Sediment Beneficial Use Support Assessment for Flathead Lake

Addresses Assessment Unit MT76O003_010

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ABSTRACT

An oligotrophic lake located 882 meters above sea level, Flathead Lake is 48.3 km long and 41.5 km wide with 259.7 km of shoreline. Examination of external loadings to the lake via an LSPC model determined that 92 to 93% of the total TSS load in the Flathead Lake watershed is from natural causes, while 7 to 8% may possibly be from human causes. Internal loading estimates included lake shoreline erosion calculated using an average slope of 0.006 m/m and the highest measured erosion rate of 2.5 m/yr for the entire Flathead Lake shoreline (259.7 km). Under these assumptions, annual shoreline erosion is equal to 1.8% of the existing LSPC TSS load to Flathead Lake. As there have been only minor changes in shoreline extent along the north shore varial zone since 1977, 1.8% is likely a gross overestimate and shoreline erosion is a much smaller component, or insignificant, when compared to the overall loading to the lake. Empirical studies also suggest erosion has declined following the construction of Kerr Dam and management operations have improved. Analysis of Flathead Lake TSS and Secchi depth data were inconclusive, but do show water transparency as stable or improving and very little difference in sediment concentrations at various locations in the lake (shallow vs. deep) and between similar, unimpaired lake systems in the Flathead Lake watershed. Water quality data in the lake do not indicate that human-caused sedimentation has degraded water quality or affected beneficial uses, including impacts to fish. The assessment finds that beneficial uses in Flathead Lake are not currently threatened or impaired by sediment.

REVISION HISTORY

Revision No.	Date	Modified By	Sections Modified	Description of Changes
1	11/7/14	C. Schmidt, K. Flynn	All	Final Version Submitted to EPA
1.1	2/17/15	C. Staten	Front Matter, 1.0	Added cover page, abstract, and revision history table. Corrected Flathead Lake Assessment Unit ID (from MT76P003_010 to MT76O003_010)

1.0 INTRODUCTION

In the summer of 2014, the Water Quality Planning Bureau of the Planning, Prevention and Assistance Division of Montana DEQ re-assessed the existing Flathead Lake sediment impairment listing (AU ID MT76O003_010). Aquatic life was first listed because of sediment in 1996, and the lake was still identified as impaired for sedimentation/siltation in 2014 (Montana Department of Environmental Quality, Planning, Prevention and Assistance Division, Water Quality Planning Bureau, 2014). The last formal assessment by DEQ was completed in 2000. Along with sediment, the lake is also listed as impaired by polychlorinated biphenyls (PCBs), mercury, Total Nitrogen (TN), and Total Phosphorus (TP). To address some of these listings, nutrient Total Maximum Daily Loads (TMDLs) for both TN and TP were completed and approved for Flathead Lake in 2001(Montana Department of Environmental Quality, 2001); the remaining considerations (e.g., PCBs and mercury) have not yet been addressed. Currently, there are no listings for habitat alteration on Flathead Lake (non-pollutant listings).

Accordingly, we present a weight-of-evidence approach to re-examine whether sedimentation or siltation currently impairs Flathead Lake. Components of this evaluation include the following: (1) an introduction to the Flathead Lake watershed (**Section 2.0**), (2) an overview of how sediment can affect beneficial uses (**Section 3.0**), (3) a description of narrative sediment water quality standards in Montana including their applicability to Flathead Lake (**Section 4.0**), (4) technical elements of the sediment re-assessment including external and internal suspended sediment loadings to the lake (e.g., from tributary inflows and shoreline erosion), in-lake response observations of both Secchi depth and total suspended solids , and comparison of regional lake TSS water quality (**Section 5.0**), and finally (5) our closing statements about the condition of the lake (**Section 6.0**). All of these activities support a conclusion of ***non-impairment*** for the Flathead Lake sediment/siltation re-assessment.

2.0 FLATHEAD LAKE WATERSHED

Flathead Lake is the largest natural freshwater lake in the contiguous United States west of the Mississippi River and is located at an elevation of 882 meters above sea level. It is 48.3 km long and 41.5 km wide, and has an approximate surface area of 510 square kilometers[1] with 259.7 km of shoreline. At its deepest point, the lake is approximately 113 meters deep. As an oligotrophic lake, Flathead Lake is classified as an A-1 waterbody meaning that it is suitable for drinking, culinary, and food processing purposes after conventional treatment for impurities. Under this classification, water quality must be suitable for bathing, swimming and recreation, growth and propagation of salmonid fishes and associated aquatic life; waterfowl and furbearers; and agricultural and industrial water supply. In addition, several public water supply diversions exist around the lake, and many local residents draw domestic supplies directly from the lake or from wells directly under the influence of the waterbody.

The Flathead Lake watershed comprises an area of 18,328.9 km^2 from headwaters of the Flathead River to the outlet of Flathead Lake at Kerr Dam (**Figure 1**). Of this area, 90.3% lies within the United States, 9.7% in Canada (North Fork Flathead River headwaters), and 4.3% within the boundaries of the Confederated Salish-Kootenai Tribe (CSKT) reservation. The Flathead Lake watershed includes two Level

[1] On the 2014 Integrated Report, the size of Flathead Lake (AU ID MT76O003_010) was reduced to 231.9 km^2 to correctly identify the waters under State of Montana jurisdiction. The remaining area of the waterbody is located within the boundaries of the CSKT Reservation.

III ecoregions: Canadian Rockies and Northern Rockies and the watershed is primarily forested (71%), with lesser percentages of rangeland (16%), pasture/hay (2%), and cultivated crops (2%).

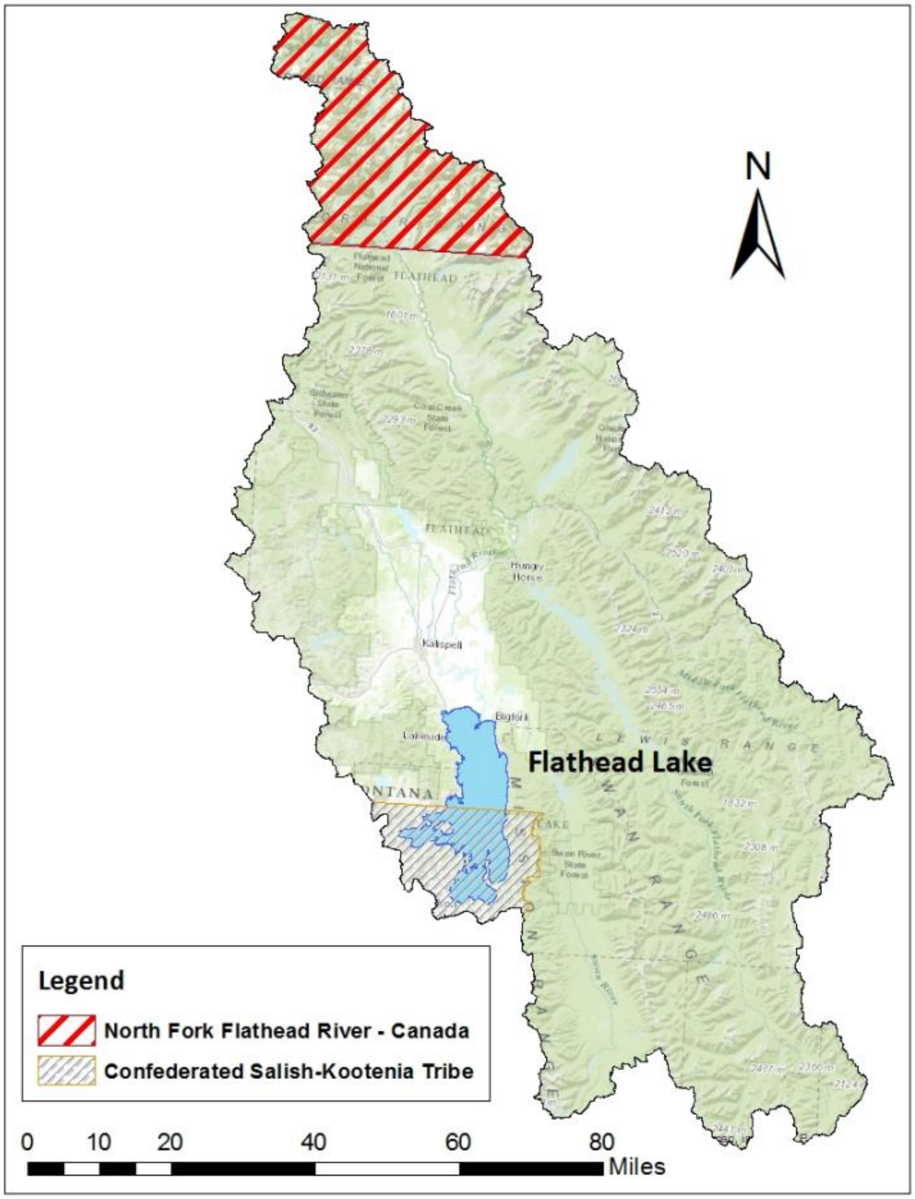

Figure 1. Flathead Lake watershed (Kerr Dam terminus)

2.1 Land Ownership

A significant portion of the total area of the Flathead basin (72%) is under federal or state administration, largely coinciding with the headwaters of major watersheds such as the North Fork, South Fork, and Middle Fork of the Flathead River. Of these lands, 53.5% are managed by the United States Forest Service (USFS), 14% by the National Park Service (NPS; e.g., Glacier National Park), and 4.4% by the Montana Department of Natural Resources and Conservation (DNRC; Stillwater and Swan River State Forests).

