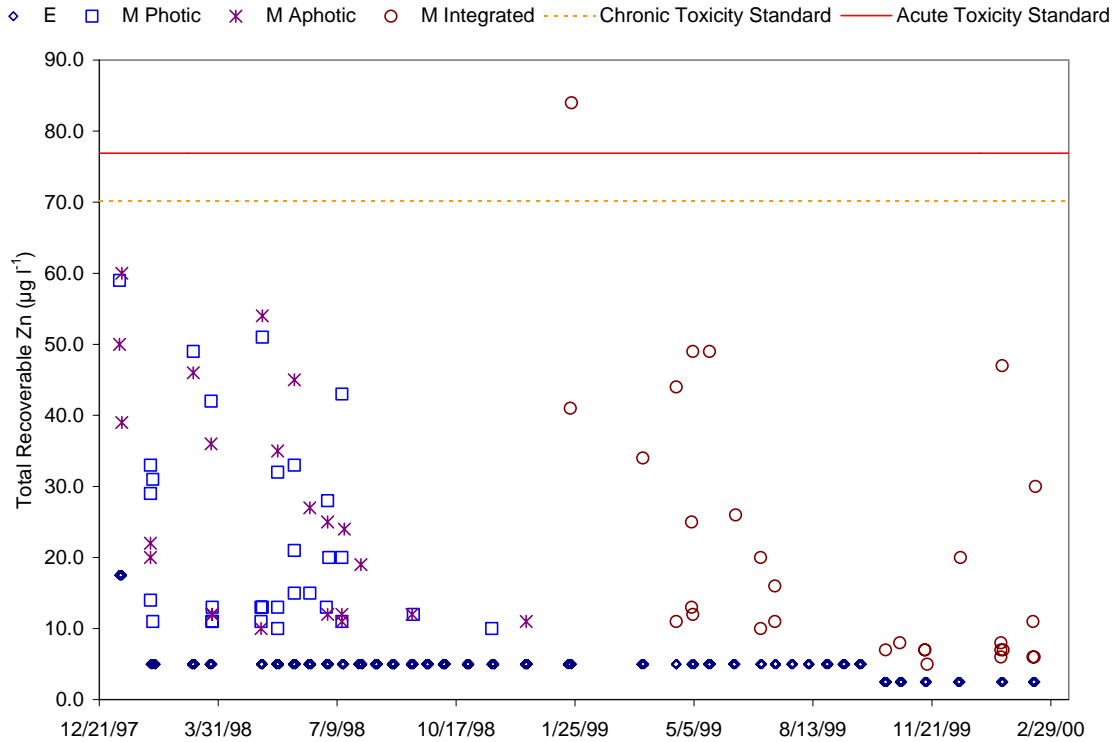


Figure 20. Total recoverable zinc concentrations ($\mu\text{g l}^{-1}$) from all locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included (based on standard mean and hardness).

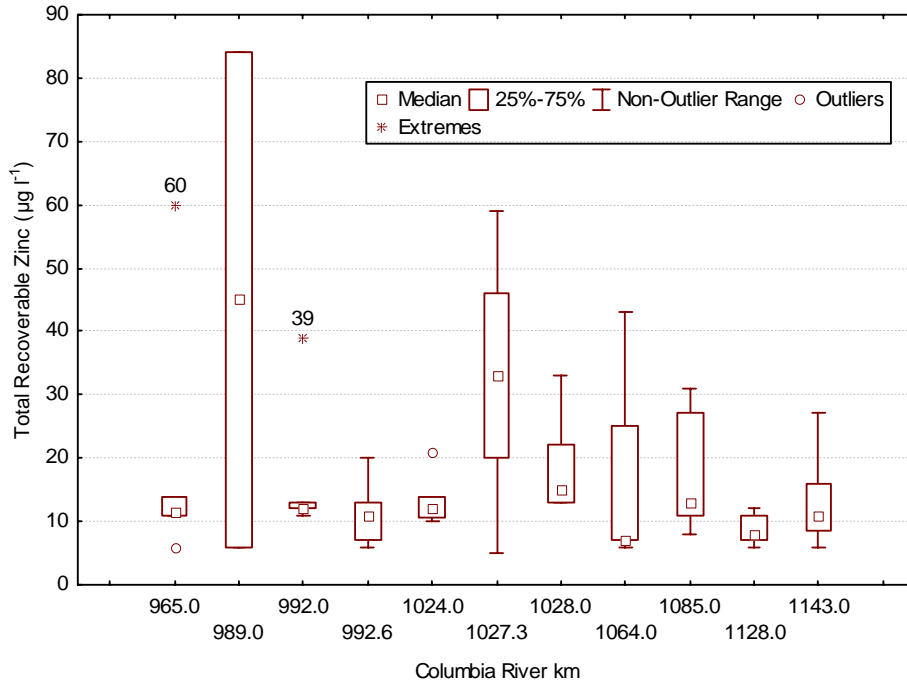


Figure 21. Box plots of total recoverable zinc concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt (measurable concentrations only) with extreme values noted.

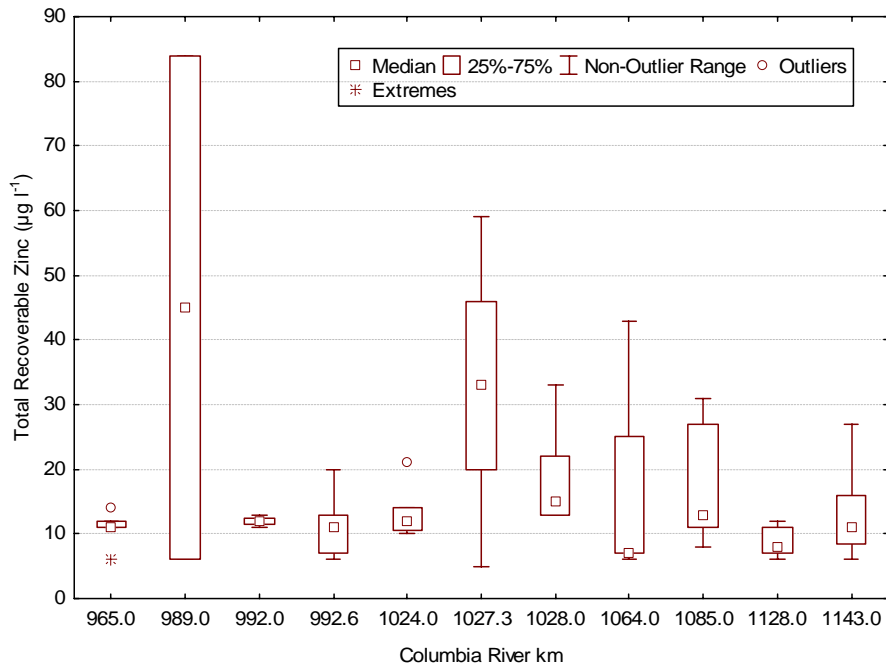


Figure 22. Box plots of total recoverable zinc concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt (measurable concentrations only). Two extreme values were removed.

Table 29. Correlation matrix of total recoverable zinc concentrations (measurable) from Lake Roosevelt surface water and other environmental variables (removed one data point with 84 $\mu\text{g l}^{-1}$ zinc because it diminished the correlation with Secchi). Italicized red correlations are significant at $P < 0.05$.

	Photic Depth	Secchi Depth	Water Retention Time	Reservoir Elevation	Inflow (5 d mean)	Outflow (5 d mean)	Inflow (15 d mean)	Outflow (15 d mean)	Total Suspended Solids	Turbidity	Hardness	Total Zn	Total SiO ₂
Photic Depth	1.00	<i>0.88</i>	<i>0.33</i>	0.16	<i>-0.34</i>	<i>-0.24</i>	<i>-0.29</i>	-0.17	<i>-0.44</i>	<i>-0.68</i>	<i>0.48</i>	<i>-0.52</i>	<i>-0.79</i>
Secchi Depth	<i>0.88</i>	1.00	<i>0.40</i>	<i>0.29</i>	<i>-0.38</i>	<i>-0.30</i>	<i>-0.31</i>	-0.18	<i>-0.60</i>	<i>-0.58</i>	<i>0.51</i>	<i>-0.64</i>	<i>-0.69</i>
Water Retention Time	<i>0.33</i>	<i>0.40</i>	1.00	<i>0.43</i>	<i>-0.39</i>	<i>-0.57</i>	<i>-0.32</i>	<i>-0.47</i>	-0.19	-0.20	<i>0.33</i>	<i>-0.27</i>	<i>-0.28</i>
Reservoir Elevation	0.16	<i>0.29</i>	<i>0.43</i>	1.00	0.17	-0.04	<i>0.24</i>	-0.06	-0.03	<i>-0.30</i>	-0.05	<i>-0.20</i>	<i>-0.24</i>
Inflow (5 d mean)	<i>-0.34</i>	<i>-0.38</i>	<i>-0.39</i>	0.17	1.00	<i>0.81</i>	<i>0.86</i>	<i>0.61</i>	0.09	-0.06	<i>-0.65</i>	0.05	0.02
Outflow (5 d mean)	<i>-0.24</i>	<i>-0.30</i>	<i>-0.57</i>	-0.04	<i>0.81</i>	1.00	<i>0.70</i>	<i>0.79</i>	<i>0.30</i>	0.01	<i>-0.57</i>	0.20	0.03
Inflow (15 d mean)	<i>-0.29</i>	<i>-0.31</i>	<i>-0.32</i>	<i>0.24</i>	<i>0.86</i>	<i>0.70</i>	1.00	<i>0.75</i>	0.15	-0.06	<i>-0.68</i>	0.01	-0.01
Outflow (15 d mean)	-0.17	-0.18	<i>-0.47</i>	-0.06	<i>0.61</i>	<i>0.79</i>	<i>0.75</i>	1.00	<i>0.33</i>	0.08	<i>-0.55</i>	0.14	0.02
Total Suspended Solids	<i>-0.44</i>	<i>-0.60</i>	-0.19	-0.03	0.09	<i>0.30</i>	0.15	<i>0.33</i>	1.00	<i>0.35</i>	<i>-0.33</i>	0.13	0.26
Turbidity	<i>-0.68</i>	<i>-0.58</i>	-0.20	<i>-0.30</i>	-0.06	0.01	-0.06	0.08	<i>0.35</i>	1.00	-0.20	<i>0.30</i>	<i>0.74</i>
Hardness	<i>0.48</i>	<i>0.51</i>	<i>0.33</i>	-0.05	<i>-0.65</i>	<i>-0.57</i>	<i>-0.68</i>	<i>-0.55</i>	<i>-0.33</i>	-0.20	1.00	<i>-0.35</i>	<i>-0.22</i>
Total Zn	<i>-0.52</i>	<i>-0.64</i>	<i>-0.27</i>	-0.20	0.05	0.20	0.01	0.14	0.13	<i>0.30</i>	<i>-0.35</i>	1.00	<i>0.56</i>
Total SiO ₂	<i>-0.79</i>	<i>-0.69</i>	<i>-0.28</i>	<i>-0.24</i>	0.02	0.03	-0.01	0.02	0.26	<i>0.74</i>	<i>-0.22</i>	<i>0.56</i>	1.00

