Flushing Flow Needs in the Madison River, Montana
2013 through 2017
Streambed and Aquatic Invertebrate Monitoring Results and Comparison with Results from 1994 through 2012

FERC Project 2188

Article 419 of Project 2188 License

Prepared for:

NorthWestern Energy
1315 N Last Chance Gulch
Helena, Montana 59601

Prepared by:

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February 22, 2018

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CONTENTS

FIGURES

TABLES

1. INTRODUCTION

On September 27, 2000, the Federal Energy Regulatory Commission (FERC) issued a license to PPL Montana (PPLM) for the Missouri-Madison Hydroelectric Project, FERC Project No. 2188. This license regulates nine hydroelectric facilities on the Missouri and Madison rivers in central Montana. Two of these facilities are on the Madison River (Hebgen and Madison) and the remaining seven are on the Missouri River (Hauser, Holter, Black Eagle, Rainbow, Cochrane, Ryan, and Morony). Article 419 of the new license required PPLM to file a plan to coordinate and monitor flushing flows in the upper Madison River downstream of Hebgen Dam.

In response to a request from PPLM, R2 Resource Consultants, Inc. (R2) prepared a plan to coordinate and monitor flushing flows (R2 2003a). This plan, prepared in consultation with agencies, required the collection of substrate core samples every year and additional geomorphic and macroinvertebrate data every five years, analyzing the data, and reviewing the results of the analyses to determine flushing flow needs.

Data reports were subsequently prepared at five-year intervals (R2 2003b; R2 2008; and R2 2013). The current plan for implementing flushing flows in the Madison River was issued by FERC on June 13, 2013 (FERC 2013). The FERC license issued to PPLM is now owned by NorthWestern Energy (NWE). R2 was contracted by NWE to prepare the 2018 data report. Recent construction activities at Hebgen dam have precluded the controlled release of flushing flows. So this report is focused on analysis of new data and comparison with data previously collected.

1.1 BACKGROUND

Madison River flows are controlled, to a large extent, by operation of Hebgen Dam. The Hebgen development has no power-generating facilities and primarily serves as a storage reservoir for downstream projects. The reservoir impounds about 380,000 acre-feet of usable storage. In 1959, an earthquake caused a major landslide across the Madison River about five miles downstream of Hebgen Dam. The landslide impounded a section of the Madison River. This impoundment, known as Quake Lake, was approximately 174 feet deep, when it was initially created. The lake is shallower now as a result of erosion of the outlet.

To limit erosion of the outlet from Quake Lake, NWE is required by the FERC License to limit the maximum releases from Hebgen Dam to 3,500 cfs (as determined near Kirby Ranch, U.S. Geological Survey [USGS] Gage 06038800) using available storage capacity in Hebgen

Reservoir. The 3,500 cfs limitation is documented in a Memorandum of Understanding with U.S. Forest Service (Montana Power Company 1976). A recent study was conducted by the USGS (2012) to look at lateral and vertical channel movement and potential for bed-material movement on the Madison River downstream from Quake Lake. Results of this study suggest that there is currently no need to revise the 3,500 cfs limitation.

Prolonged exposure to excessive high flows would lead to erosion and undermining of the outlet structure of Quake Lake. The volume of material that blocked the Madison River below Hebgen Dam and formed Quake Lake has been estimated to range from 37 to 43 million cubic yards. This volume of material would become an excessive source of sediment to the Madison River downstream from Quake Lake. The erosion and transport of this sediment to the Madison River downstream from Quake Lake would increase turbidity levels, disrupt the geomorphic integrity of the Madison River, and increase the risk of downstream flooding. Thus, it is important to maintain the structural integrity of the outlet of Quake Lake.

The 3,500 cfs constraint on flows in the Madison River near Kirby Ranch is supported by observations of the outlet of Quake Lake, when high flows were released from Hebgen Dam in 1970 and 1993. In 1970, flow releases from Hebgen Dam peaked at 4,500 cfs. Although concurrent flows were not measured near Kirby Ranch, large boulders were moved in the Quake Lake spillway, and Highway 287 was washed out just downstream from Quake Lake. In 1993, flow releases from Hebgen Dam peaked at 3,500 cfs and the resultant flows near Kirby Ranch peaked at 5,030 cfs. Erosion was observed in the outlet channel of Quake Lake. Thus, limit further erosion of the outlet of Quake Lake, the 3,500 cfs maximum flow constraint near Kirby Ranch should be maintained, and is a requirement of the FERC license.

Madison Dam is located on the Madison River 63 miles downstream of Hebgen Dam (Figure 1-1). The powerhouse, with an installed capacity of 8.6 megawatts, is located about one mile downstream of the dam. The project currently is, and will continue to be, primarily operated as a run-of-the-river facility.

NWE, through operation of Hebgen Dam, has the capability of releasing flows to both the upper Madison River (between Hebgen Dam and Ennis Lake) and the lower Madison River (between Madison Dam and the confluence with the Jefferson and Gallatin rivers). Flow releases from Hebgen Dam are designed to satisfy downstream minimum flow requirements below Hebgen Dam, near Kirby Ranch, and below Madison Powerhouse. This study plan is focused on the determination of the need for flushing flows, and the development of a plan for releasing flushing flows while still meeting current operational constraints of Hebgen Dam.

Flushing flows, when needed, are important for maintaining spawning gravel quality for salmonids in the Madison River. Excessive levels of fine sediments in spawning gravel may suffocate salmonid eggs during the incubation period and impair the emergence of fry from the gravel matrix.

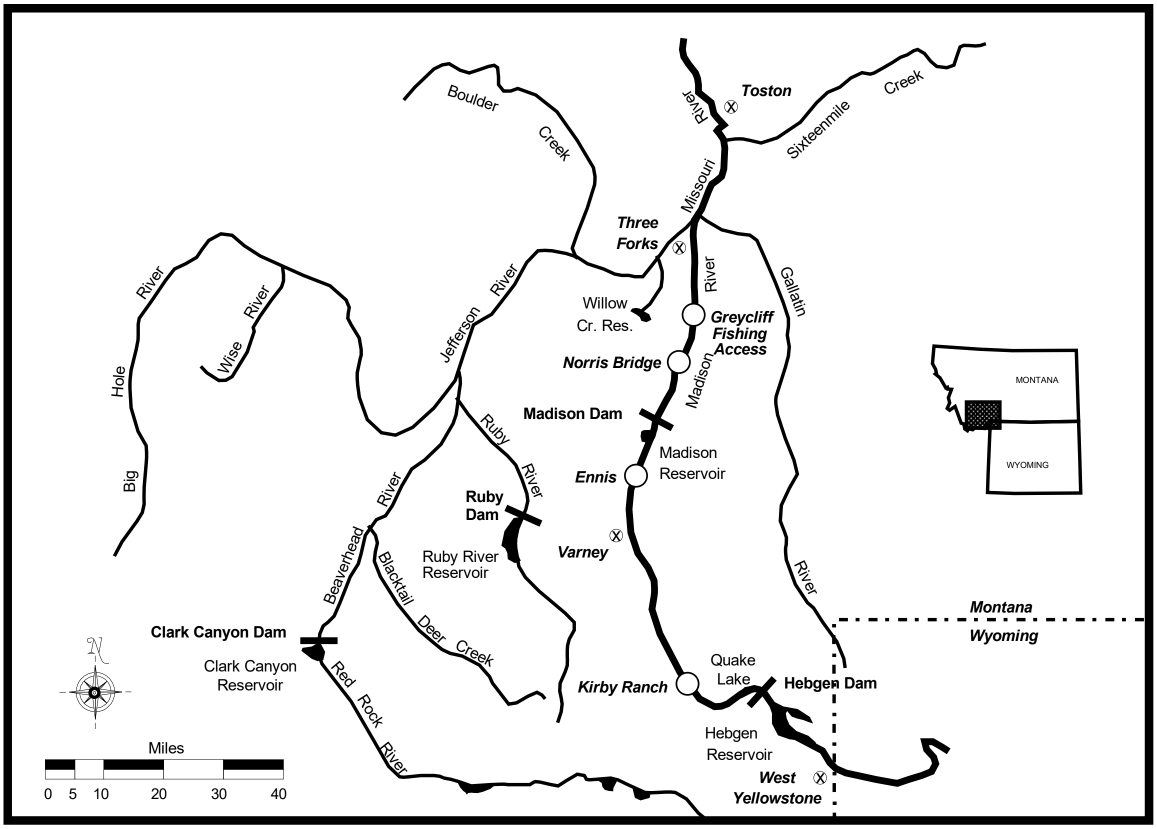

Figure 1-1. Hebgen Dam and Madison Dam located on Madison River, Montana.

1.2 SUMMARY OF PREVIOUS STUDIES

A series of studies designed to address the need for flushing flows in the Missouri and Madison rivers was initiated in 1992. The initial study, conducted by EA Engineering, Science, and Technology (EA 1992), involved the collection of field data from nine locations, three on the Madison River and six on the Missouri River. In a subsequent study performed by R2 (1994a), the data collected by EA were analyzed and a draft streambed-monitoring plan was developed for further monitoring of flushing flow needs on the Missouri and Madison rivers. Seven sites were suggested for future monitoring, four on the Madison River and three on the Missouri River.

Streambed and aquatic invertebrate monitoring were performed at two sites on the Madison River (Norris Bridge and Greycliff Fishing Access) by R2 in 1994 (R2 1994a, R2 1994b, and R2 1994c). At each site; channel cross-sections and water surface elevations were surveyed; flows were measured; pebble count surveys were performed and McNeil samples collected; embeddedness was assessed; and macroinvertebrate samples were collected via a modified Hess Sampler and a kick-screen. Results of the study suggested that further monitoring should be performed at the Norris Bridge and Greycliff Fishing Access sites, as well as other sites located upstream from Madison Dam. A draft streambed-monitoring plan was subsequently developed for further monitoring of flushing flow needs on the upper and lower Madison River.

In 1995, a three-year streambed-monitoring program was initiated at four sites on the Madison River. Two sites were selected on the upper Madison River (Kirby Ranch and Ennis) and two sites on the lower Madison River (Norris Bridge and Greycliff Fishing Access). The streambed at these sites was monitored in 1995, 1996, and in 1997 and the results were reported by R2 (R2 1996, R2 1997, and R2 2000). During the course of these studies, the protocol for collecting and analyzing data was refined based on agency input and for consistency with similar studies performed on the Missouri River. Important elements of the data collection program included: cross-section surveys; embeddedness measurements; scour chain monitoring; McNeil samples; modified Hess samples; and kick-net samples.

Between the 1995 and 1996 data collection sessions, a flushing flow occurred in June 1996. Daily flow releases from Madison Dam over a three-day period averaged about 7,600 cfs. Analyses of McNeil samples indicated that there was a significant reduction in the percentage of fines in the samples collected from the Norris Bridge and Greycliff Fishing Access sites. A similar reduction was not observed at the Kirby Ranch and Ennis sites because the percentage of fines in those samples was low even before the flushing flow occurred. At the end of these studies (R2 2000), further monitoring was recommended at five-year intervals, beginning in 2002.

A comprehensive set of field data, including substrate core samples, geomorphic surveys, and macroinvertebrate samples, were collected in September 2002. These data were analyzed and compared with hydrologic and water temperature records, as well as the results of previous studies. Results of this study were reported by R2 (2003b).

Annual substrate core samples were collected and analyzed by PPLM in 2003, 2004, 2005, and 2006, and a comprehensive set of field data, including substrate core samples, geomorphic surveys, and macroinvertebrate samples, were collected in September 2007. These field data were analyzed and compared with additional hydrologic and water temperature records, and the results of previous studies. Flushing flows were released from Hebgen Dam in 2006, 2008, and 2010. Although the peak flows in the lower Madison River in 2006 did not reach the magnitudes that occurred in 1996, changes in the cross-sectional shape of Transect 3 at the Ennis Campground Site between 2002 and 2007 suggest that the flushing flows were sufficient to mobilize streambed sediments in the upper Madison River. A comprehensive summary of monitoring results from 1994 through 2007 was compiled by R2 (2008).

Annual substrate core samples were collected and analyzed by PPLM in 2008, 2009, 2010, 2011, and 2012. In addition, macroinvertebrate samples were collected and analyzed by Dan McGuire (McGuire 2012) in 2008, 2009, 2010, and 2011. These results and the combined results from monitoring efforts since 1994 were reviewed within the context of the previously developed plan to coordinate and monitor flushing flows in the Madison River (R2 2003a). Recommended changes to the plan were developed (R2 2013).

1.3 NEW DATA AND RECENT CONSTRUCTION ACTIVITY

Construction activities at Hebgen Dam in recent years have precluded the release of flushing flows. With this in mind, this report will summarize and present data collected from 2013 through 2017, and compare with results collected from 1994 through 2012. Data collected since the previous plan was submitted include the following:

- **Redd Surveys** – performed in the spring and fall at Kirby Ranch, Ennis Campground, Norris Bridge, and Greycliff Fishing Access.
- **Macroinvertebrate Samples** – collected in the summer at Yellowstone National Park, Hebgen Dam, Kirby Ranch, Ennis Campground, Madison Powerhouse, Norris Bridge, and Greycliff Fishing Access.
- **McNeil Gravel Samples** – collected in the fall at Kirby Ranch, Ennis Campground, Norris Bridge, and Greycliff Fishing Access.
- **Scour Chains** – installed in 2014 at Ennis Campground, Norris Bridge, and Greycliff Fishing Access.
- **River Cross-Section Surveys** – performed in 2015 at Kirby Ranch, Ennis Campground, Norris Bridge, and Greycliff Fishing Access.

1.4 OPERATIONAL CONSTRAINTS AT HEBGEN DAM

Flushing flows, when released from Hebgen Dam, are subject to the following constraints:

1. Minimum flows of 150, 600, and 1,110 cfs must be provided in the Madison River below Hebgen Dam, near Kirby Ranch, and below Madison Powerhouse, respectively.
2. The flow in the Madison River near Kirby Ranch must be kept below 3,500 cfs to limit erosion from the outlet of Quake Lake.
3. The reservoir level of Hebgen must be filled to at least elevation 6,530.26 ft by June 20^{th} and to full pool (elevation 6,534.87 ft by late June or early July).
4. Flow releases from Hebgen Dam cannot be changed by more than 10% per day.

These operational constraints under the current FERC license have been designed to provide the following benefits:

- reducing the risk of erosion at the outlet of Quake Lake, thereby preventing excessive turbidity levels in the river, preserving the geomorphic integrity of the stream, and reducing the risk of downstream flooding,
- reducing the magnitude and frequency of floods, thereby reducing the risk of flood damage in downstream communities such as Ennis, and reducing the risk of bridge failure at downstream highway crossings,
- providing a recreational benefit in Lake Hebgen during the summer months,
- assuring adequate water supply for downstream water temperature control through pulse flow releases from Hebgen Dam,
- reducing the risk of trapping and stranding by limiting ramping rates when flow releases from Hebgen are decreasing,
- and assuring adequate water supply to ensure downstream minimum instream flow requirements are met.

2. REVIEW OF MONITORING METHODS

Flushing flow needs of the Madison River are currently monitored at the four locations (Kirby Ranch, Ennis, Norris Bridge, and Greycliff Fishing Access) shown in Figure 1-1. Substrate core samples are currently collected from all four locations every year for the term of the license. Additional geomorphic and macroinvertebrate data are currently collected from all four study sites every five years thereafter for the term of the license.

These four sites were also monitored in 1995, 1996, 1997, 2002, 2007 and 2015. Plan views of the site layouts of the Kirby Ranch, Ennis, Norris Bridge, and Greycliff Fishing Access sites are shown in Figures 2-1, 2-2, 2-3, and 2-4, respectively. Collectively, these four sites provide a representative indicator of the overall condition of the Madison River below Hebgen Dam. The methods used to collect and analyze data from these four sites are described herein.

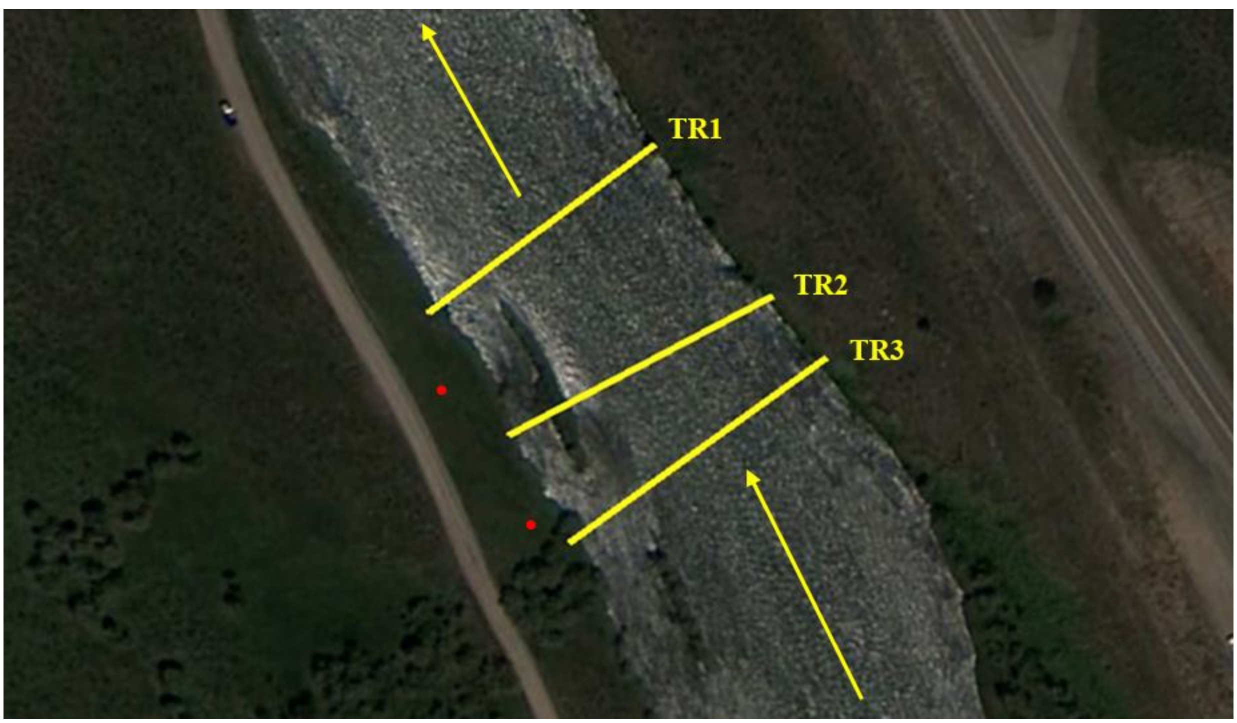

Figure 2-1. Alignment of transects and locations of benchmarks (red dots) at the Kirby Ranch Site.

Figure 2-2. Alignment of transects and location of benchmark (red dot) at the Ennis Site.

Figure 2-3. Alignment of transects and locations of benchmarks (red dots) at the Norris Bridge Site.

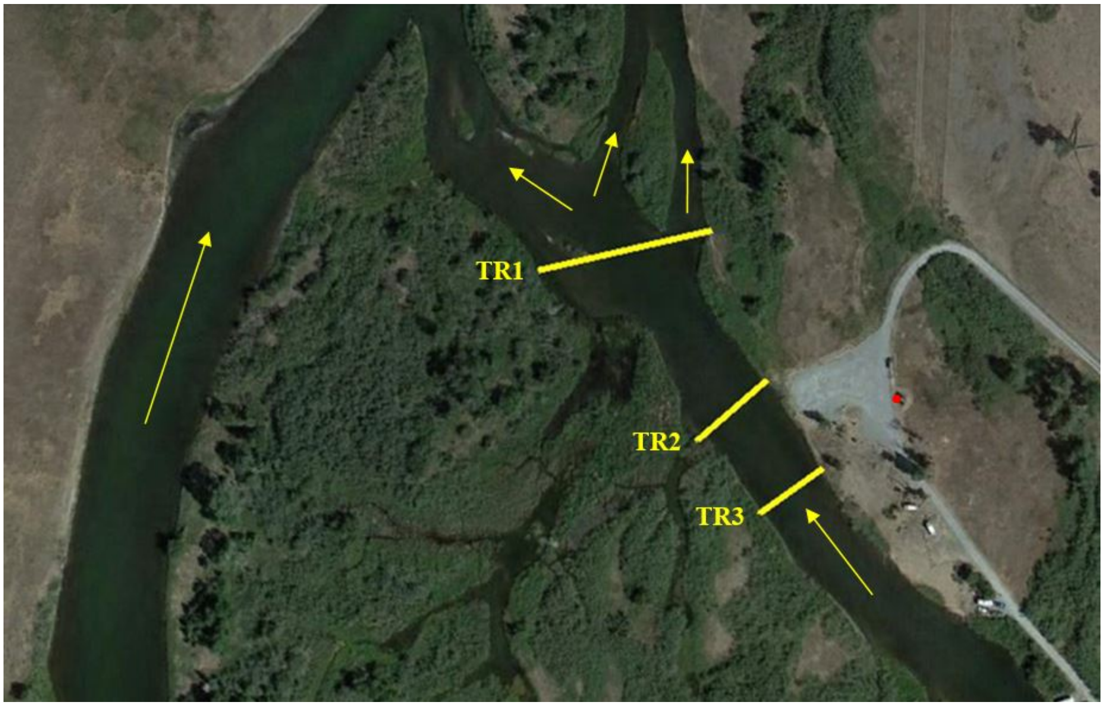

Figure 2-4. Alignment of transects and location of benchmark (red dot) at the Greycliff Fishing Access Site.

2.1 DATA COLLECTION

To maximize visibility, accessibility, and worker safety in the stream channel, each of the four sites are visited during the low flow period in September. Stable flows are provided by NWE when field data are collected. Streamflow records are obtained from the USGS for the gages on the Madison River below Hebgen Lake (Gage No. 06038500) and below Ennis Lake (Gage No. 06041000). Available water temperature records are obtained from the Madison River below Ennis Lake during the summer period.

2.1.1 Channel Morphology and Sediment Characteristics

At each site in 1995, 1996, 1997, 2002, 2007, and 2015 channel cross-sections were surveyed Substrate core samples were collected from spawning gravel deposits in 1995, 1996, 1997, and every year starting in 2002. Embeddedness has been measured at each cross-section in 1995, 1996, 1997, 2002, and 2007.

In 1996, 1997, and 2002, scour chains were monitored and reinstalled. However, the scour chains had become corroded in 2002, and the chain links had become locked together, rendering them ineffective. The scour chains were not replaced in 2002, and the old chains have not been monitored since then.

Channel cross-sections are surveyed using benchmarks and headpins established at permanent transects in 1995, as shown in Figures 2-1, 2-2, 2-3, and 2-4. Benchmarks and three channel transect alignments were established at each of the four Madison River streambed monitoring locations by installing headpins on the left and right banks. These transects are aligned perpendicular to the direction of flow. Using the benchmarks as a reference, the relative elevations of the headpins, streambed, and water surfaces are surveyed for each transect. Bed elevations along each transect are surveyed relative to the benchmarks using a Leica (TCR-1205) total station instrument.

In September 1995, two scour chains were installed vertically into the channel bed at each streambed monitoring location to be used in evaluating streambed mobilization. Each scour chain was made from a 2.5-ft-long heavy-duty steel chain attached to a 1 ft^2 plate of 0.25-inch thick steel used as an anchor. Scour chains were installed by digging a hole of appropriate depth in the streambed using a hand shovel. After placing the steel plate of the scour chain into the bottom of the hole, the chain was held vertically while the bed materials were replaced. In September 2002, scour depth was determined by excavating down to the chain and measuring the length of the disturbed chain. The scour chain was then reinstalled by replacing the bed material and the length of exposed chain was measured. Scour chain monitoring was discontinued after September 2002. By that time the chains had accumulated rust, and the chain links were no longer flexible.

The scour chain program was resumed in 2014. Two scour chains were installed at three of the four monitoring sites (Ennis Campground, Norris Bridge, and Greycliff Fishing Access). Each scour chain was co-located at documented locations of salmonid spawning.

The composition of substrates within each sediment monitoring location is sampled using a 12-inch diameter core sampler, designed after a 6-inch version developed by McNeil and Ahnell (1964) (Figure 2-5). At each site, samples are collected from five locations, representative of salmonid spawning gravel areas. Substrate samples are collected to a depth of 8 inches below the streambed level. The samples encompass an area of the streambed that is 12 inches in diameter and 8 inches high; samples weigh approximately 60 pounds each (dry weight). Beginning in 2013, sediment cores were colocated at previously recorded salmonid spawning locations.

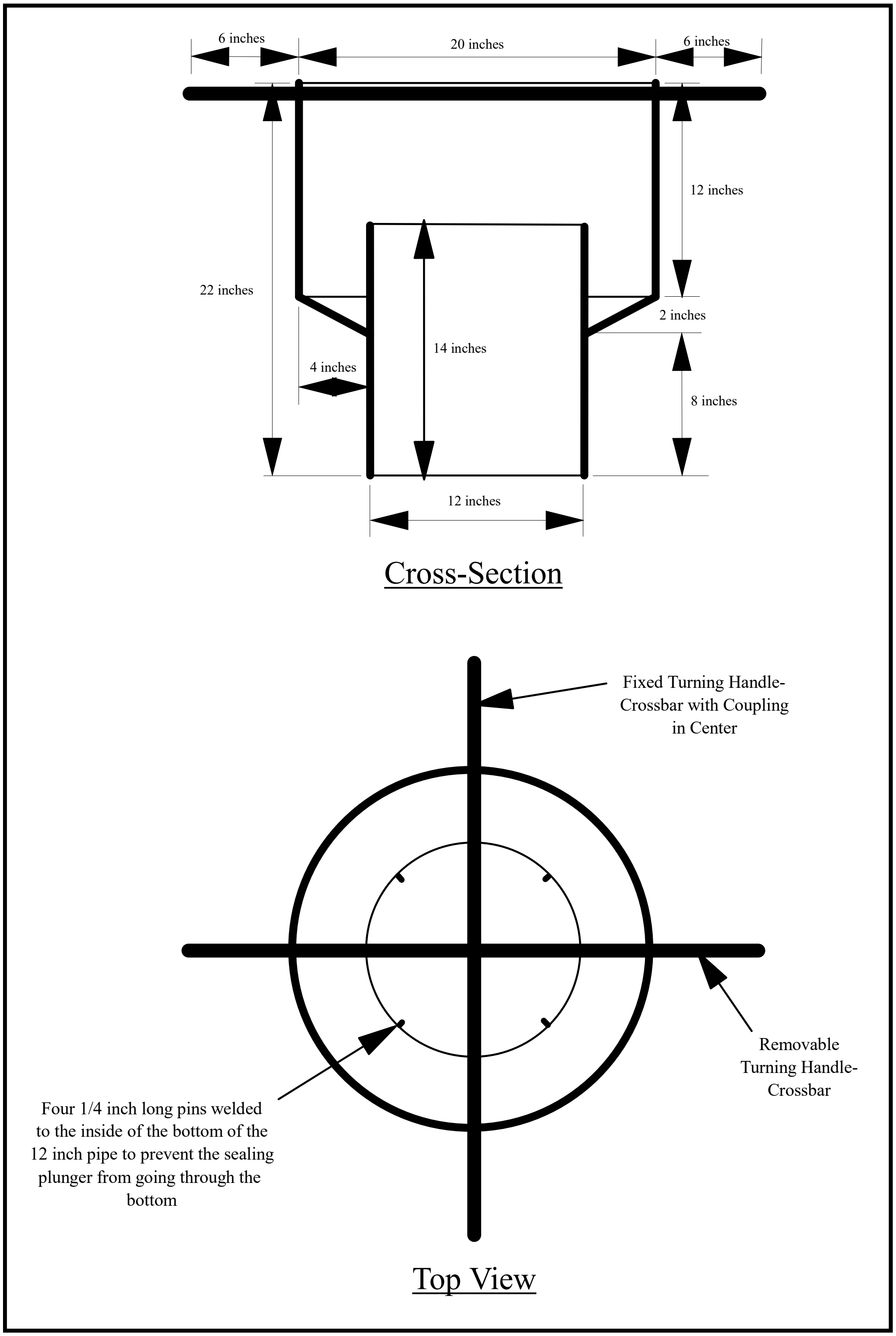

Figure 2-5. Schematic of 12-inch diameter substrate sampler, modeled after the original 6-inch diameter sampler developed by McNeil and Ahnell (1964).

An estimate of embeddedness, as defined by Platts et al. (1983), was performed at regularly spaced intervals across each transect. Embeddedness was visually estimated as the percentage of the surface of the dominant particle size covered by fine sediment within one meter of the sample location. Performing visual estimates of embeddedness was discontinued in 2012.

2.1.2 Aquatic Macroinvertebrate Sampling

Macroinvertebrate sampling was conducted for the Madison River Flushing Flow program in 1996-1997, 2002, and 2007. During this same time period, macroinvertebrates were also collected for the Madison/Missouri Water Quality program, at seven sites in the Madison River (Table 2-1). Beginning in 2008, macroinvertebrate sampling for the Madison/Missouri Water Quality and the Madison River Flushing Flow programs were consolidated. Both studies are improved by implementation of a consistent sampling design and development of a more comprehensive database.

Table 2-1. Period of record for Madison River aquatic macroinvertebrate monitoring sites.

Madison River Stations	Water Quality Program August Samples	Flushing Flow September Samples
YNP	1995-2016	
HWY 287	1996-2008	
Hebgen	1995-2016	
Kirby Ranch	2008-2016	1996-97, 2002, 2007
Ennis Campground	1997-2016	1996-97, 2002, 2007
Madison Powerhouse	1995-2016	
Norris Bridge	2000-2006, 2008-2016	1996-97, 2002, 2007
Greycliff Fishing Access	2000-2006, 2008-2016	1996-97, 2002, 2007

Five macroinvertebrate samples are collected at each site using the modified kick-net procedure described by Hauer et al. (1991). This sampling technique is standard for NWE studies on the Madison and Missouri rivers (MDHES 1993). To better characterize the benthic fauna at each site, sampling effort was partitioned among wadeable habitats at each site. Four samples were stratified by depth (shallow/deep) and water velocity (slow/fast). The fifth sample was taken from the most abundant (typical) habitat type at the site.

Each sample is taken with a kick-net with a 0.5 by 0.2 m rectangular opening and 800-900 μm mesh netting. Within a selected habitat, a sampling grid (delineating a 0.25 m^2 area) is randomly placed on the stream. Samples are collected in the substrate by hand scrubbing cobbles and vigorously kicking and agitating smaller substrate particles within the 0.25 m^2 plot while holding the kick net directly downstream. The contents of the net are then transferred to labeled containers and preserved in 90% ethanol. Surface substrate size composition within the sampled plot is visually estimated. In addition, water depth is recorded and mean water column velocity is measured with a Marsh-McBirney current meter.

Processing of the benthic macroinvertebrate samples is consistent with the techniques and procedures used for NWE annual macroinvertebrate monitoring on the Madison and Missouri rivers (McGuire 1999), using the EPA Rapid Bioassessment Protocols (Plafkin et al. 1989) to obtain a 300-organism fixed-count subsample. The use of a fixed-count subsample standardizes kick sample data and allows quantitative comparisons to a reference condition (Barbour and Gerritsen 1996).

For processing, a sample is first emptied into a U.S. Standard #30 sieve and rinsed with water. Subsampling protocols differ, depending upon the volume of sample material. For small samples (<0.5 liters), the entire sample is then evenly distributed within a gridded enamel pan ranging from 9" x 12" to 14" x 20", depending on the sample's volume. All macroinvertebrates in a randomly selected grid square are removed. This process is repeated until 270 to 330 organisms (300±10%) had been picked. The remainder of the sample was scanned and any organism suspected of not being represented in the subsample was retained. These rare taxa were identified and included on the site taxa list and in the estimated taxa richness for the entire sample. Additionally, all New Zealand mud snails in the sample were counted.

Larger samples (>0.5 liters) are processed in batches (30 to 100 ml), with each batch distributed into the gridded enamel pan. For each batch, macroinvertebrates are removed from 10 or 20% of the grids (random selection; minimum of 2 grids per pan). This procedure is repeated for each batch until the entire sample has been processed. If this process results in more than 300 organisms, only the first ~300 organisms recovered are used to calculate metrics. An estimate of the total number of organisms in the sample was based on the percentage of sample used to obtain the approximately 300 organisms.

Macroinvertebrates are identified to taxonomic levels specified in the Montana Department of Environment Quality (MDEQ) Rapid Bioassessment Protocols SOPs (MDEQ 1998) using the most recent published taxonomic literature.

2.1.3 Hydrologic Data

Daily streamflow data and annual instantaneous peak flow data are obtained from the U.S. Geological Survey (USGS). Streamflow data are obtained from the USGS gages located on the

Madison River below Hebgen Lake (Gage No. 06038500), at Kirby Ranch (USGS Gage 06038800), and below Ennis Lake (Gage No. 06041000).

2.1.4 Water Temperature Data

Available Madison River water temperature data are obtained from the USGS for the warm summer portion of the year.

2.1.5 Redd Surveys

Redd surveys were conducted at all four sites in the spring (Rainbow Trout) and in the fall (Brown Trout). Redd surveys were monitored according to the following schedule:

- Kirby Ranch
    - Spring – 2013, 2015, 2016, and 2017
    - Fall – 2014, 2015, 2016, and 2017
- Ennis Campground
    - Spring – 2013, 2015, 2016, and 2017
    - Fall – 2013, 2014, 2015, 2016, and 2017
- Norris Bridge
    - Spring – 2013, 2015, 2016, and 2017
    - Fall – 2013, 2014, 2015, 2016, and 2017
- Greycliff Fishing Access
    - Spring – 2013, 2015, 2016, and 2017
    - Fall – 2012, 2013, 2014, 2015, 2016, and 2017

The location of each redd was recorded with GPS. The dimensions of each redd (depth, length, and width) were measured.

2.2 DATA ANALYSIS

The channel morphology, sediment, macroinvertebrate, streamflow, and water temperature data are analyzed to help determine whether there is a need for flushing flows in the upper Madison and/or lower Madison reaches. The methods for performing these analyses are described in this section.

2.2.1 Channel Morphology and Sediment Characteristics

Cross-sectional plots are prepared of each of the three transects at each of the four monitoring sites. These plots allow for a visual comparison with cross-sections surveyed in 1995, 1996, 1997, 2002, 2007 and 2015. The average channel bed elevation is calculated for each transect and compared with channel bed elevations previously determined from 1995, 1996, 1997, 2002, 2007 and 2015.

When the scour chains were initially installed in 1995, they appeared as shown in Figure 2-6.

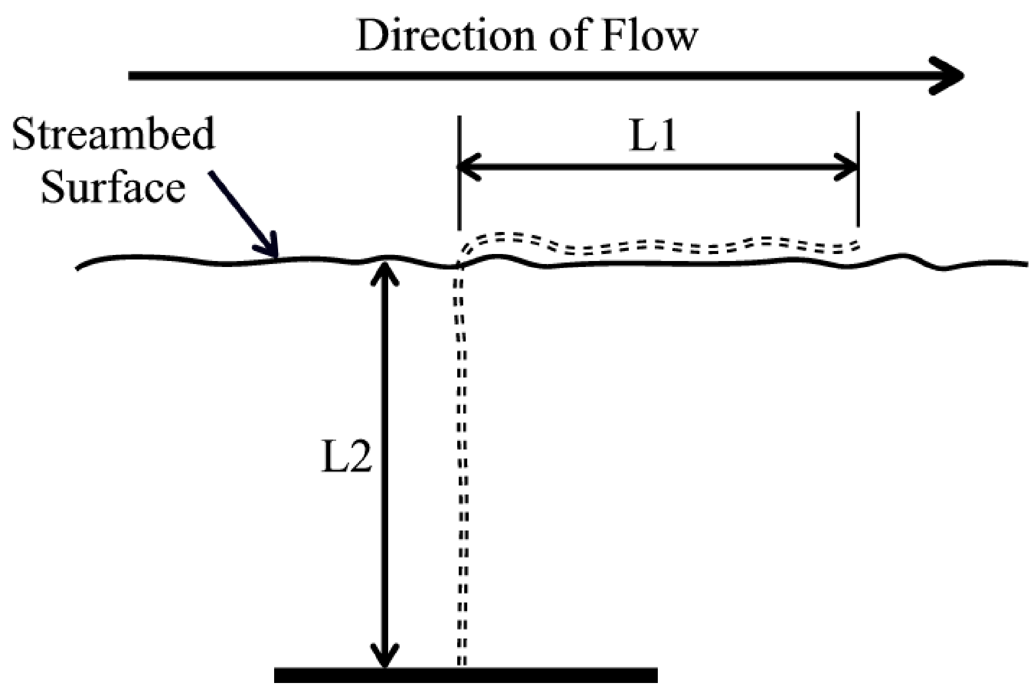

Figure 2-6. Scour chain when initially installed.

During a subsequent monitoring session, the scour chain might look as shown in Figure 2-7. The total length of scour chain would remain unchanged between sessions.

$$\text{Length of scour chain} = L1 + L2 = L3 + L4$$

The maximum depth of scour between sessions was determined as follows:

$$\text{Maximum scour depth} = L2 - L4 = L3 - L1$$

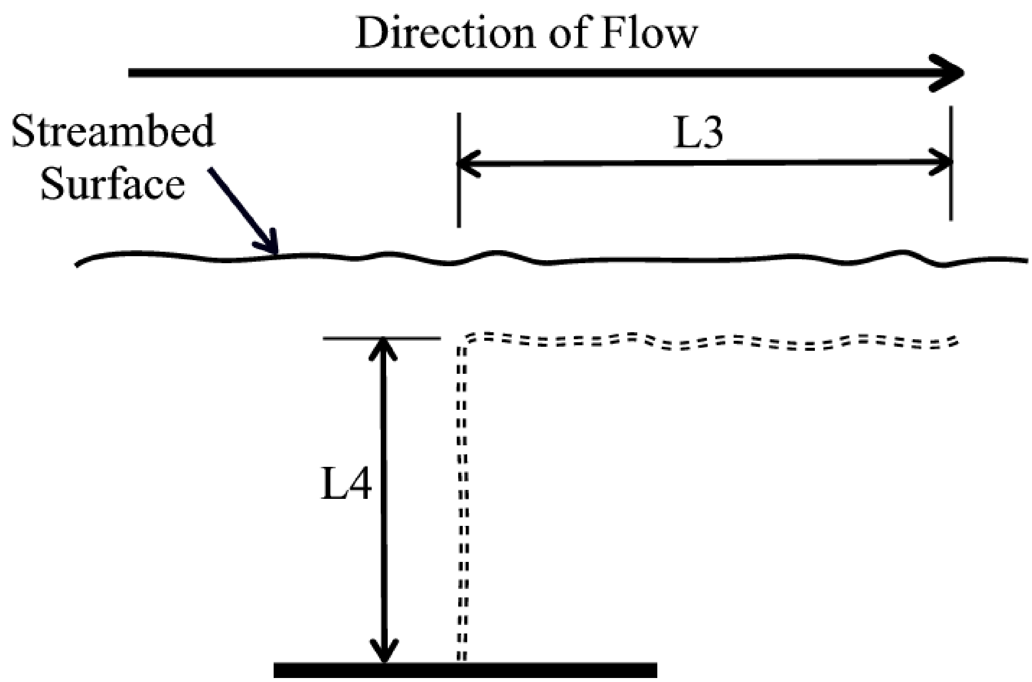

Figure 2-7. Scour chain during monitoring session.

The maximum depth of scour was determined by measuring L3 (current length of exposed chain) and L1 (length of exposed chain when it was installed), and by then applying the formula shown above.

After the monitoring session, the reinstalled scour chain would look as shown in Figure 2-8. The total length of scour chain would still remain unchanged.

$$Length\ of\ scour\ chain = L1 + L2 = L5 + L6$$

If L6 were greater than L2 (L1 is greater than L5), then there would have been net fill between monitoring sessions. The depth of net fill would be as follows:

$$Depth\ of\ net\ fill = L6 - L2 = L1 - L5$$

If L2 were greater than L6 (L5 is greater than L1), there would have been net scour between monitoring sessions. The depth of net scour would be as follows:

$$Depth\ of\ net\ scour = L2 - L6 = L5 - L1$$

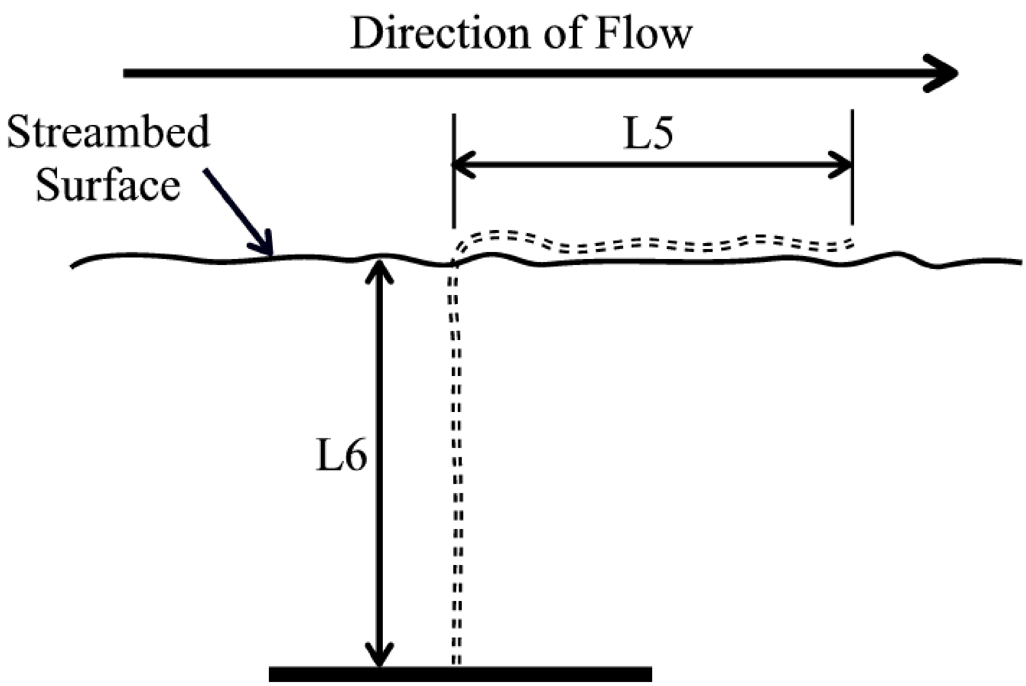

Figure 2-8. Scour chain after reinstallation.