Approximately 23.7% of USFS administered lands in the watershed (4347.2 km^2) are designated wilderness areas, most of which falls in the South Fork Flathead River watershed (64.6% of this watershed is designated wilderness). Also including wilderness areas are large portions of the Swan River and Middle Fork Flathead River watersheds. The contribution of the watershed located in British Columbia, Canada is administered almost entirely as provincial forest, though a portion is in the Waterton Lakes National Park north of the international boundary and Glacier National Park.

2.2 Dam Operations

Two large hydropower facilities exist in the watershed: (1) Hungry Horse Dam on South Fork Flathead River, and (2) Kerr Dam immediately downstream of Flathead Lake. For the purpose of re-assessment, the effect of Hungry Horse Dam on Flathead Lake is considered natural (MCA 75-5-306)[2]. On the other hand, the effects of dam operations on shoreline erosion in Flathead Lake are discussed later in the document.

3.0 Effects of Sediment on Beneficial Uses

Erosion includes the weathering and erosion of surficial deposits and the transport of sediment to, and via, streams and lakes/reservoirs. Yet, excessive erosion caused by human activity or the absence of natural sediment barriers (e.g., riparian vegetation, woody debris, beaver dams, and overhanging vegetation) can cause elevated levels of suspended sediment in streams and potential in-filling of lakes or reservoirs. In addition, excess suspended sediment in lakes and reservoirs can impact beneficial uses including recreation, aquatic life, and drinking water. Each of these impacts are briefly described below.

3.1 Effects of Sediment on Aquatic Life

The effects of sediment on aquatic life are primarily related to spawning and rearing of fish, though aquatic insect populations can also be affected due to sediment smothering. When fine sediments accumulate on stream bottoms, they reduce the flow of water through gravels harboring incubating eggs. This hinders the emergence of newly hatched fish, depletes oxygen supplies to embryos, and eventually causes metabolic wastes to accumulate around embryos, all resulting in higher mortality rates.

Excess sediment can also directly affect aquatic organisms by clogging gills and causing abrasive damage. Both processes can limit fish populations by reducing food supplies, the availability of suitable spawning sites, and/or smothering eggs or hatchlings. Deposited sediments can also obscure sources of food, habitat, hiding places, and nesting sites for invertebrate organisms. High levels of suspended sediment also reduce light penetration through water, which can limit the growth of aquatic plants and cause a decline in primary productivity.

[2] It should be added that a great deal of sediment from the South Fork of the Flathead River is trapped within Hungry Horse Reservoir, greatly reducing the sediment load to Flathead Lake (by perhaps up to 20%). While this behavior is important to note for understanding sediment dynamics in the watershed, it cannot be used in the re-assessment per 75-5-306.

3.2 Effects of Sediment on People

Effects of suspended sediment on people are primarily drinking water or recreationally-related. Excess sediment can influence both taste and odor, and cause increased water treatment costs to provide safe drinking water. High concentrations of suspended sediment in lakes and reservoirs can affect humans by creating murky or discolored water, decreasing recreational use and aesthetic amenity.

4.0 Sediment Water Quality Standards

To assess sediment impairment, conditions in the watershed must be compared to water quality standards. Narrative sediment water standards currently exist for Flathead Lake. Specifically the following applies from 17.30.628(2)(f), MCA:

> *No increases are allowed above naturally occurring concentrations of sediment or suspended sediment (except as permitted in 75-5-318 , MCA) , and settleable solids, oils, or floating solids, which will or are likely to create a nuisance or render the waters harmful, detrimental, or injurious to public health, recreation, safety, welfare, livestock, wild animals, birds, fish, or other wildlife.*

The above is interpreted to mean that sedimentation increases that are harmful, detrimental or injurious to beneficial uses are prohibited. Typically, such limits are quantified as an allowable increase above “naturally occurring”, which is sometimes difficult to apply because of lack of specificity and varied interpretations. To determine whether or not narrative standards are being met, DEQ often uses “reference conditions”.

A reference condition defines the condition a waterbody would attain if all reasonable land, soil, and water conservation practices were put in place. Simply put, all reasonable land, soil, and water conservation practices include, but are not limited to, implementation of best management practices (BMPs). In this regard, the reference condition reflects a waterbody’s greatest potential for water quality given historic and current land-use activities.

The preferred approach to establishing the reference condition is to use reference site data from a minimally impacted site. In the absence of such data, modeling, professional judgment, and literature values may also be used. We draw comparisons with the reference condition later in the document, as part of the re-assessment of Flathead Lake.

5.0 Flathead Lake Sediment Assessment

DEQ has not developed an updated assessment methodology that evaluates whether beneficial uses are being attained for lakes or reservoirs. For the purposes of this assessment, DEQ applies a weight of evidence approach to evaluate the impact of fine sediment to Flathead Lake. This approach includes the following components:

- A review of the 303(d) listing history, including the basis of the initial listing
- Results of sediment load modeling and source assessments for the contributing area
- Dam operation and shoreline erosion calculations

- Flathead Lake TSS and Secchi depth trend analysis
- Regional lakes TSS data comparison

The assessment seeks to answer the question of whether fine sediment loading to Flathead Lake is currently impairing beneficial uses.

5.1 Flathead Lake Watershed Sediment 303(d) Listing History

Flathead Lake was first listed as impaired by sediment in 1996 due to hydrologic modification. Neither the 1996 report nor the DEQ assessment file notes specifically what the term hydrologic modification addresses, but is believed to be the term given the observed shoreline effects from dam-maintained pool elevation based on the identified causes from the 1988 303(d) list. Subsequently, the 2014 303(d) list identifies sedimentation/siltation as impairing the beneficial use of aquatic life. There are no listings for non-pollutants (e.g. habitat alterations) for the lake.

In reviewing the listing history, the original 1988 threatened listing on Flathead Lake was linked to shoreline erosion from Kerr Dam operations and Hungry Horse Reservoir releases (Montana Department of Health and Environmental Sciences, 1988). The Lake was subsequently listed on the 1992 303(d) list, with breaks in listing in 1990 and 1994. (Note: The breaks in listing are the reason why the 1996 impairment listing is considered the cycle first listed.)

5.2 Analysis of Loading to Flathead Lake

Sediment loading analysis to Flathead Lake is a primary component of the reassessment. Specifically, a mass balance on the spatial distribution of loadings of sediment can be used to differentiate whether sources are naturally occurring/reference condition (e.g., originating from wilderness areas or Glacier National Park) or human-caused (originating from the valley areas). In addition, the total mass of sediment delivered from various sources (e.g., tributaries, shoreline erosion, etc.) may be useful in scaling analysis to determine the magnitude of such sources.

Sediment loading to Flathead Lake is believed to occur from two principal sources: external loadings (allochthonous) and internal sources (autochthonous). External loadings are received directly from tributaries (e.g., Flathead River, Swan River, etc.) while internal loading sources are generated primarily from shoreline erosion or direct streambank erosion from the lower river (due to lake elevation fluctuations). We examine each of these components as part of this assessment.

5.2.1. Tributary Loading Analysis

Water quality modeling efforts were initiated in the Flathead Lake watershed as part of the TMDL to compute external sediment loadings to the lake. A Loading Simulation Program in C++ (LSPC) watershed model was constructed to characterize the magnitude of source loadings from various land uses throughout the watershed. The model was calibrated to observed total suspended sediment (TSS) data and then a much longer period being simulated (Tetra Tech, 2014). Thus, it reflects the best available long-term record of sediment loading to the lake. Details on the LSPC model are provided elsewhere (Tetra Tech, 2014). Results applicable to the sediment re-assessment are described below.

5.2.1.1 Flathead Lake Watershed Model

Sediment loads from the following sources were considered as part of the LSPC modeling effort: forest, rangeland, grassland, agriculture, unpaved roads, golf courses, urban areas, point sources, streambed and bank erosion, and erosion from bluffs adjacent to the river. Accordingly, **Figure 2** presents annualized source loadings of sediment load to Flathead Lake from for the simulated period of record in LSPC (2002-2012). As noted, primary sources of sediment are bank erosion (61%), followed by natural background sources (32%), and then a number of other minor sources (7%).

In this regard, most of the sediment loading can be linked to either natural sources or bank erosion, though at this point it is unclear whether bank erosion is attributable to natural or anthropogenic causes (i.e., LSPC uses a simple bank erosion algorithm that cannot differentiate the two). We expound on this topic in a subsequent paragraph. However, with respect to the minor sources, we assume bluff erosion, forest fire, and South Fork of the Flathead are natural (3%) [3], which means <5% of the load can be related to anthropogenic activity (i.e., the yellow/orange/red area representing agriculture, harvest, unpaved roads, etc.). It is important to point out that not all loadings from these source categories are in fact human-caused; some loading would still occur from these land uses even if in a naturally occurring condition.

