Stillwater River Flood Rehabilitation River Assessment Triage Team (RATT) 2023 Summary Report

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Stillwater Valley Watershed Council

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List of Figures

List of Tables

Contents

Executive Summary

In mid-May of 2022, the Stillwater River at Absarokee was at an all-time low flow for that date (395 cfs on May 15). About a month later, an "atmospheric river" of moisture from the Pacific reached southern Montana, dropping 2-3 inches of rain on the mountain snowpack. This caused an estimated 4-9 inches of water to rapidly run off the Beartooth Mountains. The Stillwater River had been running at normal flows in early June, but then it rose rapidly to 6,400 cfs the night of June 11. Although this is a typical spring runoff peak, it was only the initial rise. By late morning on June 13, a massive runoff peak estimated at 16,900 cfs reached Absarokee. Flows dropped within a day to 10,000 cfs, but the overall waning of the peak lasted 3 ½ days. After this event, there were three additional smaller magnitude flood peaks, all of which exceeded 6,000 cfs, that lasted into the first week of July. Our preliminary post-flood evaluation of West Rosebud Creek indicates that the peak flow of Rosebud Creek near Absarokee could have been 50 percent larger if Mystic Lake hadn't captured so much runoff.

The June 13 event was an all-time record flood that exceeded a 500-year event on the Stillwater River (a 500-year event has a 1 in 500 chance of occurring in any given year). Damage from the main flood event as well as the subsequent smaller peaks was extensive, although it was concentrated on more dynamic segments of the river that are not geologically confined by erosion-resistant materials. Across the evaluated segments of East Rosebud Creek, West Rosebud Creek, and the Stillwater River, just over 300 acres of ground was mapped as eroded due to bank movement. The river channels widened and created entirely new threads, increasing overall channel area. Approximately 10.8 miles of side channels became disconnected from the river during low flows due to extensive deposition of coarse bedload material. Thirteen bridges and an estimated 17 structures were destroyed. Numerous irrigation diversions were damaged or lost. Thousands of feet of public roadways were damaged, and approximately 5 miles of access road to East Rosebud Lake on U.S. Forest Service property were destroyed or rendered inaccessible. Massive debris piles consisting of large trees, pieces of destroyed structures, bridge decks, etc. accumulated in the channel and on the floodplain.

To document these flood impacts and develop response strategies, the Stillwater Valley Watershed Council (SVWC) organized numerous local funders to assemble and support a River Assessment Triage Team (RATT). The team included a professional geomorphologist, hydrologist, fishery biologist, geographic information specialist and writer/community educator.

The RATT work was performed during the winter of 2022-2023. The team performed scientific assessments of the flood, visited landowners in the river corridor, assessed flood impacts on each property, developed conceptual rehabilitation alternatives to address those impacts, and identified potential conservation opportunities. The goals of the RATT effort are to effectively document the nature and impacts of this flood, and to identify means of responding to the event that can support local economies while promoting the sustainability of both long-term land uses and ecological function of the Stillwater River, East Rosebud Creek, and West Rosebud Creek.

1. Introduction

This report focuses on documenting the physical impacts of the June 2022 flood on the Stillwater River, West Rosebud Creek, and East Rosebud Creek within Stillwater and Carbon Counties, Montana through the analyses of the scientists of the RATT as well as the landowners directly impacted. Specific impacts are described, and recommendations are provided for flood mitigation strategies associated with each type of impact. Remarks and impressions offered by many landowners during the site visits are highlighted in blue insets throughout the report. Ultimately, the response to impacts of the flood requires thoughtful consideration of geomorphic process, ecological processes, and cost-benefit ratios. The goal of the RATT team is to provide information to help the community in its commitment to supporting the local economy as well as the long-term integrity of the remarkable resource that is the Stillwater River watershed.

The report is divided into the following eight chapters and two appendices:

Chapter 1: Introduction

Chapter 2: General Location and Setting

Chapter 3: Other Ongoing Efforts Related to June 2022 Flood

Chapter 4: Hydrologic Context

Chapter 5: Major Human Influences on River Function

Chapter 6: Major Impacts of the 2022 Flood

Chapter 7: Recommendations for Flood Impact Mitigation

Chapter 8: Summary and Discussion

Appendix A: Summary of Bank Protection Alternatives

Appendix B: Summary of Potential Funding Sources

Note: Data for the flood are continuing to be analyzed by hydrologists. The numbers below reflect the best available data at the time of this work. Numbers related to flood magnitudes and frequencies may change as more hydrologic analysis is completed.

1.1. Summary of Recommendations for Landowner Flood Response Projects

General impressions and recommendations from the RAT Team regarding landowner approaches to addressing flood damages include the following:

"Man, I've got a lot of respect for this river"

1. The June 2022 flood was an "event of geologic scale", causing major changes both to the river channels and the valleys they occupy. These changes are long-term and thus will require sensible adaptations. Riparian landowners now border a new river with new challenges. It is important to understand the profound geomorphic change in many sections of the river and to consider how to address those changes without unnecessarily impacting the natural character and associated ecological health of the river with "fixes" that might prove cost ineffective and detrimental.

2. When floods cause massive changes in a stream, there is typically a long period of adjustment as the river reworks flood sediment and vegetation begins to recover. Continued adjustments on the assessed streams should be expected for many years as the river re-establishes equilibrium conditions of width, slope, and riparian integrity. After major flooding, it is common for landowners to feel the need to "put things back how they were", however, in other places in Montana that experienced similar flooding in 2011 (notably the Musselshell), those landowners that simply monitored areas of concern for the first few years ended up with the best outcome, both financially and in terms of river health. Sometimes a rapid response can backfire as the river continues to adjust.

3. There are places that warrant well-engineered erosion control treatments to protect infrastructure and high value property. This includes impacted transportation infrastructure (roads and bridges), residences under immediate threat of undermining or which are vulnerable to the next flood, and irrigation diversions.

4. The most popular erosion control treatment used on private lands has often been quarried rock riprap. This approach is typically expensive, and often unnecessary. Rock riprap locks streams into place, and it is often detrimental for long-term river health, be it bankline conditions (no vegetation, shade, or undercutting) or long-term channel movement that supports riparian health. Professional engineering plans are often required by regulatory agencies for significant bank protection and restoration projects. Landowners should be aware that engineers will commonly design projects using conservative assumptions and factors of safety that usually produce more protective but more expensive projects. Landowners should have a detailed discussion with their engineer and contractor of the value of the property to be protected, the minimum acceptable design flood flow and water depth (10, 25, 50 or 100-year event), and the costs versus benefits of several options. There are plenty of options beyond traditional full-bank rock riprap such as brush matrices, root wads and other woody debris, or toe rock (quarried or native boulders) with a sloping planted upper bank. Less aggressive erosion control treatments can be applied as short-term, temporary protective measures; this can be an effective approach as problem areas shift in coming years as the river continues to change. These alternatives can be incorporated into engineering designs. We encourage all flood-affected property owners to review the wide variety of streambank restoration options described in Appendix A of this report as well as the "Montana Stream Permitting Guide" available from the Montana Department of Natural Resources (2020). Landowners can also contact scientists and engineers in public agencies and in the private sector for assistance.

5. Rock riprap can and does fail. Between 2001 and 2011, at least 4 miles of riprap failed on the Yellowstone River, and most of that failure was driven by flanking and then accelerated erosion behind the treatment, leaving the rock sitting out in the river (USACE and YRCDC, 2015). Typical

failure mechanisms include flanking on either the upstream or downstream ends or loss of the rock toe due to scour. Flanking is a common problem where property lines result in the treatment starting or ending at an inappropriate location on the bank. If the channel down cuts along the bank, this can cause rock to launch, damaging the bank treatment. These failure mechanisms should be considered at any potential armoring site.

6. It is important to understand that erosion control will not stop flooding. Floodwater management tends to be most effective when it includes restoring/maintaining overflow channels, preserving/restoring an intact riparian zone, and avoiding the construction of obstacles to flow or structures in the floodway. Building new floodplain barriers (e.g. berms/levees/dikes) can have unintended impacts, and thus aren't typically permittable.

7. Cost-benefit analysis is a key component of strategy development. Bank stabilization projects are expensive, typically costing at least $100 per cubic yard for placed riprap, which may need to be placed at a density of 1.5 cubic yards per yard of bank. Landowners should compare the cost of treatments (design, permitting, construction, and maintenance) to the value of the land.

8. Riparian landowners and local governments should consider setting structures back from the riverbanks for the best insurance against flood risk. Once residences (or other structures) are built on streambanks, the "die is cast", and most landowners will eventually employ aggressive erosion control measures that will cumulatively destroy key aspects of the river's ecological integrity such as riparian health, and fish and wildlife habitats. Our findings showed clearly that wider housing setbacks would have prevented costly damage and allowed the river to accommodate major flooding, which science indicates could become more common in coming decades. The bank erosion we observed against high terraces demonstrated how bank height alone will not protect landowners from the risk of damage.

"In retrospect, building this close to the riverbank might not have been the best idea."

9. Bank erosion during the flood recruited huge volumes of sediment that was then deposited within the active channel, in places raising the streambed and causing flooding to occur at flows lower than normal. This is the reason many people experienced flooding well after flows dropped below the pre-flood bankfull discharge. This phenomenon will likely affect Stillwater valley residents in coming years until the river reestablishes a more typical form. Coarse gravel flood deposits can be reshaped to shift areas of high erosion pressure, restore channel capacity, and construct bank treatments. Care should be taken to maintain low flow channel complexity when sediment is disturbed in the channel (avoid creating a trapezoidal channel cross section). Sediment disturbance between Nye and Woodbine is highly discouraged due to the critical importance of this reach to spawning trout. Woody debris accumulations in the channel and on the floodplain can be similarly rearranged to improve floodplain flow routing and in-stream channel dynamics. Any plans for in-

stream work should be discussed with permitting agencies early in project development to identify potential issues.

1.2. Acknowledgements

We would like to extend our thanks to the Stillwater Valley Watershed Council for coordinating project contracting, management, and field work. Lindsey Clark and Tommy Flanagan were instrumental in baseline data collection from landowners regarding flood damages. Site visit coordination was effectively carried out by Lindsey and Tommy such that we could not have completed the project without their direct support. Additional financial and logistical support was provided by Sharon Flemetis of the Stillwater Conservation District (SCD).

We would like to extend our sincere appreciation for the groups that have contributed to funding this effort, including:

- Absarokee Civic Club
- Columbus Community Foundation
- Nye Community Foundation
- Stillwater Protective Association
- Stillwater Conservation District
- Absarokee Community Foundation
- Beartooth RC&D (Resource Conservation & Development)
- Montana Watershed Coordination Council, Watershed Fund Capacity Support Grant
- Private donations.

We would also like to recognize and thank all of the landowners who requested our assistance, provided access to their lands, and shared their experiences regarding the nature of the flooding, its impacts, and associated challenges they currently face. Their observations of river process were thoughtful and greatly helped us understand the nature of this unprecedented event. Several of their quotes are inserted throughout this report.

Our favorite field assistant, Harper Clark, deserves a special commendation for her perseverance, humor, and navigational abilities during some demanding days in the field.

2. Project Location and General Conditions

The Stillwater River Watershed lies within the Yellowstone River Basin of Montana and Wyoming (Figure 1). It is approximately 1,066 square miles in area, and about 40% (403 square miles) of that is occupied by the East/West Rosebud Creeks sub-watershed (Figure 2). The headwaters are located in the Beartooth Mountains of south-central Montana and the rivers flow northeastward to meet the Yellowstone River at Columbus, Montana. The Stillwater is 65 miles long from its headwaters in the Beartooth Mountains to its mouth at Columbus (Feltis and Litke, 1987).

The watershed extends into Park and Sweetgrass Counties, however the streams focused on in this assessment are within Stillwater and Carbon Counties (Figure 2).

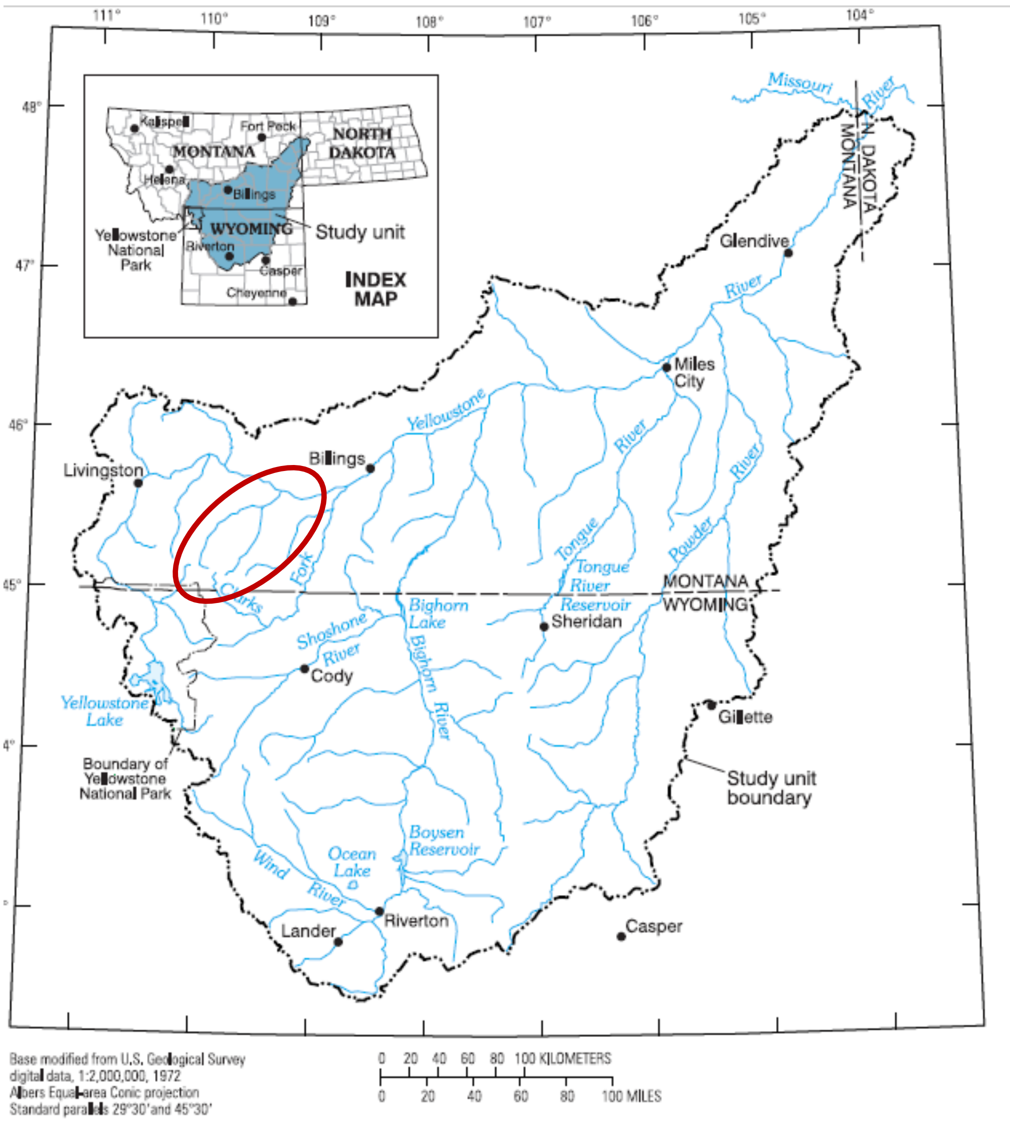


Figure 1. Yellowstone River Watershed with project area circled (USGS, 1998).

