Water Quality Data Summary for Major Tributaries, Lakes, and Reservoirs in the Flathead Lake Watershed: 2007-2008

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ABSTRACT

Detailed monitoring efforts were completed in the Flathead Lake watershed during 2007-2008 by Montana Department of Environmental Quality (DEQ) to characterize the spatial attributes of streamflow and water quality, seasonal and annual loading rates of nitrogen and phosphorus to the lake, and to support watershed model development for the Phase II TMDL. We also evaluated consequential changes brought about by upstream lakes and reservoirs. Sampling was completed at over 20 sites as part of the program including the North Fork (N F), Middle Fork (M F), and South Fork (S F) of the Flathead River, the Swan River, Stillwater River, Whitefish River, and Ashley Creek. Data was also collected on Hungry Horse Reservoir (3 sites), Swan Lake (2 sites), and Whitefish Lake (2 sites). The riverine sites were sampled approximately ten times per year and lacustrine sites 8. From examination of the data, several things were apparent. First, waterbodies with direct wastewater discharges (i.e., both Ashley Creek and the Whitefish River) had the highest nutrient concentrations. By estimating daily loads from these waterbodies [using the U.S. Geological Survey LOAD ESTimator (LOADEST) program], we found that that despite the point source input, loads from these watersheds were insignificant when compared to the overall load in the watershed. The largest tributary contribution of nitrogen (N) and phosphorus (P) was from the N F and M F of the Flathead River (62 and 89 percent respectively), while the S F added an additional 22 and 4 percent each. The remaining tributaries even when summed therefore contributed only a minor portion. By taking the loads at the mountain-valley interface and subtracting them from the load entering Flathead Lake we were able to quantify the anthropogenic input to the Flathead Lake. The unaccounted for load was 0.47 tons/day for total N and 0.27 tons/day for total P (depending on season). This load originates from both point and non-point source pollution. The overall increase amounts to 8.6 and 26.9% of the respective watershed load. It should be noted that our figures are a rough estimate given limitations of the LOADEST regressions. Watershed models are recommended in the future to reduce this uncertainty.

The influence of upstream lakes and reservoirs was also evaluated. Based on analysis of inflow and outflow concentrations of each waterbody (i.e., Hungry Horse Reservoir, Swan Lake, and Whitefish Lake), all systems were an N source (due to aerial deposition) and a P sink (due to particulate settling). We first identified that inflow was a large percentage of the outflow to make this comparison. We also characterized the water quality mechanics of each system. At each site, depth profiles were similar and had the following pattern: the onset of stratification began in early May, was completed by mid July or early August, and then quickly went isothermal starting in September. Hungry Horse was somewhat delayed due to its size and also had a much thicker hypolimnion. Nutrients and primary productivity in each system were fairly consistent and all sites had secchi depth greater than 15 feet on average. Hence these waterbodies are a net benefit to Flathead Lake due to the fact that they buffer contributing watershed area sediment and nutrient loads and provide good quality water year round. Such information will be valuable in facilitating future water quality planning and management in the basin.

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

LIST OF ACRONYMS

Acronym	Definition
AMLE	Adjusted Maximum Likelihood Estimation
BOR	Bureau of Reclamation
CKST	Confederated Salish and Kootenai Tribe
DEQ	Department of Environmental Quality (Montana)
DNRC	Department of Natural Resources & Conservation
DO	Dissolved Oxygen
EWI	Equal Width Increment Integration
FLBS	Flathead Lake Biological Station
HUC	Hydrologic Unit Code
LR	Loading Ratio
NASA	National Aeronautics and Space Administration
NWIS	National Water Information System
SC	Specific Conductance
SRP	Soluble Reactive Phosphorus
STORET	EPA STOrage and RETrieval database
TDS	Total Dissolved Solids
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TSS	Total Suspended Solids
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WQX	EPA's Water Quality Exchange System
WRCC	Western Regional Climate Center
WWTP	Wastewater Treatment Plants

INTRODUCTION

PURPOSE

This summary report has been prepared to document the results of monitoring completed by the Montana Department of Environmental Quality (DEQ) in the Flathead Lake Watershed during 2007-2008. Included is a spatial summary of streamflow and water quality estimates entering the lake, seasonal and annual loading rates of nitrogen and phosphorus, and consequential changes brought about by upstream lakes and reservoirs. The type and extent of this data are highlighted to facilitate future use.

BACKGROUND

Flathead Lake is located in the Flathead Valley in northern Montana (**Figure 1**). It is one of the 300 largest natural lakes in the world and the largest natural freshwater lake in the continental western United States (Stanford, et al., 1997b). Often compared to Lake Tahoe (Mann, 2006; Thomas, 2005; Flathead Lakers,1996; 1997; 2000), Flathead Lake has significant aesthetic amenity and recreational appeal. This is due to its excellent water quality. Unfortunately, the popularity of the lake is also placing a growing strain on its water resources. Subsequently, water quality has been in decline.

According to Stanford, et al., (1997b), Stanford and Ellis (2002), and Ellis, et al., (2005), upward shifts in primary productivity and reductions in hypolimnetic dissolved oxygen concentration have been identified. In 1984 and 1994, lake-wide blooms of nuisance algae were observed, something that had not occurred in over 100 years of monitoring by the Flathead Lake Biological Station (FLBS). The primary cause is believed to be the sustained increase in human activity around the lake (Stanford, 2009). Changes have occurred despite numerous measures to maintain water quality including a watershed ban on domestic phosphorus detergent, increases in municipal sewer hookups, tertiary wastewater treatment upgrades, good forestry best management compliance, and a higher level of awareness about water quality by local citizens. The proactive steps in the basin likely have been offset by a 42 percent increase in population from 1980 to 2000 (Montana Department of Environmental Quality, 2001). Nearly 70 percent of the growth has occurred outside the incorporated cities and towns using on-site wastewater treatment systems (Stanford, et al., 1997a).

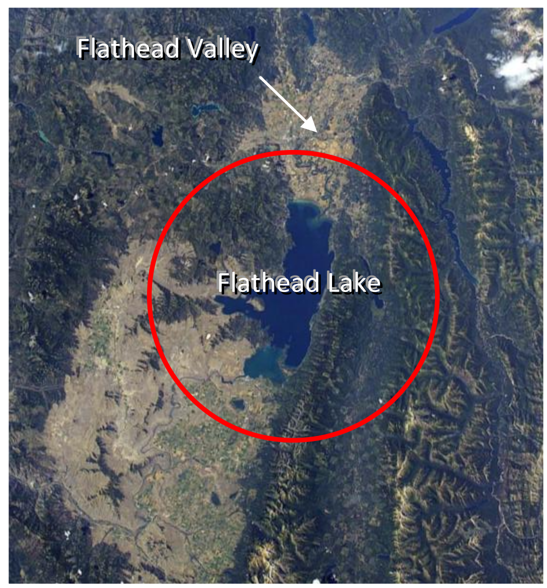


Figure 1. NASA image S105-E-5428 of Flathead Lake and surrounding valley.
Enhanced by James Conner.

Flathead Lake was consequently placed on the state's 303(d) list of impaired waters in 1996 (Montana Department of Environmental Quality, 2006). In 2001, a nutrient Total Maximum Daily Load (TMDL) was drafted by DEQ which consisted of a two-phased reduction strategy. Phase I was to reduce nutrients from the core urban and agricultural area north of the lake by 25 percent over the short-term. Phase II was to refine the Phase I TMDL through modeling. The latter was necessary to fill a deficiency in the initial allocation methodology which relied heavily on a watershed-wide synoptic monitoring event in 1996 that was unable to apportion loads to specific source categories or differentiate between the anthropogenic and natural fractions. Models would also aid in predicting water quality as a function of precipitation, changes in land use or management practices, or other engineering controls.

More recently, work has been done to develop a monitoring and modeling strategy in preparation for the Phase II TMDL. This has included identification of a management framework for TMDL source allocations (Flynn, et al., 2007), implementation of a watershed-scale and waterbody-specific monitoring program during 2007-2010 (Montana Department of Environmental Quality, 2007), and detailed characterization of pollutant sources and their influence in the watershed (Gildea, J., personal communication 2011).

WATERSHED DESCRIPTION

The contributing watershed to Flathead Lake is shown in **Figure 2**. It encompasses 7,067 mi^2 and consists of seven major tributaries and five 8-digit USGS Hydrologic Unit Codes (HUCs). These include the (1) North Fork (N F), (2) Middle Fork (M F), and (3) South Fork (S F) of the Flathead River which drain Glacier National Park and the Bob Marshall Wilderness east of the lake, (4) the Swan River which discharges directly to Flathead Lake near Bigfork from the Swan and Mission mountain ranges to the south, and (5) the Whitefish River, Stillwater River, and Ashley Creek (Flathead Lake HUC) which drain the northwestern portion of the watershed including the Whitefish Range and Salish mountains. Water quality entering Flathead Lake is adequately described by these seven locations.

As the receiving point of these drainages, Flathead Lake is very sensitive to nutrient pollution. Productivity is co-limited by both nitrogen (N) and phosphorus (P) (Stanford, et al., 1997b; Spencer and Ellis, 1990), hence each nutrient is of concern. Known nutrient sources in the watershed include nine permitted municipal wastewater treatment plants (WWTP), three industrial sources, ten stormwater permits, two centralized animal feeding operations, and numerous nonpoint sources (e.g., agriculture, forestry, urbanization). Recent concerns in the watershed are related to non-native species (lake trout and mysis shrimp) which have upset the food web in the lake and significantly depleted native species (Ellis, 2006).

The valley north of the lake is where most of the activity has been centered. It is one of the fastest growing places in the state (Stanford, et al., 1997a) and Lake and Flathead counties have grown by over 30 percent between 1990 and 2005 (United States Census Bureau, 2006). Development has occurred primarily along the western shore of the lake outside incorporated areas along U.S. Highway 93, and throughout the remaining valley to the north (Stanford, et al., 1997a; Montana Department of Environmental Quality, 2001). The southern half of the lake is within the reservation boundary of the Confederated Salish and Kootenai Tribe (CKST) and has remained relatively unaltered.

The watershed draining to the lake is primarily high elevation forest under the management of the National Park Service, USDA Forest Service, or Montana Department of Natural Resources and Conservation (DNRC). These high-elevation areas are largely un-altered or are at least well-managed by the administering agency (Stanford, 2009). Private land holdings (e.g., agriculture, urban, etc.) are thought to be more of a concern, and high concentrations of pollutants have been observed in these areas. Quantitative information on the effect of private land holdings on water quality is poorly understood however.