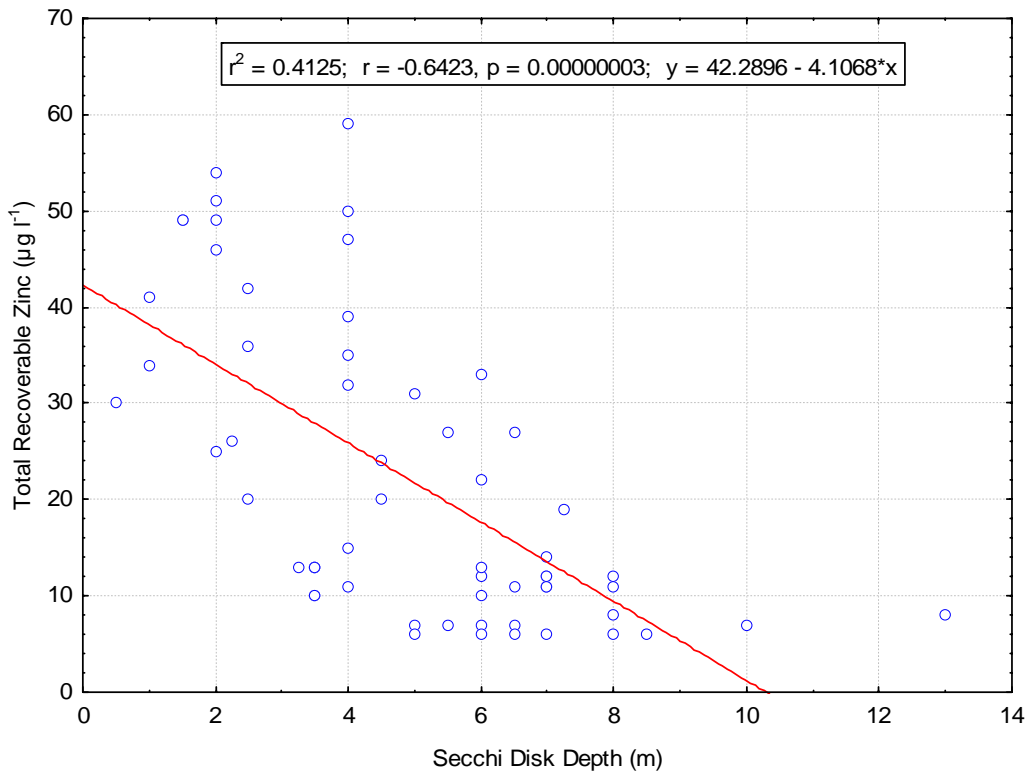


Figure 23. Regression plot of total recoverable zinc concentration (measurable) and Secchi disk depth with one outlier removed (6 m Secchi, 84 $\mu\text{g l}^{-1}$ Zn).

Hardness

Mean hardness was about 63 mg l^{-1} and ranged from 26 to 117 mg l^{-1} in Lake Roosevelt during the study period (Table 30; Table 31). Differences between location means were insignificant (ANOVA, $P \geq 0.24$). Hardness varied considerably more at Porcupine Bay (SD = 19.9) than at other locations (SD ranged from 5.9 to 9.6; Table 30; Figure 24). Seasonally, hardness was generally lowest in late spring early summer and greatest in late winter (Table 31; Figure 24).

Table 30. Mean, median, standard deviation (SD), sample size (n), and ranges of hardness concentrations (mg l^{-1}) from Lake Roosevelt surface water grouped by sampling location.

Location	Mean	Median	SD	n	Min	Max
Evan's Landing	63.6	62.4	9.6	58	50.6	117.0
Kettle Falls	61.8	62.1	6.5	58	47.5	74.2
Gifford	62.8	61.8	6.8	58	50.3	76.0
Hunters	63.0	62.9	6.8	58	48.9	74.4
Spokane R. Confluence	63.9	63.2	6.7	43	47.6	78.4
Seven Bays	61.5	62.3	7.9	56	44.6	73.9
Sanpoil R. Confluence	63.9	62.7	5.9	43	50.8	74.1
Keller Ferry	61.7	61.1	7.2	58	50.1	74.9
Spring Canyon	62.6	62.4	6.9	58	50.6	75.2
Porcupine Bay	62.7	61.8	19.9	60	26.0	97.3
Sanpoil R.	61.8	62.2	6.7	58	49.8	73.8
Overall	62.6	62.2	9.2	608	26.0	117.0

Table 31. Mean, median, standard deviation (SD), sample size (n), and ranges of hardness concentrations (mg l^{-1}) from Lake Roosevelt surface water grouped by month.

Month	Mean	Median	SD	n	Min	Max
Jan	67.6	68.5	4.5	42	51.1	73.7
Feb	73.2	73.2	5.2	31	57.5	89.8
Mar	70.1	72.4	6.3	64	41.8	74.7
Apr	65.2	65.9	7.1	11	46.4	72.8
May	57.5	60.0	7.9	66	32.7	72.1
Jun	54.7	56.6	7.5	66	26.0	64.5
Jul	57.2	58.0	5.2	80	39.1	70.5
Aug	59.8	60.9	5.5	62	50.3	81.5
Sep	62.8	62.8	9.2	62	47.5	97.3
Oct	64.1	62.6	9.4	62	54.2	95.8
Nov	69.3	66.4	13.1	31	55.5	117.0
Dec	66.1	65.1	4.9	31	57.8	82.6
Overall	62.6	62.2	9.2	608	26.0	117.0

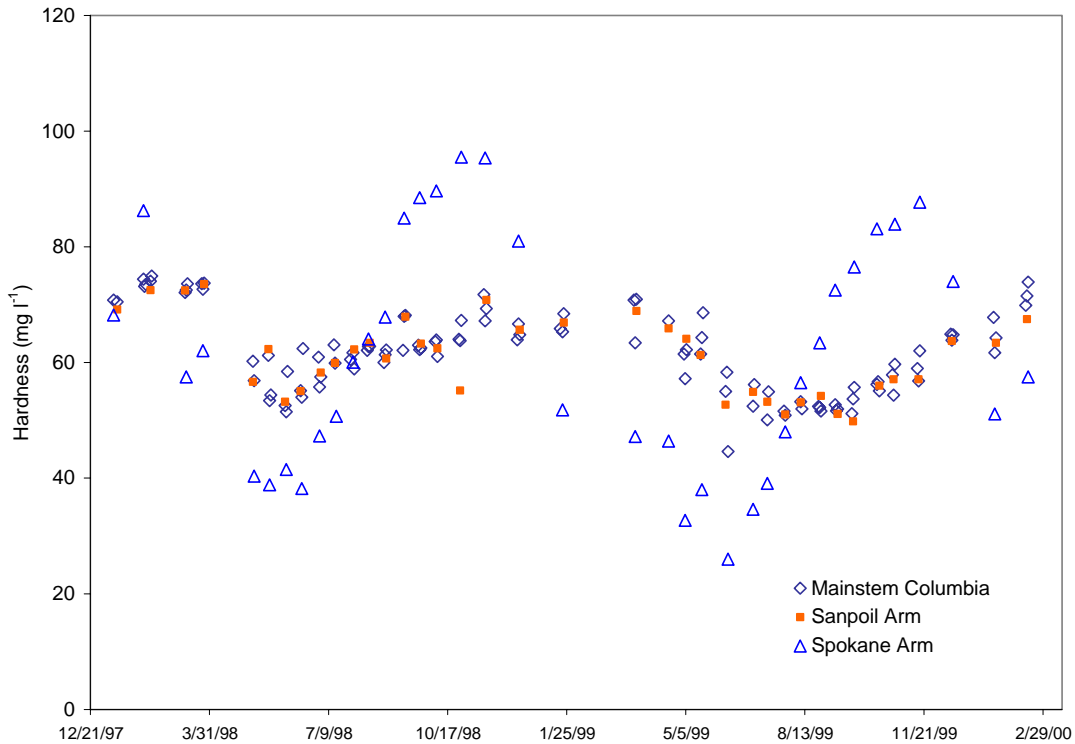


Figure 24. Mean hardness on the mainstem and reservoir arms of Lake Roosevelt.

Other Elements

Of the 608 samples analyzed for aluminum only 40% were at or above the MRL. Mean ($69.2 \mu\text{g l}^{-1}$) and median ($30.0 \mu\text{g l}^{-1}$) aluminum concentrations (estimated concentrations included) were considerably different (Table 32). Measurable aluminum concentrations ranged from 11 to $6000 \mu\text{g l}^{-1}$. There was at least one extreme outlier ($6000 \mu\text{g l}^{-1}$) originating from the Spokane River Confluence in February of 1998. Mean annual aluminum concentration was highest at Porcupine Bay and seasonally was generally highest in the spring (Table 33; Table 34). In addition to higher aluminum concentrations at Porcupine Bay other surface water constituents including calcium, magnesium, iron, manganese, potassium, silica, and sodium were markedly different (Table 34).

Of the 520 samples analyzed for barium 100% were at or above the MRL. Mean ($30.7 \mu\text{g l}^{-1}$) and median ($29.0 \mu\text{g l}^{-1}$) barium concentrations did not vary substantially (Table 32). Barium concentrations ranged from 15 to $152 \mu\text{g l}^{-1}$. There was at least one outlier

(152 $\mu\text{g l}^{-1}$) measured at Evan's Landing in July of 1998. There were no distinct spatial or temporal differences noted in barium concentrations.

Calcium and magnesium were at measurable concentrations in all 608 samples. Mean calcium and magnesium concentrations were respectively, 17862 and 4376 $\mu\text{g l}^{-1}$. Mean and median calcium and magnesium concentrations did not vary substantially (Table 32). Spatial and temporal differences in calcium and magnesium concentrations were reflected in the hardness estimations (Table 33; Table 34).

Of all 608 samples analyzed for iron only 5% were below the MRL. Mean (56.8 $\mu\text{g l}^{-1}$) and median (34.0 $\mu\text{g l}^{-1}$) iron concentrations were considerably different (Table 32). Measurable iron concentrations ranged from 6 to 1260 $\mu\text{g l}^{-1}$. There were at least four outliers with the largest (1260 $\mu\text{g l}^{-1}$) recorded from Porcupine Bay in February of 2000. Iron appears to be highest at Porcupine Bay and highest reservoir wide in spring and winter (Table 33; Table 34).

Of 608 samples analyzed for manganese 66% were at or above the MRL. Mean (5.8 $\mu\text{g l}^{-1}$) and median (4.0 $\mu\text{g l}^{-1}$) manganese concentrations were similar (Table 32). Measurable manganese concentrations ranged from 1 to 88 $\mu\text{g l}^{-1}$. At least three outliers were present with the highest (88 $\mu\text{g l}^{-1}$) from Porcupine Bay in September of 1998. Manganese was highest at Porcupine Bay and highest reservoir wide in the spring (Table 33; Table 34).

Of 608 samples analyzed for potassium 37% were at or above the MRL. Mean (631 $\mu\text{g l}^{-1}$) and median (450 $\mu\text{g l}^{-1}$) potassium concentrations were relatively different (Table 32). Measurable concentrations ranged from 438 to 1860 $\mu\text{g l}^{-1}$. Potassium concentrations (measurable) generally increased from upstream to downstream and were highest at Porcupine Bay (Table 33). Seasonally, potassium concentrations (measurable) were greatest in late winter and spring (Table 34).