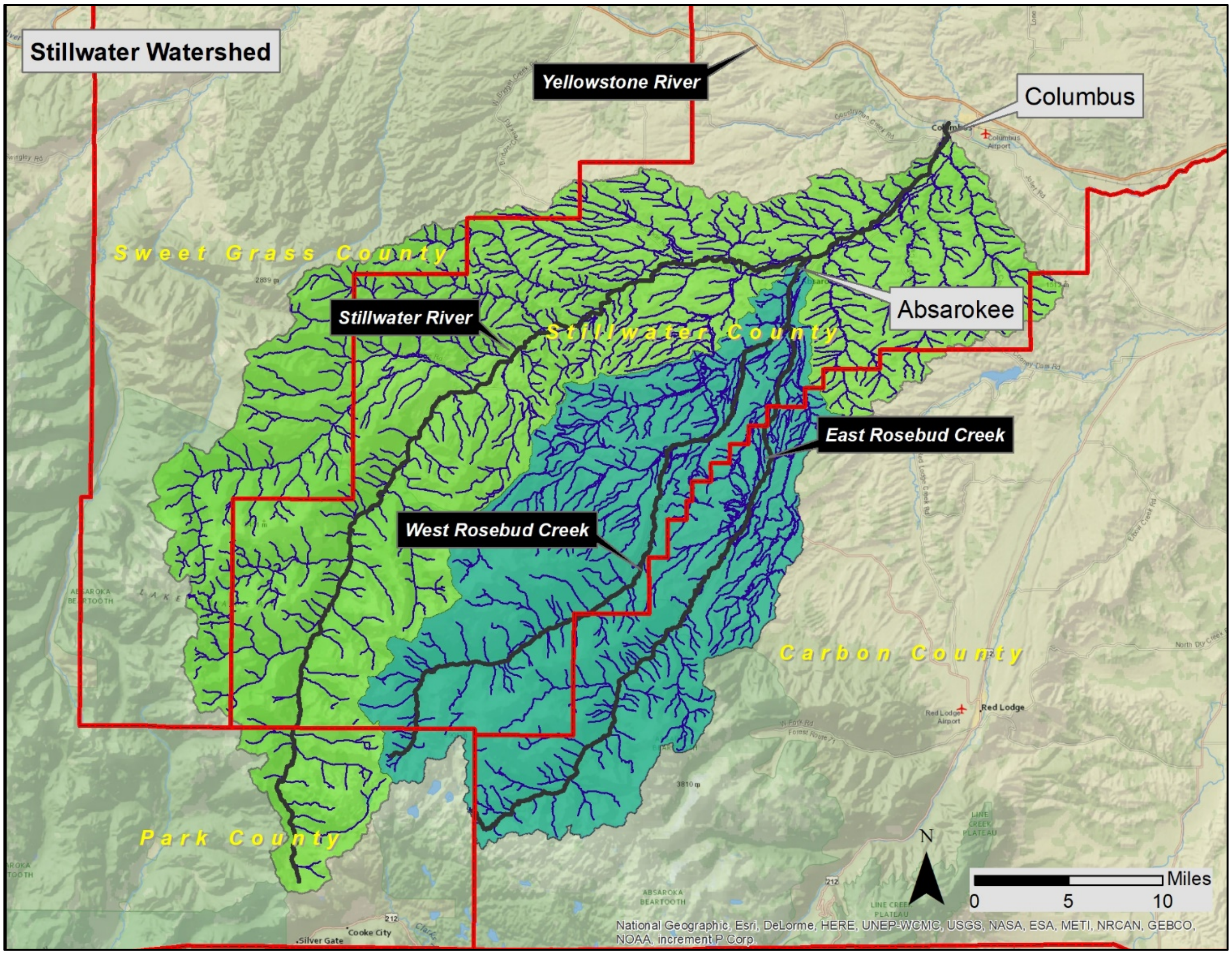


Figure 2. Stillwater River Watershed highlighting the Stillwater River, West Rosebud Creek, and East Rosebud Creek within Stillwater and Carbon Counties.

2.1. Geology

As the Stillwater River and Rosebud Creek flow northeastward out of the mountains towards the Yellowstone River Valley, they transition from confined channels within narrow, deep glaciated canyons carved into metamorphosed granitic bedrock to broad alluvial valley streams that are bounded by sedimentary rocks and young alluvial terraces. Some of the oldest terrace gravels laid down by the ancestral Stillwater River are perched 200 to 600 feet above the modern valley bottom, forming caps on bedrock.

Probably the most famous geologic feature in the watershed is the Stillwater Complex, which lies along the northern margin of the Beartooth Mountains. The Stillwater Complex is a highly unique mineral deposit formed within Precambrian age, mafic to ultramafic layered intrusive rocks (Figure 3). Magma was intruded into sedimentary rocks as a horizontal sill that was subsequently tilted such that the ore body now stands nearly vertical (USGS, 1998). Mineral deposits in the Stillwater Complex include chromium, nickel, copper, and platinum-group elements (PGE). The complex has been identified as having the largest identified PGE and chromium resources in the United States. The outcropping mineralized body is about 30 miles long and up to 5 miles wide, extending from the upper project area on the Stillwater River to the northwest where it is also mined in the Boulder River Watershed (USGS 1979).

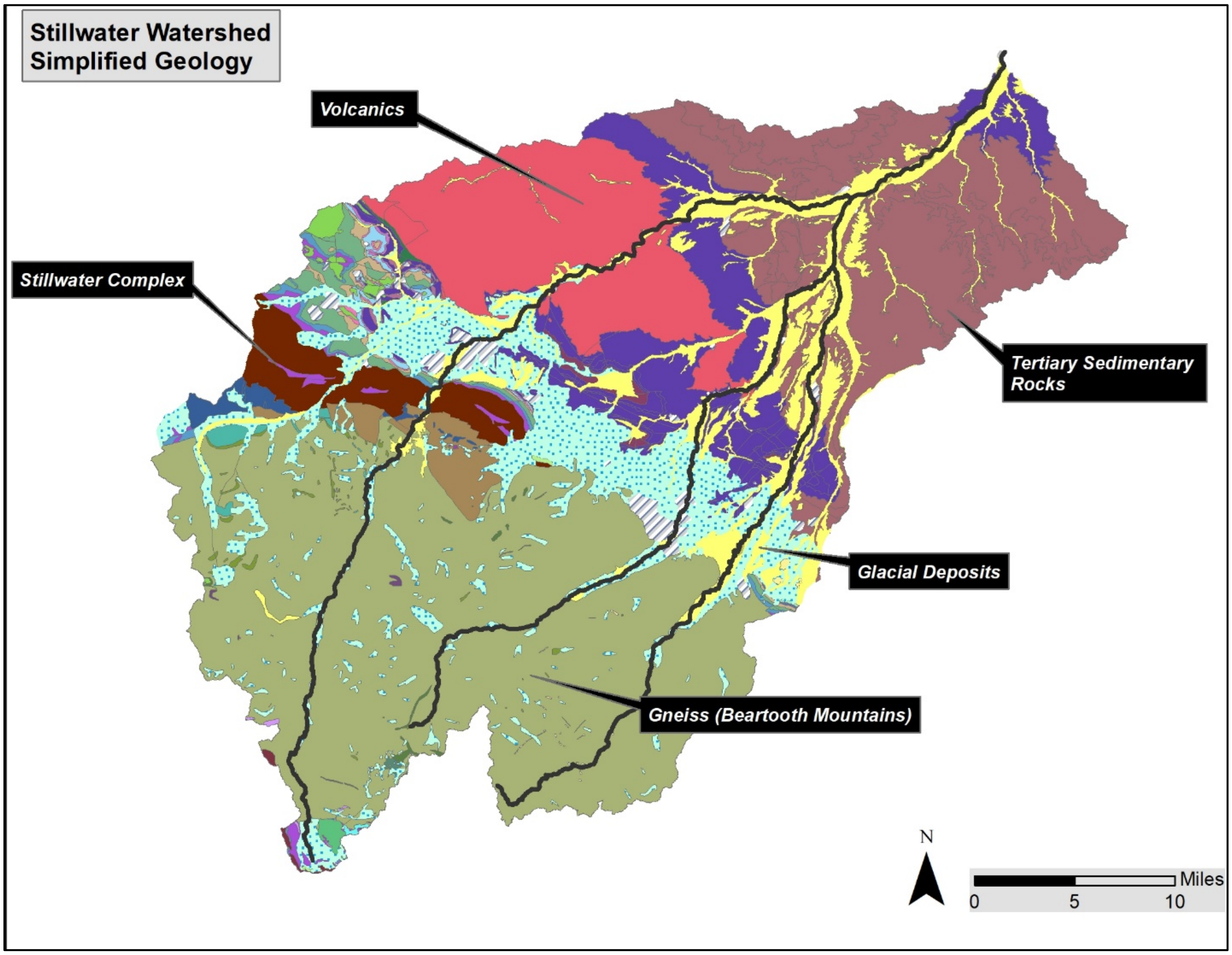


Figure 3. Simplified geologic map of the Stillwater Watershed (modified from MBMG).

Downstream of the Stillwater Complex lies the Sliderock Mountain area, which contains volcanic lava flows and mudflows (lahars). Figure 3 shows how the Stillwater River and East/West Rosebud Creeks all flow northward off the Beartooth Mountains which are largely made up of metamorphic rocks (gneiss), then cross several miles of glacial deposits before entering larger stream valleys in the lower basin. The mapped down-valley extent of the most recent limit of ice in the valley bottoms is shown in Figure 4. Glaciers extended below Nye on the Stillwater River and down to within a few miles of Roscoe on East Rosebud Creek. As the rivers flow northeastward beyond the glacial deposits, they tend to show notable changes in slope.

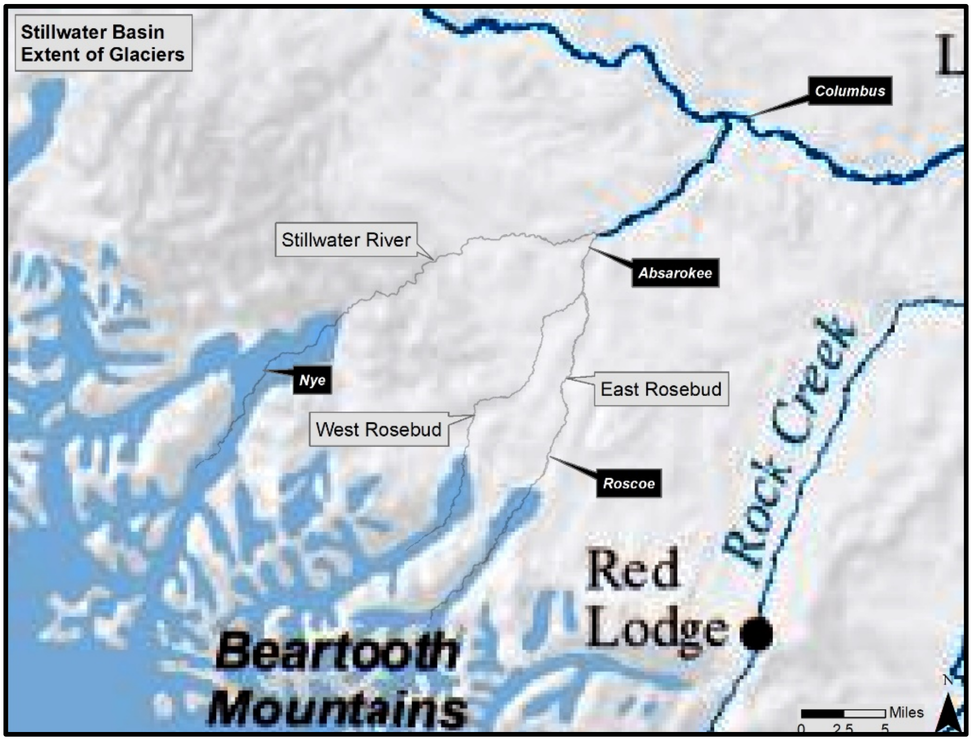


Figure 4. Map showing last glacial limit of Cordilleran Ice Sheet and Alpine Glaciers in blue (Smith et. al, in press).

2.2. Geomorphology

The general geomorphology of the project area streams includes high elevation headwaters areas of the Beartooth Plateau draining through confined canyons that ultimately broaden downstream. Within the upper watersheds, massive landslide deposits are common (Figure 5) as well as extensive glacial deposits consisting of highly variable sediments ranging from sands to massive glacial erratic boulders. These deposits can strongly influence river valley size, shape, and slope (Figure 6). We observed reaches where the Stillwater and Rosebud valleys were impinged upon by landslide deposits and alluvial fans from side drainages. Further downstream the glacial headwaters are evident, with very coarse boulder bedload material stored in both the riverbed and banks (Figure 7).

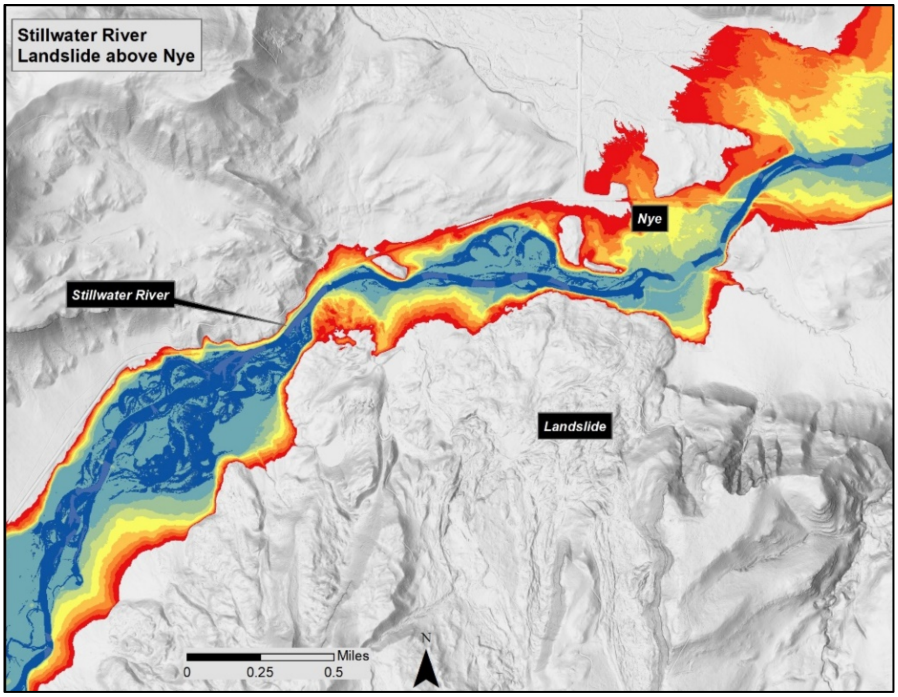


Figure 5. LiDAR hill-shade showing relative elevations in stream corridor; steeper terrain of valley margins (orange) grades to gentler (blue) within the valley. Note the massive landslide on south side of river just upstream of Nye that confines the river valley bottom.

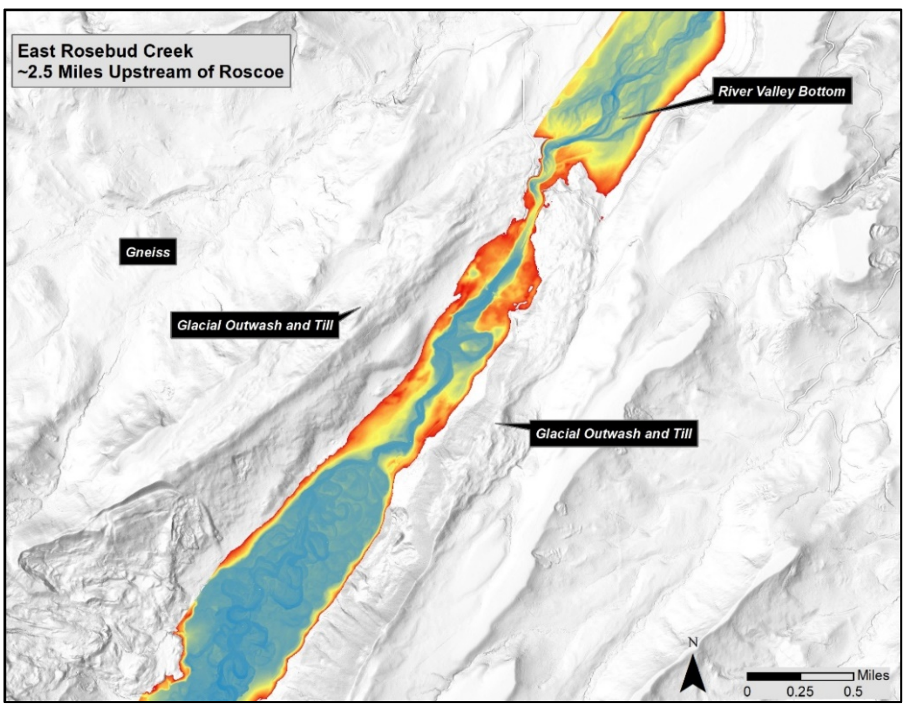


Figure 6. LiDAR hill-shade showing relative elevations in stream corridor; note influence of glacial outwash/till deposits on valley form on East Rosebud Creek. The creek steepens substantially as it exits the outwash/till deposits.

