MADISON RIVER DRAINAGE 2188 PROJECT MONITORING REPORT 2020

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Introduction

Montana Fish, Wildlife & Parks (FWP) monitors the Madison River Fishery to establish population estimates and to detect any changes to the fishery over time. Results from these monitoring efforts are evaluated to determine the potential effects from the operations at Hebgen and Ennis dams on fisheries in the Madison River Drainage. This work is funded through an agreement with NorthWestern Energy (NWE), the owner and operator of the dams. The agreement between FWP and NWE is designed to assist NWE in meeting the terms and conditions of the Federal Energy Regulatory Commission (FERC) license issued to NWE in 2000 to operate hydropower systems on the Madison and Missouri rivers. This includes Hebgen and Ennis dams (Figure 1), as well as seven dams on the Missouri River collectively referred to by FERC as the 2188 Project. The 2188 license details requirements NWE must follow for the operation of the dam and hydropower facilities on the Madison and Missouri Rivers.

NWE entered into a 10-year Memorandum of Understanding (MOU) with state and federal resource management agencies to provide annual funding to implement FERC license requirements for the protection, mitigation, and enhancement (PM&E) of fisheries, recreation, and wildlife resources. The MOU established Technical Advisory Committees (TACs) to collectively allocate annual funding to implement PM&E programs and the provisions of the 5-year fisheries and wildlife PM&E plans in a way that maintains flexibility to respond to emerging needs. The Madison Fisheries Technical Advisory Committee (MadTAC) comprised of representatives from NWE, FWP, the U.S. Fish & Wildlife Service (USFWS), the U.S. Forest Service (USFS), and the U.S. Bureau of Land Management (BLM) is responsible for the allocation of funds to address fisheries issues related operations of the Hebgen and Madison Dams under the 2188 license.

This report summarizes work that is ongoing and completed by FWP in 2020 with funding provided by the MadTAC to address requirements of FERC 2188 license; specifically, Articles 403, 408, 409, 412, and 419 that pertain to the Madison river fishery. Work included 1) fish abundance assessments in the Madison River, 2) assessment of fish populations in Hebgen reservoir, 3) conservation and restoration of Arctic Grayling populations, 4) conservation and restoration of Westslope Cutthroat Trout populations, 5) enhancement and restoration of tributary streams, and 6) flushing flow evaluation.

Study Area

The Madison River originates in Yellowstone National Park at the confluence of the Gibbon and Firehole rivers and flows North for 180 miles through Southwest Montana to its confluence with the Missouri River near Three Forks. The Madison transitions from a narrow-forested river valley in the headwaters to a broad valley bounded by the Madison and Gravelly mountain ranges south of the town of Ennis. North of Ennis the river flows through a steep canyon for 11 miles before it transitions into a broad alluvial valley bottom and floodplain where it joins the Jefferson and Gallatin Rivers, forming the Missouri River (Figure 1).

Two dams impound the Madison River; Hebgen Dam forms Hebgen Reservoir and the Madison Dam forms Ennis Lake (Figure 1). Hebgen Reservoir is operated as a water storage facility to control inflow to the downstream Madison Dam, which is a power generating facility. Madison and Hebgen dam operations are coordinated to provide year-round minimum flows of 1,100 cubic feet per second and mitigate thermal issues in the in the Madison river below Ennis Dam (Figure 1).

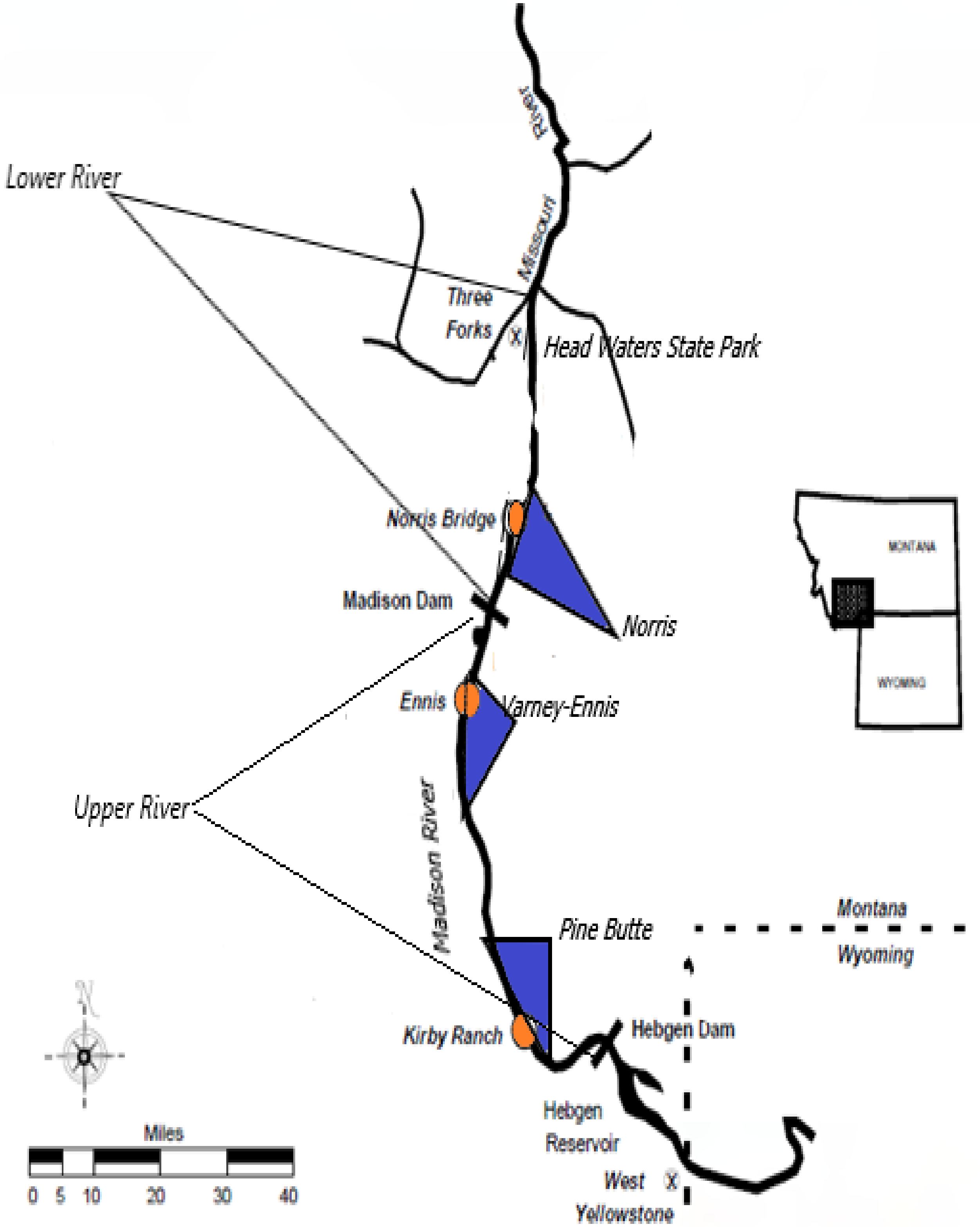


Figure 1. Locations of NWE dams on the Madison River (FERC Project 2188) and delineation of the upper and lower Madison River. FWP annual abundance estimate sections are shown in blue and NWE monitoring sites in orange.

Monitoring and Projects

Article 403-River Discharge

Minimum and maximum instream flows in various sections of the Madison River are described in Article 403 of the Project 2188 FERC license. Specifically, NWE is obligated to maintain a continuous minimum flow of at least 150 cfs in the Madison River below Hebgen Dam (gage no. 6-385), 600 cfs on the Madison River at Kirby Ranch (USGS gage no. 6-388), and 1,100 cfs on the Madison River at gage no. 6-410 below the Madison development. Flows at USGS gage no. 6-388 (Kirby Ranch) are limited to a maximum of 3,500 cfs under normal conditions excepting catastrophic conditions to minimize erosion of the Quake Lake outlet. License requirements also require the establishment of a permanent flow gauge on the Madison River at Kirby Ranch (USGS Gauge No. 6-388). FWP and NWE continue to jointly monitor river flows to avoid deviations from operational conditions. No deviation from the conditions for flow requirements in article 403 occurred in 2020.

Article 408-1) Effects of Project Operations on Hebgen Reservoir Fish Populations

FWP monitors trends in Hebgen Reservoir fish assemblages for the purpose of assessing the effects of project operations with annual gill netting surveys. Gross changes in fish assemblage or trends would warrant a review of and potential change to project operations to address identified issues.

The entire timeseries of Hebgen Reservoir gill net data was analyzed to optimize future monitoring design. Historically, 27 125-foot variable mesh experimental gillnets (13 sinking and 14 floating nets) have been used to characterize the Brown and Rainbow Trout fisheries of Hebgen Reservoir over three nights of sampling each spring. However, fewer gill nets reliably characterized trout populations of other lakes and reservoirs in the region (e.g., Clark Canyon and Ruby reservoirs). Three gill netting intensities were assessed to determine the effort needed to monitor the trout populations of Hebgen Reservoir most cost-effectively. Using historical sampling data, we evaluated the trends and sampling errors associated with 1) the full historical effort, 2) a combination of eight sinking and floating gill nets (i.e., Top 8) with the highest Brown and Rainbow Trout catch-per-unit effort (*C/f*), respectively, and 3) a combination of four sinking and floating gill nets (Top 4) with the highest Brown and Rainbow Trout *C/f*, respectively. We assessed the precision of the three sampling intensities described above by comparing the mean 95% confidence intervals (CI) of *C/f* and total length of Brown and Rainbow Trout among years.

All three sampling efforts yielded similar trends for mean Brown and Rainbow Trout *C/f* (Figure 2) and total length (Figure 3) in Hebgen Reservoir. In general, the mean 95% CI width of *C/f* and total length increased with decreased effort (Table 1); however, 95% CIs overlapped most years for both species so the ability to detect statistical differences among years was similar among sampling scenarios. Therefore, FWP recommends reducing sampling intensity for future monitoring as the Top 4 effort provided comparable precision and accuracy in characterizing the Hebgen Reservoir trout populations to the other sampling intensities analyzed. Although the Top 4 effort was statistically sufficient, that approach concentrated sinking gill nets along the west shoreline and floating gill nets in the main body leaving large areas of the reservoir unsampled. Therefore, we replaced a sinker that was historically set immediately next to 9S with 15S, which is another sinker with relatively high *C/f* of Brown Trout that is set across the Madison Arm on Horse Butte (Figure 4). We also added two floaters (14F and 21F), which provided improved distributions of nets in the Grayling and Madison arms. As a result, FWP recommends four sinkers and six floaters to annually monitor the trout populations in Hebgen Reservoir (Figure 4). The revised monitoring plan will improve efficiency by providing similar data while expending fewer FWP and NWE resources and minimizing the number of trout sacrificed during sampling.

Table 1. Mean 95% confidence interval width of catch-per-unit-effort (*C/f*; fish/net) and total length (TL; mm) of brown and Rainbow Trout captured in gill nets set in Hebgen Reservoir. Full effort represents the entire historical sampling effort of 27 nets (13 sinkers and 14 floaters) while the Top 8 and Top 4 efforts include a combination of the eight and four sinking and floating gill nets, respectively, with the highest *C/f* of Brown Trout in sinkers and Rainbow Trout in floaters over the last 20 years.

Species	Metric	Full Effort	Top 8	Top 4
Brown Trout	*C/f*	3.6	4.1	4.1
	TL	18.7	18.1	22.9
Rainbow Trout	*C/f*	2.4	3.0	4.0
	TL	25.7	28.0	34.8

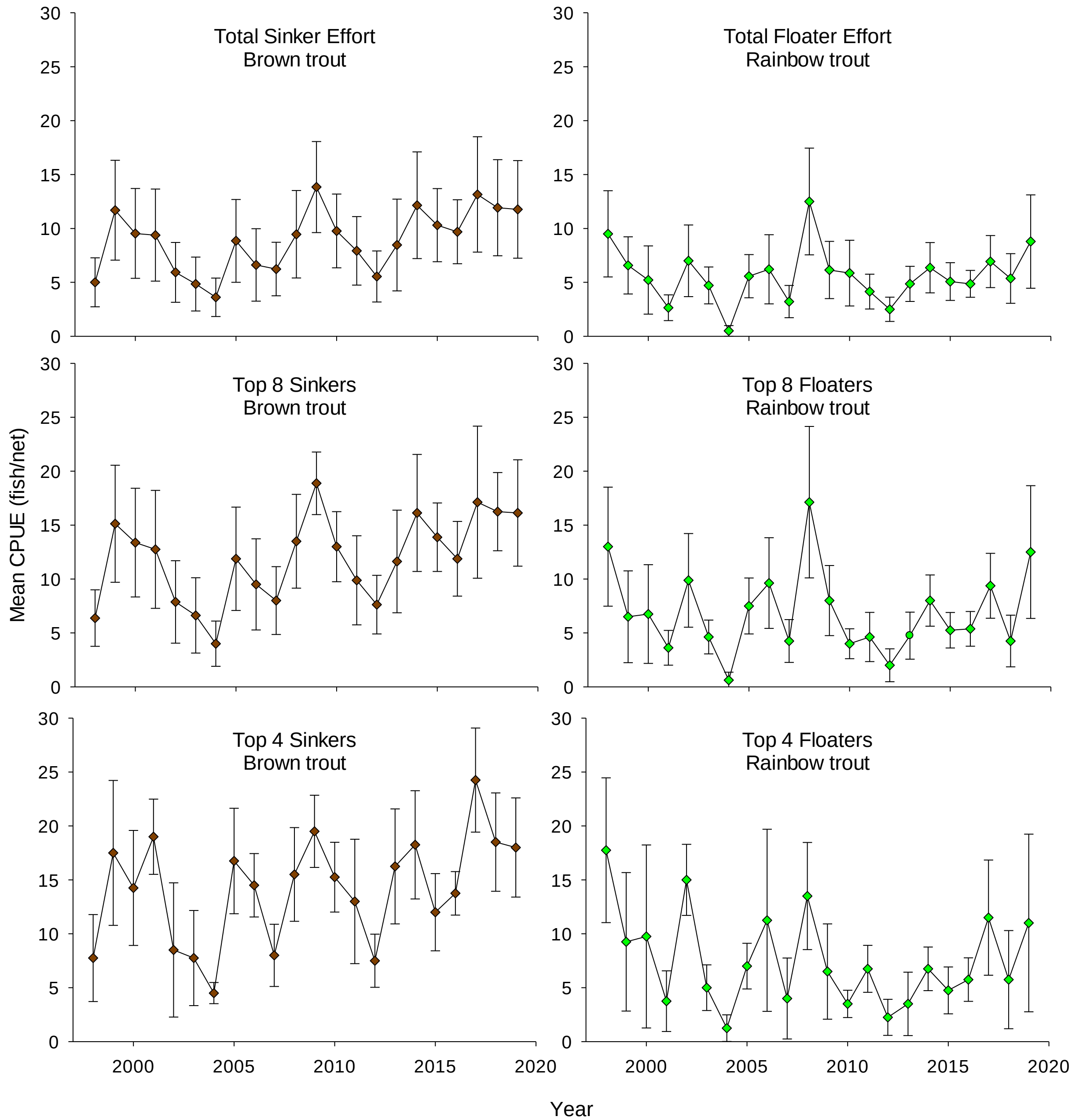


Figure 2. Mean catch-per-unit-effort (*C/f*) of sinking and floating gill nets set in Hebgen Lake for sampling Brown and Rainbow Trout, respectively, under three potential sampling intensities. Total effort illustrates the full historical sampling effort (13 sinkers and 14 floaters) followed by reduced efforts that rely on the either the top 8 or 4 sinkers and floaters to characterize the Hebgen Lake trout fishery. Error bars are 95% confidence intervals.

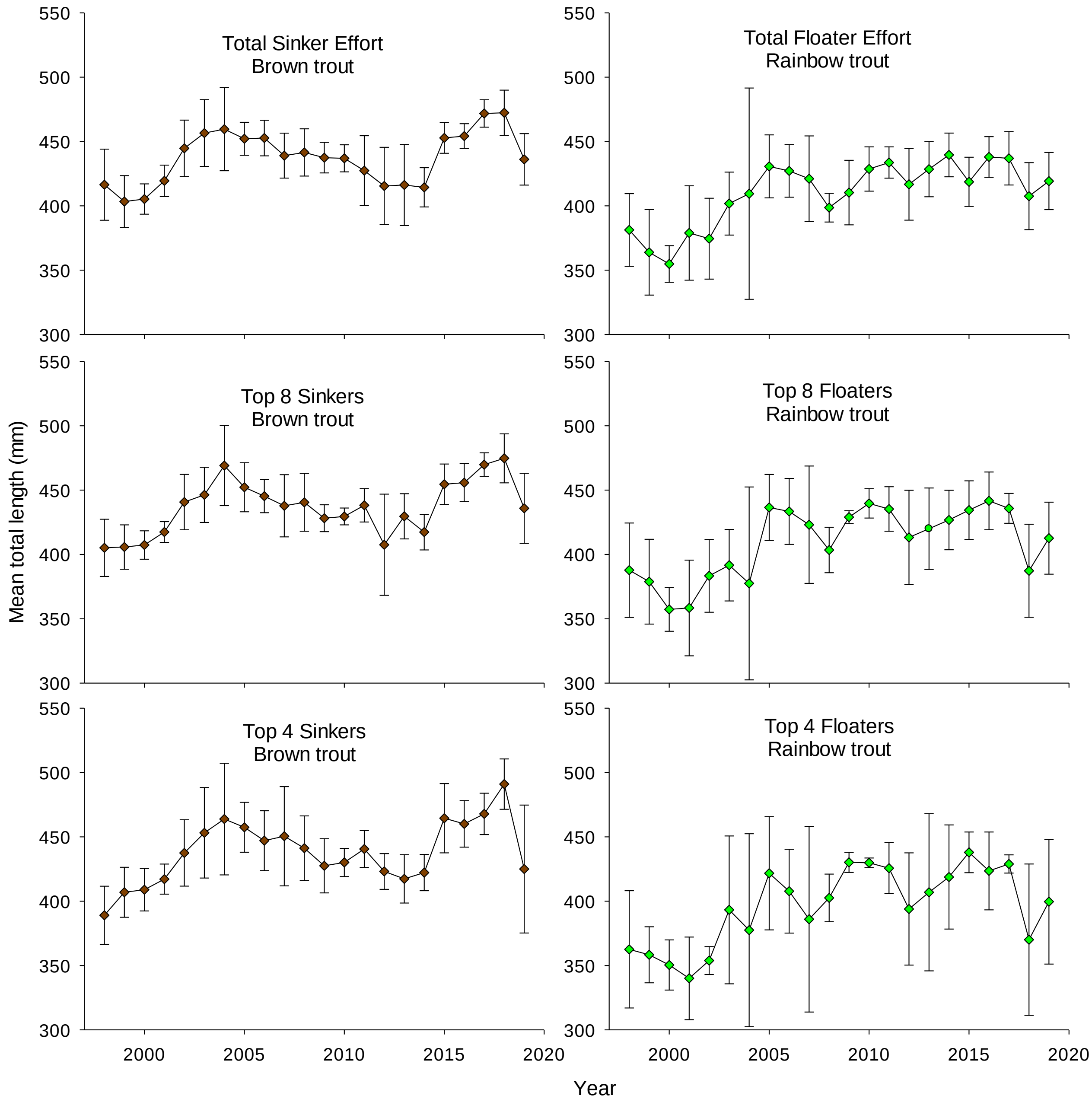


Figure 3**.** Mean total length (mm) of sinking and floating gill nets set in Hebgen Lake for sampling Brown and Rainbow Trout, respectively, under three potential sampling intensities. Total effort illustrates the full historical sampling effort (13 sinkers and 14 floaters) followed by reduced efforts that rely on the either the top 8 or 4 sinkers and floaters to characterize the Hebgen Lake trout fishery. Error bars are 95% confidence intervals.

