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Moses Lake Phosphorus-Response Model and Recommendations to Reduce Phosphorus Loading

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Moses Lake Phosphorus-Response Model and Recommendations to Reduce Phosphorus Loading

by
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Table of Contents

List of Appendices

List of Figures

List of Tables

Abstract

Moses Lake and its watershed have been altered by human activities, especially irrigation, lake phosphorus dilution with irrigation feed water, and urban development. The last intensive water quality study of Moses Lake was completed in 1988, summarized by Welch et al. (1989; 1992). This current report updates that work and complements the historical review and preliminary phosphorus loading capacity evaluation by Carroll et al. (2000).

Intensive sampling of Moses Lake and its vicinity was conducted from October 2000 through September 2001 to assess the status of the lake and its tributaries. The mean total phosphorus (TP) concentration for the whole lake from May through September was 38 ug/L. This report recommends establishing a seasonal water quality TP criterion of 50 ug/L for Moses Lake.

A hydrodynamic, unsteady-state water quality model was developed for Moses Lake and calibrated to the 2001 water quality data. The model was used to estimate the capacity of the lake to assimilate TP loads from point and nonpoint sources and meet the recommended water quality criterion.

Using critical loading conditions, the lake model showed that a 35% load reduction in TP from Rocky Ford Creek, Crab Creek, Rocky Coulee Wasteway baseflow, and groundwater was necessary to meet the proposed TP criterion with only a 10% exceedance probability. Further reductions in external phosphorus loads only marginally reduced TP concentrations in the lake because under these conditions internal sources begin to dominate in-lake concentrations.

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Introduction

Problem Statement

The Washington State Department of Ecology (Ecology) recognizes Moses Lake as an important natural resource of Washington State, providing wildlife habitat, recreation, and water supply. Ecology's Eastern Regional Office (ERO) is concerned about the water quality in Moses Lake which is on the 1996 303(d) list for total nitrogen and total phosphorus (TP). Several restoration projects have been conducted on Moses Lake and its watershed over the last 20 years, including lake dilution (with inter-basin pumping), sewage diversion, agricultural best management practices, and construction of a tributary nutrient retention pond. Despite improvement in lake water quality as a result of these projects, total nitrogen and TP levels remain elevated, resulting in the persistence of blue-green algae blooms (Welch et al., 1989, 1992; Jones and Welch, 1990).

As a result, ERO requested that Ecology's Environmental Assessment (EA) Program report on the status of Moses Lake water quality. The primary goal of the ERO request was to have the EA Program develop recommendations and strategies to improve lake water quality. The EA Program completed the report, *Moses Lake Proposed Phosphorus Criterion and Preliminary Load Allocations Based on Historical Data,* in October 2000 (Carroll et al., 2000).

Although Moses Lake was listed for both TP and total nitrogen on the 303(d) list, historical studies on Moses Lake reviewed by Carroll et al. (2000) show that TP is the appropriate nutrient to control in order to limit algal biomass. The strategy of managing TP to control algal biomass is supported in the literature, even for lakes where nitrogen may be temporarily limiting the growth rate. On this basis, the 2000 report recommended that Moses Lake be de-listed for total nitrogen from the 303(d) list and that future lake management activities and decisions focus on the control of TP to manage algal biomass in Moses Lake.

While Carroll et al. (2000) presented preliminary phosphorus allocations, a major conclusion was that additional work should be completed before establishing a final load capacity and phosphorus reduction strategies for the lake. No comprehensive water quality assessment of the lake had been done since 1988, and multiple sources of data were used to develop the historical review.

Beneficial Uses and 303(d) Listings

Moses Lake is classified as Lake class under Washington State water quality standards (Chapter 173-201A WAC). Rocky Ford Creek is classified as Class A, and Crab Creek as Class B. Lake class and Class A waters are required to meet or exceed the requirements for all, or substantially all, of the following characteristic uses: domestic, industrial, and agricultural water supply; stock watering; salmonid and other fish migration, rearing, spawning, and harvesting; wildlife habitat; recreation (primary-contact recreation, sport fishing, boating, and aesthetic enjoyment); and commerce and navigation. Class B waters are required to meet or exceed the requirements for most of the preceding uses.

Moses Lake was first listed on the 1996 303(d) list as not supporting characteristic uses because of excess total nitrogen and TP. The water quality criterion for Lake class calls for no measurable change from natural conditions. Carroll et al. (2000) proposed the establishment of nutrient criteria for Moses Lake, with which this report concurs in establishing nutrient loading allocations. Rocky Ford Creek is presently listed for violations of temperature, dissolved oxygen, and pH criteria. Cusimano and Ward (1998) investigated the causes of these listings. The upper part of Crab Creek is presently listed for violations of pH criterion.

Brief History of Moses Lake

Moses Lake is a natural lake originally created by wind-blown sand dunes which dammed part of the Crab Creek watershed. As one of the largest lakes in Washington State, Moses Lake is an important natural resource providing recreational and aesthetic opportunities. The primary water quality problem identified in the historical studies of Moses Lake is the hypereutrophic blooms of blue-green algae, which can impair recreational uses of the lake during the summer months (Carroll et al, 2000).

As a large, shallow hypereutrophic lake, Moses Lake has garnered the attention of limnologists and engineers in the last 30 years as a candidate for lake restoration, which has resulted in many studies. Blue-green algae have been observed to form into floating mats to be blown onto the shore to decompose as recently as 1998 (Smith et al, 2000).

Moses Lake and its watershed have been altered since the inception of the Columbia Basin Irrigation Project (CBIP) in the early 1950s, when the U.S. Bureau of Reclamation (USBR) began importing Columbia River water into the upper Crab Creek watershed to promote the development of irrigated cropland. Previous studies indicated that anthropogenic (human) activities, primarily agricultural practices and operations associated with the CBIP, were creating a hypereutrophic state in Moses Lake through nutrient enrichment.

Welch et al. (1989; 1992), Jones and Welch (1990), and Carroll et al. (2000) provide detailed review of historical studies of the lake and its watershed, and beneficial uses of the lake.

Project Goal

The major goal of this current study was to assess the assimilative capacity of Moses Lake with respect to the in-lake proposed TP criterion of 50 ug/L. Data were collected and used in this assessment. A TP allocation plan is recommended to achieve the in-lake TP criterion.

Project Objectives

- Assess the current water quality condition of Moses Lake by conducting surface and groundwater quality surveys.
- Measure lake inflows and outflows.

- Identify TP watershed loading contributions to the lake from surface and groundwater sources.
- Develop an approach for modeling the water quality of the lake, then use the model to assess the capacity of the lake to assimilate TP with respect to maintaining the in-lake TP criterion of 50 ug/L.

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Study Design and Methods

Design

Carroll et al. (2000) recommended that a dynamic computer model for Moses Lake be developed to look at the seasonal and spatial effects of annual phosphorus loading changes throughout the entire lake. Under this study plan, the EA Program's Watershed Ecology Section (WES) assessed the tributary loading to Moses Lake for one year (October 2000 through September 2001) and monitored lake water quality monthly from March through September 2001 to develop a model of the lake, in order to simulate the hydrodynamics and estimate the water column TP concentration. Tributary sampling surveys occurred monthly from October 2000 through February 2001 as part of routine monthly monitoring conducted by Ecology. More intensive surveys of the tributaries and the lake occurred twice per month from March through September 2001.

Methods

Field Sampling

Figure 1 shows the lake and tributary sampling locations. The Quality Assurance (QA) Project Plan (Carroll, 2001) for this study listed the tributary and lake sampling stations that WES monitored. Sampling station continuity with earlier historical sampling stations was intended where applicable. The QA Project Plan lists the parameters and frequency of monitoring. During the synoptic surveys, grab samples were collected once or twice a day from the tributary stations on the first day of the survey, and once from each of the lake stations on the second day of the survey.

As part of this project, the EA Program's Environmental Monitoring and Trends Section (EMTS) sampled three tributary and one lake sampling station from October 2000 through September 2001, once per month:

1. Rocky Ford Creek at Highway 17 (Hwy 17)
2. Crab Creek at the USGS Gaging Station at Road 7 NE (CC1)
3. Rocky Coulee Wasteway at Road K bridge (RC1)
4. Moses Lake at the Outlet (ML7)

EMTS sampled these stations for dissolved oxygen, conductivity, pH, temperature, total suspended solids, turbidity, fecal coliform bacteria, and nutrients following their quality assurance procedures (Ehinger, 1996). WES and EMTS staggered their sampling times so that these sites were monitored twice per month, approximately two weeks apart.

During each WES survey (approximately monthly from March to September), water column data were collected at one-meter intervals at each lake station using a Hydrolab® Surveyor 2. Secchi

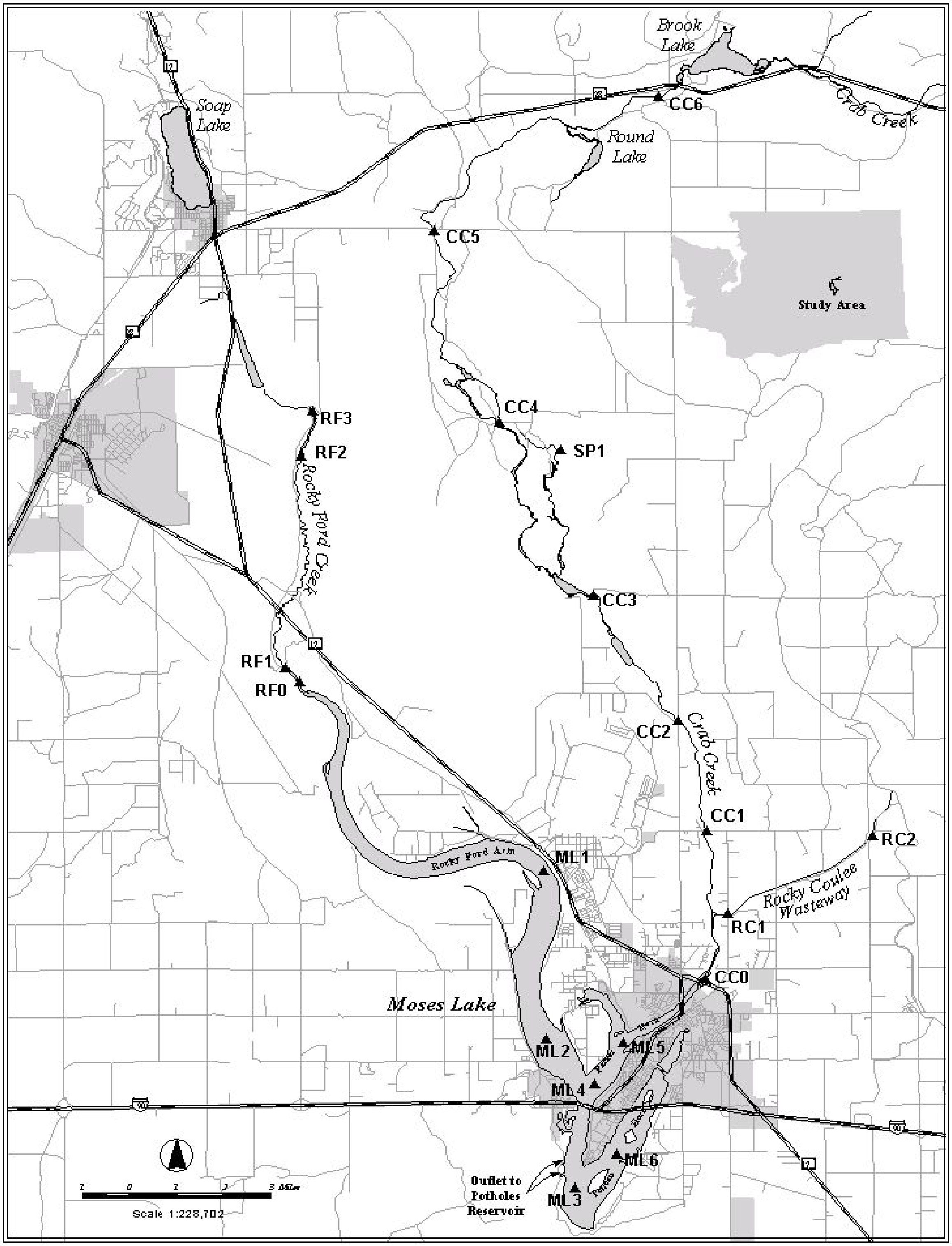

Figure 1. Vicinity map of Moses Lake and partial watershed with sampling stations. (Additional Rocky Ford Creek stations are shown in Figure 4.)

depths were measured at lake stations. Water grab samples were taken at three-meter intervals from the surface to the bottom for laboratory analyses. In addition, *in situ* Hydrolab® dataloggers (Datasonde 3) were placed at the mouth of Crab Creek and Rocky Ford Creek to collect continuous conductivity, pH, and temperature measurements for water entering the lake from March through September 2001.

Water collection for laboratory analyses followed the design outlined in the QA Project Plan. Parameters collected included turbidity, total suspended solids, total dissolved solids, alkalinity, chlorophyll *a*, total and dissolved organic carbon, conductivity, pH, dissolved oxygen, temperature, chloride, biochemical oxygen demand, and nutrients. Nutrient analyses included total nitrogen (persulfate digestion), ammonia-N, nitrate+nitrite-N, TP, and orthophosphate (ortho-P). Ortho-P methodology measures dissolved reactive phosphorus but will be referred as ortho-P throughout this report.

Vertical profiles of light extinction were measured at all lake stations during most lake surveys. Phytoplankton samples also were collected at selected stations during each lake survey to provide data on species composition and biovolume.

The U.S. Geological Survey (USGS) maintained gaging sites on Rocky Ford Creek (USGS station 12470500; located near station RF1A on Figure 4) and on Crab Creek (USGS station 12467000; located near station CC1 on Figure 1. USGS also monitored continuous stage levels in Moses Lake.

EMTS measured tributary stream flows to the lake during the study period, October 2000 through September 2001. They recorded continuous stage height data at two stations (RF0 and RC1) and developed rating curves to calculate continuous discharge from these sites. EMTS also calculated continuous discharge data for the northern outlet (Evans and Larson, 2002). The outlet, operated by the Moses Lake Irrigation and Rehabilitation District, had only one culvert partially opened in a stationary position for the entire study period.

Continuous flow through the south outlet, operated by USBR, was modeled by Northwest Hydraulic Consultants using HEC-RAS version 3.0, software developed by the U.S. Corps of Engineers. Flow measurements were made by Ecology and USBR using acoustic Doppler current profilers during various flow conditions (e.g., full pool, low pool, submerged backwater, unsubmerged backwater, restricted flow, and unrestricted flow).

Groundwater discharge to Moses Lake was characterized for water quality parameters by the Watershed Ecology Section (Pitz, 2003).

Data Analysis and Lake Water Quality Modeling

All project data were entered in Microsoft Excel spreadsheets or retained in text files. Data analysis included evaluation of data distribution characteristics and, as necessary, appropriate distribution transformations. Estimation of univariate statistical parameters and graphical presentation of the data (box plots, time series, regressions) were made using SYSTAT/SYGRAPH8, EXCEL, or WQHYDRO (Aroner, 1994) computer software.

Using the tributary flow data and concentration data, a log linear regression model was used to estimate the daily fluvial loads for each tributary to Moses Lake. The log linear model requires estimation of a constant, a linear and quadratic fit to the logarithm of flow, and sinusoidal (Fourier) functions to account for the effect of annual seasonality:

$$\log(C) = b_o + b_1 * \log(Q) + b_2 * \log(Q)^2 + b_3 * \sin(2\pi T) + b_4 * \cos(2\pi T) + b_5 * \sin(4\pi T) + b_6 * \cos(4\pi T) + \varepsilon$$

Log (C) is the logarithm of each parameter concentration, log Q is the logarithm of flow, and T is time measured in years. The error term (ε) is assumed to be independent and normally distributed with zero mean. The b terms are the parameters of the model that must be estimated from multiple regressions. A simple SYSTAT code provided the regression coefficients and appropriate statistical parameters, following the approach presented in Cohn et al. (1989).

The project required a model capable of simulating the transport and fate of phosphorus in a lake environment, including a mechanism accounting for the settling and flux (release) of phosphorus to and from the sediments. In addition, the model needed to include (1) hydraulic routing as a variable that can be easily changed, due to the managed hydrology of the watershed, and (2) groundwater phosphorus loading directly to the lake.

CE-QUAL-W2 Version 3.1 was chosen to apply to Moses Lake. CE-QUAL-W2 is a two dimensional (longitudinal-vertical), laterally-averaged hydrodynamic and water quality model that has been under-development by the Corps of Engineers Waterways Experimentation Station (Cole and Wells, 2002). The model was calibrated to the field data collected during the study. The calibrated model then was used to assess the capacity of the lake to assimilate TP seasonally and spatially with respect to maintaining the in-lake TP criterion of 50 ug/L. Boundary conditions, model set-up, and calibration are discussed below.

The model results were used with the historical data to finalize an allocation plan. This allocation plan included setting load allocations and wasteload allocations necessary to meet the in-lake TP criterion of 50 ug/L.

Data Quality Objectives and Analytical Procedures

Ecology's Manchester Environmental Laboratory (MEL, 2000) publishes reporting limits for the analytical methods they perform. These reporting limits met the data quality objectives for this project. Field measurements and laboratory analyses used are listed in the QA Project Plan, including the methods, corresponding reporting limits, target precision, and target bias acceptable range.

Data Assessment Procedures

Laboratory data reduction, review, and reporting followed procedures outlined in MEL's Lab Users Manual (MEL, 2000). All water quality data were entered into Ecology's Environmental Information Management (EIM) system. Data were verified, and 100% of data entry was reviewed for errors.

Quality Assurance and Quality Control

All data collected for this Moses Lake study were evaluated to determine whether data quality objectives for the project were met. Water quality objectives are described in the Quality Assurance (QA) Project Plan (Carroll, 2001).

All water samples for laboratory analysis were collected in pre-cleaned containers supplied by Ecology's Manchester Environmental Laboratory (MEL), except dissolved organic carbon and ortho-P which were collected in a syringe and filtered into a pre-cleaned container. The syringe was rinsed with ambient water at each sampling site three times before filtering. All samples for laboratory analysis were preserved as specified by MEL (MEL, 2000) and delivered to MEL within 24 hours of collection. Laboratory analyses listed in the QA Project Plan were performed in accordance with MEL (2000).

Field Parameters

Field Quality Assurance

Field sampling and measurement protocols followed were those specified in WAS (1993) for dissolved oxygen (Winkler titration), streamflow (Marsh-McBirney, 2000), and *in situ* temperature, dissolved oxygen, pH, and specific conductance (Hydrolab® multi-parameter meters).

Meters were pre- and post-calibrated for pH, dissolved oxygen, and conductivity. The manufacturer's instructions were followed for pH calibration, using pH 7 and pH 10 standard buffer solutions. All post-calibration readings were within 0.25 pH units of buffer values and were considered acceptable. Post calibration standard checks for conductivity were all within 5 µmhos/cm of the expected value and were considered acceptable.

The dissolved oxygen sensor was calibrated against theoretical water-saturated air, in accordance with manufacturer's instructions. Daily field samples were collected for Winkler titrations and check standards. Winkler titrations were judged to have greater accuracy than meter measurements. If necessary, Winkler titration dissolved oxygen measurements were used to adjust meter data for data analyses. After meter data were adjusted, all dissolved oxygen data were considered acceptable except that from March 26 – 28, 2001. The pooled average difference between Winkler and meter readings was 0.12 mg/L with a pooled RMSE of 0.44 mg/L.

Precision

Replicate samples were collected for at least 10% of the total number of laboratory samples in order to assess total variation for field sampling and laboratory analysis. Precision was estimated using replicates. Precision was calculated by pooling the %RSD for all pairs of replicates with detectable analytes. Results are listed in Table 1. As expected, %RSD for field replicates is higher than that for lab duplicates. Many of the results were heavily influenced by replicates collected on August 1, 2001. Field variation was apparently high on that date.

Table 1. Field precision. Results at the detection limit were excluded from consideration.

Parameter	Number of Duplicate Pairs	Average %RSD
Alkalinity	24	1.1
Ammonia-Nitrogen	11	50.5
Chlorides	24	3.6
Chlorophyll	22	31.9
Conductivity	23	1.1
Dissolved Organic Carbon	23	6.7
Nitrite-Nitrate Nitrogen	16	6.1
Orthophosphate	15	10.9
Total Dissolved Solids	24	3.4
Total Organic Carbon	23	4.5
Total Phosphorus (TP)	23	9.5
Total Persulfate Nitrogen	22	9.1
Total Suspended Solids	16	21.0
Turbidity	23	23.4

Bias

Field blank sample results are presented in Table 2. Except for specific conductance which was measured in two of the blank samples, all other field blanks were below reporting limits. In reviewing all field and laboratory quality control (QC) data, it does not appear that there was any contamination or positive bias in either the sampling or analytical procedures.

Table 2. Field blank results. Results qualified with a "U" or "UJ" mean that the blank had no detection at the reporting limit for the parameter, therefore reporting limit is reported as the result.

Parameter	Date	Result		
Alkalinity	06/26/01	5.0	mg/L	U
	08/01/01	5.0	mg/L	U
Ammonia-Nitrogen	06/26/01	0.010	mg/L	U
Chlorides	06/26/01	0.10	mg/L	U
	08/01/01	0.10	mg/L	U
Conductivity	06/26/01	1.53	µmhos/cm	
	08/01/01	2.7	µmhos/cm	J
Dissolved Organic Carbon	06/26/01	1.0	mg/L	U
Nitrite-Nitrate Nitrogen	06/26/01	0.010	mg/L	U
Orthophosphate	06/26/01	0.005	mg/L	U
Total Dissolved Solids	06/26/01	1.0	mg/L	U
Total Organic Carbon	06/26/01	1.0	mg/L	U
	08/01/01	1.0	mg/L	UJ
Total Phosphorus (TP)	06/26/01	0.010	mg/L	U
Total Persulfate Nitrogen	06/26/01	0.010	mg/L	U

Laboratory Parameters

Laboratory Quality Assurance

Laboratory data were generated according to QA and QC procedures followed by MEL (2000). MEL was used for all laboratory analysis. Laboratory QC requirements include the use of check standards, reference materials, samples spiked with higher concentrations, blanks, and lab split samples (duplicates). Lab splits and samples spiked with higher concentrations are discussed below. In addition, field blanks and laboratory standards (for TP) were collected to determine the presence of any positive bias in the analytical method. The phosphorus standards were included because it is the main parameter of concern for the study. Replicate, blank, and standard QA samples were introduced in the field and submitted "blind" with the routine batches of samples to the laboratory.

For the most part, data quality for this project met all lab QA/QC criteria as determined by MEL. Exceptions that caused the results to be qualified as an estimate are qualified with a "J" qualifier in the data appendix (Appendix B). All qualifications were taken under consideration for the purpose of data analysis.

Results not detected at or above the reporting limits listed in the QA Project Plan were qualified by MEL with a "U." These data were excluded from consideration in determining lab and field data quality.

Lower reporting limits for all parameters were listed in the QA Project Plan. Two were listed incorrectly: turbidity, with a lower reporting limit of 0.5 NTU, and alkalinity with a lower reporting limit of 10 mg/L.

Precision

To determine precision, the relative standard deviation (%RSD—the coefficient of variation expressed as a percentage) was calculated for each pair of lab split results (with detectable levels of analytes), and the %RSDs were subsequently pooled for each parameter. In interpreting QA/QC results, it is important to note that a pair of values that are low in magnitude with a low residual may have a high %RSD, while a pair of values high in magnitude with a high residual may have a low %RSD. Results (Table 3) were all under the acceptable %RSD listed in the QA Project Plan.

In addition to duplicate samples, check standards for TP were submitted to the lab on five occasions. There was a low recovery bias (approximately 10%; CV=12.7%) as can be seen in Figure 2. QA/QC check standards should be within ±2 times the target for %RSD of the true value (Lombard and Kirchmer, 2001). All check standards fall within 20% RSD, indicating acceptable precision for TP; therefore, no correction to the data was made. Check standards are summarized in Table 4.

Table 3. Lab precision. Results at the detection limit were excluded from consideration.

Parameter	Number of Duplicate Pairs	Pooled %RSD
Alkalinity	29	0.4
Ammonia-Nitrogen	9	3.0
Chlorides	27	2.6
Chlorophyll	27	8.3
Conductivity	24	0.1
Dissolved Organic Carbon	21	2.4
Nitrite-Nitrate Nitrogen	23	6.4
Orthophosphate	19	1.2
Total Dissolved Solids	27	1.8
Total Non-Volatile Suspended Solids	10	9.5
Total Organic Carbon	22	2.4
Total Phosphorus (TP)	37	4.3
Total Phosphorus – Dissolved	7	1.9
Total Persulfate Nitrogen	32	4.1
Total Persulfate Nitrogen – Dissolved	8	1.5
Total Suspended Solids	19	3.6
Turbidity	26	1.3

Table 4. Summary of results for TP check standards.

Known Concentration (mg/L)	Pooled %RSD	Average % Recovery
0.010	6.1	101.9
0.050	10.3	93.3
0.100	6.8	95.5

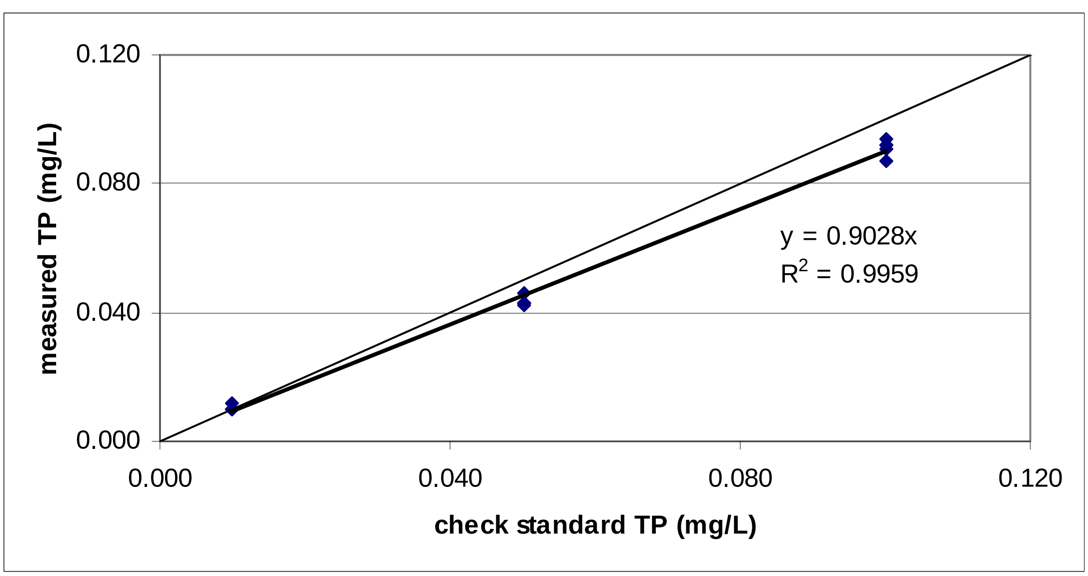

Figure 2. Check standard concentrations of TP compared to measured concentrations of TP.

Bias

Check standards also were used to evaluate bias for TP. The percent recovery was calculated for each check standard submitted. All results fall within the target bias limit of ±10% recovery. The average percent recovery for each concentration is listed in Table 4.

Lab bias was further evaluated using samples spiked with higher concentrations. A spike is performed once for every 20 samples analyzed. Many results affected by matrix interference are qualified by the lab with a "J" qualifier, indicating the result is an estimate. These results are listed in the qualification table in the data appendix (Appendix B).

All of the TP samples collected during the September 24-26, 2001 surveys were qualified as estimates. All samples were manually digested (method SM4500PH) due to a contamination problem with the automated in-line TP analyzer instrument. Samples were digested on the last day of their hold date or afterwards. In addition, samples exceeded sample temperature limit of 4° C while in holding storage.

In all, the TP sample results from these dates seem to show good relative precision, but a negative bias. In most cases, TP results were generally equal to or lower than associated ortho-P results. Ortho-P results for this sample set were deemed excellent.

Accordingly, TP results were rejected for use in comparison with other TP results from other sample dates; however, relative comparison within the qualified sample set was deemed satisfactory (i.e., relative increases or decreases from one station to another were assessed within the qualified data set). Additionally, TP results for some stations were estimated from established TP to ortho-P ratios and used in load determinations and analysis. This was only done if there was a strong linear correlation shown between the two phosphorus partitions at the station in question throughout the study period and if estimated values were within the range of previous values assessed. Figure 3 presents a typical satisfactory correlation at Rocky Ford Creek station RF2.

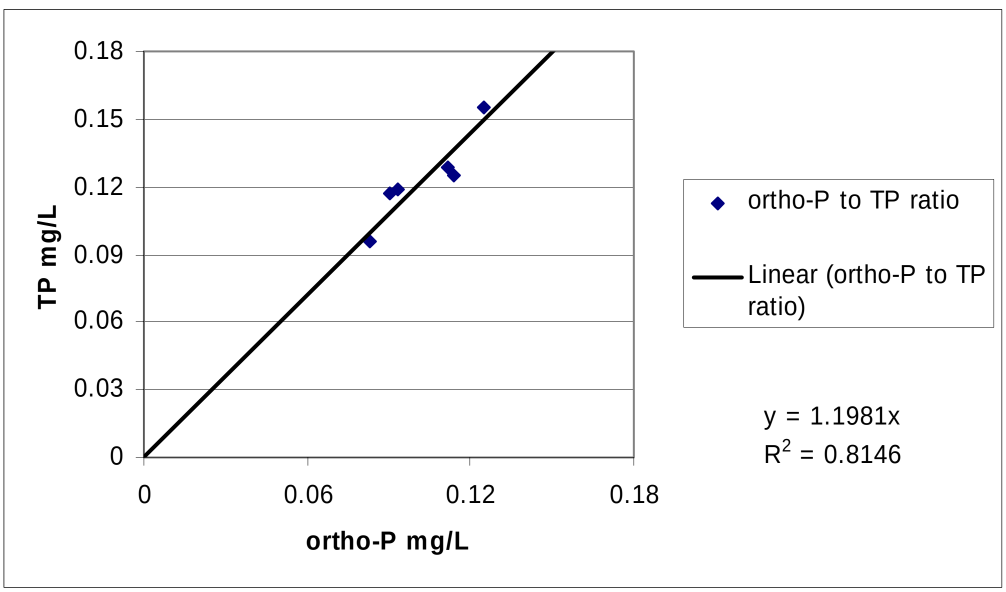

Figure 3. Ortho-P to TP ratio correlation from Rocky Ford Creek station RF2.

Conclusion

The QA and QC review suggest that the Ecology data are of good quality and are properly qualified.

Water Quality Evaluation

1. Rocky Ford Creek

Rocky Ford Creek is one of two natural tributaries to Moses Lake. It is unique as a tributary because of its small watershed size (104 km^2) and yet relatively large mean annual flow. Rocky Ford Creek originates as a series of springs at the Troutlodge 1 fish hatchery and then flows south from the springs for approximately eight miles, discharging to the north end of the main arm of Moses Lake (Figure 4). The Troutlodge 2 hatchery also uses Rocky Ford Creek about a mile downstream of the headsprings.

Most of the flow at the head of Rocky Ford Creek is diverted through both fish hatcheries. Just above the mouth of the creek is a small detention pond created by a dam built in 1987 to retain phosphorus and prevent carp from entering the creek.

Historical Data Review

Rocky Ford Creek is a Class A surface water that has been listed as violating water quality criteria for temperature, pH, and dissolved oxygen. Cusimano and Ward (1998) conducted a Total Maximum Daily Load (TMDL) study in 1997 on Rocky Ford Creek. They concluded that the temperature violations were due to natural conditions and recommended that the creek be delisted for temperature. It was also concluded that the dissolved oxygen and pH violations were most likely due to algal/plant growth and decomposition within the creek and adjacent wetlands.

Cusimano and Ward (1998) noted that setting quantitative nutrient loading limits might not be feasible due to the complex nature of wetland and rooted macrophyte processes; however, they conducted their work during an extreme high-flow year when Rocky Ford Creek was flooding its channel. Cusimano and Ward (1998) also suggested that nutrient allocations for Rocky Ford Creek may need to be established as part of the Moses Lake study in order to protect the lake water quality.

Carroll et al. (2000) reviewed the historical data on Rocky Ford Creek in context to its nutrient contribution and impact on Moses Lake. The review established that, on the average, Rocky Ford Creek contributes 37% of the annual TP load to Moses Lake.

Hydrology

Rocky Ford Creek has an annual average flow of 78.2 cfs (Cusimano and Ward, 1998). The 90^{th} and 10^{th} percentile flows for Rocky Ford Creek are 94 and 46 cfs, respectively. Figure 5 shows a Weibull distribution probability plot of the annual mean flows for Rocky Ford Creek from 1977 through 2001. The mean flow for the 2000-01 water year was 57 cfs, nearly a 20^{th} percentile flow for the 1977 to 2001 time period. Figure 6 shows box plots of the daily flow records by month. The flows in Rocky Ford Creek are relatively stable (day to day) and most of the time range between 40 and 100 cfs. There is a slight seasonal variation, with higher flows occurring during the latter half of the year (May – Dec).

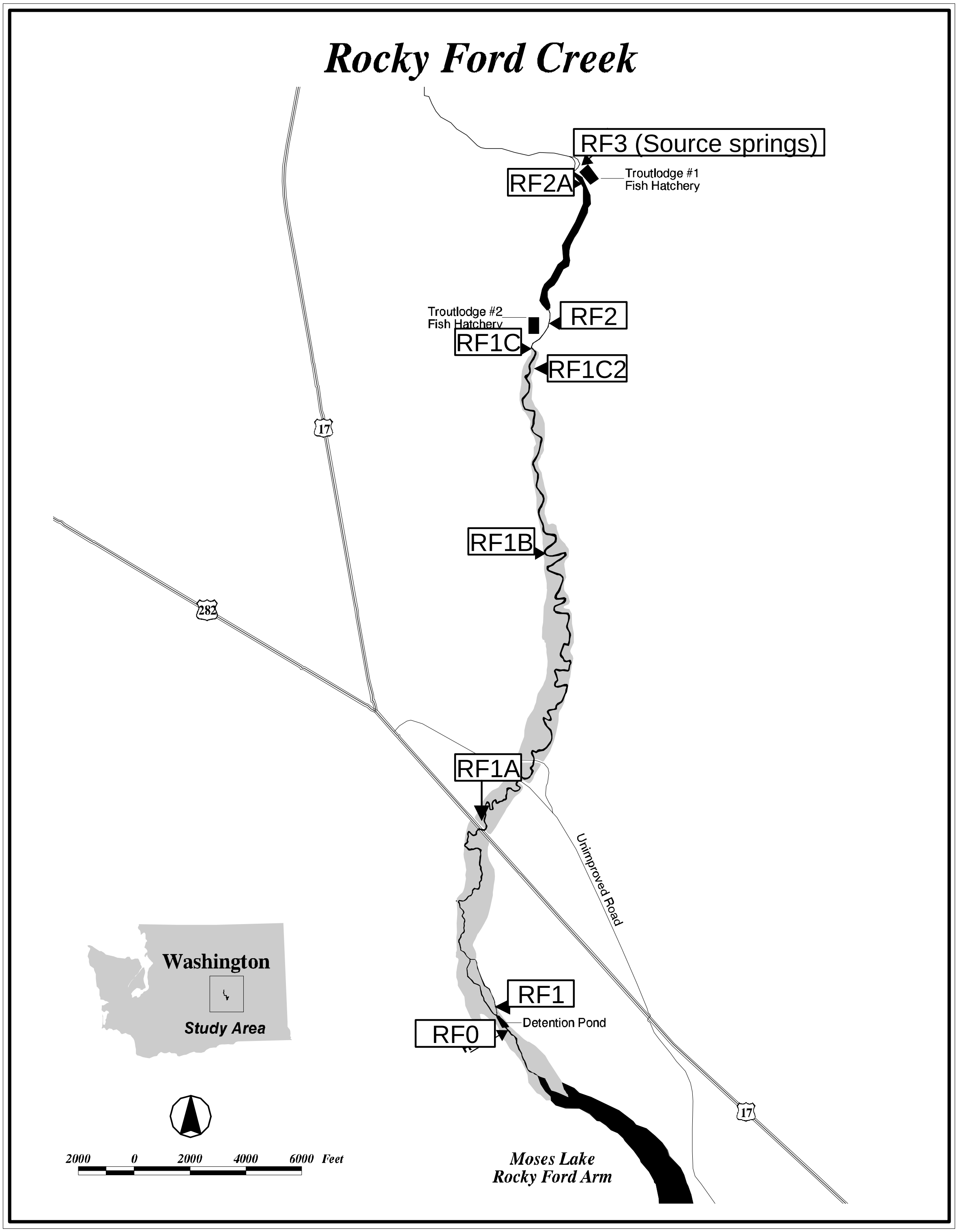

Figure 4. Vicinity map of Rocky Ford Creek and sampling stations.

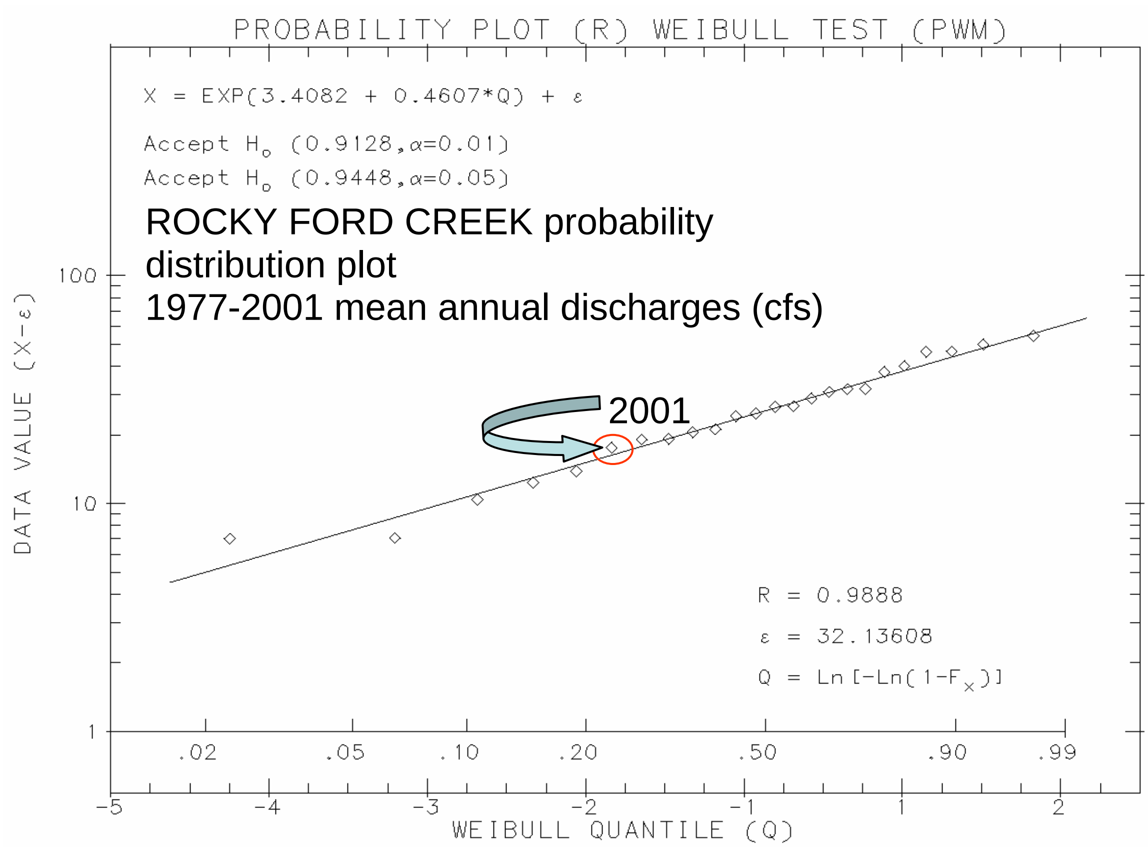

Figure 5. Probability distribution plot of Rocky Ford Creek annual flows (1977 – 2001).

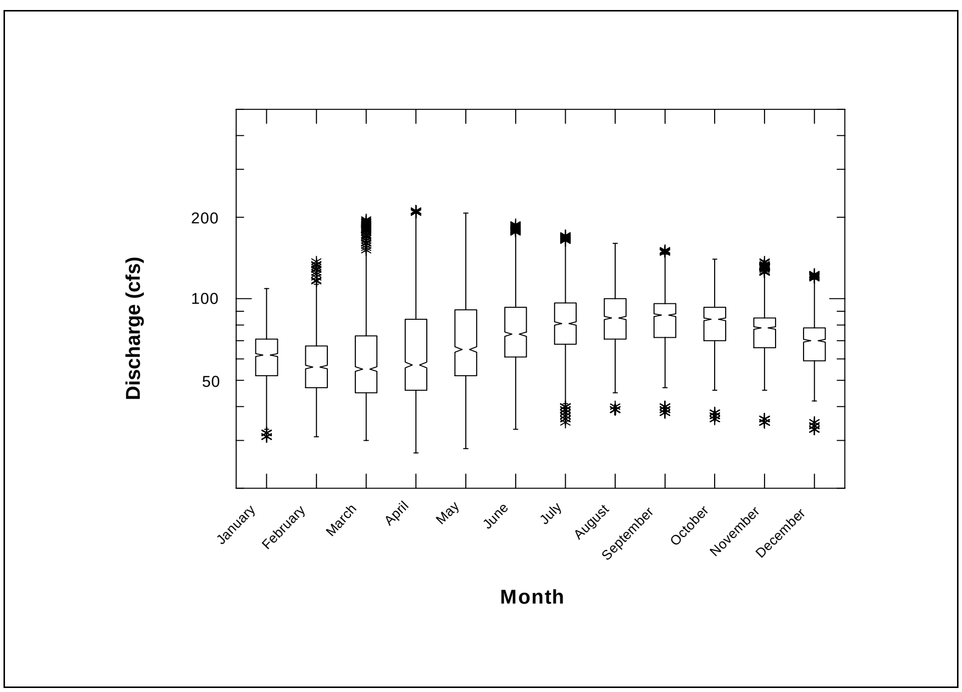

Figure 6. Box plots of daily flow for Rocky Ford Creek from USGS station 12470500 data (1942 – 1991). (See Appendix A for an explanation of box plots.)

USGS operated a gaging station (USGS station 12470500) located about one mile below the springs above Troutlodge 2 from 1942 through September 1991 (located near station RF2 on Figure 4). After 1991 the USGS continued making instantaneous bi-monthly measurements at Highway 17, about four miles downstream of the original gaging station (located near station RF1A on Figure 4). The original gaging station was abandoned because the control for the station was being influenced by the diversion of flow at the Troutlodge 2 hatchery. It was felt that because of the stable nature of the flow on Rocky Ford Creek, the linear interpolation between bi-monthly instantaneous measurements would be sufficient to characterize the daily discharge (Smith, 2001).

USGS never correlated flow at the new USGS gaging site at Highway 17 and the old USGS gaging station; however, Cusimano and Ward (1998) found flow increased approximately 20% (22-26 cfs) from the USGS monitoring station to the lake, suggesting groundwater inflows to Rocky Ford Creek en route to Moses Lake. An increase was also observed in the 2000-01 water year. During a synoptic flow survey conducted on September 25, 2001, measured flow at the old USGS station was 48.7 cfs, while flow at the mouth of Rocky Ford Creek was 81.7 cfs (i.e., a 33 cfs or 68% increase). Most of this increase (24 cfs) occurred between Highway 17 and the mouth of Rocky Ford Creek.

Ecology installed a continuous flow station at the mouth of Rocky Ford Creek (just below the dam) for the 2000-01 study period. Figure 7 presents the flow for this station compared with the USGS interpolated flow data at Highway 17 and the source springs for the 2000-01 water year. There was a seasonal increase of flow from the headsprings to the mouth beginning in May (beginning of irrigation season), and peaking in October (end of irrigation season). This pattern extended from the previous water year as well (i.e., peak in late September 2000) with flows subsiding until there was essentially equal wintertime flow along the entire length of the creek from late December until the beginning of the 2001 irrigation season. Most of the increases in downstream flow took place below the Highway 17 bridge USGS gaging site. This suggests that a locally elevated water table provides a sub-surface seasonal discharge to Rocky Ford Creek, particularly in the last few downstream miles.

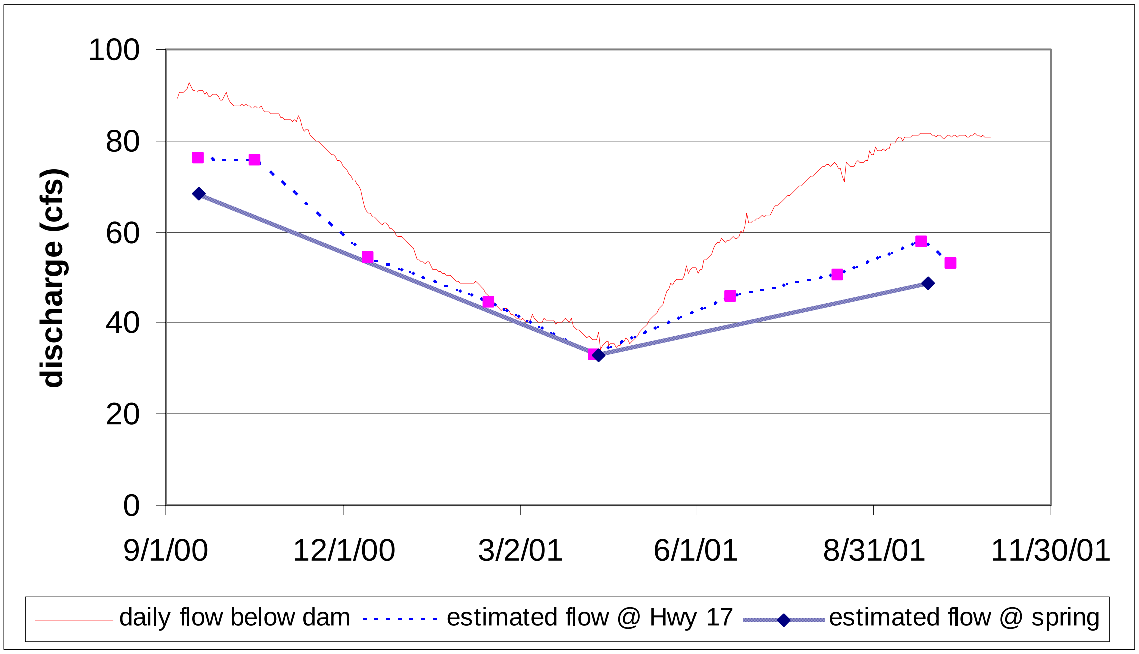

Figure 7. Comparison of study-period flows in Rocky Ford Creek below the dam (near mouth, station RF0), at the Highway 17 bridge, and at the source spring. Estimated flows are made using straight-line interpolation between measured instantaneous flows.

A plot of monthly mean flows in Rocky Ford Creek (Figure 8) from 1942 to 2001 indicates the variability and changing time periods of high versus low discharges that have taken place in Rocky Ford Creek since 1942. Rocky Ford Creek had higher flows in the late 1990s (90^{th} percentile flows from 1997 to 1999), resulting in flooded channels and extended wetlands (Cusimano, 1998). During the late 90s, there was also increased aquatic plant growth (rooted plants) which severely choked the channel, constricted flows, and caused further flooding in the watershed. These conditions did not exist during the 2000-01 water year. The creek remained confined to a distinct channel, and there was no noticeable severe plant-induced choking of the channel, although wetland-like conditions exist more plentifully in the last few miles of Rocky Ford Creek (the creek is multi-channeled and braided below Highway 17).

The most recent evidence (Pitz, 2003) indicates that the Rocky Ford Creek source spring discharge is predominantly derived from shallow groundwater northeast of the springs. The baseline discharge from the spring probably varies with fluctuating regional water table levels, which may reflect the variation in climatic conditions over the region or perhaps greater trends in irrigation patterns. The observed seasonal inflow seen in the lower part of the creek seems to remain fairly constant in either high- or low-flow years (observed flow increases ranged between 22 and 32 cfs for a 20^{th} and 90^{th} percentile annual flow year, respectively), suggesting fairly stable year-to-year groundwater inflows.

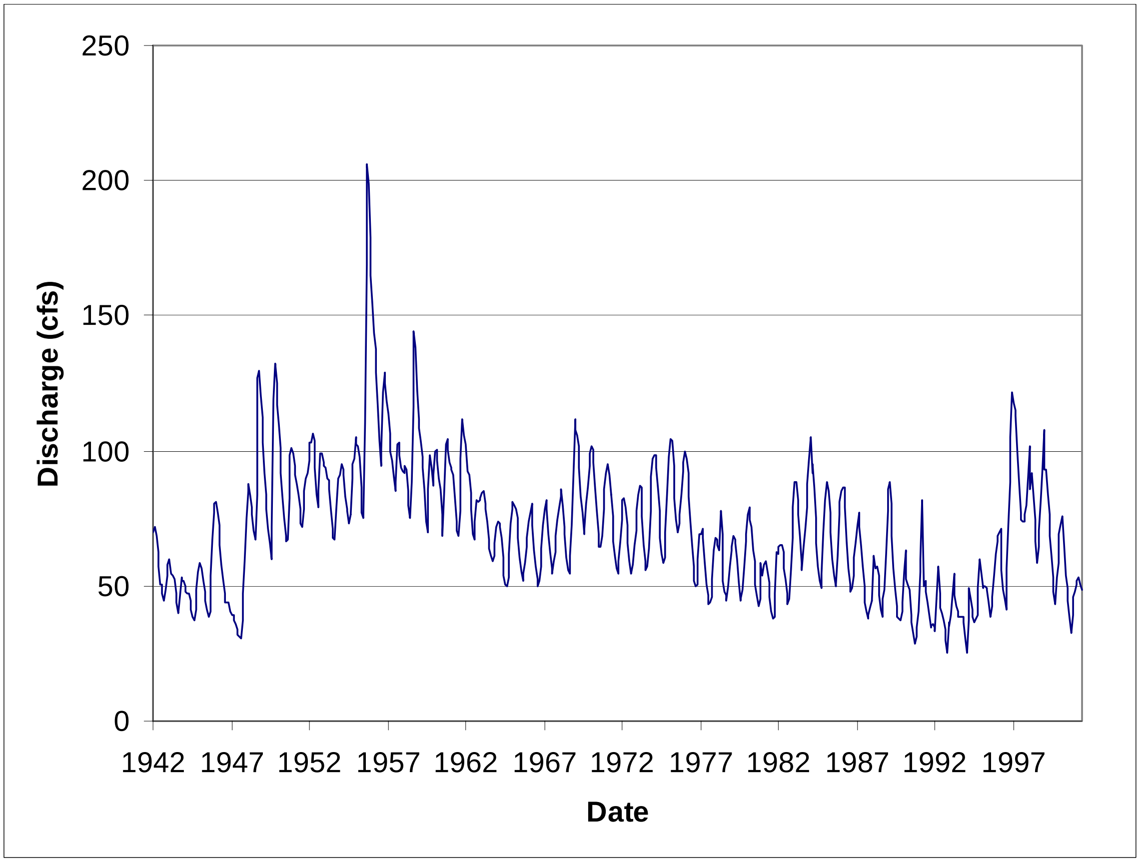

Figure 8. Rocky Ford Creek monthly mean flows from USGS station 12470500 (1941 to 2001). (From October 1991 through October 2001, monthly mean flows were interpolated from bi-monthly USGS data.)

Water Quality Evaluation

2000-01 Monitoring Results

Figure 9 shows all pH, dissolved oxygen, and temperature data collected as instantaneous measurements during the study period. Most sampling and measurements on Rocky Ford Creek were taken before 10 AM. Only five instantaneous temperature measurements were measured in excess of the 18° C criterion for Rocky Ford Creek. They were all afternoon measurements made at Highway 17 and the mouth from May to September. For the most part, the predominance of early morning instantaneous measurements missed the peak diurnal temperatures of the afternoon.

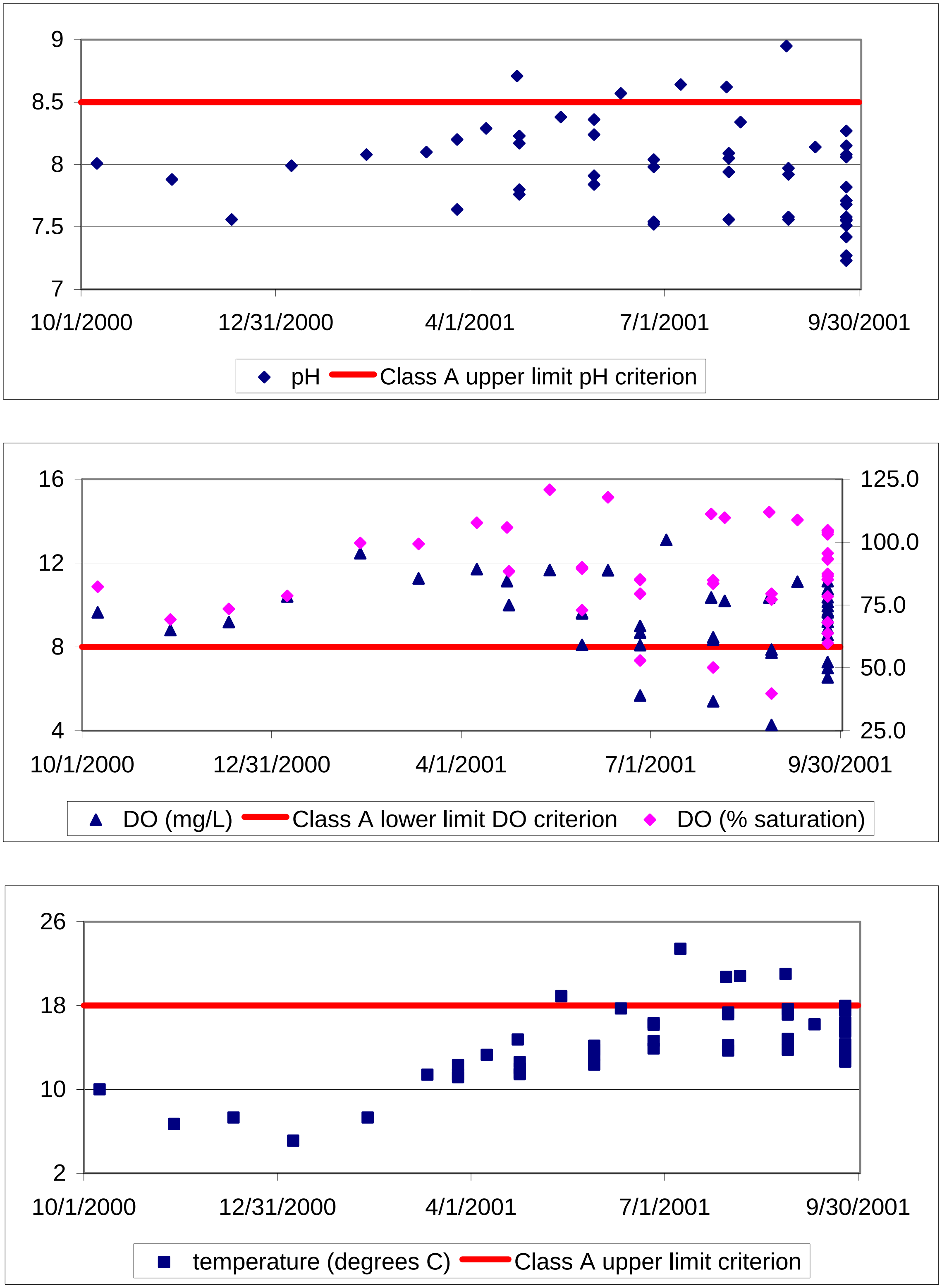

Figure 9. pH, dissolved oxygen, and temperature instantaneous data collected from all sites sampled on Rocky Ford Creek during the study period.

Continuous temperature monitoring at the mouth of Rocky Ford Creek from May to October 2001, presented in Figure 10, illustrates that water temperatures often exceed the 18° C criterion from May through August.

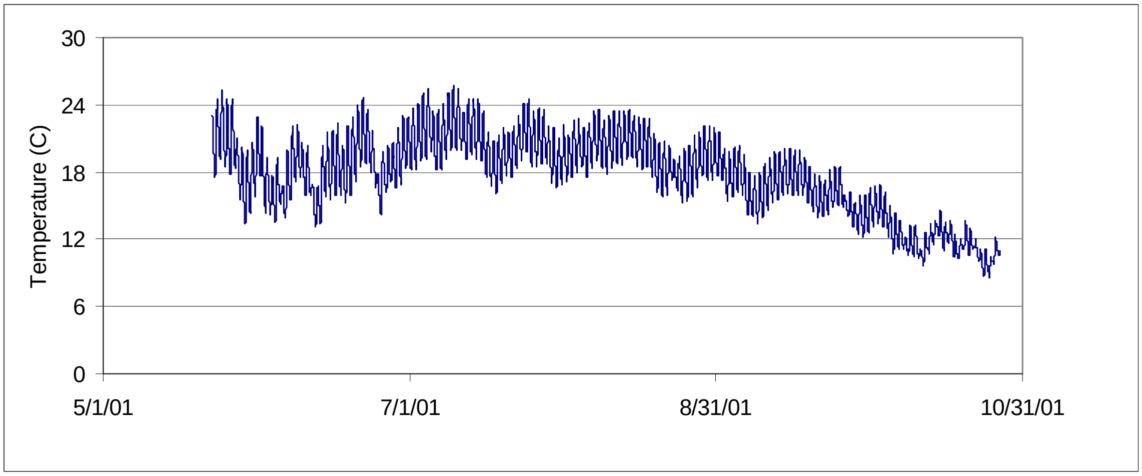

Figure 10. Continuous temperature data collected at the mouth of Rocky Ford Creek.

There were also pH excursions observed at the mouth and Highway 17 sites. Again, these excursions only occurred during the few early to late afternoon observations, and are associated with diurnal pH fluctuations found in Rocky Ford Creek (higher pH occurs in the afternoon due to photosynthesis). For the most part, Rocky Ford Creek is well buffered – total dissolved solids were >240 mg/L and alkalinity was approximately 170 mg/L throughout the study period – which has the effect of dampening pH fluctuations.

Dissolved oxygen (DO) also exhibited a diurnal fluctuation in Rocky Ford Creek, with lower DO concentrations occurring at night and early morning due to plant and algal respiration. In this case, early morning sampling was timely for measuring low DO excursions below the 8.0 mg/L criterion. The site in the downstream reach below the Troutlodge 1 hatchery (station RF2) consistently had very low DO concentrations from the end of June through September during the early hours. The lowest DO concentration measured at this site was 4.3 mg/L (about 35% of saturation) on 8/28/01 at 7:30 in the morning. On this same day, DO excursions were measured at two other sites (RF0 and RF1). On the several occasions it was measured, the headwater springs had a concentration of DO greater than 9.0 mg/L and was consistently about 25% under-saturated.

During a synoptic survey on 9/24/01, station RF2 again violated the DO criterion with a concentration of 7.0 mg/L (56% saturation) at 9:45 AM, but exhibited a net DO production with a concentration of 11.1 mg/L (90% saturation) at 13:45 PM, giving a net DO diurnal range of over 4 mg/L. Cusimano and Ward (1998) reported a DO diurnal range of 3.6 to 9.2 mg/L at the old footbridge above Highway 17 during their August 1997 survey. In 2001, the upper part of Rocky Ford Creek, in particular the reaches immediately below the fish hatcheries, were the most productive reaches of the creek and the most likely to have pH and DO violations.

In general, Rocky Ford Creek exhibited depressed DO concentrations relative to saturation year-round at all sites sampled up and down the creek (average of 76% saturation). Again, most samples were taken in the early morning, but even mid-afternoon DO concentrations were rarely super-saturated. Cusimano and Ward (1998) suggested that the decomposition of wetland plants and algae probably accounts for the year-round depression of DO.

The station below the dam (RF0) was the only station with consistent turbidity violations, though slight, with an average increase of 6.0 NTU over background (background estimated to be 1.0 NTU) from April through August.

Synoptic Survey – September 24, 2001

An intensive synoptic survey of Rocky Ford Creek was conducted on September 24, 2001. This survey occurred during the period of seasonal groundwater inflow in the lower part of the creek. Table 5 summarizes the load contribution or loss (kg/day) at each of the sample stations for nutrients and chlorophyll *a*. Additionally, stations were grouped into categories to analyze the percent contribution of the total load to Moses Lake from various similar sources or sinks within the Rocky Ford Creek watershed.

A summary of findings include:

- The source spring accounted for most (86%) of the nitrate in the creek. There was a net loss of nitrate in the fish hatcheries (-6.5%), probably due to biological uptake associated with photosynthetic activity (i.e., plants and algae) within the hatchery races. Additional sources of nitrate (around 20%) entered Rocky Ford Creek via the seasonal inflows in the lower reaches.

- The fish hatcheries discharged most of the ammonia to the creek. Ammonia is a product of fish metabolism. This readily available nutrient was evidently biologically utilized in the immediate downstream reaches below the fish hatcheries, either as ammonia or the oxidized form of nitrate during nitrification (18% loss). The immediate downstream reaches showed little to no increase in nitrate.

- The fish hatcheries were the major contributor of chlorophyll *a* (i.e., algae) to the creek (38.7%), most likely sloughed from periphyton mats within the hatchery facilities. This is consistent with the uptake of nitrate within the hatchery. There was no (< 1%) chlorophyll in the source springs. The immediate downstream reaches below the fish hatcheries, with their supplies of available ammonia, contributed another nearly 25% of the chlorophyll *a* to the creek.

- The majority of TP and ortho-P originated from the source springs (40% and 49%, respectively). The fish hatcheries contributed 24% of the TP and 17% of the ortho-P, while the immediate downstream reaches below both hatcheries contributed almost another 10% of the TP and ortho-P load. In all, the fish hatcheries and their immediate downstream reaches had a 34% and 26% net contribution of TP and ortho-P, respectively.

Table 5. Summary of results from synoptic survey on Rocky Ford Creek on September 24, 2001

Site	Conductivity			Nitrate			Ammonia			TP			Ortho-P			Chlorophyll a		
	cumulative load *	change in load	% of total load to lake	cumulative load (kg/day)	change in load	% of total load to lake	cumulative load (kg/day)	change in load	% of total load to lake	cumulative load (kg/day)	change in load	% of total load to lake	cumulative load (kg/day)	change in load	% of total load to lake	cumulative load (kg/day)	change in load	% of total load to lake
Spring origin (RF3)	46954		60.3%	240.9		86.1%	1.1		14.6%	8.5		39.7%	10.0		49.4%	0.01		0.9%
Troutlodge I (RF2A)	46824	-129	-0.2%	225.0	-15.9	-5.7%	7.2	6.1	80.3%	11.5	3.0	13.9%	12.2	2.2	10.9%	0.12	0.12	18.2%
Reach below Troutlodge I (RF2)	50637	3812	4.9%	234.1	9.1	3.3%	5.1	-2.1	-28.2%	12.6	1.2	5.4%	13.9	1.6	8.1%	0.28	0.16	24.7%
Troutlodge II (RF1C)	50756	119	0.2%	231.7	-2.4	-0.9%	7.1	2.1	27.5%	14.8	2.1	10.0%	15.1	1.3	6.2%	0.41	0.13	20.5%
Reach below Troutlodge II (RF1C2)	50398	-357	-0.5%	229.9	-1.8	-0.6%	6.8	-0.4	-4.7%	15.3	0.5	2.2%	15.0	-0.1	-0.6%	0.33	-0.08	-12.1%
Reach above Swanson land (RF1B)	50756	357	0.5%	227.0	-3.0	-1.1%	7.9	1.1	14.9%	15.7	0.4	1.9%	15.3	0.3	1.5%	0.41	0.08	12.1%
Reach above Hwy 17 (RF1A)	60028	9272	11.9%	258.8	31.8	11.4%	8.8	0.8	11.1%	18.3	2.6	12.4%	17.8	2.5	12.4%	0.49	0.08	13.1%
Reach above mouth (RF0)	77853	17825	22.9%	279.8	21.1	7.5%	7.6	-1.2	-15.4%	21.4	3.1	14.4%	20.3	2.5	12.2%	0.64	0.14	22.6%
Total load to Moses Lake	77853		100.0%	279.8		100.0%	7.6		100.0%	21.4		100.0%	20.3		100.0%	0.64		100.0%

* Conductivity load calculated as (umhos/cm-1) x (cfs)

Summarized % contribution of total load to Moses Lake (inflows or net biological uptake/release)

	Conductivity	Nitrate	Ammonia	TP	Ortho-P	Chlorophyll a
Spring	60%	86%	15%	40%	49%	1%
Fish hatcheries	0%	-7%	108%	24%	17%	39%
Downstream reaches directly below hatcheries	5%	2%	-18%	10%	9%	25%
Lower creek	35%	19%	-4%	27%	25%	36%

Source Springs and Troutlodge Hatcheries

The source springs originate on the property of the Troutlodge 1 hatchery. The facility is located adjacent to a bluff, from which the springs emerge at the base. Historically the springs emerged to the ground surface, but in past years Troutlodge buried interceptor lines that run parallel to the bluff and intercept the springs. The water is conveyed through the interceptor lines to a number of manifold vaults where the water is directed into the hatchery. Ecology sampled one manifold vault monthly beginning with the April sampling. However, during the synoptic sampling on September 24, 2001, two additional vaults also were sampled.

The synoptic sampling of the three spring manifold vaults revealed variable results (Table 6) leaving the representativeness of any individual spring vault sample in regards to the total source spring inflow contribution unknown to Ecology. Table 7 presents the summary of results from all the spring source samples collected during 2001.

Table 6. Summary of results from Rocky Ford Creek source spring samples taken on September 24, 2001.

Parameter	Mean	Minimum	Maximum
TP (ug/L)	Rejected data	----	----
Ortho-P (ug/L)	91	66	109
Total nitrogen (mg/L)	3.40	3.04	3.95
Nitrate-nitrite-N (mg/L)	2.17	2.07	2.53
Conductivity (umhos/cm)	424	401	436

Table 7. Summary of results from Rocky Ford Creek source spring samples, April through September 2001.