The depth of net scour or fill was determined by measuring L5 (the length of exposed chain after it is reinstalled) and L1 (the length of exposed chain when it was originally installed), and by then applying one of the two previously mentioned formulas.

Particle grain size distributions are determined based on dry weight using sieve analyses. The following sieve sizes are used:

Sieve Size	Sieve Size	Sieve Size
5" (127 mm)	3/8" (9.5 mm)	#10 (2.00 mm)
4" (102 mm)	5/16" (7.9 mm)	#20 (0.84 mm)
2 ½" (63.5 mm)	¼" (6.35 mm)	#35 (0.50 mm)
1 ¼" (31.8 mm)	#4 (4.75 mm)	#230 (0.062 mm)
5/8" (15.9 mm)	#5 (4.00 mm)	

The grain size distribution of each sample is analyzed to determine five characteristic grain sizes ($D_{15.9}$, D_{25}, D_{50}, D_{75}, and $D_{84.1}$). The geometric mean diameter (Dg), sorting coefficient (So), and Fredle Index (Fi) is then determined from the following equations:

$$Geometric\ mean\ diameter = D_g = \sqrt{D_{15.9} * D_{84.1}}$$

$$Sorting\ Coefficient = S_o = \sqrt{\frac{D_{25}}{D_{75}}}$$

$$Fredle\ index = F_i = \frac{D_g}{S_o}$$

The percentage of each sample finer than 0.84 mm and 6.4 mm is also determined.

Average embeddedness is determined for each transect and also for each site. Embeddedness assessments are compared with embeddedness assessments from 1995, 1996, 1997, and 2002.

2.2.2 Aquatic Macroinvertebrates

The total number of macroinvertebrates per sample is extrapolated from the percentage of the sample used to obtain approximately 300 organisms. A total of 30 metrics were used to quantify community structure, taxonomic composition, and functional feeding groups. Unless explicitly stated, all metric values were based on 300-count subsamples. The following metrics and biotic indices were calculated for each invertebrate sample collected in the Madison River:

Community Structure Metrics

Community Density – Extrapolated from sample counts to estimated number per 1.0 m^2. Provides a relative measure of macroinvertebrate community standing crop. Kick-net samples are considered semi-quantitative because burrowing organisms and those tightly attached to substrates tend to be under-collected. Nevertheless, kick-net sampling can provide approximate density estimates for each site.

Taxa Richness – The number of different types, or taxa, of invertebrates occurring in a given ecosystem or sample. Taxa richness generally increases with increasing water quality and/or habitat diversity, and is used as a relative measurement of the health of the benthic invertebrate community. The mean taxa richness for the five samples at each site and the total taxa richness for the site are reported.

Shannon-Weaver Diversity Index – A commonly used index of ecological diversity (Pielou 1966; Ricklefs 1979) that combines the number of taxa present in a sample with the relative abundance of taxa in that sample. The Shannon-Weaver Index (Weber 1973) is calculated as follows:

$$H = -\sum p_i \ln p_i$$

where p_i is the proportion of each taxa in a sample. This diversity index increases as the number in a sample increases and the distribution of taxa in a sample is more uniform. The maximum value of H for a sample is a function of the number of taxa in a sample and the uniformity of the taxa distribution, where common taxa contribute to a relatively high fraction of this index, and rare taxa contribute a relatively low fraction of this index.

Percent Relative Abundance of Dominant Taxon – The percent contribution of the numerically dominant taxon to the total number of invertebrates present in a sample. A community dominated by a single species may indicate environmental stress.

Community Composition Metrics

EPT Richness – The number of distinct taxa within the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). The EPT Richness index summarizes taxa richness within the insect orders containing many pollution-sensitive species. EPT Taxa Richness values generally increase with increasing water quality. Both mean and total EPT taxa richness values were determined.

Percent Relative Abundance of EPT – The percent abundance of the insect orders Ephemeroptera, Trichoptera, and Plecoptera in a sample.

Percent Relative Abundance of Chironomidae – The insect family Chironomidae (midges) includes several highly tolerant species (Lenat 1983). A disproportionate number of Chironomidae may indicate environmental stress.

Ratio of Baetidae to Ephemeroptera – The percent contribution of the family Baetidae to the total abundance of mayflies. The family Baetidae includes many of the most pollution tolerant mayflies (Hubbard and Peters 1978). Environmental stress is often indicated when baetids comprise most of the mayfly fauna.

Ratio of Hydropsychinae to Trichoptera – The percent contribution of the caddisfly subfamily Hydropsychinae to total caddisfly abundance. Members of this subfamily (primarily *Hydropsyche*, *Ceratopsyche*, and *Cheumatopsyche*) are generally more tolerant of pollutants than most caddisflies (Harris and Lawrence 1978). Environmental stress is often indicated when these are the predominant caddisflies at a site.

Ordinal Relative Abundance – The percent relative abundances of six major taxonomic groups: Ephemeroptera, Plecoptera, Trichoptera, Coleoptera, Diptera, and Non-insects. The relative abundance of major taxonomic groups provides information on a stream community's structure and the relative contribution of the populations to the total fauna (Barbour et al. 1999).

Functional Feeding Group Relative Abundance – Each aquatic invertebrate taxon was placed in one of five functional food groups, which identify its trophic status (i.e., food requirements). The functional food group categories were: 1) scapers/grazers, which feed upon attached algae or periphyton; 2) shredders, which feed upon coarse particulate organic matter (CPOM) such as leaves; 3) collectors, which feed upon fine particulate organic matter (FPOM); 4) filter feeders, which feed upon FPOM within the water column; and 5) predators. Invertebrate functional food groups were taken from MDEQ's RBP (MDEQ 1998).

Biotic Indices

Modified Hilsenhoff Biotic Index – The modified Hilsenhoff Biotic Index (HBI; Hilsenhoff 1987) is used to portray the overall pollution tolerance of the benthic invertebrate community as a single value (Plafkin et al. 1989). Tolerance values range from 0 to 10, with 0 describing very little or no tolerance to organic pollution, and 10 describing very high tolerance to organic pollution. The HBI is calculated as:

$$HBI = \frac{\sum x_i \; t_i}{n}$$

where x_i is number of individuals within a given taxon, t_i is the tolerance value for this taxon, and n the total number of organisms in a sample. Tolerance values used for this study were obtained from MDEQ's RBP (MDEQ 1998).

Metals Tolerance Index – (McGuire 1993) Metals tolerance values range from 0 to 10, with 0 describing low tolerance to metals pollution, and 10 describing very high tolerance to metals pollution. The calculation of this index is based on Hilsenhoff's biotic index and is calculated as:

$$MTI = \frac{\sum_{i=1}^{n} x_i t_i}{n}$$

where x_i is number of individuals with a given taxon, t_i is the metals tolerance value for this taxon, and n the total number of organisms in a sample. Tolerance values used for this study were obtained from MDEQ's RBP (MDEQ 1998).

Sediment Indices

Six metrics have been used to evaluate sediment/ macroinvertebrate relationships in the Madison River:

Number of Sediment-Tolerant Taxa

Number of Sediment- Intolerant Taxa

Relative Abundance (%) of Sediment-Tolerant Taxa

Relative Abundance (%) of Sediment-Intolerant Taxa

Estimated Percentage Surface Fines (<0.06 mm)

Estimated Percentage of Sand (<2 mm)

These metrics are based on differential tolerances of stream dwelling macroinvertebrate taxa to fine sediments. Sediment tolerance and optimal values have been calculated for many stream dwelling macroinvertebrate taxa found in the western United States by Yuan (2006), Huff et al. (2006), and Relyea et al. (2001). Taxa richness and relative abundance metrics are categorical classifications (tolerant/intolerant) and use pooled data (all replicates combined). Estimates of surface fines and sand are calculated based on taxa optima using the formula:

$$Percent\ substrate = [Sum\ (x_i\ t_i)] / n$$

where x_i is number of individuals within a given taxon, t_i is the optimal value for this taxon, and n the total number of organisms in a sample for which optima have been established.

Optimum fine sediment (< 0.06 mm) values are from Huff et al. (2006) while sand substrate (< 2 mm) optima are from Yuan (2006). Application of these metrics to the Madison River is exploratory. These data establish a baseline for the Madison River, but macroinvertebrate-based criteria have not been developed.

Multimetric Bioassessment

Missouri-Madison River Multimetric Assessment (MMRMA) – The multimetric approach quantifies attributes of community composition, structural, and functional organization into a single number estimate of biological integrity (Barbour et al. 1995). This index is a mathematical combination of six metrics that measures the overall response of the community to environmental alteration and stressor conditions (Karr et al. 1986). The most appropriate multimetric assessment for this investigation was developed from NWE annual biomonitoring on the Missouri and Madison rivers. The metrics and rating criteria for estimating biointegrity (Table 2-2) were developed using Madison and Missouri River data collected from 1994-1998 (McGuire 1999). The number of macroinvertebrate taxa (distinct types) is a reliable measure of overall environmental condition for most streams (Hellawell 1978; Plafkin et al. 1989). Consequently, the multimetric assessment is heavily weighted with species richness metrics (total taxa richness, EPT richness, and Shannon diversity). Community composition is characterized by EPT richness, and the relative abundances (percentages) of EPT and chironomids in the sample. The Biotic Index is based on the indicator organism approach to water quality assessment and was developed to measure organic pollution. The MMRMA score ranges from 0 to 100%. High scores are characteristic of minimally impacted stream reaches.

Table 2-2. Metrics and criteria for the Missouri-Madison River Multimetric Assessment (MMRMA) used to assess trends in Madison and Missouri River benthic macroinvertebrate assemblages (McGuire 1999).

Metric	**Scoring Criteria**					
	5	**4**	**3**	**2**	**1**	**0**
Taxa richness	<32	32-28	27-23	22-18	17-13	<13
EPT richness	>16	16-13	12-9	8-5	4-1	0
Shannon diversity	>3.3	3.3-3.1	3.0-2.8	2.7-2.5	2.4-2.2	<2.2
Biotic index	<4.1	4.1-4.6	4.7-5.2	5.3-5.8	5.9-6.4	>6.4
% EPT	>70	70-61	60-51	50-41	40-31	<31
% Chironomidae	<21	21-25	26-30	31-35	36-40	>40

Assessment score calculated as the sum of metric scores divided by the maximum possible score.
All values are per 300 organism subsample.

2.2.3 Streamflow Analysis

Annual instantaneous peak flows and annual maximum three-day averaged flows are determined for the Madison River below Hebgen Lake (Gage No. 06038500) and below Ennis Lake (Gage No. 06041000). The annual maximum three-day averaged flow is particularly meaningful with regard to flushing flows in the lower Madison (R2 2000).

2.2.4 Water Temperature

Available water temperature records from the Madison River are reviewed. Particular attention is paid to the summer months in the lower Madison River.

2.2.5 Redd Surveys

The total number of redds was determined for Kirby Ranch, Ennis Campground, Norris Bridge, and Greycliff Fishing Access. Annual total redd counts were determined for the spring and fall monitoring sessions.

3. REVIEW OF MONITORING RESULTS

This section presents the results of channel morphology surveys, sediment sampling, aquatic macroinvertebrate sampling, sediment/macroinvertebrate correlation analyses, streamflow assessment, and water temperature evaluations.

3.1 CHANNEL MORPHOLOGY AND SEDIMENT CHARACTERISTICS

Channel cross-sectional profiles are depicted in Figures 3-1, 3-2, 3-3, and 3-4 for Kirby Ranch, Ennis, Norris Bridge, and Greycliff Fishing Access, respectively. In 2015, survey crews struggled to relocate the transects as many of the headpins had been removed. Crews used GPS, aerial photographs, and field notes to best locate and recreate previously surveyed Madison River transects. Average streambed elevations for each cross-section at all four sites are summarized in Table 3-1 for 1995, 1996, 1997, 2002, 2007 and 2015. From 1995 to 2015, the net change in average streambed elevation has been no more than 0.1 feet at Kirby Ranch Transects 1 and 3, Transects 1 and 3 at the Ennis Site, Norris Bridge Transects 1-3, and Greycliff Fishing Access Transect 2.

Kirby Ranch Transect 3 shows an increase in average streambed elevation of 0.3', although it appears it may be a product of a slight difference in survey alignment compared with years past (as shown by the additional width surveyed on the right bank).

The 2015 survey at Transect 2 at the Ennis Site shows some of the lowest elevations surveyed. Although the average streambed elevation at Transect 3 at the Ennis Site has changed by only 0.1 feet from 1995 to 2015, one side of the cross-section has accumulated sediment while the other side of the cross-section has scoured. The Ennis Site is located just upstream from a bridge and is vulnerable to ice scour. Numerous mainstem and tributary sediment sources in the upper watershed most likely contribute to the dynamic nature of the river morphology at the Ennis Site.

Based on an examination of the transect profiles at Greycliff Fishing Access, it is possible that the 2015 survey alignments differed slightly from years past. Greycliff Transects 1 and 3 show notable upward shifts from years past, while the 2015 Transect 2 profile appears to have included a swampy area off the main channel that was not included before. It is unclear if these changes and shifts seen in 2015 are temporary, long-term, or a product of transect misalignment.

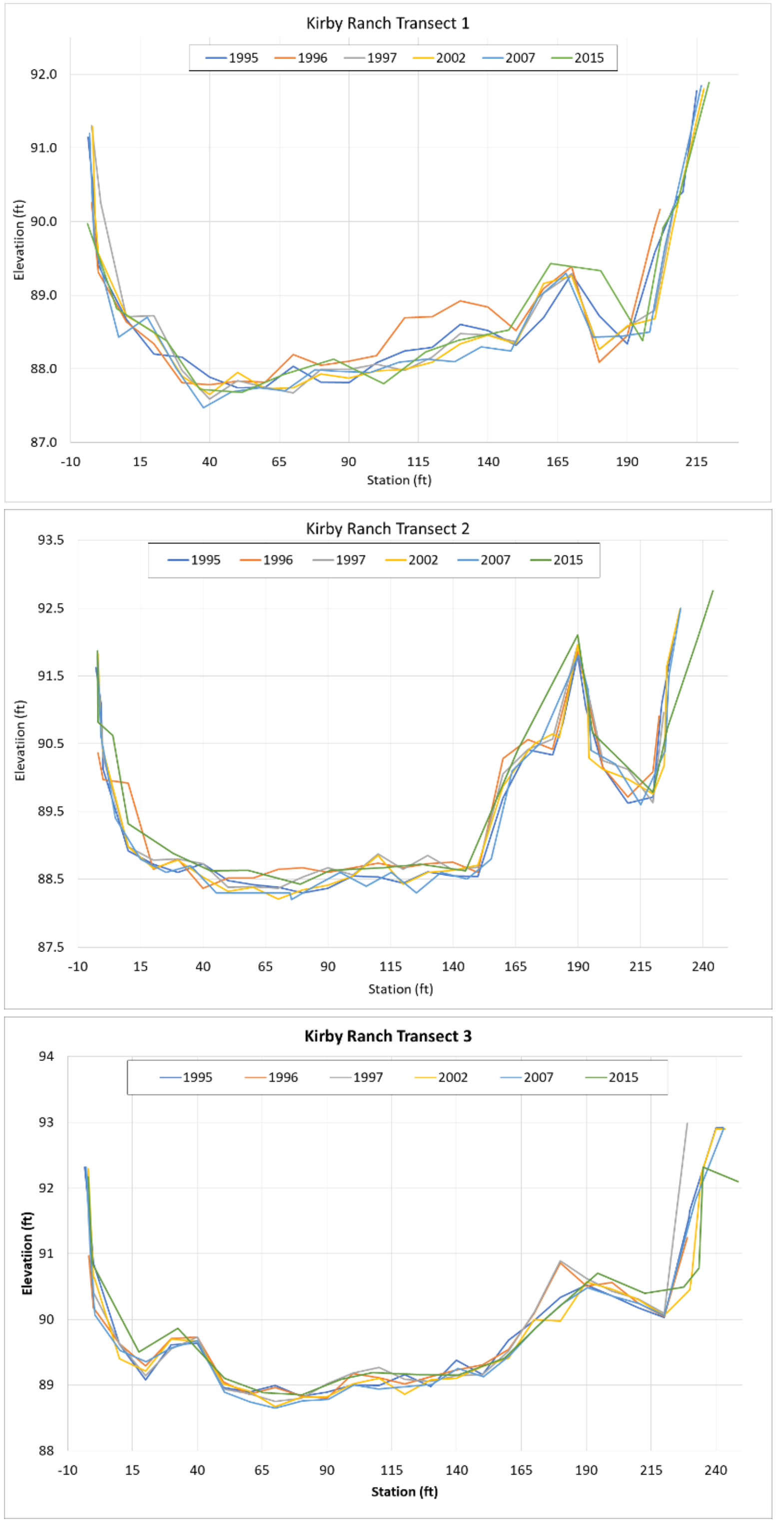

Figure 3-1. Cross-sectional profiles from reference Transects 1, 2, and 3 of the Kirby Ranch Site of the Madison River, Montana, 1995, 1996, 1997, 2002, 2007 and 2015.

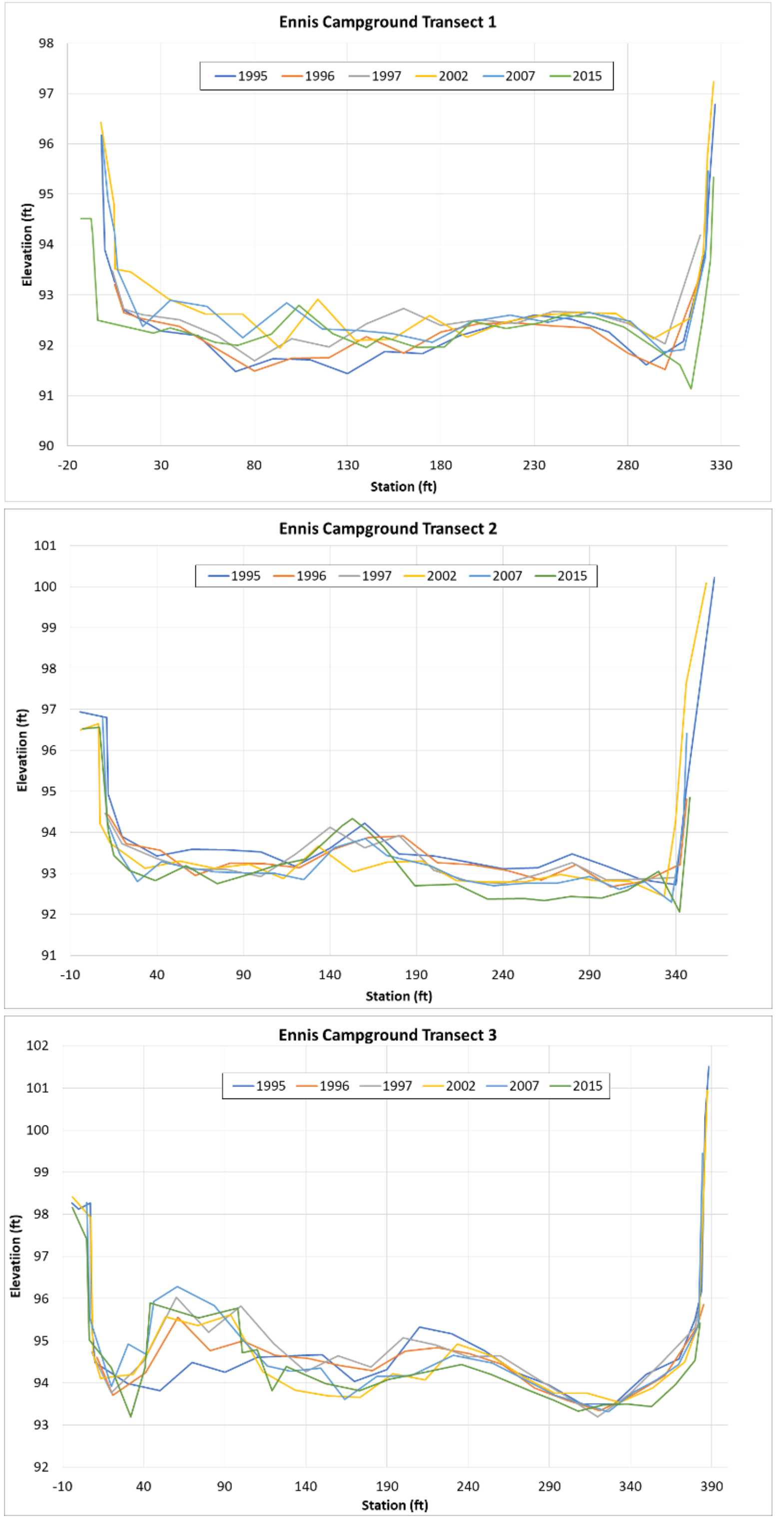

Figure 3-2. Cross-sectional profiles from reference Transects 1, 2, and 3 of the Ennis Site of the Madison River, Montana, 1995, 1996, 1997, 2002, 2007, and 2015.

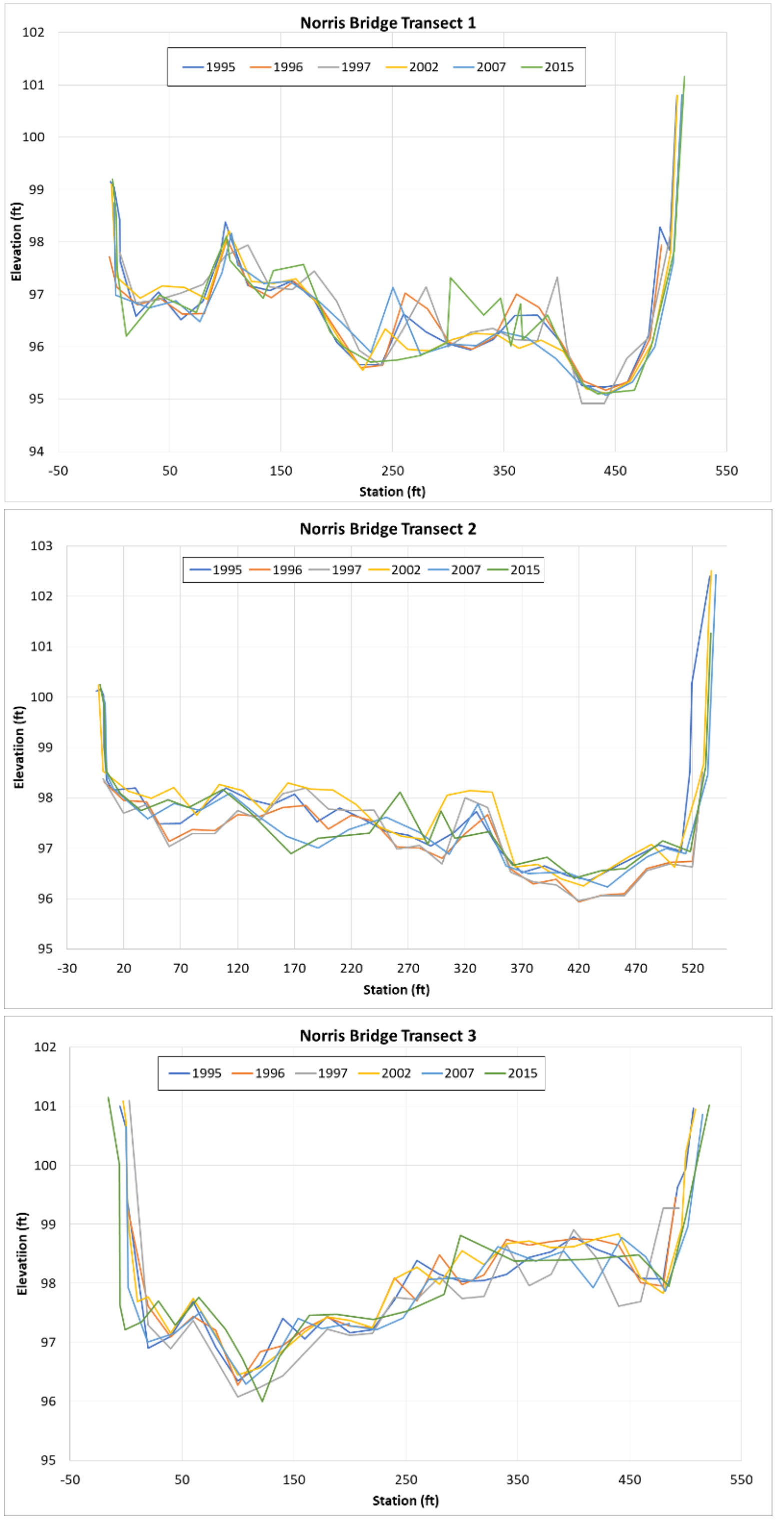

Figure 3-3. Cross-sectional profiles from reference Transects 1, 2, and 3 of the Norris Bridge Site of the Madison River, Montana, 1995, 1996, 1997, 2002, 2007, and 2015.

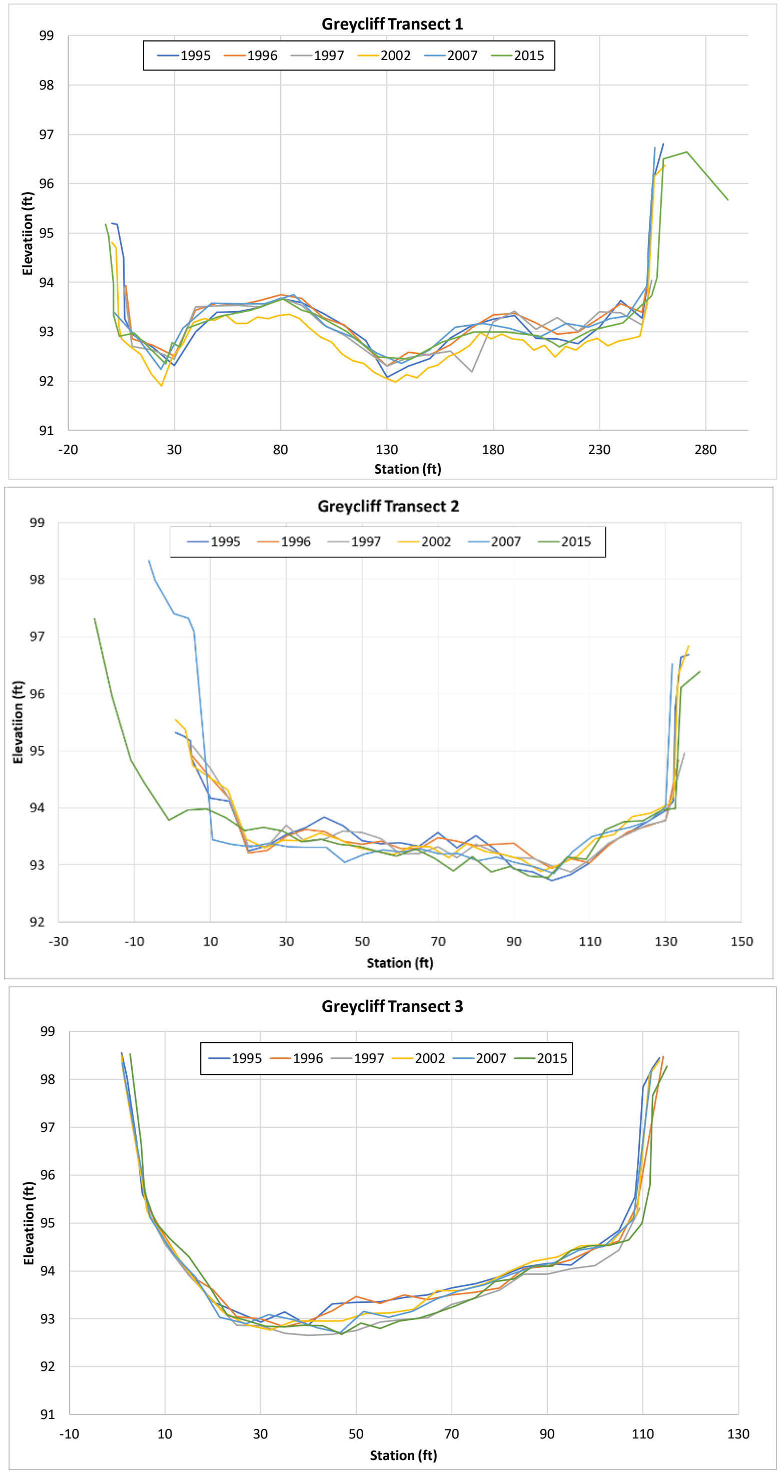

Figure 3-4. Cross-sectional profiles from reference Transects 1, 2, and 3 of the Greycliff Fishing Access Site of the Madison River, Montana, 1995, 1996, 1997, 2002, 2007 and 2015.

Table 3-1. Changes in average of relative streambed elevations by transect surveyed in September 1995, 1996, 1997, 2002, 2007, and 2015, Madison River, Montana.

		End Stations Used for Streambed Elevation Calculation		**Average Streambed Elevation (ft)**						**Elevation Change (ft)**					
Site	**Transect**	**Left Station (ft)**	**Right Station (ft)**	**1995**	**1996**	**1997**	**2002**	**2007**	**2015**	**1995-1996**	**1996-1997**	**1997-2002**	**2002-2007**	**2007-2015**	**1995-2015**
Kirby Ranch	1	0	200	88.3	88.5	88.3	88.3	88.2	88.4	0.2	-0.2	0.0	-0.1	0.2	0.1
	2	0	220	89.1	89.3	89.2	89.1	89.1	89.4	0.2	-0.1	-0.1	0.0	0.3	0.3
	3	0	220	89.5	89.5	89.5	89.4	89.4	89.6	0.0	0.0	-0.1	0.0	0.2	0.1
Ennis	1	5	320	92.1	92.1	92.4	92.5	92.5	92.2	0.0	0.3	0.1	0.0	-0.3	0.1
	2	10	340	93.4	93.3	93.2	93.1	93.0	93.0	-0.1	-0.1	-0.1	-0.1	0.0	-0.4
	3	20	380	94.3	94.4	94.5	94.3	94.4	94.2	0.1	0.1	-0.2	0.1	-0.2	-0.1
Norris Bridge	1	0	490	96.5	96.5	96.6	96.4	96.4	96.4	0.0	0.1	-0.2	0.0	0.0	-0.1
	2	0	510	97.4	97.1	97.2	97.6	97.3	97.3	-0.3	0.1	0.4	-0.3	0.0	-0.1
	3	10	490	97.7	97.8	97.6	97.9	97.7	97.8	0.1	-0.2	0.3	-0.2	0.1	0.1
Greycliff	1	10	250	93.0	93.1	93	92.7	93.1	93.0	0.1	-0.1	-0.3	0.4	-0.1	0.0
	2	5	130	93.5	93.5	93.5	93.5	93.4	93.4	0.0	0.0	0.0	-0.1	0.0	-0.1
	3	10	110	93.7	93.7	93.6	93.6	93.6	93.5	0.0	-0.1	0.0	0.0	-0.1	-0.2

Results of historical scour chain monitoring are summarized in Table 3-2. The scour chains show signs of substrate movement at Ennis, Norris Bridge, and Greycliff over the period from 1997 to 2002. The net change at all sites was relatively small.

Table 3-2. Scour, fill, and net bed elevation change from 1997 to 2002, as determined from scour chain measurements.

Site	Sample	Length of Exposed Chain (ft)			Scour (ft)	Fill (ft)	Net Change (ft)
		1997	2002	Re-Installed			
	KR-1	0.80	0.80	0.80	0.00	0.00	0.00
Kirby Ranch	KR-2	1.20	1.20	1.20	0.00	0.00	0.00
	EN-1	0.20	0.20	0.00	0.00	more than 0.20**	more than 0.20**
Ennis	EN-2	--	--	--	--	--	--
	NB-1	1.00	1.00	1.00	0.00	0.00	0.00
Norris Bridge	NB-2	1.30	1.75	1.50	0.45	0.25	-0.20
	GC-1	0.80	1.40	1.10	0.60	0.30	-0.30
Greycliff	GC-2	0.70	1.05	0.65	0.35	0.40	0.05

** - Scour Chain EN-1 is completely buried and resides in an area of ongoing deposition.

New scour chains were installed at the Ennis, Norris Bridge, and Greycliff sites in 2014 at the locations shown in Figures 3-5, 3-6, and 3-7, respectively. Since they were installed in 2014, the scour chains have been monitored each year, and there has been no measurable scour or fill.

Figure 3-5. Locations of scour chains installed at the Ennis Campground Site in 2014.

Figure 3-6. Locations of scour chains installed at the Norris Bridge Site in 2014.

Figure 3-7. Locations of the scour chains installed at the Greycliff Fishing Access Site in 2014.

Trends in percent fines less than 0.84 mm and less than 6.4 mm, Fredle Index, and geometric mean grain size are shown in Figures 3-8, 3-9, 3-10, and 3-11, respectively.

Trends in embeddedness are shown for the upper and lower Madison River sites for the time period including 1995, 1996, 1997, 2002, and 2007 in Figure 3-12. Embeddedness has remained generally low in the upper Madison River sites except for 1997 when embeddedness approached 40%. Embeddedness in the lower Madison River sites remained stable from 1995 through 2002 with annual averages in the 40% to 60% range, and then increased to about 80% in 2007.

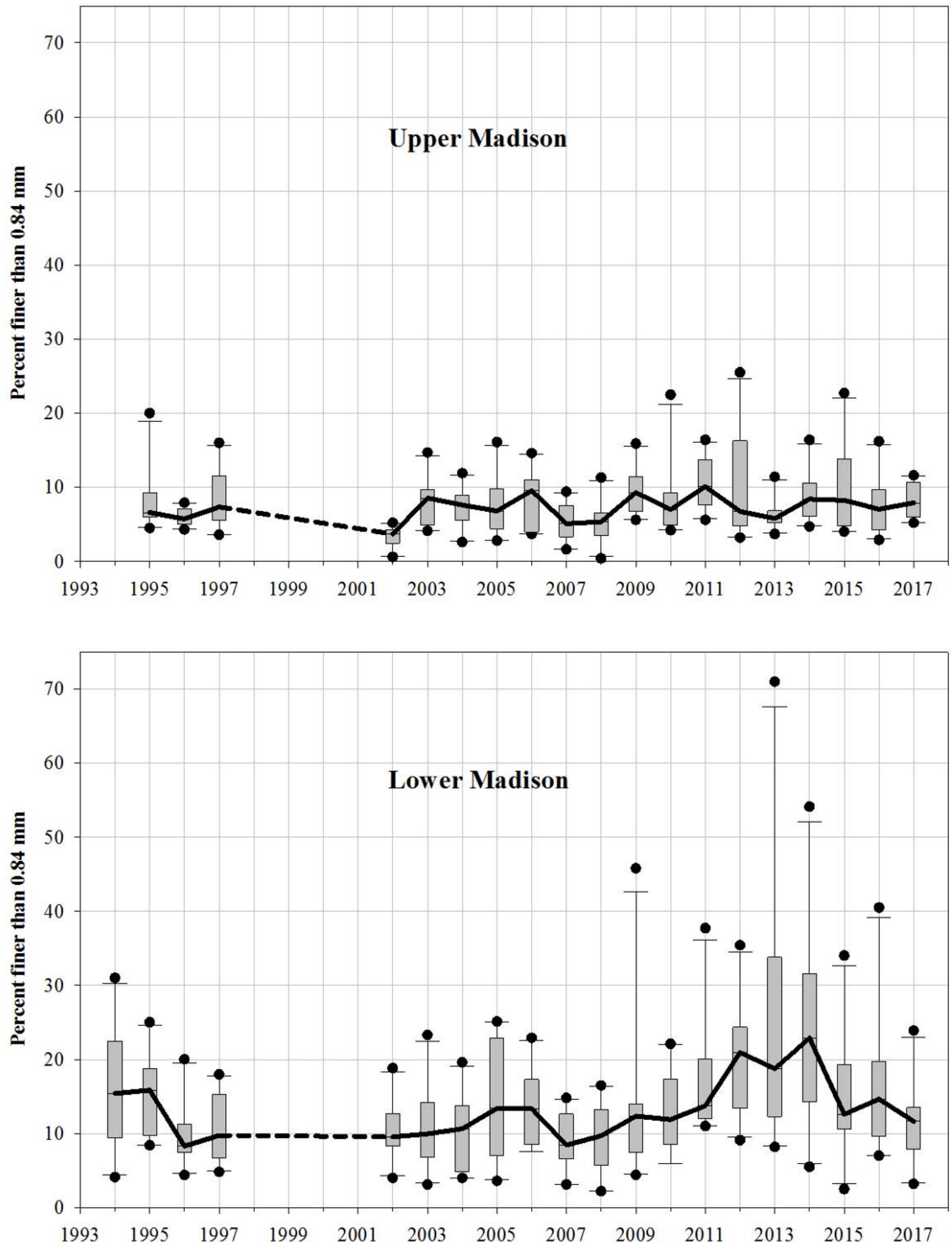

Figure 3-8. Trends in percent fines less than 0.84 mm of spawning gravel samples collected from the upper and lower reaches of the Madison River.

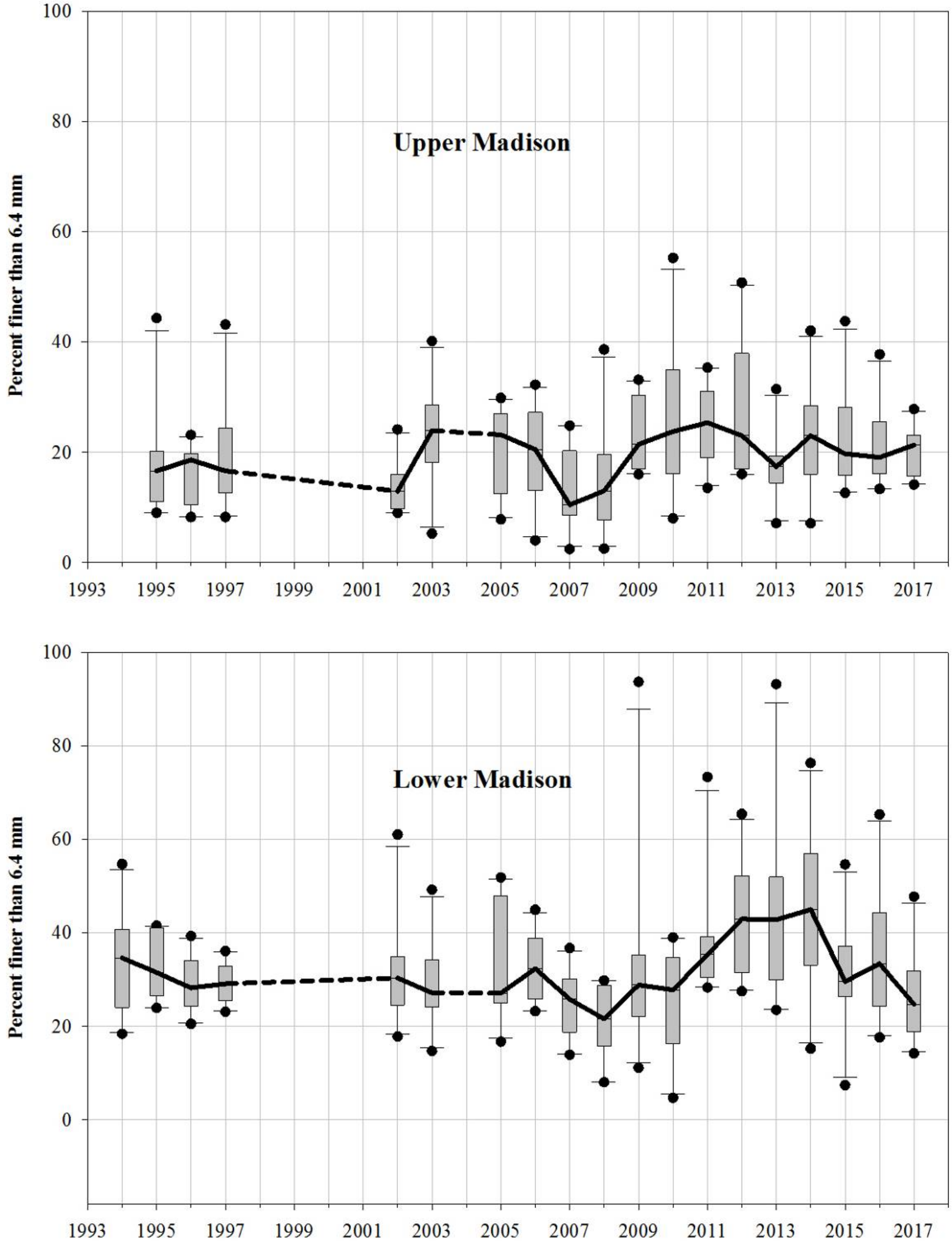

Figure 3-9. Trends in percent fines less than 6.4 mm of spawning gravel samples collected from the upper and lower reaches of the Madison River.