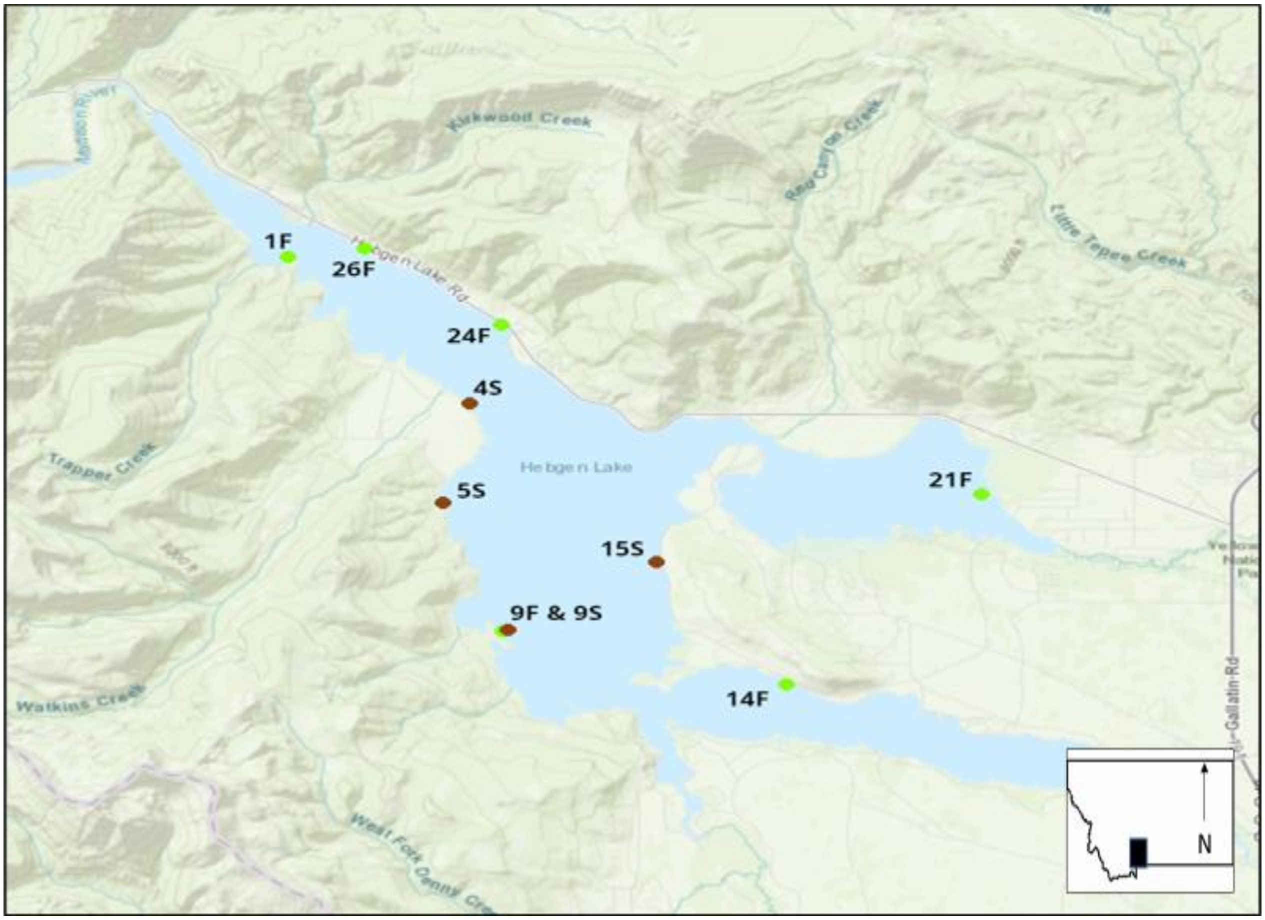


Figure 4**.** Updated Hebgen Reservoir gill net locations and names. Brown and green circles are sinking (N = 4) and floating (N = 6) gill nets, respectively.

FWP developed Hebgen Reservoir fishery management goals so that management actions can be implemented and evaluated to regularly and realistically maintain a fishery of above average condition. Hebgen Reservoir management goals for Rainbow Trout are 7.5 fish/net with 66% ≥ 406 mm (≈16”) while brown trout management goals are 15.5 fish/net with 75% being ≥ 406 mm (≈ 16”). Management goals for the Brown and Rainbow Trout fisheries in Hebgen Reservoir were established using the 66th percentiles of data collected over the past 20 years.

Brown and Rainbow Trout abundances were below management goals in 2020 (Figure 5). Brown Trout abundances decreased to 11.8 fish/net and Rainbow Trout to 6.3 fish/net (Figure 4), which are 29% and 25% lower than in 2019, respectively. However, both remain near the long-term averages (1998-2020) of 12.9 Brown Trout/net and 6.3 Rainbow Trout/net. Brown Trout have decreased by 56% since reaching a 20-year peak of 21.0 fish/net in 2017. Although this is concerning when considering recent declines in Brown Trout elsewhere in Montana including the Madison River, similar trends have been observed over the last 20 years. Rainbow Trout abundances have been trending upwards since a recent low of 3.2 fish/net in 2012, which is encouraging as the reservoir transitions to a wild trout fishery since FWP ceased stocking hatchery-reared Rainbow Trout in 2016. The size structure of the Rainbow Trout population rebounded above the management goal in 2020, but Brown Trout population size structure remained below the management goal (Figure 6). However, mean total lengths of Brown (435 mm; ≈ 17”) and Rainbow (412 mm; ≈ 16”) Trout remained near the long-term averages (Figure 5).

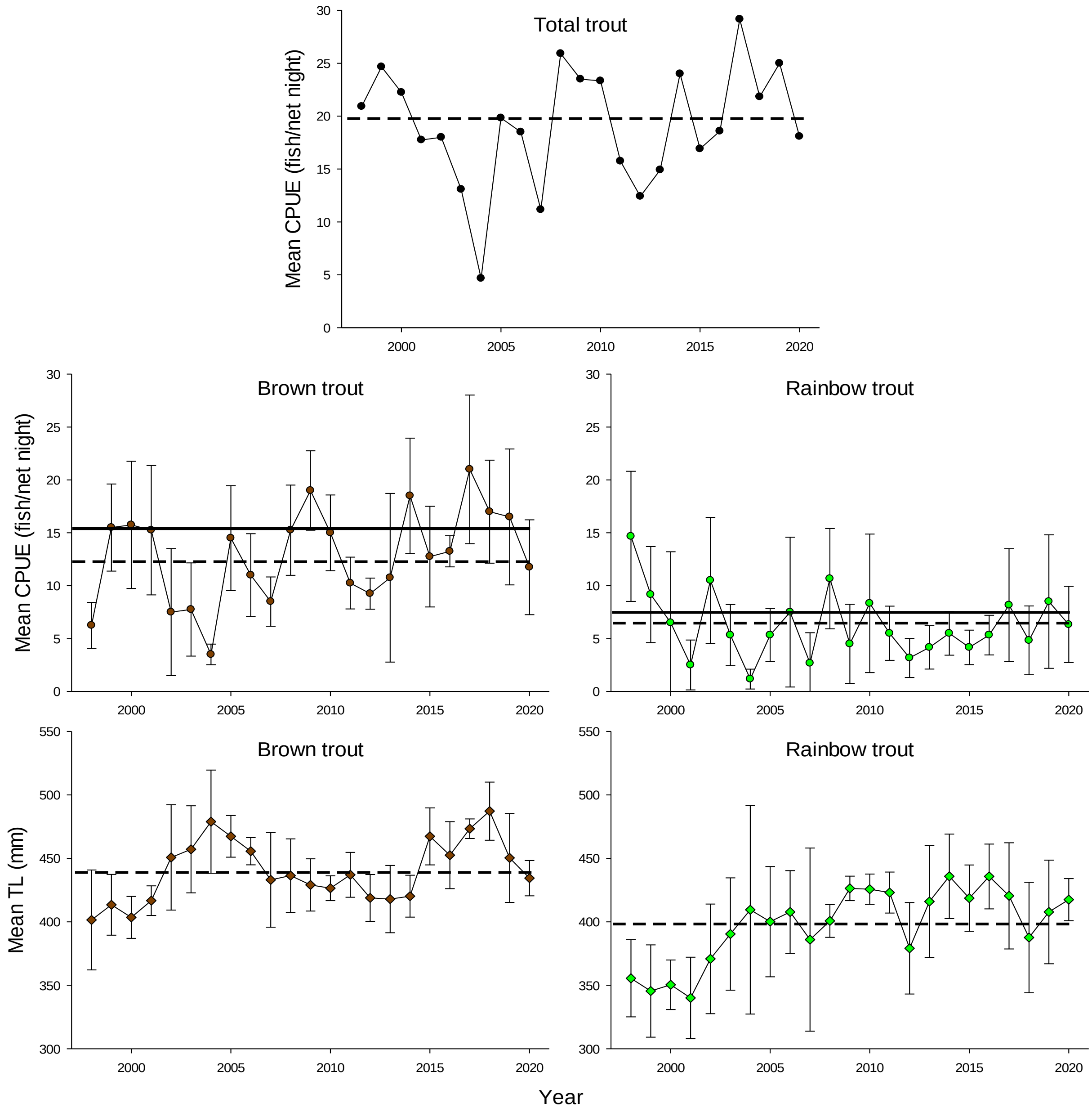


Figure 5**.** Mean *C/f* of total, Brown and Rainbow Trout captured in Hebgen Reservoir in 2020. Total trout abundances represent all trout captured in four sinking gill nets and six floating gill nets. Brown and Rainbow Trout *C/f* were limited to either sinking or floating gill nets, respectively. Mean total lengths were calculated using all Brown and Rainbow Trout captured each year. Dashed lines are the long-term averages (1998-2020). Solids lines are the management goals: Brown Trout = 15.5/net; Rainbow Trout = 7.5/net. Error bars are the 95% confidence intervals.

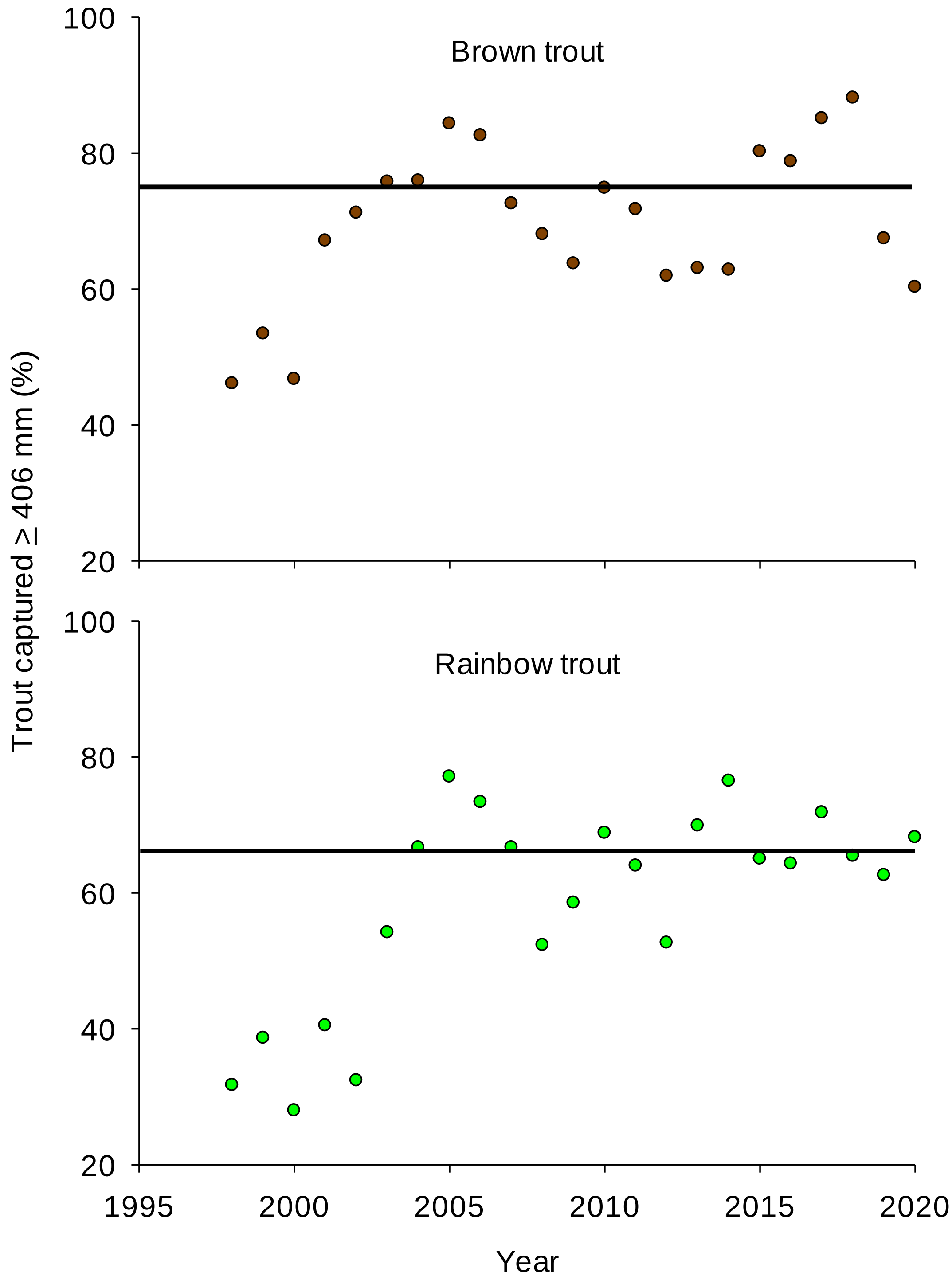


Figure 6. Percentages of trout captured in Hebgen Reservoir that were ≥ 406 mm (≈ 16”). Black lines are the management goals, which represent the 66th percentile of sampling data since 1998: Brown Trout = 75%; Rainbow Trout = 66%.

408-3) Reservoir Draw Down Effects on Fish

The interaction between Hebgen Reservoir elevation and operations, trophic status, and the trout population has been assessed annually by FWP since 2006. Reservoir elevation may influence juvenile trout success by increasing or reducing the amount of habitat along shorelines and the abundance of zooplankton. Large releases of water can impoverish the plankton community through the loss of nutrients and may result in deteriorated food conditions for juvenile trout, until they can switch to macroinvertebrates or piscivory (Axelson 1961; Haddix and Buddy 2005). Hebgen Reservoir has a full pool elevation of 6,534.87 feet (msl) and current operational standards require NWE to maintain reservoir elevations between 6530.26 and 6534.87 feet from June 20 through October 1 and reach full pool elevation by late June or early July.

Trophic status was assessed by taking Secchi disk measurements in conjunction with zooplankton tows to establish a Trophic State Index number (TSI; Carlson 1977). A Secchi disk was used to measure light penetration (in meters) into the water column and Secchi depths were recorded as the distance from the water surface to the point in the water column where the disk colors became indiscernible. Zooplankton samples were collected with a Wisconsin® plankton net with 153-micron mesh (1 micron = 1/1,000th millimeter) towed vertically through the entire water column at one meter per second. Tows were taken at locations with a minimum depth of 10 meters. Samples were rinsed and preserved in a 95% ethyl alcohol solution for enumeration. Zooplankton were identified to groups (i.e., cladocera or copepoda) and densities from each sample were calculated. Linear regression was used to determine whether mean zooplankton abundances and TSI were correlated with reservoir elevation. Months selected for analysis were June, July, and August because they correspond with the emigration of juvenile trout from natal tributaries to Hebgen Reservoir and their recruitment to the fishery could be influenced by the environmental conditions in the reservoir at the time of emigration (Watschke 2006; Clancey and Lohrenz 2007, 2008, 2009). Additionally, linear regression was used to assess whether reservoir elevation or zooplankton abundance were correlated with the relative abundance of trout ≤406 mm observed in annual gillnetting. Relative abundance of Brown and Rainbow Trout ≤406 mm at time t were compared to environmental covariates at time at t_{-1}, t_{-2} and t_{-3} to assess cohort-specific effects on juvenile trout.

Contemporary Hebgen Reservoir operations appear to have little influence on limnology and trout abundance. Mean zooplankton densities in June (23.72 individuals/L, ± 1.18; 95% *CI*) were the highest observed in 2020, with copepoda constituting 57% and cladocera 43% of the sample on average (Figure 7). Copepoda was the dominant group observed in May (84%), July (60%), August (58%), and September (54%; Figure 8). No statistically significant relationships ($P \geq 0.05$) were observed between reservoir elevation and zooplankton abundance, trophic status, or trout abundance or between zooplankton and trout abundances. However, trout cohorts emigrate to the reservoir at multiple ages and there was not adequate resolution to determine the exact year of emigration using fish length data from gillnets, which may have precluded inference. Moreover, the minimal mean fluctuation in reservoir elevation below full pool during the summer (June 0.70’, July 0.58’, August 1.91’) and the narrow operational range of between 6530.26’ and 6534.87’ from June 20 - October 1 reduces the likelihood of observing and describing interannual variability among these factors; no relationships exist or are expected under contemporary operations because conditions are similar each year. Therefore, it is expected that similar patterns will be observed within and among years and it is recommended that limnological sampling be suspended or reduced except in years where reservoir elevations fall outside of typical operational ranges.

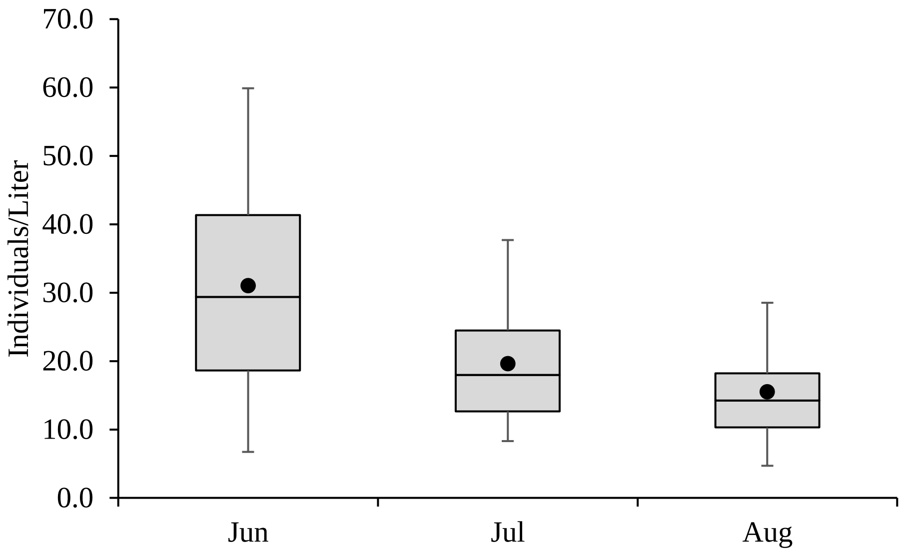


Figure 7. Total zooplankton abundance among months June, July, August 2006-2020. Within each box, ●’s denotes mean values, boxes extend from the 25th to the 75th percentile of each group's distribution of values, horizontal lines within each box are the median value, and whiskers are the 5th and 95th percentiles.

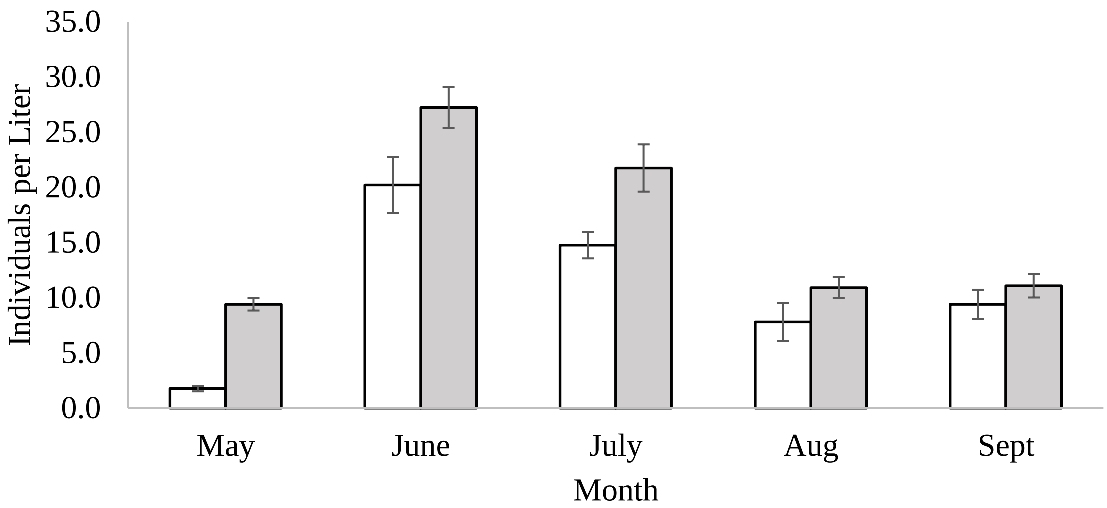


Figure 8. Calculated zooplankton abundances (individuals/liter) for the months of May-September 2020. White bars are cladocera and grey bars are copepoda. Error bars are 95% confidence intervals.