All (n = 608) samples analyzed for sodium had concentrations at or above the MRL. Mean (2083 $\mu\text{g l}^{-1}$) and median (1945 $\mu\text{g l}^{-1}$) sodium concentrations were fairly similar (Table 32). Similar to potassium, sodium concentrations increased from upstream to

downstream and were greatest at Porcupine Bay (Table 33). Sodium concentrations were greatest in the spring (Table 34).

All of the 608 samples analyzed for silica had concentrations at or above the MRL. Mean (2841 $\mu\text{g l}^{-1}$) and median (2550 $\mu\text{g l}^{-1}$) silica concentrations were moderately different (Table 32). Silica concentrations like potassium and sodium increased from upstream to downstream and were greatest at Porcupine Bay (Table 33). Seasonally silica concentrations were greatest in the spring (Table 34).

Elements such as antimony, beryllium, chromium, cobalt, and silver had no concentrations at or above the MRL. Mean concentrations listed for those elements are all half the MRL for the given element (Table 32). Nickel and selenium concentrations were mostly (99%) estimates as well. Of the 520 samples measured for total recoverable nickel 6 had concentrations at or above the MRL (Figure 25; Figure 26). Of the 519 samples measured for total recoverable selenium 6 had concentrations at or above the MRL (Figure 27; Figure 28).

Table 32. Mean, median, standard deviation (SD), sample size (n), and ranges of various element concentrations (total recoverable, $\mu\text{g l}^{-1}$) from Lake Roosevelt surface water. Table includes all data. The last column of table lists the percent of estimated concentrations present in data. Estimated concentrations determined by dividing minimum reporting level in half.

Analyte	Mean	Median	SD	n	Min	Max	% E
Aluminum	69.2	30.0	260.9	608	5.0	6000.0	60
Antimony	23.4	25.0	4.3	520	10.0	25.0	100
Barium	30.7	29.0	11.7	520	15.0	152.0	0
Beryllium	0.5	0.5	0.1	520	0.5	2.0	100
Calcium	17861.6	18000.0	2566.2	608	6730.0	33800.0	0
Chromium	3.3	3.5	0.5	520	2.0	3.5	100
Cobalt	3.3	3.5	0.5	520	2.0	7.0	100
Iron	56.8	34.0	91.8	608	5.0	1260.0	5
Magnesium	4375.9	4200.0	872.5	608	2230.0	8860.0	0
Manganese	5.8	4.0	8.1	608	0.5	88.0	33
Nickel	7.4	7.5	1.9	520	5.0	29.0	99
Potassium	630.5	450.0	305.7	608	425.0	1860.0	63
Selenium	38.8	40.0	6.6	519	25.0	98.0	99
Silica	2840.5	2550.0	1024.2	608	1500.0	8530.0	0
Silver	4.7	5.0	0.8	520	2.5	5.0	100
Sodium	2083.3	1945.0	658.3	608	1070.0	5730.0	0

Table 33. Mean concentrations (total recoverable, $\mu\text{g l}^{-1}$) of various elements from Lake Roosevelt surface water grouped by location. Table includes all data.

Location	Ag	Al	Ba	Be	Ca	Co	Cr	Fe	K	Mg	Mn	Na	Ni	Sb	Se	SiO₂
Evan's Landing	4.7	48.1	34.9	0.5	18436.2	3.3	3.3	57.5	520.0	4276.7	4.8	1795.3	7.2	23.2	38.6	2314.0
Kettle Falls	4.7	48.3	31.3	0.5	17955.2	3.4	3.3	52.1	517.2	4132.2	5.2	1777.6	7.2	23.2	39.2	2361.7
Gifford	4.7	44.1	33.0	0.5	18224.1	3.3	3.3	41.7	557.4	4200.5	4.8	1903.4	7.2	23.2	39.0	2396.2
Hunters	4.7	45.2	32.9	0.5	18260.3	3.3	3.3	44.6	559.8	4219.1	5.4	1885.3	7.4	23.2	38.0	2414.8
Spokane R. Confluence	5.0	56.2	31.2	0.5	18427.9	3.5	3.5	58.9	516.8	4334.7	6.6	1953.3	7.5	25.0	40.0	2639.3
Seven Bays	4.6	47.5	29.4	0.5	17633.9	3.3	3.3	42.1	587.9	4242.5	5.0	1940.2	7.6	23.1	37.9	2640.9
Sanpoil R. Confluence	5.0	49.0	30.8	0.5	18397.7	3.5	3.5	44.5	549.2	4346.0	3.7	1995.3	7.5	25.0	41.5	2748.1
Keller Ferry	4.7	57.4	28.9	0.5	17765.5	3.3	3.3	51.9	576.6	4224.3	3.8	1971.9	7.3	23.2	38.0	2758.8
Spring Canyon	4.7	40.5	30.2	0.5	18027.6	3.3	3.3	35.3	624.8	4269.8	3.2	1973.4	7.5	23.2	38.0	2668.4
Porcupine Bay	4.7	128.7	25.7	0.5	15894.0	3.3	3.3	116.8	1188.0	5599.7	14.8	3434.7	7.6	23.3	39.8	4990.7
Sanpoil R.	4.7	82.8	29.4	0.5	17800.0	3.3	3.3	73.8	666.4	4224.5	6.2	2177.4	7.3	23.2	38.0	3155.3
Overall	4.7	69.2	30.7	0.5	17861.6	3.3	3.3	56.8	630.5	4375.9	5.8	2083.3	7.4	23.4	38.8	2840.5

Table 34. Mean concentrations (total recoverable, $\mu\text{g l}^{-1}$) of various elements from Lake Roosevelt surface water grouped by month. Table includes all data.

Month	Ag	Al	Ba	Be	Ca	Co	Cr	Fe	K	Mg	Mn	Na	Ni	Sb	Se	SiO₂
Jan	3.9	70.1	29.0	0.5	19114.3	2.8	2.8	66.1	665.4	4836.9	4.2	1914.5	9.2	20.5	33.3	2738.6
Feb	2.5	132.2	28.2	0.5	20712.9	2.0	2.0	141.3	832.5	5221.9	7.9	1960.3	5.0	15.0	38.4	3008.7
Mar	3.9	75.1	29.0	0.5	19985.9	2.8	2.8	65.1	725.2	4908.4	4.7	2019.1	6.4	20.5	35.5	3096.4
Apr	5.0	107.8	33.1	0.5	18409.1	3.5	3.5	125.6	1165.1	4665.5	10.2	2632.7	7.5	25.0	40.0	3795.5
May	5.0	92.4	29.0	0.5	16397.4	3.5	3.5	84.8	604.0	4013.8	7.2	2343.0	7.5	25.0	40.0	3787.1
Jun	5.0	68.5	29.5	0.5	15659.2	3.5	3.5	85.8	484.2	3798.0	7.0	2355.5	7.6	25.0	41.6	3187.3
Jul	5.0	49.8	40.3	0.5	16278.8	3.5	3.5	43.8	642.5	4016.6	6.5	2208.9	7.5	25.0	40.0	2793.3
Aug	5.0	40.9	27.8	0.5	17130.6	3.5	3.5	37.4	590.0	4136.8	6.7	1861.5	7.5	25.0	40.0	2417.7
Sep	5.0	33.2	27.1	0.5	18158.1	3.6	3.5	29.0	579.9	4249.7	7.0	1740.2	7.8	25.0	40.9	2301.5
Oct	4.3	27.7	27.7	0.5	18358.1	3.1	3.1	13.7	604.2	4432.7	3.1	1926.1	6.8	20.6	35.6	2337.7
Nov	4.3	27.8	32.0	0.5	19783.9	3.1	3.1	17.8	569.4	4828.7	2.7	2233.9	6.8	20.6	35.6	2556.1
Dec	4.3	46.1	31.2	0.5	18577.4	3.1	3.1	49.2	628.5	4796.5	4.4	2209.0	6.8	20.6	35.6	2524.5
Overall	4.7	69.2	30.7	0.5	17861.6	3.3	3.3	56.8	630.5	4375.9	5.8	2083.3	7.4	23.4	38.8	2840.5

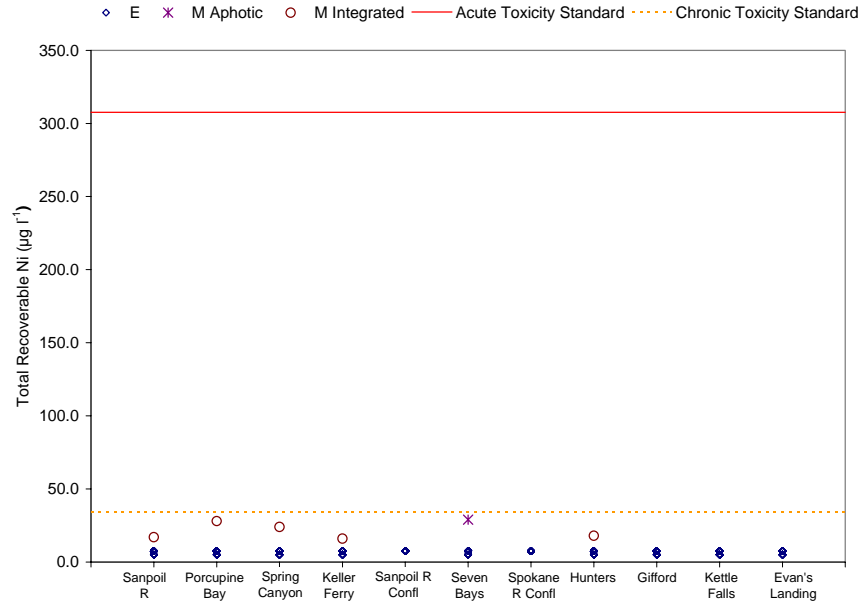


Figure 25. Total recoverable nickel concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included (based on standard mean and hardness).

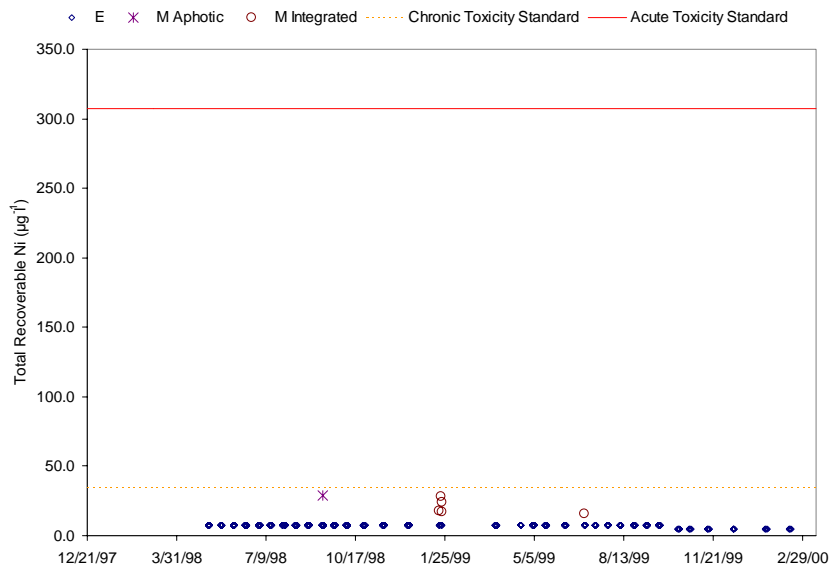


Figure 26. Total recoverable nickel concentrations ($\mu\text{g l}^{-1}$) from all locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included (based on standard mean and hardness).