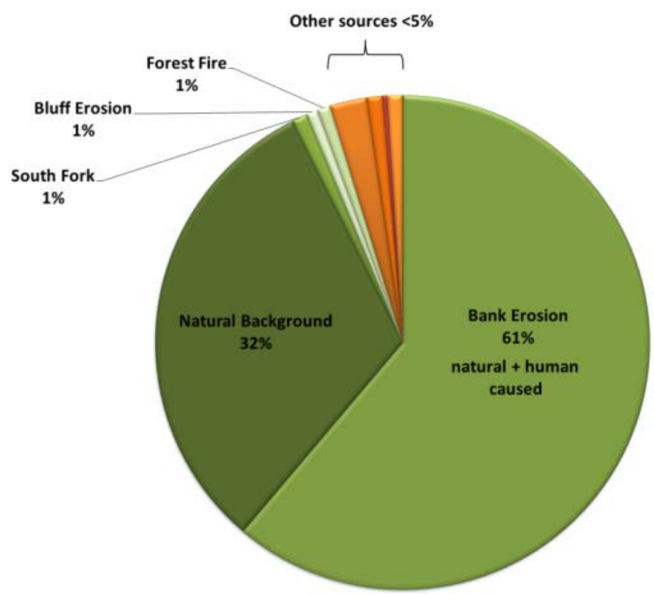

Figure 2. TSS load percentages for the Flathead Lake watershed

To better constrain uncertainty about bank erosion, we further examine the spatial sources of loading. Total sediment loads (both landscape and streambank) from the LSPC model are differentiated by 4th code HUC in **Table 1**. Much of the total loading in **Figure 2** comes from the North Fork and Middle Fork of the Flathead River (77%), with lesser percentages from the remaining HUCs, and it can be seen that the overall percentages of both upland and bank erosion loading are generally consistent across each of the HUCs examined, with the exception of the South Fork of the Flathead River.

[3] This is an appropriate assumption based on watershed management and stakeholder perception in the basin.

Table 1. Flathead Lake watershed annual TSS loading by respective 4th code Hydrologic Unit Code

4th code HUC	Area (sq. km.)	TSS load (tons/yr)	TSS load % of total	Upland Load (%)	Bank load (%)
Flathead Lake	3,084.46	30,869	8%	53%	47%
Middle Fork Flathead	2,939.43	151,486	40%	36%	64%
North Fork Flathead	4,058.05	139,126	37%	42%	58%
South Fork Flathead	4,340.52	3,822	1%	100%	0%
Stillwater	2,018.38	22,232	6%	30%	70%
Swan	1,888.1	29,549	8%	29%	71%
Flathead Lake Watershed	18,328.94	377,083	100%	39%	61%

While values in **Table 1** provide a preliminary inclination about loading mechanisms (i.e., where a large portion of the total load originates from), the bank component must still be decomposed into a natural and anthropogenic contribution. A summary of the bank erosion loads from each 4th code HUC are provided in **Table 2** along with the associated decomposition calculations. To partition these loads into natural and human caused effects, we used the following assumptions made during prior TMDLs:

- **Flathead Lake HUC:** Human-caused bank erosion in Ashley Creek was estimated to be 51% of the total load (Ashley Creek TMDL; unpublished)

- **North Fork of the Flathead River (and similar HUCs):** Human-caused bank erosion constituted <1% of the total estimated bank erosion load based on several streams evaluated for sediment impairment (U.S. Environmental Protection Agency et al., 2004). We extended this value to the Middle Fork also.

- **Stillwater River HUC:** Human-caused sources of bank erosion in the lower watershed (e.g., Haskill Creek, Logan Creek, Sheppard Creek) ranged from <1% to 7%. (unplublished).

- **Swan River HUC:** Less than 4% of the eroding bank length was due to anthropogenic sources according to a basin wide bank erosion inventory; see Appendix G of (Land & Water Consulting, Inc. et al., 2004)

Accordingly, the estimates of the percent contribution of human-caused bank erosion can be made by combining the assumptions described in prior bullets, along with loadings in **Table 1**. Subsequently, 4% to 5% of the bank erosion load is due to human causes. The remaining percentage is natural. In this regard, ***92-93%[4] of the total TSS load in the Flathead Lake watershed is from natural causes, while 7-8% may possibly be from human causes***. As mentioned previously, the controllable load is likely smaller given that a portion of the human load may still be natural[4].

[4] It is likely the actual natural percentage is higher due to the fact that we have assumed all of the loading associated with agriculture, timber harvest, unpaved roads, golf courses, and urban areas are human-caused. In fact, a percentage of the loading from these sources is actually natural (i.e., there would still be a load associated with the land use under ordinary conditions).

Table 2. Estimated fraction of bank erosion loads attributable to human-caused sources

4th code HUC	LSPC bank erosion (tons/year TSS)	Bank erosion as % of total LSPC bank erosion for Flathead Lake Watershed (%)	Percent of bank erosion that is human-caused in the 4th code HUC (%)	Bank erosion attributable to human-causes as % of total LSPC bank erosion for Flathead Lake Watershed (%)
Flathead Lake	14,454	6%	51%	3.1%
Middle Fork Flathead	96,518	42%	1%	0.4%
North Fork Flathead	80,860	36%	1%	0.4%
South Fork Flathead	0.00	0%	0%[1]	0.0%
Stillwater	15,573	7%	1% – 7%	0.1% - 0.5%
Swan	20,897	9%	4%	0.4%
Flathead Lake Watershed	**228,302**	**100%**	**NA**	**∑ =4%-5%[2]**

[1]Loading from the South Fork is considered natural due to Hungry Horse Reservoir; [2] Overall percentage of bank erosion that is human-caused, or 0.05 × 228,302 = 11,415 tons/year.

Results above provide useful information about sedimentation processes in the watershed. They also fit very well with what is known about land management in each of the above listed watersheds. For example, very little human-caused bank erosion was estimated to occur in the Middle and North Fork watersheds, which are largely administered by the USFS. These are forest service lands, wilderness areas, or are within Glacier National Park. In the North Fork, Glacier National Park comprises 28.5% of the total watershed, while 32% is administered by the USFS. In the Middle Fork watershed, Glacier National Park comprises 48% of the watershed; the Flathead National Forest administers 51% of which a large part is the Bob Marshall and Great Bear Wilderness. In this regard, a very persuasive argument can be made that a large contribution of the loading to Flathead Lake is natural (i.e., 92-93%), and of the remaining percentage attributed to human causes (7-8%), some is also natural.

5.2.2 Lower Watershed Bank Erosion

One thing to note in review of **Table 2** is that a large human-caused bank erosion contribution was identified to occur in the Flathead Lake HUC (3.1%), relative to others. Primarily, this was because we assumed that 51% of all the bank erosion was human-caused. However, the assumption was based on Ashley Creek, which is only a small percentage of the total loading from that HUC (7%). On the other hand, a common perception amongst stakeholders is that a great deal of bank erosion occurs in the lower Flathead River. To evaluate this consideration, a statistical model called LOAD ESTimator (LOADEST) (Runkel et al., 2004) was used to analyze loading in the lower watershed (Columbia Falls to the Flathead Lake delta). Data at four locations (**Table 3**) were used to construct the loading balance over the period 10/1/2006-9/15/2013 (**Figure 3**).

Table 3. Summary of USGS gage data used in Flathead River LOADEST model.

USGS station ID	Station name	SSC data time period	# of SSC observations
12369000	Flathead River near Bigfork	2007-2013	39
12363000	Flathead River at Columbia Falls	2002-2013	48
12365500	Stillwater River near Kalispell	2007-2010	30
12366000	Whitefish River near Kalispell	2007-2010	29

Note: Ashley Creek was not included in the final model due to a lack of SSC data; though preliminary analyses reveals that Ashley Creek contributes <1% of the total SSC load to the lake, therefore, absence of the SSC load from Ashley Creek should not noticeably affect the results; the coefficient of determination (R^2) for SSC in LOADEST was above 0.90 for all gages except the Flathead River near Columbia Falls (R^2=0.85).

The results in **Figure 3** indicate that while the lower watershed acts both as a sediment source and sink (the former adding load to the river and latter removing sediment load from the river), on an annual basis there is 28% less sediment passing the Bigfork gage and presumably entering Flathead Lake than observed from the summation of the upstream gage sites. What this means on a long-term basis is the lower watershed acts as a sediment sink[5]. Accordingly, sedimentation processes in the lower reaches of the river are likely not as large of a concern as once thought, and perhaps the human contribution identified in **Table 2** for the Flathead Lake HUC (3.1%) could in fact be reduced. (Note: we have not made any changes to values in **Table 2** for subsequent analysis, but this is an important point to convey.)

