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Muddy Creek Master Plan

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SUN RIVER WATERSHED GROUP

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Executive Summary

Muddy Creek is a 44-mile-long tributary to the Sun River west of Great Falls, Montana. Along much of its path, the stream flows along the northern and eastern margin of a broad alluvial terrace that is capped by ancestral Sun River gravels, called the Greenfields (or Fairfield) Bench. The Greenfields Bench lies within the boundaries of the Sun River Project, a large irrigation project originally envisioned and surveyed by the US Government in the late 1800s. Key components of the Sun River Project include the Sun River Diversion Dam and Pishkun Canal, built in the early 1900s to divert/convey water to irrigate the bench in the Muddy Creek Watershed. The distribution system built out over the following decades, replacing dryland farming on the bench with an extensive irrigation water delivery system. The shift to a trans-basin irrigation system drove massive changes in the hydrology of Muddy Creek, as return flows from the bench overwhelmed the small stream. The increased magnitude and duration of flows have driven dramatic downcutting of Muddy Creek, with up to 30 feet of incision over about 20 miles of channel. The historic floodplain is now perched as a high terrace well above the creek. Tributaries have responded to both the flow augmentations and drop in base level at their confluences with Muddy Creek.

A tremendous amount of work was performed in the 1990s to stabilize the actively incising stream. Rock grade controls, rock barbs, and revetments were built on the channel to stabilize grade and streambanks. The stabilization work has performed well, although it is beginning to show risk of failure and reintroduction of systemic instability. However, since the stream gradient has been largely stable for approximately 30 years, opportunities now exist to build upon that previous work. These opportunities include optimizing geomorphic resiliency, addressing stressors of flow augmentation, and restoring fisheries and riparian habitats.

During the spring and summer of 2021, a series of stakeholder interactions were held to gather local input regarding project needs and opportunities in the basin. The result of the meetings was a list of potential projects that range from infrastructure improvements to erosion control and habitat enhancements. These potential projects were subsequently ranked based on a series of criteria including anticipated ecological benefit, improvements to water use efficiency, economic impact, and scale.

This plan acknowledges there are a myriad of issues on Muddy Creek, and some of them may not be directly addressed by the work proposed herein; the presumption made here is that reducing the influences causing system destabilization coupled with improving system resiliency is the best approach for creating a stable foundation for long-term management. That said, this plan should be implemented in conjunction with any additional vetted strategies that will directly improve other issues such as adjusting modifying agricultural practices to improve water quality.

1 Introduction

The following report summarizes the results of a planning effort to address physical instability and associated water quality/habitat issues on Muddy Creek through a contract with the Sun River Watershed Group (SRWG). The project was initiated by several local sponsors to develop a long-range basin-wide water management plan that provides a strategy for project identification, prioritization, and implementation.

In February of 2021, Restoration Engineering was contracted to oversee the Muddy Creek Master Plan development, along with subcontractors from Applied Geomorphology, Inc. DTM Consulting, Inc., and Troutwater Restoration, LLC (project team).

1.1 Project Objectives and Tasks

The primary objective of this project is to develop a locally-vetted plan to help SRWG and their project partners move forward towards effectively restoring and managing Muddy Creek and its tributaries. This project focuses on developing strategies to manage/reduce irrigation return flows from the Greenfields Bench, reduce bank erosion and sediment/phosphorous loading, and improve geomorphic resilience and associated habitat functions. The plan leverages previous work, recognizing that some previous efforts have performed well but are reaching the end of their design life and thus need reconsideration. It also leverages new technologies currently being embraced by water managers. It is important to acknowledge that there are additional issues on Muddy Creek that may not be explicitly addressed herein; however, previous work has made it clear that dampening the drivers of destabilization coupled with increasing the inherent ability of the stream channels to withstand those drivers is a fundamental aspect of achieving long-term watershed health. The intent is also to integrate stakeholder input into the planning process, to better understand current issues and identify future project priorities. As such, the primary project tasks include:

1. ***Data Compilation:*** This task includes the compilation of hydrologic data, air photos, LiDAR data, and results from previous studies to provide context for plan development. Core GIS data layers were also compiled such as available imagery, historical mapping, and LiDAR elevation data.
2. ***Remote Watershed Assessment:*** Prior to the field visit and stakeholder meetings, stream channels were evaluated remotely using available data. Previous projects were mapped and reviewed, and clear evidence of ongoing issues were identified.
3. ***Stakeholder Engagement, Field Work, and Restoration Strategy Development:*** A key component of the plan development was gaining local support through stakeholder engagement. To that end, the project included a field review and public meetings to

gather local perspectives and ideas. Submitted project ideas were compiled and ranked by the project team in collaboration with SRWG based on anticipated level of benefit.

4. ***Preliminary Design:*** The planning process includes the conceptual design of one project that packages multiple implementation strategies. The design utilizes a range of restoration techniques on a section of Lower Muddy Creek that could be applied in other areas of stream destabilization.
5. ***Reporting:*** This report summarizes the tasks above. The goal is to summarize the evolution and current condition of Muddy Creek, to track ongoing efforts in the watershed, to describe the project development and ranking process, and to provide an implementation strategy that can be updated as projects are initiated and completed.

1.2 Muddy Creek Resource Organizations

The two lead organizations that have been involved in developing the Muddy Creek Master Plan are the Sun River Watershed Group and Greenfields Irrigation District.

1.2.1 The Sun River Watershed Group (SRWG)

SUN RIVER WATERSHED GROUP
Local solutions for local problems

The Sun River Watershed Group was formed in 1994 by a group of citizens who were primarily concerned with water quality issues on Muddy Creek. Since then, the group has expanded its area of focus, now extending from Gibson Dam in Sun River Canyon to the Missouri River confluence in Great Falls. The group grew out of an older organization known as the Muddy Creek Task Force, which originally formed in the early 1990s. SRWG has nine directors that collectively represent Conservation Districts, Irrigation Districts, local landowners, and the conservation community. Working groups that support the mission of the SRWG include a Water Management Working Group, a Fish Working Group, and a Water Quality Working Group. Tracy Wendt joined SRWG as the watershed coordinator in October 2018.

> "The Sun River Watershed Group works collaboratively to protect and restore the resources of the Sun River watershed and its communities"

1.2.2 Greenfields Irrigation District (GID)

Greenfields
IRRIGATION DISTRICT

A key partner in the development of the Muddy Creek Master Plan is Greenfields Irrigation District (GID). GID was established in 1926 to operate and maintain irrigation canals in the Greenfields division of the Sun River Project. The district delivers water to between 500 and 600 water users annually, many of whom are agricultural producers within the Muddy Creek Watershed.

1.3 Acknowledgements

We would like to extend our sincere appreciation to Tracy Wendt of SRWG for her contributions towards all aspects of the project, including contract management, stakeholder identification, meeting logistics, plan development, and document review. Tenlee Atchinson from Cascade Conservation District helped organize our outreach efforts, which proved to be a critical piece of stakeholder engagement. Erling Juel of Greenfields Irrigation District was very generous with his time in describing GID operations and opportunities in the area. GID provided their irrigation system GIS data files, which were used extensively in this evaluation. Al Rollo provided valuable historic perspectives and we greatly appreciate the day he spent with us on site. Al's retrospective writeup that is included as an Appendix to this report has been an invaluable, concise summary of decades of work on the system. Mark Lee took extra time to show us his project on Spring Coulee, and we are grateful for his generosity and input. And lastly, we would like to acknowledge the landowners and other stakeholders who provided their input regarding challenges and opportunities in the Muddy Creek watershed. Their input was notably thoughtful and creative, and we hope to have effectively captured their input.

2 General Setting, Human Impacts, and System Response

The following section contains a summary of the physiographic setting of the Muddy Creek watershed to provide some context for project needs and prioritizations. Primary land uses are also described with an emphasis on their impacts to stream health.

2.1 The Muddy Creek Watershed

All references to River Mile (RM) reflect the distance upstream from the mouth of Muddy Creek based on a 2019 channel centerline.

The Muddy Creek Watershed is a 256-square-mile drainage located just north of Vaughn, Montana. Muddy Creek is about 44 miles long, flowing southeastward from a small drainage divide near Freezeout Lake to its confluence with the Sun River near Vaughn. The watershed is geologically bisected by the relatively flat alluvial gravel terrace of the Greenfield Bench to the south, and more dissected sedimentary units to the north (Figure 2-1). Much of Muddy Creek and its northern tributaries have downcut into soft glacial silts that were deposited in Glacial Lake Great Falls during the last ice age (Colton, et. al, 1961).

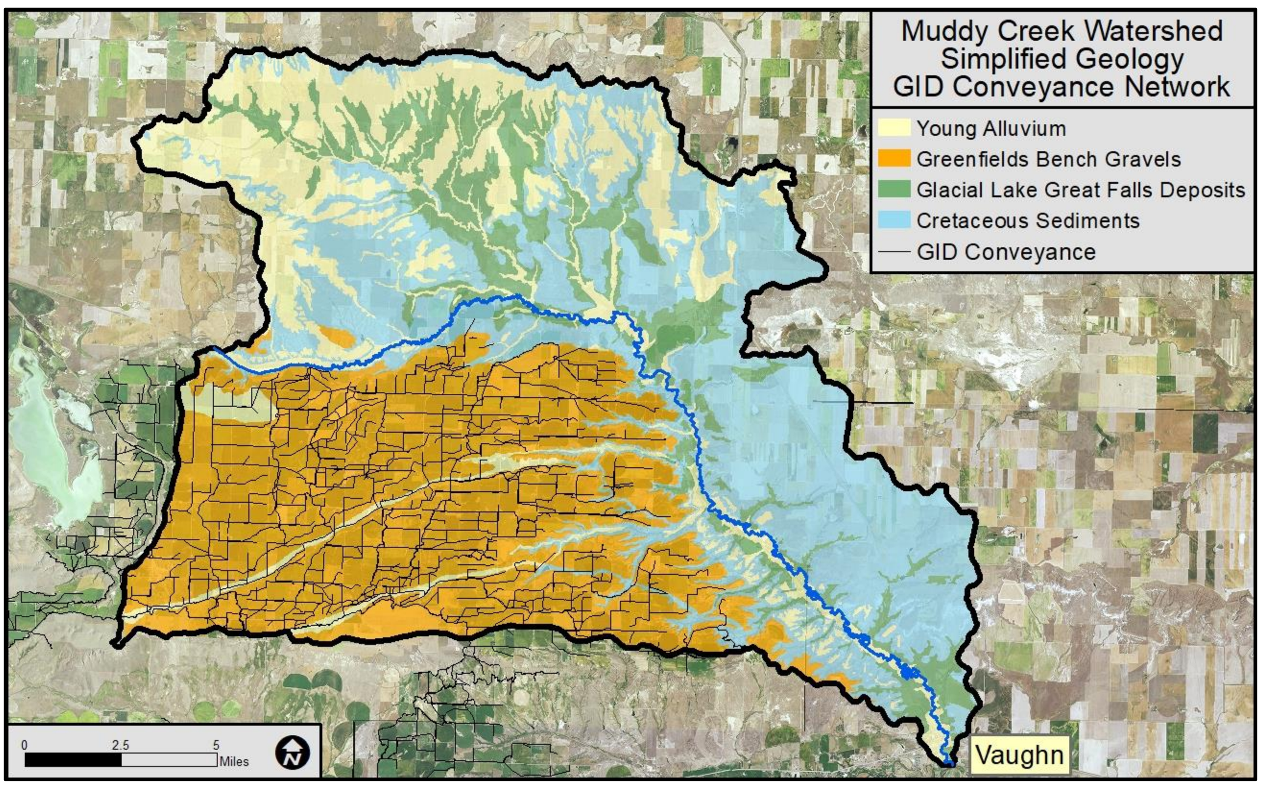


Figure 2-1. Simplified geologic map of Muddy Creek Watershed (modified from Vuke et. al, 2002).

The Greenfields Bench is comprised of sandstones and shales that are capped by 10 to 60 feet of young gravels deposited by the ancestral Sun River. The contact of the gravel and bedrock around the periphery of the bench commonly is marked by springs and seeps, which is likely a natural condition that has been exacerbated by the application of imported irrigation water onto the permeable gravels.

2.2 Major Human Influences Affecting Muddy Creek

Muddy Creek has been long-recognized as a highly unstable channel due to decades of downcutting into the fine sediments of the alluvial valley (Photo 2-1). Understanding the drivers of this instability is an important consideration in developing feasible strategies to help restore an equilibrium condition throughout the drainage network. Whereas the delivery of trans-basin diversion water has driven much of the instability, other land uses such as riparian grazing have contributed to the decline in watershed health.

Photo 2-1. Active bank failure following Muddy Creek incision; the historic floodplain is at top of bank (2021 photo).

2.2.1 Riparian Grazing

The establishment of small communities in the Sun River area during the late 1800s included the arrival of livestock herds, supplied in part by cattle drives from Texas. By 1890, there was evidence of overgrazing by sheep and cattle in the Augusta area (DEQ, 2004). The Muddy Creek corridor was grazed hard as well; the earliest reported land use impact due to development was aggressive grazing in the valley bottoms (Appendix A). Some of the major projects completed on Muddy Creek in the 1990s focused on grazing management, with the construction of 8 miles of riparian fencing, construction of off-stream watering sources for livestock, and overall improved grazing management in riparian areas.

In 2004, the TMDL effort on Muddy Creek estimated that there would need to be a 66% reduction in Total Nitrogen and an 83% reduction in Total Phosphorous to meet TMDL goals on Muddy Creek. This reduction was described as coming from fertilizers, irrigation, riparian grazing, and fallow cropping (DEQ, 2004). The TMDL notes that "intense riparian livestock grazing increases near stream erosion on Muddy Creek and tributaries", and that "the near stream erosion contributes phosphorous loads during high flow". Restoration recommendations included off-stream water, cross fencing, pasture rotation management, and riparian fencing.

2.2.2 Irrigation on the Greenfields Bench

The irrigation potential of the Greenfields Bench (also known as the Fairfield Bench) was recognized by the Federal Bureau of Reclamation in the late 1800s, when early surveys indicated that a dam built on the Sun River could divert irrigation water to the Fairfield area. The US government responded by keeping about 70,000 acres of land in trust that had been previously let out for homesteading, and from 1909-1914 homesteading came to a halt (Choteau Acantha). The Sun River Diversion Dam, located about 35 miles west of Fairfield, was completed in 1916, and irrigation water was first delivered through the canal system in 1918 (Figure 2-2 and Photo 2-2). The diverted flows from the Sun River Diversion Dam are conveyed down the Pishkun Canal, Sun River Slope Canal, and then into a delivery system network in the Muddy Creek drainage. The Greenfields Irrigation District (GID) was established in 1926 to operate and maintain canals in the Greenfields Division of the Sun River Project, which encompasses 83,230 acres of irrigated land on the Greenfields Bench. When Gibson Dam was completed upstream of the Sun River Diversion Dam in 1929 (Photo 2-3), stream flows became much more reliable and settlement on the bench expanded, and by the 1930s irrigated agriculture was extensive (Photo 2-4). The system currently consists of 120 miles of canals and a lateral distribution system that support flood, pivot, and wheel line irrigation. Principal crops on the Greenfields Bench are barley, wheat, oats, alfalfa, silage, and pasture (GID, 2020).

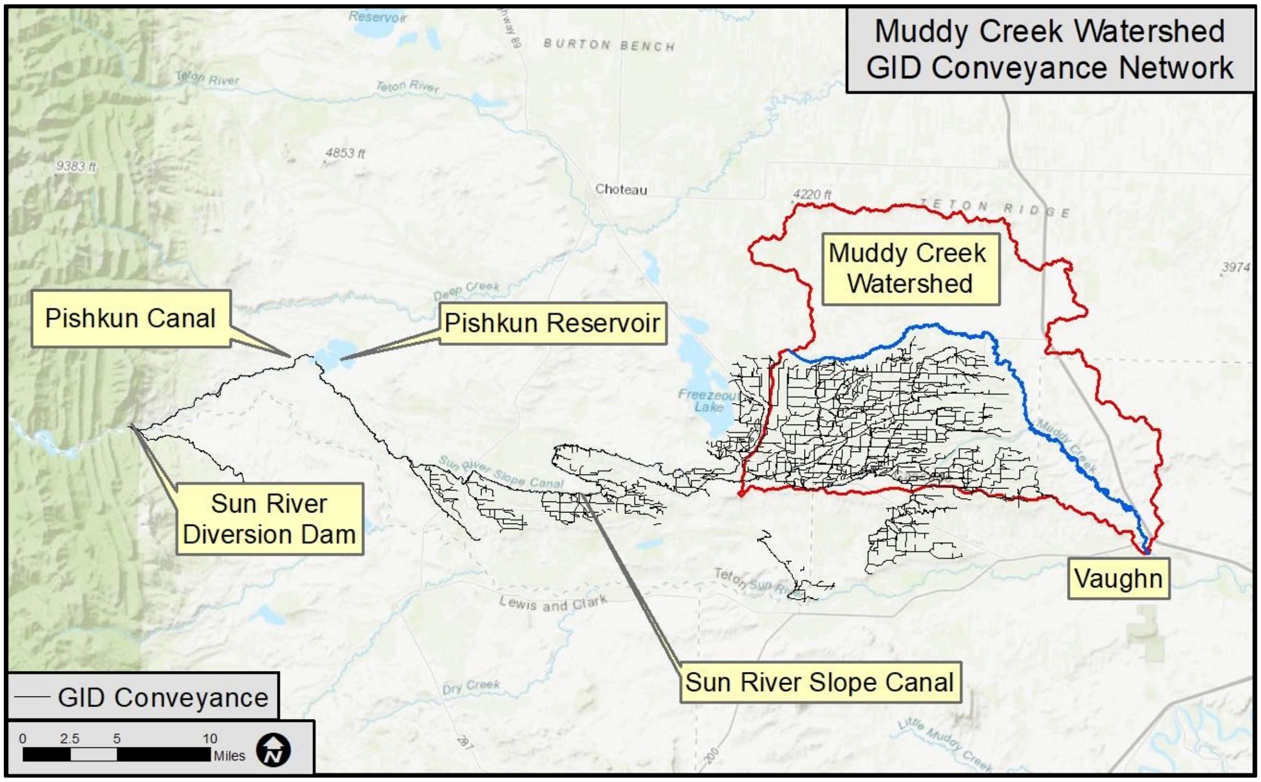


Figure 2-2. General schematic showing Greenfields Irrigation District conveyance system to the Muddy Creek Watershed.

Photo 2-2. Sun River Diversion Dam was constructed in 1916 (USBR).

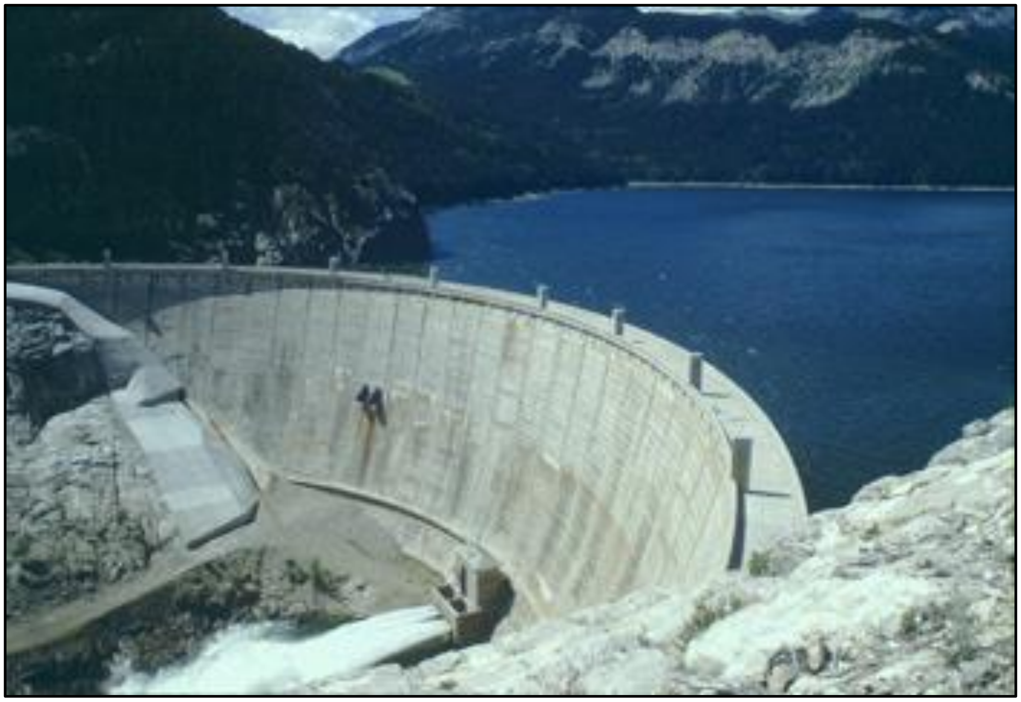


Photo 2-3. Gibson Dam was constructed in 1929 (USBR).