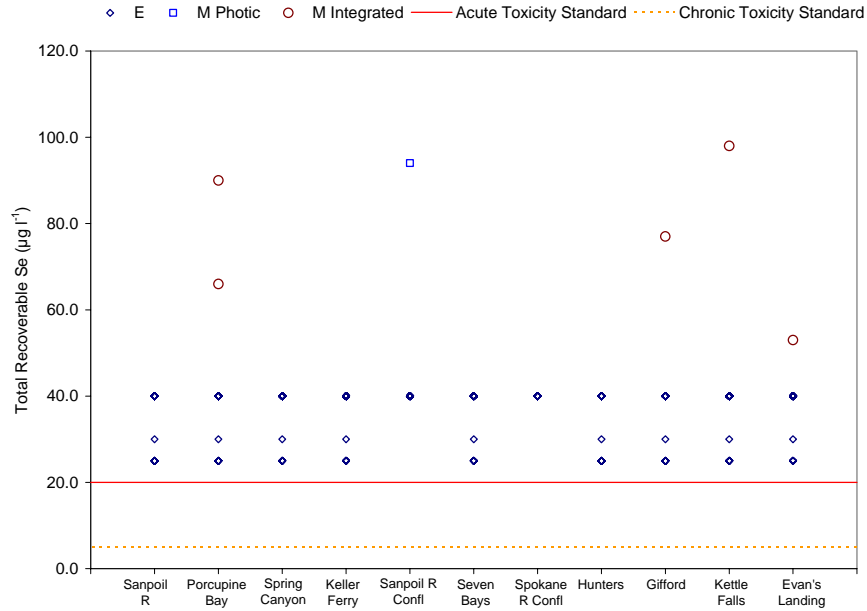


Figure 27. Total recoverable selenium concentrations ($\mu\text{g l}^{-1}$) from locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included.

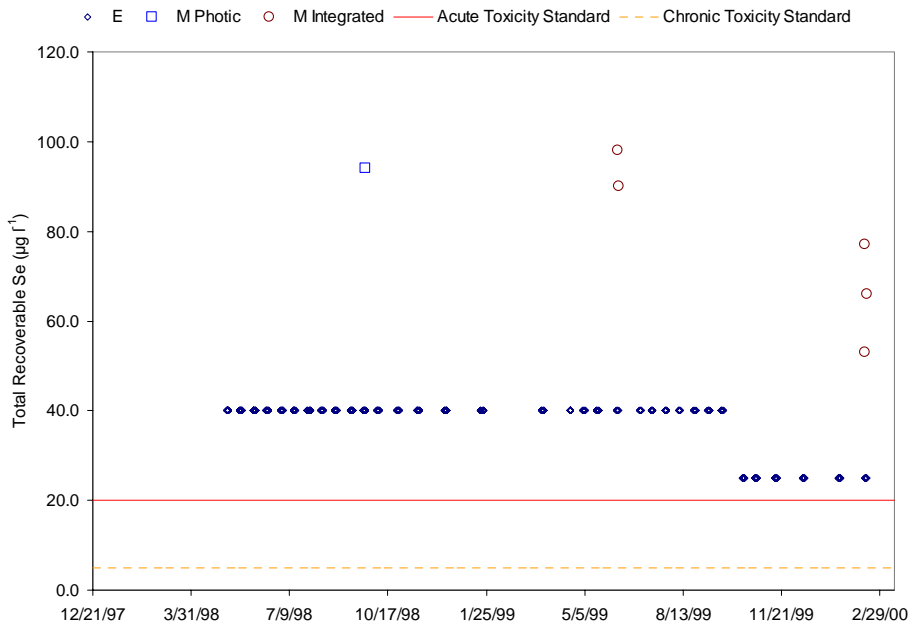


Figure 28. Total recoverable selenium concentrations ($\mu\text{g l}^{-1}$) from all locations on Lake Roosevelt including estimated (E) values and measured (M) values separated by sampling technique (all data is included). Spokane Tribe acute and chronic toxicity water quality standards also included.

Water Quality Standards

Spokane Tribal and Washington State water quality standards were used to assess potential negative effects to organisms utilizing Lake Roosevelt. Spokane Tribal standards are similar to Washington State standards (Table 35). Since most water quality standards are based on dissolved concentrations, using total recoverable concentration data makes for conservative exceedance estimates or worst case exceedances.

Consideration of a method's MRL was important when comparing a contaminant concentration to a given criteria because if the MRL was above criteria there was effectively no way to assess exceedances.

Mean arsenic MRL was $42.3 \mu\text{g l}^{-1}$ and mean acute and chronic toxicity criteria ranged from 150 to $360 \mu\text{g l}^{-1}$ (Table 35). So determining exceedance of arsenic criteria was possible. For all concentrations measured and estimated arsenic did not exceed acute or chronic criteria for both Tribal and State standards (Table 36; Figure 7; Figure 8).

The mean cadmium MRL was $5.2 \mu\text{g l}^{-1}$ whereas mean acute and chronic toxicity criteria ranged from 0.7 to $2.3 \mu\text{g l}^{-1}$ (Table 35). So, in most cases analytical sensitivity was not low enough to allow for assessment with criteria. Tribal and State criteria resulted in the same number of exceedances for both acute and chronic criteria (Table 36). Acute and chronic criteria were exceeded in 85 and 100% of samples, respectively (Table 36; Figure 9; Figure 10). However, most of those samples were estimated concentrations.

The mean copper MRL was $6.7 \mu\text{g l}^{-1}$ and mean acute and chronic criteria ranged from 5.9 to $10.7 \mu\text{g l}^{-1}$ (Table 35). Assessment of copper criteria would have benefited from a slightly lower copper MRL since it was not always below the criteria. Differences between Tribal and State criteria in this case for numbers of exceedances were at most only by a count of two. So, acute and chronic criteria were exceeded in 1.0 – 1.2% and 1.5 – 2.1% of samples, respectively (Table 36; Figure 11; Figure 12).

The mean lead MRL was $1.0 \mu\text{g l}^{-1}$ and mean acute and chronic criteria ranged from 1.5 to $38.7 \mu\text{g l}^{-1}$ (Table 35). Since MRL were generally lower than the criteria an assessment of exceedances was possible. Tribal and State criteria resulted in the same

number of exceedances for both acute and chronic criteria (Table 36). Acute and chronic criteria were exceeded in 0.5 and 56% of samples, respectively (Table 36; Figure 13; Figure 14). Unfortunately the number of exceedances due to sample contamination by the lead weighted water sampler is unknown.

The mean mercury MRL was $0.2 \mu\text{g l}^{-1}$ and mean acute and chronic criteria ranged from 0.012 to $1.4 \mu\text{g l}^{-1}$ (Table 35). Acute criteria were assessable but chronic criteria were not because of the high MRL. Tribal and State criteria resulted in the same number of exceedances for both acute and chronic criteria (Table 36). Acute and chronic criteria were exceeded in 0 and 100% of samples, respectively (Table 36; Figure 17; Figure 18). Most of the mercury exceedances were estimated concentrations.

The mean zinc MRL was $10.5 \mu\text{g l}^{-1}$ and mean acute and chronic criteria ranged from 70.2 to $76.9 \mu\text{g l}^{-1}$ (Table 35). Both acute and chronic criteria were assessable since MRL were below mean criteria concentrations. Tribal and State criteria resulted in the same number of exceedances for both acute and chronic criteria (Table 36). Acute and chronic criteria were exceeded in 0.3 and 0.8% of samples, respectively (Table 36; Figure 19; Figure 20).

Table 35. Mean minimum reporting level (MRL) and water quality criteria from the Spokane Tribe and Washington State (acute and chronic criteria dependent on hardness concentrations except for arsenic and mercury).

Trace Element	Mean MRL ($\mu\text{g l}^{-1}$)	Criteria Type	Spokane Tribe Mean Criteria Conc. ($\mu\text{g l}^{-1}$)	Washington State Mean Criteria Conc. ($\mu\text{g l}^{-1}$)
Arsenic	42.3	Acute	340	360
		Chronic	150	190
Cadmium	5.2	Acute	2.3	2.2
		Chronic	0.7	0.7
Copper	6.7	Acute	8.4	10.7
		Chronic	5.9	7.4
Lead	1.0	Acute	38.7	38.7
		Chronic	1.5	1.5
Mercury	0.2	Acute	1.4	2.1
		Chronic	0.012	0.012
Zinc	10.5	Acute	76.9	76.9
		Chronic	70.2	70.2

Table 36. Number and percent of samples exceeding Spokane Tribe (STI) or Washington State (WA) water quality criteria (acute and chronic). Samples separated into measured (M) and estimated concentrations (E).

	Parameter	STI Acute Toxicity				WA Acute Toxicity				STI Chronic Toxicity				WA Chronic Toxicity			
		Above Crit		Below Crit		Above Crit		Below Crit		Above Crit		Below Crit		Above Crit		Below Crit	
		E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M
Number	As				608				608				608				680
	Cd	509	8	91		509	8	91		600	8			600	8		
	Cu		6	506	8		5	506	9	2	9	504	5		8	506	6
	Pb		3	206	399		3	206	399		343	206	59		343	206	59
	Hg			544	1			544	1	544	1			544	1		
	Zn		2	516	90		2	516	90		5	516	87		5	516	87
Percent	As	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100.0
	Cd	83.7	1.3	15.0	0.0	83.7	1.3	15.0	0.0	98.7	1.3	0.0	0.0	98.7	1.3	0.0	0.0
	Cu	0.0	1.2	97.3	1.5	0.0	1.0	97.3	1.7	0.4	1.7	96.9	1.0	0.0	1.5	97.3	1.2
	Pb	0.0	0.5	33.9	65.6	0.0	0.5	33.9	65.6	0.0	56.4	33.9	9.7	0.0	56.4	33.9	9.7
	Hg	0.0	0.0	99.8	0.2	0.0	0.0	99.8	0.2	99.8	0.2	0.0	0.0	99.8	0.2	0.0	0.0
	Zn	0.0	0.3	84.9	14.8	0.0	0.3	84.9	14.8	0.0	0.8	84.9	14.3	0.0	0.8	84.9	14.3

Discussion

Data quality and sensitivity are important factors especially when ambient concentrations are at or near the MRL as was the case in the present study. The magnitude of variability can increase greatly when concentrations are near the MRL, as is likely the case with some of the RPD values that exceeded 25% here. A major weakness of the current study was that strict data quality objectives and acceptable detection limits were not established prior to beginning the study. Additionally, methodology describing how to address or censor data that does not meet data quality objectives should have been defined prior to the study as well. The current study would have also benefited from methodology employing field blanks and field spikes to assess possible artificial contamination arising during field sampling. Minimizing sampling error is important, especially when the natural variability is as high as it appears to be in the current study. Serdar (1993) also observed highly variable contaminant metal concentrations in Lake Roosevelt. Use of clean hand / dirty hand (ultra-clean) field techniques (Method 1669) as describe by the EPA could have helped minimize sampling error (EPA 1996). Contamination can arise too easily when working with such low analyte concentrations. For example, mercury contamination can be introduced to a water sample when someone with mercurial fillings breathes on an open water bottle (EPA 1996).