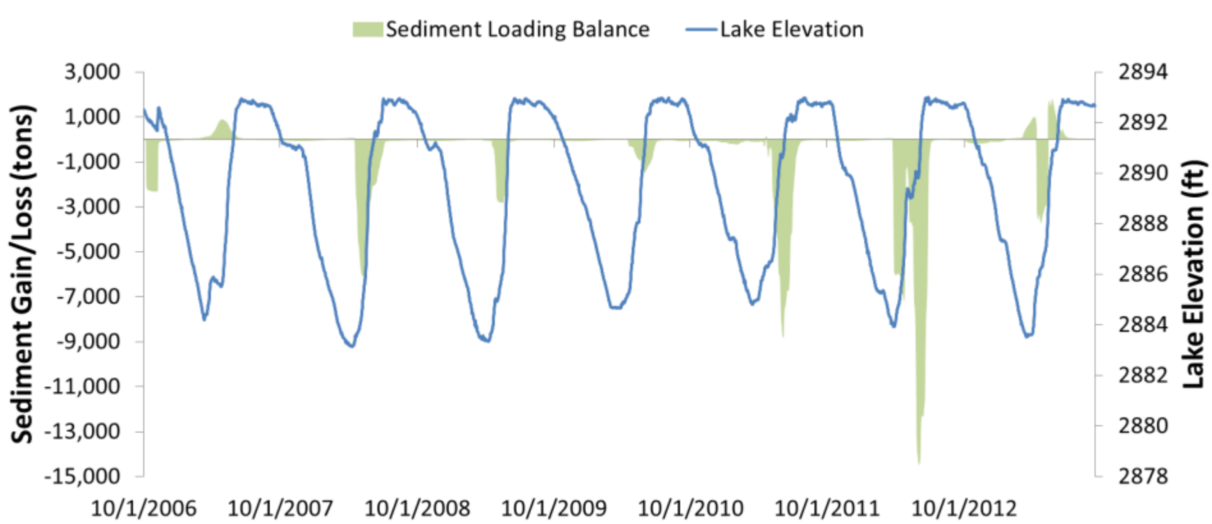

Figure 3. Estimated Gain (+) or Loss (–) in Daily Suspended Sediment Load in the lower Flathead River as Determined from the LOADEST Load Balance Modeling.

5.2.3 Loading From Within the Lake (Shoreline Erosion)

As demonstrated in previous sections, a very small percentage of the loading to Flathead Lake from external sources is attributable to human-causes (7-8%). Some investigators, though, have suggested that shoreline erosion within Flathead Lake itself is also an important sedimentation process. Shoreline

[5] LOADEST results are supported by recent work on Flathead River channel migration (Applied Geomorphology, Inc. and DTM Consulting, Inc., 2010), where the river surface slope decreases from 0.05% to <0.01% and the reduction in slope corresponds with a reduction in average annual channel migration rates (i.e., more deposition than in the upper watershed).

erosion from hydrologic modification (e.g., changes in pool elevation from dam management) was the primary cause for 1988 303(d) sediment threatened listing, and, based on this consideration, further analysis was conducted to evaluate the magnitude of shoreline erosion in Flathead Lake.

5.2.3.1 Past Studies

There have been a handful of studies to assess shoreline erosion in Flathead Lake, and these are summarized below[6].

1. Lorang and Stanford (1993) studied north shore erosion of Flathead Lake, which was believed to represent maximum erosion given fetch and wave energy relative to other areas of the lake[7]. Retreat rates were examined using headstakes in the varial zone immediately to the east of the Flathead River mouth. Transects displayed varying results, with retreat rates ranging from 1 -2.5 m/yr. The north shore varial zone slope was determined to be 0.006 m/m.

2. In a separate study, Lorang et al. (1993) noted that the most extensive erosion occurred along the low-lying dissipative north shoreline from wave action directed at a single elevation when Flathead Lake was at full pool for an extended period. The authors noted that while extensive erosion had occurred along the north shoreline between 1938 and 1946 immediately following Kerr Dam construction, shoreline retreat had decreased steadily from 1946 to 1986. They concluded that the retreat rate had decreased greatly thereafter noting that an equilibrium profile had progressively developed.

5.2.3.2 Shoreline Erosion Loading Calculations

We used the information above to construct a rough estimate of maximum probable shoreline erosion for Flathead Lake. Based on the average slope of 0.006 m/m, and the highest measured erosion rate of 2.5 m/yr, annual shoreline erosion over the entire Flathead Lake shoreline (259.7 km) would total 6,878 tons/yr[8], or 1.8% of the existing TSS load (tons/yr) to Flathead Lake (see **Table 1**). However, such an assumption is likely a gross overestimate.

To support this point (i.e., that it is not possible that the shoreline has retreated at a rate of 2.5 m/yr), DEQ investigated shoreline planimetric data, which suggest there have been only minor changes in shoreline extent along most of the north shore varial zone of Flathead Lake since 1977 (**Figure 4**). This analysis was also conducted for south shore varial zone areas in Polson Bay and Skidoo Bay. Therefore the 1.8% loading approximation is a maximum value, and in fact we suggest shoreline erosion is a much smaller component, or insignificant, when compared to the overall loading to Flathead Lake.

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[6] Shoreline erosion in Flathead Lake is believed to be caused by changes in pool elevation of Kerr Dam (joint Pennsylvania Power and Light (PPL)/CSKT operation), and subsequent wind-generated waves. However, the dam has only raised the potential inundation level of Flathead Lake 3 meters above the natural outlet elevation (www.pplmontana.com) and mean lake elevations post Kerr Dam is only 1.5 meters higher than the pre-dam averages .

[7] This is the only varial zone identified in Figure 1 in Lorang and Stanford, 1993 that falls with the State of Montana jurisdiction.

[8] Using an assumed bulk density of 16 kg/m^3 (silt).

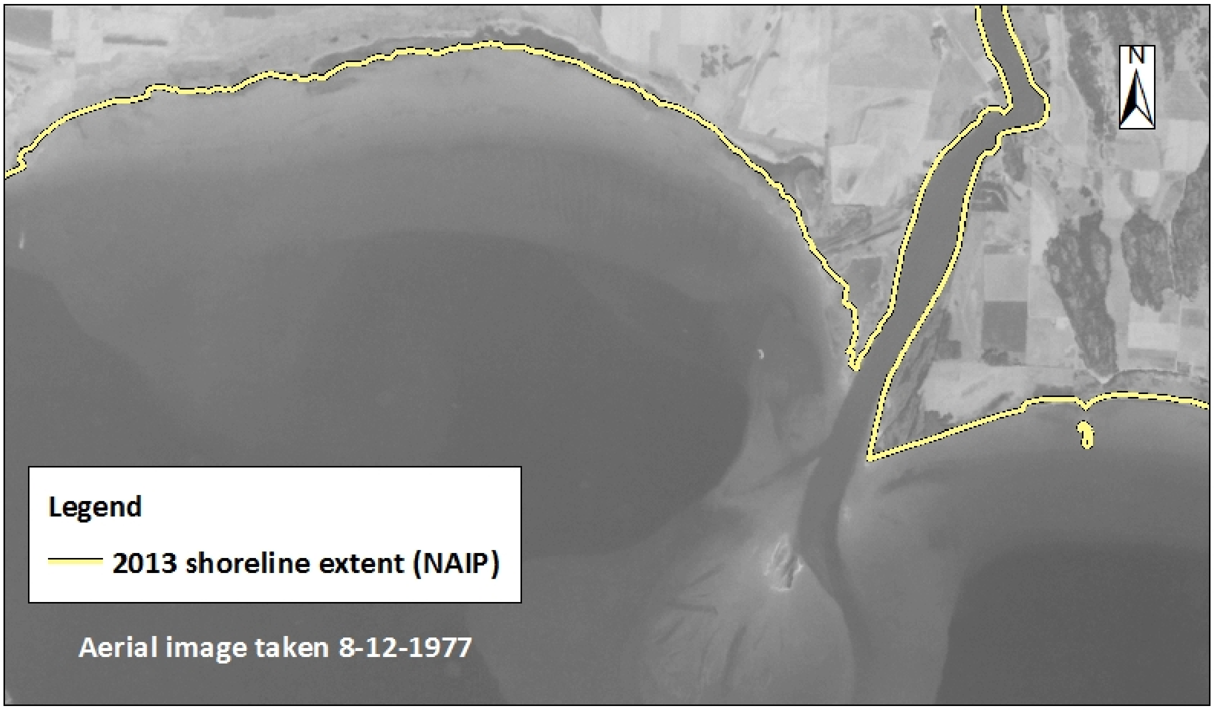

Figure 4. Comparison of 2013 shoreline extent to 1977 aerial image for north shore Flathead Lake.

In reviewing the calculations above, it is important to point out that since the original 1988 303(d) listing and the 1993 studies, there have been changes in dam management at Kerr Dam and Hungry Horse Dam. Operations now minimize changes in lake elevation during the summer to assure that boat launches have a stable water level throughout the summer, and the pool elevation is reduced from 2893 feet to 2891 feet by November 1st every year to lessen shore erosion impacts from fall storms. Construction of an erosion beach system was also completed in 2013 on lands administered by the US Fish and Wildlife Service (USFWS) as Waterfowl Production Areas (WPA) on the north shore of the lake.

5.2.4. Loading Analysis Summary

Combining the results of the LSPC model results and shoreline erosion calculations (LOADEST not considered since we chose to not modify bank erosion estimates), a quantitative understanding of sediment loading into Flathead Lake can be made (**Table 4**). Accordingly, approximately 91%-92% of the TSS load generated within the Flathead Lake watershed is due to natural sources and human-caused sources are between 8-9%. It is important to note that we have likely overestimated the human effect (see Footnote 4), and as a consequence, we suggest that human-enhanced sediment delivery is not a primary concern in Flathead Lake. We address the receiving water response to these loadings, and associated linkages with beneficial uses in subsequent sections.