Photo 2-4. "Opening gate in irrigation ditch. Fairfield Bench Farms, Montana, May 1939" (Library of Congress).

The capacity of the outlet works at the Sun River Diversion Dam feeding the Pishkun Supply Canal is 1,400 cfs and as of 2004, the system was delivering an average of about 250,000 acre-feet of irrigation water per year (MTDEQ, 2004). The gravel cap on the bench makes it especially prone to flow infiltration and lateral groundwater flow at the gravel/shale contact. Groundwater in the gravel aquifer generally flows east and north towards Muddy Creek at an estimated rate between 3.7 and 26 feet per day, or from 0.25 to almost 2 miles per year (Nimick and others, 1996). Osborne (1983) estimated that 56,770 acre-feet of water ended up as recharge to the Muddy Creek system which was 39% of the total water delivered that year. Local reports indicate that it would take 10 years of no irrigation for the aquifer to naturally drain and stop contributing diverted flows to Muddy Creek.

Mean monthly flows in Muddy Creek at Vaughn have increased by an order of magnitude in summer months with irrigation development. Figure 2-3 shows estimated natural flows generated by the Bureau of Reclamation (Rollo; Appendix A) compared to current average monthly flows measured since 2020 at the USGS Vaughn gage. Whereas the estimates of natural flows include a peak monthly discharge of 29.3 cfs in March, flows currently peak at about 10 times that amount in July.

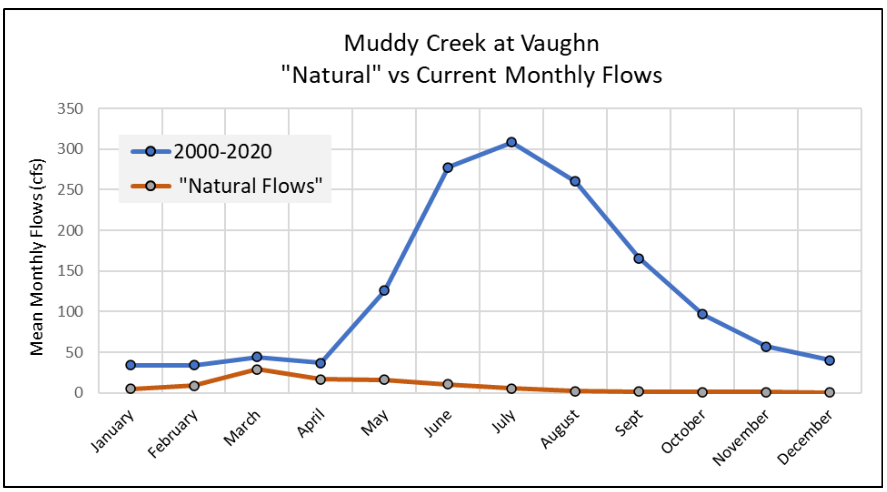


Figure 2-3. Mean monthly flows for Muddy Creek at Vaughn (USGS 0608850) for natural and current conditions (Rollo, Appendix A).

A coarse estimate of the impacts of irrigation return flows on Muddy Creek flood frequency discharges is shown in Table 2-1. This table compares flood frequency values calculated at Vaughn for the following two conditions: 1: a natural (non-irrigated) condition based on basin characteristics above Vaughn; and 2: actual flow measurements collected over 86 years at the USGS Vaughn Gage (USGS 06089000). These estimated "natural flows" as compared to measured flows show that the two-year flow is currently almost triple what would be estimated under pristine conditions (470 cfs higher). More rare flood events show a smaller impact, but the 5-year flood at Vaughn is still about twice what it would be if the hydrology was unaltered (571 cfs unaltered, 1180 cfs currently).

Table 2-1. Estimate flood recurrence discharges based on flow data (USGS Gaging Station at Vaughn) and basin characteristics data above Vaughn (USGS StreamStats).

Flood Frequency	Basin Characteristics above Vaughn (cfs)	Gage Data Muddy Creek at Vaughn USGS 06089000	Difference (cfs)	Difference (%)
2-yr	176	646	470	267%
5-yr	571	1180	609	107%
10-yr	1060	1720	660	62%
25-yr	2150	2700	550	26%
50-yr	3450	3730	280	8%
100-yr	5190	5080	-110	-2%

Table 2-1 shows that one of the impacts of flow returns on Muddy Creek is an increase in peak flow rates during floods. Although this is an important aspect altered hydrology, perhaps more critical with respect to channel stability is the length time that those flows are seen (flow duration). In order to graphically demonstrate the concept of altered flow duration, Figure 2-4 shows median daily flow hydrographs for the Sun River and Muddy Creek, respectively. Whereas the Sun River hydrograph shows a typical snowmelt runoff pattern with an abrupt rise and fall between late May and early June, the Muddy Creek hydrograph shows how high flows are sustained for months. These long duration high flows during the summer months have several impacts on Muddy Creek, including the following:

- Long periods of persistently high summer flows drive bank erosion due to the increased flow energy in the channel, increasing sediment and phosphorous loading
- Long periods of bank saturation can accelerate bank collapse when the flows drop, either at the end of the growing season or during mid-season fluctuations
- High water levels throughout the growing season do not allow vegetation expansion on the banks during those critical months

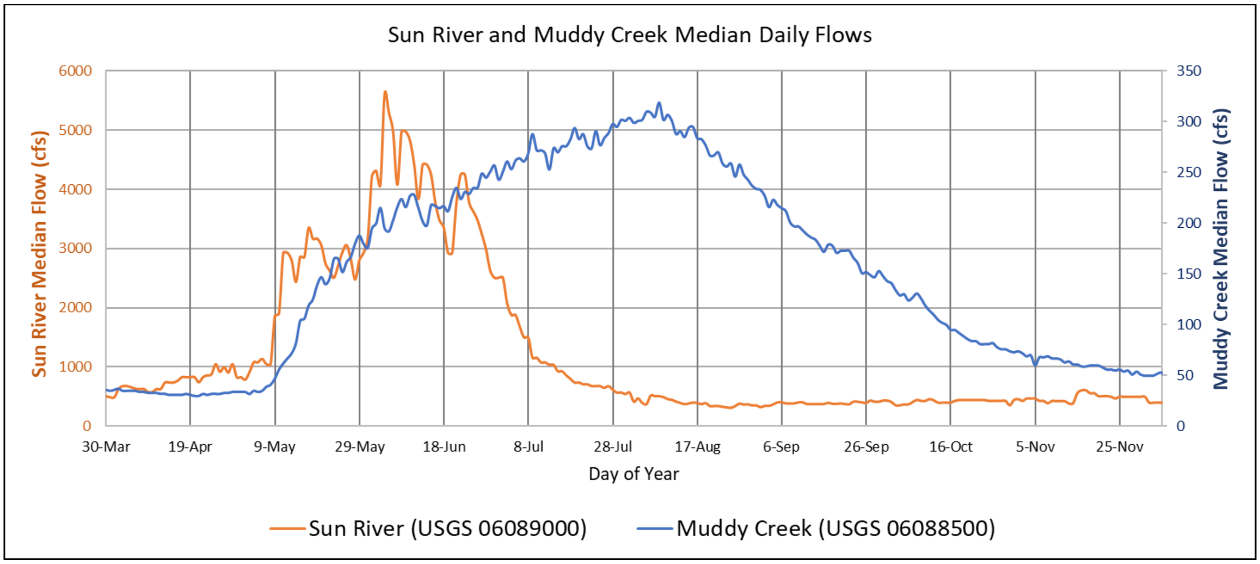


Figure 2-4. Median daily flow hydrographs for Sun River and Muddy Creek.

2.2.2.1 Conversion from Flood to Sprinkler Irrigation

Stakeholders have indicated that the progressive conversion from flood to pivot/wheel line irrigation on the Greenfields bench has resulted in substantially longer durations of flow in the system canals. Figure 2-5 shows GID mapping of irrigated fields as of late 2021. Although the conversion to pivot irrigation has been rapid in the two decades, substantial acreage is still under flood irrigation. In 2022 it was estimated that, within the Muddy Creek Watershed boundaries, a total of 28,186 acres (60%) were under pivot, 3,947 acres (8%) were under wheel line, and the remaining 14,920 acres (32%) were under flood irrigation (Figure 2-6). It is interesting that both pivot and flood irrigated ground is spatially intermixed across the Greenfields Bench, highlighting the complex interplay between water delivery systems and return flow patterns/magnitudes to Muddy Creek and its tributaries.

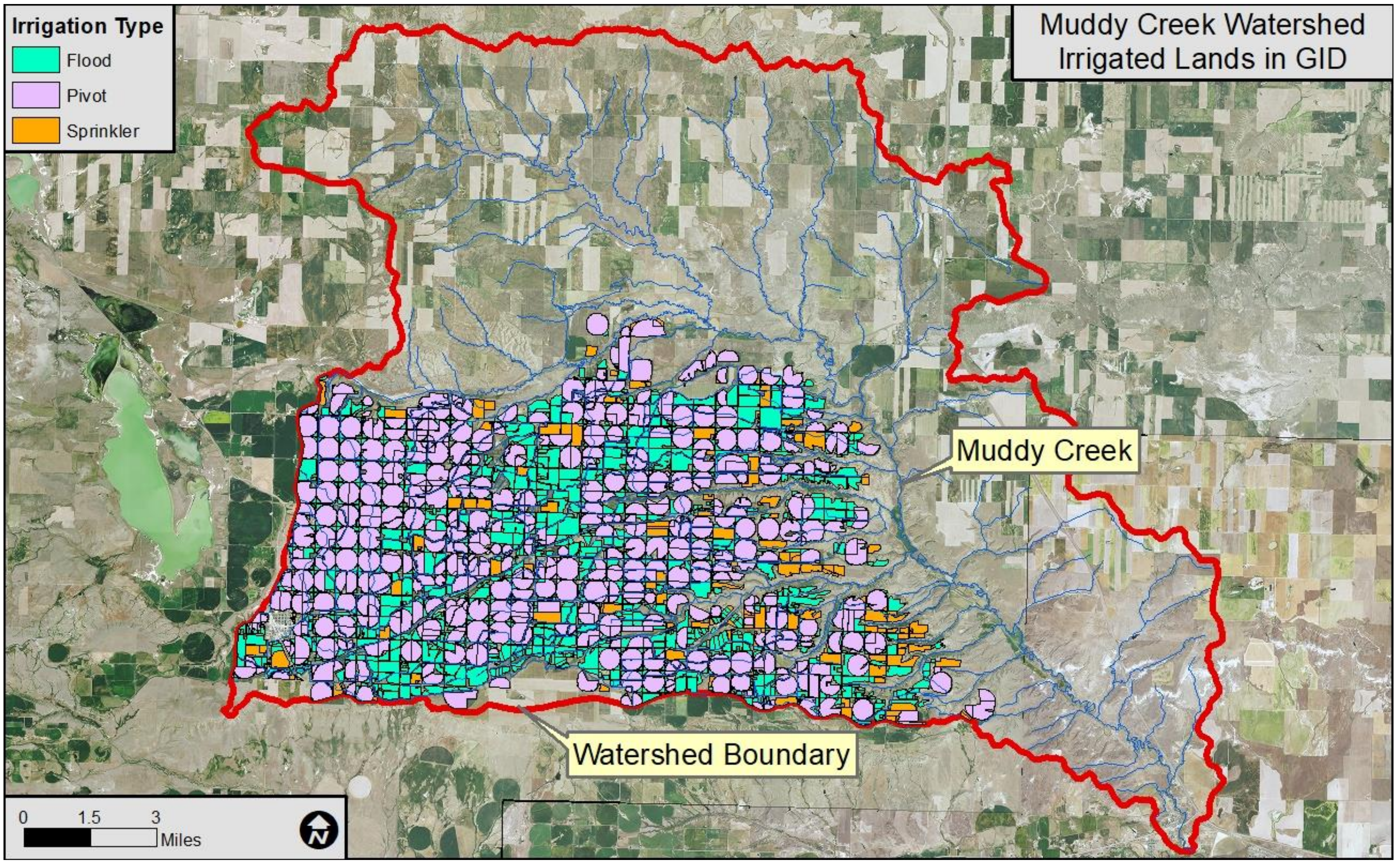


Figure 2-5. GID Irrigation Plan on Greenfields Bench showing irrigated lands polygons; most of the conversion from flood to sprinkler/pivot occurred after 1995.

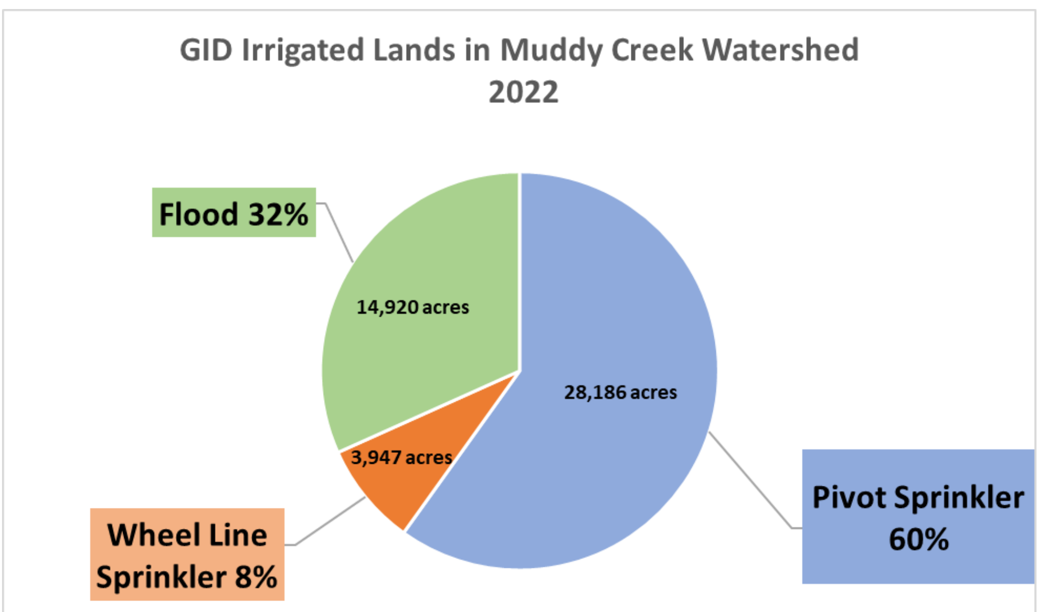


Figure 2-6. Relative extent of sprinkler and flood irrigated lands within the Muddy Creek Watershed/GID boundaries, 2022 (GID).

A review of historic imagery indicates that most of the conversion to sprinkler irrigation within the GID boundary has occurred since 1995. Figure 2-7 shows median daily flow hydrographs for one timeframe dominated by flood irrigation (1940-1995) and another dominated by flood/sprinkler (2005-2021). The earlier timeframe shows an abrupt increase in flows in mid-May from 40 cfs to ~150 cfs, followed by a continual gradual rise to ~350 cfs in early August. During the more recent sprinkler era, the spring rise has been more rapid and more intense, increasing rapidly from 40 cfs to ~250 cfs in late May, then slowly climbing to ~350 cfs through late July. Muddy Creek has typically run about 50 cfs higher during summer months with sprinkler irrigation as compared to when it was largely flood.

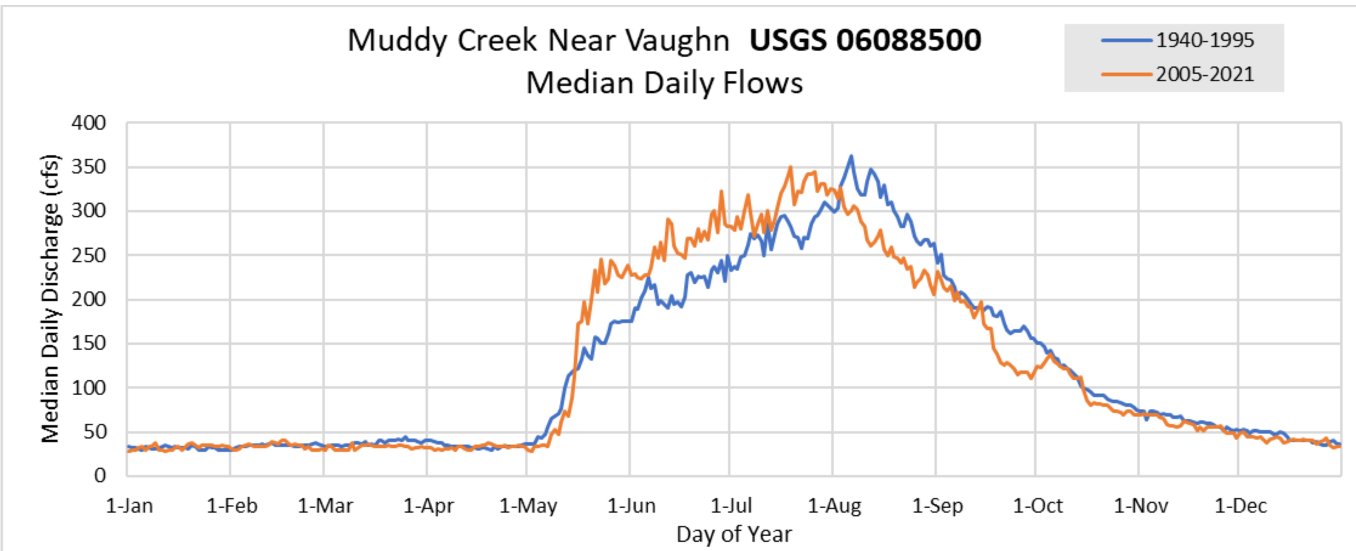


Figure 2-7. Median daily flows for Muddy Creek during flood irrigation (1940-1995) and following major conversion to pivots (2005-2021).

Although the conversion of flood to sprinkler results in potentially increased crop yields (and increased evapotranspiration losses), it also results in a change from periodic water application on fields via flooding to persistent application using sprinklers. As a result, the canals are running more frequently to support the sprinklers. Furthermore, as it takes approximately two days for water to get to the bench from Pishkun Reservoir, short-term wet weather patterns may result in over-delivery of water, causing unused water to pass through the system.

Figure 2-8 shows the variability in median daily flows for timeframes that reflect predominantly flood irrigation (1940-1995) and more recent flood/sprinkler irrigation (2005-2021). The data which are summarized by month, show that there is typically more flow variability in May with sprinkler irrigation, and generally higher flow in early summer months. The higher variability in flow can lead to increased bank erosion in the early season due to flow fluctuations and saturated bank collapse.