Parameter	Mean	Minimum	Maximum	90th percentile
TP (ug/L)	103	75	119	125
Ortho-P (ug/L)	82	65	109	103
Total nitrogen (mg/L)	3.03	2.51	3.95	3.74
Nitrate-nitrite-N (mg/L)	2.57	1.92	3.02	2.98
Conductivity (umhos/cm)	529	401	705	705
Chloride (mg/L)	6.73	3.35	11.1	11.22

The water quality influence of Troutlodge 1 on Rocky Ford Creek was assessed from April through September 2001. Sampling was affected because of access issues on site of the hatchery grounds (i.e., direct hatchery effluent), so samples were taken just downstream of the hatchery facility in a zone assumed to be completely mixed. Troutlodge 2 performance was assumed to equal the performance of Troutlodge 1.

The Troutlodge 1 hatchery is situated so that most, if not all, of the flow from the source springs is directed through the facility and then emerges into the creek channel directly below the facility (station RF2A). Samples were collected from this site directly below the facility for the synoptic survey on September 24, 2001. Otherwise, all other samples from April through September 2001 were collected further downstream at the old USGS gaging station (RF2).

The change in nutrient loading after source spring water passed through the Troutlodge 1 hatchery was assessed by comparing source spring and downstream parameter loads and is summarized in Table 8 along with data collected by Cusimano and Ward (1998). In general, the hatchery increased TP, ortho-P, and ammonia loads, while reducing the total nitrogen and nitrate loads. While ammonia concentrations were below detection limits in the spring water, ammonia loads increased sharply from hatchery contributions, though un-ionized ammonia was not present in toxic quantities.

Table 8. Change in Rocky Ford Creek source spring nutrient loads passing through the Troutlodge 1 hatchery.

Change in Load	Nitrate		Ammonia		TP		Ortho-P	
	kg/day	%	kg/day	%	kg/day	%	kg/day	%
During 9/24/01 synoptic survey	-15.9	-7.1	6.1	650	3.0	25.9	2.2	18.1
During 8/20/97 survey (Cusimano and Ward, 1998)	-22.6	-1.9	19.5	660	11.5	52.9	11.5	52.6

Troutlodge 1 produced and discharged less TP and ortho-P in 2001 than in 1997. The 2001 production level (based on feed use) was close to half of that reported for 1997. The percent changes from upstream TP loads were also reduced for both years. If the percent increase of TP in 2001 were normalized to 1997 production levels, the hatchery would have contributed a higher percentage of TP to the creek than in 1997.

Cusimano and Ward (1998) warned that the percent contribution of TP to Rocky Ford Creek, and ultimately to Moses Lake, from the hatcheries could become substantially higher due to changes in the creek flow and fish hatchery production levels. Troutlodge estimated that the hatcheries had a combined usage of approximately 1.25 million pounds of feed in the 2001 calendar year, with fairly stable month-to-month usage (Parsons, 2002). In addition, Troutlodge indicated that they expected increased production from both hatcheries in the future. The 2001 level was less than the 1997 feed level reported by Cusimano and Ward (1998) and only 25% of the maximum permitted feed level of over 5 million pounds.

The cumulative effect of the Troutlodge 1 hatchery effluent and immediate downstream biological activity on nutrient loads were assessed from April through September 2001 by comparing source spring loads with downstream parameter loads at station RF2. A summary of these monthly results reflect the same trend of increasing TP, ortho-P, and ammonia, with decreasing total nitrogen and nitrate-N (Table 9).

Table 9. Percent change in source spring nutrient loads passing through Troutlodge 1 hatchery.*

Month of 2001 sampling	Total Nitrogen (%)	Nitrate (%)	Ammonia (%)	TP (%)	Ortho-P (%)
April	-29.5	-37.6	1000	19.4	25.0
May	-33.7	-36.0	770	28.0	25.8
June	-23.8	-28.6	1140	7.2	43.1
July	-45.4	-34.6	1200	8.4	13.1
August	-29.4	-36.1	990	13.6	12.9
September	-38.6	-30.6	480.0	30.2	16.8
Mean, April – September	-33.4	-33.9	930.0	17.8	22.8

* Includes immediate downstream reach measured at station RF2

Three of seven sites (RF1B, RF1C, RF2) exhibited low dissolved oxygen excursions during the synoptic survey on September 24, 2001; all three sites were in downstream reaches directly below the hatcheries. These excursions occurred in the morning hours, but not in the afternoon, reflecting the dissolved oxygen dynamics of plant and algal photosynthesis and respiration. Kendra (1989) summarized the work of numerous investigators who documented water quality degradation downstream of fish hatcheries, including increased downstream algal and periphyton growth and productivity.

According to the Troutlodge facilities manager, both hatcheries pump cleaning wastewater and solids to off-line settling ponds. The settling ponds have no direct return to Rocky Ford Creek, but seep to groundwater (Witt, 2002). The nutrient increases observed from the hatchery were in the dissolved phase (i.e., ortho-P, ammonia) and were in the normal process water running through the hatchery.

Between the work compiled by Cusimano and Ward (1998) and this study, the TP contribution from the Troutlodge hatcheries during a high-flow year and a low-flow year are represented. However, the production levels were below normal in 1997 and apparently even lower in 2001, so the effect of increasing production levels at the hatcheries is still unclear, although it warrants consideration when determining potential TP loading to Rocky Ford Creek and ultimately to Moses Lake.

Seasonal Inflows

Water samples were collected once per month from Rocky Ford Creek at Highway 17 and below the dam; however, they were not collected on the same day (there was a two-week interval between collection times). Constituent loads were calculated for Rocky Ford Creek at Highway 17 and below the dam (station RF0). Figure 11 shows the increase in conductivity load occurring between the two sites during 2001. Again, the seasonal increase in conductivity load follows the same timing pattern as the seasonal increase in flow. Conductivity was considered to be a conservative tracer in this instance and confirms the increase in flow between the two sites.

An average conductivity of 350 umhos/cm for the inflowing groundwater was back-calculated from the increase in conductivity load between the two sites during the four-month period of June through September. This compares well with the average conductivity (323 umhos/cm) measured in groundwater sampled from a mini-piezometer near this area during the same period (Pitz, 2003).

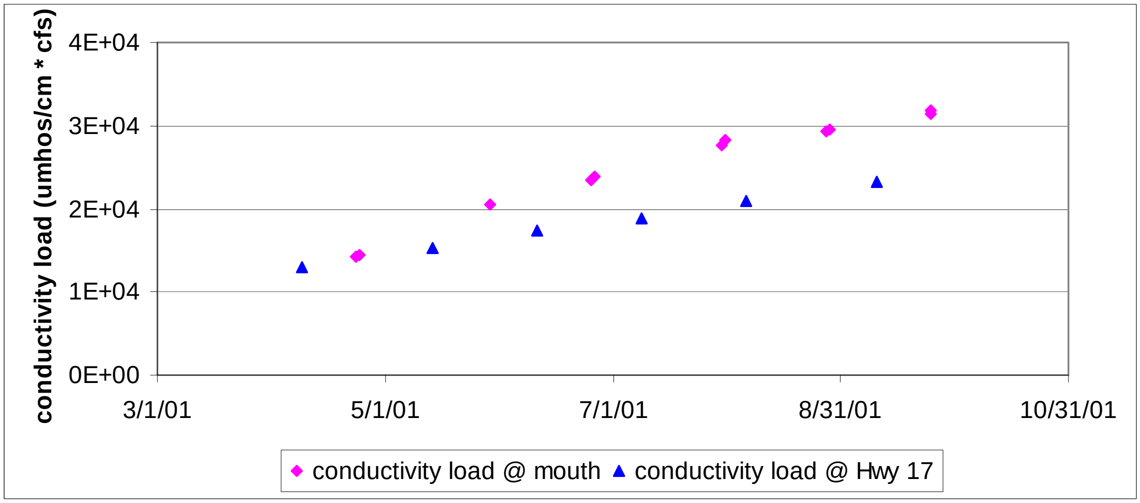

Figure 11. Comparison of conductivity loads in Rocky Ford Creek near the mouth of the creek (station RF0) and at the Highway 17 bridge.

Figure 12 show the calculated TP and ortho-P loads for Rocky Ford Creek at Highway 17 and its mouth. While one might expect to see increases in the loads of other constituents, similar to the conductivity load increase, phosphorus showed no increase in loads for the whole growing season. Integrating the loads from March through September indicated there was no apparent increase in phosphorus loads, though shorter integrated periods indicated compensating gain and loss periods for TP and ortho-P (Table 10). Differences in loads were often small compared to variability observed, except for the conductivity.

Table 10. Comparison of differences of integrated loads by parameter at two sites (Hwy 17 and RF0) on Rocky Ford Creek and associated variability for each parameter.

Parameter	% difference of integrated loads between Rocky Ford Creek at Hwy 17 and near mouth (RF0)			Pooled coefficient of variation for paired field duplicates at station RF0
	March thru June	July thru September	March thru September	
Total Phosphorus	-6.4%	10.4%	2.9%	9.7% n=5
Ortho-P	-9.6%	8.4%	0.5%	2.9% n=2
Total Nitrogen	-5.5%	1.9%	-1.6%	4.2% n=5
Nitrate-N	2.3%	2.3%	2.1%	3.8% n=5
Conductivity	17.5%	24.7%	21.4%	2.5% n=5

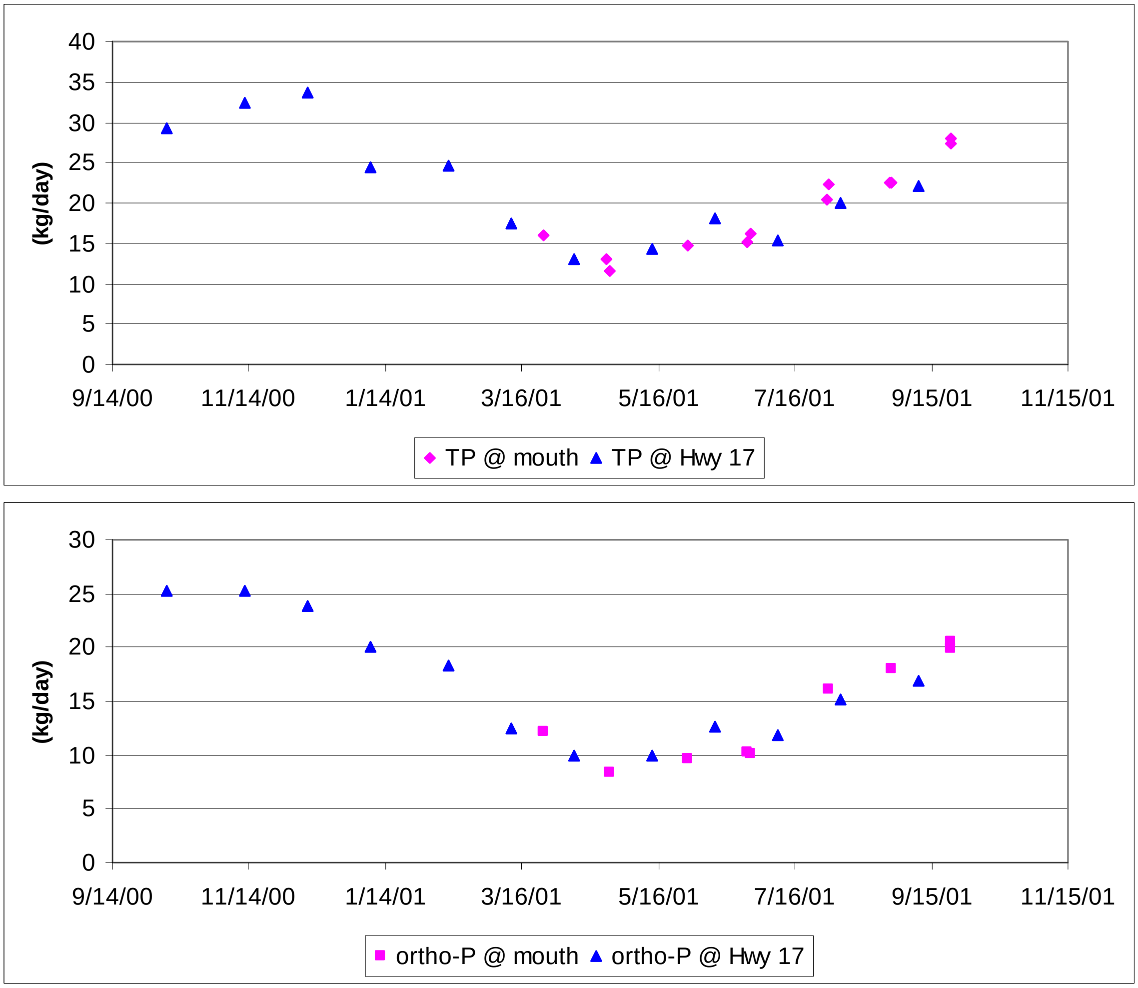

Figure 12. Comparison of TP and ortho-P loads in Rocky Ford Creek near the mouth of the creek (station RF0) and at the Highway 17 bridge.

Detention Pond

The designed detention pond near the mouth and above station RF0 was sampled to assess its removal of nutrients. The detention pond structure was built near the mouth of Rocky Ford Creek in 1987. It was designed to trap nutrients associated with suspended sediments entering the pond. Sediment settling and plant uptake within the detention pond was hoped to assist with nutrient removal from Rocky Ford Creek. An additional benefit of the dam for the detention pond was to keep carp from moving upstream from Moses Lake into Rocky Ford Creek. The state Department of Wildlife attempted to eradicate the remaining carp in Rocky Ford Creek following construction of the dam in 1987, but carp have moved back into the creek since, either by incomplete earlier eradication or upstream passage over the dam when it was vandalized in the mid-90s.

The detention pond has not shown any phosphorus reduction in the past. Various reports (Welch et al., 1989; Cusimano and Ward, 1998) have shown there has not been any significant difference in TP concentrations between samples taken directly above and below the detention pond. The detention pond's ineffective nutrient removal was further corroborated by data collected for this current study. An assumption of this present analysis is that the flow entering and exiting the detention pond are equal. This assumption is reasonable in that the detention pond is only about 400 meters long (about a quarter mile) which is a short distance for substantial sub-surface recharge. Additionally, the head level of the water is artificially high in this location due to the pond, further reducing the likelihood of substantial sub-surface recharge within the short pond reach due to the reduced vertical hydraulic gradients.

Figure 13 shows the concentrations of TP and ortho-P forms upstream and downstream of the detention pond. A paired t-test was done to evaluate if the differences in upstream and downstream concentrations were significantly different from zero. There were no significant differences ($\alpha = 0.05$) between the upstream and downstream sites for TP, total nitrogen, and ortho-P during the growing season of 2001. However, nitrate-N slightly decreased, and ammonia-N slightly increased, in Rocky Ford Creek as it passed through the detention pond. Cusimano and Ward (1998) showed a decrease in nitrate during their study year as well. The percentage of ortho-P to TP averaged 75% upstream of the detention pond and 72% downstream of the detention pond throughout the growing season. During the same period, the percentage of nitrate-nitrite to total nitrogen averaged 89% upstream of the detention pond and 87% downstream of the detention pond.

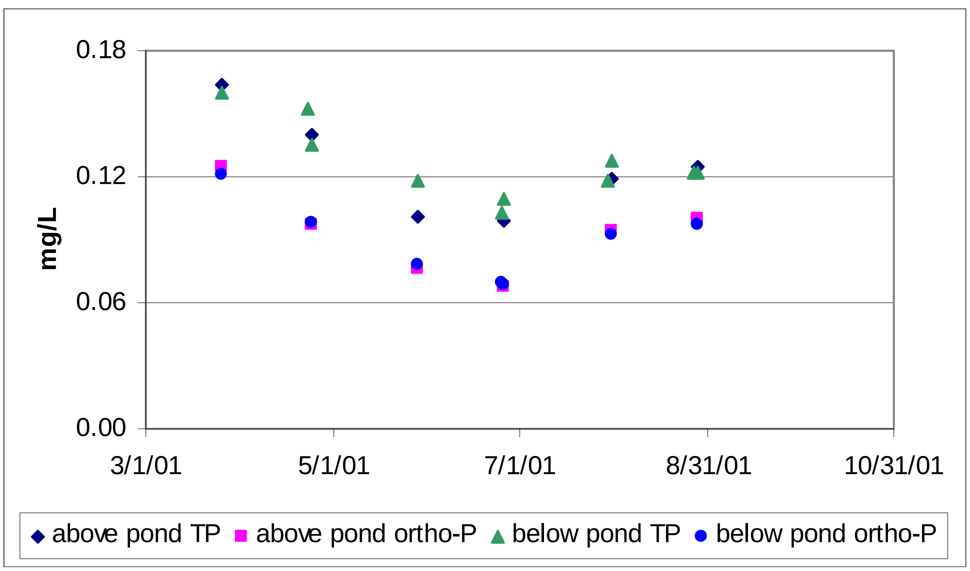

Figure 13. Comparison of phosphorus forms above and below the detention pond near Rocky Ford Creek.

The detention pond is small and is silted in, so the residence time for the water is short. The pond basically behaves as a flow-through system and does not assist in the removal of phosphorus loads to Moses Lake as intended. Still, when the dam is intact, it acts as an effective barrier to upstream migration of undesirable fish from Moses Lake.

The dam was the object of vandalism in the mid 90s and has been a source of contention among local landowners. Contrary to some beliefs, the retention of water in the detention pond has no effect on upstream (above Highway 17) hydraulics, flooding, or weed growth. Carp have repopulated Rocky Ford Creek and, though the state Department of Fish and Wildlife is considering further rehabilitation measures, the carp probably present no serious detriment to other fisheries in Rocky Ford Creek at this time (Korth, 2002). The carp may in fact help reduce the aquatic weed growth which has had a greater impact on the fisheries through productivity-related dissolved oxygen depletion, than a direct adverse effect on trout *per se*. Trout fish kills have taken place in years with high aquatic weed growth in Rocky Ford Creek.

Phosphorus Loading to Moses Lake

Daily nutrient loads from Rocky Ford Creek were developed from a seasonal and flow-weighted regression using continuous flow data and monthly to bi-weekly sampling data. Since concentration data were collected only from the mouth (station RF0) throughout the latter part of the study (mid-March through September 2001), concentration data collected at Highway 17 was used for October 2000 through March 2001. Again, flows at both sites were relatively equal throughout the winter, and nutrient loads were assumed to be relatively the same between the two sites during the non-growing season. The regression had a root mean squared error (RMSE) of 1.5 kg/day with a coefficient of variation of 7.4% (n= 20).

The October 2000 through September 2001 (study period) monthly TP loads are compared with historical (1960-89) mean and 90th percentile loads in Figure 14. Seasonal variation was present, with the highest TP loads occurring at the end of 2000 and the lowest TP loads occurring during the summer months of 2001. The TP loads were 62% of the average April through September loads, reflecting the less than average flow in Rocky Ford Creek for the study period (the study period had about a lower 20th percentile flow). In addition, there was also seasonal variation in phosphorus concentrations (Figure 15). Concentrations were higher than average in the winter months and lower than average in the summer months. The ratio of ortho-P to TP for the study period was 74.5% (standard deviation of 6.2%; n=13) for the year, with slightly higher ratios occurring in the winter months.

Based on data collected in 1997 (sampled in August and November), the fish hatcheries on Rocky Ford Creek were estimated to contribute an average of 21% of the TP load to the creek, and ultimately 10% of the TP load to Moses Lake (Cusimano and Ward, 1998). During 2001, the fish hatcheries were estimated to contribute 14% of the TP load from Rocky Ford Creek to Moses Lake on average from May to September (Figure 16). Cusimano and Ward (1998) indicated that the fish hatcheries' percent contributions to the Rocky Ford Creek nutrient load could be substantially higher in years with lower creek flows and higher fish hatchery production levels. Fish hatchery contributions could approach 75% of the nutrient load to Moses Lake in extreme cases.

The annual TP load from Rocky Ford Creek to Moses Lake was 7,930 kg for October 2000 through September 2001 (study period), with an average annual flow rate of 57 cfs and an average TP concentration equal to 155 ug/L. When the study period's annual TP load and average flow is plotted with the same data from other studies spanning the last 40 years, the consistent nature of the TP loading from Rocky Ford Creek is evident (Figure 17).

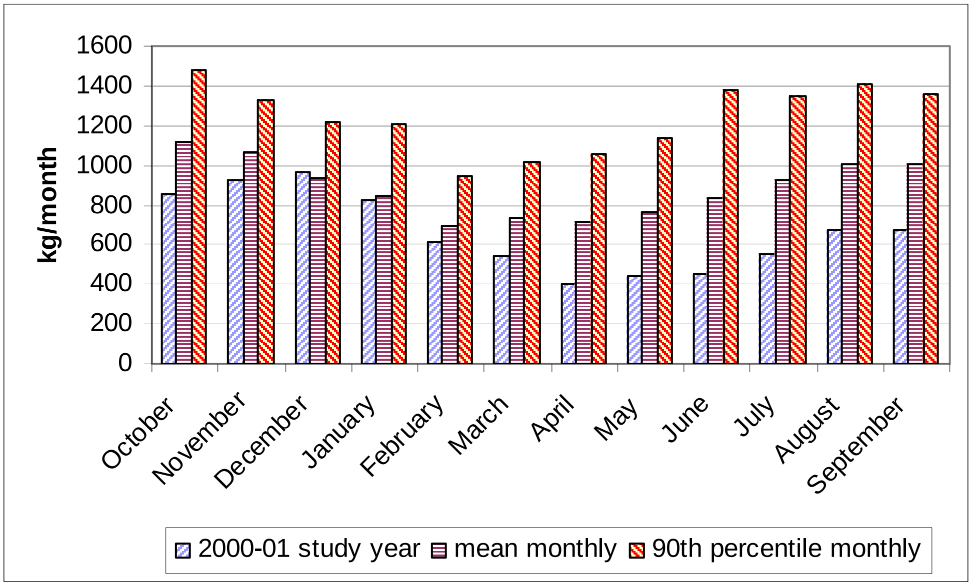

Figure 14. Study-period TP loads from Rocky Ford Creek to Moses Lake compared to historical mean and 90th percentile loads (means and 90th percentiles from Carroll et al., 2000).

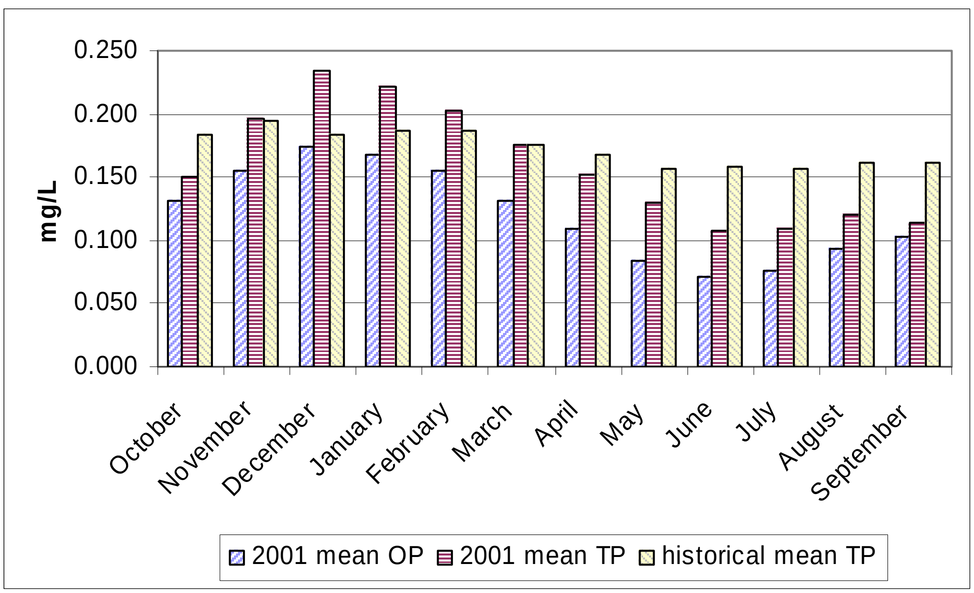

Figure 15. Study-period ortho-P and TP concentrations at the mouth of Rocky Ford Creek compared to historical TP concentrations (historical means from Carroll et al., 2000).

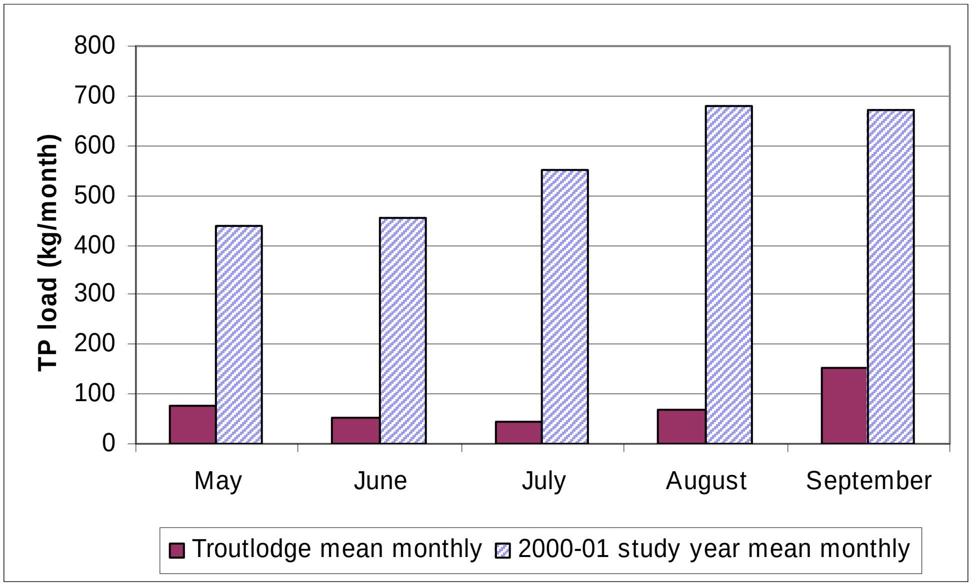

Figure 16. Rocky Ford Creek TP load to Moses Lake compared to apportioned load attributable to Troutlodge fish hatcheries, May through September 2001.

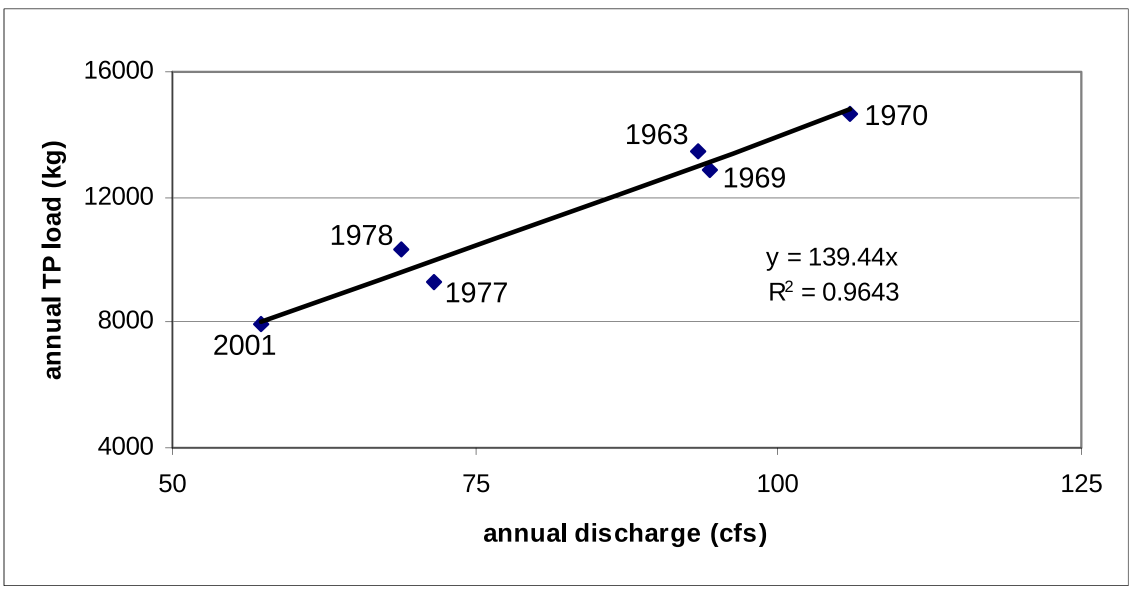

Figure 17. Plot of 2000-01 study-period and historical annual discharges from Rocky Ford Creek and related estimated TP loads (from various sources; see Carroll et al. (2000) for historical review).

The estimated annual TP loads have been a linear function of the flow (RMSE = 454 kg; CV= 4%) for the last 40 years. This constant relation of TP load with flow suggests that contribution from the hatcheries or other sources have not changed in the last 40 years. The average annual TP concentration derived from this relationship is 156 ug /L of TP.

Because of the consistently moderate flow and elevated nutrient levels, Rocky Ford Creek contributes substantially to the annual nutrient loading to Moses Lake. Nutrient concentrations have remained high in Rocky Ford Creek since water quality monitoring began in the early 1960s, despite some attempts at nutrient reduction (i.e., the detention pond). The origin of the particularly high phosphorus levels in the source springs has been the subject of speculation and inquiry. Pitz (2003) states that the area background ortho-P concentration for groundwater in the surficial aquifer system is less than 50 ug/L.

2. Crab Creek

Historical Data Review

Crab Creek is the more variable natural tributary to Moses Lake compared to Rocky Ford Creek. Crab Creek is designated as Class B surface water even though it is a feeder tributary to Moses Lake. It has been listed as violating water quality criterion for pH. Carroll et al. (2000) reviewed the historical data on Crab Creek in the context of its nutrient contribution to and impact on Moses Lake. The review established that, on the average, Crab Creek contributes 13% of the TP load to Moses Lake, although there is a large variability associated with this contribution. Flow regimes during different study years have resulted in Crab Creek contributing from 11% (Sylvester and Oglesby, 1964) to 49% (Welch et al., 1973) of the TP load to Moses Lake.

Hydrology

Although its watershed area is 2040 mi^2, Crab Creek has a lower annual mean flow to Moses Lake than Rocky Ford Creek. During the summer, much of Crab Creek flow goes underground. Prior to the beginning of the Columbia Basin Irrigation Project (CBIP) in 1952, Crab Creek surface flow was negligible except during periods of heavy winter/spring runoff. A USGS discharge monitoring station (USGS station 12467000), located 3.2 miles upstream of Moses Lake, provides a long-term flow record for Crab Creek (located near station CC1 on Figure 1). Since 1960, the mean annual flow has been 44.5 cfs. However, Crab Creek essentially has two flow regimes (winter and summer) and each warrants examination and separate consideration as to the impact it has on the water quality of Moses Lake.

Figure 18 shows box plots of Crab Creek daily flow by month. There are two distinct seasons to Crab Creek flow: highly variable (unpredictable) flow beginning in January and running through April, and relatively stable (predictable) flow from May to December. High flows can occur from January through April and, in some years, large winter/spring runoff events have produced flows greater than the entire annual flow of Rocky Ford Creek. Figure 19 shows discharge for Crab Creek from 1960 to the present. Large winter/spring runoffs (>500 cfs) have occurred during 40% of the last 40 years, with four large events occurring in four successive years in the late 1990s.

During the October 2000 through September 2001 study period, there was not a winter/spring runoff event. In fact, the 2000-01 water year flow was the lowest since 1977 (Figure 20). There was discontinuous flow below Brook Lake the entire year, until a gradual accumulation of sub-surface seepage (and possible irrigation returns) around the Gloyd Seeps area again provided for a small surface flow into Moses Lake. Summer time flows into Moses Lake from Crab Creek initiate from these sub-surface (or return) flows near Gloyd Seeps.

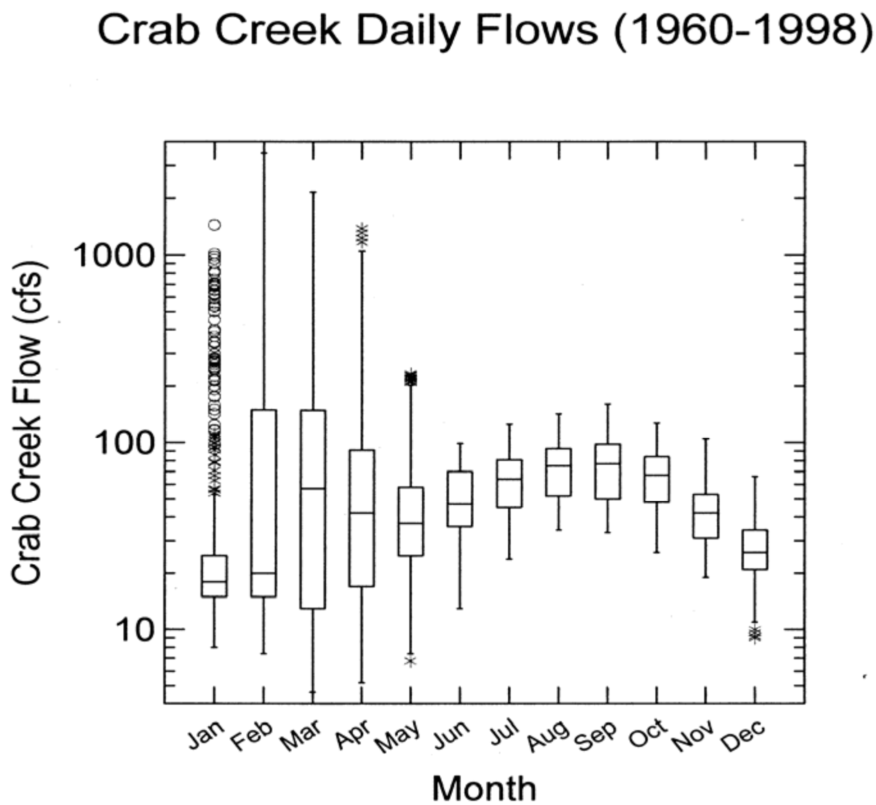

Figure 18. Box plots of daily flows for Crab Creek from USGS station 12467000 data from 1960 to 1998. (See Appendix A for an explanation of box plots.)

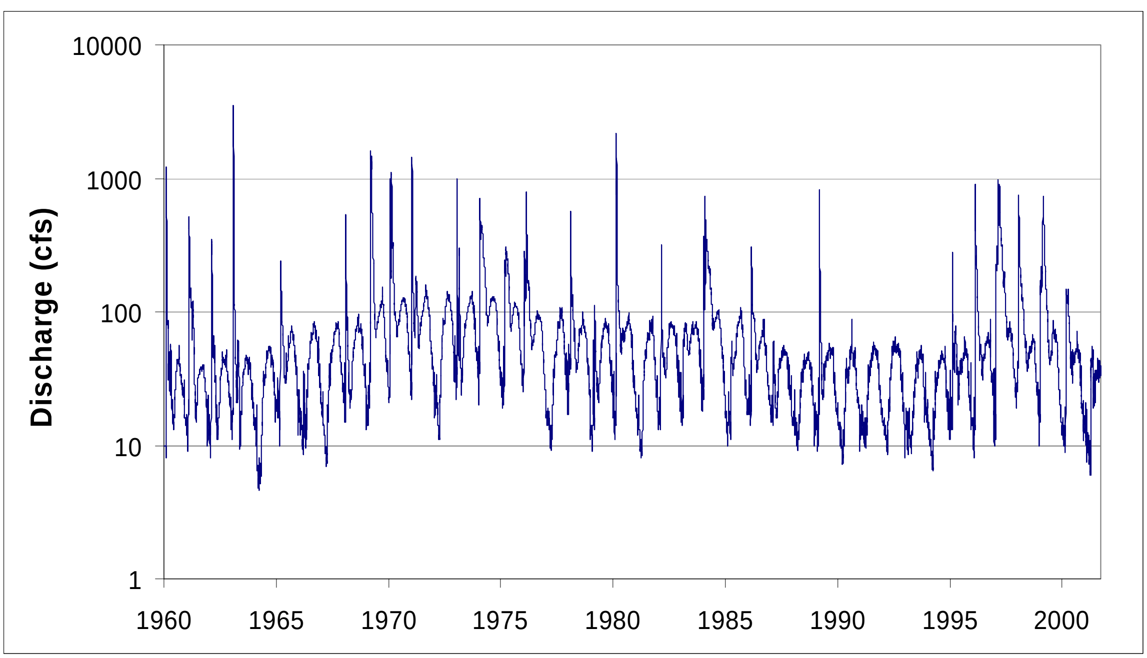

Figure 19. Crab Creek above Moses Lake daily flows from USGS station 12467000 data from 1960 to October 2001.

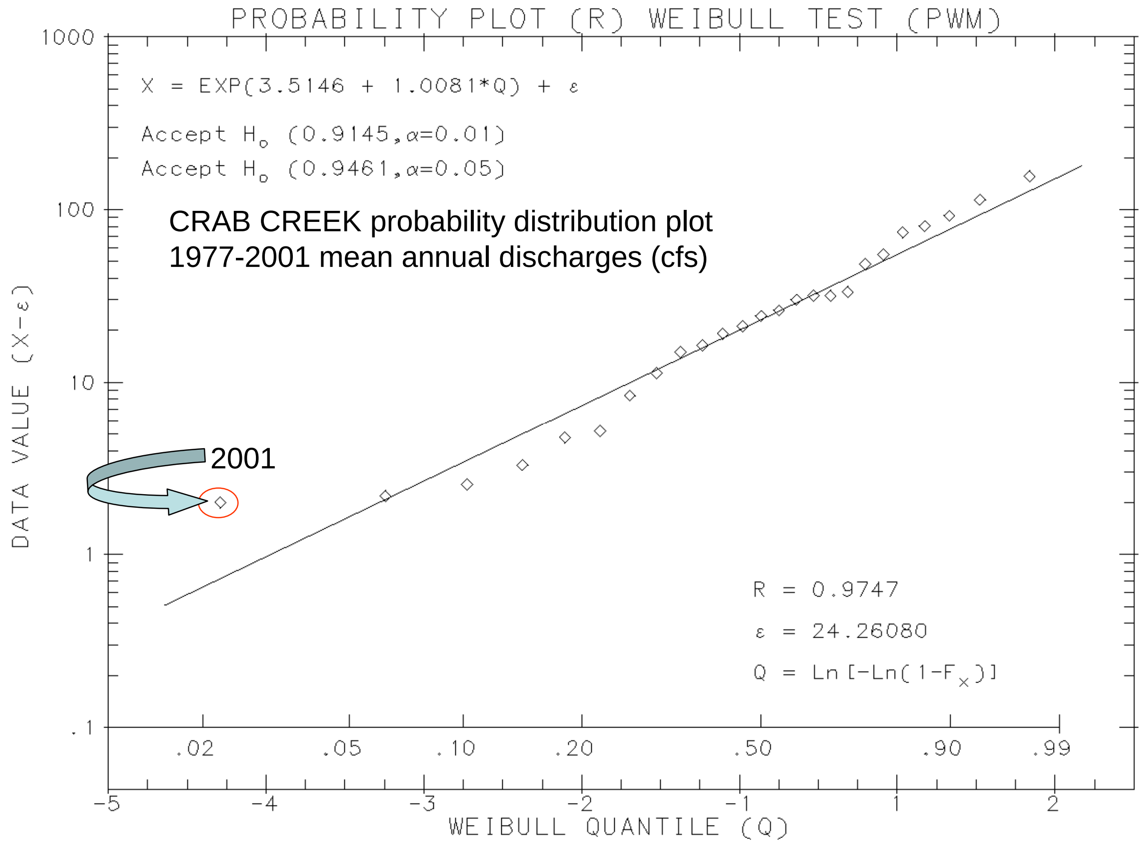

Figure 20. Probability distribution plot of mean annual discharges for Crab Creek from 1977 to 2001.

Water Quality Evaluation

2000-01 Monitoring Results

Figure 21 shows all the pH, dissolved oxygen, and temperature data collected as instantaneous measurements during the study period for Crab Creek. Most temperature measurements made from June through August exceeded the 21º C Class B temperature standard.

There also were high pH excursions observed from May through July at many Crab Creek sites. Most pH measurements were taken in the early afternoon when high pH is associated with diurnal pH fluctuations found in Crab Creek (higher pH occurs in the afternoon due to photosynthetic utilization of carbon dioxide). This was despite the fact that Crab Creek is well buffered (alkalinity was >200 mg/L throughout the study period), which has the effect of dampening pH fluctuations.

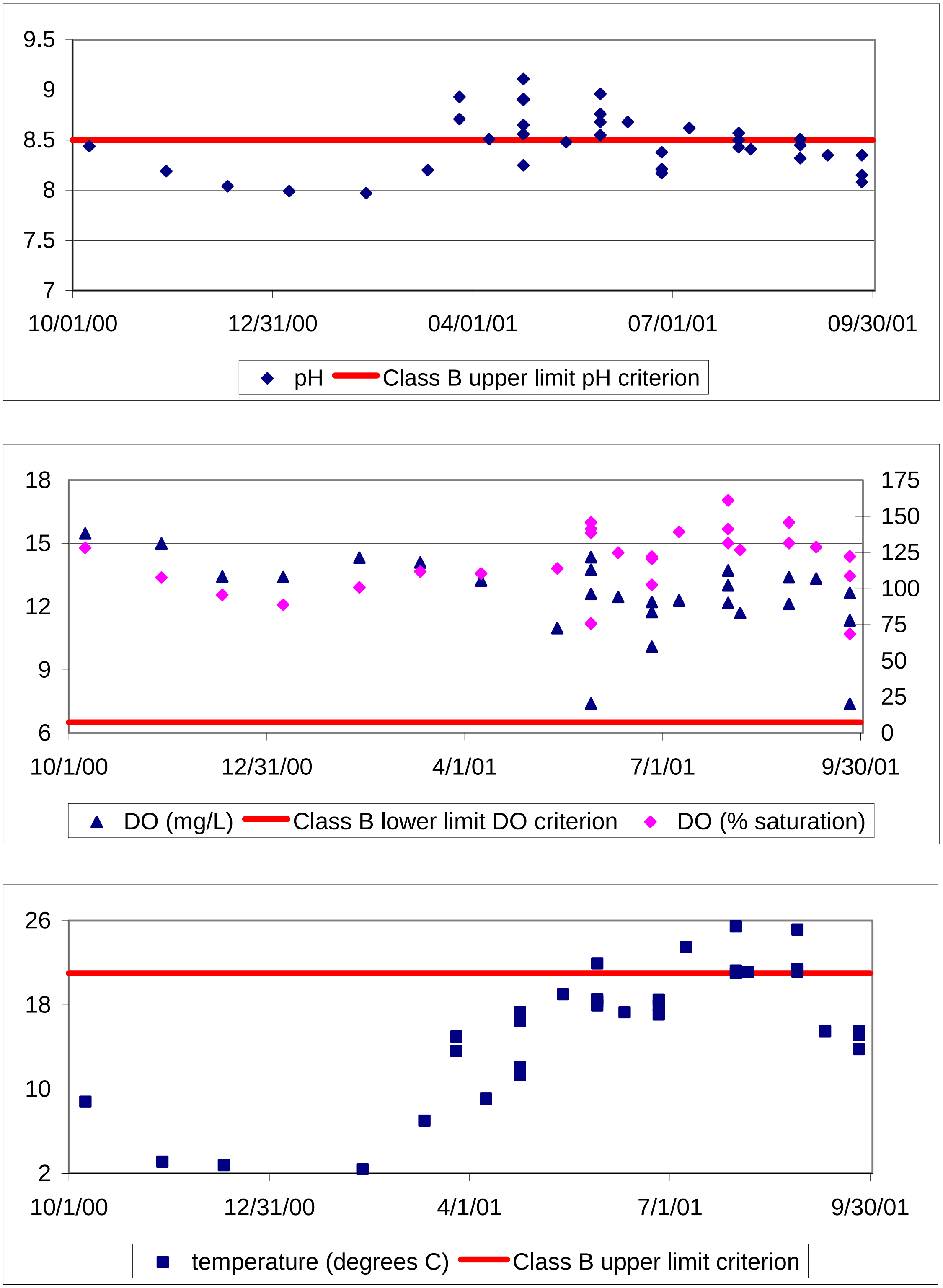

Figure 21. Data plots of all pH, dissolved oxygen, and temperature instantaneous data collected from all Crab Creek stations (CC1, CC2, CC3, CC4, CC5, and CC6) during the study period.

Likewise, dissolved oxygen also exhibits diurnal fluctuations in Crab Creek, with lower dissolved oxygen concentrations occurring at night and in early morning due to plant and algal respiration, and higher dissolved oxygen readings in the afternoon due to photosynthetic production of oxygen. Afternoon sampling on Crab Creek resulted in predominantly higher dissolved oxygen measurements and supersaturated conditions particularly through the summer. The only low dissolved oxygen measurements at station CC1 was taken on 9/25/01 at 8:10 A.M.

Phosphorus Loading to Moses Lake

Historically, during certain years Crab Creek has delivered large TP loads to Moses Lake during large winter/spring runoff events >500 cfs. These events discharge water down the entire length of Crab Creek, using portions of the creek channel that are usually dry year-round. The runoff is usually produced by large rain or snow events. The ground is usually still frozen, impeding infiltration and causing a large runoff of precipitation and snowmelt into the Crab Creek channel where erosive action transports stored sediment downstream. As much as 83% of the phosphorus load from Crab Creek to Moses Lake can occur in March and April during these events.

Horner et al. (1985) examined Crab Creek during a median flow year (winter-1982-83) and found limited contributions from the upper Crab Creek watershed above Brook Lake to Moses Lake. Although Lincoln County Conservation District has conducted limited nutrient sampling of the upper watershed, a more detailed source study of TP in the upper watershed would be beneficial during a high-flow event (greater than 500 cfs).

Much of upper Crab Creek has inadequate riparian cover. Because the channel is often dry, it has been left unprotected and has even been used for agriculture (e.g., plowing lines and cable irrigation lines go right across the channel in some places).

A large runoff event did not occur in Crab Creek during the 2000-01 study period, so water quality of such an event could not be characterized. However, the winter of 1996-97 produced a large runoff, and on March 27, 1997, Bain (1998) measured a TP concentration of 200 ug/L in Crab Creek (station CC1). Turbidity and total suspended solids of the turbid water were 40 NTU and 40 mg/L, respectively. Also, for that day the USGS reported an average daily discharge of 832 cfs, meaning the daily TP load to Moses Lake was 407 kg for that day alone. Assuming the 200 ug/L TP concentration were sustained through the month, and based on the USGS daily flow record for the month of March, Crab Creek would have discharged nearly 9000 kg of TP into Moses Lake that month.

Most of the variation in annual nutrient loading from Crab Creek to Moses Lake is a function of winter/spring runoff flow magnitude. These large runoff events do not occur after April. In effect, these events dictate the initial spring conditions of Moses Lake (March/April), although the settling of sediments to the lake bottom will eventually influence sediment oxygen demand and the release of bound phosphorus from the sediments later in the growing season. The summer flow from Crab Creek to Moses Lake is more predictable.

Daily TP and ortho-P loads from Crab Creek were developed for 2001 from seasonal and flow-weighted regressions using continuous flow data and monthly or bi-weekly sampling data at station CC1. The TP load regression had a RMSE of 0.8 kg/day with a coefficient of variation of 24.6% (n= 20). The ortho-P load regression had a RMSE of 0.2 kg/day with a coefficient of variation of 15.3% (n= 20).

The mean annual TP concentration and load in Crab Creek (data collected 1960 to 1989 at station CC1) was 97 ug/L and 3613 kg/yr, respectively. The mean annual TP concentration and annual TP load for the 2000-01 study period was 69 ug/L and 1343 kg/yr, respectively. Again, this study period was one of the lowest flow years since 1977, and the historical annual mean concentration and load were highly influenced by the variable winter/spring runoff events. This can be seen in a comparison of historical and study period mean monthly TP concentrations (Figure 22) and TP loads (Figure 23). Particularly, the study period had lower than average TP concentrations and loads in the months of February, March, and April. During the study period, Crab Creek concentrations of TP from May through September were 66% of average.

The mean annual ortho-P concentration in Crab Creek (station CC1) for the 2000-01 study period was 26 ug/L. Welch et al. (1989) reported annual mean soluble reactive phosphorus levels of 18 ug/L and 7 ug/L for the aggregate years of 1977-79 and 1986-88, respectively, at this station, which was greatly reduced from a mean of 32 ug/L in 1969-70. The study period mean ortho-P concentration from May through September was 13 ug/L (Figure 22). The total annual load of ortho-P to Moses Lake was 478 kg for the study period.

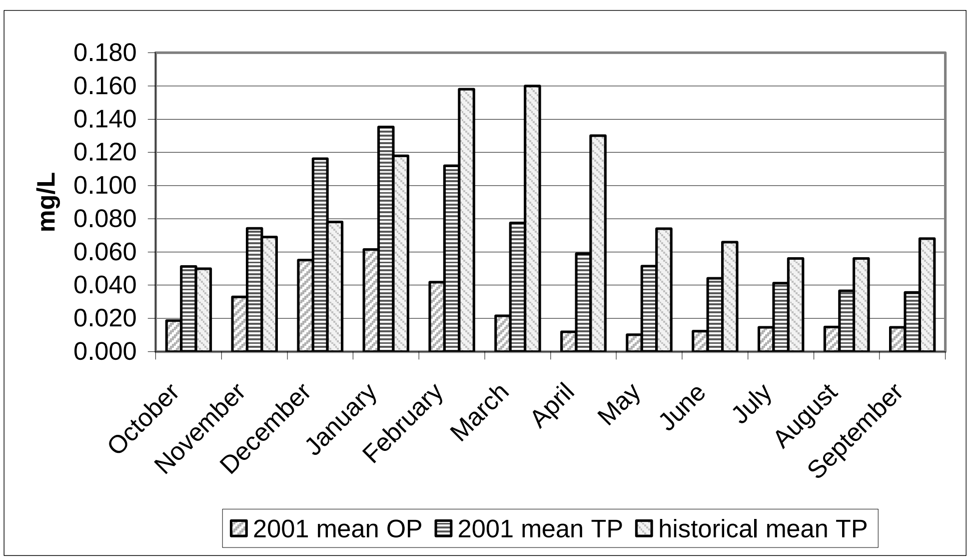

Figure 22. Ortho-P and TP concentrations in Crab Creek (station CC1) for the 2000-01 study period compared to historical TP concentrations.

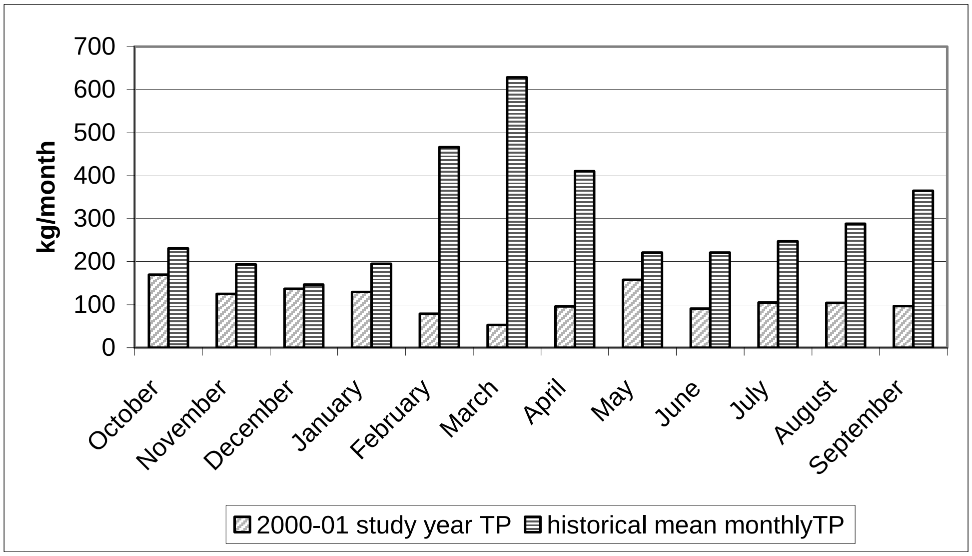

Figure 23. TP mean loads (kg/month) in Crab Creek (station CC1) for the 2000-01 study period compared to historical TP mean loads.

3. Rocky Coulee Wasteway

Historical Data Review

Rocky Coulee Wasteway is an artificial tributary to Moses Lake (via Crab Creek) constructed for the Columbia Basin Irrigation Project (CBIP) as a drain for irrigation return water and as a route for irrigation feed water. The wasteway also was constructed to drain natural runoff (baseflow). It contains the flow from the spring originating at the Columbia Basin Hatchery. The flow during the 2000-01 water year was dominated by feed water (i.e., Columbia River water). Carroll et al. (2000) presented historical flow data concerning feed water and the relation of their magnitude to climactic variation (e.g., there is an inverse relationship of feed water flow to natural flow from the Crab Creek watershed).

Hydrology

Figure 24 shows a Weibull distribution probability plot of the annual mean flows for Rocky Coulee Wasteway from 1977 through 2001. The 2000-01 study period had the fifth highest feed water within that time period, corresponding close to a 90th percentile flow.

Water Quality Evaluation

2000-01 Monitoring Results

Rocky Coulee Wasteway is a specially classified surface water of the State of Washington as a tributary to Crab Creek, and is designated as Class B surface water. All instantaneous measurements of dissolved oxygen, pH, and temperature from the study period are presented in Figure 25. The measurements are compared with Class B standards. With the exception of some pH violations in the mid-summer months, Rocky Coulee Wasteway had acceptable pH, dissolved oxygen, and water temperature during the 2000-01 study period, often meeting the water quality criteria of a Class A stream. Of course, the water quality of Rocky Coulee Wasteway was greatly influenced by the feed water of high-quality Columbia River water.

Columbia Basin Hatchery Spring

The Columbia Basin Hatchery was evaluated from April through September 2001 for baseflow and nutrient loading. The spring at the hatchery flows year-round, with generally higher flows in the summer associated with irrigation recharge to groundwater. A majority of the spring water is diverted through the hatchery complex as normal process water. Solids are removed periodically to a settling pond. The settling pond discharges downstream into the spring channel just downstream of where all of the normal process water is returned. The spring channel flows south for about one and half miles until it discharges to Rocky Coulee Wasteway.

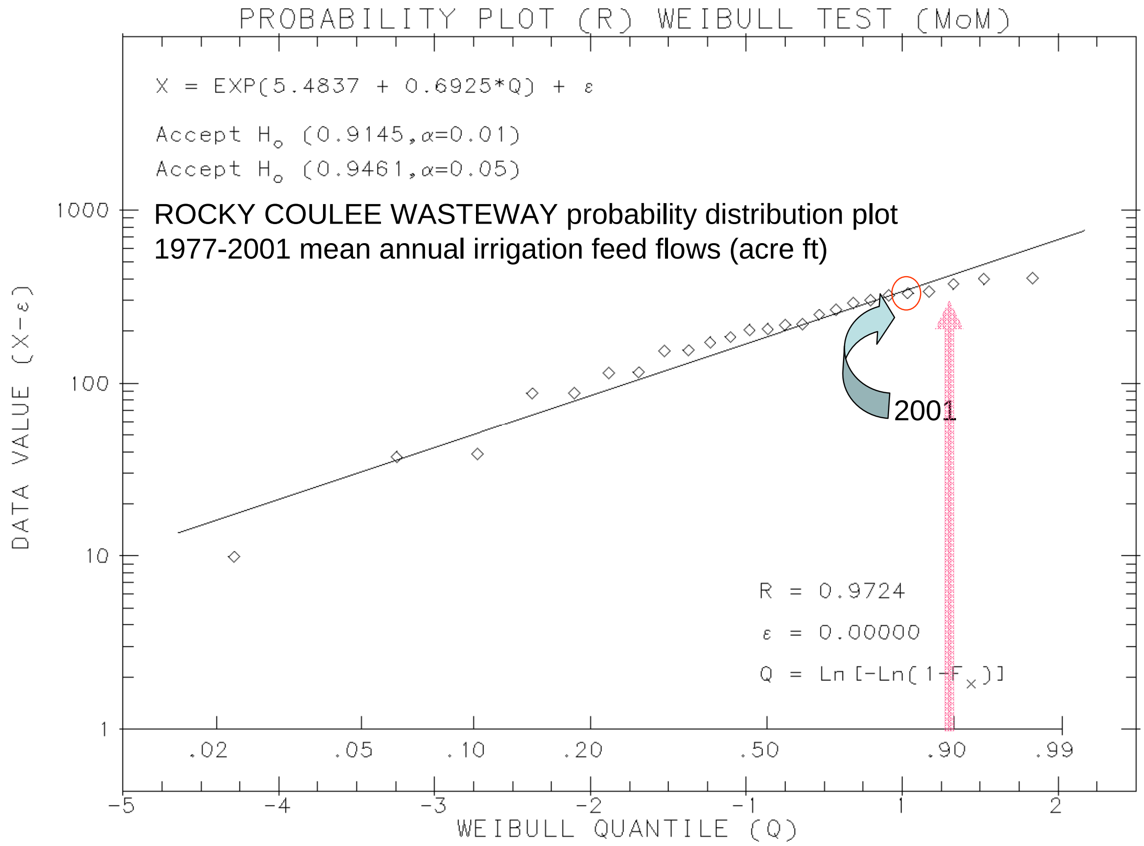

Figure 24. Distribution probability plot of mean annual feed water discharges to the Rocky Coulee Wasteway from 1977 to 2001.

The spring supplies most of the baseflow found in Rocky Coulee Wasteway. During 2001, the flow from the spring steadily increased from 15 cfs in May to just over 22 cfs in September. From 1977 to 1979, Patmont (1980) estimated the annual baseflow in Rocky Coulee Wasteway to be 35 cfs. The flow in 2001 was probably lower because of less sub-surface recharge.

Spring concentrations of TP and ortho-P had an average increase of 16% and 13%, respectively, downstream of all Columbia Basin Hatchery effluent discharges for the 2001 period (Figure 26). The average TP concentration was 87 ug/L for the period, with 67% of that in dissolved phase (ortho-P). The monthly average TP loads for the Columbia Basin Hatchery, the spring, and the total combined are presented in Figure 27.

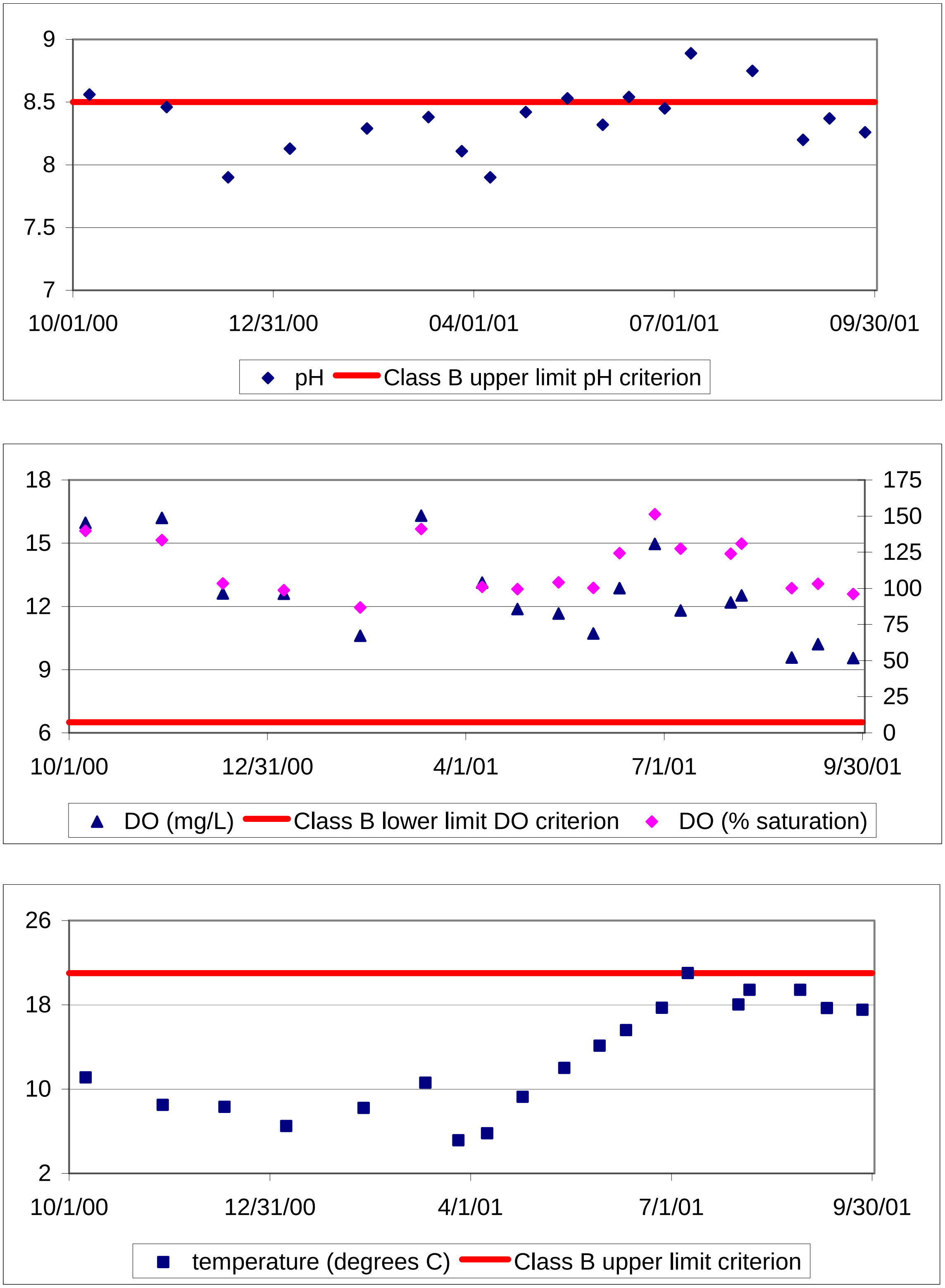

Figure 25. Data plots of all pH, dissolved oxygen, and temperature instantaneous data collected from Rocky Coulee Wasteway at Rd. K (station RC1) during the study period.

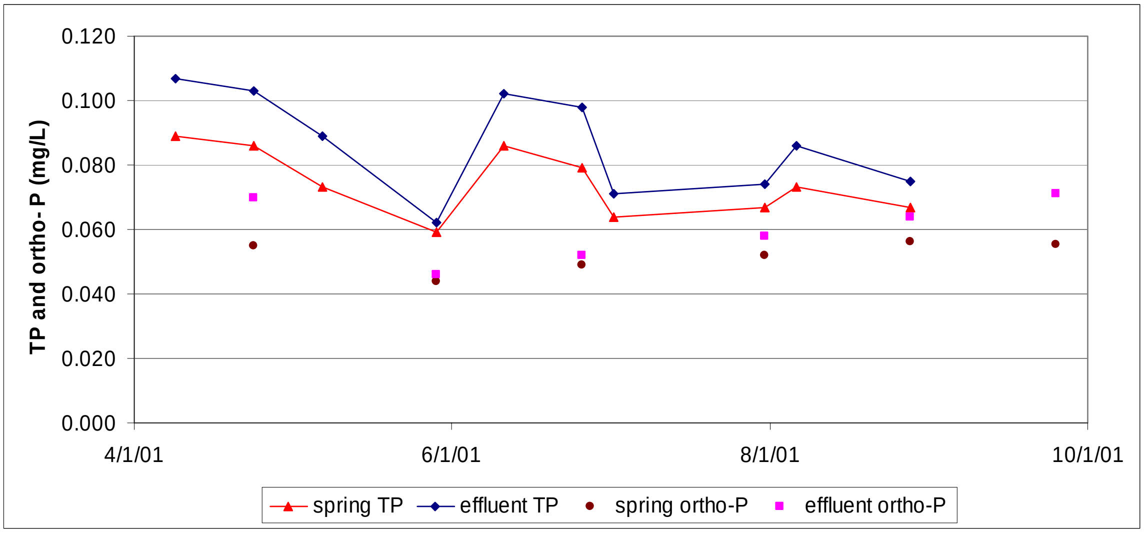

Figure 26. Comparison of spring and downstream (of effluent discharge) concentrations of TP and ortho-P at the Columbia Basin Hatchery.

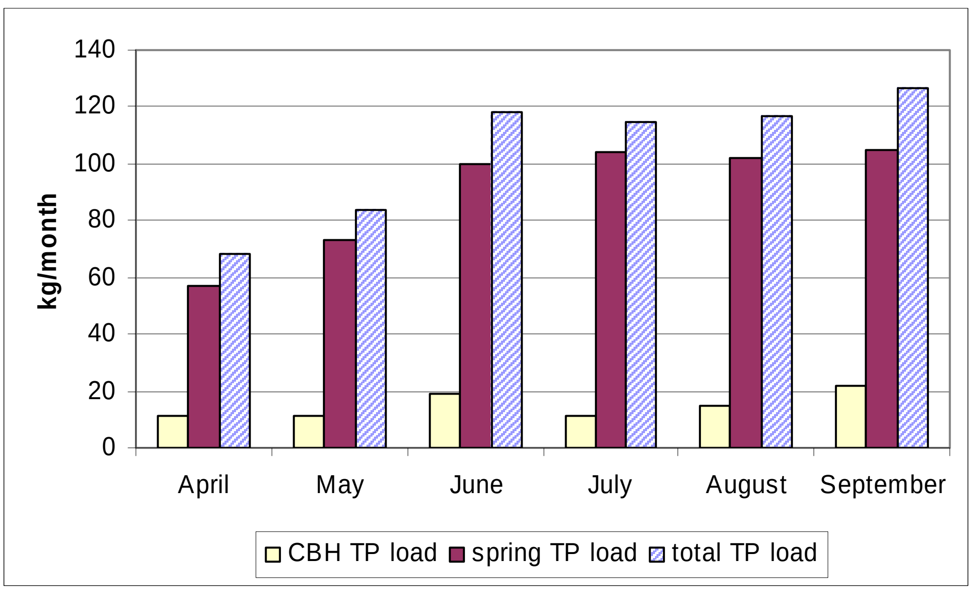

Figure 27. Comparison of apportioned TP loads from the Columbia Basin Hatchery and spring with the total TP load to Rocky Coulee Wasteway.

Phosphorus Loading to Moses Lake

Daily TP and ortho-P loads from Rocky Coulee Wasteway were developed from seasonal and flow-weighted regressions using continuous flow data and monthly to bi-weekly sampling data at station RC1. The TP load regression had a root mean squared error (RMSE) of 3.2 kg/day with a coefficient of variation of 20% (n= 20). The ortho-P load regression had a RMSE of 1.3 kg/day with a coefficient of variation of 34% (n= 20).

The TP concentration of the water that Rocky Coulee Wasteway discharged to Crab Creek depended on the ratio mix of Columbia River water to baseflow water (Columbia Basin Hatchery spring) as can be seen in Figure 28. When discharges were high from feed water (i.e., very high ratio of Columbia River Water to baseflow), the TP concentrations were generally low, dominated by low-nutrient Columbia River water.