408-4) Monitor the Effects of Modified Project Operations on Upper Madison River Fish Populations- Madison River Fisheries Assessment

FWP estimated trout abundances using mark-recapture procedure in two long-term monitoring sections in the upper Madison River (Pine Butte and Varney; Figure 1) to evaluate the influence of modified project operations at Hebgen Dam on the fishery. Although only the influence of project operations are reported here, other potential population drivers (i.e., angling pressure, disease, etc.) are hypothesized to be influential and are being evaluated elsewhere. Trout were collected by electrofishing from a drift boat mounted mobile anode system (Figure 9). Fish captured in the initial trip (marking run) were weighed in grams and measured to the nearest millimeter, marked with a fin clip, observed for hooking scars, and released to redistribute. After ten days, FWP conducted a second trip (recapture run) where fish were examined for marks administered during the marking run, length recorded for marked fish, and length and weight recorded for unmarked fish. Length-specific mark-recapture log-likelihood closed population abundance estimates were generated and standardized to stream mile for Brown and Rainbow Trout using an R-based proprietary FWP fisheries database and analysis tool.

Figure 9. Mobile anode electrofishing (shocking) in the Norris section of the Madison River.

FWP developed management goals for total trout abundances (trout ≥ 252 mm [≈ 10”]; Figure 10) and size structure (percentages of trout ≥ 252 mm that are also ≥ 402 mm (≈ 16”]; Figure 11) for each of the long-term sampling sections using the 66th percentiles of data collected over the past 20 years. Evaluating PM&E (Protection, Mitigation and Enhancement) activities and management actions (e.g., flushing flows) in the context of these goals provides a better understanding of how they influence the Madison River trout fishery relative to other potential population drivers.

In 2020, abundances of trout ≥ 252 mm were below the management goals in the Pine Butte and Varney sections as well as the Norris section in 2021 (Figure 10). However, the size structure management goals for the percentages of trout ≥ 402 mm were exceeded in the most recent sampling efforts in all three sections (Figure 11). Except for Rainbow Trout in the Varney Section, estimated abundances of Brown and Rainbow Trout ≥ 152 mm (≈ 6) remained below the 20-year averages in the upper Madison River in 2020 (Figure 12). In the Pine Butte Section, 2020 sampling yielded an estimate of 2,152 Rainbow Trout/mile, which was similar to 2019 abundance. However, Brown Trout declined in Pine Butte to 1,367 Brown Trout/mile, which represents a decrease of about 15% from 2019 abundance. Primarily because of the highest abundance of age-1 fish observed in over 20 years (Figure 13), Rainbow Trout abundances (2,401 trout/mile) in the Varney Section nearly tripled from 2019 to 2020 (Figure 12). Estimated abundances of Brown Trout in the Varney Section remained relatively stable for the fourth consecutive year at 1,339 fish/mile, which is 82% of the 20-year average for that reach. In the Norris Section, Brown Trout abundance decreased to a 20-year low of 459 fish/mile in 2021 (Figure 12). Most concerning was the near lack of Brown Trout 152-277 mm captured in the Norris section in 2021 (Figure 13). Rainbow Trout abundance was 1,414 fish/mile, which was similar to 2018 but below the 20-year average for the Norris section. We will complete age and growth analyses using otoliths collected in 2020 to provide insight into factors limiting the growth and survival of Brown and Rainbow Trout and develop management actions to address these factors.

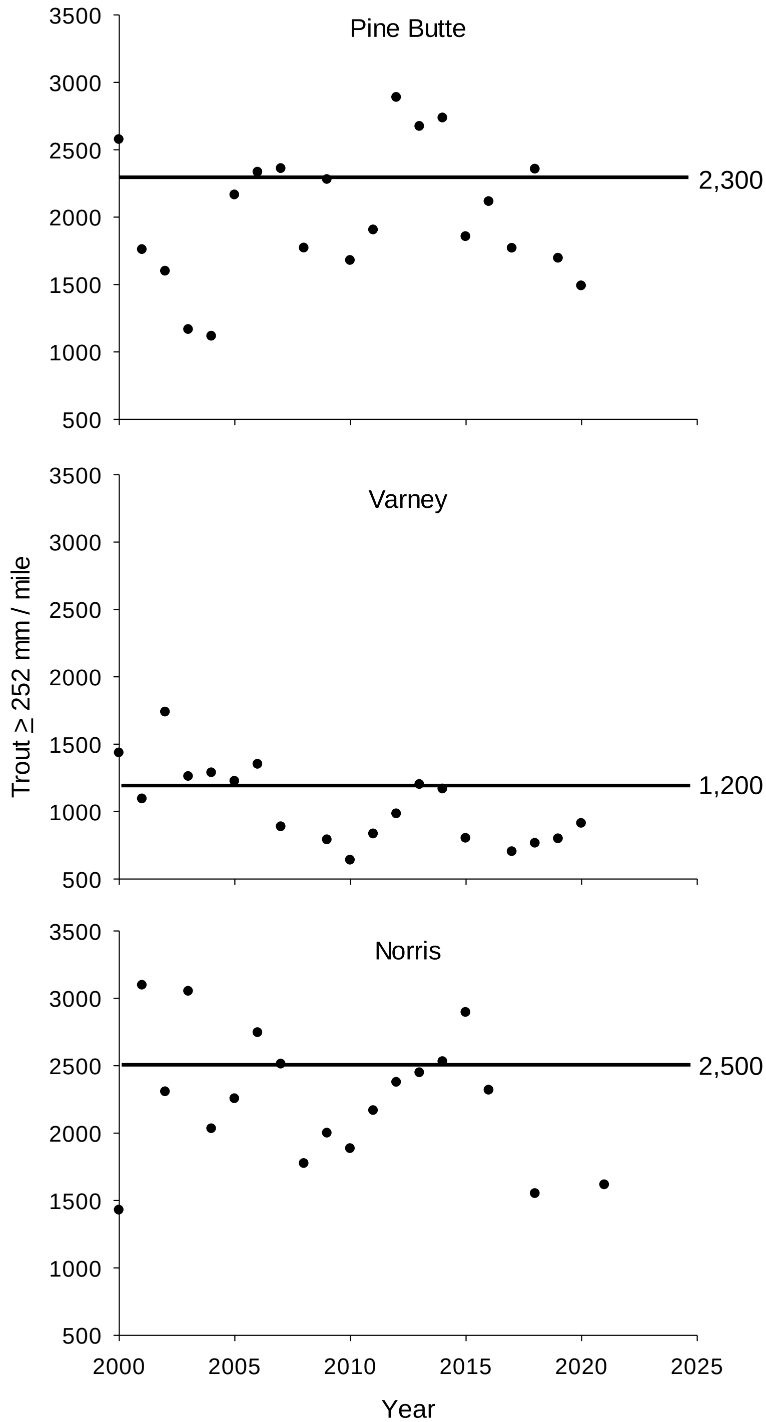


Figure 10. Estimated abundances of trout ≥ 252 mm (≈ 10”) in the Madison River. Black lines are the management goals for each section, which represent the 66th percentile of estimates over the last 20 years in each section. The Norris graph contains 2021 data.

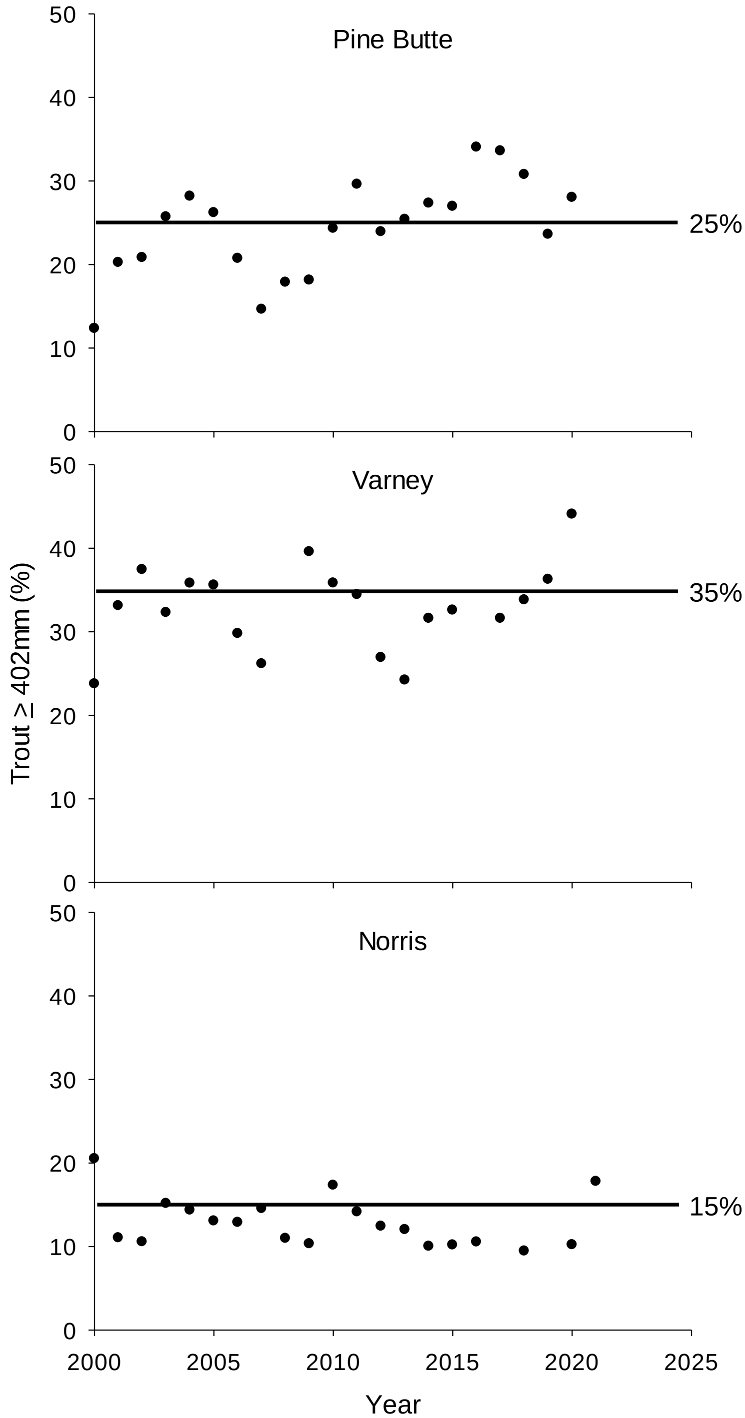


Figure 11. Percentages of ≥ 252 mm (≈ 10") trout captured in the Madison River that were ≥ 402 mm (≈ 16"). Black lines are the management goals for each section, which represent the 66th percentile of sampling data over the last 20 years in each section. The Norris graph contains 2021 data.

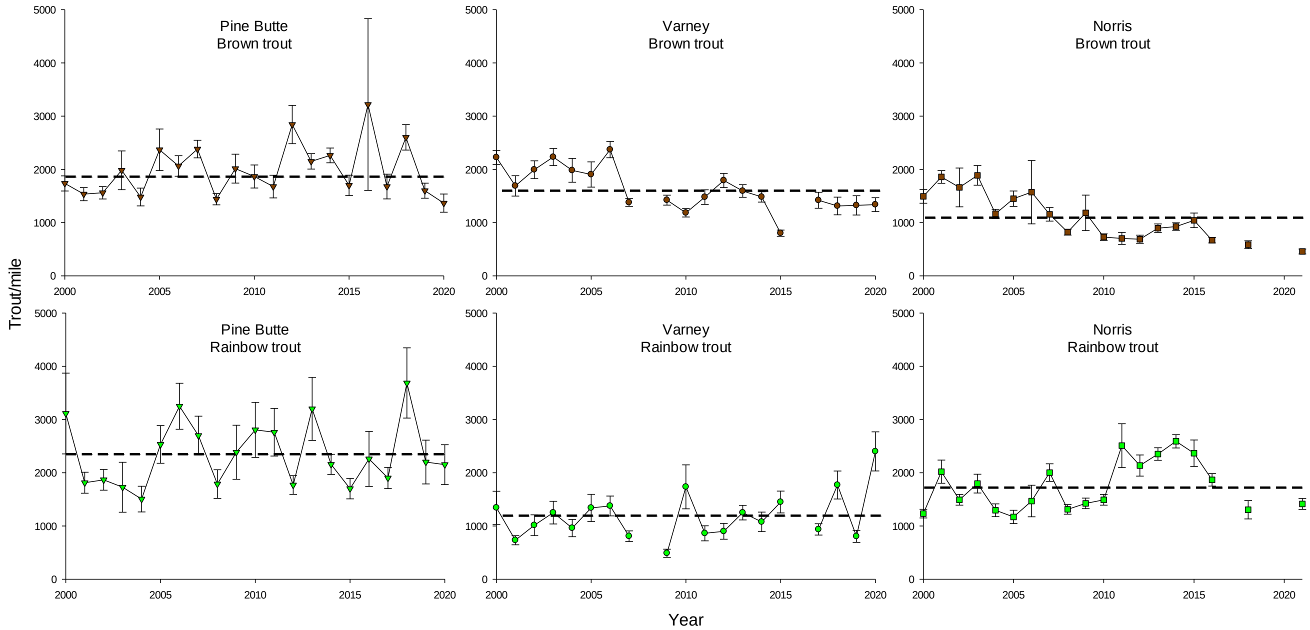


Figure 12. Estimated abundances of Brown (brown symbols) and Rainbow (green symbols) trout ≥ 152 mm (≈ 6”) captured in the three long-term sampling sections of the Madison River. Dashed lines are the 20-year averages of estimated abundances and error bars are the 95% confidence intervals for each sampling event. The Norris graphs include 2021 data.

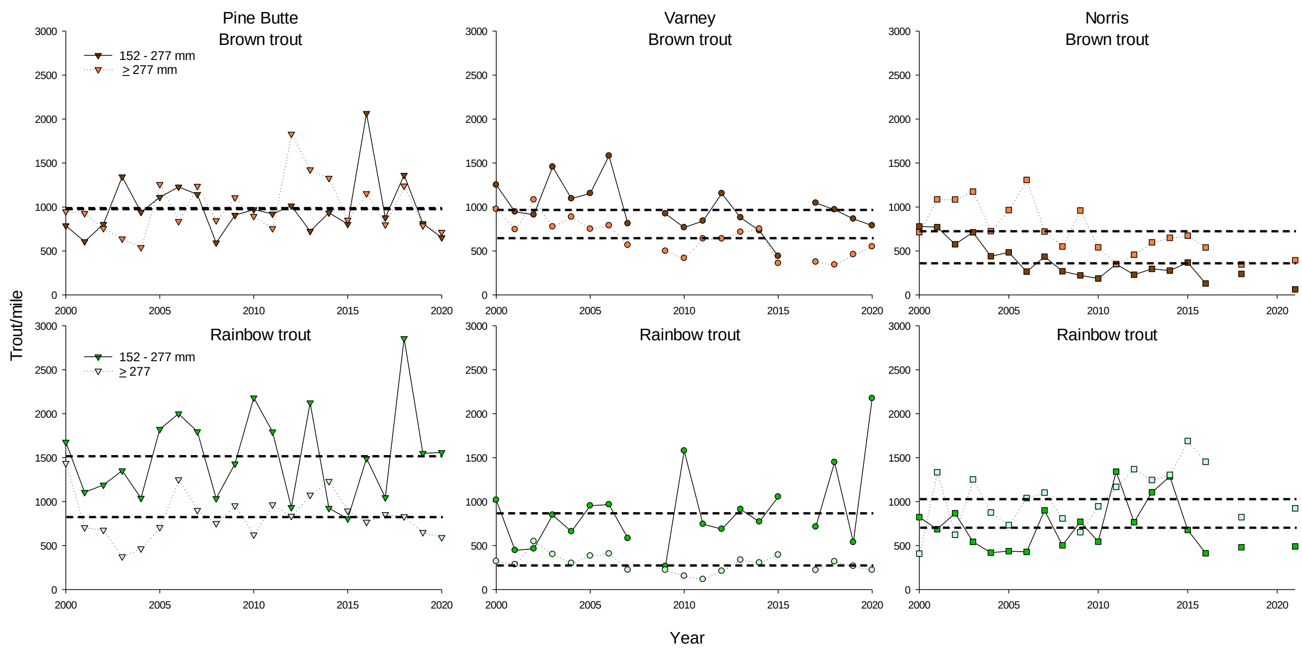


Figure 13. Estimated abundances of 152 – 277 mm (≈ 6 – 11”) and > 277 mm Brown and Rainbow Trout in the Pine Butte and Varney sections of the Madison River. Dashed lines are the 20-year averages of estimated abundances (nearly overlapping lines for Pine Butte Brown Trout). Norris graphs contain 2021 data.

408-4) Monitor the effects of modified operations on Upper Madison Fish Populations-Surface Release

During 2012-2015 and 2017 water was released from the surface of Hebgen Reservoir as repairs to the outlet structure used for mid-reservoir release was completed. The depth of water withdrawal from reservoirs can change the thermal characteristics of downstream waters. Surface release generally results in an increase of Spring-Summer water temperatures, whereas subsurface or hypolimnetic release can moderate or reduce Spring-Summer water temperatures, creating conditions that are optimal for cold water fish species such as trout. However, relative increases in water temperature can be beneficial; slight changes in temperature can move fish towards their ideal ranges for metabolic processes and influence fish growth and dispersion (Zoudd, 2018).

A general linear model and *t*-tests were used to evaluate whether water temperatures, trout abundances and trout condition in the Pine Butte, Varney, and Norris monitoring sections significantly differed between periods of mid-reservoir and surface release. We characterized mid-reservoir release as pre-surface (2000-2011) and post surface release 2016, 2018-2020. Surface releases occurred from 2012-2015 and in 2017. Mean daily water temperatures were calculated for the period July 1 through September 15 for the years 2000-2020. A one-way analysis of variance (ANOVA) was used to compare mean daily water temperatures between pre-surface, surface, and post surface release events. To evaluate if there was a response to surface release in age-1 trout abundances two sample t-tests were conducted at α=.05 confidence interval between estimated abundances of age-1 trout at time t and t_{-1} during years of mid-reservoir and surface release. Similarly, two sample t tests were also used to evaluate if surface release effected the proportion of trout ≥406 mm and trout condition (W*r*) at time t and $t_{-1.}$

On average, mean daily water temperatures were 2.0 $^{\circ}$F higher in the Pine Butte monitoring sections during surface release than pre or post surface release (ANOVA *F*=129.9; *df*=2.0; *P*<0.05; Figures 14 and 15). No significant differences existed in mean daily water temperatures in the Varney or Norris sections among surface release and pre or post surface release periods.

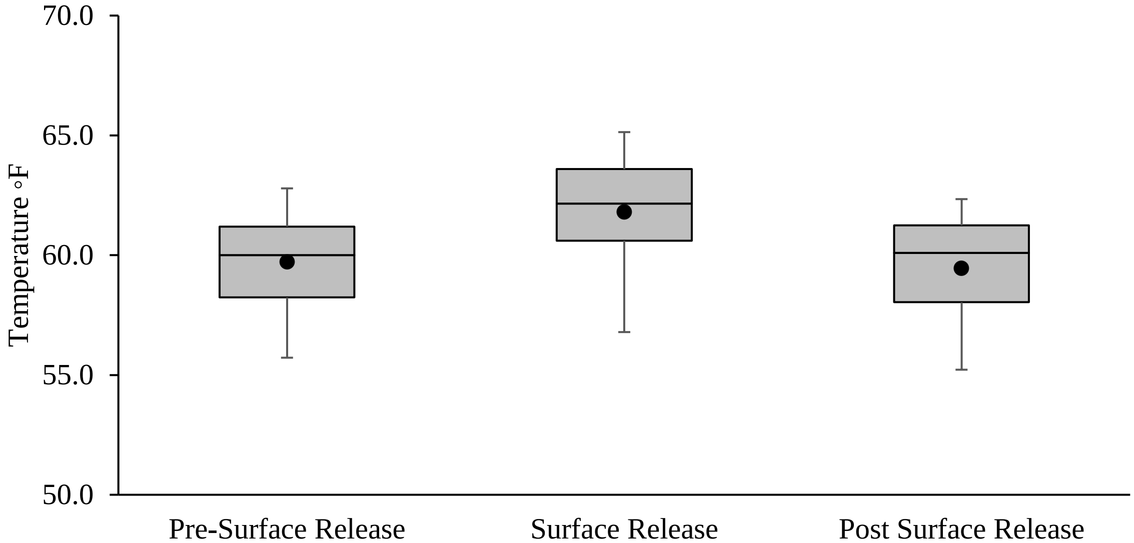


Figure 14. Boxplots of mean daily temperatures pre-surface release, during surface release, and post surface release for the Pine Butte monitoring section of the Madison River. Within each box, ●'s denotes mean values. Boxes extend from the 25th to the 75th percentile of each group's distribution of values and whiskers are the 5th and 95th percentiles.