Refinement of sampling and analytic techniques would likely have improved the interpretability of the data. The current study can attest to this in that ambient concentrations were either below or very close to the MRL resulting in highly variable concentrations or artificial concentrations estimated from the MRL. New analytical techniques are available and allow for reduced MRLs for trace metals in surface water (Field and Sherrell 2003). Lower MRLs would likely ease interpretation of any temporal or spatial trends as well as allow for better assessment of water quality criteria. A hypothetical metal concentration plotted across time illustrates the issues with high MRLs (Figure 29). Temporal patterns are hidden beneath the MRL and would not be apparent from estimated concentration (Figure 29). Looking for contaminants in a media other than surface water may be more useful considering the variability and low

concentrations of these contaminants of concern. Other researchers have looked at contaminants taken up in organism biomass such as in attached algae or benthic invertebrates (Lowe and Pan 1996; Farag et al. 1998; Fore and Grafe 2002; Maret et al. 2003). Sessile organisms may be especially useful because they represent an integration of conditions at a particular site over time and often bioaccumulate the contaminant so extremely low MRLs are not as crucial.

Of the contaminants of concern field and analytical techniques for arsenic, cadmium, copper, and mercury definitely need improvement to lower MRLs and increase precision. Measurable concentrations for those elements ranged from 0.2 to 2.7% (n for measurable concentrations ranged from 1 to 15). With such small sample sizes of measurable concentrations determining meaningful temporal, spatial, and environmental relationships was difficult. However, lowering the MRL alone will not be all that is required to determine relationships as illustrated by results for lead concentrations. Measurable lead concentrations were the most variable of all contaminants of concern (greatest coefficient of variation at 188). Increasing precision of measurements by improved field and analytical techniques will help reduce variability obscuring true temporal, spatial, and environmental relationships. More recent work by the USGS (2001) and WDOE (2005) reflect lower MRLs but similar levels of precision (Table 38). Arsenic, cadmium, and mercury means from the USGS (2001) and WDOE (2005) were considerably lower because the estimated concentrations included in the mean were derived from lower MRLs.

In the current study, lead results were highly variable, in part, due to poor field technique involving use of lead fishing weights to hold water samplers at a given depth. As a result of this mistake, lead results are questionable. The lead concentration data suggest that contamination may have been sporadic and or below the MRL in some cases since 34% of all lead samples were below the MRL. Mean total recoverable lead measured at Northport by USGS (2001) and WDOE (2005) were only slightly lower than mean lead in the current study but the range of lead concentrations in the current study were much wider which resulted in a larger standard deviation as well (Table 38). At best, lead

contamination of samples occurred randomly and acted as a field spike to slightly raise the overall mean.

It appears that this sampling error likely obscured observable relationships lead had with spatial, temporal, and environmental variables since no reported relationship was distinct. However, lead did appear to be at higher concentrations from samples taken in the upper reservoir as suggested by a higher mean at Gifford, more measurable lead concentrations observed at Evan's Landing, and median measurable lead concentrations decreased with distance downstream. Higher lead concentrations in the upper reservoir would not be totally unexpected considering that higher concentrations of lead in sediment have been observed in the upper reaches of Lake Roosevelt as well (Era and Serdar 2001; Majewski et al. 2003; Cox et al. 2005). Cox et al. (2005) also observed generally higher concentrations of lead in sediment pore water from sediment cores taken in upper reaches of Lake Roosevelt. Lead concentrations were found to be higher in the photic zone samples compared to aphotic zone samples in the current study which could be related to lead complexes segregating in the water surface microlayer of other waters as reported by Eisler (1988).

Zinc in Lake Roosevelt sediments has been found in higher concentrations at upper reservoir locations as well (Era and Serdar 2001; Majewski et al. 2003; Cox et al. 2005). However, a similar trend in zinc surface water concentrations was not detectable in the current study, in part, due to the variability of results. Surface water zinc concentrations at Porcupine Bay were approximately 3 times greater than at mainstem locations. Sediment core samples from the Spokane Arm have elevated concentrations of zinc in sediments compared to mainstem cores (Cox et al. 2005). Zinc concentrations are elevated in the Spokane Arm because of mining practices in the Silver Valley region of the Coeur d' Alene River basin (Serdar 1993; Farag et al. 1998). Surface water at Porcupine Bay in general appears to be distinct from the mainstem reservoir because along with zinc, other surface water constituents such as aluminum, calcium, iron, manganese, magnesium, potassium, silica, and sodium were markedly different. Most measurable arsenic concentrations from the current study originated from Porcupine Bay as well. Other water quality measurements such as primary producer biomass, nutrients,

and trophic status are often higher at Porcupine Bay compared to the mainstem reservoir (McLellan et al. 2003, Lee et al. 2003; Scofield et al. 2004).

Most of the measurable zinc concentrations in surface water from the current study originated from Porcupine Bay. Zinc was most strongly correlated with Secchi disk depth and silica concentrations likely related to the binding of zinc cations with clays, colloids, and organics. Spring runoff likely physically mobilizes silicate clays with bonded zinc which increase total recoverable silica concentrations, total suspended solids, and turbidity (or decreased transparency). Cox et al. (2005) reported that most of the contaminant trace metals (including zinc) from Lake Roosevelt sediment cores are weakly sorbed to sediment surfaces or incorporated in iron and magnesium oxide coatings increasing their potential for remobilization. Benthic flux of contaminant trace metals also associated with ferric oxides has been identified as an important contaminant loading source in Lake Coeur d' Alene when the hypolimnion goes hypoxic and increases solubility of some contaminant metals from sediments (Woods and Beckwith 1997; Kuwabara et al. 1999).

Zinc leaching from sediments is most pronounced under conditions with high dissolved oxygen and low pH, but zinc toxicity can be greatest when dissolved oxygen, pH, and alkalinity are low and temperatures are high (Eilser 1993). The water column in Lake Roosevelt is predominantly well oxygenated year round, potentially increasing the chance of mobilization of zinc from sediment. However, in late summer / early fall Porcupine Bay regularly experiences low dissolved oxygen concentrations and warm temperatures (McLellan et al. 2003, Lee et al. 2003; Scofield et al. 2004). So, at Porcupine Bay where zinc concentrations were highest, these late summer / early fall reservoir conditions may induce the greatest degree of zinc toxicity in aquatic organisms. The current study did not observe any vertical differences in zinc surface water concentrations. However, Wilson et al. (1996) sampled more intensely for vertical differences and often noted zinc concentration up to 2.3 times greater at depth than at the surface in the Spokane Arm.

Understanding the biogeochemistry of contaminant trace elements and limnologic controlling factors of the reservoir is important. Along with zinc being made more toxic under anaerobic conditions mercury can be methylated in anaerobic sediments and methyl mercury is more toxic and more bioavailable than inorganic mercury (Eisler 1987). Herrin et al. (1998) documented larger fluxes of methyl mercury to the entire water column during destratification of a mercury contaminated lake in Wisconsin with a seasonally anaerobic hypolimnion. Methyl mercury body burdens of phytoplankton and zooplankton within this lake increased two to four times between the time of peak stratification and complete mixis (Herrin et al. 1998).

In the current study no measurable mercury concentrations were observed at Porcupine Bay. Yet, Munn and Short (1997) reported higher mercury concentrations in walleye collected from the Spokane Arm. Higher mercury concentrations in walleye were not correlated to sediment concentrations but were thought to arise from site specific factors affecting growth and development (Munn and Short 1997). Perhaps methyl mercury enters the food chain at concentrations below the MRL of the current study but provides mercury that will biomagnify and contribute to the higher mercury body burdens of those walleye. As of 1998 reservoir wide (Lake Roosevelt) walleye mercury tissue concentrations have decreased 50% since 1994 and may be explained by the shortening of water retention times over that period hence reducing stagnant water and anoxia in sediments (Munn 2000). However, late summer / early fall hypoxic conditions have consistently been observed at Porcupine Bay since at least 1999 (McLellan et al. 2003, Lee et al. 2003; Scofield et al. 2004). Realization of these trace metal biogeochemistry issues related to water column dissolved oxygen concentration may give more weight to maintaining and increasing summer time dissolved oxygen in the Spokane Arm.

Lowering the mercury MRL and increasing sampling precision might help show mercury release from sediments to water column during hypoxic periods and fall mixis at Porcupine Bay. Achieving a lower MRL is actually necessary to assess the Tribal and State mercury chronic water quality criteria. In addition to mercury MRLs should be lowered to assess chronic and acute cadmium criteria and chronic copper criteria because at the current MRLs, exceedances of criteria for these contaminants cannot be assessed.

Work done by the USGS (2001) and WDOE (2005) indicate that mean dissolved cadmium concentrations at Northport (0.0 to 0.5 $\mu\text{g l}^{-1}$; Table 38) did not exceed the mean cadmium criteria given in the current study (0.7 to 2.3 $\mu\text{g l}^{-1}$; Table 35). Mean dissolved copper concentrations at Northport (0.9 $\mu\text{g l}^{-1}$; Table 38) did not exceed the mean copper criteria given in the current study (5.9 to 10.7 $\mu\text{g l}^{-1}$; Table 35; USGS 2001; WDOE 2005). Mean mercury concentrations at Northport (0.0009 to 0.0019 $\mu\text{g l}^{-1}$; Table 38) did not exceed the mean mercury criteria given in the current study (0.012 to 2.1 $\mu\text{g l}^{-1}$; Table 35; USGS 2001; WDOE 2005).

In the current study, lead exceeded chronic criteria most often with 56% exceedances. Unfortunately, the number of exceedances due to sampler contamination via the lead weighted water sampler is unknown, but considering that 34% of samples were below the MRL suggesting that not all samples were contaminated, and that lead concentrations were observed more often at some upper reservoir locations known to have lead contaminated sediments, it is likely that a portion of these exceedances are legitimate. Some lead related organism effects based on laboratory studies include: High bioconcentration rates observed in *Selenastrum capricornutum* (freshwater green algae) at 5 $\mu\text{g Pb}^{2+} \text{l}^{-1}$; *Daphnia magna* reproduction was impaired at 1 $\mu\text{g Pb}^{2+} \text{l}^{-1}$; and juvenile *Oncorhynchus mykiss* (rainbow trout) experienced acute toxicity with 3.5 $\mu\text{g tetramethyl Pb l}^{-1}$ (Eilser 1988). The water quality standards are based upon laboratory test results such as these and are useful as benchmarks but may not account for additional controlling factors occurring in a natural system since laboratory conditions are strictly controlled. The standards may not be protective enough since they will not account for potential additive, synergistic, or antagonistic relationships with other contaminants, such as those observed in the current study, or other contaminants such as organic compounds, also present in the study area (Verslycke et al. 2003). Macroinvertebrate communities in a Colorado stream were more adversely affected by multiple contaminant metals compared to a single metal contaminant (Clements et al. 2000; Clements 2004).