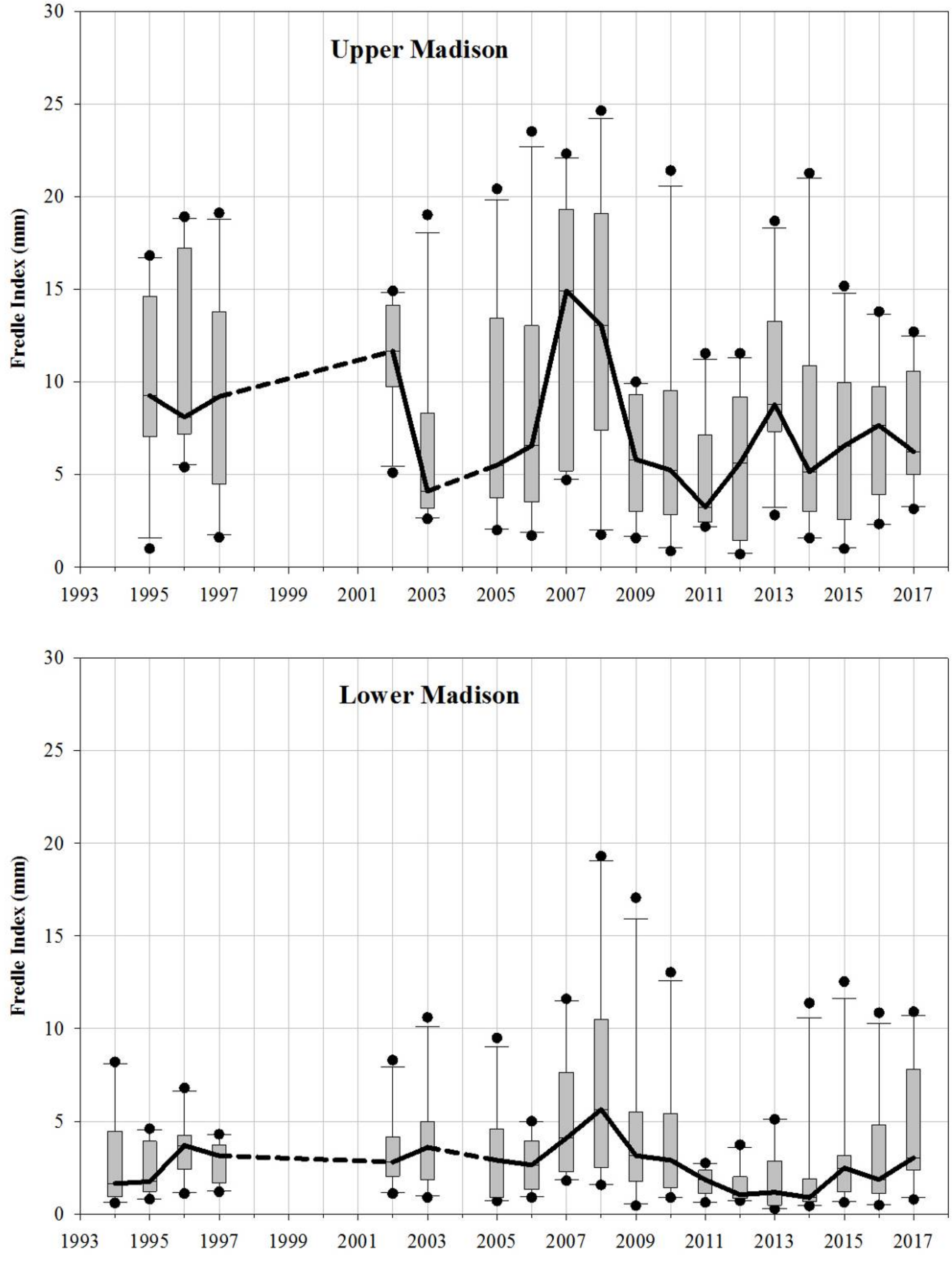

Figure 3-10. Trends in the Fredle Index computed from of spawning gravel samples collected from the upper and lower reaches of the Madison River.

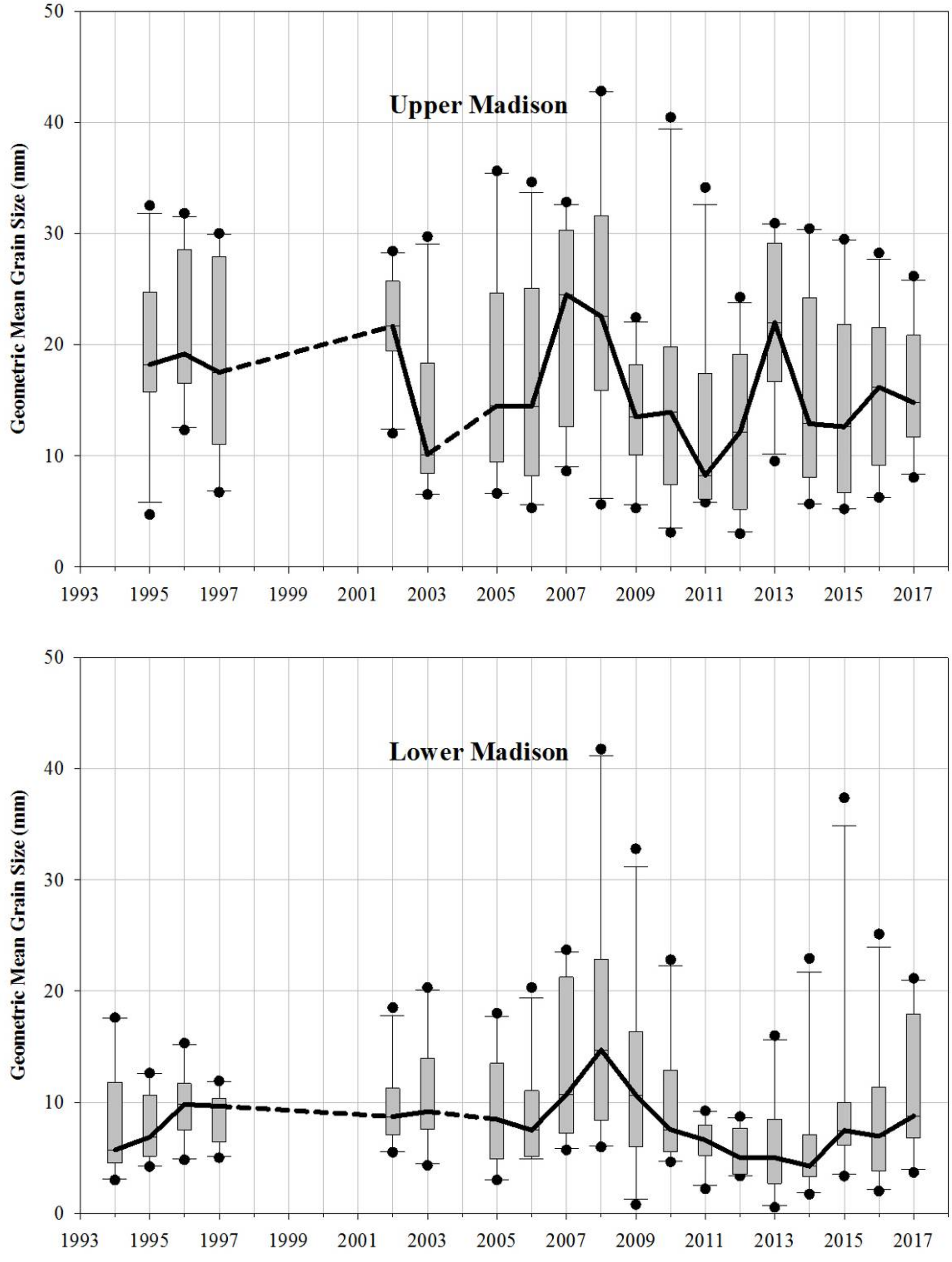

Figure 3-11. Trends in the geometric mean grain size of spawning gravel samples collected from the upper and lower reaches of the Madison River.

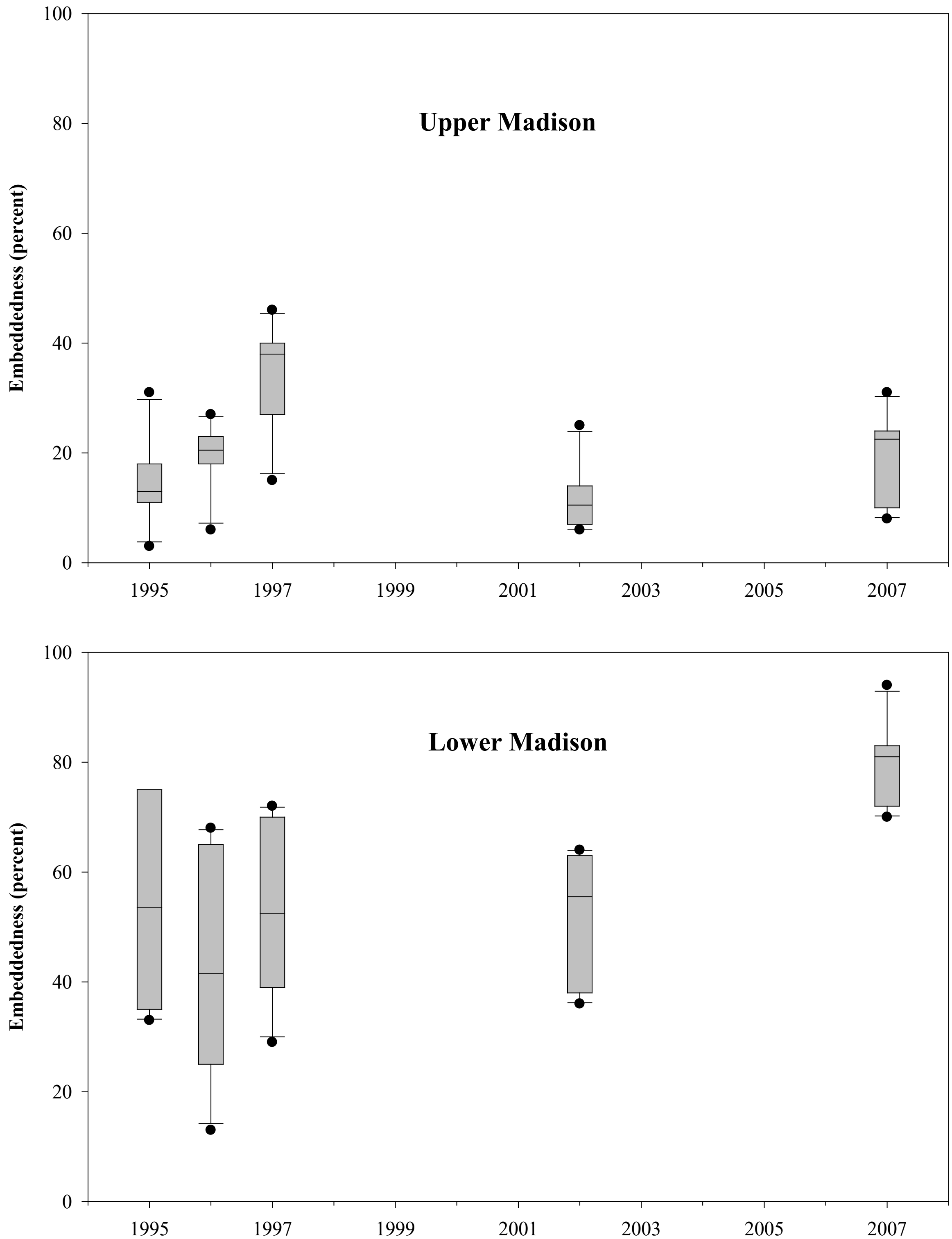

Figure 3-12. Trends in embeddedness values of substrate in the upper and lower reaches of the Madison River.

3.2 AQUATIC MACROINVERTEBRATES

Macroinvertebrate sampling results for August 2016, and temporal trends since 2008 are discussed below. Detailed results of each macroinvertebrate sample for 2016, including taxa counts, calculated metric values, and their associated means and standard deviations are presented in Appendix B (Tables B-1 through B-4). The macroinvertebrate samples were collected and analyzed by McGuire Consulting (Appendix C). The McGuire data report is included in Appendix C.

3.2.1 2016 Macroinvertebrate Survey

A total of 102 macroinvertebrate taxa were identified from the 2016 samples. A presence/absence list of taxa collected at each site is provided in Appendix B (Table B-5). Dipterans were the most diverse insect order with 29 taxa including 23 chironomid genera. Mayflies were represented by 20 species, and caddisflies included 22 taxa. Six stonefly taxa and 4 riffle beetle (Elmidae) genera were found. Single species of dragonfly, and aquatic moth were also collected. Non-insects were represented by 20 taxa including 7 worm taxa, 4 snail genera, 2 genera of fingernail clams, 2 flatworm taxa, and single taxa of scud, sowbug, crayfish, and water mite. The Greycliff site had the richest fauna with 73 taxa, and the Norris site had the fewest taxa with 55 (Table 3-3).

In August 2016, macroinvertebrate mean density estimates ranged from an estimated 6,851 individuals/m^2 at Kirby to 8,328 individuals/m^2 at Greycliff (Table 3-3). Insects dominated the Madison River macroinvertebrate fauna (Figure 3-10 and Table 3-3), accounting for 73% of the macroinvertebrates collected at Kirby, 83% at Ennis, and more than 90% of the fauna at the Norris and Greycliff sites. Caddisflies (Trichoptera) were the most abundant macroinvertebrates at Kirby (27%) and Ennis (58%), while mayflies (Ephemoptera) were more abundant at Norris (31%) and Greycliff (34%). The caddisfly *brachycentrus occidentalis* was the most abundant taxon in the Kirby, Ennis, and Greycliff samples, accounting for 10%, 24%, and 11%, respectively, of total community composition at these sites. This taxon was not prevalent at the Norris site, which had the midge *polypedilum sp*. (18%) as the most dominant taxon.

Table 3-3. Mean metric scores calculated for macroinvertebrate samples collected at four sites on the Madison River, Montana, August 2016.

	Kirby	**Ennis**	**Norris**	**Greycliff**
Community Structure Metrics:				
Mean Density (Indiv./m^2)	6,851	6,938	7,149	8,328
Mean Taxa Richness	35.4	34.4	35.0	40.4
Total Taxa Richness	62	61	55	73
Shannon-Weaver Index (log e)	2.84	2.55	2.76	3.04
% Dominant Taxa	18.4%	25.3%	21.5%	15.2%
Community Composition Metrics:				
Mean EPT Richness	16.0	15.4	15.2	18.4
Total EPT Richness	28	24	23	32
% EPT	44.4%	65.0%	50.6%	60.2%
% Chironomidae	14.8%	7.8%	29.2%	21.2%
Baetidae/Ephemeroptera	0.53	0.72	0.61	0.63
Hydropsychinae/Trichoptera	0.31	0.26	0.42	0.38
Ordinal Relative Abundances (Mean %):				
Ephemeroptera	14.9%	6.1%	30.6%	33.9%
Plecoptera	3.0%	1.0%	0%	0.3%
Trichoptera	26.6%	58.0%	19.9%	26.0%
Coleoptera	13.0%	18.8%	2.3%	8.8%
Diptera	15.9%	9.7%	29.8%	22.5%
Non-insect	26.7%	5.4%	17.0%	7.8%
Functional Feeding Groups (Mean %):				
Scrapers/Grazers	18.6%	19.6%	3.1%	3.2%
Shredders	1.9%	3.9%	4.8%	2.5%
Filter-feeders	21.4%	39.7%	11.2%	29.5%
Collector-Gatherers	49.5%	31.0%	67.1%	58.8%
Predators	8.7%	5.8%	13.8%	6.0%
Tolerance Indices:				
Mean Modified HBI	4.82	3.68	4.86	4.74
Mean Metals Tolerance Index (MTI)	3.97	3.79	3.19	3.55
Total Sediment Tolerant Taxa	12	12	16	23
Total Sediment Intolerant Taxa	7	7	0	3
% Sediment Tolerant	30.4%	8.8%	14.6%	25.3%
% Sediment Intolerant	6.2%	6.9%	0%	0.4%
Macroinvertebrate-Based Estimate of Sediment:				
% Surface Fines (<0.06 mm)	11.4%	0.4%	11.0%	10.7%
% Sands (<2 mm)	27.7%	0.9%	29.8%	29.4%

In general, the two lower Madison River sites, Norris and Greycliff, have similar compositions in terms of major taxa groups, although Norris has more non-insects and Diptera taxa (Figure 3-13). The Ennis site is dominated by caddisflies, mainly comprised of *brachycentrus occidentalis* (41% of caddisflies), but also *Helicopsyche borealis* (18%) and *Hydropsyche occidentalis* (12%). Kirby had a relatively high composition of non-insects (27%), mainly due to the snails *Physella sp*. and *Fossaria sp*. Stoneflies were relatively rare at all sites, but somewhat more prevalent at the upper two sites, Kirby (3%) and Ennis (1%), than at Norris or Greycliff (both with less than 0.5%) (Table 3-3). No stoneflies were counted in the Norris samples, although at least one was observed in the uncounted portion of the sample (*Skwala sp.).*

Although mayflies were the numerically dominant taxa group at both Norris and Greycliff (Figure 3-13 and Table 3-3), the prevalent mayfly taxa differed. Most of the mayfly abundance at Greycliff was comprised of *Baetis tricaudatis* (29% of mayflies), *Tricorythodes sp* (24%), and *Plauditus sp.* (19%), while mayflies at the Norris site were mainly comprised of *Diphetor hageni* (26% of mayflies), *Acerpenna pygmacus* (24%), *Choroterpes sp.* (22%), and *Ephemera simulans* (16%). Mayfly taxa at the Kirby and Ennis sites were more similar to the Greycliff site, with *Baetis tricaudatis* comprising 56% of Ephemeroptera at Kirby, and 75% at Ennis.

Caddisflies were numerically dominant at Ennis, and were the dominant insect taxa group at Kirby (Table 3-3). Caddisfly numbers at both sites and at Greycliff were dominated by *Brachycentrus occidentalis* (approximately 40% of Trichoptera at all three sites). However, this taxon comprised only 4% of the caddisflies at the Norris site, which had higher prevalence of *Cheumatopsyche spp*. (26%), *Nectopsyche sp.* (24%), *Hydropsyche occidentalis* (17%), and *Ochrotrichia sp.* (13%).

In terms of functional feeding groups, the Madison River sites are generally dominated by collector-gatherer taxa, although the Ennis site has a higher proportion of filter-feeders. The upper sites of Kirby and Ennis showed higher relative abundance of scrapers/grazers compared to Norris and Greycliff. The Norris site had a relatively high predator abundance (Figure 3-14 and Table 3-3).

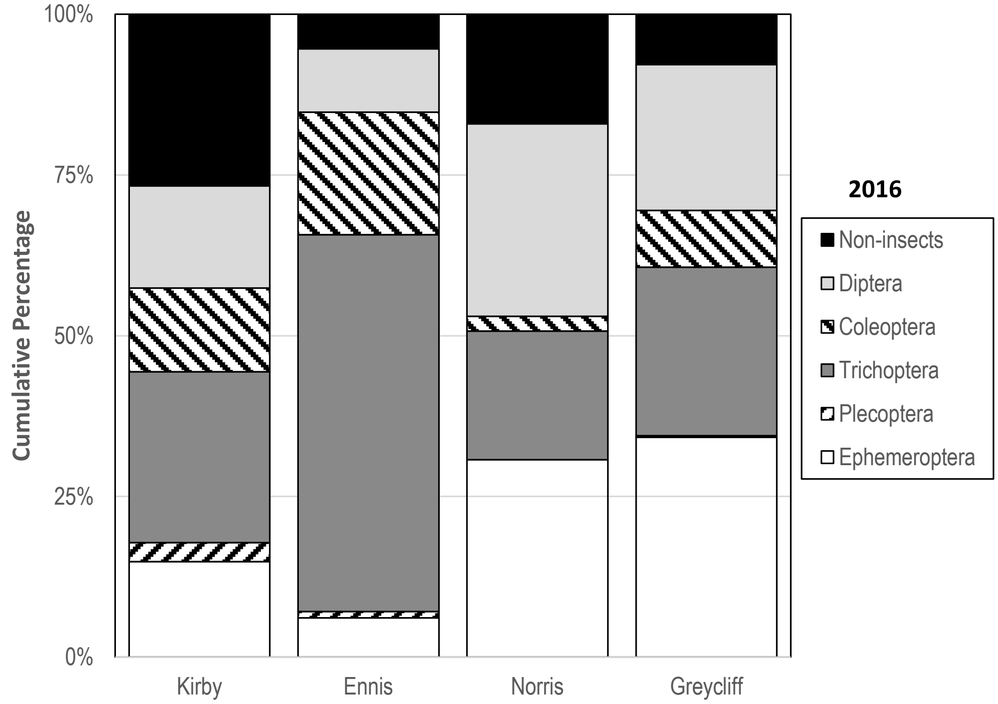

Figure 3-13. Community compositions by ordinal relative abundances of six major taxonomic groups at four sites on the Madison River, Montana (August 2016).

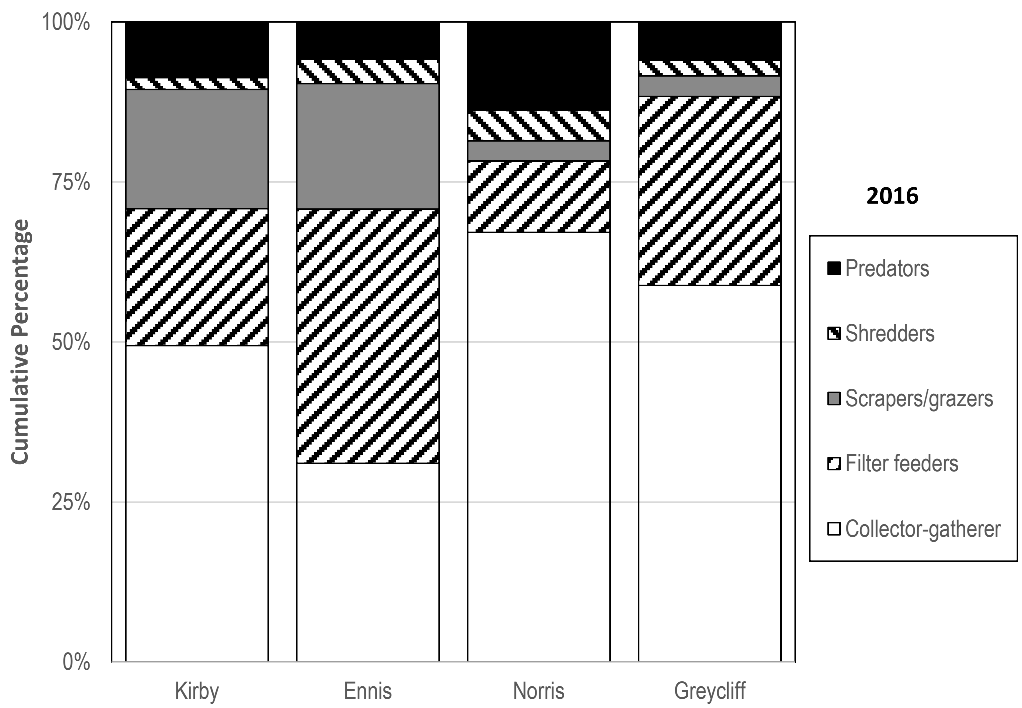

Figure 3-14. Functional feeding groups by ordinal relative abundances at four sites on the Madison River, Montana (August 2016).

Sediment tolerance indices calculated for 2016 sampling at the four Madison River sites show a longitudinal trend in the number of sediment tolerant taxa, with an increase in taxa and a decrease in intolerant taxa from Kirby and Ennis to Norris and Greycliff (Table 3-3; Figure 3-15). There is an increase in the relative abundance of sediment tolerant taxa from Ennis to Norris to Greycliff, but there is a high relative abundance of sediment tolerant taxa at the Kirby site (Table 3-3; Figure 3-16). Sediment intolerant taxa were very rare at Norris and Greycliff. The experimental approach of estimating the amount of finer sediments using benthic macroinvertebrate optima suggests that the amount of surface fines (<0.06 mm) and sands (<2 mm) are very low at the Ennis site, but at higher similar levels at the other three sites (fines about 11% and sands about 30%; Table 3-3 and Figure 3-17).

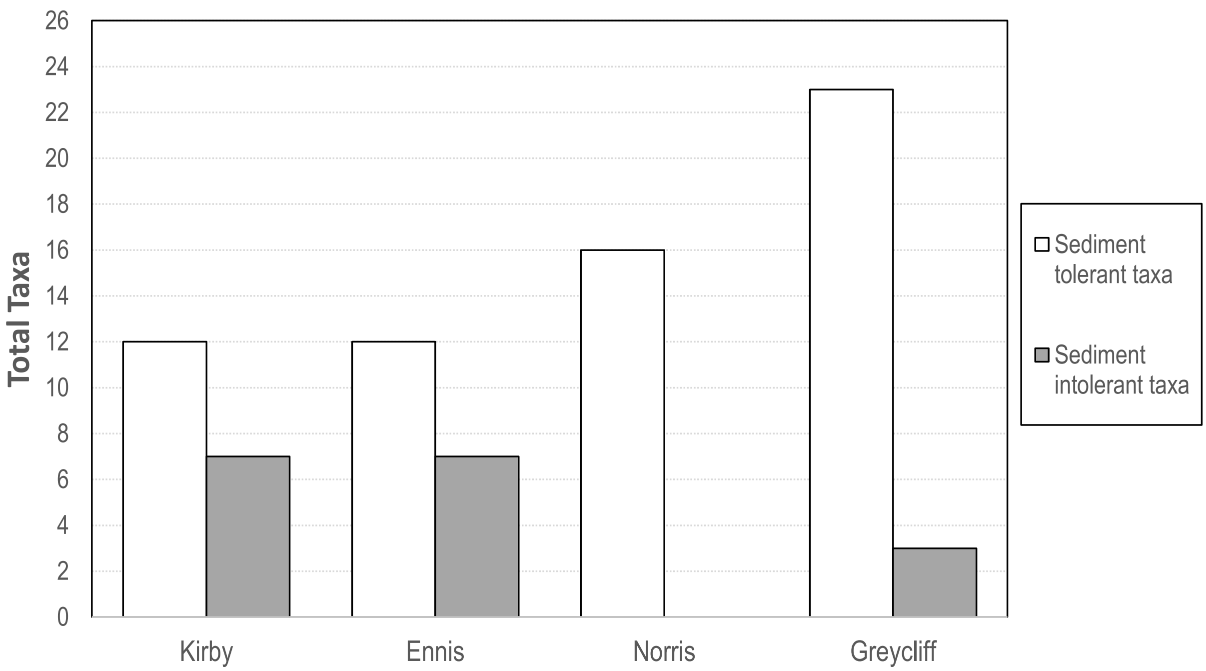

Figure 3-15. Number of sediment tolerant and intolerant taxa at four sites on the Madison River, Montana (August 2016).

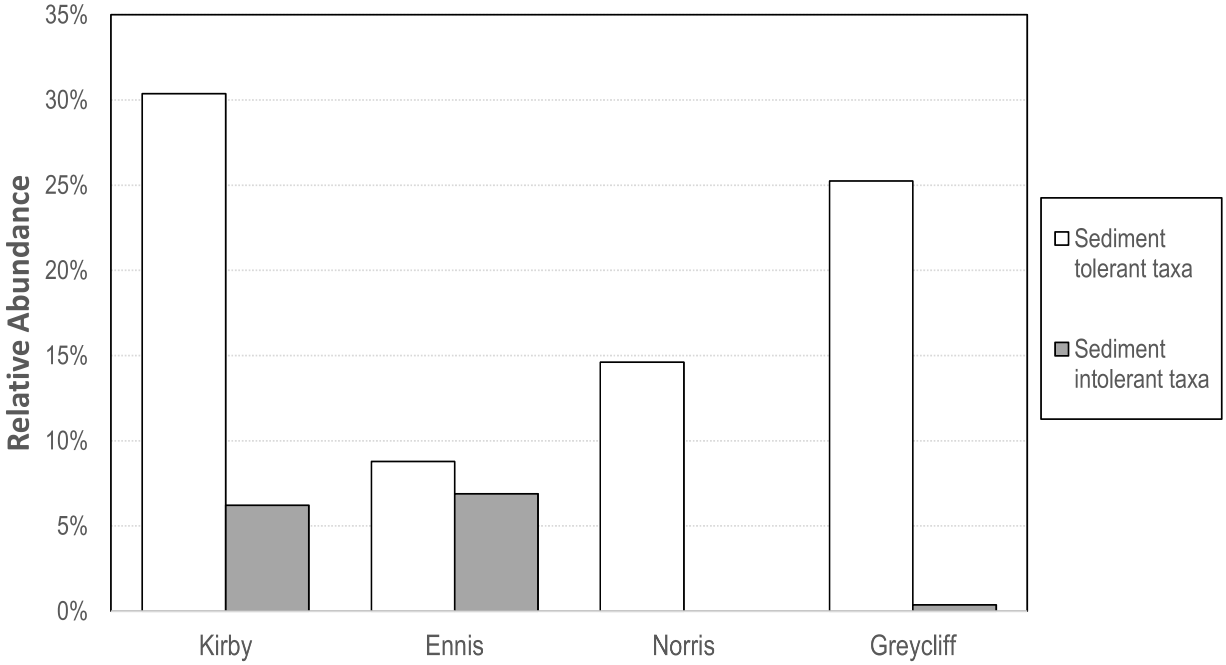

Figure 3-16. The ordinal relative abundances of sediment tolerant and sediment intolerant organisms at four sites on the Madison River, Montana (August 2016).

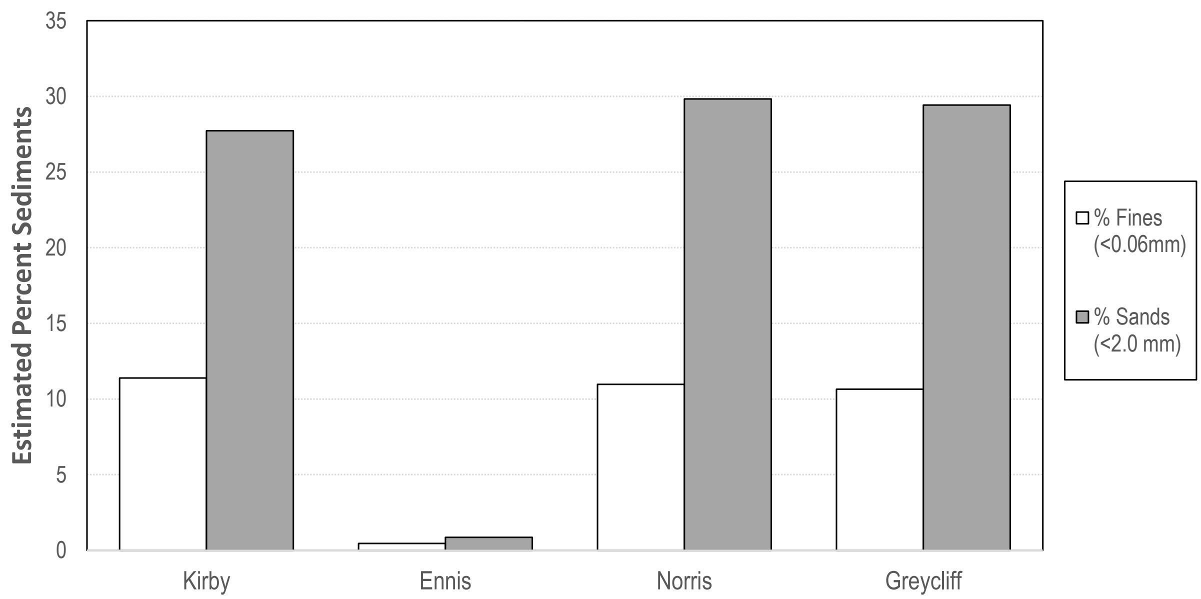

Figure 3-17. Macroinvertebrate-based estimates of fine sediments at four sites on the Madison River, Montana (August 2016).

3.2.2 Temporal Comparisons

Aquatic macroinvertebrate data from 2016 are presented and compared with data obtained at the same study sites in 2012-2015. Inference is also drawn from comparable macroinvertebrate data obtained during NWE annual 2188 Madison River biomonitoring beginning in 1996. Discussion of the most relevant metrics is presented in this section.

3.2.2.1 Multimetric Bioassessments

MMRMA bioassessments for 2012-2016 are presented in Tables 3-4 through 3-8 and Figure 3-18, and a longer term view of the scores at each site is presented in Figures 3-19 through 3-21. For 2012-2016, assessment scores averaged 67% at Kirby, 94% at Ennis, 79% at Norris, and 89% at Greycliff. These values indicate healthy macroinvertebrate communities at Ennis and Greycliff. Norris has been fluctuating between relatively poor (60% in 2015) and healthy scores (90% in 2014 and 2012) in recent years (Figure 3-18).

The multimetric assessment developed for Missouri and Madison River kick samples (Table 2-2) indicated slight environmental stress at the Norris during 2016, with a score of 77% (Table 3-8). Ennis had a relatively high score of 93%, and Kirby and Greycliff were also considered non-impaired at 80% and 83%, respectively. The primary indicators of environmental stress at Norris were a relatively low percentage of EPT taxa, a relatively high % of chironomids, and a relatively high HBI.

With a score of 80% in 2016, the Kirby site was at the highest level observed since 1997. Based on visual review of the trend in Figure 3-19, biointegrity was high in the 1990s at the Kirby site, but has fluctuated in the impaired range since 2002. Ennis routinely had the highest bioassessment scores of the Madison River sampling sites, and it has been consistently over 90% since 2008 (Figure 3-20). Norris has had the most variability in biointegrity through time, ranging from 50% in 2001 and 2003 to 100% in 2011 (Figure 3-21). The 60% score in 2015 was the most impaired score since 2003, but environmental stress is evident in more than 50% of the years sampled. Greycliff has been over 80% in every year sampled, and shows no signs of impairment (Figure 3-22).

3.2.2.2 Macroinvertebrate Metrics

Changes in the structure, composition, and pollution tolerance of Madison River macroinvertebrate communities through time were evaluated using selected metrics. All metric values are based on site averages of 300-count subsamples.

Table 3-4. Mean metric values and bioassessment scores at four sites on the Madison River, Montana (August 2012). Scores based on Madison-Missouri River criteria (Table 2-2) using 5 replicates per site, with ≈300 organism subsamples from 0.25 m^2 kick samples.

2012						
METRICS	**Kirby**	**Ennis**	**Norris**	**Greycliff**	**Mean**	**St. Dev.**
Taxa richness	28.8	35.4	36.4	35.6	34.1	3.5
EPT richness	14.6	18.8	18.0	17.6	17.3	1.8
Shannon diversity	3.4	4.0	3.9	4.0	3.8	0.3
Biotic index	5.3	4.3	4.5	4.5	4.7	0.4
% EPT	27.3	51.1	59.3	71.9	52.4	18.8
% Chironomidae	11.8	4.9	19.8	10.3	11.7	6.1
METRIC SCORE						
Taxa richness	4	5	5	5	4.8	0.5
EPT richness	4	5	5	5	4.8	0.5
Shannon diversity	5	5	5	5	5.0	0.0
Biotic index	2	4	4	4	3.5	1.0
% EPT	0	3	3	5	2.8	2.1
% Chironomidae	5	5	5	5	5.0	0.0
Total Score	20	27	27	29	25.8	3.9
Percentage of possible	**67%**	**90%**	**90%**	**97%**	86%	13%

Table 3-5. Mean metric values and bioassessment scores at four sites on the Madison River, Montana (August 2013). Scores based on Madison-Missouri River criteria (Table 2-2) using 5 replicates per site, with ≈300 organism subsamples from 0.25 m^2 kick samples.

2013						
METRICS	**Kirby**	**Ennis**	**Norris**	**Greycliff**	**Mean**	**St. Dev.**
Taxa richness	25.8	32.6	34.2	32.2	31.2	3.7
EPT richness	11.6	18.0	16.0	15.6	15.3	2.7
Shannon diversity	3.2	3.8	3.9	3.9	3.7	0.3
Biotic index	5.7	3.7	4.8	4.7	4.8	0.8
% EPT	24.3	63.6	48.6	63.8	50.1	18.6
% Chironomidae	6.0	8.4	22.1	15.2	12.9	7.2
METRIC SCORE						
Taxa richness	3	5	5	5	4.5	1.0
EPT richness	3	5	4	4	4.0	0.8
Shannon diversity	4	5	5	5	4.8	0.5
Biotic index	2	5	3	3	3.3	1.3
% EPT	0	4	2	4	2.5	1.9
% Chironomidae	5	5	4	5	4.8	0.5
Total Score	17	29	23	26	23.8	5.1
Percentage of possible	**57%**	**97%**	**77%**	**87%**	79%	17%

Table 3-6. Mean metric values and bioassessment scores at four sites on the Madison River, Montana (August 2014). Scores based on Madison-Missouri River criteria (Table 2-2) using 5 replicates per site, with ≈300 organism subsamples from 0.25 m^2 kick samples.

2014						
METRICS	**Kirby**	**Ennis**	**Norris**	**Greycliff**	**Mean**	**St. Dev.**
Taxa richness	30.4	36.6	35.8	31.0	33.5	3.2
EPT richness	13.6	16.8	17.0	15.0	15.6	1.6
Shannon diversity	3.4	3.8	3.9	3.7	3.7	0.2
Biotic index	5.5	3.6	4.5	4.4	4.5	0.8
% EPT	24.5	58.9	64.0	77.5	56.2	22.5
% Chironomidae	15.0	13.6	21.8	7.3	14.4	6.0
METRIC SCORE						
Taxa richness	4	5	5	4	4.5	0.6
EPT richness	4	5	5	4	4.5	0.6
Shannon diversity	5	5	5	5	5.0	0.0
Biotic index	2	5	4	4	3.8	1.3
% EPT	0	3	4	5	3.0	2.2
% Chironomidae	5	5	4	5	4.8	0.5
Total Score	20	28	27	27	25.5	3.7
Percentage of possible	**67%**	**93%**	**90%**	**90%**	85%	12%

Table 3-7. Mean metric values and bioassessment scores at four sites on the Madison River, Montana (August 2015). Scores based on Madison-Missouri River criteria (Table 2-2) using 5 replicates per site, with ≈300 organism subsamples from 0.25 m^2 kick samples.

2015						
METRICS	**Kirby**	**Ennis**	**Norris**	**Greycliff**	**Mean**	**St. Dev.**
Taxa richness	33.8	28.2	29.6	31.6	30.8	2.4
EPT richness	15.6	16.6	11.4	14.8	14.6	2.3
Shannon diversity	4.0	3.4	3.6	3.5	3.6	0.2
Biotic index	4.7	3.3	5.7	4.5	4.6	1.0
% EPT	32.3	70.4	32.1	74.0	52.2	23.2
% Chironomidae	32.4	4.4	26.4	8.1	17.8	13.7
METRIC SCORE						
Taxa richness	5	4	4	4	4.3	0.5
EPT richness	4	5	3	4	4.0	0.8
Shannon diversity	5	5	5	5	5.0	0.0
Biotic index	3	5	2	4	3.5	1.3
% EPT	1	5	1	5	3.0	2.3
% Chironomidae	2	5	3	5	3.8	1.5
Total Score	20	29	18	27	23.5	5.3
Percentage of possible	**67%**	**97%**	**60%**	**90%**	78%	18%

Table 3-8. Mean metric values and bioassessment scores at four sites on the Madison River, Montana (August 2016). Scores based on Madison-Missouri River criteria (Table 2-2) using 5 replicates per site, with ≈300 organism subsamples from 0.25 m^2 kick samples.

2016						
METRICS	**Kirby**	**Ennis**	**Norris**	**Greycliff**	**Mean**	**St. Dev.**
Taxa richness	35.4	34.4	35.0	40.4	36.3	2.8
EPT richness	16.0	15.4	15.2	18.4	16.3	1.5
Shannon diversity	4.1	3.7	4.0	4.4	4.0	0.3
Biotic index	4.8	3.7	4.9	4.7	4.5	0.6
% EPT	44.4	65.0	50.6	60.2	55.0	9.3
% Chironomidae	14.8	7.8	29.2	21.2	18.2	9.1
METRIC SCORE						
Taxa richness	5	5	5	5	5.0	0.0
EPT richness	4	4	4	5	4.3	0.5
Shannon diversity	5	5	5	5	5.0	0.0
Biotic index	3	5	3	3	3.5	1.0
% EPT	2	4	3	3	3.0	0.8
% Chironomidae	5	5	3	4	4.3	1.0
Total Score	24	28	23	25	25.0	2.2
Percentage of possible	**80%**	**93%**	**77%**	**83%**	83%	7.2%

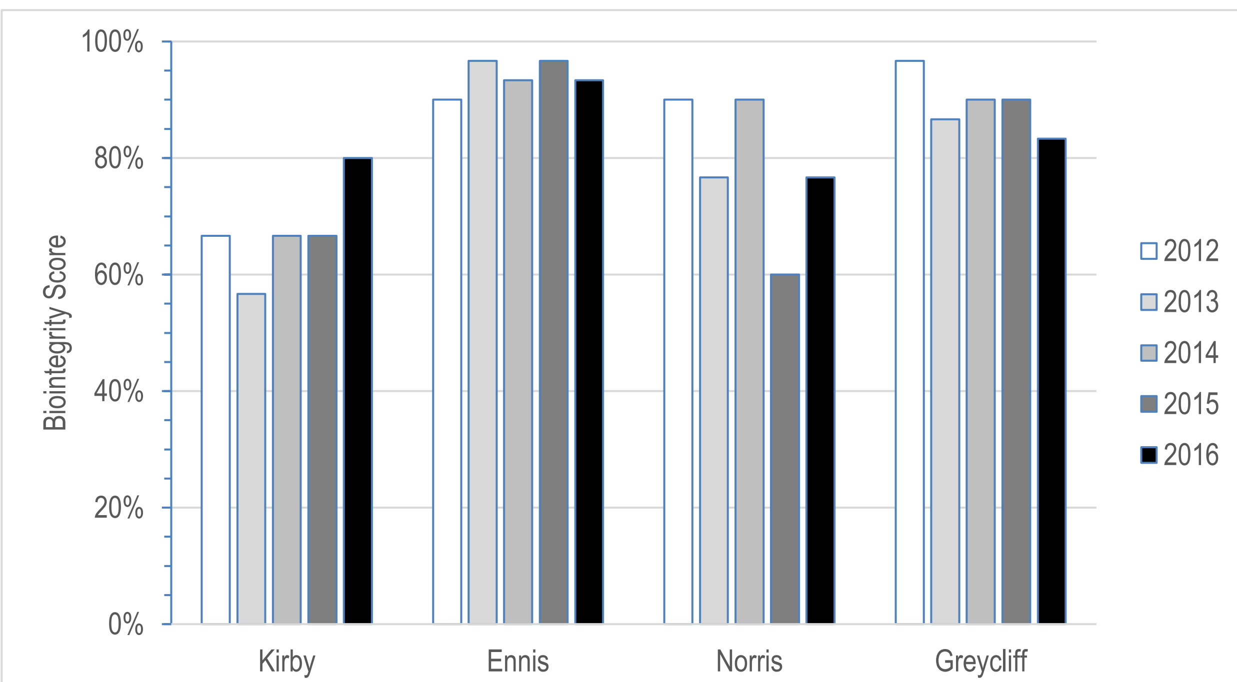

Figure 3-18. MMRMA bioassessment scores for 2012 through 2016 at four sites on the Madison River, Montana (August).