Figure 7. Large boulders in bed material, Stillwater River below Nye.

Figure 8 through Figure 10 show water surface profiles for the segments of the streams evaluated in this report. The East Rosebud, West Rosebud, and upper Stillwater all show geologically controlled slope breaks, in which the reaches immediately below the bedrock canyons tend to have lower slopes as they traverse the thick glacial outwash deposited from the melting of the montane glaciers, then abruptly steepen below. Below Absarokee, the Stillwater River has a fairly consistent slope 0.62%.

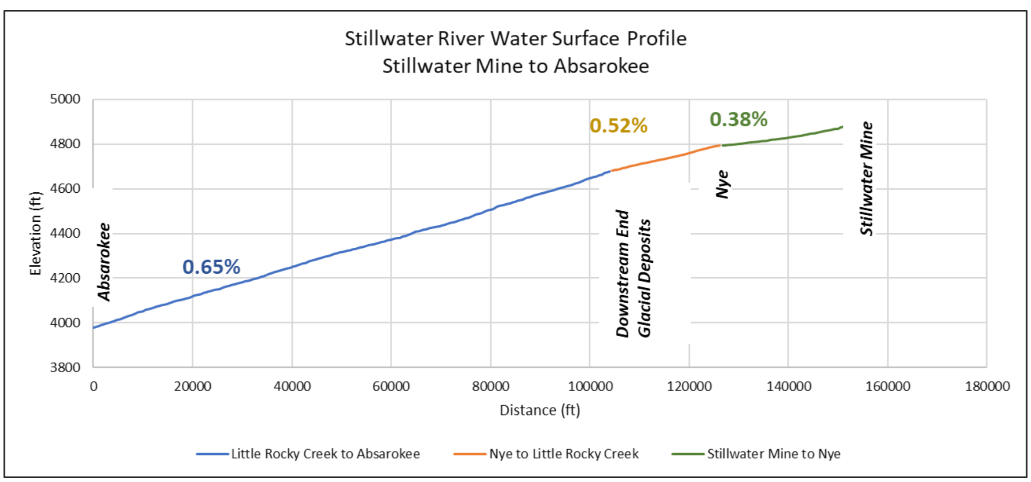


Figure 8. Water surface profile extracted from LiDAR for upper and middle Stillwater River.

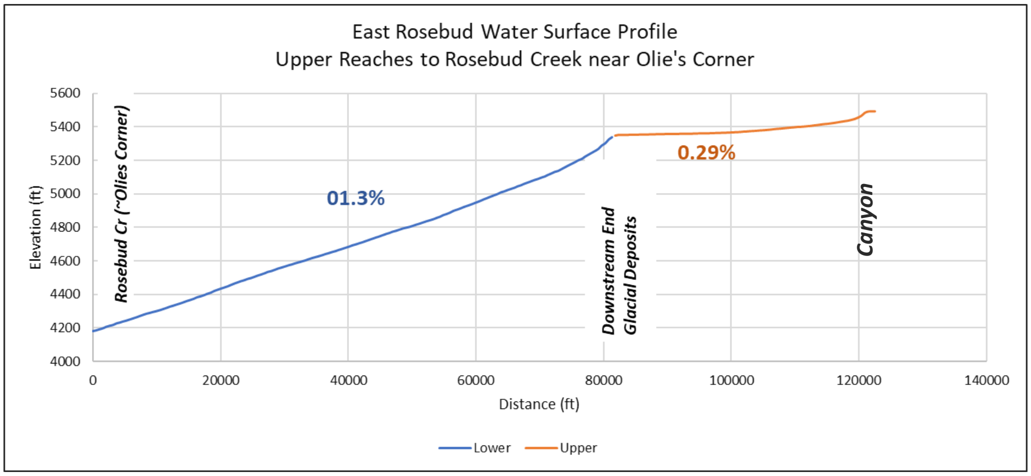


Figure 9. Water surface profile extracted from LiDAR for East Rosebud Creek.

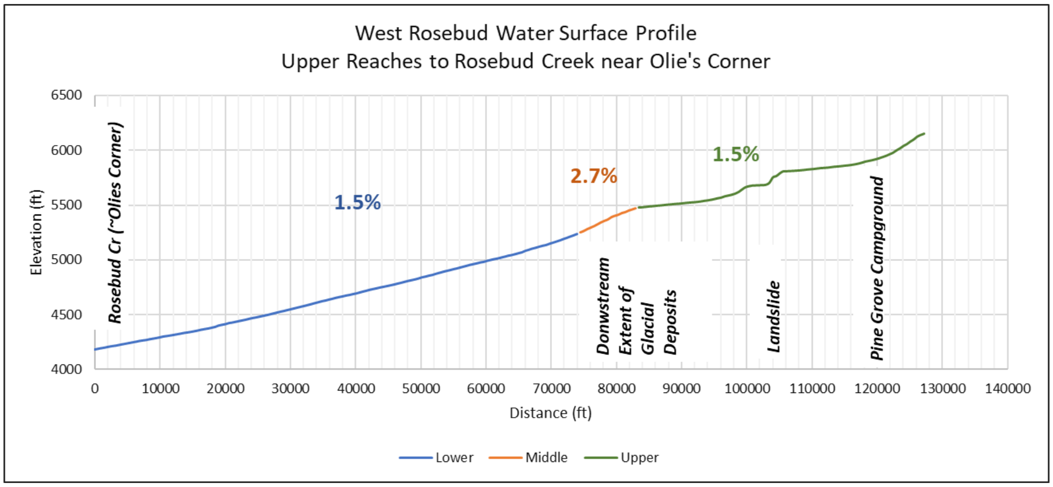


Figure 10. Water surface profile extracted from LiDAR for West Rosebud Creek.

2.3. Fisheries

The Stillwater River historically supported native cutthroat trout, and small remnant populations are still present in upper tributaries and lakes in the Beartooth Mountains. Throughout the project area cutthroat are not present and the fishery is dominated by non-native brown trout and rainbow trout. In the Montana Statewide Fisheries Plan (MTFWP, 2019), the Stillwater River is described as a priority water under FWPs drought policy and faces potential fishing closures during severe drought conditions that can occur in late summer. The Stillwater River has nine fishing access sites and supports high recreational use including angling and recreational floaters, bank angling, and camping. East Rosebud Creek and West Rosebud Creek are described as having desirable fisheries but limited public access. The Montana Fish, Wildlife and Parks (MTFWP) fisheries management direction for the Stillwater River and its tributaries are summarized in Table 1.

Table 1. Fisheries Management Direction for the Stillwater River Drainage (MTFWP, 2019, subject to updates).

Water Body	Miles	Species	Recruitment Source	Management Type	Management Direction
Stillwater River and Tributaries	**70 miles in mainstem and 451 miles in tributaries**	Rainbow Brown trout	Wild	Restrictive Regulations	Manage harvest to support high quality angling opportunity. Reduce numbers/ prevent invasion where Yellowstone cutthroat trout are potentially impacted
		Yellowstone Cutthroat Trout	Wild	Liberal Regulations/ Conservation	Allow harvest as part of Combined Trout limit for this drainage. Protect populations via habitat projects and removal of nonnatives where opportunities exist. Consider establishing new populations where opportunities exist.
		Mountain Whitefish	Wild	General	Maintain Numbers
		Brook Trout	Wild	General/ Suppression	Reduce numbers/prevent invasion where Yellowstone cutthroat trout are potentially impacted. Manage for sport fishery with high levels of harvest in other areas.
		Nongame species (native and	Wild	Conservation	Maintain connected populations, support ecosystem function.
Habitat needs and activities: Reduce entrainment of trout in irrigation ditches. Protect existing trout spawning habitat.					

2.3.1. Electrofishing Trends on the Stillwater River (Moraine and Absarokee)

Fish sampling in the Moraine reach of the Stillwater River has recorded primarily a brown trout fishery, with very few resident rainbow trout. The population density of brown trout has declined over time from over 1200 to about 200 fish per mile since 2000 (Figure 11). FWP also found an increasing percentage of larger fish caught, which indicates that recruitment (successful spawning) has substantially decreased (Figure 12). This has been attributed to decreased snowpack/annual flows over time and a loss of juvenile fish habitat. This declining brown trout trend is being seen on many Montana rivers.

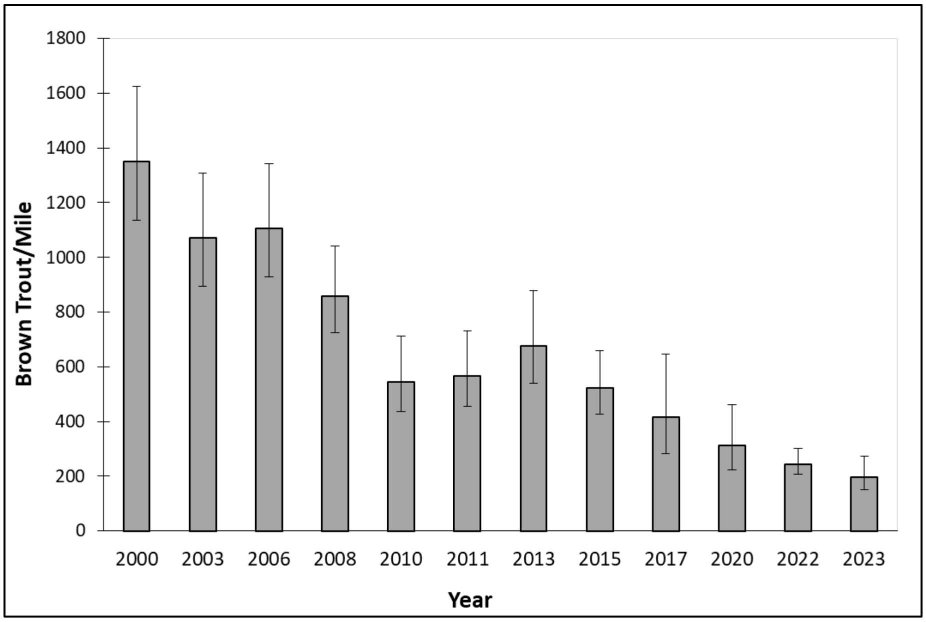


Figure 11. Brown Trout population estimates for fish 7 inches and greater for the Moraine electrofishing section of Stillwater River by year. The error bars represent the upper and lower 95% confidence intervals.

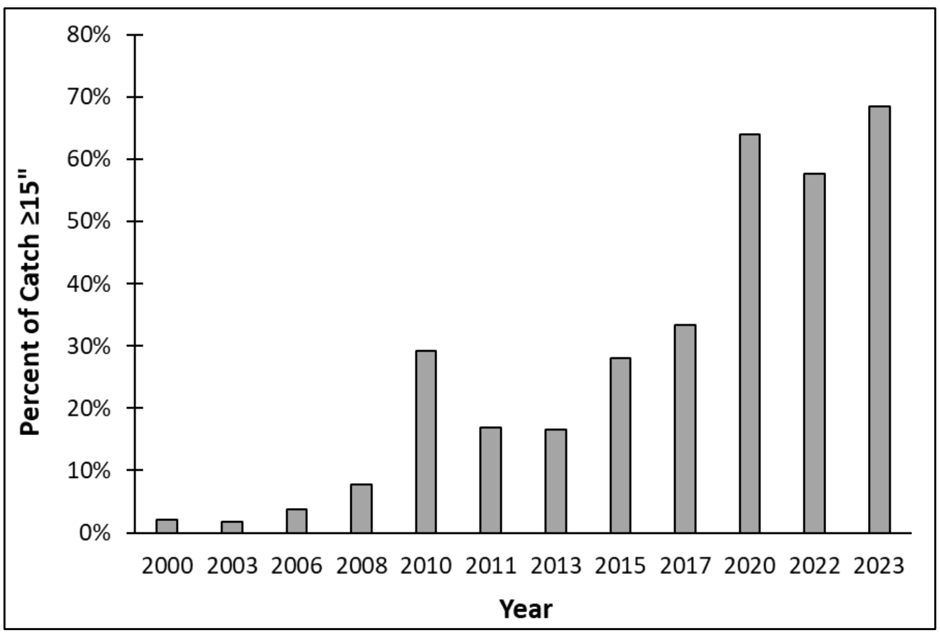


Figure 12. Percent of brown trout caught electrofishing ≥15 inches by year.

Near Absarokee, resident brown and rainbow trout are both present in approximately equal numbers. The population density for the combined trout population has remained stable over time at about 1600 fish per mile (Figure 13). Overall, the fish on this lower stretch of river are smaller, indicating more successful spawning in this area. Whereas about 70 percent of the fish caught in the Moraine section were over 15 inches in length, less than 10 percent were that big at Absarokee (Figure 14).

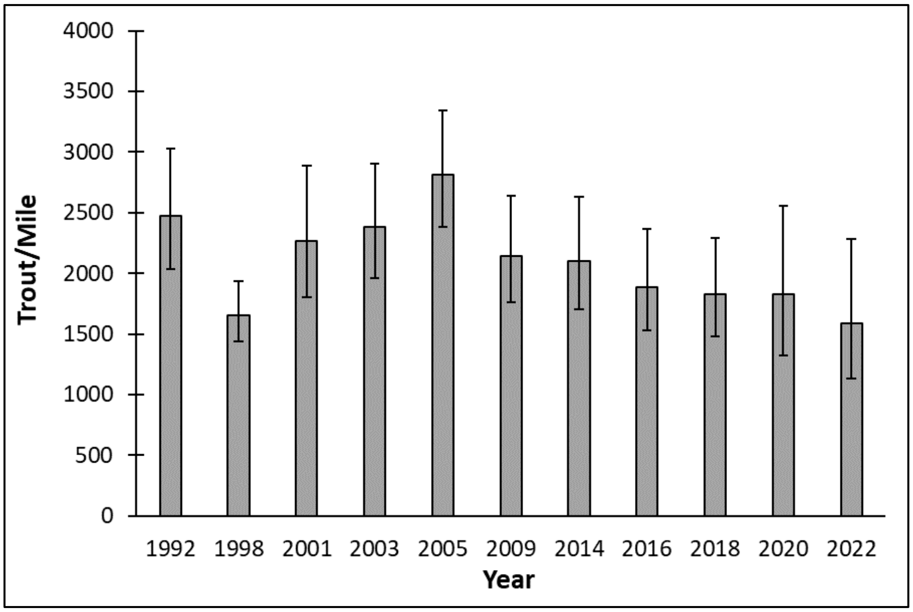


Figure 13. Combined brown and rainbow trout population estimates for fish 7 inches and greater for the Absarokee electrofishing section of Stillwater River by year. The error bars represent the upper and lower 95% confidence intervals.