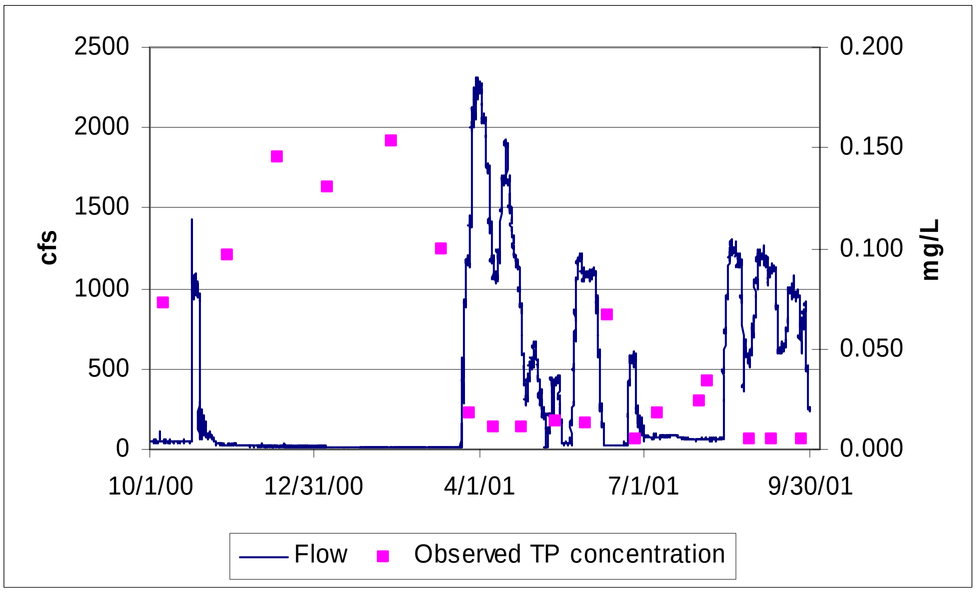

Figure 28. Comparison of observed TP concentrations in Rocky Coulee Wasteway (station RC1) with the continuous flow record of Rocky Coulee Wasteway.

A sampling site was selected upstream of any baseflow discharges into Rocky Coulee Wasteway (station RC2) to characterize the Columbia River water entering from the East Low Canal. At this station the March through September TP and the ortho-P concentrations were at or below their respective detection limits of 10 ug/L and 5 ug/L, with two exceptions for TP (15 ug/L in March and 13 ug/L in May). The Columbia River water provides a low-phosphorus concentration water supply to Moses Lake.

While the concentration of TP in the feed water was low, the quantity of water was substantial enough in some months to result in large loads of TP to Moses Lake, particularly in March, April, and May (Figure 29). This still resulted in a dilution because the higher TP concentration lake-water was displaced and washed out of the outlet. The calculated annual TP load from Rocky Coulee Wasteway to Moses Lake for the study period was 4,570 kg. From May to September, the contribution was 1,580 kg with 35% of that attributable to the Columbia Basin Hatchery and its spring (Figure 29). The proportion of ortho-P in the TP load of the feed water was relatively low (Figure 30).

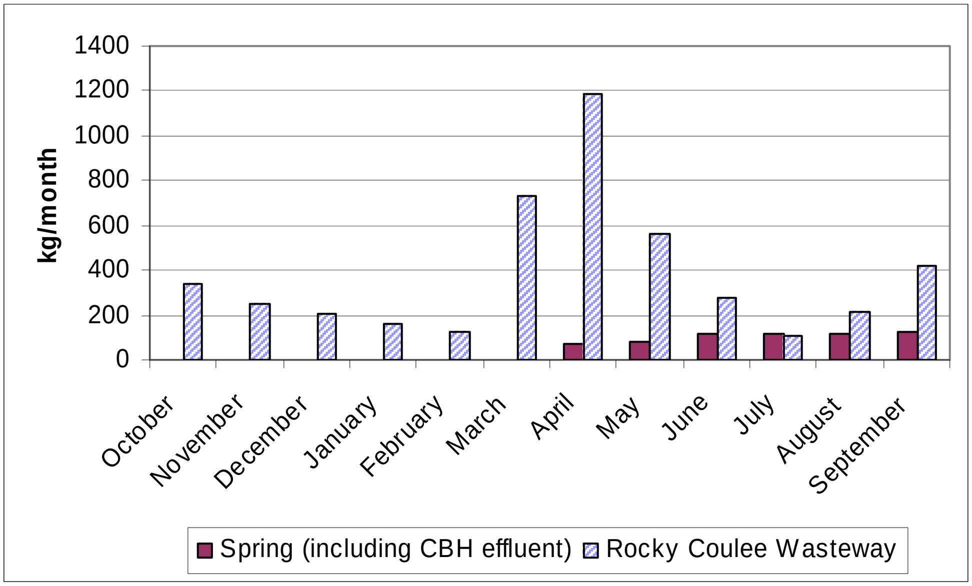

Figure 29. Comparison of the TP load attributable to the Columbia Basin Hatchery spring with TP loads from Rocky Coulee Wasteway during the 2000-01 study period. (October through March data not available for the spring.)

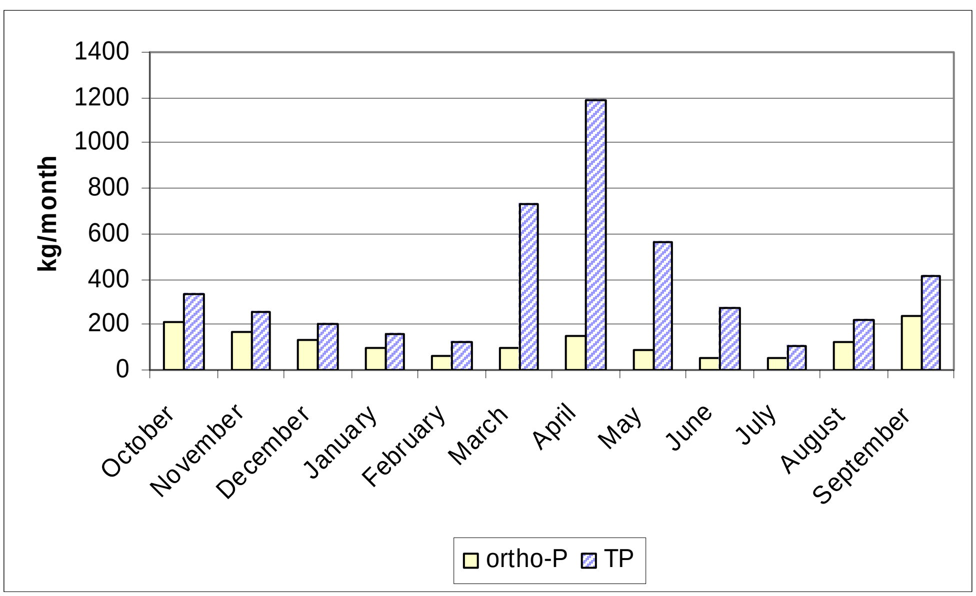

Figure 30. Comparison of ortho-P and TP loads in Rocky Coulee Wasteway for the 2000-01 study period.

4. Moses Lake

Historical Data Review

Moses Lake has been studied since the early 1960s. Carroll et al. (2000) provided a summary of some of the major studies and their conclusions. Readers are advised to reference the original studies reviewed by Carroll et al. (2000) for analytical details.

Hydrology

The hydrology of Moses Lake is complex even without anthropogenic (human-caused) influences. Moses Lake water level was unregulated until 1929 when the first dam was built on the outlet. Prior to 1929, the vagaries of climatic events most likely kept Moses Lake in a constant state of change. Drought conditions, flood events from Crab Creek, fluctuating groundwater discharges (to Rocky Ford Creek, Crab Creek, and the lake itself), and changing water levels (i.e., compromised or shifting sand dunes changing the elevation at the outlet) all would have affected the lake hydrology, as well as the water quality, prior to human-caused changes in the Columbia Basin.

Extensive lake regulation began with the arrival of the Columbia Basin Irrigation Project (CBIP) in the 1950s, including the addition of another dam in 1968, resulting in some predictable stability (i.e., regulated lake stage). Still, this stability is only achieved by compensating for or dampening the effects of the natural climatic cycles. For example, during the 2000-01 study period, Rocky Ford Creek and Crab Creek had below average discharges to Moses Lake and yet were supplemented by the fifth highest feed water addition through Rocky Coulee Wasteway. Enough Columbia River water was diverted through Moses Lake to completely fill the lake twice in 2001 (Figure 31).

As explained in Carroll et al. (2000), most of the feed water delivered to Moses Lake is routed downstream to Potholes Reservoir where it is used for irrigation in the southern part of the CBIP. Moses Lake is not a storage reservoir for the CBIP, like Potholes Reservoir, but is rather a part of the conveyance path for feed water. The U.S. Bureau of Reclamation (USBR) does not deliver water through Moses Lake unless there is a downstream irrigation need, though an agreement was made in 1977 to use Moses Lake as one of the more consistent feed routes. The USBR does have an agreement to maintain a summer lake stage in Moses Lake. Moses Lake and Potholes Reservoir are filled up in the early spring (from winter stage to summer stage) either by natural runoff or feed water, but usually a combination of the two. However, a large winter/spring runoff from Crab Creek can fill Moses Lake, as well as Potholes Reservoir, alleviating the need to have any feed water, as in 1984 when no feed water was diverted through the lake. The USBR does not consider the quality of the water used to maintain lake stage in Moses Lake and has not conveyed feed water (i.e., high quality Columbia River water) through Moses Lake for the sole purpose of enhancing water quality.

In summary, the hydrology of Moses Lake has been substantially altered by the CBIP, probably increasing its beneficial uses by maintaining a regulated lake stage and improving water quality with feed water additions.

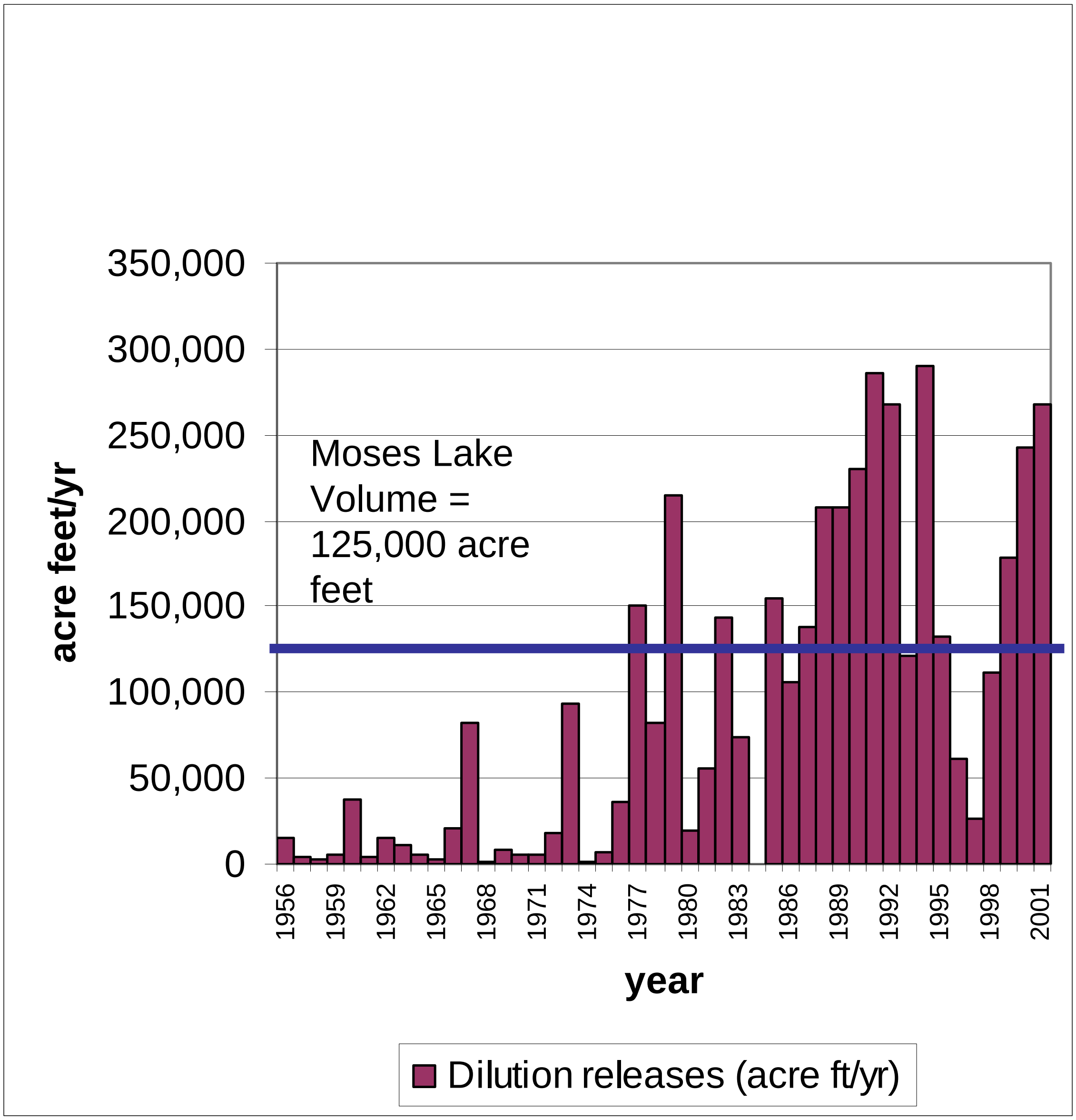

Figure 31. Annual feed water of Columbia River water through Moses Lake from 1956 to 2001, compared with the volume of Moses Lake.

2000-01 Water Budget

The water budget for the 2000-01 study period was developed for the water balance calibration for the CE-QUAL-W2 model (see below). All efforts were made to accurately measure all surface inflows and outflows. The rating curve for Rocky Ford Creek had a RMSE of 0.9 cfs (CV = 1.3%; n=5) for the whole range of flows. The rating curve for Rocky Coulee Wasteway had a RMSE of 34.9 cfs (CV = 5.5%; n=8) for the whole range of flows. Crab Creek was gaged and rated by the USGS.

The two outlets, both to Potholes Reservoir, have been historically difficult to measure. Not only has the extremely high velocity of the water passing through the gates been difficult to measure with velocity meters, but day-to-day and seasonal operational changes at the outlets create very different hydraulic regimes. The north outlet, operated by the Moses Lake Irrigation and Rehabilitation District, only had one gate open and in one position for the 2000-01 study period. The flow there was calculated as a function of head difference in Moses Lake and Potholes Reservoir (Evans and Larson, 2002).

The south outlet is the main outlet and is operated by the USBR. This structure has five radial arm gates and had never been rated. Flow measurements were made by Ecology and USBR in front of the south outlet structure using acoustic Doppler current profilers during various flow conditions (e.g., full pool, low pool, submerged backwater, unsubmerged backwater, restricted flow, and unrestricted flow). Continuous flow was then calibrated and modeled by Northwest Hydraulic Consultants using HEC-RAS version 3.0. The simulated flows had a RMSE of 71.7 cfs (CV = 7.8%; n=13) for the whole range of flows and operational regimes.

A water budget was calculated by subtracting inflows from outflows, while adjusting for a change in storage on a continuous basis (every hour) throughout the 2000-01 study period. In addition the water budget was fine-tuned using a water balance utility for CE-QUAL-W2 that matches simulated and actual water levels in the lake (see below). The resulting residual was averaged daily and applied as a net groundwater inflow if positive or as a net groundwater outflow if negative. The distribution of groundwater around the lake followed an analysis reported by Pitz (2003). Pitz also made estimates of groundwater flux ranges for different areas of Moses Lake. The 2001 residual applied as groundwater fell within the ranges reported by Pitz (Figure 32). Comparison of simulated chloride using the CE-QUAL-W2 model with field data (see below) confirmed this approximation of groundwater inflow to Moses Lake. CE-QUAL-W2 has an internal evaporation model that was used to estimate evaporative water loss.

Figure 33 presents the summary of inflow contributions for the hydrologic water year from October 2000 through September 2001. The inflows were dominated by feed water delivered through Rocky Coulee Wasteway. Direct groundwater inflows, Rocky Ford Creek, and Crab Creek each contributed 18%, 11%, and 5%, respectively.

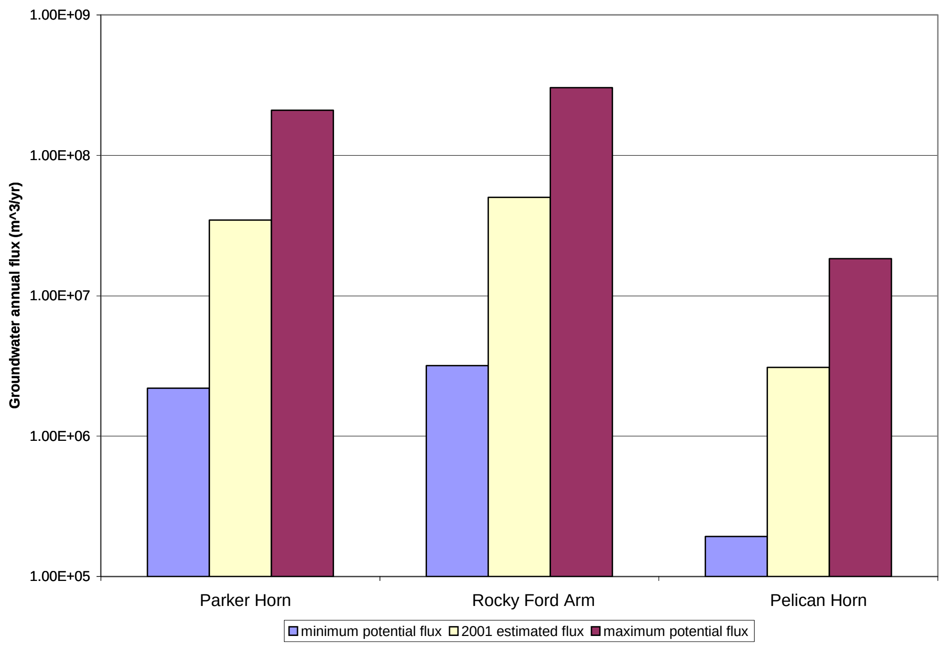

Figure 32. Comparison of 2001 groundwater flux with minimum and maximum potential fluxes reported by Pitz (2003).

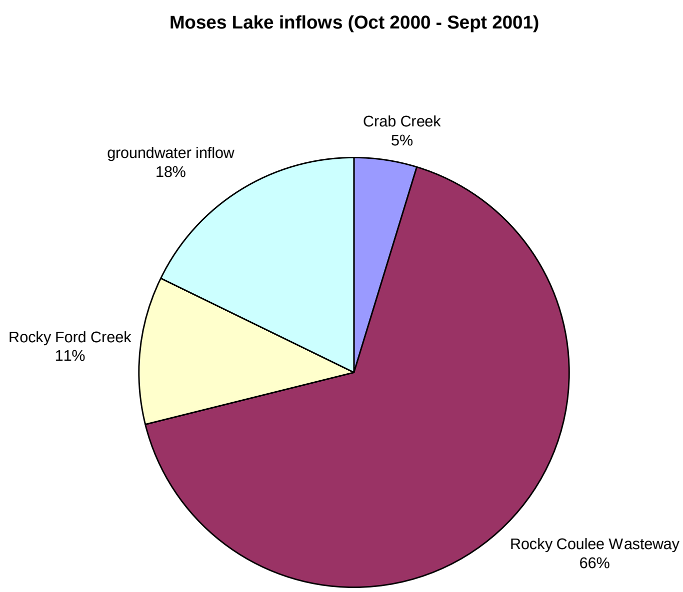

Figure 33. Summary of percent contribution from various inflows to total inflow to Moses Lake from October 2000 through September 2001 (the study period).

2000-01 Monitoring Results

By historical comparison, Moses Lake had greatly improved water quality during the 2000-01 study period. There were no significant blue-green algae blooms, and the average in-lake TP concentration for the whole lake was 38 ug/L from May through September. Obviously, the amount of feed water added to Moses Lake was substantial during 2001 and favorably impacted the water quality. The average monthly fraction of feed water in Parker Horn ranged from 29% in July to 65% in September. From May through September, the whole lake average fraction of feed water was 27%. Still, Moses Lake would have been considered a moderately productive eutrophic system in 2001.

Temperature, dissolved oxygen, and pH

Time and depth plots of temperature and dissolved oxygen (DO) for the two deep basins (Cascade and South basins; stations ML-2 and ML-3) are presented in Figures 34 and 35. A time and depth plot of pH for the Cascade basin is presented in Figure 36. Moses Lake is relatively shallow and polymictic which means it can mix or circulate several times per year. Beginning in April, weak thermal stratification occurred in Moses Lake because of uneven heating of the water column from solar radiation resulting in the development of water density gradients or layers, typically referred to as the epilimnion (upper water) and the hypolimnion (deeper water). Strong wind events periodically mixed the water column and disrupted the stratification, as in May and July. The strongest period stratification occurred in August. The entire water column was mixed by the end of September, due to wind mixing and waning solar radiation.

During stratification periods, DO was depleted in the isolated hypolimnion due to oxidation of organic materials. The resulting anoxia affected the solubility of phosphate in the sediments, causing a release of phosphate, as well as an increase in conductivity and other soluble constituents, to the overlying water. Generally, DO and pH levels in the euphotic zone were elevated (maximum supersaturated DO greater than 15 mg/L and pH greater than 9.0) during periods of high algal productivity and lower during periods of low algal productivity. There were substantial periods when much of the water column was below 8 mg/L.

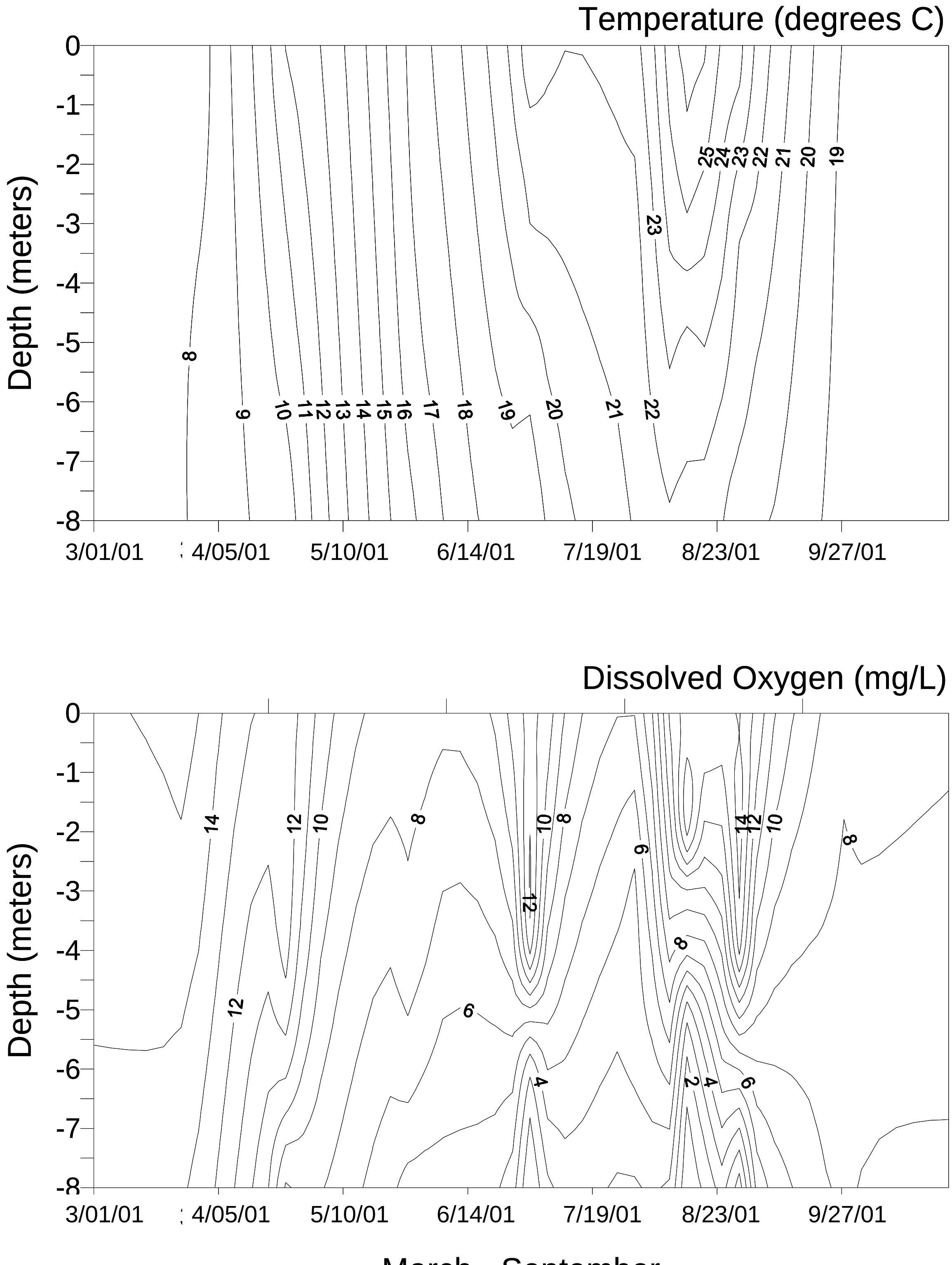

Figure 34. Temperature and dissolved oxygen isopleths based on field data collected in the Cascade basin of Moses Lake (station ML-2).

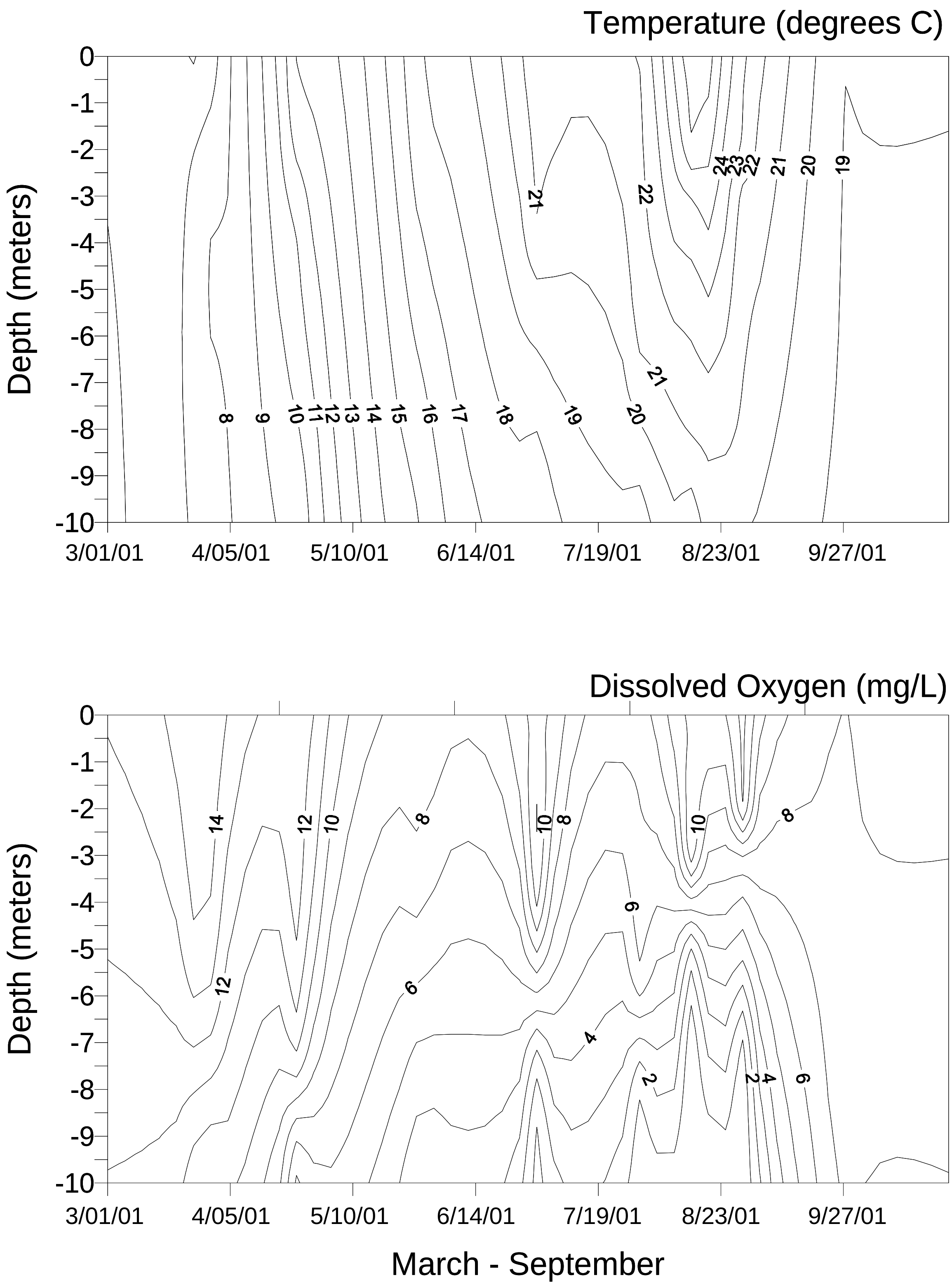

Figure 35. Temperature and dissolved oxygen isopleths based on field data collected in the South Basin of Moses Lake (station ML-3).

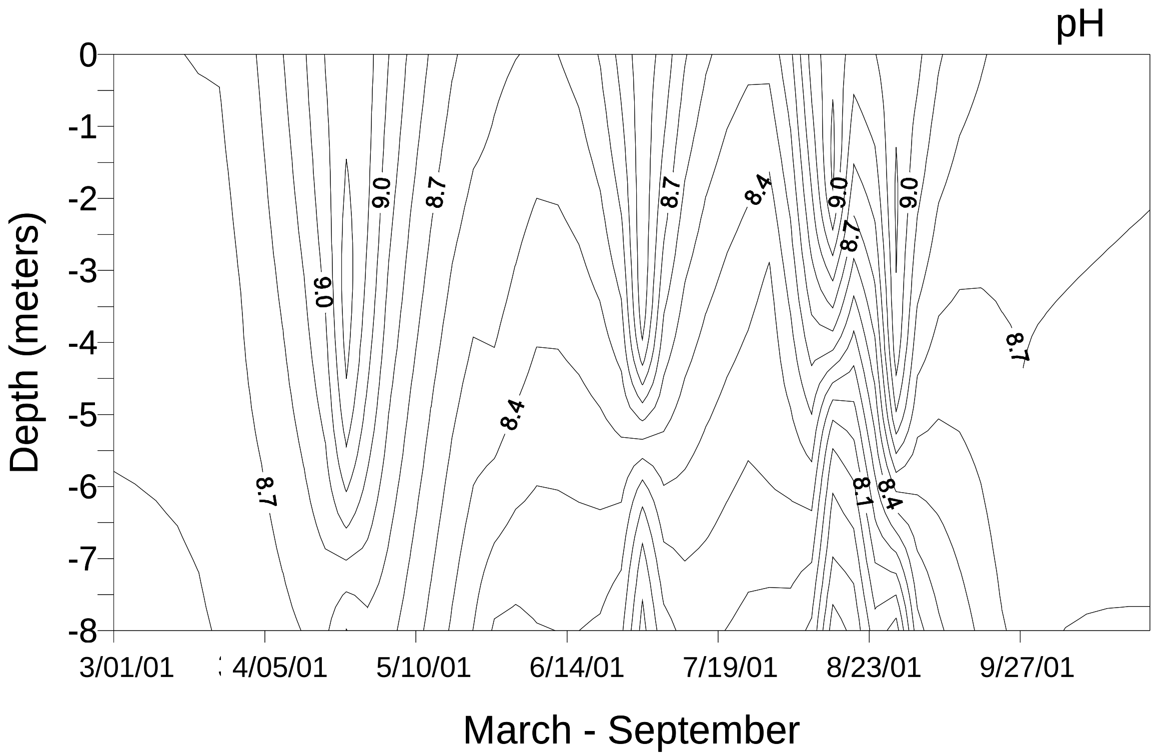

Figure 36. pH isopleths based on field data collected in the Cascade basin of Moses Lake (station ML-2).

Algae

Algal species densities and biomass were assessed March through September in Moses Lake. Densities and biovolumes of the major algal groups are presented as stacked plots in Figure 37. The first sampling in late March took place during a spring diatom bloom almost completely dominated by *Asterionella formosa*. This species is very common as an early dominator of spring algal blooms in mesotrophic and eutrophic lakes, when phosphorus is limiting and there is plentiful silica (Reynolds, 1984). By late April, the diatom bloom had experienced a successional change in species and was newly dominated by *Fragilaria pinnata* with sub-dominants, *Fr. crotenensis* and *Melosira ambigua*.

After the spring diatom bloom crashed in May, there was a transitional lull in algal productivity until late June when summer biomass began to build. The summer biomass predominantly consisted of diatoms and dinoflagellates, particularly *Melosira granulata*, *Fragilaria crotonensis*, *Rhodomonas minuta*, and *Cryptomonas erosa,* though a number of other algal groups including a few blue-greens were in the assemblage.

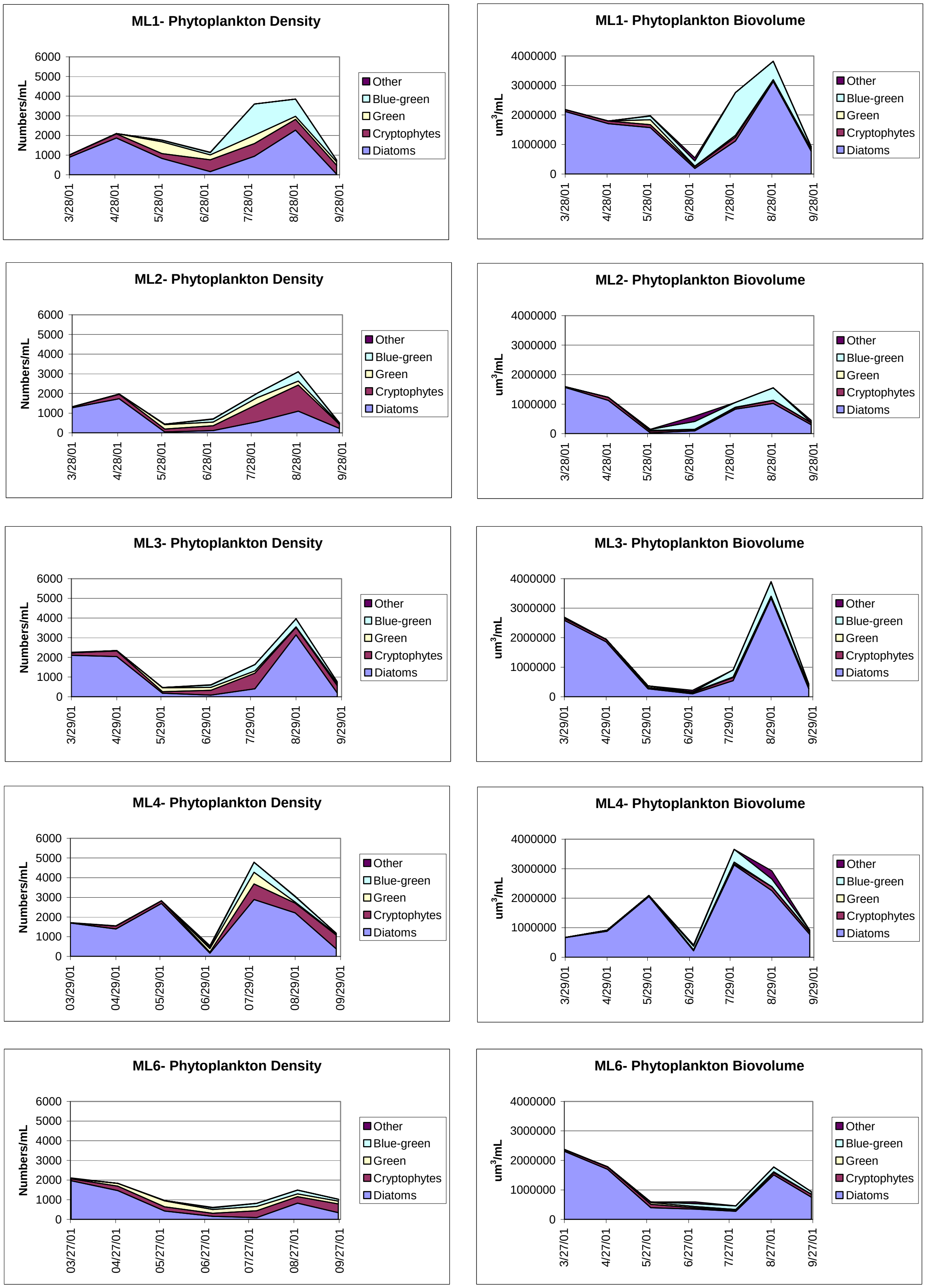

Figure 37. Densities and biovolumes of major algal groups in Moses Lake at all stations. Graphs are stacked line plots where algal groups are cumulatively stacked for each sampling date.

There was an exception in the upper part of Rocky Ford Arm (ML-1) with its rich nutrient replenishment from Rocky Ford Creek and relative isolation from the added feed water. This upper part of Moses Lake continued to experience high algal biomass through May with the biomass dominated by the diatom, *Fragilaria crotenensis,* and the green algae, *Oocystis pusilla*. This succession led to a blue-green algal bloom in July and August composed of *Aphanizomenon flos-aquae*; however, a substantial diatom biomass composed of *Melosira granulata* developed in August as well.

For the most part, though, during the 2000-01 study period, Moses Lake had the seasonal algal succession typical of a less productive, eutrophic lake system. The spring diatom bloom has always been common to Moses Lake, but the summer algal biomass in Moses Lake varies in relation to the nutrient supply. Historically, as a highly eutrophic lake system, Moses Lake has been dominated in the summer by nitrogen-fixing blue-green algae blooms consisting of *Aphanizomenon* and *Microcystis* species, even since dilution began in 1977 (Welch et al., 1989). The development of a summer diatom succession in 2001 was perhaps due to the timing and exceptional quantity of low-nutrient feed water added to Moses Lake. While silica concentrations can be limiting for summer diatom development, dissolved silica concentrations were still 5 to 10 times higher than limiting levels (<0.5 mg/L) in Moses Lake at the end of the 2001 growing season, discounting silica as a limiting resource.

Lake Water Quality Modeling

Purpose and Scope

A water quality model of Moses Lake was used to better understand the fate and transport of TP in the lake. Using the model as a diagnostic tool, the various physical, biological, and chemical processes that affect the fate and transport of TP were simulated. The model was used to assess the capacity of Moses Lake to assimilate TP with respect to maintaining the proposed in-lake TP criterion of 50 ug/L during a worst-case, little dilution year. The model then was used as a tool to evaluate various management alternatives in order to develop a phosphorus allocation plan based on meeting the in-lake TP criterion.

Model Description

CE-QUAL-W2 simulates the hydrodynamics, water temperature, and water quality of a water body in two dimensions. The model simulates longitudinal and depth dimensions while averaging along the lateral dimension (width of the water body). Therefore, CE-QUAL-W2 is best applied to water bodies with distinct variations in length and depth but with few distinctions in width. Moses Lake is an ideal application for CE-QUAL-W2 because of its dendritic morphology (long and narrow branches). CE-QUAL-W2 is a dynamic model, and the fundamental fate and transport of TP in Moses Lake is dependent on dynamic conditions.

Numerical algorithms within CE-QUAL-W2 dictate how the sources, sinks, and transport of water, heat, and constituents are simulated. A description of the model's conceptual framework and numerical expressions is available in the user manual by Cole and Wells (2002) and at the following website: www.ce.pdx.edu/w2/.

Model Setup

CE-QUAL-W2 was calibrated to water quality in Moses Lake for February 19 through September 30, 2001 (julian day 415 through 630 in the model). CE-QUAL-W2 is a complex water quality model and requires many types of boundary, calibration, and meteorological data. The data used to set up the Moses Lake application were collected by several organizations (Table 11).

Table 11. Sources of boundary, calibration, and meteorological data used in the Moses Lake CE-QUAL-W2 model.

Data Type	Data Source
Bathymetry	Sylvester (1964), Ecology
Discharge and withdrawal rates	USGS, USBR, Ecology, Moses Lake Irrigation and Rehabilitation District
Water elevations of Moses Lake and Potholes Reservoir	USGS, USBR
Water Temperatures	Ecology, USBR
Meteorology	National Climactic Data Center (Moses Lake airport), Hanford Meteorological Station
2000-01 water quality data	Ecology
Historical water quality data	Ecology, Patmont (1980), Welch et al. (1989), Bain (1998)

Moses Lake Bathymetry and Model Grid

The model grid of Moses Lake was developed from a bathymetric map published by Sylvester and Olglesby (1964). The bathymetric data were field-checked by Ecology in 2001. The bathymetry was found to be unchanged in most of the lake, except for Rocky Ford Arm and the Cascade basin (station ML-2). The Rocky Ford Arm was shallower than the old data by up to one foot. The Cascade basin lacked the deepest section of the basin present in the 1960s. In fact, in no place did the depth exceed 9.0 meters (>30 ft) in the Cascade basin. Sediment focusing may explain the increased accumulation of sediments in the Cascade basin. The South Basin (station ML-3) morphology had not changed since the 1960s. The narrow and shallow causeway under Highway 90 between the two main basins may act as a dike to the passage of settling solids originating from the tributaries or up-lake to the South Basin.

The corrected bathymetric map was scanned and brought into Arcview 3.2. With Image Analyst extension, the image was geo-referenced and rectified to existing ortho-photo coverage of the lake. The resulting image was made into a polygonal shape file and then sliced into 74 model segments (Figure 38), developing a table of segment area-to-depth measurements for use as a bathymetric input file for CE-QUAL-W2. There was a maximum of 12 depth layers for each segment. Each layer was approximately one meter in depth.

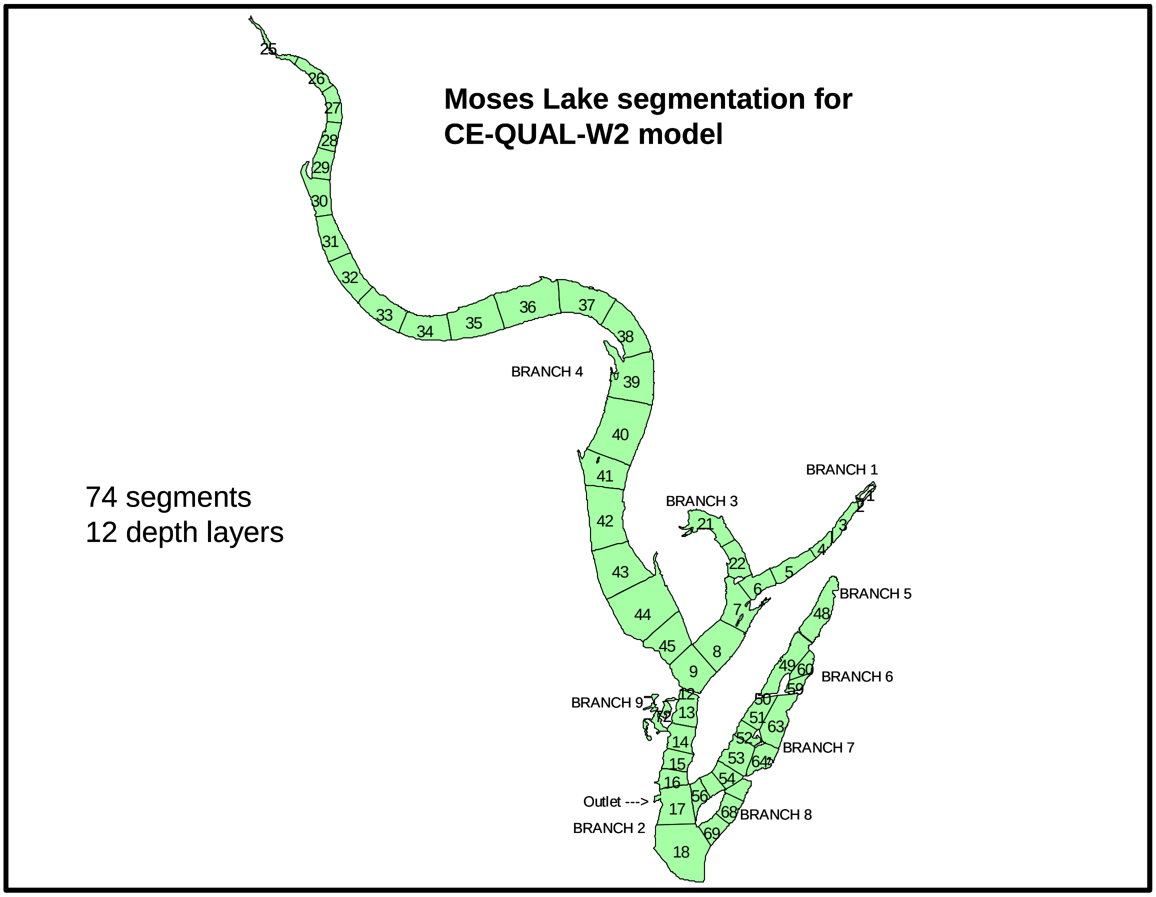

Figure 38. Model segments of Moses Lake showing segments and branches used in CE-QUAL-W2.

Volumetric calculation of the segments also was done following the methodology outlined by Wetzel (1983). Figure 39 shows a very favorable comparative plot of volume-to-elevation curve for Moses Lake developed by volumetric calculation and a volume-to-elevation curve developed from CE-QUAL-W2 bathymetric output. It is essential to accurately represent the geometry of Moses Lake to accurately model the hydrodynamic movement of water through the lake.

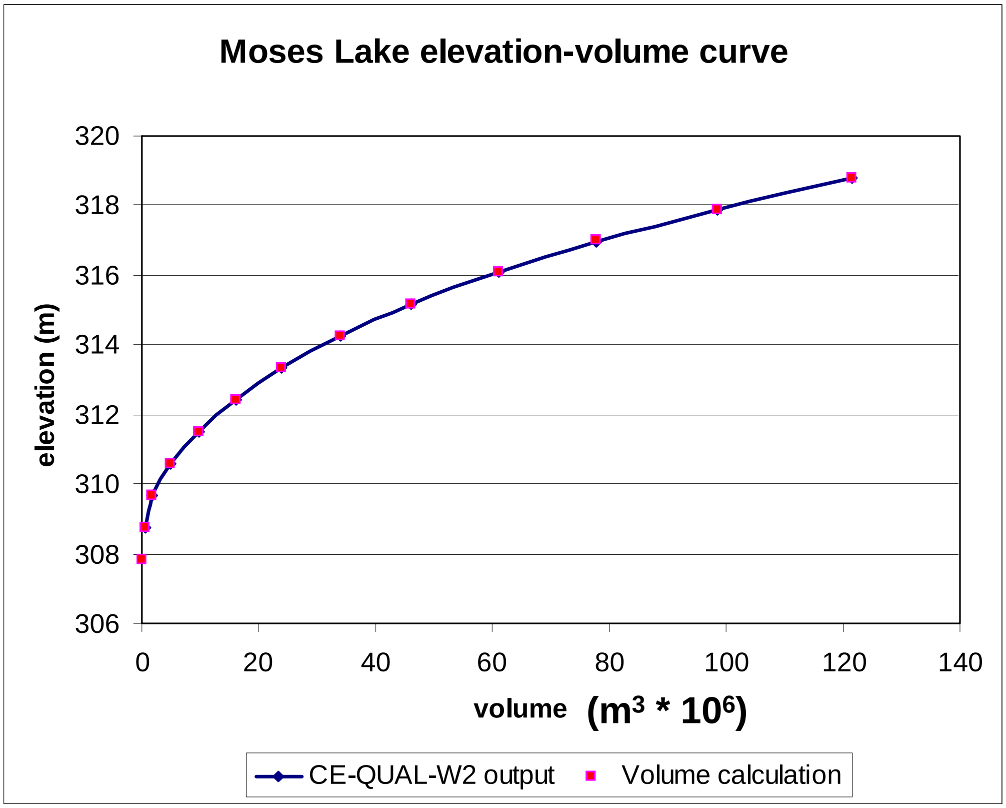

Figure 39. Moses Lake volume-to-elevation curves as represented by CE-QUAL-W2 and as an independent volume calculation.

Water Balance

All known major surface inflows and outflows to Moses Lake were measured for the 2000-01 study period. The initial water balance was based on the difference of continuous discharge measurements of the outflows (north and south outlets) and the inflows (Rocky Ford Creek, Crab Creek, and Rocky Coulee Wasteway), taking into account the change in storage of the lake (Moses Lake stage recorded by USGS). From this water budget, a residual was calculated that consisted of ungaged inflows and outflows (e.g., net groundwater inflow/outflow and irrigation withdrawal) as well as error in the measurements of gaged surface inputs and outputs (e.g., error in rating curves and error in volumetric displacement in the Moses Lake bathymetry). Additionally, CE-QUAL-W2 incorporates a water balance utility that fine tunes the residual by comparing the simulated Moses Lake stage with the USGS stage during each specified time-step of a model simulation and creating a correction file of hourly residual flows. Figure 40 shows a favorable comparison of the USGS water level data to model results for the 2000-01 study period.

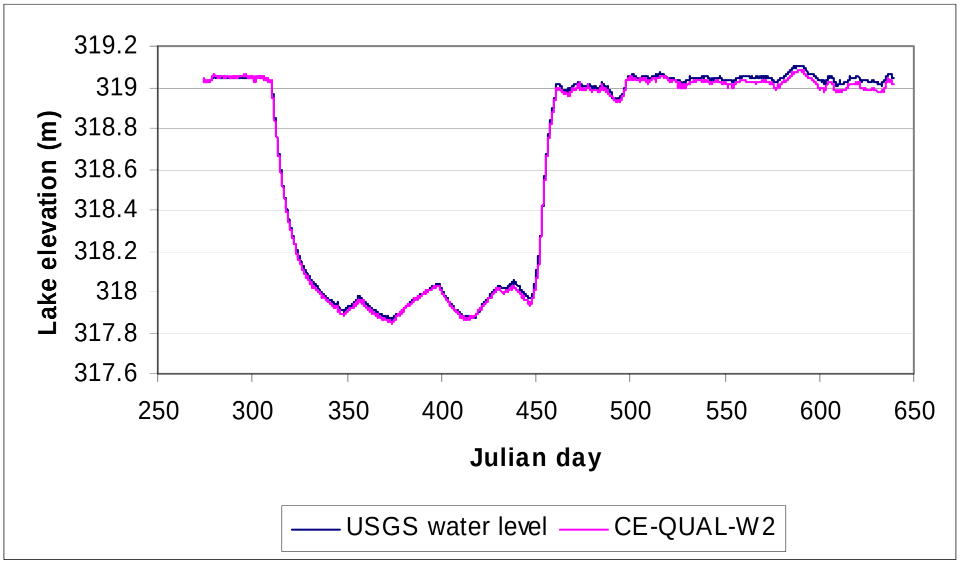

Figure 40. Moses Lake CE-QUAL-W2 water level results compared to Moses Lake USGS water level data from October 2000 to September 2001.

Water Quality Boundary Conditions

Water quality boundary conditions were assessed for each of the hydrologic inflows/outflows to Moses Lake. These included Rocky Ford Creek, Crab Creek, and Rocky Coulee Wasteway (described in above sections) as well as groundwater inputs and lake outlets. Groundwater water quality was assessed by samples drawn from mini-piezometers driven into the lake sediments near the shore (Pitz, 2003). The south outlet of Moses Lake was sampled routinely throughout the study period to measure the outflow of constituents.

Initial Conditions

The initial conditions of Moses Lake for the calibration year were determined by Ecology's first intensive lake assessment in March 2001. Prior sampling was not possible because of low lake levels and ice covering. The lake was being filled at the time of the March sampling with feed water; however, this only affected a small portion of the lake at the time. The rest of the lake was well mixed, and a single initial value for each parameter was used to characterize the initial conditions. The initial condition of some parameters in the upper part of the Rocky Ford Arm may have been under-estimated initially; however, the initial values have less importance as the lake equilibrates quickly with the relative large hydrologic input from the boundaries.

Model Water Quality Calibration

One lake survey per month provided the measured field data for calibration. Calibration was accomplished by adjustment of model coefficients during successive or iterative model runs, until optimum goodness of fit between the model results and observed field values was achieved. Goodness of fit was measured using the root mean squared error (RMSE), a commonly used measure of model variability (Reckhow et al., 1986). The RMSE is defined as the mean of the squared difference between the measured and simulated values. It is similar to a standard deviation of the error. All model coefficients were adjusted within acceptable ranges as described by Cole and Wells (2002), Chapra (1997), EPA (1985), and EPA (1987).

Water Temperature

Water temperature affects the rates of chemical and biological reactions as well as determines the solubility of oxygen in water. The heat budget which determines the water temperature is based on physical processes which can be accurately modeled by CE-QUAL-W2. The water temperatures in Moses Lake were accurately simulated with an overall RMSE of 0.67 ºC (CV = 4%; n = 263). Figures 41 to 46 present a comparison of simulated and measured water temperatures at each sampling station.

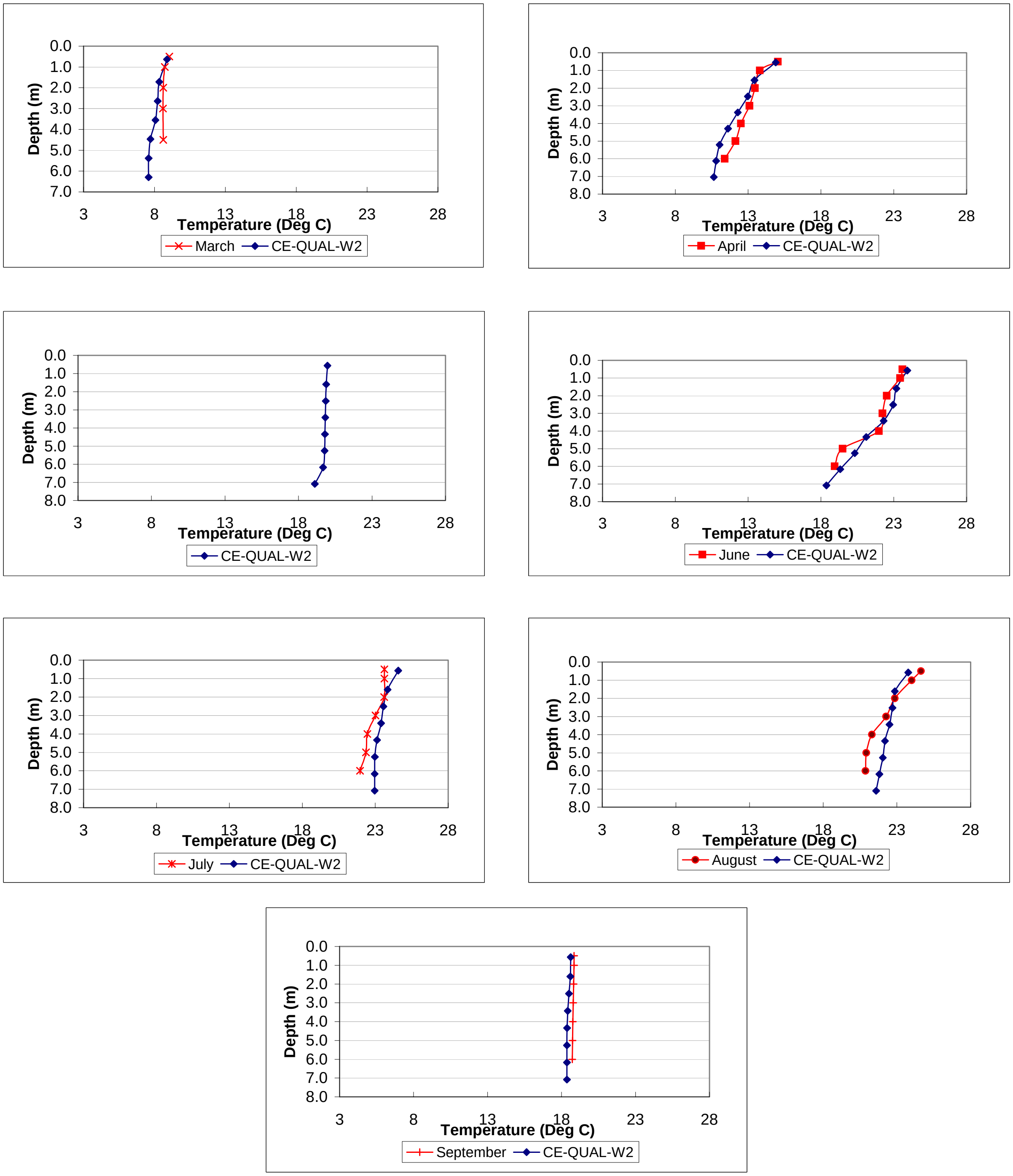

Figure 41. Comparison of model-predicted vertical temperature profiles with 2001 data for Moses Lake station ML-1.

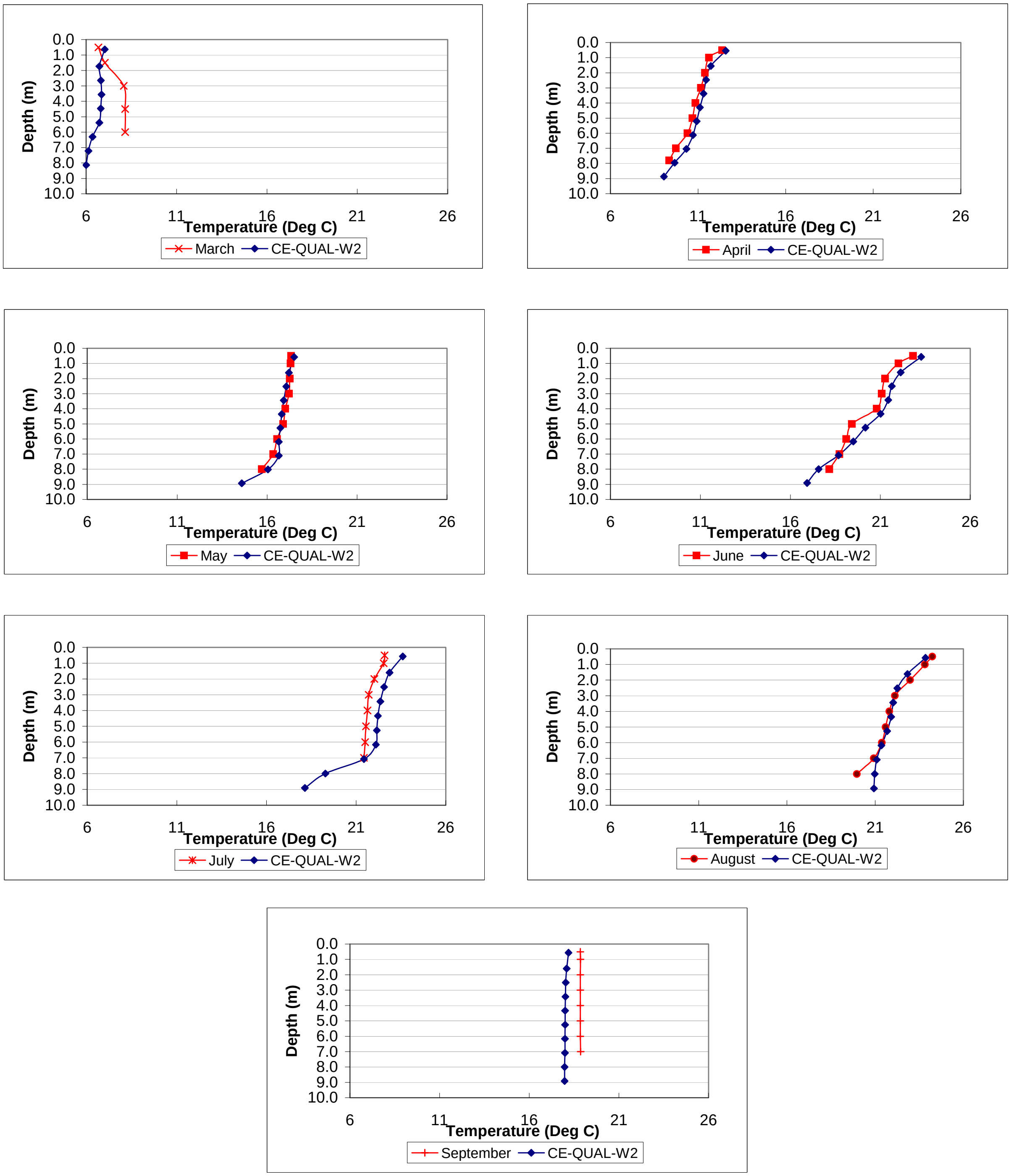

Figure 42. Comparison of model-predicted vertical temperature profiles with 2001 data for Moses Lake station ML-2.

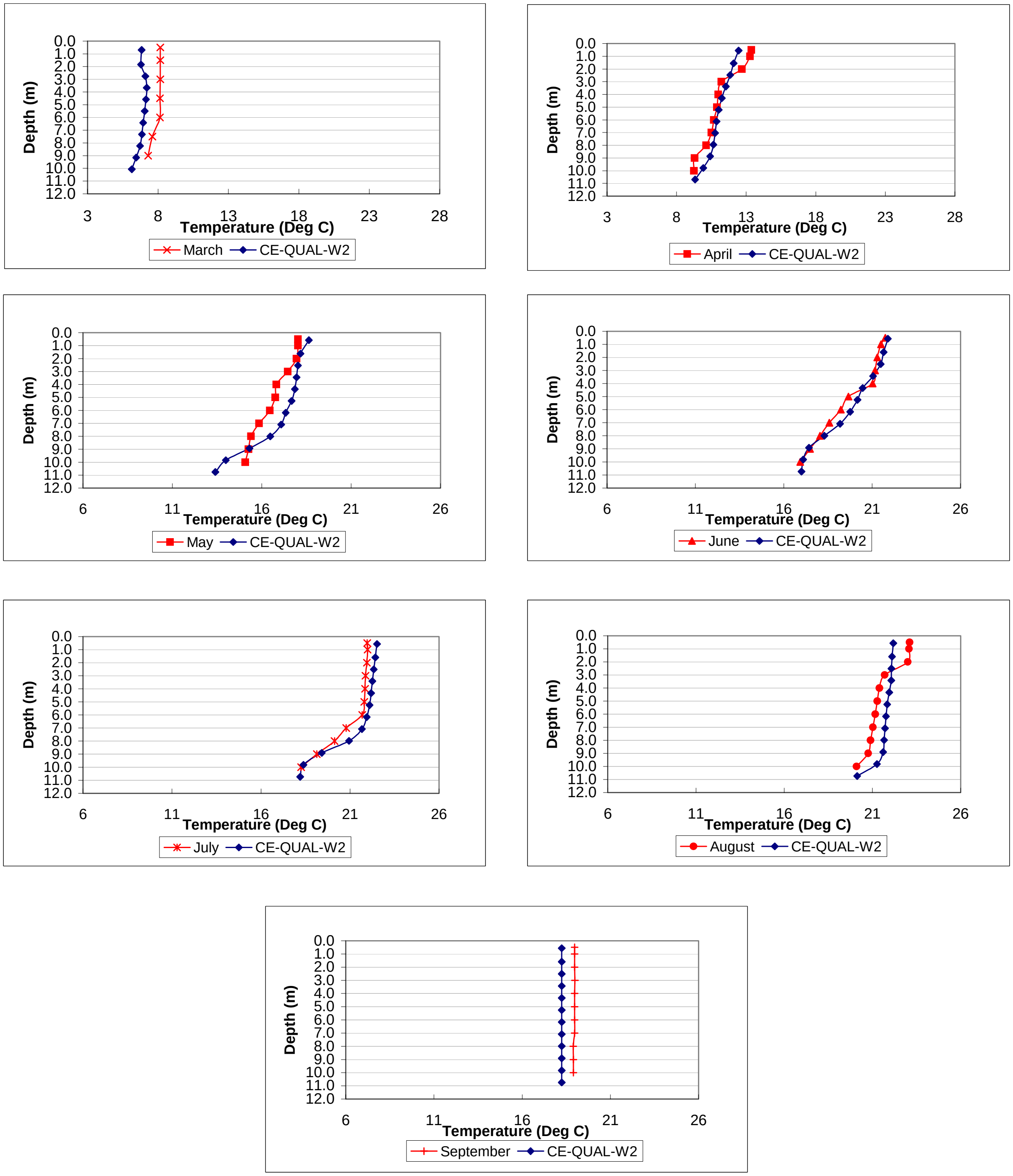

Figure 43. Comparison of model-predicted vertical temperature profiles with 2001 data for Moses Lake station ML-3.

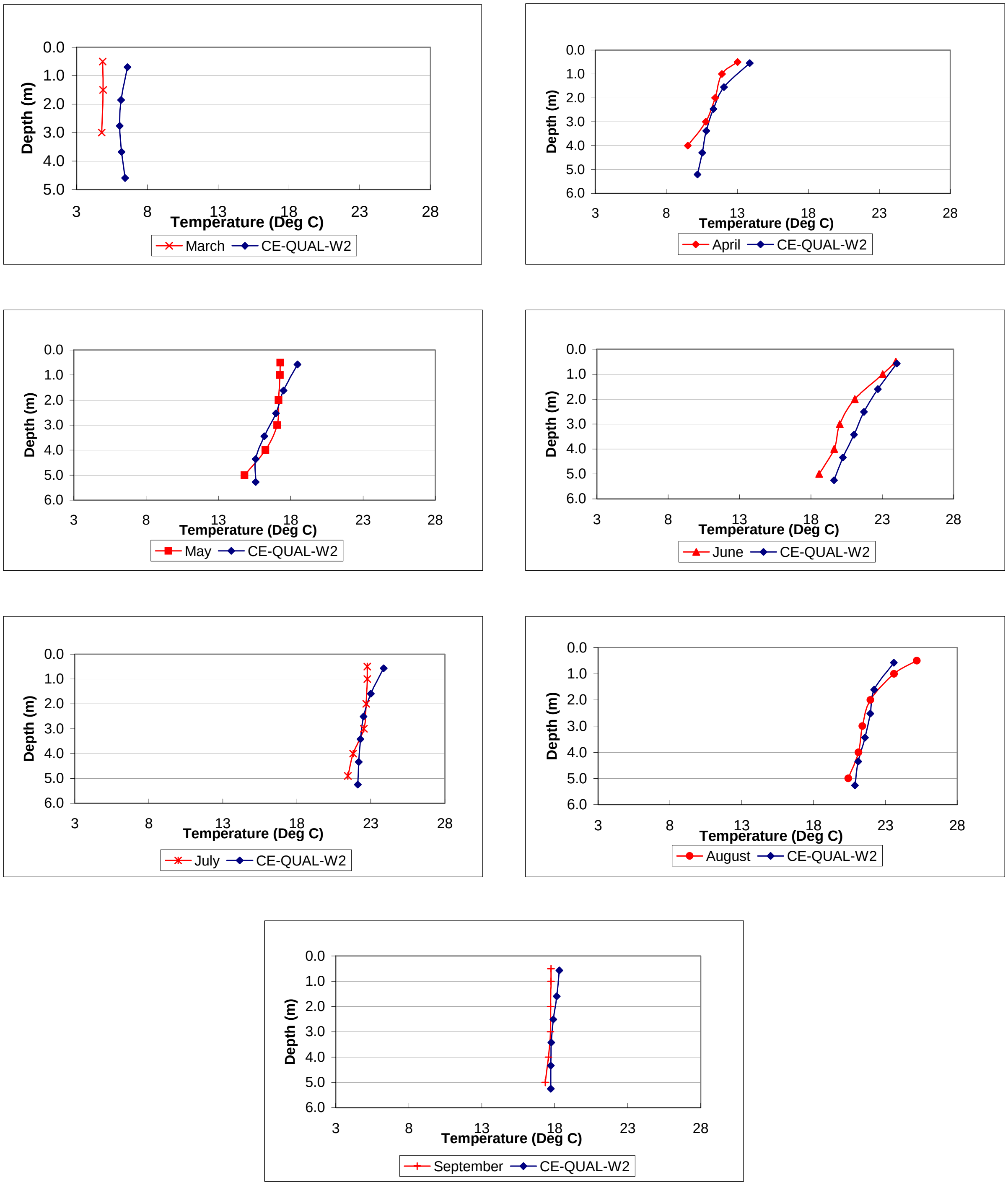

Figure 44. Comparison of model-predicted vertical temperature profiles with 2001 data for Moses Lake station ML-4.