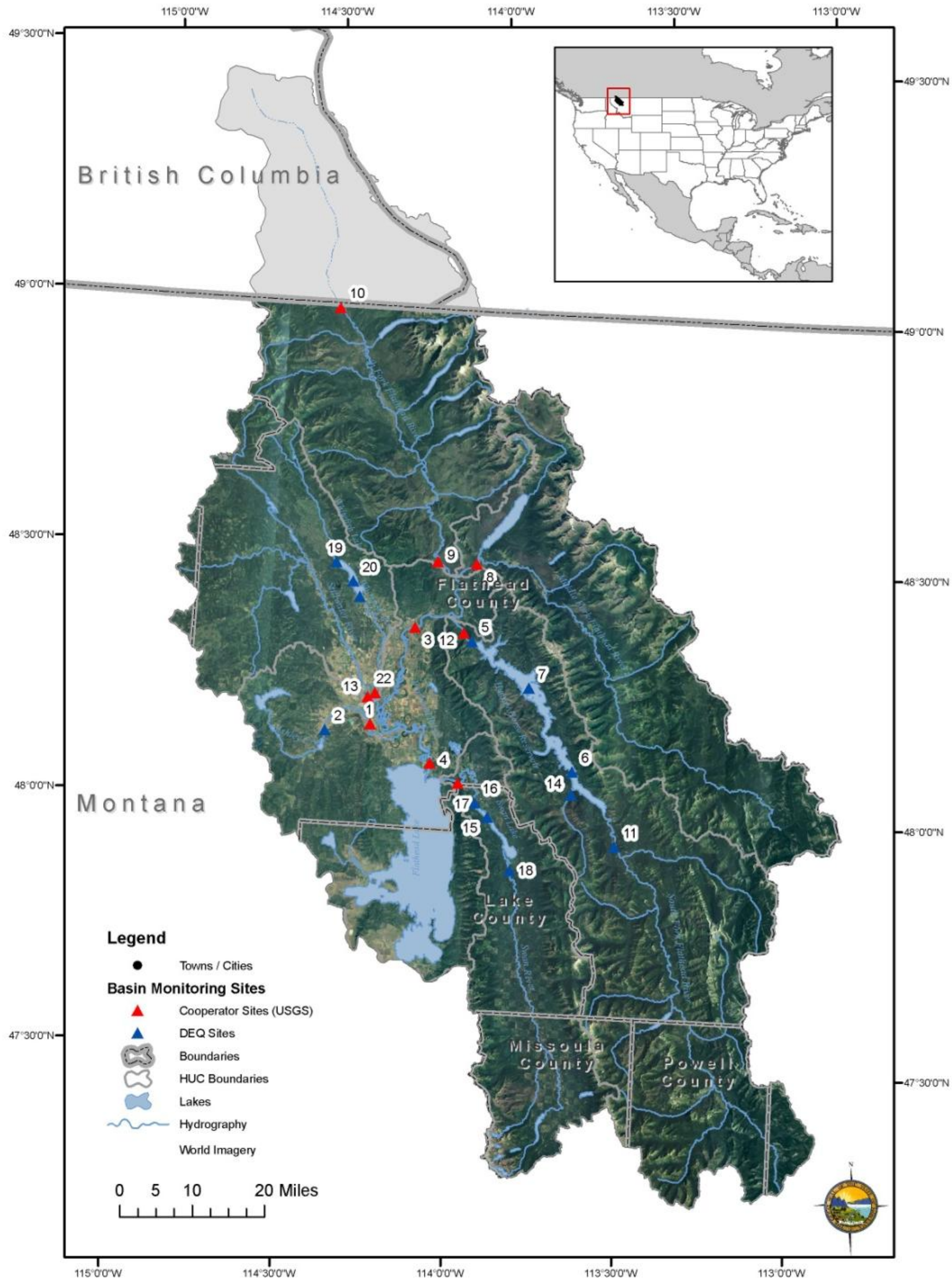


Figure 2. Flathead Lake Watershed and associated monitoring locations.

Mountain hydrology is the dominant watershed process of the basin. Orographic precipitation and temperature fluctuations drive the hydrologic regimen of the system, and annual rainfall accumulations range from between 15 inches in the valleys to over 50 inches in the mountains. Air temperatures have similar but inverse gradients and are cooler in the mountains and warmer in the valleys (Western Regional Climate Ceter (WRCC), 2006). Much of the hydro-climatic variation results in large winter precipitation accumulation and then significant spring and summer snowmelt. A percentage of runoff also occurs as spring and fall rains. Streamflow is partially reservoir regulated, and Hungry Horse Reservoir on the South Fork of the Flathead River has over 3.5 million acre-feet of conservation pool storage.

MONITORING PROGRAM

The monitoring program was designed to acquire information on key locations of interest for the Phase II TMDL. Objectives were threefold: to develop a rigorous set of water quality data to calibrate and validate water quality models (i.e., spatially identify seasonal and annual loading rates of N and P in the watershed), (2) to provide baseline data for monitoring long-term status and trends, and (3) provide general data in support of the TMDL.

Monitoring locations were selected to characterize the following: (1) the influence of major rivers or streams that contribute to the lake, (2) the influence of major lakes and reservoirs upstream of Flathead Lake (e.g., Swan Lake, Whitefish Lake, and Hungry Horse Reservoir), and (3) the aggregation of loads entering Flathead Lake. Site selection was based on spatial location, contributing watershed area, and lake or reservoir volume and outflow. To the extent possible, spots were coincident with the U.S. Geological (USGS) gaging network and two new gages were funded through the project to acquire better spatial information. These were: Ashley Creek at Kalispell (USGS 12367800) and Flathead River near Bigfork (USGS 12369000).

A description of the sites, cooperating organizations, and sampling frequency are shown in **Table 1**. Site numbers correlate with the ID’s shown on the map in **Figure 2**. USGS was a major contributor in the effort and matched 40 percent of the water quality costs of their stations and the installation and operation of the two new gages. DEQ funded the remaining portion of the project.

METHODS

Standard USGS and DEQ monitoring protocols were implemented to collect the data. Isokinetic and equal width increment integration (EWI) samples were used on the streams and rivers. Limnological samples were collected using Van Dorn samplers[1]. Temperature, pH, conductivity, turbidity, and dissolved oxygen (DO) were measured at the time of sampling. The following chemistry data was collected: total nitrogen (TN), ammonia-N (NH_4), nitrate plus nitrite (NO_2+NO_3), total phosphorus (TP), soluble reactive phosphorus (SRP), total organic carbon (TOC), total suspended solids (TSS), phytoplankton chlorophyll a (Chl*a*), and total dissolved solids (TDS). Monitoring was conducted ten times annually for the rivers and 8 times for the lakes and reservoirs. Frequency was partially a function of site access availability and hydrologic conditions.

[1] In the lakes and reservoirs, field profiles were taken first with a YSI sonde or hydrolab. Sampling was commenced from the midpoint of the epilimnion, metalimnion, and hypolimnion of each location as determined from these profiles.

Table 1. Sites monitored in the Flathead Lake watershed during 2007-2008.

Site No.[1,2]	Description	Agency	Lat	Long	Data Type[4]	Frequency
1	Ashley Creek at Kalispell (USGS 12367800)	USGS	48.16	-114.30	T	10 x
2	Ashley Creek below Smith Lake (C11AHLYC04, 05)	DEQ	48.15	-114.44	T	10 x
3	Flathead R at Columbia Falls (USGS 12366300)	USGS	48.36	-114.18	T	4 x
4	Flathead R nr Bigfork (USGS 12369000)	USGS	48.09	-114.12	T	10 x
5	Hungry Horse Reservoir, outlet (C08HHRSR02)	DEQ	48.34	-114.01	L/R	8 x
6	Hungry Horse Reservoir, midpoint (C08HHRSR03)	DEQ	48.25	-113.83	L/R	8 x
7	Hungry Horse Reservoir, inlet (C08HHRSR04)	DEQ	48.09	-113.69	L/R	8 x
8	M F of the Flathead R nr W Glacier (USGS 12358500)	USGS	48.50	-114.01	T	10 x
9	N F Flathead R above M F (USGS 12355500)	USGS	48.50	-114.13	T	10 x
10	N F Flathead R at Border (USGS 12355000)	USGS	48.99	-114.47	T	10 x
11	S F Flathead R nr H Horse (USGS 12359800)	DEQ	47.95	-113.55	I	8 x
12	S F Flathead R nr Columbia Falls (USGS 12362500)	USGS	48.36	-114.04	T	10 x
13	Stillwater R at Kalispell (USGS 12365700)	USGS	48.22	-114.31	T	10 x
14	Sullivan Creek nr mouth (C08SULLC03)	DEQ	48.05	-113.69	L/R	4 x
15	Swan Lake, midpoint (C10SWANL01)	DEQ[3]	47.99	-113.94	L/R	8 x
16	Swan Lake, outlet (C10SWANL02)	DEQ[3]	48.02	-113.98	L/R	8 x
17	Swan R above Dam near Big Fork (USGS 12370100)	USGS	48.06	-114.03	T	10 x
18	Swan R at Porcupine Bridge (C10SWANR05)	DEQ[3]	47.89	-113.86	I	8 x
19	Swift Creek at Mouth nr Whitefish (C09SWFTC01)	DEQ[3]	48.49	-114.43	I	8 x
20	Whitefish Lake, midpoint (DEQ C09WHTFL01)	DEQ[3]	48.45	-114.38	L/R	8 x
21	Whitefish Lake, outlet (C09WHTFL02)	DEQ[3]	48.42	-114.36	L/R	8 x
22	Whitefish R nr mouth at Kalispell (USGS 12366080)	USGS	48.23	-114.29	T	10 x

[1] Site numbers correspond to monitoring locations in **Figure 2**.
[2] The monitoring frequency, constituents, and locations were reduced in 2009 and 2010 and are not presented in this report.
[3] Data collection by Whitefish Lake Institute and PBS&J
[4] Data type: T=inflowing tributary, L/R=lake or reservoir, I=inflow to lake or reservoir

TRIBUTARY DATA SUMMARY

Tributary results are presented in this section. Analysis is not meant to be all-inclusive, rather just highlight some aspects of the data.

STREAMFLOW

Hydrographs from the tributaries monitored during 2007-2008 are shown in **Figure 3** (log scale). Approximately 86.2 percent of the water yield came from the Flathead River (N F, M F, and S F), 9.2 percent from the Swan River, and the remaining percentages from the Stillwater River, Whitefish River, and Ashley Creek. Streamflow is typical of a rising limb in May, peak flow in June and July, and then a gradual transition toward baseflow during August. The only exception is the S F of the Flathead River which is moderated by Hungry Horse Reservoir. Conservation storage shifts the seasonal flow distribution by nearly 50 percent, which influences downstream water quality.

Average annual water yield over the period is shown in **Table-2**. Mean flows were similar to the long-term averages reported by McCarthy (2004), but varied considerably each year. They were lower than average during 2007 (-21%), and higher than average during 2008 (+17%). This represents a suitable range of streamflow conditions for loading analysis.

Table 2. Flow contributions during the 2007-2008 monitoring period.

Tributary	2007-2008 Avg. Annual Water Yield (ft^3/s)	Flow Contribution (%)
N F Flathead River	2,937	26.5
M F Flathead River	2,971	26.8
S F Flathead River	3,642	32.9
Swan River	1,021	9.2
Stillwater River	283	2.6
Whitefish River	197	1.8
Ashley Creek	27	0.1

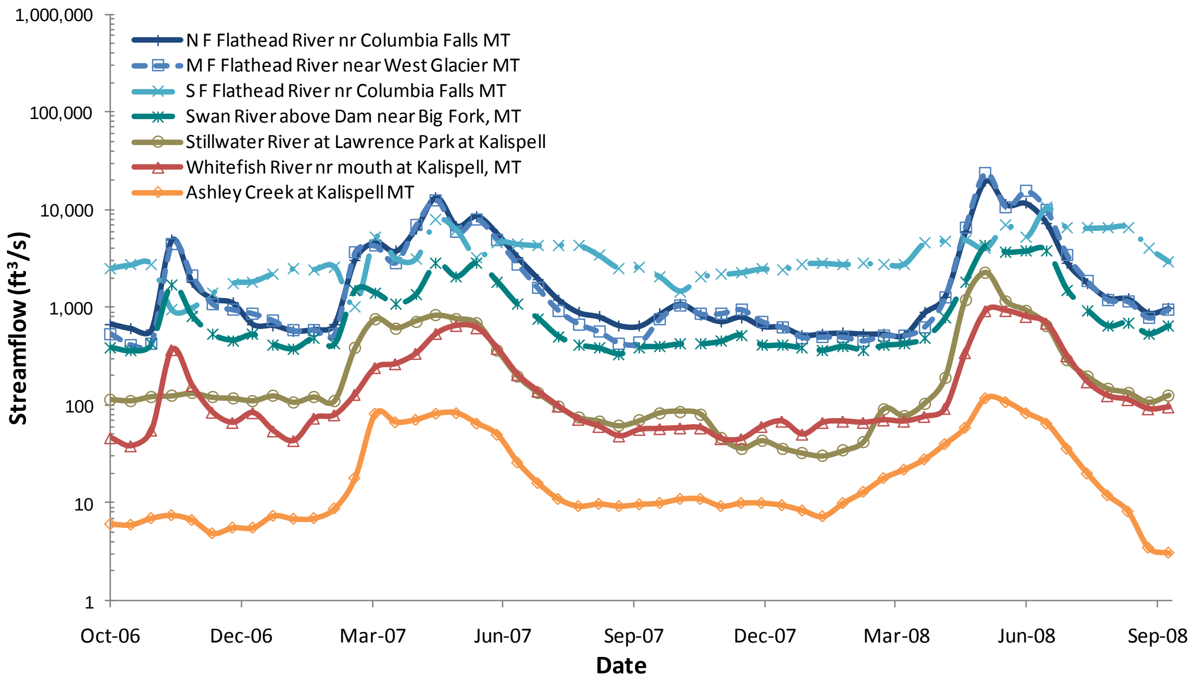


Figure 3. Annual hydrographs for major tributaries to Flathead Lake during 2007-2008.