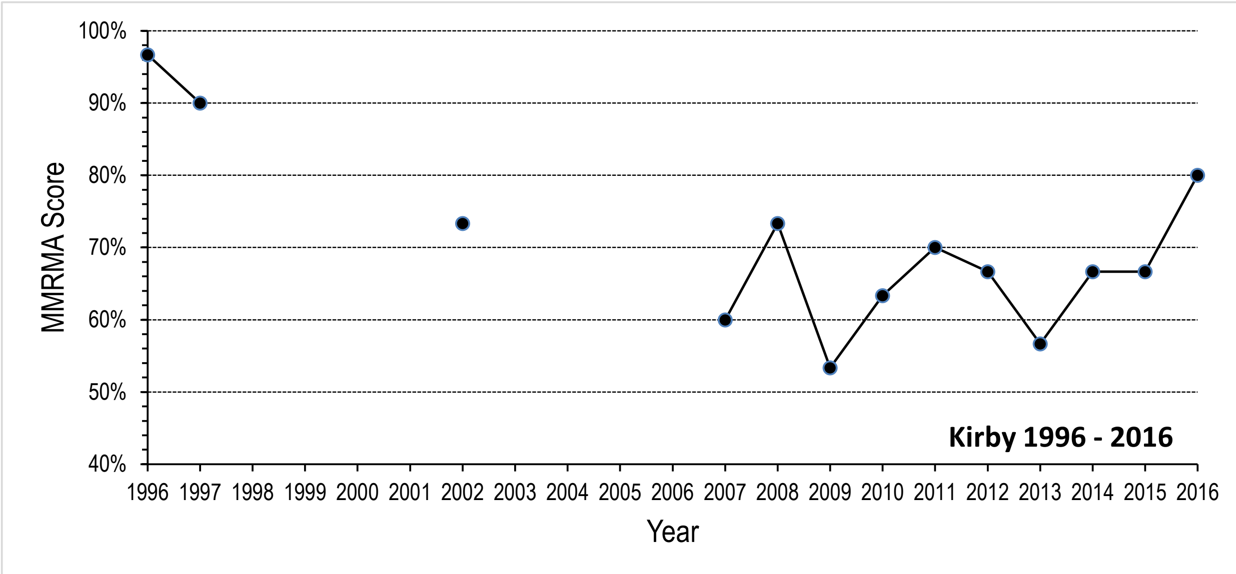

Figure 3-19. MMRMA bioassessment scores for NWE 2188 annual biomonitoring efforts at Kirby over a period from 1996-2016.

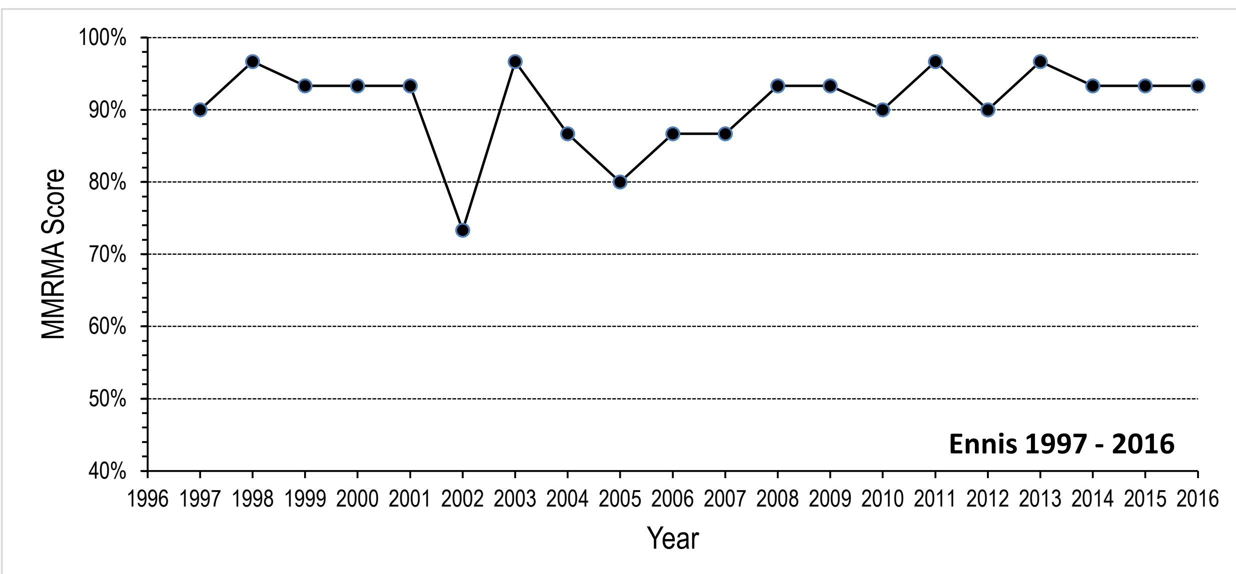

Figure 3-20. MMRMA bioassessment scores for NWE 2188 annual biomonitoring efforts at Ennis over a period from 1997-2016.

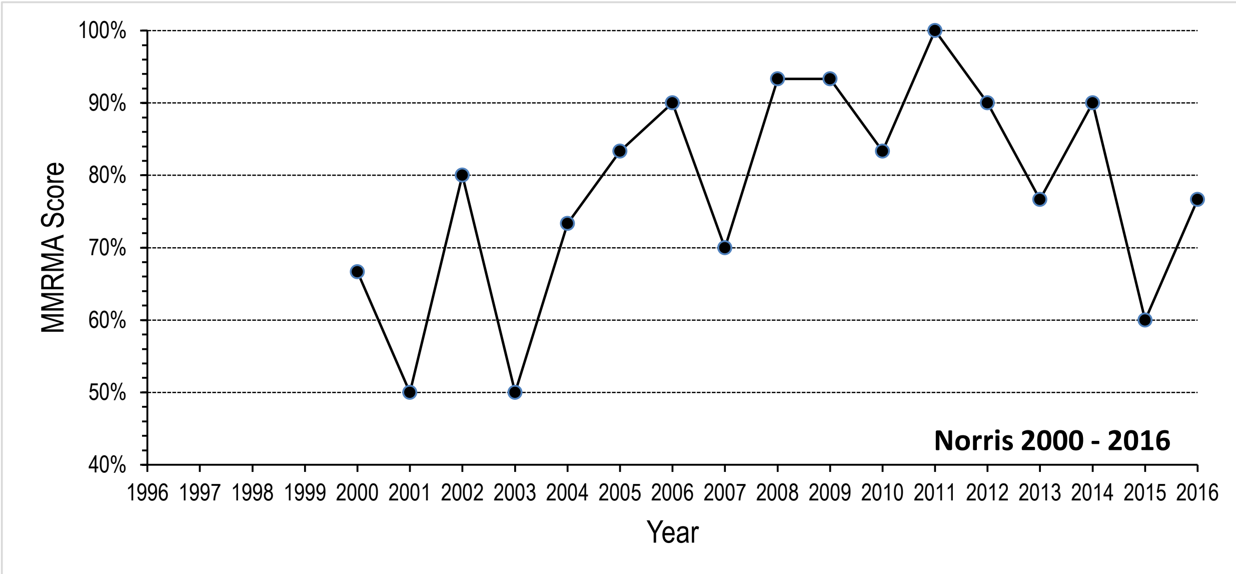

Figure 3-21. MMRMA bioassessment scores for NWE 2188 annual biomonitoring efforts at Norris over a period from 2000-2016.

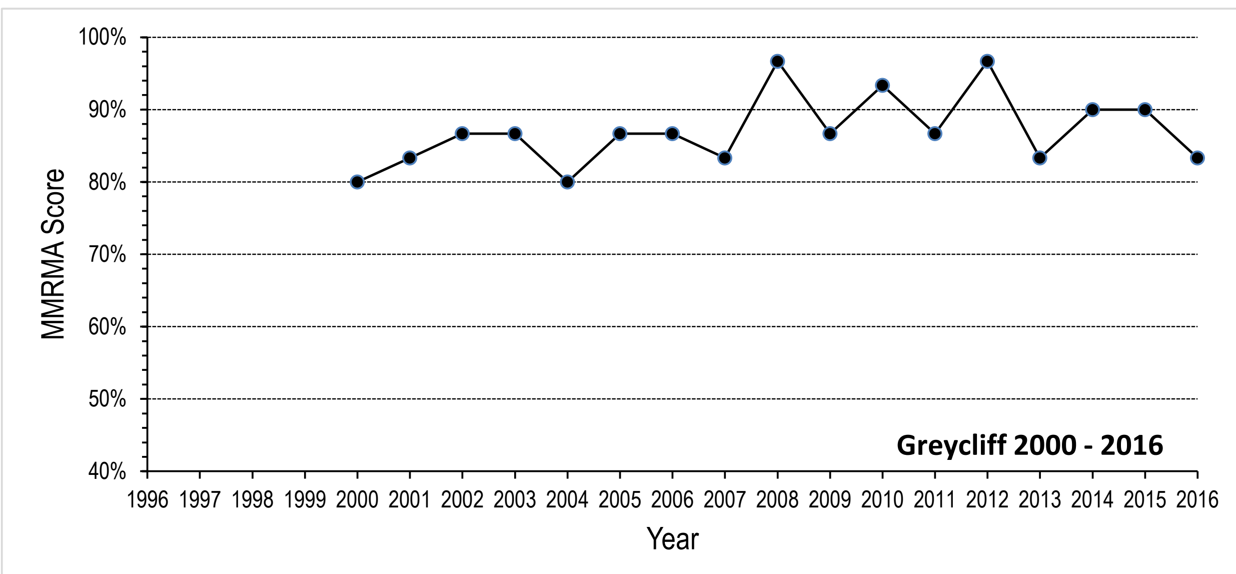

Figure 3-22. MMRMA bioassessment scores for NWE 2188 annual biomonitoring efforts at Greycliff over a period from 2000-2016.

Community Compositions

Figures 3-23 through 3-26 depict the relative abundance of major macroinvertebrate groups at each site since 2008. The Kirby site had large proportions (≥ 25%) of non-insects, mainly snails, in most years, but these were lower in 2009, 2011, and 2015 (Figure 3-23). The lower relative abundance of Mollusca in these years was accompanied by increases in chironomidae at the site (Table 3-8). There has been a decline in Coleoptera over the past 5 years, and the combined EPT taxa have high relative abundance in 2015 and 2016.

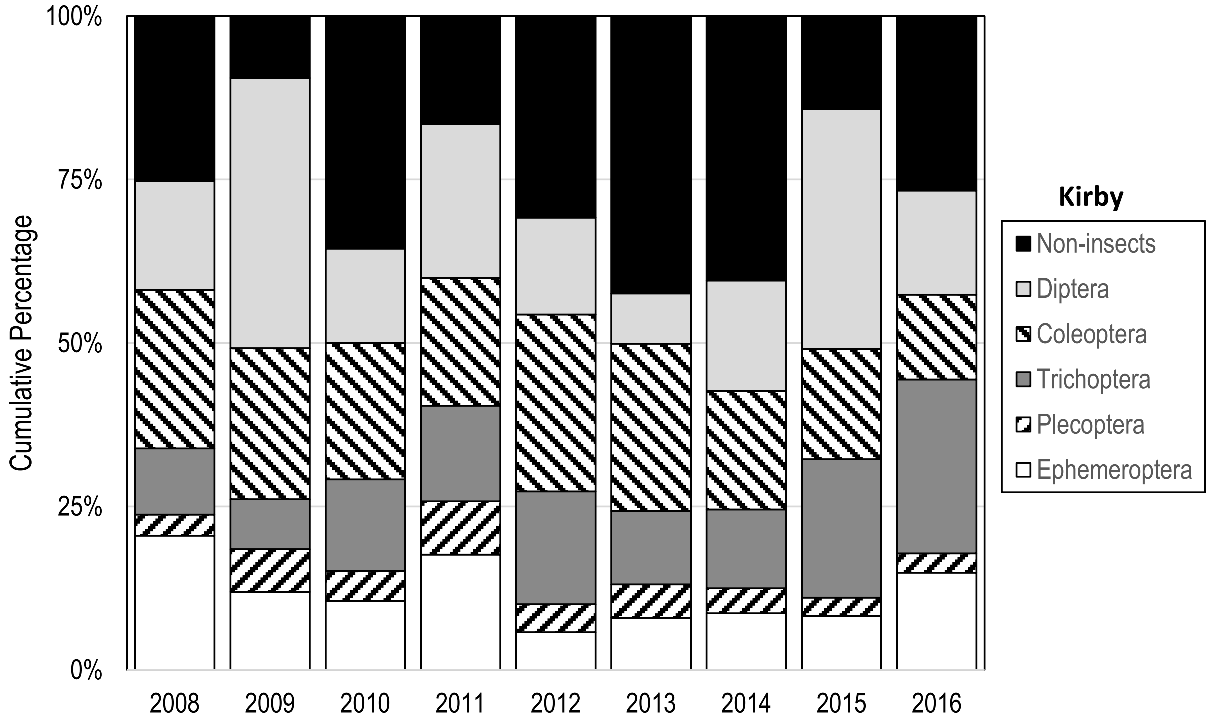

Figure 3-23. Community compositions by ordinal relative abundances of six major taxonomic groups at the Kirby station on the Madison River, Montana for August surveys from 2008-2016.

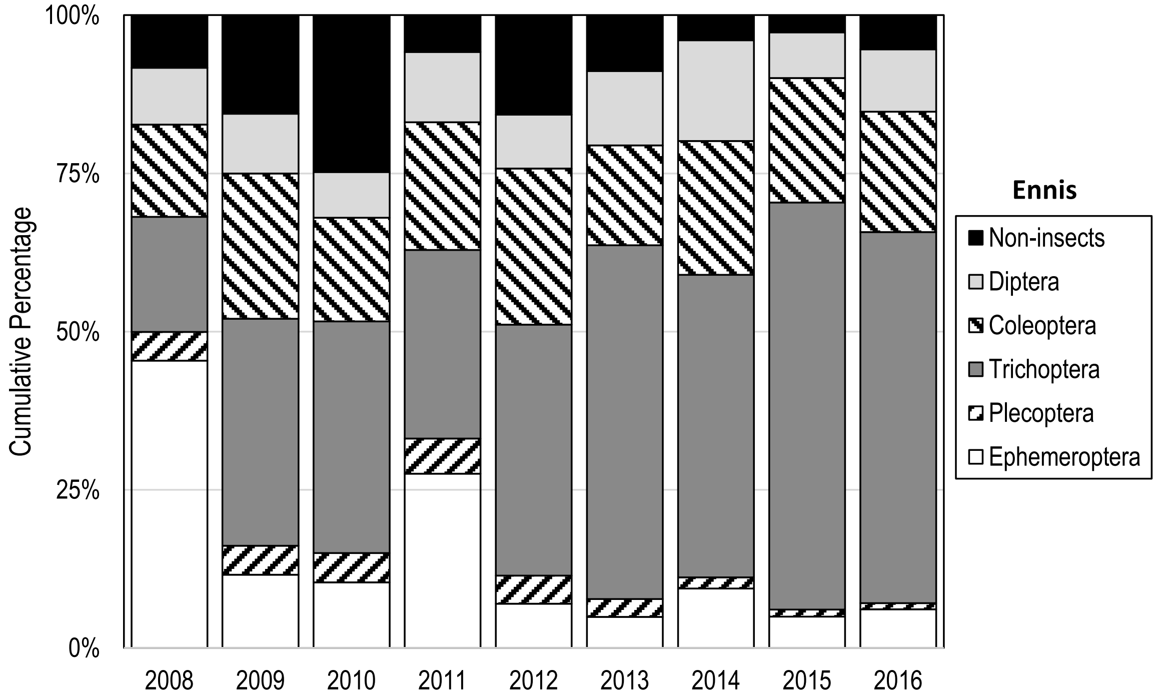

Figure 3-24. Community compositions by ordinal relative abundances of six major taxonomic groups at the Ennis station on the Madison River, Montana for August surveys 2008-2016.

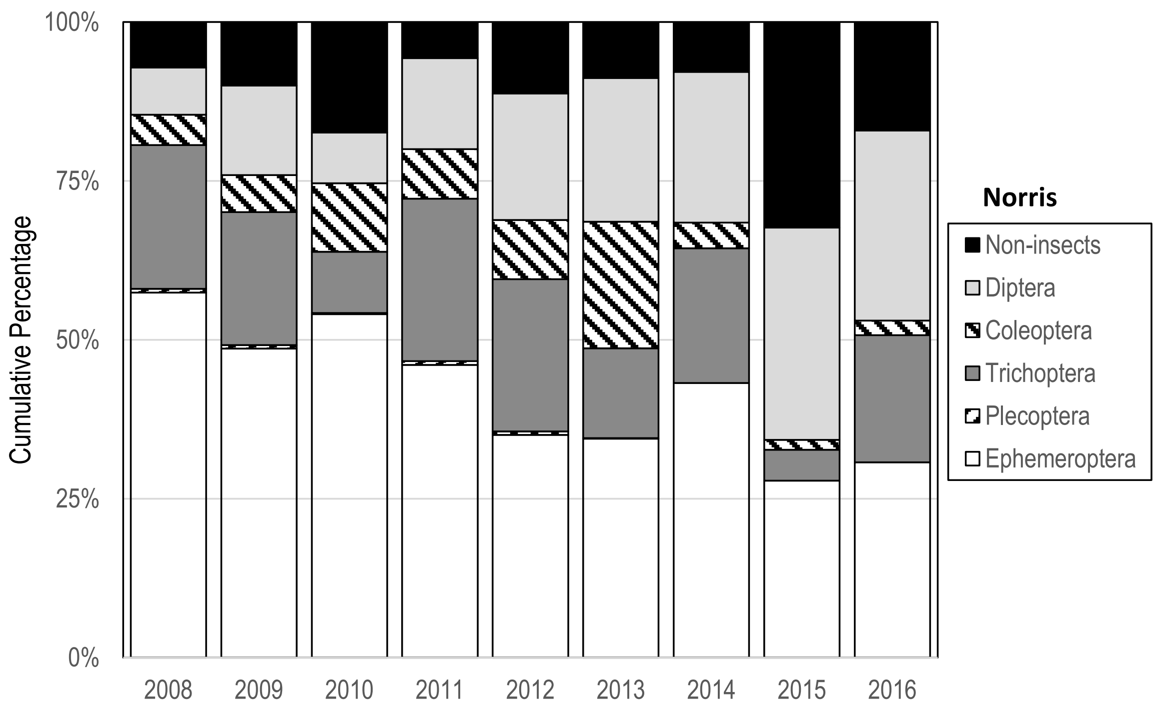

Figure 3-25. Community compositions by ordinal relative abundances of six major taxonomic groups at the Norris station on the Madison River, Montana for August surveys 2008-2016.

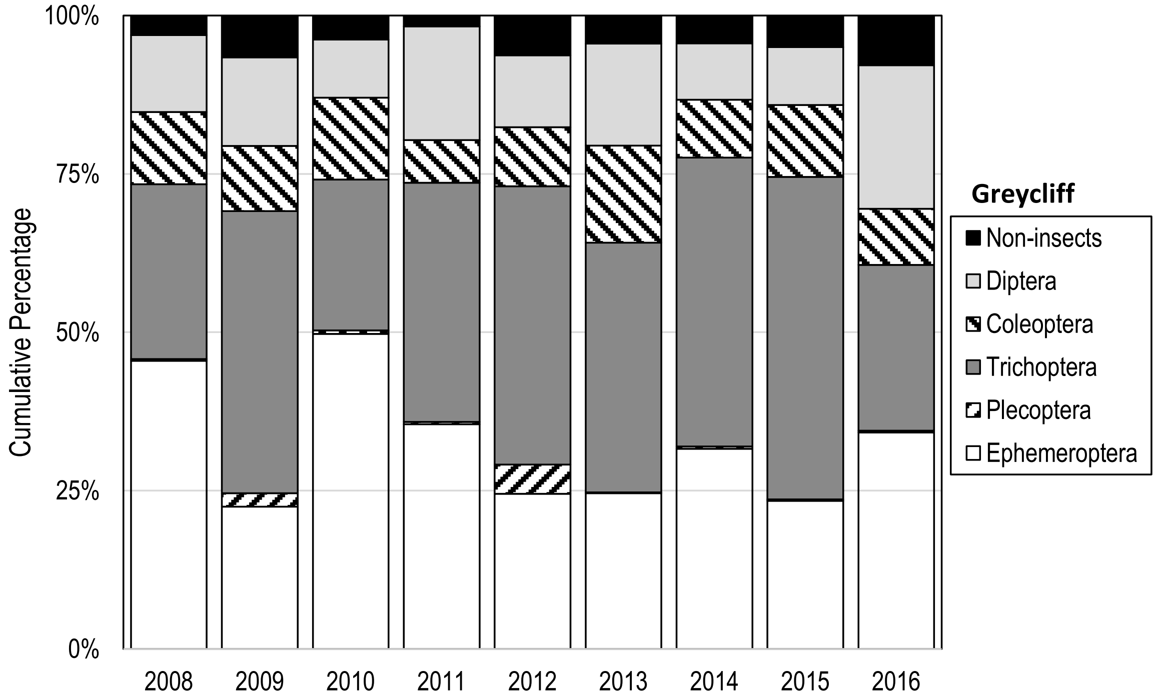

Figure 3-26. Community compositions by ordinal relative abundances of six major taxonomic groups at the Greycliff station on the Madison River, Montana for August surveys 2008-2016.

The Ennis site has had an increase in Trichoptera taxa, and these were at their highest relative abundances in the most recent two years of sampling (Figure 3-24). There has been an accompanying decline in Ephemeroptera taxa and non-insect (mainly Mollusca) relative abundance during this period.

The Norris site has had a decrease in ephemeroptera taxa over the past nine years. The total EPT relative abundance was very low in 2015 (Figure 3-25). In 2015, the non-insect relative abundance was very high, due to a very high abundance of *Hyallela azteca*, accompanied by lower relative abundances of Coleoptera and Trichoptera. The Greycliff site had the most consistent community structure during this time period, although 2016 had a relatively high abundance of Diptera taxa combined with a relatively low level of Trichoptera (Figure 3-26).

In addition to changes over time, the macroinvertebrate community compositions at the four Madison River sites also show distinct and consistent spatial differences. The Kirby and Ennis sites have consistently lower relative abundances of Ephemeroptera than Norris and Greycliff (Figure 3-27). Kirby and Ennis also show consistently higher relative abundances of Plecoptera than Norris and Greycliff (Figure 3-28).

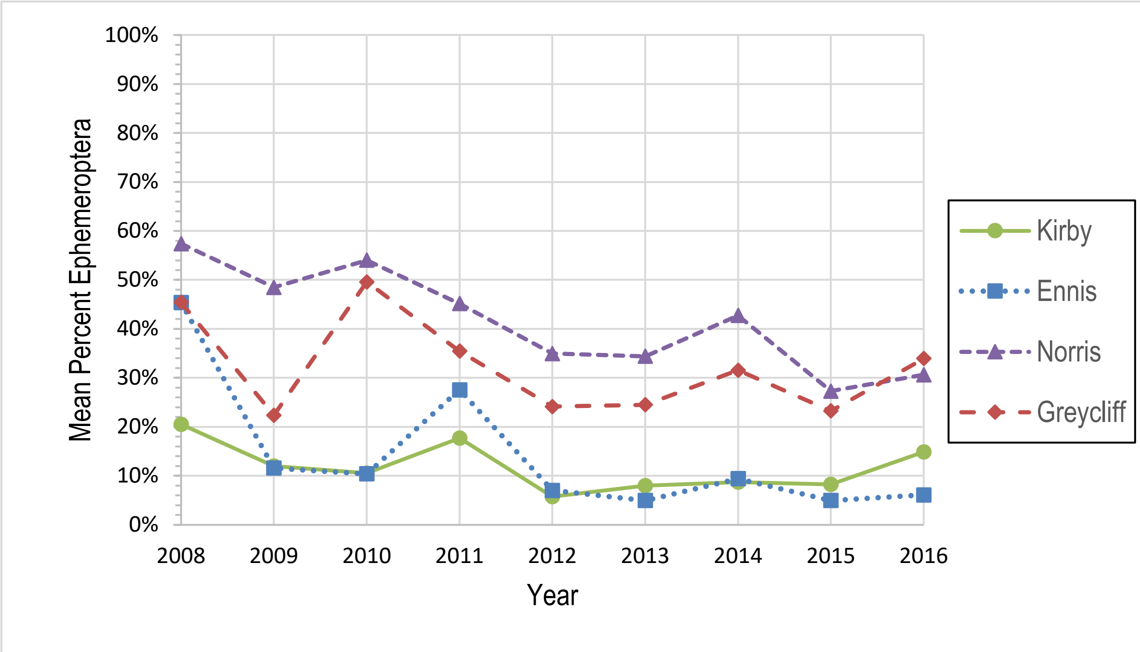

Figure 3-27. Mean relative abundances of Ephemeroptera at four sites on the Madison River, Montana for August surveys 2008-2016.

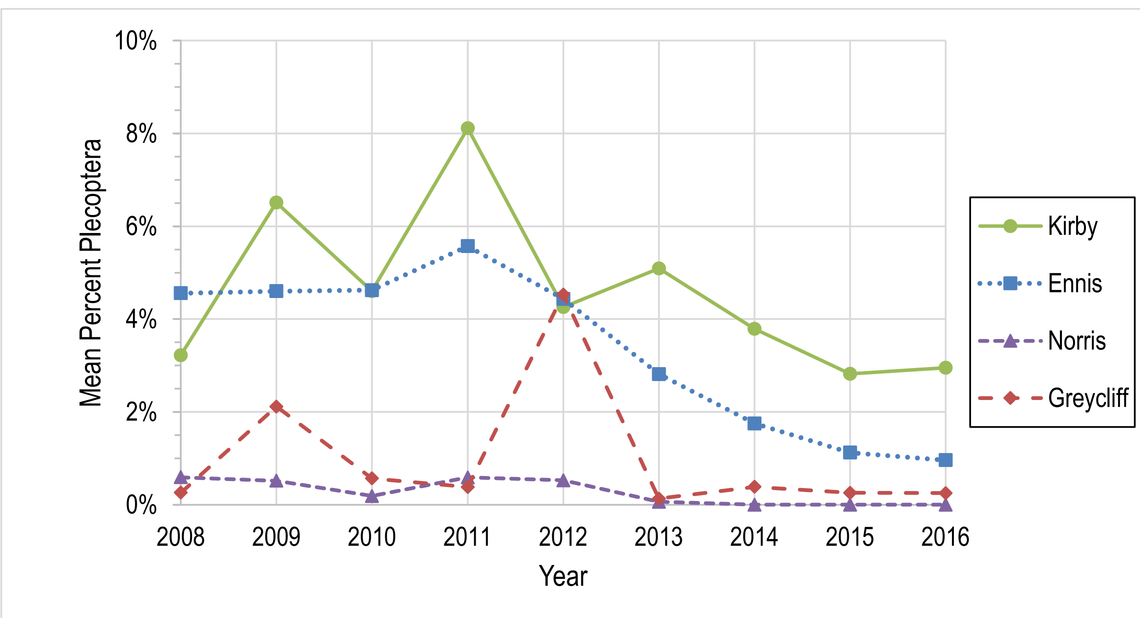

Figure 3-28. Mean relative abundances of Plecoptera at four sites on the Madison River, Montana for August surveys 2008-2016.

Taxa Richness

Taxa richness values were generally indicative of healthy to slightly impaired benthic communities in the Madison River. Mean taxa richness was at least 28 at each site on the majority of sampling dates (Figure 3-29). The four sites experienced similar levels of variability in the richness indicator, and no temporal patterns are evident. Mean taxa richness was highest at Greycliff in 2016 with 40.4 taxa, and lowest at Greycliff in 2011 with 25.4. The site averages in the most recent period (2012-2016) ranged from 30.8 at Kirby to 34.2 at Norris and Greycliff. For all sites combined, taxa richness averaged 34 in 2012, 31 in 2013, 33 in 2014, 31 in 2015, and 36 in 2016.

EPT Taxa Richness and Relative Abundance

Mayflies, stoneflies and caddisflies were fairly abundant and diverse at the Madison River sites. Mean EPT richness across all sites and years was 15.7 taxa per subsample and ranged from 11.4 at Norris in 2015 to 19.2 at Ennis in 2011 (Figure 3-30). No temporal trends in EPT richness are evident. With the exception of 2015 and 2016, EPT richness has generally been lower at Kirby and higher at Ennis.

The combined relative percentage of mayflies, stoneflies and caddisflies in Madison River samples is generally above 50% at three sites, but relatively low at the Kirby site (Figure 3-31).

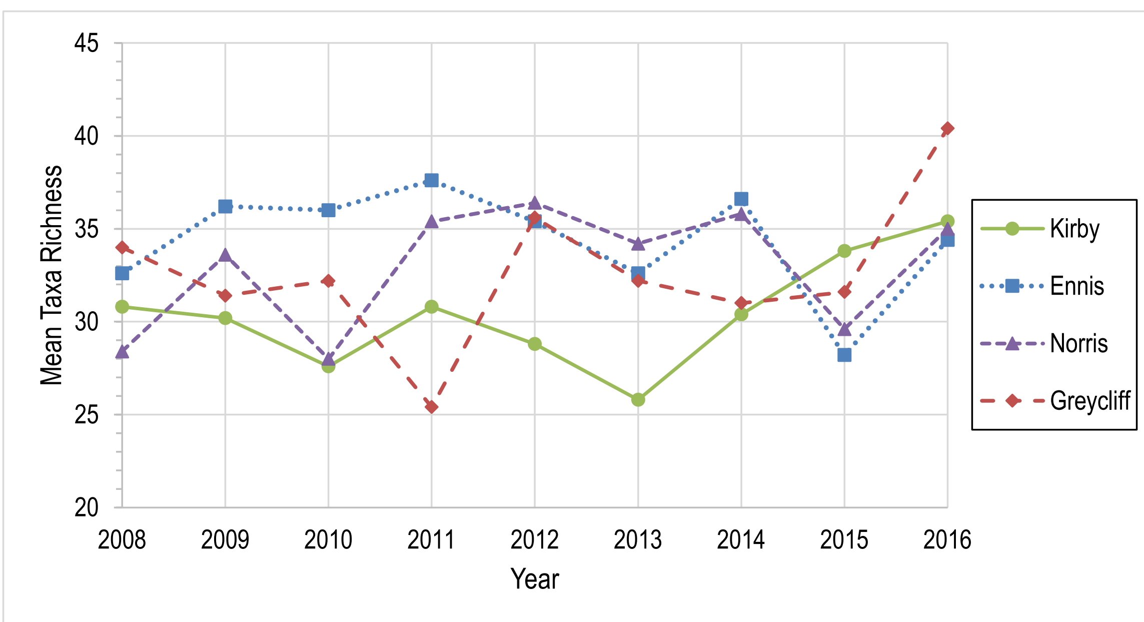

Figure 3-29. Mean taxa richness at four sites on the Madison River, Montana during August 2008-2016.

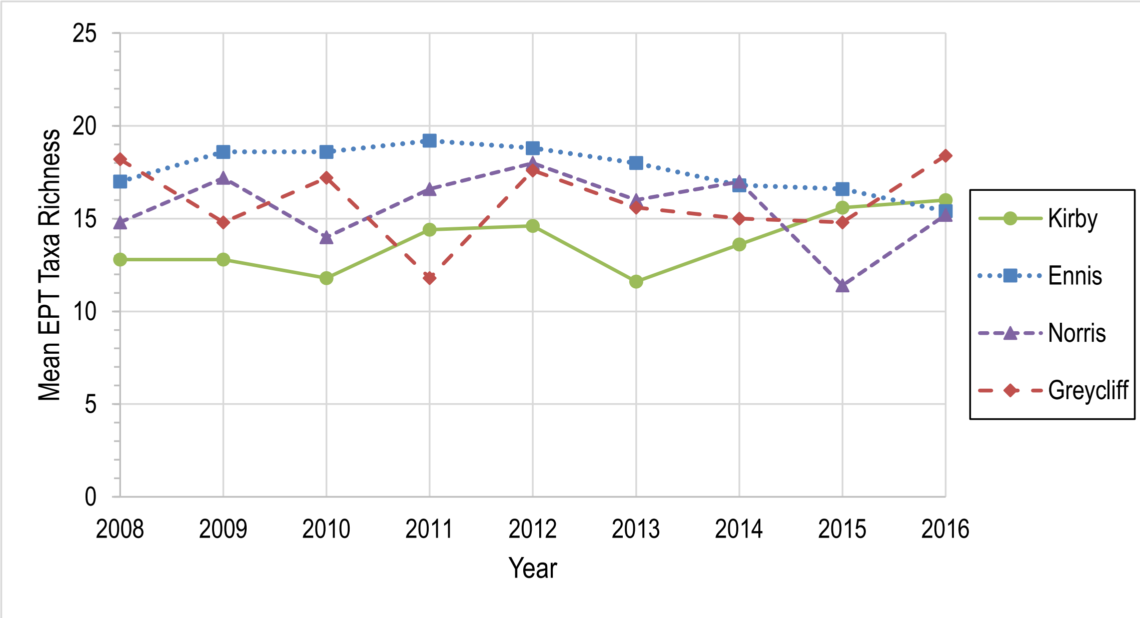

Figure 3-30. Mean EPT taxa richness at four sites on the Madison River, Montana during August 2008-2016.

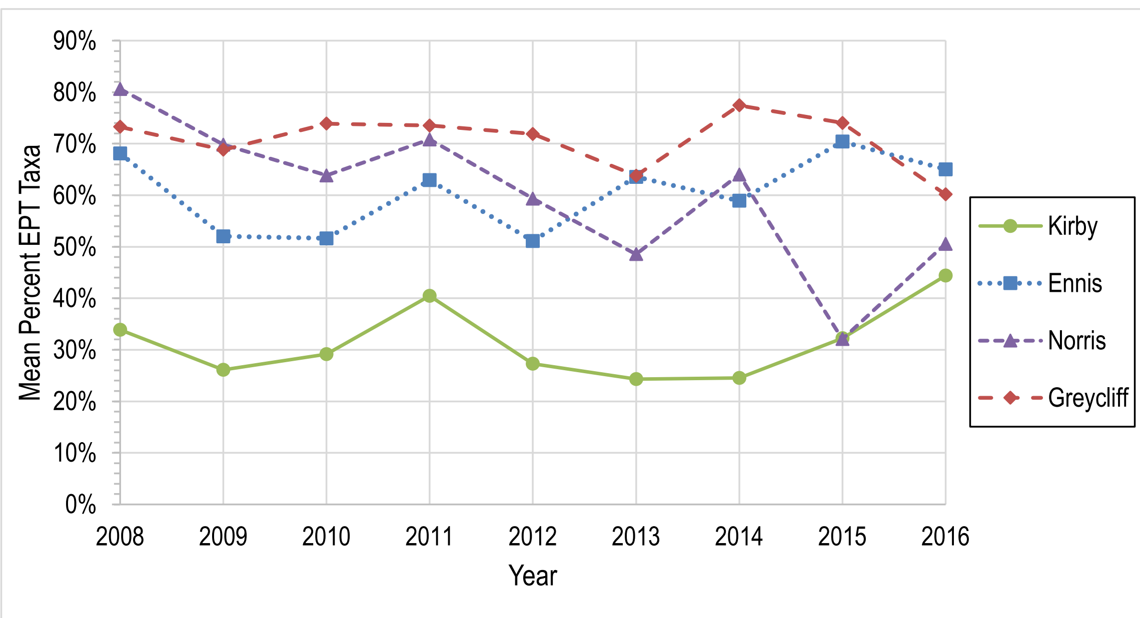

Figure 3-31. Mean percent abundance of EPT taxa at four sites on the Madison River, Montana during August 2008-2016.

The Norris site appears to be trending downwards since 2008: average EPT% was 71% in the 2008-2011 time period, and was 51% in the 2012-2016 time period. The nine-year averages for the four sites are Kirby is 31%; Ennis, 60%; Norris, 60%; and Greycliff, 71%.

Biotic Index

The modified HBI is primarily a measure of organic pollution and trophic status (Hilsenhoff 1987). Montana Foothill and Valley streams free of significant nutrient or organic pollution are characterized by values less than 4.0 (Bukantis 1998). Bollman (1998) found the Montana BI to be correlated with water temperature, substrate embeddedness, and the percentage of fine sediments in small streams. Biotic index values indicated some impairment at the Kirby site between 2012 and 2014 (based on a score of 2 out of a possible 5 from Table 2-2), and at Norris in 2015 (Figure 3-32). Conditions at the lower Madison sites Norris and Greycliff sites appear to be trending slightly upward, and are bordering on impaired conditions in 2016. The upper Madison River sites have been more consistent during this time, with unimpaired conditions at Ennis (based on a score of 5 out of a possible 5 from Table 2-2) and slightly impaired conditions at Kirby (based on a score of 3 out of a possible 5 from Table 2-2). Mean HBI values for these years were 5.1, 3.9, 4.6 and 4.4 at Kirby, Ennis, Norris and Greycliff, respectively.

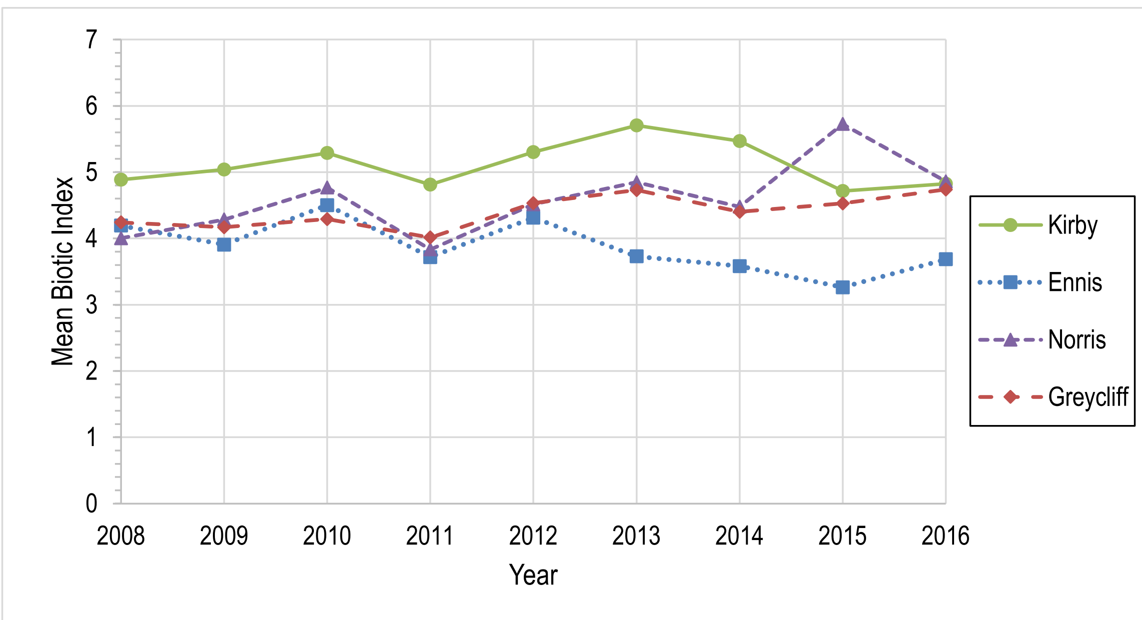

Figure 3-32. Mean modified HBI scores at four sites on the Madison River, Montana during August 2008-2016.

3.3 STREAMFLOW ANALYSIS

The average annual flow in the Madison River below Ennis Lake is 1,744 cfs based on 79 years of record from Water Year 1939 through 2017. Average annual flows at this location were analyzed to determine multi-year periods when the average flow during each period was either above or below the long-term average, i.e., sustained wet and dry periods. Results of these evaluations are summarized in Table 3-9. The 8-year period from Water Year 1993 through 2000 was a sustained wet period with an average flow of 2,050 cfs, while the 16-year period from Water Year 2001 through 2016 was a sustained dry period with an average flow of 1,570 cfs. The trend appears to have shifted in 2017, showing signatures of a change to a wet period. However, more time must pass to determine if this shift really materializes or is simply a one year anomaly away from the overall trend of a dry period.

Table 3-9. Sustained wet and dry periods in the Madison River below Ennis Lake derived from 74 years of records from Water Year 1939 through 2017.