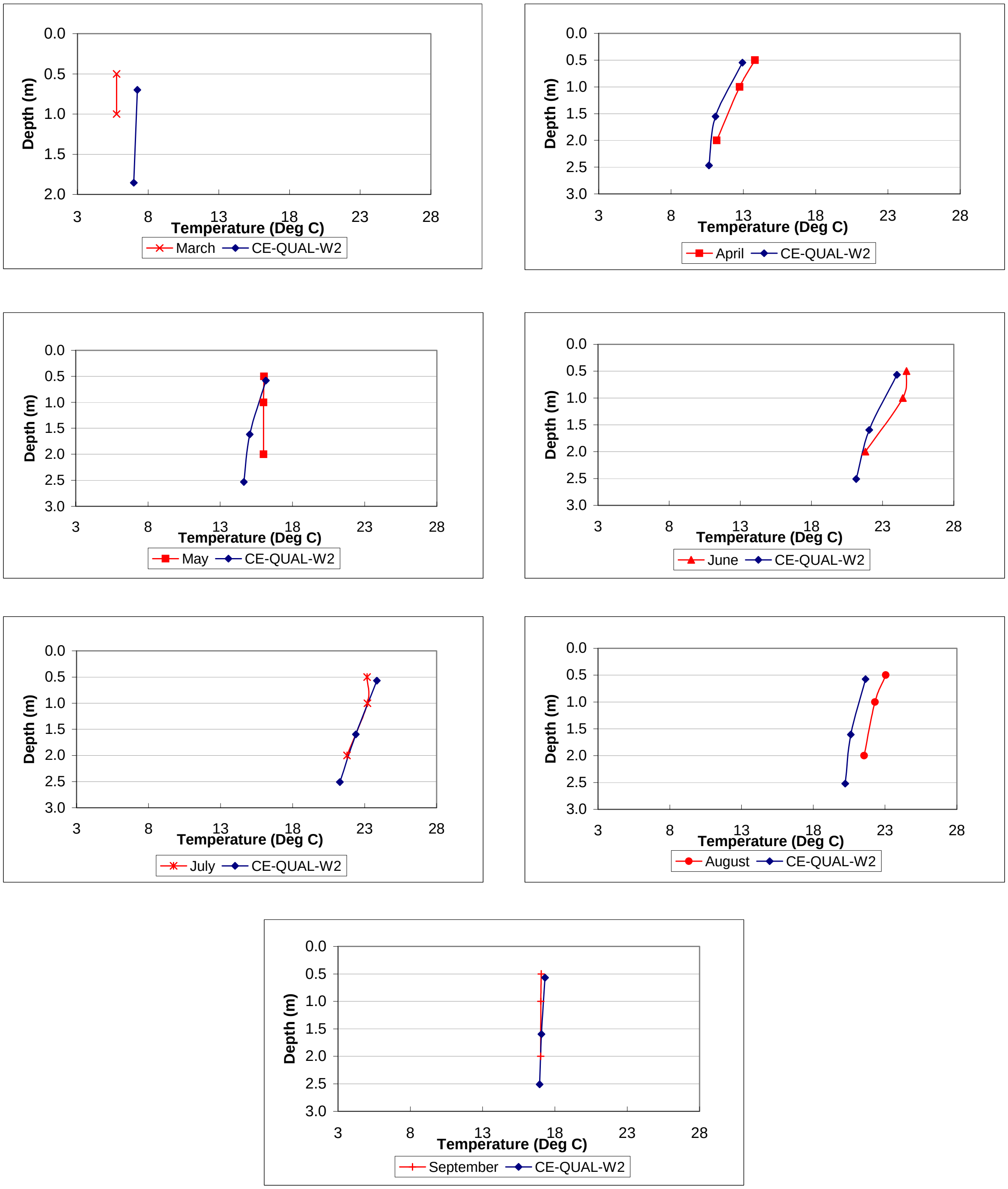

Figure 45. Comparison of model-predicted vertical temperature profiles with 2001 data for Moses Lake station ML-5.

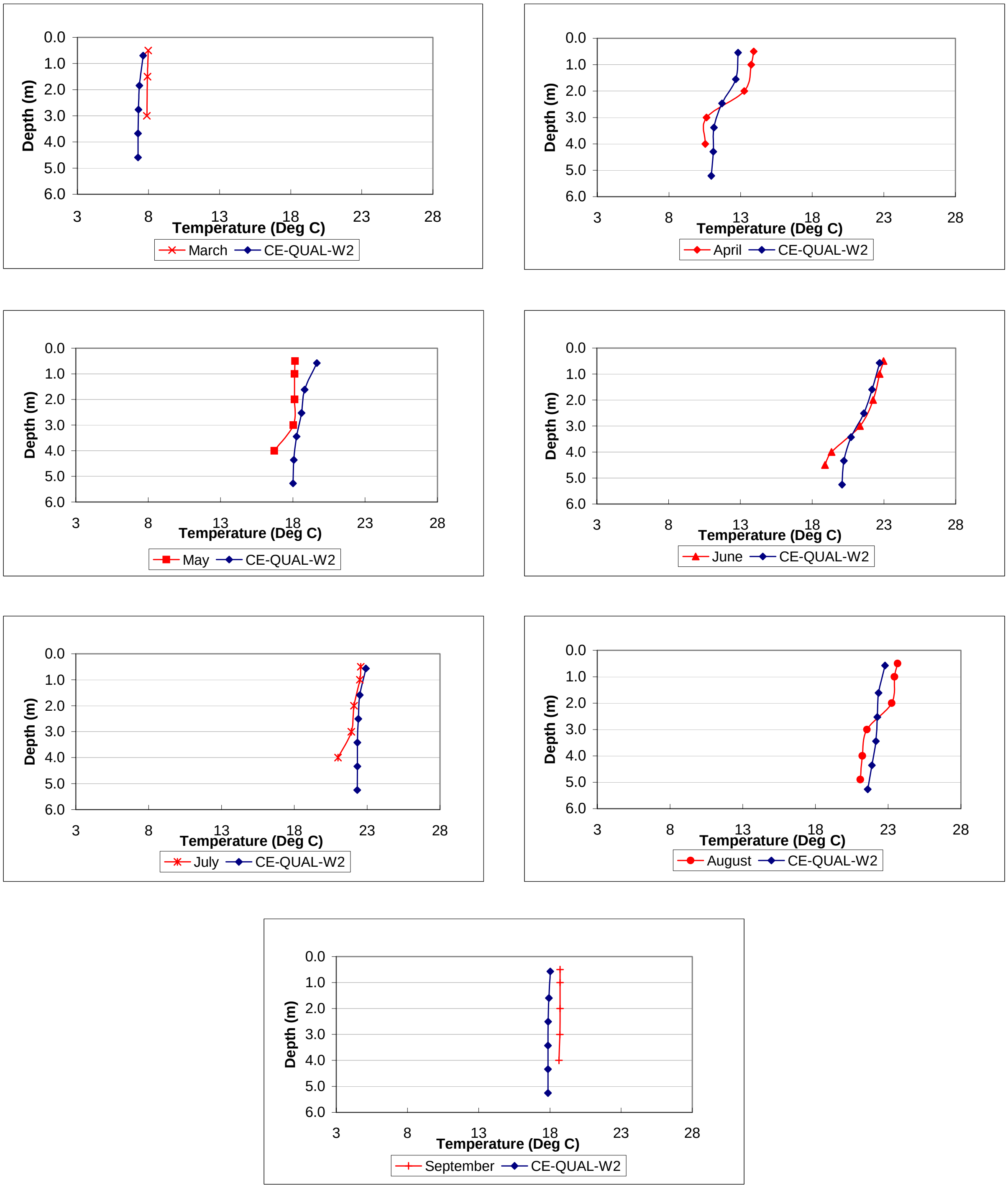

Figure 46. Comparison of model-predicted vertical temperature profiles with 2001 data for Moses Lake station ML-6.

Conservative Tracer: chloride

Chloride was simulated in CE-QUAL-W2 as a conservative tracer. A conservative tracer provides a good diagnostic check to see if the model is missing any substantial sources or sinks of water. This is particularly useful when the incoming sink or source concentration is greatly different (higher or lower) from the ambient concentration, as is often the case for groundwater. Geometric mean chloride concentrations of inflowing groundwater varied from 7.8 mg/L in Rocky Ford Arm to 26.2 mg/L in Pelican Horn for 2001. Conversely, the average chloride concentration of feed water (Columbia River water) was approximately 1.0 mg/L. Simulating the mixing of these different strengths of chloride is also a good test of the accuracy of the CE-QUAL-W2 transport processes of advection and dispersion.

Figures 47 to 52 show a comparison of measured and simulated chloride concentrations for Moses Lake. The model showed good agreement with an overall RMSE of 0.57 mg/L (CV = 14%; n = 108). In 2001, conductivity which has often been used in Moses Lake as a conservative tracer was not found to be conservative. A substantial source of conductivity associated with anoxic sediment release of ions to the overlying water caused the CE-QUAL-W2 model to consistently under-predict conductivity, particularly when this higher conductivity water was entrained to upper waters during mixing events. Based on the 2001 data, conductivity is not a suitable conservative tracer for Moses Lake.

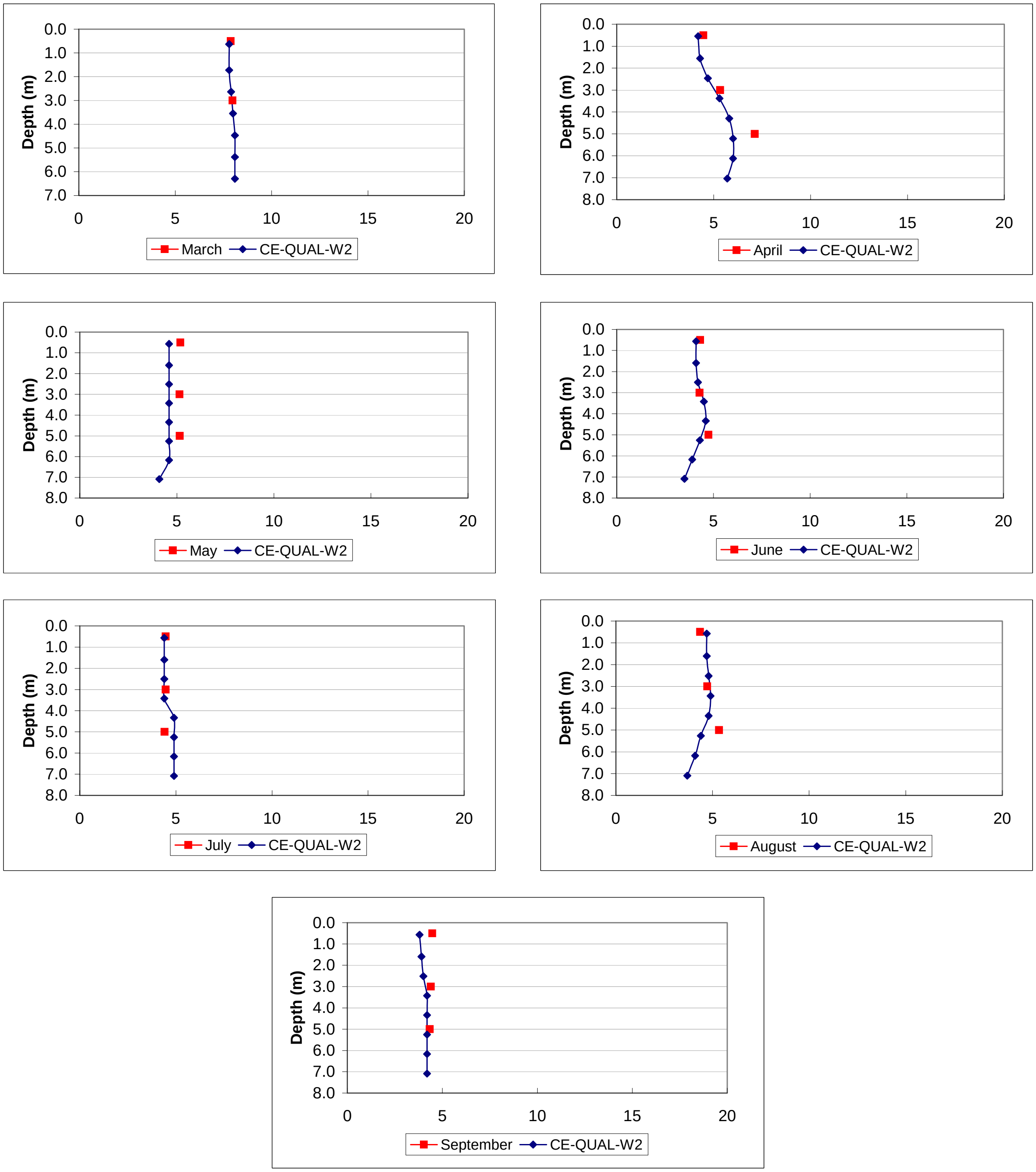

Figure 47. Comparison of model-predicted vertical chloride profiles with 2001 data (mg/L) for Moses Lake station ML-1.

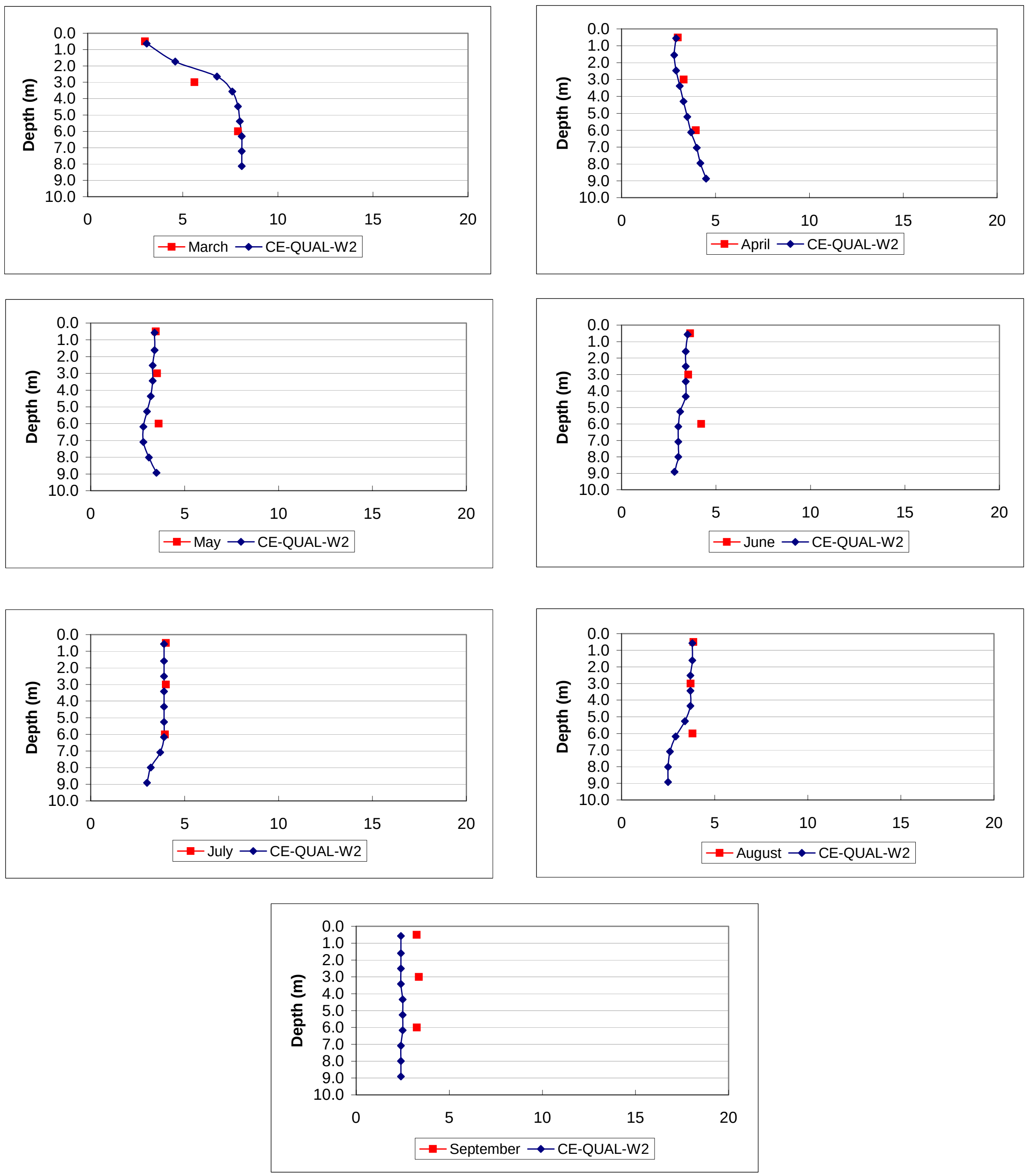

Figure 48. Comparison of model-predicted vertical chloride profiles with 2001 data (mg/L) for Moses Lake station ML-2.

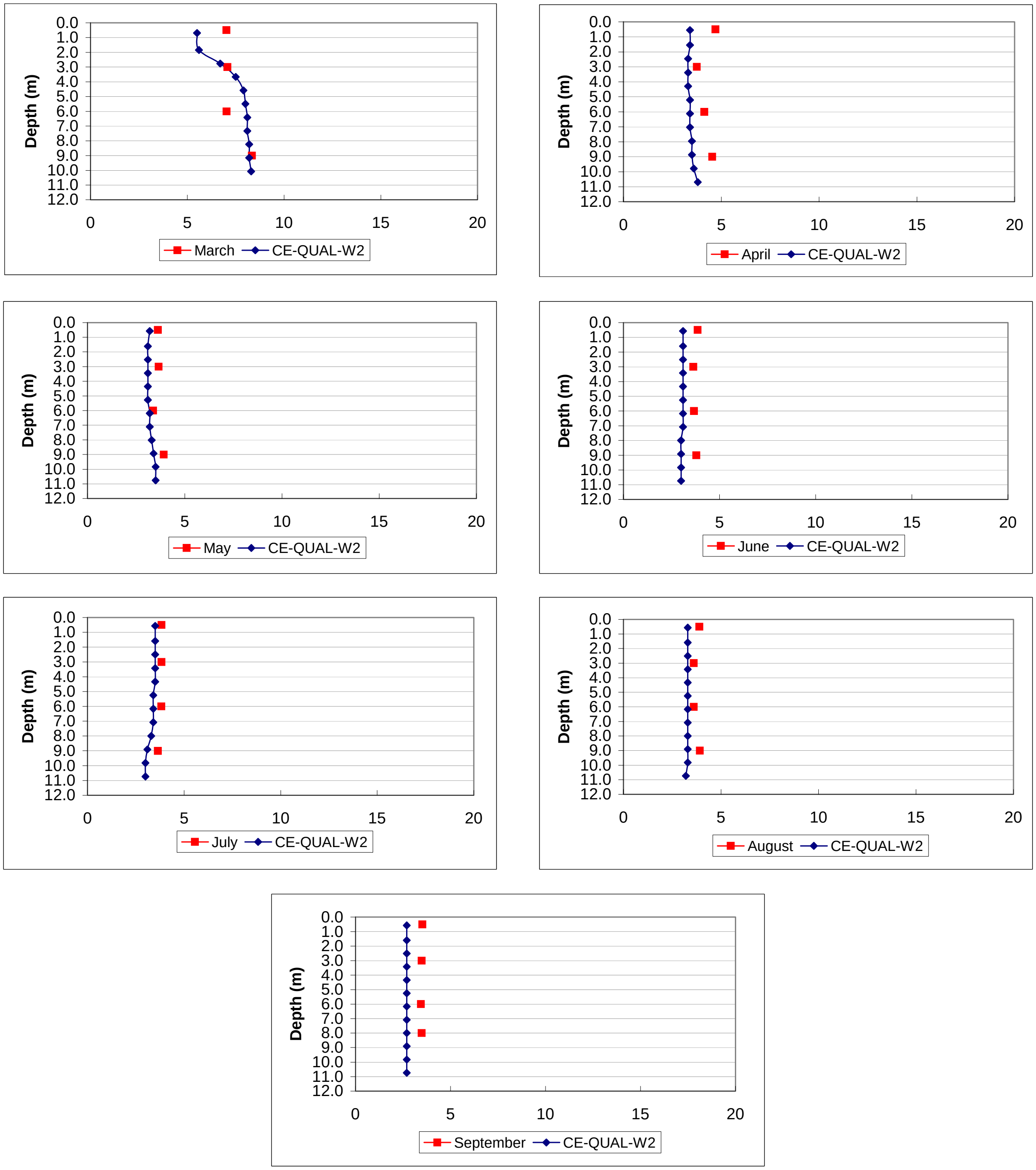

Figure 49. Comparison of model-predicted vertical chloride profiles with 2001 data (mg/L) for Moses Lake station ML-3.

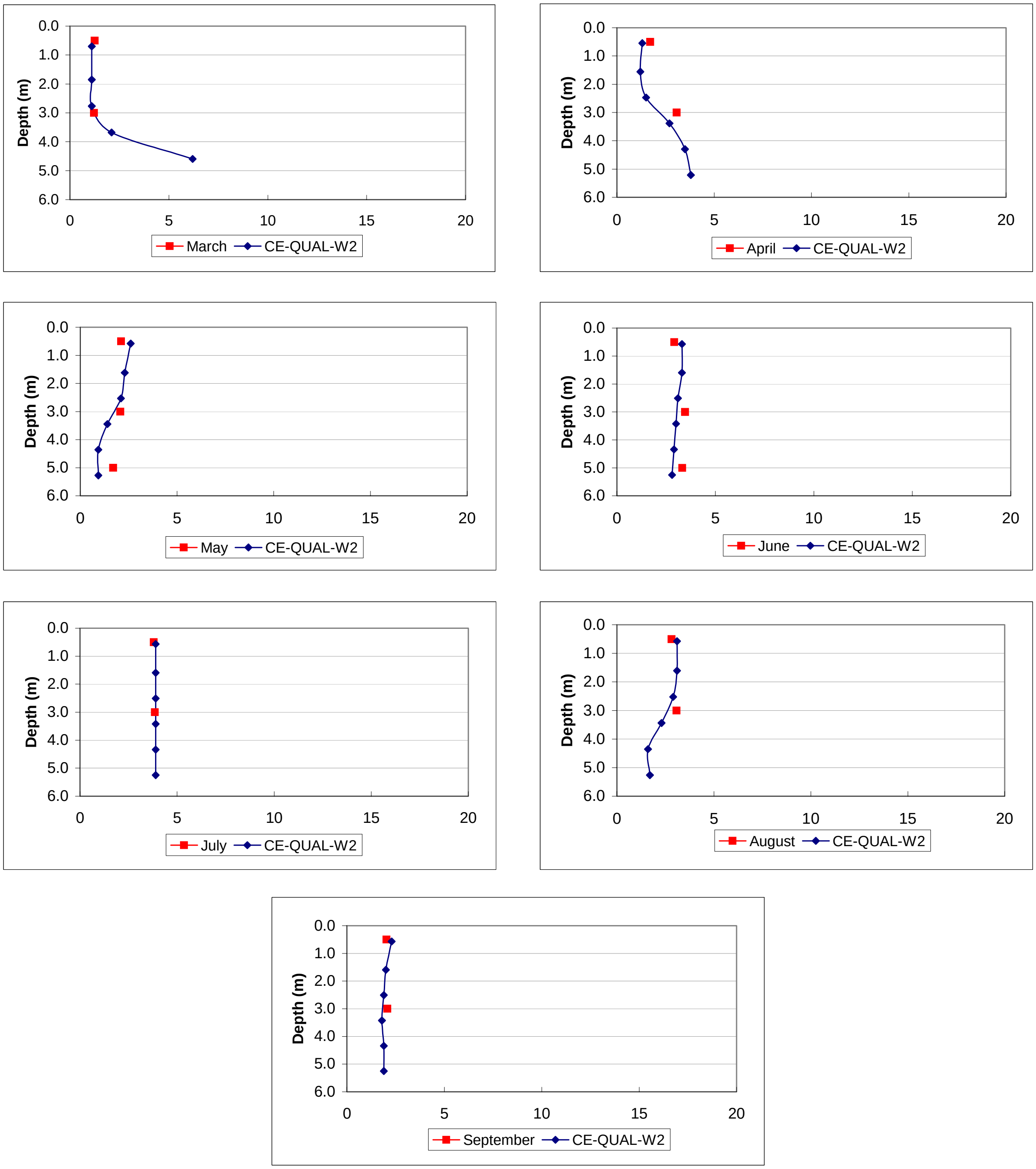

Figure 50. Comparison of model-predicted vertical chloride profiles with 2001 data (mg/L) for Moses Lake station ML-4.

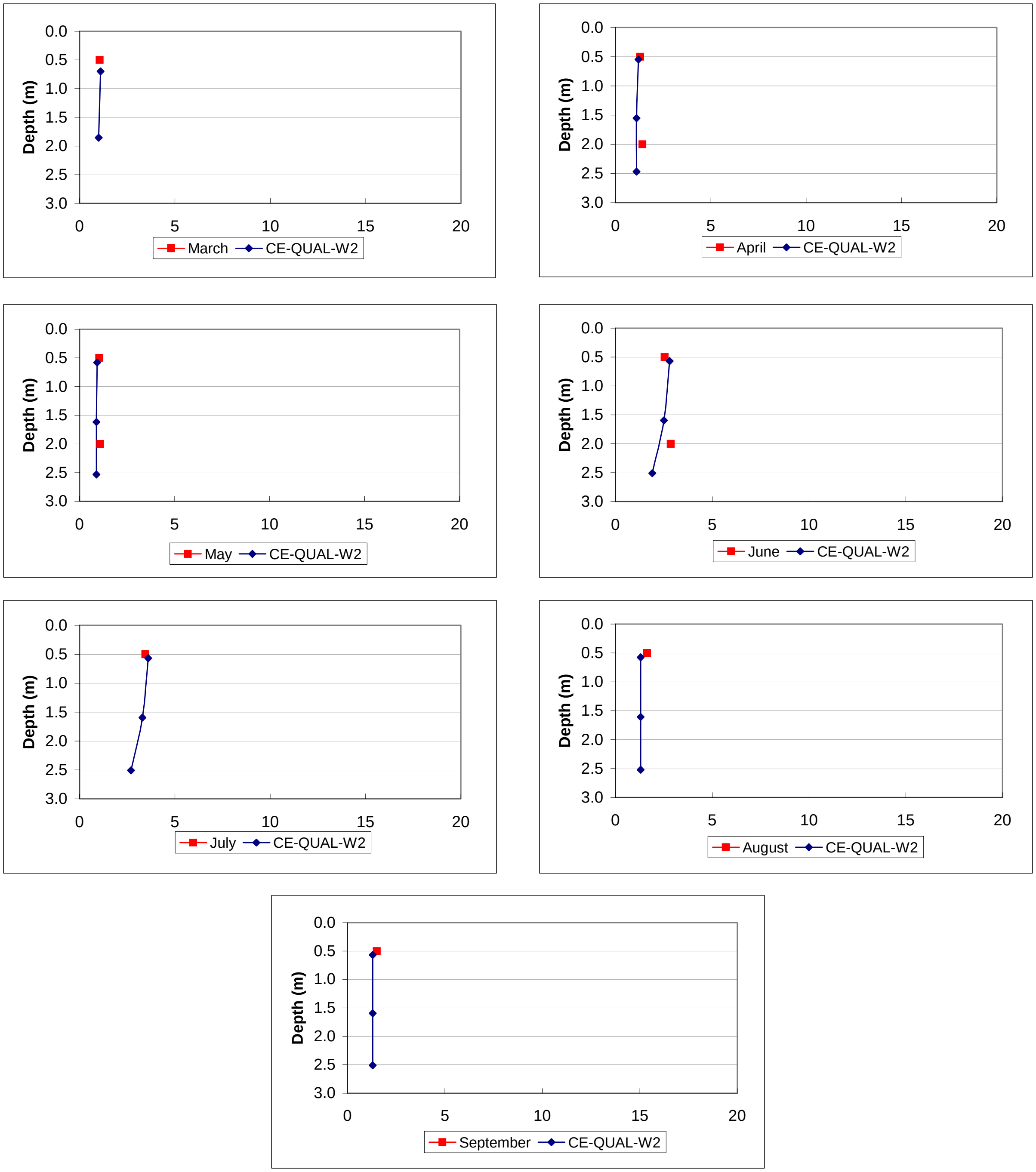

Figure 51. Comparison of model-predicted vertical chloride profiles with 2001 data (mg/L) for Moses Lake station ML-5.

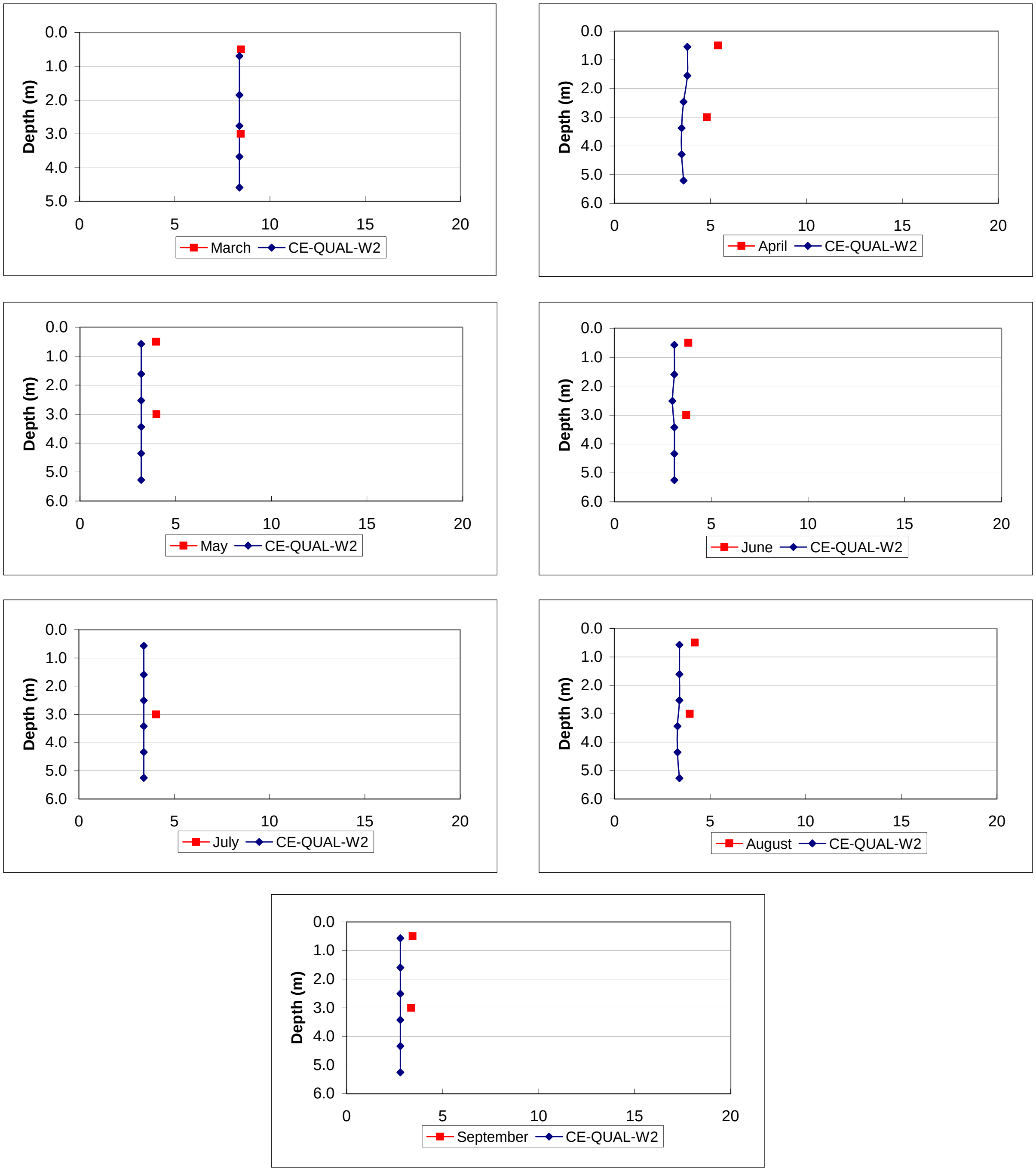

Figure 52. Comparison of model-predicted vertical chloride profiles with 2001 data (mg/L) for Moses Lake station ML-6.

Total Phosphorus

CE-QUAL-W2 simulates TP as the summation of phosphorus in ortho-P, algae, and dissolved and particulate organic matter. The concentration of TP in the water column is therefore unaffected by algal uptake and respiration, and decomposition processes of organic matter. The mass is conserved in those processes. The processes that do affect TP include settling, sediment release/resuspension, and boundary inflows/outflows. The calibrated model of Moses Lake simulated TP reasonably well, with an overall RMSE of 14 ug/L TP (n=107) throughout the water column for all sampling sites (Table 12). The total %RSD for TP measurements was approximately 10% or 5 ug/L at a concentration of 50 ug/L.

Table 12. Summary of error statistics for the 2001 calibration of TP. Spatial, temporal, and overall error expressed as RMSE (mg/L).

	ML5	ML4	ML3	ML1	ML2	ML6	*Total*
March	0.003	0.001	0.007	0.005	0.005	0.011	0.007
April	0.005	0.006	0.005	0.008	0.006	0.006	0.006
May	0.007	0.005	0.042	0.005	0.015	0.005	0.023
June	0.004	0.010	0.007	0.007	0.009	0.008	0.008
July	0.014	0.004	0.012	0.016	0.014	0.006	0.012
August	0.005	0.013	0.029	0.016	0.015	0.007	0.019
September	0.012	0.014	0.011	0.015	0.013	0.005	0.012
							Overall
Mar-Sept	0.007	0.009	0.021	0.012	0.012	0.007	0.014

The model simulated TP very well in some parts of Moses Lake, particularly Parker Horn (stations ML-4 and ML-5) and Pelican Horn (station ML-6) with seasonal RMSEs under 9 ug/L. Figures 53 to 58 present a comparison of model-predicted vertical TP profiles and the 2001 TP data for Moses Lake from March to September.

Much of the variability in the overall RMSE is the result of the model's under-prediction of a distinct increase in water column TP concentrations during May in the deeper basin stations of ML-2 and ML-3. This was most likely associated with a substantial increase in pH throughout the whole water column in late April and early May. Sediment release of phosphorus, even in aerobic waters, is possible with increases in pH above 8.0. The sediment release rate of phosphorus at a pH of 9.0 may be ten times greater than at a pH of 8.0 (Bostrom et al., 1982). Both basins had an increase in pH (>9.0) throughout the water column, resulting from the large vernal diatom bloom. CE-QUAL-W2 does not have an algorithm to model this type of phosphorus release.

The TP load leaving through the north and south outlets was assessed using the continuous discharge records (described above) and the simulated outflow TP concentrations. Simulated outflow TP concentrations were compared to measured outflow TP concentrations and had an overall RMSE of 9 ug/L (CV = 42%; n=8) for May through September.

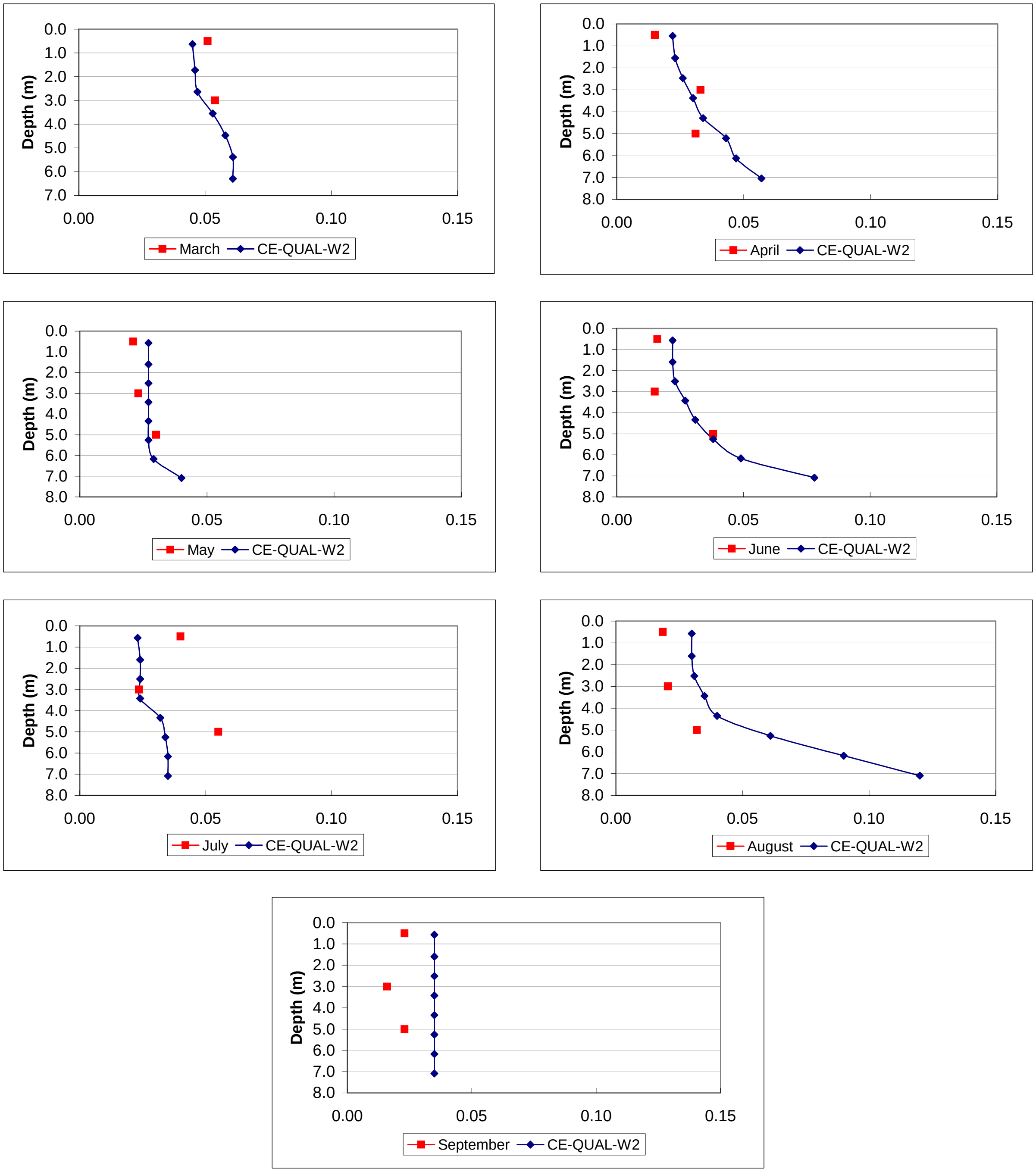

Figure 53. Comparison of model-predicted vertical TP profiles with 2001 data for Moses Lake station ML-1. (TP in mg/L)

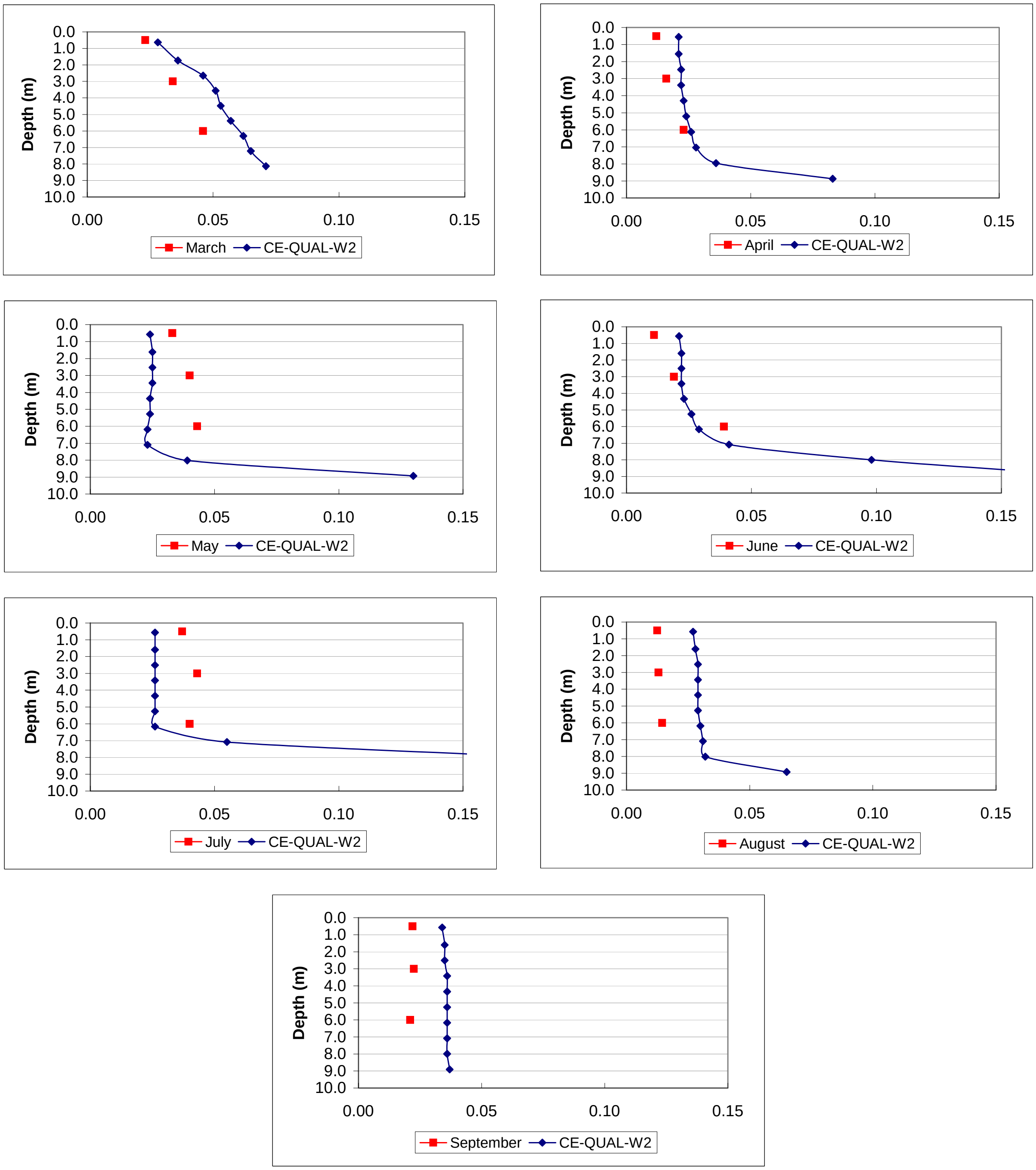

Figure 54. Comparison of model-predicted vertical TP profiles with 2001 data for Moses Lake station ML-2. (TP in mg/L)

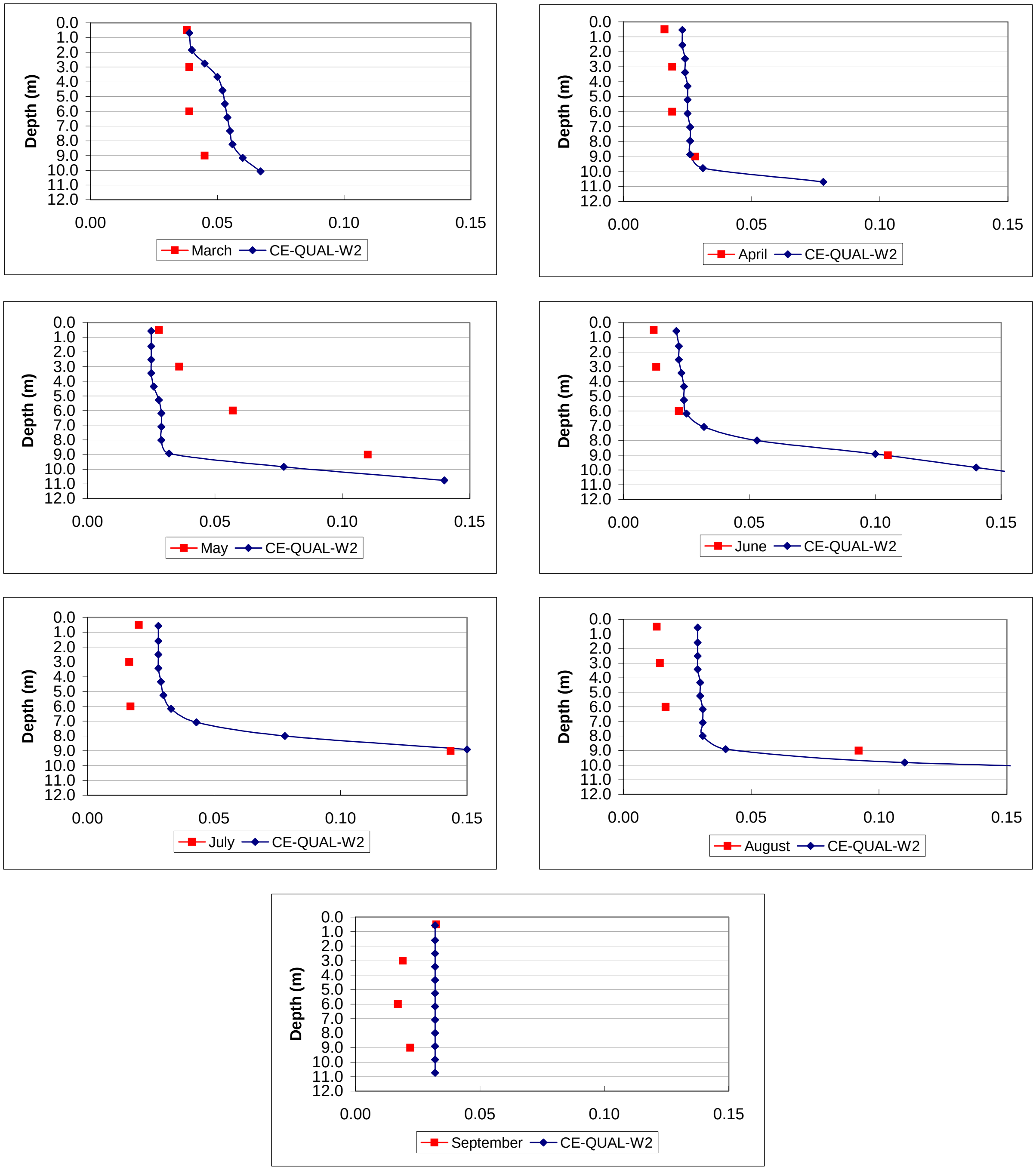

Figure 55. Comparison of model-predicted vertical TP profiles with 2001 data for Moses Lake station ML-3. (TP in mg/L)

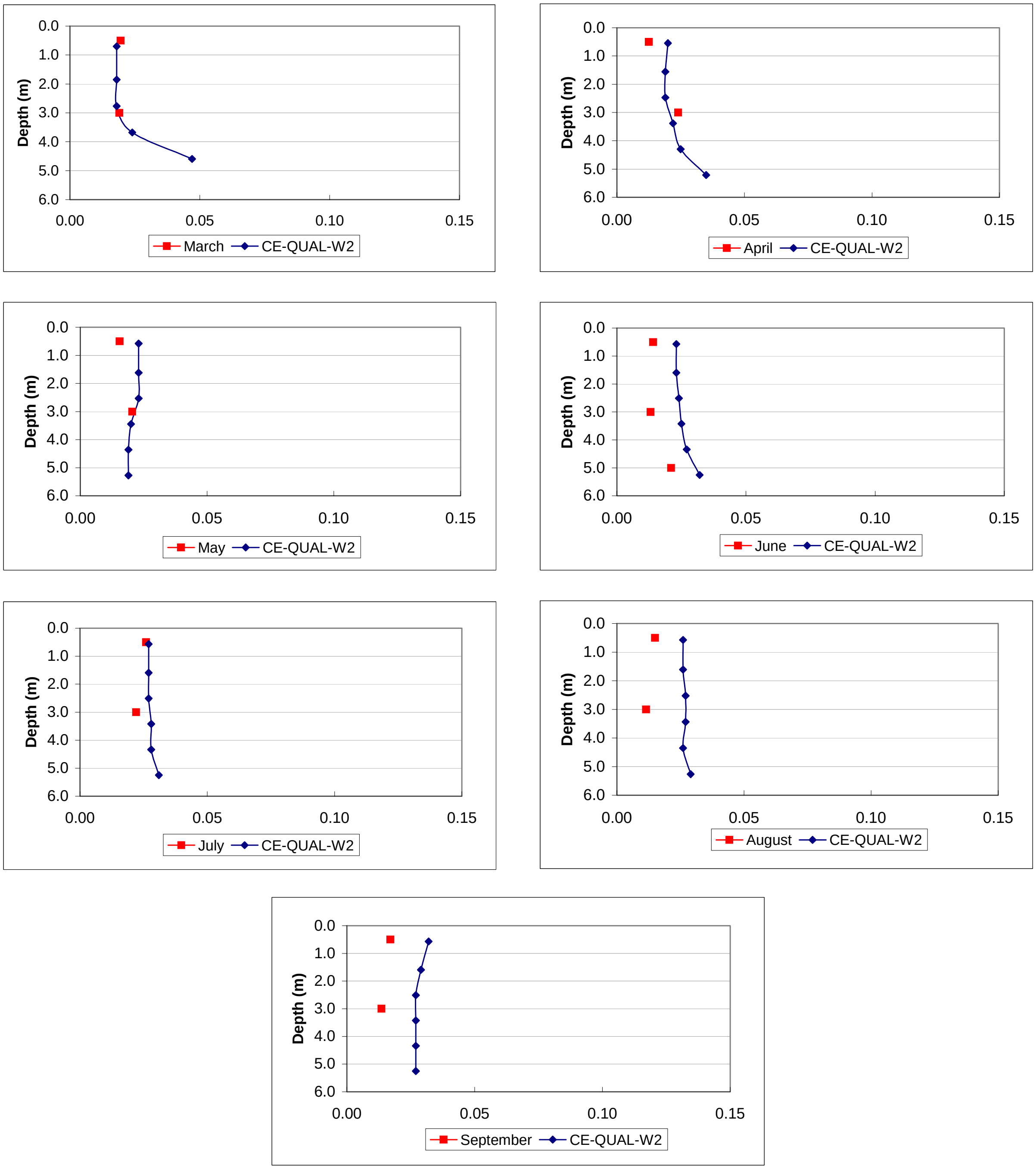

Figure 56. Comparison of model-predicted vertical TP profiles with 2001 data for Moses Lake station ML-4. (TP in mg/L)

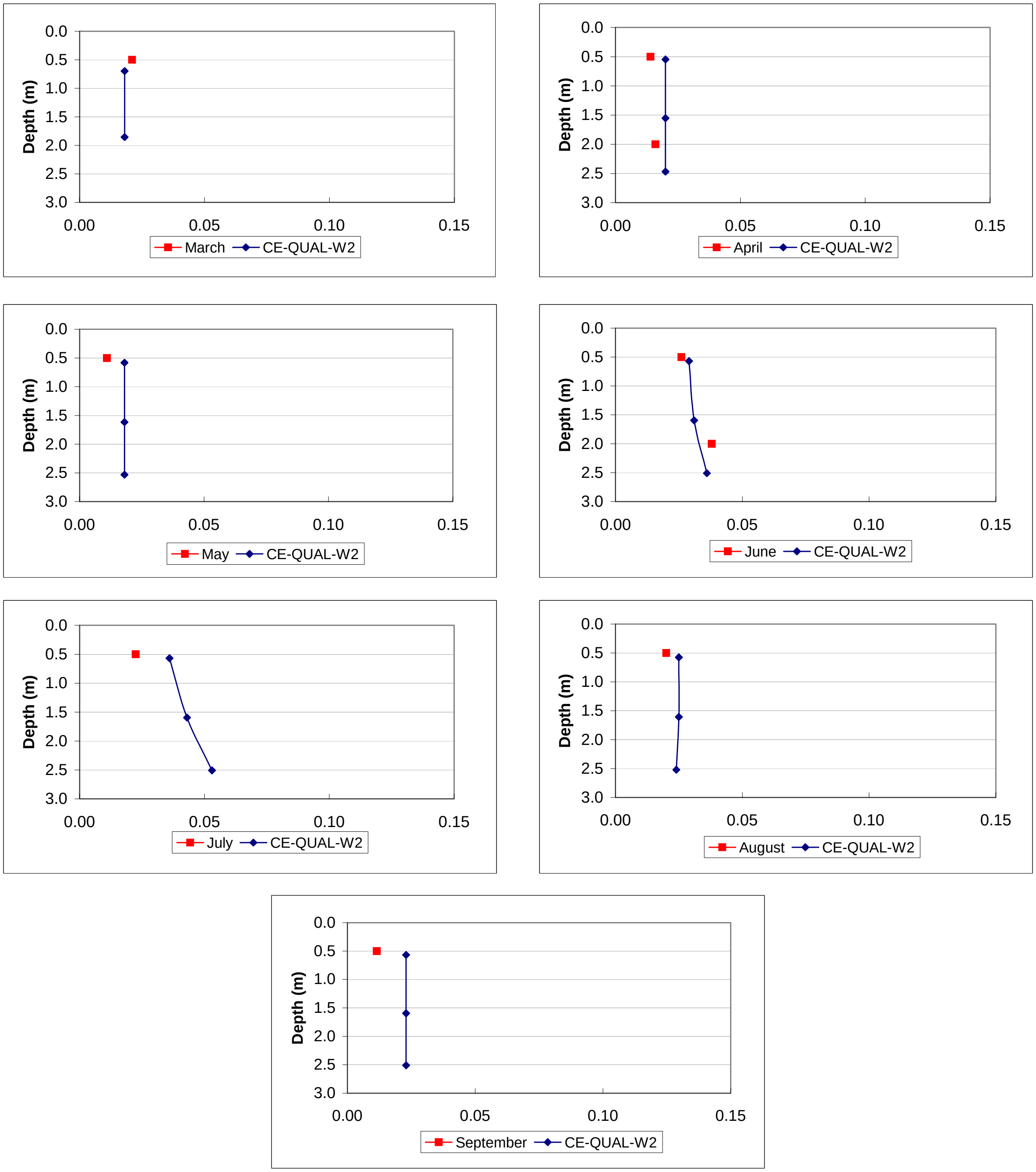

Figure 57. Comparison of model-predicted vertical TP profiles with 2001 data for Moses Lake station ML-5. (TP in mg/L)

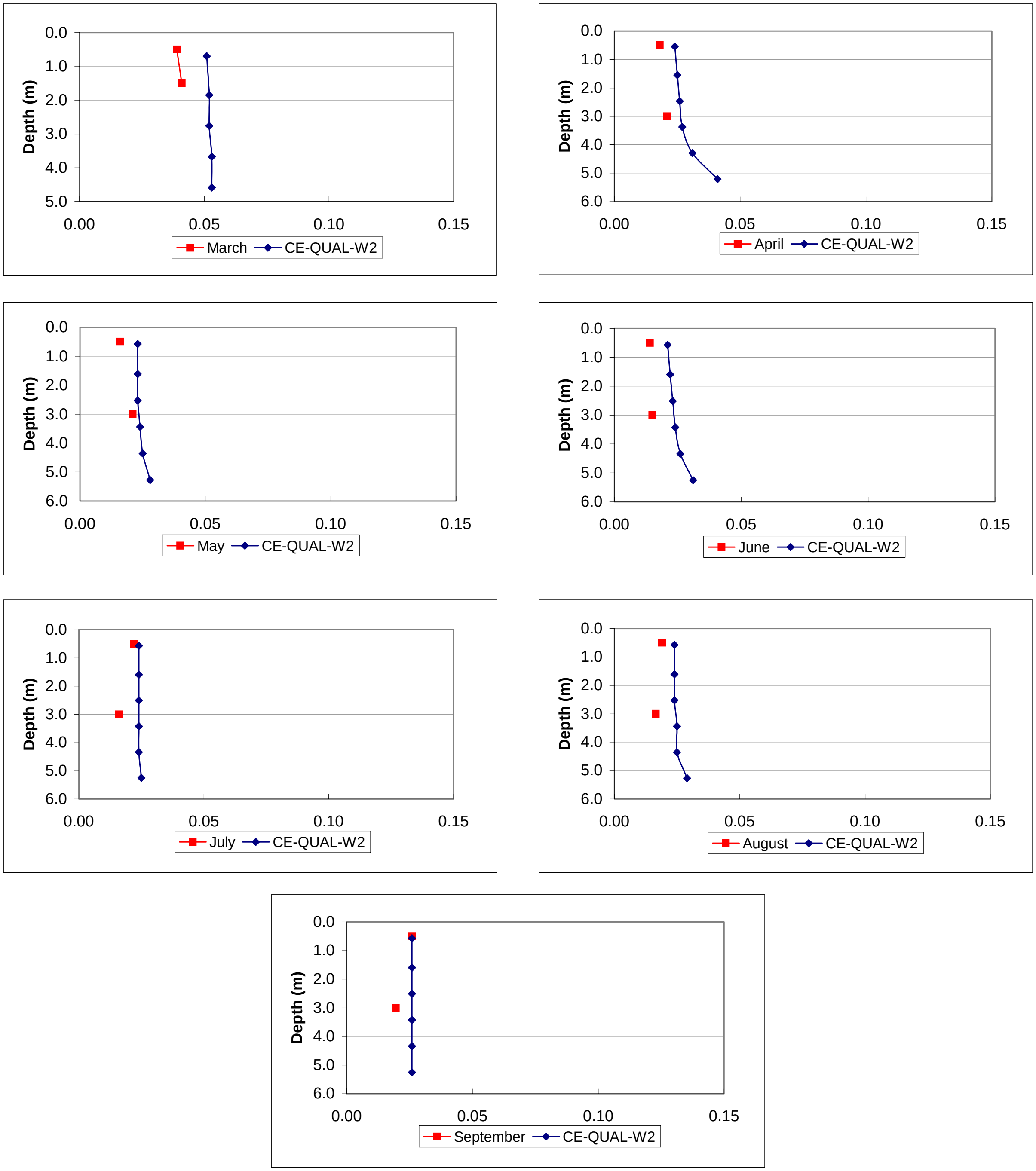

Figure 58. Comparison of model-predicted vertical TP profiles with 2001 data for Moses Lake station ML-6. (TP in mg/L)

External TP Loading to Moses Lake

Figure 59 presents the monthly TP and ortho-P loads to Moses Lake from Crab Creek, Rocky Ford Creek, groundwater, and Rocky Coulee Wasteway. A total of 22,500 kg of TP (of which 16,677 kg was dissolved ortho-P) were discharged to Moses Lake from these four external sources. The majority of the TP load to the lake came from Rocky Ford Creek and groundwater, though Rocky Coulee Wasteway contributed a large TP load in April, May, and June associated with the large amount of feed water during that period. A large fraction (74%) of the TP load was in the dissolved ortho-P phase. Accordingly, the load contribution of ortho-P to Moses Lake was dominated by groundwater and Rocky Ford Creek throughout the year as well. The fraction of total load contribution (expressed as a percentage) from various sources is shown for May through September in Figure 60.

Groundwater had a substantial influence on the TP load to Moses Lake, especially in the fall and winter. Patmont (1980) also found that groundwater flow entered Moses Lake primarily in the fall and winter, coincident with an increase in groundwater levels in the upper aquifer and the annual winter drawdown of Moses Lake.

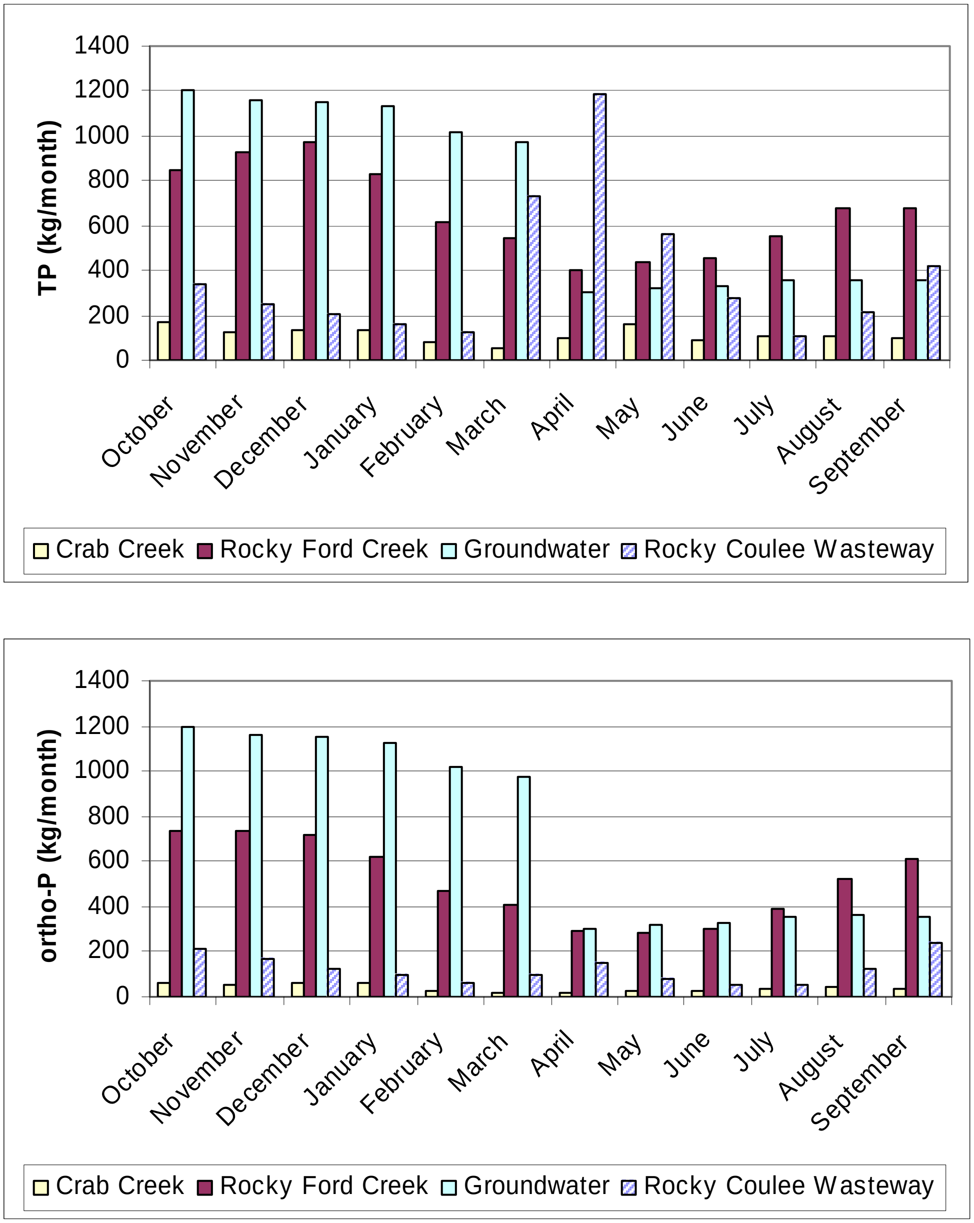

Figure 59. TP and ortho-P loadings from external sources during the 2000-01 study period.

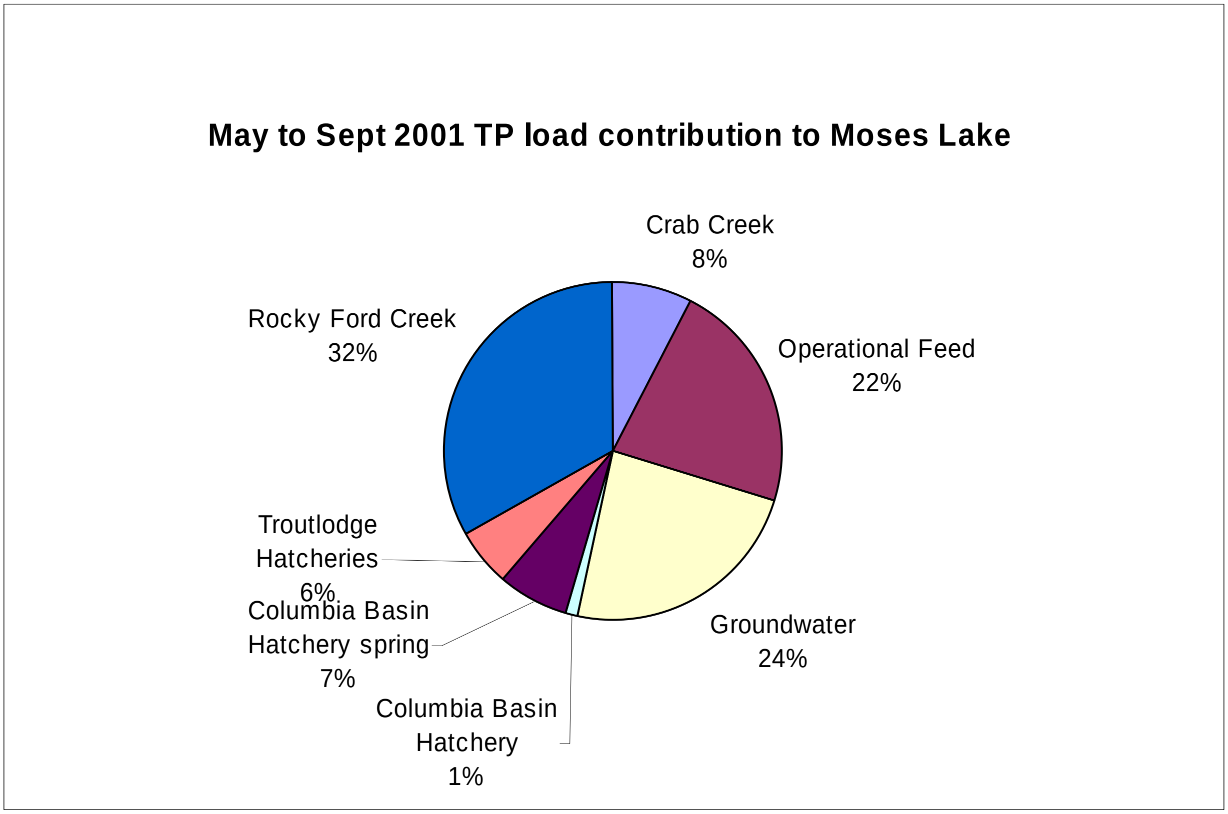

Figure 60. Percent contributions of the TP load to Moses Lake from external sources, May through September 2001.