The conversion of flood to sprinkler/pivot irrigation on the Greenfields Bench appears to have contributed to the following alterations in Muddy Creek hydrology:

- A faster rise in return flows in May due to direct canal/tributary delivery versus primarily seepage.
- Overall higher flows during most of the summer
- Potentially more rapid flow fluctuations causing accelerated bank collapse in early summer and fall months

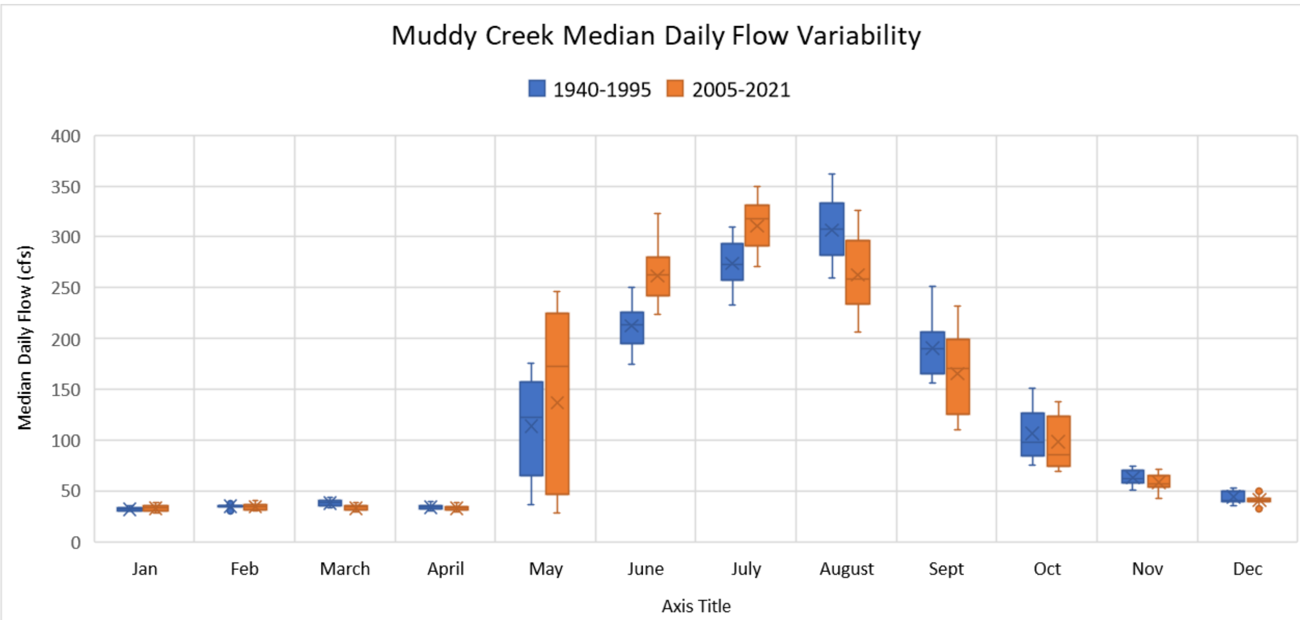


Figure 2-8. Box and whisker plot showing variability in Muddy Creek median daily flows comparison for primarily flood irrigation conditions (1945-1995) and primarily sprinkler/pivot irrigation (2005-2021).

2.3 System Response to Human Impacts

Flow augmentations, land use changes, riparian grazing, and stream modifications have all contributed to geomorphic change on Muddy Creek and its contributing drainages. Ultimately, the major driver of change is the dramatic increase in streamflows due to irrigation returns off the Greenfields Bench. The system response includes wholesale geomorphic destabilization which included downcutting, channel enlargement, gravitational bank collapse, and accelerated lateral bank erosion. This geomorphic destabilization resulted in secondary impacts to water quality, riparian vegetation, and the fishery.

2.3.1 Geomorphology and Channel Stability

The best pre-irrigation geomorphic information for Muddy Creek is probably the 1869 General Land Office (GLO) survey notes from the area. The maps show a sinuous channel that commonly follows older perched channel remnants on the former Muddy Creek floodplain. The notes for the survey describe conditions along section lines and provide some context as to the stream condition. For example, the notes for survey lines between Sections 13/14 River Mile (RM) 3.4 and 10/11 (RM 6) both describe the "Dry Bed of Big Muddy Creek". The survey was completed in early September of 1869; currently, the creek flows are around 200-250 cfs in August/September. The notes for Sections 24/25 (RM 0.4) and 3/10 (RM 7.3) both describe the creek as "30 links wide" which is about 20 feet. Photo 2-5 shows a perched older remnant of Muddy Creek that has preserved some historic channel character. Today, the channel is 40-60 feet wide and deeply entrenched.

Photo 2-5. Perched historic Muddy Creek remnant at Gordon Road Bridge crossing (RM 11.7).

The first photograph of Muddy Creek found in available documents is from 1936 (Photo 2-6). The creek is small in this photo but clearly already entrenched and detached from its older floodplain. Some woody riparian vegetation is growing on the upper banks. The historic floodplain is visible in the photo as an expansive grassed flat, indicating wide valley bottom hydrologic connectivity prior to the entrenchment. Photo 2-7 shows Muddy Creek at a point of intense destabilization, probably in the 1970s. The banks are fine grained and prone to gravitational collapse, especially when saturated. Fine sediment loading is clearly high, and the floodplain is perched such that there is no riparian zone on the channel margins. The lower banks are too erodible and/or steep to provide riparian colonization areas. All of these processes can be amplified by rapid flow fluctuations as banks are continually saturating and draining.

Photo 2-6. Muddy Creek in early stages of downcutting, 1936 (MT DEQ, 2004).

Photo 2-7. Massive bank failure driven by Muddy Creek incision at height of instability.

A 2021 photo of Muddy Creek extracted from a drone flight is shown in Photo 2-8. The creek has widened and incised up to 30 feet below its historic floodplain. It also appears to have increased its overall length under the higher flow regime, which is a typical channel response to increased flow energy. Since 1869 it has evolved from a ~20' wide, commonly dry channel to a 40-100 foot perennial stream. Photo 2-8 also shows the broad, flat historic floodplain surface perched well above the channel with several intermediate surfaces below that record various stages of downcutting. Sloping surfaces between the historic floodplain and existing channel document channel migration that was synchronous with the downcutting.

Photo 2-8. Fall 2021 drone flight clip showing deep incision along Muddy Creek (~RM 5).

2.3.2 Water Quality

Degraded water quality has long been a primary issue of concern on Muddy Creek. Over the last several decades, numerous investigations and projects have been carried out throughout the watershed to address water quality impairments, many of which researchers have found to be inextricably linked to channel destabilization. The commonality between water quality degradation and channel instability stems from a similar set of drivers that includes irrigation practices, land use, and channel modifications. Although some of the water quality/physical stability issues are only indirectly related, some are directly linked, such as water quality impairments stemming from streambank erosion.

The consequences of downcutting and cross section enlargement of Muddy Creek have included massive fine sediment recruitment to the creek. In 2002 it was estimated that 8 acres of Muddy Creek bottomland were eroded annually. Evaluations of fine sediment recruitment showed that the 1960s were the worst timeframe for water quality degradation, with about 200,000 tons (10,000 dump truck loads) per year of sediment entering Muddy Creek due to erosional processes. This sediment recruitment is directly associated with phosphorous loading and associated water quality impairments (DEQ, 2004). By 2002, sediment recruitment had dropped to less than 50,000 tons per year with the installation of erosion control measures on the creek (Sessoms and Bauder, 2002).

2.3.3 Riparian Vegetation

Stream downcutting can have a major influence on riparian vegetation due to the hydrologic disconnection of the stream and adjacent floodplain surface. Figure 2-9 shows a schematic example of the downcutting process and the associated loss of habitat and ecosystem benefits. Progressive downcutting results in the desiccation of the historic floodplain and subsequent conversion of riparian areas to upland. Currently, the only areas for riparian vegetation to establish and be sustained are within the narrow margins of the incised channel.

The establishment of riparian vegetation on Muddy Creek and its tributaries is also hindered by the non-natural fluctuations in streamflow that cause periodic over-inundation in areas otherwise amenable to its growth. Browse by both beaver and domestic livestock, as well as saline soils, have also proven to be problematic issues on previous revegetation projects.

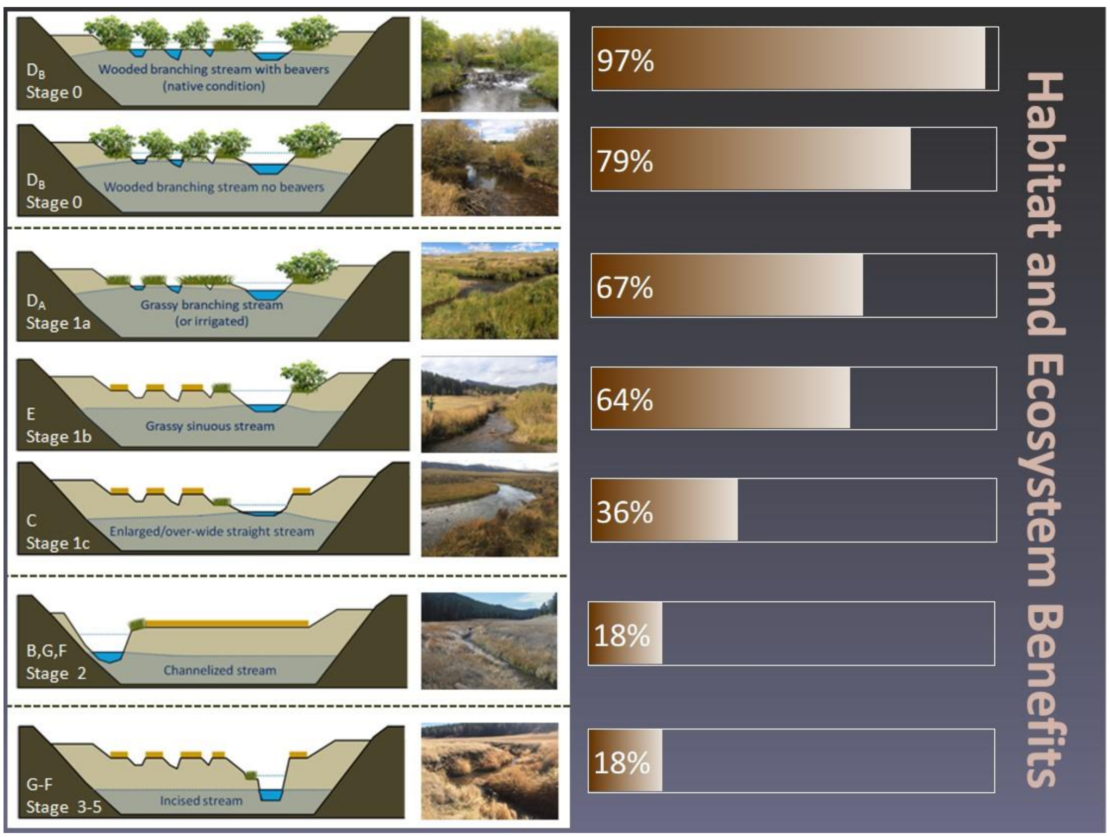


Figure 2-9. Lost ecosystem benefits associated with systemic stream downcutting (Ecometrics).

2.3.4 Fisheries

Although Muddy Creek supports Brown Trout and Whitefish with fewer Rainbow Trout, the fishery is impaired by flow augmented channel destabilization, as described in previous sections. Habitat quality and quantity is limited by fine sediment deposition, low bed form diversity both longitudinally and in cross section, limited vegetation-mediated bank stability, lack of floodplain connectivity, and water quality. As described in GLO survey notes, some reaches of Muddy Creek were periodically dry and the extent to which Muddy Creek supported a fishery is unknown. Without a historic fisheries baseline, there is no foundation to compare current condition to a more pristine time in history, rather it is more useful to think of the potential of the Muddy Creek fisheries in the current context. By addressing influences causing system destabilization and improving system resiliency the Muddy Creek fishery has the potential to be markedly improved especially in its tributaries.

Habitat connectivity is also an issue. Some culverts in the system are perched and steep, creating at least partial barriers to fish migrations. Irrigation and water supply diversions create additional migration barriers. During a project team field visit, for example, Rainbow Trout were observed unsuccessfully trying to leap over the Power water diversion structure.

In terms of current fish populations, electrofishing results from a Muddy Creek sampling event in 1981 included the identification of the following species (MTDEQ, 2004):

- Upper Muddy Creek near Cleiv Springs (RM 40): Rainbow Trout, White Sucker, Fathead Chub, Lake chub, Longnose Dace, and Brassy Minnow. The Rainbow Trout ranged in length from 11.9 to 13.7 inches.
- Middle Muddy Creek near Power (RM 22): No trout; captured Lake Chub, White Sucker, Longnose Sucker, Mountain Sucker, Mottled Sculpin.
- Lower Muddy Creek near Gordon Road (RM 11): Brown Trout, Mountain Whitefish, Longnose Sucker, Mottled Sculpin. The Brown Trout ranged in length from 10.8 to 19.7 inches.

In terms of fish densities, fish recapture sampling on Spring Coulee in 1998 and 1999 documented fairly low densities of trout, ranging from 4 to 22 trout per 1,000 feet of channel (21 to 120 fish per mile; Shepard, 2000). Montana Fish Wildlife and Parks plans to survey lower Muddy Creek in 2022 and determine an interval for future population surveys. Some project work undertaken in recent decades to improve the fishery on Muddy Creek tributaries are described in Section 3.

3 Early Projects -- 1970s to 2010

The history of Muddy Creek project work is summarized in Appendix A. These summary documents, which effectively chronicle both studies and on-the-ground projects undertaken in the basin since 1970 were written by Al Rollo (former Sun River Watershed Group coordinator) and provided to our project team by Erling Juel (GID District Manager). A summary of their compilation is provided below, and a much higher level of detail can be found in Appendix A.

The broad recognition of systemic instability on Muddy Creek began in the 1970s with Muddy Creek characterized as one of Montana's worst non-point pollution problems due to massive sediment delivery to the Sun River. The 1970s were described as "the study phase" as efforts were spent to evaluate the erosion problem and develop solutions. The original Muddy Creek Task Force was created in 1979.

3.1.1 Stream Stabilization

By 1980, serious erosion issues were regularly being documented on Muddy Creek and projects began to be implemented to address those issues. In 1980, USDA soil scientists wrote that the most effective approach to solving the erosion problem was "to decrease the source of water entering the stream and to minimize fluctuations and to minimize fluctuations from high to low flows" (USDA, 1980). Additional proposed solutions included bank stabilization and construction of a dam to trap sediment. During the 1980s, several irrigation water management projects were installed to help reduce the tailwater inputs to Muddy Creek, but these efforts were not effective in measurably reducing erosion rates.

The lack of positive results from the 1980s projects prompted local landowners to request assistance from the State of Montana in 1992 and a new Muddy Creek Task Force was established. This group developed and began to implement an Action Plan in 1993, when the Muddy Creek Task Force collaborated with the Cascade Conservation District to "stabilize the planform and gradient of the stream". This included two phases of work, the first addressing about four miles of channel beginning about three miles upstream of the mouth where the erosion was considered most severe. The Phase 1 project was anchored by a large rock sill structure built in February 1994 at RM 3.15 to hold grade at that location. An additional 10 rock grade control structures were built upstream of the sill to circumvent additional downcutting. The project also included 30-rock barbs constructed on the stream banks (Photo 3-1).

The original demonstration project continued to expand with additional rock grade controls and barbs. In total, the 1990s demonstration project on Muddy Creek included one large rock sill at the bottom of the project, 11 grade controls, seven revetments and three cutoff revetments. With time, over 160 barbs were installed over 8 river miles between Gordon and Vaughn, and another 33 barbs were built above Gordon (Wittler, 1998). These projects were considered highly effective, reducing the sediment load into the Sun River from an average of 200,000 tons/year to 40,000 tons/year. Although the rock grade control structures were constructed largely at grade, their short lengths and longitudinal spacing allowed for additional downcutting between the structures causing them to steepen into high velocity chutes. High velocities flow over the grade controls creates eddies that exacerbate bank erosion immediately downstream of the structures and highlight a possible failure mechanism for the structures. The downstream sill that anchored the project was designed for zero drop, but on-going downstream incision had created a 1.2 foot drop by 1996 and during the project team's site inspection in 2021, the drop had grown to approximately 3 feet (Photo 3-2). The other 11 grade control structures had a cumulative drop of 14 feet by 1996. This constitutes 87% of the total design drop being consumed within a few years of project completion.

Photo 3-1. Demonstration project including rock drops (left) and barbs (right) constructed on Muddy Creek in the early 1990s.

Photo 3-2. View downstream of lowermost sill at RM 3.15; note mass failure on left bank and erosion on right.

A final review of the stabilization project (CRDA-96-1) concluded that, in 1998, the project elements were functioning well, holding up to high flows and ice jams. Reviewers concluded that the grade control structures had stopped headcuts from migrating upstream, which would have caused additional instability and fine sediment production. The group made recommendations at that time for additional grade controls, barbs, longitudinal dikes to control slip failures, cutoff prevention efforts, erosion suppression, and revegetation. In the 2000s the demonstration project was further expanded, with an additional 165 barbs built over 10 miles of Muddy Creek channel.

Although many of the structures built in Muddy Creek have remained functional, some of the grade controls have generated large scour holes that have driven hillslope failure, increasing their risk of failure in coming years. Others are at risk of flanking (Photo 3-3). Some of the barbs have been winnowed or completely eroded out, but many are still functional (Photo 3-4).

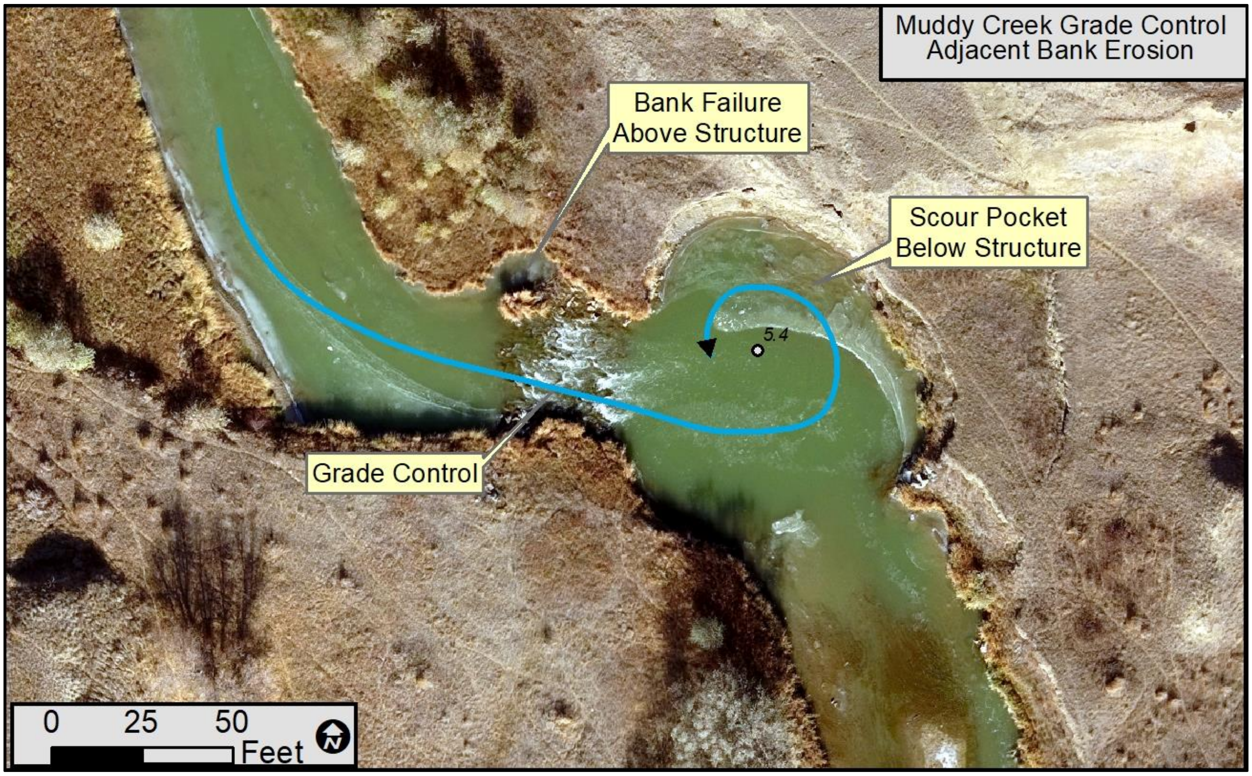


Photo 3-3. Grade control at risk of flanking around left bank just above and below structure.