Period	Duration (years)	Average Flow (cfs)	Hydrologic Regime
1939 to 1963	25	1,610	Sustained dry period
1964 to 1976	13	2,080	Sustained wet period
1977 to 1981	5	1,650	Sustained dry period
1982 to 1986	5	2,040	Sustained wet period
1987 to 1992	6	1,470	Sustained dry period
1993 to 2000	8	2,050	Sustained wet period
2001 to 2016	16	1,570	Sustained dry period

Streamflow records of the Madison River below Hebgen Lake, at Kirby Ranch, and below Ennis Lake are shown in Figure 3-33 for the period covered by Water Years 1993 to 2017. Annual maximum three-day, daily, and instantaneous flows are summarized in Table 3-10.

During this 25-year period, the maximum flow release from Hebgen Dam occurred in Water Year 1993. During the same period, maximum flows in the Madison River below Ennis Lake occurred in 1996 and 1997. A higher instantaneous peak occurred in this reach in 1996, while a higher three-day flow occurred in 1997.

The highest flows in the Madison River below Hebgen Dam did not coincide with the highest flows in the Madison River below Ennis Lake. The reason for this is that the Madison River receives additional unregulated flow downstream from Hebgen Dam. The timing of these natural inflows does not always coincide with the timing of flow releases from Hebgen Dam.

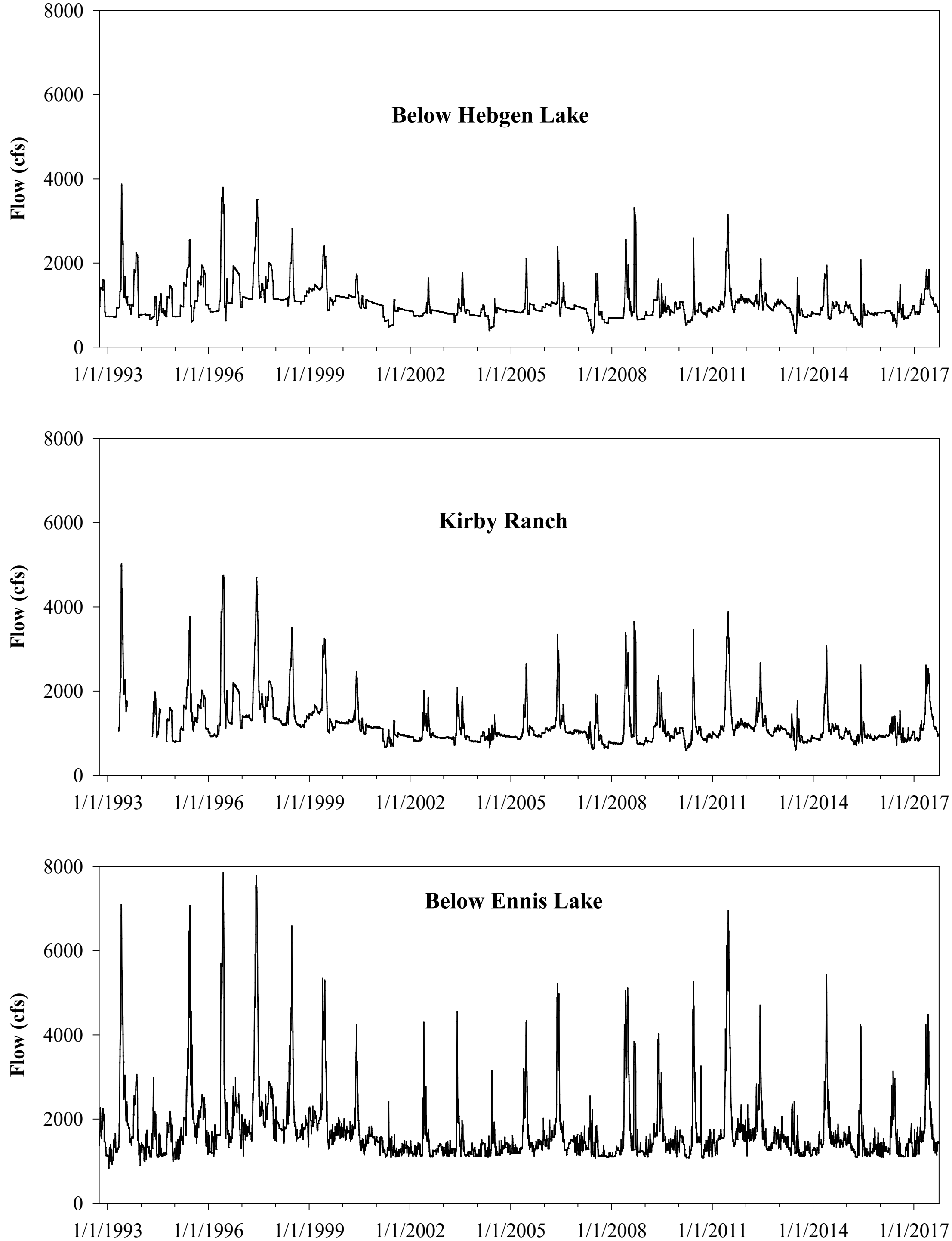

Figure 3-33. Streamflow records of the Madison River below Hebgen Lake, at Kirby Ranch, and below Ennis Lake, water years 1993 to 2017.

Table 3-10. Annual maximum three-day, daily, and instantaneous flows for the Madison River below Hebgen Lake, at Kirby Ranch, and below Ennis Lake, water years 1993 to 2017.

	Maximum Three-Day Flow (cfs)			Maximum Daily Flow (cfs)			Maximum Instantaneous Flow (cfs)		
Water Year	Below Hebgen Dam	Kirby Ranch	Below Ennis Lake	Below Hebgen Dam	Kirby Ranch	Below Ennis Lake	Below Hebgen Dam	Kirby Ranch	Below Ennis Lake
1993	3,860	n/a	7,030	3,870	n/a	7,090	3,970	5,030	7,300
1994	2,240	n/a	3,030	2,240	n/a	3,060	2,260	1,980	3,140
1995	2,560	3,690	6,830	2,560	3,770	7,080	2,600	3,950	7,360
1996	3,750	4,700	7,620	3,800	4,750	7,850	3,880	4,840	7,980
1997	3,510	4,700	7,750	3,520	4,700	7,800	3,570	4,700	7,910
1998	2,760	3,500	6,200	2,820	3,520	6,590	2,860	3,560	6,820
1999	2,410	3,220	5,290	2,410	3,260	5,350	2,430	3,340	5,500
2000	1,730	2,440	4,030	1,740	2,470	4,260	1,750	2,520	4,450
2001	1,140	1,300	2,310	1,140	1,310	2,410	1,140	1,330	2,460
2002	1,650	1,910	4,070	1,650	2,020	4,310	1,670	2,050	5,180
2003	1,760	2,040	4,480	1,780	2,090	4,560	1,890	2,170	4,670
2004	1,120	1,350	2,480	1,170	1,440	3,160	1,270	1,490	3,440
2005	2,110	2,650	4,260	2,120	2,660	4,350	2,180	2,720	4,470
2006	2,330	3,300	5,130	2,400	3,360	5,230	2,410	3,450	5,390
2007	1,710	1,870	2,350	1,770	1,940	2,560	1,880	1,960	3,400
2008	3,290	3,610	5,080	3,330	3,660	5,130	3,710	3,680	5,390
2009	1,630	2,350	4,040	1,640	2,390	4,040	1,640	2,460	4,050
2010	2,500	3,350	5,110	2,610	3,480	5,280	2,670	3,510	5,540
2011	3,060	3,800	6,780	3,170	3,910	6,970	3,230	4,050	7,100
2012	2,110	2,640	4,400	2,120	2,690	4,730	2,160	2,760	4,810
2013	1,630	1,730	2,360	1,670	1,790	2,440	1,750	1,840	2,850
2014	1,940	3,020	5,280	1,970	3,090	5,460	1,990	3,200	5,560
2015	2,020	2,490	4,050	2,100	2,640	4,270	2,260	2,740	4,490
2016	1,470	1,510	3,010	1,510	1,550	3,160	1,530	1,590	3,190
2017	1,860	2,550	4,390	1,880	2,640	4,520	2,040	2,740	4,660

3.4 WATER TEMPERATURE

Water temperatures measured in the Madison River below Ennis Lake (USGS Gage 06041000) were analyzed to characterize the long-term thermal regime of the river. Daily average water temperatures were obtained for Water Years 1978 through 2017. For each day of the year, the maximum, median, and minimum daily average water temperatures were determined from the 40-year period of record. The seasonal pattern of daily average water temperatures is shown in Figure 3-34. Warmest temperatures generally occur in July and August.

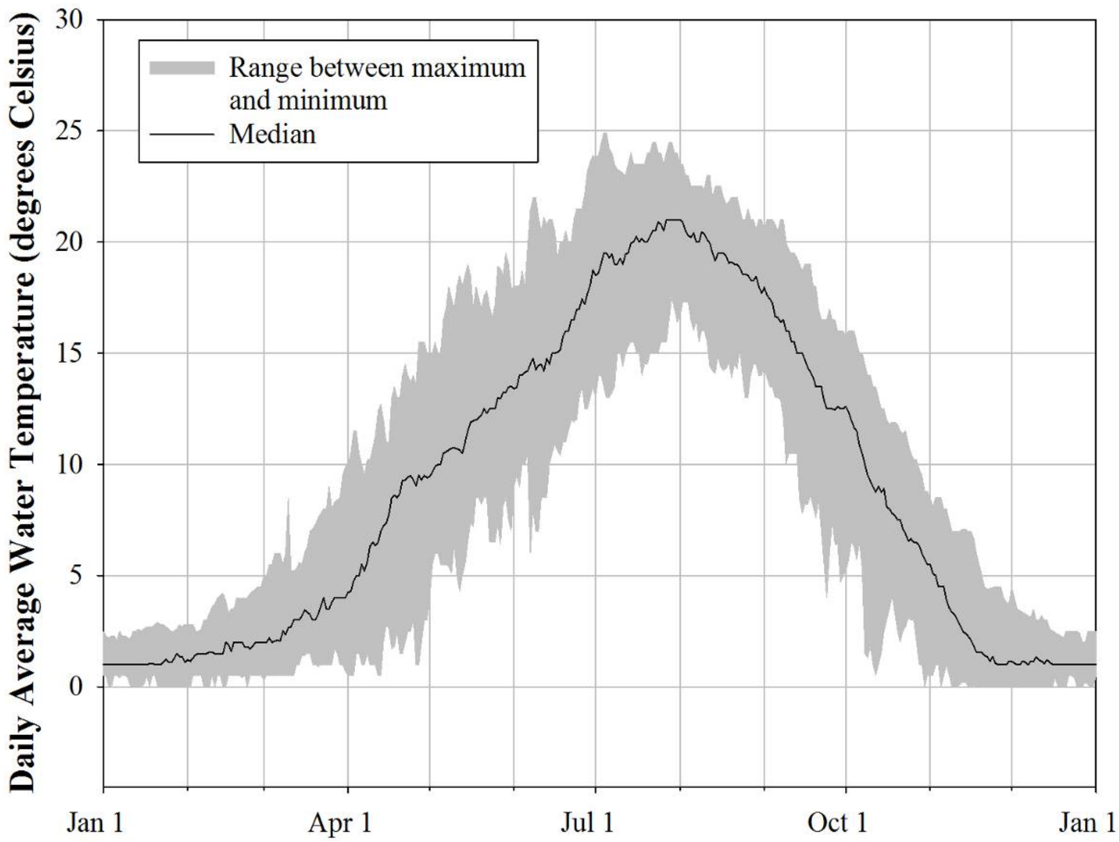

Figure 3-34. Seasonal pattern of daily average water temperatures measured in the Madison River below Ennis Lake, derived from 40 years of record from Water Year 1978 through 2017.

From the daily average water temperatures measured in the Madison River below Ennis Lake, the average temperature during the warmest part of the year (July and August) was calculated for each to the 40 water years from 1978 through 2017. Results of these calculations are shown in Figure 3-35. The average July/August water temperature was relatively cool during the first 20 years (18.8 degrees Celsius), and relatively warm during the last 20 years (20.2 degrees Celsius.

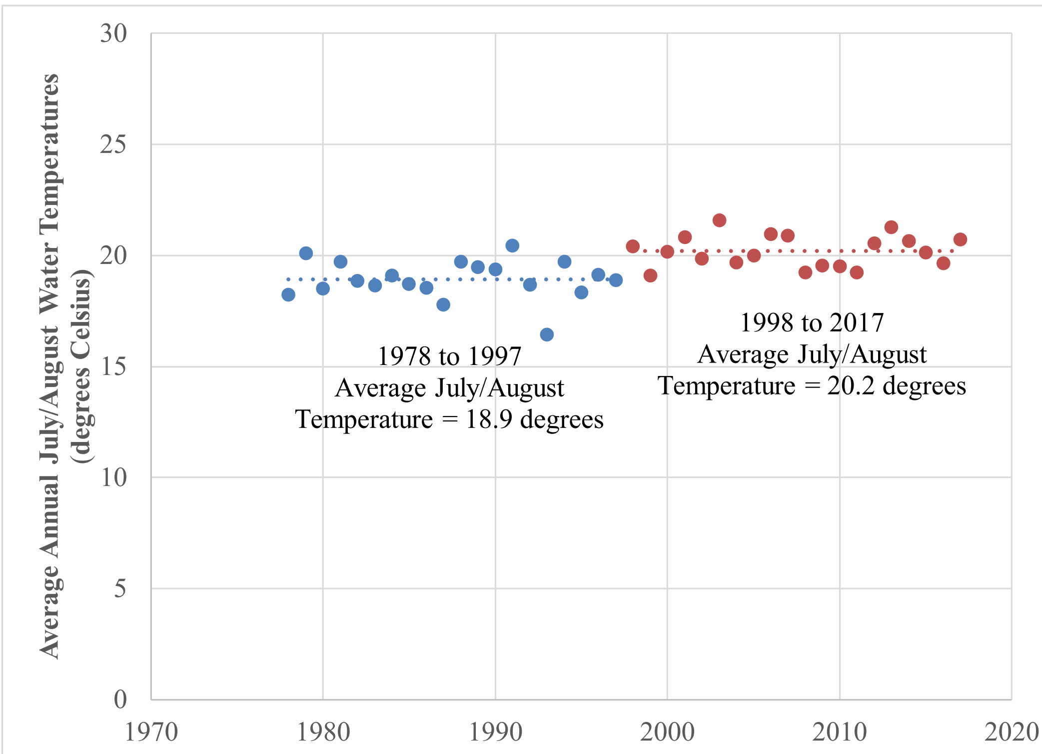

Figure 3-35. Average annual July/August water temperatures in the Madison River below Ennis Lake, 1978 through 2017.

3.5 REDD SURVEYS

The locations of redds that were surveyed at the Kirby Ranch Site are shown in Figure 3-36. Spawning activity was focused on the left bank (looking downstream). Most of the redds were located upstream from the monitoring site. Annual fall and spring redd counts at the Kirby Ranch Site are shown in Figure 3-37. The highest redd counts were observed in spring, 2016 and spring, 2017, while the lowest redd counts were observed in fall, 2016.

The locations of redds that were surveyed at the Ennis Campground Site are shown in Figure 3-38. Most of the redds were located upstream from the monitoring site. Annual fall and spring redd counts at the Ennis Campground Site are shown in Figure 3-39. The highest redd counts were observed in spring, 2016, while the lowest redd counts were observed in fall, 2017.

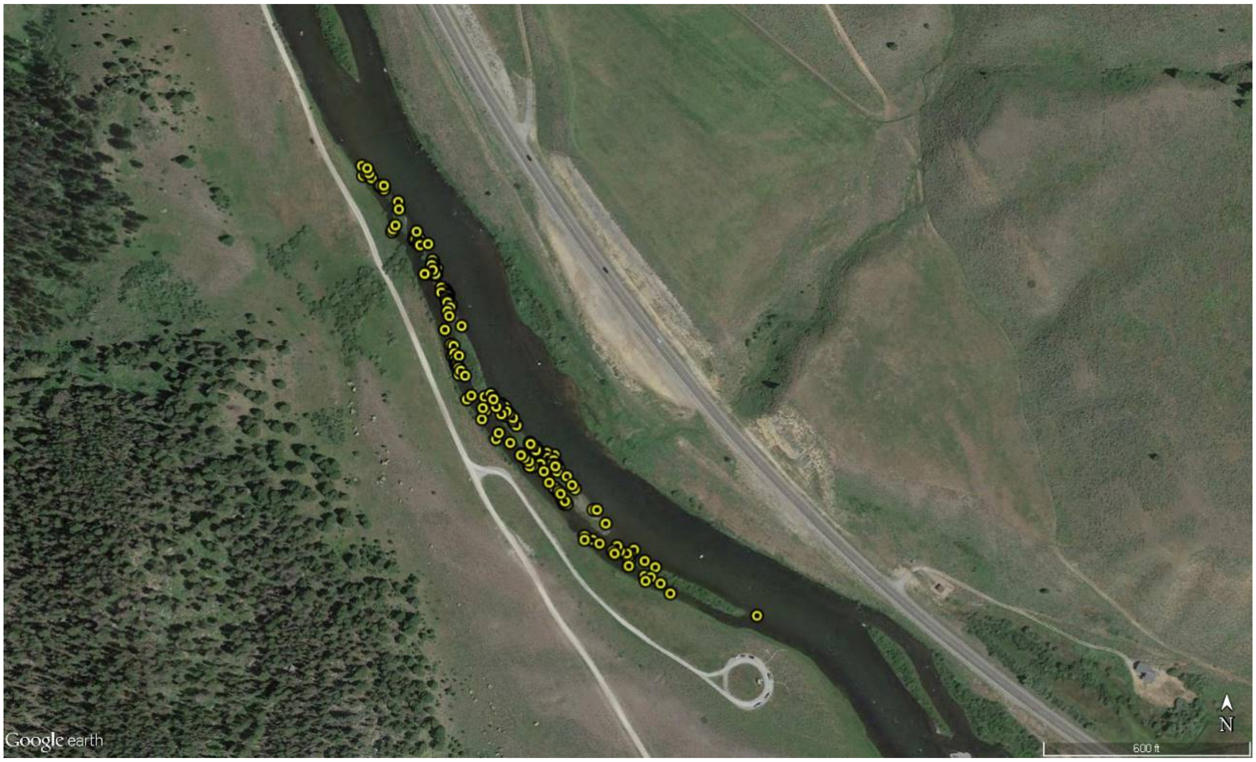

Figure 3-36. The locations of redds surveyed at the Kirby Ranch Site from spring, 2013 through fall, 2017.

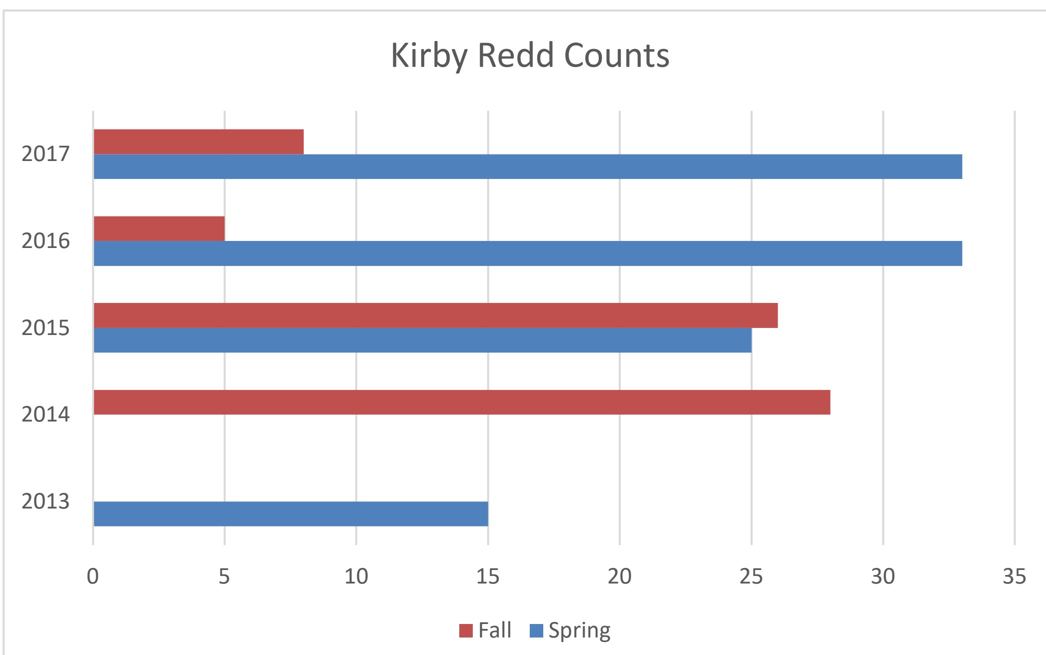

Figure 3-37. Annual fall and spring redd counts observed at the Kirby Ranch Site from spring, 2013 through fall, 2017.

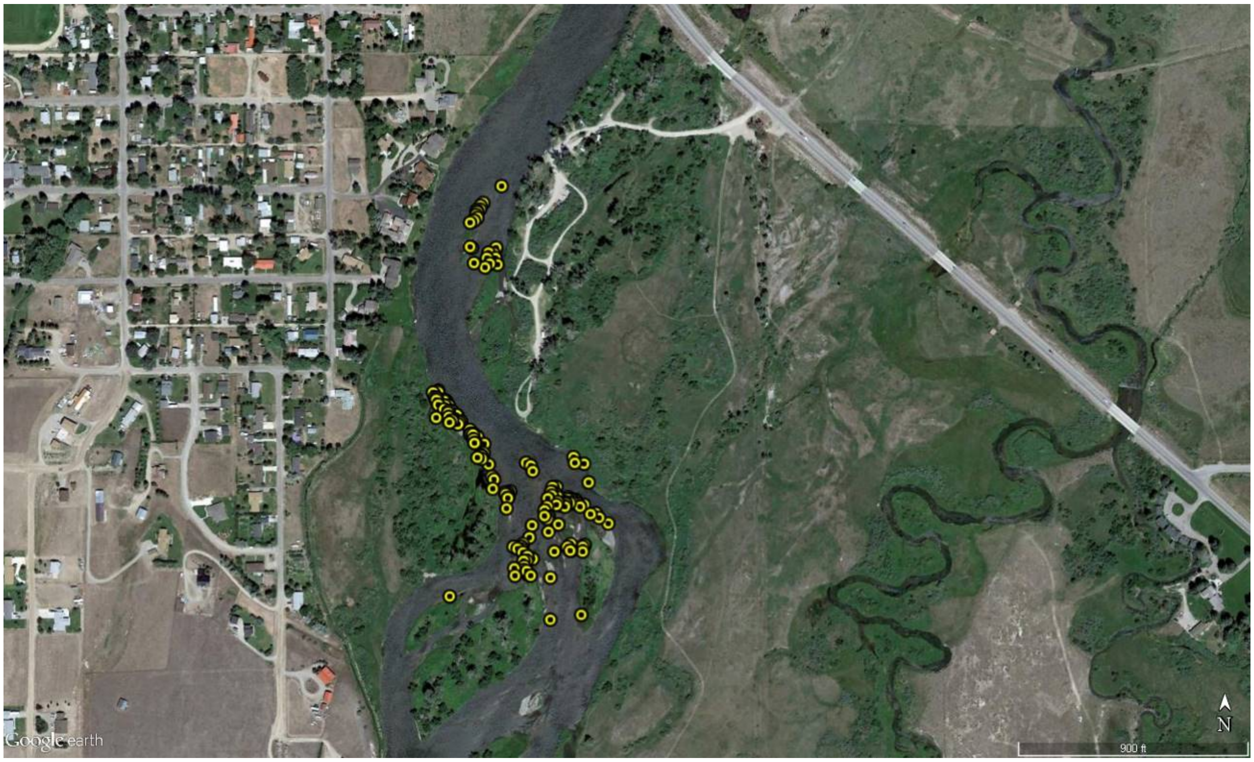

Figure 3-38. The locations of redds surveyed at the Ennis Campground Site from spring, 2013 through fall, 2017.

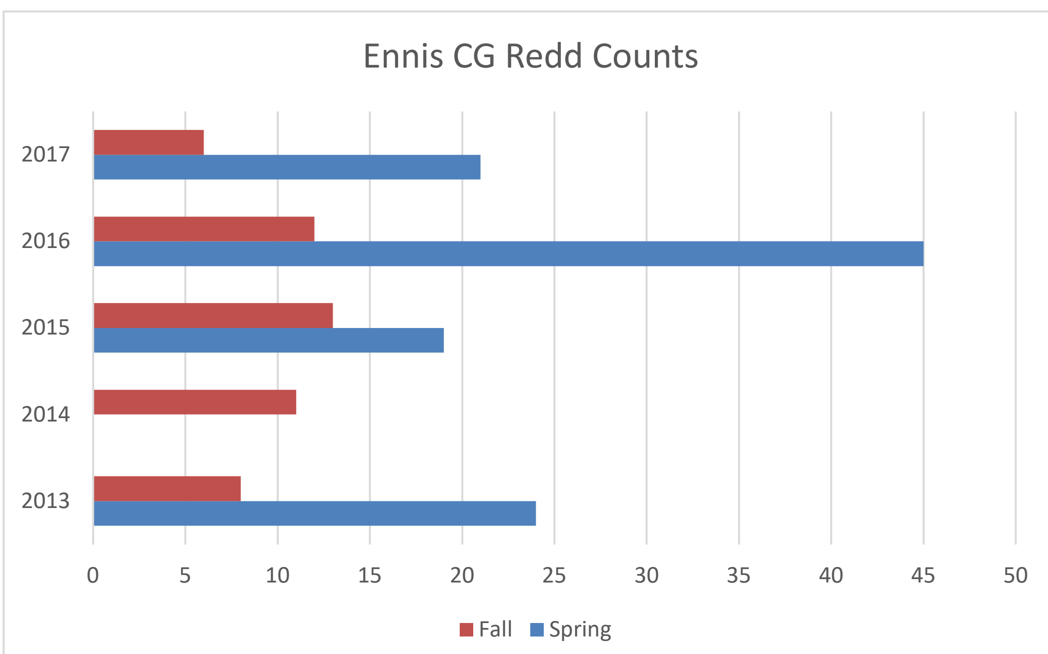

Figure 3-39. Annual fall and spring redd counts observed at the Ennis Campground Site from spring, 2013 through fall, 2017.

The locations of redds that were surveyed at the Norris Bridge Site are shown in Figure 3-40. Most of the redds were located within and downstream from the monitoring site. Annual fall and spring redd counts at the Norris Bridge Site are shown in Figure 3-41. The highest redd counts were observed in spring, 2017, while the lowest redd counts were observed in fall, 2014.

The locations of redds that were surveyed at the Greycliff Fishing Access Site are shown in Figure 3-42. Most of the redds were located downstream from the monitoring site. Annual fall and spring redd counts at the Greycliff Fishing Access Site are shown in Figure 3-43. The highest redd counts were observed in spring, 2015 and spring, 2017, while the lowest redd counts were observed in fall, 2014.

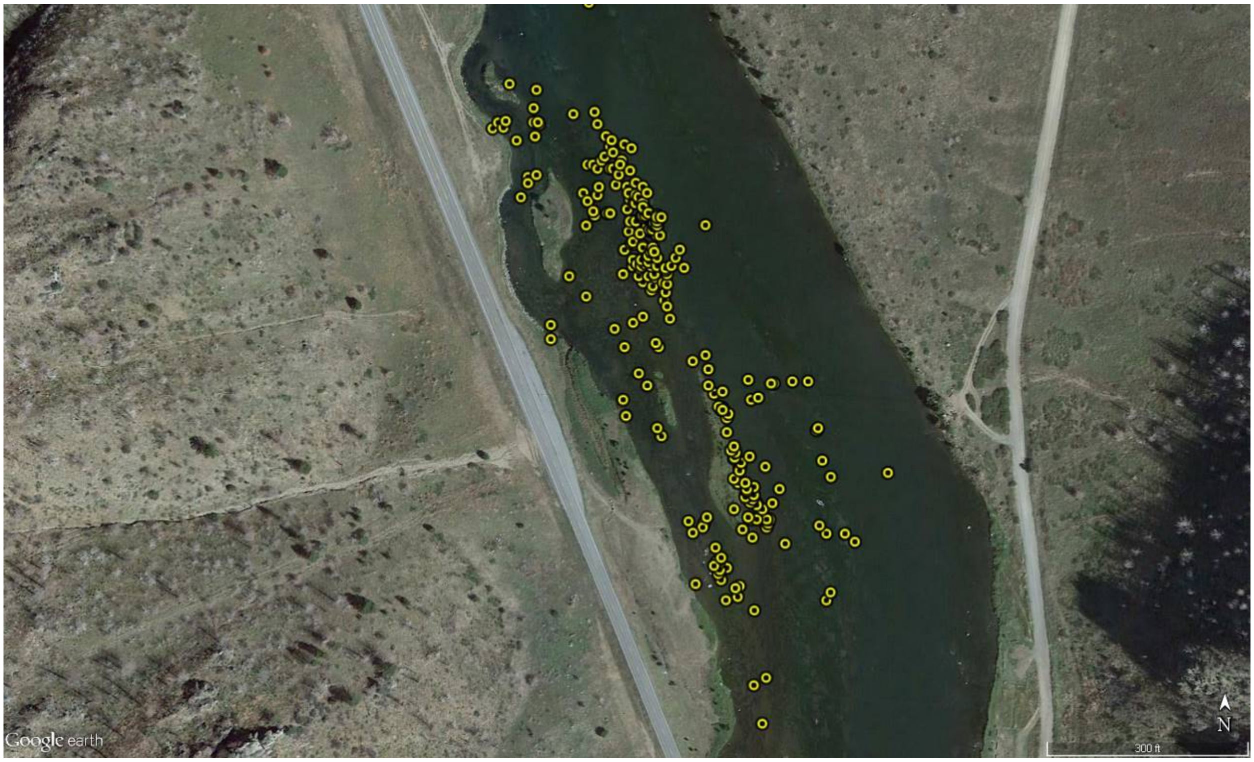

Figure 3-40. The locations of redds surveyed at the Norris Bridge Site from spring, 2013 through fall, 2017.

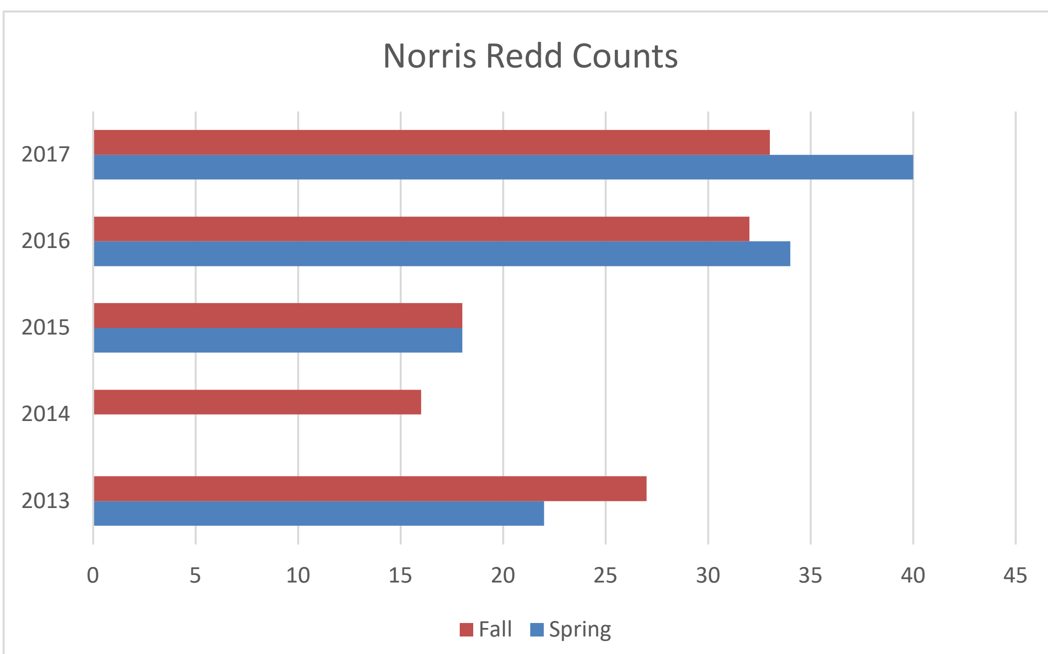

Figure 3-41. Annual fall and spring redd counts observed at the Norris Bridge Site from spring, 2013 through fall, 2017.

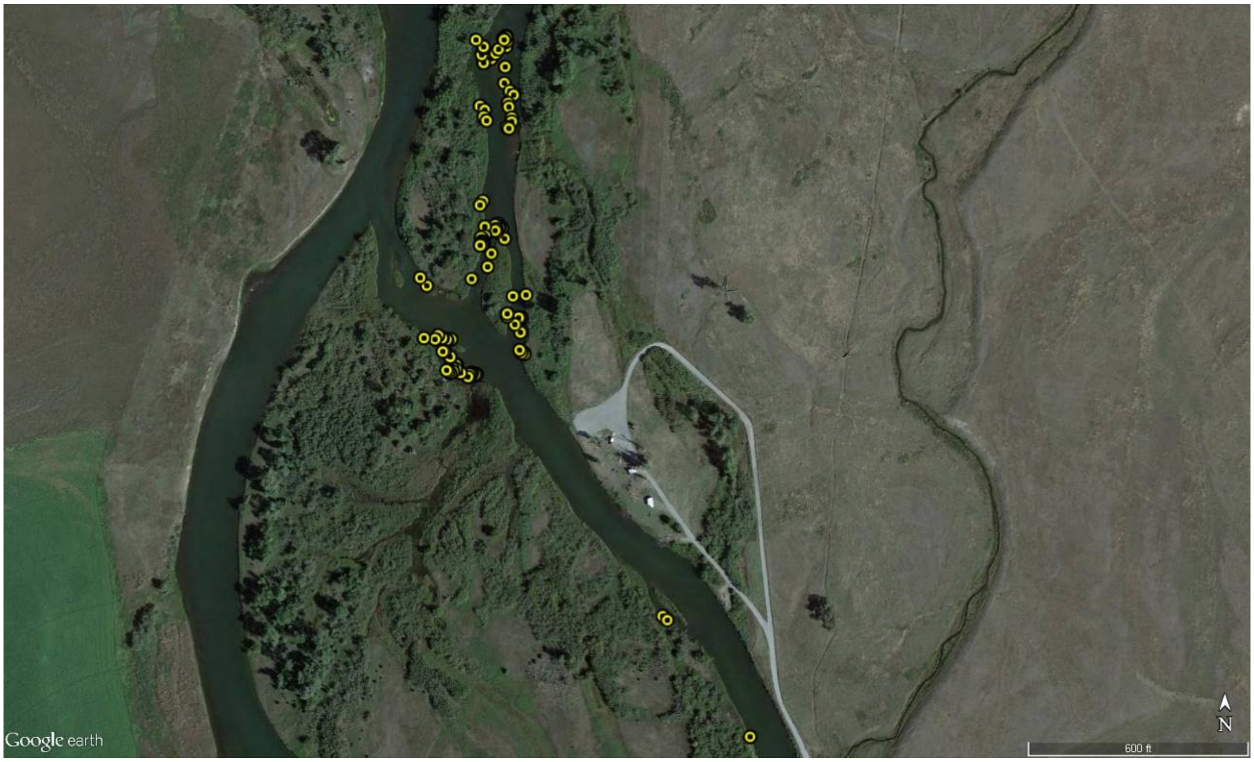

Figure 3-42. The locations of redds surveyed at the Greycliff Fishing Access Site from spring, 2013 through fall, 2017.

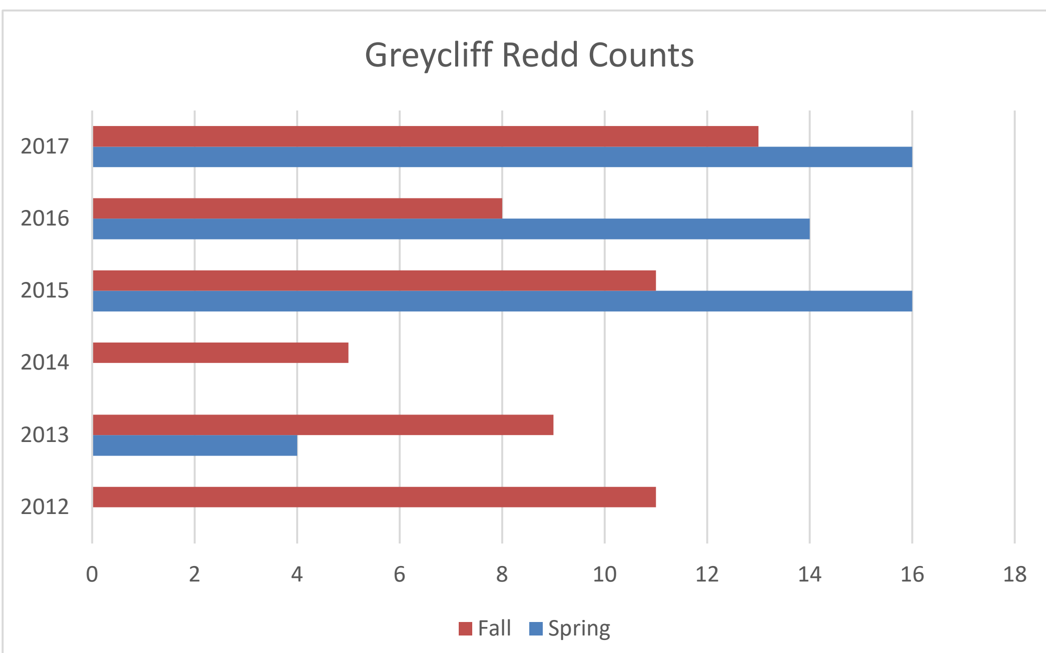

Figure 3-43. Annual fall and spring redd counts observed at the Greycliff Fishing Access Site from spring, 2013 through fall, 2017.

4. DISCUSSION

Channel morphology and sediment characteristics, aquatic macroinvertebrates, hydrology, and water temperature have all been monitored in the Madison River since 1994. Two distinct reaches of the Madison River have been identified: the upper Madison River extending from Hebgen Dam to Ennis Lake; and the lower Madison River extending from Madison Dam to the confluence with the Jefferson and Gallatin rivers.

Monitoring results from two sites on the upper Madison River (Kirby Ranch and Ennis) suggest that sediment characteristics are relatively good (low concentration of fine sediments in gravel substrates), and that temperature conditions are not stressful for fish. Monitoring results from two sites on the Lower Madison River (Norris Bridge and Greycliff Fishing Access) suggest that sediment characteristics are not as good as in the upper Madison River (higher concentration of fine sediments in the gravel substrates) and temperature conditions are more stressful to fish than in the upper Madison River.

These results are supported by aquatic macroinvertebrate data. Sediment-intolerant taxa were most diverse in the upper Madison River. Macroinvertebrates considered intolerant of fine sediments were rare in the lower Madison River. Coldwater taxa were more diverse, and abundant, in the upper river while warm water taxa predominated in the lower river.

To maintain channel morphology, and potentially manage the concentrations of fine sediments in the gravel substrates in the lower Madison River, a flushing flow releases from Hebgen Dam were initiated in 2006. To provide temperature relief in the lower Madison River during the warm summer months, pulse flows are released from Hebgen Dam and passed through Madison Dam to maintain lower Madison River temperatures below 80°F. The protocol for releasing these pulse flows is described by FERC (2004).

Initial monitoring results from 1994 and 1995 indicated relatively high concentrations of fine sediment in the lower Madison River. In 1996, flows in the Madison River downstream from Madison Powerhouse peaked with a three-day average flow of 7,600 cfs. Gravel monitoring following these high flows indicated a reduction in the percentage of fine sediments. Peak flows with a similar magnitude and duration also occurred in the lower Madison River in 1997. However, there was no further reduction in the concentrations of fine sediment.

Reservoir operation modeling was conducted by R2 (2003a) to determine the feasibility of releasing flushing flows from Hebgen Dam given the operational constraints discussed in Section 1.1. It was determined that while it may not be very feasible to provide flushing flows with a magnitude of 7,600 cfs for a duration of three days in the lower Madison River, it would be more feasible to provide flushing flows with a magnitude of 5,400 cfs for a duration of three days. Flows with this magnitude would help to maintain channel morphology, and potentially maintain spawning gravel quality.

With this in mind, flushing flows were released in 2006, 2008 and 2011. The peak three-day average flows in the lower Madison River were 5,100 cfs in 2006 and 2008, and 6,800 cfs in 2011. Gravel monitoring results suggest that these flows were not effective in maintaining low concentrations of fine sediments.

Biological criteria with regard to fine sediment concentrations were reviewed and the results are presented herein. It has long been recognized that survival to emergence of salmonid redds can be impaired if there is an excessive portion of fine sediment in the gravel matrix. Two reference grain sizes (0.84 mm and 6.4 mm) for assessing fine sediment have become prevalent in studies of survival to emergence. The smaller grain size (0.84 mm) is important for assessing survival of the egg phase during incubation. An excessive quantity of sediment finer than 0.84 mm can reduce the permeability of a gravel matrix and potentially deprive the eggs in a redd of dissolved oxygen needed for survival. McNeil and Ahnell (1964) performed laboratory studies of gravel permeability and found that as percent fines less than 0.833 mm in the gravel increased, the permeability of the gravel matrix decreased, as shown Figure 4-1. Kondolf (2000) compiled the results of previous investigations of embryo survival of Coho Salmon and Rainbow Trout. The percent fines less than 0.83 mm was determined for the 50% survival level. It was found that 50% survival was associated with percent fines ranging from 7.5% to 21% with a median level of 12%, as shown in Figure 4-2. The reference grain size of 0.83 mm evaluated by Kondolf is practically the same size as the reference grain size of 0.84 mm used in this study.