WATER QUALITY

Water quality summaries for tributary sites are shown in **Figure 4**. There was very little difference between any of the locations. The N F, M F, and S F of the Flathead River were probably the most different with the lowest temperature and highest DO. The pH was relatively consistent at all locations; and very little distinction could be made at the 50th percentile. Conductivity (specific conductance, SC) was similar at all sites except at Ashley Creek, which is wastewater dominated. It had considerably higher SC than the other waterbodies which is attributed to WWTP discharge from the city of Kalispell.

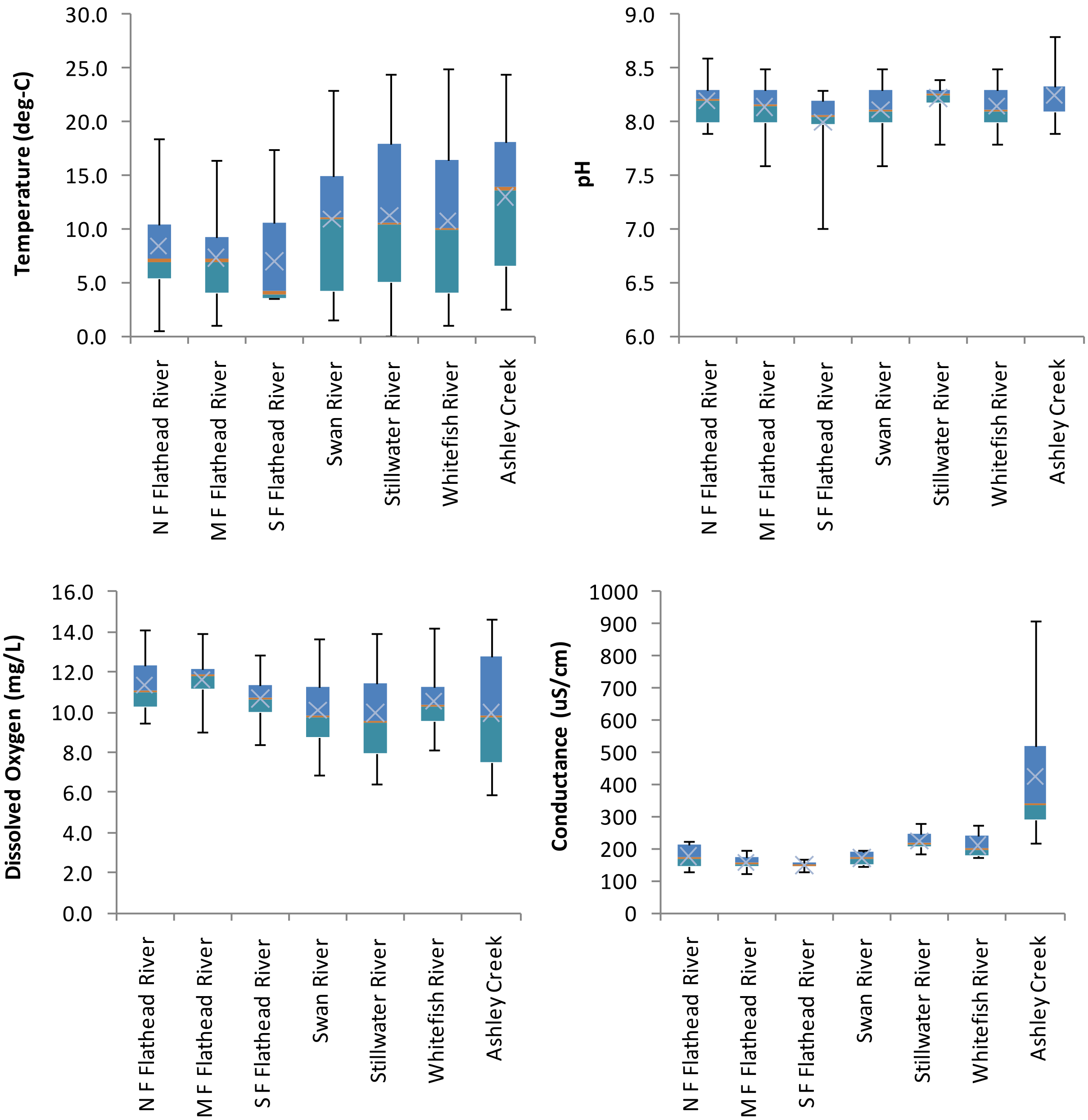


Figure 4. Water quality summaries for major tributaries to Flathead Lake during 2007-2008.
Box plot legend: whiskers = minimum and maximum, boxes = quartiles, and X = mean.

Nutrient summaries are shown in **Figure 5**. Waterbodies with direct wastewater discharges (i.e., both Ashley Creek and the Whitefish River) had the highest, or near highest, total and soluble nutrient concentrations, although TP was also high in the two watersheds with large suspended sediment yields (i.e., N F and M F of Flathead River). The influence of upstream lakes and reservoirs was also evident. Total nutrient concentration variability was much lower on the S F of the Flathead River and Swan River than other waterbodies. This is attributed to the long linear lakes and reservoirs upstream of these monitoring locations (such as Hungry Horse Reservoir and Swan Lake) that buffer water quality conditions and cause suspended particles to settle out.

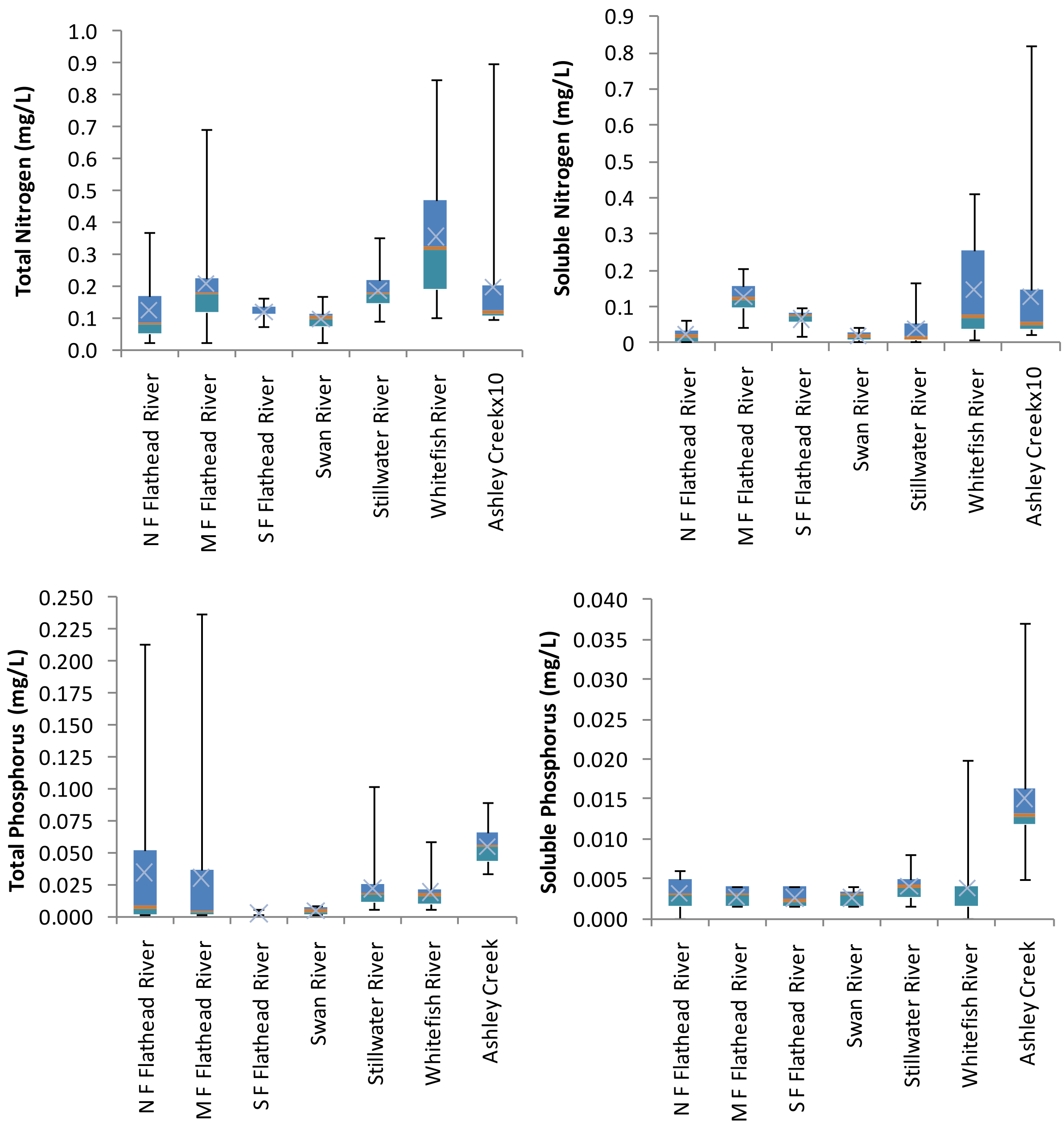
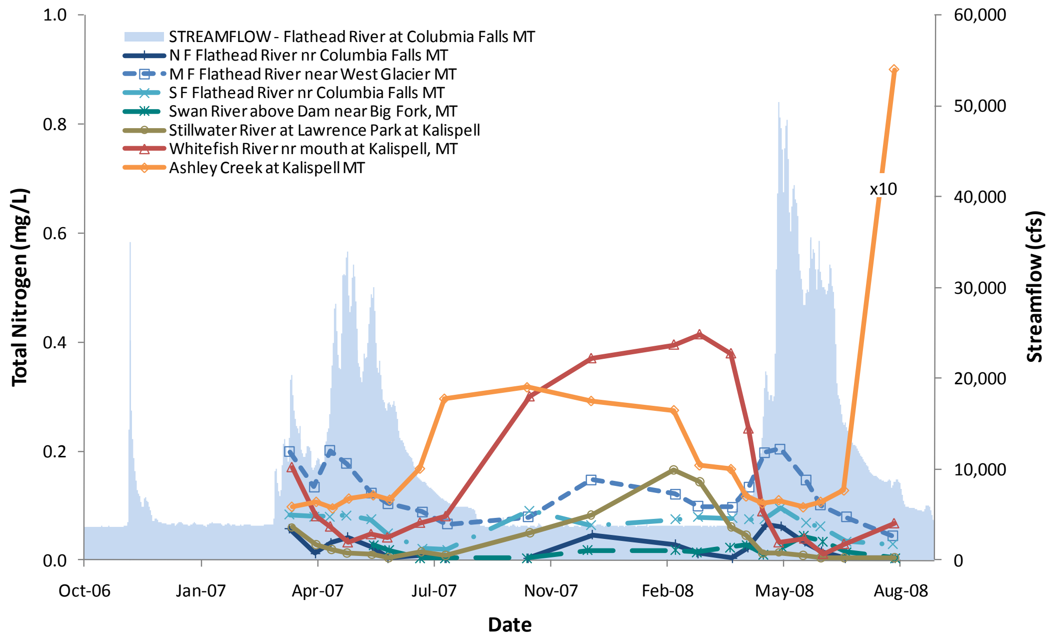


Figure 5. Nutrient summaries for major tributaries to Flathead Lake during 2007-2008.
Box plot legend: whiskers = minimum and maximum, boxes = quartiles, and ╳ = mean.
Note that Ashley Creek N is ten times (10x) higher.