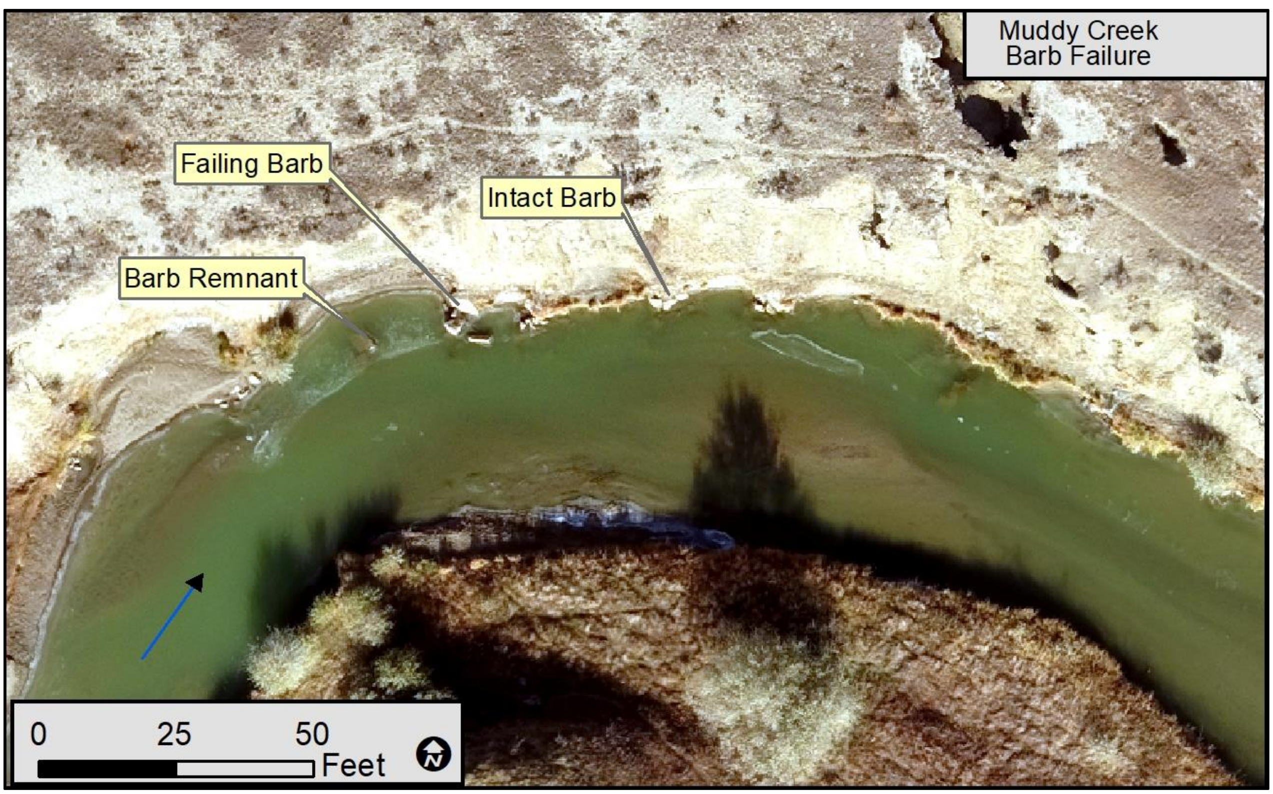


Photo 3-4. Barbs constructed at toe of high bank showing local failures.

3.1.2 Water Quality—TMDL Planning

The most comprehensive plan to address water quality issues was completed in 2004, when a TMDL restoration plan developed for the Sun River Watershed included the assessment of water quality impairments including siltation, suspended solids, nutrients, thermal modification, and salinity/TDS/sulfates (DEQ, 2004).

To address the salinity impairment, cropping-related mitigation strategies were prioritized because "major irrigation drainages from the Greenfields Bench appear to contribute approximately 90 percent of the total TDS loads to Muddy Creek during the summer irrigation season" (DEQ, 2004). The strategies thus focus on reducing those contributions by implementing fallow cropping BMPs in certain areas prone to both salt and selenium sourcing.

Muddy Creek was also identified as having elevated nutrients (nitrogen and total phosphorous). The majority of nitrogen was delivered by six major Greenfields Bench drainages, and the potential sources of those nutrients include fertilizers, domestic septic systems, soil organic nitrogen, stock animals, and geologic sources. In contrast, the total phosphorous loading on Muddy Creek is largely due to bank erosion on Muddy Creek itself. Increased irrigation flow from the Greenfields Bench and poor riparian management on Muddy Creek was attributed as a cause of accelerated bank erosion and increased phosphorous loads. Restoration approaches developed in the Watershed Restoration Plan for nutrients include careful selection of fertilizers and irrigation modifications to reduce the amount of leaching of the nitrates into groundwater. Irrigation management was also a recommended practice to reduce return flows and associated bank erosion/phosphorous loading on Muddy Creek. Additional restoration measures for nutrients include fallow cropping BMPs, riparian area grazing management, and livestock waste management.

In addition to phosphorous, the most direct linkage between water quality and physical stream stability on Muddy Creek is with respect to sediment. Irrigation returns off the Greenfields Bench have caused Muddy Creek to rapidly downcut into fine sediment, primarily during the 1950s-1970s. This prompted the formation of the Muddy Creek Task Force and Sun River Partnership to help slow the erosion and fine sediment production. Grants were obtained by these partners to physically stabilize the stream, restore/manage riparian areas, reduce return flows, and rehabilitate the fishery. Substantial measurable benefits were achieved by these actions which are described in some detail in the TMDL. The TMDL restoration strategy for sediment includes (DEQ, 2004):

- Capturing all or most surface irrigation wastewater and/or devising a more efficient approach to water delivery on Greenfields Bench
- Preventing on-farm surface irrigation water runoff from exiting fields or ditches
- Strategically lining ditches

- Installing headgates for full control
- Using efficient irrigation methods on Greenfields Bench
- Leaving crop residue on fields by using low/no till methods when possible.

3.1.3 Revegetation

Rollo (2020, Appendix A) noted that willows were actively removed from the banks of Muddy Creek as landowners settled the area. Since then, there have been numerous revegetation projects on impacted stream channels. Thousands of willows were planted along Muddy Creek in the mid-1990s, however there were major challenges in getting that vegetation established. According to people directly involved in those efforts (A. Rollo, pers. comm.), poor revegetation survival rates were due to a combination of factors, including:

- Flow fluctuations that exceeded the wetting/drying tolerance of the plants
- Browse by beaver
- Browse by livestock
- Ice scouring
- High flow events in entrenched channel resulting in high stream power and erosion of planted surfaces
- Overirrigation adjacent to the bank causing erosion
- Lack of browse protection (fence) maintenance

This indicates that any future revegetation efforts should include secure browse protection, and planting sites should be selected where stream power is relatively low at higher flows. It also shows how efforts to reduce the amount and fluctuation rates of flow returns off the Greenfields Bench will passively benefit riparian recovery. Rollo (pers comm) also noted that natural seedling recruitment on point bars has shown high survival rates, which highlights the value of creating these types of surfaces in stream restoration designs.

3.1.4 Fish Habitat Improvements

In the late 1990s, the Future Fisheries program funded an aquatic habitat restoration project on Spring Coulee. The project is about 3.5 miles upstream of the mouth and includes riparian fencing, grade control structures, and bank treatments. Log drop structures were placed over about 1,300 feet of channel to control grade, and banks were rehabilitated (Photo 3-5).

Photo 3-5. View upstream of log drop structure on Spring Coulee, 2021.

Electrofishing data were collected as part of the Spring Coulee project monitoring in 1999 (Shepard, 2000). FWP captured trout and estimated about 60 Brown Trout (~8-29"), 84 Rainbow Trout (~11-24"), and 35 Brook Trout (~6-14") over 5,500' of channel. Very few Rainbow Trout less than 10 inches long were captured. Trout densities peaked out at 22 fish per 1,000 feet of channel in a recently treated channel segment (Figure 3-1). FWP concluded that the population densities of trout in Spring Coulee Creek are low, and that small fish are notably absent from the population.

In comparing data through time, the treatment sections show an increase in trout numbers from 1998 to 1999, although that may be in part related to better sampling efficiencies due to cooler water temperatures in 1999 (Figure 3-1; Shepard, 2000).

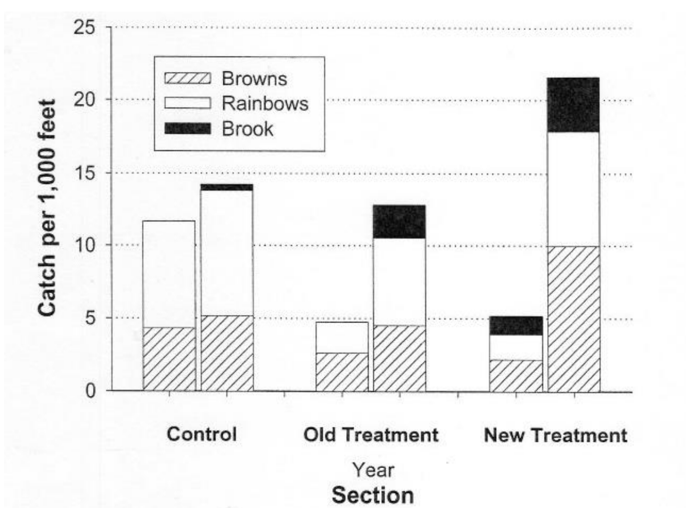


Figure 3-1. "Relative catch data" from a Montana Future Fisheries project located along 1-mile of Spring Coulee; bars reflect 1998 and 1999 data (Shepard, 2000).

3.1.5 Grazing Management

Early land use changes on in the Muddy Creek corridor included extensive valley bottom grazing. Since the mid-1990s there have been several projects completed to improve grazing management in the stream corridors. This has included the installation of miles of riparian fencing to keep livestock off streambanks and to reduce animal waste in the creek. Off-stream watering has been developed. Much of this work was implemented in the mid-1990s.

Two decades after the completion of the Spring Coulee project, low floodplain surfaces adjacent to the channel that are protected by riparian fencing were supporting robust stands of willows (Photo 3-6).

Photo 3-6. Riparian expansion on Spring Coulee floodplain bench where livestock are excluded.

3.1.6 Public Outreach

Public outreach has been in important component of Muddy Creek work over recent decades. Outreach efforts have included grazing workshops, creation of videos telling the Muddy Creek Story, watershed tours, and water quality educational workshops. In 1994, a “Know Your Watershed” workshop was held in Great Falls sponsored by Montana Watercourse and the Cascade Conservation District.

4 Recent Strategies Taken to Address Muddy Creek Instability

Issues identified in the Muddy Creek Watershed extend from the headwater areas on the Fairfield Bench down to the confluence of the creek with the Sun River at Vaughn. In general, however, the strategic approaches to addressing those issues can be described as issues associated with stressors on the system (flow augmentations) and issues that have arisen in response to those stressors (loss of resilience, water quality impairments, and habitat degradation). Figure 4-1 shows a conceptual framework for addressing those factors through a series of strategies ranging from irrigation water management to channel restoration to habitat expansion. Floodplain connectivity and wetland expansion also provide benefits towards drought and climate resiliency by improving surface-groundwater connections along primary stream channels. The ideal outcomes for this work include a geomorphically stable system that can support a more intact aquatic/riparian ecosystem while meeting the needs and rights of water users throughout the watershed.

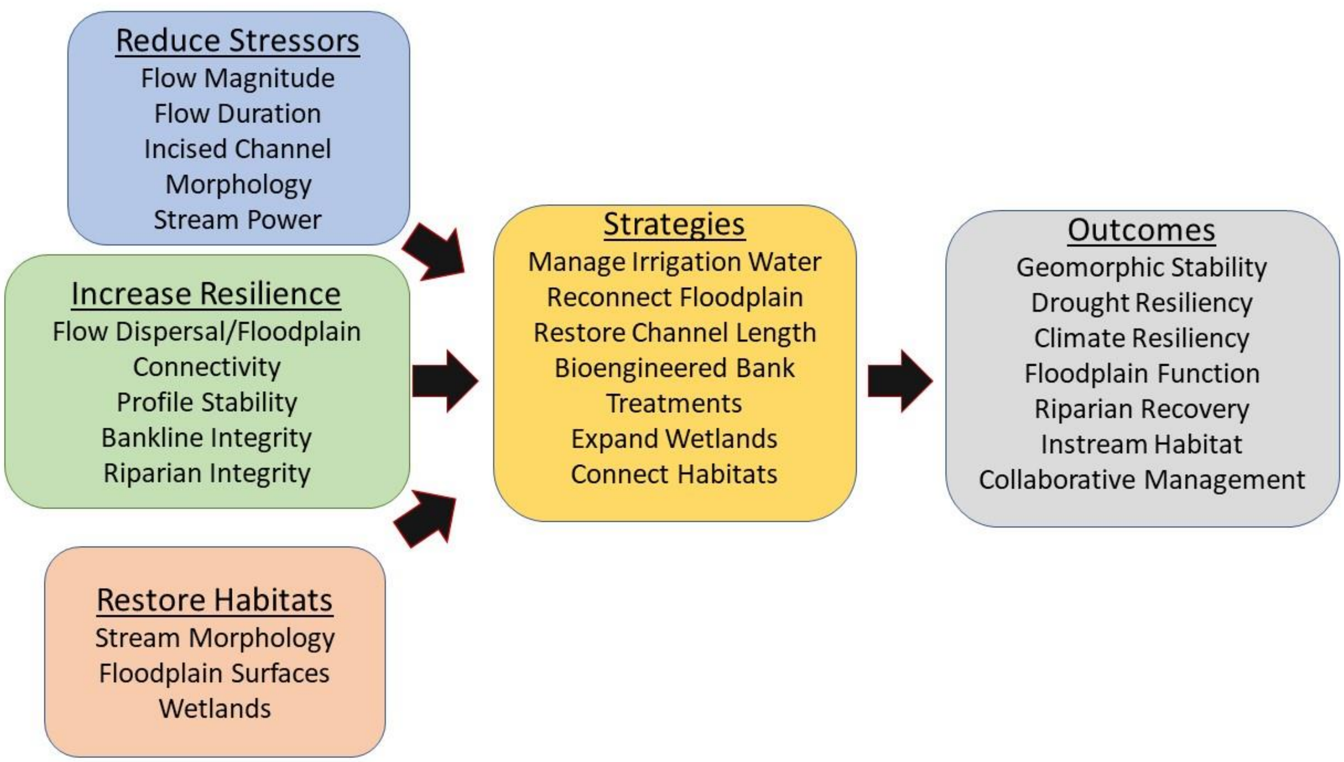


Figure 4-1. Conceptual framework for increasing overall resiliency of Muddy Creek and its tributaries.

Another important benefit of irrigation management is that, if irrigation water can be used more efficiently, there is the potential to maintain higher flows in the Sun River, which has been described as chronically dewatered due to irrigation diversions (MTFWP, 2019). The Sun River Watershed Group has recently completed a Sun River Watershed Restoration Plan (SRWG, 2022), which specifies minimum flow requirements for survival of aquatic species on several segments of the Sun River; any efficiencies realized as part of irrigation management on the Greenfields Bench will help managers meet these minimum flow objectives.

4.1 Strategies Taken to Reduce Stressors: Irrigation Water Management

GID has shown a high level of commitment to reduce the stressors on the system associated with flow augmentations. GID is responsible for distributing water to approximately 83,230 acres of irrigated land in the Greenfields Division of the Sun River project, which typically consumes about 3,000 acre-feet of water per day during the irrigation season. About 47,000 of those acres are within the Muddy Creek watershed. As the water is diverted from the Sun River over 30 miles to the west, and as Pishkun Reservoir is only partially regulating, the flows that leave the Sun River are conveyed the entire distance to the distribution system without any opportunities for reregulation along that route. Reregulation of flows within the distribution system itself has been described as one of the most important priorities for GID to pursue (Erling Juel, pers. comm.).

GID is focusing on the following strategies to reduce the magnitude and frequency of stressor impacts:

1. ***Reregulation:*** Reregulation reduces operational losses, return flows and emergency releases during power outages. It allows diverted water to be temporarily detained and used later rather than lost from the system.
2. ***Pump Backs:*** Pumps situated in drain ditch laterals can pump water back up and into the primary distribution system. This reduces flows in the natural drainages leaving the District, as well as the overall volume of water required to be diverted from the Sun River.
3. ***District Modernization:*** Now that over two thirds of GIDs irrigated acres are serviced by pivots, the demands on infrastructure have changed. Efforts are being considered to modernize the infrastructure to enhance water management and improve conservation while reducing operation spills and emergency releases.
4. ***Expanded Water Usage:*** Increased usage of water in the upper reaches of the drainage through the provision of additional water rights would reduce the quantity of water in Muddy Creek.

Example projects that have been completed in recent years by GID to improve flow management capabilities include the conversion of 60 miles of open laterals to closed concrete and PVC pipeline, computerized water ordering and scheduling, and use of HYDROMET, SNOTEL, and Agrimet station data to improve water management and inflow forecasting.

Major projects that are currently being implemented to help reduce system stressors associated with flow augmentations are described below.

4.1.1 Electronic Water Management Plan - Automated Flow Measurements (GID- Current)

In 2021 GID was awarded Small-Scale Water Efficiency Project Funding to automate flow measurements at four major canal sites. The project was projected to save approximately 10 cfs or 4,000 acre-feet over the irrigation season to remain in the Sun River. In the grant application GID noted that the system "suffers a water deficiency of 30,000 acre-feet in most years while wasting over 50,000 acre-feet into Muddy Creek."

4.1.2 SRS-71 Headworks Replacement and Reregulation Storage (GID- Current)

The Montana DNRC Renewable Resource Grant 2022-2023 biennium budget ranks the SRS-71 Headworks and SRS Reregulation project as 19th out of 76 projects and was recommended for full funding of $125,000 (MTDNRC, 2021). The site is located high on the Sun River Slope Canal below the Highway 287 Bridge. The SRS-71 project will replace the existing headworks and check structure and construct a new reregulating area to improve management of the delivery system. DNRC also noted that the project could develop wetland areas with the creation of the 900 acre-feet reregulating area upstream of the structure. The project is anticipated to realize an additional 2,800 acre-feet of water annually for crops, reduce delivery times, and leave more water in Gibson and Willow Creek reservoirs late in the irrigation season. The first phase of this project is slated for fall 2022 construction.

4.1.3 J Reregulation and Wasteway Phase 1: GM-100 Headworks (GID- 2020)

J-Wasteway is a regulating reservoir located at the head of Upper Spring Coulee. It has two outlet controls, one into Upper Spring Coulee (J-Wasteway) and the other into the Greenfields Main Canal Lateral 100 (GM-100). Both headworks controls have been prioritized for replacement and automation. Phase 1 of the project consisted of replacing the GM-100 headworks with a smart headgate. The project was completed in 2020 and will improve management of J-Wasteway and associated overflows into Spring Coulee (Photo 4-1).

Photo 4-1. New smart headgate at head of GM-100 at J-Wasteway outlet, Spring 2020 (E. Juel).

4.1.4 J-Reregulation and Wasteway Phase 2: Spring Coulee Headworks (GID-Current)

The Spring Coulee Headworks control flows at the second outlet for J-Wasteway (the other outlet is controlled by the GM-100 headworks described above). The structure was originally constructed in the 1930s to convey excess water into J-Wasteway/Upper Spring Coulee and prevent overtopping of the GM-100 canal. The Montana DNRC Renewable Resource Grant 2022-2023 biennium budget ranked the Spring Coulee Headworks Replacement project as 21st out of 76 projects and recommended that it receive full funding of $125,000 (MTDNRC, 2021). Replacing the structure will allow GID operators to reduce the amount of water spilled into the Spring Coulee drainage via J-Wasteway. The project is anticipated to realize an additional 5,471 acre-feet of water annually for crops from the additional storge while reducing sediment loads generated from Spring Coulee flows by about 1,700 tons per year. Phase 2 of the project, which will complete the headworks replacement, is under construction as of spring 2022. The overall project won't be fully implemented until Phase 3 is completed, which is the expansion of confinement berms to expand the operational capacity of J-Wasteway. A photo of the older headworks is shown in Photo 4-2; a March 2022 photo of the ongoing construction of the foundation slab is shown in Photo 4-3.