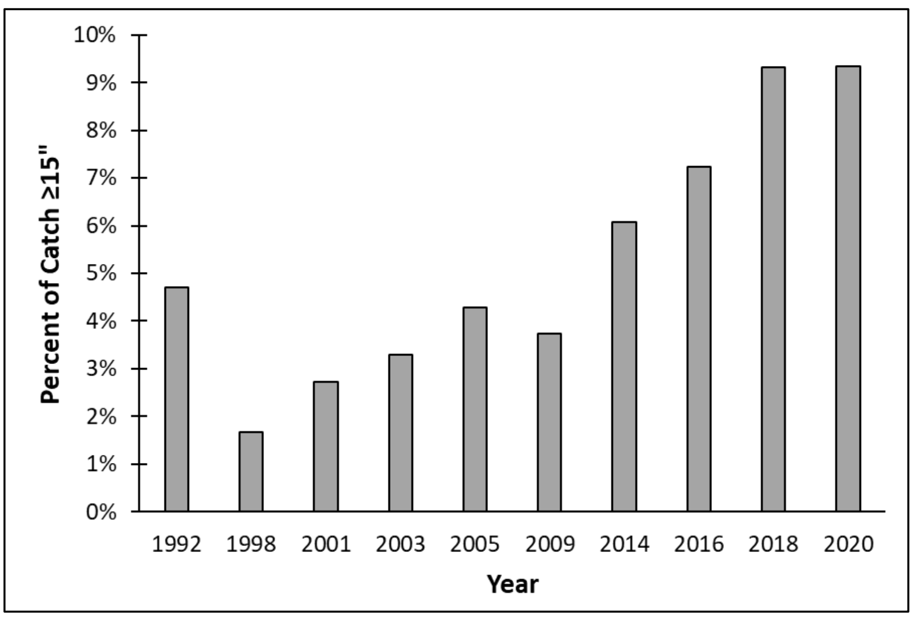


Figure 14. Percent of trout caught electrofishing ≥15 inches by year for the Absarokee electrofishing section of the Stillwater River by year.

3. Previous and Ongoing Efforts Related to Flooding and River Management

Several groups and agencies have been involved in stream related resource management and flood response in the project area.

3.1. Stillwater Valley Watershed Council (SVWC)

The Stillwater Valley Watershed Council formed in 2010 as a group of volunteers who promote collaboration towards the protection, restoration, and conservation of natural resources of the watershed. The Council is led by Lindsey Clark (coordinator), along with twelve community volunteer board members who are elected to serve three-year terms.

STILLWATER VALLEY WATERSHED COUNCIL

The SVWC Mission Statement is as follows**:**

> "The Stillwater Valley Watershed Council will provide an open forum in which all interested parties may work in a collaborative effort to sustain our rural quality of life to protect and enhance our natural resources. We seek to understand all points of view, come to a common goal and work for practical solutions. We are committed to research and educating valley residents and the public about our watershed and the steps we can take to preserve and maintain the integrity of the river, the land and the beauty of our valley. As a group of dedicated volunteers, we have received dedicated support from Stillwater County Weed District, SCD, Stillwater Sibanye Mining, MT Fish, Wildlife & Parks, US Forest Service, Rocky Mountain Elk Foundation, local community foundations, among others. The SVWC will endeavor to bring together public, private and government resources, funding, and grants to achieve our goals."

3.1.1. Stillwater Flood Landowner Surveys and Permitting Workshop

Shortly after the June 2022 flood, SVWC sent out a landowner survey to affected stakeholders (Figure 15). The survey asked recipients to provide information related to the extent and nature of flooding, whether they had received flood-related cost share assistance, post-flood mitigation work, and if they would be interested in a RATT team visit. This information provided the primary basis for the site visits and field observations used in this document.

On May 3, 2023, the SVWC hosted a permitting workshop with a panel that represented the SCD, Corps of Engineers, Department of Emergency Services, Stillwater County Economic Development, and Montana Fish Wildlife and Parks (FWP). Attendees could ask questions regarding permitting requirements under both emergency and non-emergency status.

Stillwater Valley Watershed Council

Post-Flood River Assessment Triage Team
Landowner Survey

THE DAWN OF JUNE 13, 2022 WILL REMAIN A HORRIFYING MEMORY for many in the Stillwater Valley. Anyone having a residence or property along the Stillwater River's main tributaries awoke to one of the most extreme natural disasters this area has ever seen in documented history. The SVWC strives to continue to strengthen community resilience and healing by establishing a River Assessment Triage Team (RATT).

The team includes a geomorphologist, hydrologic engineer, fisheries biologist, local Conservation District and SVWC. This team will assess local rivers (Stillwater, East Rosebud, Rosebud and West Rosebud) as a whole, focusing priority reaches and landowners, landscapes and natural resources most impacted by the June flood disaster.

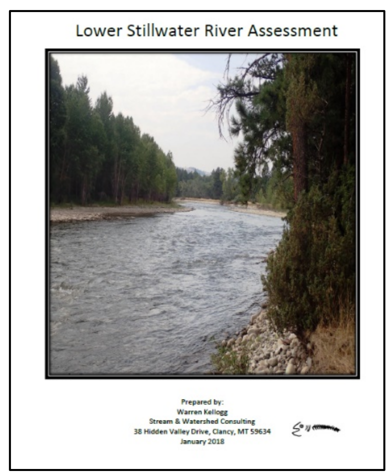
RATT Objectives:

1) Evaluate the impacts of the June 2022 flood on major Stillwater watershed tributaries to document the character of the event and its ramifications.
2) Document impacts, described in terms of primary geomorphic processes at work, and conceptual alternatives providing flood mitigation strategies that are cost-effective and support the long-term health of the river systems and landowners involved.
3) Present permitting requirements with a summary of potential funding opportunities. The RATT team study is a necessary precursor to many future grants.
4) Ease the financial burden for landowners, providing specific site reports as well as best practice recommendations for river cleanup and stream bank restoration efforts.

IN ORDER TO ENSURE THE SUCCESS OF THE RATT, WE NEED YOUR INPUT.
We appreciate your time as you take a few minutes to complete the brief survey below, giving the SVWC and Triage Team a better idea of local needs and concerns.

Figure 15. Introductory text for SVWC Landowner Survey.

3.1.2. Lower Stillwater Watershed Assessment (Kellogg, 2018)



Between 2014 and 2016, Warren Kellogg of Watershed Consulting was hired by SVWC to perform three stream assessments in the Stillwater Watershed. The assessment reports include data compilations as well as conceptual recommendations and prioritizations for restoration opportunities.

Recommendations provided by Kellogg (2018) relate to:

1. Site specific descriptions of conditions and opportunities for improvements, especially focusing on irrigation infrastructure.
2. Riparian management recommendations such as limiting clearing and mowing of riparian vegetation on small tracts.
3. Livestock management recommendations for livestock numbers, grazing duration, season of use, and water source development.
4. The need for aggressive weed control.

3.1.3. Irrigation Infrastructure Improvements

SVWC has collaborated with the SCD in procuring grants to address irrigation infrastructure concerns. The grants have been used to repair/replace diversion structures to improve water delivery efficiencies and improve recreational safety on the river.

3.1.4. Weed Control

Weeds have been a long-term problem in the watershed, with leafy spurge arriving decades ago with upper Stillwater mineral development. Since 2022 the SVWC has partnered with FWP and the US Forest Service to cooperatively treat over 450 acres of invasive species on public land (SVWC).

Kellogg (2018) listed major problematic weeds on the lower Stillwater as Canada thistle, leafy spurge, mullein, and houndstongue. Lesser densities of the following weeds were also noted: spotted knapweed, burdock, birdsfoot trefoil, yellow toadflax, oxeye daisy, and common tansy (used as an ornamental).

3.1.5. Stillwater Rosebud Water Quality Initiative

The Stillwater Rosebud Water Quality Initiative (SRWQI) is a baseline water quality monitoring project adopted by the SVWC, which kicked off in October 2020 and has completed 30 months of stream monitoring since its inception. The SVWC has obtained grants and donations to cover the cost of laboratory analyses through September 2023. All labor and operating costs are donated by volunteers or covered by cooperating organizations including the SVWC, SCD and NRCS.

The project involves monitoring basic water quality parameters including temperature, pH, conductivity, dissolved oxygen, nutrient and sediment levels at nine sites in the Stillwater-Rosebud drainages usually mid-month. Comparison of SRWQI results over 24 months with USGS data collected from 1993 – 2013 indicates very little change in average nutrient and suspended sediment levels, but recent data had larger maximum values of Total Phosphorous (TP) and Total Suspended Solids (TSS). Temporal trends were distinguishable for all lab parameters. NO2+NO3-N and TN increased gradually from July through winter months, then falling as runoff increased from spring to early summer, indicating contributions from groundwater sources. Aquatic bio-growth may have also contributed to depressed NO2+NO3-N levels throughout summer months. TP was highly correlated with TSS throughout the sampling record, with peak values associated with runoff events indicating TP absorption and transport with the particulate load.

SVWC has clarified that the data collected by this project is of a non-regulatory nature, intended to provide some basic indicators of stream health to inform the residents of the Stillwater Valley and protect all the uses we make of our streams for this generation and those to come.

3.2. Conservation Districts

The SCD has administered several RRGL (Renewable Resource Grant and Loan) grants in the watershed that have focused on irrigation infrastructure improvements. They have also recently administered grants related to groundwater availability studies, river water quality sampling, aquatic invasive species work focusing on public education, outreach events, invasive grasses workshops, and field demonstrations.

Stillwater Conservation District

The SCD is currently partnering with the USDA Natural Resources Conservation Service (NRCS) by providing local sponsorship for the Emergency Watershed Protection (EWP) program to landowners in both Carbon and Stillwater Counties.

Through EWP, local NRCS personnel conducts flood damage assessments to determine program eligibility and evaluate potential alternatives to protect properties from further damage. After site assessments are complete, the conservation district develops an agreement with the landowner that describes available financial and technical assistance.

3.3. Montana Office of Disaster and Emergency Services (DES)

Following the Flood, DES accessed FEMA funds to clear out vegetation debris and construction debris from identified places along rivers in Park, Stillwater, and Carbon Counties. The debris slated for removal included materials in the streambed such as trees, concrete slabs, building materials, etc.

Since the original debris removal plan was announced, there have been numerous stakeholder/agency discussions regarding the nature of "debris" to be removed. The original intent was for DES to remove all human debris (concrete, parts of houses, fridges, etc.) as well as all natural woody debris. Other agencies commented and generally supported removal of all human debris and ***some*** of the natural woody debris. Wood that had accumulated directly upstream of infrastructure such as bridges and headgates was supported for removal. Some of the woody debris originally proposed for removal posed no immediate threat to infrastructure, and some of it was enhancing bank stability and fish habitat. In these situations, it was recommended the debris be left in place due to its benefits to habitat and local channel stability.

Since the flood, FEMA, the state DES office, and local DES office have coordinated extensively to locate and quantify the amount of debris to be removed. As of early May 2023, DES had equipment staged for debris removal. The volumes are large; near the Sibanye-Stillwater Mine, an estimated 20,000-30,000 cubic yards of debris was deposited over 1.5 miles of channel. A typical truck can carry 80 cubic yards of debris. Because of landfill capacity limitations and debris transport costs, the debris will be burned on site in very hot incinerators that reduce the wood to ash. The ash will be disposed of or, if appropriate, spread on farm fields as fertilizer. The incinerators can burn an estimated 10,000-20,000 cubic yards of woody debris per day.

Resource agencies have requested that contractors use the least invasive method/best management practices (BMP) to retrieve the debris. Those include not driving down the middle of the channel, not removing riparian habitat to get to the sites, and minimizing time in the actual channel. In places, heavy equipment may be required to restore channel capacity and reopen overflow channels, sloughs and irrigation diversion channels which have been blocked by large deposits of cobbles. Concerns persist that debris removal activities could have substantial negative impacts to channel form and function if BMPs are not followed. Removal from the Stillwater River between Nye and Woodbine is highly discouraged by FWP due to the critical value of that reach for trout spawning.

DES is also working to identify and quantify in-stream sediment accumulations that are creating major problems with the intent of removing some of that material.

DES also makes sandbags available in the event of additional flooding. They have also purchased weather stations to help better predict future flooding and are exploring the financial feasibility of putting an additional stream gage on the Stillwater River near Woodbine.

DES has improved their flood messaging capabilities on the county website for flood alerts and routine messaging. They are working on the capacity to provide alerts via mobile phones to people who have signed up in the system.

3.4. FEMA

Shortly following June 2022, FEMA announced the opening of a Disaster Recovery Center (DRC) and Mobile Registration Intake Center (MRIC) in Carbon and Stillwater Counties. They were set up to allow impacted residents to apply for financial assistance. FEMA has also provided support to local agencies including DES to remove debris.

3.5. Montana State Library

Shortly after the flood, the Montana State Library created a "2022 Flood GIS Data Hub" with the following compiled information:

- Montana Department of Revenue EagleView Oblique Imagery (licensed for government use only)
- MT DNRC Video and Drone Imagery
- Montana Department of Transportation Ortho-imagery (by request)
- USDA NAIP Imagery 2021 and Earlier
- Montana Freshwater Partners Flood Aerial Photo Viewer
- Montana State Library LiDAR Data Viewer
- USGS Flood Event Viewer

https://montana-state-library-2022-floods-gis-data-hub-montana.hub.arcgis.com/?utm_medium=email&utm_source=govdelivery

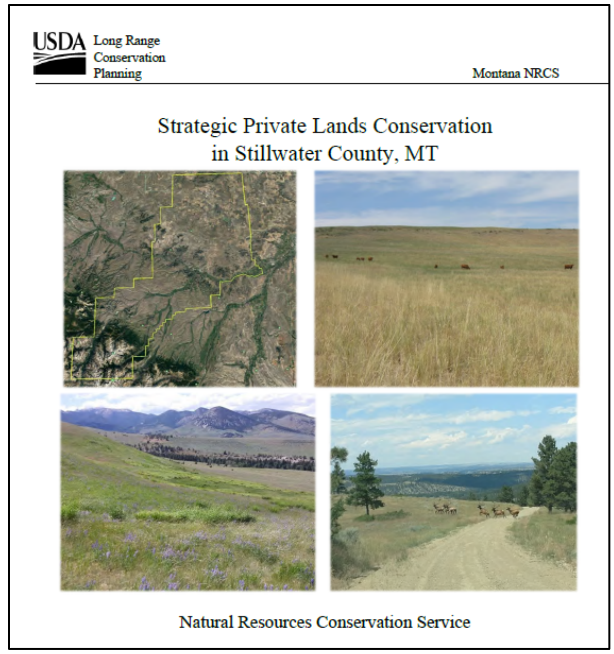
3.6. NRCS

The NRCS has developed a Strategic Private Lands Conservation Long Range Plan for Stillwater County that is intended to "develop a guideline that directs the use of technical and financial resources by strengthening partnerships to more effectively prioritize and address natural resource concerns in Stillwater County" (NRCS, 2019).

Major issues identified in the NRCS Plan include:

- Rangeland Resource Management
- Excessive Plant Pest Pressure
- Soil Erosion, including Streambank Erosion

- Soil Health



Especially relevant to this report is the following Soil Resource Concerns Solutions provided by the NRCS with respect to Streambank Erosion (NRCS, 2019):

Streambank Erosion Solutions*:* The go-to solution for most streambank erosion is to install riprap to the area and armor the bank. This solution, while usually effective, has several negative aspects to it. Riprap is very expensive and maintenance of it is also expensive. Riprap does armor the bank; however, it usually deflects the water's energy downstream or into the opposite side of the river, possibly impacting neighbors. Sometimes riprap is the only option. To minimize the need for riprap in the future, the following actions will help:

- Continued public education on the value of maintaining deep-rooted native plant communities to stabilize streambanks to protect land/property.
- Continued public education on the value of maintaining separate riparian pastures to allow the landowner to manage the health of the riparian plant community and micromanage the grazing of their livestock/animals.
- Continued public education on the impact that noxious/invasive species have on native riparian plant communities.
- Continued public education on the value of maintaining tailwater ditches to return water to river rather than letting tailwater flow over existing riverbank. Also continue education on the value in maintaining those native riparian buffers to stabilize banks to prevent sloughing from irrigation induced ground saturation.
- Continue to provide timely technical assistance. Investigate financial assistance when necessary.

3.7. Emergency Watershed Protection Program (NRCS, Stillwater CD and Carbon CD)

The NRCS has partnered with the Stillwater and Carbon County Conservation Districts to implement their Emergency Watershed Protection (EWP) Program. The authority of NRCS to provide technical and financial assistance after a flood disaster is limited by statute to emergency measures that protect lives and property from floods and the products of erosion caused by the disaster. The EWP program becomes available after a natural disaster to assist with flood recovery on private property. The goal of the program is to reduce the threat to life and property from further damage and potentially provide temporary protection so more permanent solutions can be evaluated. Immediate flood recovery efforts focus on protecting property that could experience additional damage from subsequent high flow events (i.e., next spring runoff).