Table 4. Estimated TSS loading to Flathead Lake from allochthonous and autochthonous sources

Loading type	Annual load (tons/yr)	% Natural	% Human-caused
Allochthonous (tributary load)	377,083	92% – 93%	7% - 8%
Autochthonous (within lake)	6,878	50%[1]	50%[1]
Flathead Lake Watershed	**383,961**	**91% - 92%**	**8% - 9%**

[1]The contribution of shoreline erosion from human-caused sources from hydrologic modification (dam operation) is difficult to quantify, and per MCA 75-5-306 could range anywhere from 0-100%. We assumed that half (50%) of the erosion was human-caused.

5.3 Flathead Lake Response to Sediment Loading (Water Quality Data)

The Flathead Biological Station (FLBS), Whitefish Lake Institute, and the Northwest Montana Lakes Volunteer Monitoring Network have all monitored Flathead Lake historically, and these data provide opportunity to evaluate water column sediment conditions and speculate on beneficial use support associated with these concentrations. Past data collection has included a number of water quality constituents going back to the late 1970s, at multiple locations. A systematic review and analysis of Flathead Lake suspended sediment data (both near-shore and deep samples) as well as Secchi depth and TSS data was undertaken to provide context regarding sediment loading in the Flathead Lake watershed.

5.3.1 Total Suspended Solids

Total suspended sediment concentration in the water column is affected by spring runoff and lake dynamics, and the literature suggests that Flathead Lake is in a state of flux from the beginning of spring runoff (May 1st) until thermal stratification in late June (Woods, 2004; Stanford et al., 1983). Several different patterns have been observed. In 1979, a plume entered the lake in early May, traveled directly south and spread throughout the lake by late June (Woods, 2004). In 1980 and 1983, the plume was deflected along the western shore until it met the constriction formed by the lake's shallow southern basin. Here, the plume split with part of the plume continuing south towards the outlet and the remainder traveling northwards along the lake's eastern shore (Woods, 2004). Strong westerly winds have also been noted to push the plume away from the eastern shore towards the center of the lake (Stanford et al., 1983). In this regard, lake concentrations are likely variable from year to year and data analysis is required to make conclusions about water quality.

To assist in the sediment re-assessment, Total Suspended Solids (TSS) data were compiled for Flathead Lake from EPA's STOrage and RETrieval (STORET) database for the entire period of record. The dataset includes a total of 164 TSS observations at multiple depths, and from 10 different sampling locations. In review of the data, information can generally be pooled into two categories: (1) data reflecting far field locations that most likely represent tributary loading impacts over time, and (2) near-shore data which may be more consistent with proximal shoreline erosion effects (**Figure 5**). Accordingly, sites are shown in **Table 5**. While much of the data is limited with respect to the current water quality status of TSS in Flathead Lake, some interpretation can be made about in-lake conditions.

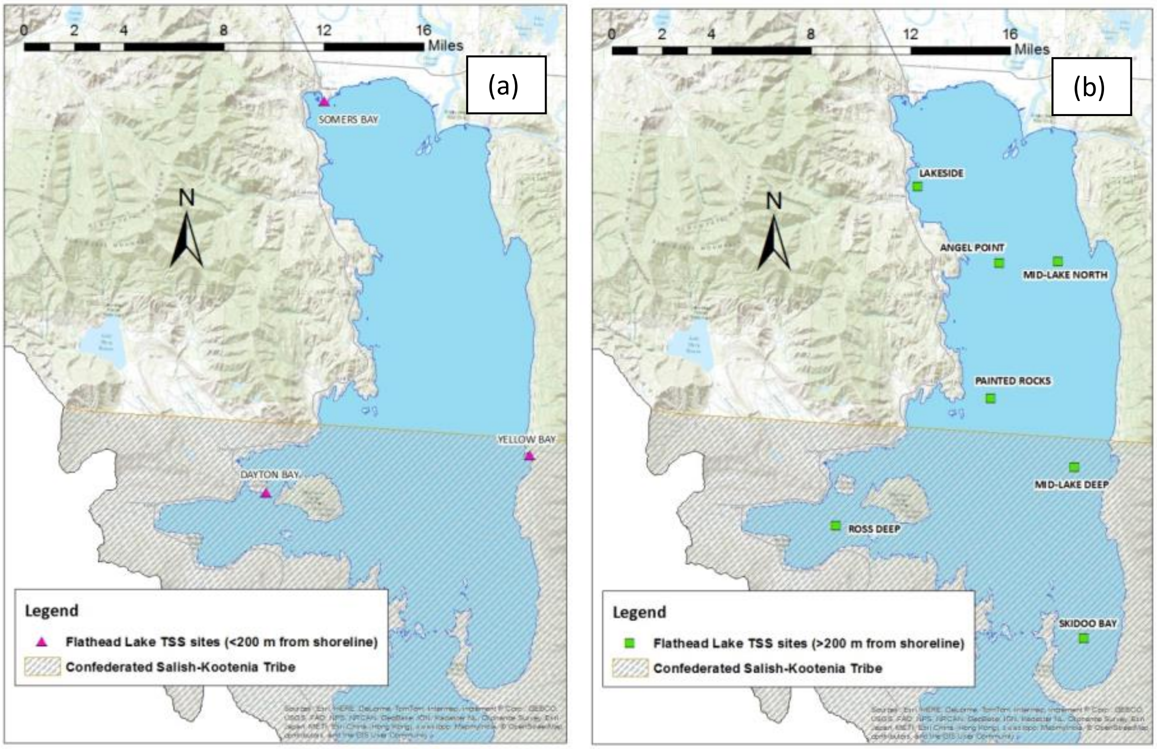

Figure 5. Flathead Lake TSS sample locations (a) <200 meters and (b) >200 meters from shoreline

Table 5. Summary of Total Suspended Solids data for Flathead Lake (1977 – 2011)[1]

Lake position	Time period	*n*[2]	# of depths	# of sites
<200 m from shore	1981-1982, 1992-1993	18	7	3
>200 m from shore	1977 – 2011	146	17	7

[1] FLBS personnel have stated that during much of the year, TSS sampling in the lake is not warranted as TSS concentrations are below detection limits.
[2] Data does not include non-detections from 1981-1982 (n=17) and 2011 (n=4) for which no detection limit was provided in the EPA compilation.

5.3.1.1 Temporal Trends in Suspended Sediment

Flathead Lake TSS data are presented in **Figure 6**, both in a day of year and time-series basis. **Figure 6a** displays seasonal differences by day of year, whereas **Figure 6b** shows the same data, but plotted over time. Accordingly, it can be seen during spring runoff/spring turnover (May 1 – June 30) concentrations tend to increase (1-9 mg/L), however, over the remaining parts of the year they are more stable (1-5 mg/L). Year to year trends are difficult to discern given the lack of consistent TSS data collection through time. As such, insufficient information exists to say much about the data in this format.

(a)

(b)