Phosphorus Budget

The change in TP mass (storage) in Moses Lake was evaluated daily from the calibrated CE-QUAL-W2 model. A summary of CE-QUAL-W2 modeling results for TP from May through September 2001 are presented in Table 13. The outflow loads also were developed from the model. A summary of the monthly TP budget for March through September 2001 is presented in Table 14. Internal loading occurred from April through September as evidenced by the decreasing net settling losses or the net internal gains (as in July and August). There was a distinct decrease in net internal loading gain in 2001 compared to that in the historical phosphorus budgets of the 1980s.

Table 13. Summary of CE-QUAL-W2 modeling results for May through September 2001. All results are means for the specified time period.

	Branch 1 Parker Horn	Branch 2 South Basin	Branch 3 Lewis Horn	Branch 4 upper Rocky Ford Arm	Branch 4 lower Rocky Ford Arm	Branch 5,6,7,8 Pelican Horn	Whole Lake
May to September							
% dilution	46	32	45	13	28	28	27
TP concentration in whole column (ug/L)	**30**	**40**	**25**	**40**	**40**	**26**	**38**
TP concentration below 6m (ug/L)	60	64	0	54	76	33	69
TP concentration above 6m (ug/L)	24	26	25	40	28	26	30
TP mass in whole column (kg)	335	1004	54	1138	1971	282	4796
TP mass below 6m (kg)	69	572	0	67	944	4	1654
% TP mass below 6m	21%	57%	0%	6%	48%	2%	34%
% Volume below 6m	10%	35%	0%	4%	25%		
% increase to [TP] by including <6m	26%	51%	0%	2%	44%	0%	24%
May							
% dilution	55	42	59	21	38	36	36
TP concentration in whole column (ug/L)	**27**	**31**	**25**	**37**	**31**	**24**	**31**
TP concentration below 6m (ug/L)	43	41	0	36	47	29	44
TP concentration above 6m (ug/L)	23	16	25	35	19	24	28
TP mass in whole column (kg)	300	772	53	1032	1507	265	3947
TP mass below 6m (kg)	49	370	0	45	585	4	1052
% TP mass below 6m	16%	48%	0%	4%	39%	1%	27%
% Volume below 6m	10%	35%	0%	4%	25%		
% increase to [TP] by including <6m	19%	92%	0%	5%	63%	0%	11%
June							
% dilution	48	37	46	17	33	32	31
TP concentration in whole column (ug/L)	**28**	**34**	**24**	**39**	**35**	**25**	**34**
TP concentration below 6m (ug/L)	47	50	0	48	61	28	55
TP concentration above 6m (ug/L)	23	16	24	37	20	25	29
TP mass in whole column (kg)	306	855	51	1101	1743	276	4349
TP mass below 6m (kg)	53	448	0	61	756	4	1319
% TP mass below 6m	17%	52%	0%	6%	43%	1%	30%
% Volume below 6m	10%	35%	0%	4%	25%		
% increase to [TP] by including <6m	21%	110%	0%	6%	76%	0%	17%
July							
% dilution	29	25	26	11	21	21	19
TP concentration in whole column (ug/L)	**34**	**47**	**26**	**37**	**43**	**25**	**40**
TP concentration below 6m (ug/L)	94	95	0	68	106	40	99
TP concentration above 6m (ug/L)	24	14	26	34	17	24	26
TP mass in whole column (kg)	375	1204	56	1040	2142	269	5096
TP mass below 6m (kg)	108	842	0	85	1318	5	2357
% TP mass below 6m	29%	70%	0%	8%	62%	2%	46%
% Volume below 6m	10%	35%	0%	4%	25%		
% increase to [TP] by including <6m	41%	233%	0%	9%	160%	1%	51%
August							
% dilution	34	19	30	6	15	19	17
TP concentration in whole column (ug/L)	**34**	**51**	**26**	**41**	**49**	**27**	**44**
TP concentration below 6m (ug/L)	82	95	0	70	116	37	104
TP concentration above 6m (ug/L)	25	18	26	38	20	27	31
TP mass in whole column (kg)	375	1308	57	1159	2448	299	5658
TP mass below 6m (kg)	94	846	0	87	1448	5	2476
% TP mass below 6m	25%	65%	0%	8%	59%	2%	44%
% Volume below 6m	10%	35%	0%	4%	25%		
% increase to [TP] by including <6m	33%	183%	0%	8%	145%	0%	45%
September							
% dilution	65	35	66	9	35	33	33
TP concentration in whole column (ug/L)	**29**	**35**	**25**	**49**	**41**	**27**	**39**
TP concentration below 6m (ug/L)	33	38	0	46	48	30	44
TP concentration above 6m (ug/L)	25	21	25	47	28	27	38
TP mass in whole column (kg)	315	873	54	1363	2009	299	4920
TP mass below 6m (kg)	38	341	0	58	599	4	1040
% TP mass below 6m	12%	39%	0%	4%	30%	1%	21%
% Volume below 6m	10%	35%	0%	4%	25%		
% increase to [TP] by including <6m	14%	64%	0%	4%	42%	0%	3%

Table 14. Summary of the monthly TP budget for March through September 2001. (load in kg)

Month	Outflows	Inflows				Change in storage	Net internal load/settling
		Ground-water	Rocky Ford Creek	Crab Creek	Rocky Coulee Wasteway		
March	1466	971	545	54	644	-1696	-2444
April	2479	304	406	92	1251	-1292	-866
May	890	320	437	160	561	268	-321
June	670	328	452	90	298	426	-72
July	210	358	550	105	111	1163	250
Aug	1304	360	672	104	209	-226	-267
Sept	2076	354	697	100	427	-729	-232
May-Sept	5150	1720	2809	560	1606	901	-643

Other Phosphorus Sources

Other phosphorus sources not specifically allocated as seasonal phosphorus loads in this evaluation are stormwater runoff (overland flow and unknown contributions from City of Moses Lake stormwater collection system), waterfowl contributions (more than 50,000 waterfowl winter on Moses Lake each year), and net pen fish production (the state Department of Fish and Wildlife operates a facility from October to March in the South basin).

Many of these sources probably have a minimum impact during the critical season of May through September because they take place mostly in the winter. Any phosphorus loads that enter Moses Lake in the winter become part of the initial conditions for the critical season. The Moses Lake CE-QUAL-W2 model was calibrated using measured initial conditions from March 2001. These initial conditions include the sum impacts of all winter phosphorus loading including stormwater runoff, waterfowl feces, and net pen fish. Soluble phosphorus in the water column initially fuels the spring diatom bloom or is washed out as the lake is filled up in the spring. Particulate phosphorus that enters Moses Lake in the winter either breaks down into soluble phosphorus, settles to the bottom sediments, or is washed out of Moses Lake. Any effects that phosphorus in the sediments may have from May through September are contained in the residual of the phosphorus mass balance as the internal phosphorus load term (i.e., release of phosphorus from the sediments during anoxic conditions in the summer). The Moses Lake CE-QUAL-W2 model incorporates a phosphorus-sediment release algorithm to account for the internal phosphorus load and was calibrated to the 2001 hypolimnion phosphorus data.

Even though Moses Lake receives minimal precipitation from May through September, summer thunderstorms can occur that may create nonpoint phosphorus loading from runoff. Lake-shore runoff can include fertilizers, pet feces, oils, and soil, among other contaminants. These could lead to temporary phosphorus spikes in the Moses Lake water column and should be included in a best management practices (BMP) evaluation for Moses Lake.

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Loading Capacity Assessment

Applicable Water Quality Criteria

Carroll et al. (2000) reviewed historical water quality studies on Moses Lake and, based on the historical review, presented an evaluation of nutrient criteria for Moses Lake. In summary, the following was established:

- Water (natural and imported) in the Columbia Basin is managed for irrigation and flood control by the Columbia Basin Irrigation Project (CBIP). Since the 1950s, CBIP management has permanently altered the hydrologic regime of the watershed to the point where there is no historical reference condition for comparison.

- Subsequent extensive study and restoration done on Moses Lake since the inception of the CBIP determined excessive phosphorus loading as the source of impairment to Moses Lake, with the impairment being the excessive blue-green algae blooms which affect the characteristic uses of recreational and aesthetic enjoyment during the summer months.

- Total nitrogen was recommended to be delisted from the 303(d) list, and future lake management activities and decisions focus on the control of TP to manage the blue-green algal biomass in Moses Lake.

- Halting accelerated hypereutrophic conditions and restoring Moses Lake to a pre-impacted condition would most likely result in a continued eutrophic state, with associated characteristic uses of a productive lake.

- Characteristic uses for eutrophic north temperate lakes are reduced aesthetic properties, reduced water contact recreation, and productive warm-water fisheries. In general, these reflect the current and historical characteristic uses and conditions of Moses Lake, and suggest a level of protection and management for Moses Lake.

- Management of Moses Lake for other than a eutrophic condition was deemed impracticable, and has not been the focus or objective of rehabilitation measures to date.

- A link between TP concentration and an endpoint indicator, chlorophyll *a* concentration, was established in historical studies. Based on historical management recommendations, it was proposed that a maximum concentration of 50 ug/L TP would limit chlorophyll *a* concentrations to an endpoint target of 20 ug/L during the growing season (May- September). The endpoint target of 20 ug/L chlorophyll a maximum concentration would substantially reduce the likelihood of hypereutrophic conditions (excessive blue-green algae biomass) in Moses Lake.

- Ecology proposed adopting the established 50 ug/L TP criterion to develop a loading capacity evaluation for Moses Lake. Based on available knowledge, the 50 ug/L TP criterion seemed to protect the characteristic lake uses, have a basis in the historical lake restoration efforts, be an achievable target, and probably be best reflected the historical development of Moses Lake.

- The proposed 50 ug/L TP criterion exceeds the action value of 35 ug/L TP established in Washington State water quality standards for lakes in the Columbia Basin ecoregion.

EPA (2001) has recently published information to support the development of state nutrient criteria for lakes and reservoirs in the xeric west ecoregion, of which Moses Lake is a part. EPA recommended a summer season reference condition and criterion of 35 ug/L of TP for the Moses Lake area sub-ecoregion. This criterion was empirically derived to represent lakes and reservoirs in this region that are minimally impacted by human activities and protective of aquatic life and recreational uses. EPA urges states to develop site-specific nutrient criteria, using the EPA reference condition for comparison.

Based on current knowledge (explained below), Ecology still recommends a maximum, mean in-lake TP criterion of 50 ug/L for Moses Lake during the May through September critical season. Load reductions necessary to achieve the 50 ug/L criterion throughout the lake were modeled.

Seasonal Variation and Impaired Uses

The management goal for Moses Lake is to control and mitigate the excessive hypereutrophic blooms of blue-green algae that have occurred in Moses Lake since the inception of the CBIP. These blue-green algae blooms have been documented as impairing the beneficial uses of Moses Lake during the summer months. Welch et al. (1989) has documented that diatoms have typically dominated the spring populations (March and April) in Moses Lake, while the excessive blue-green algae blooms have occurred during May through September. May through September will be considered the critical season of concern for Moses Lake.

There are several factors that affect the biomass of algae during the critical season:

- The initial conditions of the lake at the start of the critical season.
- The exchange rate of water entering the lake through the critical season.
- The replenishment of nutrients to the lake during the critical season.
- The meteorological conditions during the critical season.

The initial conditions of Moses Lake in May are influenced by the percentage of natural runoff versus feed water that fills Moses Lake during its winter to summer stage transition. This mix first affects the extent and magnitude of the early spring diatom bloom (March and April) and then the algal assemblage of the May through September period.

The exchange rate of water during May through September will affect the algal biomass. Higher exchange rates occur when continued or additional feed water extend into this period. Exchange rates can be high enough to effectively dilute the nutrient concentrations in the lake (when using low-nutrient feed water) and, to some minimal extent, wash out algal cells. Higher exchange rates are associated with dry years when more feed water is needed to meet irrigation demand.

Lower exchange rates occur in wet years when Rocky Ford Creek and Crab Creek are the only surface water discharge to Moses Lake and irrigation demand is lower.

The replenishment of phosphorus, particularly ortho-P, to Moses Lake during May through September must occur to fuel the summer algal biomass development. The vernal diatom bloom will usually respond with enough intensity to deplete the initial bio-available phosphorus mass within the euphotic zone, so additional phosphorus sources are required. Disregarding internal loading of phosphorus (i.e., sediment release) and short-term recycling, the only other phosphorus replenishment comes from the tributary or groundwater inflows to Moses Lake. During wet years, summer flows in Rocky Ford Creek and Crab Creek (both which originate from groundwater) and direct groundwater inflows are higher. Thus, wet years are more likely to introduce higher replenishing loads of phosphorus throughout the summer than dry years when low-P feed water predominates the inflows.

Meteorological conditions (primarily wind) during the critical season will determine how much mixing will take place. High mixing (i.e., windy summer) will entrain the phosphorus released from sediments up into the euphotic zone where it can fuel algal biomass development. In a season with little mixing, the sediment-released phosphorus is trapped in the hypolimnion where it is not available for algal growth; however, there can be an aerobic release of sediment phosphorus to the epilimnion. In addition, hot summers with clear sunny weather will provide better growing conditions than cloudy, cool summers.

Loading Capacity Assessment

The nutrient target of 50 ug/L represents a whole-lake mean concentration. However, a whole-lake mean TP concentration is difficult and costly to ascertain. Traditionally, therefore, lake managers have relied on lake modeling to relate a whole-lake mean TP concentration to a certain amount of incoming TP load to the lake, which is easier to measure.

Carroll et al. (2000) suggested preliminary TP load allocations for Moses Lake based on applying the steady-state solution model of the mass balance equation to the annual flux of TP. While this was an effective solution for calculating load allocations, its shortfalls are that it assumes that the entire lake is mixed, that the entire lake has reached a steady state, and that phosphorus sedimentation/bottom release is uniform throughout Moses Lake. None of these conditions are true in Moses Lake every year.

Jones and Welch (1990) calibrated and verified three steady-state solution models for three separate sections of the lake, incorporating the variability of up to nine years of historical data. These models were relevant because they specifically modeled the critical season of concern (May through September) rather than annual conditions, and they had independent settling velocity coefficients for the three sections of the lake, but they did not address the whole lake or the loading interactions between the separate sections of the lake. Carroll et al. (2000) suggested that a hydrodynamic model capable of temporal and spatial analysis of TP fate and transport be developed to establish load allocations for Moses Lake.

The hydrodynamic CE-QUAL-W2 model of Moses Lake calibrated with the 2000-01 study period data was used to predict monthly mean in-lake TP concentrations from May through September during critical load conditions.

Design Criteria for Critical Load Conditions

- The season of concern is May through September when excessive blue-green algae blooms can occur. Evaluation of TP concentration compliance with the TP criterion was limited to this season.

- In order to develop an allocation strategy to improve Moses Lake's water quality, all of the major loading components to Moses Lake were characterized.

- The hydraulic conditions of 1980 were chosen to model critical flow conditions. The year represents an approximate 90th percentile flow for Rocky Ford Creek and Crab Creek and a 10th percentile flow for feed water through Rocky Coulee Wasteway (based on flow records from 1977-2001). The probability of these conditions occurring is approximately one in ten years on the average, which Ecology considers an acceptable exceedance probability (i.e., approximately 10%).

- The lake simulations began in mid-February. Initial phosphorus concentrations in the lake for all simulations were those used in the calibrated 2001 model. The 2001 data set was the most current depiction of initial conditions following the winter season and reflects current conditions. For instance, the initial conditions in Moses Lake prior to 1984 would reflect the discharge from the Moses Lake Wastewater Treatment Plant to Moses Lake.

- The year-to-year variation in TP concentration for Rocky Ford Creek varies little; its load depends more on variation in flow. Crab Creek was assumed to behave similarly during its predictable flow period from May through September. The CE-QUAL-W2 model uses ortho-P as a state variable, as part of TP. Most of Rocky Ford Creek's TP is ortho-P (75%). The long-term May through September ortho-P mean concentration of 106 ug/L was used as the initial starting concentration for a critical condition in Rocky Ford Creek. All of the groundwater phosphorus was considered to be ortho-P, and the 2001 concentration data were used for initial starting concentrations. The long-term May through September mean ortho-P concentration of 14 ug/L was used for starting concentrations in Crab Creek. Other phosphorus compartments for the critical load conditions, including that in algae and organic matter, were considered to be the same as the 2001 data set for all tributaries.

- The critical flow year (1980) had a winter/spring runoff flow from Crab Creek which began on February 24 at a flow rate of 12.3 cubic meters/second (cms), peaked on March 2 at 60.9 cms, declined rapidly to 10.5 cms by March 11, and then slowly declined to a baseflow of 2.0 cms by the end of April. For February 24 to March 11, an ortho-P concentration of 61 ug/L was used; this is the average ortho-P concentration from limited historical sampling of these events. Inorganic and organic matter concentrations were roughly tripled and doubled, respectively, from baseflow conditions for the high-flow period.

- Rocky Coulee Wasteway annual baseflow was estimated by Patmont (1980) to be 35 cfs. Annual loading was calculated using this baseflow and nutrient data collected from the 2000-01 study period. The baseflow was considered primarily spring-fed and thus assumed to be relatively constant throughout the year.

- Because Rocky Ford Creek and Crab Creek, which are groundwater driven, had an average increase of 30% for the critical seasonal flow compared to the 2001 seasonal flow, groundwater inflows were assessed to be 25% greater than the 2001 year inflows to account for a critical load groundwater flux.

- When evaluating model simulations, the entire water column TP was averaged for compliance with the TP criterion. Even though the algae grow in the euphotic zone, the entire water column was averaged because Moses Lake is polymictic (capable of mixing several times during the growing season). This avoided the complex task of trying to identify a critical meteorological conditions data set, by conservatively assuming any internal phosphorus loading is potentially available for algae growth. The 2001 year meteorology data were used for the simulation runs.

- Nutrient loading by atmospheric deposition and direct precipitation onto Moses Lake were not modeled. Both are considered negligible during the May through September critical season of concern, and any effects they may have are considered uncontrollable from a load reduction standpoint. In addition, any effects these loads might have are contained in the residual of the phosphorus mass balance and would be part of the terms controlling the internal loading process, in this case as phosphorus gain.

- In all assessments, the pump that conveys 50 cfs of water from Parker Horn to Pelican Horn was simulated as continuously running from April 2 through the end of September.

Loading Capacity Findings

Using the calibrated 2001 CE-QUAL-W2 model of Moses Lake, the critical load conditions were modeled in Moses Lake. A summary of the results for critical load conditions are presented in Table 15. Moses Lake was divided into different branches for analysis and comparison with the 50 ug/L criterion. The TP criterion was considered to be met when the May through September mean TP concentration was below the criterion in all the branches. For the critical load conditions, the mean TP concentration in the whole column was predicted to be 62 ug/L for May through September. The South Basin was predicted to have the highest seasonal monthly means ranging from 58 to 69 ug/L. The month of June was predicted to have the highest percentage (14%) of feed water in the whole lake, while the seasonal whole-lake average was predicted to be 8%. Figure 61 presents the percent contributions from external TP sources during critical load conditions.

Table 15. Summary of CE-QUAL-W2 modeling results for critical load conditions. All results are means for the specified time period.

	Branch 1 Parker Horn	Branch 2 South Basin	Branch 3 Lewis Horn	Branch 4 upper Rocky Ford Arm	Branch 4 lower Rocky Ford Arm	Branch 5,6,7,8 Pelican Horn	Whole Lake
May to September							
% dilution	19	9	22	3	8	7	8
TP concentration in whole column (ug/L)	**56**	**64**	**49**	**68**	**62**	**49**	**62**
TP concentration below 6m (ug/L)	98	98	0	82	112	57	105
TP concentration above 6m (ug/L)	48	49	49	68	51	49	55
TP mass in whole column (kg)	505	1471	80	1585	2765	399	6811
TP mass below 6m (kg)	68	667	0	33	919	3	1689
% TP mass below 6m	13%	45%	0%	2%	33%	1%	25%
% Volume below 6m	8%	30%	0%	2%	18%		
% increase to [TP] by including <6m	16%	29%	0%	0%	22%	0%	13%
May							
% dilution	23	4	31	1	4	3	7
TP concentration in whole column (ug/L)	**55**	**63**	**51**	**68**	**61**	**57**	**62**
TP concentration below 6m (ug/L)	84	81	0	73	90	63	85
TP concentration above 6m (ug/L)	48	39	51	66	44	57	58
TP mass in whole column (kg)	482	1457	80	1544	2678	451	6714
TP mass below 6m (kg)	58	552	0	29	736	3	1379
% TP mass below 6m	12%	38%	0%	2%	27%	1%	21%
% Volume below 6m	8%	29%	0%	2%	19%		
% increase to [TP] by including <6m	14%	61%	0%	2%	38%	0%	7%
June							
% dilution	31	16	37	4	15	12	14
TP concentration in whole column (ug/L)	**50**	**58**	**43**	**68**	**59**	**48**	**59**
TP concentration below 6m (ug/L)	83	85	0	79	100	52	93
TP concentration above 6m (ug/L)	44	33	43	67	40	48	53
TP mass in whole column (kg)	449	1340	69	1575	2583	382	6396
TP mass below 6m (kg)	58	580	0	32	824	3	1496
% TP mass below 6m	13%	43%	0%	2%	32%	1%	23%
% Volume below 6m	8%	30%	0%	2%	19%		
% increase to [TP] by including <6m	15%	76%	0%	2%	47%	0%	11%
July							
% dilution	17	11	18	4	9	7	8.9
TP concentration in whole column (ug/L)	**57**	**67**	**53**	**66**	**65**	**42**	**63**
TP concentration below 6m (ug/L)	134	127	0	110	150	59	138
TP concentration above 6m (ug/L)	47	29	53	64	37	42	50
TP mass in whole column (kg)	506	1518	85	1521	2826	328	6787
TP mass below 6m (kg)	93	867	0	44	1223	3	2236
% TP mass below 6m	18%	57%	0%	3%	43%	1%	33%
% Volume below 6m	8%	30%	0%	2%	19%		
% increase to [TP] by including <6m	22%	133%	0%	3%	76%	0%	27%
August							
% dilution	13	7	14	3	6	6	6
TP concentration in whole column (ug/L)	**59**	**69**	**48**	**67**	**67**	**45**	**65**
TP concentration below 6m (ug/L)	123	126	0	86	150	56	137
TP concentration above 6m (ug/L)	50	32	48	66	40	45	53
TP mass in whole column (kg)	541	1600	82	1602	2999	378	7208
TP mass below 6m (kg)	85	856	0	34	1229	3	2203
% TP mass below 6m	16%	53%	0%	2%	41%	1%	31%
% Volume below 6m	8%	30%	0%	2%	18%		
% increase to [TP] by including <6m	19%	115%	0%	2%	69%	0%	23%
September							
% dilution	9	5	8	2	5	7	5
TP concentration in whole column (ug/L)	**59**	**61**	**48**	**70**	**61**	**54**	**62**
TP concentration below 6m (ug/L)	65	69	0	61	69	56	69
TP concentration above 6m (ug/L)	54	41	48	69	48	54	61
TP mass in whole column (kg)	548	1435	83	1684	2734	457	6941
TP mass below 6m (kg)	45	469	0	25	568	3	1110
% TP mass below 6m	8%	33%	0%	1%	21%	1%	16%
% Volume below 6m	7%	29%	0%	2%	18%		
% increase to [TP] by including <6m	9%	49%	0%	1%	26%	0%	2%

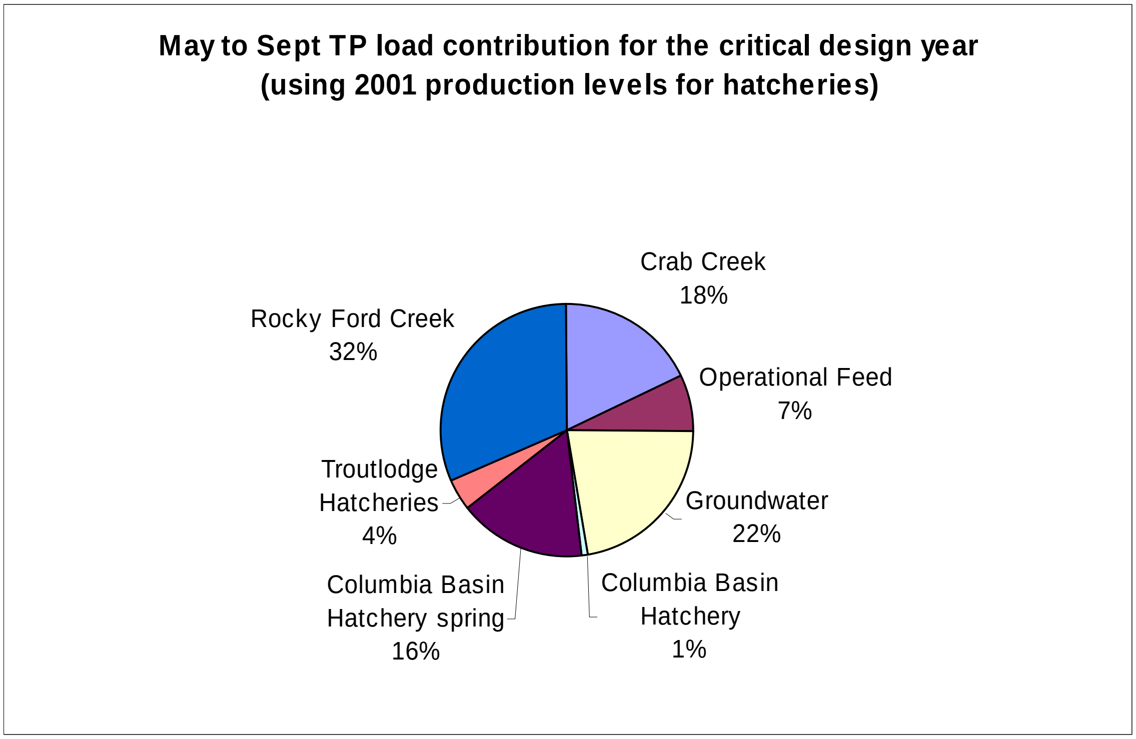

Figure 61. Pie diagram showing percent contributions of external TP sources during critical load conditions.

Next, the critical load conditions were modeled with the addition of a 50th percentile feed water flow. The feed water flow for 1982 represented this median flow. The feed water was added to the lake at the same rate as in 1982. A summary of results are presented in Table 16. A 50th percentile operational flow was predicted to reduce the TP concentration of the lake enough to meet the 50 ug/L criterion. The whole lake was predicted to have an average of 27% feed water during the May through September season. This further confirms the results from Welch et al. (1989) which found that the water quality goals are met when adequate dilution is available. The amount of feed water delivered to Moses Lake in this scenario was approximately half the amount delivered in 2001 or just over one lake volume (Figure 31). An addition of this much feed water in a critical flow year such as 1980 would require an operational change from the USBR normal operating procedures, but warrants consideration.

In the absence of an adequate feed water addition, a TP load reduction is necessary to meet the 50 ug/L TP criterion. As an initial allocation strategy, ortho-P and organic phosphorus were reduced by an equal percentage from all manageable phosphorus loading sources during the May through September critical season until the TP criterion was met.

Crab Creek, Rocky Ford Creek, and the Rocky Coulee Wasteway baseflow are supplied by groundwater emerging as springs during the summer. Groundwater also directly enters Moses Lake. All of these groundwater sources affect algae growth in Moses Lake during the critical season of concern by replenishing nutrients to the lake. All are considered manageable sources

Table 16. Summary of CE-QUAL-W2 modeling results for critical load conditions with a 50th percentile addition of feed water. All results are means for the specified time period and location.

	Branch 1 Parker Horn	Branch 2 South Basin	Branch 3 Lewis Horn	Branch 4 upper Rocky Ford Arm	Branch 4 lower Rocky Ford Arm	Branch 5,6,7,8 Pelican Horn	Whole Lake
May to September							
% dilution	48	35	50	10	28	25	27
TP concentration in whole column (ug/L)	**40**	**39**	**33**	**62**	**50**	**36**	**48**
TP concentration below 6m (ug/L)	79	53	0	72	95	37	76
TP concentration above 6m (ug/L)	34	34	33	62	40	36	44
TP mass in whole column (kg)	367	910	55	1442	2236	292	5312
TP mass below 6m (kg)	55	360	0	29	778	2	1223
% TP mass below 6m	15%	40%	0%	2%	35%	1%	23%
% Volume below 6m	8%	30%	0%	2%	18%		
% increase to [TP] by including <6m	17%	17%	0%	0%	25%	0%	11%
May							
% dilution	63	35	73	10	30	25	32
TP concentration in whole column (ug/L)	**34**	**43**	**26**	**61**	**47**	**42**	**47**
TP concentration below 6m (ug/L)	65	56	0	61	73	45	65
TP concentration above 6m (ug/L)	29	27	26	60	33	42	44
TP mass in whole column (kg)	298	994	42	1401	2045	333	5116
TP mass below 6m (kg)	45	379	0	25	599	2	1050
% TP mass below 6m	15%	38%	0%	2%	29%	1%	21%
% Volume below 6m	8%	30%	0%	2%	19%		
% increase to [TP] by including <6m	18%	62%	0%	2%	41%	0%	7%
June							
% dilution	69	50	72	14	40	36	39
TP concentration in whole column (ug/L)	**31**	**34**	**27**	**62**	**45**	**33**	**44**
TP concentration below 6m (ug/L)	54	43	0	69	74	33	60
TP concentration above 6m (ug/L)	27	22	27	61	31	33	41
TP mass in whole column (kg)	274	792	43	1433	1975	260	4772
TP mass below 6m (kg)	37	294	0	28	604	2	965
% TP mass below 6m	14%	37%	0%	2%	31%	1%	20%
% Volume below 6m	8%	30%	0%	2%	19%		
% increase to [TP] by including <6m	16%	59%	0%	2%	44%	0%	7%
July							
% dilution	61	45	60	11	35	30	33.4
TP concentration in whole column (ug/L)	**38**	**38**	**32**	**60**	**51**	**30**	**47**
TP concentration below 6m (ug/L)	108	61	0	92	124	30	95
TP concentration above 6m (ug/L)	29	19	32	59	28	30	39
TP mass in whole column (kg)	333	861	51	1372	2235	233	5105
TP mass below 6m (kg)	74	414	0	37	1019	2	1537
% TP mass below 6m	22%	48%	0%	3%	46%	1%	30%
% Volume below 6m	8%	30%	0%	2%	19%		
% increase to [TP] by including <6m	29%	93%	0%	3%	84%	0%	22%
August							
% dilution	32	30	32	10	24	22	21
TP concentration in whole column (ug/L)	**49**	**42**	**39**	**61**	**57**	**34**	**52**
TP concentration below 6m (ug/L)	109	63	0	78	139	37	103
TP concentration above 6m (ug/L)	41	23	39	60	32	34	43
TP mass in whole column (kg)	449	971	65	1458	2560	288	5798
TP mass below 6m (kg)	75	427	0	31	1128	2	1670
% TP mass below 6m	17%	44%	0%	2%	44%	1%	29%
% Volume below 6m	8%	29%	0%	2%	18%		
% increase to [TP] by including <6m	20%	78%	0%	2%	79%	0%	20%
September							
% dilution	15	16	12	6	13	14	11
TP concentration in whole column (ug/L)	**51**	**40**	**41**	**64**	**53**	**41**	**51**
TP concentration below 6m (ug/L)	57	42	0	57	64	38	54
TP concentration above 6m (ug/L)	47	28	41	64	41	41	51
TP mass in whole column (kg)	480	931	71	1550	2362	348	5766
TP mass below 6m (kg)	39	284	0	23	526	2	873
% TP mass below 6m	8%	30%	0%	1%	22%	1%	15%
% Volume below 6m	7%	29%	0%	2%	18%		
% increase to [TP] by including <6m	9%	44%	0%	1%	29%	0%	1%

and can be reduced. The water quality of the groundwater in the Moses Lake area is directly affected by land-use practices in the Moses Lake watershed. These include agricultural sources (fertilizers, irrigation, and animals) and urban sources around the lake. Pitz (2003) has shown that the magnitude of phosphorus loading from groundwater to Moses Lake is variable, with the highest phosphorus loading associated with urban development. The reservoir of phosphorus already in groundwater may persist for a long time, but efforts should be made to reduce further loading.

In addition to these nonpoint sources, there are four permitted point sources. They are all fish-rearing operations: the Columbia Basin Hatchery discharging through Rocky Coulee Wasteway, the two Troutlodge fish hatcheries on Rocky Ford Creek, and a state Department of Fish and Wildlife net pen facility in Moses Lake. The net pen facility is in operation only during the winter, so it does not have a direct impact on algae growth in the summer. The other three facilities are direct sources of nutrients to Moses Lake year-round and are manageable sources.

Internal loading was considered an uncontrollable source of TP to Moses Lake, although considering internal loading as uncontrollable also builds in a margin of safety because eventually internal loads would be suppressed after external loads were reduced on a long-term basis. Apparently internal loading is already suppressed from rates observed since the 1980s.

Without dilution, a 35% reduction in phosphorus from all manageable sources of phosphorus is predicted to most closely meet the proposed 50 ug/L criterion in all branches of the lake (Table 17). The whole-lake May through September mean TP is predicted to be 47 ug/L with a 35% external load reduction of phosphorus, but the South basin still had a May through September mean TP of 51 ug/L because of internal loading from the basin. Further load reduction is predicted to bring diminishing returns in reducing TP concentrations, because internal loading begins to be the dominating phosphorus source. The South basin was the most critical location for TP reduction due to this effect. Interestingly, if a 35% external reduction is achieved, the mean TP concentration in the whole lake above 6 meters, including the South basin, is predicted to be approximately 39 ug/L (conveniently close in agreement with the EPA TP criterion recommendation of 35 ug/L) if there is no internal load feedback. This indicates years with a low-mixing critical season (i.e., not a windy summer) will experience comparable water quality to, generally, the good water quality conditions of 2001.

Because of the dominating effect of internal loading after external load reduction, it is probably impractical to set a TP criterion any lower than the proposed 50 ug/L. It would be impossible to meet a lower TP criterion (e.g., 35 ug/L) without controlling internal loading.

Table 18 presents the May through September external TP loads during critical load conditions and the allocated maximum loads resulting after a 35% across-the-board reduction in TP load.

Table 17. Summary of CE-QUAL-W2 modeling results for critical load conditions with a 35% reduction of phosphorus from controllable external loads. All results are means for the specified time period and location.

	Branch 1 Parker Horn	Branch 2 South Basin	Branch 3 Lewis Horn	Branch 4 upper Rocky Ford Arm	Branch 4 lower Rocky Ford Arm	Branch 5,6,7,8 Pelican Horn	Whole Lake
May to September							
% dilution	19	9	22	3	8	7	8
TP concentration in whole column (ug/L)	**41**	**51**	**33**	**46**	**48**	**35**	**47**
TP concentration below 6m (ug/L)	85	85	0	67	99	44	92
TP concentration above 6m (ug/L)	35	37	33	46	37	35	39
TP mass in whole column (kg)	374	1185	55	1072	2137	282	5110
TP mass below 6m (kg)	59	580	0	27	811	2	1481
% TP mass below 6m	16%	49%	0%	2%	38%	1%	29%
% Volume below 6m	8%	29%	0%	2%	19%		
% increase to [TP] by including <6m	19%	38%	0%	1%	31%	0%	20%
May							
% dilution	23	4	31	1	4	3	7
TP concentration in whole column (ug/L)	**43**	**52**	**37**	**53**	**49**	**44**	**49**
TP concentration below 6m (ug/L)	73	71	0	63	79	53	75
TP concentration above 6m (ug/L)	37	31	37	52	35	44	45
TP mass in whole column (kg)	378	1183	59	1210	2158	346	5348
TP mass below 6m (kg)	51	483	0	25	645	3	1207
% TP mass below 6m	13%	41%	0%	2%	30%	1%	23%
% Volume below 6m	8%	30%	0%	2%	19%		
% increase to [TP] by including <6m	15%	69%	0%	2%	43%	0%	10%
June							
% dilution	31	16	37	4	15	12	14
TP concentration in whole column (ug/L)	**38**	**47**	**31**	**48**	**46**	**35**	**45**
TP concentration below 6m (ug/L)	72	74	0	66	89	41	81
TP concentration above 6m (ug/L)	33	26	31	47	30	35	39
TP mass in whole column (kg)	340	1100	50	1114	2032	275	4923
TP mass below 6m (kg)	50	502	0	26	732	2	1312
% TP mass below 6m	15%	46%	0%	2%	36%	1%	27%
% Volume below 6m	8%	29%	0%	2%	19%		
% increase to [TP] by including <6m	17%	84%	0%	2%	56%	0%	16%
July							
% dilution	17	11	18	4	9	7	8.9
TP concentration in whole column (ug/L)	**41**	**54**	**34**	**43**	**50**	**27**	**47**
TP concentration below 6m (ug/L)	124	115	0	97	140	45	127
TP concentration above 6m (ug/L)	31	20	34	41	24	27	33
TP mass in whole column (kg)	364	1227	55	983	2195	212	5046
TP mass below 6m (kg)	86	781	0	39	1143	2	2052
% TP mass below 6m	24%	64%	0%	4%	52%	1%	41%
% Volume below 6m	8%	30%	0%	2%	19%		
% increase to [TP] by including <6m	31%	175%	0%	4%	109%	0%	43%
August							
% dilution	13	7	14	3	6	6	6
TP concentration in whole column (ug/L)	**42**	**55**	**32**	**42**	**51**	**30**	**47**
TP concentration below 6m (ug/L)	106	111	0	66	133	41	120
TP concentration above 6m (ug/L)	34	23	32	41	26	30	35
TP mass in whole column (kg)	388	1300	54	999	2265	250	5249
TP mass below 6m (kg)	73	754	0	26	1090	2	1949
% TP mass below 6m	19%	58%	0%	3%	48%	1%	37%
% Volume below 6m	8%	29%	0%	2%	18%		
% increase to [TP] by including <6m	23%	138%	0%	3%	93%	0%	36%
September							
% dilution	9	5	8	2	5	7	5
TP concentration in whole column (ug/L)	**43**	**47**	**33**	**44**	**45**	**38**	**44**
TP concentration below 6m (ug/L)	50	55	0	40	53	42	53
TP concentration above 6m (ug/L)	39	31	33	43	35	38	43
TP mass in whole column (kg)	398	1109	57	1053	2030	327	4977
TP mass below 6m (kg)	34	374	0	16	433	2	859
% TP mass below 6m	9%	34%	0%	2%	21%	1%	17%
% Volume below 6m	7%	29%	0%	2%	18%		
% increase to [TP] by including <6m	9%	51%	0%	2%	27%	0%	3%

Table 18. External TP load contributions to Moses Lake (May through September) during critical load conditions and TP loads following 35% load reduction.

External Source	TP (kg)	TP load after 35% reduction (kg)
Crab Creek	1765	1147
Operational Feed	687	447
Groundwater	2150	1398
Columbia Basin Hatchery[1]	77	50
Columbia Basin Hatchery spring	1582	1028
Troutlodge Hatcheries[1]	398	259
Rocky Ford Creek	3089	2008

[1]Hatcheries contributions based on 2001 production levels

Margin of Safety

There were a number of implicit margin of safety factors or conservative assumptions used to evaluate the TP loading capacity of Moses Lake. A margin of safety is included to account for uncertainty related to the estimation of loads and loading capacity of Moses Lake.

The following assumptions were considered implicit margins of safety in the data evaluation and modeling:

- When evaluating model simulations, the entire water column TP was averaged for compliance with the TP criterion. Even though the algae grow in the euphotic zone, the entire water column was averaged because Moses Lake is polymictic (i.e., capable of mixing several times during the growing season). The potential entrainment of elevated hypolimnetic concentrations of TP was considered a margin of safety and included in the available TP pool. The hypolimnion represents less than 20% of the volume of the lake. During May through September 2001, the average seasonal whole column TP was 24% more than the average seasonal euphotic zone TP in the whole lake. This could be considered an implicit 24% margin of safety and account for the natural variation (uncertainty) associated with internal loading which has been shown to have a variability of up to 100% (Welch et al., 1989).

- The hydraulic conditions of 1980 were chosen to model critical flow conditions. The year represents an approximate 90th percentile flow for inflows from Rocky Ford Creek and Crab Creek and a 10th percentile flow for feed water through Rocky Coulee Wasteway (based on flow records from 1977-2001). The probability of these conditions occurring is approximately one in ten years on average, which Ecology considers an acceptable exceedance probability (i.e., approximately 10%).

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Conclusions

2000-01 Water Quality Study

The major findings of this report regarding the 2000-01 water quality study are as follows:

- Intensive sampling of Moses Lake and its vicinity was conducted from October 2000 through September 2001 (study period) to assess the status of the lake and its tributaries. In addition, a separate study of the water quality of groundwater directly entering Moses Lake was conducted (Pitz, 2003). The last intensive water quality study of Moses Lake was completed in 1988, summarized by Welch et al. (1989). This current report updates that work and complements the historical review and preliminary loading capacity evaluation by Carroll et al. (2000).

- Rocky Ford Creek and Crab Creek experienced low-flow conditions during the 2000/01 study period. Accordingly, the U.S. Bureau of Reclamation (USBR) delivered a large amount of feed water through Moses Lake. This had the effect of diluting Moses Lake during 2001, resulting in lower total phosphorus (TP) mass and algal biomass.

- The mean TP concentration for May through September 2001 for the whole lake was 38 ug/L. This was below the proposed TP criterion threshold of 50 ug/L. There were no excessive blooms of blue-green algae that threatened the beneficial uses of Moses Lake during 2001.

- Groundwater discharging directly to Moses Lake was found to be a substantial source of phosphorus to the lake. It was estimated that 24% of the phosphorus load to Moses Lake from May through September 2001 came from direct groundwater flux. Pitz (2003) found higher concentrations of phosphorus in the groundwater than found in the past, particularly associated with up-gradient urban wastewater sources.

- It was estimated that background and in-creek sources of Rocky Ford Creek contributed a total of 32% of the phosphorus to Moses Lake from May through September 2001. Additionally, the fish hatcheries on Rocky Ford Creek were estimated to contribute 6% of the phosphorus during the same period.

- As of 2001, there is no indication that TP and ortho-P concentrations in Rocky Ford Creek have changed from measured historical concentrations, suggesting that the mechanisms of anthropogenic contamination of phosphorus are the same as before and that restoration measures applied to date, including the detention pond on Rocky Ford Creek, have not succeeded. Though Crab Creek TP and ortho-P concentrations have declined dramatically since 1969-70s (attributed to a switch from surface rill or furrow irrigation to sprinkler irrigation), May through September 2001 ortho-P concentrations in Crab Creek were slightly higher than those observed in the 1980s.

- There was no winter/spring runoff event in Crab Creek in 2001, so the water quality of such an event could not be characterized.

Phosphorus Modeling

The major findings of this report regarding the phosphorus modeling are as follows:

- A hydrodynamic, unsteady-state model of temperature and water quality, based on the CE-QUAL-W2 model, was developed for Moses Lake and calibrated to the 2001 water quality data. The model was used to evaluate the capacity of the lake to assimilate TP loads from point and nonpoint sources and meet the recommended water quality criterion.

- This report concurs with the recommendation by Carroll et al. (2000) to establish a water quality TP criterion of 50 ug/L for Moses Lake. This criterion should be applied to the critical season of concern, May through September, when blue-green algae blooms take place.

- Using critical load conditions, representing approximately a 90th percentile phosphorus load to the lake, the lake model showed that an across-the- board 35% load reduction in TP from Rocky Ford Creek, Crab Creek, Rocky Coulee Wasteway baseflow, and groundwater was necessary to meet the proposed TP criterion with only a one-in-ten-year chance on average of exceeding the criterion (10% exceedance probability). Further load reduction was predicted to bring diminishing returns in reducing TP concentrations in the lake because internal loading begins to dominate as a phosphorus source. The model indicated that it probably would be impossible to meet a lower TP criterion (e.g., 35 ug/L) without controlling internal loading.

- Internal sediment release of phosphorus is an important loading source to Moses Lake, though apparently not as important as in earlier years. Because Moses Lake is polymictic, nearly all of the phosphorus released from the sediments may be available in the epilimnion during the growing season. This presents a definite restoration limitation for Moses Lake and a continued indication that it will remain eutrophic. However, reductions in phosphorus loading should reduce sediment concentrations and improve water quality over time, as may have been seen in 2001.

- A variable mixture of Crab Creek winter/spring flow and USBR feed water determine the initial water quality conditions of Moses Lake in the spring. Initial conditions of the water column in Moses Lake at the start of the growing season are important as far as the extent and magnitude of the spring diatom bloom, but may not be as important in late summer algal production. The replenishment of phosphorus, particularly ortho-P, from the tributaries and groundwater is necessary to fuel summer algal growth.

- Sufficient feed water through Moses Lake (i.e., dilution flow) can mitigate the excessive nutrient loading and undesirable algae growth during the summer. The lake model showed that a 50th percentile feed water addition to Moses Lake during critical load conditions will reduce average TP concentration below the 50 ug/L criterion. If this level could be provided annually, then the criterion is predicted to be met every year with only a 10% exceedance probability.

Recommendations

The following recommendations address strategies to reduce phosphorus loading to Moses Lake:

Dilution Strategies for Moses Lake

Dilution has been critical to achieving the water quality goals in Moses Lake since 1977. However, currently feed water is not supplied every year due to operational infrastructure limitations and/or legal contractual constraints in spilling feed water. The U.S. Bureau of Reclamation (USBR) only provides dilution water on an "as available" basis, primarily when there is need for feed water in the southern part of the Columbia Basin Irrigation Project. Dilution is a beneficial restorative management technique and may be necessary to achieve water quality goals in the future because of the persistence of phosphorus in the local aquifer. More precise management of feed water may be important for retaining enough total phosphorus (TP) (i.e., algal biomass) in Moses Lake to limit the expansion of macrophytes in the lake.

Alternate ways of providing annual feed water (dilution water), especially throughout the critical season of May through September, should be explored with the USBR. Allocation of reliable feed water to Moses Lake will depend largely on local interest in improving the lake's water quality. In order to be considered a permanent restoration technique for Moses Lake, the delivery of dilution water needs to be reliable.

Nonpoint Control of Winter/Spring Runoff from Crab Creek

Historically, during certain years Crab Creek experiences large winter/spring runoff events. These events are unpredictable and vary in size, but large events (>500 cfs) have occurred in 40% of the last 40 years. These flow events carry large TP loads to Moses Lake. Implementation of nonpoint controls and best management practices (BMPs) to improve the water quality of these watershed flushings is recommended. Examples would be the use of erosion controls and riparian buffers. BMPs might include better management of fertilizer application and irrigation water. Also testing of soils for phosphorus content may indicate the need for less phosphorus fertilizer application.

The water quality of Crab Creek winter/spring runoff events should be characterized at the point where they enter Moses Lake and at points upstream to identify source reaches. Characterization should include sampling for TP, ortho-P, nitrate, ammonia, total organic carbon, dissolved organic carbon, total suspended solids, and total non-volatile suspended solids. At a minimum, sampling should occur over several days, trying to capture the beginning, peak, and end of the runoff event.

Reduction of Phosphorus from Diffuse Nonpoint Sources Supplying Baseflow to Moses Lake from May through September

Groundwater in the Moses Lake vicinity needs to be protected from further nutrient loading. Unidentified, diffuse, nonpoint sources supply phosphorus to the baseflow of Rocky Ford Creek, Crab Creek, Rocky Coulee Wasteway, and groundwater entering Moses Lake directly. A watershed-wide 35% reduction of phosphorus from these sources is recommended. The recommendations put forth by Pitz (2003) should be followed.

Increased on-site septic systems and near-shore development have the greatest impacts on groundwater quality in the vicinity of Moses Lake. It is recommended that the city of Moses Lake and Grant County work together to develop and adopt local ordinances to reduce these impacts. The Columbia Basin Groundwater Management Area (GWMA), currently working on reducing nitrate in groundwater, may be able to provide assistance and resources for reducing phosphorus in groundwater.

Irrigation and fertilizer controls as well as management to control phosphorus were initiated in the mid-1980s, concentrating on the Crab Creek watershed, but the study project concluded in 1990. It is recommended to continue the implementation of existing BMPs and apply more extensive BMPs on agricultural lands within the Moses Lake vicinity. The GWMA or the Moses Lake Irrigation and Rehabilitation District may be able to provide assistance in implementing BMPs.

Reduction of Phosphorus from Point Sources

While controls are being designed for groundwater TP sources, TP limits for the fish hatcheries also should be established. The same 35% reduction in phosphorus recommended for nonpoint sources should be applied to fish hatcheries.

Nutrient limits for fish hatcheries on Rocky Ford Creek also may address the dissolved oxygen and pH listings for the creek. During the 2001 water quality study, the reaches immediately below the fish hatcheries on Rocky Ford Creek were more likely to violate dissolved oxygen standards.

Kendra (1989) and Cusimano and Ward (1998) recommended that phosphorus reduction could be achieved through reduced fish production during critical seasons. For Moses Lake this would be May through September. Also the use of low-phosphorus feed and decreased food wastage may reduce phosphorus. In some cases, enhanced wastewater treatment may be required. The Columbia Basin Hatchery should clean their abatement pond more regularly. Personnel for the state Department of Fish and Wildlife indicated they are considering installing a new wastewater treatment system for the Columbia Basin Hatchery. Kendra (1989) also lists operational BMPs to reduce solids.

Upstream and downstream phosphorus monitoring during May through September should be required of the hatcheries and reported in the discharge monitoring report.

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Appendix A

Key to Box Plots

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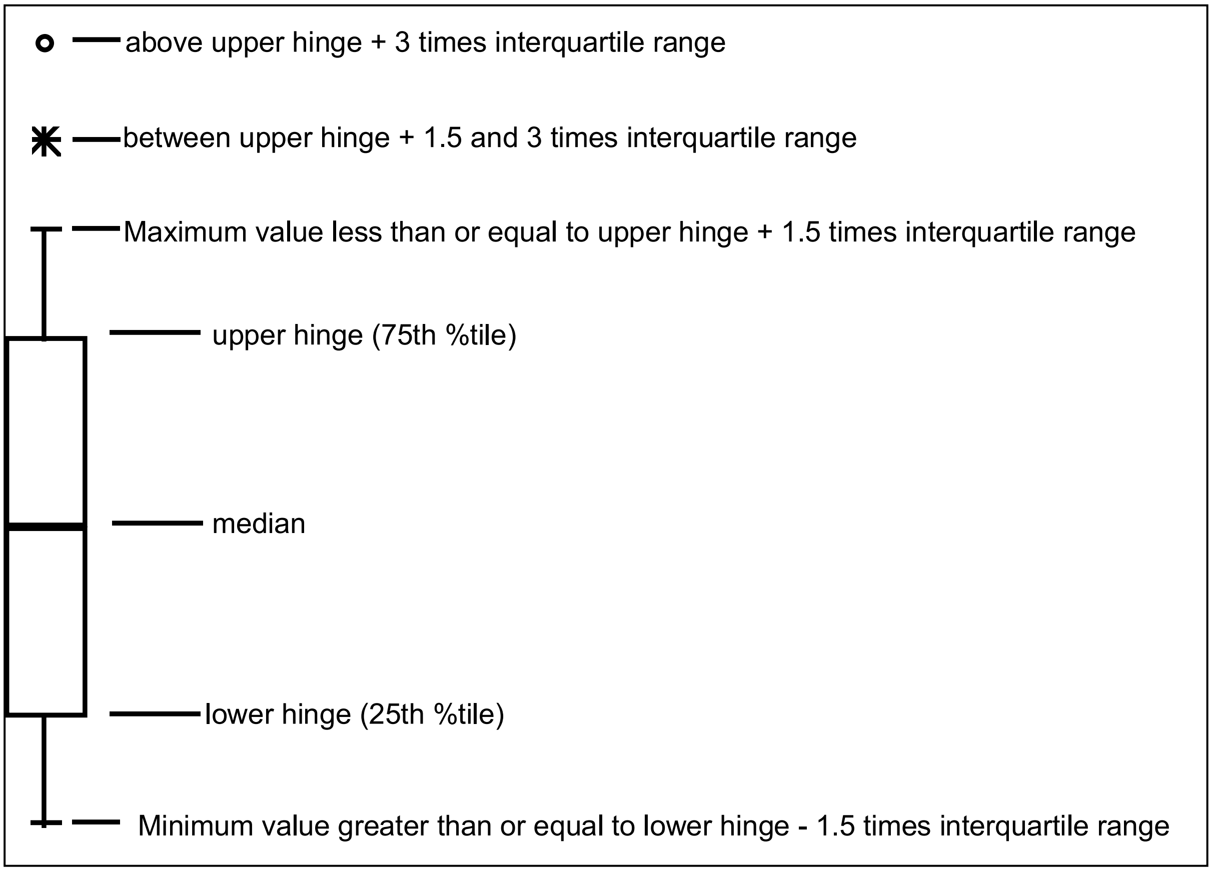
Appendix A. Key to Box Plots



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Appendix B

Field and Laboratory Data

Table B-1 - page 1. Field and Laboratory Data

station	date	time	depth (m)	Chlorophyll (ug/L) (SM10200H3M)	Total Suspended Solids (mg/L) (EPA160.2)	Total Persulfate Nitrogen (mg/L) (SM4500NB)	Total Organic Carbon (mg/L) (EPA415.1)	Total Non-Volatile Suspended Solids (mg/L) (EPA160.4)	Total Dissolved Solids (mg/L) (EPA160.1)	Total Alkalinity (mg/L) (SM2320)	Total Alkalinity (mg/L) (EPA310.2)	Sulfate (mg/L) (EPA300.0)	Temperature, water (deg C) (TEMPTHERM)	Silicon (ug/L) (EPA200.7)	Phosphorus (mg/L) (SM4500PI)
CBH-A	4/9/01		0			2.25									0.207
CBH-A	8/6/01		0			1.5									0.16
CBH-A	7/2/01		0			1.69 J									0.093 J
CBH-A	6/11/01		0			1.5									0.153
CBH-A	5/7/01		0			1.61									0.129
CBH-A	9/20/01		0			1.82 J									
CBH-D	4/24/01	14:50	0			3.02									0.103
CBH-D	8/28/01	11:45	0			2.38				245			16.22		0.075
CBH-D	7/31/01	11:50	0			3.18				245			16.2		0.074
CBH-D	6/26/01	14:30	0			3.34				253			16.38		0.098
CBH-D	5/29/01	12:45	0			3.06									0.062
CBH-D	9/25/01	14:55	0		1	2.36 J		1 U	330	252			14.86		
CBH-E	4/9/01		0			3.74									0.107
CBH-E	8/6/01		0			2.63									0.086
CBH-E	7/2/01		0			2.85 J									0.071 J
CBH-E	6/11/01		0			2.57									0.102
CBH-E	5/7/01		0			3.79									0.089
CBH-E	9/20/01		0			2.44 J									
CBH-I	4/9/01		0			4.01									0.089
CBH-I	4/24/01	14:40	0			2.92							16.9		0.086
CBH-I	8/6/01		0			2.59									0.073
CBH-I	8/28/01	11:30	0			2.36				246			15.02		0.067
CBH-I	7/2/01		0			3.16 J									0.064 J
CBH-I	7/31/01	11:30	0			3.05				247			15.5		0.067
CBH-I	6/11/01		0			3.37									0.086
CBH-I	6/26/01	14:05	0			3.33				264			15.84		0.079
CBH-I	5/7/01		0			2.93									0.073
CBH-I	5/29/01	12:10	0			3.34							15.8		0.059
CBH-I	9/20/01		0			3.43 J									
CBH-I	9/25/01	14:45	0		2	2.51 J		1	335	251			14.78		
CC0	4/23/01	16:30	0		4	0.102			86 J		66.1		8.75		0.013
CC0	4/24/01	16:10	0	4.75	3.5	0.073	1.5		76 J		65.9		10.12		0.013
CC0	8/27/01	16:10	0		2	0.487		2	134	104					0.017
CC0	8/27/01	18:00	0										18.96		
CC0	8/28/01	10:35	0	2.1 J	2	0.4985	2.05	1.5	141	107			18.89		0.0175
CC0	7/30/01	18:00	0		2	1		2	223	168					0.027
CC0	7/31/01	18:00	0										22.27		
CC0	7/31/01	10:25	0	1.83 J	1.5 U	1.1575	2.25 J	1 U	244.5	178.5			17.28		0.024
CC0	6/25/01	14:45	0		6	0.176			107	79.1					0.018
CC0	6/26/01	16:50	0	2.7	3	0.243	2		126	93.3			18.76		0.014
CC0	3/26/01	11:50	0	14	10	0.152	2		90		66.9		5.73		
CC0	5/29/01	10:45	0	2.55 J	4	0.1215	1.45 J		94	69.5			13.98		0.016
CC0	9/25/01	15:30	0		2	0.493 J		1 U	140	104			16.88	5920	
CC0	9/25/01	7:45	0	2 J	2	0.434 J	1.5	1	127	95.3			16.64		
CC1	4/24/01	14:05	0	8.6	6	0.203	3.4		218 J		189		17.3		0.037
CC1	8/28/01	13:10	0	6.7	7	0.892	3		296	241			21.15		0.037
CC1	7/31/01	13:10	0	5.22	9	0.663	3.1 J		259	206			21.01		0.034
CC1	6/26/01	13:40	0	12.3	12	0.785	3.1		263	207			18.5		0.039
CC1	3/26/01	14:20	0	30.55	11	0.5845	6.15		378 J		303.5		13.63		
CC1	5/29/01	13:45	0	9.8	9	1.07	2.9 J		274	218			17.96		0.036
CC1	9/25/01	8:10	0	5.5 J	5	0.887 J	2.7	4	316	251			13.8		
CC2	4/24/01	13:30	0		21	0.359									0.049
CC2	8/28/01	13:30	0		5	0.893							21.38		0.036

Table B-1 - page 2. Field and Laboratory Data

Phosphorus (mg/L) (SM4500PH)	Phosphorus (mg/L) (EPA365.1)	pH (pH) (WASPH)	Ortho-Phosphate (mg/L) (SM4500PG)	Ortho-Phosphate (mg/L) (EPA365.3M)	Nitrite-Nitrate (mg/L) (SM4500NO3I)	Dissolved Oxygen (mg/L) (DOFM)	Dissolved Organic Carbon (mg/L) (EPA415.1)	Turbidity (NTU) (SM2130)	Conductivity (umhos/cm) (EPA120.1)	Conductivity (umhos/cm) (CONDMETER)	Chloride (mg/L) (EPA300.0)	Flow (cfs) (MIDSECTION)	Ammonia (mg/L) (SM4500NH3H)	Ammonia (mg/L) (EPA350.1)
					1.98									0.071
					1.25								0.179	
					1.26 J								0.16 J	
					1.07								0.224	
					1.33								0.096	
0.116 J					1.51								0.226	
		8.23		0.07	2.74				557	508	4.74			0.092
		7.98	0.064		2.03	9.19			503	472	4.22	18.5	0.064	
		8.02	0.058		2.29	10.04			498	496	4.1	20.14	0.048	
		8.05	0.052		2.73	10.65			515	485.9	4.4	14.47	0.054	
			0.046		2.7				521		4.1	14.04	0.04	
0.063 J		7.86	0.071		2.13	8.14			511	506	3.72		0.073	
					2.82									0.089
					2.33								0.035	
					2.63 J								0.047 J	
					2.63								0.055	
					2.86								0.045	
0.056 J					2.28								0.04	
					2.85									0.01 U
		8.05		0.055	2.68				564	516	4.34			0.01 U
					2.28								0.01 U	
		7.87	0.056		1.95	10.32			505	482	4.17		0.01 U	
					2.78 J								0.01 UJ	
		7.92	0.052		2.39	10.48			503	505	4.24		0.01 UJ	
					2.76								0.01 U	
		7.83	0.049		2.96	9.5			538	504.6	4.71		0.01 U	
					2.8								0.01 U	
		7.96	0.044		2.77	11.27			541	521	4.25		0.01 U	
0.043 J					2.22								0.01 U	
0.043 J		7.67	0.0555		2.23	8.81			509	505	3.53		0.01 U	
		8.71			0.03	13			150	130.8	1.02			0.01 U
		8.79		0.005 U	0.027	12.61	1.5	1.4	150	131.3	0.971			0.01 U
					0.395				235		1.93		0.01 U	
		8.33				10.6				385				
		8.14	0.0115		0.4085	9.47	1.85	1.25	241.5	226	2.015		0.01 U	
					0.859				352		3.22		0.01 U	
		8.94				13.5				353				
		8.31	0.0145		0.992	10.9	2 J	0.8	385.5	376	3.605		0.01 U	
			0.006		0.096				178		1.18		0.01 U	
		8.5	0.007		0.15	11.17	1.9	1.4	206	181.5	1.37		0.011	
	0.022	8.13		0.005 U	0.051		1.9	3.8	155	130.9	1.2			0.01 U
		8.4	0.005 U		0.06	10.65	1.4 J	1.55	157	146.4	0.8945		0.01 U	
0.014 J		8.15	0.011		0.376	9.22			234	225	1.87		0.01 U	
0.013 J		7.96	0.01		0.321	8.68	1.6	0.8	216	217	1.68		0.01 U	
		9.11		0.008	0.025		3.3	3.3	378	339	4.08			0.012
		8.32	0.016		0.67	12.13	2.5	3.8	472	447	3.11		0.014	
		8.43	0.014		0.438	12.17	2.8 J	4.1	412	408	2.56		0.01 U	
		8.21	0.012		0.626	11.74	2.7	5.6	414	377.7	3.02		0.015	
	0.084	8.71		0.02	0.2635		5.4	5.4	595	533	7.55			0.012
		8.96	0.012		0.895	14.35	2.9 J	4.6	431	413	3.8		0.015	
0.021 J		8.08	0.015		0.695	7.38	2.6	2.8	497	490	3.09		0.01 U	
		8.91		0.007	0.184				347	312	3.78	6.21		0.022
		8.51	0.017		0.722	13.39			392	371	2.29	23.33	0.01 U	

Table B-1 - page 3. Field and Laboratory Data

station	date	time	depth (m)	Chlorophyll (ug/L) (SM10200H3M)	Total Suspended Solids (mg/L) (EPA160.2)	Total Persulfate Nitrogen (mg/L) (SM4500NB)	Total Organic Carbon (mg/L) (EPA415.1)	Total Non-Volatile Suspended Solids (mg/L) (EPA160.4)	Total Dissolved Solids (mg/L) (EPA160.1)	Total Alkalinity (mg/L) (SM2320)	Total Alkalinity (mg/L) (EPA310.2)	Sulfate (mg/L) (EPA300.0)	Temperature, water (deg C) (TEMPTHERM)	Silicon (ug/L) (EPA200.7)	Phosphorus (mg/L) (SM4500PI)
CC2	7/31/01	13:35	0		4	0.827							21.25		0.03
CC2	6/26/01	13:00	0		5	0.93							17.1		0.031
CC2	3/26/01	16:32	0		30	0.838									
CC2	5/29/01	14:10	0		9	1.17							18.54		0.034
CC2	9/25/01	14:00	0		8	1 J							15.13		
CC3	4/24/01	12:55	0		12	0.292							16.7		0.043
CC4	4/24/01	11:40	0		17	2.31							16.47		0.08
CC4	8/28/01	14:20	0	7.8	9	6.16	3		390	249			25.14		0.04
CC4	7/31/01	14:20	0	5.81	12	5.66	3 J		370	222			25.46		0.047
CC4	6/26/01	11:10	0	29.5	11.5	3.5	3.6		391	253.5			17.95		0.061
CC4	3/26/01	15:10	0	107	42	2.19	5.5		301		201		14.98		
CC4	5/29/01	14:55	0		14	1.28			381	264			21.95		0.057
CC4	9/25/01	9:15	0	2.9 J	4	5.46 J	2.4	3	274 J	283			15.55		
CC5	4/24/01	11:00	0		5	0.064							11.37		0.015
CC6	4/24/01	9:55	0	29.5 J	26	0.313	6.9		272 J		172		12.1		0.076
CC6	5/29/01	15:35	0										18.29		
CC6	5/29/01	15:45	0		21	0.34				184					0.061
ML1	4/25/01	13:41	0.5										15.05		
ML1	4/25/01	13:43	1										13.8		
ML1	4/25/01	13:45	0.4	10.2 J		0.177									0.017
ML1	4/25/01	13:45	2										13.47		
ML1	4/25/01	13:45	3										13.1		
ML1	4/25/01	13:45	4										12.51		
ML1	4/25/01	13:46	5										12.13		
ML1	4/25/01	13:49	6										11.39		
ML1	4/25/01	13:55	0.5	7.2 J		0.15	2.3		157		116				0.015
ML1	4/25/01	14:05	3	11.9 J		0.234	2.7		174		128				0.033
ML1	4/25/01	14:15	5	36.6 J		0.431	3.4		200		149				0.031
ML1	8/1/01	14:30	0.4	33.9		0.427									0.043
ML1	8/1/01	14:44	0.5										23.63		
ML1	8/1/01	14:44	1										23.63		
ML1	8/1/01	14:45	2										23.62		
ML1	8/1/01	14:45	3										23.02		
ML1	8/1/01	14:46	4										22.46		
ML1	8/1/01	14:47	5										22.36		
ML1	8/1/01	14:48	6										21.96		
ML1	8/1/01	15:00	0.5	35.4		0.367	3.5 J		167	130					0.04
ML1	8/1/01	15:05	3	36	13	0.3155	3.6 J	7	172	130					0.0235
ML1	8/1/01	15:20	5	20.1		0.493	3.1 J		179	133					0.055
ML1	8/29/01	13:27	0.4	16.8		0.333									0.017
ML1	8/29/01	13:36	0.5										24.64		
ML1	8/29/01	13:43	5										20.92		
ML1	8/29/01	13:50	0.5	23.3		0.344	3.6		151	116					0.02
ML1	8/29/01	14:05	0.5	25.8	7	0.333	2.9	3	156	116					0.017
ML1	8/29/01	14:15	3	59.8	18	0.3345	4.3	10	159	119					0.0205
ML1	8/29/01	14:27	5	29.5		0.808	3.4		193	140					0.032
ML1	8/29/01		1										24		
ML1	8/29/01		2										22.86		
ML1	8/29/01		3										22.27		
ML1	8/29/01		4										21.3		
ML1	8/29/01		5												
ML1	8/29/01		6										20.87		
ML1	7/2/01		1										23.44		