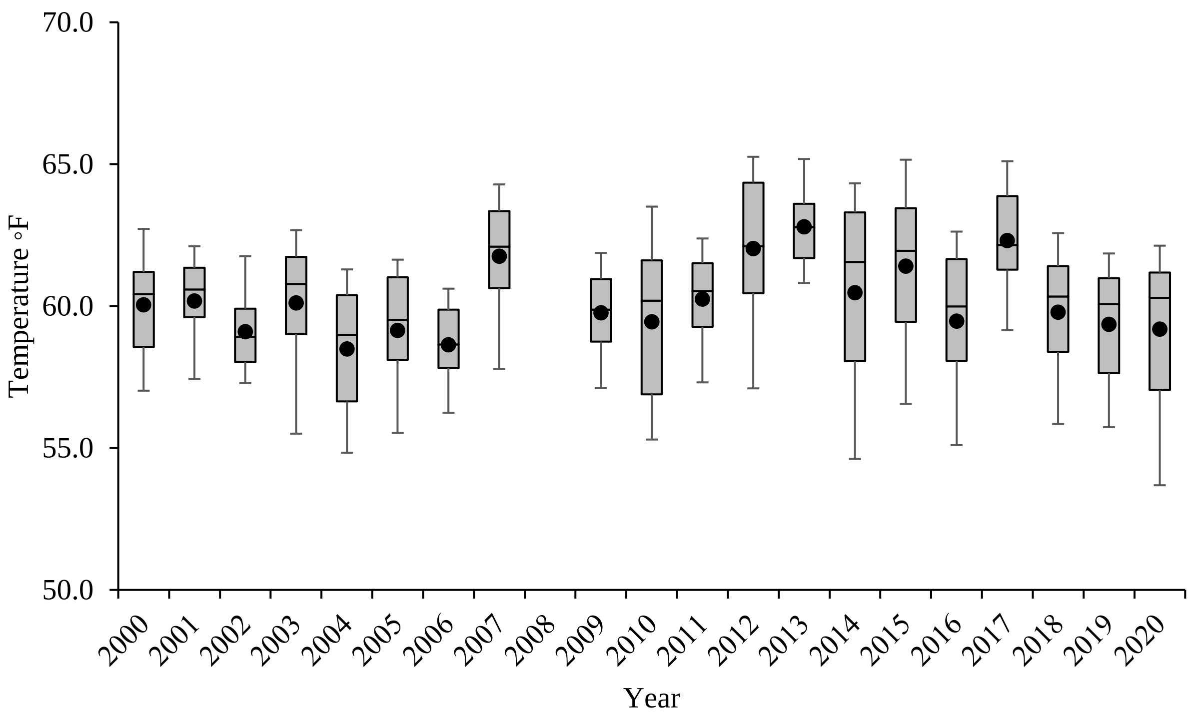


Figure 15. Mean daily water temperatures from July 1 - September 15, 2000-2020 at Pine Butte. 2008 data is missing. Years of surface-release are 2012-2015, 2017. Within each box, ●'s denotes mean values, boxes extend from the 25th to the 75th percentile of each group's distribution of values, horizontal lines within each box are the median value and whiskers are the 5th and 95th percentiles.

No significant difference was observed in the estimated abundance of age-1 Brown or Rainbow trout between mid-reservoir and surface release; however, there was an increase in the proportion of fish ≥406 mm that was marginally significant at time t (*t*-test, *P*=0.06) and statistically significant at time t_{-1} (*t*-test, *P*=0.03) during years of surface release in the Pine Butte monitoring section (Figure 16). This equated to roughly a 4% increase in the proportion of trout ≥406 mm at time t and a 5% increase at time t_{-1}. Surface release did not influence the proportion of trout ≥406 mm in the Varney or the Norris monitoring sections. A significant negative relationship between surface release and W*r* of age-1 trout in the Pine Butte monitoring section at time t and t_{-1} (*t*-test *P*<0.01; Figure 17) was observed; however, this relationship was not observed in the Varney or Norris monitoring sections, and there was no relationship between surface release and the W*r* of trout ≥ 406 mm in any of the monitoring sections.

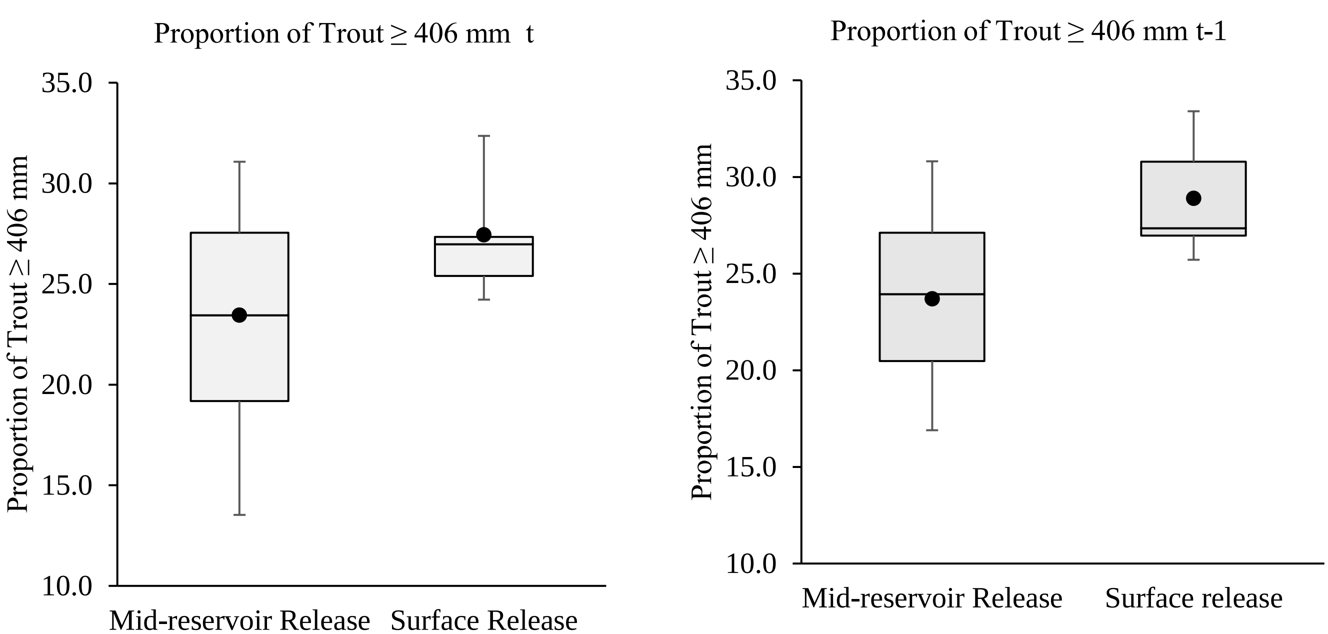


Figure 16. Boxplot of the proportion of fish ≥406 mm at t (*t*-test, *P*=.056) and t_{-1} (*t*-test, *P*=.028) during periods of mid-reservoir release and surface-release. Within each box, ●'s denotes mean values, boxes extend from the 25th to the 75th percentile of each group's distribution of values, horizontal lines within each box are the median value, and whiskers are the 5th and 95th percentiles.

The observed increase in the proportion of fish ≥406 mm during periods of surface release in the Pine Butte section suggest surface release may be a viable management action to regularly meet management goals for large trout, although the concurrent decline in juvenile W*r* is problematic. The decline in W*r* observed in age-1 Brown and Rainbow trout may be behaviorally related to the increase in the proportion of fish ≥406 mm during these events where juvenile trout evaded predation by a higher abundance of large trout in suboptimal habitat. The increase in the proportion of large trout was not driven by the low abundance of juvenile trout; there was no difference in age-1 abundance observed between mid-reservoir and surface release. Improved proportion of large trout and lower juvenile trout W*r* was not observed in the downstream Varney and Norris sections. It is recommended that discussions be initiated to evaluate surface release as a potential option for improving the proportion of large trout in the Pine Butte section.

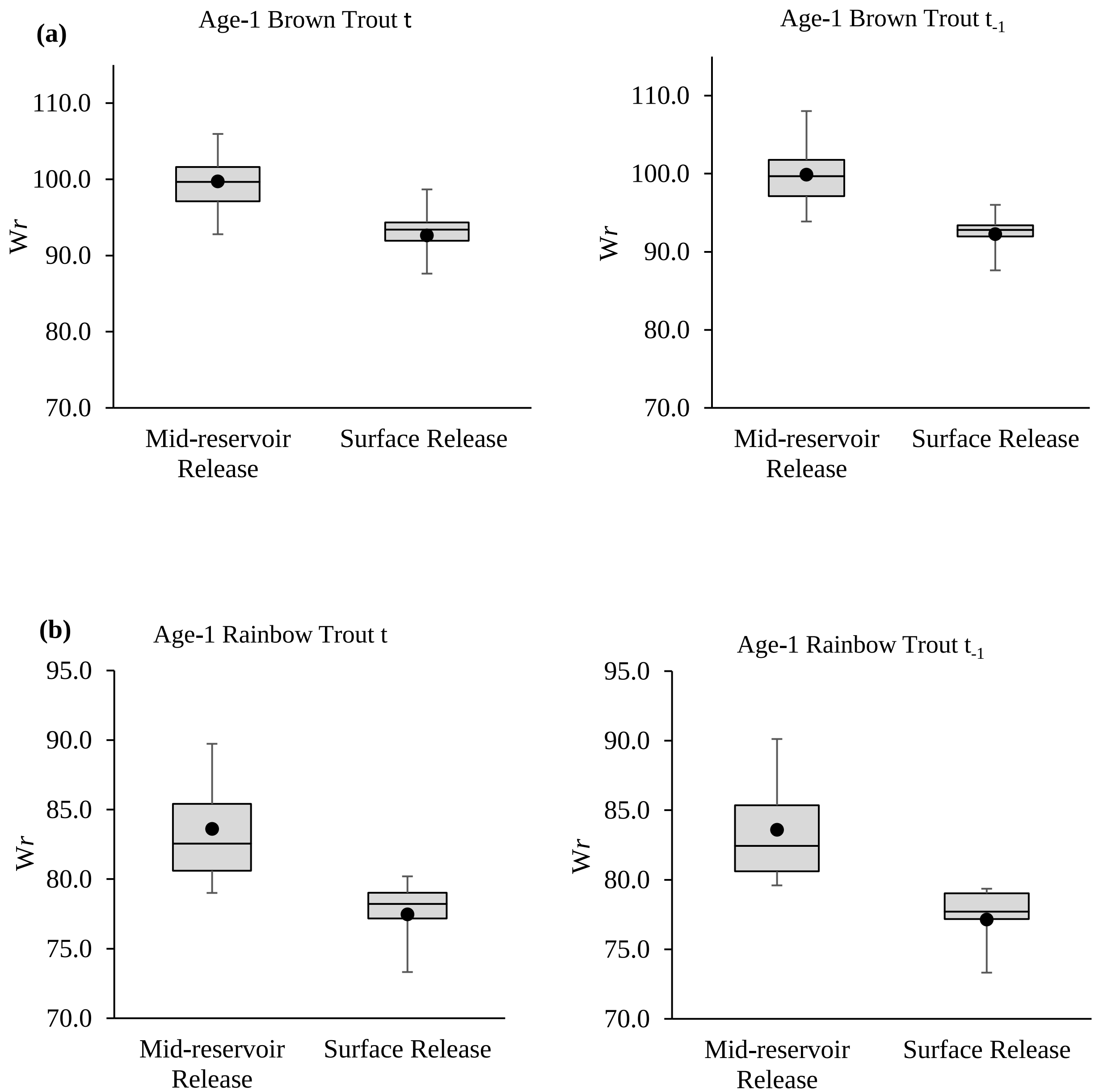


Figure 17**.** Boxplot of W*r* of age-1 **(a)** Brown Trout and **(b)** Rainbow Trout at t and t_{-1} during mid-release and surface release in the Pine Butte section. Within each box, ●'s denotes mean values, boxes extend from the 25th to the 75th percentile of each group's distribution of values, horizontal lines within each box are the median value, and whiskers are the 5th and 95th percentiles.

408-7) Monitor Species of Special Concern; Madison Artic Grayling; Westslope Cutthroat Trout

Opportunities to recover, conserve, and expand native fish distributions are regularly pursued by FWP and partner agencies. NWE is committed to implementing PM&E measures under Articles 408, 409, 412 of the 2188 FERC License from Hebgen Reservoir to Three Forks Montana to mitigate adverse effects to native fish species associated with Madison Project operations (FERC 2000).

Arctic Grayling reintroduction occurred in several Madison River tributaries between 2014 and 2020. Introductions were carried out by placing eggs in remote site incubators (RSI; Figure 18) and allowing eggs to hatch and fry to enter the stream. To date there have been 689,200 eggs placed in Madison tributaries and hatching success of eggs and fry emigration out of RSI's in tributary streams has been good to fair every year introductions took place except for the 2017 Blaine Spring Creek introductions (Table 2). In 2020, 300,000 eggs from the Green Hollow and Axolotl Lake Big Hole Arctic Grayling genetic reserve brood ponds were evenly divided into Blaine Spring Creek and Moore Creek (Figure 19) to assess whether eggs stocked at higher densities resulted in higher abundances of juvenile Grayling. During autumn electrofishing surveys, six and zero young-of-the-year Grayling were observed in Moore and Blaine Spring creeks, respectively. The number of Grayling observed in Moore Creek was the most observed since introductions were initiated, suggesting simply stocking more fish may be a viable option for successful re-establishment. However, relative suitability of reintroduction streams may be influenced by density of juvenile Brown Trout; there are relatively few juvenile Brown Trout in Moore Creek whereas high densities of juvenile Brown Trout occur in Blaine Spring Creek and the other streams where Grayling were previously introduced. Future restoration efforts will use substantially more eggs (i.e., >100,000) at introduction sites and focus on waters with low juvenile Brown Trout densities.

Figure 18. Remote site incubators used to hatch Arctic Grayling eggs.

Table 2. Arctic Grayling introduction sites. Site, year, quantity of eggs introduced and egg survival and emigration success.

Site	Year	# eggs	Egg survival and emigration
West Fork Madison Upper	2014	1,200	Poor
West Fork Madison Middle Spring	2014	10,000	Good
	2015	30,000	Good
	2016	5,000	Good
Lake Creek	2014	13,000	Good
	2015	27,000	Good
	2016	5,000	Good
Upper O’Dell Creek Grainger Ranch	2015	36,000	Good
	2017	32,000	Good
	2018	60,000	Good
	2019	15,000	Good
O’Dell Creek Longhorn Ranch	2019	45,000	Good
Blaine Spring Creek	2015	15,000	Fair
	2016	5,000	Fair
	2017	1,000	Poor
	2018	42,000	Fair
	2019	10,000	Fair
	2020	150,000	Fair
Moore’s Creek	2015	5,000	Fair
	2016	5,000	Fair
	2017	20,000	Fair
	2020	150,000	Fair
Denny Creek	2017	5,000	Good
	2018	2,000	Good

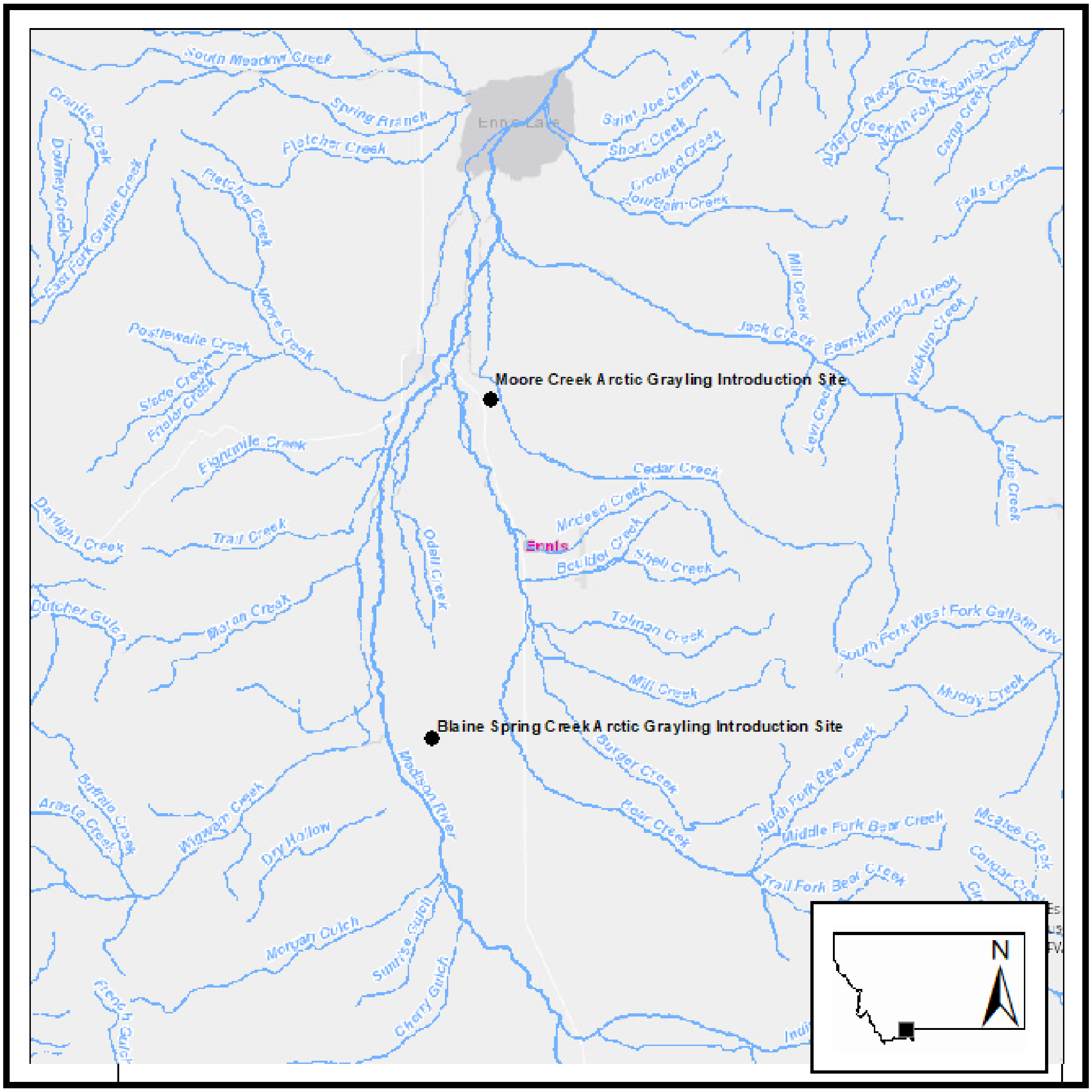


Figure 19. 2020 Arctic Grayling introduction sites Moore and Blaine Spring Creek.

FWP's Fisheries Management Plan calls for the protection and reintroduction of WCT with less than 10 hybridization by non-native fish (i.e., conservation populations) to 20% of historically occupied waters (Montana Statewide Fisheries Management Program and Guide 2018). The MadTAC has granted funding to FWP to pursue these conservation efforts under Articles 408, 409, and 412 of the 2188 project FERC license. WCT PM&E activities in 2020 included evaluation of the Tepee Creek fish barrier and the Ruby Creek WCT restoration project.

The Tepee Creek fish migration barrier is a natural waterfall that was improved to create a 12 ft vertical drop in 2019 by a Forest Service explosives crew. In the Summer of 2020 FWP initiated evaluation of the Tepee Creek fish migration barrier to 1) to examine whether the potential for fish passage exists during high flows, and 2) to directly assess whether fish passage occurs. FWP visited the barrier site during Spring runoff on June 10 and identified several potential issues that could compromise the effectiveness of the barrier. A pinch point occurs directly downstream of the barrier where debris could collect and cause the formation of a pool of sufficient depth for fish to jump over the barrier. Additionally, areas of reduced stream velocity and drop appear to be developing because of fractures in the rock on river left at the barrier site (Figure 20). FWP collected 90 fish above the barrier on July 15 and July 28 by electrofishing. Collected fish were marked with a left pelvic fin clip, moved below the barrier, and released. FWP will evaluate whether low-cost alterations can be made to address potential problems and will survey above the barrier for marked fish in 2021. If low-cost solutions cannot be identified or if upstream migration is still possible WCT recovery efforts in Tepee Creek will likely be abandoned or delayed.

Figure 20**.** Tepee Creek barrier and potential points of failure.