Time-series graphs for nutrients are shown in **Figure 6** (flow from the Flathead River superimposed for comparison). In general, total nutrient concentrations fluctuate with discharge, with the highest values occurring on the rising limb of the hydrograph (due to winter buildup), lower values during the summer (from algal nutrient uptake), and higher values during the winter (from decreases in biological productivity). The pattern is similar for both N and P. The exceptions are Ashley Creek and the Whitefish River, both of which are wastewater influenced. Their trends are reversed (reflective of unassimilated nutrient loads), although TP in the Whitefish River is similar to the other sites. Ashley Creek had the highest percentage of wastewater contribution which may explain the difference in TP trend.



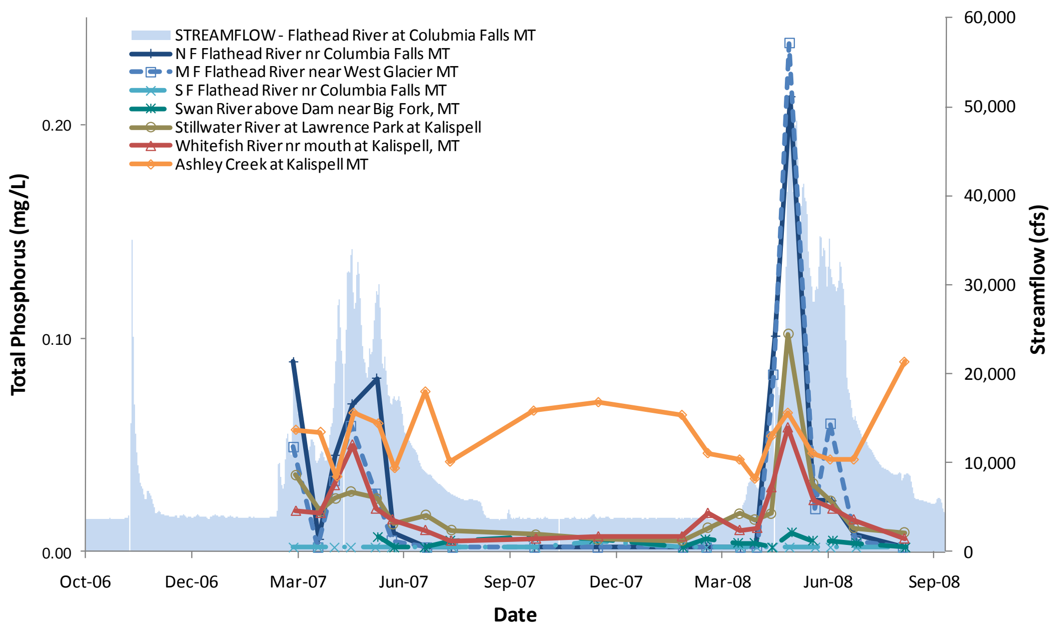


Figure 6. Time-series summaries of TN and TP concentrations for tributaries to Flathead Lake.

NUTRIENT LOAD ESTIMATES

The data presented previously was used to make nutrient load estimates for each of the major tributaries using the USGS LOAD ESTimator (LOADEST) program (Runkell, et al., 2004). Multiple linear regression was completed using adjusted maximum likelihood estimation (AMLE) procedures whereby constituent loads were regressed using a time-series of daily streamflow and associated constituent concentrations. Nine explanatory models were evaluated for each site, and the most efficient one was selected to model the daily load at each observation site.

An example AMLE equation for the N F and M F of the Flathead River is shown in **Equation 1**. It reflects the seasonal variability between natural log load and natural log streamflow, where fitted coefficients are shown in **Table 3** and model structure and residuals are shown in **Figure 7** and **Figure 8**. An actual time-series of predicted vs. observed log loads from the equation is shown in **Figure 9**. Overall, the model fits the data quite well (r^2=0.95, and 0.93), and normally distributed residuals suggest use of AMLE is valid.

Equation 1. $\ln(\hat{L}) = a_o + a_1 \ln Q + a_2 \sin(2\pi t) + a_3 \cos(2\pi t)$¶

where:

$\hat{L}$ = constituent load [kg/d]
$a_{0,1,2,3}$ = model coefficients
ln*Q* = ln(*Q*) - center of ln(*Q*)
t = (decimal time - center of time)

Table 3. Fitted AMLE coefficients for the N F and M F of the Flathead River for TN.

	Coefficients			
Model	a_0	a_1	a_2	a_3
North Fork	6.442	1.548	0.628	0.188
Middle Fork	6.949	1.297	0.473	-0.132

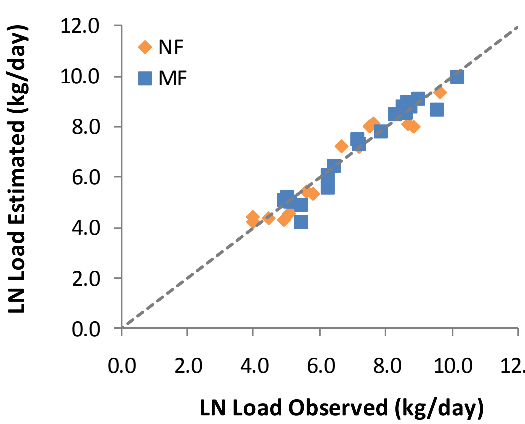


Figure 7. LOADEST AMLE model predictions for the N F and M F of the Flathead River.

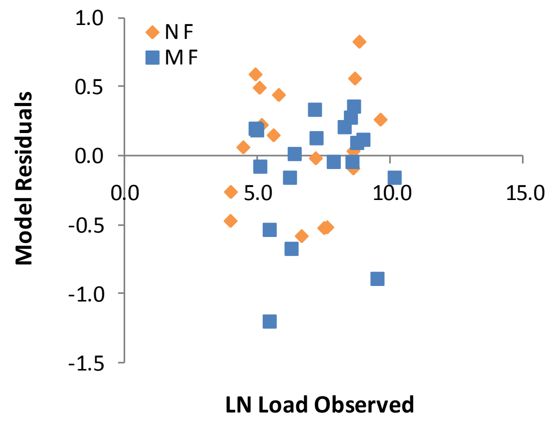


Figure 8. Example of AMLE model normally distributed residuals for N F and M F Flathead.

Daily load estimates for all of the tributaries from the LOADEST model are shown in **Figure 10** (log scale). The largest contribution of both N and P originates from the N F and M F of the Flathead River during runoff, whereas the S F adds the greatest contribution during summer and winter low flows. This contribution is primarily from stored conservation water in Hungry Horse Reservoir. The remaining sites, including those that are wastewater-impacted, contribute only minor percentages to the overall load to Flathead Lake. They were less than 10 percent individually, or 15 percent when combined.

Consequently, nutrient mitigation measures in these areas (Swan River, Stillwater River, Whitefish River or Ashley Creek) will not reduce the overall nutrient load to Flathead Lake by any significant percentage (given the large amount of load that occurs naturally from the N F, M F, and S F of the Flathead River). Annualized load estimates are shown in **Table 4** and **Figure 11**. Loading sources to the lake in decreasing order are the N F, M F, and S F of the Flathead River for TN, and the N F and M F of the Flathead River and Stillwater River for TP.

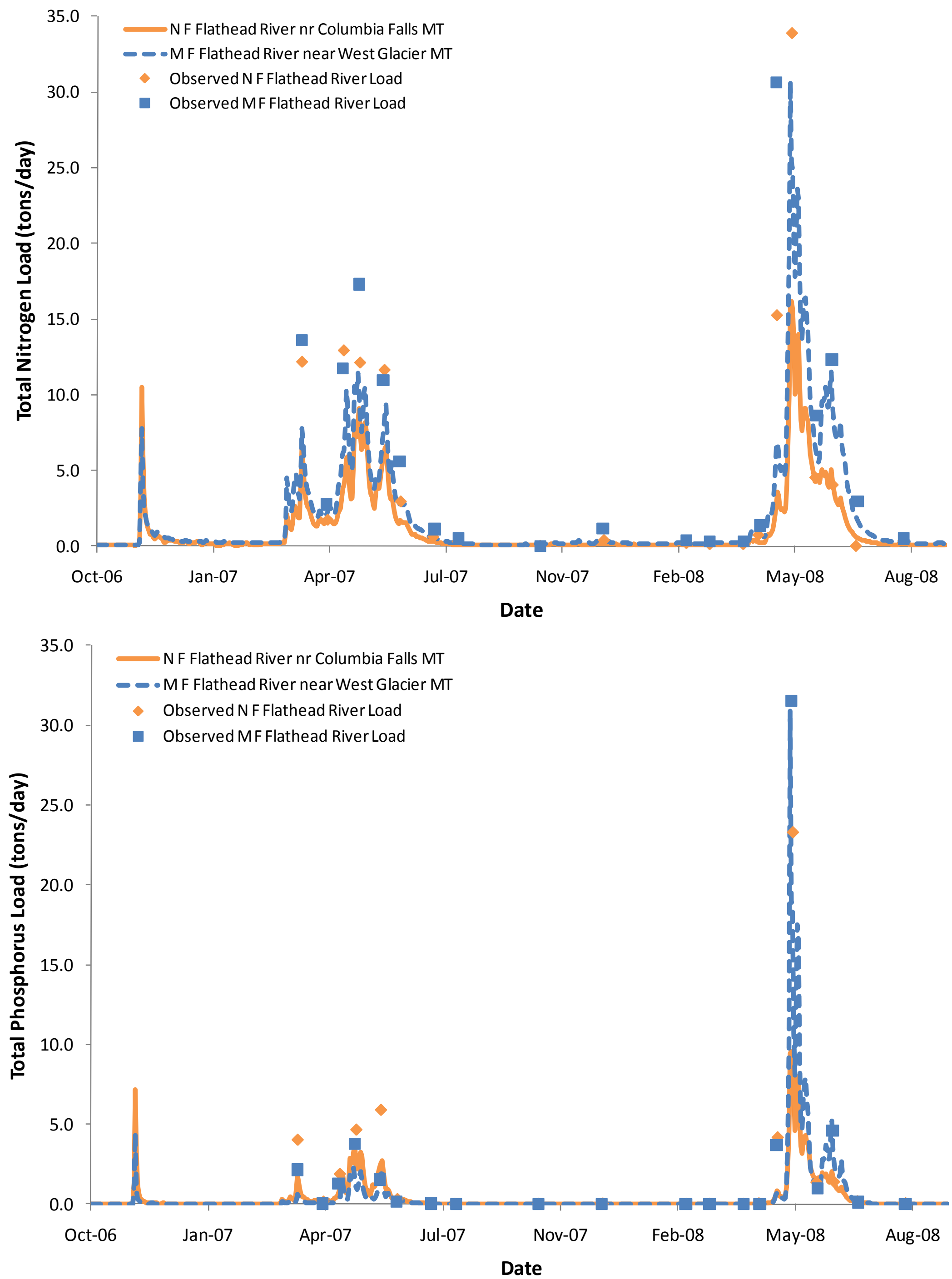
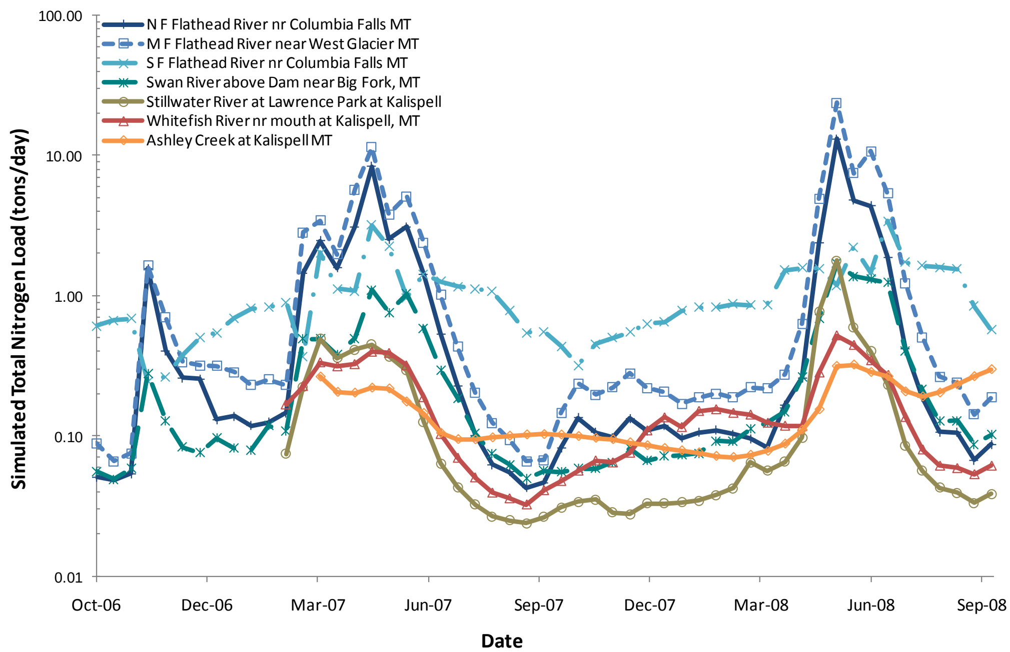


Figure 9. Observed vs. predicted N and P loads for 2007-2009.
Shown for AMLE model of the North and Middle Fork of the Flathead River.