The larger grain size (6.4 mm) is important for assessing survival of the alevin phase during incubation. Alevins need space within the gravel matrix to move and eventually emerge from the substrate. An excessive quantity of sediment finer than 6.4 mm can block the interstitial spaces within the gravel matrix and potentially trap the alevins within the substrate, preventing their emergence.

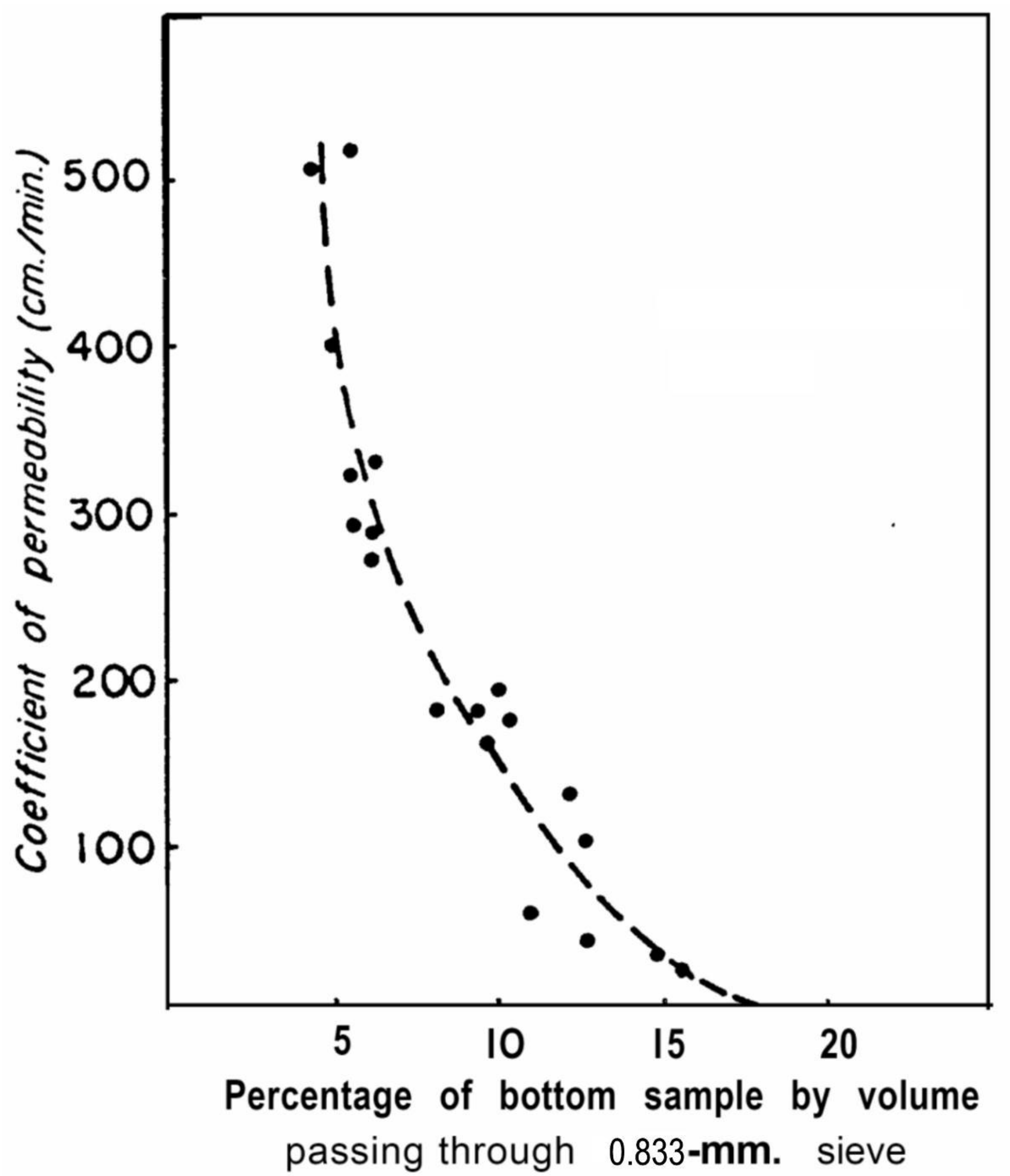

Figure 4-1. Relationship between coefficient of permeability and percent sediments finer than 0.833 mm from laboratory tests of gravel samples conducted by McNeil and Ahnell (1964).

Kondolf (2000) also compiled the results of previous investigations of survival to emergence of Chinook Salmon, Cutthroat Trout, Kokanee, Rainbow Trout, and steelhead. The percent fines less than 6.35 mm was determined for the 50% survival level. It was found that 50% survival was associated with percent fines ranging from 15% to 40%, with a median level of 30%, as shown in Figure 4-2. A criterion of 30% fines less than 6.4 mm was adopted for this study to assess the results from gravel samples collected from the Madison River.

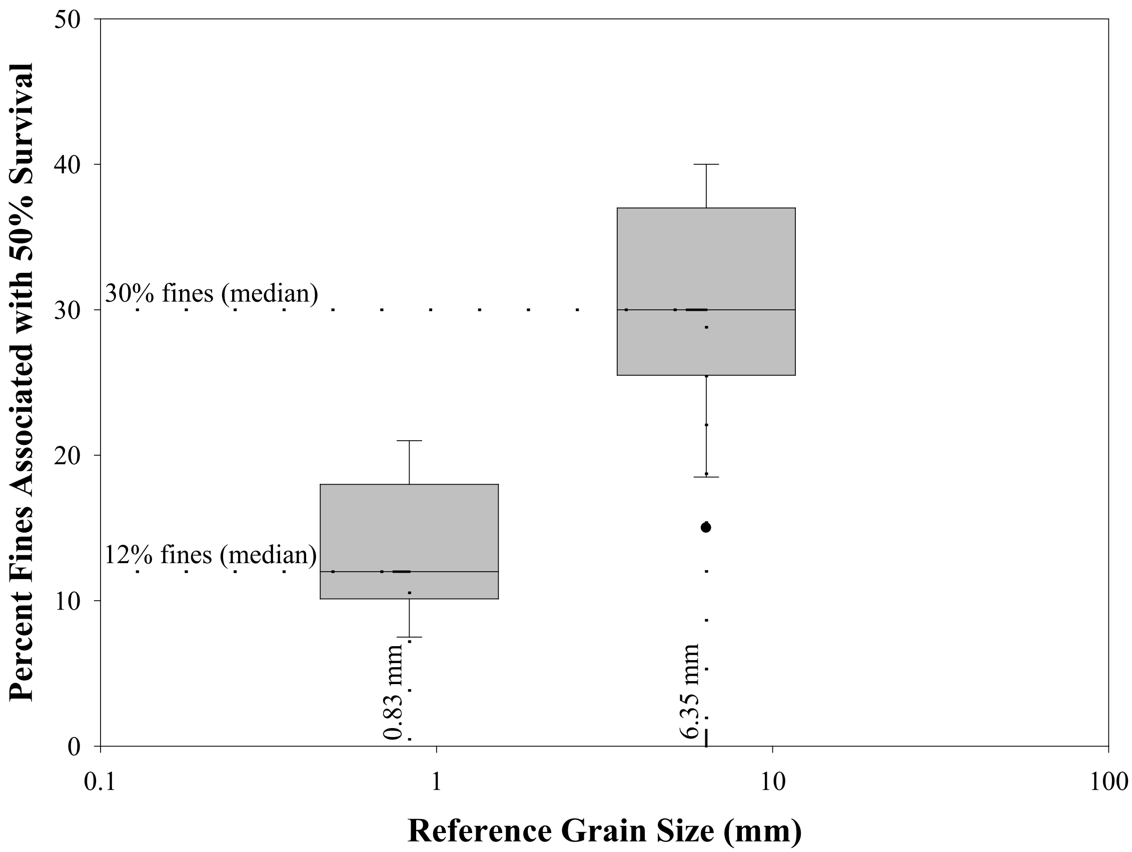

Figure 4-2. Percent fines associated with 50% survival based on reference grain sizes of 0.83 mm (Coho Salmon and Rainbow Trout) and 6.35 mm (Chinook Salmon, Cutthroat Trout, Kokanee, Rainbow Trout, and steelhead) as reported by Kondolf (2000).

Lotspeich and Everest (1981) determined survival-to-emergence for Coho Salmon and steelhead as related to the Fredle index using data reported by Phillips et al. (1975). These results, shown in Figure 4-3, indicate that 50% survival-to-emergence is associated with a Fredle index of about 2.7 mm. This criterion was adopted for this study to assess the results from gravel samples collected from the Madison River with regard to Rainbow and Brown trout spawning.

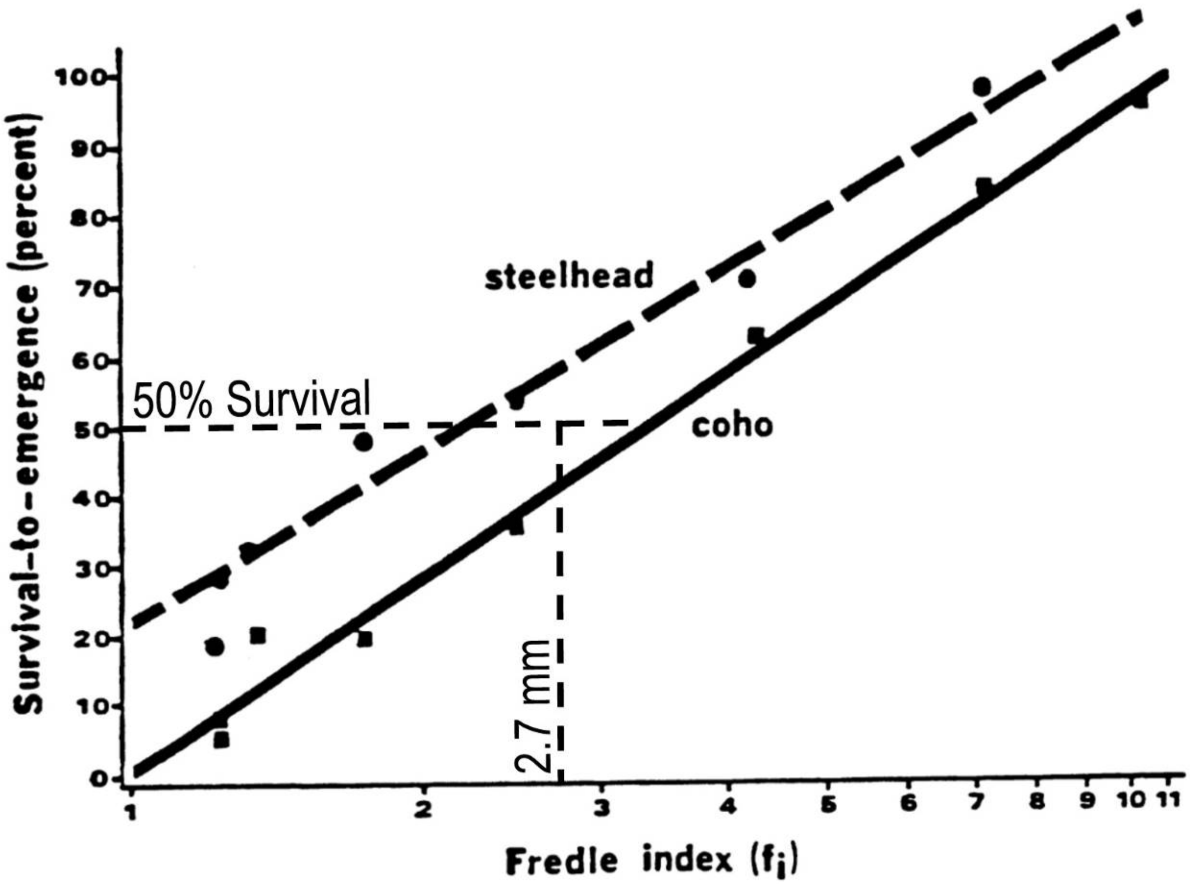

Figure 4-3. Survival-to-emergence of Coho Salmon and steelhead as related to the Fredle index, as reported by Lotspeich and Everest (1981).

Shirazi and Seim (1979) collected and analyzed the results of embryo survival studies of Coho Salmon, Cutthroat Trout, Sockeye Salmon, and steelhead. A relationship was found between embryo survival and geometric mean diameter of the spawning gravel matrix, as shown in Figure 4-4. From the results shown in Figure 4-4, 50% embryo survival would be associated with a geometric mean diameter of 10.8 mm. Another reason for selecting the 50% threshold for geometric mean diameter is that similar thresholds can be identified for percent fines less than 0.84 mm and 6.4 mm, and for the Fredle index.

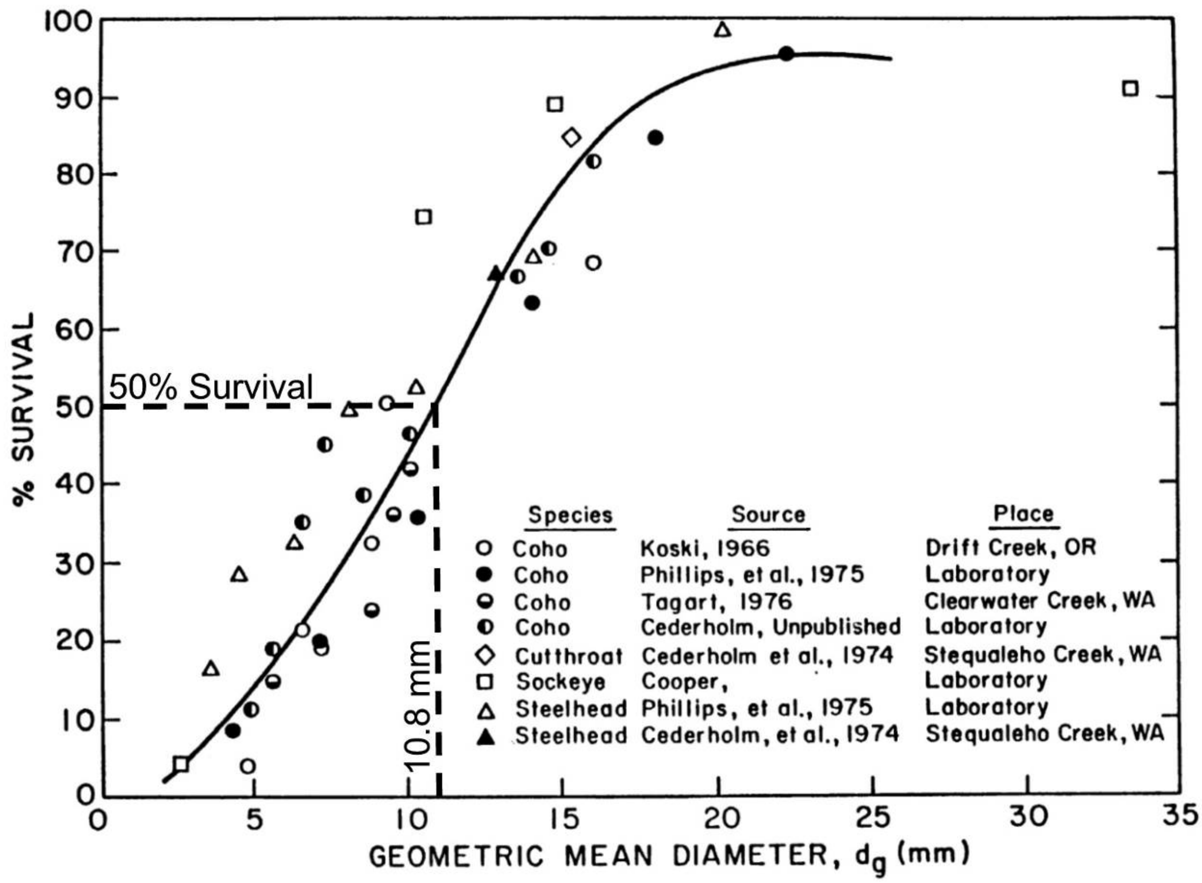

Figure 4-4. Relationship between percent embryo survival (Coho Salmon, Cutthroat Trout, Sockeye Salmon, and steelhead) and substrate composition expressed in terms of geometric mean diameter (Shirazi and Seim 1979).

With these biological criteria in mind, a trend analysis was performed within the context of dynamic geomorphic equilibrium, and results are reported herein. A river is considered to be stable in a geomorphic sense when the cross-sectional dimensions (width and depth), longitudinal slope, and substrate surface texture have adjusted to convey the water and sediment supplied to the river with no changes to the long-term averages of these characteristics (Biedenharn et al. 2008). A river with this condition of stability is referred to as a “graded stream” (Mackin 1948).

A graded stream may exhibit temporary morphological changes in response to large floods. The stream may be restored to its graded condition by subsequent moderate floods. A river that responds in this manner to the hydrologic regime is said to be in “dynamic equilibrium.” The geometric and sediment characteristics of a graded stream may fluctuate from year-to-year but the long-term average of these characteristics will remain stable, as illustrated in Figure 4-5. If a stream is not in grade, then the geometric and sediment characteristics will trend towards a new equilibrium value and approach it asymptotically. The gradual approach to a new dynamic equilibrium of a disturbed stream may take decades, and it may require 10 years of monitoring to determine whether a stream is in dynamic equilibrium or whether it is evolving towards a new dynamic equilibrium.

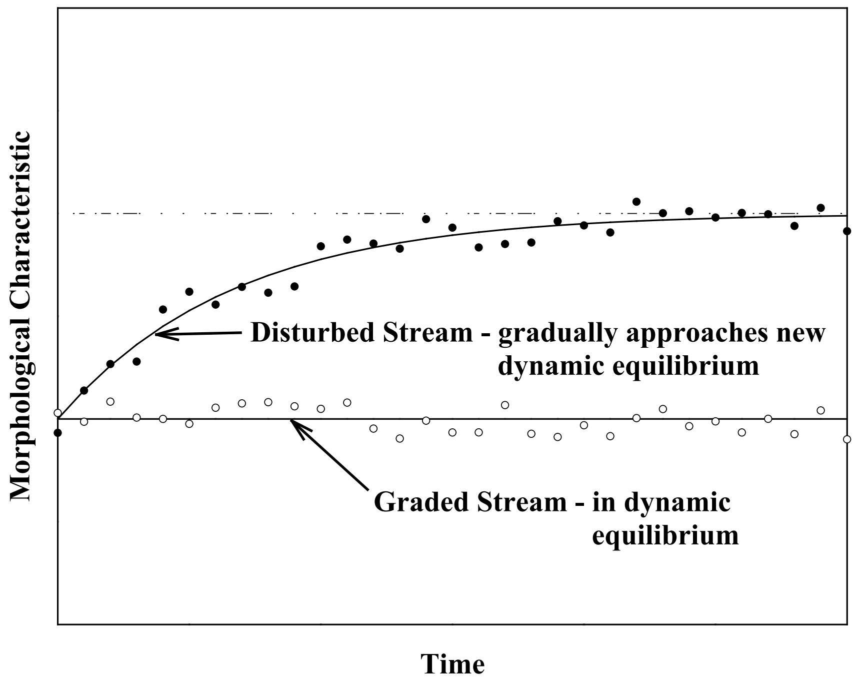

Figure 4-5. Conceptual illustration of the dynamic equilibrium of a graded stream and the gradual approach to a new dynamic equilibrium of a disturbed stream.

The alteration in streamflows and the interruption in sediment transport that accompany the operation of a water control reservoir can initiate downstream changes in channel morphology affecting habitat conditions, riparian communities and aquatic ecology. Reservoir operations can result in the reductions in both peak flows and base flows, alteration in seasonal runoff patterns, and trapping of sediments from upstream in the watershed. A common response to these actions is coarsening and degradation of the streambed just downstream from a dam. These effects will gradually attenuate in the downstream direction as the river receives sediment from downstream sources.

Historical annual median values were developed for percent fines less than 0.84 mm, percent fines less than 6.4 mm, Fredle Index, and Geometric Mean Grain Size for both the Upper and

Lower Madison Rivers. Results of the analyses are shown in Figures 4-6, 4-7, 4-8, and 4-9, respectively. The data show much scatter. Instead of calculating trend lines of these metrics, median values from all of the years were calculated for the Upper and Lower Madison Rivers.

Generally speaking, the quality of spawning gravels is higher in the Upper Madison River than it is in the Lower Madison River. This is supported by all four of the spawning gravel metrics:

- **Percent fines less than 0.84 mm** – The median is 7.1 percent in the Upper Madison River and 12.5 percent in the Lower Madison River.
- **Percent fines less than 6.4 mm** – The median is 20.1 percent in the Upper Madison River and 29.6 percent in the Lower Madison River.
- **Fredle Index** – The median is 6.5 mm in the Upper Madison River and 2.8 mm in the Lower Madison River.
- **Geometric Mean Diameter** – The median is 14.6 mm in the Upper Madison River and 7.5 mm in the Lower Madison River.

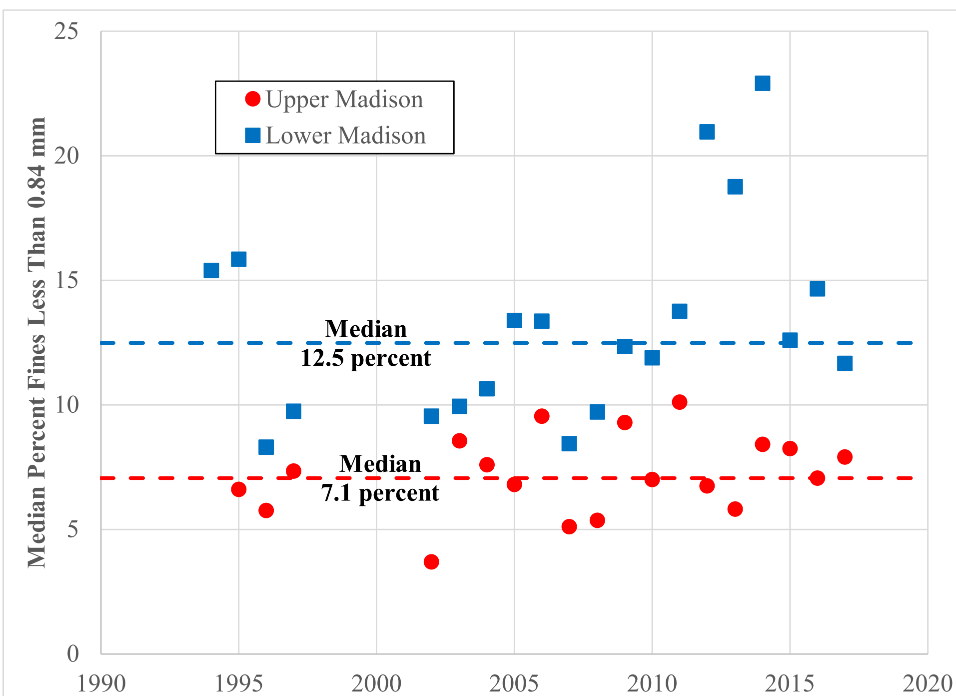

Figure 4-6. Median annual percent fines less than 0.84 mm.

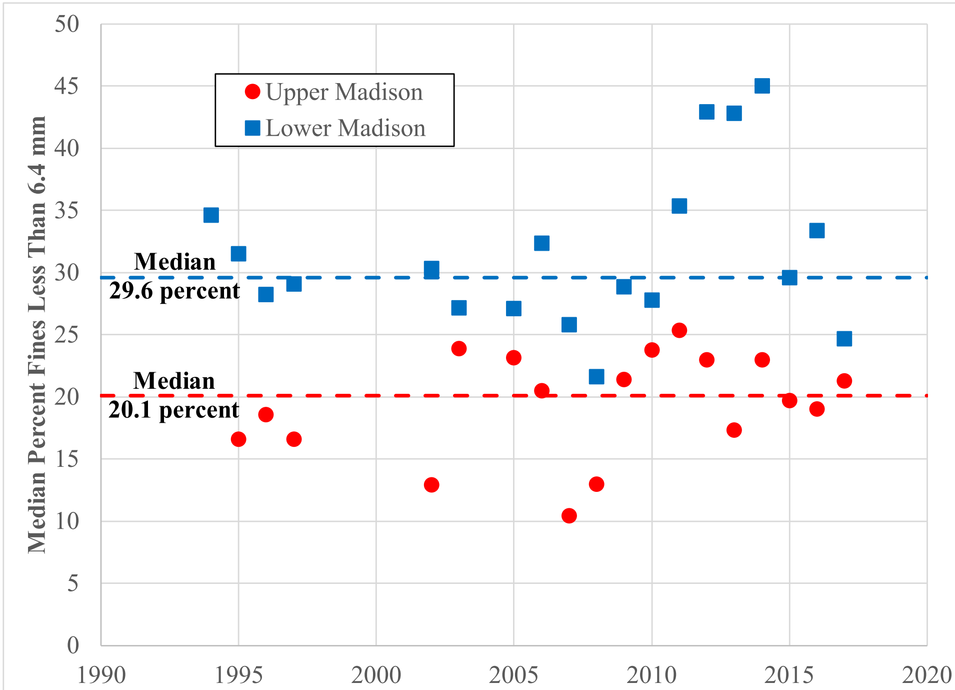

Figure 4-7 Median annual percent fines less than 6.4 mm.

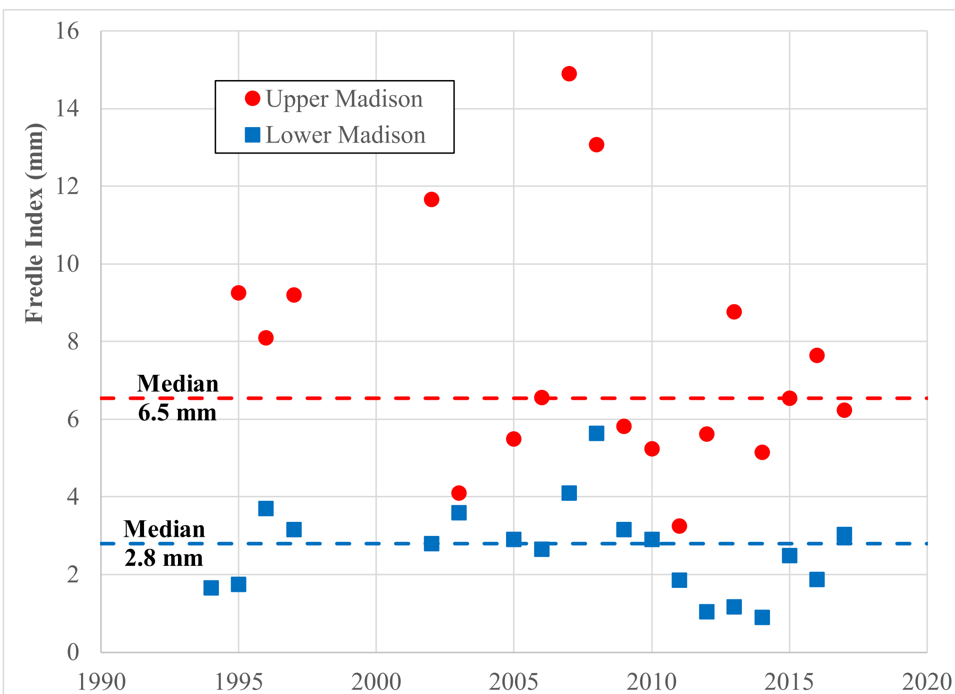

Figure 4-8. Median annual Fredle Index.

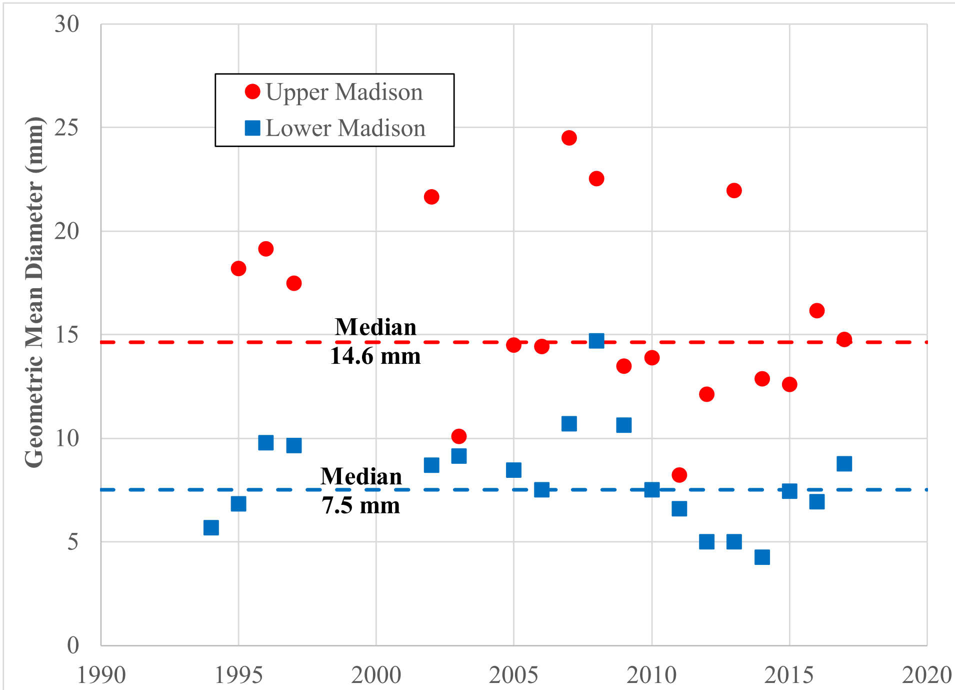

Figure 4-9. Median annual Geometric Mean Diameter.

Results from recent monitoring years should be reviewed with caution. The presence of high outliers in percent fines less than 0.84 mm (Figure 3-5) in the lower Madison River suggest a slight bias towards selecting smaller gravels. The sizes of substrate sediments will vary spatially in a river, as a result of the hydraulic capacity of the river to sort the particles. For example, sediment particles are sorted in both the downstream and lateral directions on a gravel bar on the inside bank of a meander bend (U.S. Army Corps of Engineers 1993). Larger sediment particles are typically found on the upstream end of a gravel bar, and smaller sediment particles are typically found on the downstream end of a gravel bar. In the lateral direction, larger sediment particles are found on the lower portion of the gravel bar closer to the thalweg and smaller sediment particles are found on the higher portion of the gravel bar closer to the bankfull elevation.

The annual fall and spring redd surveys are currently used to identify locations for collecting core samples. The core samples are collected after emergence of rainbow trout (spring spawners), and prior to spawning of brown trout (fall spawners). Collection of core samples from these locations provides a solid foundation for assessing spawning gravel quality in the Upper and Lower Madison Rivers.

Potential sources of fine sediments in the lower Madison River were considered. These potential sources include flow releases from Madison Dam, downstream tributary input, and streambank erosion.

Some of the incoming sediments to Ennis Lake are stored in the lake, and the rest are passed through. The trap efficiency of Ennis Lake was examined on a grain size specific basis for sediment size fractions ranging from very fine clay to small cobbles using a method that the U.S. Bureau of Reclamation recommends for turbulent flow (Borland 1971; Chen 1975; and Raudkivi 1993). This method is based on the following equation:

$$E_i = 100\left[1 - \exp\left(\frac{-w_i A}{Q}\right)\right]$$

where E_i is the trap efficiency for a particular size fraction, w_i is the sediment particle fall velocity, A is the surface area of the reservoir, and Q is the flow through the reservoir.

The surface area of Ennis Lake is about 3,700 acres. The water temperature was assumed to be 10 degrees C for these evaluations. Results of the analysis are shown in Figure 4-10. Ennis Lake will trap all sediments larger than very fine silt (medium and coarse silt, sand, gravel, and cobble). Ennis Lake will trap some clay and very fine silt, and pass the rest downstream. These particles would be considered wash load in the lower Madison River, and there would be limited potential to interact with the river substrates.

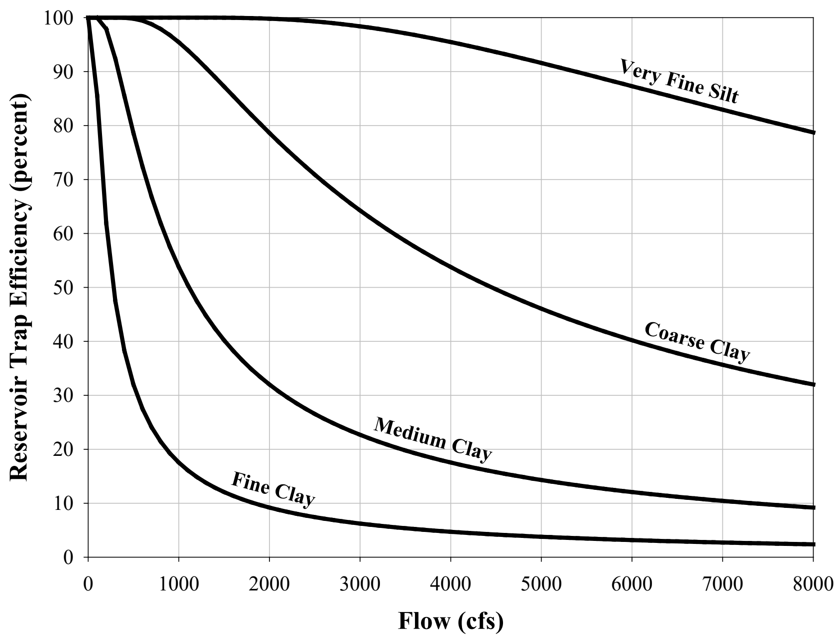

Figure 4-10. Sediment trap efficiencies for Ennis Lake, for particles ranging in size from fine clay to very fine silt.

Flow releases from Ennis Lake would be relatively clear and free of fine sediment, especially in the sand and silt size range. Potential sources of fine sediment in the lower Madison River appear to be from tributaries and from streambank erosion. The release of flushing flows from Madison Dam may potentially erode downstream streambanks.

When monitoring began in the mid-1990s, the Madison River supported a healthy macroinvertebrate community. Although taxonomic composition changed along the thermal and sediment gradients in the river, benthic macroinvertebrate assemblages were diverse and typically dominated by caddisflies and mayflies. Macroinvertebrate community composition has changed at most monitoring sites since 1995 (R2 2008). In general, the multimetric assessment developed for Missouri and Madison River kick samples indicates increased environmental stress at the Kirby Ranch in comparison to sampling in 1996-1997 (Figure 3-9). In contrast, NWE 2188 annual biomonitoring data indicated an overall increase in biological integrity at Norris from 2000 to 2011 followed by a decrease from 2011 to 2016. Multimetric scores for Ennis, spanning the 1997-2011 period, show relatively stable and healthy conditions, with MMRMA scores averaging 90%. Likewise, conditions at Greycliff are stable.

Results of analyses completed for the 2008-2011 period have indicated that increased environmental stresses were most evident in the Madison River from Hebgen Reservoir downstream to Kirby Ranch (Figure 3-9), which is subject to the influences of increased hypolimnetic flow releases below Hebgen Reservoir. Benthic communities below hypolimnetic releases generally have a less diverse fauna, with less mayfly, stonefly, and caddisfly taxa (Brittain and Saltveit 1989; Stanford and Ward 1989; Munn and Brusven 1991). Results confirm that Kirby Ranch has lower contributions of EPT taxa, specifically mayflies and caddisflies, and an increased contribution of chironomids and non-insect taxa (mostly snail taxa). Contrary to the studies is the result that Kirby Ranch also showed higher stonefly contributions than the other sites (Figure 3-18), which may be an indication of favorable cooler water conditions preferable to some stonefly taxa. In addition, flow stability may also be a factor, given that the flow in the Madison River near Kirby Ranch must be kept below 3,500 cfs to limit erosion from the outlet of Quake Lake.

5. RECOMMENDATIONS

While there may be some potential for the release of high flows from Madison Dam to the Madison River to increase downstream streambank erosion, it would be premature to abandon the flushing flow program. The release of flushing flows from Hebgen Dam has been precluded in recent years as a result of construction activities at Hebgen Dam. Several recommendations are made for future monitoring:

- **Channel Morphology and Sediment Characteristics**
    - Channel cross-section surveys have been performed at all four sites over the 20-year period from 1995 to 2015. Average bed elevations have been very stable (Table 3-1). All of the sites are accessible to the public, and it has been difficult to maintain horizontal and vertical survey control. Given these considerations, channel cross-section surveys should be discontinued, or performed no more frequently than once every five years. If channel cross-section surveys are continued, then horizontal and vertical survey control should be re-established at all of the sites.
    - Spring and fall spawning surveys should be conducted at the Kirby Ranch, Ennis, Norris Bridge, and Greycliff Fishing Access sites to identify locations for collection of McNeill samples in late summer. The redds should be marked and surveyed with RTK GPS for precise relocation in late summer.
    - Scour chains should be monitored at the Ennis, Norris Bridge, and Greycliff Fishing Access sites.
- **Aquatic Macroinvertebrates**
    - Aquatic macroinvertebrates are currently monitored in August each year at numerous sites in the upper and lower Madison River as part of the water quality monitoring program. Results of these monitoring efforts should continue to be obtained and reviewed for the flushing flow program.
- **Streamflow**
    - Streamflow records from USGS gages on the Madison River should be obtained and reviewed.
- **Water Temperature**
    - Water temperature records from USGS gaging stations should be obtained and reviewed.

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APPENDIX A

Article 419
FERC Project 2188

143 FERC ¶ 62,165
UNITED STATES OF AMERICA
FEDERAL ENERGY REGULATORY COMMISSION

PPL Montana, LLC Project No. 2188-154

ORDER APPROVING MADISON RIVER FIVE-YEAR FLUSHING FLOW PLAN UNDER ARTICLE 419

(Issued June 3, 2013)

1. On March 22, 2013, PPL Montana, LLC (licensee) filed a revised Five-Year Flushing Flow Plan with the Federal Energy Regulatory Commission (Commission), pursuant to Article 419 of the license[1] for the Missouri-Madison Project No. 2188. The project consists of nine developments, and is located on the Madison and Missouri Rivers in Gallatin, Madison, Lewis and Clark, and Cascade Counties, in southwestern Montana.

BACKGROUND AND LICENSE REQUIREMENTS

2. License Article 419 requires that the licensee file for Commission approval, a plan to coordinate and monitor flushing flows in the upper Madison River, downstream of Hebgen Dam. The plan should include, but not be limited to, a provision for monitoring flushing flow needs in the upper Madison River near Kirby Ranch in 2002 and every five years thereafter, and a provision to coordinate flushing flows in the lower Madison River below Madison Dam with flushing flow requirements in the upper Madison River. The licensee filed an interim flushing flow plan with the Commission on March 27, 2002, which was approved by an ensuing Commission order on July 23, 2002.[2] Subsequent flushing flow plans were filed with the Commission on March 3, 2003 and April 11, 2008, and approved by Commission orders dated January 23, 2004[3] and September 18, 2008,[4] respectively.

3. Among the elements of the most recent plan approved on September 18, 2008, the licensee is to conduct geomorphic and macroinvertebrate studies to assess the impacts of

[1] *See* 92 FERC ¶ 61,261. Order Issuing New License (issued September 27, 2000).

[2] *See* 100 FERC ¶ 62, 054. Order Modifying and Approving Interim Madison River Flushing Flow Plan, Article 419.

[3] *See* 106 FERC ¶ 62,054. Order Modifying and Approving Madison River Flushing Flow Plan, Article 419.

[4] *See* 124 FERC ¶ 62,207. Order Approving Madison River Flushing Flow Plan.

the license-required flow regime. The required monitoring is to include core sediment samples, scour chain monitoring, macroinvertebrate sampling, cross-sectional surveys, and particle size distribution surveys. The licensee is also to compile daily streamflow data, peak-flow data, and water temperature data from the USGS. Additionally, ordering paragraph (B) of the January 23, 2004 order requires in part, that the licensee file for Commission approval, revised Madison River Flushing Flow Plans every five years, beginning March 1, 2008. The plans are to be prepared in consultation with the U.S. Forest Service (FS), U.S. Fish and Wildlife Service (FWS), Montana Department of Fish, Wildlife and Parks (MFWP), Montana Department of Environmental Quality (MDEQ), and other interested parties. The revised plans should contain documentation of agency consultation and the licensee's response to any agency comments.

LICENSEE'S PROPOSAL

4. The licensee's filing included the results of monitoring for the 2008-2012 period and a proposal to continue its monitoring studies. The licensee conducted channel morphology surveys, sediment sampling, aquatic macroinvertebrate sampling, sediment/macroinvertebrate correlation analyses, streamflow assessment, and water temperature evaluations. The studies indicated that the percent of fine sediments in the upper Madison River were generally below the upper threshold limit of 10 percent, while the managed flushing flows in the spring have generally not been successful in reducing fine sediment in the lower Madison River. The licensee's macroinvertebrate studies also indicated that sediment-intolerant and coldwater taxa were most diverse in the upper Madison River, while warmwater taxa were more prevalent in the lower Madison River. Finally, the licensee states that the flushing flow program to date, does not appear to have had a positive effect on spawning gravels or in fine sediment reduction.

5. The licensee proposes to continue implementing its approved monitoring program. However, the licensee proposes three changes to the program. Specifically, the licensee proposes to implement visual trout spawning surveys to better locate flushing flow data collection sites and more accurately correlate flushing flows with trout spawning efficiency and success. The licensee would also eliminate embeddedness surveys from the flushing flow plan. Finally, the licensee would implement scour chain monitoring at the Ennis, Norris, and Greycliff monitoring sites in years of moderate or high flow.

AGENCY CONSULTATION

6. The licensee developed its revised plan in consultation with the FS, U.S. Bureau of Land Management (BLM), FWS, MFWP, and MDEQ. During development of the plan, the licensee received formal comments from the MFWP. The MFWP's comments consisted of correction of grammatical and formatting errors, and requests to clarify several elements of the plan, to which the licensee provided the requested information.