Table B-1 - page 4. Field and Laboratory Data

Phosphorus (mg/L) (SM4500PH)	Phosphorus (mg/L) (EPA365.1)	pH (pH) (WASPH)	Ortho-Phosphate (mg/L) (SM4500PG)	Ortho-Phosphate (mg/L) (EPA365.3M)	Nitrite-Nitrate (mg/L) (SM4500NO3I)	Dissolved Oxygen (mg/L) (DOFM)	Dissolved Organic Carbon (mg/L) (EPA415.1)	Turbidity (NTU) (SM2130)	Conductivity (umhos/cm) (EPA120.1)	Conductivity (umhos/cm) (CONDMETER)	Chloride (mg/L) (EPA300.0)	Flow (cfs) (MIDSECTION)	Ammonia (mg/L) (SM4500NH3H)	Ammonia (mg/L) (EPA350.1)
		8.57	0.013		0.658	13.01			375	370	2.43	23.25	0.01 U	
		8.38	0.012		0.782	12.22			384	354.9	3.02	21.36	0.01 U	
	0.108			0.011	0.441				581		8.12			0.032
		8.76	0.013		1.01	13.75			409	395	3.59	13.5	0.013	
0.025 J		8.35	0.017		0.824	11.35			408	401	2.65	19.58	0.01 U	
		8.65		0.009	0.022					483	9.54	0.23		0.034
		8.9		0.01	1.98					446	13.8	0.58		0.048
		8.45	0.014		4.58		2.5	5.5	597	579	14	1.16	0.024	
		8.5	0.012		4.5	13.71	2.8 J		562	556	14.3	0.83	0.038	
		8.17	0.0125		2.955	10.09	3.2	7.6	595	557.8	14.35	1.15	0.0445	
	0.096	8.93		0.008	1.88		3	19	479	436	13	0.35		0.023
		8.68	0.015		0.945	12.6			583	569	14.2	0.5	0.042	
0.014 J		8.15	0.014		4.91	12.65	2.4	3.3	653	650	12.2	1.23	0.017	
		8.25		0.005 U	0.01 U					117.9	0.83	2.63		0.01 U
		8.56		0.006	0.01 U		6.8	21	448	402	14.8	14.51		0.035
		8.55				7.4				459				
			0.009		0.013						14.3		0.042	
		9.3				12.15				233				
		9.32				12.54				233				
				0.005 U	0.042									0.01 U
		9.34				12.66				235				
		9.36				12.94				268				
		9.35				13.05				290				
		9.19				10.79				305				
		9				7.36				310				
				0.005 U	0.014		2.1	2.2	260		4.47			0.01 U
				0.005 U	0.055		2.3	4.3	288		5.33			0.017
				0.005 U	0.211		3.1				7.12			0.013
			0.006		0.01 U								0.01 UJ	
		8.99				11.03				284				
		8.99				11.02				284				
		8.98				10.97				285				
		8.94				9.97				282				
		8.83				8.04				287				
		8.71				7.12				289				
		8.16				1.38				310				
			0.005		0.01 U		2.9 J	9.3	286		4.47		0.01 UJ	
			0.006		0.01 U		2.9 J	9.7	286		4.47		0.01 UJ	
			0.014		0.019		2.7 J				4.41		0.028	
			0.005 U		0.01 U								0.01 U	
		9.09				12.58				246				
			0.005 U		0.01 U		3	4.9	257		4.36		0.01 U	
			0.005 U		0.01 U		3.6 J	5.1	260		4.36		0.01 U	
			0.005 U		0.01 U		3	11	267		4.73		0.01 U	
			0.006		0.174		2.9				5.34		0.255	
		9.12				13.19				244				
		9.16				13.56				248				
		9				9.22				255				
		8.72				5.56				279				
		8.36				2.07				295				
		8.1				0.25				301				
		8.95				11.96				261				

Table B-1 - page 5. Field and Laboratory Data

station	date	time	depth (m)	Chlorophyll (ug/L) (SM10200H3M)	Total Suspended Solids (mg/L) (EPA160.2)	Total Persulfate Nitrogen (mg/L) (SM4500NB)	Total Organic Carbon (mg/L) (EPA415.1)	Total Non-Volatile Suspended Solids (mg/L) (EPA160.4)	Total Dissolved Solids (mg/L) (EPA160.1)	Total Alkalinity (mg/L) (SM2320)	Total Alkalinity (mg/L) (EPA310.2)	Sulfate (mg/L) (EPA300.0)	Temperature, water (deg C) (TEMPTHERM)	Silicon (ug/L) (EPA200.7)	Phosphorus (mg/L) (SM4500PI)
ML1	7/2/01		2										22.52		
ML1	7/2/01		3										22.23		
ML1	7/2/01		4										21.98		
ML1	7/2/01		5										19.49		
ML1	7/2/01		6										18.94		
ML1	7/2/01	12:25	0.4	9.1											
ML1	7/2/01	12:30	0.5										23.6		
ML1	7/2/01	12:40	0.5	7.6		0.171	3.8		157	121					0.016
ML1	7/2/01	12:45	3	5.9		0.162	3.7		152	121					0.015
ML1	7/2/01	12:55	5	17		0.593	3.6		193	148					0.038
ML1	3/28/01	13:00	1										8.73		
ML1	3/28/01	13:02	2										8.62		
ML1	3/28/01	13:03	3										8.6		
ML1	3/28/01	13:03	4.5										8.62		
ML1	3/28/01	13:30	0.5	58.6			3.4		379		175				
ML1	3/28/01	13:45	3	47.8			3.2		248		180				
ML1	3/28/01	12:52	0.5										9.05		
ML1	5/30/01	9:25	0.4	18.4 J		0.336									0.024
ML1	5/30/01	9:39	0												
ML1	5/30/01	9:42	0.5										17.08		
ML1	5/30/01	9:43	1										16.89		
ML1	5/30/01	9:44	2										16.86		
ML1	5/30/01	9:44	3										16.59		
ML1	5/30/01	9:45	4										16.32		
ML1	5/30/01	9:46	5										16.02		
ML1	5/30/01	9:47	6										16.4		
ML1	5/30/01	9:55	0.5	15.1		0.329	2.9 J		178	133					0.021
ML1	5/30/01	10:10	3	16		0.316	3.2 J		177	133					0.023
ML1	5/30/01	10:20	5	14.7		0.328	3.1 J		172	133					0.03
ML1	9/26/01	13:11	0.5										18.85		
ML1	9/26/01	13:11	1										18.85		
ML1	9/26/01	13:12	2										18.82		
ML1	9/26/01	13:13	3										18.79		
ML1	9/26/01	13:13	4										18.77		
ML1	9/26/01	13:14	5										18.75		
ML1	9/26/01	13:14	6										18.73		
ML1	9/26/01	13:20	0.5	12.7		0.682 J	3.4 J		162	118					
ML1	9/26/01	13:25	3	13.05	6	0.50425 J	3.2	3	162	117				5170	
ML1	9/26/01	13:50	5	14.2		0.455 J	3.2		165	117					
ML2	4/25/01	11:52	0.5										12.38		
ML2	4/25/01	11:54	1										11.62		
ML2	4/25/01	11:55	2										11.39		
ML2	4/25/01	11:56	3										11.16		
ML2	4/25/01	11:57	4										10.85		
ML2	4/25/01	11:58	5										10.68		
ML2	4/25/01	11:59	6										10.4		
ML2	4/25/01	12:00	7										9.73		
ML2	4/25/01	12:02	7.8										9.35		
ML2	4/25/01	12:05	0.5	6.9 J		0.105	1.9		124		96.3				0.012
ML2	4/25/01	12:15	3	12.5 J		0.127	2.3		122		100				0.016
ML2	4/25/01	12:25	6	21.8 J		0.16	1.8		146		111				0.023
ML2	4/25/01	12:50	0.4	11.2 J		0.131									0.014
ML2	8/1/01	15:45	0.4	14.5		0.462									0.048

Phosphorus (mg/L) (SM4500PH)	Phosphorus (mg/L) (EPA365.1)	pH (pH) (WASPH)	Ortho-Phosphate (mg/L) (SM4500PG)	Ortho-Phosphate (mg/L) (EPA365.3M)	Nitrite-Nitrate (mg/L) (SM4500NO3I)	Dissolved Oxygen (mg/L) (DOFM)	Dissolved Organic Carbon (mg/L) (EPA415.1)	Turbidity (NTU) (SM2130)	Conductivity (umhos/cm) (EPA120.1)	Conductivity (umhos/cm) (CONDMETER)	Chloride (mg/L) (EPA300.0)	Flow (cfs) (MIDSECTION)	Ammonia (mg/L) (SM4500NH3H)	Ammonia (mg/L) (EPA350.1)
		9				12.17				260				
		9.01				12.41				260				
		9				12.12				260				
		8.18				1.92				303				
		7.9				1.12				333				
		8.95				11.73				262				
			0.006		0.01 U		3.5 J	4.4	269		4.31		0.01 U	
			0.005 U		0.01 U		3.2 J	4.7	266		4.28		0.01 U	
			0.013		0.063		3	10.5			4.74		0.291	
		8.8								347				
		8.79								349				
		8.77								349				
		8.75								353				
	0.051			0.006	0.379		2.3	9.9	390		7.88			0.013
	0.054			0.006	0.369		2.2	9.9	396		7.97			0.015
		8.85								343				
			0.005 U		0.114								0.024	
						10.8								
		9.04				10.79				300				
		9.04				10.66				301				
		9.03				10.67				301				
		9.02				10.57				301				
		9				10.56				304				
		8.99				10.66				306				
		8.96				10.16				301				
			0.005 U		0.117		2.7 J	4.9	299		5.18		0.026	
			0.005 U		0.113		2.6 J	5.2	299		5.14		0.026	
			0.005 U		0.111		2.6 J				5.15		0.03	
		8.78				7.72				263				
		8.79				7.8				262				
		8.82				7.99				262				
		8.84				8.07				262				
		8.85				8.15				262				
		8.85				8.15				262				
		8.85				8.04				262				
0.023 J			0.0036		0.059		2.8	4.1	267		4.47		0.093	
0.016 UJ			0.0038		0.0585		2.75	4.1	268		4.395		0.0875	
0.023 J			0.0036		0.056		2.8				4.34		0.077	
		9.18				12.15				197				
		9.16				12.32				180				
		9.22				12.64				192				
		9.32				12.84				212				
		9.29				12.84				221				
		9.22				11.7				219				
		9.08				10.53				219				
		8.84				8.6				219				
		8.48				5.75				224				
				0.005 U	0.01 U		1.8	2	217		3			0.01 U
				0.005 U	0.01 U		1.9	3.2	225		3.31			0.01 U
				0.005 U	0.014		2.7	5.1			3.95			0.01 U
				0.005 U	0.01 U									0.01 U
			0.024		0.01 U								0.133	

Table B-1 - page 7. Field and Laboratory Data

station	date	time	depth (m)	Chlorophyll (ug/L) (SM10200H3M)	Total Suspended Solids (mg/L) (EPA160.2)	Total Persulfate Nitrogen (mg/L) (SM4500NB)	Total Organic Carbon (mg/L) (EPA415.1)	Total Non-Volatile Suspended Solids (mg/L) (EPA160.4)	Total Dissolved Solids (mg/L) (EPA160.1)	Total Alkalinity (mg/L) (SM2320)	Total Alkalinity (mg/L) (EPA310.2)	Sulfate (mg/L) (EPA300.0)	Temperature, water (deg C) (TEMPTHERM)	Silicon (ug/L) (EPA200.7)	Phosphorus (mg/L) (SM4500PI)
ML2	8/1/01	16:30	0.5	12.1	5	0.4415	3.4 J	2	175	132					0.037
ML2	8/1/01	16:45	3	11.2	5	0.4635	3.3 J	4	173	132					0.0395
ML2	8/1/01	17:10	6	9.94	5	0.4815	3.2 J	4	170	133					0.04
ML2	8/1/01	8:10	0.5										22.59		
ML2	8/1/01	8:10	1										22.53		
ML2	8/1/01	8:11	2										22.01		
ML2	8/1/01	8:12	3										21.7		
ML2	8/1/01	8:13	4										21.63		
ML2	8/1/01	8:14	5										21.55		
ML2	8/1/01	8:15	6										21.5		
ML2	8/1/01	8:16	7										21.43		
ML2	8/1/01		3	11.4	4	0.4895	3.3 J	2	173	132					0.0465
ML2	8/14/01	15:10	0.5										27.02		
ML2	8/14/01		1										26.53		
ML2	8/14/01		2										25.46		
ML2	8/14/01		3										25.25		
ML2	8/14/01		4										24		
ML2	8/14/01		5										22.86		
ML2	8/14/01		6										22.44		
ML2	8/14/01		7										22.16		
ML2	8/14/01		8										21.54		
ML2	8/15/01	17:38	0.5										27.39		
ML2	8/15/01	8:36	0.5										25.48		
ML2	8/15/01		1										25.765		
ML2	8/15/01		2										25.56		
ML2	8/15/01		3										24.57		
ML2	8/15/01		4										23.55		
ML2	8/15/01		5										22.665		
ML2	8/15/01		6										22.335		
ML2	8/15/01		7										21.91		
ML2	8/15/01		8										21.48		
ML2	8/16/01	17:45	0.5										27.5		
ML2	8/16/01		1										26.11		
ML2	8/16/01		2										25.62		
ML2	8/16/01		3										25.01		
ML2	8/16/01		4										23.27		
ML2	8/16/01		5										22.52		
ML2	8/16/01		6										22.28		
ML2	8/16/01		7										21.98		
ML2	8/16/01		8										21.51		
ML2	8/29/01	14:56	0.4	6.9		0.254									0.011
ML2	8/29/01	15:30	0.5	8.5	5	0.258	3	3	137	113					0.0125 U
ML2	8/29/01	15:42	3	20.6	12	0.256	4	7	150	111					0.013 U
ML2	8/29/01	15:53	6	47.8	11	0.301	4.1	6	154	118					0.0145
ML2	8/29/01	16:07	0.5										24.24		
ML2	8/29/01		1										23.82		
ML2	8/29/01		2										22.98		
ML2	8/29/01		3										22.12		
ML2	8/29/01		4										21.8		
ML2	8/29/01		5										21.59		
ML2	8/29/01		6										21.38		
ML2	8/29/01		7										20.92		
ML2	8/29/01		8										19.96		

Phosphorus (mg/L) (SM4500PH)	Phosphorus (mg/L) (EPA365.1)	pH (pH) (WASPH)	Ortho-Phosphate (mg/L) (SM4500PG)	Ortho-Phosphate (mg/L) (EPA365.3M)	Nitrite-Nitrate (mg/L) (SM4500NO3I)	Dissolved Oxygen (mg/L) (DOFM)	Dissolved Organic Carbon (mg/L) (EPA415.1)	Turbidity (NTU) (SM2130)	Conductivity (umhos/cm) (EPA120.1)	Conductivity (umhos/cm) (CONDMETER)	Chloride (mg/L) (EPA300.0)	Flow (cfs) (MIDSECTION)	Ammonia (mg/L) (SM4500NH3H)	Ammonia (mg/L) (EPA350.1)
			0.026		0.01 U		3 J	3.6	292		4		0.143	
			0.03		0.01 U		3.1 J	3.6	294		4		0.167	
			0.03		0.01 U		3.1 J	4.6	294		3.95		0.182	
		8.51				6.83				291				
		8.48				6.55				291				
		8.37				5.37				292				
		8.27				4.49				292				
		8.22				4.65				294				
		8.26				4.6				295				
		8.25				4.89				291				
		8.12				3.46				295				
			0.03		0.01 U		3 J	3.8	291		4.01		0.163	
		9.11				14.2				239				
		9.16				14.7				238				
		9.11				14.73				244				
		8.98				12.4				246				
		8.75				10.4				256				
		8.2				4.2				280				
		7.96				2.2				284				
		7.86				1.25				287				
		7.66				0.2				307				
		9.06				14.15				236				
		9.06				12.95				239				
		9.075				14.245				237.5				
		9.09				14.53				237				
		8.705				7.37				262.5				
		8.385				5.03				273				
		8.02				2.705				281.5				
		7.865				1.4				285.5				
		7.76				0.23				291.5				
		7.63				0.22				306				
		8.93				13.81				245				
		9.02				14.69				242				
		9.15				16.41				233				
		9.05				14.54				234				
		8.12				2.7				280				
		7.82				1.3				286				
		7.75				0.26				287				
		7.69				0.2				294				
		7.56				0.18				313				
			0.005 U		0.01 U								0.01 U	
			0.005 U		0.01 U		2.8	3.3	248		3.86		0.01 U	
			0.005 U		0.01 U		2.7	5.7	243		3.71		0.01 U	
			0.005 U		0.011		2.6	4.8	266		3.81		0.034	
		9.07				13.9				236				
		9.09				14.55				237				
		9.12				14.48				232				
		9.1				14.12				232				
		9.08				13.55				239				
		8.91				9.49				250				
		8.52				5.97				250				
		8.16				2.89				240				
		7.82				0.22				227				

Table B-1 - page 9. Field and Laboratory Data

station	date	time	depth (m)	Chlorophyll (ug/L) (SM10200H3M)	Total Suspended Solids (mg/L) (EPA160.2)	Total Persulfate Nitrogen (mg/L) (SM4500NB)	Total Organic Carbon (mg/L) (EPA415.1)	Total Non-Volatile Suspended Solids (mg/L) (EPA160.4)	Total Dissolved Solids (mg/L) (EPA160.1)	Total Alkalinity (mg/L) (SM2320)	Total Alkalinity (mg/L) (EPA310.2)	Sulfate (mg/L) (EPA300.0)	Temperature, water (deg C) (TEMPTHERM)	Silicon (ug/L) (EPA200.7)	Phosphorus (mg/L) (SM4500PI)
ML2	7/2/01	14:40	0.4	3.8											
ML2	7/2/01	14:45	0.5										22.82		
ML2	7/2/01	15:00	0.5	6.7		0.144			147	116					0.011
ML2	7/2/01	15:10	3	7.1		0.156	3.3		153	119					0.019
ML2	7/2/01	15:20	6	5.5		0.407	3.4		174	132					0.039
ML2	7/2/01		1										22.01		
ML2	7/2/01		2										21.27		
ML2	7/2/01		3										21.08		
ML2	7/2/01		4										20.8		
ML2	7/2/01		5										19.42		
ML2	7/2/01		6										19.11		
ML2	7/2/01		7										18.73		
ML2	7/2/01		8										18.17		
ML2	3/28/01	14:47	0.5										6.68		
ML2	3/28/01	14:47	0												
ML2	3/28/01	14:49	1.5										7.04		
ML2	3/28/01	14:50	3										8.08		
ML2	3/28/01	14:51	4.5										8.16		
ML2	3/28/01	14:52	6										8.16		
ML2	3/28/01	15:00	0.5	12.9			2.2		127		98.4				
ML2	3/28/01	15:10	3	28.6			3		195		143				
ML2	3/28/01	15:25	6	37.3			3.1		252		181				
ML2	5/30/01	10:50	0.4	4.1		0.358									0.032
ML2	5/30/01	11:02	0.5										17.33		
ML2	5/30/01	11:03	1										17.3		
ML2	5/30/01	11:03	2										17.26		
ML2	5/30/01	11:04	3										17.22		
ML2	5/30/01	11:05	4										17.01		
ML2	5/30/01	11:05	5										16.89		
ML2	5/30/01	11:06	6										16.55		
ML2	5/30/01	11:07	7										16.34		
ML2	5/30/01	11:08	8										15.71		
ML2	5/30/01	11:15	0.5	3.8		0.25	2.3 J		145	112					0.033
ML2	5/30/01	11:25	3	4.2		0.26	2.3 J		145	112					0.04
ML2	5/30/01	11:40	6	3.5		0.29	2.3 J		153	115					0.043
ML2	5/30/01		0												
ML2	9/26/01	11:30	0.5										18.85		
ML2	9/26/01	11:40	0.5	8.3	13	0.374 J	2.4	11	141	107				4480	
ML2	9/26/01	11:55	3	8.4	13	0.3615 J	2.6	11	142	109					
ML2	9/26/01		1										18.86		
ML2	9/26/01		2										18.85		
ML2	9/26/01		3										18.85		
ML2	9/26/01		4										18.85		
ML2	9/26/01		5										18.85		
ML2	9/26/01		6										18.85		
ML2	9/26/01		7										18.87		
ML2	9/26/01	12:05	6	8.6	15	0.465 J	2.4	13	138	108				4495	
ML3	4/25/01	10:02	0.5										13.38		
ML3	4/25/01	10:03	1										13.27		
ML3	4/25/01	10:03	2										12.69		
ML3	4/25/01	10:04	3										11.22		
ML3	4/25/01	10:04	4										10.99		
ML3	4/25/01	10:05	5										10.9		

Table B-1 - page 10. Field and Laboratory Data

Phosphorus (mg/L) (SM4500PH)	Phosphorus (mg/L) (EPA365.1)	pH (pH) (WASPH)	Ortho-Phosphate (mg/L) (SM4500PG)	Ortho-Phosphate (mg/L) (EPA365.3M)	Nitrite-Nitrate (mg/L) (SM4500NO3I)	Dissolved Oxygen (mg/L) (DOFM)	Dissolved Organic Carbon (mg/L) (EPA415.1)	Turbidity (NTU) (SM2130)	Conductivity (umhos/cm) (EPA120.1)	Conductivity (umhos/cm) (CONDMETER)	Chloride (mg/L) (EPA300.0)	Flow (cfs) (MIDSECTION)	Ammonia (mg/L) (SM4500NH3H)	Ammonia (mg/L) (EPA350.1)
		8.95				11.25				252				
			0.005		0.01 U			1.5	261		3.63		0.01 U	
			0.005 U		0.01 U		3.1	1.8	259		3.53		0.01 U	
			0.027		0.021		2.9	2.4	293		4.21		0.191	
		8.97				11.67				249				
		8.98				12.11				248				
		9				12.41				249				
		9.01				12.67				254				
		8.53				6.43				266				
		8.11				2.48				285				
		7.93				1.59				279				
		7.84				0.8				269				
		8.69				15.21				196				
						15.25								
		8.71				15.32				232				
		8.67				14.59				336				
		8.68				14.16				357				
		8.66				13.57				363				
	0.023			0.005 U	0.118		1.9	2.8	223		3.01			0.01 U
	0.034			0.005 U	0.239		2.1	5.5	320		5.61			0.01 U
	0.046			0.005	0.346		2.3	5.6			7.9			0.023
			0.017		0.031								0.079	
		8.58				8.3				239				
		8.57				8.28				239				
		8.58				8.15				239				
		8.56				8.15				239				
		8.53				7.75				241				
		8.48				7.22				243				
		8.36				6.83				246				
		8.32				6.5				244				
		8.07				3.37				249				
			0.018		0.029		2.2 J	1.4	252		3.47		0.071	
			0.019		0.029		2.2 J	1.4	253		3.53		0.073	
			0.029		0.029		2.2 J	1.6	259		3.62		0.1	
						8.19								
		8.72				8.09				232				
0.022 UJ			0.0063		0.032		2.3	9.7	238		3.25		0.083	
0.0225 UJ			0.0064		0.031		2.3	9.9	241		3.37		0.093	
		8.72				8.03				231				
		8.72				7.9				231				
		8.71				7.89				232				
		8.7				7.9				231				
		8.7				7.79				232				
		8.69				7.79				234				
		8.68				7.68				232				
0.021 UJ			0.0066		0.031		2.3	11			3.26		0.093	
		9.35				12.32				239				
		9.36				12.45				239				
		9.36				12.36				228				
		9.34				12.7				210				
		9.3				12.52				208				
		9.26				12.03				207				

Table B-1 - page 11. Field and Laboratory Data

station	date	time	depth (m)	Chlorophyll (ug/L) (SM10200H3M)	Total Suspended Solids (mg/L) (EPA160.2)	Total Persulfate Nitrogen (mg/L) (SM4500NB)	Total Organic Carbon (mg/L) (EPA415.1)	Total Non-Volatile Suspended Solids (mg/L) (EPA160.4)	Total Dissolved Solids (mg/L) (EPA160.1)	Total Alkalinity (mg/L) (SM2320)	Total Alkalinity (mg/L) (EPA310.2)	Sulfate (mg/L) (EPA300.0)	Temperature, water (deg C) (TEMPTHERM)	Silicon (ug/L) (EPA200.7)	Phosphorus (mg/L) (SM4500PI)
ML3	4/25/01	10:06	6										10.68		
ML3	4/25/01	10:07	7										10.5		
ML3	4/25/01	10:08	8										10.12		
ML3	4/25/01	10:13	9										9.3		
ML3	4/25/01	10:15	10										9.25		
ML3	4/25/01	10:20	0.5	9.25 J		0.14	2.6		136.5 J		117.5				0.016
ML3	4/25/01	10:40	3	16 J		0.141	2.6		134		106				0.019
ML3	4/25/01	10:50	6	19.9 J		0.154	1.9		148		111				0.019
ML3	4/25/01	11:00	9	14.3 J		0.389	2.4		153		121				0.028
ML3	4/25/01	11:30	0.4	8.4 J		0.122									0.015
ML3	8/1/01	18:45	4.5			0.426	3.4 J		173	133					0.041
ML3	8/1/01	9:05	0.4	11.2 J		0.328									0.02
ML3	8/1/01	9:24	0.5										21.96		
ML3	8/1/01	9:25	1										21.98		
ML3	8/1/01	9:26	2										21.95		
ML3	8/1/01	9:27	3										21.87		
ML3	8/1/01	9:28	4										21.84		
ML3	8/1/01	9:28	5										21.8		
ML3	8/1/01	9:29	6										21.68		
ML3	8/1/01	9:29	7										20.78		
ML3	8/1/01	9:30	8										20.13		
ML3	8/1/01	9:31	9										19.13		
ML3	8/1/01	9:32	10										18.25		
ML3	8/1/01	9:45	0.5	12.1 J	4	0.301	3.8 J	2	167	125					0.015 U
ML3	8/1/01	10:10	3	12	4	0.2975	3.8 J	2	170	125					0.0165 U
ML3	8/1/01	10:30	6	13.3	4	0.308	4 J	2	165	125					0.017
ML3	8/1/01	10:45	9	4.68	3	1.0815	3.1 J	1	192	137		13			0.1435
ML3	8/1/01		0.5	11.8 J	5	0.295	3.7 J	2	161	125					0.0255
ML3	8/14/01	16:03	0.5										27.23		
ML3	8/14/01		1										26.4		
ML3	8/14/01		10										19.75		
ML3	8/14/01		2										25.85		
ML3	8/14/01		3										23.48		
ML3	8/14/01		4										23.33		
ML3	8/14/01		5										22.41		
ML3	8/14/01		6										22.03		
ML3	8/14/01		7										21.59		
ML3	8/14/01		8										21.1		
ML3	8/14/01		9										20.19		
ML3	8/15/01	18:20	0.5										27.95		
ML3	8/15/01	9:50	0.5										25.69		
ML3	8/15/01		1										26.205		
ML3	8/15/01		10										19.28		
ML3	8/15/01		2										25.72		
ML3	8/15/01		3										24.41		
ML3	8/15/01		4										23.31		
ML3	8/15/01		5										22.625		
ML3	8/15/01		6										22.09		
ML3	8/15/01		7										21.535		
ML3	8/15/01		8										21.16		
ML3	8/15/01		9										20.245		
ML3	8/16/01	18:00	0.5										27.83		
ML3	8/16/01		0.3										28.22		

Table B-1 - page 12. Field and Laboratory Data

Phosphorus (mg/L) (SM4500PH)	Phosphorus (mg/L) (EPA365.1)	pH (pH) (WASPH)	Ortho-Phosphate (mg/L) (SM4500PG)	Ortho-Phosphate (mg/L) (EPA365.3M)	Nitrite-Nitrate (mg/L) (SM4500NO3I)	Dissolved Oxygen (mg/L) (DOFM)	Dissolved Organic Carbon (mg/L) (EPA415.1)	Turbidity (NTU) (SM2130)	Conductivity (umhos/cm) (EPA120.1)	Conductivity (umhos/cm) (CONDMETER)	Chloride (mg/L) (EPA300.0)	Flow (cfs) (MIDSECTION)	Ammonia (mg/L) (SM4500NH3H)	Ammonia (mg/L) (EPA350.1)
		9.19				11.54				213				
		9.12				11.02				211				
		9.04				9.01				224				
		8.48				4.78				247				
		8.23				4.05				249				
				0.005 U	0.01 U		2.15	3.2	265		4.705			0.01 U
				0.005 U	0.01 U		2	4	239		3.75			0.01 U
				0.005 U	0.01 U		3.4	5			4.13			0.01 U
				0.005	0.015		2.1				4.54			0.198
				0.005 U	0.01 U									0.01 U
			0.019		0.011		2.6 J	4.8			3.89		0.096	
			0.006		0.01 U								0.024	
		8.64				7.16				275				
		8.65				7.12				275				
		8.63				7.1				275				
		8.61				6.9				275				
		8.6				6.83				274				
		8.59				6.83				276				
		8.58				6.82				271				
		8.08				1.52				285				
		7.81				0.25				290				
		7.61				0.21				309				
		7.47				0.19				322				
			0.005		0.01 U		3.2 J	3.3	277		3.83		0.021	
			0.005		0.01 U		3.3 J	4.4	277		3.83		0.025	
			0.006		0.01 U		3.1 J	3.6			3.82		0.032	
			0.127		0.01 U		3 J				3.64		0.697	
			0.006		0.01 U		3.1 J	3.3	276		3.83		0.021	
		8.77				10.2				256				
		8.81				10.7				255				
		7.46				0.19				303				
		8.79				10.72				255				
		8.8				10.69				258				
		8.69				6.91				265				
		8.17				3.86				273				
		7.91				1.58				275				
		7.76				0.49				274				
		7.71				0.26				279				
		7.56				0.21				294				
		8.75				10.54				253				
		8.8				10.16				256				
		8.775				10.41				254.5				
		7.27				0.17				320				
		8.785				10.63				254.5				
		8.79				10.54				255.5				
		8.425				6.38				269				
		8.01				2.08				274.5				
		7.79				1.07				276.5				
		7.71				0.205				278.5				
		7.67				0.185				280.5				
		7.525				0.18				293.5				
		8.76				10.72				252				
		8.74				10.77				254				

Table B-1 - page 13. Field and Laboratory Data

station	date	time	depth (m)	Chlorophyll (ug/L) (SM10200H3M)	Total Suspended Solids (mg/L) (EPA160.2)	Total Persulfate Nitrogen (mg/L) (SM4500NB)	Total Organic Carbon (mg/L) (EPA415.1)	Total Non-Volatile Suspended Solids (mg/L) (EPA160.4)	Total Dissolved Solids (mg/L) (EPA160.1)	Total Alkalinity (mg/L) (SM2320)	Total Alkalinity (mg/L) (EPA310.2)	Sulfate (mg/L) (EPA300.0)	Temperature, water (deg C) (TEMPTHERM)	Silicon (ug/L) (EPA200.7)	Phosphorus (mg/L) (SM4500PI)
ML3	8/16/01		1										26.68		
ML3	8/16/01		2										25.93		
ML3	8/16/01		3										24.3		
ML3	8/16/01		4										23.71		
ML3	8/16/01		5										22.64		
ML3	8/16/01		6										22.17		
ML3	8/16/01		7										21.54		
ML3	8/16/01		8										21.06		
ML3	8/16/01		9										20.69		
ML3	8/29/01	9:15	0.4	9.8 J		0.331									0.016
ML3	8/29/01	9:30	0.5										23.11		
ML3	8/29/01	10:00	0.5	12 J	7	0.2665	3.5	5	154	119					0.013 U
ML3	8/29/01	10:13	3	30.2 J	10	0.2525	3.8	7	158	117					0.015 U
ML3	8/29/01	10:27	3	28.2 J	12	0.262	3.7	7	152	115					0.0135 U
ML3	8/29/01	10:38	6	20.2 J	6	0.398	3	3	176	122					0.0165
ML3	8/29/01	10:54	9	4.8 J	4	0.79	2.9	2	138	132					0.092
ML3	8/29/01		1										23.07		
ML3	8/29/01		10										20.1		
ML3	8/29/01		2										23		
ML3	8/29/01		3										21.7		
ML3	8/29/01		4										21.4		
ML3	8/29/01		5										21.27		
ML3	8/29/01		6										21.16		
ML3	8/29/01		7										21.03		
ML3	8/29/01		8										20.89		
ML3	8/29/01		9										20.76		
ML3	7/2/01	9:42	0.4	5.1											
ML3	7/2/01	9:50	0.5										21.75		
ML3	7/2/01	10:15	0.5	5		0.16	3.3		160	122					0.012
ML3	7/2/01	10:20	3	8		0.154	3.5		157	121					0.013
ML3	7/2/01	10:35	6	6.5		0.189	3.2		157	120					0.022
ML3	7/2/01	10:35	9	1.8		0.565	3		159	124					0.105
ML3	7/2/01		1										21.5		
ML3	7/2/01		10										16.93		
ML3	7/2/01		2										21.29		
ML3	7/2/01		3										21.17		
ML3	7/2/01		4										21.03		
ML3	7/2/01		5										19.66		
ML3	7/2/01		6										19.23		
ML3	7/2/01		7										18.58		
ML3	7/2/01		8										18.05		
ML3	7/2/01		9										17.49		
ML3	3/28/01	8:41	0												
ML3	3/28/01	8:42	0.5										8.16		
ML3	3/28/01	8:43	1.5										8.16		
ML3	3/28/01	8:43	3										8.16		
ML3	3/28/01	8:44	4.5										8.14		
ML3	3/28/01	8:44	6										8.14		
ML3	3/28/01	8:47	7.5										7.6		
ML3	3/28/01	8:51	9										7.3		
ML3	3/28/01	10:55	0.5										4.84		
ML3	3/29/01	9:00	0.5	38.2		0.482	3		217		164				
ML3	3/29/01	9:10	3	40		0.466	3		223		163				

Table B-1 - page 14. Field and Laboratory Data

Phosphorus (mg/L) (SM4500PH)	Phosphorus (mg/L) (EPA365.1)	pH (pH) (WASPH)	Ortho-Phosphate (mg/L) (SM4500PG)	Ortho-Phosphate (mg/L) (EPA365.3M)	Nitrite-Nitrate (mg/L) (SM4500NO3I)	Dissolved Oxygen (mg/L) (DOFM)	Dissolved Organic Carbon (mg/L) (EPA415.1)	Turbidity (NTU) (SM2130)	Conductivity (umhos/cm) (EPA120.1)	Conductivity (umhos/cm) (CONDMETER)	Chloride (mg/L) (EPA300.0)	Flow (cfs) (MIDSECTION)	Ammonia (mg/L) (SM4500NH3H)	Ammonia (mg/L) (EPA350.1)
		8.8				11.2				252				
		8.87				12.17				250				
		8.63				8.9				260				
		8.46				7.32				269				
		8.11				3.33				273				
		7.86				0.79				276				
		7.72				0.21				279				
		7.65				0.18				280				
		7.55				0.16				284				
			0.005 U		0.01 U								0.01 U	
		9				12.19				243				
			0.005 U		0.01 U		3.5	4.4	258		3.89		0.01 U	
			0.005 U		0.01 U		3.1	5.2	257		3.65		0.01 U	
			0.005 U		0.01 U		2.8	5.7	256		3.57		0.01 U	
			0.005 U		0.013		2.5	3.1			3.61		0.145	
			0.079		0.01 U		2.7				3.92		0.491	
		9				12.23				244				
		7.5				0.15				311				
		9				12.25				244				
		8.78				7.86				244				
		8.42				5.67				246				
		8.21				4.49				249				
		8.01				2.52				257				
		7.84				0.77				267				
		7.72				0.17				271				
		7.65				0.15				277				
		8.96				10.12				260				
			0.005 U		0.01 U		2.7 J	2.3	268		3.86		0.01 U	
			0.005 U		0.01 U		2.9 J	2.2	265		3.63		0.01 U	
			0.008		0.01 U		2.9 J	1.6			3.67		0.025	
			0.1		0.01 U		2.9				3.79		0.34	
		9				10.76				258				
		7.66				0.61				276				
		9.06				11.22				256				
		9.04				11.07				257				
		9.01				10.65				257				
		8.79				8.26				256				
		8.56				5.92				256				
		8.27				2.93				263				
		7.99				1.4				266				
		7.8				0.63				267				
						14.84								
		8.82				14.84				322				
		8.82				14.82				323				
		8.82				14.71				323				
		8.81				14.61				322				
		8.8				14.51				325				
		8.67				11.22				364				
		8.48				8.9				368				
	0.038			0.005 U	0.266		2.5	5.7	365		7.02			0.01 U
	0.039			0.005 U	0.265		2.9	6	364		7.07			0.011

Table B-1 - page 15. Field and Laboratory Data

station	date	time	depth (m)	Chlorophyll (ug/L) (SM10200H3M)	Total Suspended Solids (mg/L) (EPA160.2)	Total Persulfate Nitrogen (mg/L) (SM4500NB)	Total Organic Carbon (mg/L) (EPA415.1)	Total Non-Volatile Suspended Solids (mg/L) (EPA160.4)	Total Dissolved Solids (mg/L) (EPA160.1)	Total Alkalinity (mg/L) (SM2320)	Total Alkalinity (mg/L) (EPA310.2)	Sulfate (mg/L) (EPA300.0)	Temperature, water (deg C) (TEMPTHERM)	Silicon (ug/L) (EPA200.7)	Phosphorus (mg/L) (SM4500PI)
ML3	3/29/01	9:20	6	38.6		0.474	2.8		219		165				
ML3	3/29/01	9:30	9	53.8		0.609	3.4 J		242		184				
ML3	5/30/01	12:05	0.4	6.9		0.201									0.018
ML3	5/30/01	12:15	0.5										18.03		
ML3	5/30/01	12:16	1										18.03		
ML3	5/30/01	12:17	2										17.95		
ML3	5/30/01	12:17	3										17.45		
ML3	5/30/01	12:18	4										16.82		
ML3	5/30/01	12:18	5										16.76		
ML3	5/30/01	12:19	6										16.45		
ML3	5/30/01	12:20	7										15.85		
ML3	5/30/01	12:21	8										15.4		
ML3	5/30/01	12:22	10										15.08		
ML3	5/30/01	12:22	9										15.26		
ML3	5/30/01	12:25	0.5	7.2		0.22	2.5 J		148	114					0.028
ML3	5/30/01	12:35	3	6.4		0.27	2.5 J		151	115					0.036
ML3	5/30/01	12:45	6	4.1		0.348	2.4 J		153	112					0.057
ML3	5/30/01	12:55	9	3		0.606	2.5 J		157	123					0.11
ML3	9/26/01	8:32	0												
ML3	9/26/01	8:33	0.5										18.97		
ML3	9/26/01	8:34	1										18.97		
ML3	9/26/01	8:35	2										18.97		
ML3	9/26/01	8:35	3										18.99		
ML3	9/26/01	8:36	4										18.97		
ML3	9/26/01	8:36	5										18.97		
ML3	9/26/01	8:37	6										18.97		
ML3	9/26/01	8:37	7										18.97		
ML3	9/26/01	8:38	8										18.89		
ML3	9/26/01	8:39	10										18.9		
ML3	9/26/01	8:39	9										18.9		
ML3	9/26/01	8:50	0.5	12.4 J	6	0.332 J	2.8	4	144	112				2890	
ML3	9/26/01	9:10	3	12 J	7	0.3365 J	2.8	4	139	113					
ML3	9/26/01	9:20	6	13.6 J	6	0.3465 J	3	4	136	113					
ML3	9/26/01	9:35	9	13.15	11	0.331 J	3.1 J	8	141	113.5				2812.5	
ML4	4/25/01	15:06	0.5										13.02		
ML4	4/25/01	15:08	1										11.92		
ML4	4/25/01	15:09	2										11.44		
ML4	4/25/01	15:10	3										10.78		
ML4	4/25/01	15:11	4										9.52		
ML4	4/25/01	15:15	0.5	4.6 J		0.107	2.3		86 J		76.05				0.0125
ML4	4/25/01	15:35	3	15.3 J		0.144	3		112 J		98.1				0.024
ML4	8/1/01	17:50	0.4	18.5 J		0.286									0.023
ML4	8/1/01	18:07	0.5										22.76		
ML4	8/1/01	18:08	1										22.76		
ML4	8/1/01	18:09	2										22.68		
ML4	8/1/01	18:10	3										22.52		
ML4	8/1/01	18:13	4										21.8		
ML4	8/1/01	18:16	4.9										21.45		
ML4	8/1/01	18:25	0.5	28.5		0.298	3.6 J		171	132					0.026
ML4	8/1/01	18:30	3	20.1	7	0.2995	3.4 J	4	174	132					0.022
ML4	8/29/01	16:20	0.4	7.2		0.227									0.014
ML4	8/29/01	16:26	0.5										25.18		
ML4	8/29/01	16:35	0.5	7		0.236	3.4		145	105					0.015

Table B-1 - page 16. Field and Laboratory Data

Phosphorus (mg/L) (SM4500PH)	Phosphorus (mg/L) (EPA365.1)	pH (pH) (WASPH)	Ortho-Phosphate (mg/L) (SM4500PG)	Ortho-Phosphate (mg/L) (EPA365.3M)	Nitrite-Nitrate (mg/L) (SM4500NO3I)	Dissolved Oxygen (mg/L) (DOFM)	Dissolved Organic Carbon (mg/L) (EPA415.1)	Turbidity (NTU) (SM2130)	Conductivity (umhos/cm) (EPA120.1)	Conductivity (umhos/cm) (CONDMETER)	Chloride (mg/L) (EPA300.0)	Flow (cfs) (MIDSECTION)	Ammonia (mg/L) (SM4500NH3H)	Ammonia (mg/L) (EPA350.1)
	0.039			0.005 U	0.268		2.4	6.1			7.03			0.013
	0.045			0.005 U	0.297		2.5				8.34			0.098
			0.01		0.015								0.045	
		8.65				8.63				241				
		8.65				8.62				241				
		8.64				8.45				246				
		8.58				7.94				251				
		8.42				7.14				230				
		8.34				6.95				230				
		8.24				5.91				241				
		8.07				4.3				255				
		7.97				4.08				256				
		7.85				2.51				261				
		7.4				3.98				256				
			0.01		0.014		2.3 J	2	255		3.62		0.045	
			0.014		0.013		2.3 J	2.1	257		3.66		0.079	
			0.032		0.019		2.1 J	2.8			3.37		0.157	
			0.073		0.01 U		2.3 J				3.92		0.35	
						7.77								
		8.69				7.73				245				
		8.69				7.69				246				
		8.68				7.72				246				
		8.69				7.67				246				
		8.68				7.66				246				
		8.69				7.62				246				
		8.69				7.65				246				
		8.68				7.62				246				
		8.65				7.43				247				
		8.64				7.33				248				
		8.64				7.4				248				
0.0325 J			0.0039		0.01		2.7	3.9	248		3.52		0.037	
0.019 UJ			0.0036		0.01		2.5	4.4	250		3.48		0.04	
0.017 UJ			0.0039		0.01 U		2.5	4.1			3.44		0.038	
0.022 UJ			0.00475		0.01 U		2.6	7.4			3.485		0.054	
		8.95				12.25				152				
		9.01				12.41				157				
		9.13				12.54				181				
		9.18				12.53				211				
		8.97				12.05				146.5				
				0.005 U	0.0235		1.9	2.05	172.5		1.71			0.01 U
				0.005 U	0.01 U		2.6	3.8	220		3.07			0.01 U
			0.005 U		0.01 U								0.01 UJ	
		8.92				10.39				285				
		8.92				10.18				285				
		8.85				9.27				286				
		8.7				8.17				287				
		8.46				3.74				294				
		8.03				2.41				296				
			0.006		0.01 U		2.7 J	4.5	288		3.8		0.01 UJ	
			0.011		0.01 U		3.1 J	4.4	288		3.86		0.04	
			0.005 U		0.022								0.01 U	
		8.95				12.08				216				
			0.005 U		0.01 U		3.4	2.2	230		2.82		0.01 U	

Table B-1 - page 17. Field and Laboratory Data

station	date	time	depth (m)	Chlorophyll (ug/L) (SM10200H3M)	Total Suspended Solids (mg/L) (EPA160.2)	Total Persulfate Nitrogen (mg/L) (SM4500NB)	Total Organic Carbon (mg/L) (EPA415.1)	Total Non-Volatile Suspended Solids (mg/L) (EPA160.4)	Total Dissolved Solids (mg/L) (EPA160.1)	Total Alkalinity (mg/L) (SM2320)	Total Alkalinity (mg/L) (EPA310.2)	Sulfate (mg/L) (EPA300.0)	Temperature, water (deg C) (TEMPTHERM)	Silicon (ug/L) (EPA200.7)	Phosphorus (mg/L) (SM4500PI)
ML4	8/29/01	16:46	3	52.9	11	0.2145	3.9	5	150	110					0.0115 U
ML4	8/29/01		1										23.6		
ML4	8/29/01		2										21.96		
ML4	8/29/01		3										21.4		
ML4	8/29/01		4										21.13		
ML4	8/29/01		5										20.41		
ML4	7/2/01	15:55	0.4	7.2											
ML4	7/2/01	15:55	0.5										23.96		
ML4	7/2/01	16:05	0.5	7.1		0.164	3.2		146	115					0.014
ML4	7/2/01	16:10	3	5.3		0.138	3.3		153	119					0.013
ML4	7/2/01	16:20	4.5	9		0.156	3.2		155	118					0.021
ML4	7/2/01		1										23.04		
ML4	7/2/01		2										21.08		
ML4	7/2/01		3										20.03		
ML4	7/2/01		4										19.63		
ML4	7/2/01		5										18.58		
ML4	3/28/01	10:55	0.5												
ML4	3/28/01	10:56	1.5										4.87		
ML4	3/28/01	10:57	3										4.77		
ML4	3/29/01	11:05	0.5	7.95		0.1315	2		87.5		67.6				
ML4	3/29/01	11:25	3	8.1		0.13	1.8		85		67.9				
ML4	5/30/01	15:00	0.4	6.3		0.192									0.013
ML4	5/30/01	15:10	0												
ML4	5/30/01	15:11	0.5										17.28		
ML4	5/30/01	15:12	1										17.26		
ML4	5/30/01	15:12	2										17.16		
ML4	5/30/01	15:13	3										17.06		
ML4	5/30/01	15:14	4										16.25		
ML4	5/30/01	15:15	5										14.8		
ML4	5/30/01	15:20	0.5	7.25		0.1315	2.2 J		121.5	91.9					0.0155
ML4	5/30/01	15:40	3	7		0.142	2.25 J		118	92.5					0.0205
ML4	5/30/01	15:55	4.5				1.9 J		110	83.6					
ML4	9/26/01	14:24	0.5										17.74		
ML4	9/26/01	14:24	1										17.74		
ML4	9/26/01	14:25	2										17.72		
ML4	9/26/01	14:26	3										17.71		
ML4	9/26/01	14:26	4										17.57		
ML4	9/26/01	14:27	4.9										17.35		
ML4	9/26/01	14:30	0.5	6.6	13	0.226 J	2	9	126	93					
ML4	9/26/01	14:40	3	6.5	4	0.193 J	1.8	3	122	92.7				4240	
ML5	4/25/01	15:54	0.5										13.8		
ML5	4/25/01	15:55	1										12.74		
ML5	4/25/01	15:56	2										11.16		
ML5	4/25/01	16:00	0.5	1.9 J		0.159	1.8		75 J		72.4				0.014
ML5	4/25/01	16:10	1.5	4.5 J		0.171	2.2		83 J		72.4				0.016
ML5	8/1/01	19:09	0.5										23.17		
ML5	8/1/01	19:10	1										23.2		
ML5	8/1/01	19:11	2										21.78		
ML5	8/1/01	19:15	0.5	41.9	14	0.3055	3.5 J	8	176	135					0.0225
ML5	8/29/01	17:08	0.5										23.05		
ML5	8/29/01	17:15	0.5	8.4	4	0.355	1.7	3	124	92					0.02
ML5	8/29/01		1										22.3		
ML5	8/29/01		2										21.54		

Phosphorus (mg/L) (SM4500PH)	Phosphorus (mg/L) (EPA365.1)	pH (pH) (WASPH)	Ortho-Phosphate (mg/L) (SM4500PG)	Ortho-Phosphate (mg/L) (EPA365.3M)	Nitrite-Nitrate (mg/L) (SM4500NO3I)	Dissolved Oxygen (mg/L) (DOFM)	Dissolved Organic Carbon (mg/L) (EPA415.1)	Turbidity (NTU) (SM2130)	Conductivity (umhos/cm) (EPA120.1)	Conductivity (umhos/cm) (CONDMETER)	Chloride (mg/L) (EPA300.0)	Flow (cfs) (MIDSECTION)	Ammonia (mg/L) (SM4500NH3H)	Ammonia (mg/L) (EPA350.1)
			0.005 U		0.01 U		2.3	4.2	244		3.07		0.01 U	
		9.03				13.44				229				
		8.97				12.26				226				
		8.82				10.41				230				
		8.57				7.9				227				
		8.23				5.21				209				
		8.89				11.26				243				
			0.005 U		0.03		2.9	2.1	251		2.91		0.01 U	
			0.005 U		0.01 U		3.1	2.6	260		3.46		0.01 U	
			0.008		0.01 U		2.8	4.2			3.32		0.012	
		8.92				10.88				246				
		8.94				11.17				249				
		8.89				10.63				252				
		8.83				9.3				253				
		8.16				2.33				249				
		8.32				15.12				129.5				
		8.3				15.06				129.6				
		8.28				15.05				129.9				
	0.0195			0.005 U	0.04		1.6	2.15	153.5		1.245			0.01 U
	0.019			0.005 U	0.038		2.3	2.3	155		1.22			0.01 U
			0.006		0.032								0.02	
						9.57								
		8.66				9.57				196				
		8.66				9.6				196				
		8.66				9.57				195				
		8.65				9.6				192				
		8.58				9.68				182				
		8.43				9.71				159				
			0.005 U		0.03		1.85 J	2.35	205.5		2.11		0.0105 U	
			0.006		0.0305		1.85 J	2.3	206.5		2.07		0.0135	
			0.005				1.8 J				1.7			
		8.67				9.41				203				
		8.67				9.5				202				
		8.67				9.5				202				
		8.66				9.3				203				
		8.64				9.18				203				
		8.57				8.95				205				
0.017 J			0.0041		0.073		1.8	2.4	208		2.04		0.01 U	
0.0135 UJ			0.0044		0.073		1.9	2.4	207		2.08		0.01 U	
		8.56				11.61				146				
		8.69				12.47				143				
		8.76				13.01				145				
				0.005 U	0.08		2.2	1	165		1.29			0.01 U
				0.005 U	0.088		2.2	1.9	165		1.41			0.01 U
		9.03				14.8				286				
		9.03				14.65				286				
		8.79				12.59				318				
			0.007		0.025		3 J	7.5	292		3.45		0.01 UJ	
		8.46				10.2				194				
			0.008		0.206		1.6	2.6	206		1.63		0.01 U	
		8.47				10.56				190				
		8.58				11.45				190				

Table B-1 - page 19. Field and Laboratory Data

station	date	time	depth (m)	Chlorophyll (ug/L) (SM10200H3M)	Total Suspended Solids (mg/L) (EPA160.2)	Total Persulfate Nitrogen (mg/L) (SM4500NB)	Total Organic Carbon (mg/L) (EPA415.1)	Total Non-Volatile Suspended Solids (mg/L) (EPA160.4)	Total Dissolved Solids (mg/L) (EPA160.1)	Total Alkalinity (mg/L) (SM2320)	Total Alkalinity (mg/L) (EPA310.2)	Sulfate (mg/L) (EPA300.0)	Temperature, water (deg C) (TEMPTHERM)	Silicon (ug/L) (EPA200.7)	Phosphorus (mg/L) (SM4500PI)
ML5	7/2/01	16:40	0.5										24.68		
ML5	7/2/01	16:50	0.5	15		0.352	3.4		163	122					0.026
ML5	7/2/01	16:55	1.5	9.9		0.619	2.6		180	137					0.038
ML5	7/2/01		1										24.42		
ML5	7/2/01		2										21.79		
ML5	3/29/01	11:58	0.5										5.77		
ML5	3/29/01	11:59	1										5.77		
ML5	3/29/01	12:05	0.5	10.9		0.126	2.1		91		64.8				
ML5	5/30/01	16:24	0.5										16.03		
ML5	5/30/01	16:25	1										16		
ML5	5/30/01	16:25	2										16		
ML5	5/30/01	16:30	0.5	3.7		0.141	1.6 J		95	71.5					0.011
ML5	5/30/01	16:40	1.5				1.6 J		102	78					
ML5	9/6/01	15:04	1										17.03		
ML5	9/26/01	15:03	0.5										17.06		
ML5	9/26/01	15:04	1												
ML5	9/26/01	15:08	2										17.01		
ML5	9/26/01	15:10	0.5	2.1	3	0.285 J	1.9	2	117	86				4470	
ML6	4/25/01	9:08	0.5										13.92		
ML6	4/25/01	9:09	1										13.74		
ML6	4/25/01	9:10	2										13.26		
ML6	4/25/01	9:10	3										10.62		
ML6	4/25/01	9:11	4										10.54		
ML6	4/25/01	9:25	0.5	14.7 J		0.169	3.1		145 J		124				0.018
ML6	4/25/01	9:35	3	23.5 J		0.17	3.3		144 J		121				0.021
ML6	8/1/01	11:10	0.4	9.37		0.27									0.019
ML6	8/1/01	11:31	0.5										22.56		
ML6	8/1/01	11:32	1										22.5		
ML6	8/1/01	11:33	2										22.09		
ML6	8/1/01	11:33	3										21.91		
ML6	8/1/01	11:34	4										21		
ML6	8/1/01	11:40	0.5	7.66		0.283	3.7 J		166	125					0.022
ML6	8/1/01	11:55	3	11.5	6	0.266	3.9 J	4	163	124					0.016 U
ML6	8/29/01	11:28	0.4	8.4		0.302									0.018
ML6	8/29/01	11:53	0.5										23.65		
ML6	8/29/01		1										23.44		
ML6	8/29/01		2										23.24		
ML6	8/29/01		3										21.54		
ML6	8/29/01		4.9										21.08		
ML6	8/29/01		4										21.22		
ML6	8/29/01	12:00	0.5	8.8		0.303	3.4		163	124					0.019
ML6	8/29/01	12:10	3	21.7	8	0.2955	3.5	5	160	126					0.0165
ML6	7/2/01	11:14	0.4	5.8											
ML6	7/2/01	11:20	0.5										22.97		
ML6	7/2/01	11:30	0.5	5.8		0.159	3.2		162	123					0.014
ML6	7/2/01	11:35	3	7.1		0.16			160	123					0.015
ML6	7/2/01		1										22.7		
ML6	7/2/01		2										22.25		
ML6	7/2/01		3										21.33		
ML6	7/2/01		4.5										18.89		
ML6	7/2/01		4										19.35		
ML6	3/28/01	10:04	0.5										7.98		
ML6	3/28/01	10:05	1.5										7.93		

Table B-1 - page 20. Field and Laboratory Data

Phosphorus (mg/L) (SM4500PH)	Phosphorus (mg/L) (EPA365.1)	pH (pH) (WASPH)	Ortho-Phosphate (mg/L) (SM4500PG)	Ortho-Phosphate (mg/L) (EPA365.3M)	Nitrite-Nitrate (mg/L) (SM4500NO3I)	Dissolved Oxygen (mg/L) (DOFM)	Dissolved Organic Carbon (mg/L) (EPA415.1)	Turbidity (NTU) (SM2130)	Conductivity (umhos/cm) (EPA120.1)	Conductivity (umhos/cm) (CONDMETER)	Chloride (mg/L) (EPA300.0)	Flow (cfs) (MIDSECTION)	Ammonia (mg/L) (SM4500NH3H)	Ammonia (mg/L) (EPA350.1)
		8.72				10.48				255				
			0.016		0.193		3	3.1	266		2.54		0.02	
			0.017		0.403		2.4	6.9	299		2.85		0.063	
		8.71				10.69				256				
		8.61				12.06				294				
		8.15				15.58				125				
		8.16				15.47				125				
	0.021			0.005 U	0.034		1.5	4	148		1.05			0.01 U
		8.45				10.8				152				
		8.46				10.78				151				
		8.46				10.77				152				
			0.005 U		0.079		1.5 J	2.7	162		1.03		0.01 U	
			0.005 U				1.6 J		165		1.09			
		8.72				12.12				186				
		8.76				12.36				187				
		8.84				12.21				186				
0.0115 UJ			0.0074		0.154		1.5	1.2	192		1.51		0.01 U	
		9.4				12.08				249				
		9.41				12.19				248				
		9.42				12.32				248				
		9.36				12.15				228				
		9.29				11.74				230				
				0.005 U	0.01 U		2.3	5.2	276		5.4			0.01 U
				0.005 U	0.01 U		2.1	6.4	266		4.82			0.01 U
			0.005 U		0.01 U								0.01 UJ	
		8.75				7.9				273				
		8.74				7.85				274				
		8.72				7.94				274				
		8.69				7.86				274				
		8.24				3.49				280				
			0.005 U		0.01 U		3.4 J	4.3	276		3.9		0.01 UJ	
			0.005 U		0.01 U		3.2 J	4.6	274		4.05		0.01 UJ	
			0.005 U		0.01 U								0.01 U	
		8.89				10.66				255				
		8.89				10.48				255				
		8.89				10.21				255				
		8.35				4.8				263				
		7.86				0.72				269				
		7.98				1.97				268				
			0.005 U		0.01 U		3.1	4.9	271		4.21		0.01 U	
			0.005 U		0.01 U		2.8	5.3	275		3.94		0.037	
		8.82				9.31				262				
			0.005 U		0.01 U		2.8	2.8	272		3.82		0.01 U	
					0.01 U			3.5	271		3.71		0.01 U	
		8.82				9.3				262				
		8.83				9.49				262				
		8.8				8.95				262				
		8.17				3.92				262				
		8.5				5.27				262				
		8.87				15.94				353				
		8.88				15.79				351				

Table B-1 - page 21. Field and Laboratory Data

station	date	time	depth (m)	Chlorophyll (ug/L) (SM10200H3M)	Total Suspended Solids (mg/L) (EPA160.2)	Total Persulfate Nitrogen (mg/L) (SM4500NB)	Total Organic Carbon (mg/L) (EPA415.1)	Total Non-Volatile Suspended Solids (mg/L) (EPA160.4)	Total Dissolved Solids (mg/L) (EPA160.1)	Total Alkalinity (mg/L) (SM2320)	Total Alkalinity (mg/L) (EPA310.2)	Sulfate (mg/L) (EPA300.0)	Temperature, water (deg C) (TEMPTHERM)	Silicon (ug/L) (EPA200.7)	Phosphorus (mg/L) (SM4500PI)
ML6	3/28/01	10:06	3										7.89		
ML6	3/29/01	10:10	0.5	50.2		0.484	3.6		240		181				
ML6	3/29/01	10:20	3	52		0.486	3.8		243		180				
ML6	5/30/01	13:10	0.4	10.3		0.181									0.016
ML6	5/30/01	13:26	0.5										18.15		
ML6	5/30/01	13:26	1										18.12		
ML6	5/30/01	13:27	2										18.12		
ML6	5/30/01	13:27	3										18.03		
ML6	5/30/01	13:27	4										16.72		
ML6	5/30/01	13:30	0.5	10.3		0.156	2.6 J		156	120					0.016
ML6	5/30/01	13:40	3	10.3		0.162	2.7 J		159	120					0.021
ML6	9/26/01	10:29	0.5										18.71		
ML6	9/26/01	10:30	1										18.71		
ML6	9/26/01	10:30	2										18.71		
ML6	9/26/01	10:31	3										18.7		
ML6	9/26/01	10:31	4										18.63		
ML6	9/26/01	10:35	0.5	13.3	8	0.3 J	2.8	5	142	116					
ML6	9/26/01	10:40	3	13.2	8	0.3285 J	3	5	151	116				2975	
ML7	4/23/01	13:35	0	15.2 J		0.138	2.5		123 J				10.98		0.018
ML7	8/27/01	15:20	0	28.4 J	7	0.262	3.7	2	155				22.43		0.021
ML7	7/30/01	17:00	0	11.3 J		0.264	3 J		162				23.32		0.022
ML7	6/25/01	15:20	0	5.4 J		0.22	3		157						0.024
ML8	8/1/01		0.5	9.14		0.337									0.034
ML8	8/29/01	11:40	0.5	9		0.235									0.032
ML8	9/26/01	11:05	0.5			0.227 J									
RC1	4/24/01	15:45	0	1.9	2	0.074	1.4		65 J		60.3		9.27		0.011
RC1	8/28/01	11:10	0	1.7 J	15	0.115	1.8		93	68.1			19.4		0.01 U
RC1	7/31/01	11:00	0	2.69 J	2	0.655	1.9 J		170	124					0.024
RC1	7/31/01	12:40	0										19.73		
RC1	6/26/01	16:15	0	2	1 U	0.083	1.7		92	67.1			17.71		0.01 U
RC1	3/26/01	12:25	0	12.2	8	0.117	1.9		82		61.8		5.12		
RC1	5/29/01	11:50	0	1.3	3	0.071	1.3 J		84	62.2			14.1		0.013
RC1	9/25/01	15:10	0	2.2	2	0.128 J	1.4	1 U	91	67.5			17.52		
RC2	4/24/01	15:15	0		2	0.051	1.4		64 J		58.5				0.01
RC2	4/24/01		0										10.3		
RC2	8/28/01	12:40	0		2	0.06	1.5			62.4			19.7		0.01 U
RC2	7/31/01	11:00	0										18.03		
RC2	7/31/01	12:40	0	1.39	3	0.11	1.9 J			65.9					0.01 U
RC2	6/26/01	15:50	0	2	1	0.061	1.6			64.2			18.15		0.01 U
RC2	3/26/01	12:50	0		4	0.0865	1.7		72.5 J		59.9		4.99		
RC2	5/29/01	13:15	0		1	0.053				60.7					0.013
RC2	5/29/01	13:35	0										14.63		
RC2	9/25/01	14:20	0	2.2	1	0.083 J	1.5	1 U	80	62.8			17.57		
RF0	4/23/01	15:50	0		21	1.57			248 J		171		14.75		0.152
RF0	4/24/01	8:00	0	5.25 J	11.5	1.38	1.8		244.5 J		172		11.54		0.1345
RF0	8/27/01	16:10	0										21.01		
RF0	8/27/01	18:00	0		12	1.37		10	248	163					0.122
RF0	8/28/01	9:00	0	4.15 J	18	1.35	1.7	15	250.5	164.5			17.63		0.11725
RF0	7/30/01	18:30	0		9	1.28		8	248	166			20.71		0.118
RF0	7/31/01	9:05	0	7.315 J	17.5	1.265	1.65 J	14.5	249.5	167			17.33		0.11175
RF0	6/25/01	16:10	0		6	1.18			254	170					0.103
RF0	6/26/01	8:10	0	5.95 J	21	1.21	1.85		256	171			16.16		0.1085
RF0	3/26/01	8:55	0	7.5 J	13	1.66	2.2		239		172		11.15		