The Ruby Creek WCT restoration project initiated in 2012 with the removal of nonnative Rainbow Trout. Ruby Creek was confirmed to be fishless by sampling for environmental DNA (eDNA) in 2015. Since 2015, 81 genetically pure aboriginal Madison WCT from McClure and Last Chance Creek have been introduced into Ruby Creek. FWP surveyed 3.96 miles of Ruby Creek (Figure 21) on August 26 and 27 to evaluate post-restoration WCT distribution, reproductive status, and density. Surveys were conducted using a backpack electrofisher and all observed fish were netted, measured to the nearest millimeter, fin clipped to collect tissue for genetic testing, and released. A total of 120 WCT of different age classes, including young-of-the-year, were observed (Figure 22). Overall WCT abundance was about 1.6 fish per 100 meters (mean length=248 mm; 95% CI, ±13.0 mm). Fin clips were submitted to University of Montana genetics lab for genotyping to determine whether both donor populations are represented in the Ruby Creek population and which donor populations will be used for future introductions in Ruby Creek. Wild fish transfers from the Last Chance Creek population are scheduled for 2021 pending genetic results. Surveys of Ruby Creek WCT distribution and density will occur in every other year moving forward beginning in 2022.

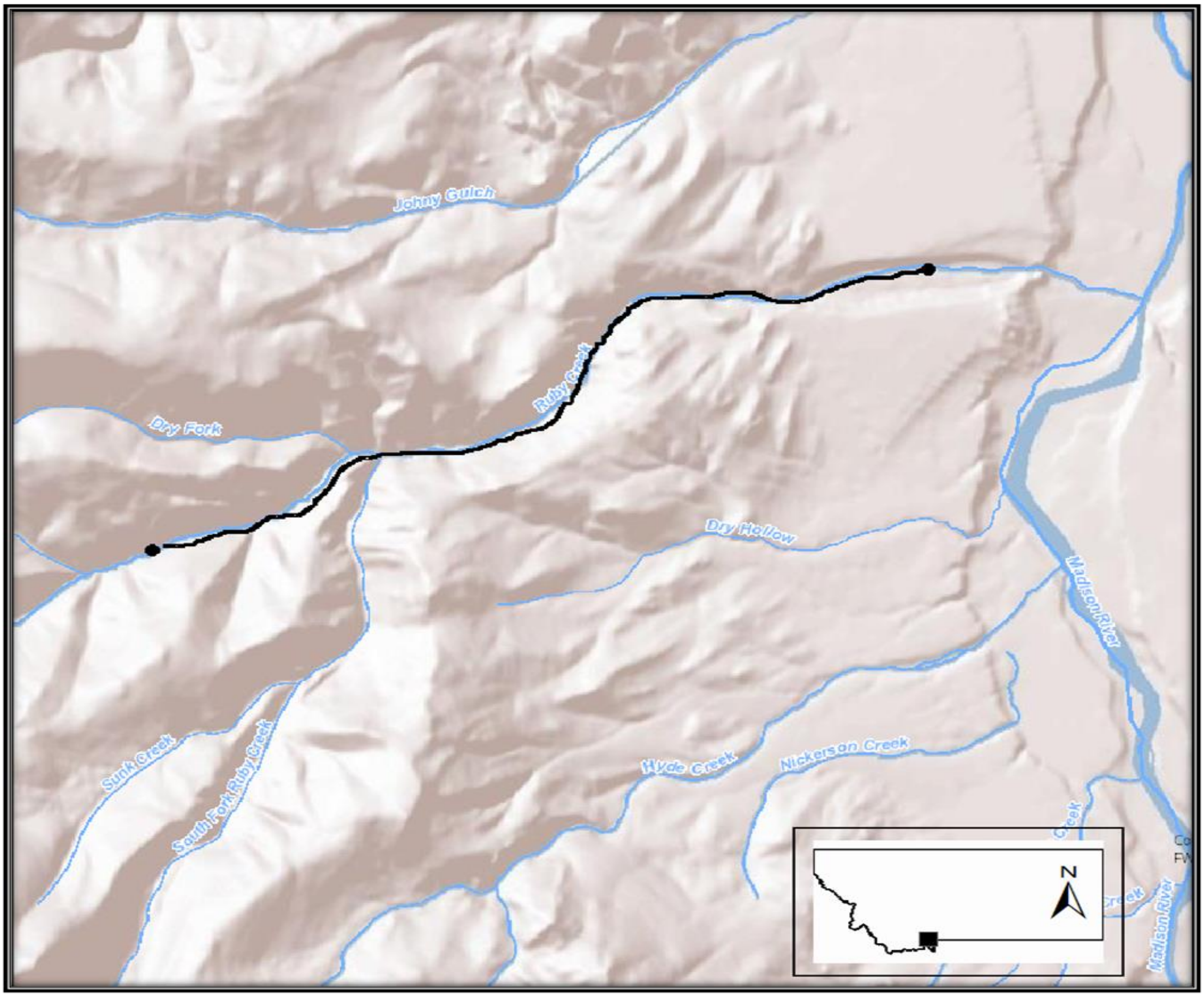


Figure 21. 2020 survey reach of Ruby Creek.

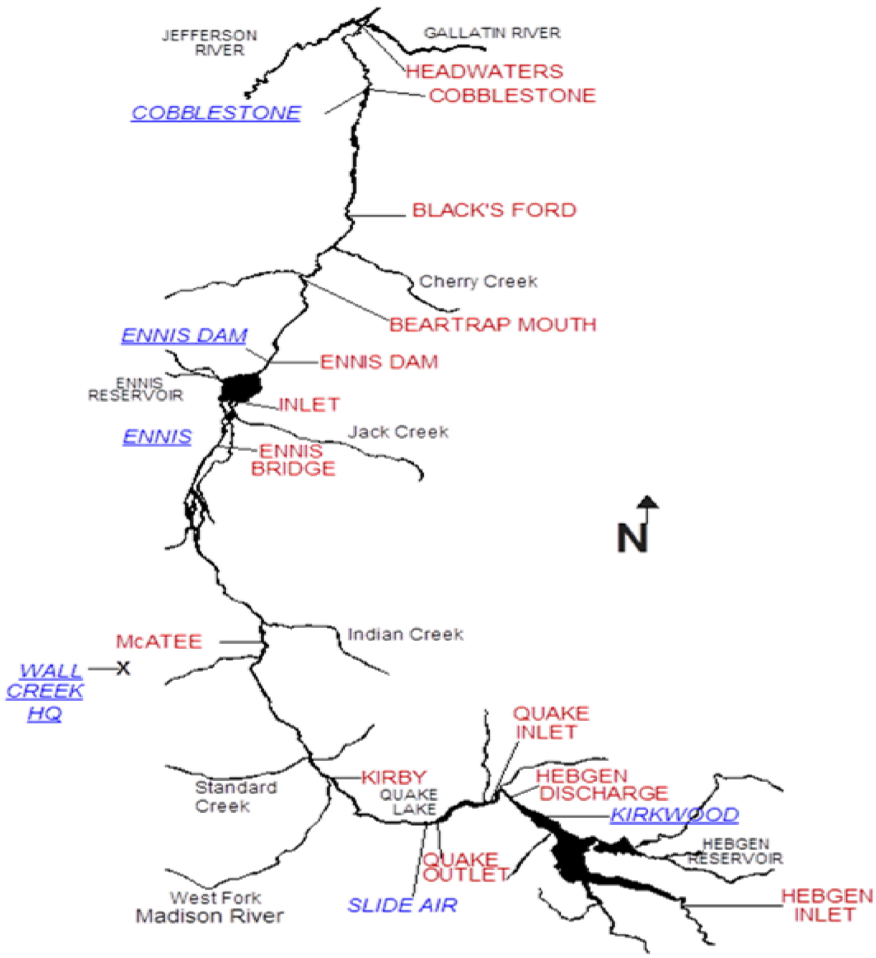
Figure 22. Age classes of WCT including young-of-the-year observed in Ruby Creek in 2020. The Ruby Creek reintroduction effort has been ongoing since 2015.

Article 409- 3) Fish habitat enhancement both in main stem and tributary streams

Previously conducted fisheries monitoring of O'Dell Creek was summarized in Appendix A.

Article 413-Pulse Flows

Temperature affects all living organisms and fish species have specific thermal ranges that are optimal for their persistence. However, exposure to extreme temperatures for extended durations can be lethal to fish. In 1988 a fish kill occurred in the Lower Madison River when temperatures reached 82.5 ^{o} F. Both FWP and NWE have since implemented monitoring programs to mitigate the effects of high-water temperatures on fish. FWP has monitored water and air temperatures throughout the Madison River basin from upstream of Hebgen Reservoir to the mouth of the Madison River at Headwaters State Park (Figure 23) since 1993. Temperature data has been used by FWP as criteria for implementing angling restrictions to reduce mortality of adult trout during periods of thermally induced stress. Angling restrictions are implemented when daily maximum water temperature $\geq 73^{o}$ F for three consecutive days. Additionally, to mitigate high water temperatures and reduce the risk of a thermally induced fish kill in the Lower Madison River, NWE implemented the Madison Decision Support System (DSS) program. The Madison DSS program is designed to predict a pulse volume of water that will limit thermal heating sufficiently to keep maximum daily water temperatures ≤80º F at Sloan and avoid the 82.5 º F lethal thermal limit of resident fish in the Lower Madison River. The Madison DSS is comprised of two methods to determine a pulse volume to the delivered to the Lower Madison River: a thermo-dynamic physics model (physics model) and a manual protocol. Pulsed flows are triggered when water temperature at the Madison (Ennis) Powerhouse is 68ºF or higher and the predicted air temperature at the Sloan Station (River Mile 17) near Three Forks, MT for the following day is 80º F or higher. NWE enters the maximum water temperature recorded at the McAllister USGS gage and the next days forecasted maximum air temperature at



Three Forks (Table 3) to the manual protocol and the physics model to derive the volume of pulse needed for the following day. NWE determines the larger derived pulse of the two methods and directs the operations to release that volume the following day from 6:00 am to noon. Timing of the release is designed to allow for travel time of the water to arrive in the lower Madison River near Black's Ford and Sloan during the late afternoon when daily solar radiation is greatest.

Figure 23. FWP temperature monitoring sites. Air temperature monitoring sites are blue and underlined; water temperature monitoring sites are red.

Table 3. Madison DSS Manual Protocol (Northwestern Energy 2020)

Today's maximum power- house release temperature at the Madison DSS website or USGS McAllister gage on or after 8:30 p.m.	**Tomorrow's predicted maximum air temperature (◦F) and corresponding pulse flows (cfs). Look up predicted high air temperature for the next day at Sloan Station near Three Forks, MT.**		
	>=75 and < 85	>=85 and < 95	>=95 and < 105
Greater than or equal 68 to and less than 69	1150	1150	1400
Greater than or equal to 69 and less than 70	1150	1400	1600
Greater than or equal to 70 and less than 71	1150	1600	2000
Greater than or equal to 71 and less than 72	1400	1600	2100
Greater than or equal to 72 and less than 73	1450	1800	2400
Greater than or equal to 73 and less than 74	1600	2100	2800
Greater than or equal to 74 and less than 75	1800	2600	3000
Greater than 75	2600	3200	3200

Daily maximum water temperatures observed in the upper river were ≥ 73^{o} F on two occasions at the Ennis Bridge and Ennis Reservoir inlet sites (Table 4); however, maximum daily temperatures at these sites did not occur in successive days and did not warrant implementation of angling restrictions. Daily maximum temperatures were ≥73^{o} F at the lower river monitoring sites Bear Trap Mouth, Black's Ford, and Cobblestone, for 25, 30, and 29 days, respectively (Table 4). Since 2000, maximum daily water temperatures at the Black's Ford monitoring site have been ≥73^{o} F an average of 43 times a year causing FWP to regularly implement restrictions that prohibited angling from 2 p.m. to 12 a.m. during Summer months. In 2020, FWP made permanent changes to Madison River angling regulations prohibiting angling between 2 p.m. and midnight from July 15th to Aug 15th from the Warm Springs Day Use Area to the confluence with the Jefferson River (Figure 23).

There were 26 days of pulse flows in 2020. Pulse flows kept maximum daily water temperatures from reaching 80^{o} F at Sloan; however, maximum daily water temperature exceeded 80^{o}F on one occasion at the Cobblestone monitoring site (Table 4). Pulse flows have been implemented an average of 20 days since 2000 and have been effective at moderating maximum daily water temperatures and preventing the occurrence of a thermally induced fish kill in the lower river (Table 5). FWP recommends continued monitoring of Madison River temperatures and that the pulse flow program continue as presently structured.

Table 4. Maximum and minimum temperatures (^oF) recorded at monitoring sites in the Madison River Drainage, 2020. Mean temperature is mean daily temperate ± 95% confidence intervals (CI). Days ≥ 73.0 ^{o} F the number of days daily maximum temperatures were at or exceeded 73.0^o F, and days ≥ 80.0 ^{o} F are the number of days daily maximum temperatures were at or exceeded 80.0 ^{o} F. NA denotes temperature data was unable to be recovered.

Deployment	Site	Max^o F	Min^o F	Mean daily temperature ± 95% CI	Days ≥73 ^{o} F	Days ≥80 ^{o} F
Water	Hebgen inlet	NA	NA	NA	NA	NA
	Hebgen discharge	67.7 ^{o}	37.0 ^{o}	54.4±1.24	0	0
	Quake Lake inlet	NA	NA	NA	NA	NA
	Quake Lake outlet	NA	NA	NA	NA	NA
	Kirby Bridge	70.2^o	36.0^o	53.6±1.06	0	0
	McAtee Bridge	71.9^o	35.7^o	54.4±1.00	0	0
	Ennis Bridge	73.2^o	39.8^o	56.5±1.00	2	0
	Ennis Reservoir Inlet	74.1^o	40.4^o	56.3±0.91	2	0
	Ennis Dam	74.2^o	41.6^o	60.9±1.11	4	0
	Bear Trap Mouth	77.6^o	40.5^o	61.2 ±1.07	43	0
	Blacks Ford	79.1^o	39.1^o	60.5 ±1.09	50	0
	Cobblestone	80.1^o	39.5^o	61.7 ±1.05	54	1
	Headwaters S.P. (Madison mouth)	NA	NA	NA	NA	NA

Table 5. The number of days that maximum daily water temperatures at Black's Ford have been ≥73°F, ≥ 80.0° F, and the number of days pulse flows occurred 2000-2020.

Year	Days ≥73° F at Black's Ford	Days ≥ 80.0° F at Black's Ford	Number of days pulsing occurred
2000	44	0	29
2001	14	0	13
2002	39	2	18
2003	61	2	39
2004	37	0	12
2005	40	0	17
2006	49	4	15
2007	55	2	43
2008	28	0	0
2009	34	0	8
2010	29	0	3
2011	27	0	0
2012	50	0	0
2013	69	1	35
2014	42	0	42
2015	50	7	11
2016	51	0	26
2017	57	0	36
2018	38	0	36
2019	40	0	10
2020	50	0	26

Article 419-Coordinate and Monitor Flushing Flows

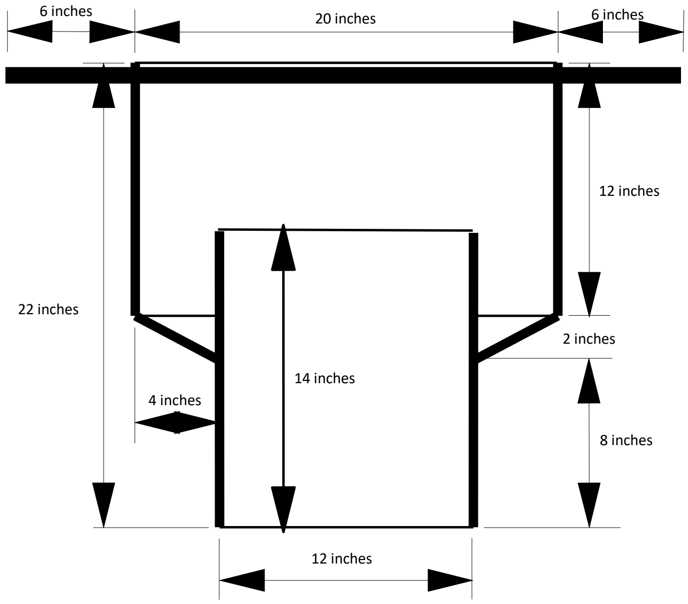
Article 419 of the 2188 FERC license requires that NWE develop and implement a plan to coordinate and monitor flushing flows in the Madison River downstream of Hebgen Dam. A flushing flow by design should be large enough to mobilize streambed materials and produce scour in some locations and deposition in other locations. This is a natural occurrence in unregulated streams and rivers that renews spawning, rearing, and food producing areas for fish as well as providing fresh mineral and organic soil for terrestrial vegetation and other wildlife needs. Impoundments such as dams interrupt the natural hydrograph of rivers and high flow events that are responsible for the replenishment and cleaning of spawning gravels are often reduced in magnitude and duration. These effects may be exacerbated by operational parameters the owner or operators of the dam prefer or must comply with. Streambed embeddedness and excessive amounts of fines (particles ≤0.84mm) in spawning gravels can adversely affect the survival of embryos and emergence of fry by inhibiting the delivery of oxygenated water and reducing the amount of interstitial space required for development (McNeil and Ahneil 1964, Kondolof 2000). Accordingly, the goal for the flushing flow program is to maintain ≤10% fines in the upper Madison River and a target of ≤15% in the lower Madison River with the understanding that release of a flushing flow from Hebgen Dam has limited influence on sediment mobility in the lower Madison River. This goal was selected because these targets are known to provide suitable conditions for salmonid spawning.

Operational constraints for Hebgen Reservoir outflow and reservoir elevation limit implementation, magnitude, and duration of a flushing flow. These constraints 1) limit discharge at USGS gage # 6-388 (Kirby gage) to no more than 3500 cubic feet per second (cfs) to limit erosion of the Quake Lake outlet, 2) limit changes in outflow from Hebgen Dam to no more than 10 percent per day for the entire year, and 3) require that snowpack and runoff forecasts allow for the filling of Hebgen to a minimum elevation of 6,532.26 msl by June 20. Several approaches have been implemented to evaluate the efficacy of flushing flows to recruit and rejuvenate spawning gravels, and maintain % fine sediment thresholds under current operational constraints, including redd counts, core sampling, and scour chains.

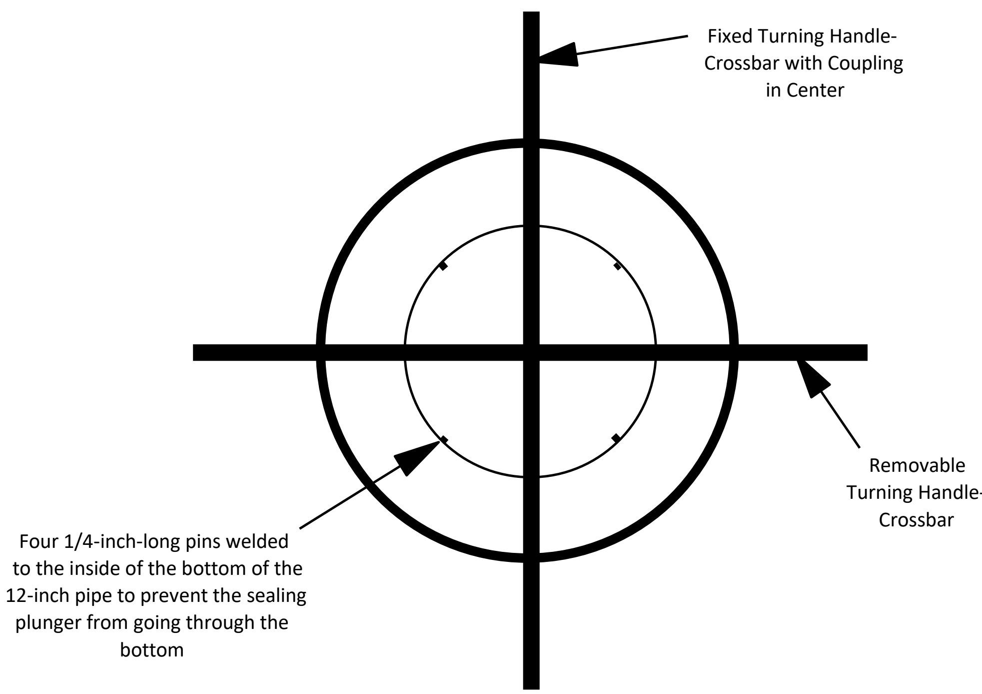
A redd is a nest constructed in the streambed by salmonids where fertilized eggs are deposited and develop until fry emerge from the gravel. Gravels selected for redd construction typically have a median diameter ≤10% of the female's body size, can be easily excavated, and contain minimal amounts of fine sediment and organic debris (Chambers et. al 1955, Kondolf and Wolman 1993). Sediment core sampling at the Kirby, Ennis, Norris, and Greycliff monitoring sections has occurred annually since 2002. These sites were selected to represent conditions in the upper (Kirby & Ennis) and lower (Norris & Greycliff) Madison River. Sediment core data provides an index of relative spawning habitat suitability during years with and without flushing flows. Redd counts were initiated in 2012 to ensure complementary substrate sampling (i.e., core samples, scour chains) occurs in actual spawning habitats.