NRCS delivers EWP assistance through a cooperative agreement (Project Agreement) with a local Sponsor. The Sponsor is typically a local government entity that agrees to represent the interests of individual landowners and other project stakeholders. The Sponsor obtains the land rights and permits needed to install project measures. The Sponsor issues and manages construction contracts to build project measures. The Sponsor will obtain funds to pay the local share of the construction cost and will ensure projects are properly operated and maintained for as long as necessary. NRCS cannot reimburse the cost of any recovery measures until a signed Project Agreement is in place with the Sponsor (NRCS 2022).

4. Flood Hydrology

The following section contains a description of the general hydrology of the Stillwater River Watershed, with special emphasis on the historic nature of the June 2022 flood.

4.1. Historical Flood Statistics and Occurrence

The Stillwater River has been measured at the USGS gaging station about one mile north of Absarokee at Miller Road Bridge for 90 years. The first period of measurements was Water Years 1911 through 1914, followed by a hiatus with no measurements until 1935. Since then, river stage and flow measurements have been continuous until present. Annual peak flow statistics for this station are provided in Table 2.

"I had to put the dogs in my pickup just to take them out to pee!"

Table 2. Annual Peak Flow Statistics for the Stillwater River near Absarokee, MT, USGS 06205000

	Calendar Day No.	Discharge, CFS
Water Years 1911-14, 1935 – 2020 (90 years)		
Average	163 (June 13)	6,739
Median	162 (June 12)	6,480
Standard Deviation	10.7	1,869

Source: (USGS 2022)

The average annual peak discharge of the Stillwater River for the 90 years of record is 6,739 CFS, and the median is 6,480 CFS. The 2-Year flow, statistically the 50% flow probability, is 6,430 CFS (StreamStats, USGS 2022). The distribution of annual peak flows over the period of record is shown in Figure 16. The largest peak, 12,000 CFS, occurred in 1967, and the smallest, 3,230 CFS, in 1987. A linear trend line (dotted line) plotted through the data points is nearly flat, indicating little change in peak flows, even though the vertical spread of points is rather large, typical for mountain-fed rivers in the northern Rockies.

A histogram of average peak flows for the Stillwater River gaging station is provided in Figure 17. Data are grouped in the category next higher than their value. The most frequent annual flood peak events (22 occurrences) are in the range of 6,000 to 7,000 CFS. Floods greater than 10,000 CFS were recorded only five times in the 90 years of record.

The USGS operated a stream gaging station, No. 06204500, on Rosebud Creek at the Niche Road bridge from Water Years 1935 through 1969 (A Water Year runs from October 1 through September 30). This location is immediately downstream of the confluence of the East Rosebud, West Rosebud and Fishtail Creeks, and therefore includes all but a small segment of the entire Rosebud Creek watershed. Annual peak flow statistics for this 35-year period of record are provided in Table 3.

Table 3. Note that the peak flows at this station are mitigated by the dam and storage at Mystic Lake. Storage reservoirs typically store water during peak flows thereby lessening the magnitude downstream.

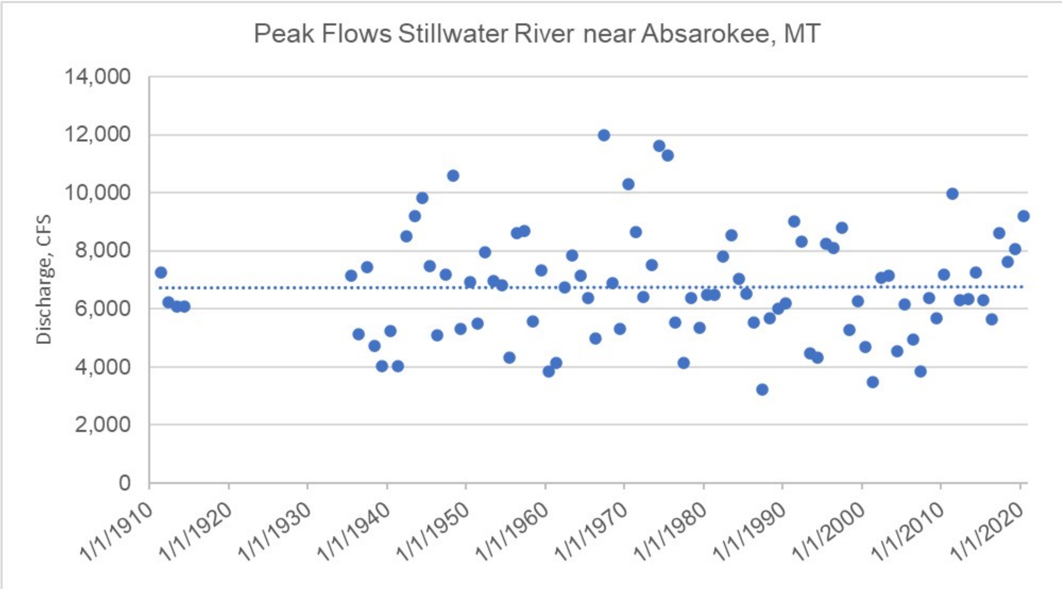


Figure 16. Distribution of annual peak flows for the Stillwater River at USGS 06205000 over the period of record. Source: USGS, 2022.

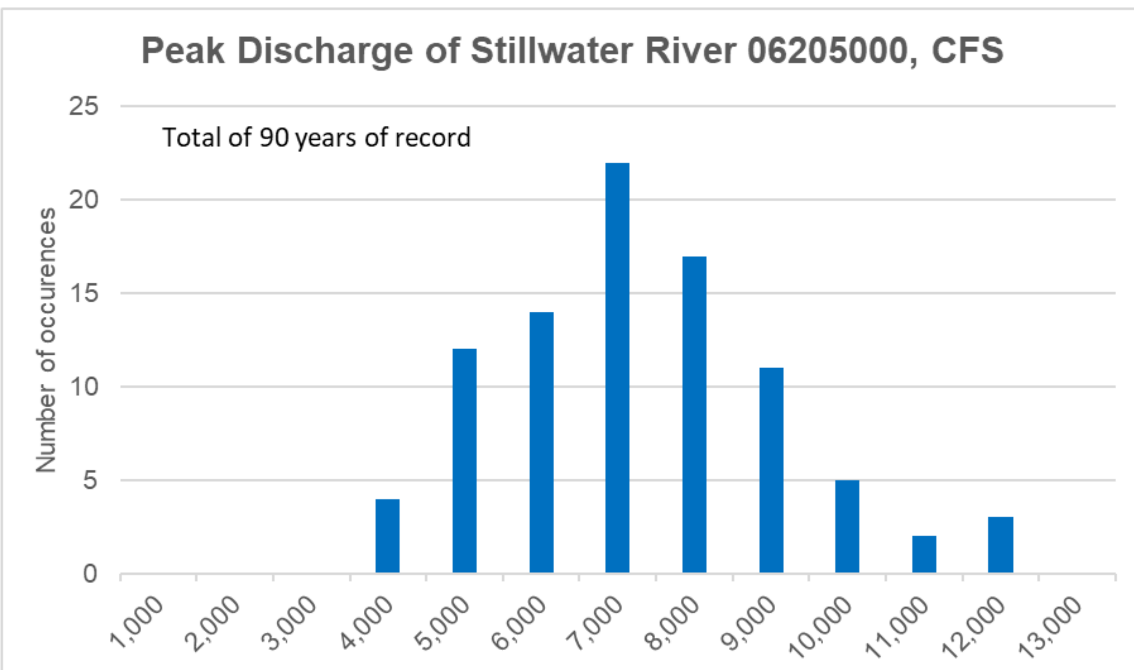


Figure 17. Histogram of Peak Floods for the Stillwater River at Gaging Station 06205000. Source: USGS, 2022.

Table 3. Annual Peak Flow Statistics for Rosebud Creek above Absarokee, MT, USGS 06204500.

	Calendar Day No.	Discharge, CFS
Water Years 1935 – 1969 (35 years)		
Average	169 (June 18)	2,522
Median	172 (June 21)	2,250
Standard deviation	13	1,061

Source: USGS, 2022.

The average annual peak discharge of Rosebud Creek for the 35 years of record is 2,522 CFS, and the median is 2,250 CFS. The average Rosebud peak is equivalent to about 38% of the average peak for the Stillwater River gage (for the same years) which includes both the Stillwater River and Rosebud Creek. The 2-year flow, statistically the 50% flow probability, is 1,270 CFS (StreamStats, USGS 2022). This would be considered close to the bankfull discharge rate. The distribution of annual peak flows over the period of record is shown in Figure 18. The largest peak, 5,790 CFS, occurred in 1967, and the smallest, 1,100 CFS, in 1960. A linear trend line (dotted line) plotted through the data points indicates a slight decline in peak flows over this 35 year period.

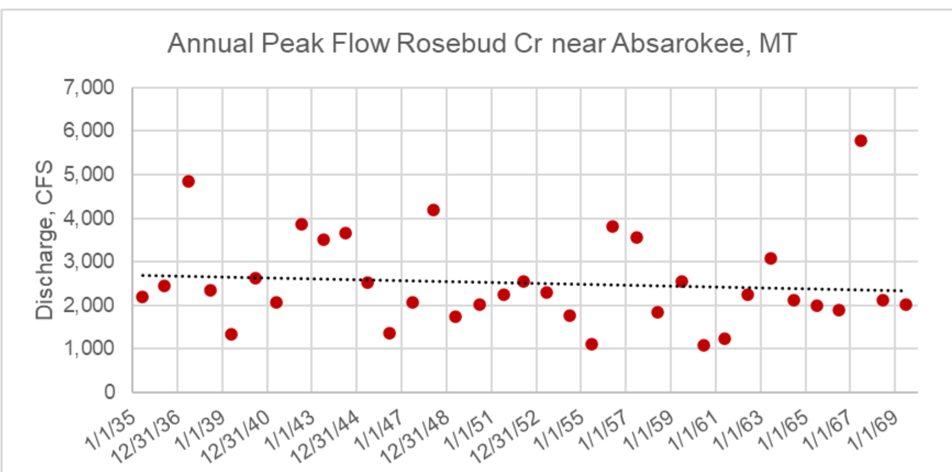


Figure 18. Distribution of annual peak flows for Rosebud Creek at USGS 06204500 over the period of record, 1925 - 1969. Source: USGS, 2022.

A histogram of average peak flows for the Rosebud Creek gaging station is provided in Figure 19. Data are grouped in the category next greater than their value. The most frequent annual flood peak (16 occurrences) are in the range of 2,000 to 3,000 CFS. Only one flood greater than 5,000 CFS was recorded in the 35 years of record.

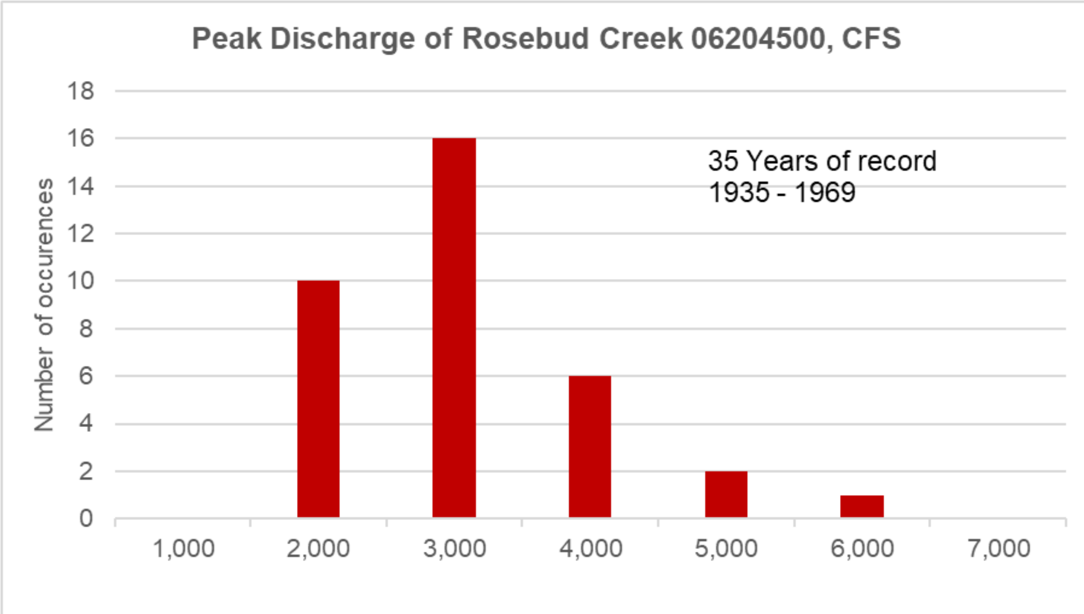


Figure 19. Histogram of Peak Floods for Rosebud Creek at Gaging Station 06204500, 1935 - 1969. Source: USGS, 2022.

4.2. Pre-Flood Hydrologic Conditions

The June 2022 flood defied prediction even just one month before it happened. 2021 was a dry year in south-central Montana. The winter of 2021-2022 was very dry in the foothills and plains as well as the Beartooth Mountains. As illustrated by Figure 20, from mid-July 2021 through mid-April 2022, Stillwater and Carbon Counties experienced Severe Drought (D2) and Extreme Drought (D3) conditions as rated by the National Integrated Drought Information System using the Standard Precipitation Index (SPI).

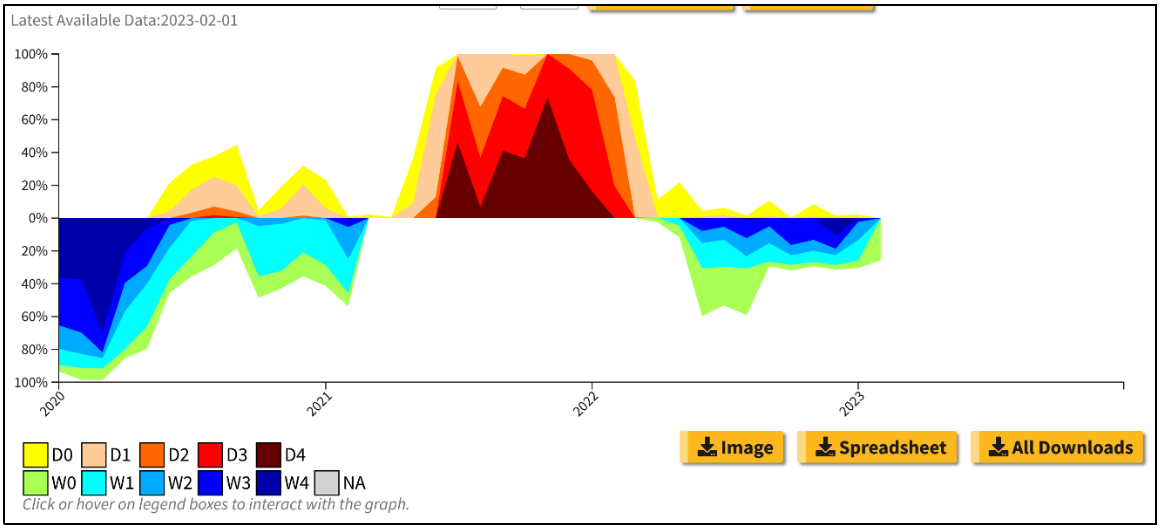


Figure 20. Drought/Wetness Conditions of Stillwater and Carbon Counties prior to the June 2022 Flood (Source: National Drought Information Service, NRCS, 2023).

The water stored in the Stillwater River basin snowpack on April 1, 2022 was among the lowest since SNOTEL records began (1967 for Fisher Creek, and 1981 for Monument Creek and Placer Basin). The snowpack at these stations were at the 16%, 7% and 14% lowest level on record for these stations, respectively (NRCS, 2023). But in April and May, repeated storms accumulated late season snow in the Beartooths, with a large dump of wet snow over Memorial Day weekend that contained 5-inches of water that prolonged runoff (heavier red line below). By that time much of the mid-elevation snowpack was near the melting point. The SNOTEL record for 2021-2022 of the composited upper Stillwater River basin is provided in Figure 21. Notice how long the snowpack accumulated and persisted into June 2022, followed by a precipitous decline.