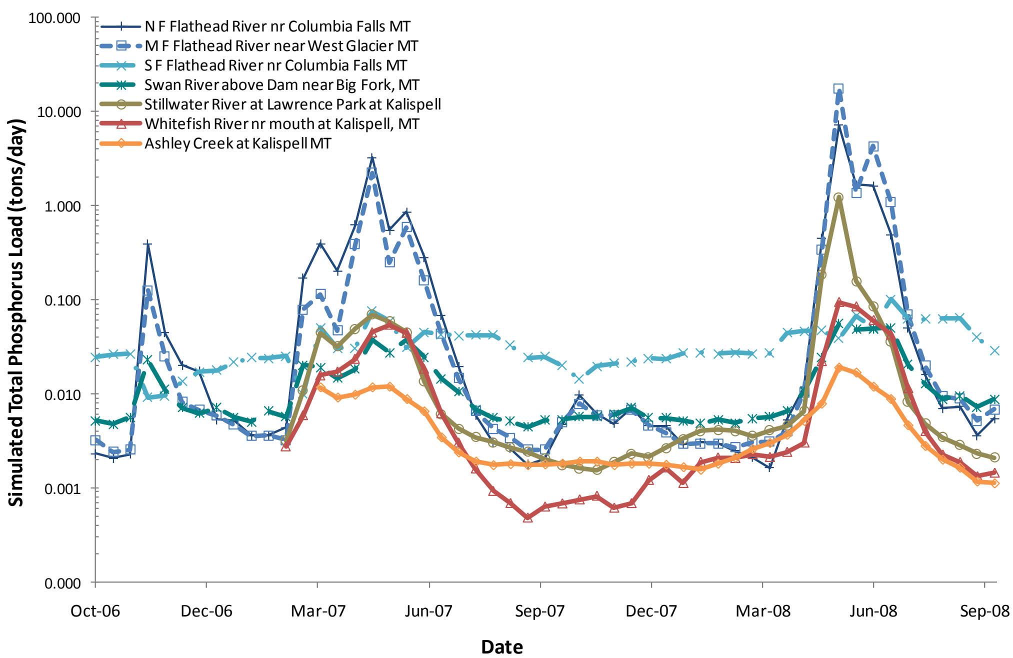


Figure 10. Daily estimated loads for major tributaries that flow to Flathead Lake during 2007-2008. Results shown for the best-fit AMLE model.

Table 4. Estimated loads from major tributaries to Flathead Lake during 2007-2008.

Tributary	Avg. Annual TN Load (tons/yr)	Avg. Annual TP Load (tons/yr)
N F Flathead River	419.8	135.1
M F Flathead River	704.5	171.6
S F Flathead River	390.6	12.8
Swan River	113.2	5.0
Stillwater River	54.8	12.6
Whitefish River	58.4	4.2
Ashley Creek	69.4	1.5

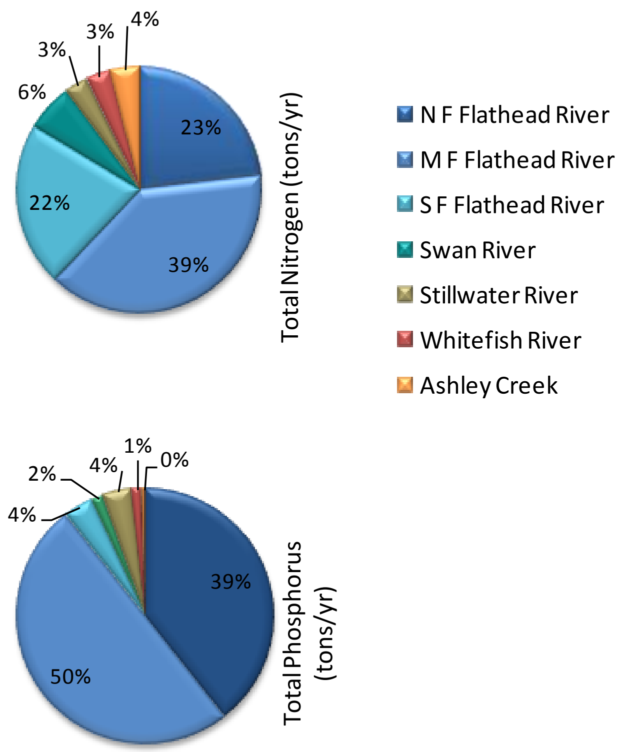


Figure 11. Estimated AMLE tributary load contributions to Flathead Lake in 2007-2008.

A large nutrient load to Flathead Lake therefore originates from relatively unaltered watersheds such as the N F, M F, and S F of the Flathead River, which for the most part, is naturally occurring. The remaining contribution is anthropogenic (man-caused).

ANTHROPOGENIC LOAD CONTRIBUTION

To estimate the anthropogenic TN and TP load contribution to Flathead Lake, loads from the previous section were normalized to a loading ratio (LR), which is the percent load contribution divided by percent flow contribution. This allows identification of areas that have abnormal nutrient contributions relative to their given flow volume. As expected LR's were high in wastewater dominated streams (e.g., Ashley Creek) and lower in areas downstream of lakes or reservoirs (e.g., South Fork of the Flathead River and Swan River) as shown in **Table 5**. A lower than normal LR is indicative of "sink potential" while a higher than normal ratio is suggestive of an external source contribution.

Table 5. Flathead Lake loading ratios for the 2007-2008 monitoring period.

Tributary	TN Load Ratio	TP Load Ratio
N F Flathead River	0.9	1.5
M F Flathead River	1.4	1.9
S F Flathead River	0.7	0.1
Swan River	0.7	0.2
Stillwater River	1.3	1.6
Whitefish River	2.0	0.8
Ashley Creek	38.3	4.4

To expand on this effort, a mass balance was then developed by assuming that nutrient loads at the mountain-valley interface were naturally occurring whereas those entering the lake reflect both natural and anthropogenic sources. This is shown in **Equation 2** for the Flathead River, where the difference in load between the lake and the mountain-valley interface is a rough estimate of the anthropogenic input to the system. A calculation for other waterbodies such as the Whitefish River or Ashley Creek (which are of interest due to their wastewater contributions) could be made with a similar approach, but were not done as part of this project.

Equation 2. $\hat{L}\ (anthropogenic) = FR - \sum(NF, MF, SF, WR, SR, AC)$

where:

FR = Load at Flathead River near Bigfork
NF = Load at North Fork of the Flathead River
MF = Load at Middle Fork of the Flathead River
SF = Load at South Fork of the Flathead River
WR = Load at Whitefish River nr Whitefish
SR = Load at Stillwater River nr Whitefish
AC = Load at Ashley Creek below Smith Lake

The subsequent LOADEST mass balance for the Flathead River suggests a number of things. First, anthropogenic loading is a concern in the valley as both N and P show a notable increase over the valley with only minor changes in streamflow. These changes are tabulated in **Table 6** (by percent) and the Whitefish River and Ashley Creek are also shown. According to the time of year and magnitude of the sources, we can approximate their origin. A time-series analysis illustrating this concept is shown in **Figure 12**. By taking the daily difference between the load summation in **Equation 2**, the rate of human-caused loading in the Flathead River was estimated to be 0.47 tons/day for TN and 0.27 tons/day for TP (during 2007-2008). This is a combination of point and nonpoint source loads as illustrated at the top of the figure[1,2].

The TP difference between the sites is likely related to sedimentation during runoff while TN sources appear to be more continuous. For example, TN decreases during the summer months indicating a net loss of nutrients (from algal uptake) and then shows a persistent signal during the winter which appears to be related to a continuous nutrient source in the watershed. This is likely a combination of municipal wastewater and septic discharges that cannot be assimilated by algae through uptake (i.e., winter months, low or no growth).

Consequently, our analysis provides evidence that anthropogenic nutrient loads do occur in the Flathead Lake watershed and contribute to Flathead Lake. These loading rates vary, and range from approximately 0-3 tons/day for TN to 0-10 tons/day TP (depending on season). Annually this amounts to an anthropogenic input of about 170 tons/year for TN and 98 tons/year TP, or 8.6 and 26.9 percent of the overall load in the Flathead River respectively. Some natural sources are included in our estimate inadvertently. However the contributions are likely small given the relative watershed area and limited amount of flow contribution from these areas. Watershed-loading models will help to refine these estimates in the future.

Table 6. Estimated TN and TP load increases from the mountain to the valley sites.

Tributary	TN Increase (%)	TP Increase (%)
Flathead River*	8.6	26.9
Whitefish River	497	365
Ashley Creek	384	271

*Includes the contribution of the Whitefish River and Ashley Creek.

[1] Daily flow on the Flathead River near Bigfork estimated due to problems with the site rating (i.e., variable backwater from the lake and storm seiches). Flow had a very good correlation with the Columbia Falls gage when summed with the remaining downstream tributaries (i.e., Whitefish River, Stillwater River, and Ashley Creek, r^2=0.99).

[2] Data for the Stillwater River near Whitefish not collected. It was synthesized based on an assumed 25 percent lower N and P concentration during low flows, and 50 percent lower during high flows (approximated from (Stanford, et al., 1997b).