Photo 4-2. Spring Coulee Headworks (May 2021).

Photo 4-3. Foundation slab construction at Spring Coulee Headworks on March 22, 2022 (E. Juel).

4.1.5 NRCS Muddy Creek Irrigation Efficiency Targeted Implementation Plan (NRCS- 2022-2024)

The NRCS recently developed a Targeted Implementation Plan (TIP) in the Muddy Creek Watershed with a stated goal to "reduce inefficient irrigation water use by converting flood and wheel line irrigation to more efficient sprinkler irrigation systems, while monitoring soil moisture throughout the season". The area focused on for the TIP include areas south and west of the creek where future work will tie into conservation projects headed up by other agencies (NRCS; Figure 4-2). The area includes 7,185 acres ground that is currently irrigated by a combination of flood (2,833 acres), wheel line (1,235 acres) and pivot (3,117 acres). The TIP indicates that the project will improve water quality in Muddy Creek during the irrigation season by reducing nutrient loading from the fields and increasing the efficiency of irrigation water delivery to reduce return flows to the creek.

The conservation practices offered by the NRCS in this TIP include sprinkler system, structure for water control, irrigation water management, nutrient management, integrated pest management, pumping plant, and irrigation pipeline.

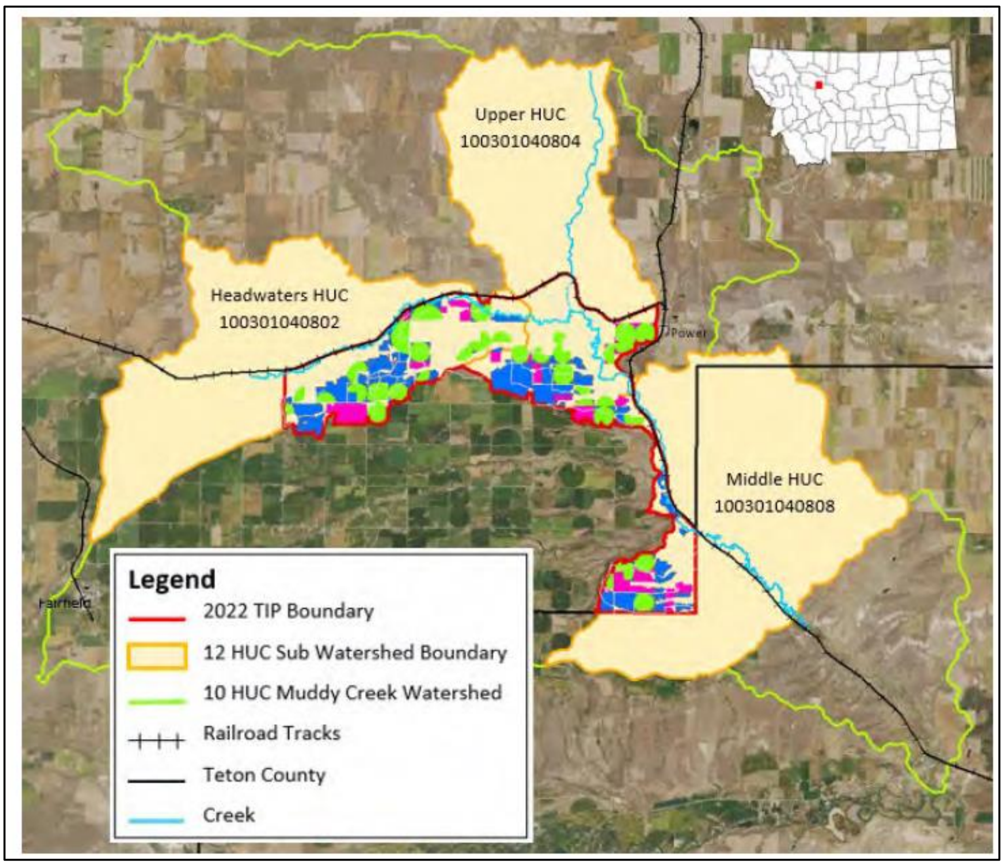


Figure 4-2. NRCS Muddy Creek Irrigation Efficiency Project area/

4.2 Strategies Taken to Absorb Stressors: Improve Resiliency and Habitat

In recent years, SRWG and its partners has renewed their focus on resiliency/habitat projects on Muddy Creek and its tributaries. Several of those efforts are described below. In addition, a comprehensive resiliency/habitat project concept design developed for a section of Muddy Creek can be found in (Appendix B).

4.2.1 Habitat Connectivity Via Culvert Replacement, Bison Ranch (2021)

One direct means of improving aquatic habitat conditions on Muddy Creek is to restore connectivity at road crossings. The SRWG has recently worked with a landowner and several other partners to replace a failing culvert crossing with a bridge on Muddy Creek (Photo 4-4 and Photo 4-5). This project provides improved access for the landowner while securing fish passage and reducing sediment inputs into Muddy Creek. The project included implementation of a grazing plan to keep livestock off the riparian area around the new bridge. Volunteers planted willows on site to help stabilize banks and improve habitat. With the improved crossing infrastructure and riparian fencing, animal waste inputs to Muddy Creek will be reduced.

Photo 4-4. Muddy Creek Crossing Project (Bison Ranch) shown before bridge installation.

Photo 4-5. View upstream of the bridge placement following culvert removal.

4.2.2 Tributary Fisheries Enhancements (Current)

As the tributary drainages of Muddy Creek are major conveyors of irrigation tailwater, they are also prone to destabilization and sediment production. As a result, improving the resilience of tributaries will substantially contribute to the health of the watershed, especially in conjunction with ongoing GID efforts to reduce return flow volumes. Tributary drainages also provide a real opportunity to establish cold water fisheries, as demonstrated by work that has been implemented collaboratively by local landowner groups, the SRWG, and other partners to improve fish habitat on Spring Coulee.

Because of the noted success of previous restoration work on Spring Coulee, this project is currently being expanded (Photo 4-6). This expansion has been driven by the landowner's interest in continuing work that will further reduce erosion and improve aquatic and riparian habitats.

Photo 4-6. View upstream of 2022 project work on Spring Coulee showing rock drop designed to stabilize grade, increase diversity, and improve floodplain access.

Other private ranches in the Sun River watershed with similar restoration and riparian buffer projects show improvements in the health of the trout fishery. If the results of relatively minor restoration efforts and riparian buffer establishment at the Spring Coulee Creek Farm are an indication of potential gains in other areas, there is significant potential for the future of trout within Muddy Creek and its tributaries. As habitat is improved on a local level it will be important to incorporate broader scale habitat connectivity by ensuring fish passage at barriers such as culverts and cross-channel structures.

4.2.3 Land Management, Revegetation, Wetlands

Other strategies that have been adopted over the years to improve the resilience of Muddy Creek and its tributaries include extensive riparian fencing, grazing management, and revegetation. There has also been discussion as to how the creation of wetland systems to detain, store and infiltrate GID releases is a potential mitigation measure for flow augmentation in Muddy Creek that will also contribute to drought resiliency on the floodplain. No sites have been specifically identified for wetland creation, although floodplain reconnection, which is described below, will have a secondary wetland/drought resiliency benefit.

4.2.4 Muddy Creek Geomorphic Resiliency Demonstration Project (Preliminary Design Phase)

A fundamental foundation for future work on Muddy Creek is to first ensure that the grade remains stable. For decades, channel downcutting was the primary degradational trend on Muddy Creek, and arresting that process was a critical first step to restoring stability. The work done in the 1990s has effectively achieved that goal. That said, the longitudinal profile has continued to adjust for some time after the grade controls were placed. As they were initially placed at grade (they were buried so their crests matched the bed profile), by 1996 they had formed steep chutes on their downstream sides (Photo 3-2). This reflects the bed adjustments post-project evolving towards a stepped profile, with a relatively flat channel between drop structures and a steep drop at each grade control. Figure 4-3 shows the water surface profile (from LiDAR) for an approximately 1.5-mile-long segment of Muddy Creek within the demonstration project reach. The lowermost, sill built by the Corps of Engineers at the bottom of the project holds several feet of drop at RM 3.1, although it was originally designed for zero drop (Wittler, 1998, Photo 3-2). Upstream, there are an additional five rock drops over 1.5 miles that have between less than a foot to about 1.5 feet of drop as captured by the water surface profile. The channel in between the drop structures is relatively flat. This evolution to a stepped profile may help explain why the riparian planting efforts that started in the early 1990s were reportedly unsuccessful. If the profile had not fully stabilized, the areas amenable to riparian vegetation would have been constantly shifting.

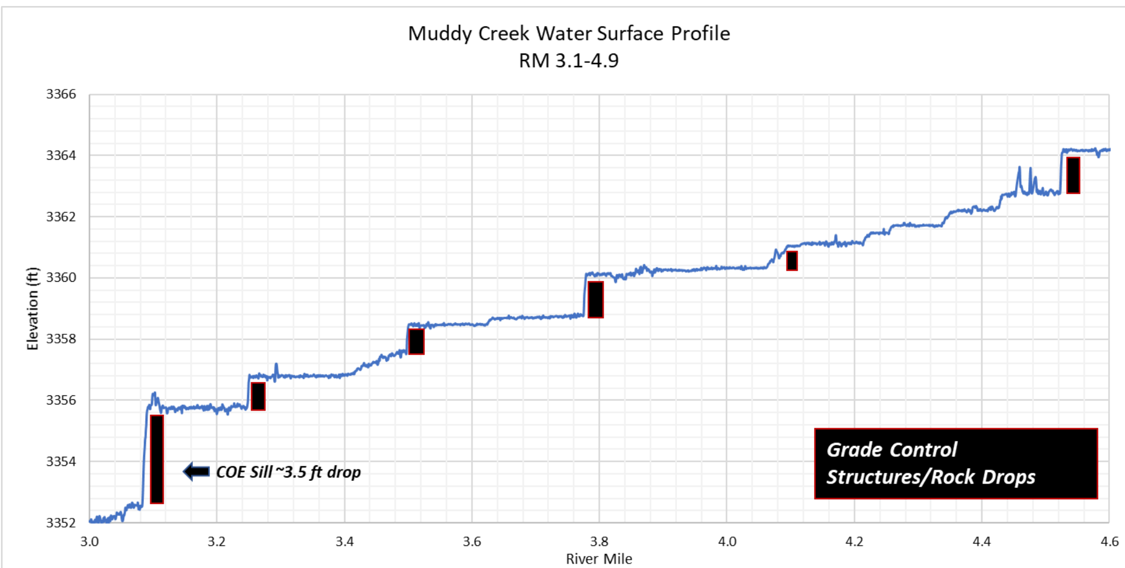


Figure 4-3. Water surface profile of Muddy Creek show stepped bed profile.

As Muddy Creek downcut, it created some perched, relatively flat surfaces (terraces) along fairly straight segments (Photo 4-7). It also created sloped surfaces on bendways where downcutting was rapid and the channel migrated as it incised (Photo 4-8). As a result, the current Muddy Creek corridor has a complex series of sloping and flat surfaces adjacent to the channel that have wide variability in terms of their potential to disperse flow energy or support riparian vegetation. Several old meanders have become perched and somewhat isolated from the channel, although some support wetlands indicating a high potential for restoration and expansion (Photo 4-9). This current state of the channel is an important consideration in the development of strategies to increase geomorphic resilience.

Photo 4-7. View upstream showing relatively flat terraces against channel above grade control on straight segment.

Photo 4-8. View upstream showing sloping point bar where the channel migrated laterally as it downcut.

Photo 4-9. View upstream of abandoned meander that supports an emergent wetland.

The conceptual restoration design that has been developed as part of this planning effort (APPENDIX B) is located within the demonstration project reach described above. A conceptual framework for the project development is shown in Figure 4-4. The basic approach has three primary tiers. The first, shown in blue, involves expanding the frequency of grade stabilization measures by constructing intermediate riffles to absorb grade and create more profile complexity. This will help ensure that the profile remains stable such that other work can be done to capitalize on that stability. That includes increasing floodplain access and associated ecosystem functions (green tier) which will in turn allow for habitat enhancements in both floodplain and channel environments (orange tier). Each tier component progressively moves Muddy Creek towards a condition of geomorphic resilience and ecological function.

The project is intended to demonstrate the application of modern concepts of riffle-based grade control, flow dispersal via floodplain reconnection, stream power reduction, and habitat renewal in an area that was originally heavily engineered to purely resist the amplified hydraulic forces on the bed and banks. In doing this, benefits are sought to improve complexity and channel structure, reduce sediment production rates, restore vegetation, improve riparian habitat, and expand wetlands and backwaters. The main components of the project are:

1) Reinforce and expand grade stabilization to create a more natural longitudinal profile (avoid steep drops and long flats),
2) Lower inset floodplain tabs to create a broad low energy floodway that can support vegetation
3) Protect the toes of high banks on bendways to reduce rates of lateral erosion and increase system roughness,
4) Increase channel length where feasible and create adjacent surfaces that are topographically complex to restore the process of natural colonization of woody vegetation.

5) Planting native riparian shrubs as whole plants and cuttings in bank treatments and on surfaces where conditions support good survival rates.

The concept plan provides multiple techniques for restoring system integrity. Given that channel incision is a common impairment throughout the watershed this project will demonstrate methods that can be applied to other sites. The project is also intended to work in concert with GID efforts to reduces stressors on the system through more efficient flow management.

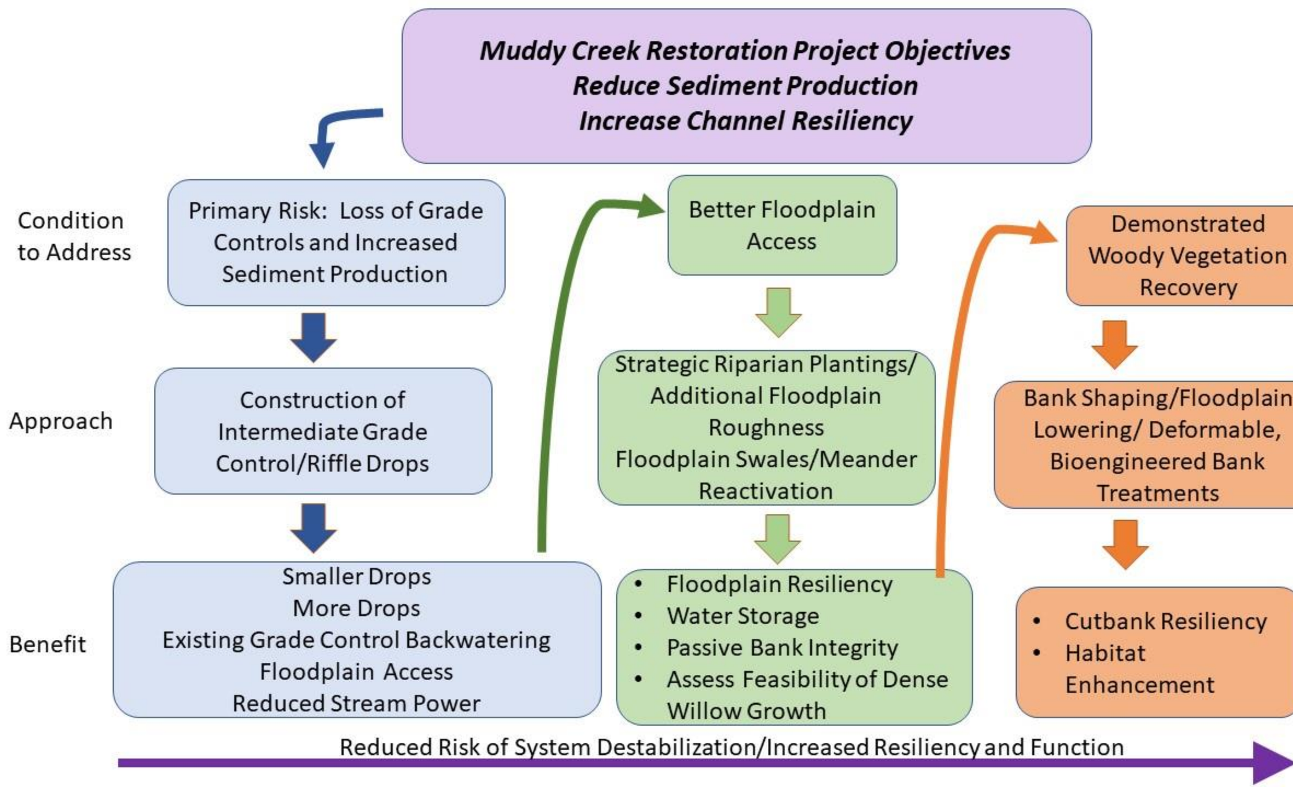


Figure 4-4. Conceptual framework for increasing geomorphic resiliency on Muddy Creek.

5 Data Compilation and Project Identification

As described earlier in this report, developing the Muddy Creek Restoration Plan included a heavy reliance on local stakeholder input, and some pre-meeting work was required to collect and compile that information. This included creating watershed maps showing existing features and known projects, and a project database used for compiling new information.

5.1 Existing Data Compilation and GIS Project Development

Spatial data were initially compiled to integrate spatial datasets in a GIS environment. Several types of existing data were available for the initial compilation, although their level of detail is variable. The core datasets that were brought into the GIS and used in the outreach process include the following:

1. **Framework Datasets** – Publicly available framework datasets were imported as foundational map layers to capture basic watershed features. These include watershed boundaries, streams, roads, county boundaries, gage locations, elevation, etc. These framework data are consistent across the United States and are useful for creating base maps and doing certain types of analysis.
2. **Air Photos:** Aerial imagery was imported into the GIS to help interpret historic and current watershed conditions. The imagery spans a 1995-2021 timeframe.
3. **Greenfields Irrigation District** – The Greenfields Irrigation District provided GIS files containing system-related data including fields, canals, laterals, drains, turnouts, pumps and wasteways.
4. **LiDAR Elevation Data** – LiDAR data usually consists of a high-resolution (one to three foot) grid of elevation points that is consistent across the landscape. 2020 LiDAR surveys for Teton and Cascade Counties provide coverage for much of the Muddy Creek watershed. There is an approximately six-mile long gap in the coverage starting four miles above Vaughn and ending at the Cascade/Teton border, but data collected to fill the gap in 2021 is currently being processed.

Additional watershed specific data were compiled to directly support the project. These included the following:

1. **Historic project locations** including the locations of the demonstration projects on the lower river (drop structures, barbs and revetments) and recent project locations on the creek and tributaries.
2. **Proposed project locations**, including areas with known issues.
3. **Relative Elevation Model** – A Relative Elevation Model (REM) was developed from the available LiDAR data. A REM provides a useful way of visualizing the relative elevations

of land adjacent to the river channel. This degree of connectivity is key for assessing the viability of potential restoration projects.

5.2 Stakeholder Engagement

Collecting stakeholder input was a critical phase of this planning process. The project team toured several sites and met landowners who summarized their observations, issues, and any project work they had done. GID representatives showed the team several key pieces of irrigation infrastructure slated for improvements. Field time spent with Al Rollo provided a context on previous and ongoing projects. On April 29, 2021, a stakeholder meeting was held in Fairfield (Photo 5-1). The goal of the meeting was to present the objectives of the master plan and to solicit input for projects and concepts that they felt should be included. A series of seven maps were developed to support public outreach with local stakeholders. The maps included base information such as imagery, property boundaries, river miles, reaches, and an initial suite of identified project locations. Input was gathered in an open forum where ideas were expressed and discussed with the other participants. Individuals were encouraged to fill out project information forms and submit them for inclusion in the Master Plan.