Redd counts were done by walking in an upstream direction and visually identifying streambed disturbances consistent with redd morphology. A typical redd consists of a defined pit where gravel was excavated with a mound of gravel (tail spill) immediately downstream of the pit (Figure 24). The number, physical dimensions, and location of individual redds within each monitoring section were recorded. Core samples were collected with a 12-inch McNeil core sampler (Figure 25) in substrate previously identified as spawning habitat during redd counts. The core sampler was manually drilled into the substrate to a depth of 8 inches. Substrate from within the 12"x 8" area was removed, dried, and sorted using a sieve method. The percent composition of the sample was then calculated according to particle size.

Figure 24. Redd (nest) at the Norris redd counting site. Pit is denoted with the X and black arrow shows the direction of stream flow over tail spill.



Cross-Section



Top View

Figure 25. Schematic of 12-inch diameter substrate sampler, modeled after the original 6-inch diameter sampler developed by McNeil and Ahnell (1964).

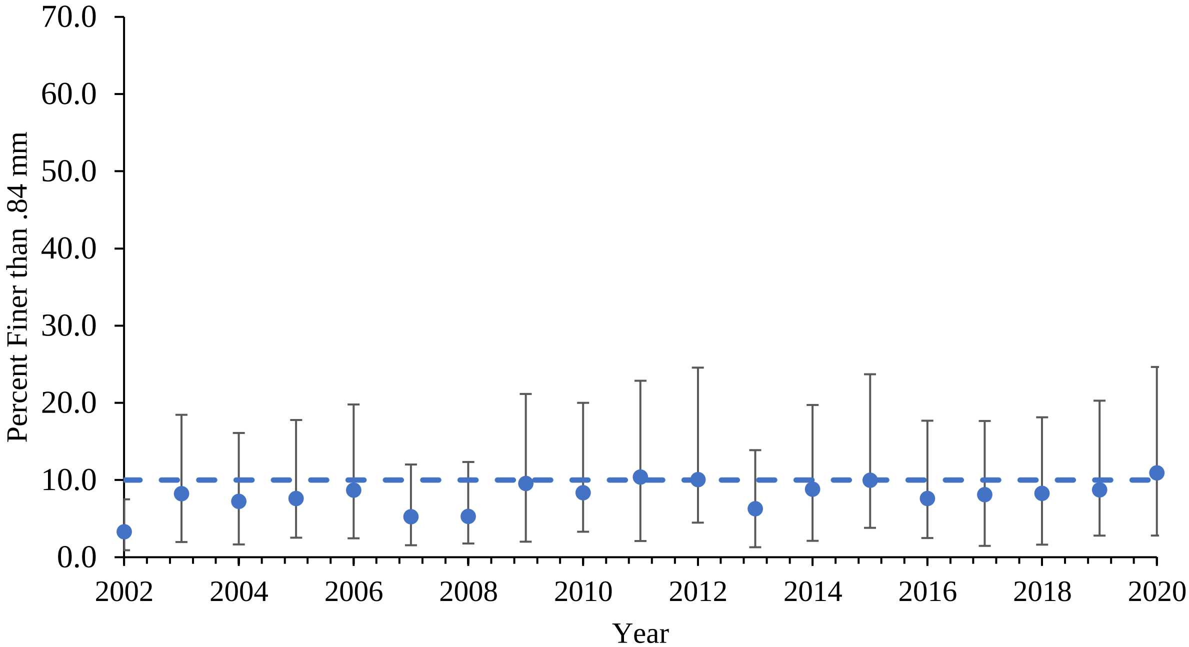
Two sample *t*-tests were conducted at $\alpha = 0.05$ to test whether the mean number of redds differed in years with and without flushing flows and 95% CI's were calculated for the mean percent fines ≤ 0.84 mm in core samples from the upper river monitoring sites (Kirby, Ennis) and the lower river monitoring sites (Norris and Greycliff). There was no significant difference in the number of redds between years with and without flushing flows; however, sparse redd data and few flushing flows precluded meaningful statistical inference at any of the sites (Table 6). The last three years of Fall Brown Trout redd data for the Norris site are the lowest recorded since counts were initiated in 2013. It is unclear if this trend is because of flushing flow implementation or related to an observed downward trend in the number of Brown Trout in the lower river. Median values for percent fines ≤0.84 mm in the upper river ranged from 3.7% (2002) to 10.7% (2020) and from 8.5% (2007) to 22.9% (2014) in the lower river (Table 6). There were no statistical differences in the percent fines ≤0.84 mm observed between years with and without a flushing flow (Figure 26).

Inconsistencies in the timing and frequency of counts likely influenced the number of redds observed between years (Table 6). Additionally, flushing flows have had no significant effect on the percent fines present in spawning habitat. Therefore, it is recommended that goals be established for conducting redd counts that differs from the original intent under the flushing flow program with protocols for redd monitoring be refined to develop a more meaningful data set to meet the newly established goals and that core sampling be expanded to include spawning habitat associated with side channels and other geomorphic features to better evaluate the flushing flow program.

Table 6. Median % fines ≤0.84mm ± standard deviation (SD) and Brown (LL) and Rainbow (RB) Trout redds in the Upper and Lower Madison River, incidence of a NWE flushing flow event, and peak flow in cubic feet per second (CFS) at USGS gage 06041000.

	Upper Madison River			Lower Madison River				
Year	**% fines<.84 mm median ±SD**	**LL Redds**	**RB Redds**	**% fines<.84mm median ± SD**	**LL Redds**	**RB Redds**	**NWE flushing flow**	**Peak Flow CFS USGS gage 0604100**
1995	6.6 ±4.4			15.9 ±5.4				7360
1996	5.8 ±1.2			8.3 ±4.5				7980
1997	7.4 ±3.9			9.8 ±4.5				7910
1998								6820
1999								5500
2000								4450
2001								2460
2002	3.7 ±1.5			9.6 ±4.1			No	5180
2003	8.6 ±3.2			10.0 ±5.7			No	4670
2004	7.6 ±2.7			10.7 ±5.2			No	3440
2005	6.9 ±4.1			13.5 ±8.0			No	4470
2006	9.7 ±3.7			13.5 ±5.0			Yes	5390
2007	5.1 ±2.5			8.5 ±4.0			No	3400
2008	5.4 ±2.9			9.7 ±4.8			Yes	5390
2009	9.3 ±3.2			12.4 ±11.7			No	4050
2010	7.0 ±5.3			11.9 ±5.7			No	5540
2011	10.1±3.4			13.8 ±8.2			Yes	7100
2012	6.8 ±7.2			15.9 ±5.4			No	4810
2013	5.8 ±2.1	8	39	18.8 ±18.7	36	26	No	2850
2014	8.4 ±3.4	39		22.9 ±13.7	21		No	5560
2015	8.3 ±6.1	39	42	12.6 ±8.3	29	34	No	4490
2016	7.1 ±4.0	17	78	14.7 ±10.2	40	48	No	3180
2017	7.9 ±2.4	14	54	11.7 ±5.7	46	56	No	4520
2018	8.7±2.6	6		11.4±4.8	20		Yes	6510
2019	7.2±4.5	5	16	10.3±11.3	14	1	No	4670
2020	10.5±4.5	23	22	19.2±6.5	16	59	Yes	6180

(a)



(b)

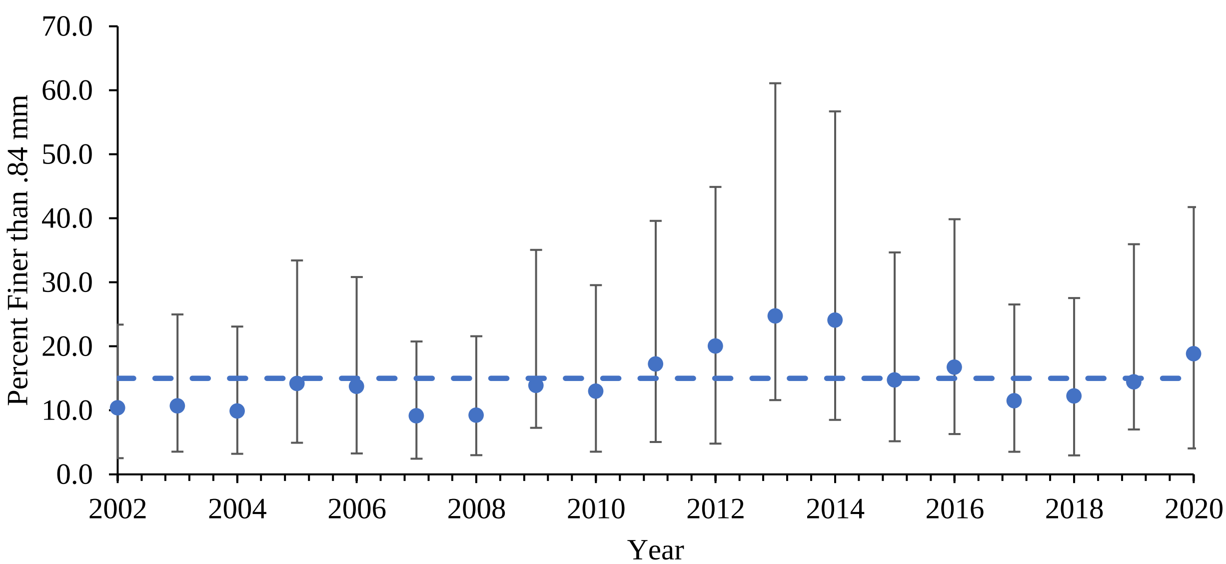


Figure 26. Mean percent fines and 95% CI's of <0.84 mm in core samples from the Madison River in the **(a)** Upper River where the blue dashed line is the 10% threshold for fines and **(b)** Lower River where the blue dashed line is the 15% threshold for fines.

Article 419-Flushing Flows Effect on Fish

We evaluated whether flushing flows under current operational constraints are beneficial or detrimental to fish recruitment and survival using FWP abundance estimates from three long-term monitoring sections (Pine Butte, Varney, and Norris) and USGS hydrograph data from 2000 to 2020. Abundance of age-1 fish was estimated in the Upper and Lower river based on Madison River length-at-age data (Table 7; Vincent 1971). We used linear regression models to determine whether abundances of age-1 Brown and Rainbow Trout in the Pine Butte and Varney sections were correlated with the occurrence of a flushing flow, peak discharge, or days discharge was ≥3,500 cfs at the USGS Kirby gage #0603880 at time periods t and t_{-1} and whether abundances of age-1 Brown and Rainbow trout in the Norris section were correlated with occurrence of a flushing flow or peak discharge at USGS gage #06041000 at t_{-1} and t_{-2}. The lag in time periods tested differed between Upper and Lower river sites because abundance estimation occurs in the fall in the Upper River and in the spring in the Lower River; post-flushing flow effects in the Lower River can be first assessed one year later than in the Upper River. A two-sample *t*-test was used to compare age-1 Brown and Rainbow Trout abundances between years when flushing flows did and did not occur at time t, t_{-1} and t_{-2} to determine whether flushing flows improved habitat conditions and produced strong cohorts. We used linear regression models to determine whether the proportion of trout ≥ 406mm in the Pine Butte and Varney section were correlated with flushing flows, peak discharge and days discharge was at or exceeded 3,500 cfs at the USGS Kirby gage #0603880 at time periods t and t_{+4} and whether the proportion of trout ≥406mm in the Norris section was correlated with occurrence of a flushing flow and peak discharge at USGS gage #06041000 at t_{-1} and t_{-4} to evaluate whether flushing flows improved habitat conditions for large trout. We considered time t and t_{-1} to assess the direct effects of a flushing flow on large trout and time t_{-4} to evaluate whether flushing flows produce strong cohorts that ultimately recruit into the adult population. A two-sample *t*-test was used to compare the proportion of trout ≥406mm at t_{-1} or t_{-4} between years with and without flushing flows.

Table 7. Madison length-at-age for Rainbow and Brown trout in the upper river (Varney and Pine Butte) and the lower river (Norris; Vincent 1973).

	Rainbow Trout			**Brown Trout**		
Location	**age-1**	**age-2**	**age-3+**	**age-1**	**age-2**	**age-3+**
Pine Butte and Varney	157<249 mm	249-348 mm	≥348 mm	157<-249 mm	249-361mm	≥360 mm
Norris	152<226 mm	226-305 mm	≥305 mm	152<-226 mm	226-328 mm	≥328 mm

Fish abundances were positively correlated with longer duration high flow events but not with flushing flow occurrence or peak flows. There were no significant differences between age-1 Brown or Rainbow Trout abundances and the occurrence of a flushing flow in any section. Similarly, there was no significant correlation between peak discharge and age-1 Brown or Rainbow Trout in any section, suggesting that peak discharge was not a population driver. However, there was a significant relationship between days ≥3500 cfs and age-1 Rainbow Trout abundances at time t (R^2=30.3%; P=0.01) in Pine Butte and age-1 rainbows at time t_{-2} and days ≥3500 cfs in the Varney section (R^2=47.5%; P<0.01). There were no significant correlations between abundances of age-1 Brown Trout and days ≥3500 cfs in the Pine Butte or Varney sections, no significant relationships between days ≥3500 cfs, or peak discharge and the proportion of fish ≥406mm at time t_{-1} or t_{-4} in any of the monitoring sections, and no statistical differences in the proportion of fish ≥406 mm at time t_{-1} or t_{-4} in any section related to the occurrence of a flushing flow. This suggests that duration of high flows is more important to relative survival of young Rainbow Trout than occurrence of flushing flow or peak flow under current operational constraints and that flushing flows do not affect large trout. Inference is limited by sparse data; planned flushing flows occurred in only four years and days ≥3500 cfs occurred in five of the twenty years used for analysis and had a relatively small range (1 to 6). There is also the potential that young fish were simply displaced from upstream habitat by high flows rather than experiencing higher survival. To better understand this dynamic, future flushing flows should emphasize extending the duration ≥3500 cfs to more than 6 days. This would require a new protocol for the flushing flow program and associated volume runoff calculations to accommodate the 3500 cfs volume for 6 days instead of the current 3 days.

Overall, considering flushing flows occurred in only 5 years, the narrow scope of monitoring to evaluate the effectiveness, and the present operational constraints for implementing a flushing flow it is difficult to make inference about their effectiveness at improving habitat conditions throughout the river.

2020 Flushing Flow Monitoring

Objectives and Methods

A flushing flow occurred in 2020 and monitoring was expanded to discern whether it was able to induce localized scour and pool maintenance at boulders, transport sediment and maintain pools and riffles in side channels, and recruit gravel from stream banks in the mainstem. Monitoring considered abundance goals for trout in FWP annual monitoring sections near Pine Butte, Varney, and Norris (Figure 1; Duncan et al. 2020) and Article 409 of the 2188 project. Duncan et al. hypothesize inadequate maintenance and development of habitats under current operational constraints in the Madison River may limit trout abundances. FERC article 409 of the 2188 License calls for *"Fish habitat enhancement both in mainstem and tributary streams, including enhancement for all life stages."* Fish abundances are often limited by quality and quantity of available habitat. Boulders tend to increase velocity and direct flow creating localized bed scour around the rock, producing a scour pool and a depositional area of sorted bed material downstream from the boulder. Scour pools provide in stream cover and reduced water velocities for fish and depositional areas associated with boulders can be utilized for spawning (Fischer and Klingeman 1984). Side channels provide spawning and rearing habitat in riverine systems and a source of gravel recruitment resulting from bank and stream bed scour as velocities increase. Scour of banks can provide recruitment of new gravels into a stream system and create undercut banks (Lawler 1993). This process could be important to the recruitment of new gravel for spawning in sections of the river where less static geomorphic conditions exist. Therefore, the specific objectives of 2020 monitoring were to evaluate 1) localized scour and pool maintenance at boulders, 2) the effects of flushing flow on sediment transport in side channels via pool and spawning gravel maintenance, and 3) gravel recruitment from stream banks in the mainstem.

Three monitoring sections, two in the upper river and one in the lower river, were selected. Monitoring sections integrated FWP annual abundance estimate sections with NWE flushing flow monitoring sections (Figure 1). Monitoring sites included areas where localized scour could potentially be induced by boulders and side channels where hydrogeomorphic processes may have a greater influence during high flows. Pre-flushing flow monitoring occurred from May 26-29 and post-flushing flow monitoring from June 29-July 2.

Boulders

Four boulders were selected in the Pine Butte-Kirby section and one in the Norris section to evaluate localized scour during the flushing flow. Monitoring consisted of installing scour chains on the upstream and downstream pool crests of each boulder (Figure 27; Lisle and Eads 1991). Stream bed elevation at each scour chain and the deepest part of the pool was measured using a self-leveling laser and stadia rod from an established benchmark. After the flushing flow elevations were resurveyed and the number of exposed links on the scour chains counted to corroborate elevation measurements.

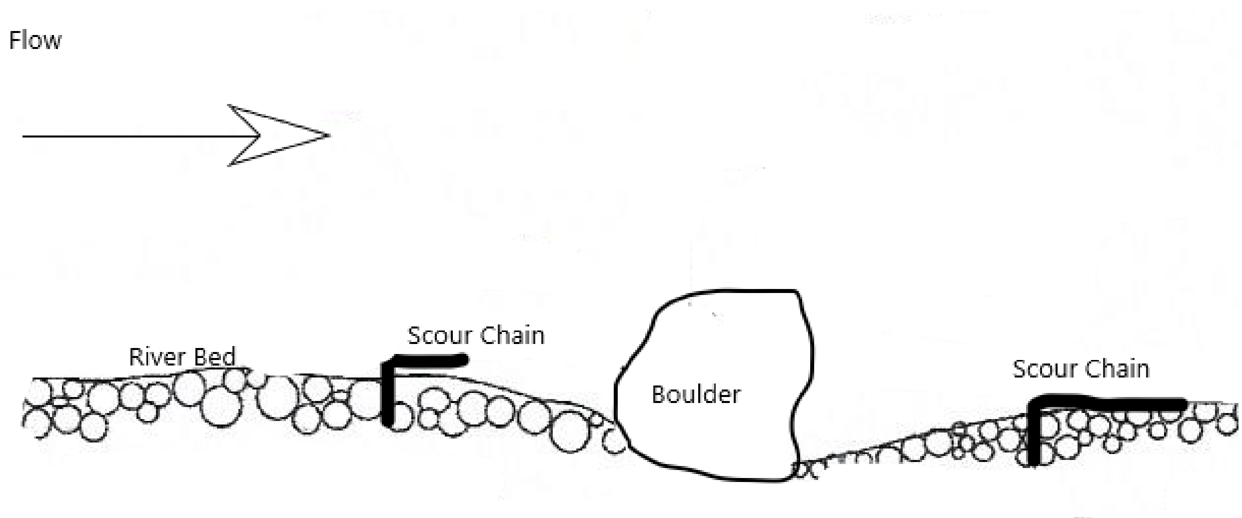


Figure 27. Scour chain placement

A substrate sample was collected at each site to evaluate sediment levels in the depositional area on the downstream side of boulders. Samples were collected with a shovel using methodology described by Grost and Hubert (1991). The shovel blade was oriented downstream and inserted vertically into the stream bed to a target depth of 20 cm, lifted until parallel with the stream bed, and allowed to drain for 2-3 seconds before being placed in a five-gallon bucket (Figure 28).

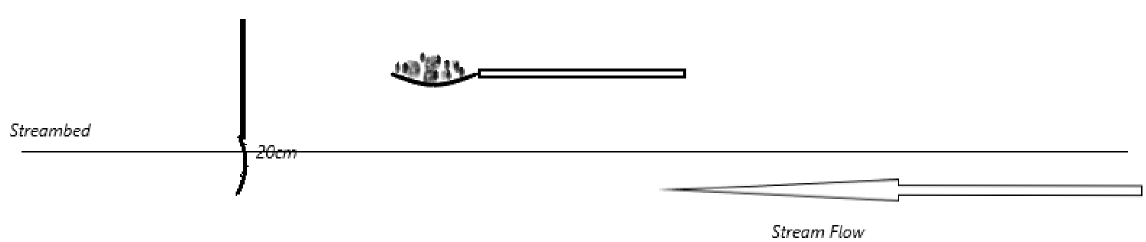


Figure 28. Substrate sampling method adopted from Grost and Hubert 1991.

Side Channels

To evaluate the effects of flushing flow on sediment transport in side channels, scour chains were installed at five locations in the Varney-Ennis section and two in the Norris section. Chains were deployed at the downstream crest of pools and elevations recorded as described above.