The standards were constructed for use with dissolved concentrations so basing criteria exceedances on total recoverable concentrations provides numbers for a worst case scenario. Some of these trace elements are associated with suspended sediments

potentially making them less bioavailable. Understanding of suspend sediment load in the current study would have benefited from a lower MRL in TSS likely requiring a larger sample volume. Bortleson et al. (1994) described ratios of dissolved metals and metals associated with sediments in Lake Roosevelt as somewhat unique because the fractions of dissolved metals were relatively large compared to sediment associated metals (Table 37). So, a larger portion of contaminant metal reported in total recoverable concentrations may actually be associated with the dissolved fraction and potentially more bioavailable in Lake Roosevelt.

Table 37. Mean relative percentages of contaminant element associated with dissolved and particulate portions of whole water observed in Lake Roosevelt (Bortleson et al. 1994).

Analyte	Dissolved	Particulate
Arsenic	80	20
Cadmium	84	16
Copper	67	33
Lead	50	50
Zinc	58	42

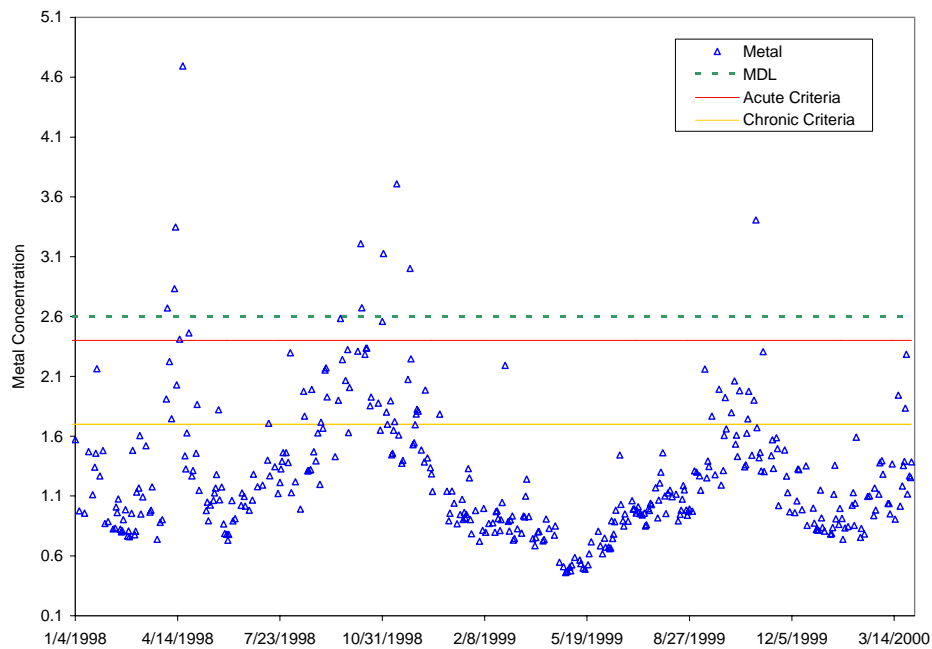


Figure 29. The high minimum reporting level (MRL) for hypothetical metal concentrations across time obscures temporal patterns and exceedances of chronic and acute toxicity criteria.

Table 38. Descriptive statistics including mean, standard deviation (SD), minimum (min), maximum (max), and number (n) for total recoverable and dissolved concentrations of elements of concern.

Parameter ($\mu\text{g l}^{-1}$)	Spokane Tribe Lake Roosevelt Sampling 1998-2000					USGS (2001) Columbia River at Northport Sampling 1996-2000 ^a					WDOE (2005) Columbia River at Northport Sampling 1994-2001				
	Mean	SD	Min	Max	n	Mean	SD	Min	Max	n	Mean	SD	Min	Max	n
Arsenic															
Dissolved	na	na	na	na	na	0.6	0.2	0.5	1.0	70	0.4	0.1	0.3	0.6	12
Total Recoverable	21.7	10.3	0.5	98.0	608	0.7	0.2	0.5	1.2	na	5.0	10.7	0.3	30.0	53
Cadmium															
Dissolved	na	na	na	na	na	0.5	0.0	0.5	0.5	56	0.0	0.0	0.0	0.2	39
Total Recoverable	2.6	0.6	2.0	7.0	608	0.5	0.0	0.5	0.6	na	0.7	2.3	0.0	15.0	45
Copper															
Dissolved	na	na	na	na	na	0.9	0.6	0.5	2.2	56	0.9	0.4	0.3	1.7	39
Total Recoverable	3.5	1.4	2.0	28.0	520	5.9	5.2	0.9	17.1	na	2.4	2.4	0.5	14.0	46
Lead															
Dissolved	na	na	na	na	na	0.5	0.0	0.5	0.5	56	0.1	0.1	0.0	0.6	39
Total Recoverable	3.9	8.8	0.5	182.0	608	2.2	0.8	1.2	4.4	na	3.5	6.7	0.1	20.0	46
Mercury															
Total Recoverable	0.10	0.05	0.10	1.20	545	0.0009	0.0012	0.0000	0.0045	na	0.0019	0.0011	0.0010	0.0070	55
Zinc															
Dissolved	na	na	na	na	na	3.2	2.0	1.1	12.1	56	2.9	0.9	1.0	5.2	39
Total Recoverable	7.9	9.1	2.5	84.0	608	34.2	25.9	6.3	84.8	na	12.5	13.8	4.2	77.0	46

^aTotal recoverable concentrations estimated from dissolved trace element concentration, suspend sediment trace element concentration, and suspended sediment concentration in river water via Bortleson et al. (1994) equation.

Summary

- Surface water was sampled from 1998 to March 2000 with 22 different water quality parameters measured. The known contaminants arsenic, cadmium, copper, lead, mercury, and zinc were focused on.
- Mean minimum reporting levels for contaminants of concern were as follows: arsenic at $42.3 \mu\text{g l}^{-1}$; cadmium at $5.2 \mu\text{g l}^{-1}$; copper at $6.7 \mu\text{g l}^{-1}$; lead at $1.0 \mu\text{g l}^{-1}$; mercury at $0.2 \mu\text{g l}^{-1}$; and zinc at $10.5 \mu\text{g l}^{-1}$. Mean relative percent differences for all water quality parameters measured ranged from 0.6 to 22%. Mean spike percent recoveries for all water quality parameters measured ranged from 77 to 108% and contaminants of concern ranged from 91 to 108%.
- Mean inflow and outflow to Lake Roosevelt during the study period ranged from 2882 to 3704 $\text{m}^3 \text{s}^{-1}$. Mean water retention time in Lake Roosevelt during the study period ranged from 32 to 46 d. Secchi (overall mean 5.9 m) and photic zone (overall mean 11.4 m) depth showed similar patterns during the study period, generally being lower in the spring and higher in the fall as well as being higher at lower reservoir locations. Turbidity (1.39 NTU) and total suspended solids (overall mean 2.74mg l^{-1}) generally showed an opposite pattern to Secchi and photic zone depth. Water flow and transparency measures were generally closely related.
- Total recoverable arsenic was measured 15 times out of 608 samples. Mean and median total recoverable arsenic concentrations were 44.7 and $57.0 \mu\text{g l}^{-1}$, respectively (estimates included). No spatial or temporal patterns were readily discernable in arsenic concentrations but measurable arsenic was most frequently measured at Porcupine Bay. Arsenic concentrations were always below chronic and acute toxicity criteria.
- Total recoverable cadmium was measured 8 times out of 608 samples. Mean and median total recoverable cadmium concentrations were 5.9 and $5.5 \mu\text{g l}^{-1}$, respectively (estimates included). No spatial or temporal patterns were readily discernable in cadmium concentrations. Cadmium concentrations exceeded acute and chronic criteria in 85 and 100% of samples respectively but most of the exceedances were estimated concentrations.
- Total recoverable copper was measured 14 times out of 520 samples. Mean and median total recoverable copper concentrations were 9.1 and $8.0 \mu\text{g l}^{-1}$,

- respectively (estimates included). No spatial or temporal patterns were readily discernable in copper concentrations. Copper concentrations exceeded chronic and acute toxicity criteria in 1.0 – 1.2% and 1.5 -2.1% of samples respectively.
- Total recoverable lead was measured 402 times out of 608 samples. Mean and median total recoverable lead concentrations were 5.6 and 4.0 $\mu\text{g l}^{-1}$, respectively (estimates included). Variability in measurable lead concentrations was high, likely in part due to sample contamination. Measurable lead concentrations were highest and most often measured at upper reservoir locations. Measured lead concentrations were also highest from photic zone depths (5.8 m) compared to aphotic depths (12.4 m). Lead concentrations exceeded standards most often. Acute and chronic exceedances in lead criteria were 0.5 and 56%, respectively.
 - Total recoverable mercury was measured 1 time out of 544 samples. Mean and median total recoverable mercury concentrations were 0.1 and 0.1 $\mu\text{g l}^{-1}$, respectively (estimates included). No spatial or temporal patterns were readily discernable in mercury concentrations. Acute and chronic exceedances in mercury criteria were 0 and 100%, respectively. However, most exceedances were estimated concentrations.
 - Total recoverable zinc was measured 92 times out of 608 samples. Mean and median total recoverable zinc concentrations were 22.5 and 14.5 $\mu\text{g l}^{-1}$, respectively (estimates included). Seasonally, zinc was highest in the spring and lowest in fall. Zinc concentrations were about 3.5 times greater at Porcupine Bay compared to mainstem reservoir locations. Most measurable concentrations of zinc originated from Porcupine Bay. Measurable zinc concentrations were correlated most with Secchi disk depth ($r = -0.64$), silica concentration ($r = 0.55$), and photic zone depth ($r = -0.52$). Exceedances of acute and chronic criteria for zinc were 0.3 and 0.8% respectively.
 - Mean hardness was 62.6 mg l^{-1} and was lowest in the summer and highest in the winter. Hardness was more variable in the Spokane Arm. Other than nickel and selenium (99% estimated) other elements analyzed for, including antimony, beryllium, chromium, cobalt, and silver, had no concentrations at or above minimum reporting level resulting in 100% estimated concentrations.
 - When ambient concentrations of analytes are highly variable and near the minimum reporting levels rigorous methodologies are required to reduce sampling error. Ultra-clean techniques would assist new methodologies available

in reaching lower minimum reporting levels and greater precision in data. Lower minimum reporting levels will be essential to better assess criteria exceedances and will help tease out temporal, spatial, and environmental relationships obscured by large sampling error or high minimum reporting levels. Looking at contaminant concentrations in sessile organisms rather than surface water may be more fruitful in that such low MRL should not be as crucial.

- Understanding the biogeochemistry of contaminants and the limnology of the system will aid in the understanding of temporal, spatial, and environmental relationships. Such as how does annual hypoxia in the Spokane Arm alter contaminant bioavailability and toxicity, especially in regards to zinc and mercury?
- Water quality standards may not be protective enough because they do not account for interacting relationships between multiple contaminants and organism.

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Appendix A

Table 39. Mean photic zone depths (m) during study period in Lake Roosevelt divided by location, year and month.