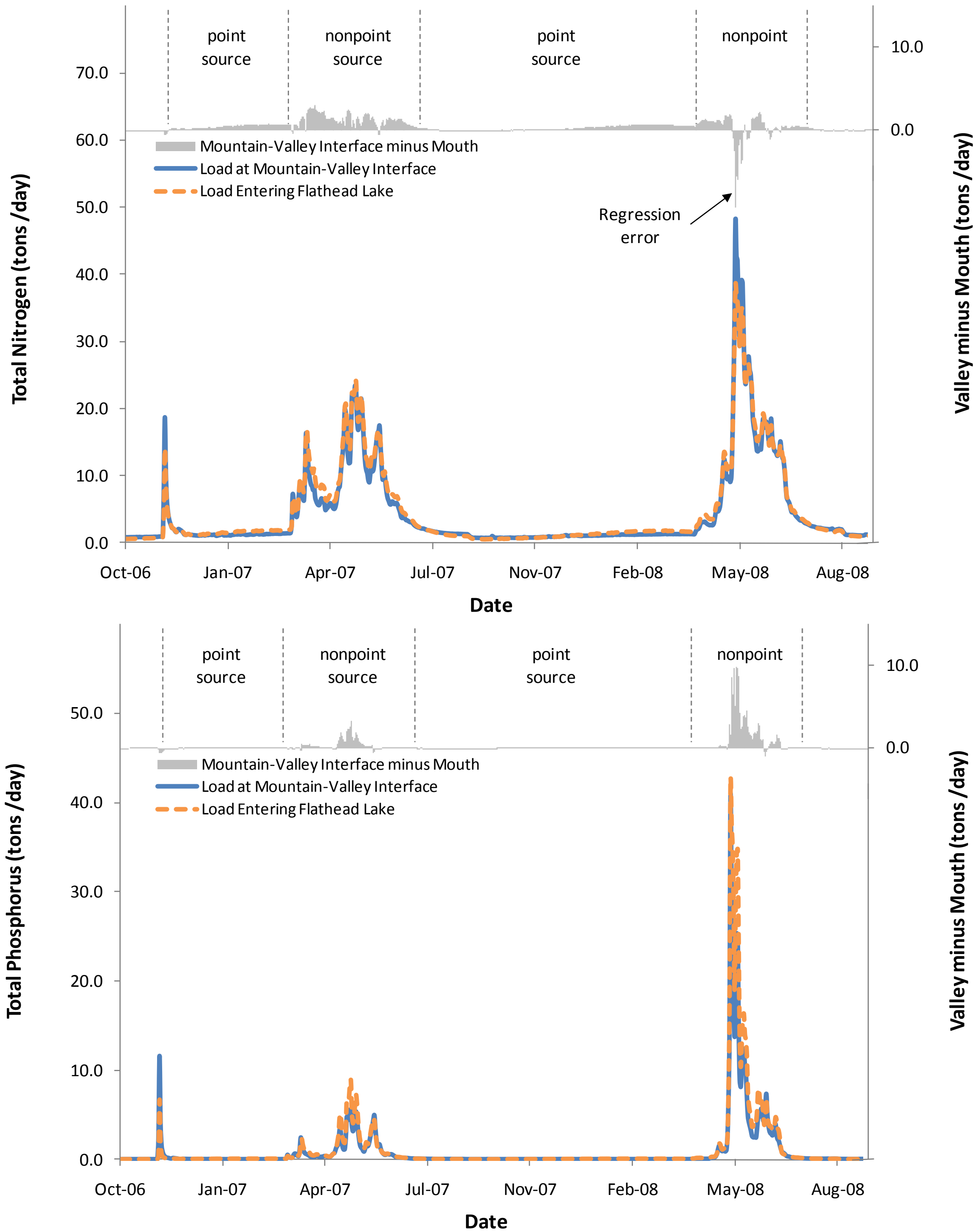


Figure 12. Estimated anthropogenic load contribution of N and P to the Flathead Lake.
Calculation shown for the Flathead River. The difference between the load at the mountain-valley interface and the load entering Flathead Lake is the anthropogenic contribution (shown on top in grey). Note the error in the regression line. This indicates that there is uncertainty present within the analysis. Times when point or nonpoint sources are most prevalent are also identified at the top of the figure according to period coinciding with runoff.

LAKE AND RESERVOIR SUMMARY

Several of the upstream lakes and reservoirs also influence Flathead Lake. The most significant of these are Hungry Horse Reservoir, Swan Lake, and Whitefish Lake, all of which were monitored during 2007-2008 to characterize their effect on water quality. At each location, multiple sites were selected to characterize spatial and vertical water quality gradients. Water temperature profiles were completed at 1-meter increments to define each layer (i.e., epilimnion, metalimnion, and hypolimnion) and water chemistry sampling was completed at the center of each layer. Sites were sampled after spring turnover, during stratification, and prior to fall turnover.

Inflow-outflow relationships, and associated water quality characterizations were made from this data. Summaries were also made with use of data from USGS annual water measurement programs or gaging operations conducted by DEQ. Again, the lake analysis is not intended to be all-inclusive, rather just illustrate some of the available data. Results are described after a brief overview of each waterbody.

OVERVIEW

Hungry Horse Reservoir is the uppermost dammed reservoir in the Columbia River system and the largest reservoir in the Flathead Lake watershed. It is located on the South Fork of the Flathead River approximately 15 miles south of Glacier National Park. The reservoir was completed July 18, 1953 and has approximately 3.46 million acre-feet of storage (U.S. Department of the Interior, Bureau of Reclamation, 2011). The facility is operated by the United States Bureau of Reclamation for flood control, power generation, and recreational use. Roughly 61 percent of all surface water inflow to Hungry Horse Reservoir is accounted for by the South Fork Flathead River (Simons and Rorabaugh, 1971). Both inflow and outflow are gaged in close proximity to the reservoir by the USGS, and a number of other smaller tributaries also flow into it. The major inflows and outflows were monitored during 2007-2008, as well as three sites within the reservoir itself during 2007-2008. Further information on Hungry Horse Reservoir can be found in Ferreira, et al., (1992).

Swan Lake is located directly east of Flathead Lake near Big Fork, MT. It is one of the largest natural impoundments upstream of Flathead Lake and it has two deep basins. One is located in the southern portion near the Swan River inlet and the other at the northwest portion of the lake. Thermal stratification in these areas is strong, while the shallower portions particularly at the northern end do not stratify. Residence time is approximately 83 days and three major tributaries enter the lake. These include the Swan River (which comprises most the inflow), Spring Creek, and Sixmile Creek. The Swan River inflow and outflow, and two lake sites were monitored in 2007-2008. Additional information on Swan Lake can be found in Butler, et al., (1995) and Chapra (1996).

Whitefish Lake is just upstream of Whitefish, MT and also a natural lake. It has three major tributaries that drain into it, Swift Creek being the largest. It enters the lake at its northern end while the two others, Lazy Creek and Hellroaring Creek enter near the northwestern and northeastern end, respectively. The city of Whitefish sits at the southern end of the lake, and private development is scattered along the lake’s shoreline. Unlike any other large lake in Montana, Whitefish Lake is located entirely within the boundary of a municipality. It was annexed by the City of Whitefish in October of 2005. The major inflows and outflows, and two sites within the lake were monitored during 2007-2008. Further information on Whitefish Lake can be found in Craft, et al., (2003).

INFLOW-OUTFLOW COMPARISONS

The relationship between inflow and outflow of each waterbody (in ft^3/s) was evaluated to determine whether loads could be adequately characterized by analysis of inflow and outflow concentration alone (due to the fact that such comparisons are easier than directly analyzing loads). Annual flow data for each system is shown in **Figure 13**. There is very little difference between the major inflow and outflow for natural lakes, whereas the relationship at Hungry Horse Reservoir maintains a similar volume but altered temporal distribution (from dam operation).

In all cases**,** the major inflows comprised greater than 59 percent of the total annual outflow while most were nearer 90 percent (Swan Lake and Whitefish Lake). Consequently, direct comparisons between inflow and outflow concentrations are suitable for water quality and associated pollutant fate and transport through each system.

Table 7. Estimated inflow-outflow relationship for lakes and reservoirs in the Flathead basin.

Tributary	% of outflow by major inflow
Hungry Horse Res.	59
Swan Lake[1]	87
Whitefish Lake[2]	90

[1] Interpolated using data from Butler, et al., (1995) due to DEQ data issues.
[2] Discrete measurements bi-weekly.

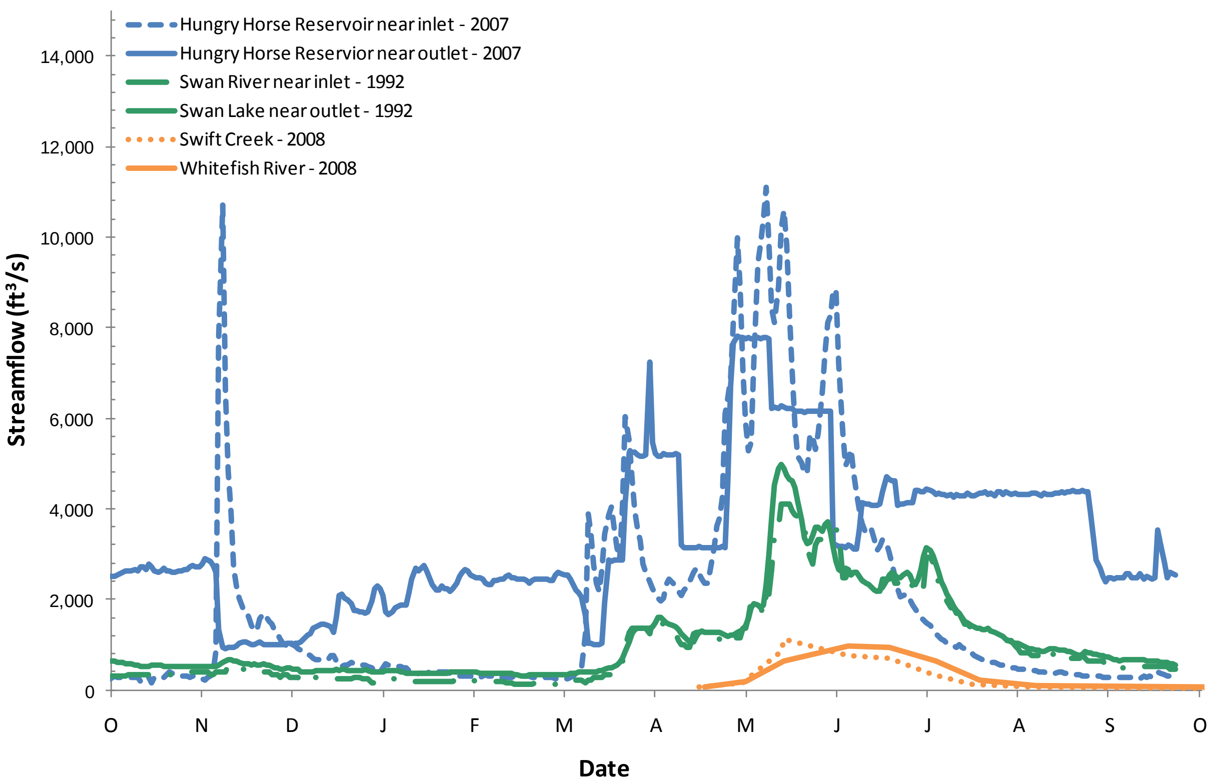


Figure 13. Inflow-outflow relationships for lakes and reservoirs in the Flathead watershed. Hungry Horse Reservoir had the largest effect on hydrology due to storage whereas Swan and Whitefish Lake are primarily flow-through systems (i.e., where the inflow very closely approximates the outflow).

WATER QUALITY

Water quality summaries for the lakes and reservoirs are shown in **Figure 14**. Because data was collected at different depths and multiple locations, it is more difficult to interpret than for the streams and rivers. A lumped approach was used to illustrate some of the field water quality parameters. Again, there were very few differences between each of the lakes and reservoirs. Swan Lake was the most different with the highest temperatures, most pH variability, and lowest dissolved oxygen (DO) concentrations. Whitefish Lake had the best clarity (median secchi depth of nearly 30 feet), although all systems had good water column transparency.