The FS, BLM, FWS, MFWP, and MDEQ all provided signed concurrence on the revised plan.

DISCUSSION AND CONCLUSIONS

7. The licensee is proposing to continue implementing its flushing flow plan, by continuing its geomorphic and macroinvertebrate studies as they relate to flushing flows. Based on the results of prior monitoring, the licensee is also proposing a few minor changes to its monitoring protocols, which would improve the overall effectiveness of its plan. The licensee's revised plan should continue to assess the impacts of the project and the required flushing flows on aquatic habitat at the project, and should be approved.

The Director orders:

(A) PPL Montana, LLC's (licensee) Five-Year Flushing Flow Monitoring Plan, filed with the Federal Energy Regulatory Commission (Commission) on March 22, 2013, pursuant to article 419 of the license for the Missouri-Madison Project No. 2188, is approved.

(B) This order constitutes final agency action. Any party may file a request for rehearing of this order within 30 days from the date of its issuance, as provided in section 313(a) of the Federal Power Act, 16 U.S.C. § 8251 (2006), and the Commission's regulations at 18 C.F.R. § 385.713 (2013). The filing of a request for rehearing does not operate as a stay of the effective date of this order, or of any other date specified in this order. The licensee's failure to file a request for rehearing shall constitute acceptance of this order.

(for) Thomas J. LoVullo
Chief, Aquatic Resources Branch
Division of Hydropower Administration
and Compliance

APPENDIX B

BMI Tables

Table B-1. Taxonomic enumeration and metrics, and habitat data for each kick sample collected at the Kirby site in the Madison River, Montana, August 2016.

NWE MACROINVERTEBRATE DATA
MADISON RIVER at Kirby - 10 AUG 2016
0.25 m^2 kicknet samples - ~300 organism subsamples

Taxon sample #:	1	2	3	4	5	present*	SUM	%RA	MEAN	S. D.
# Grids picked	2/8	2/16	2/16	3/10	4/20					
COLEOPTERA								13%	40	
Optioservus spp.	2	20	54	60	63		199	12.9%	39.8	27.2
DIPTERA								16%	49	
Thienemannimyia gp.	4	7	0	1	2		14	0.9%	2.8	2.8
Diamesa spp.	0	6	18	18	14		56	3.6%	11.2	7.9
Pagastia sp	12	6	1	1	3		23	1.5%	4.6	4.6
Potthastia sp.	2	0	0	1	0		3	0.2%	0.6	0.9
Cardiocladius spp.	0	0	1	0	1		2	0.1%	0.4	0.5
Cricotopus spp.	10	3	26	8	14		61	4.0%	12.2	8.7
Cricotopus nostococladius	1	0	0	0	0		1	0.1%	0.2	0.4
Eukiefferiella spp.	0	1	1	0	3		5	0.3%	1.0	1.2
Orthocladius spp.	2	2	1	7	10		22	1.4%	4.4	3.9
Symbiocladius sp	0	0	0	0	0	*	0	0.0%	0.0	0.0
Synorthocladius sp.	2	0	1	0	2		5	0.3%	1.0	1.0
Tvetenia sp.	0	0	4	2	2		8	0.5%	1.6	1.7
Cryptochironomus sp.	0	1	0	0	0		1	0.1%	0.2	0.4
Microtendipes sp	14	4	0	0	0		18	1.2%	3.6	6.1
Phaenopsectra sp	0	1	1	0	0		2	0.1%	0.4	0.5
Polypedilum spp.	1	0	0	0	3		4	0.3%	0.8	1.3
Rheotanytarsus sp.	4	0	0	0	0		4	0.3%	0.8	1.8
Antocha sp.	0	0	1	1	0		2	0.1%	0.4	0.5
Hexatoma sp.	0	0	1	0	0		1	0.1%	0.2	0.4
Simulium spp.	2	4	2	0	5		13	0.8%	2.6	1.9
Chelifera sp.	0	0	0	0	1		1	0.1%	0.2	0.4
EPHEMEROPTERA								15%	47	
Acentrella insignificans	0	0	7	2	2		11	0.7%	2.2	2.9
Baetis tricaudatus	3	6	45	13	63		130	8.4%	26.0	26.6
Diphetor hageni	0	1	3	1	6		11	0.7%	2.2	2.4
Attenella margarita	3	5	5	7	4		24	1.6%	4.8	1.5
Drunella flavilinea	0	0	4	0	2		6	0.4%	1.2	1.8
Epeorus albertae	0	0	3	0	2		5	0.3%	1.0	1.4

Paraleptophlebia sp.	1	11	1	2	0		15	1.0%	3.0	4.5
Tricorythodes sp	13	17	0	0	1		31	2.0%	6.2	8.2
PLECOPTERA								3%	9	
Claassenia sabulosa	0	0	4	5	3		12	0.8%	2.4	2.3
Hesperoperla pacifica	0	0	2	5	4		11	0.7%	2.2	2.3
Skwala sp.	0	0	0	0	1		1	0.1%	0.2	0.4
Pteronarcys californica	0	1	4	5	11		21	1.4%	4.2	4.3
TRICHOPTERA								26%	81	
Arctopsyche grandis	0	0	9	1	0		10	0.6%	2.0	3.9
Cheumatopsyche spp.	1	11	17	41	28		98	6.3%	19.6	15.5
Hydropsyche occidentalis	0	0	2	4	1		7	0.5%	1.4	1.7
Hydropsyche(C.) cockerelli	0	0	0	2	4		6	0.4%	1.2	1.8
Psychoglypha sp.	0	1	0	0	0		1	0.1%	0.2	0.4
Hydroptila spp.	9	1	2	1	0		13	0.8%	2.6	3.6
Leucotrichia pictipes	0	0	1	0	2		3	0.2%	0.6	0.9
Lepidostoma sp.	0	0	6	0	0		6	0.4%	1.2	2.7
Ceraclea sp.	1	0	4	0	0		5	0.3%	1.0	1.7
Oecetis sp.	24	8	10	5	6		53	3.4%	10.6	7.7
Psychomyia sp.	0	1	1	0	0		2	0.1%	0.4	0.5
Amiocentrus sp.	0	0	1	0	0		1	0.1%	0.2	0.4
Brachycentrus americanus	0	0	0	0	0	*	0	0.0%	0.0	0.0
Brachycentrus occidentalis	46	56	10	46	2		160	10.4%	32.0	24.2
Helicopsyche borealis	0	2	3	0	0		5	0.3%	1.0	1.4
Glossosoma sp.	0	1	30	4	2		37	2.4%	7.4	12.7
ANNELIDA								8%	23	
Lumbricidae	5	13	14	4	9		45	2.9%	9.0	4.5
Lumbriculidae	15	8	0	1	0		24	1.6%	4.8	6.6
Naididae	0	1	0	0	0		1	0.1%	0.2	0.4
Tubificidae	21	3	2	0	0		26	1.7%	5.2	8.9
Glossophonia complanata	5	9	1	1	0		16	1.0%	3.2	3.8
Helobdella stagnalis	4	0	0	0	0		4	0.3%	0.8	1.8
CRUSTACEA								2%	6	
Hyalella azteca	30	1	0	0	0		31	2.0%	6.2	13.3
MOLLUSCA								16%	50	

Physella sp.	34	37	12	19	19	121	7.8%	24.2	10.8
Fossaria sp.	18	60	2	7	12	99	6.4%	19.8	23.2
Potamopyrgus antipodarum	1	0	0	0	0	1	0.1%	0.2	0.4
Pisidium sp.	11	1	1	6	8	27	1.7%	5.4	4.4
OTHER									
Turbellaria	2	12	4	1	0	19	1.2%	3.8	4.8
*(+) present in these samples but not in subsamples									
ID's by D. McGuire & D. Stagliano									
SUBSAMPLE count	303	322	322	282	315	1544		309	17
TAXA RICHNESS	32	35	43	32	35	62		35.4	4.5
EPT RICHNESS	9	14	23	16	18	28		16.0	5.1
SHAN. DIVERSITY (log2)	4.21	4.05	4.34	3.85	4.03	4.73		4.10	0.19
BIOTIC INDEX	5.77	4.86	4.20	4.46	4.83	4.82		4.82	0.60
% EPT	33%	38%	54%	51%	46%	44%		44%	9%
% Chironomidae	17%	10%	17%	13%	17%	15%		15%	3%
TEMPERATURE METRICS									
Warm water					taxa	16	Percent	32%	
Cold water					taxa	9	Percent	8%	
Cool water - eurithermal					taxa	35	Percent	59%	
temp estimate - C					max T	23	opt T	19	
SEDIMENT METRICS									
Sediment tolerant taxa	10	11	8	6	5	12		8.0	2.5
% Sediment tolerant	48%	44%	12%	27%	22%	30%		30%	15%
Sediment intolerant taxa	0	2	7	4	5	7		4	3
% Sediment intolerant	0%	1%	18%	5%	7%	6%		6%	7%
fines estimate (%< 0.06mm)	14	12	9	11	11	14		11	2
sand estimate (%<2mm)	34	28	24	27	26	29		28	4
Baetidae/Ephemeroptera	0.15	0.18	0.81	0.64	0.89	0.65		0.53	0.35
Hydropsychinae/Trichoptera	0.01	0.14	0.20	0.45	0.73	0.27		0.31	0.29
% R.A. DOMINANT	15%	19%	17%	21%	20%	13%		18%	2%
Shannon-Weaver Index (loge)	2.92	2.81	3.01	2.67	2.79	3.28		2.84	0.13
METALS TOLERANCE	3.62	3.28	4.17	4.30	4.49	3.97		3.97	0.51
ORDINAL RELATIVE ABUNDANCE (%)									
EPHEMEROPTERA	7%	12%	21%	9%	25%	15%		15%	8%
PLECOPTERA	0%	0%	3%	5%	6%	3%		3%	3%

TRICHOPTERA	27%	25%	30%	37%	14%	26%	27%	8%
COLEOPTERA	1%	6%	17%	21%	20%	13%	13%	9%
DIPTERA	18%	11%	18%	14%	19%	16%	16%	3%
NONINSECT	48%	45%	11%	14%	15%	27%	27%	18%
FUNCTIONAL FEEDING GROUP RELATIVE ABUNDANCE (%)								
SCRAPERS/GRAZERS	20%	31%	18%	11%	12%	19%	19%	8%
SHREDDERS	0%	1%	3%	2%	3%	2%	2%	1%
FILTER FEEDERS	21%	22%	13%	35%	15%	21%	21%	9%
COLLECTOR-GATHERER	45%	34%	59%	45%	63%	50%	49%	12%
PREDATORS	13%	11%	7%	6%	6%	9%	9%	3%
% of sample used:	25%	13%	13%	30%	25%			
ENTIRE SAMPLE								
estimated total organisms	1212	2576	2576	940	1260		1713	797
total Potamopyrgus	1	0	0	0	0		0	0
HABITAT								
type	SLOW/SHAL	SLOW/DEEP	FAST/SHAL	FAST/DEEP	TYPICAL			
depth (ft)	1.4	0.5	0.5	1.2	1.5		1.0	0.5
water velocity(ft/sec)	1.00	1.19	2.18	2.80	3.72		2.2	1.1
% fines (<0.062 mm)	10	20	10	2	2		9	7
% sand (.062-2mm)	20	10	10	10	3		11	6
% gravel (2-64 mm)	10	70	80	80	35		55	31
% cobble (64-256 mm)	60	0	0	10	60		26	31
% boulder (> 256 mm)	0	0	0	0	0		0	0
% vegetation cover	0	10	0	1	0		2.2	4.4

Table B-2. Taxonomic enumeration and metrics, and habitat data for each kick sample collected at the Ennis site in the Madison River, Montana, August 2016.

NWE MACROINVERTEBRATE DATA
MADISON RIVER at Ennis - 11 AUG 2016
0.25 m^2 kicknet samples - ~300 organism subsamples

Taxon sample #:	1	2	3	4	5	present*	SUM	%RA	MEAN	S. D.
# grids picked:	4/10	2/16	4/16	2/16	3/10					
COLEOPTERA								19%	62	
Optioservus spp.	41	41	55	49	44		230	14.1%	46.0	6.0
Zaitzevia sp.	7	5	29	20	17		78	4.8%	15.6	9.8
DIPTERA								10%	32	
Thienemannimyia gp.	0	3	0	0	0		3	0.2%	0.6	1.3
Pentaneura sp.	2	1	0	1	0		4	0.2%	0.8	0.8
Diamesa spp.	0	0	0	1	0		1	0.1%	0.2	0.4
Pagastia sp	4	2	1	2	4		13	0.8%	2.6	1.3
Potthastia sp.	0	1	1	0	0		2	0.1%	0.4	0.5
Cardiocladius spp.	0	0	0	0	1		1	0.1%	0.2	0.4
Cricotopus spp.	2	2	4	7	0		15	0.9%	3.0	2.6
Cricotopus nostococladius	5	14	23	7	0		49	3.0%	9.8	8.9
Eukiefferiella spp.	0	0	2	3	2		7	0.4%	1.4	1.3
Orthocladius spp.	1	0	0	0	2		3	0.2%	0.6	0.9
Tvetenia sp.	0	1	2	1	0		4	0.2%	0.8	0.8
Cryptochironomus sp.	0	0	0	1	0		1	0.1%	0.2	0.4
Microtendipes sp	2	1	0	1	0		4	0.2%	0.8	0.8
Phaenopsectra sp	1	0	0	0	0		1	0.1%	0.2	0.4
Polypedilum spp.	2	5	1	6	2		16	1.0%	3.2	2.2
Cladotanytarsus sp.	0	1	1	0	0		2	0.1%	0.4	0.5
Rheotanytarsus sp.	0	0	1	2	0		3	0.2%	0.6	0.9
Antocha sp.	0	1	4	1	0		6	0.4%	1.2	1.6
Hexatoma sp.	0	0	1	1	0		2	0.1%	0.4	0.5
Simulium spp.	5	0	3	1	2		11	0.7%	2.2	1.9
Chelifera sp.	2	0	5	2	2		11	0.7%	2.2	1.8
Hemerodromia sp.	0	0	2	0	0		2	0.1%	0.4	0.9
EPHEMEROPTERA								6%	20	
Acentrella sp.	0	1	1	0	0		2	0.1%	0.4	0.5
Baetis tricaudatus	2	2	21	25	26		76	4.7%	15.2	12.2
Diphetor hageni	0	1	1	4	0		6	0.4%	1.2	1.6
Attenella margarita	0	2	1	1	0		4	0.2%	0.8	0.8
Rhithrogena sp.	2	1	1	2	5		11	0.7%	2.2	1.6

Tricorythodes sp	1	0	0	1	0		2	0.1%	0.4	0.5
LEPIDOPTERA										
Petrophila sp.	0	0	4	10	4		18	1.1%	3.6	4.1
PLECOPTERA								1%	3	
Claassenia sabulosa	0	0	0	0	1		1	0.1%	0.2	0.4
Hesperoperla pacifica	0	0	2	0	0		2	0.1%	0.4	0.9
Skwala sp.	1	0	1	0	5		7	0.4%	1.4	2.1
Pteronarcys californica	0	0	1	0	4		5	0.3%	1.0	1.7
Kathroperla sp.	0	0	0	0	0	+	0	0.0%	0.0	0.0
TRICHOPTERA								58%	188	
Arctopsyche grandis	0	0	1	1	4		6	0.4%	1.2	1.6
Cheumatopsyche spp.	2	9	13	42	29		95	5.8%	19.0	16.2
Hydropsyche occidentalis	13	20	39	25	13		110	6.8%	22.0	10.8
Hydropsyche C. cockerelli	3	1	1	10	20		35	2.2%	7.0	8.2
Lepidostoma sp.	0	4	1	4	2		11	0.7%	2.2	1.8
Ceraclea sp.	0	2	0	0	0		2	0.1%	0.4	0.9
Oecetis sp.	3	8	6	6	2		25	1.5%	5.0	2.4
Psychomyia sp.	2	1	2	2	7		14	0.9%	2.8	2.4
Brachycentrus occidentalis	63	87	102	73	64		389	23.9%	77.8	16.6
Rhyacophila brunnea gp.	0	0	0	0	1		1	0.1%	0.2	0.4
Helicopsyche borealis	83	72	2	7	9		173	10.6%	34.6	39.4
Protoptila sp.	0	0	0	0	1		1	0.1%	0.2	0.4
Glossosoma sp.	9	5	4	34	24		76	4.7%	15.2	13.2
ANNELIDA								2%	5	
Lumbricidae	0	0	0	0	0	+	0	0.0%	0.0	0.0
Lumbriculidae	0	15	1	0	0		16	1.0%	3.2	6.6
Naididae	0	0	0	0	0	+	0	0.0%	0.0	0.0
Tubificidae	0	4	2	0	0		6	0.4%	1.2	1.8
Erpobdellidae	0	2	0	2	0		4	0.2%	0.8	1.1
MOLLUSCA								2%	6	
Physella sp.	3	6	1	1	0		11	0.7%	2.2	2.4
Ferrissia sp.	1	2	0	1	2		6	0.4%	1.2	0.8
Fossaria sp.	3	6	0	1	0		10	0.6%	2.0	2.5
Potamopyrgus antipodarum	0	1	0	0	0		1	0.1%	0.2	0.4

Pisidium sp.	0	1	0	2	0		3	0.2%	0.6	0.9
OTHER										
Dugesia sp.	13	3	7	2	4		29	1.8%	5.8	4.4
Hydracarina	0	0	0	0	0	+	0	0.0%	0.0	0.0
*(+) present in these samples but not in subsamples										
ID's by D. McGuire & D. Stagliano										
SUBSAMPLE count	278	334	350	362	303		1627		325	35
TAXA RICHNESS	28	37	39	39	29		61		34.4	5.5
EPT RICHNESS	12	15	18	15	17		24		15.4	2.3
SHAN. DIVERSITY (log2)	3.31	3.65	3.63	3.97	3.86		4.06		3.68	0.26
BIOTIC INDEX	3.49	3.82	3.95	3.79	3.38		3.70		3.68	0.24
% EPT	66%	65%	57%	65%	72%		65%		65%	5%
% Chironomidae	7%	9%	10%	9%	4%		8%		8%	3%
TEMPERATURE METRICS										
Warm water					taxa		16	Percent	22%	
Cold water					taxa		8	Percent	3%	
Cool water - eurithermal					taxa		35	Percent	76%	
temp estimate - C					max T		24	opt T	21	
SEDIMENT METRICS										
Sediment tolerant taxa	7	8	5	8	2		12		6.0	2.5
% Sediment tolerant	5%	9%	5%	14%	10%		9%		9%	4%
Sediment intolerant taxa	2	3	6	4	6		7		4	2
% Sediment intolerant	4%	3%	3%	11%	13%		7%		7%	5%
fines estimate (%< 0.06mm)	8	8	8	9	8		10		8	0
sand estimate (%<2mm)	27	27	26	26	25		30		26	1
Baetidae/Ephemeroptera	0.40	0.57	0.92	0.88	0.84		0.83		0.72	0.23
Hydropsychinae/Trichoptera	0.10	0.14	0.31	0.38	0.35		0.26		0.26	0.13
% R.A. DOMINANT	30%	26%	29%	20%	21%		24%		25%	4%
Shannon-Weaver Index (loge)	2.29	2.53	2.52	2.75	2.67		2.82		2.55	0.18
METALS TOLERANCE	3.60	3.49	4.15	3.94	3.78		3.81		3.79	0.27
ORDINAL RELATIVE ABUNDANCE (%)										
EPHEMEROPTERA	2%	2%	7%	9%	10%		6%		6%	4%
PLECOPTERA	0%	0%	1%	0%	3%		1%		1%	1%
TRICHOPTERA	64%	63%	49%	56%	58%		58%		58%	6%
COLEOPTERA	17%	14%	24%	19%	20%		19%		19%	4%

DIPTERA	9%	10%	15%	10%	5%	10%	10%	3%
NONINSECT	7%	12%	3%	2%	2%	5%	5%	4%
FUNCTIONAL FEEDING GROUP RELATIVE ABUNDANCE (%)								
SCRAPERS/GRAZERS	36%	28%	3%	15%	15%	19%	20%	13%
SHREDDERS	2%	5%	7%	3%	2%	4%	4%	2%
FILTER FEEDERS	31%	35%	46%	43%	44%	40%	40%	6%
COLLECTOR-GATHERER	23%	26%	37%	34%	34%	31%	31%	6%
PREDATORS	8%	5%	7%	4%	5%	6%	6%	1%
% of sample used:	40%	13%	25%	13%	30%			
ENTIRE SAMPLE								
estimated total organisms	695	2672	1400	2896	1010		1735	993
total Potamopyrgus	0	1	0	0	0		0	0
HABITAT								
type	SLOW/SHAL	SLOW/DEEP	FAST/Deep	FAST/Shal	TYPICAL			
depth (ft)	0.6	0.8	1.2	0.7	0.9		0.8	0.2
water velocity(ft/sec)	1.33	1.58	2.61	2.08	1.84		1.9	0.5
% fines (<0.062 mm)	1	2	1	1	1		1	0
% sand (.062-2mm)	10	5	10	15	15		11	4
% gravel (2-64 mm)	40	20	10	5	15		18	14
% cobble (64-256 mm)	50	75	80	80	70		71	12
% boulder (> 256 mm)	0	0	0	0	0		0	0
% vegetation cover	0	5	0	0	0		1	2.2

Table B-3. Taxonomic enumeration and metrics, and habitat data for each kick sample collected at the Norris site in the Madison River, Montana, August 2016.

MADISON RIVER below Hebgen - 9 AUG 2016
0.25 m^2 kicknet samples - ~300 organism subsamples

Taxon sample #:	1	2	3	4	5	present*	SUM	%RA	MEAN	S. D.
# grids picked:	2/16	3/8	2/16							
COLEOPTERA								2%	7	
Optioservus spp.	1	1	1	4	8		15	0.9%	3.0	3.1
Zaitzevia sp.	1	2	1	1	3		8	0.5%	1.6	0.9
Microcylloepus sp.	3	2	1	3	4		13	0.8%	2.6	1.1
DIPTERA								30%	95	
Thienemannimyia gp.	5	1	3	10	1		20	1.2%	4.0	3.7
Pentaneura sp.	1	5	6	2	5		19	1.2%	3.8	2.2
Pagastia sp	0	0	1	0	0		1	0.1%	0.2	0.4
Potthastia sp.	0	0	0	1	0		1	0.1%	0.2	0.4
Cricotopus spp.	8	11	23	8	10		60	3.7%	12.0	6.3
Cricotopus nostococladius	0	0	0	0	0	+	0	0.0%	0.0	0.0
Eukiefferiella spp.	0	0	0	0	0	+	0	0.0%	0.0	0.0
Orthocladius spp.	6	16	11	1	0		34	2.1%	6.8	6.8
Tvetenia sp.	2	1	0	7	1		11	0.7%	2.2	2.8
Cryptochironomus sp.	0	2	0	0	0		2	0.1%	0.4	0.9
Microtendipes sp	2	1	3	3	0		9	0.6%	1.8	1.3
Phaenopsectra sp	5	2	2	0	0		9	0.6%	1.8	2.0
Polypedilum spp.	43	38	80	85	40		286	17.9%	57.2	23.2
Pseudochironomus sp.	0	1	1	0	0		2	0.1%	0.4	0.5
Cladotanytarsus sp.	1	0	1	0	1		3	0.2%	0.6	0.5
Rheotanytarsus sp.	0	1	0	1	1		3	0.2%	0.6	0.5
Tanytarsus sp.	0	0	2	0	1		3	0.2%	0.6	0.9
Simulium spp.	2	3	4	2	0		11	0.7%	2.2	1.5
EPHEMEROPTERA								31%	99	
Acerpenna pygmacus	39	21	30	14	13		117	7.3%	23.4	11.1
Baetis tricaudatus	7	1	1	16	2		27	1.7%	5.4	6.4
Centroptilum sp.	1	0	0	0	0		1	0.1%	0.2	0.4
Plauditus sp.	10	4	0	5	1		20	1.2%	4.0	3.9
Diphetor hageni	7	18	20	11	72		128	8.0%	25.6	26.5
Ephemerella sp.	0	0	0	0	0	+	0	0.0%	0.0	0.0
Heptagenia sp.	0	4	0	0	0		4	0.2%	0.8	1.8
Choroterpes sp.	12	17	23	6	49		107	6.7%	21.4	16.7

Ephemera simulans	37	23	11	0	8		79	4.9%	15.8	14.4
Tricorythodes sp	3	2	3	2	1		11	0.7%	2.2	0.8
LEPIDOPTERA										
Petrophila sp.	0	1	4	0	0		5	0.3%	1.0	1.7
PLECOPTERA								0%	0	
Skwala sp.	0	0	0	0	0	+	0	0.0%	0.0	0.0
TRICHOPTERA								20%	64	
Cheumatopsyche spp.	14	1	5	33	30		83	5.2%	16.6	14.4
Hydropsyche occidentalis	7	0	1	45	1		54	3.4%	10.8	19.3
Hydropsyche C. cockerelli	2	2	0	5	0		9	0.6%	1.8	2.0
Leucotrichia pictipes	1	2	0	6	0		9	0.6%	1.8	2.5
Ochrotrichia sp.	8	22	8	4	1		43	2.7%	8.6	8.0
Nectopsyche sp.	52	12	8	1	3		76	4.7%	15.2	21.0
Oecetis sp.	6	3	1	0	1		11	0.7%	2.2	2.4
Amiocentrus sp.	0	1	0	1	2		4	0.2%	0.8	0.8
Brachycentrus occidentalis	5	3	3	0	2		13	0.8%	2.6	1.8
Polycentropus sp.	0	1	0	0	0		1	0.1%	0.2	0.4
Helicopsyche borealis	11	4	1	0	2		18	1.1%	3.6	4.4
Protoptila sp.	0	0	0	0	0	+	0	0.0%	0.0	0.0
ANNELIDA								1%	2	
Lumbricidae	0	0	0	0	3		3	0.2%	0.6	1.3
Tubificidae	3	0	5	0	0		8	0.5%	1.6	2.3
CRUSTACEA								5%	15	
Orconectes sp.	1	1	1	1	1		5	0.3%	1.0	0.0
Hyalella azteca	7	13	4	2	2		28	1.7%	5.6	4.6
Caecidotea sp.	11	4	20	7	2		44	2.7%	8.8	7.1
MOLLUSCA								1%	3	
Physella sp.	0	0	2	0	0		2	0.1%	0.4	0.9
Ferrissia sp.	0	8	0	3	0		11	0.7%	2.2	3.5
Potamopyrgus antipodarum	1	0	0	0	0		1	0.1%	0.2	0.4
Sphaerium sp.	1	1	1	0	0		3	0.2%	0.6	0.5
OTHER										

Dugesia sp.	25	53	27	13	49	167	10.4%	33.4	17.0
*(+) present in these samples but not in subsamples									
ID's by D. McGuire & D Stagliano									
SUBSAMPLE count	351	309	319	303	320	1602		320	19
TAXA RICHNESS	37	40	36	31	31	55		35.0	3.9
EPT RICHNESS	17	18	13	13	15	23		15.2	2.3
SHAN. DIVERSITY (log2)	4.28	4.29	4.01	3.78	3.54	4.42		3.98	0.32
BIOTIC INDEX	4.79	4.69	5.23	5.16	4.44	4.86		4.86	0.33
% EPT	63%	46%	36%	49%	59%	51%		51%	11%
% Chironomidae	21%	26%	42%	39%	19%	29%		29%	11%
TEMPERATURE METRICS									
Warm water					taxa	23	Percent	34%	
Cold water					taxa	2	Percent	0%	
Cool water - eurithermal					taxa	29	Percent	66%	
temp estimate - C					max T	22	opt T	19	
SEDIMENT METRICS									
Sediment tolerant taxa	11	11	13	7	8	16		10.0	2.4
% Sediment tolerant	14%	13%	17%	17%	13%	15%		15%	2%
Sediment intolerant taxa	0	0	0	0	0	0		0	0
% Sediment intolerant	0%	0%	0%	0%	0%	0%		0%	0%
fines estimate (%< 0.06mm)	11	10	12	11	11	12		11	1
sand estimate (%<2mm)	31	30	30	30	28	30		30	1
Baetidae/Ephemeroptera	0.55	0.49	0.58	0.85	0.60	0.59		0.61	0.14
Hydropsychinae/Trichoptera	0.22	0.06	0.22	0.87	0.74	0.45		0.42	0.36
% R.A. DOMINANT	15%	17%	25%	28%	23%	18%		22%	5%
Shannon-Weaver Index (loge)	2.97	2.97	2.78	2.62	2.45	3.07		2.76	0.22
METALS TOLERANCE	3.03	2.87	3.46	3.93	2.67	3.19		3.19	0.51
ORDINAL RELATIVE ABUNDANCE (%)									
EPHEMEROPTERA	33%	29%	28%	18%	46%	31%		31%	10%
PLECOPTERA	0%	0%	0%	0%	0%	0%		0%	0%
TRICHOPTERA	30%	17%	8%	31%	13%	20%		20%	10%
COLEOPTERA	1%	2%	1%	3%	5%	2%		2%	1%
DIPTERA	21%	27%	43%	40%	19%	30%		30%	11%
NONINSECT	14%	26%	19%	9%	18%	17%		17%	6%
FUNCTIONAL FEEDING GROUP RELATIVE ABUNDANCE (%)									

SCRAPERS/GRAZERS	4%	6%	2%	3%	1%	3%	3%	2%
SHREDDERS	15%	4%	3%	1%	1%	5%	5%	6%
FILTER FEEDERS	9%	4%	4%	28%	11%	11%	11%	10%
COLLECTOR-GATHERER	62%	65%	79%	60%	70%	67%	67%	8%
PREDATORS	11%	21%	12%	8%	18%	14%	14%	5%
% of sample used:	13%	38%	13%	17%	33%			
ENTIRE SAMPLE								
estimated total organisms	2808	824	2552	1782	970		1787	898
total Potamopyrgus	1	0	0	0	0		0	0
HABITAT								
type	SLOW/SHAL	SLOW/DEEP	FAST/SHAL	FAST/DEEP	TYPICAL			
depth (ft)	0.7	1.2	0.6	1.5	1.1		1.0	0.4
water velocity(ft/sec)	0.06	0.57	0.71	1.70	1.29		0.9	0.6
% fines (<0.062 mm)	20	10	10	1	5		9	7
% sand (.062-2mm)	40	30	15	15	15		23	12
% gravel (2-64 mm)	40	15	50	5	50		32	21
% cobble (64-256 mm)	0	40	25	80	30		35	29
% boulder (> 256 mm)	0	15	0	0	0		3	7
% vegetation cover	80	20	20	10	10		28	29.5

Table B-4. Taxonomic enumeration and metrics, and habitat data for each kick sample collected at the Greycliff site in the Madison River, Montana, August 2016.

NWE MACROINVERTEBRATE DATA
MADISON RIVER at Greycliff - 9 AUG 2016
0.25 m^2 kicknet samples - ~300 organism subsamples

Taxon sample #:	1	2	3	4*	5	present*	SUM	%RA	MEAN	S. D.
# grids picked:			2/16		3/16					
COLEOPTERA								9%	27	
Optioservus spp.	10	22	1	4	3		40	2.5%	8.0	8.5
Zaitzevia sp.	0	1	7	3	4		15	0.9%	3.0	2.7
Microcylloepus sp.	29	18	12	10	8		77	4.9%	15.4	8.5
Dubiraphia minima	0	3	0	0	0		3	0.2%	0.6	1.3
DIPTERA								22%	70	
Thienemannimyia gp.	4	5	9	8	7		33	2.1%	6.6	2.1
Pentaneura sp.	2	10	3	2	6		23	1.5%	4.6	3.4
Potthastia sp.	0	1	0	0	1		2	0.1%	0.4	0.5
Cardiocladius spp.	0	0	0	0	1		1	0.1%	0.2	0.4
Cricotopus spp.	3	9	4	2	9		27	1.7%	5.4	3.4
Cricotopus nostococladius	0	1	0	0	2		3	0.2%	0.6	0.9
Eukiefferiella spp.	0	0	1	0	0		1	0.1%	0.2	0.4
Orthocladius spp.	2	1	1	1	2		7	0.4%	1.4	0.5
Parametriocnemus sp.	0	0	0	0	1		1	0.1%	0.2	0.4
Tvetenia sp.	6	6	13	19	10		54	3.4%	10.8	5.4
Cryptochironomus sp.	0	0	0	0	0	+	0	0.0%	0.0	0.0
Microtendipes sp	0	2	1	0	1		4	0.3%	0.8	0.8
Phaenopsectra sp	3	3	6	5	3		20	1.3%	4.0	1.4
Polypedilum spp.	12	19	4	15	6		56	3.5%	11.2	6.2
Pseudochironomus sp.	0	1	0	0	0		1	0.1%	0.2	0.4
Paratanytarsus sp.	0	1	0	0	0		1	0.1%	0.2	0.4
Rheotanytarsus sp.	39	18	17	14	8		96	6.1%	19.2	11.7
Tanytarsus sp.	0	0	0	0	1		1	0.1%	0.2	0.4
Tabanidae	0	0	0	0	0	+	0	0.0%	0.0	0.0
Simulium spp.	3	5	4	5	2		19	1.2%	3.8	1.3
Hemerodromia sp.	0	0	1	0	0		1	0.1%	0.2	0.4
EPHEMEROPTERA								34%	108	
Acerpenna pygmacus	16	7	0	1	11		35	2.2%	7.0	6.7
Baetis tricaudatus	29	24	37	36	32		158	10.0%	31.6	5.3
Baetis intercalris	0	0	4	0	0		4	0.3%	0.8	1.8

Plauditus sp.	33	9	13	13	36		104	6.6%	20.8	12.7
Camelobaetidius sp.	0	1	0	0	0		1	0.1%	0.2	0.4
Diphetor hageni	11	7	6	6	2		32	2.0%	6.4	3.2
Fallceon quilleri	0	0	0	0	3		3	0.2%	0.6	1.3
Epeorus albertae	0	0	0	0	1		1	0.1%	0.2	0.4
Heptagenia sp.	0	0	0	1	5		6	0.4%	1.2	2.2
Rhithrogena sp.	0	0	1	0	0		1	0.1%	0.2	0.4
Choroterpes sp.	0	7	3	1	3		14	0.9%	2.8	2.7
Ephemera simulans	12	5	0	0	2		19	1.2%	3.8	5.0
Asioplax edmundsi	5	8	6	3	7		29	1.8%	5.8	1.9
Tricorythodes sp	22	6	31	34	38		131	8.3%	26.2	12.7
LEPIDOPTERA										
Petrophila sp.	3	0	0	1	7		11	0.7%	2.2	2.9
ODONATA								0%	0	
Ophiogomphus sp.	1	0	1	0	0		2	0.1%	0.4	0.5
PLECOPTERA								0%	1	
Skwala sp.	0	0	0	0	0	+	0	0.0%	0.0	0.0
Isoperla sp.	0	1	1	1	1		4	0.3%	0.8	0.4
TRICHOPTERA								27%	84	
Cheumatopsyche spp.	2	9	42	28	9		90	5.7%	18.0	16.5
Hydropsyche occidentalis	2	3	30	43	2		80	5.1%	16.0	19.3
Hydropsyche C. cockerelli	2	0	2	6	1		11	0.7%	2.2	2.3
Limnephilus sp.	1	0	0	0	0		1	0.1%	0.2	0.4
Hydroptila spp.	0	1	1	1	1		4	0.3%	0.8	0.4
Leucotrichia pictipes	0	0	1	0	7		8	0.5%	1.6	3.0
Ochrotrichia sp.	0	0	0	0	0	+	0	0.0%	0.0	0.0
Nectopsyche sp.	13	7	2	2	5		29	1.8%	5.8	4.5
Oecetis sp.	1	0	2	2	4		9	0.6%	1.8	1.5
Psychomyia sp.	1	0	0	0	6		7	0.4%	1.4	2.6
Amiocentrus sp.	0	0	0	0	0	+	0	0.0%	0.0	0.0
Brachycentrus americanus	0	2	1	1	0		4	0.3%	0.8	0.8
Brachycentrus occidentalis	14	10	58	24	62		168	10.6%	33.6	24.7
Helicopsyche borealis	0	0	2	0	1		3	0.2%	0.6	0.9
Protoptila sp.	0	0	2	0	0		2	0.1%	0.4	0.9
Glossosoma sp.	0	0	3	0	1		4	0.3%	0.8	1.3

ANNELIDA							1%	4	
Lumbricidae	3	1	1	2	0	7	0.4%	1.4	1.1
Lumbriculidae	0	0	0	0	1	1	0.1%	0.2	0.4
Naididae	1	0	0	0	0	1	0.1%	0.2	0.4
Tubificidae	0	0	2	0	7	9	0.6%	1.8	3.0
Erpobdellidae	0	1	0	0	0	1	0.1%	0.2	0.4
Helobdella stagnalis	0	1	0	0	0	1	0.1%	0.2	0.4
CRUSTACEA							4%	12	
Orconectes sp.	1	2	1	0	1	5	0.3%	1.0	0.7
Hyalella azteca	0	11	0	0	0	11	0.7%	2.2	4.9
Caecidotea sp.	5	40	0	1	0	46	2.9%	9.2	17.3
MOLLUSCA							1%	3	
Physella sp.	1	0	0	0	0	1	0.1%	0.2	0.4
Ferrissia sp.	4	1	1	2	4	12	0.8%	2.4	1.5
Pisidium sp.	2	0	0	0	0	2	0.1%	0.4	0.9
Sphaerium sp.	0	0	0	0	2	2	0.1%	0.4	0.9
OTHER									
Dugesia sp.	2	2	2	7	7	20	1.3%	4.0	2.7
*(+) present in these samples but not in subsamples									
ID's by D. McGuire & D Stagliano									
SUBSAMPLE count	300	292	340	304	344	1580		316	24
TAXA RICHNESS	36	42	42	34	48	73		40.4	5.5
EPT RICHNESS	15	16	21	17	23	32		18.4	3.4
SHAN. DIVERSITY (log2)	4.34	4.65	4.22	4.17	4.54	4.81		4.39	0.21
BIOTIC INDEX	4.89	5.43	4.33	4.66	4.37	4.71		4.74	0.45
% EPT	55%	37%	73%	67%	70%	61%		60%	15%
% Chironomidae	24%	26%	17%	22%	17%	21%		21%	4%
TEMPERATURE METRICS									
Warm water					taxa	33	Percent	39%	
Cold water					taxa	5	Percent	1%	
Cool water - eurithermal					taxa	33	Percent	60%	
temp estimate - C					max T	23	opt T	20	
SEDIMENT METRICS									

Sediment tolerant taxa	11	15	11	8	12	23	11.4	2.5
% Sediment tolerant	16%	34%	28%	25%	24%	25%	25%	6%
Sediment intolerant taxa	0	0	2	0	2	3	1	1
% Sediment intolerant	0%	0%	1%	0%	1%	0%	0%	1%
fines estimate (%< 0.06mm)	11	14	10	10	9	9	11	2
sand estimate (%<2mm)	28	31	29	30	29	31	29	1
Baetidae/Ephemeroptera	0.70	0.65	0.59	0.59	0.60	0.63	0.63	0.05
Hydropsychinae/Trichoptera	0.17	0.38	0.51	0.72	0.12	0.43	0.38	0.25
% R.A. DOMINANT	13%	14%	17%	14%	18%	11%	15%	2%
Shannon-Weaver Index (loge)	3.01	3.23	2.93	2.89	3.15	3.33	3.04	0.14
METALS TOLERANCE	2.98	3.70	3.78	3.91	3.40	3.55	3.55	0.37
ORDINAL RELATIVE ABUNDANCE (%)								
EPHEMEROPTERA	43%	25%	30%	31%	41%	34%	34%	7%
PLECOPTERA	0%	0%	0%	0%	0%	0%	0%	0%
TRICHOPTERA	12%	11%	43%	35%	29%	27%	26%	14%
COLEOPTERA	13%	15%	6%	6%	4%	9%	9%	5%
DIPTERA	25%	28%	19%	23%	17%	22%	22%	4%
NONINSECT	6%	20%	2%	4%	6%	8%	8%	7%
FUNCTIONAL FEEDING GROUP RELATIVE ABUNDANCE (%)								
SCRAPERS/GRAZERS	3%	1%	3%	2%	8%	3%	3%	3%
SHREDDERS	5%	3%	1%	1%	2%	2%	2%	2%
FILTER FEEDERS	21%	16%	45%	40%	25%	30%	30%	12%
COLLECTOR-GATHERER	68%	73%	45%	51%	57%	58%	59%	11%
PREDATORS	3%	7%	6%	7%	8%	6%	6%	2%
% of sample used:	43%	40%	13%	7%	18%			
ENTIRE SAMPLE estimated total organisms	706	730	2720	4343	1911		2082	1522
total Potamopyrgus	0	0	0	0	0		0	0
HABITAT								
type	SLOW/SHAL	SLOW/DEEP	FAST/SHAL	FAST/DEEP	TYPICAL			
depth (ft)	1.0	0.8	0.5	1.3	0.8		0.9	0.3
water velocity(ft/sec)	0.93	1.29	1.86	2.23	1.68		1.6	0.5
% fines (<0.062 mm)	5	5	10	1	5		5	3
% sand (.062-2mm)	15	15	10	15	5		12	4
% gravel (2-64 mm)	30	50	50	20	30		36	13
% cobble (64-256 mm)	50	30	30	50	60		44	13

% boulder (> 256 mm)	0	0	0	15	0			3	7
% vegetation cover	75	50	20	10	25			36	26.3

*mean value for field split

Table B-5. Taxonomic "Presence/Absence" list of macroinvertebrate taxa collected in kick samples at the four sampling sites in the Madison River, Montana, August 2016.