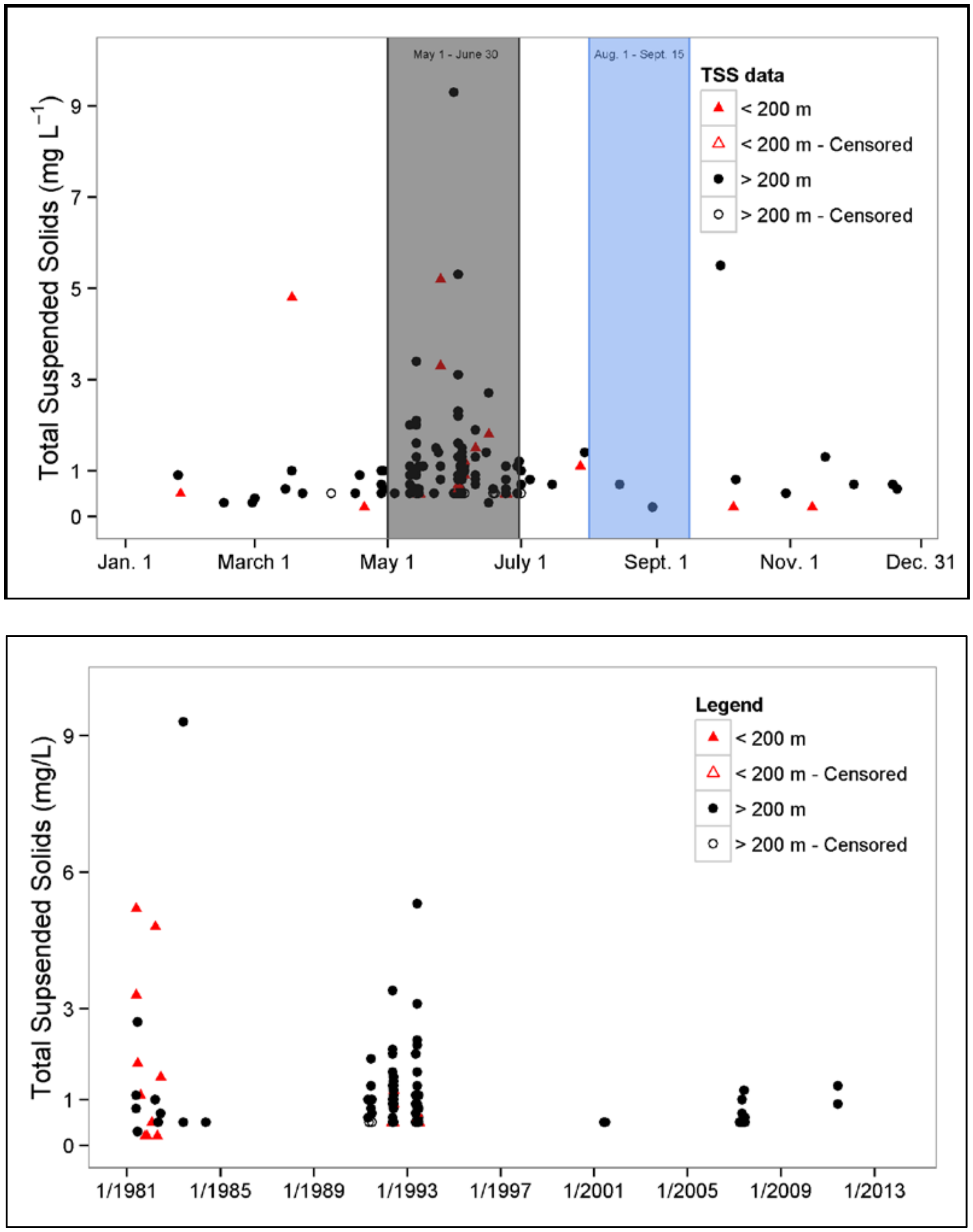

Figure 6. (a) Total Suspended Sediment data for Flathead Lake by month/day (2007-2013); (b) Total Suspended Sediment data for Flathead Lake by date (2007-2013)

5.3.1.2 Spatial Statistics (Near-shore vs. Deep samples)

Spatial statistics are another way to analyze the data, and in this instance we pooled data into near-shore and deep sites (**Table 6**). This was done as shoreline erosion may influence water quality in the nearshore environment, possibly exerting a greater influence than in the deep locations. Data were analyzed with a two sample *t*-test and unequal variances. The mean difference of the sites ($\mu_1 - \mu_2 = 0$) was not statistically different than zero (p=0.33), thus there appears to be no localized near-shore increase in suspended sediment concentration. Non-detects were common however (24% of the time), and most of the data is below 1.5 mg/L suggesting water quality is good.

Table 6. Summary of Total Suspended Solids data for Flathead Lake

Distance from shore (all sites)	Time period	*n*	# of NDs[1]	≥ 1 mg/L	Average (mg/L)	Median (mg/L)	75th percentile (mg/L)
<200 m (*n*=3)	1981-1982, 1992-1993	18	3	11	1.34	0.65	1.43
>200 m (*n*=7)	1977-1984, 1991-1993, 2001, 2007, 2011	146	37	107	0.97	0.65	1.10
All sites (*n*=10)	1977-1984, 1991-1993, 2001, 2007, 2011	164	40	118	1.01	0.65	1.10

[1] 0.5 mg/L (detection limit) used to calculate summary statistics for non-detects

5.3.2 Secchi depth

One of the limitations of the TSS analysis above is the number of observations. In this section, we attempt to extend the record using Secchi observations. Secchi disk transparency is another measure of water transparency that can be influenced by suspended sediment concentration. But Secchi depth also integrates scattering and adsorption characteristics of water and of its dissolved and particulate matter (Wetzel, 1975). If the color of the water is consistent however, and phytoplankton and detritus comprise a small portion of the overall light attenuation in the water column, Sechhi depth may be a suitable surrogate for suspended sediment concentration.

Secchi depth data were compiled from EPA's STOrage and RETrieval (STORET) data warehouse for Flathead Lake and were analyzed for correlations with TSS. The full dataset includes a total of 1170 Secchi depth measurements from 19 different sampling locations (**Table 7 and Figure 7**).

Table 7. Summary of Secchi depth data for Flathead Lake (1977 – 2011)

Lake position	Time period	*n*	# of sites
<200 m from shore	1991-2007	527	6
>200 m from shore	1991–2011	644	13

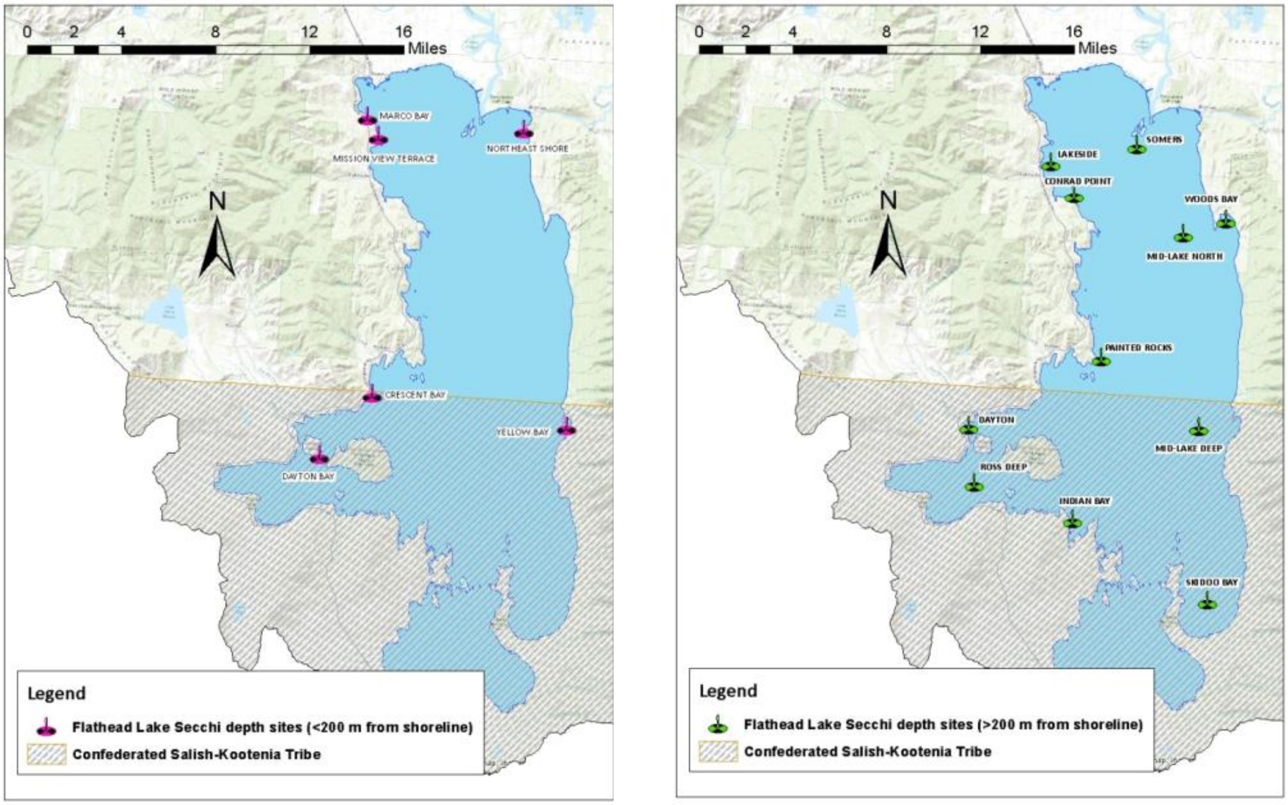

Figure7. Flathead Lake Secchi depth sample locations (a) <200 meters and (b) >200 meters from shoreline

5.3.3.1 Temporal Trends in Secchi Depth

Similar to TSS, Secchi depth in Flathead Lake exhibits a seasonal pattern with the seasonal minimum occurring during spring runoff/spring turnover (May 1 – June 30) and the seasonal maximum occurring in late summer (August 1 – September 15) (**Figure 8a**). The late summer period most likely represents the non-turbid period in the lake prior to the start of fall turnover and there appears to be little separation in Secchi depth observations between sample locations within 200 m of shore and those farther out, with some possible exceptions in the mid- to late-winter period (January 1 – March 1). While seasonal patterns are observable in **Figure 8b**, there do not appear to be any apparent trends in near-shore Secchi depths with minimum and maximum values generally consistent through time. A decreasing trend in Secchi depths may indicate increased siltation or excess amounts of fine sediment present in the water column, whereas an increasing trend may suggest improvements in water clarity over time.

Four sample locations within the Flathead Lake Secchi depth dataset have long term measurements and these were analyzed for potential trends (Marco Bay, Somers Bay, Mission View Terrace, Mid-lake Deep) (**Figure 9**). Of the four sites, the Mission View Terrace and Marco Bay sites are both within 200 m of the shore, while the other locations are deep sites. A nonparametric statistical test, Spearman's rho (ρ), was used to measure the statistical dependence between measured Secchi depth and time. Spearman's rho tests the monotonic relationship between parameters; as the value of one parameter increases the other parameter may either increase or decrease.