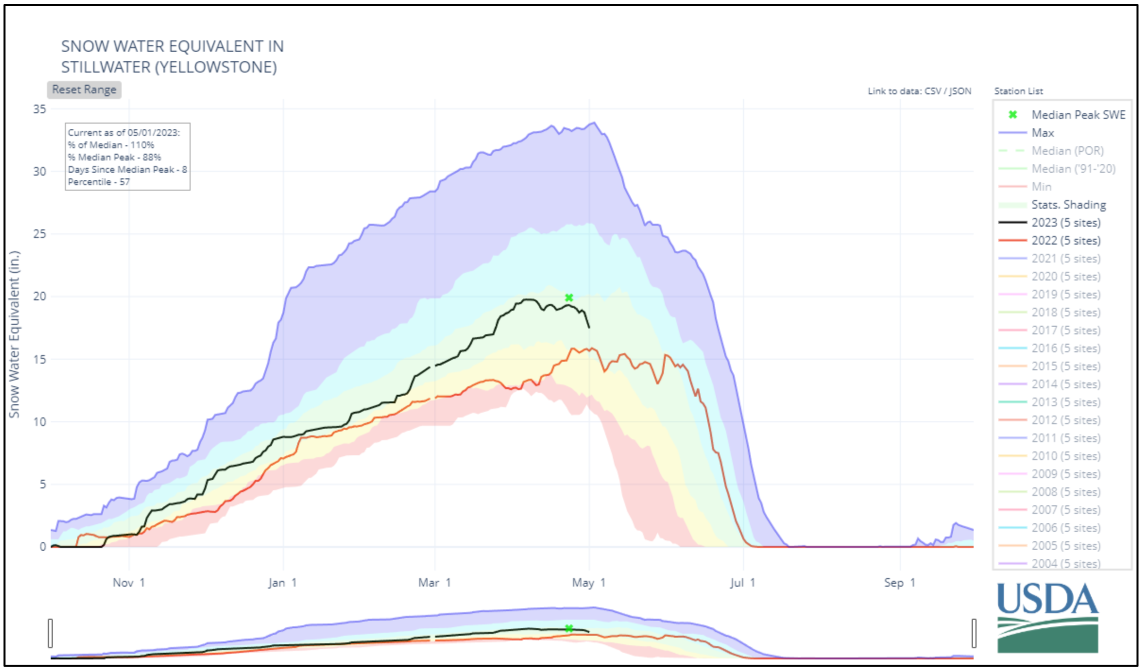


Figure 21. SNOTEL snow water equivalent composited record for the upper Stillwater River basin in 2023 (black line) and 2022 (red line), (Source: NRCS SNOTEL, 2023).

4.3. The June 2022 Flood Magnitude and Extent

Note: Data for the flood are continuing to be analyzed by hydrologists. The numbers below reflect the best available data at the time of this work. Numbers related to flood magnitudes and frequencies may change as more hydrologic analysis is completed.

The June 2022 flood is put in context by comparing those flows to median flows (Figure 22). After a winter of slightly lower flows, April and May were characterized by abnormally low flows. When the SVWC watershed sampling team conducted its monthly sampling event on May 16, 2022, the Stillwater River was at its all-time low flow for that date, 395 cubic feet per second (CFS) at the USGS gage downstream of Absarokee. This gage has been measured continuously since 1935. The reason for this was the lingering effect of the 2021 drought and a cool spring which had delayed snowmelt. But in the summer of 2022, flows stayed far above normal from June 10 through July 23. By late July 2022 streamflow was back in the normal range and fell to below normal in September.

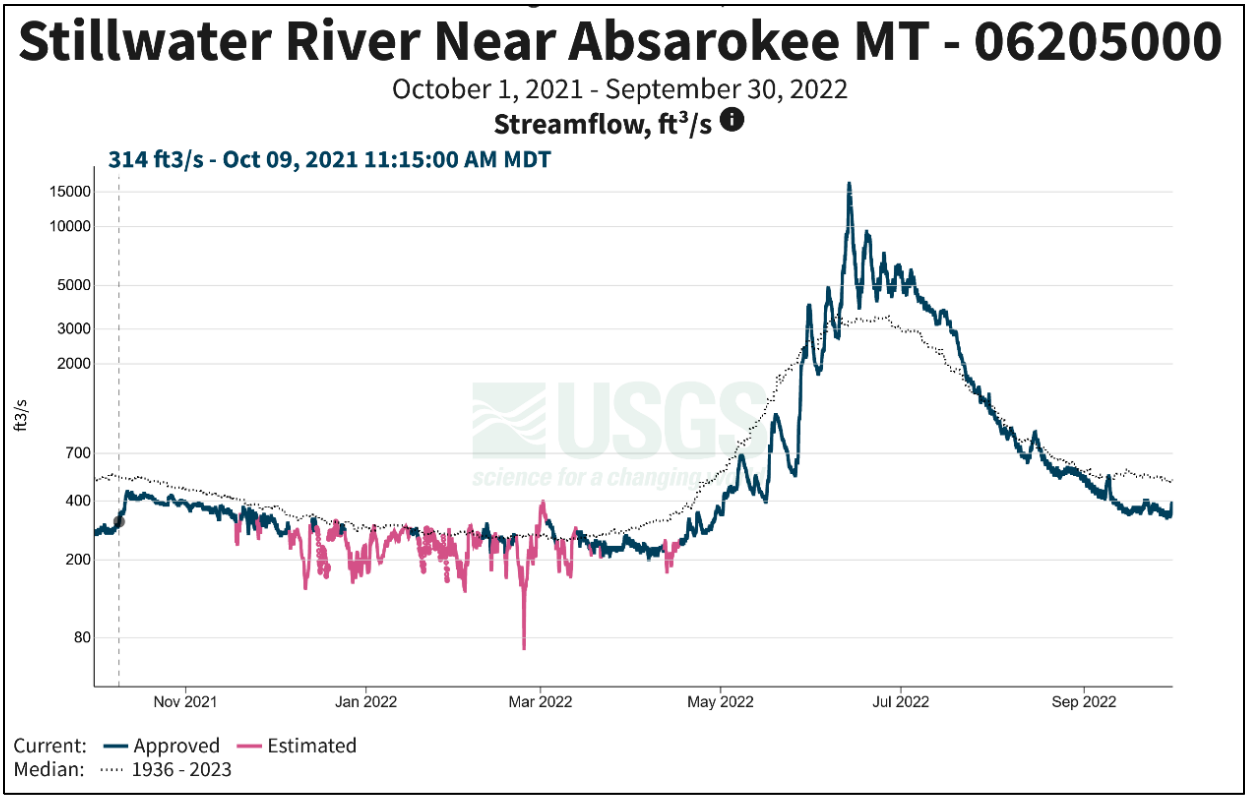


Figure 22. Stillwater River Streamflow in Water Year 2022 (bold lines) overlain on median flows (light line). Note that the vertical axis depicting the flow rate is a logarithmic scale (Source: USGS, 2023).

4.3.1. Meteorologic Causes

An "atmospheric river" of moisture from the Pacific reached southern Montana June 10-12, 2022. Although rainfall amounts on the plains were moderate, 2-3 inches fell in the mountains. Rain melts snow much more rapidly than even warm temperatures. The NWS reported that the rain plus snowmelt caused 4 to 9 inches of water to quickly run off and reach the rivers all around the Beartooth-Absaroka mountains (Lester, 2022).

4.3.2. Flood Runoff Peak and Timing

The Stillwater River, which had recovered to near normal by the first week of June, shot up the night of June 11 to over 6,400 cfs, the typical annual flood peak. By about 4:45 am on June 13, the flow hit 12,000 cfs, which is the previous all-time record flood that occurred in 1967. The massive peak reached the Stillwater River gaging station at about 11:45 am on June 13, which the USGS has revised to 16,900 cfs. 23-hours later, the discharge measured at the gage was 10,500 cfs. The recession from the peak lasted through June 16, about 3 1/2 days. A hydrograph of the river from May 15 to July 15 is shown in Figure 23, along with flood statistics for various return intervals.

"We woke up and it was everywhere, it was a lake, we were totally flooded. Knowing what that river is doing further up would be a tremendous help."

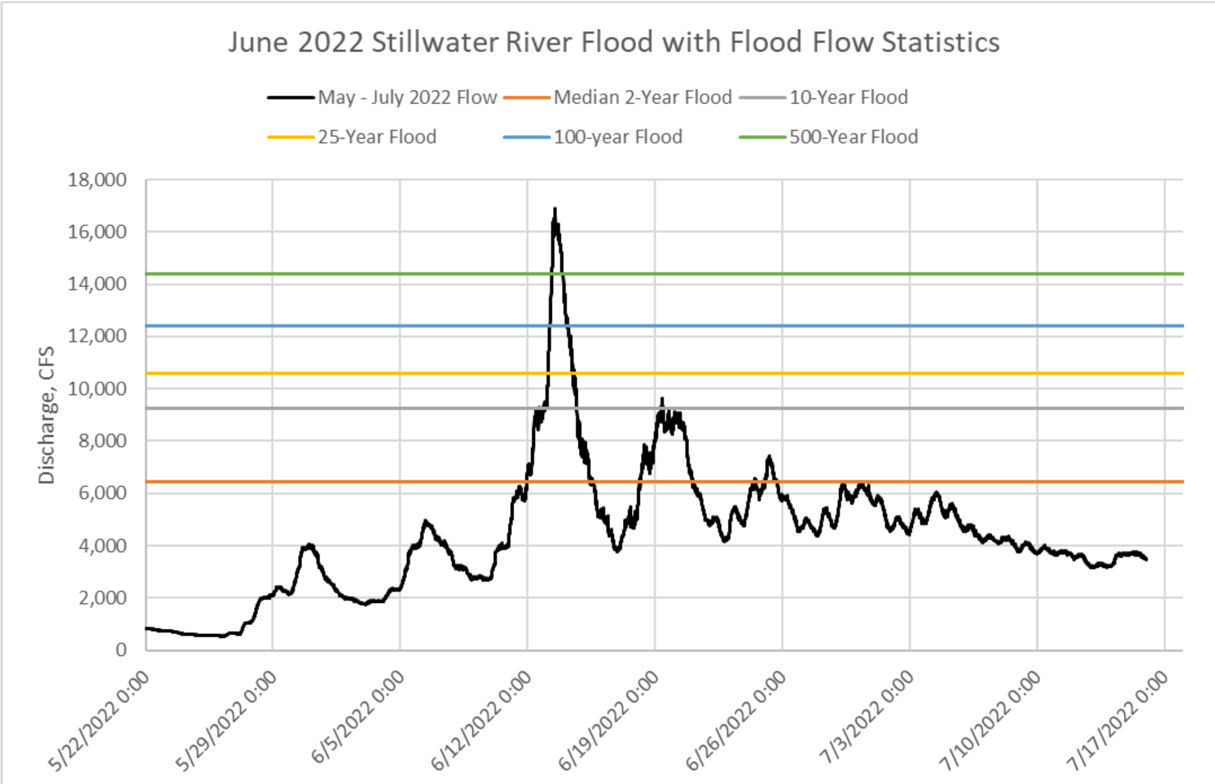


Figure 23. 2022 Flood Hydrograph for the Stillwater River Gage near Absarokee, MT, with Peak Flow Statistics. Note vertical axis is arithmetic (Source: USGS, 2023).

The gage height, or stage, of the Stillwater River at the USGS gaging station also hit an all-time high on June 13. Stream gaging stations are usually established at locations which exhibit a relatively stable relationship between river stage and discharge. Many corresponding measurements of stream discharge and stage are used to establish a mathematical relationship between these parameters. The National Weather Service (NWS) uses the stream stage measurements along with hydrologic forecast models to predict when and how serious flooding will be along rivers throughout the nation. For the Stillwater River gage, the NWS determined that the stage at which minor flooding was initiated was 7.5 ft. Very few floods other than the June 2022 flood reached that level.

A plot of river stage versus discharge for all annual floods from 1943 through 2022 is shown in Figure 24. The stage-discharge relationship is quasi-linear for all points except for the 2022 flood, which, at 10.49 ft is far higher than any previous flood. Since large floods can induce scour or aggradation of the streambed, or erode banks near the gage, it is possible that with further study, the USGS and/or NWS may be revising the stage-discharge datum. Note that the relationship between river stage and discharge can vary due to changes in channel geometry over time.

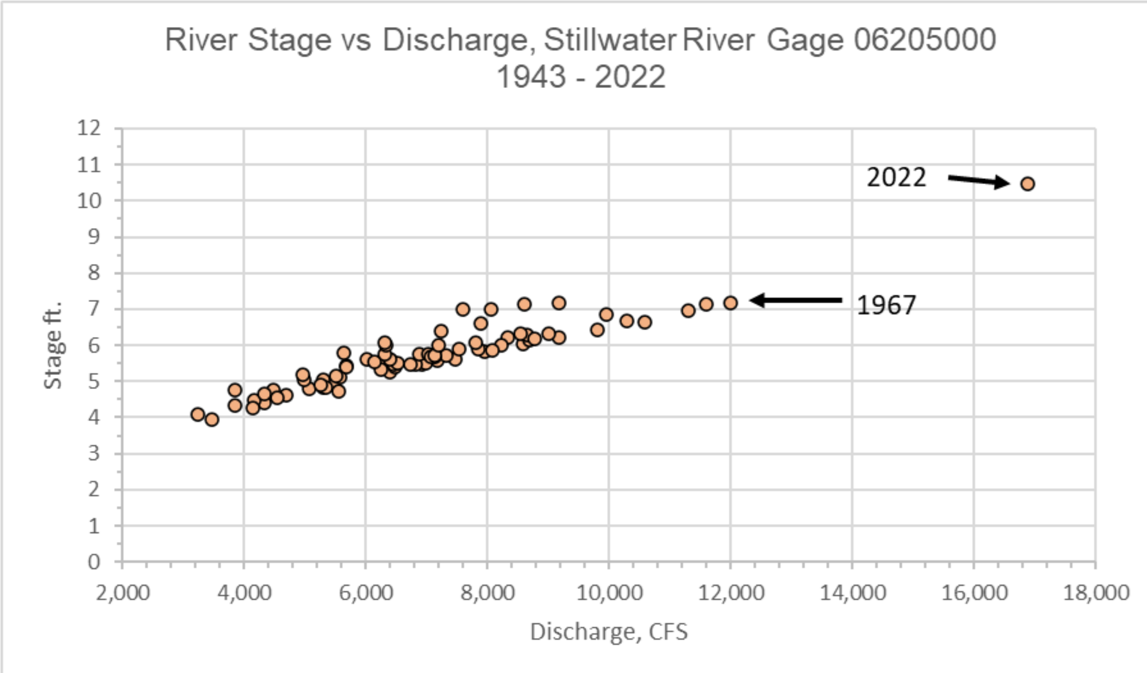


Figure 24. Stage-discharge data for Stillwater River (USGS 06205000). Source USGS, 2023.

4.3.3. Peak Flow Statistics

The June 2022 flood peak of 16,900 CFS was much larger than the statistical 500-year flood event of 14,400 CFS as estimated by the U.S. Geological Survey. The June 13 peak was equivalent to about 2.5 average annual floods combined. Figure 19 indicates that the median annual flood of 6,430 CFS was exceeded on four different dates during and after the peak as the river fell and repeatedly rose again. The 10-year flood was exceeded on two occurrences. Many riparian property owners reported that the most erosion and flood damage appeared to occur on June 14. Both the magnitude of the peak and the long duration of high flows combined to amplify bank erosion and damage to property.

A comparison of the June 2022 peak flow with a standard chart of flood flow versus predicted return intervals ranging from the 2-Year through the 500-Year flood is provided in Figure 25. The trajectory of the plotted line suggests that the return interval of the June 2022 flood was, for the Stillwater River, well beyond a 500-year event, and beyond the range of prediction by standard hydrologic statistics.

A similar chart for Rosebud Creek near the mouth is provided in Figure 26. The USGS used surveys of peak flood watermarks and channel geometry to indirectly calculate the peak flow for the 2022 flood. The peak of 6,200 CFS is equivalent to about 37% of the total peak of 16,900 CFS determined at the USGS gaging station below Absarokee.