Following the meeting, landowners and agency personnel were contacted to expand and flesh out project concepts. The result was a continued expansion and refinement of a stakeholder-developed projects database that was ultimately use in the ranking process.

Photo 5-1. Muddy Creek Watershed Plan stakeholder meeting, April 2021.

6 Results

The project team collaborated with stakeholders to generate a preliminary list of 36 projects focused on improving infrastructure, habitat, and water quality. Prior to ranking, the project team consolidated the initial list. Where multiple projects addressed the same issue, they were combined into a single project to facilitate their implementation as a larger effort. Some projects that were considered too vague for critical prioritization were removed from the list entirely. This reduced the number of projects down to 26, which were categorized by type and location in the watershed.

Each project was assigned one or more Project Types that captured the primary goals or issues addressed. The number of projects that address each issue in some form is shown in Table 6-1. The projects were further categorized based on their position within the Muddy Creek watershed (Table 6-2).

Table 6-1. Types and number of issues addressed by 26 proposed projects.

Project Type	Number of Projects
Sediment Control	11
Bank Stabilization	10
Fisheries	9
Irrigation Efficiency	7
Riparian	7
Grade Control	6
Water Management	5
Irrigation Infrastructure	4
Data Collection	3
Monitoring	2
Studies	2

Table 6-2. Ranked projects by region.

Region	Number of Projects
Lower Muddy Creek (Incised Section)	4
General Projects – Upper Basin (Above Power Diversion)	3
General Project – Lower Basin (Below Power Diversion)	3
Tributary Work, Including Spring Coulee and Tank Coulee	5
Greenfields Irrigation District	7
General Projects and Studies	4
Total	26

6.1 Project Ranking

The Project Team met in-person to discuss and rank the final list of 26 projects. The group evaluated each project with respect to eight potential benefits listed in the Project Ranking Criteria (Table 6-3). Each project was scored in terms of its likelihood to provide a high (3), medium (2), low (1), or no (0) benefit for each of the criteria. The process resulted in a range of project scores from a high of 22 (three projects), to a low of 4 (one project). Four of the projects were somewhat unique in that they reflect general studies, data collection efforts, or large scale landscape issues (hillslope failures); these are maintained in the project list as they are supported by SRWG but they were not ranked as they are very general in nature.

Table 6-3. Project Ranking Criteria.

I. Aquatic Habitat Benefits- Reduced temperature, instream flow, physical habitat improvements, recovery of natural processes		
Score	Criteria	Examples
0	Project will have ***no*** Aquatic Habitat Benefit	• Full bank rock riprap
1	May have ***indirect*** Aquatic Habitat Benefit	• Riparian plantings
2	Will have ***some direct*** Aquatic Habitat Benefit	• Bioengineered bank stabilization
3	Will have ***substantial direct*** Aquatic Habitat Benefit	• Instream flows, lower temperatures • Meander/oxbow reactivation • Channel morphology/habitat improvements • Fish passage • Wetland Restoration
II. Water Quality Benefits- Temperature, salinity, sediment, nutrients, metals, etc.		
Score	Criteria	Examples
0	Project will have ***no*** Water Quality Benefit	
1	May have ***indirect*** Water Quality Benefit	• Meander reactivations
2	Will have ***some direct*** Water Quality Benefit	
3	Will have ***substantial direct*** Water Quality Benefit	• Sediment controls • Salinity controls
III. Riparian Benefit - Project will result in increased quantity of quality of riparian habitat		
Score	Criteria	Examples
0	Project will have ***no*** Riparian Benefit	• Full bank rock riprap
1	***Low likelihood*** that Riparian conditions or functions will be improved	• Bioengineered bank stabilization
2	***Moderate likelihood*** that Riparian conditions or functions will be improved	
3	***High likelihood*** that Riparian conditions or functions will be improved	• Meander/oxbow reactivations • Floodplain expansion/enhancement • Riparian plantings
IV. Water Use/Delivery Efficiency - Project will result in increased efficiency of water delivery and use through the irrigation system.		
Score	Criteria	Examples
0	***No benefit*** to water use	
1	Some improvement to delivery/use system but not critical for delivering water	• Climate data, soil moisture data • Other irrigation infrastructure improvements
2	***Substantial improvement*** to delivery system, but not critical for delivering water	• Secondary ditch improvements

3	***Major improvements*** to delivery system, and/or failure will cause major ***delivery challenges***	• Major ditch, canal, or diversion improvements • Reregulation, pump backs, terminal basins • Automation of major infrastructure
V. Increased Public Benefit - Opportunities and/or Use for General Public		
Score	Criteria	Examples
0	***No significant*** public benefit	
1	***Indirect*** public benefit	• High visibility
2	***Some direct*** public benefit	• Demonstration potential • Fisheries enhancements
3	***Broad*** public benefit	• Outreach efforts - Weeds, soil health, AIS • Improved public access
VI. Short-term Economic Risk - 1 to 3 years		
Score	Criteria	Examples
0	No impact from No-Action	
1	Minimal impact from No-Action and/or few impacted	
2	Moderate impact from No-Action and/or many impacted	
3	Major short-term impact from No-Action affecting a broad sector	• Drop structure maintenance
VII. Long-term Economic Benefit		
Score	Criteria	Examples
0	No lasting economic benefit	
1	Benefits last several years	
2	Benefits last 5 to 10 years	
3	Long-term, lasting impact	• Stream gaging stations
VIII. Scale of Benefit		
Score	Criteria	Examples
0	No people directly affected and/or small spatial extent	
1	Few people affected and/or small spatial extent	
2	Moderate number of people affected and/or moderate spatial extent	
3	Large number of people affected and/or large spatial extent	

The scoring results are shown by area in Table 6-4. Each project has a unique ID # that links the GIS to the projects database. The associated anticipated benefits for each project that collectively define the scores are shown in Figure 6-1. Project locations maps are shown in Figure 6-2 and Figure 6-3.

Table 6-4 - Project Scoring Results.

ID	Name	Location	Type of Project	Score
Lower Muddy Creek (Incised Section)				
4	Muddy Creek Geomorphic Resiliency Enhancements -	Multiple sites from Sun River to Power.	Bank Stabilization, Grade Control	**20**
10	Demonstration Drop Structure Maintenance	Multiple sites on lower river	Maintenance, Grade Control	**18**
12	Reactivate Oxbows/Meanders	Multiple sites in lower Muddy Creek	Riparian, Fisheries, Water Management	**16**
24	Grade Control at New Botha Bridge	Botha Property RM 5.7	Sediment Control, Grade Control	**15**
General Projects - Upper Basin (Above the Power Diversion)				
2, 23	Little Muddy Creek Grade and Erosion Control	Little Muddy Creek - Leonard and Schaefer Properties and BOR land.	Bank Stabilization, Grade Control, Sediment Control	**18**
21	Restore Channelized Segments and Floodplain Reconnection	Example site includes RM 39.7 to 40.9	Riparian, Fisheries, Water Management	**18**
9	Power Water Diversion Fish Passage	RM 29.5	Fisheries	**14**
General Projects - Lower Basin (Below the Power Diversion)				
3	Cutoff Revetment Repairs	Multiple sites (e.g., RM 18.2/RM18.6)	Bank Stabilization, Sediment Control	**19**
1	Sun River Ditch Drop	End of Sun River Valley Ditch	Irrigation Infrastructure	**9**
8	John Scott Septic	Lower Muddy Creek RM 2.4 Left	Bank Stabilization, Sediment Control	**4**
Tributary Work, including Spring Coulee and Tank Coulee				
5	Lower Spring Coulee Habitat Improvements	Lower Spring Coulee and Muddy Creek	Bank Stabilization, Fisheries, Riparian	**20**
25	Tank Coulee Habitat Enhancements Study	Tank Coulee (Extensive BOR and State lands)	Study	**19**
26	Spring Coulee Continued Work	Upper Spring Coulee	Fish Habitat, Grazing Management	**18**
13	Side Drainage Sediment Controls	For example, RM 10.3	Sediment Control, Irrigation Infrastructure	**15**
18	Culvert Replacement - Spring Coulee	13th Ln NE	Fish passage	**15**

ID	Name	Location	Type of Project	Score
Greenfields Irrigation District (GID) - Projects are under the direction of GID, but are included and scored according to their impact on Muddy Creek				
16	GID Expand J-Lake and Automate Outlet Controls	J-Lake, J-Wasteway, GM-100 Canal	Irrigation Efficiency	**22**
38	GID Reregulation Sites	Sites To Be Determined	Irrigation Efficiency	**22**
39	GID Pump-back Sites	Sites To Be Determined	Irrigation Efficiency	**22**
40	GID Terminal Basins	Sites To Be Determined	Irrigation Efficiency	**17**
22	Wasteway Controls (Thompson Drain)	0.25 mi west of 9th Ln NE	Irrigation Infrastructure	**13**
15	Thompson Drain / Schafer Property	Along Thompson Drain	Irrigation Infrastructure	**6**
41	GID Allocate More Water Rights	Sites To Be Determined	Irrigation Efficiency	**0**
General Projects and Studies - Not Ranked but Supported by SRWG				
11	Hillslope Failures Evaluation at Lower Spring Coulee	Multiple sites on Lower Spring Coulee	Study, Sediment Control, Irrigation Infrastructure	**NA**
27	Fill LiDAR Data Gap		Data Gap	**NA**
28	Stream Gages	Multiple Locations	Data Gap, Monitoring	**NA**
29	Fisheries Studies	TBD	Data Gap, Monitoring	**NA**

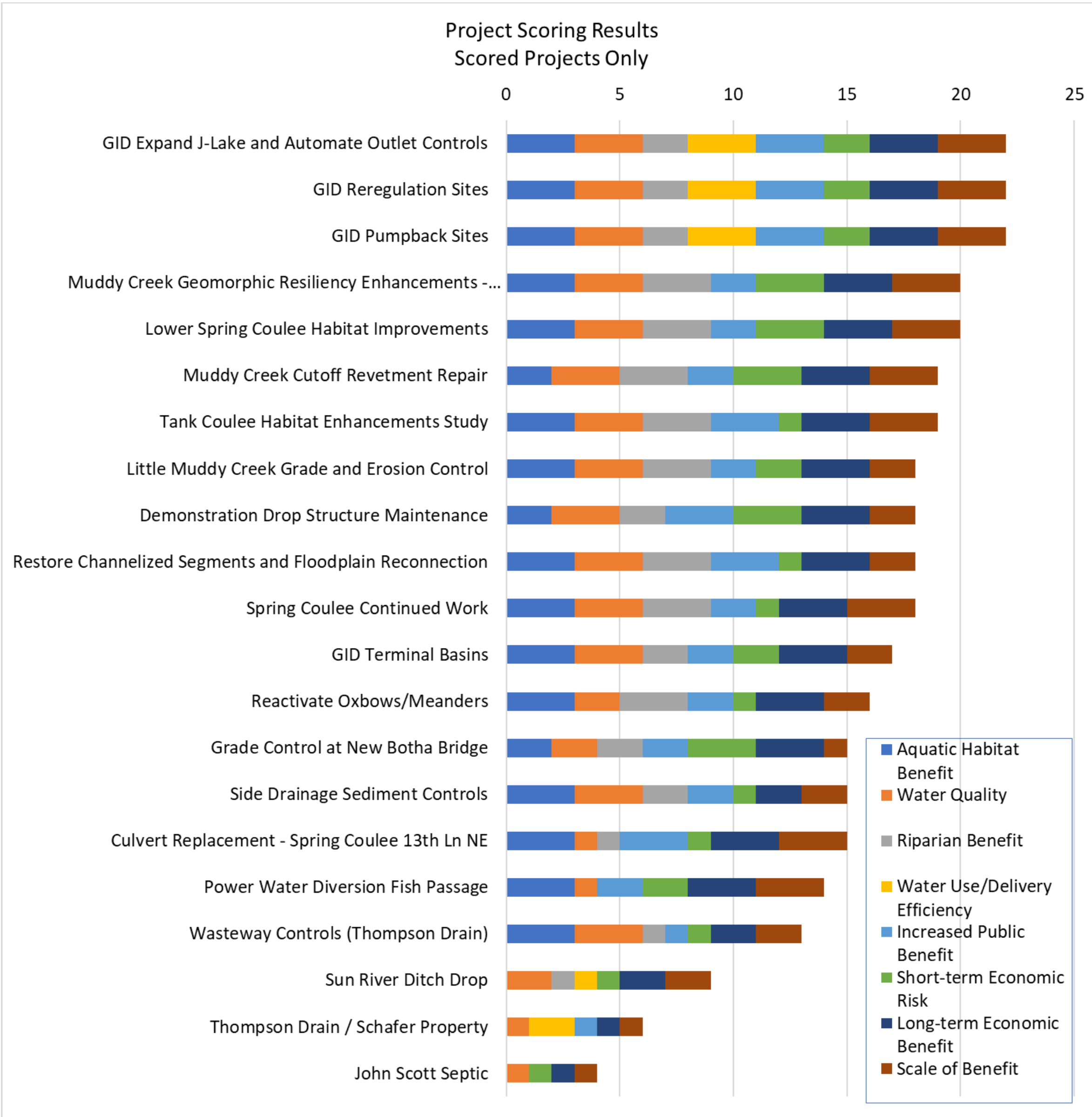


Figure 6-1. Project scoring results showing anticipated benefits for each project and resulting total score.

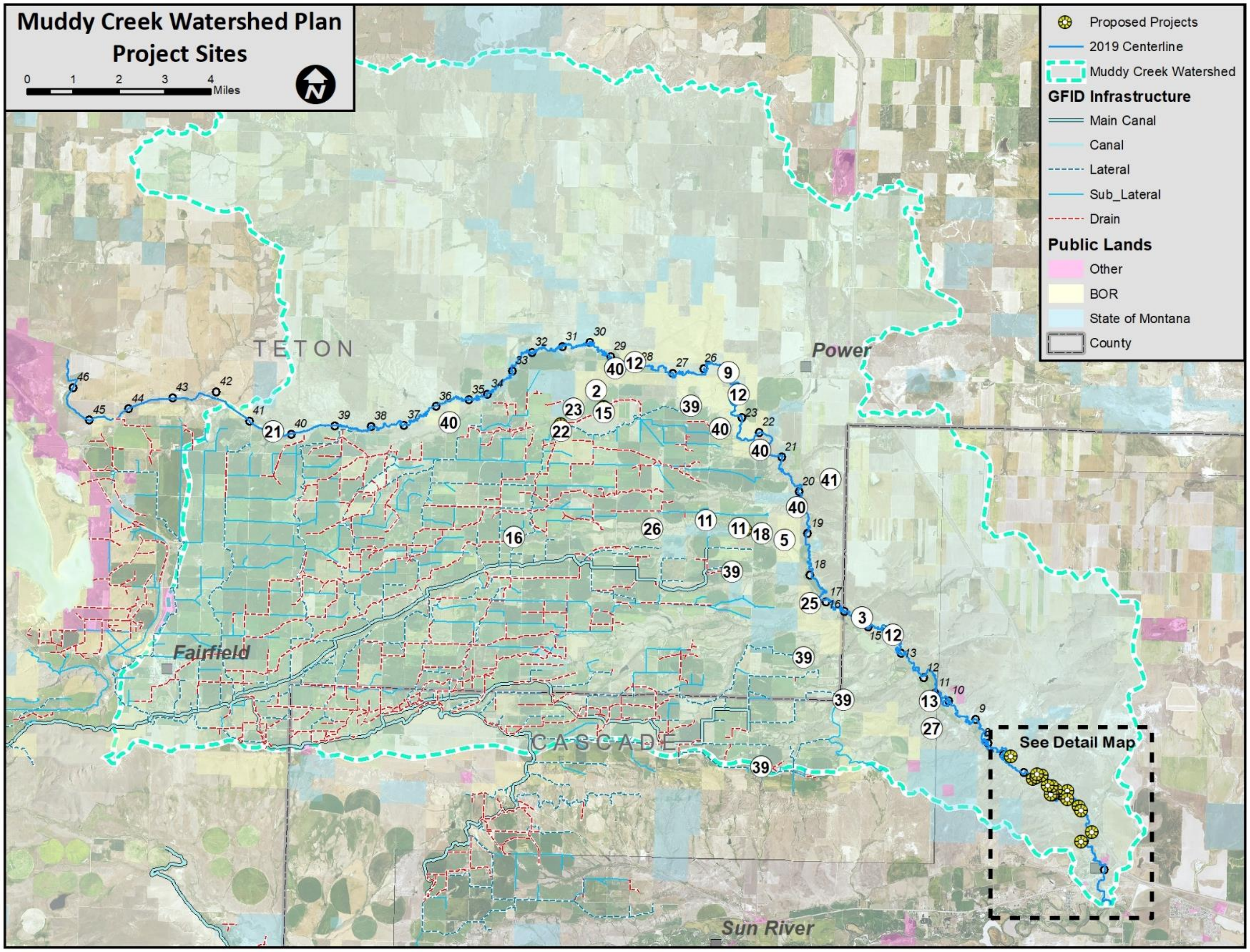


Figure 6-2. Muddy Creek project locations; numbers reflect ID in ranking table.

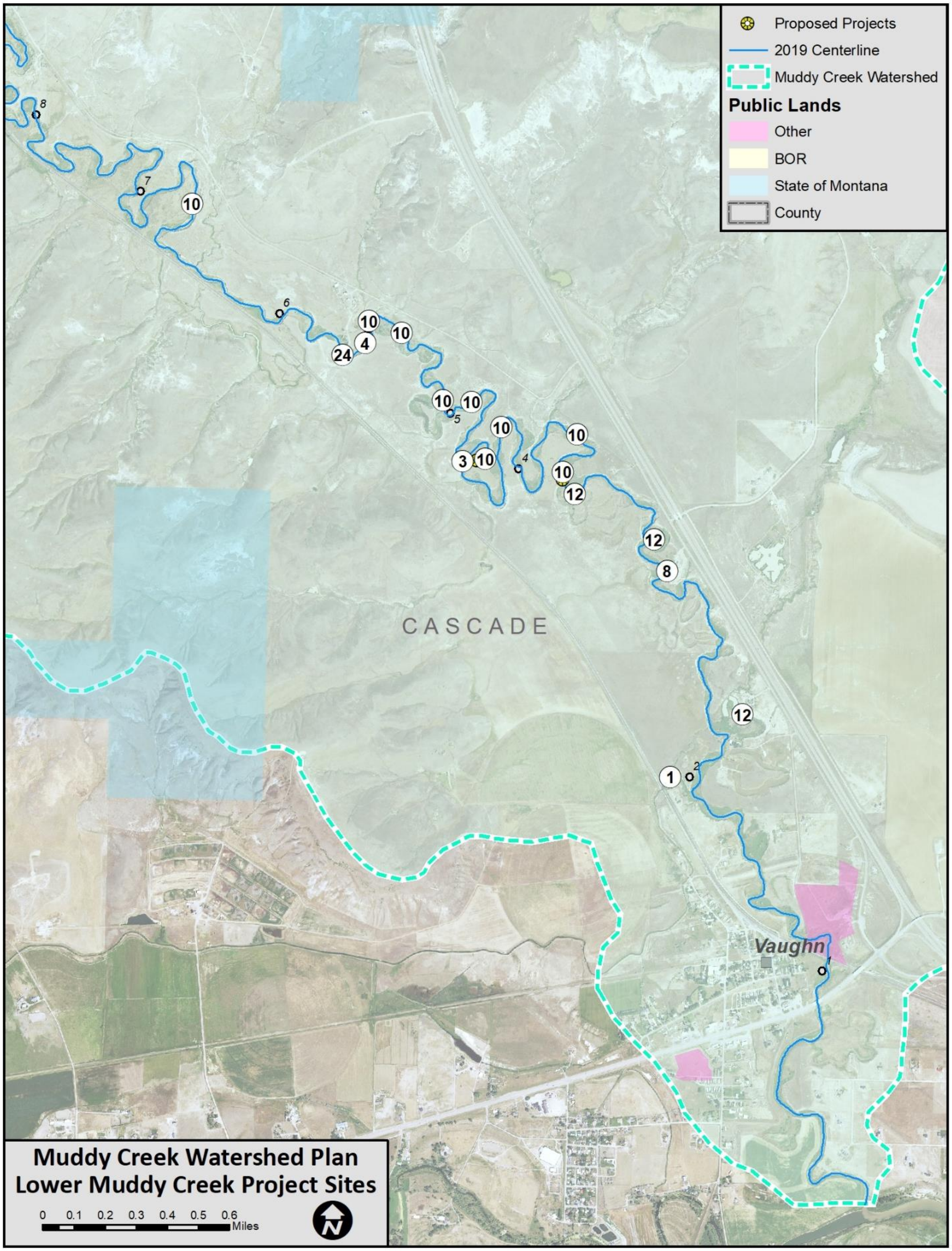


Figure 6-3. Lower Muddy Creek project locations.