Taxa	Kirby	Ennis	Norris	Greycliff
COLEOPTERA				
Optioservus spp.	X	X	X	X
Zaitzevia sp.		X	X	X
Microcylloepus sp.			X	X
Dubiraphia minima				X
DIPTERA				
Chironomidae				
Cardiocladius spp.	X	X		X
Cladotanytarsus sp.		X	X	
Cricotopus nostococladius	X	X	X	X
Cricotopus spp.	X	X	X	X
Cryptochironomus sp.	X	X	X	X
Diamesa spp.	X	X		
Eukiefferiella spp.	X	X	X	X
Microtendipes sp	X	X	X	X
Orthocladius spp.	X	X	X	X
Pagastia sp	X	X	X	
Parametriocnemus sp.				X
Paratanytarsus sp.				X
Pentaneura sp.		X	X	X
Phaenopsectra sp	X	X	X	X
Polypedilum spp.	X	X	X	X
Potthastia sp.	X	X	X	X
Pseudochironomus sp.			X	X
Rheotanytarsus sp.	X	X	X	X
Symbiocladius sp	X			
Synorthocladius sp.	X			
Tanytarsus sp.			X	X
Thienemannimyia gp.	X	X	X	X
Tvetenia sp.	X	X	X	X
Other Diptera				
Antocha sp.	X	X		
Chelifera sp.	X	X		
Hemerodromia sp.		X		X
Hexatoma sp.	X	X		
Simulium spp.	X	X	X	X

Taxa	Kirby	Ennis	Norris	Greycliff
Tabanidae				X
EPHEMEROPTERA				
Acentrella insignificans	X	X		
Acerpenna pygmacus			X	X
Attenella margarita	X	X		
Asioplax edmundsi				X
Baetis intercalris				X
Baetis tricaudatus	X	X	X	X
Camelobaetidius sp.				X
Centroptilum sp.			X	
Choroterpes sp.			X	X
Diphetor hageni	X	X	X	X
Drunella flavilinea	X			
Epeorus albertae	X			X
Ephemera simulans			X	X
Ephemerella sp.			X	
Fallceon quilleri				X
Heptagenia sp.			X	X
Paraleptophlebia sp.	X			
Plauditus sp.			X	X
Rhithrogena sp.		X		X
Tricorythodes sp	X	X	X	X
LEPIDOPTERA				
Petrophila sp.		X	X	X
ODONATA				
Ophiogomphus sp.				X
PLECOPTERA				
Claassenia sabulosa	X	X		
Hesperoperla pacifica	X	X		
Isoperla sp.				X
Kathroperla sp.		X		
Pteronarcys californica	X	X		
Skwala sp.	X	X	X	X
TRICHOPTERA				

Taxa	Kirby	Ennis	Norris	Greycliff
Amiocentrus sp.	X		X	X
Arctopsyche grandis	X	X		
Brachycentrus americanus	X			X
Brachycentrus occidentalis	X	X	X	X
Ceraclea sp.	X	X		
Cheumatopsyche spp.	X	X	X	X
Glossosoma sp.	X	X		X
Helicopsyche borealis	X	X	X	X
Hydropsyche(C.) cockerelli	X	X	X	X
Hydropsyche occidentalis	X	X	X	X
Hydroptila spp.	X			X
Lepidostoma sp.	X	X		
Leucotrichia pictipes	X		X	X
Limnephilus sp.				X
Nectopsyche sp.			X	X
Ochrotrichia sp.			X	X
Oecetis sp.	X	X	X	X
Polycentropus sp.			X	
Protoptila sp.		X	X	X
Psychoglypha sp.	X			
Psychomyia sp.	X	X		X
Rhyacophila brunnea gp.		X		
ANNELIDA				
Erpobdellidae		X		X
Glossophonia complanata	X			
Helobdella stagnalis	X			X
Lumbricidae	X	X	X	X
Lumbriculidae	X	X		X
Naididae	X	X		X
Tubificidae	X	X	X	X
CRUSTACEA				
Orconectes sp.			X	X
Hyalella azteca	X		X	X
Caecidotea sp.			X	X
MOLLUSCA				
Physella sp.	X	X	X	X

Taxa		Kirby	Ennis	Norris	Greycliff
Ferrissia sp.			X	X	X
Fossaria sp.		X	X		
Pisidium sp.		X	X		X
Potamopyrgus antipodarum		X	X	X	
Sphaerium sp.				X	X
OTHER					
Dugesia sp.			X	X	X
Hydracarina			X		
Turbellaria		X			
Total:	**102**	**62**	**61**	**55**	**73**

APPENDIX C

Madison and Missouri River Macroinvertebrate Biomonitoring: 2016 Data Summary

Prepared by McGuire Consulting

For NorthWestern Energy

Madison and Missouri River Macroinvertebrate Biomonitoring: 2016 Data Summary

Prepared for
Northwestern Energy
Butte, MT

Prepared by
McGuire Consulting
Espanola, NM

July 2017

1.0 INTRODUCTION

Northwestern Energy conducts aquatic macroinvertebrate surveys as part of its environmental monitoring for hydroelectric facilities on the Madison and Missouri rivers (FERC Project 2188). Biomonitoring has been conducted annually since 1995. This report presents and summarizes macroinvertebrate data collected during August, 2016. More detailed temporal and site-specific analyses were recently provided (McGuire 2012, 2017a and b).

2.0 STUDY AREA

Monitoring is conducted on the Madison and Missouri Rivers from Yellowstone National Park downstream to the Great Falls of the Missouri.

<u>Macroinvertebrates are collected annually from 11 sites:</u>

- Madison River in Yellowstone National Park (YNP) near USGS 6-375
- Madison River 2 km below Hebgen Dam (HEB) ~ 1 km below USGS #6-385
- Madison River at Kirby Ranch (KIR)
- Madison River at Ennis Campground (ENN)
- Madison River below Madison Powerhouse at USGS gauge 6-410 (MPH)

- Madison River above Norris Bridge (NOR)
- Madison River at Greycliff Fishing Access (GCF)
- Missouri River at Toston near USGS gage 6-545 (TOS)
- Missouri River about 100 m below Hauser Dam - east bank (HAU)
- Missouri River about 1 km below Holter Dam –west bank (HOL)
- Missouri River about 100 m below Morony Dam (MOR)

3.0 METHODS

3.1 Field Work

Field work occurred during the first half of August. The modified kick-net procedure described by Hauer et al. (1991) was used to obtain five samples per site. A sampling grid (delineating 0.25 m^2) was placed on the stream bottom in a selected habitat type. A large rectangular net (50 cm wide by 20 cm tall; mess 800 X 900 microns) was held immediately downstream from the grid. Cobbles were hand scrubbed and smaller sediments were vigorously stirred by foot. The contents of the net (macroinvertebrates, vegetation, sediment and debris) were preserved in 90% ETOH.

To better characterize the benthic fauna, sampling effort was partitioned among wadeable habitats at each site. Four samples were stratified by depth (shallow/deep) and water velocity (slow/fast). The fifth sample was taken from the most abundant (typical) habitat type at the site. Water depth and velocity were measured and substrate composition was estimated at each sampling location.

3.2 Laboratory Analysis

We began to migrate the macroinvertebrate monitoring program to a new principle investigator with the 2016 lab work. Dave Stagliano processed 33 samples while Dan McGuire processed 25 samples. We worked closely to insure consistent sample processing and taxonomy. Three of the larger samples were split in the field, with each taxonomist analyzing approximately 50% of the sample (see Appendix A).

Samples were placed in a U.S. Standard #30 sieve and rinsed with water. Initially, a subsample consisting of approximately 300 organisms was obtained using RBP III techniques* (Plafkin et al. 1989). The remainder of the sample was scanned and any organism suspected of not being represented in the subsample was retained. These rare taxa were identified and included on the site taxa list and in the estimated taxa richness for the entire sample. Additionally, all New Zealand mud snails in each sample were counted. Macroinvertebrates were identified to lowest practical taxonomic level, usually genus or species.

*Subsampling: For small samples (< 0.5 liters), the entire sample was evenly distributed in a gridded enamel pan. Depending on sample volume, pan size ranged from 9"X12" to 14"X20". All macroinvertebrates in a randomly selected grid square were removed. This process was repeated until 270 to 330 organisms had been picked. Larger volume samples were processed in portions (30 to 100 ml). Macroinvertebrates were removed from 10 or 20% of the grids (random selection; minimum of 2 grids per pan). This procedure was repeated until the entire sample had been processed; however, only the first ~300 organisms recovered were used to calculate metrics. The total number of organisms in the sample was estimated from the percentage of sample used to obtain the subsample.

Data analysis

Community densities, taxonomic composition, and biointegrity scores for 2015 are presented graphically. Community composition is depicted by the percent relative abundance of five major insect Orders (mayfly, stonefly, caddisfly, beetle, and diptera) and noninsects (primarily segmented worms, snails, isopods and amphipods). The biointegrity score is a composite value based on six metrics and has a theoretical range of 0 to 100%. High scores are characteristic of minimally impacted stream reaches. Metrics and rating criteria for estimating biointegrity (Table 2) were established using data collected from 1994-1998 (McGuire 1999). MDEQ tolerance values (Bukantis 1997) were used to calculate the Biotic Index. Temperature metrics are being developed for the Madison River (McGuire 2012). Relative abundances of cold-water taxa (thermal tolerance less than or equal to ~18 C) and warm-water taxa (thermal tolerance greater than ~ 22 C) are presented for the past nine years.

Table 2. Metrics and criteria used to assess biointegrity trends in Madison and Missouri River benthic macroinvertebrate assemblages.

Metric	Scoring Criteria					
	5	4	3	2	1	0
Taxa richness	<32	32-28	27-23	22-18	17-13	<13
EPT richness	>16	16-13	12-9	8-5	4-1	0
Shannon diversity	>3.3	3.3-3.1	3.0-2.8	2.7-2.5	2.4-2.2	<2.2
Biotic index	<4.1	4.1-4.6	4.7-5.2	5.3-5.8	5.9-6.4	>6.4
% EPT	>70	70-61	60-51	50-41	40-31	<31
% Chironomidae	<21	21-25	26-30	31-35	36-40	>40

Assessment score calculated as the sum of metric scores divided by the maximum possible score.
All values are per 300 organism subsample.

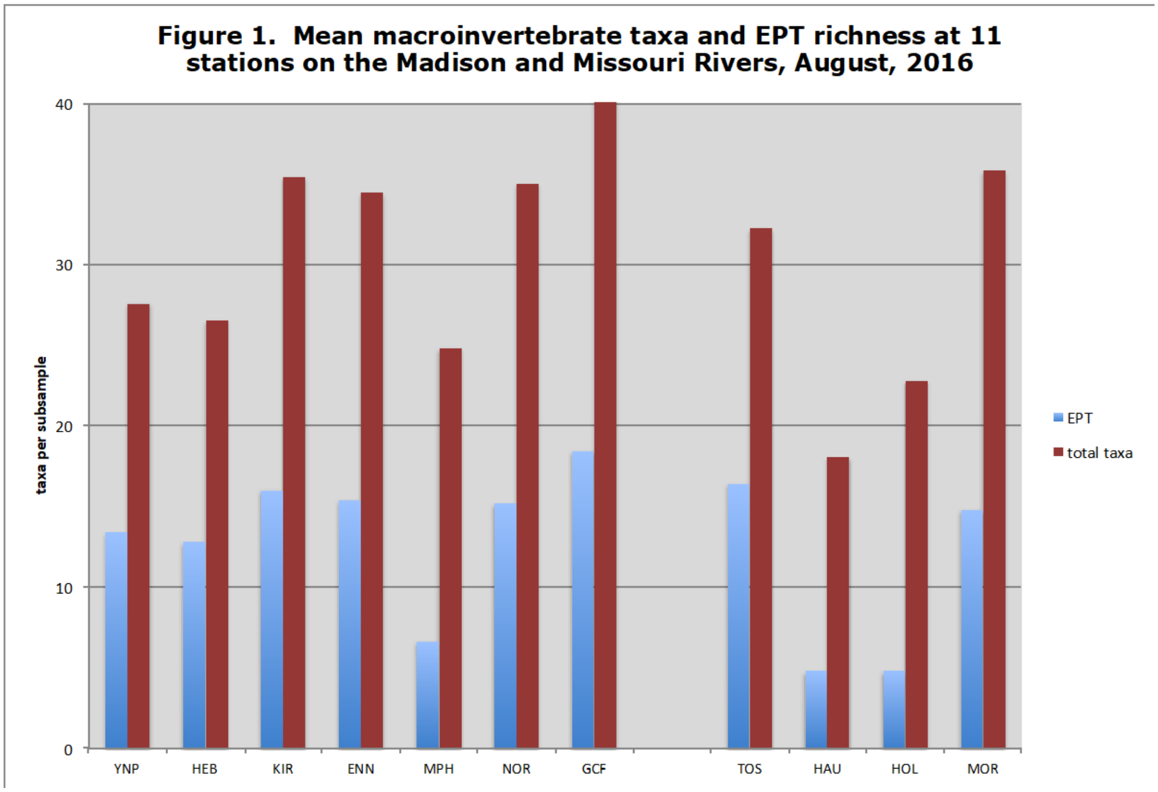
4.0 RESULTS

The 2016 data (identifications, counts, metric values, and summary statistics) are presented in Appendix A. Community density, taxa richness, taxonomic composition, and biointegrity estimates for 2016 are presented graphically. Appendix B contains long-term data for each station, including means of selected metrics and annual biointegrity estimates.

4.1 Taxa richness and EPT (combined mayfly, stonefly and caddisfly species) richness

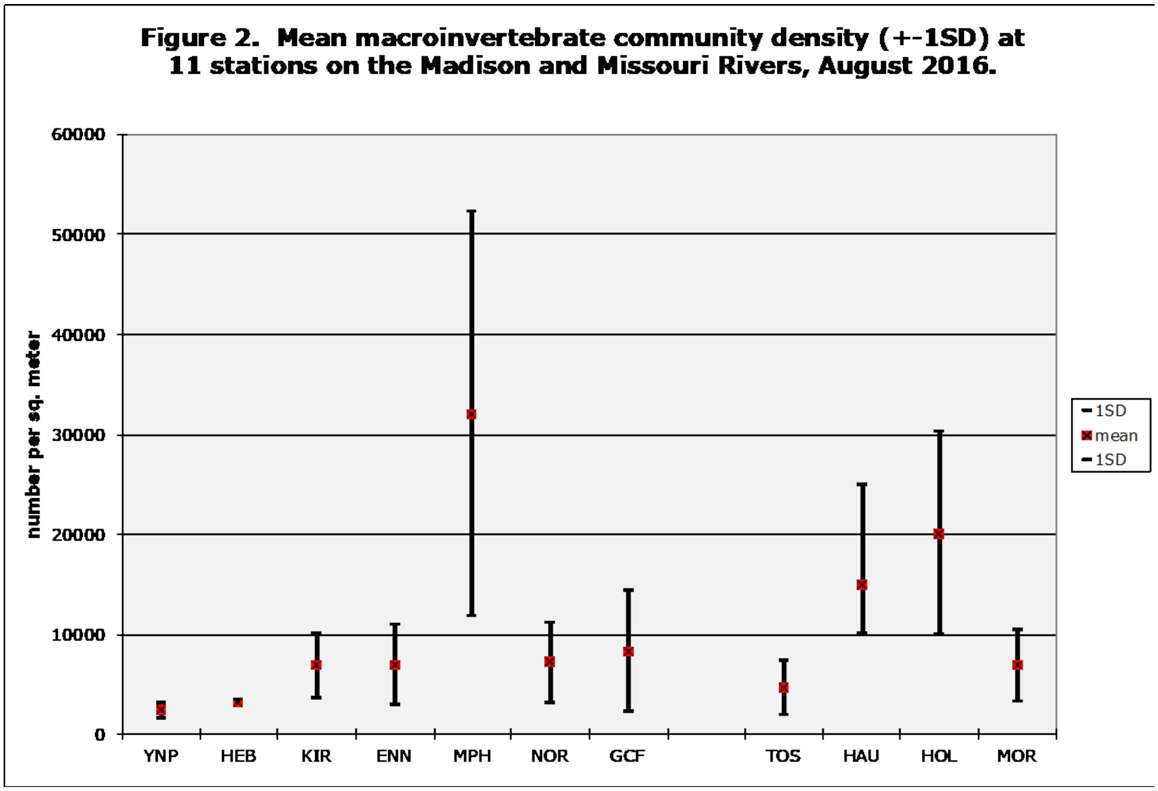
A total of 141 macroinvertebrate taxa were identified from the 2016 samples (Appendix A). Dipterans were the most diverse group with 44 taxa. Caddisflies, mayflies and stoneflies were represented by 27, 26, and 7 species, respectively.
Macroinvertebrate taxa per site ranged from 31 below Hauser to 73 at Greycliff.

Benthic assemblages were least diverse below Hauser and Holter reservoirs and the Madison Powerhouse (Figure 1). The mean number of taxa per sample ranged from 23 at Hauser to 40 at Greycliff. EPT taxa ranged from 13 to 18 at most sites, but was less than 10 below the Madison Powerhouse, Hauser, and Holter Dams.



4.2 Community Density

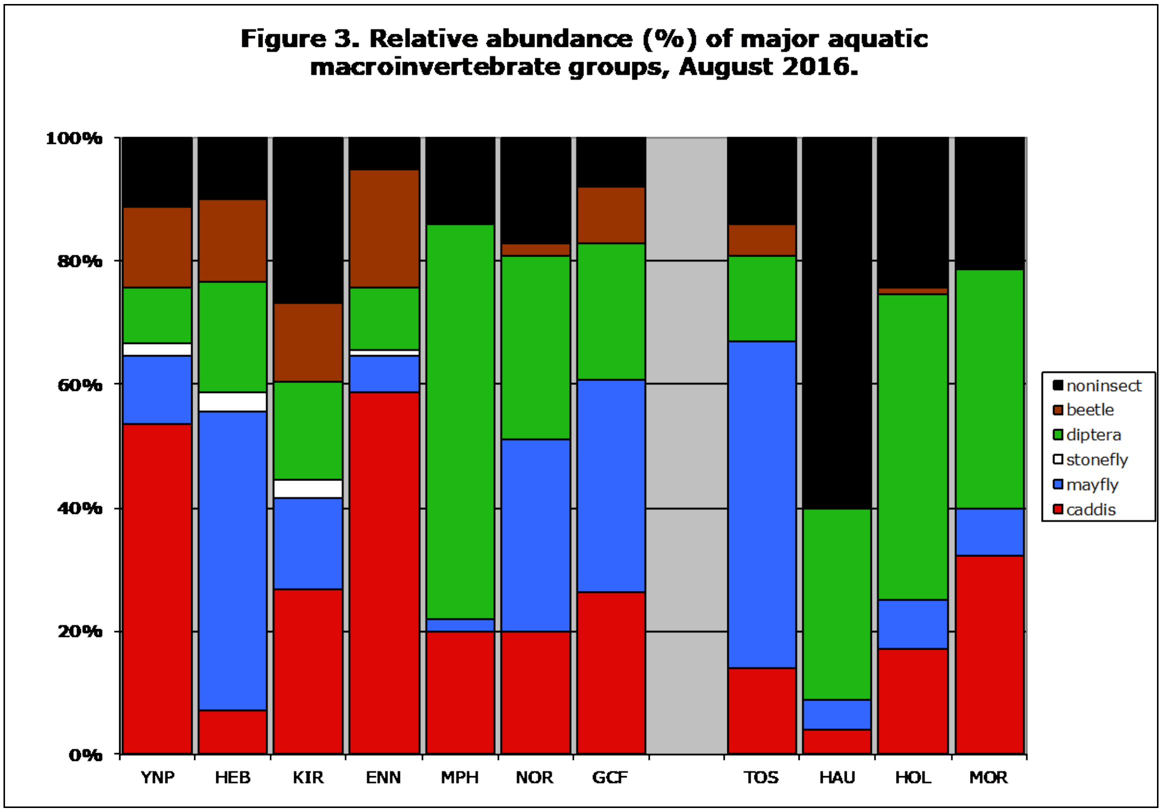
Our widely spaced, 0.25 m^2 kick samples provide a coarse estimate of benthic macroinvertebrate density. Mean densities ranged over an order of magnitude; from about 2,400 at YNP to more than 32,000 below the Madison Powerhouse. At most sites, macroinvertebrate densities were a few thousand per square meter. However, standing crops were substantially higher immediately below Ennis, Hauser, and Holter dams (Figure 2). Secondary production is much higher below these reservoirs than in other reaches of the Madison and Missouri rivers.



4.3 Community Composition

Community composition varied throughout the drainage with six major taxonomic groups accounting for most of the benthos. Dipterans, caddisflies, mayflies, and noninsects were present at all sites while beetles and stoneflies had more limited distributions (Figure 3).

Mayflies were present throughout the drainage, attaining greatest relative abundance in the Madison River at Hebgen, Norris, and Greycliff and in the Missouri River at Toston. Caddisflies were also widely distributed and were numerically dominant at two Madison River sites (YNP and ENN). However, caddisflies were relatively minor faunal components at sites below the large reservoirs. Stoneflies were common in the upper Madison River, but were mostly absent downstream from Ennis Reservoir. Blackflies (Diptera) and sowbugs (noninsect-crustaceans) were extremely abundant below Ennis, Holter, and Hauser Reservoirs. Noninsects have become more abundant throughout the monitoring area and accounted for 60% of the benthos below Hauser Dam. Snails were abundant in the Madison River below Hebgen Reservoir and at Kirby and were generally distributed throughout the system.



Thirty-two taxa comprised at least 5% of the macroinvertebrates collected at one or more sites on the Madison and Missouri rivers.

Table 3. Percent relative abundance (%) of numerically dominant macroinvertebrates at 7 Madison River sites, Aug 2016

	YNP	HEB	KIR	ENN	MPH	NOR	GCF
Caddisflies							
Cheumatopyche	36%		6%	6%	5%	5%	6%
Hydropsyche occidentalis				7%	12%		5%
Brachycentrus occidentalis	7%		10%	24%			15%
Glossosoma	5%			5%			
Nectopsyche sp.						5%	
Helicopsyche sp.				11%			

Mayflies							
Drunella grandis		17%					
Acerpenna pygmacus						7%	
Baetis tricaudatus	5%	21%	8%	5%			11%
Diphitor hageni						8%	
Plauditus punctiventris							7%
Choroterpes albiannulata						7%	
Ephemera simulans						5%	
Tricorythodes							8%
Black flies							
Simulium spp.					35%		
Midges							
Pagastia sp.		6%					
Cricotopus spp.					5%		
Parachironomus spp.					7%		
Polypedilum spp.						18%	
Rheotanytarsus spp.							6%
Beetles							
Optioservus spp.		13%	13%	14%			
Ziatzevia	9%			5%			
Microcylloepus							5%
Flatworms							
Dugesia sp.						10%	
Worms							
Tubificidae	10%						
Sowbugs							
Caecidotea					5%		
Snails							
Physella			8%				
Fossaria			6%				

Table 4. Percent relative abundance (%) of numerically dominant macroinvertebrates at 4 Missouri River sites, Aug 2016

	TOS	HAU	HOL	MOR
Caddisflies				
Cheumatopyche				18%

Hydroptila sp			10%	
Mayflies				
Baetis tricaudatus	10%			
Tricorythodes	28%			
Moths				
Petrophila				6%
Black flies				
Simulium spp.		23%	34%	
Midges				
Cricotopus spp.				12%
Dicrotendipes			12%	
Polypedilum spp.				9%
Flatworms				
Dugesia sp.	8%	33%	5%	
Scuds				
Gammarus spp.		5%	7%	
Sowbugs				
Caecidotea		14%	6%	8%
Snails				
Physella		6%		

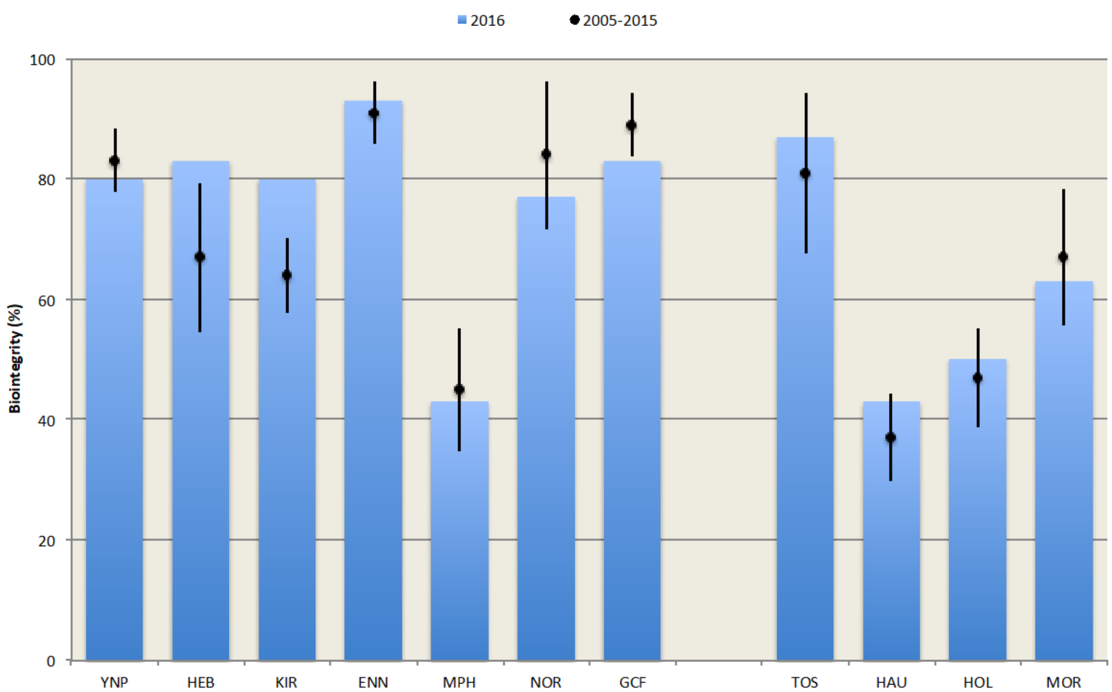
4.4 Multimetric Bioassessment Scores

Biological integrity scores are composite values based on six metrics (see Appendix B) with a theoretical range of 0 to 100%. The multimetric assessments reflect distinct water quality, productivity, flow, and thermal regimes within the drainage and exhibited a consistent longitudinal profile over the past decade. Bioassessment scores (Figure 4) typically exceeded 80% at five sites (YNP, ENN, NOR, GCF, and TOS) and 60% at three other (HEB, KIR, and MOR). Bioassessment scores were lowest (<50%) immediately downstream Hauser and Holter reservoirs and the Madison Powerhouse.

The 2016 biointegrity scores ranged from 43% to 93%, with the highest score at Ennis and the lowest scores at the Madison Powerhouse and Hauser (Figure 4). The most recent assessment indicated improved environmental conditions during 2016 in the upper Madison River from

Hebgen to Ennis and in the Missouri River at Toston. Biointegrity estimates were relatively high (~ near or above 80%) for all Madison River sites except at the Madison Powerhouse.

Figure 4. Macroinvertebrate based bioassessment scores for Madison and Missouri River sites during August, 2005 to 2015 (mean and SD) and 2016



4.5 Madison River Temperature Metrics

Characterization of macroinvertebrate assemblages based on temperature tolerance showed a clear dichotomy between the upper and lower reaches of the Madison River. Coldwater taxa were more abundant (Figures 6 and 8) in the upper river while warm water taxa predominated in the lower river (Figures 7 and 9).

The influence of the thermal regime on community composition was evident below Hebgen Reservoir (Figure 10). Changes in the relative abundances of cold-water and warm-water macroinvertebrates were evident during the past nine years. Normally (i.e., 2008 and 2016), the dam releases colder hypolimnetic water during the summer. However, due to construction at the dam, warmer surface water was released from 2009 through 2015. Subsurface releases were resumed during 2016. Community responses to changes in the thermal regime appear to be cumulative over several years.

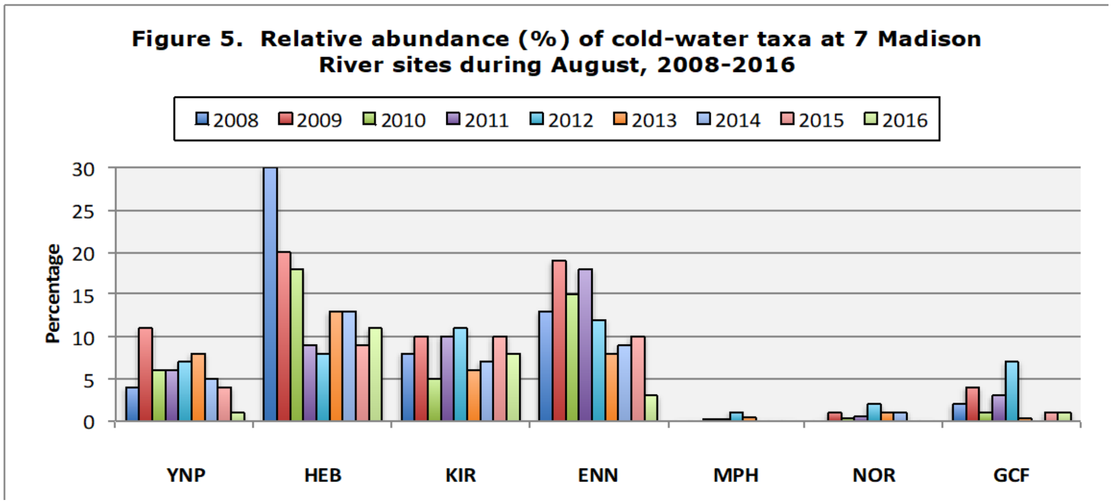


Figure 5. Relative abundance (%) of cold-water taxa at 7 Madison River sites during August, 2008-2016
2008 2009 2010 2011 2012 2013 2014 2015 2016
Percentage
30 25 20 15 10 5 0
YNP HEB KIR ENN MPH NOR GCF

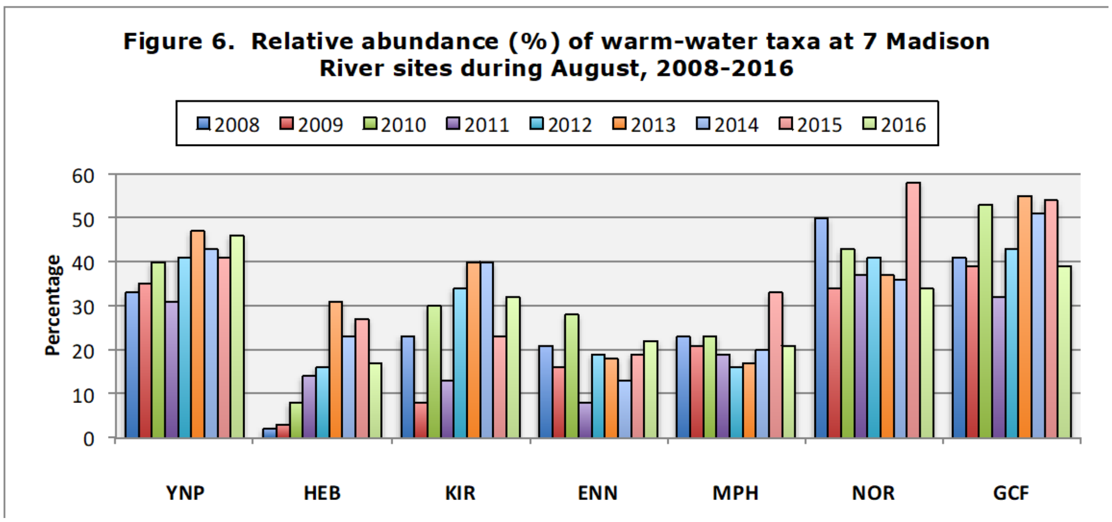


Figure 6. Relative abundance (%) of warm-water taxa at 7 Madison River sites during August, 2008-2016
2008 2009 2010 2011 2012 2013 2014 2015 2016
Percentage
60 50 40 30 20 10 0
YNP HEB KIR ENN MPH NOR GCF

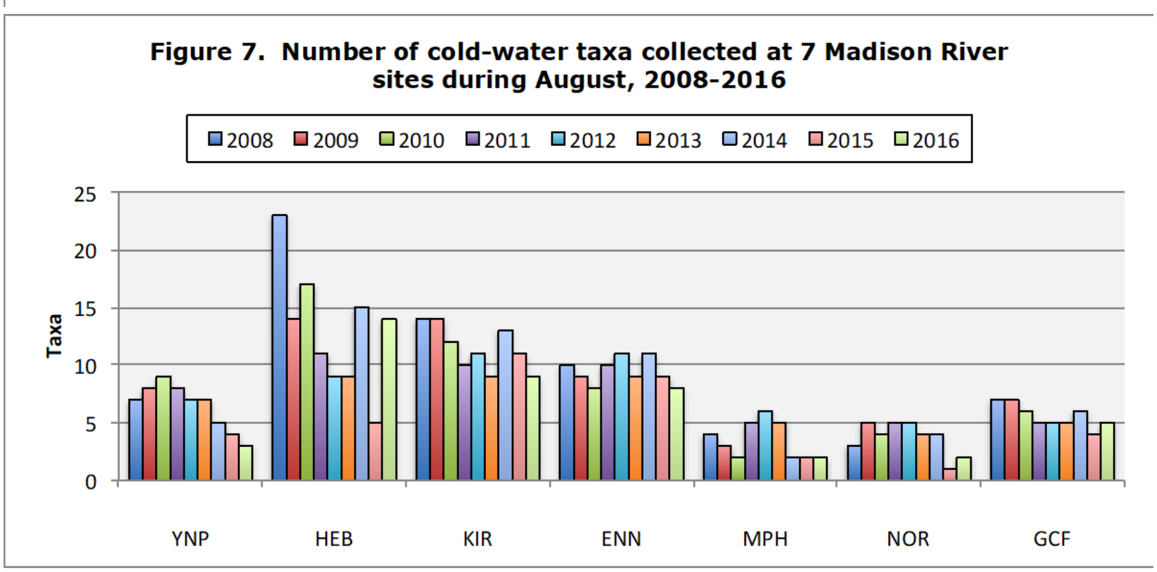
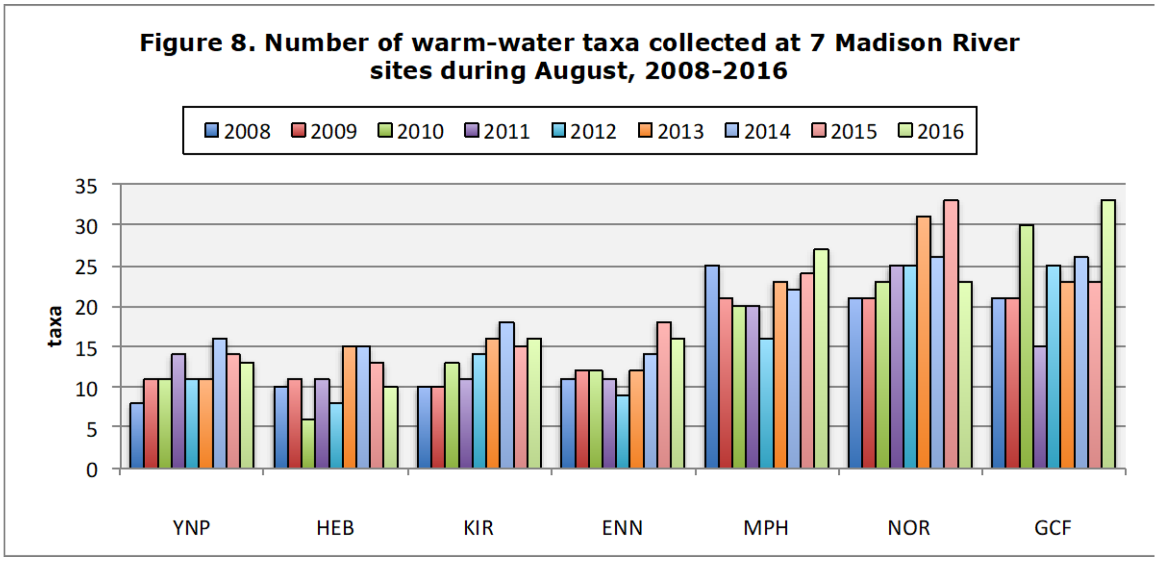
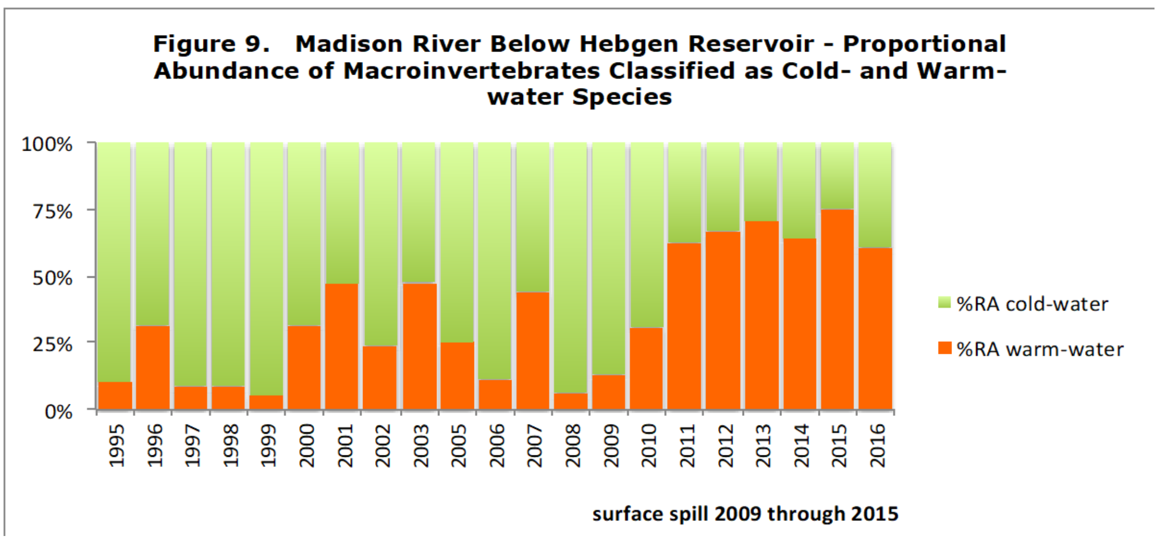


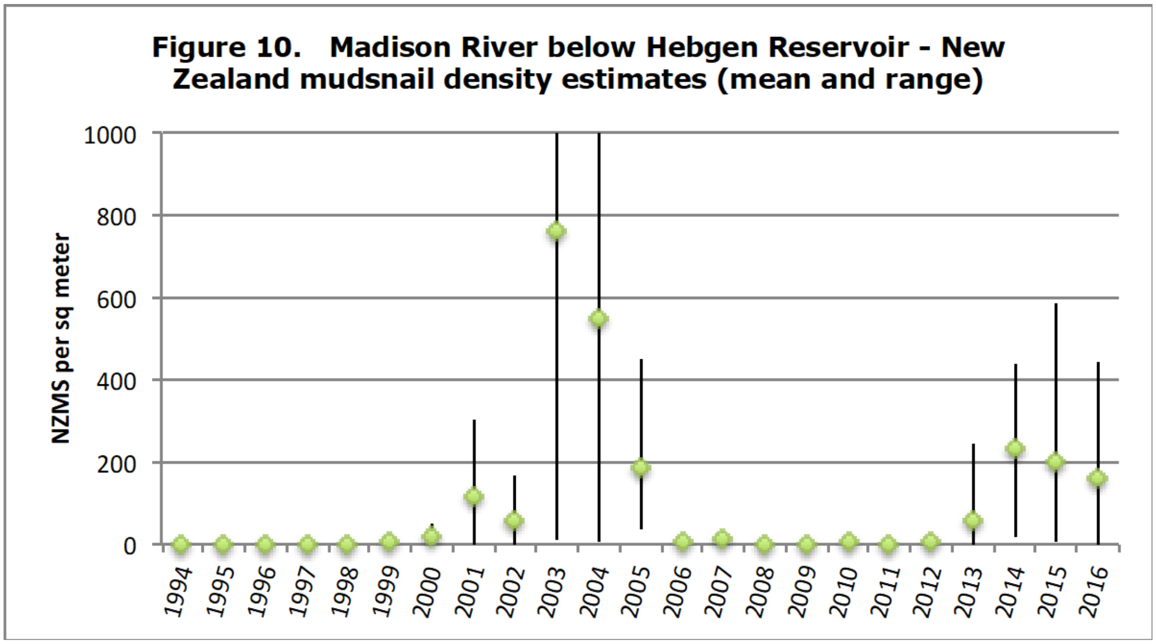
Figure 7. Number of cold-water taxa collected at 7 Madison River sites during August, 2008-2016
2008 2009 2010 2011 2012 2013 2014 2015 2016
Taxa
25 20 15 10 5 0
YNP HEB KIR ENN MPH NOR GCF





4.6 New Zealand mudsnails (NZMS)

NZMS were collected at five Madison River sites during 2016. They were most numerous below Hebgen Reservoir, where NZMS accounted for approximately four percent of the macroinvertebrates collected. Estimated NZMS density below Hebgen was about 160 per square meter, and has been stable for the past three years (Figure 8). A few specimens were also collected in 2016 from the Madison River at Kirby, Ennis, Madison Powerhouse, and Norris and from the Missouri River below Holter Dam. Several individuals of a newly arrived exotic snail, *Menetus diatatus*, were also collected at the Holter site in 2016.



5.0 LITERATURE CITED

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THE FOLLOWING APPENDICES ARE AVAILABLE UPON REQUEST:

APPENDIX A: 2016 macroinvertebrate checklist and data
APPENDIX B: Summary of biointegrity scores and selected metric values for all sites, 1995 through 2016.