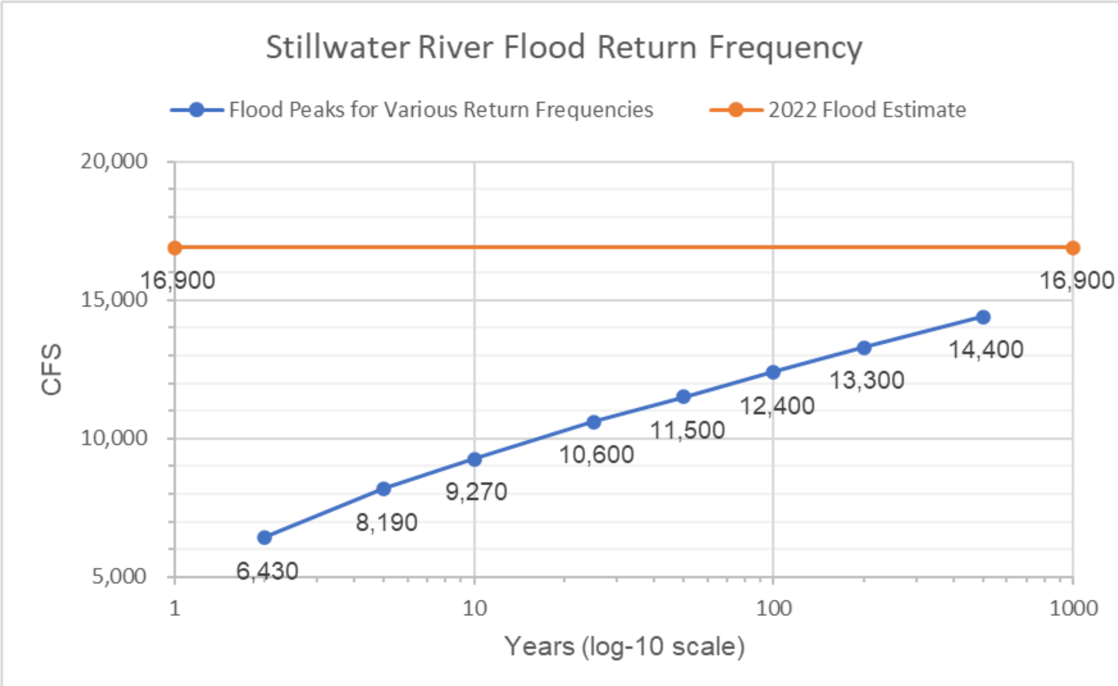


Figure 25. Stillwater River Flood Magnitude vs. Flood Interval compared to the June 2022 Flood (Source: USGS, 2023).

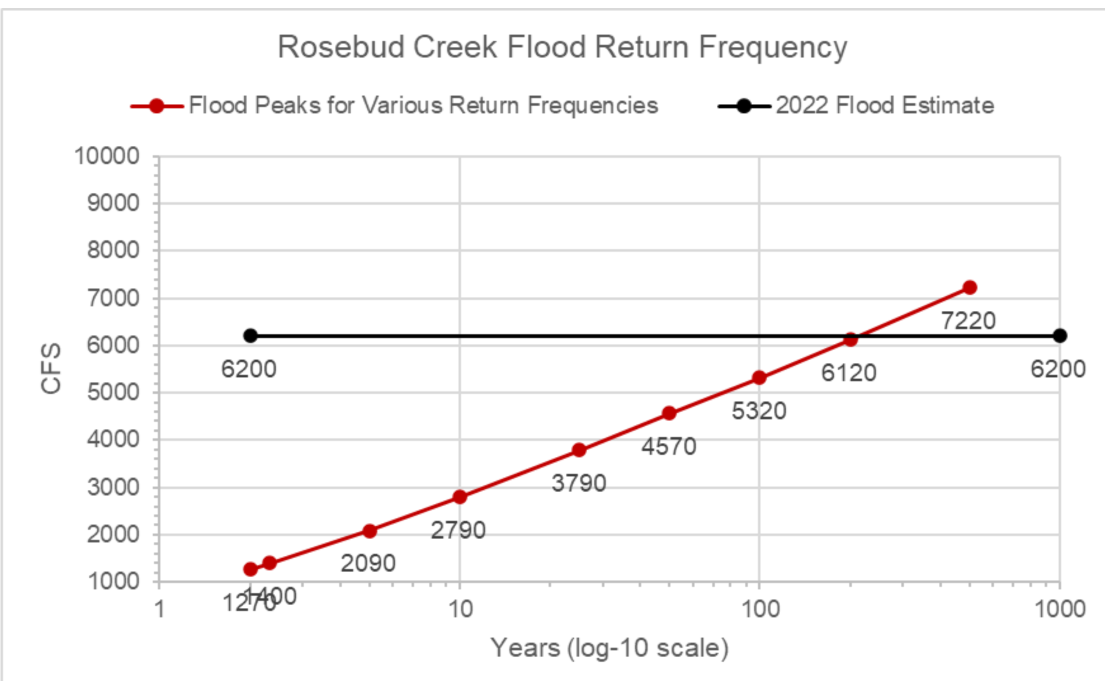


Figure 26. Rosebud Creek Flood Magnitude vs. Flood Interval. (Source: USGS, 2023)

4.3.4. West Rosebud Creek

West Rosebud Creek contributed only about 600 to 700 CFS or 10 to 12 percent of the calculated peak of Rosebud Creek, based on the measurements of USGS Station 06204070 south of Fishtail near Emerald Lake and the estimated travel time to the Absarokee area. West Rosebud Creek at this station saw a peak of 1,180 CFS at this gage which didn't occur until June 19.

The water storage afforded by Mystic Lake played a significant role in mitigating the peak flow of Rosebud Creek. The lake holds 20,977 acre-feet of water with no dead storage. Hourly lake elevation data during June 2022 were provided by Northwestern Energy which operates the Mystic Lake dam (J. Hanson, pers comm). These data show that lake elevation rose by 16.15 ft in the 24-hours between 12:00 pm June 12 and 12:00 pm June 13. This equated to a storage change of 7,100 acre-feet, equivalent to an average flow rate of 3,580 CFS. By 12:00 pm June 14 the lake rose 26.5 ft to hold a volume of 18,000 ac-ft, further lessening the post-peak downstream flow rate.

Field reconnaissance during August 2022 in the West Rosebud watershed above Mystic Lake showed extensive evidence of extreme runoff in the steep tributary drainages, with large new alluvial fan deposits. A 160-acre lake named Island Lake occupies the West Rosebud valley directly upstream from Mystic Lake. The June flood breached the natural rock embankment across West Rosebud Creek holding the lake causing a drop of five to six feet in the water level and the catastrophic release of that stored water into Mystic Lake. Extensive areas of the bed of Island Lake are now bare sand flats, and the "island" which was the namesake of the lake can now be easily reached by foot from the new lower shoreline.

Our preliminary post-flood evaluation of West Rosebud Creek indicates that the peak flow of Rosebud Creek near Absarokee could easily have been 50 percent or more greater than it was were it not for the runoff captured by Mystic Lake.

4.3.5. Post-Flood Hydrologic Conditions

The flood peak on the Stillwater River and Rosebud Creek quickly receded from 16,900 CFS mid-day on June 13 to 3,850 CFS at 1:00 am on June 17. However, there were four subsequent minor peaks that continued into the first week of July, each of which exceeded 6,000 CFS. The first three of these subsequent peaks exceeded the median annual flood of 6,430 CFS. Each of these subsequent peaks were large enough to potentially cause further bank erosion and damage to structures. The long duration of high flows inhibited emergency work and recovery. Following the first week of July, streamflows gradually receded to normal, and eventually below normal flows by September.

4.4. Duration of Bankfull Flows

"Bankfull discharge" is dominant channel forming flow with a recurrence interval in the range of 1 to 2 years (USACE 2022). The bankfull discharge at a specific river cross-section is, in effect, the discharge that fills the channel to the top of its banks and therefore marks the condition of incipient flooding. Although different definitions exist, this characteristic discharge is accepted as being an important indicator in river forming processes. This discharge is considered to have morphological significance because it represents the breakpoint between the processes of channel formation and floodplain formation. The estimated bankfull flow for the Stillwater River at the USGS gage near Absarokee is 5,822 CFS. For this site, the river stage (gage height) which is associated with this flow is about 5.5 feet. These values will generally hold for all the lower Stillwater River to the Yellowstone, but they will be smaller for the

Stillwater River and Rosebud Creek above their confluence. A chart showing the hydrograph of the Stillwater River at the USGS gage from May to October 2022 with the bankfull discharge is provided in Figure 27. Discharge above the bankfull line would in theory, cause over-bank flooding, while below the line, the river would be contained within its banks. However, the 2022 flood caused so much bank erosion which was deposited within the active channel that in places the streambed was raised and over-bank flooding occurred at lesser discharge. This is the reason many people experienced flooding well after the flow rate declined below below the pre-flood bankfull discharge. This phenomenon will likely affect Stillwater Valley residents in 2023 and beyond, until the river reestablishes a more typical form.

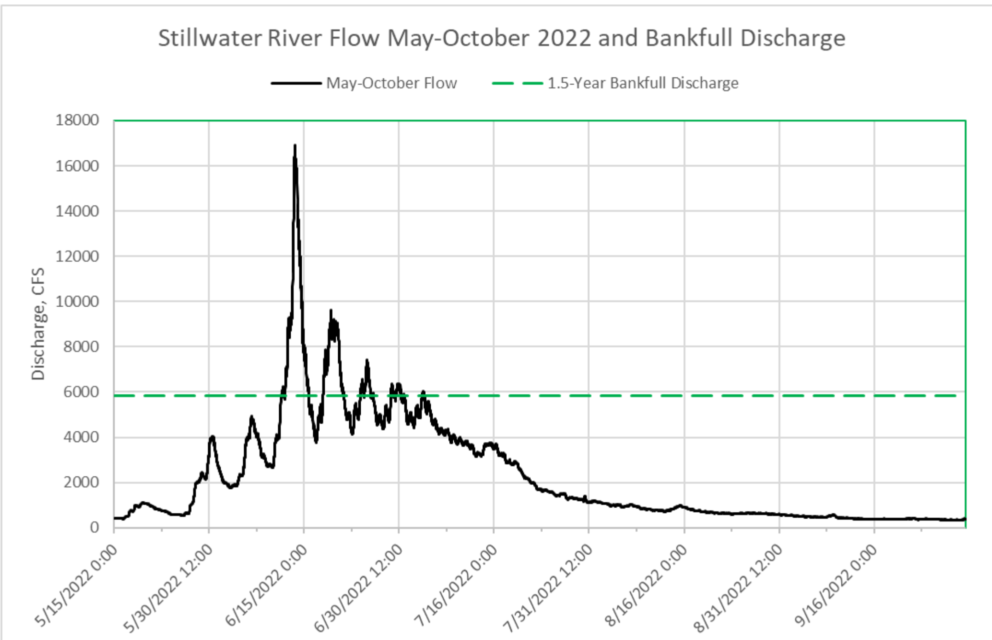


Figure 27. Stillwater River Discharge, May – October 2022 with Bankfull Discharge Indicated. Source: USGS, 2023.

4.4.1. Historic Bankfull Flows and Flood Stages on the Stillwater River and Rosebud Creek

The Stillwater River at the USGS gaging station has exceeded the bankfull discharge rate of 5,822 CFS in 62 of the 92 years of available records. 2016 was the most recent year in which the annal peak flow did not exceed bankfull. The bankfull discharge of Rosebud Creek at the former USGS gaging station on Niche Road, based on data from 1935 through 1969 was 1,040 CFS. There is no more current information for Rosebud Creek.

4.4.2. Flood-Caused Changes to Bankfull Flows and Flood Stages

In general, the massive June 2022 flood made two dramatic changes to the Rosebud Creek and Stillwater River channels. They widened and became more sinuous due to bank erosion, and aggraded, that is, the streambeds raised due to the large increase in sediment bedload. The first of these processes, channel widening, tends to decrease the depth (or stage height) of the bankfull flow since the cross-sectional area of the channel is wider. The second, aggradation, tends to increase the elevation of the bankfull discharge and the river stage due to the accumulated sediment filling the former channels. The process of aggradation will lead to overbank flooding at a lower river stage and lower discharge rate than before the flood. These effects were already reported in places by landowners where ice choked channels caused flooding during winter of 2022-2023.

Note that these processes vary greatly along the many miles of stream channels and the changes to bankfull stage and discharge need to be interpreted at specific locations of interest.

5. Major Human Influences on River Function

This section provides a brief summary of human modifications to the natural function of the streams evaluated.

5.1. Flow Alterations

There are no major water storage projects on the Stillwater River or East Rosebud Creek such that flows have retained their general signature of a snowmelt runoff hydrograph. West Rosebud Creek is regulated to some degree by storage in and releases from Mystic Lake which has a capacity of 20,997 acre-feet. Irrigation water is derived entirely from surface water bodies rather than deep wells (NRCS). A map of historically irrigated lands in the Stillwater and Rosebud basins is provided in Figure 28.

According to Kuzara et. al (2021), "Irrigation effects dominate the hydrology of most of the alluvial valleys" of the Stillwater Watershed. Kuzara evaluated the connectivity between surface and groundwater on a portion of the middle Stillwater River and found a high level of connectivity between the alluvial aquifer and surface flows. The results of MODFLOW modeling also showed that a simulation of groundwater/surface water flow patterns under a "no irrigation" scenario resulted in a water-level-head drop of up to 18 feet in the alluvial aquifer. This resulted in a reduction in Stillwater River base flows by about 6 cfs. The authors concluded that "because of the close connection between irrigation water, shallow groundwater, and river water, the alluvial aquifer in the study area is very sensitive to land use changes".

The effect of irrigation on streamflow is illustrated in Figure 29, using Rosebud Creek as the example. The blue line on this chart shows the average monthly streamflow of Rosebud Creek at the Niche Bridge as measured by the U.S. Geological Survey (1935 -1969). The yellow line shows the predicted monthly flow from the USGS's StreamStats program, which gives estimates of average monthly flows at the same location in the absence of regulation or diversions. The measured flow is lower than estimated during May and June, and larger than estimated during mid-summer and fall months. This correlates with the pattern of early streamflow diversions for irrigation along with storage for energy production in Mystic Lake, followed by releases from storage and irrigation return flows later in the year. A similar, but more muted effect, would be expected for the Stillwater River which has no storage reservoirs and fewer irrigated acres above Absarokee.

A long-range plan developed by the NRCS (2019) listed 9 primary irrigation entities and 29 other small private ditches in Stillwater County. Many of these structures were impacted by the flood.

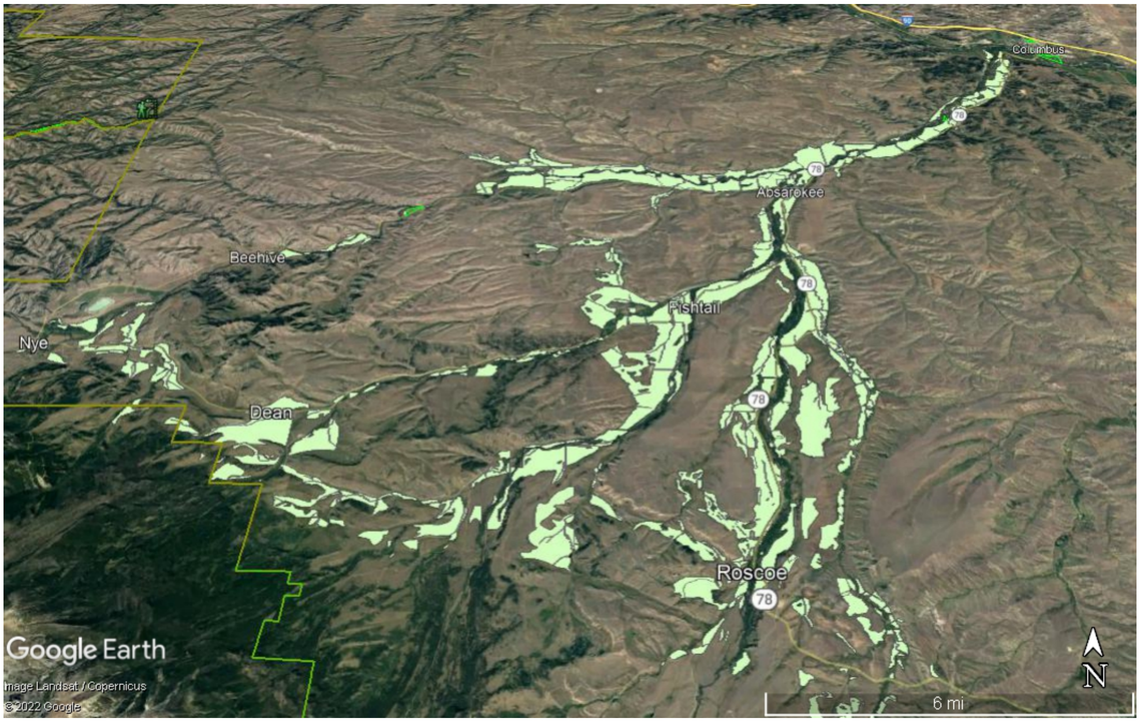


Figure 28. Aerial oblique view of historically irrigated lands in the Stillwater River basin. (Source: Carbon and Stillwater Counties Water Resources Surveys).