6.2 Top Scoring Project Descriptions

The following section summarizes the 11 projects that received a minimum score of 18. The most recent available information has been used to describe the location, primary objectives, likely benefits, and status of each.

6.2.1 GID – J Reregulation and Wasteway Phases 1-3

J-Wasteway is a small reregulating facility at the head of Upper Spring Coulee that is on-line with the Greenfields Main Canal Lateral 100 (GM-100). It has two outlets including J-Wasteway, which feeds Upper Spring Coulee, and GM-100, which is a large canal that flows northwest for over 5 miles across the Greenfields Bench. The project consists of re-building the headworks on each of the two outlets and enlarging J-Wasteway by enlarging lateral containment berms. The two outlet controls will be able to communicate via automation upgrades. Phase 1 of the project replaced the GM-100 headworks with a smart headworks and was completed in 2020 (Section 4.1.3). Phase 2, which is the Spring Coulee headworks replacement, is under construction as of March 2022 (Section 4.1.4). The project will be fully functional when Phase 3 is completed, which is the expansion of J-Wasteway by raising the existing confinement berms. This project will allow for much better reregulation of irrigation water on the Greenfields Bench, which will reduce tailwater inputs into Upper Spring Coulee. As such, the project will generate substantial opportunities for Spring Coulee habitat restoration work.

Photo 6-1. View to the west of J-Lake from the original J-Wasteway Control Structure (May 2021).

6.2.2 Additional GID Reregulation Sites

Reregulation allows diverted water to be temporarily detained within the distribution system, which can dramatically increase the effectiveness of irrigation water management. This is an established strategic goal of GID, which is supported by the SRWG. Reregulation reduces operational losses, return flows, and emergency releases during power outages. The J-Wasteway Reregulation project as well as the SRS-71 headworks replacement on the Sun River Slope Canal are two examples of such projects; more projects like these will help reduce tailwater inputs into Muddy Creek and its tributaries, reducing the magnitude of augmented flow stressors on those channels. Additional projects to reregulate flows are considered highly beneficial to the system and thus were ranked high by the team.

6.2.3 GID Pump Back Sites

The concept of a Pump Back site is to use pumps in drain ditches to pump what would otherwise be irrigation tailwater back up gradient, higher into the distribution system. This allows that water to be distributed through the system a second time, which would reduce overall diversion requirements as well as tailwater volumes entering Muddy Creek. Similar to reregulation efforts, pump backs would reduce the overall inputs and geomorphic stressors on Muddy Creek and its tributaries. Pump Backs are considered a high priority for GID.

6.2.4 Muddy Creek Geomorphic Resiliency Enhancements - Grade Control and Bank Stabilization

As described earlier in this report, Muddy Creek has suffered from severe incision due to irrigation tailwater contributions for almost a century. Substantial work was performed in the 1990s to arrest the incision and control accelerated lateral bank erosion. Now, over 25 years later, there is substantial opportunity to enhance and expand these earlier projects to contribute additional geomorphic resiliency to Muddy Creek. Appendix B contains a preliminary design for such a project on about four miles of lower Muddy Creek.

Maintaining a stable channel profile is the foundation for this approach to improve resiliency on Muddy Creek. Arresting the downcutting process, which was the goal of the 1990s work, is critical as downcutting is the largest driver of bed/bank erosion and the largest threat to any other restoration work. The general concept proposed in Appendix B for future work is to stabilize, smooth, and lift the existing grade, to narrow the channel using bioengineered bank treatments, and to lower existing inset floodplain surfaces such that broad complex floodplain surfaces and abandoned meanders can support riparian vegetation, wetlands, and high flow side channels (Photo 6-2).

Photo 6-2. View upstream of perched meander with high potential for reactivation and restoration.

6.2.5 Lower Spring Coulee Habitat Improvements

Lower Spring Coulee has a high potential for restoration, especially with concurrent work happening upstream to reduce irrigation water inflows at J-Lake. With those upstream improvements slated for completion in the next few years, there will soon be an opportunity to evaluate the resulting flow conditions on Spring Coulee and develop restoration strategies accordingly. Lower Spring Coulee has suffered from some downcutting and accelerated bank erosion, although it also supports a good gravel substrate and broad valley bottom, both of which provide opportunities for restoring geomorphic process and generating high quality fish habitat. As with Muddy Creek, this will require an incorporation of grade stabilization measures if incision is ongoing, and bioengineered bank treatments can be used to narrow the channel, improve bank cover, and expand floodplain connectivity. Stakeholders noted that the section of creek below the 13th Lane NE road crossing is especially unstable and landowners expressed interest in restoration projects that may include floodplain reconnection, riparian recovery, and fish habitat improvements. Replacing the culverts at the road crossing was also discussed to improve habitat connectivity and sediment transport continuity (Photo 6-3 and Photo 6-4).

The mouth of Spring Creek Coulee is at River Mile 18 on Muddy Creek. Any restoration actions on Spring Creek Coulee that reduce either sediment or flow inputs therefore have the potential to benefit almost half of the length of Muddy Creek.

Photo 6-3. View downstream of Lower Spring Coulee and road crossing culverts at 13th LN NE.

Photo 6-4. View upstream of Lower Spring Coulee and road crossing culverts at 13th LN NE.

6.2.6 Muddy Creek Cutoff Revetment Repair

Lower Muddy Creek is highly sinuous on its lower reaches, and in several locations specific bank treatments were built in the 1990s to prevent large bends from cutting-off and causing additional oversteepening and downcutting of the channel. Several stakeholders have expressed concern that these treatments need repair and maintenance to prevent cutoffs to occur over some bends where the neck of the meander is especially narrow. Figure 6-4 is one example of a high-risk meander cutoff at RM 4.7 on Muddy Creek; whereas the cutoff revetments were typically built on the upstream limb of the meander, the erosion risk is commonly on the downstream limb, especially where grade controls create large scour holes that accelerates erosion on both banks.

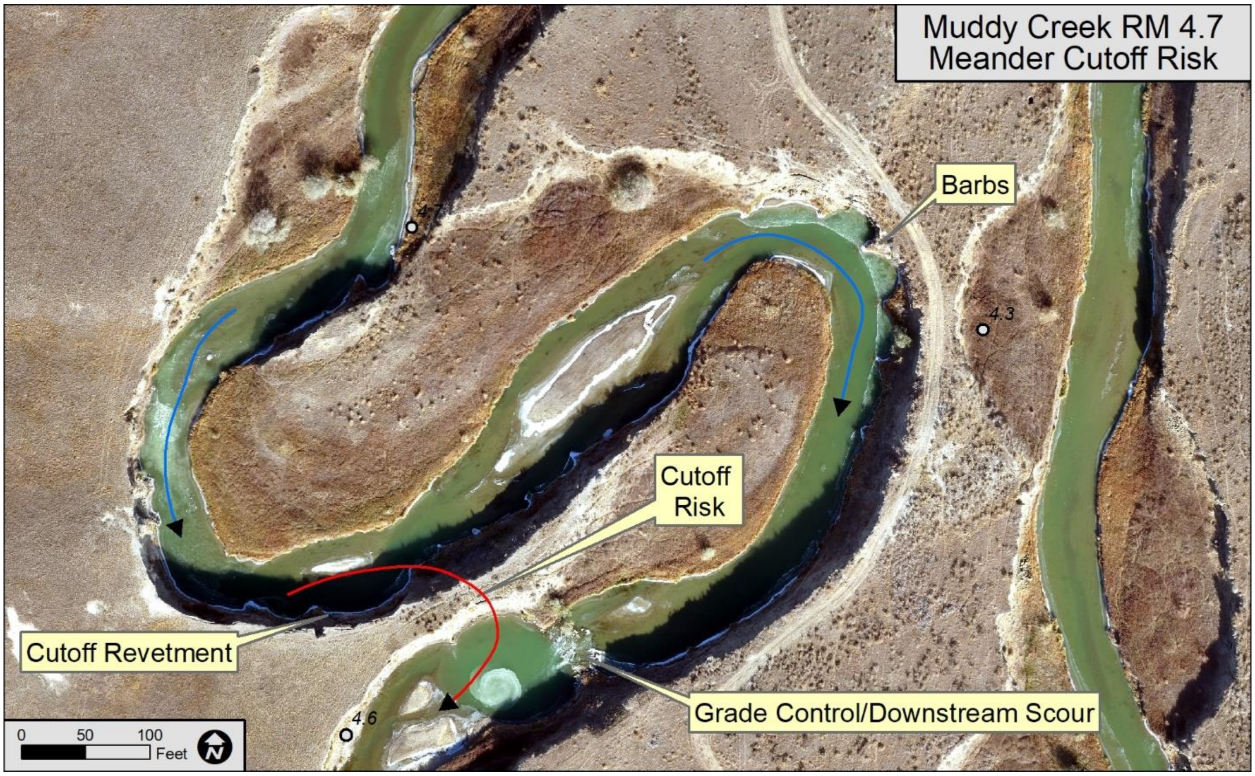


Figure 6-4. Muddy Creek meander cutoff risk, RM 4.7; note scour hole-driven bank erosion on downstream limb of meander below grade control.

6.2.7 Tank Coulee Habitat Enhancements Study

Tank Coulee is a ~6-mile-long tributary that enters Muddy Creek at RM 17, about a mile downstream of Spring Coulee. Similar to Spring Coulee, Tank Coulee has enlarged and incised in response to irrigation tailwater inflows. The coulee has extensive swaths of public lands (Bureau of Reclamation and State of Montana) within a wide valley bottom which makes it especially amenable to large scale restoration efforts that can benefit the public (Photo 6-5). There are currently no established plans to mitigate inflows into Tank Coulee in a similar fashion to Spring Coulee. As a result, the proposed Tank Coulee Habitat Enhancements Study is a multi-pronged evaluation of the potential to reduce stressors on the system (reduce flow augmentation) and improve resilience and habitat. Tank Coulee has a gravel-rich sediment load which will benefit fisheries restoration projects.

Photo 6-5. View upstream of Lower Tank Coulee segment owned by the State of Montana.

6.2.8 Little Muddy Creek Grade and Erosion Control

Little Muddy Creek is located fairly high in the Muddy Creek Watershed, entering Muddy Creek at RM 28.5. This small stream receives substantial inputs from the Greenfields Bench to the south, where a dense network of drains parallel to the creek. Thompson Drain was noted by landowners as especially problematic, with Little Muddy Creek receiving irrigation returns through canal leakage, wasteways, etc. Up to 12 feet of downcutting has been noted on the creek, and mass failure of banks is common (Photo 6-6). Proposed strategies to remedy Little Muddy Creek instability includes flow control, grade control, and bank stabilization.

Photo 6-6. Mass failure of streambank on Little Muddy Creek below Thompson Drain.

6.2.9 Demonstration Drop Structure Maintenance

The Muddy Creek Task Force collaborated with the Cascade Conservation district in the mid-1990s to "stabilize the planform and gradient of the stream" which resulted in the demonstration project described at several locations in this report. The project was anchored by a large rock sill structure built in February 1994 at RM 3.15 to hold gradient at that location (Photo 6-7). An additional 10 rock grade control structures were built upstream of the sill to accommodate additional downcutting. Although the structures were constructed largely at grade, the additional downcutting caused them to become steep drops, rapidly reaching a cumulative drop of 15 feet as of October 1996.

The mid-1990s grade and bank stabilization efforts on Muddy Creek have proven to be an effective means of arresting additional downcutting and reducing rates of bank erosion. As they were built ~25 years ago, they appear to have met primary project objectives regarding channel stabilization. They are becoming increasingly at risk of flanking however, as large scour holes on the downstream sides of the structures have caused massive bank destabilization. The Demonstration Drop Structure Maintenance project would consist of a careful inventory of grade control stability and prioritization of maintenance needs. Any maintenance efforts could include the incorporation of fish passage at each structure.

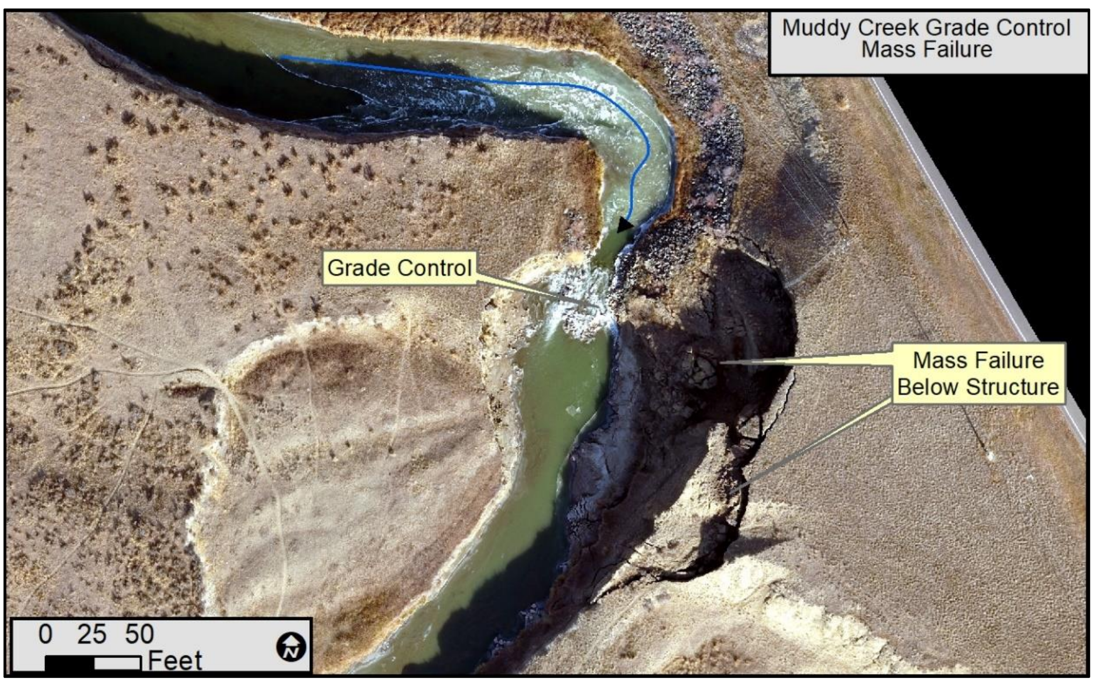


Photo 6-7. November 2021 drone image of hillslope destabilization below lowermost grade control sill, Muddy Creek RM 3.1.

6.2.10 Restore Channelized Segments and Floodplain Reconnection—Upper Muddy Creek

Sections of upper Muddy Creek have been straightened which, coupled with flow augmentations, has caused the small channel to downcut, reducing floodplain access and ecological function (Photo 6-8). Because the creek is relatively small and the incision relatively minor, there are excellent opportunities to apply relatively low-cost restoration techniques (such as beaver dam analogs) to restore connectivity, promote aggradation, and re-hydrate the historic floodplain. Approaches described as “low-tech process-based restoration” utilize simple, low-cost structural additions such as wood and simulated beaver dams to mimic natural functions and initiate recovery processes. This work can commonly be done very inexpensively with volunteer labor (Wheaton, et. al 2019).

Photo 6-8. Upper Muddy Creek showing small inset floodplain surface (RM 34.4).

6.2.11 Upper Spring Coulee Continued Work

Section 3 describes a habitat improvement project on Upper Spring Coulee that was initiated in the late 1990s (Photo 6-9). The project has been successful and there are ample opportunities for its expansion. Project elements discussed for Upper Spring Coulee include reed canary grass removal/replacements, fisheries enhancements, grade control, bank reshaping, channel realignment and riparian protections. This is an excellent project to couple with ongoing GID work upstream at J Wasteway. Currently, low tech process-based restoration approaches, such as beaver dam analogs (BDAs), would be inappropriate on Spring Coulee due to the high flows delivered through J-wasteway. However, if that project can effectively mitigate flow pulses, there is excellent opportunity to apply relatively low-cost approaches that have proven to yield excellent results (e.g. bioengineered bank treatments to narrow the channel, BDAs to raise the bed and slow flows).

Photo 6-9. View downstream, Upper Spring Coulee project site.

7 Preliminary Implementation Strategy

As many of the projects outlined in this report are largely conceptual, it is somewhat premature to develop a detailed implementation strategy at this time. However, it is possible to assign likely leadership roles for given project types, while acknowledging that most projects will require partnerships. The projects can also be assigned a rough timeline based on the current understanding of stakeholder interest, feasibility, and need. In terms of funding, both well-established and new funding sources can be tracked for future work.

7.1 Project Leads

In general, the Greenfields Irrigation District has taken major responsibility for system upgrades in the distribution system to help reduce the stressors on receiving stream channels. The Sun River Watershed Group has shown effective partnering capabilities with the Cascade, Teton, and Lewis and Clark Conservation Districts to acquire funds and implement projects on the stream channels themselves. These different entities have access to different funding mechanisms as well, so the leadership role is an important consideration in early project development.

Figure 7-1 shows an example layout for project leads for the top-ranked projects described in Chapter 6. The primary lead for irrigation infrastructure upgrades is GID, and these top-ranked projects include reregulation and pump backs. Higher priority projects that focus on Muddy Creek resilience could be led by SRWG in partnership with local CDs. Projects with a direct aquatic habitat component could effectively integrate expertise and funding from Montana Fish Wildlife and Parks (FWP).

7.2 Project Timeline

Project timelines depend on a range of factors including feasibility, sponsor capacity, and funding. Presuming those factors are effectively met, a proposed timeline can be developed that reflects the overall scale of benefit of a project coupled with our general understanding of stakeholder interest and imminent need (Figure 7-2). This proposed timeline includes “Active,” “0-5 Years” and “Greater than 5 Years” to implement.

Active projects are those already in progress. As a conceptual design has been recently developed for a Muddy Creek Geomorphic Resiliency Project it can be considered active. GID projects related to reregulation that have substantial momentum are active, including the J-Reregulation and SR-71 Headworks projects. The Upper Spring Coulee project is active as it was expanded in 2022 with new construction. Projects with a 0-5-year target for implementation include strategies known to be highly effective (pump back sites and more reregulation), projects of imminent need to maintain channel stability on Muddy Creek (cutoff revetment repair and drop structure maintenance), and projects shown to be effective where landowner interest is high (Lower Spring Coulee habitat work). Projects in the Greater Than 5 Year timeframe include those that are less developed and thus will likely take longer to implement, such as work on Upper Muddy Creek, Tank Coulee, and Little Muddy Creek.