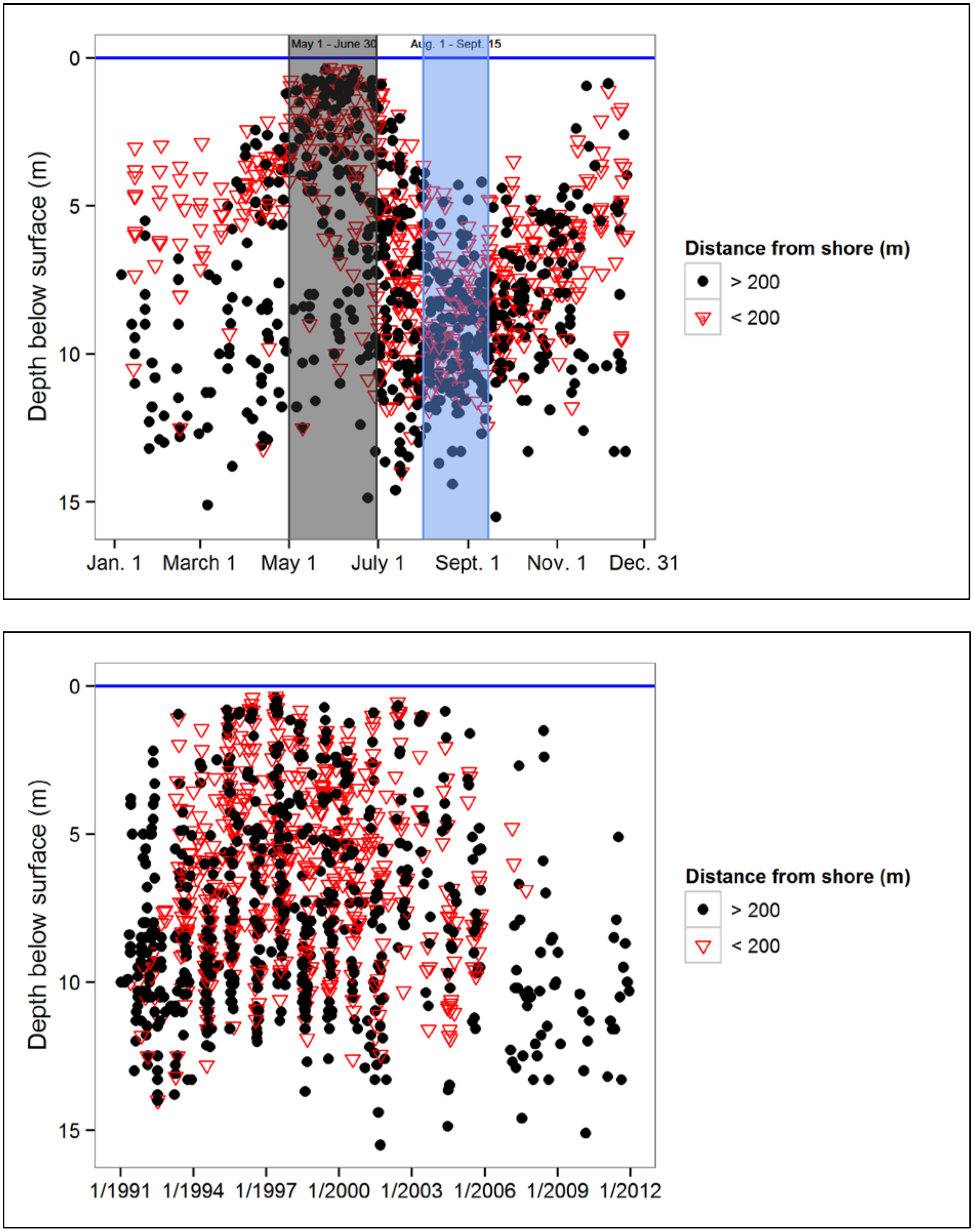

Figure 8. (a) Flathead Lake Secchi depth data (1991-2011) . (b) Secchi depth measurements for Flathead Lake over time (1991-2011)

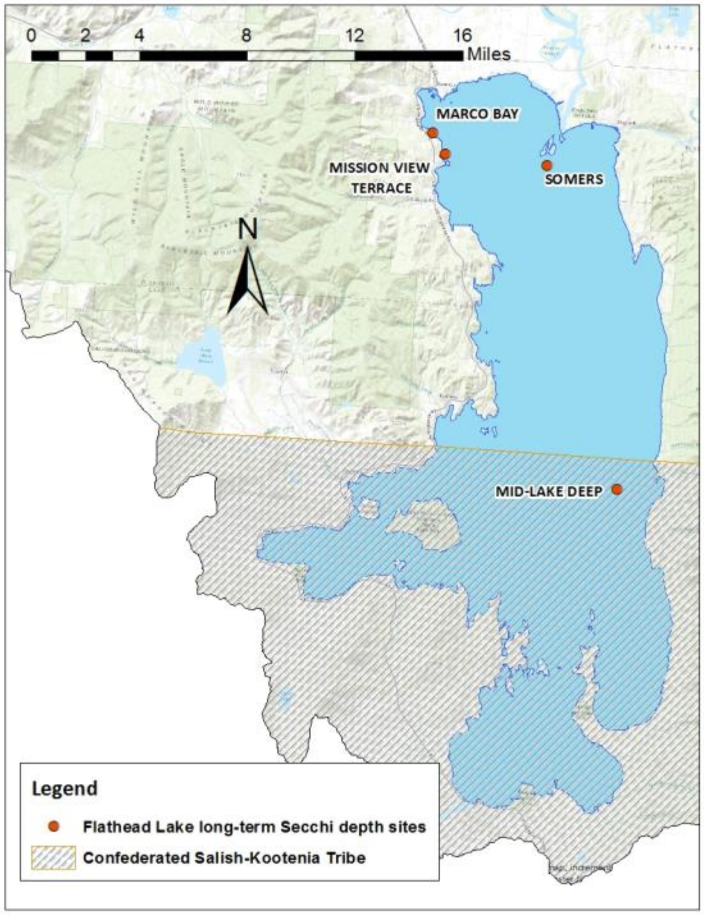

Figure 9. Flathead Lake long-term Secchi depth sample locations

Results of the Spearman's rho (ρ) test are as follows: only the Mission View Terrace sample location demonstrated a significant monotonic trend (p =0.014, ρ=0.182; i.e., clarity improving), thus none of the other sites have significant correlation with time (note: this does not mean that there is not a non-monotonic relationship in the data as clearly there is). Secchi depth therefore is stable through time, or increasing (Mission View Terrace sample site) throughout Flathead Lake.

5.3.2.1 Secchi depth as a predictor of TSS

Due to the lack of consistent and recent TSS data collection in Flathead Lake, Secchi depth was investigated as a potential predictor of TSS. Analysis of the Flathead Lake TSS/Secchi depth dataset yielded 30 pairs of data. Paired data included only those TSS values collected at 5 meters below the surface as this depth was closest to recorded Secchi depth. Non-detects (n=8) were assigned ½ the detection limit (detection limit = 0.50 mg/L) and a linear regression yielded an R^2 value of 0.60 using Secchi depth as a predictor variable (**Figure 10**). Additional explanatory power would likely be provided by including chlorophyll *a* data, but none could be identified for the paired Secchi depth/TSS dataset.

Given the regression yielded a significant relationship between Secchi depth and TSS (p=0.05), the entire Secchi depth dataset for Flathead Lake (n=1170) was used to predict TSS values using **Equation 1.**

$$\text{TSS (mg/L)} = -0.1296(\text{Secchi depth } (m)) + 1.8572 \qquad \textbf{Eq. 1}$$

where *m* is the depth (meters).

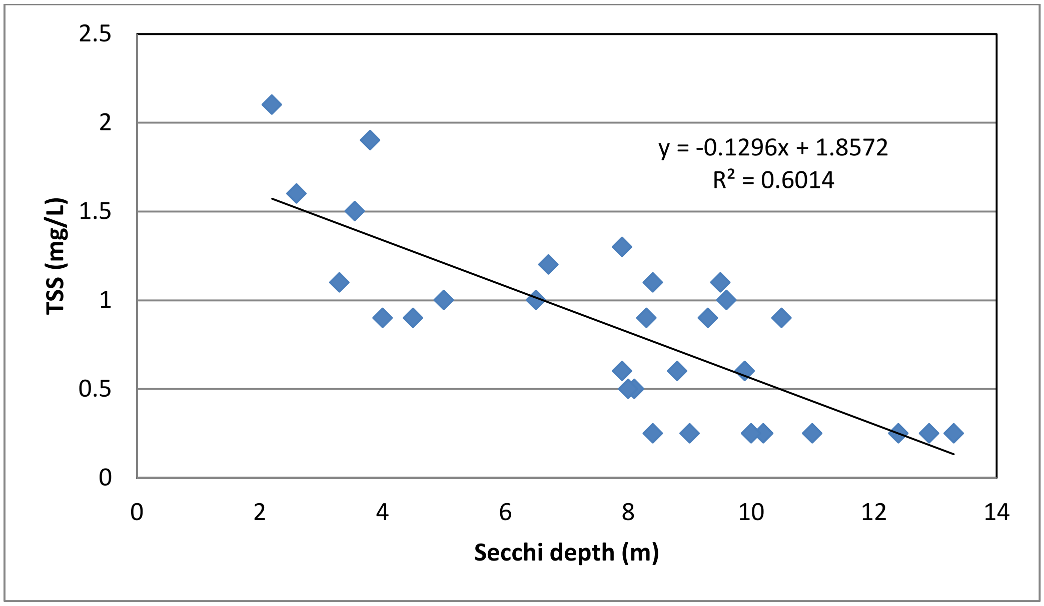

Figure 10. Linear regression analysis of paired Secchi depth/TSS data for Flathead Lake (1991-2011)

Summary statistics for predicted TSS concentrations using **Equation 1** are presented in **Table 8**. Data are much more extensive than the TSS data presented previously (**Table 6**), and in this case suggest that the mean between the near-shore and deep sites are different ($p<0.001$; pooled variance). Average and median predicted TSS concentrations, however, are still < 1.1 mg/L and the small difference between average, median, and 75th percentiles suggest that predicted TSS values (based on actual Secchi depth measurements) are well buffered against large swings in predicted suspended sediment concentration.