Table B-1 - page 22. Field and Laboratory Data

Phosphorus (mg/L) (SM4500PH)	Phosphorus (mg/L) (EPA365.1)	pH (pH) (WASPH)	Ortho-Phosphate (mg/L) (SM4500PG)	Ortho-Phosphate (mg/L) (EPA365.3M)	Nitrite-Nitrate (mg/L) (SM4500NO3I)	Dissolved Oxygen (mg/L) (DOFM)	Dissolved Organic Carbon (mg/L) (EPA415.1)	Turbidity (NTU) (SM2130)	Conductivity (umhos/cm) (EPA120.1)	Conductivity (umhos/cm) (CONDMETER)	Chloride (mg/L) (EPA300.0)	Flow (cfs) (MIDSECTION)	Ammonia (mg/L) (SM4500NH3H)	Ammonia (mg/L) (EPA350.1)
		8.87				15.62				354				
	0.039			0.005 U	0.249		2.7	8.8	399		8.48			0.01 U
	0.041			0.005 U	0.248		2.6	9.1	399		8.46			0.01 U
			0.005 U		0.01 U								0.01	
		8.8				9.18				255				
		8.8				9.18				255				
		8.8				9.15				255				
		8.79				9.08				255				
		8.5				6.68				254				
			0.005 U		0.01 U		2.4 J	2.7	266		3.98		0.011	
			0.005 U		0.01 U		2.4 J	3	266		4		0.015	
		8.74				8.01				250				
		8.75				8.01				252				
		8.75				7.94				252				
		8.74				7.94				250				
		8.74				7.94				250				
0.026 J			0.003 U		0.01 U		2.7	4.4	255		3.44		0.014	
0.0195 J			0.003 U		0.01 U		2.6	4.6	255		3.36		0.013	
		9.11		0.005 U	0.01 U	12.52	2			209	3.57			0.01 U
		8.95	0.005 U		0.01 U	11.45	2.5			245	3.63		0.01 U	
		8.95	0.005 U		0.01 U	9.14	2.5 J			269	3.82		0.01	
			0.01		0.01 U		2.8				3.59		0.039	
					0.01 U								0.01 UJ	
			0.005 U		0.01 U								0.01 U	
0.026 J			0.0038		0.01 U								0.01 U	
		8.42		0.005 U	0.014	11.87	1.6	0.8	139	120.6	0.854			0.01 U
		8.2	0.005 U		0.048	9.57	1.8	0.7	159	148	1.15		0.01 U	
			0.016		0.574		1.8 J	0.9	274		2.46		0.01 U	
		6.26				9.31				151				
		8.45	0.005 U		0.021	14.97	1.7	0.7	156	137.3	1.02		0.01 U	
	0.018	8.11		0.005 U	0.023		1.7	2.8	142	120.4	1.02			0.01 U
		8.32	0.005 U		0.017	10.72	1.3 J	1.1	143	133.4	0.763		0.01 U	
0.01 UJ		8.26	0.0041		0.048	9.55	1.4	0.7	157	153	1.08		0.01 U	
				0.005 U	0.01 U		1.5	0.7	135		0.787			0.01 U
		8.13	0.005 U		0.01 U	9.38	1.9	0.6	145	130	0.889		0.01 U	
		8.66				12.18				270				
			0.005 U		0.036		1.5 J	1	154		0.971		0.01 U	
		8.37	0.005 U		0.01 U	9.93	1.7	0.7	149	137.2	0.917		0.01 U	
	0.0135	7.61		0.005 U	0.01 U		1.65	1.65	136.5	116	0.9315			0.01 U
			0.005 U		0.01 U			0.8	139		0.73		0.01 U	
		8.42				10.98				129.6				
0.01 UJ		8.26	0.003 U		0.01 U	9.89	1.6	0.8	146	141	0.921		0.01 U	
		8.71			1.33	11.14			408	372	8.16			0.091
		8.23		0.0975	1.28	9.99	1.7	4.3	411	373	8.05			0.1065
		8.95				10.36				220				
					1.23				389		6.57		0.036	
		7.97	0.097		1.19	7.87	1.75	6.75	390	367	6.235		0.056	
		8.62			1.09	10.35			389	385	6.78		0.029	
		8.09	0.092		1.11	8.46	1.4 J	5.2	394.5	389	6.405		0.038	
			0.07		1.02				390		6.7		0.018	
		8.04	0.069		1.05	8.68	1.9	7.95	398.5	372.2	6.585		0.029	
	0.16	8.2		0.121	1.43		2.2	4.9	414	371	7.57			0.103

Table B-1 - page 23. Field and Laboratory Data

station	date	time	depth (m)	Chlorophyll (ug/L) (SM10200H3M)	Total Suspended Solids (mg/L) (EPA160.2)	Total Persulfate Nitrogen (mg/L) (SM4500NB)	Total Organic Carbon (mg/L) (EPA415.1)	Total Non-Volatile Suspended Solids (mg/L) (EPA160.4)	Total Dissolved Solids (mg/L) (EPA160.1)	Total Alkalinity (mg/L) (SM2320)	Total Alkalinity (mg/L) (EPA310.2)	Sulfate (mg/L) (EPA300.0)	Temperature, water (deg C) (TEMPTHERM)	Silicon (ug/L) (EPA200.7)	Phosphorus (mg/L) (SM4500PI)
RF0	5/29/01	8:35	0	4 J	18.5	1.405	1.9 J		262	173.5			13.77		0.1125
RF0	9/24/01	16:05	0	2.6	10	1.58 J	1.3	9	251	163				16350	
RF0	9/24/01	16:10	0										17.95		
RF0	9/24/01	11:45	0	3.7 J	5.5 U	1.61 J	1.45 J	4.5 U	248	163			16.4		
RF1	4/24/01	7:45	0		16	1.29							12		0.14
RF1	8/28/01	8:29	0		21	1.38							17.13		0.125
RF1	7/31/01	8:30	0		14	1.32							17.15		0.119
RF1	6/26/01	7:45	0		8	1.22							16.33		0.099
RF1	3/26/01	8:35	0		18	1.69									
RF1	3/26/01		0										11.4		
RF1	5/29/01	8:15	0		16	1.41							14.15		0.101
RF1A	9/24/01	15:50	0	3.4 J	5	2.05 J	1.4	4	275	172			17.54		
RF1A	9/24/01	11:20	0	3.6 J	10	2.04 J	1.3	8	274	172			15.48		
RF1B	9/24/01	15:25	0	3	1 U	3.27 J	1.4	1 U	275	171			16.37		
RF1B	9/24/01	10:40	0	3.9 J	11	3.27	1.4 J	9	271	172			14.11		
RF1C	9/24/01	14:15	0	3.6	7	3.84 J	1.4	5	268	171					
RF1C	9/24/01	8:40	0	3.3 J	7	2.91	1.3 J	6	275	171			13.02		
RF1C2	9/24/01	14:45	0	2.8	4	1.93 J	1.9	4	274	170			15.61		
RF2	4/24/01	7:10	0		2	1.77							11.44		0.117
RF2	8/28/01	7:30	0		2	2.21							13.78		0.125
RF2	7/31/01	7:55	0		2	2.13							13.71		0.129
RF2	6/26/01	7:10	0			2.02							13.88		0.119
RF2	3/26/01	7:25	0		2	1.96							12.3		
RF2	5/29/01	7:25	0		2	1.73							12.35		0.096
RF2	9/24/01	13:45	0	2.1	2	2.65 J	1.3	2	272	171			14.31		
RF2	9/24/01	9:45	0	2.6 J	12	3.61	1.1	10	270	172			12.93		
RF2	9/25/01	13:10	0			2.09 J									
RF2A	9/24/01	13:20	0	1.2	1 U	2.27	1.1 J	1 U	428 J	169			14.18		
RF2A	9/24/01	9:20	0	1 J	3	3.19	1 J	3	274	170			13.07		
RF3	4/24/01	6:40	0		1 U	2.51	1.1		287 J		220		12.6		0.098
RF3	8/28/01	6:45	0		1 U	3.13	1.1		448	312			14.8		0.11
RF3	7/31/01	7:00	0		1 U	3.9	1.2 J			310			14.2		0.119
RF3	6/26/01	6:35	0		1 U	2.65	1 J		275	193			14.61		0.111
RF3	5/29/01	6:45	0		1 U	2.61	1.2 J		291	206			13.26		0.075
RF3	9/24/01	6:50	0	0.05 UJ	3	3.95	1 U	2	276	198			14.25		
RF3A	9/24/01	7:15	0	0.05 UJ	1 U	3.22	1 U	1 U	259	158			13.53		
RF3B	9/24/01	7:30	0	0.05 UJ	1 U	3.04 J	1.2 J	1 U	279	168			12.64		
SP1	4/24/01	12:10	0			3.39					307				0.104
SP1	7/31/01	15:00	0		1 U	3.44	1.6 J		350	263			17.5		0.054
SP1	6/26/01	12:05	0	0.15	1 U	4.19	1.5		380	287			13.72		0.055
SP1	9/25/01	9:55	0	0.05 UJ	1 U	2.5 J	1.2		345	265					

Table B-1 - page 24. Field and Laboratory Data

Phosphorus (mg/L) (SM4500PH)	Phosphorus (mg/L) (EPA365.1)	pH (pH) (WASPH)	Ortho-Phosphate (mg/L) (SM4500PG)	Ortho-Phosphate (mg/L) (EPA365.3M)	Nitrite-Nitrate (mg/L) (SM4500NO3I)	Dissolved Oxygen (mg/L) (DOFM)	Dissolved Organic Carbon (mg/L) (EPA415.1)	Turbidity (NTU) (SM2130)	Conductivity (umhos/cm) (EPA120.1)	Conductivity (umhos/cm) (CONDMETER)	Chloride (mg/L) (EPA300.0)	Flow (cfs) (MIDSECTION)	Ammonia (mg/L) (SM4500NH3H)	Ammonia (mg/L) (EPA350.1)
		8.36	0.078		1.205	9.63	1.6 J	6	405.5	385	7.305		0.0935	
0.106 J			0.1		1.39		1.2	3.7	388		5.86		0.031	
		8.27				10.15				386				
0.1075 J		8.15	0.103		1.41	9.72	1.25	3.75	390	387	5.975		0.042	
		8.17		0.097	1.31			5.4		366	8.02			0.102
		7.92	0.1		1.22	7.72		6.6		369			0.045	
		8.05	0.094		1.14	8.35		4.2		388	6.66		0.033	
		7.98	0.068		1.07	8.09		3.3		372.1	6.46		0.013	
	0.164			0.125	1.46			6.3			7.59			0.107
		8.24	0.076		1.22	9.6		4.9		386	7.25		0.082	
0.128 J		8.06	0.125		1.82	10.37	1.3	4.1	425	424	8.07		0.057	
0.131 J		8.08	0.127		1.84	9.65	1.4	4	424	421	7.43		0.067	
0.134 J		7.71	0.129		1.91	8.89	1.3	2.6	426	423	7.4		0.059	
0.129 J		7.68	0.128		1.9	7.28	1.3	0.8	426	421	7.22		0.074	
0.122 J			0.123		1.94		1.2	2.6	424		7.34		0.055	
0.126 J		7.56	0.131		1.95	6.55	1.3	2.5	428	427.8	7.33		0.065	
0.128 J		7.82	0.126		1.93	10.75	1.5	1.6	423	421	7.9		0.057	
		7.76		0.09	1.66					372	8.2			0.1
		7.56	0.114		1.93	4.28				395	7.77		0.099	
		7.56	0.112		1.83	5.4				417	8.32		0.12	
		7.52	0.093		1.65	5.68				395.2	9.52		0.114	
	0.155	7.64		0.125	1.85					369	7.46			0.067
		7.84	0.083		1.58	8.1				399	7.87		0.077	
0.103 J		7.71	0.115		1.96	11.13	1.3	0.9	424	418	7.36		0.037	
0.109 J		7.51	0.118		1.97	6.99	1.1	1.1	426	418	7.43		0.048	
0.1105 J			0.116		1.99								0.057	
0.1 J		7.58	0.107		2.03	9.95	1.2	0.5 U	422	417	7.5		0.087	
0.107 J		7.55	0.114		2.03	8.56	1 U	1.3	423	416	7.19		0.043	
		7.8		0.072	2.66		1.3	0.5 U	473	422	4.16			0.01 U
		7.58	0.101		3.02		1.2	0.5 U	704	668	11		0.01 U	
		7.94	0.099		2.8		1.1 J	0.5 U	705	696	11.1		0.01 UJ	
		7.54	0.065		2.31	9	1.3 J	0.5 U	423	394.8	3.77		0.01 U	
		7.91	0.066		2.47		1 UJ	0.5 U	447	415	3.76		0.01 U	
0.052 J		7.42	0.0659		2.53	9.2	1	0.5 U	436	441	3.35		0.01 U	
0.083 J		7.23	0.0966		1.92	9.2	1 UJ	0.5 U	401	401.7	7.2		0.01 U	
0.095 J		7.27	0.109		2.07	9.4	1	0.5 U	434	434.3	9.19		0.01 U	
				0.047	3.27				622		5.16			0.013
		7.58	0.038		2.32		1.6 J	0.5 U	543	534	4.42		0.01 UJ	
		7.52	0.039		3.32	9.42	1.6	0.5 U	593	552.6	5.87		0.01 U	
0.026 J			0.04		2.41		1.4	0.5 U	547		5.15		0.01 U	

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Appendix C

Response to Comments

The study was started as a Total Maximum Daily Load (TMDL) project in response to the 1996 Section 303(d) listing of Moses Lake. Since that time it was decided to publish the study findings as a scientific study (not a TMDL).

This *Response to Comments* section was generated during the review and comment phase of the TMDL study.

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DEPARTMENT OF ECOLOGY

October 16, 2003

TO: David T. Knight and James Bellatty
Water Quality Program, Eastern Regional Office

FROM: Jim Carroll, Watershed Studies Unit
Environmental Assessment Program

THROUGH: Karol Erickson, Unit Supervisor, Watershed Studies Unit
Environmental Assessment Program

SUBJECT: RESPONSE TO REVIEW COMMENTS ON THE DRAFT MOSES LAKE TOTAL MAXIMUM DAILY LOAD PHOSPHORUS STUDY TECHNICAL DOCUMENT

The draft technical report, entitled Moses Lake TMDL Phosphorus Study, was distributed to the Moses Lake Advisory Board and interested parties the week of November 25th, 2002. At the Moses Lake Advisory Board meeting in Moses Lake on December 12th, 2002, the technical information in the document was presented and a comment period deadline of December 31st, 2002 was announced for reviewers of the draft technical report. Ecology received written review comments from Jim Parsons (Troutlodge, Inc.), Jack Rensel (Rensel and Associates on behalf of Troutlodge), Anne Henning (City of Moses Lake), Larry Gadbois (US EPA), William Riley (Big Bend Economic Development Council), and Dean White (Lincoln County Conservation District) within the deadline period. Jim Parsons of Troutlodge, Inc. sent additional comments on January 7th, 2003 after receiving a deadline extension for that date. Additional comments were received from Jack Rensel (Rensel Associates) on January 10th, 2003, presumably on behalf of Troutlodge, Inc.

Ecology also contracted with Professor Emeritus Dr. Eugene Welch (University of Washington), who has extensive experience with water quality issues on Moses Lake, to peer-review the technical draft. His written comments were received January 13, 2003.

General Final Response:

We believe the collected work completed for this project meets accepted standards for environmental regulatory modeling. The current model (as calibrated) can be used to determine the impact of point and nonpoint source loading of phosphorus to Moses Lake in regards to meeting a 50 ug/L in-lake total phosphorus criterion. Specifically, the model results show that the current load of phosphorus to the lake is too high to meet an in-lake criterion of 50 ug/L during May through September critical conditions.

Beginning with Dr. Welch's, the reviewing comments are listed below (as italics text) with our responses following each specific comment.

Comments received by peer-reviewer Dr. Eugene Welch on 1/13/03:

- *General*

  The report is thorough and generally clear and well written. Assumptions about flows, hydrodynamic processes, critical flow year, partitioning of the lake, etc., are well justified and reasonable and calibrations with temperature and Cl confirm that. While use of such a complex water quality model just to predict TP is not justified, because there are no observational data to verify the myriad rate constants that were adjusted in calibration, the TP results are nonetheless reliable, assuming internal loading and settling rates are reasonable. A table of constants and basis for changes during calibration should be included in the appendix. More direct comparisons of 2001 data with past values would be helpful. More specific comments follow.

Ecology believes that the use of CE-QUAL-W2, although complex, is essential to our development of a TP TMDL for Moses Lake because the hydrodynamics play a large part in the fate of P in the Moses Lake system. Additionally, the model allowed Ecology to assess the fate of P in the whole lake, not just portions of the lake as earlier models. Ecology is committed to protecting the entire lake from water quality degradation. All rate constants used in the model conform to published ranges used in other CE-QUAL-W2 applications that have been applied successfully in hundreds of cases world-wide. A separate calibration document has been completed that documents the calibration of the Moses Lake model and will be made available upon request. While it may have been interesting to compare the current assessment of the lake with historical data, the technical document met a specific project goal and was not meant to be a synthesis of all water quality work conducted on Moses Lake to date. The project goal was specifically to "…assess the assimilative capacity of Moses Lake with respect to the in-lake proposed TP criterion of 50 ug/L. Data were collected and used in this assessment. A TP allocation plan is recommended to achieve the in-lake TP criterion."

- *p. 1, lines 23-24 – most accurate to say that TP limits biomass (i.e., sets upper limit), while growth rate is a function of soluble nutrient concentration, either N or P, on short term basis.*

Changed the text to read "…managing TP to control algal biomass is supported in the literature, even for lakes where nitrogen may be temporarily limiting the growth rate."

- *lines 3-4 from bottom – UW work went through 1988, so late rather than mid 1980s and historical work is 14 years old, not 20. Same comment for 1st para in abstract.*

Changed the text to read "…now 14-20 years old.", and the abstract to read "last intensive water quality study of Moses Lake was completed in 1988…"

- *line 1 from bottom to top p. 2 – state more accurately, "all incoming loads" were addressed for 12 consecutive years, 1977-1988, so word as "…incoming loads separately and did…set a maximum incoming load of TP to achieve a lake wide goal of 50 ug/L.." May be useful to stipulate that the 50 ug/L criterion is really for a worst-case year of no dilution – both here and line 9 of abstract. Also, the 50 ug/L suggested in 80s was a surface water concentration, not a whole lake; setting 50 for whole lake means that the surface water, or epilimnetic concentration is lower (see model section for more on that).*

Deleted this section of the text from the report.

- *p. 2, line 17 – stick with TN, TP, etc. throughout as defined on p. 1. Reference the historical publications to let the reader know the sources, e.g., line 9 – they are not likely to search out the 2000 report.*

Changed the text to "TP" and "TN" throughout. Added following references: "…Welch et al. (1989;1992), Jones and Welch (1990)".

- *p. 2, last para – the lake has received more than attention and studies – would be useful to state here under history that a routine pattern of addition of low-nutrient Col. R. water was started in 1977 with relatively high volumes during most of the past 15 years. Fig 31 could well go here to reinforce that. While the USBR might say now that their normal route is through ML, that was not the case in the late 60s and early 70s. There was great resistance to putting water through ML. Convincing USBR and the South District that moving the water through a very polluted ML would not harm their irrigating systems was not easy. EPA failed to convince them in 1968 and "flushing" was abandoned, i.e., not water through the lake on routine basis! The primary route to Potholes was not through ML then. But the South District was convinced in 1976 that the process was really "dilution", not "flushing", and a more or less routine pattern of transfer through the lake began in 1977.*

Noted but not included in the text.

- *p. 3 – Stipulate for a non-dilution water year when the 50 ug/L criterion is stated.*

The 50 ug/L TP criterion is for any year, but allocations are being recommended in order to meet the criterion during a critical condition, in the case at Moses Lake, a low-dilution water year. This is discussed further in the report.

- *p. 5 – Looks like ML 1, ML 2, ML 4, ML 5, ML 6 conform to stations 12, 8, 7, 5, 9 and 10, respectively, from UW work. Would be useful to state that to alert the reader that sampling continuity was intended. RF0, CC1, CC0 and RC1 are same as 13, 3, 4 and 2 for UW work. Someone might want to revisit the data.*

Ecology did sample at historical sampling sites to provide continuity with earlier work. Will add statement to text.

- *Line 6 from bottom – from how many depths were water samples collected for lab anal., chl, TP etc.? Apparently Secchi depth was not measured. Unfortunate, because it is the most widely used and reliable piece of limno data!*

Changed the text to read: "Secchi depths were measured at lake stations. Water grab samples were taken at 3 meter intervals from the surface to the bottom…..".

- *p. 7, bottom – Not clear how model was used to estimate tributary loads. Load (conc X flow) does not show up in the model. Is this model to determine the distribution of concentration with flow and time and that result is used to determine load?*

Ecology did use this model to determine the distribution of concentration with flow and time, which was input into the model.

- *p. 8 - Need appendix of actual model formulation and what state variables and rate coefficients were used and some justification for assumptions and calibration changes.*

Ecology has separate documentation discussing the calibration of the model available on request.

- *p. 12 – SRP is preferred over ortho-P in the limno literature; method measures > ortho-P. TP is often redefined and often spelled out in spite of being defined in introduction. Once is enough – use TP and other abbreviations throughout.*

Ecology's laboratory method EPA 356.3 is for the measurement of orthophosphate. Not changed in the text.

- *Line 8 from bottom – "….TP results for Sept 24-26.."? Were filters held in DI water overnight before filtration? P from filters can often give SRP>TP.*

Ecology's laboratory experienced a problem with their in-line digestion for their automated TP analysis.

- *Line 3 from bottom – "…between the two P partitions at the station in question…"*

Changed the text to read: "…shown between the two phosphorus partitions at the station in question…".

- *Table 4 – A blank of 5-10 ug/L is too high for P - should be ±1 ug/L. Shows contamination of DI water.*

Ecology unfortunately had a reporting limit of 10 ug/L for TP. The blanks were listed as not detectable at the reporting limit. It should be noted that the model does not use TP as a state variable. Ortho-P had a reporting limit of 5 ug/L and was used as state variable in the model.

- *p. 15 – add "…1987 to retain P from entering the lake and carp from entering the creek"*

Changed the text to read: "in 1987 to retain phosphorus and prevent carp from entering the creek."

- *p. 17 – para 2 – This states limits were recommended even though not feasible? Is that correct? Or, DO/pH control in creek not feasible by setting nutrient limits?*

Deleted this portion of the text.

- *Line 14 – The 12 years loading data in Jones and Welch 1990 (excluding wastewater) shows mean of 40% of RFC. How many historical years were used and was wastewater excluded to compare with current situation? This loading was not annual, which is stated online 14.*

Ecology calculated historical annual loading data using the USGS flow record for Rocky Ford Creek (up to 1998) to calculate mean monthly flows and concentration data reported up until 1989 to calculate mean monthly concentrations. These were compared to other annual loads, including wastewater.

- *p. 19 – Might state here that historical TP loading calculations were based on flow at the USGS gauging station.*

Noted but not changed in the text.

- *p. 20 – What kind of "plants" choked the channel – filamentous algae or rooted plants. Makes a difference, because algae respond most to nutrients in the water and rooted plants to water level and substratum.*

Changed the text to indicate "rooted plants", though there is filamentous algae and periphyton in the creek as well. The late 1990s had extensive flooding in the creek which resulted in extensive rooted plant growth. These conditions did not exist in 2001.

- *p. 21 – 18C is understood ungeit style; also 10AM*

Style noted and changed for the time unit.

- *p. 23, line 5 – "…late afternoon observations…" line 8, period not year.*
  RFC is a trout stream and diurnal DO range of 2.6-9.2 is not a healthy situation, because fish growth is dependent on the daily minimum not the mean or max.

Rocky Ford Creek is on the 303(d) list for dissolved oxygen, pH, and temperature violations.

- *p. 24, para 1 – Diurnal DO problem is probably due more to periphyton on rocks and plants rather than to macrophytes per se.*
  para 6 – Chl measured in water was probably sloughed from periphyton mats, which did the nutrient assimilation, not the measured sloughed material. Discussion of this is a little confusing.

Changed the text to read: “the major contributor of chlorophyll *a* (i.e., algae) to the creek (38.7%), most likely sloughed from periphyton mats…..”.

- *Table 5 – Units not indicated.*

Changed the format of the table to indicate units better.

- *Tables 8 and 9 titles could more clearly indicate the difference in sampling location; Sept ’01 sampling (Table 9) shows 30% increase in TP load from hatchery, while Table 8 shows 35% increase (11.5/8).*

Footnoted the title of Table 9 to indicate the difference in sampling location.

- *p. 29 – Was “significance” tested statistically or only by comparison of increase with variation? Term significance usually implies stat. Test.*

Changed the text to delete “significant”

- *p. 31, para 3 – Again, the term significant is given wo/ any prob. statement. Ratio is 0.75, not 75%; nitrate + nitrite?*

Changed the text to read: “There were no significant differences (α =0.05) between the upstream and downstream sites for TP….”. Changed “ratio” to “percentage”.

- *p. 32, line 1- “….oxygen depletion, than a direct adverse effect on trout per se”.*

  Line 8 – “preserved”?

Changed the text to include suggestions.

- *p. 34, last para (Fig 17) – This constant relation of TP load w/ flow may suggest that contribution from the hatcheries or other sources have not changed.*

Ecology agrees, though in-creek sources have probably changed over time (e.g., hatcheries have probably had different production over the years).

- *p. 40, para 4 – Weinmann, Horner (UW), Bain, et al. conducted a basin-wide loading analysis w/ Dick Bain when at Brown and Caldwell; see NALMS proceedings ~ 1984 – may be earlier.*

Changed the text to read: “Horner et al. (1985) examined Crab Creek during a median flow year (winter-1982-83) and found limited contributions from the upper Crab Creek watershed above Brook Lake to Moses Lake. Although Lincoln County Conservation District has conducted limited nutrient sampling of the upper watershed, a more detailed source study of TP in the upper watershed would be beneficial during a high-flow event (greater than 500 cfs).”

- *p. 41, para 4 – Should be worth mentioning the decline in CC TP and SRP since 69-70 means of 119 and 32, respectively. That has benefited the lake. The irrigation method switched from largely ril to largely spray during the 1970s.*

Changed the text to include: "which was greatly reduced from a mean of 32 ug/L in 1969-70."

- *p. 46, last para – This is first mention of method detection limit for P; these are too high – the lab is obviously not using a 10 cm cell, which is necessary for lake work. This procedure would be useless in majority of WA lakes, which are oligotrophic. So what values were used in load calculation when below detection, the detection limit?*

Agree. The Department of Ecology now has reporting limits of 1ug/L for TP and 3ug/L for ortho-P. They had not changed methodology for the 2001 Moses Lake work. In any case, the CE-QUAL-W2 model uses dissolved P as the state variable which was the lower of the reporting limits at time, ranging from 3 to 5 ug/L.

- *p. 49, para 4 – There is no credibility given here to the initiation of greater feeds through Moses Lake starting in 1977 for purposes of dilution (see comments for p. 1). Fig 31 shows that prior to 1977 there were two years only when sizable amounts were passed through the lake. Until the USBR and South District were persuaded in 1976 to allow more through – and WQ would not be degraded – most flow went around ML. The change in routing was why Brown and Caldwell got the EPA grant to evaluate dilution effects.*

Ecology understands from the Bureau of Reclamation that the initiation of feed water through Moses Lake in 1977, while convenient for a dilution program, was initiated in order to facilitate the conveyance of more irrigation water to the expanding South District.

- *p. 50, Fig 31 – A scale on right for 106 m3 would help, since most of report is in metric.*

Ecology used metric figures when possible, but certain numerical values only have meaning within the Columbia Basin Irrigation Project based on units of acre feet so they were left intact for this report.

- *p. 53, line 1 – Greatly improved water quality would be more accurate? Document the comparison with 1986-1988 values for South L and Lower Parker (DOE 3 and 4) – 44 ug/L TP in 80s versus ~20 ug/L in 2001.*

Changed the text to read: "…Moses Lake had greatly improved water quality during the 2000-01".

- *p. 56, para 2 – Term population refers to one species; algal biomass is more accurate. Useful to make the point that >60% of biomass in mid to late 80s was blue greens at 3 and 4 (Welch et al. 1992). Fig 37 is difficult to read, i.e., blue green fraction.*

Changed the text to read, "…summer biomass..." Historical significance of bluegreens in Moses Lake is referenced in the next paragragh.

- *p. 58, line 3 – Experience high algal biomass; line 10 – algal biomass or sp. composition, not population; para 4, line 1 – no verb; line 5 – "…criterion of 50 ug/L during a worst-case, no dilution year."*

Changed the text to read: "…continued to experience high algal biomass…"; added:"… was used…."; and added, "during a worst-case, little dilution year."

- *p. 61, Fig 39 – Abscissa legend should be X 10-6.*

Corrected the legend.

- *p. 62, line 5 from bottom – Equilibrates rather than re-initializes. Last para – The basis that was used to change coefficients should be included in the appendix table.*

Changed the text to read: "…lake equilibrates quickly with the relative large hydrologic input from the boundaries." Separate documentation is available on request which describes the model calibration.

- *p. 77, para 3 – Aerobic P release also occurs from decomposition of surficial sediment organic matter related to temperature and from loosely sorbed P; aerobic release was determined from ML sediment in laboratory indicating one or both of these processes. Contained in UW thesis by V. Okereke in mid 80s.*

The mechanism of increased P release seems distinct to a specific period of time when there is an increase in pH from the vernal diatom bloom. Though temperature related, a general aerobic release from the sediments would probably not be as temporally constrained, and is most likely included, though not mechanistically, in the calibrated anaerobic P release.

- *p. 86 – Need to justify use of predicted TP for TP budget rather than observed TP. Table 14 – The difference between internal load in '01 and the 80s should be discussed. According to '01 mass balance, the lake was a net sink for P (-1718 kg), while in 1988, there was a net internal load of 12, 467 kg. Although high, that was not the highest internal load. Only in 1978 and 1980 (Mt. St. Helens ash) was there no net internal loading. The reason is not due to an underestimate of ground water load in '88, which was about twice the estimate as 2001.*

Predicted P from the model was used to develop the TP budget because the modeled TP accurately portrayed the spatial and temporal distribution of P in Moses Lake which was the reason why we used the hydrodynamic model. The calibrated model provides greater resolution than just using vertical profile sample data.

There appeared to be less internal load in 2001 than in earlier years. Whether this was from the particular meteorology of 2001 (i.e., less mixing), or a reduced sediment component because of successive years of dilution and reduced productivity, or successful reduction in external loading, or a combination of all these events remains unknown.

- *p. 89-90 – Hypereutrophic is not hyphenated. First para – Identify 50 ug/L wo/ dilution water. Last line – Cell washout rate extremely small (i.e., lake flushing rate) compared to growth rate, so dilution of TP is the big effect.*

Hyphen was taken out. Changed the text to read: "Exchange rates can be high enough to effectively dilute the nutrient concentrations in the lake (when using low-nutrient feed water) and, to some minimal extent, wash out algal cells."

- *p. 91, para 3 – There is aerobic P release as well.*

Changed the text to read: "…however, there can be an aerobic release of sediment phosphorus to the epilimnion."

- *p. 92, last para – Suggest using cms earlier to be consistent.*

Ecology used cfs in the report to reflect earlier reported values. The CE-QUAL-W2 model operates with metric terms only and thus the design criteria are given in metrics.

- *p. 93, para 4 – Suggest giving an equivalent mean lake epilimnetic TP for the whole lake 50 ug/L, because original recommended criterion was for surface water and chl is related to epilimnetic TP, not whole lake TP. As Table 15 indicates, epilimnetic mean TP, which algae depend on, is <50 ug/L, and closer to the EPA recommended criterion.*

Ecology concurs, however, Moses Lake is known to be polymictic and the hypolimnetic P is available to the epilimnion during the growing season in any given year. This is stated in the text as: "When evaluating model simulations, the entire water column TP was averaged for compliance with the TP criterion. Even though the algae grow in the euphotic zone, the entire water column was averaged because Moses Lake is polymictic (capable of mixing several times during the growing season). This avoided the complex task of trying to identify a critical meteorological conditions data set, by conservatively assuming any internal phosphorus loading is potentially available for algae growth. The 2001 year meteorology data were used for the simulation runs." The conservative assumption that hypolimnetic P is available at all times builds in an implicit margin of safety for this TMDL. The epilimnetic response is shown in Table 15.

- *p. 95, last para – Need to emphasize how much internal load has decreased since the 80s, which means external has proportionally more effect now than earlier.*

Changed the text to read: "Apparently internal loading is already suppressed from rates observed since the 1980s."

- *p. 97 and Table 17 – With the 35% reduction in load, the mean epilimnetic TP is conveniently 35 ug/L – in agreement with the EPA recommendation.*

Ecology agrees this is convenient.

- *p. 99 – While bottom water TP is available at times, chl is determined by the epilimnetic TP concentration. For example, the whole lake TP in Sammamish is 22 ug/L, but the amount of algae one gets is dependent on, fortunately, the 12 ug/L TP in the epilimnion. Same situation holds for all lakes. If algae get some of the P from bottom water, then it shows up in the epilimnetic TP concentration.*

Ecology concurs, however, Moses Lake is known to be polymictic and the hypolimnetic P is available to the epilimnion during the growing season in any given year. This is stated in the text as: "When evaluating model simulations, the entire water column TP was averaged for compliance with the TP criterion. Even though the algae grow in the euphotic zone, the entire water column was averaged because Moses Lake is polymictic (capable of mixing several times during the growing season). This avoided the complex task of trying to identify a critical meteorological conditions data set, by conservatively assuming any internal phosphorus loading is potentially available for algae growth. The 2001 year meteorology data were used for the simulation runs." The conservative assumption that hypolimnetic P is available at all times builds in an implicit margin of safety for this TMDL.

- *p. 101, para 1 – Late 1980s (1988 is not mid); para 6 – CC p concentrations did change dramatically since 1970, which is worth mentioning.*

Changed the text to read: "The last intensive water quality study of Moses Lake was completed in 1988…." and "Though Crab Creek TP and ortho-P concentrations have declined dramatically since 1969-70s (attributed to a switch from rill to spray irrigation), May through September 2001 ortho-P concentrations in Crab Creek were slightly higher than those observed in the 1980s."

- *p. 102, para 4 – Internal loading apparently is not as great a limitation as earlier and important to mention that; last para – and reach a mean epilimnetic TP of 35 ug/L.*

Changed the text to read: "Internal sediment release of phosphorus is an important loading source to Moses Lake, though apparently not as important as in earlier years."

- *p. 103, para 2 – More precise management of dilution water is important for keeping enough TP and algae in the lake to limit expansion of macrophytes. That needs to be mentioned.*

Added the following sentence to the text: "More precise management of feed water may be important for retaining enough TP (i.e., algal biomass) in Moses Lake to limit the expansion of macrophytes in the lake."

- *p. 104, para 3 – N control was emphasized in mid 1980s and should have been P*.

Ecology concurs. No change in text.

Comments received from Jim Parsons of Troutlodge on December 5, 2002:

- *Dear Jim,*

  Thank you for the opportunity to review the draft Moses Lake TMDL Phosphorus Study document. We have a variety of comments that will be presented by Dr. Jack Rensel (unfortunately I'll be at our facility in Chile that week) at the meeting. However, there is one item that I feel is important to clarify prior to this meeting.

  I was concerned about the feeding numbers when I saw the historical comparison, and this prompted a bit more digging on my part. It didn't make sense that our feed numbers would be down when in fact our biomass was higher than in 1997. In searching the numbers I found that I made a rather large error in calculating feed usage at the facilities for the calendar year of 2001. Our fiscal year runs from July through June, and I incorrectly assumed that we used only one feed supplier during the entire calendar year of 2001. In fact, during the first half of the year we actually received feed from two feed suppliers. The numbers that I gave you ignored this second supplier, as I was using feed purchase records to document our usage on each facility. During the period from January to June we actually utilized approximately 400,000 lbs. of additional feed, bringing the total for the calendar year to 1.25 million lbs.

  I apologize for this error, but feel it is important to advise you of this prior to the meeting on the 12th. Perhaps if the draft would have been shared with us (as a cited reference) prior to distribution I could have caught this sooner and cleared it up.

  Best regards,

  Jim Parsons
  Vice-President
  Technical Services
  Troutlodge, Inc.

We corrected the feed numbers in the report to reflect the number of pounds indicated above.

Comments received from Jack Rensel on behalf of Troutlodge on December 9, 2002:

- *Hi Jim*

- *Here are the TL1 and TL2 biomass values for summer 2002. This is one of three things I wanted to present at the meeting and have permission to discuss. Remember, feed rates can not be applied directly to these as the size of fish (planting fish vs broodstock) have very different rates. I can't tell you what those are for Troutlodge. I simply do not know. You can see that most of the summer, TL2 was far less than TL1 although it was increasing, particularly toward the time of your September synoptic survey.*

Biomass

	TL1 P1	**TL1 P2**	**TL1 Total**	**TL2**	**total**
May	144,750	47,950	192,700	82,850	275,550
June	130,325	48,975	179,300	88,925	268,225
July	115,900	50,000	165,900	95,000	260,900
Aug	136,400	41,200	177,600	115,500	293,100
Sept	116,000	40,000	156,000	119,500	275,500

- *I did not have actual values for June, so I interpolated for that month. I really don't know if Bill Witt, the on site manager, can resurrect data from other months as it seemed to be a special effort for him to provide these numbers each time I did a field survey.*

- *All the best,*

- *Jack*

- ***

- *J.E. Jack Rensel Ph.D.*
- *Rensel Associates Aquatic Science Consultants*
- *4209 234th Street NE*
- *Arlington WA 98223 USA*
- *360-435-3285*
- *Fax: 360-435-7409*
- *Cell: 360-927-0305*
- *jackrensel@att.net*

Ecology adjusted the P loading for Troutlodge II based on the reduced production at that facility compared to Troulodge I as indicated in the above table. The percent contribution of P from the hatcheries to Moses Lake during the May to September, 2001 time period fell from 9% to 6% as a result. Before this correction, Troutlodge II was assumed to have equal production rates and P loading as Troutlodge I.

Comments received from Anne Henning of the City of Moses Lake on December 12, 2002:

- *I just finished reading the report, and noticed a few things that I thought you might want to fix before the final report. I love to edit things, so sometimes I get carried away when I read draft documents, but I tried to stick to only typos and things that really make a difference in what you are saying. Please disregard my comments if you don't think they apply or if my problem was that I didn't understand something. I also had a few questions and general comments.*

  p.7, 2nd full paragraph--Evans 2002 isn't in the References. (I didn't check each work you cited, but I noticed this one because I was wondering what it was, but it wasn't listed).

The Evans (2002) report was included in the Appendix and is now referenced as such.

- *p.23, under Figure 10, last sentence--doesn't read quite right--Is this how you meant to say it?*

Could not find exactly which sentence you were referring to.

- *p.58, Purpose and Scope--first sentence is a fragment.*

Sentence was corrected.

- *p.64 Chart shows no data for May--Is this correct?*

The field data for that month was questionable. It was unclear from the field notes where the temperature data was collected and therefore was not used.

- *p.91, 2nd full paragraph--I don't think "meterology" is the right term, since you are talking about the physical process and not the science of it. Maybe "meterological conditions" or simply "weather"?*

We agree. Text changed to “meteorological conditions”.

- *p.104, 1st full paragraph--last sentence has an unnecessary "the" before "reducing P"*

We agree. Text changed to delete “the”.

- *It would be helpful for readers like me, who don't deal with all these terms every day, to have an acronym glossary. That way, when I can't remember what RMSE means, I don't have to try to find the first place you used it. Also, depending on the intended audience, a glossary of technical terms might be appropriate. Things like hypolimnion (which I didn't go back and find, so may have spelled wrong) and the word that means mixing (which I can't remember* *and can't find in the report now that I want it), which your average person wouldn't be familiar with. You did explain those terms as you used them, but I am probably not the only person who forgot and had to track down the place where they were first used. But if your audience is people who would know those terms, then it wouldn't be needed.*

Ecology did produce the technical document with the intention that it would be reviewed by a technical audience familiar with the technical terms and vocabulary, although an attempt was made to make it as readable as possible. We regret we will not be providing a glossary.

- *As I read the report, I wondered if you have coordinated at all with Dave Burgess with Fish & Wildlife. He is doing a study of the lake, for fish habitat. Recently, he was looking at collecting some data at the outfall, which is what made me think of it in the first place. His supervisor is Jeff Korth, who I think is involved in the TMDL meetings.*

Ecology attempted to collaborate on data collection with Dave Burgess of the State Fish & Wildlife during the 2001 study period, but Fish & Wildlife apparently lost funding for the position to collect the data and were unable to collect the data they had planned to.

- *Do you have any thoughts on what would happen if there were dilution water available in a wet year? What would that do to the various forms or P that year? Would the extra water flowing through the system cause problems downstream?*

Actually, one of the modeling scenarios described in the draft technical report predicts that Moses Lake would meet the TP criterion if the median (50^{th} percentile) amount of feed water (dilution) were added to the lake during a 90^{th} percentile wet year. However, the Bureau of Reclamation has explained that it cannot deliver that amount of feed water during a wet year because the extra water would violate downstream contractual agreements.

- *I have been working on updating the City's Shoreline Master Program. We have talked quite a bit about requiring vegetated shoreline buffers. Would this have any impact on the nutrient problem in the lake? Or would the buffers need to be so big that it would be unreasonable? (the typical shoreline residential lot is 100' deep and requires a 25' setback from the street. So that leaves 75' for the house and buffer. Right now, we have no required setback from the lake, so people can and do build houses only a few feet from the lake. Even those who don't have a house right on the shoreline typically want a bulkhead across the width of their property.)*

Ecology would encourage any shoreline buffers that would reduce phosphorus inputs into Moses Lake. While the majority of P in the groundwater around the city of Moses Lake appears to be of waste water origin, there is probably over-use of fertilizers and irrigation water on lawns which contribute P as well. Unfortunately, the soils around Moses Lake facilitate quick leaching to the groundwater table which eventually interacts with the lake water, somewhat de-emphasizing the utility of shoreline buffers.

Comments received on December 17, 2002 from Larry Gadbois of the US EPA:

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 10 HANFORD PROJECT OFFICE
712 SWIFT BOULEVARD, SUITE 5
RICHLAND, WASHINGTON 99352

December 17, 2002

James V. Carroll
Washington State Department of Ecology
Environmental Assessment Program
Olympia, Washington 98504-7710

Subject: EPA Comments on "Moses Lake Total Maximum Daily Load Phosphorus Study", Review Draft Dated November 25, 2002.

Dear Mr. Carroll:

The U.S. Environmental Protection Agency (EPA) has reviewed the subject document. This document was very well written. It presents the technical information in a highly reader-friendly format. The layout is very good, and the writing very clear. Thank you for making review of the information so easy. Our comments are enclosed. If you have any questions, please contact me at 509-376-9884.

Sincerely,

Larry Gadbois

Larry Gadbois
Environmental Scientist

Enclosure

Cc: Marcie Mangold, Ecology's Moses Lake TMDL Project Manager

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1) Abstract. 2nd paragraph.
EPA understands that the 50 ug/L target is a high target relative to benchmarks such as:

a) WAC 173-201A-030(6)(a)(table 1) which has 35 ug/L as the highest numeric criteria.
b) EPA, (2001) "Ambient Water Quality Criteria Recommendations. Information Supporting the Development of State and Tribal Nutrient Criteria for Lakes and Reservois in Nutrient Ecoregion III (Xeric West), EPA-822-B-01-008 which recommends a criteria of 35 ug/L
c) TP of 50 ug/L gives a Carlson Trophic Status Index of 60.6 which is considered hypertrophic (EPA, 1999) "Protocol for Developing Nutrient TMDLs", EPA-841-B-99-007, page 4-11.
d) Ecology, (third draft - August 1996) "Nutrient Criteria: review and Analysis for Washington State Lakes", which proposes 35 ug/L as the criteria for the lakes in the Columbia Basin.

The EPA intends to accept that target because it is calculated relative to a 90th percentile worst case year for phosphorus loading from external inputs and a 10th percentile year for diluting flow from Rocky Coulee Wasteway. Based on Ecology's analysis, for about 90 percent of years, external loading will be such that TP would otherwise be substantially below 50 ug/L however internal loading from sediments would sustain the higher TP levels. Thus in most years there would be a net release of phosphorus from the lake sediment. This has the potential over the long term to reduce the phosphorus sink within the sediments. The gradual depletion of the phosphorus from the lakebed sediments under Ecology's proposed TP target would be a good addition to this document. But for depletion of the sediment sink to occur, phosphorus loads need to be controlled year-round, so that off-season loading doesn't accumulate in the sediment. The year-round nature of phosphorus control is not a strong component of the document, and would be a valuable addition to the document as well as the key to long-term water quality. Ecology should ensure that algal mass and TP are monitored during implementation of this TMDL and the data analyzed (a) to ensure that the TP target is met, (b) that 50 ug/L TP is low enough to preserve the aesthetic values of the water, and (c) to document the conclusion of this document that ambient TP levels will usually be significantly lower than 50 ug/L as predicted by Ecology's modeling for about 90 percent of future years. If monitoring data does not support the target selected in the TMDL, Ecology should re-consider the numeric target in light of Ecology and EPA guidance such as cited above.

2) Abstract, last paragraph.
The document states that "specific load allocations for nonpoint sources and wasteload allocations for point sources within each of these major source categories were not established in this study." It is not clear why this statement is in the abstract when pages 103-104 state "watershed-wide 35% reduction of P from these sources is recommended" for diffuse non-point sources, and "the same 35% reduction in P recommended for non-point sources should be applied to the fish hatcheries."

3) Page 95, 2nd last paragraph.
The document states "a Dept. of Fish and Wildlife net pen facility…is only in operation during the winter months, so it does not have a direct impact on algae growth in the summer." This statement can confuse management efforts because the general conclusion in this document is that internal cycling of phosphorus from sediment will maintain relatively high phosphorus levels during the summer. Therefore year-round control of loads/wasteloads is necessary to prevent re-supplying the sediment with phosphorus during the off-season.

Response to comment #1:
Ecology agrees that the TMDL set for Moses Lake should be adaptive in the sense that follow-up monitoring will determine if the proposed strategy is working to reduce water quality degradation in Moses Lake most of the time. Numeric criteria and load allocations should be reconsidered if post-monitoring data shows continued exceedances.

Response to comment #2:
The last sentence of the abstract was misleading and was deleted.

Response to comment #3:
It is true that year-round loads are involved with supplying P to the sediments. Winter time loading sources such as the net-pens, waterfowl wintering on the lake, and winter runoff in the tributaries are examples of possible sediment loading. Reducing inputs from these sources would reduce the P to sediments. The technical report recommends monitoring the Crab Creek winter run-off (which happens only ~40% of the years) for quality and source identification. Non-point source control of erosion in the upper watershed is recommended. Waterfowl and net-pens activities take place in the winter. Their impact on the water column chemistry is incorporated in the initial conditions that were measured in the lake in March of 2001. Most of the water is flushed out in April and May of every year so the initial conditions of the water column (from the winter) have little effect on summer growing season. Waterfowl and net pens contributions to the sediments may have a delayed effect on the lake by being released to the overlying water during anoxic conditions of summer. The CE-QUAL-W2 model of Moses Lake has a P-release sediment term in its algorithms. The model dynamically simulates the release of P whenever the dissolved oxygen level drops below 0.1 mg/L in the bottom of the lake. The dynamic P release calibrated very well with hypolimnetic P concentrations observed in 2001. In essence the model is accounting for these sources of P already.

Comments received on December 23, 2002 from William Riley of the Big Bend Economic Development Council:

- *-----Original Message-----*
  From: *BBEDC [mailto:bbedc@moseslake-wa.com]*
  Sent: *Friday, December 20, 2002 4:38 PM*
  To: *Mangold, Marcie*
  Subject: *Comments of the Moses Lake TMDL*

Without spending exorbitant amounts of money, the exact cause of all pollutants in the Moses Lake system will never be known. Several things jump out of the report: Moses Lake is a water body that was not naturally created.

Ecology believes that phosphorus sources to the lake can be relatively defined and that best management practices, some of which are already in place, can be utilized in economical ways to reduce phosphorus loading to the lake. Moses Lake was naturally created by the damming of the Crab Creek with wind-blown sand.

- *The seasonality of irrigation cause the lake to virtually disappear from Nov 1 to the start of irrigation in the following April. This allows full access to the lake bottom for dredging. or for installation of pipes. Orthophosphates and nitrates in the water are fertilizers. The lake water is currently being minimally used to irrigate. This use of lake water to irrigate crops and lawns should be expanded, and the water previously used should be re-routed to the lake. A strategy could be developed to inject BOR water at other points in the lake to flush it, while a system of pipes laid at the lake water could send the denser, bottom water with its pollutants out of the lake, either as a discharge or for irrigation.*

Ecology will work with the Moses Lake Advisory Board to develop a Supplemental Implementation Strategy (SIS) that will identify effective strategies to reduce phosphorus loads into the lake.

- *There is an extensive number of geese, ducks, and other waterfowl, that inhabit the lake and their wastes are in the lake.*

Waterfowl activities take place in the winter. Their impact on the water column chemistry is incorporated in the initial conditions that were measured in the lake in March of 2001. Most of the water is flushed out in April and May of every year so the initial conditions of the water column (from the winter) have little effect on summer growing season. Waterfowl contributions to the sediments may have a delayed effect on the lake by being released to the overlying water during anoxic conditions of summer. The CE-QUAL-W2 model of Moses Lake has a sediment P-release term in its algorithms. The model dynamically simulates the release of P whenever the dissolved oxygen level drops below 0.1 mg/L in the bottom of the lake. The dynamic P release calibrated very well with hypolimnetic P concentrations observed in 2001. In essence the model is implicitly accounting for these sources of P already.

- *The discussion of any action to take regarding the lake should be an evaluation of what is doable, what is the cost, who will pay, and what are the anticipated results. A cost analysis of all proposed action should be done.*

Ecology will work with the Moses Lake Advisory Board to develop a Supplemental Implementation Strategy (SIS) that will identify the most cost-effective strategies to reduce phosphorus loads to Moses Lake.

William Riley-BBEDC
410 W 3rd Ave
Moses Lake, WA 98851

Comments received on December 31, 2002 from Dean White of the Lincoln County Conservation District:

-----Original Message-----
From: Dean White [mailto:deanwhite61@hotmail.com]
Sent: Tuesday, December 31, 2002 8:51 PM
To: Mangold, Marcie
Subject: Comments on Moses Lake Technical Reports

December 31, 2002

Marcie Mangold
Moses Lake TMDL
Department of Ecology
4601 N Monroe Street
Spokane, Washington 99205-1295
Phone: (509) 329-3450
Email: dman461@ecy.wa.gov

Marcie,

The two recently released technical reports on phosphorous in Moses Lake were well done for the most part and I appreciated receiving the CD version of the reports in the mail. There are some points and clarifications in my mind that I would like to bring to your attention.

Comments on the Moses Lake Total Maximum Daily Load Phosphorus Study by Jim Carroll

- *In the report, there can be some ambiguity over the words "Crab Creek" and what particular section of Crab Creek is being referred to at a given point in the report. Most of the work/sampling done on Crab Creek in the report was done on sites "CC6" through "CC1", which lie on that portion of Crab Creek between Brook Lake and the mouth of Crab Creek at Parker Horn.*

  From my perspective, this portion of Crab Creek is "Middle Crab Creek". Crab Creek from the headwaters just west of Reardan downstream all the way through Brook Lake is "Upper Crab Creek". Crab Creek below Potholes Reservoir to its junction with the Columbia River at Schwana is "Lower Crab Creek".

  As a resident of the "Upper Crab Creek" area, it does make a difference to me when references are made to "Crab Creek" when what is really being referred to here most of the time is "Middle Crab Creek" and the associated irrigated farming area just north of Moses Lake. In other words, this does not include "Upper Crab Creek" and its associated cropland and rangeland most of the time. It is not uncommon for Crab Creek to have no continuous surface flow or no flow at all between Brook Lake and Moses Lake for an entire year or more, as was the case of the study year of 2001 and subsequent year 2002. When there is no continuous surface flow in Crab Creek between Brook Lake and Moses Lake, "Upper Crab

Creek" and the Upper Crab Creek watershed do not contribute any phosphorus at all in suspended sediments in surface water to Moses Lake.

Ecology believes the report clearly states what portion of Crab Creek was evaluated (Figure 1 shows the sample sites for Crab Creek) and distinguishes where the sources of phosphorus originate from within the Crab Creek corridor. "Middle Crab Creek" is not a common designation for the area Ecology sampled.

- *On page 39, the pH, DO and temperature data for all six stations between Brook Lake and Parker Horn (CC6-CC1) are all lumped into the same charts with no symbols identifying which station is being represented for each data point on the charts. I think it would be helpful to see the individual data from each station to see how water quality may change from upstream to downstream here along Middle Crab Creek.*

Ecology sampled from Brook Lake to Moses Lake, however, as you previously noted, there was discontinuous flow between those sites in 2001, and in fact, very little flow at all except at the sites CC1 and CC2. Regretfully, it would not be very instructive to look at any changes in the water quality between the sites because of the discontinuous flow. Most of the data points on Figure 21 are from CC1 and CC2 because the other sites were dry. The data appendix contains all the data if it warrants your consideration.

- *On page 40, it is mentioned that the TP loads in Crab Creek from large winter/spring runoff events are composed of washed out accumulated TP in sediments from the creek channel. I would beg to differ on this point. High flow events certainly do wash out accumulated sediments from the stream channel and from eroded streambanks and carry them downstream into Moses Lake. However, I would guess that during high flow events, a more significant amount of suspended sediments in Crab Creek comes from runoff waters from the surrounding uplands and that a significant portion of these suspended sediments does not have enough time to settle to the bottom of creek channel or to the bottom of Sylvan Lake and Brook Lake before it is delivered to Moses Lake. The suspended sediments that do settle out on the creek channel bottom most likely were delivered there during the waning periods of late winter/early spring runoff events because this is the only predominate time of the year when there is enough water to carry much sediment load to the creek channel. How would necessary nonpoint controls and improved BMP's on surrounding agricultural lands (mentioned on page 103)significantly reduce the phosphorus load from Crab Creek into Moses Lake if the TP loads in large winter/spring runoff events primarily come from …"washed out accumulated TP …in the creek channel"?*

It is Ecology's understanding that the large run-off events in Crab Creek occur when there is a significant rain event in the upper Crab Creek watershed at a time when the ground is still frozen. Sheet run-off occurs during these frozen conditions allowing a large amount of run-off water to reach the creek channel quickly. The channel is quickly inundated and flooding occurs. The force of the water scours and erodes the stream bed of any accumulated sediments, suspending them in the flood water en route to Moses Lake. In this case, the surrounding uplands are not losing soil because it is frozen in place, relatively. However, the surrounding uplands are surely the origin of the sediment in Crab Creek. Erosion occurs with rain events during unfrozen ground conditions, however, these simply do not have the flood magnitude or potential as rain on frozen ground. Any work towards reducing erosion in the uplands throughout all seasons will help reduce the amount of phosphorus load reaching Moses Lake during a flood event.

- *On page 86, the pie chart in Figure 60 has "Crab Creek" labeled as contributing 8 % of the TP load to Moses Lake. What this 8 % contribution really represents is the contribution from "Middle Crab Creek" because there was no continuous surface water flow from Brook Lake to Moses Lake in 2001.*

Ecology agrees and believes the text supports this assertion.

- *On page 101 in the second to last paragraph, it is mentioned that as of 2001, TP and ortho-P concentrations in Moses Lake have not been significantly reduced even though restoration measures such as the retention pond on Rocky Ford Creek and agricultural BMP's in the "Crab Creek basin" had been implemented. What time period and what area are being referred to here? Is this the time period between the mid 80's and 2001 in the irrigated farmland area around "Middle Crab Creek"?*
  Although there is still room for improvement, farming practices have steadily improved since the 1950's and have greatly reduced the amount of soil erosion, spring runoff and flooding occurring along all sections of Crab Creek compared to the 1920's and 1930's, for example. Many landowners who have participated in Watershed Planning for WRIA #43 have mentioned in meetings that you just don't see the spring runoff floods along Crab Creek that they experienced when they were kids in the "good old days". This makes me wonder if significantly larger amounts of sediments were carried by Crab Creek into Moses Lake during high flow events in the first half of the 20th Century compared to today.

The reference to page 101 of the draft that we understand you are referring to now says: "As of 2001, there is no indication that TP and ortho-P concentrations in Rocky Ford Creek have changed from measured historical concentrations, suggesting that the mechanisms of anthropogenic contamination of phosphorus are the same as before and that restoration measures applied to date, including the detention pond on Rocky Ford Creek, have not succeeded." The unchanged TP and ortho-P is in reference to Rocky Ford Creek and not Moses Lake and is comparing concentrations in 2001 to earlier concentrations measured in the past 40 years. Furthermore, the report goes on to say about Crab Creek: "Though Crab Creek TP and ortho-P concentrations have declined dramatically since 1969-70s (attributed to a switch from rill to spray irrigation), May through September 2001 ortho-P concentrations in Crab Creek were slightly higher than those observed in the 1980s." The concentrations compared here are from Crab Creek near the mouth of Moses Lake during the summer time low flows. Ecology was not able to sample a high flow event in Crab Creek during 2001 because there was not one. Ecology recommends that a high flow event be sampled in the future as per the recommendations section of the report. Ecology will work with the Moses Lake Advisory Board to develop a Supplemental Implementation Strategy that should include a plan for sampling a high flow event in Crab Creek.

- *On page 102, an across the board 35 % reduction in TP loads for all sources of phosphorus to Moses Lake is recommended for a critical design year with a 90th percentile load (during a high flow year). Is this* *really a fair and equitable method for load reduction allocation? If Upper Crab Creek only has high flow years 40 % of the time and assuming that phosphorus from Brook Lake does not contribute to the high TP levels in Rocky Ford Creek, shouldn't Upper Crab Creek be given credit for the 60 % of the time that it is not contributing very much if any phosphorus to Moses Lake? After all, Rocky Ford Creek and direct groundwater inputs deliver a higher overall level of TP to Moses Lake all year long, including summertime when available phosphorus is most readily converted into problematic algal blooms.*

Ecology did not include a 35% reduction in P from upper Crab Creek in its allocations. Allocations were given to May through September controllable P load inflows to Moses Lake only. However, Ecology does recommend an assessment of the P loads from upper Crab Creek and strategies to reduce that P load. A reduction in upper Crab Creek P load during a high flow year will reduce the P mass in the lake leading to more favorable initial conditions at the start of the growing season (May to September).

Sincerely,

Dean White
Water/Soil Resources Technician
Lincoln County Conservation District
Phone: (509) 725-4181 ext 3
Email: dean-white@wa.nacdnet.org

Comments received on January 7, 2003 from Jim Parsons of Troutlodge, Inc:

Comments to DOE – Jim Carroll
Moses Lake TMDL Phosphorus Study – Draft Report
1/7/03

Jim Parsons – Troutlodge, Inc.

Dear Jim,

Thank you for the opportunity to comment on the Draft Moses Lake Phosphorus TMDL report. Listed below, in no particular order, are several points that Troutlodge (TL) feels are relevant and should be dealt with in future versions of this document.

1. *As previously noted by email, the feed amounts for the TL facilities provided to you were faulty. As a result of this, and the lower loadings on the TL 2 facilities as reviewed with you by Dr. Rensel, the efficiencies of both TL hatcheries are higher than suggested, and the overall contribution to Moses Lake phosphorus lower.*

2. *TL remains concerned about the extremely high background levels of TP in the source springs to Rocky Ford creek. There seems to be much confusion as to the origin of this high phosphorus content. If indeed anthropogenic in origin, TL believes that this must be addressed as it represents a potential threat to the nature of our business. We suggest*

that additional studies to further define the source are called for before any adequate TMDL can be presented.

3. *DOE recommends a reduction of 35% of all sources of TP to the lake in order to meet the proposed water column concentration of 50 ug/l. However, no analysis that has been presented shows that a reduction to that level will affect a change in beneficial uses of the lake.*

4. *A 35% reduction of TP lading at the TL facilities would not be economically or technically possible. In fact, this suggested reduction is far below that requested of Idaho trout farms in the middle Snake River of Idaho, where net concentration limits of 0.082 mg/l have been proposed. TL's net TP concentrations are currently well below these guidelines. Additionally, assuming a 6% contribution of TL to the TP in Moses Lake, such a reduction would amount to an overall reduction in the lake of around 2%.*

5. *DOE's plan calls for a reduction from TL facilities that might at best yield an overall 2% improvement, but 95% of the remaining sources are left to be handled by BMP's and non-point controls that remain undefined. The eventual success of these other controls are much more important to the overall effects on Moses Lake, but are not dealt with directly by this plan. TL suggests that until inputs from Crab Creek and other instream inputs are dealt with, it makes little sense to propose such a restrictive TMDL plan.*

6. *Dissolved oxygen concentrations downstream of TL facilities are most likely due to instream macrophytes. In previous years, the TL2 facility had to utilize supplemental oxygenation for the early morning hours due to the high macrophyte loads in the stretch of Rocky Ford creek between the facilities. There is no evidence to suggest that the presence of the trout hatcheries is the sole, or even major cause of this problem. High concentrations of nutrients in the insource water would lead to high plant growth, and subsequent low DO's and pH without the presence of the TL facilities. Lack of cause and effect data suggests that removal of this inference from the report is warranted.*

I would be happy to provide further inputs on any of these issues should you need additional information.

Sincerely,

Jim Parsons
Vice-President/Technical Services
Troutlodge, Inc.

Ecology officially responded to the comments above by Troutlodge, Inc. as follows:

Response to comments to DOE
Moses Lake TMDL Phosphorus Study – Draft Report
Received: 1/7/03

To: Jim Parsons – Troutlodge, Inc.

Dear Jim,

Thank you for your comments on the Draft Moses Lake Phosphorus TMDL report. Jim Carroll and I have worked together to respond to your comments. Before we address your comments, we would like to explain parts of the TMDL process that will provide you some background information.

Often in the TMDL process, especially in TMDLs primarily from non point pollution, sources are not known at the beginning of the implementation planning. It is difficult to pin point the exact source and frequently there are various sources contributing to the problem. In the case of the Moses Lake TMDL, it will be documented that exact sources are not known and that further investigation would be useful. The goal as suggested by Jim Carroll in his technical report is to proceed with a 35 % across the board reduction in phosphorus to the Moses Lake watershed. It is expected that if the various sources can meet this reduction then Moses Lake will be protected for its beneficial uses.

We anticipate discussions regarding the need for future monitoring and source identification. As we proceed into the Summary Implementation Strategy (SIS) step of the process, it is important to remember that this is just the first step in implementation. The SIS is an outline or "idea list" of what things need to be done to reduce the phosphorus. Some of the strategies in the SIS may include future monitoring for source identification which will further help the implementation process. Other strategies are Best Management Practices (BMPs) that are already in place. Due to your experience in management and operations, many or your BMPs will be added to the SIS.

In order to give you a overall picture of the TMDL process and how EPA is involved we would like to explain some guidelines that we must follow as they directly relate to you.

> EPA states in their "1991 Guidance for Water Quality-based Decisions: The TMDL Process" (page 15) that "Under the [Clean Water Act], the only federally enforceable controls are those for point sources through the NPDES permitting process. In order to allocate loads among both non-point and point sources, there must be reasonable assurances that non-point source reduction will in fact be achieved. Where there are not reasonable assurances, under the CWA, the entire load reduction must be assigned to point sources. With the phased approach, the TMDL includes a description of the implementation mechanisms and the schedule for implementation of non-point source control measures."

In the event that successful non-point controls cannot be established with reasonable assurance, there would be no capacity for any TP loading from any permitted discharges (i.e., zero allocation).

We are hopeful that the combined efforts of the watershed interests working to reduce phosphorus will lower both point sources and non point sources to an acceptable level. Ecology feels that the 35% across-the-board reduction is an initial allocation strategy that favors fair participation from all those responsible for TP loading to Moses Lake. This strategy supports a process where everyone is a partner in the clean-up actions. Across-the-board participation encourages a solution-based, proactive response from all local stakeholders.

We have listed each of your comments below, followed with our response. Please note that some portions of the comments may have been addressed in the previous paragraphs.

1. As previously noted by email, the feed amounts for the TL facilities provided to you were faulty. As a result of this, and the lower loadings on the TL 2 facilities as reviewed with you by Dr. Rensel, the efficiencies of both TL hatcheries are higher than suggested, and the overall contribution to Moses Lake phosphorus lower.

We understand that the feed amounts you provided us were incorrect. Jack Rensel did provide me with updated 2001 biomass numbers for both facilities which I used to calculate a new overall P contribution to Moses Lake. The overall hatcheries contribution dropped from 9% to 6%.

2. TL remains concerned about the extremely high background levels of TP in the source springs to Rocky Ford creek. There seems to be much confusion as to the origin of this high phosphorus content. If indeed anthropogenic in origin, TL believes that this must be addressed as it represents a potential threat to the nature of our business. We suggest that additional studies to further define the source are called for before any adequate TMDL can be presented.

Although the Moses Lake technical documents do not identify the origin of high P in Rocky Ford Creek springs, a TMDL for Moses Lake will still proceed. As noted above a SIS is the first step in the TMDL implementation process and will contain strategies for P reduction, which may include recommendations for further studies or identification of sources.

Ecology did ascertain that the bulk of the spring water during July of 2001 was most likely from irrigation recharge in the Adrian sink area (between Brook Lake and Rocky Ford Creek springs); however, it is uncertain if this recharge is the source of high P. This could be addressed by a review of agricultural P management for that area, with subsequent recommended BMPs, a sampling program, or both.

3. DOE recommends a reduction of 35% of all sources of TP to the lake in order to meet the proposed water column concentration of 50 ug/l. However, no analysis that has been presented shows that a reduction to that level will affect a change in beneficial uses of the lake.

EPA mandates that the TMDL establish a TP criterion for Moses Lake. State of Washington guidelines as well as EPA guidelines suggest that the TP criterion for Moses Lake be 35 ug/L. We believe that 35 ug/L is too stringent for Moses Lake and not achievable with external controls only. At some point, with external P reduction, the internal loading of P from the lake sediments dominates as the major source of P to the lake. The lake modeling exercises showed that it would be difficult to reduce the lake concentration below 50 ug/L during a critical year (90th percentile flow regime) without internal load controls. Internal loading has been considered uncontrollable for Moses Lake due to the impractical nature of applying internal controls to such a large lake. Historical studies on Moses Lake have established that a 50 ug/L criterion is not only achievable, but would also result in a reduction in excessive blue-green algae blooms.

4. A 35% reduction of TP loading at the TL facilities would not be economically or technically possible. In fact, this suggested reduction is far below that requested of Idaho trout farms in the middle Snake River of Idaho, where net concentration limits of 0.082 mg/l have been proposed. TL's net TP concentrations are currently well below these guidelines. Additionally, assuming a 6% contribution of TL to the TP in Moses Lake, such a reduction would amount to an overall reduction in the lake of around 2%.

(The reductions listed in the report are recommendations based on a simple assessment of how much loading would need to be reduced across all sources to meet the proposed criterion. However, an alternative list of reductions can be determined as part of the SIS as long as the total load reductions would meet the in lake criterion. Ecology's regional office together with the Advisory Board will need to determine what management practices might reduce loading to the system. We expect that EPA will not approve the TMDL unless some reductions from the point sources are included in the SIS.) (added text not in original response)

An Ecology report, "Quality and Fate of Fish Hatchery Effluents During the Summer Low Flow Season" (Kendra, 1989) reviewed the then-current BMPs and some of the recommendations that may prove helpful in reducing phosphorus concentration. This publication is available on line at http://www.ecy.wa.gov/biblio/8917.html or it can be ordered from our Publications Office at (360) 407-7472.

We would also like to suggest optimizing feed formulations (low-P feed). During our sampling surveys we also noticed that the hatchery waters were not shaded. Shading would limit phytoplankton and epiphyton production in the facility, and maintain cooler water temperatures, thus increasing dissolved oxygen saturation.

5. DOE's plan calls for a reduction from TL facilities that might at best yield an overall 2% improvement, but 95% of the remaining sources are left to be handled by BMP's and non-point controls that remain undefined. The eventual success of these other controls are much more important to the overall effects on Moses Lake, but are not dealt with directly by this plan. TL suggests that until inputs from Crab Creek and other instream inputs are dealt with, it makes little sense to propose such a restrictive TMDL plan.