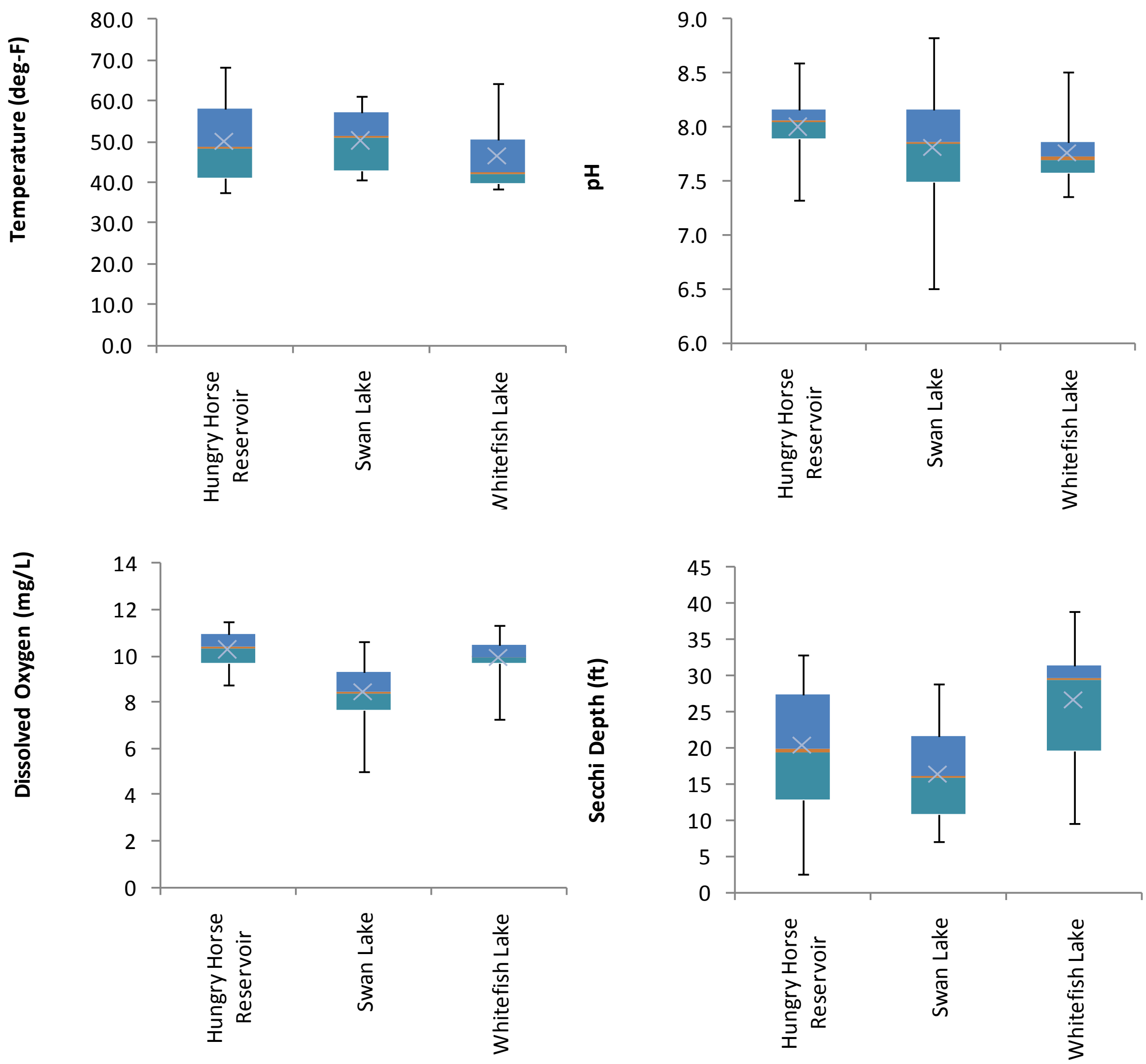


Figure 14. Water quality summaries for lakes and reservoirs in the Flathead during 2007-2008.

Water quality mechanics for the systems were also similar (**Figure 15**). The onset of stratification began in early May, was completed by mid July or early August, and then went quickly isothermal starting in September. Hungry Horse was somewhat delayed due to its size. Productivity in each system was also fairly consistent. Swan Lake had the highest productivity (as measured by phytoplankton chlorophyll *a*) followed Whitefish Lake and then Hungry Horse Reservoir. In 2007 productivity peaked in early May, whereas in 2008, the systems were more productive in September. The remaining variables are detailed on a lake-by-lake basis in the following pages.

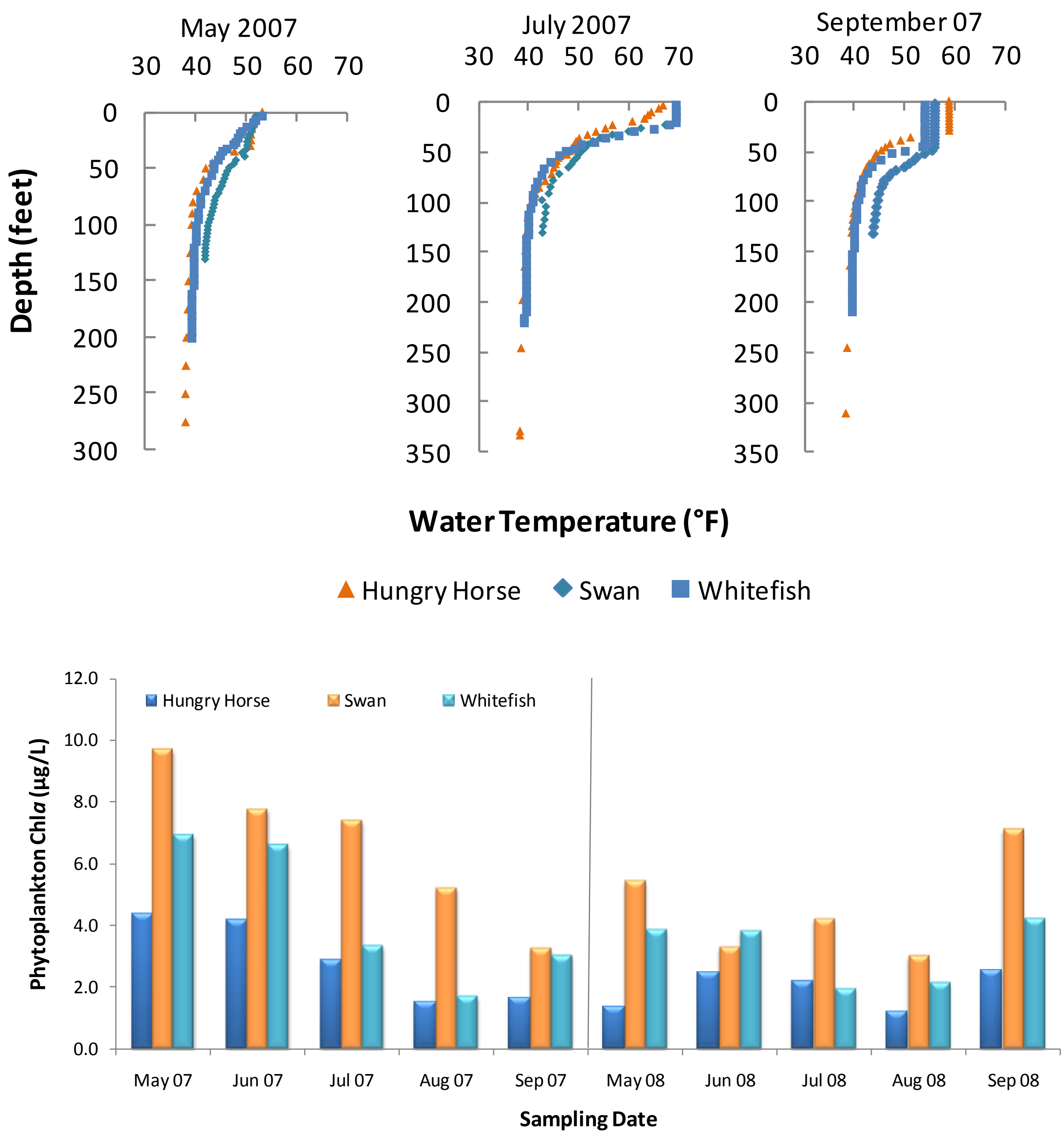
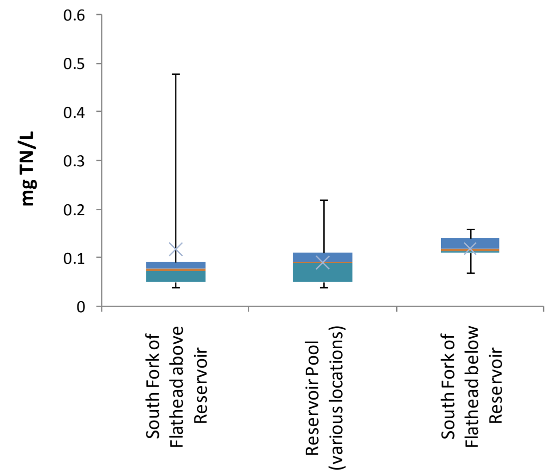
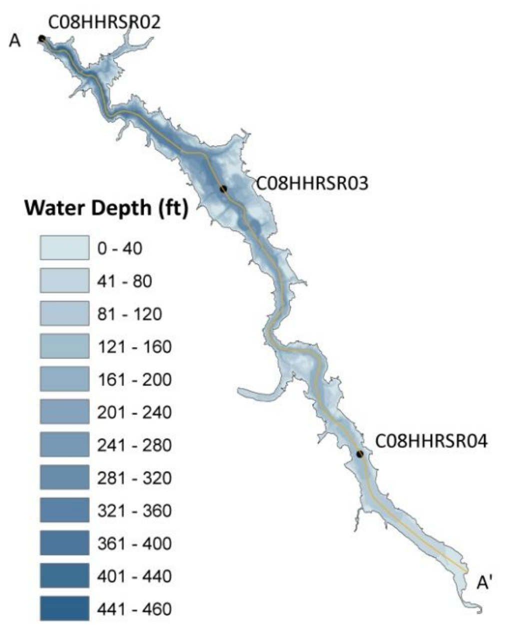


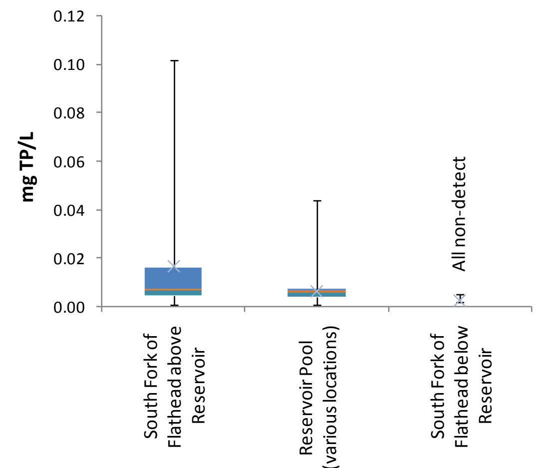
Figure 15. Comparative plot of water quality mechanics for the three systems evaluated.
(Top) Water temperature profiles for selected months. (Bottom) Productivity plots by month.

HUNGRY HORSE RESERVOIR

A basic summary regarding Hungry Horse Reservoir is presented here. Overall, the reseroir is a net source of N (aerial deposition) and sink for P (particulate settling) (**Figure 16**). Much of the depth is characteristic of hypolimnetic conditions year round giving it somewhat static water quality. The riverine site (CO8HHRSRO4) showed the most variability due to influence of the S F Flathead River inflow.







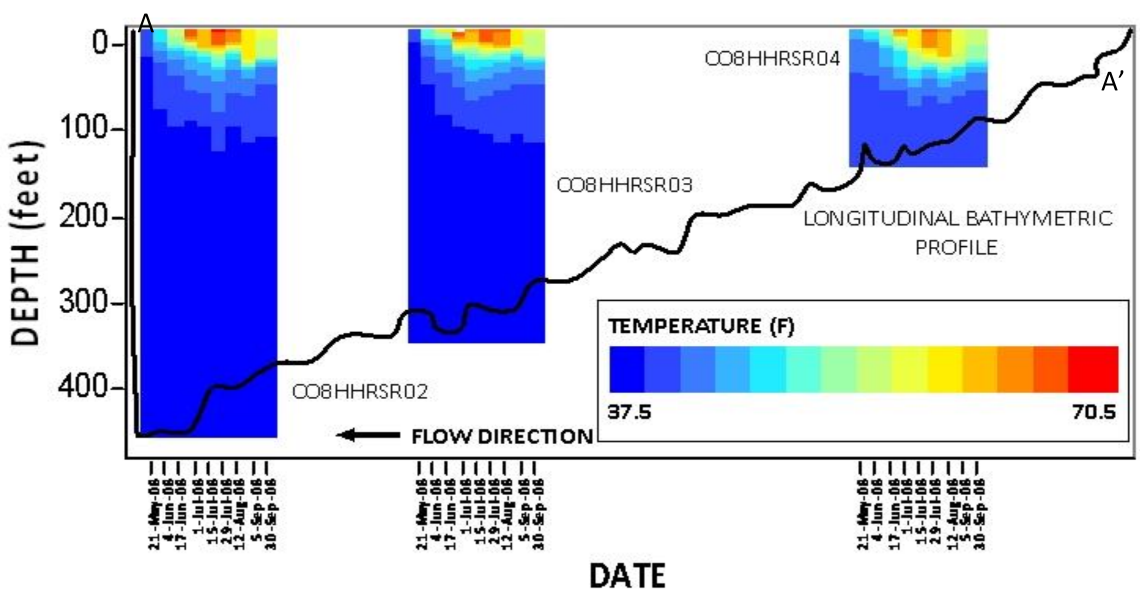
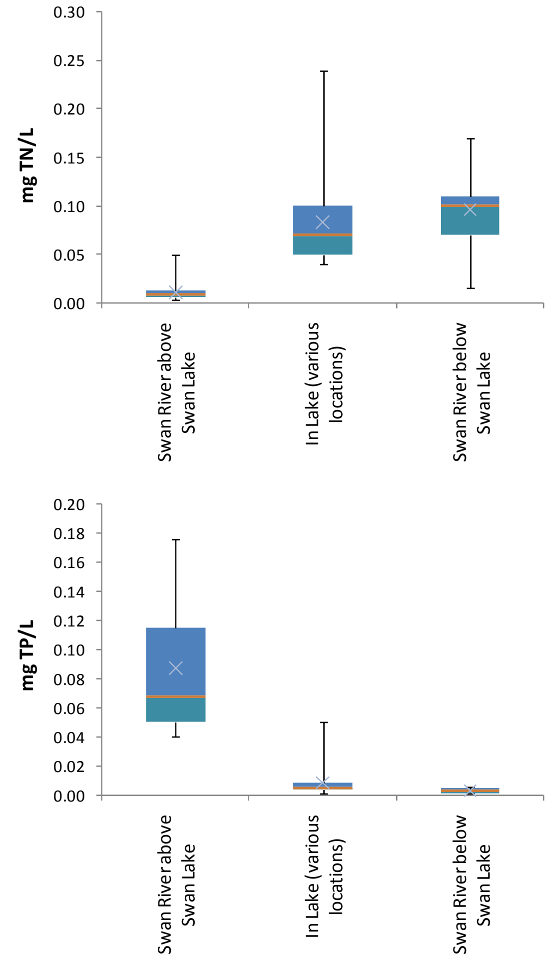
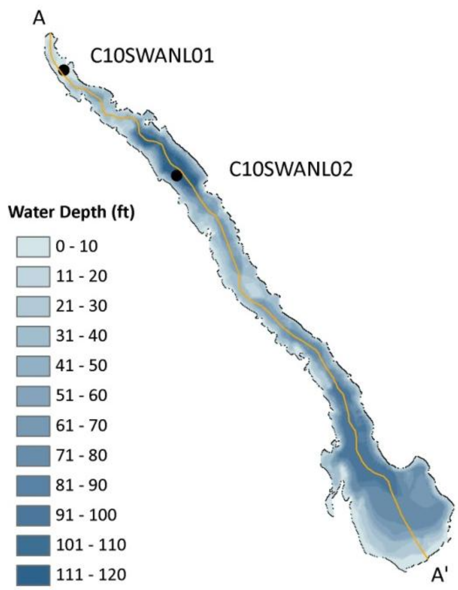