Table 8. Summary of predicted Total Suspended Solids concentration data for Flathead Lake using Secchi depth/TSS regression

Distance from shore (all sites)	Time period	*n*	≥ 1 mg/L	Average (mg/L)	Median (mg/L)	75th percentile (mg/L)
<200 m (*n*=6)	1981-1982, 1992-1993	527	241	1.04	1.05	1.33
>200 m (*n*=13)	1977-1984, 1991-1993, 2001, 2007, 2011	644	418	0.86	0.79	1.19
All sites (*n*=19)	1977-1984, 1991-1993, 2001, 2007, 2011	1171	659	0.95	0.91	1.26

5.3.3 Interpretation of Water Quality Data and Beneficial Use Support

The review of TSS and Secchi depth data for Flathead Lake indicate that clarity and suspended sediment concentrations are heavily influenced by seasonal changes in the hydrograph. However, the following can be concluded about the components examined: (1) water transparency appears to be stable or improving based on trend analysis of the data and (2) there appears to be little difference in observed suspended sediment concentrations between near-shore and far-field sites (0.2 mg/L difference depending on approach used). However, the real consideration is how do these data relate to other unimpaired lakes within northern Montana or beneficial use support?

With respect to the first part of the question above, **Figure 11** presents boxplots of TSS data for Hungry Horse Reservoir[9], Swan Lake[10], Whitefish Lake[9], and Flathead Lake[11], most of which are not directly impaired for sedimentation. Concentrations in Flathead Lake are therefore similar to those found in other lakes in the Flathead Lake watershed; though it should be noted that the boxplot is strongly affected by detection limits[12]. Comparing the proportion of TSS observations per lake that are <1 mg/L yields very similar fractions amongst the four lakes: Hungry Horse (64%), Swan (61%), Whitefish (65%) and Flathead (61%), which suggests that Flathead Lake TSS concentrations are within the range observed in other lakes unimpaired by TSS (sediment).

[9] Hungry Horse Reservoir and Whitefish Lake are not impaired by sediment; updated impairment assessment for Whitefish Lake completed in September 2014.
[10] A sedimentation/siltation TMDL was written for Swan Lake in 2004 for particulate organic matter to address a threatened condition of low dissolved oxygen in the lake.
[11] Not included in **Figure 11** were *n*=8 Flathead Lake TSS observations without an identified detection limit.
[12] In **Figure 11**, detection limits were substituted for all non-detections (ND) in the dataset.

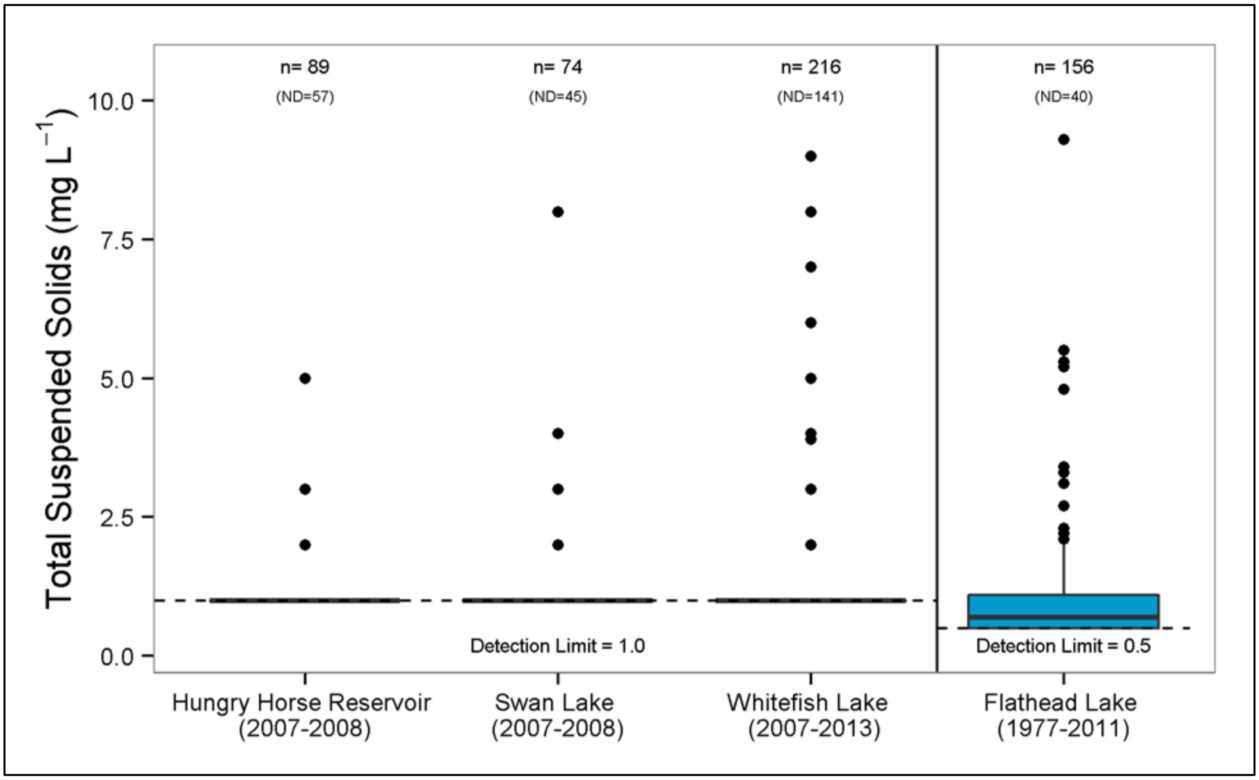

Figure 11. TSS observations for several lakes in the Flathead Lake watershed (ND = non-detect)

Finally, regarding, beneficial use support, currently, there are no data to suggest that recreation on the lake is impaired by sedimentation. To the contrary, the lake's clarity is well-documented and Flathead Lake is a popular recreational destination. Likewise, there are no known impacts on the biological community from sediment; though the introduction of nonnative fish and Mysis shrimp have significantly affected the system. Lastly, TSS exposures in the lake (i.e., concentration × duration) appear to be within reasonable limits based on the Newcomb and Jensen (1996) severity of ill effects (SEV) scale. At most, they lead to alarm reactions, abandonment of covers, or avoidance response in fishes, though it is important to note that the Newcomb and Jensen work is not intended to evaluate concentrations as low as those observed in Flathead Lake. Thus, we conclude that water quality data indicate human-caused sediment sources do not appear to be large enough to sufficiently impact beneficial use support.

6.0 SUMMARY

The 2014 Flathead Lake sediment assessment presents a weight-of-evidence approach to determine if impairment from sedimentation/siltation currently exists for Flathead Lake. We conclude that Flathead Lake is ***not impaired*** for sediment based on the following lines of evidence:

1. At most, ***8% - 9% of the modeled sediment load to the lake was linked to human activities***. Such an increase is not believed to not be harmful, detrimental, or injurious to public health, recreation, safety, welfare, livestock, wild animals, birds, fish, or other wildlife (in the case of Flathead Lake). The fact that our analysis did not account for load trapping from the South Fork of the Flathead River (Hungry Horse Reservoir) further validates this assumption.

2. Shoreline erosion, which was the cause of the original listing, is believed to be minimal. ***At most, a 1.8% increase in annual loading to Flathead Lake has occurred***, though the actual value is likely much lower. We assumed that up to 50% of this increase may be attributed to human causes. Empirical studies also suggest erosion has declined following the construction of Kerr Dam and management operations have improved. Based on these factors, we suggest the cause of the original listing is no longer applicable to Flathead Lake.

3. Analysis of TSS and Secchi depth data for Flathead Lake were inconclusive, but do show water transparency as stable or improving (greater clarity) and very little difference in sediment concentrations at various locations in the lake (shallow vs. deep) and between similar, unimpaired lake systems in the Flathead Lake watershed. ***Finally, observed suspended concentrations do not appear to differ from other unimpaired lakes in the Flathead watershed, nor exceed levels that cause impacts to fish***. Thus we conclude water quality data in the lake do not indicate that human-cause sedimentation has degraded water quality or affected beneficial uses.

Accordingly, our weight-of-evidence reassessment finds that beneficial uses in Flathead Lake are ***<u>not</u> currently threatened or impaired by sediment***.

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