It is important to remember that Ecology has not established any plan for how phosphorus will be reduced in Moses Lake. Over the next couple of months the advisory committee will be developing some strategies to reduce the phosphorus loading. The actual planning stage will begin after the TMDL receives approval from EPA. It will be the advisory committee that will guide the activities which will be implemented to reduce the phosphorus. The other sources, such as failing septic systems and agriculture, will need to be addressed by the advisory group. (However, as mentioned in our response to your comment #4 we expect that EPA will require that some reductions be made in point source loading.) (added text not in original response)

6. Dissolved oxygen concentrations downstream of TL facilities are most likely due to instream macrophytes. In previous years, the TL2 facility had to utilize supplemental oxygenation for the early morning hours due to the high macrophyte loads in the stretch of Rocky Ford creek between the facilities. There is no evidence to suggest that the presence of the trout hatcheries is the sole, or even major cause of this problem. High concentrations of nutrients in the insource water would lead to high plant growth, and subsequent low DO's and pH without the presence of the TL facilities. Lack of cause and effect data suggests that removal of this inference from the report is warranted.

In addition to satisfying the Moses Lake TMDL TP allocations, Troutlodge also must satisfy any allocations that address the water quality violation listings on Rocky Ford Creek which include dissolved oxygen, pH, and temperature violations. Again, if the high concentrations of nutrients in the in-source water cannot be mitigated to an extent that the water quality standards are met, then there would be no capacity for additional permitted loading.

After further discussion and conversations with Dr. Gene Welch, we are under the opinion (without direct evidence right now, but we believe it could be modeled) that the diurnal dissolved oxygen (and pH) problem is more due to periphyton (i.e., attached algae) on the substrate and plants than to the macrophytes per se. Periphyton responds more to nutrients in water, while macrophytes respond more to water level and substratum nutrients. All of my data suggest that the most productive areas in all of Rocky Ford Creek were in the reaches directly below your hatchery returns. The ammonia releases from the hatchery in combination with the dissolved P would provide ready available fuel for such productivity.

We hope these comments have helped to address your concerns. We would be happy to discuss any of these issues in more detail with you at your convenience
.

Sincerely,

Jim Carroll and Marcie Mangold

Comments received on January 10, 2003 from Jack Rensel of Rensel Associates (Jack Rensel was contracted by Troutlodge, Inc. as a consultant):

RENSEL ASSOCIATES ***Aquatic Science Consultants***

January 10, 2003

Mr. James Carroll
Washington Department of Ecology
Olympia Washington
By Email

Dear Jim,

Below are my comments on the surface water TMDL report for Moses Lake including Rocky Ford Creek. We have discussed and emailed comments about many facets of the report but I thought it necessary to summarize them here in one place. I appreciate both the quality of the report and the difficulty in preparing it, but there remain some unanswered questions in my view:

- *Probability estimates of feed water to lake*

  I remain unconvinced that discharge volume of Columbia River source ("feed") water to the lake via the BOR canal system should include historical data back to 1977. These data were used to estimate overall probability of flows (Figure 5), which in turn drives the water budget and the estimates of how much phosphorus reduction is required to achieve any particular goal. Use of long term flow data would be appropriate if irrigation use and climate conditions were static or fluctuating normally during the selected years. But I do not believe the former to be true and the report does not deal with it in any form. The question of climate change or oscillation is open too, but it seems as climatologists are often unable to discern effect and trends until well after change has occurred.

  I believe only more recent years should be used in the probability estimates, not data from several decades ago when use patterns and total volumes were less. I understand there has been increased efficiency in irrigation, but most probably this has been outweighed by the constant increase in total acreage irrigated. Many crops grown in the service area are still profitable and desirable for agricultural interest to pursue, such as high value alfalfa and timothy.

  In Figure 31 of the report (page 50) there is an apparent increase of feed water discharge in recent years, with only the relatively wet years of 1996 and 1997 showing major decreases. Flow increase in recent years is likely due to the build out of the irrigation system demand and not solely due to reduced throughput during wet years. The report states (page 95, 2^{nd} para.) that "In the absence of feed water *addition, a TP load reduction is necessary to meet the 50 ug/L TP (proposed) criterion". But feed water is added every year, as the flow data shows. There are no known climate trends for the area that suggests an increase in rainfall, so the question remains, will the extreme years such as 1980 that they modeled be more frequent than 10% of the time. Looking at the feed water flow data (in Figure 31 on page 50) there were 3 of 17 years since 1985 that had less than the total volume of the lake (assuming 1984 data not available). Only two of these years had relatively low volumes of feed water, and 2/17 = 0.12 or 12% of the time. This is very close to the estimated 10% frequency or "acceptable exceedence probability" used by Ecology in TMDL analysis.*

In this same context, the report should try to do more to justify the notion that the situation is unchanged in the lake from the 1980s when algal blooms were apparently more frequent and extensive. As your report points out, the 2001 lake data show the lake well within compliance (~33 ug/L) for the proposed TP criterion (50 ug/L) and no major blue green algae blooms. There are no other lake data from recent years as lake monitoring is not done routinely which hampers our ability to understand if the system is static or is actually trending toward improvement.

You told me about internal loading and either you or Dr. Welch advised me that this source of P from sediments in summer is no longer a significant factor, as it once was thought to be. Is this evidence of a change, possibly induced by relatively high amounts of feed water in the past two decades?

Ecology performed a trend analysis on the Columbia River feed additions to Moses Lake for the period of record from 1977 to 2001, the same used to define the feed water addition for a critical flow year. Using WQHYDRO (Aroner, 2001), a graphically-oriented statistical and analysis program for hydrological data, a Spearman Rho trend analysis was performed on the feed water data in two ways. One, directly with the actual annual feed water totals for each year, and two, with a log transformed ratio of feed water inflow to natural inflow for each year. The first way showed a weak increasing trend at only an 80% confidence interval. The second way showed no trend at or above an 80% confidence interval. Ecology believes while build out of the Columbia Basin Irrigation Project has undoubtedly taken place over the time interval, so too has more efficient use of water, negating any significant trend increase (>90% confidence interval) in feed water supply over the time period. Ecology believes the assumptions it used to define the critical flow year are well justified and reasonable.

- *2) Detection limits and changes in feed water content*

A related topic is detection limits for total P used in this, and all Department of Ecology studies. As I expressed to you on at least one occasion, I am amazed that Ecology's laboratory services continue to provide such poor detection limit data to their clients. A detection limit of 10 µg/L is at least an order of magnitude and perhaps two higher than that available from commercial and academic laboratories. This comes into play in the present project in regards to the feed water which originates from Lake Roosevelt and the Columbia River. I note in the data appendix *of the report many "U" symbols, which mean non-detected or less than the above mentioned detection limit.*

As a result, I am wondering if the feed water concentration of P is less than actually estimated, and as I have pointed out, is therefore significantly less than that which occurred in the water source 20 years or more ago. There is evidence that the Columbia River waters have declined significantly in P loading for several decades, with a particularly large drop in 1995 commensurate with the closing of the Cominco plant in Trail, B.C. that was putting out up to 8,000 kg of P per day into the system and now contributes virtually none. As you know, I have over a decade of low detection limit P data from the Grand Coulee Dam area of the river, and have been tracking this situation for many years. I also know that Ecology's data collection in the same area is spotty which is consistent with a policy of measuring tributary systems, while somewhat ignoring the mainstem except for a few far downstream stations.

Ecology's laboratory (MEL) reports phosphorus data unqualified down to the method detection limit (MDL). An MDL is determined by analyzing a low-level standard (5-10 ug/L for total phosphorus) seven times and determining the standard deviation of the results. Multiplying the student-t value for this number of samples (3.14) times the standard deviation gives you the MDL. This MDL indicates the lowest concentration that can be determined with a 99% confidence that the analyte is present. Most labs will not report results less than a practical quantitation limit (PQL) which is typically ten times the MDL. Sample results at or above the PQL are expected to meet all usual QA/QC criteria. That is not generally true for results below the PQL. The MEL reporting limit for low level TP is currently 1 ug/L and for ortho-phosphorus it is 3 ug/L.

Ecology is reluctant to report values lower than the MDL, because our data are used to make regulatory decisions and data below the MDL are usually consider noise. In any case, the CE-QUAL-W2 model uses dissolved P as the state variable which was the lower of the reporting limits at the time, ranging from 3 to 5 ug/L. Ecology concurs that if there is decreasing trend in the P content of the feed water, there will be a more effective response to feed water additions in Moses Lake.

- *3) Explanation of phosphorus goals for lake and benefits*

Another facet of the report is that there is little discussion or explanation on how improving the lake from apparent hyper-eutrophic present conditions to eutrophic condition will result in any tangible benefits and improvement in use to the public. There is so much TP available, from all sources, that the algal bloom situation is undoubtedly controlled more by summer weather than any other single factor. If the summer is wet early on, then turns dry, hot and calm, harmful algal blooms are very predictable. This is not unique to Moses Lake but applies to many other lakes too, and coastal marine waters as well. Nutrients are a necessary factor for blue green algal blooms, but often it is an imbalance of nitrogen and phosphorus that leads to the loss of relatively benign diatoms or green microalgae, which are replaced by *undesirable blue-green algae that can produce their own nitrogen from nitrogen gas. The process is slow, but they can fix the nitrogen after other types of algae "crash". In this regard, I do not find any discussion of dissolved N to P ratios and how the blue greens respond to observed changes. I suppose much of this is from historical literature, and not the subject of your report, but some limited discussion seems appropriate.*

Ecology believes that the historical work clearly shows that reducing P in the lake will control algal biomass, regardless of summer weather. The "dilution" program in 2001 (a year that was dry, hot and calm) further showed that reducing P in the lake will control harmful algal blooms. Ecology is mandated to manage Moses Lake to lake class standards, one criterion of which is the establishment of the proposed maximum in-lake 50 ug/L of TP. It is our best professional judgement, based on the historical success in controlling P with the "dilution" program, that a 50 ug/L TP criterion will result in reduced algal biomass even in years without dilution water. Furthermore, the scope of the technical report was not to look at specific algal population response to a reduction in external P loading. That is research question beyond the scope of this work and has been addressed in the historical literature on Moses Lake. The project goal was specifically to "…assess the assimilative capacity of Moses Lake with respect to the in-lake proposed TP criterion of 50 ug/L. Data were collected and used in this assessment. A TP allocation plan is recommended to achieve the in-lake TP criterion." A 35% across-the-board reduction in TP from controllable external sources is recommended to meet the 50 ug/L TP criterion in years without dilution water.

- *4) Uncertainty of ultimate sources of P and likelihood of mitigation*

As a TMDL is supposed to identify sources of a pollutant, and the report goes a long way to achieving that goal but I believe that there is still some significant unknowns that will hamper effective mitigation.

The source of much of the problem near the lake is urban septic drainage, and the chances of fixing that are nil in the short run given economic realities. Even if this was done in the long run, the companion groundwater report notes that there is an underground reservoir of "sorbed P" in the sediments, waiting to be released even if cutback in new P production occurred. This is not a reason to oppose such remediation, but rather evidence that Ecology's future remediation plans are not likely to bear much fruit in any reasonably short time frame.

More to the point, phosphorus loads in the Rocky Ford Springs remain high compared to what would be expected from local groundwater, but both reports are vague about the actual sources of such high P loading. It will be difficult and probably impossible to achieve any meaningful change in up slope land management practices that may affect the springs given the uncertainty. The groundwater report suggests that the source may be from anthropogenic sources as far away as the neighboring county, that are fed to porous lakes or streams northwest of the springs.

The above leaves very few clearly identified sources of phosphorus that can be quickly addressed, indeed none that are significant in volume. As Mr. Parsons points out in his letter, even if Troutlodge was to reduce discharged P by 35%, it would be a tiny fraction of the loading to the lake (~2%) and certainly not measurable against background variation in the entire system. This is not an argument to avoid reducing P output from Troutlodge, but an acknowledgement that Ecology will have a very difficult time identifying and initiating meaningful reductions of P loading to the lake under the present circumstances.

Ecology agrees there are unknown non-point sources that will be difficult to ascertain. Ecology often faces these uncertain situations across the state where non-point sources are involved. It seems to be the nature of working with non-point sources. This TMDL will have to have a "roll up our sleeves" commitment to achieve adequate P reduction. The technical report calculates the amount of P that Moses Lake can assimilate and offers a first-cut recommendation (35% across-the-board for controllable sources) to reduce P for a critical season. Most likely, many sources contribute to the non-point P load. It would not be reasonable to exclude any sources from consideration because the constitute only a small percentage, because eliminating or reducing a wide range of small contributing sources will be how the TMDL will be achieved. Troutlodge, as a point-source contributor of P to Moses Lake, will be asked to do their share in reducing P input to the lake.

- *5) D.O. and pH conditions in Rocky Ford Creek*

The report states on p.104 that nutrient controls on the TL hatcheries "may" address dissolved oxygen and pH problems downstream. I am not convinced that this is the case, and the report does not provide much detail in that regard. Some of the effect could be due to nitrogenous wastes demanding D.O. but the report my experience is that ammonia from fish culture facilities is very rapidly altered to nitrate through nitrification by bacteria. I know this from repeated mass balance measurements upstream and downstream of facilities. It is then curious that the report identifies actual nitrogen uptake from the hatcheries (page 24) results in less nitrate output than intake.

As suggested by Mr. Parsons in his letter, the report should examine the likely possibility that early morning D.O. depressions in the creek near the hatcheries are related to algal respiration which normally occurs in the early morning hours before daylight. The report states that the hatcheries were major sources of chlorophyll, and indeed fouling by algae occurs in the raceways, but much of this is removed during the growing season by the more or less continuous cleaning that occurs by hatchery staff. It is more likely that D.O. depressions in the creek are due to combined microalgal and macroalgal respiration and decay, which is in part a result of the good growing conditions and backwaters wetlands that fringe the creek.

There is no compelling evidence or argument in the report that advanced treatment or changes in feed will have a significant effect on this D.O. situation. Microalgae will respire most in the early AM hours, not the fish. Macrophytes respire too, but *tend to do more so later in the season when self shading becomes a problem and P_g and P_n decline. After seasonal biomass maximum is achieved respiration losses increase of course until senescence. For fish, numerous excellent physiological studies of salmonids show their rates of D.O. consumption in hatcheries relate more to time of initial feeding in the late morning and early afternoon, not before daylight when they are least active. Finally, nutrients are so abundant in the source spring water that is is entirely possible that all forms of algae in the upper creek are not limited in any form by nutrients. Other factors such as advection of microalgae by flow and competition for substrate and light by macrophytes are indeed more likely limiting factors. In short, I do not believe the report should implicate the hatcheries in this matter without any plausible evidence or theory.*

Ecology references a summary of the work of numerous investigators who documented water quality degradation downstream of fish hatcheries, including increased downstream algal and periphyton growth and productivity. After further discussion and conversations with Dr. Gene Welch, we are under the opinion (without direct evidence right now, but we believe it could be modeled) that the diurnal dissolved oxygen (and pH) problem is more due to periphyton (i.e., attached algae) on the substrate and plants than to the macrophytes per se. Periphyton responds more to nutrients in water, while macrophytes respond more to water level and substratum nutrients. All of my data suggest that the most productive areas in all of Rocky Ford Creek were in the reaches directly below the hatchery returns (with alarmingly low dissolved oxygen readings as low as 4.3 mg/L observed in August 2001). The ammonia releases from the hatchery in combination with the dissolved P would provide ready available fuel for such productivity.
In addition to satisfying the Moses Lake TMDL TP allocations, Troutlodge also must satisfy any allocations that address the water quality violation listings on Rocky Ford Creek which include dissolved oxygen, pH, and temperature violations. If the high concentrations of nutrients in the in-source water cannot be mitigated to an extent that the water quality standards are met, then there would be no capacity for additional permitted loading.

- *6) Potential bias in time of day sampling*

Most of the data collected for the report at the Troutlodge hatchery, RFC springs and immediately downstream was during the 7 to 9 AM time period. I have conducted studies of major hatcheries where we collected TP and other measures around the clock and found that TP production was at about twice as high in the morning to mid-afternoon, compared to other times of day. A reasonable explanation is that the fish are relatively quiescent throughout the dark hours of the night, but continue to defecate. When feeding is first commenced in the early morning, fish respond with activity bursts that stir up the water. This results in relatively higher output of TP during that time period. Every hatchery is different in configuration and operation, but I suspect this is a real phenomenon at many hatcheries. The report should acknowledge that production rates of P from the hatchery are based on the assumption that P is produced at a steady hourly rate, which may or may not be true. If it is true for these hatcheries, there must be other sources of TP contributing to the calculated loads of P at the mouth of the creek.

Ecology conducted a synoptic sampling on September 24, 2001, when morning as well as afternoon samples were taken. The morning samples taken at stations RF2A and RF1C (both directly below the hatcheries) were 107 and 126 ug/L, respectively, which was 7 and 4 ug/L, respectively, higher than their counterpart afternoon samples, but well within the 10% precision expected for TP analysis. Troutlodge, Inc. is known to have done more extensive sampling in 2001 and may better be able provide data as to morning and afternoon differentiation of P loading from the hatcheries.

- *7) Miscellaneous comments*

1) The draft report does not present the actual data used to prepare figures of stream flow, nutrient concentration in the springs or loading values (i.e., the basis for Figures 7 and 16 and Table 6). Although the appendix includes the raw data, I can not recreate the same values for any of these relationships. Some data were rejected or qualified, but we have no way of knowing specifically what was done.

Ecology did include stream flow data and concentration data in the appendix. Loading values were calculated from this data. Ecology does not include all worksheets in the technical reports in the interest of brevity and not to be cumbersome. Ecology will provide any worksheets or model files used to develop summary data upon request.

2) Production of orthophosphate assumption. On page 28 Ecology suggests that most P produced by the hatcheries will be in the dissolved form, probably orthophosphate. The literature clearly shows rather that is TP that is produced, fortunately, as TP is much easier to control through sedimentation.

Ecology measured both TP and ortho-P increases below the hatcheries (compared to upstream values) on September 24th, 2001 and the majority of the P increase at both locations was in the dissolved phase (58% and 75%). Ecology is reporting observed data.

3) Page 31. Reference to “pond”, was that a typo, should have been “lake”?

The “pond” referred to on page 31 of the draft is the retention pond at the mouth of Rocky Ford Creek. There is no typo.

4) Page 35, Referring to the companion groundwater study, the last sentence of paragraph one is misleading. Yes, anthropogenic sources of P may dominate the Rocky Ford system, but the bulk of the anthropogenic sources are from irrigation infiltration above the springs, not from uses of the creek per se.

Ecology believes the sentence is clear, that anthropogenic sources of P probably dominate in the source springs.

5) Page 43. No summary of nutrient data from Rocky Coulee Wasteway (i.e., the feed water) is provided.

Ecology did provide the data in the appendix.

6) General comment: The Wiebull diagrams need brief explanation, not the probability part but the rest of it.

The Wiebull diagrams are simply probability plots. Ecology is unsure what needs to be explained if the probability part is clear.

Thank you for the opportunity to comment on this report. I appreciate your openness and willingness to entertain my comments and suggestions. I also appreciate your courtesy extended to me in the field work.

Sincerely,

J.E. Jack Rensel, Ph.D.
Rensel Associates Aquatic Science Consultants
4209 234th St. N.E. Arlington WA 98223

DEPARTMENT OF ECOLOGY

February 20, 2004

TO: Marcie Mangold, David T. Knight and James Bellatty
Water Quality Program, Eastern Regional Office

FROM: Jim Carroll, Watershed Studies Unit
Environmental Assessment Program

THROUGH: Karol Erickson, Unit Supervisor, Watershed Studies Unit
Environmental Assessment Program

SUBJECT: RESPONSE TO ADDITIONAL REVIEW COMMENTS ON THE DRAFT MOSES LAKE TOTAL MAXIMUM DAILY LOAD PHOSPHORUS STUDY TECHNICAL DOCUMENT

Introduction:

The draft Moses Lake TMDL Phosphorus Study report was distributed to the Moses Lake Advisory Board and interested parties the week of November 25, 2002. A comment period deadline of December 31, 2002 was announced for reviewers of the draft report. Ecology received written review comments from Jim Parsons (Troutlodge, Inc.), Jack Rensel (Rensel and Associates on behalf of Troutlodge), Anne Henning (City of Moses Lake), Larry Gadbois (US EPA), William Riley (Big Bend Economic Development Council), and Dean White (Lincoln County Conservation District) within the period. Jim Parsons of Troutlodge, Inc. sent additional comments on January 7, 2003 after receiving a deadline extension for that date. Additional comments were received from Jack Rensel (Rensel Associates) on January 10, 2003, presumably on behalf of Troutlodge, Inc.

Ecology also contracted with Professor Emeritus Dr. Eugene Welch (University of Washington), who has extensive experience with water quality issues on Moses Lake, to peer-review the draft report. A response summary addressing all of the above comments is available at the Moses Lake TMDL website:
http://www.ecy.wa.gov/programs/wq/tmdl/watershed/moseslake/technical.html.

At the October 1, 2003 Moses Lake Advisory Board meeting, members of the board requested that the Moses Lake TMDL Phosphorus Study report be reviewed again by a candidate of their choice. A list of six potential candidates to review the report was sent to Ecology by Chairman Dent. Ecology invited reviews from all six candidates. Comments were received from Dr. Peter Burgoon of Water Quality Engineering, Inc. and Dr. Clinton Shock of Oregon State University.

General Responses:

1. *Model Calibration and Model Uncertainty*: Ecology's goal was to develop a modeling tool that can be used to manage water quality in Moses Lake. While no numerical model can recreate perfectly the complex, time-varying interactions of every physical, chemical, and biological process, our goal is to have the CE-QUAL-W2 model represent the primary processes that control the fate and transport of phosphorus. The objective was to collect enough data to develop a scientifically based model application that is a **good approximation** of the system. We believe the Moses Lake CE-QUAL-W2 model was appropriately developed using the best available data. We also believe the model clearly demonstrates that it is a good approximation of the major forcing processes and features that affect water quality, such as the hydrodynamics, temperature stratification, and tributary and diffuse groundwater P loading to Moses Lake. Ideally, the model could be calibrated to more than one year of data; however, due to resource and time limitations, there is no plan to collect another year of data to confirm the model calibration. Still, Ecology believes the model is an effective tool for recommending P allocations as calibrated.

   The U.S. Environmental Protection Agency (EPA) has not provided specific guidance on model uncertainty analysis or guidance on what are the "acceptable" variances for determining when a water quality model is adequately "calibrated" to a specific variable so it can be used for establishing waste load and load allocations. The goal in the model calibration is to minimize the differences between model predictions and measured values and reproduce major physical and chemical processes (e.g., hydrodynamic flow in Moses Lake, temperature stratification, and major variable concentrations). An important aspect of model calibration is to provide a model which does not have significant systematic model biases that could bias the evaluation of proposed management strategies. As part of the reporting documentation for the development of the CEQUALW2 model, we are providing commonly used error statistics for the major variables which clearly show that the model does not have any systematic biases.

2. Ecology appreciates receiving eleven sets of comments for the Moses Lake TMDL Phosphorus Study technical report. We believe the incorporation of the received comments has strengthened this TMDL project.

Beginning with Dr. Shock, reviewer comments are listed below (as italicized text) with a response following each specific comment.

Comments received by Dr. Clinton Shock on 1/15/04:

January 15, 2004

David T. Knight
Unit Supervisor, Water Quality Program
State of Washington Department of Ecology
4601 N. Monroe St.
Spokane, WA 99205-1295

Dear David Knight,

Thank you for asking me to review the "Moses Lake Total Maximum Daily Load (TMDL) Phosphorus Study". I will refer to the "Moses Lake Total Maximum Daily Load Phosphorus Study" in the letter that follows as the "TMDL P Study". I spent three days carefully reading the "Moses Lake Total Maximum Daily Load Phosphorus Study" and pertinent parts of Pitz 2003 "Moses Lake Total Maximum Daily Load Groundwater Study". I have examined data associated with the TMDL P Study and several other supporting references. The opinions below are my own, and do not represent the opinions of the College of Agricultural Sciences or Oregon State University.

General comments

The "TMDL P Study" was very thoughtful and competently done; however there are several key parts which deserve careful reconsideration. P movements and budgets are exceedingly complex and most of the observations and evaluations are appropriate. The efforts to model water and P in the Moses Lake watershed are impressive, and the model helps quantify changes that might occur given different management scenarios.

Importance of P in aquatic systems

It is essential and appropriate that a TMDL for Moses Lake consider the P loading to the lake. P is a key limiting element in the growth of alga and lake eutrophication. Algae and other microorganisms in the water greatly affect dissolved oxygen. Under algal bloom conditions, the algae have a negative effect on reservoir fisheries because of periodic oxygen depletion associated with algae respiration and decomposition. During the day they pick up carbon dioxide and release oxygen through photosynthesis so the dissolved oxygen in the water rises. At night their metabolism requires them to take up oxygen and release carbon dioxide. These fluctuations can be large. When an excess of algae grow and sink deeper into the water, their rate of photosynthesis can no longer be maintained, and they decompose at the cost of dissolved oxygen. Lake water samples show that total P and ortho phosphate are high and observations of Moses Lake have determined that it is eutrophic.

Response:

Ecology agrees.

Opportunities for a better understanding of the watershed

If Moses Lake has always been eutrophic, then the Department of Ecology and the citizens of Washington need to determine this fact before embarking on an ambitious restoration effort. There is a real opportunity to objectively examine the P loading and eutophication of Moses Lake in the past. By sampling sediment cores of the lake bottom, the enrichment over the past 50 years could be compared with prior enrichment. Many very strong tools are available to help date these changes.

Response:

Carroll et al. (2000), page 33, states "A review of sediment profiles from Moses Lake revealed large and consistent P and N loads for at least 100 years, suggesting the lake probably experienced algal blooms even in its "natural" state (Patmont, 1980). Therefore, management of Moses Lake for other than a eutrophic condition has been deemed impracticable, and has not been the focus or objective of rehabilitation measures to date (Welch *et al*, 1973; Brown and Caldwell, 1980; Patmont 1980)." Restoration has always been focused on reducing the hypereutrophic conditions in the lake. The apparent fact that Moses Lake has always been a productive, eutrophic lake is part of the reason that a higher TP criterion of 50 ug/L is proposed. Ecology's current Water Quality Standards recommend a TP criterion of 35ug/L for the Columbia Basin Ecoregion.

Opportunities for remediation

1. The strong stratification of P with depth in Moses Lake provides an opportunity to recycle P from the lake to agricultural irrigation. This can be accomplished by providing an alternative managed outflow. A deeply buried pipe could capture water richer in P, so that when the lake is diluted with irrigation water, P unloading could be greatly enhanced.

Response:

This may be addressed in the Summary Implementation Strategy (SIS) part of this TMDL.

2. The community has the opportunity to determine human caused contributions of P and take actions to reduce these contributions. Rural and domestic sewer systems in and around the town of Moses Lake would seem to deserve special attention.

Response:

Ecology agrees.

Statements and conclusions that need a stronger foundation of reason

1. Page 15, last paragraph. Hydrology of Rock Ford Creek

By carefully examining the oscillations of flows in Rocky Ford Creek (largely from the spring) prior to the development of the irrigation projects, the creek had patterns of flow somewhat similar to those after the development of irrigation. The conclusions about the influence of irrigation on the flows in Rocky Ford Creek are unsubstantiated.

Response:

Ecology's groundwater study (Pitz, 2003) did not examine and establish a cause and effect influence of irrigation recharge on the discharge rate of Rocky Ford Springs, so references to flows being influenced by irrigation will be deleted on page 15, 18, 19, 27, and 28.

Charles Pitz replied: *"My study did not examine the influence of irrigation recharge on the discharge rate of Rocky Ford Springs……However, numerous studies have show that irrigation in the Columbia Basin project area has significantly impacted the region's subsurface and surface hydrologic regime, and has greatly altered groundwater/surface water interactions throughout the region. While the basic seasonal patterns or cycles of surface discharge, spring flow, and water table position remain intact, water management efforts and recharge from large-scale irrigation has clearly modified these patterns throughout the project area. The arid Quincy-Pasco subunit of the Central Columbia plateau (the subunit encompassing the Rocky Ford Creek/Moses Lake area) now has the highest annual recharge rate in the Columbia Basin as a result of irrigation. In turn, water table positions in the subunit have changed significantly from pre-irrigation conditions, and numerous springs and wetlands now are present that didn't exist before. Significant changes have also been imposed on the area hydrology as a result of irrigation canal leakage, installation of tile drain systems, transfers of water between project-related reservoirs, and inflows and outflows to/from wasteways. One small case study of these effects very close to the spring area is mentioned in my report under the discussion regarding the Soap Lake Protective Works. It would be difficult to imagine a scenario where irrigation project-derived recharge has not in some way altered or influenced the character of discharge at the Rocky Ford Creek spring.*

A very brief reference list of literature regarding irrigation water influence in the Columbia Basin:

- *USGS Open-File Report 95-445, by Sarah J. Ryker and Joseph L. Jones*
- *Williamson, A.K., Munn, M.D., Ryker, S.J., Wagner, R.J., Ebbert, J.C., and Vanderpool, A.M., 1998, Water Quality in the Central Columbia Plateau, Washington and Idaho, 1992-95: U.S. Geological Survey Circular 1144, on line at <URL: http://water.usgs.gov/pubs/circ1144>, updated March 3, 1998.*
- *Whiteman, Vaccaro, Gonthier, 1989, USGS Professional Paper 1413-B*
- *Hansen, Vaccaro, Bauer, 1994, Water Resources Investigation Report 91-4187"*

2. Page 28, paragraph 1. The last line is speculation, not established fact.

Response:

> Ecology agrees and will remove the sentence, as it does not add to the established facts that are being reported.

3. Page 34 and Page 101, paragraph 6. Based on the work of Bain and Pitz, the TMDL P Study concludes that the fundamental source of P in Rocky Ford Creek is from irrigated agriculture. The data on which this conclusion is based are the presumed direction of groundwater flow and the chemical characteristics of a very limited number of groundwater samples from the Brook Lake area being similar in chemical composition to the water at the Rocky Ford Springs. The data presented are insufficient to prove a cause and effect relationship for P enrichment from agriculture at Rocky Ford Spring. A reinforcing source of doubt is the Rocky Ford Spring water flow patterns prior to irrigation, which seem to be fundamentally unaltered.

The words "still dominate" at the end of the paragraph on page 34 seems odd, since the human caused effects seem to be still unproven.

Response:

> Ecology will remove the last part of the sentence that states, "….suggesting that anthropogenic sources of phosphorus still dominate the source springs of the Rocky Ford Creek system."
>
> Charles Pitz replied with the following concerning the source of P in the Rocky Ford Creek spring:
>
> *"My study never claimed to prove a cause and effect relationship between P enrichment in the spring and upgradient agricultural activities. I did attempt to lay out the facts as we know them:*
>
> - *Groundwater and hydrogeologic data indicate that the majority of the spring discharge is derived from the area northeast of the spring. As early as 1952, the USGS recognized and reported on a hydraulic connection between Crab Creek in the Adrian/Brook Lake area and the spring discharge.*
> - *Land use activities hydraulically upgradient of the spring include irrigated crop farming and other activities that can release surplus phosphorus to the subsurface.*
> - *The soils/sediments underlying these areas have characteristics that suggest a limited phosphorus attenuation capacity.*
> - *There is abundant evidence in the scientific literature that dissolved phosphorus can be transported significant distances from source areas by advective groundwater transport, given the right aquifer conditions. Many of those conditions exist in the Rocky Ford Springs area (coarse grained calcareous aquifer sediments, low fine and organic content, high permeability rates, high groundwater velocities).*
> - *The geochemistry of the spring water best matches water with a relatively short residence time in the aquifer system.*
> - *Available groundwater quality data do not indicate a natural background condition for ortho-P much above ~50 ug/L, in the area of interest (as I recall, Jones and Wagner (1995) reported that ~95% of all groundwater samples collected in the basin report an ortho-P concentration less than the median ortho-P concentration measured at the spring*

during the 2001 water year). This suggests that values above this level may be derived from anthropogenic sources raising the ambient phosphorus condition in the aquifer.

- *There is an extensive body of literature that has demonstrated the significant influence of irrigated agriculture on the movement and occurrence of nitrate in the Columbia Basin; many of these same factors apply to the movement and occurrence of phosphorus. Phosphorus-bearing fertilizer is applied to the irrigated land upgradient of the spring.*

Again, I never claimed to prove a cause and effect relationship. I gathered and reviewed the facts and available data; to me the weight of evidence suggests that losses of phosphorus from upgradient irrigated agricultural fields is one perfectly reasonable explanation for the elevated P observed at the springs."

4. Starting on page 62, Figure 40 through page 83, figure 58. The figures and the discussion deal with how the data was fitted to the model. Yet the results are presented as if the lake performance was predicted by the model.

Response:

Text and figure titles were changed to differentiate the model-predicted results from the observed data.

5. The modeling and P balance of Moses Lake commingles the effects of groundwater from the region close to town and nutrient contributions from surface runoff and water fowl. The discussion then deals with this fraction of P as if it was coming from groundwater.

Response:

The entire section concerning other P sources was re-written for better explanation as follows:

"Other P Sources

Other P sources not specifically allocated as seasonal P loads in this TMDL evaluation are stormwater runoff (overland flow and unknown contributions from City of Moses Lake stormwater collection system), waterfowl contributions (more than 50,000 waterfowl winter on Moses Lake each year), and net pen fish production (the state Department of Fish and Wildlife operates a facility from October to March in the South basin).

Many of these sources probably have a minimum impact during the critical season of May through September because they take place mostly in the winter. Any P loads that enter Moses Lake in the winter become part of the initial conditions for the critical season. The Moses Lake CE-QUAL-W2 model was calibrated using measured initial conditions from March 2001. These initial conditions include the sum impacts of all winter P loading including stormwater runoff, waterfowl feces, and net pen fish. Soluble P in the water column initially fuels the spring diatom bloom or is washed out as the lake is filled up in the spring. Particulate P that enters Moses Lake in the winter either breaks down into soluble P, settles to the bottom sediments, or is washed out of Moses Lake.

Any effects that P in the sediments may have from May through September are contained in the residual of the P mass balance as the internal P load term (i.e., release of P from the sediments during anoxic conditions in the summer). The Moses Lake CE-QUAL-W2 model incorporates a P-sediment release algorithm to account for the internal P load and was calibrated to the 2001 hypolimnion P data.

Even though Moses Lake receives minimal precipitation from May through September, summer thunderstorms can occur that may create non-point P loading from runoff. Lake-shore runoff can include fertilizers, pet feces, oils, and soil among other contaminants. These could lead to temporary P spikes in the Moses Lake water column and should be included in a BMP evaluation for Moses Lake."

6. Page 88, Table 14. Rather than calculating the net P outflow, the study should have calculated an estimate from the collected data.

Response:

The Moses Lake TMDL study did not calculate a net P outflow. The outflow P load was calculated from daily outflow discharges and the simulated daily outflow P concentrations reported in the CE-QUAL-W2 model. Discharge at the outflow dam was calculated using a HEC-RAS model (version 3.0) and was calibrated by Northwest Hydraulic Consultants of Seattle. Actual discharges from 2001 were used to calibrate the model. The simulated flows had a RMSE of 71.7 cfs (CV = 7.8%; n=13) for the whole range of flows and operational ranges. The simulated outflow TP concentrations were compared to measured outflow TP concentrations and had an overall RMSE of 9 ug/L (CV = 42%; n=8) for May through September. Ecology believes this is the best estimate of the TP load discharged from Moses Lake. Again, the estimate is not a net measurement, nor is it a residual calculation from the TP mass balance.

7. P 93, paragraph 3. By using an average P content by depth, the TMDL risks being overly restrictive.

Response:

The TMDL technical report states on page 99: "When evaluating model simulations, the entire water column TP was averaged for compliance with the TP criterion. Even though the algae grow in the euphotic zone, the entire water column was averaged because Moses Lake is polymictic (i.e., capable of mixing several times during the growing season). The potential entrainment of elevated hypolimnetic concentrations of TP was considered a margin of safety and included in the available TP pool. The hypolimnion represents less than 20% of the volume of the lake. During May through September 2001, the average seasonal whole column TP was 24% more than the average seasonal euphotic zone TP in the whole lake. This could be considered an implicit 24% margin of safety and account for the natural variation (uncertainty) associated with internal loading which has been shown to have a variability of up to 100% (Welch et al., 1989)."

Ecology recognizes that there will be data and model uncertainty associated with recommending WLAs and LAs to meet any TMDL. The Clean Water Act requires that any lack of knowledge about the system must be accounted for by establishing a margin of safety (MOS) in developing a TMDL. The implicit (conservative assumptions) or explicit (reserving a portion of the loading capacity) MOS must be identified as part of the TMDL as it undergoes public review.

As stated, there could be an implicit MOS of as much as 24%, but Ecology believes the MOS is also tempered by establishing a high TP criterion of 50 ug/L for Moses Lake. Ecology does not believe it is overly restrictive in using a whole-column average in its determination of TP for compliance with the criterion.

8. Page 99, Table 18, and Page 102, paragraph 3. The TP 35% reduction fails to deal with relative feasibilities or fairness of the P load reductions.

Response:

The proposed allocations in the technical document were presented as an initial allocation strategy, taking a first-hand cut at what might be done. The premise was that an across-the-board equal percentage reduction was a fair action, particularly for the point-source contributors. In the suggested course of action, the largest contributors (e.g., groundwater) have the largest nominal load reductions and vise versa.

The next step of the TMDL process includes developing a Summary Implementation Strategy (SIS) that takes input from the public through the Advisory Board to address the most effective and economical means of reducing P in Moses Lake. The bottom-line in the technical report is that the P lake-response model shows that a maximum external P load of 6,340 kg TP is allowable from May through September in order to meet the 50 ug/L TP criterion (in 9 out of 10 years on the average). How the reductions are divided between sources can be addressed in the development of the SIS. As is often the case for non-point sources, it may be that further assessment is needed to address a particular non-point source. That appears to be the case for Rocky Ford Creek, as the source of elevated P in the springs is unknown. On the other hand, other non-point sources, such as wastewater contributions to groundwater, could begin to be addressed immediately.

My sincere thanks for the opportunity to review the TMDL P Study. I have attached a list of smaller issues and technical corrections and questions.

Dr. Clinton C. Shock
Superintendent and Prof.

Technical corrections and questions (35 items)

1. Abstract, line 1. Edit to read "... especially irrigation, lake P dilution with irrigation water flow through, and urban development."

Noted and changed in the text.

2. Abstract, paragraph 3, line 2. Substitute "estimate" for "evaluate".

Noted and changed in the text.

3. Page 1, paragraph 6. Edit to read ".. now 15 years old."

Noted and changed in the text.

4. Page 2, paragraph 4, last line. The years of occurrence and references are lacking.

Added citation – "Carroll et al, 2000" to text. This document reviewed the historical studies from 1964 through 1989.

5. Page 2, paragraph 5, line 2. References are missing.

Removed line 2. Added line referencing observed blue-green algae bloom in 1998. This was supposed to be a short history and not a justification as to why Moses Lake was on the 303(d) list (see general comment #1 above).

6. Page 7, paragraph 1. Please state the frequency of measurements.

Stated in text that samples were taken approximately monthly from March to September

7. Page 7, paragraph 3. The word "biovolume" does not have a clear meaning. Do you mean to say "concentration"? In what units?

The unit "biovolume" is a calculated unit by Jim Sweet of Aquatic Analyst. It is in cubic micrometers per square centimeter. He multiplies the density of a single species (#/cm^2) times the mean unit biovolume for that species. This is also in Standard Methods (1998) as method SM10200I.

8. Page 7, paragraph 4. Starting here, all designations of locations should be consistently named in all figures, tables, and the text. As written, the text needs substantial careful cross referencing by the cautious reader to figure out what spots are under consideration. For example, see the legend of Figure 6 on page 17, the locations at the top of page 18, etc. I figured them all out at considerable effort.

> The confusion seems to be caused by stations that were not Ecology project stations (e.g., USGS stations). The text was changed to associate Ecology station names (which are correctly mapped) with these stations so they can be located on the location maps provided.

9. Page 9, paragraph 5. Please specify the accuracy and inaccuracy ranges of the tests.

> The following was added to the text: "The pooled average difference between Winkler and meter readings was 0.12 mg/L with a pooled RMSE of 0.44 mg/L."

10. Page 10, paragraph 1. The dense algal bloom reported here is in contradiction to the lake P level. This is disconcerting.

> Agree. There is no corroborating evidence of "an extremely dense algal bloom" in either the lab data or the field notes for that date. The sentence will be deleted.

11. Page 10, Table 2. The "blank" levels for total P and orthophosphate are vastly too high. The public could understand the table if these were "detection limits", not "blanks".

> Text was changed to explain that the field blanks had no detections above the reporting limits for the parameters.

12. Page 11, line 7. Should read "(for TP)"

> Noted and changed.

13. Page 11, paragraph 3. Omit the jargon word "analyte" which makes it harder for the public to read the report.

> Noted and removed "analyte" from text.

14. Page 11, paragraph 6. Please clarify the bias.

> The bias for the check standards had a CV of 12.7%.

15. Page 12, Figure 2. For public understanding, the graph should have the same scale in x and y and have decimal units on the axis. Some of the other graphs share these problems, so the comment will not be repeated.

This is an artifact of the word processing Ecology uses. Most of the graphs had the same scale in the Excel files they were created in, but when imported into the Word document, Word automatically re-scaled the graph to fit the format of the document. Ecology apologizes for any difficulty in the interpretation of the data on the graphs because of the re-scaling, but the data and relationships are still accurate. We will try to fix them if we can.

16. Page 13, paragraph 2. Omit "matrix spikes" here and elsewhere in the text and add "samples spiked with higher P concentrations" so the text is readable by the public.

The text was changed throughout the document to remove “matrix spikes” and replace with the suggested change.

17. Page 15, paragraph 3. The words "primary productivity" will not be generally understood by the public.

Changed “primary productivity” to “algal/plant growth”

18. Page 15, paragraph 5. Based on what years?

A citation is included (Carroll et al, 2000). The TP load data was calculated using average monthly flow from 1960 to 1999 and average monthly TP concentration reported from 1964 to 1989. This was done as part of the historical review of data.

19. Page 18, paragraph 2, line 7. Edit to read "...a 33.7 cfs or 69.2 % increase)."

Error concurred. Edited text to read “a 33 cfs or 68% increase”.

20. Page 19, figure 7. Clearly state in the legend that the estimated flow is a calculation, not a measurement.

Changed the text of Figure 7 title to include “Estimated flows are made using straight-line interpolation between measured instantaneous flows”

21. Page 19, paragraph 1. Relate the higher flows to the rainfall pattern.

It was not an objective to relate higher flows in Rocky Ford Creek to rainfall patterns, particularly because Rocky Ford Creek is spring fed.

22. Page 28. The mixed units in figure 11 do not make sense.

It has been Ecology's practice to calculate a conductivity load with the units that conductivity is measured in (umhos/cm) times the flow (cfs). There is a standard method to convert conductivity to a dissolved solids concentration from which a load of dissolved solids could be calculated, but it would be a redundant effort to using the conductivity load as expressed in the report.

23. Page 30, last paragraph. Whether the detention pond is or is not silted in is an objective fact. If it is silted in change the text to "... and is silted in" and change the text to " ... it acts as an ineffective barrier ..."

The text was changed as suggested.

24. Page 31, paragraph 3. Replace the word "normal" with the word "average".

The text was changed as suggested.

25. Page 31, paragraph 4. Clarify whether the P contribution is seasonal or annual.

Estimates were based on the average of the samplings for 1997, which were done in August and November (seasonal). Changed text to include this information.

26. Page 33, paragraph 1. "Annual estimated total P loads ..."

Noted and changed.

27. Page 37, paragraph 1. Why are there water quality standards for Crab Creek when it did not even flow during the summer prior to irrigation?

It is a water of the State of Washington.

28. Page 37, paragraph 3. The claims in the first two sentences are not supported by scientific evidence.

Presumed the page number was supposed to be "Page 39" rather than "Page 37". First two sentences were deleted from the text of Page 39, paragraph 3.

29. Page 47, paragraph 2. "... were generally low, ..."

Noted and changed.

30. Page 47, last paragraph. Emphasize how this water represents a substantial dilution.

Added sentence to text: “This still resulted in a dilution because the higher TP concentration lake-water was displaced and washed out of the outlet.”

31. On page 51 the discussion of the model needs to mention how evaporation was considered.

Added sentence to text: “CE-QUAL-W2 has an internal evaporation model that was used to estimate evaporative water loss.”

32. Page 77, last paragraph. The P outflow numbers have a very large error term.

The outflow TP concentrations appear to be slightly biased high. The average difference between the observed and predicted concentrations was 6 ug/L (n=8) for May through September data with a RMSE of 9 ug/L. The rather large CV of 42% was because the observed average TP concentration was so low (22 ug/L TP) for that time period.

33. Page 101, paragraph 6, last sentence. "... switch from surface rill or furrow irrigation to sprinkler irrigation)."

Noted and changed in text.

34. Page 103, paragraph 3. The last sentence is speculation and should be omitted.

The following sentence was removed from the text as it does not pertain to the Moses Lake TMDL: “Reducing phosphorus probably will help address pH listings in the upper Crab Creek watershed.”

35. Page 103, paragraph 3. The claims in the first two sentences are not supported by scientific evidence.

The following portion of the text was removed: “…, essentially flushing the Crab Creek store of nutrients into Moses Lake.”

Comments received by Dr. Peter Burgoon on 1/15/04:

Comments regarding the Moses Lake TMDL Phosphorus Study *January 15, 2004*

To:
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From:
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Clearly a lot of work has been done to model the lake and provide a good basis for establishing a TMDL. However, the TMDL study and supporting documentation (Carroll et al 2000) fall short in establishing and presenting any argument that the BMPs implemented over the last 20 years are ineffective for protecting current use and recreation in the lake. Although phosphorus goals of <50 ug/L were not met with the BMPs, the beneficial uses have improved.
There are no reports referenced in the TMDL Study or Carroll et al (2000) since 1989 that support the premise that a TMDL is required to eliminate existing blue green algae problems or other degradation of beneficial uses in the lake. Blue green algae that dominated in 1989 (Welch et al), Microcsytis and Aphanizomenom, both pose serious public health hazards due to release of cyanotoxins. These algae cause regular closures of lakes in Washington but Moses Lake has not had any public health advisories within the last 15 years due to blue green algae. There is no documentation that beneficial uses are impaired in the lake since the implementation of dilution, BMPs, and management efforts of the Moses Lake Irrigation and Rehabilitation District (MLIRD). If beaches have been closed, nuisance odors produced, or fish kills have been documented in the last 15 years shouldn't they be referenced.

Response:

The technical study's sole objective was to assess the TP assimilative capacity of Moses Lake with respect to the in-lake proposed TP criterion of 50 ug/L. Data were collected and analyzed in the assessment, and a TP allocation plan was recommended to achieve the in-lake TP criterion. TMDL studies focus on the whether or not the water body meets the water quality criteria, assuming they are the appropriate targets to protect the beneficial uses.

Ecology agrees that the beneficial uses of Moses Lake have improved since the 1960s and 70s as a result of water quality restoration measures to the lake and watershed, most notably the large additions of Columbia River water (dilution water) to the lake beginning in 1977. The restoration measures (mainly dilution) have worked so well that Moses Lake, at times, meets the P goal of <50 ug/L.

Another effective BMP was the 1984 cessation of discharging Moses Lake WWTP effluent into Pelican Horn. Welch et al, (1989) clearly showed the resulting dramatic reduction of TP from Pelican Horn, a decline that seems to be continuing today probably as a result of another BMP that increases circulation in Pelican Horn (MLIRD seasonally pumps water from Parker Horn to Pelican Horn) combined with the burial of high-P sediments.

However, Ecology documents also clearly show a year-to-year climatic effect on the water quality of Moses Lake. During years with wet winters in the upper Crab Creek drainage, high winter run-off can fill Moses Lake and Potholes Reservoir to the point that very little Columbia River water (i.e., dilution water) is required the following irrigation season. This high winter runoff occurs about 4 out of 10 years on the average, most recently in the late 1990s.

In Carroll et al (2000) on page 37, two references are given (Bain, 1998 and Hallock, 1999) for data collected during the "wet years" of 1997 and 1998 that show that the beneficial uses in Moses Lake were impaired. Bain specifically compared his 1997 data with the established quantifiable water quality goals for TP, chlorophyll a, and water clarity (secchi disk) and found the targets were not met. Hallock's 1998 data was published in 2000 (Water Quality Assessments of Selected Lakes Within Washington State, 1998; Smith et al, 2000; Department of Ecology; Publication No. 00-03-039; available on the web at: http://www.ecy.wa.gov/biblio/0003039.html) and shows that the TP criterion was not met and includes descriptions of "thick" Aphanizomenon blue-green algae blooms occurring throughout the summer months.

It is important to distinguish what "BMPs" are being discussed here. Clearly, the use of Columbia River water to dilute Moses Lake is the most effective BMP to date, and the data clearly shows that not only have the beneficial uses improved (with the exception of a growing aquatic weeds nuisance), but Moses Lake also meets the goal of having less than 50 ug/L of in-lake TP when adequate dilution water is available. Moses Lake could have been described as nearly mesotrophic in 2001. Again, adequate dilution water is not available every year and the TMDL is proposing a reduction in TP loading to protect beneficial uses during years when adequate dilution water is not available.

There is reliable anecdotal evidence from MLIRD that the lake ecology has changed due to implementation of BMPs. Specifically, the necessity for removal of macrophytes with harvesting equipment has increased dramatically over the years. This implies that problems of low visibility due to algae have been resolved resulting in rampant growth of submerged aquatic plants. This has resulted in impairment of beneficial use for boating and may impact fisheries. The result is an intensive annual effort to remove the nuisance vegetation. Generally these plants are significant problems in both mesotrophic and eutrophic lakes. Given the significant *quantities of phosphorus in the sediment is it reasonable to assume that the TMDL will not help in control of submerged aquatic plants?*

Response:

Anecdotally, there is agreement that the need for harvesting has increased dramatically in recent years (unfortunately, MLIRD does not have written records for their macrophyte harvesting program). Your assessment of visibility is correct. Yes, it is reasonable to assume that with no high, winter run-off events the last 4 or 5 years, large amounts of Columbia River water (supplemental feed water) have been diverted through Moses Lake to Potholes Reservoir for irrigation (enough water was run through Moses Lake from March to September 2001 to fill the entire lake twice-over). Water quality attributes of the Columbia River water include very good water clarity. When Moses Lake is filled with Columbia River water, light penetrates the clearer lake water and macrophytes emerge in the shallow parts of the lake. This is particularly the case in shallow parts of Parker Horn where the Columbia River water is introduced to Moses Lake and Pelican Horn where Columbia River water is pumped from Parker Horn. There is insignificant macrophyte growth in the rest of the lake.

Because Moses Lake is eutrophic, sediment P has been and probably always will be sufficient for macrophyte growth. Macrophyte growth in Moses Lake will most likely always be limited only by light penetration so it really is a water clarity issue. It is a case of "too much of a good thing" where the "dilution water" program is creating very good water clarity which allows the macrophyte growth. The TMDL does not propose control of the dilution water and thus the macrophyte problem will continue with the additions of Columbia River water. If they were available, records would show there were less macrophytes in 1997 and 1998 in Parker Horn and Pelican Horn when the water clarity was very poor. There are very few macrophytes in the upper end of the Rocky Ford Arm (despite shallow P-rich sediments) because there is poor water clarity there every year. The proposed TMDL and the TP criterion of 50 ug/L support eutrophic conditions in Moses Lake, meaning there will be enough P in the water, in a year without dilution water, to support enough algal productivity (i.e., less water clarity) to minimize macrophyte growth.

On the other hand the growth and removal of the submerged aquatic vegetation may have beneficial impacts on phosphorus reduction in the lake. There are two important points to consider.

First, in proper conditions, submerged aquatic vegetation cause significant rates of precipitation of phosphorus from the water column. The calcium precipitate formed in alkaline water is relatively insoluble and occurs at rates much greater than can be achieved through TP removal via uptake in wetland plants. Wetland filters, using submerged aquatic vegetation, are being implemented in Florida to protect the Everglades, a national park, from TP in agricultural runoff. Pilot testing of filters in the Lake Chelan area have regularly achieved removal of >80% of the soluble reactive phosphorus and >50% of the TP during the growing season.

Secondly, removal of P by harvest of wetland plants has always been considered impractical due to the cost of harvesting. In this case harvesting in Moses Lake is paid for by lake users and preliminary estimates show that significant enough amounts are removed to have significant TP load reduction. Based on TP and water content in the submerged aquatic vegetation in Manson Lakes (Burgoon-unpublished data) the MLIRD may have removed from 20 – 30 kg of phosphorus in 2003. Although this is only about 2-3% of the recommended reduction of 1000 kg/yr, the MLIRD harvest was low for 2003. It is also significant since it is about equal to the 35% reduction estimated for the Columbia Basin Hatchery (Table 18 of TMDL study).

Can the model be improved to account for the impacts of growth and removal of submerged aquatic vegetation? Shouldn't significant natural changes in ecology and lake management be integrated into the model?

Response:

> A subroutine has been developed for CE-QUAL-W2 that models the growth of macrophytes (but not the harvesting) which may be available in the next version of the model. Ecology believes the extent of macrophyte coverage in the whole lake is minimal and for now is a minor player compared to the other forcing processes that affect water quality in Moses Lake, but macrophytes could be added in the future to the Moses Lake model.

On p 89, the TMDL Assessment summarizes the problems and solution.
A bulleted paragraph discusses "A link between TP and an endpoint indicator, Chlorophyll a concentration" that was established historically and was the basis for the 50 ug/L TP. On page 90 discussions continues with, "The goal of this TMDL is to manage and mitigate the extensive hypereutrophic blooms of blue green algae that have occurred since the inception of the CBIP." As mentioned above there is no documentation that blue green algae blooms have been a problem in the last 15 years.

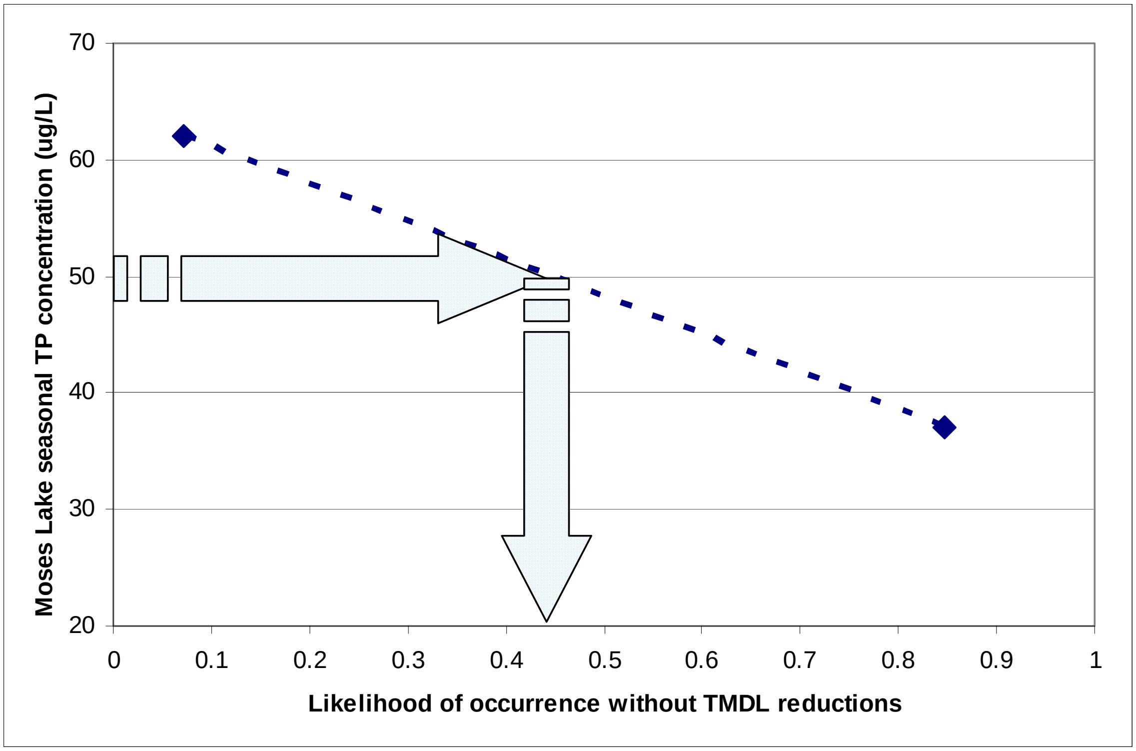
Response:

> See above response to the first comment concerning Ecology 1998 data (Smith et al, 2000).

If the purpose of the TMDL is to protect against blue green algae blooms, then a probability of protection would be helpful to assure that efforts will protect the beneficial uses of the lake. For instance, could a statement be made that without the TMDL beneficial use may be impaired X% of the time but with the TMDL beneficial use will be achieved y% of the time?

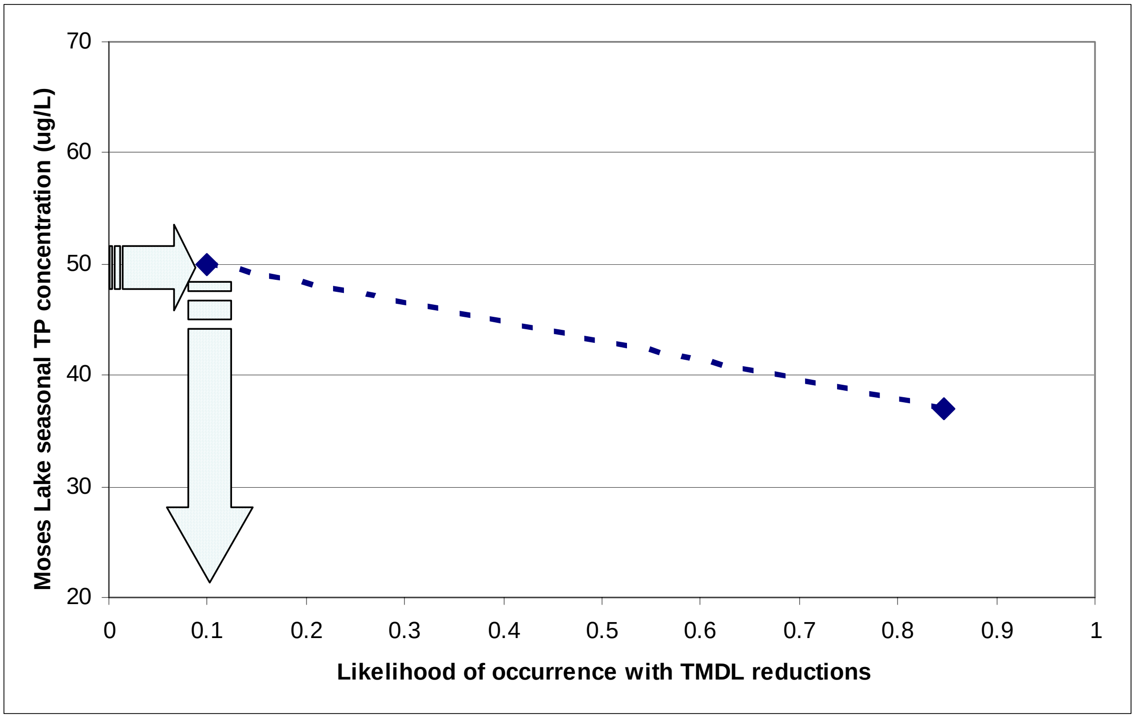
Response:

> Yes, without a TMDL Moses Lake may exceed 50 ug/L of TP roughly 40% of the time on the average (or the beneficial uses of Moses Lake may be impaired roughly 40% of the time on the average). This is best illustrated by the figure below:



The Moses Lake TMDL technical analysis established that the seasonal in-lake TP concentration for 2001 and a defined critical design year (i.e., a year without adequate dilution water) were 37 ug/L and 62 ug/L, respectively. These two years are representative of two extremes (approximate lower and upper 10th percentiles) of dilution water flow to Moses Lake through Rocky Coulee Wasteway based on the probability distribution of dilution water flows from 1977 to 2001. This data is plotted on the above figure. Using linear interpolation between these two points, the current likelihood of a particular year exceeding a seasonal 50 ug/L TP concentration would be slightly greater than every 4 out of 10 years on the average.

With the TMDL the likelihood of Moses Lake exceeding the 50 ug/L of TP criterion would be approximately 10% of the time on the average. This would be illustrated by pivoting the linear line in the above figure as approximated in the figure below:



Is it valid to claim or imply that keeping the TP below 50 ug/l will control excessive blue green algae? There are several studies from lakes in western Washington that show that problems with blue green algae and release of cyanotoxins are simply unpredictable. Even in mesotrophic lakes, closure is often required due to excessive growth of blue green algae and public health concerns.

Response:

> Ecology agrees that blue-green algae blooms can be unpredictable, however the goal of the TMDL is not to eliminate, but to reduce the likelihood of occurrence of excessive blue-green algae blooms in Moses Lake. The 50 ug/L TP criterion has been adopted from historical Moses Lake studies as a level that has been shown to be achievable and protective of the beneficial uses of the lake by reducing likelihood of excessive blue-green algae blooms.

As I understand the model development, it was calibrated using the data collected in 2000-2001 and then used to predict appropriate load allocations. On p 77, Table 12 shows that some stations are better modeled than others. The Study notes that a RMSE of 9 ug/L TP (18% of 50 ug/L target) is "very good" for some of the lake stations and appears to be about the best that the model can do. The RMSE for all stations is 14 ug/L (28% of 50 ug/L). Most stations have greatest RMSE in July, August, and September when blue green algae blooms maybe expected to be worst. ML3 was the worst with a maximum RMSE of 42 ug/L in May and a station average of 21 ug/L. Please clarify how the TMDL accounts for this relatively large error in the model when it states that a 35% across the board reduction in TP is required. How effective can the model be if the error is often as large as the required reduction in concentrations?

Please see general response #1 in the beginning of this response summary. It is important to step back and look at the overall model response instead of focusing on a few discrete data and model comparisons. It is important to observe if the model is behaving in a manner that shows there are no systematic errors. For example, it is clear that the model is accurately predicting increasing TP in the deeper bottom waters of Moses Lake through the summer even though the prediction error is greater because the values are much greater.

It is also important to realize that the RMSE for a single station on a certain date is an error analysis comparing all model-predicted and observed data values for the whole water column at that station. If we were to average all the values for the water column (like what has historically been done for simpler steady-state modeling), the error would be much less. Because the Moses Lake CE-QUAL-W2 model is predicting TP at one-meter depth increments at a station, there may be considerable error in the model's capability to predict a single observed TP value at a given depth interval if there is a strong TP gradient change (as in the bottom waters). The power of the Moses Lake CE-QUAL-W2 model is how often the model did accurately predict the observed values at a given observed depth. When the model did not, it often did within only a few meters above or below the observed value's depth, as can be seen in the calibration Figures 53-58.

Because most of the errors for a single station were for bottom waters where there were strong gradient changes, an error analysis of only the epiliminion (upper water above 6 meters) was conducted to quantify the error in the zone where algae grow. The following is a reproduction of Table 12, looking at the epilimnion-only error:

TP mg/L	RMSE error statistics by site and month						
	ML5	ML4	ML3	ML1	ML2	ML6	**Total**
March	0.003	0.001	0.007	0.005	0.005	0.011	0.006
April	0.005	0.006	0.006	0.008	0.008	0.006	0.006
May	0.007	0.005	0.008	0.005	0.012	0.005	0.007
June	0.004	0.010	0.009	0.007	0.007	0.008	0.008
July	0.014	0.004	0.010	0.016	0.014	0.006	0.012
August	0.005	0.013	0.015	0.016	0.015	0.007	0.014
September	0.012	0.014	0.009	0.015	0.013	0.005	0.012
							Overall
Mar-Sept	0.007	0.009	0.009	0.012	0.011	0.007	0.010

As can be seen, the error associated with the model-predicted values is much lower, with an overall RMSE of 10 ug/L TP. The model does a very good job of predicting TP even in the months of July, August, and September (when blue-green algae blooms are expected). For station ML3, there was a RMSE of 8 ug/L TP in May and a station average of 9 ug/L TP in the epilimnion. Ecology believes the Moses Lake CE-QUAL-W2 model is adequately calibrated and is an effective tool for recommending seasonal P allocations to limit exceedences of the 50 ug/L TP criterion.

The TMDL needs to better establish that the model is a reliable management tool for the lake. The modeling effort shows that there is significant error in prediction of TP, the primary TMDL parameter. The real proof of a model is in its ability to model other data sets. Some effort to show that the model can simulate conditions measured in at other times may help establish the credibility of the model and provide additional sensitivity analysis to improve the model. Can the model predict the trends that have been documented to date?

As discussed in the response to the previous comment, Ecology disagrees that there is significant error in the capabilities of the Moses Lake CE-QUAL-W2 model to predict TP. Again, as stated above, Ecology believes the Moses Lake CE-QUAL-W2 model is a reliable tool for predicting the fate and transport of phosphorus. Please also see general response #2 in the beginning of this response summary.

Ecology would like to make it clear that it agrees that conditions in Moses Lake have improved since restoration measures were implemented in the 1970s. This means that the parameters or calibration of the model would have to be changed from the current calibration for the Moses Lake CE-QUAL-W2 model to predict historical conditions and trends. Not that this wouldn't be an instructive endeavor to show the models credibility, but it probably would not improve the calibration of current conditions. Another year of data collection would be necessary for a model confirmation of current conditions.

The model should be available as a tool for future managers to make decisions for implementation of an SIS. Can the model be used to help stakeholders decide how to make the most effective decisions? For instance, could simulations be run showing the effects of a 50% reduction in phosphorus from groundwater if sewer discharges are controlled? This is only one example; obviously numerous other scenarios are possible. The main point is that the SIS process needs tools and information to help make effective decisions. The model should be made available for refinement and possible use as a management tool.

The Moses Lake CE-QUAL-W2 model will be made available to any parties interested. It would be a useful tool for making further lake management decisions such as you have described. However, it should be noted that the model can be cumbersome to set up, particularly if there are hydrologic changes, which would require the water balance to be redone. If decisions are needed during the SIS implementation, Ecology's Eastern Regional Office may request that additional modeling scenarios be developed for that process.

References:

Carroll et al. 2000. Moses Lake Proposed Phosphorus Criterion and Preliminary Load Allocations Based on Historical Review. DOE Publication No. 00-03-036

Burgoon. 2004. Unpublished data. Three filters have been operated for two growing seasons north of Lake Chelan. The project is being used to test use of submerged aquatic vegetation filters for removing phosphorus from agricultural drain water.

Bain 1998. Water Quality Monitoring Report. Prepared for Moses Lake Irrigation and Rehabilitation District.