Additionally, a measurement of total channel width was recorded at the time of installation. Substrate samples were collected using the shovel method at each site to evaluate sediment levels in the depositional area downstream of pools. Additional samples were collected throughout the Varney-Ennis sections at sites visually estimated to have sediment levels of ≤10% and ≥15% to evaluate sediment transport.

Mainstem

To assess the extent of scour on and potential gravel recruitment from stream banks resulting from flushing flows, bank pins were installed in three randomly selected sites in the Varney-Ennis section (Figure 1). A 4-foot length of ½" rebar was inserted horizontally into the stream bank, leaving 3-4 inches protruding from the surface (Figure 29). Two pins were inserted at each site to account for the degree of bank scour at different heights from the water surface. The lowest pin was set at the wetted edge of the stream and the upper pin was set 12 inches above the lower pin. Scour was quantified by taking a measurement from the end of the rebar to the vertical surface of the bank before and after the flushing flow (Figure 29; Lawler 1993).

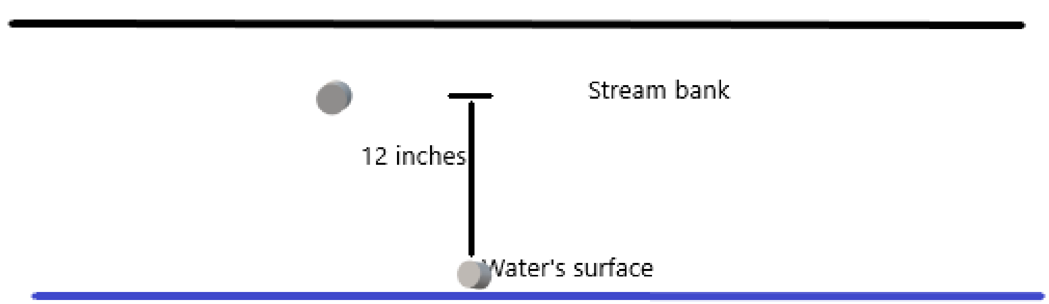


Figure 29. Bank Pin installation

Standard Monitoring

Scour chains were deployed at established NWE monitoring sites in the mainstem Madison at Ennis and Norris (Figure 1). Additionally, three substrate samples were taken at NWE monitoring sites as a control for particle distribution in areas of documented salmonid spawning in both the upper and lower river.

Results

NWE began increasing outflows from Hebgen Dam by 10% per day from May 27 to June 5. Discharges increased from May 27-29 as follows: Kirby gage (USGS 06038800) 1,380 cfs-2,180 cfs, Varney gage (USGS 0604000) 2,000-3,400 cfs, and McAllister gage (USGS 0604100) 2,300 cfs-3,780 cfs. Flows at Kirby peaked June 7 at 3,640 cfs and at Varney and McAllister on June 1 at 5,920 cfs and 6,110 cfs, respectively. On June 8 NWE began reducing flows out of Hebgen

Dam (Figure 30). The magnitude and duration of the 2020 flushing flow similar to those conducted in previous years (Table 8).

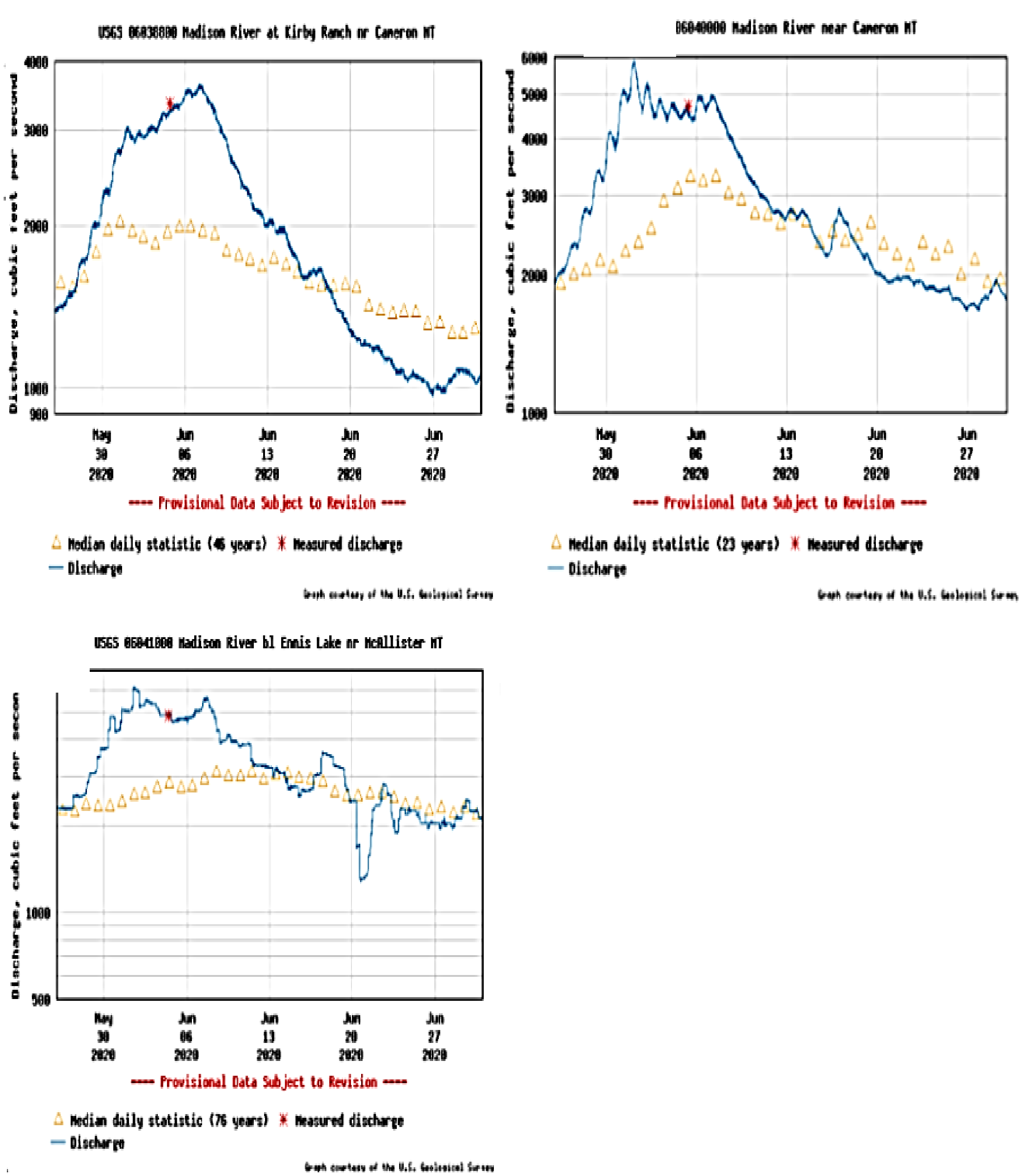


Figure 30. Discharge in cfs at the Kirby gage (USGS 06038800) gage May 26-June 29, the Varney gage (USGS 06040000) May 26-June 29 and, the McAllister gage (USGS 0604100) May 26-June 29.

Table 8. Peak discharge in cubic feet per second (cfs) measured at the McAllister gage (USGS 0604100) in years when a flushing flow was implemented on the Madison River.

Year	Discharge in cfs
2006	5,390
2008	5,390
2011	7,100
2018	6,510
2020	6,110

Substrate monitoring was hindered by developing and implementing the additional monitoring too close to the actual flushing flow when flows were already relatively high and turbid. At the time of deployment, spring runoff in Madison River tributaries was underway, which affected water clarity, river stage, and discharge (Figure 31). Substrate samples were going to be collected with a McNeal substrate sampler; however, depth and turbidity made site selection difficult and reduced the effectiveness of the McNeal sampler. Consequently, the potentially coarser shovel method was alternatively used to collect substrate samples. The shovel could be used as a probe to identify substrate type, was easy for one person to operate, and the approach lent itself to deeper water conditions (Pritchett and Pyron 2011).

Figure 31**.** Water conditions at Varney June 1, 2020.

Boulders

Localized scour and deposition occurred at all boulder sites and associated pools. All downstream crest locations showed a gain in elevation indicating deposition occurred during the flushing flow. The number of scour chain links exposed generally coincided with observed elevation changes; if scour occurred more links were exposed and if deposition occurred less links were exposed (Table 9). Analysis of substrate samples collected from depositional areas on the downstream side of boulders before and after the flushing flow has not been completed.

Table 9. Change in feet for chain/crest elevation and mid pool elevations adjusted for measurement error and scour chain links exposed pre and post flushing flow at boulder monitoring sites in Pine Butte-Kirby (PB) and Norris. NA is chain not recovered or unable to determine amount of deposition or scour.

	Chain/crest change in elevation		**Mid pool changes in stream bed elevation**		**Scour chain links exposed**			
Location	**Upstream**	**Downstream**	**Upstream**	**Downstream**	**Pre-Upstream**	**Pre-Downstream**	**Post Upstream**	**Post Downstream**
PB rock 8-1	-0.9	+0.23	-0.73	-0.21	25	23.5	NA	0
PB rock 13-2	-0.43	+0.51	+0.09	-0.31	19	22	27	0
PB rock 62-3	NA	+0.93	NA	+1.24	NA	22.5	NA	8
PB rock 72-4	+0.22	+0.31	+0.09	+0.21	20	NA	0	NA
Norris rock1	+0.52	+1.73	-0.07	+0.28	21	13	4	NA

Side Channels

The greatest scour and deposition in side channels occurred in the Varney-Ennis section at locations with a channel width of approximately 50 feet or less (Table 10). The number of scour chain links exposed generally coincided with observed elevation changes, except for the Norris 1 site. Measurements indicated a decrease in both pool depth and crest elevation, but the number of chain links exposed at recovery suggested pool crest deposition (Table 10). Evaluation of particle distribution in substrate samples has not been completed.

Table 10**.** Change in elevation (ft) at side channel and main channel for chain/crest and mid pool elevations adjusted for measurement error at Varney-Ennis and Norris monitoring sites. NA is chain not recovered or measurement not taken. MC is main channel where no channel width measurement was taken.

Location	**Channel width**	**Chain/crest change in elevation**	**Mid Pool changes in stream bed elevation**	**Scour chain length exposed**	
				Pre	**Post**
Varney-Ennis 29-1	87.3	NA	NA	NA	NA
Varney-Ennis 25-2	59.6	+0.08	+0.06	22.5	13
Varney-Ennis 21-3	22.2	+0.11	+0.24	22.5	6
Varney Ennis 23-4	31.7	-0.17	-0.24	18	NA
Varney -Ennis 6-5	50.9	+0.99	+1.59	22	0
Varney-Ennis NWE 1	MC	+0.02	+0.37	20	20
Norris 1	19.3	-0.12	-0.04	17	0
Norris 2	MC	+0.08	NA	15	15
Norris 4	MC	-0.05	NA	NA	NA

Mainstem

Scour chain sites at Varney-Ennis NWE 1 and Norris 2 showed little elevation change, which was corroborated by the scour chains. Norris 4 was not recovered but the elevation measurement suggests that minimal scour occurred here too. Bank pins indicated scour was induced during the 2020 flushing flow (Table 10). Though little scour was observed at the Varney-Ennis banks 1 and 2, 10 inches of bank scour occurred at Varney-Ennis 3 (Table 11).

Table 11. Bank pin change in inches pre and post flushing flow Varney-Ennis section.

	Pin change inches	
Location	**Water's surface**	**12 inches above**
Varney-Ennis Bank 1	+1.0	-0.1
Varney-Ennis Bank 2	-1.1	0.0
Varney-Ennis Bank 3	-10.0	-5.4

Standard Monitoring

No scour or elevation change at the mainstem NWE sites was observed.

Conclusions

Flushing flows may have benefits to mainstem and side channel habitats that are not captured by the historic monitoring program. Monitoring of stream bed mobilization with scour chains in the mainstem at NWE monitoring sites in the Ennis and Norris sections were consistent with NWE findings since 2014 that have shown no substantial scour or fill occurring at these sites during flushing flows. Results of the 2020 monitoring suggests that flushing flows may beneficially maintain and enhance habitats associated with geomorphic features such as boulders or those found in side channels where increased flows in conjunction with smaller channel dimensions can more efficiently mobilize stream bed materials. It is uncertain whether substrate samples collected pre and post flushing flow will show an increase or decrease in the percent fines ≤0.84mm. Analysis of these samples may be helpful to further characterize the effect of flushing flows. A broader more comprehensive assessment of flushing flow magnitude, substrate content and availability, and reach-specific geomorphic process is needed to understand the potential for flushing flows to improve fish habitats and the degree to which they can be used as a management tool.

High flows hampered the amount and scope of monitoring originally planned. Five sections on the Madison were originally selected for monitoring; however, efforts were limited to three because of changing stream conditions and water clarity. Monitoring efforts should continue; however, a more concise protocol and well-developed schedule for pre flushing flow measurements and installation of monitoring devices needs to be developed. Moreover, monitoring in more diverse habitats may better clarify the full benefit of flushing flows. At the very least, the monitoring conducted in 2020 should result in discussion and further investigation of how flushing flows may be used to enhance or maintain fish habitat features other than spawning gravels.

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Appendix A

8 December 2020

O'Dell Creek Report 2005-2012

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Introduction

The purpose of this report is to describe fish populations using O'Dell Creek before and after channel restoration and flow improvement in the headwaters of O'Dell Creek. From 2005 to 2009 stream restoration activities on O'Dell Creek resulted in channel narrowing, increased stream sinuosity, lowering of streambank elevation, and an increase in water surface elevations. Montana Fish, Wildlife & Parks (FWP) monitored responses in Brown Trout abundance and size structure, as Brown Trout are the predominant gamefish species inhabiting O'Dell Creek in the restoration area. Additional restoration work has occurred downstream of the monitoring area annually.

Study Area

O'Dell Creek is a spring fed tributary of the Madison River. It originates from its headwaters 13 miles Southeast of Ennis Montana and flows North for approximately 13 miles to its confluence with the mainstem Madison 1.5 miles below the town of Ennis and roughly 5 miles above Ennis Reservoir (Figure 1). Monitoring occurred in the headwater reaches of O'Dell Creek (Figure 2).

Figure 1. Study area in the headwaters of O'Dell Creek.

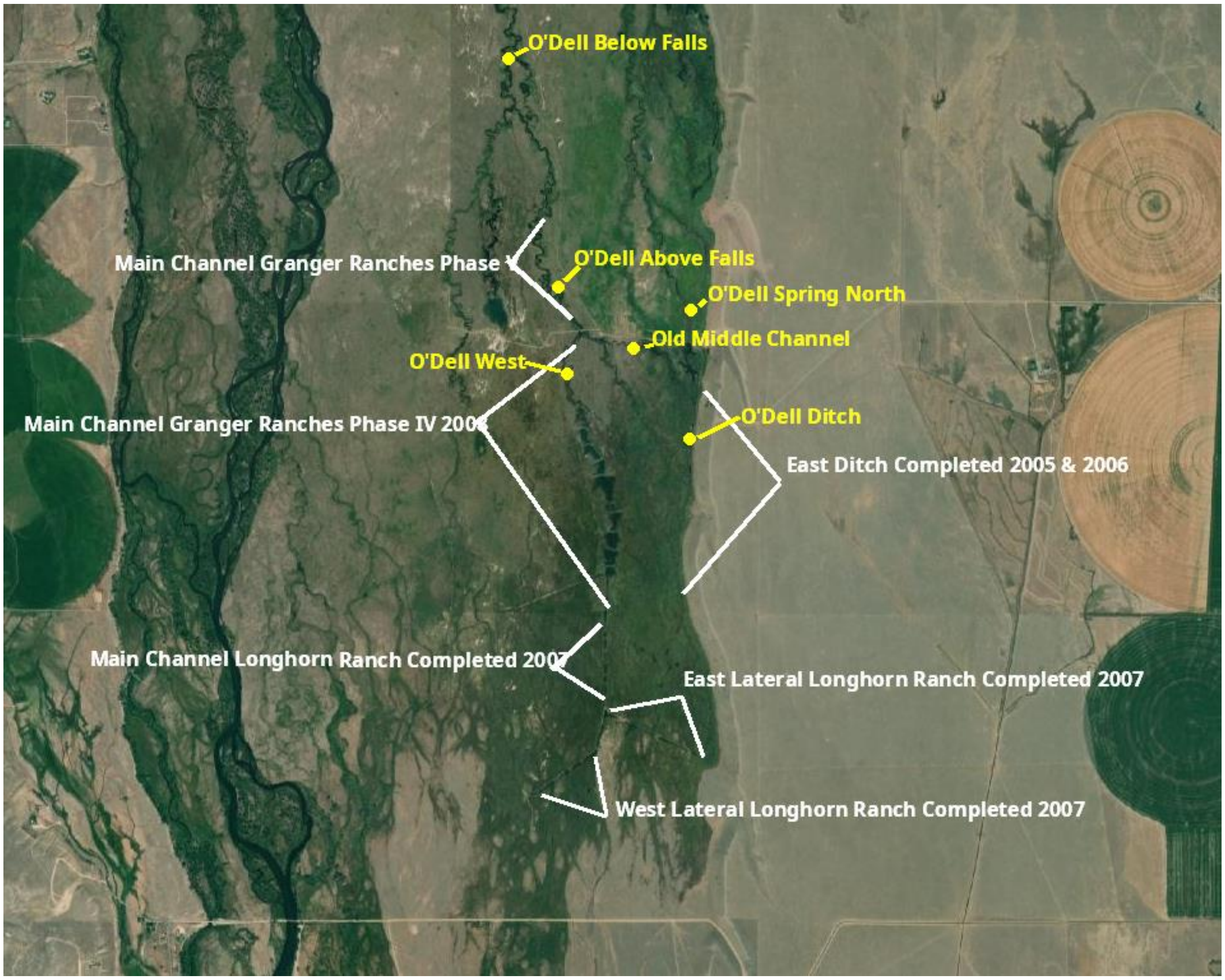


Figure 2. Restoration activities denoted in white and O'Dell Creek monitoring sections in yellow.

Methods

Six monitoring sections were established throughout the restoration area. The restoration schedule and actions in O'Dell monitoring sections are summarized in Figure 2 and Table 1. Fish were collected by a crew of three to four individuals using a mobile anode crawdad electro-fisher in all sections except the O'Dell Spring North section where a backpack electrofisher was used. Catch-per-unit-effort (C/f; number of fish sampled per section length) was used in all sampling sections to determine relative abundance and was calculated as the number of fish per mile by dividing the number of fish captured during a sampling event by the section length converted to miles. Sampling efficiency was assessed by completing three mark-recapture abundance estimates between sections and years and ranged from 47%-98%. Accordingly, comparisons of relative abundance among sections and years should be made cautiously. All captured Brown Trout were measured to the nearest tenth of an inch and weighed to the nearest hundredth of a pound, which were converted to millimeters and grams. Not all fish handled were weighed during every sampling event or in every section, specifically in the Old

Middle Channel prior to restoration and the O'Dell Spring North sampling sections. Biomass per mile was calculated by multiplying the mean weight observed by the calculated C/f for each individual section where weights were taken. Age was assigned as 0: 0-150 mm, 1: 151-277 mm, 2: 278-404 mm, >2: >404 mm in total length as was done in previous monitoring (Inter-Fluve, Inc. 1989).

Table 1. Summary of stream restoration actions and fish monitoring sections at O'Dell Creek, 2005 - 2012.

Monitoring site	Result of stream channel modification	Monitoring section length (ft)	Years sampling occurred
O'Dell Ditch	Backfilled	500	2005
O'Dell Spring North	Increase in stream discharge, no physical modifications	500	2005-2010
Old Middle	Historic channel reconnected and reconstructed	500	2005-2012
O'Dell West	Channel narrowed & deepened, increase in stream discharge	500	2005
Above Falls	Increase in stream discharge, stream channel restoration	1000	2005-2010
Below Falls	Increase in stream discharge, no physical modifications	1000	2005-2008

Results

Median lengths and weights were significantly different among years in all sections, although some differences may not be biologically significant. In general, the Above (Table 2) and Below Falls (Table 3) sections had larger fish in 2008 and fish size in the Old Middle (Table 4) and North Spring (Table 5) sections increased through time. Variation in capture efficiency (47%-98%) precluded assessment of differences in abundance among years and sections. For example, a C/f of 1000 fish per mile could describe a point estimate of abundance between 1020 and 2127 fish per mile. Unless there was an at least two-fold difference in C/f among years inference is somewhat speculative. In the Above Falls section, fish abundance decreased immediately following restoration then returned to pre-restoration levels within 5 years. In the Below Falls section, fish abundance did not change following increased flows and was lower in 2008 than other years. It is unclear whether abundance changed following restoration in the Old Middle and North Spring sections; similar relative abundances were observed before and after restoration. The population was comprised of primarily juvenile fish in all sections and years; however, North Spring was skewed towards younger ages than in other sections.