Figure 15. General water quality summary for Hungry Horse Reservoir.

SWAN LAKE

Swan Lake was similar to Hungry Horse Reservoir. Total N concentration increased longitudinally but perhaps more than natural (**Figure 17**). The urban influence from the Town of Swan Lake is one possible explanation, as is increased aerial deposition. Again, P declined significantly due to settling. Overall, stratification was strong in the north basin of the lake (C10SWAN01) whereas the outlet (C10SWAN02) was fairly well mixed year-round.





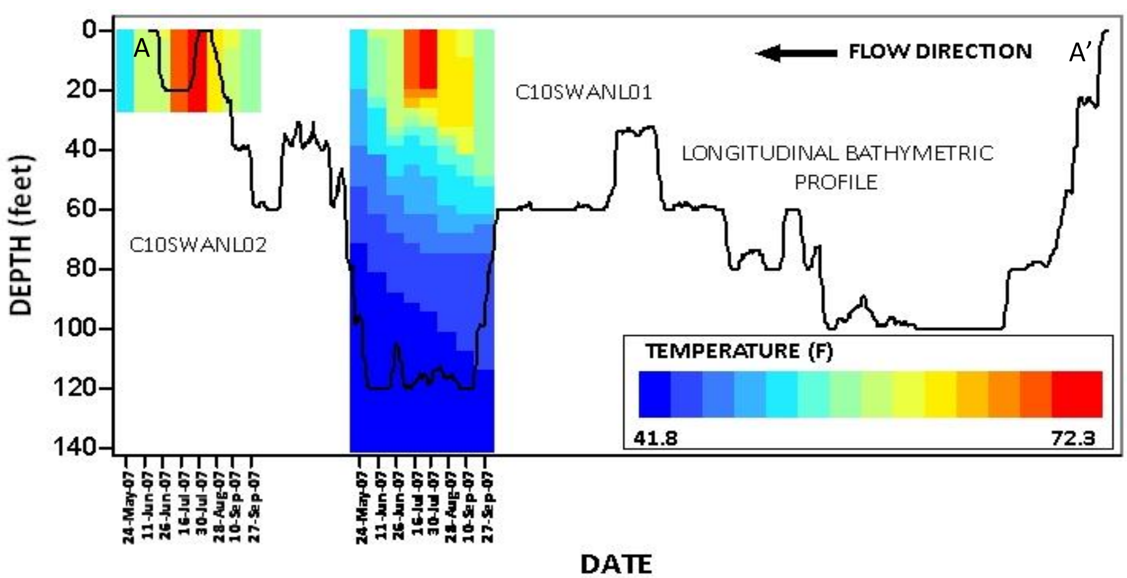
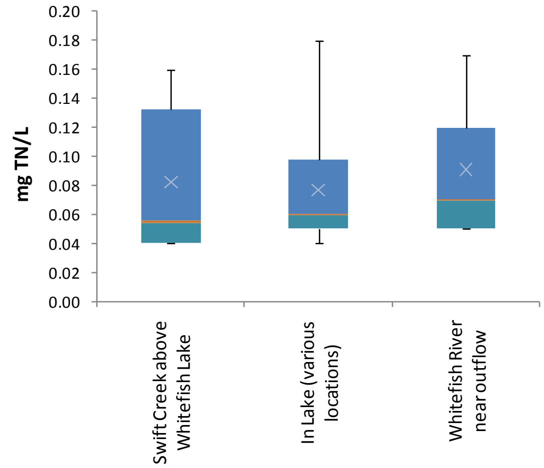
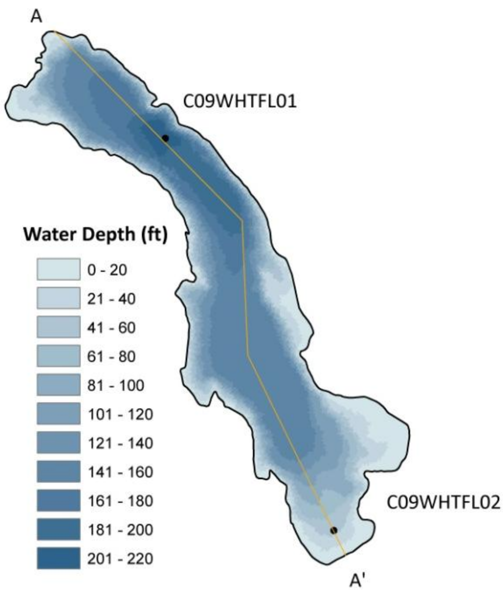


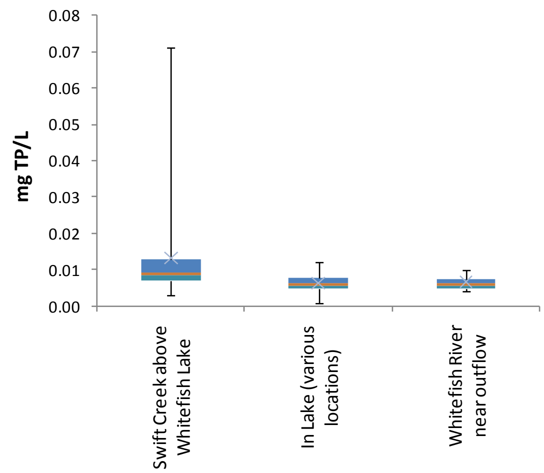
Figure 16. General water quality summary for Swan Lake.

Whitefish Lake

Whitefish Lake was the most consistent and showed less of an increase in N over its length (**Figure-17**). Perhaps this is related to less aerial deposition or just a smaller surface area. For P it acted as a sink, albeit much less then the others. There were no apparent increases in nutrients despite a signficant amount of human activity near the lake. It also showed similar temperature dynamics to Swan Lake as its deep site was stongly stratified over the summer months wheras its outlet was only slightly stratified.







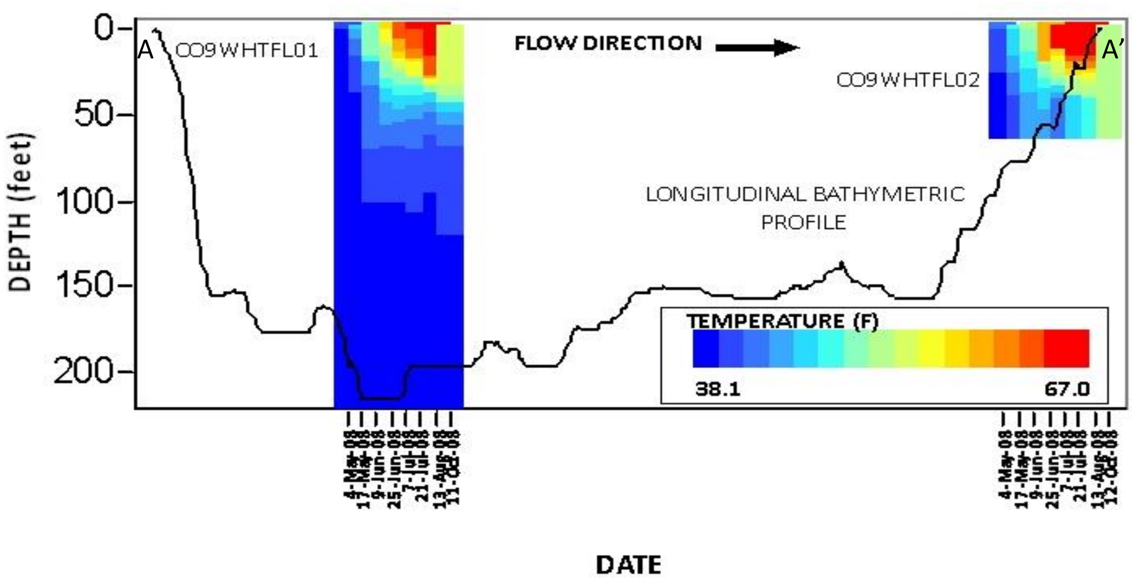


Figure-17. General water quality summary for Whitefish Lake.

SUMMARY

Water quality summaries of major tributaries and lakes or reservoirs upstream of Flathead Lake were detailed for the period of 2007-2008. Samples were taken at numerous locations to evaluate water chemistry and compute load estimates from different locations in the watershed. From application of LOADEST regressions, a majority of the nutrient load in the watershed originates from the forested mountains areas of the North Fork, Middle Fork, and South Fork of the Flathead River. The load correlates well with the water yield and is believed to occur naturally.

Analysis of the data also indicates that anthropogenic loads were present in the Flathead valley. These were estimated to range from 0-3 tons/day TN and 0-10 tons/day TP (depending on season) and amounted to an annual anthropogenic load of 170 tons/year TN and 98 tons/year TP (or 8.6 and 26.9 percent of the load respectively). Sources are believed to be both point and nonpoint source in origin.

Lakes and reservoirs upstream of Flathead Lake were also evaluated for their influence on downstream water quality. Each acted as a source of N (due to aerial deposition) and a P sink (from particulate settling). Some human activity is potentially masked in this estimate. Hungry Horse Reservoir had the largest moderating effect in the watershed due to its water quality, annual flow volume, and flow contribution during late summer and winter flow conditions. Both Swan and Whitefish Lake had very good water quality as well and all act as a buffer from contributing watershed sediment and nutrient loads. Finally, we must qualify our findings with an appropriate *caveat emptor*. Much of the work relied on estimations from simple regression models. Users should therefore make certain that their intended use aligns with the simplicity of the analysis. We recommend watershed modeling be completed in the future to refine these estimates.

This report has been prepared by DEQ in support of the Flathead Lake Phase II TMDL. To gain access to the data in the report, go to EPA's STORET warehouse at the following link: http://www.epa.gov/storet/dw_home.html and choose: (1) Org = MDEQ_WQ_WQX and (2) Project = FLATRES.

The USGS data can be obtained directly from the National Water Information System (NWIS) at: http://waterdata.usgs.gov/nwis.

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