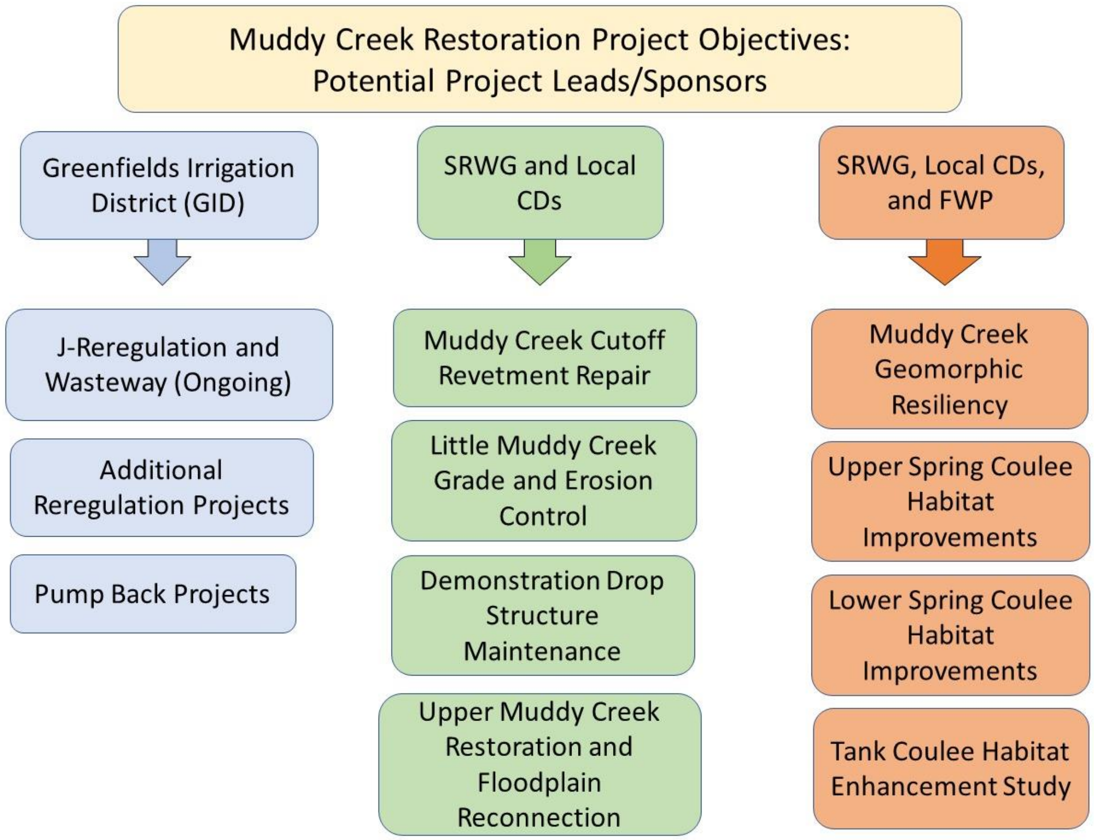


Figure 7-1. Schematic diagram of potential leads for specific projects.

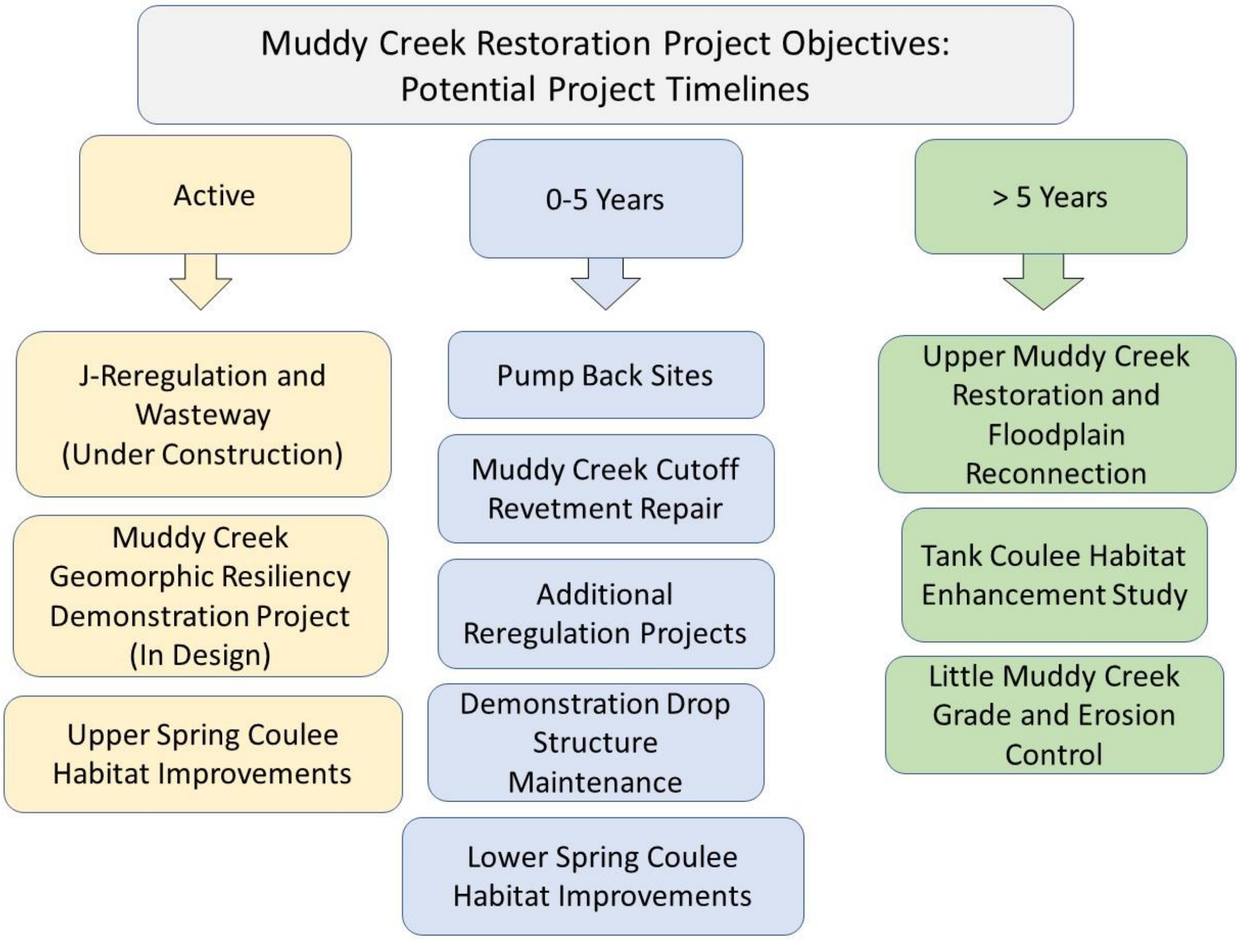


Figure 7-2. Schematic showing potential timeline for project implementation.

7.3 Potential Funding Sources

Projects implemented on Muddy Creek in recent decades have typically been funded primarily by state and federal agencies. Table 7-1 summarizes the range of funding sources that have been tapped for projects in the Muddy Creek Watershed since 1990 (Rollo, 2020). These are all somewhat traditional funding sources from government agencies. Appendix C contains a much broader list of funding sources that may be applicable.

Table 7-1. Summary of primary funding sources for Muddy Creek Projects, 1990-2015 (Rollo, 2020)

Fiscal Agent	Funding Source	Project Type
Sun River Watershed Group	EPA/DEQ	Muddy Creek Stream Projects Coordinator Salary USGS Gages Saline Seep Assessment
Conservation Districts	DNRC	Coordinator salary Muddy Creek Erosion Control
	Title III Coal Tax (DNRC)	Software
	Bureau of Reclamation	Rock used for Muddy Creek Erosion Control Aerial Survey
	US EPA/DEQ	Water Quality Monitoring Muddy Creek Stream Projects Coordinator Salary
	Montana Department of Environmental Quality	Muddy Creek Demonstration Project
	Montana FWP	Riparian Enhancements
	Fish and Wildlife Foundation	Muddy Creek Demonstration Project
GID	Bureau of Reclamation	Project Assistance Muddy Creek Crossing Pump Project to Reduce Wastewater J-Wasteway Project to Reduce Wastewater
	DNRC	Wastewater and Erosion Reduction; Pump Installation
State of Montana	Old West Regional Commission	Water Quality Sampling
Individual Landowners	Montana FWP	Spring Coulee Habitat Enhancements Upper Muddy Creek Stream Project

8 Relevant Best Management Practices

The following section contains a summary of some best management practices that can be applied broadly to support the Muddy Creek management/restoration strategy described in this report.

8.1 Grazing, Livestock, and Riparian Management BMPs

Grazing Management BMPS are intended to protect water quality and aquatic/riparian habitats by improving the health and vigor of desired plant communities, reducing erosion, and improving soil conditions. Livestock exclusions can help protect sensitive areas such as streambanks, wetlands, and riparian zones. Assistance in grazing and livestock management can be obtained through the NRCS Conservation Stewardship Program and NRCS Montana Focused Conservation. Some useful hyperlinks are provided below.

https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/csp/#

https://www.nrcs.usda.gov/wps/portal/nrcs/mt/technical/cp/

https://www.nrcs.usda.gov/wps/portal/nrcs/mt/water/resources/nrcs144p2_057479/

8.1.1 Riparian Buffers and Filter Strips

Riparian Buffers

- ✓ Nitrogen
- ✓ Phosphorous
- ✓ Sediment
- ✓ Temperature
- ✓ Terrestrial/Aquatic Habitat

Riparian areas are important sources of livestock grazing, as one acre of riparian meadow can potentially support 10 to 15 times the stocking rate of uplands (EPA, 2015). However, riparian grazing has become an increasing concern due to its negative effects on stream and floodplain health. The degradation of riparian vegetation by livestock results in a loss of streambank stability, shading/temperature, woody debris recruitment to channels for fish habitat, overhanging bank habitat, and capture of sediment from adjacent hillslopes. Applying BMPs for grazing in riparian areas is often a foundational strategy to improve stream health as they help arrest several causes of stream health decay, including physical habitat degradation, temperature spikes, and nutrient loading. Filter strips are a type of riparian buffer that is placed on the downgradient edge of a field, pasture, or animal confinement area. The strip will help absorb pollutant runoff from these facilities by filtering out particulate matter and absorbing nutrients.

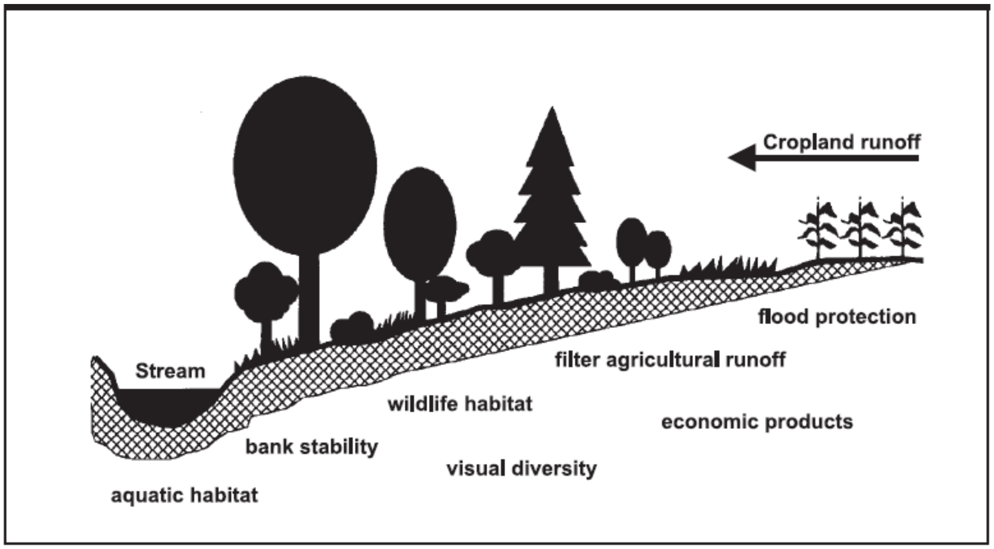


Figure 8-1. Types of benefits provided by riparian buffers (EPA, 2015).

8.1.1 Grazing Management

Grazing management BMPs are intended promote uniform forage usage and uniform nutrient deposition. Grazing management can greatly improve plant growth while reducing soil erosion and pollutant runoff. Common approaches to grazing systems include rotation, rest-rotation, deferred rotation, short-duration grazing, and high intensity-low frequency grazing.

Grazing Management

- ✓ Nitrogen
- ✓ Phosphorous
- ✓ Sediment
- ✓ Temperature

The Montana Rangeland Partnership has a program where ranchers work one-on-one with partnership technicians to create grazing plans that incorporate all grazing lands of the operation. More information can be found at:

http://montanarangelandspartnership.org/

8.1.2 Corral/Pen Relocation

Moving part or all of an animal confinement structure away from streams and wetlands will reduce or prevent off-site transport of pollutants into those waterbodies.

Relocate Corrals

- ✓ Nitrogen
- ✓ Phosphorous
- ✓ Sediment
- ✓ Temperature

8.1.3 Off-Stream Watering

Off-Stream Watering

- ✓ Nitrogen
- ✓ Phosphorous
- ✓ Sediment
- ✓ Temperature

Off-stream watering refers to a permanent or portable watering system for livestock or wildlife. These systems can be placed away from live waterbodies to reduce the impacts of cattle trampling and waste. There have been developments in plastics and pipes that have increased the options for watering livestock on pasture. Although electricity is often the most reliable and cheapest sources of energy to run pumps, other options include solar, wind-powered, 12-volt battery, or gas/diesel generators.

Livestock watering can provide the following benefits (Powder Basin Watershed Council):

- Provides more flexibility in managing grazing systems, manure distribution and pasture utilization
- Provides a year-round supply of disease-free, freeze-proof water for livestock that is warmer in the winter and cooler in the summer
- When used in conjunction with protected heavy-use areas, they provide a solid, mud-free watering area
- Off-channel watering decreases soil erosion and helps maintain stable stream banks as well as reduces damage to irrigation ditches, preventing leakage and improving efficiency
- Improves water quality in streams while reducing incidents of injury and illness in livestock

8.1.4 Water Gaps

Water Gaps

- ✓ Nitrogen
- ✓ Phosphorous
- ✓ Sediment
- ✓ Temperature

Water gaps control livestock access to drinking water on a stream by creating a controlled access point. The NRCS recommends that water gaps be designed to admit only one animal at a time.

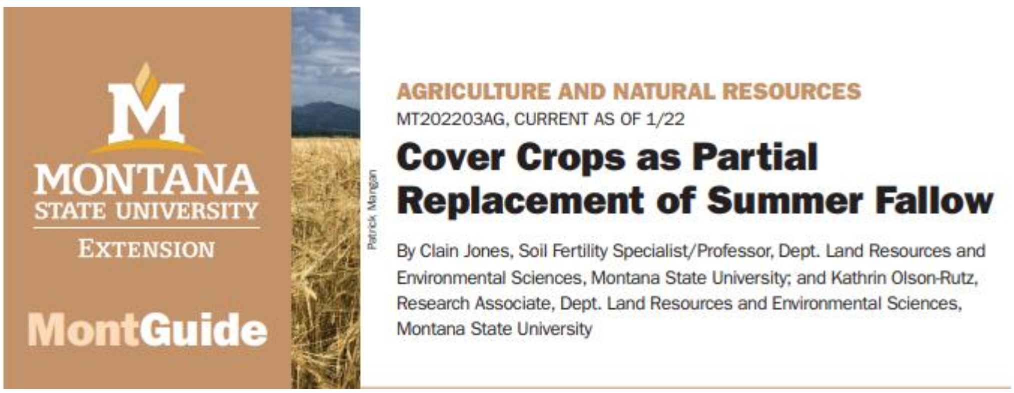
8.2 Irrigation and Crop Management BMPs

8.2.1 Cover Crops

Cover Crops

- ✓ Nitrogen
- ✓ Phosphorous
- ✓ Sediment
- ✓ Salinity

Planting vegetation on what would otherwise be fallow ground can prevent mobilization and transport of pollutants when the crop itself is unavailable to perform similar functions. Cover crops can potentially improve subsequent crop yields through enhanced soil health, reduced soil erosion, reduced fertilizer, herbicide and pesticide crops, and protect water quality. According to Montana State University Extension, research on mixed cover crops is in its infancy, so many benefits may be as yet unknown.


MONTANA STATE UNIVERSITY EXTENSION

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Patrick Mangan

AGRICULTURE AND NATURAL RESOURCES

MT202203AG, CURRENT AS OF 1/22

Cover Crops as Partial Replacement of Summer Fallow

By Clain Jones, Soil Fertility Specialist/Professor, Dept. Land Resources and Environmental Sciences, Montana State University; and Kathrin Olson-Rutz, Research Associate, Dept. Land Resources and Environmental Sciences, Montana State University

8.2.2 Irrigation Tailwater Control

Tailwater Control

- ✓ Nitrogen
- ✓ Phosphorous
- ✓ Sediment
- ✓ Salinity

Irrigation tailwater control practices may include wasteway rehabilitation, tailwater capture and reuse, settling basins, remotely controlled headgates, or revegetation of tailwater induced erosional features. Tailwater capture and reuse refers to reusing excess water from gravity irrigation systems that convey water back to the irrigation system for reuse through a pump and pipeline or ditch system. Other approaches increase management efficiencies or mitigate tailwater-induced erosion.

8.3 Restoration BMPs

Restoration-related BMPs involved on-the-ground work to restore natural processes.

NRCS

8.3.1 Restoration of Hydrologic Function

The NRCS describes this as a BMP to re-establish connectivity, groundwater elevations, stream flow, and wetland functions to altered systems. Reestablishing floodplain function or reconnecting a disconnected floodplain can also help address non-point source pollution while improving aquatic and terrestrial habitats. Practices may include breaching or removing dikes, levees, railroad grades or road grades or relocating channels to higher abandoned floodplain surfaces.

Hydrologic Function

- ✓ Nitrogen
- ✓ Phosphorous
- ✓ Sediment
- ✓ Salinity
- ✓ Terrestrial/Aquatic Habitat

8.3.2 Settling Basins or Sediment Traps

Sediment traps can be constructed as pits, or depressions and also using straw wattles, silt fences or other techniques to trap or settle sediment out of a water column. These features commonly need to be periodically cleaned out to maintain function. On Muddy Creek tributaries, bioswale detention ponds be used to trap sediment derived from tailwater-induced erosion.

Sediment Traps

- ✓ Phosphorous
- ✓ Sediment

8.3.3 Revegetation

Planting, protecting, or reestablishing permanent vegetative cover in upland or riparian areas can be effective in reducing non-point source pollution. It may include seeding, sprigging, shrub planting, fencing, willow lifts, sod mats, non-native plant removal and native plant reintroduction.

Revegetation

- ✓ Nitrogen
- ✓ Phosphorous
- ✓ Sediment
- ✓ Temperature
- ✓ Terrestrial/Aquatic Habita

8.4 Culvert Replacement

Poorly functioning culverts can create major issues for flood hazards and impede aquatic organism passage and movement. They can also cause accelerated erosion. Culverts can be replaced by better functioning culverts or bridges. Culverts that serve no real purpose can be entirely removed.

Culvert Replacement

- ✓ Phosphorous
- ✓ Sediment
- ✓ Aquatic Habitat Connectivity
- ✓ Flood Mitigation
- ✓ Road Stability

9 Summary

Since the Greenfields Bench was developed for irrigation in the early 1900s, Muddy Creek has experienced intense flow augmentations from irrigation return flows that are sourced outside of its watershed. Managing the resulting erosion and water quality degradation on the stream and its tributaries has proven to be a formidable challenge over the last several decades, although extensive work has been completed over the years to better manage the tailwater delivery and its impacts. Although landowners who live and work in the Muddy Creek Watershed have indicated that they manage to adapt to the altered environment, they are clearly concerned about the future of their land and water.

Since the last big push for Muddy Creek restoration and management in the late 1990s, technological advances have become available to help guide restoration work including Geographic Information Systems (GIS), LiDAR topography, better aerial imagery, and drone capabilities. New techniques have been developed that concentrate on process-based restoration that goes beyond traditional engineered structural designs. In addition, advances in irrigation infrastructure technology, such as telemetered headgates, can enable water managers to better manage the tailwater delivery to receiving stream channels. All of these advances are reflected in the suite of projects compiled and locally vetted in this plan.

The SRWG and GID are well aligned to collaboratively implement this plan as a living document that can be updated regularly to acknowledge achievements, track progress, set aspirational timelines and identify new opportunities. With a continually evolving plan in hand, we are confident that SWRG and its partners can efficiently and effectively restore key functions of Muddy Creek that provide long-term resiliency towards drought, climate change, and continued land use pressures.

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