Sampling of the O'Dell Ditch has not occurred since the completion of phase one of the project in the summer of 2005 when the ditch was backfilled. In 2005 sampling yielded and 137 Brown Trout in 500 ft (C/*f* = 1,522 trout/mile). Brown Trout ranged in TL from 51 to 254 millimeters, mean total length of 157mm±0.8 SE.

Table 2**.** Median length and weight (interquartile range), biomass, and overall and by age group relative abundance for Above Falls section 2005, 2006, 2007, 2008, 2010. Asterisks denote pre-restoration monitoring. Median lengths and weights with different superscripts are significantly different among years (α = 0.05).

				C/*f* (fish/mile) by age group				
Year	Median length (mm)	Median weight (grams)	C/f (fish/mile)	0+	1+	2+	>2+	Biomass (kilograms/mile)
2005*	180^{a} (109)	73^{a} (170)	1063	374	389	274	26	180.71
2006*	174^{a} (71)	77^{a} (130)	1916	316	1258	300	42	291.23
2007	178^{a} (79)	54^{a} (100)	543	137	374	32	0	54.30
2008	264^{b} (157)	213^{b} (290)	837	174	316	321	26	201.72
2010	173^{a} (110)	59^{a} (33)	1137	268	658	200	11	133.03
	178 (99)	68 (168)	1099 ±229	253 ±44	599 ±175	225 ±53	21 ±7	172.20 ±34.96

Table 3. Median length and weight (interquartile range), biomass, and overall and by age group relative abundance for Below Falls section 1989, 2005, 2006, 2007, 2008. Asterisks denote pre-restoration monitoring. Median lengths and weights with different superscripts are significantly different among years (α = 0.05).

Year	Median length (mm)	Median weight (grams)	C/f (fish/mile)	C/*f* (fish/mile) by age group				Biomass (kilograms/mile)
				0+	1+	2+	>2+	
1989*	161	145	1121	705	195	121	100	162.55
2005*	206[a] (145)	91[a] (227)	721	90	389	168	74	167.42
2006*	221[a] (150)	127[a] (254)	763	121	411	163	68	183.12
2007	188[a] (121)	82a (204)	537	53	358	105	21	99.35
2008	319[b] (97)	358[b] (324)	221	21	32	142	26	89.28
	221 (142)	118 (272)	672 ±132	198 ±114	277 ±64	140 ±11	57.8 ±13	139.94 ±16.94

Table 4. Median length and weight (interquartile range), biomass, and overall and by age group relative abundance for Old Middle Channel section 2007, 2008, 2009, 2010, 2012. Asterisks denote pre-restoration monitoring. Median lengths and weights with different superscripts are significantly different among years (α = 0.05).

				C/f (fish/mile) by age group				
Year	Median length (mm)	Median weight (grams)	C/*f* mile (fish/mile)	0+	1+	2+	>2+	Biomass (kilograms/mile)
2005*	123^{a} (25)	-	2211	1989	222	0	0	-
2006*	147^{b} (62)	-	1289	712	522	33	22	-
2007	163^{bc} (53)	54^{a} (64)	1056	279	733	44	0.0	81.31
2008	168^{c} (102)	41^{a} (109)	2422	900	1366	156	0.0	203.45
2010	221^{d} (138)	154^{b} (218)	1922	511	878	522	11	332.51
2012	216^{d} (127)	127^{b} (213)	1367	289	700	367	11	233.76
	154 (97)	73 (150)	1711 ±206	780±238	737 ±142	224 ±86	7 ±3	212.76 ±44..80

Table 5. Median length (interquartile range), and overall and by age group relative abundance for O'Dell Spring North section 2005, 2006, 2007, 2008, 2009, 2010, 2012. Asterisks denote pre-restoration monitoring. Median lengths and weights with different superscripts are significantly different among years (α = 0.05).

			C/*f* (fish/mile) by age group			
Year	Median length (mm)	C/*f* (fish/mile)	0+	1+	2+	>2+
2005*	156^{a} (81)	1367	289	700	0	0
2006	117^{ab} (25)	2044	1789	256	0	0
2007	114^{abc} (25)	1033	956	78	0	0
2008	124^{abcd} (28)	1144	1011	133	0	0
2010	132^{ad} (33)	811	622	189	0	0
2012	144^{a} (26)	867	500	356	11	0
	127 (41)	861 ±197	867 ±197	285 ±84	11 ±0	0

O'Dell Brown Trout Trapping

A rigid style weir was installed 23 September 2010 and operated until 5 November 2010 on O'Dell Creek above the Highway 287 bridge outside of the town of Ennis to evaluate use by Madison River Brown Trout during the fall spawning period. The weir was installed in a shallow glide approximately 1.5-2.0 ft in depth with two trap boxes positioned at the right and left bank. The right bank trap box was oriented downstream to capture fish ascending O'Dell Creek and the left bank trap box oriented upstream to capture downstream migrants. Fish captured were identified to species, measured, weighed, tagged with a uniquely numbered floy-tag and given a fin clip as a secondary mark for identification in the event the tag was not retained. Additionally, water temperature, staff gauge height, and weather conditions were recorded daily during trap operation.

Little use of O'Dell Creek by spawning Madison River Brown Trout was observed. Trapping yielded one adult male Brown Trout (444.5 mm in TL) in the upstream trap and 11 juvenile fish (6 Brown Trout, 2 Rainbow Trout, and 3 Mountain whitefish) from 76-101.6 mm TL in the downstream trap. The adult Brown Trout was tagged, and the adipose fin was removed. No increase in upstream migration was observed on the ascending or descending limbs of the hydrograph during seasonal weather events. Increased movement has been observed during increasing flows on other streams where trapping has occurred. Additionally, fluctuations in water temperature and daily weather conditions appeared to have little to no effect on fish movement. It appeared there was not significant use of O'Dell Creek for spawning by Madison River Brown Trout.

O'Dell Creek Fish Movement

Movements of adult trout in O'Dell Creek were assessed by opportunistically implanting radio transmitters during 2010 fisheries monitoring. Two Brown Trout and three Rainbow Trout were telemetered on 4 May 2010. Radio tags were surgically implanted into the body cavity of fish after they were anesthetized. The incision was closed using stainless steel surgical staples and the fish was held in a live car until the anesthesia wore off and fish demonstrated the ability to stay upright and swim on their own. Fish relocations were conducted on foot on four separate occasions in the restoration area, and once by aerial survey of the Madison River and O'Dell Creek. Transmitter batteries expired around the end of August 2010.

Brown Trout exhibited only localized movements; fish remained in the reach they were initially captured in throughout the summer. Rainbow Trout movements are ambiguous; two fish were never relocated, and one shed its transmitter or died downstream of where it was captured (Table 6). Failure to relocate fish may be attributed to their predation and removal from the study area, movement out of the study area, or tag failure. Migration into the Madison River was not observed, although inference is severely limited by small sample size and infrequent detections.

Table 6. Species Rainbow Trout (RB) and Brown Trout (LL), length in inches and relocation and date of radio transmitter fish in O'Dell Creek 2010.

Species	Length (mm)	Date, survey type and area relocated				
		14-May Foot	17-May Foot	26-May Foot	15-Jul Aerial	23-Aug Foot
RB	419	X	X	X	X	X
RB	445	X	X	X	X	X
RB	422	O'Dell Middle	O'Dell Middle	X	Longhorn Granger Boundary	Tag Recovered @ Longhorn Granger Boundary
LL	356	O'Dell Middle	O'Dell Middle	O'Dell Middle	X	O'Dell Middle
LL	424	O'Dell Middle	O'Dell Middle	O'Dell Middle	O'Dell Middle	O'Dell Middle

O'Dell Creek Temperature

One of the objectives of the restoration on O'Dell Creek was to reduce water temperatures. Temperature monitoring at the Below Falls site was conducted by DJP Consulting from 2006-2009. Restoration activities above this site appeared to have minimal if any effect on stream temperature at the Below Falls site during this time (Figure 3a, 3b, 3c, 3d; Peters 2010); however, temperatures in upper (mile 0.9) and lower (mile 5.0) were similar, indicating minimal gain in temperature through the system (Figure 4).

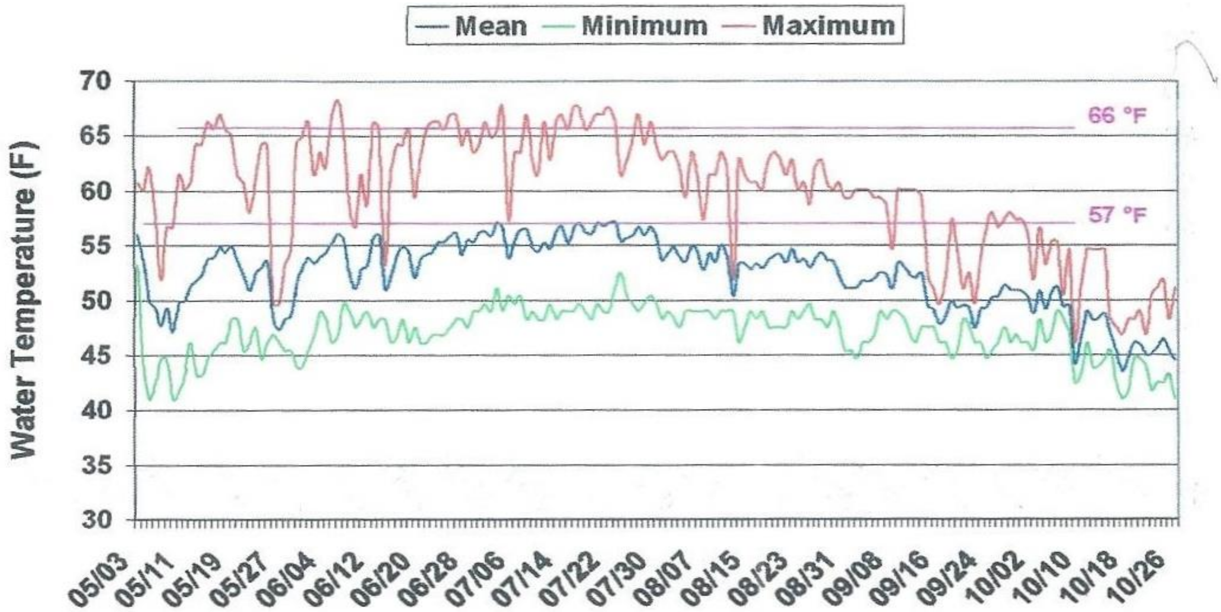


Figure 3a. Mean, minimum, and maximum daily temperatures for the Below Falls monitoring site 2006 (Peters 2010).

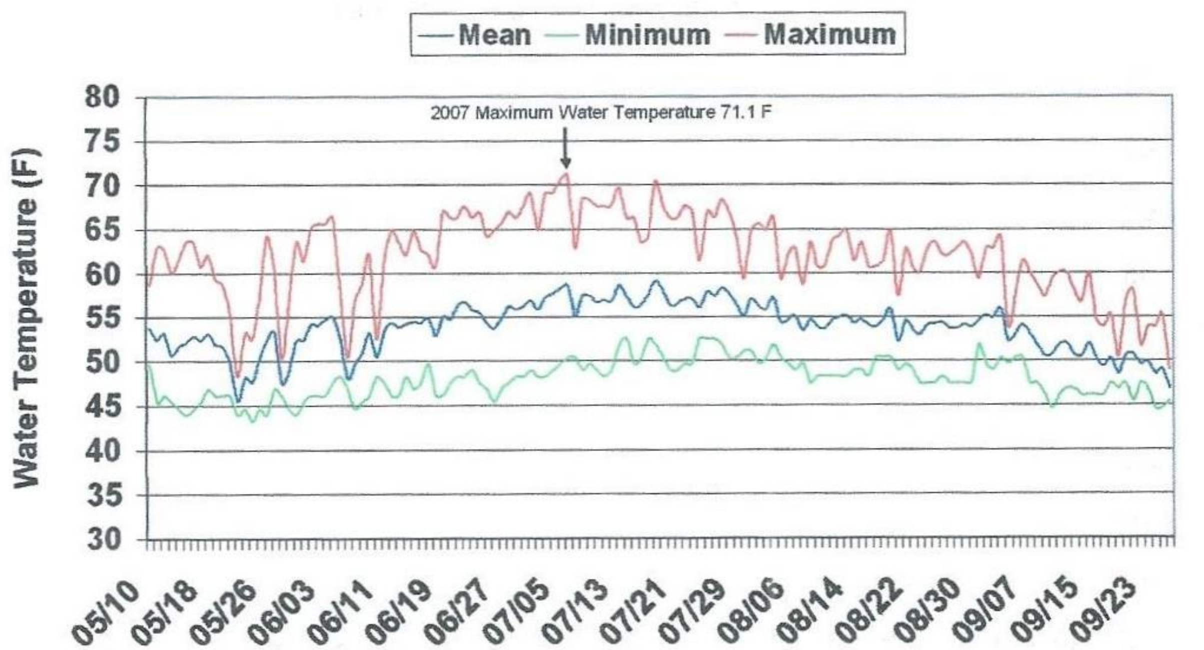
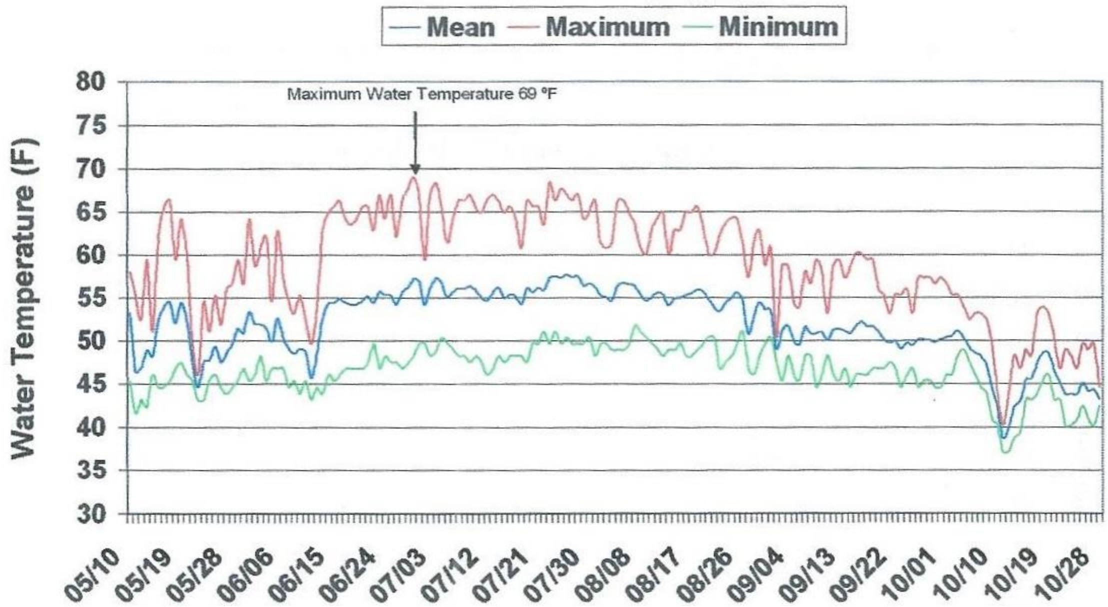


Figure 3b. Mean, minimum, and maximum daily temperatures for the Below Falls monitoring site 2007 (Peters 2010).



Figue 3c**.** Mean, minimum, and maximum daily temperatures for the Below Falls monitoring site 2008 (Peters 2010).

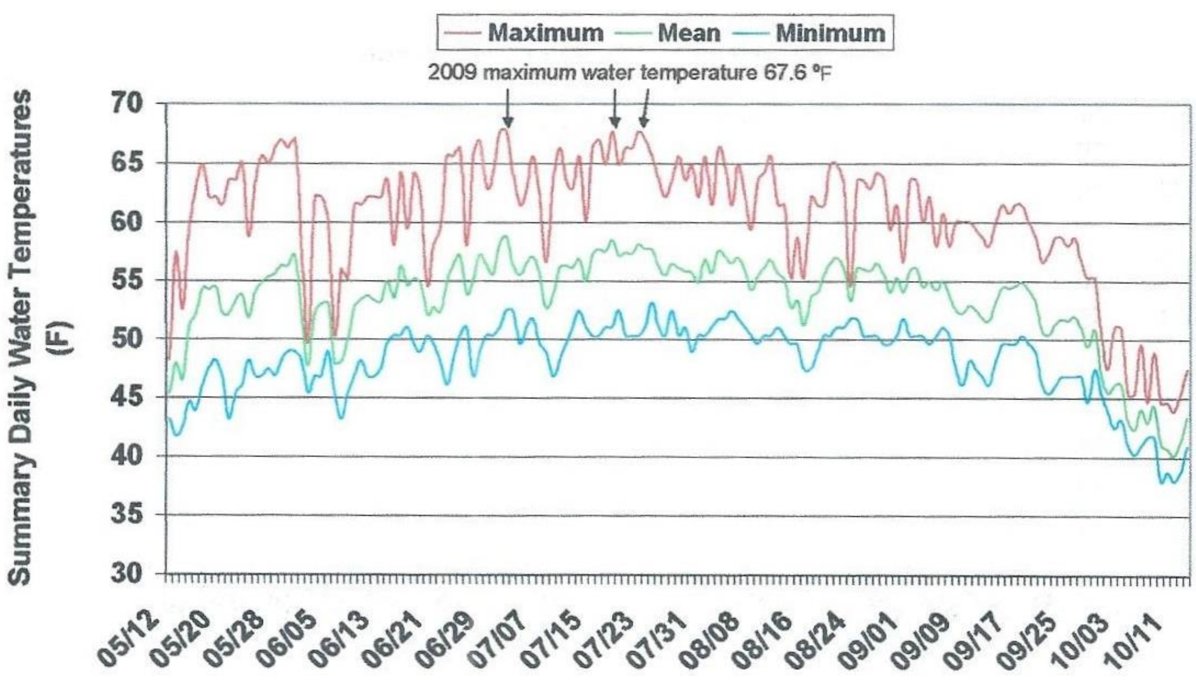


Figure 3d. Mean, minimum, and maximum daily temperatures for the Below Falls monitoring site 2009 (Peters 2010).

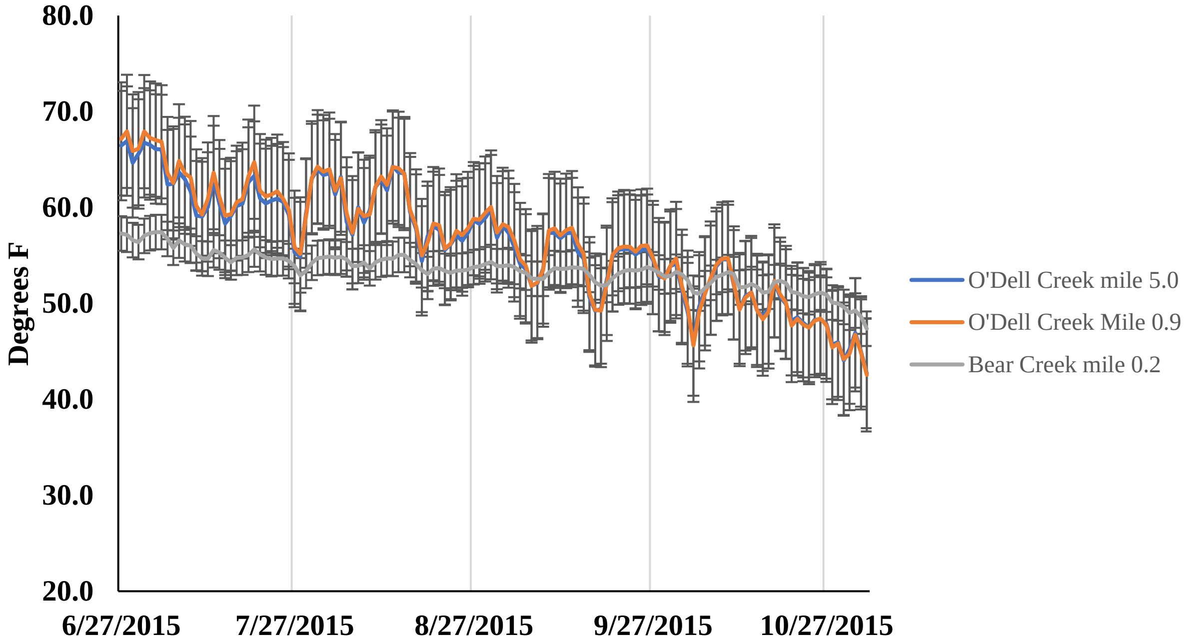


Figure 4. Daily mean water temperatures for O'Dell Creek stream mile 5, 0.9 and 0.2. Error bars are standard deviations.

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