Year	Location Name	Rkm	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	Evan's Landing	1143	4.5	15.0	8.5		8.0	8.3	9.5	13.5	13.8	12.8	14.0	12.0
	Kettle Falls	1128	8.0	5.5	12.5		6.3	9.7	9.9	13.0	13.3	11.5		13.0
	Gifford	1085	13.0	12.0	14.0		7.8	8.2	10.1	13.0	14.5	13.8	14.0	13.0
	Hunters	1064	11.0	5.0	12.3		7.5	8.0	10.8	10.5	15.0	14.3	14.0	12.0
	Spokane R. Confl	1028	14.0	16.0	13.3		7.5	8.0	10.0	12.5	12.8	11.3	16.0	12.0
	Porcupine Bay	1027.3	8.5	3.5	3.0		7.5	6.3	10.7	11.5	14.5	13.0	16.0	12.0
	Seven Bays	1024	13.0	15.0	11.5		8.5	7.8	10.5	12.0	14.0	10.3	15.0	15.0
	Sanpoil R.	992.6	12.5	15.0	10.5		5.3	8.0	10.4	14.3	14.0	14.5	13.0	15.0
	Sanpoil R. Confl	992	10.0	10.5	11.0		8.5	12.0	11.3	14.5	14.5	15.3	18.0	17.5
	Keller Ferry	989	14.5	14.0	9.3		5.8	11.0	12.2	14.3	15.0	10.3	17.0	17.0
Spring Canyon	965	15.0	12.0	12.5		8.3	11.5	12.6	15.0	15.0	12.5	15.0	15.0	
1999	Evan's Landing	1143	15.0	13.0	10.0	6.0	8.0	5.5	9.5	11.8	12.5	15.8	9.5	16.0
	Kettle Falls	1128	14.0	13.5	10.0	5.5	3.5	6.8	9.5	11.3	13.5	14.5	10.0	14.0
	Gifford	1085	15.0	13.5	10.0	7.0	6.0	6.8	9.5	11.5	13.8	14.0	15.0	15.0
	Hunters	1064	14.0	14.0	10.0	11.0	6.0	7.8	8.6	12.5	12.0	14.0	17.0	14.0
	Spokane R. Confl	1028	13.0	13.0	8.0	8.0	7.0	8.5	8.5	11.3	12.8	15.8	18.0	10.5
	Porcupine Bay	1027.3	2.0	4.5	3.0	5.0	3.8	6.5	8.8	14.0	14.5	15.5	17.0	11.3
	Seven Bays	1024	13.0	13.0	4.0	7.0	8.0	8.4	9.0	10.5	12.8	15.8	18.5	14.0
	Sanpoil R.	992.6	12.0	9.5	9.0	3.0	4.0	7.5	11.3	12.5	14.0	15.5	16.5	12.5
	Sanpoil R. Confl	992	13.0	9.0	4.0	8.0	7.5	8.8	11.3	13.0	15.8	17.0	17.5	14.0
	Keller Ferry	989	13.0	10.0	4.0	7.0	7.0	8.0	10.3	13.0	15.5	17.0	18.0	14.0
Spring Canyon	965	14.0	10.0	8.0	7.0	7.5	9.0	10.5	14.8	14.0	17.3	18.0	17.0	
2000	Evan's Landing	1143	16.0	18.0	13.0									
	Kettle Falls	1128	17.0	17.5	15.5									
	Gifford	1085	15.5	16.0	11.0									
	Hunters	1064	11.0	15.5	13.0									
	Spokane R. Confl	1028	12.0		10.0									
	Porcupine Bay	1027.3	11.0	1.5	4.5									
	Seven Bays	1024	11.0	15.0	8.0									
	Sanpoil R.	992.6	13.5	16.0	12.0									
	Sanpoil R. Confl	992	14.5	14.0										
	Keller Ferry	989	14.5	15.0	12.0									
Spring Canyon	965	15.5	16.5	12.0										

Appendix B

Figure 30. Simple linear regression of total recoverable lead and total recoverable manganese.

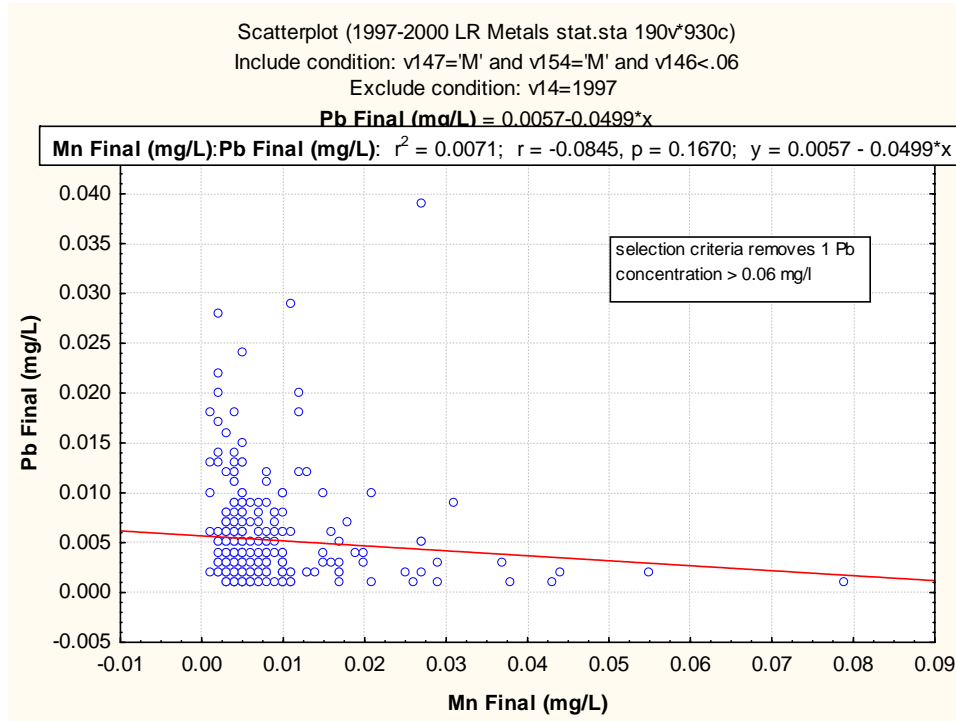


Figure 31. Simple linear regression of total recoverable lead and total recoverable iron.

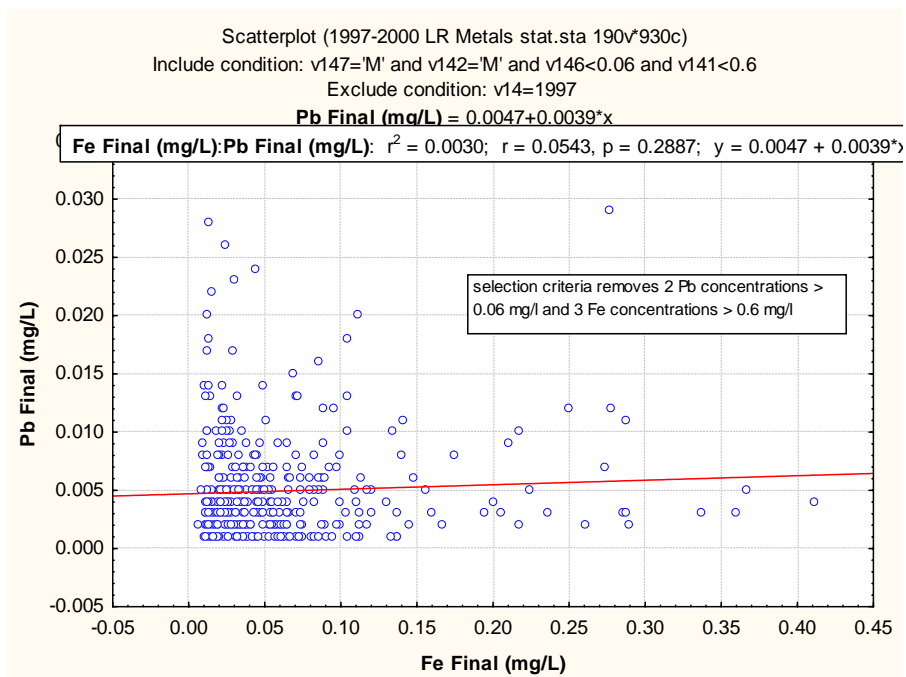


Figure 32. Simple linear regression of total recoverable lead and total recoverable magnesium.

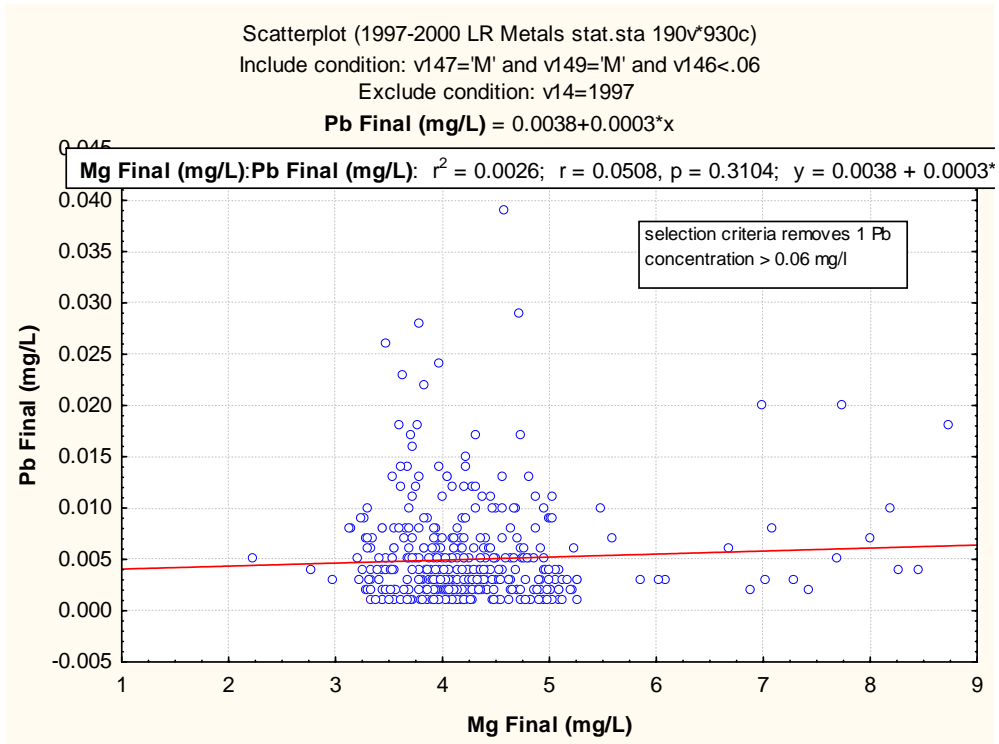
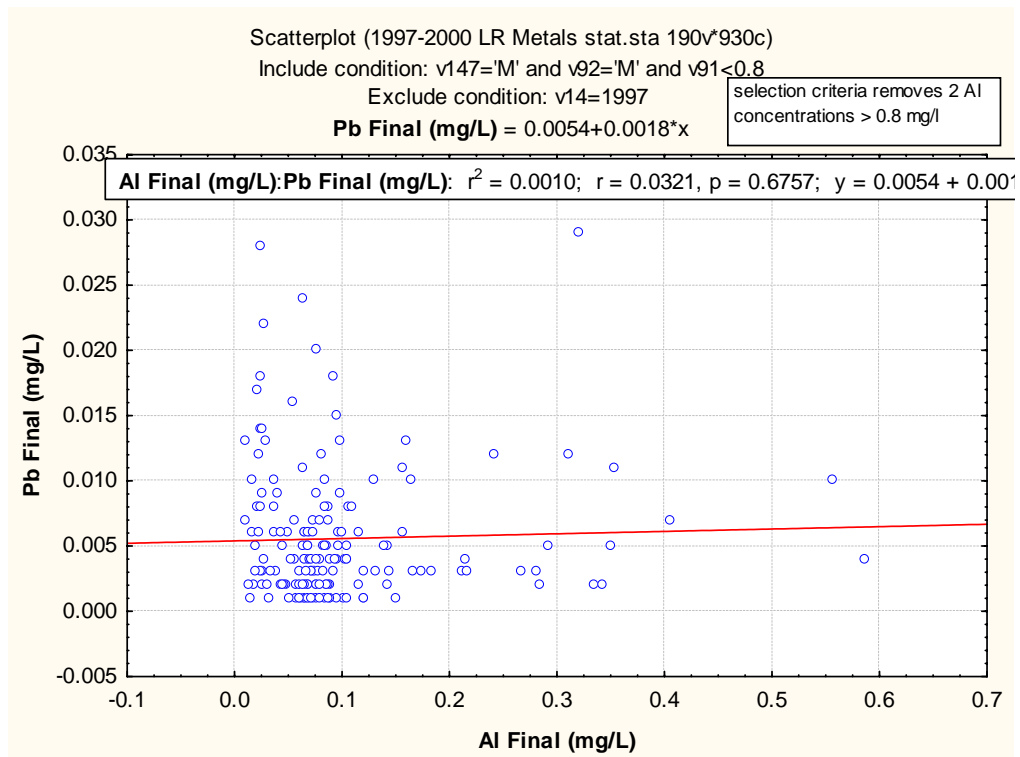


Figure 33. Simple linear regression of total recoverable lead and aluminum.



Appendix C

Figure 34. Simple linear regression of total recoverable zinc and total recoverable manganese.

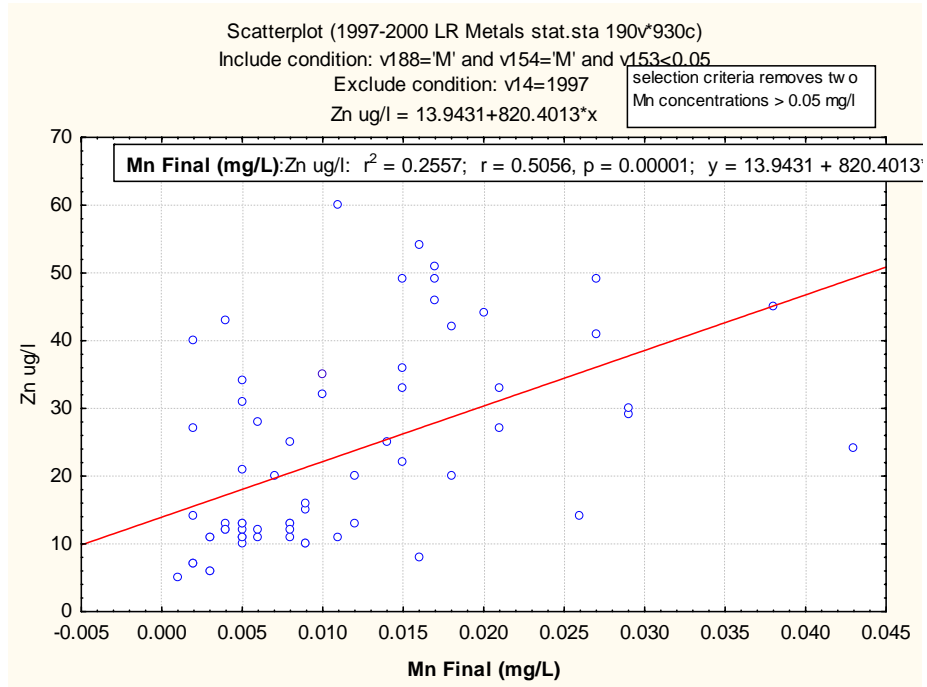


Figure 35. Simple linear regression of total recoverable zinc and total recoverable aluminum.

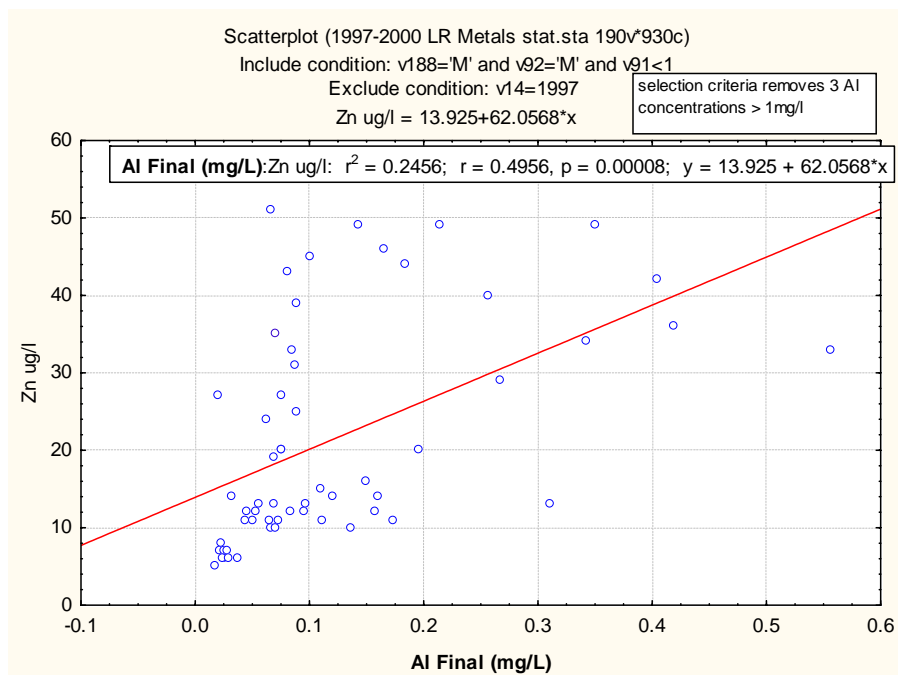


Figure 36. Simple linear regression of total recoverable zinc and total recoverable iron.

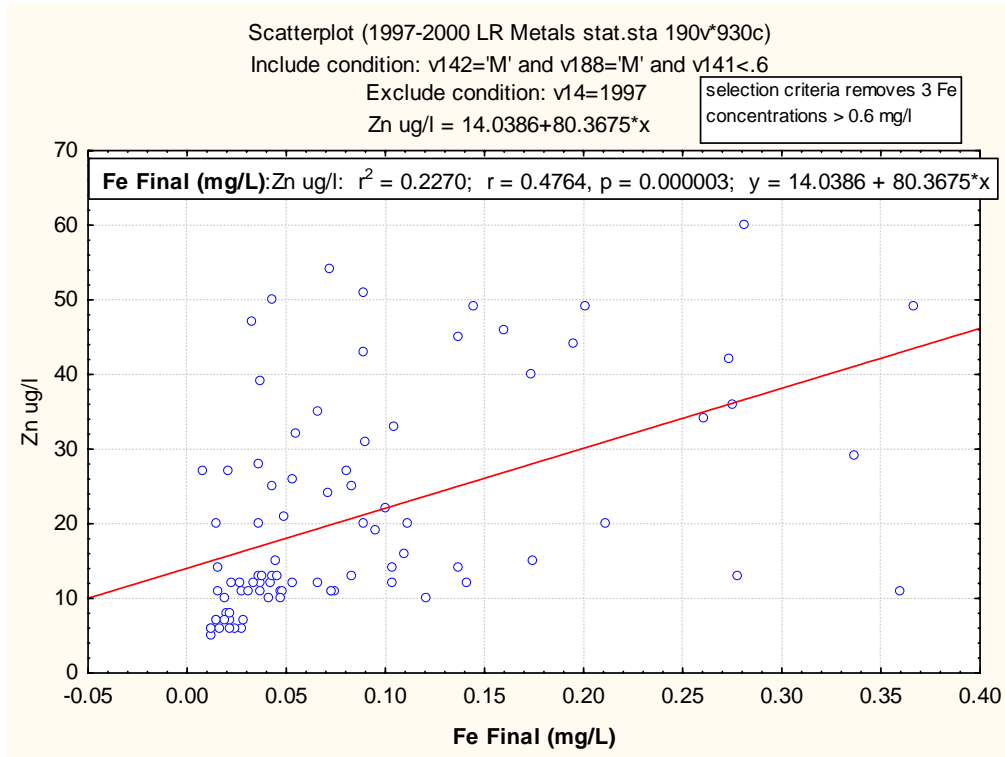


Figure 37. Simple linear regression of total recoverable zinc and total recoverable magnesium.

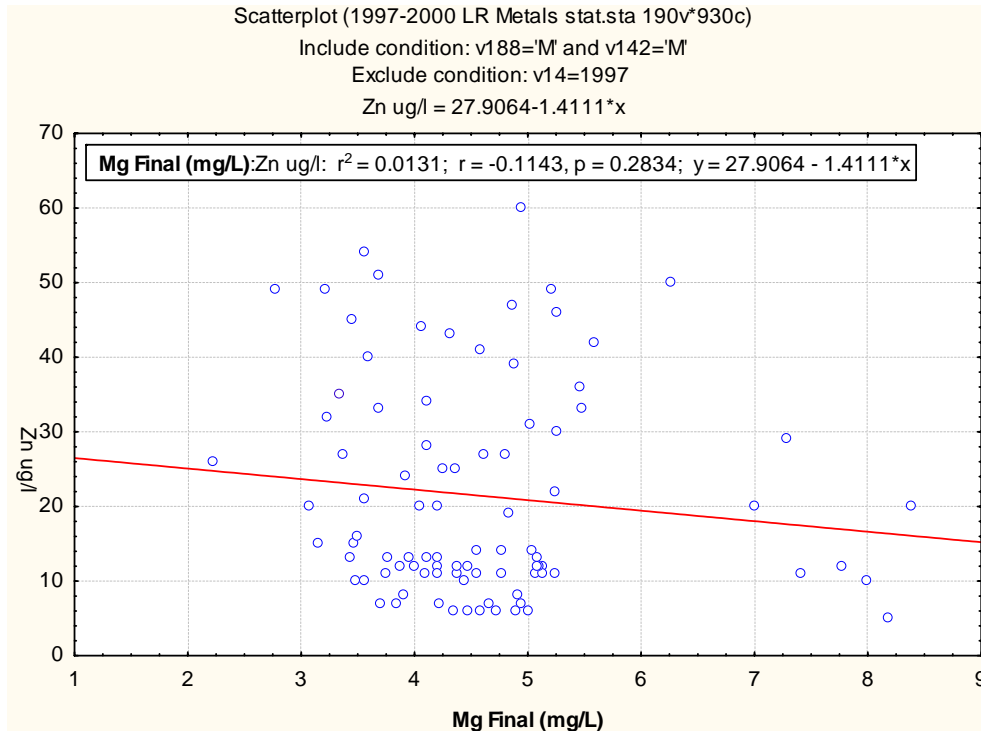


Figure 38. Simple linear regression of total recoverable zinc and total recoverable lead.