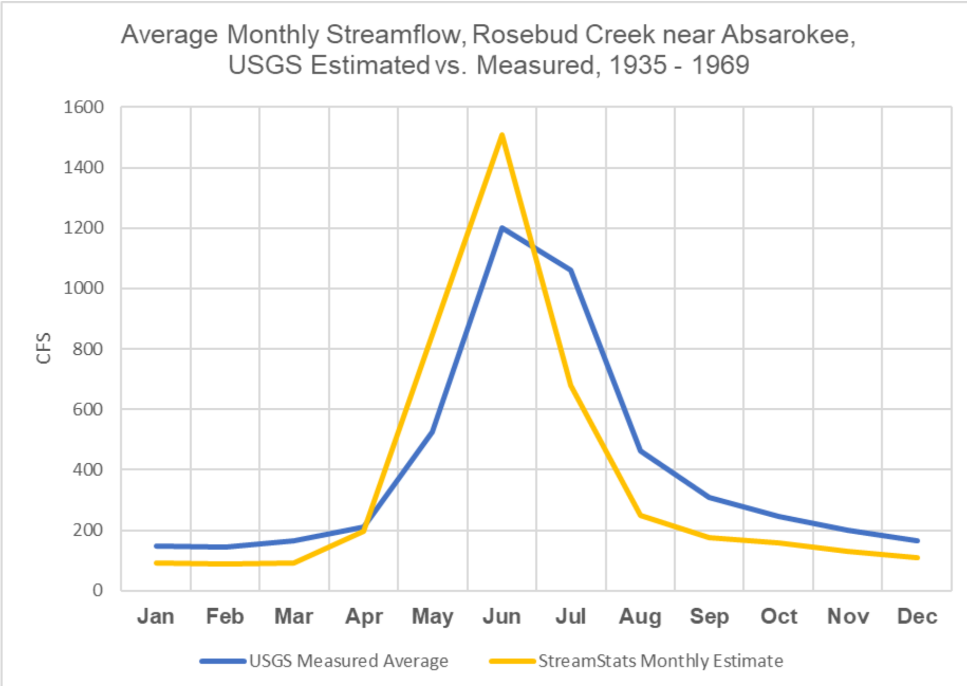


Figure 29. Average monthly streamflow based on measurements (USGS) and flow estimated via basin characteristics. Source: USGS 2022.

5.2. Residential Development

Cadastral data was used to map concentrated small property parcels along streambanks (Figure 30). The two stream segments most impacted by higher density development patterns are between Nye and Cliff Swallow Fishing Access Site and at Absarokee on Rosebud Creek. In each of these sections about a third of the streambank is divided into small parcels. Although only 7% of the bankline has small tract development between the Sibanye-Stillwater Mine and Nye, this section had the most structural damage. Most of the existing homes on streambanks have some form of bank armoring or retaining wall protection (Figure 31), and the subdivisions between Nye and the Cliff Swallow FAS are located in geologically confined areas that withstood the flooding with minimal damage.

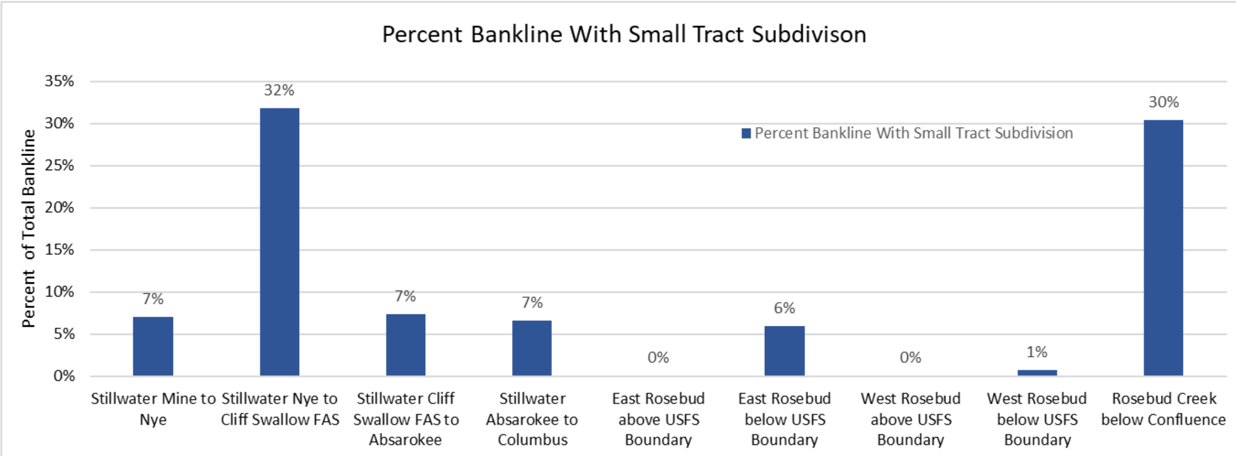


Figure 30. Percent of total bankline that is adjacent to small tract subdivisions by segment.

Figure 31. Cement retaining wall on streambank in area of small tract development, Stillwater River.

5.3. Bank Armoring

Bank armor on the river is common and typically on banklines adjacent to bridges or streamside residences. Most of the armoring in place during the flood was rock riprap. However, eighteen landowners who responded to the SVWC survey described riprap bank treatments as having been damaged or destroyed by the event. These projects have limited lateral channel movement for decades, which can both protect infrastructure while simultaneously interfering with natural channel processes. As evidenced after the June 2022 flood, rock riprap is not always effective in protecting the banks during large floods, for reasons including inadequate size, lack of being keyed into the bed/bank, poor placement and deterioration/lack of maintenance.

5.4. Floodplain Clearing

Although the rivers evaluated commonly have broad cottonwood-dominated riparian corridors, there has been some local losses in the density of woody floodplain vegetation since at least the 1950s (Figure 32). This may reflect management activities (e.g. clearing or herbicide application) or loss of natural cottonwood regeneration processes such as lateral channel migration that can result in “aging out” of riparian stands. The implications can be substantial regarding floodplain roughness and integrity, both of which can dissipate flood energy and support habitat.

Figure 32. Example loss of woody riparian density since the 1950s, Stillwater River at RM 10.3

5.5. Climate

The Montana Climate Assessment (MCA) was developed as an effort to "synthesize, evaluate, and share credible and relevant scientific information about climate change in Montana with the citizens of the

State (Whitlock, et. al, 2017). The report was developed by the Montana Institute on Ecosystems, a statewide center based at the University of Montana and Montana State University. The authors of this report are well-respected both nationally and internationally, and their work provides a glimpse into the anticipated changes in the timing and amount of runoff within Montana's river systems in coming decades.

The Stillwater Watershed is located in Montana's South Central climate division (Figure 33). As part of the climate assessment, temperature and precipitation trends were evaluated throughout the state since the mid-20th Century, then coupled with an ensemble of large scale climate models "downscaled" to the division level.

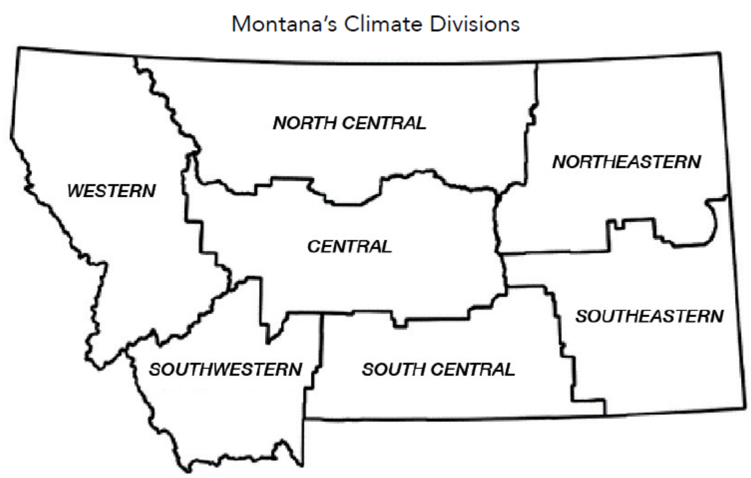


Figure 33. Montana's seven climate divisions (Whitlock et. al, 2017).

Some relevant results from the assessment of the South Central Climate Division include the following (Whitlock, et. al, 2017):

- Historic temperate trends from 1950-2015 show temperature increases at a rate of 0.44 degrees Fahrenheit per decade.
- Historic precipitation trends from 1950-2015 show no significant changes in total precipitation.
- The projected mid-century increase in the number of days with temperatures above 90 degrees ranges from 20 to 35 days, depending on scenario (one is business as usual, and the other is a 2040 peak in greenhouse emissions followed by a decline).
- The projected mid-century increase in annual precipitation ranges from approximately 1 to 2 inches.
- For the Yellowstone River watershed above Billings, the April 1 snowpack is anticipated to drop in snow water equivalent by about 10-40%, depending on scenario.

- Snowmelt runoff expected to occur earlier, with substantial anticipated increases in March-May streamflows, especially under a "business as usual" scenario.

In the Stillwater Basin, it appears that although a lighter snowpack will reduce overall water yield and typical snowmelt flood peaks, warming will increase the frequency of rain-on-snow events and associated short duration, intense flooding. The June 2022 rain-on-snow-driven flood is consistent with this climate trend noted by Whitlock, et.al.

"It was just mother nature doing her thing but I gotta tell ya, I don't trust her. It could happen again".

There is preliminary evidence that rivers draining the Beartooth-Absaroka mountains have already experienced earlier runoff trends. The trend in "center of volume" (COV) dates which we evaluated for the Stillwater River and Yellowstone River at Corwin Springs indicate that runoff is trending earlier, as the trendline slopes downward (Figure 34 and Figure 35). Center of Volume is the date on which half of the total volume of runoff for any particular Water Year passes the stream gage.

Although there is considerable variability in the COV date year to year, the long-term trend is for earlier dates. This trend is similar for nearly all the other streams draining the Yellowstone-Absaroka region. For the Stillwater River the median COV date for Water Years 1935-1996 is June 13 while the median COV date for Water Years 2001 -2022 is June 7.

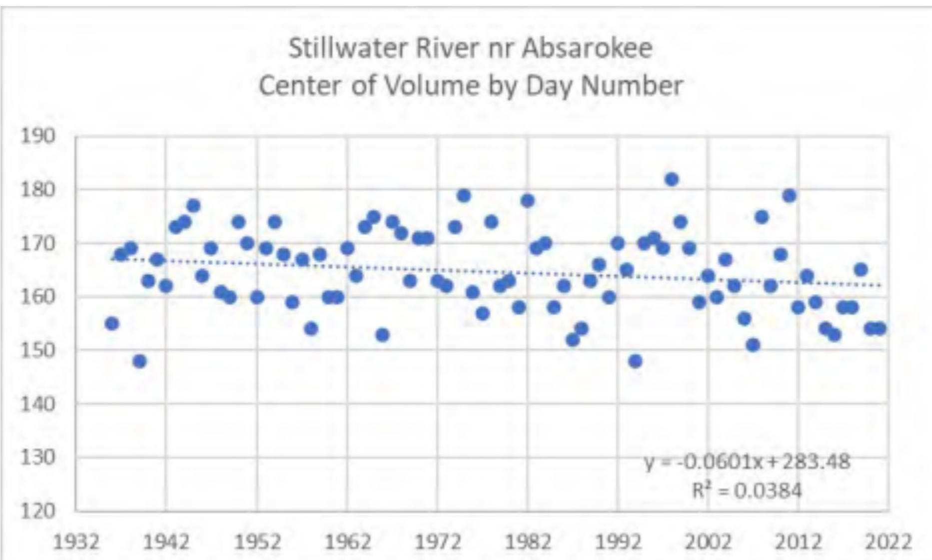


Figure 34. "Center of Volume" plot showing trends towards earlier runoff on the Stillwater River.

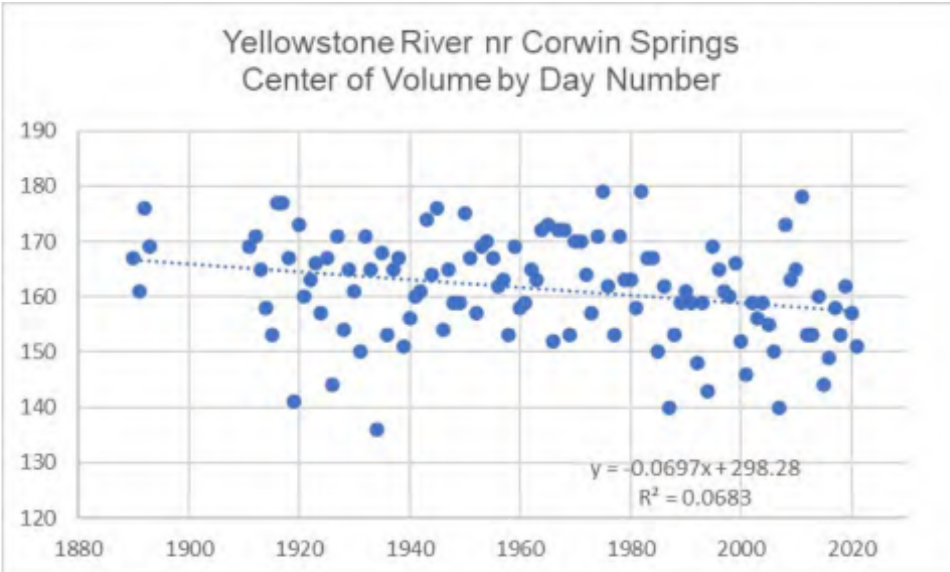


Figure 35. "Center of Volume" plot showing trends towards earlier runoff on the Yellowstone River.

6. Major Impacts of the 2022 Flood

The following section describes the watershed-wide context of the 2022 flood to provide some context for site-specific treatments described in Chapter 7.

6.1. Methods

The impacts of flooding were evaluated using geographically registered pre- and post- flood aerial imagery, landowner input, and field observations focusing on the nature, location, and types of impact.

6.1.1. Mapping and GIS Analysis

Two primary sets of imagery were used to assess pre-flood conditions and post-flood impacts. 2021 color National Agriculture Imagery Program (NAIP) imagery (0.6 meter) for Stillwater and Carbon Counties were used for pre-flood. For post-flood, high-resolution satellite imagery was sourced from LAND INFO Worldwide Mapping. These images are collected from various private imagery services at irregular intervals, and thus appropriate cloud free imagery for all the project waterways was not available. Pleiades imagery (0.5 meter) from July 23, 2022 was available for all but the upper reaches of East and West Rosebud Creeks which were filled in with SPOT imagery (1.5 meter) from August 31, 2022. All imagery was pan-sharpened and orthorectified to allow for direct comparison of river locations between imagery sets.

Banklines representing bankfull margins were digitized for both pre- and post-flood imagery at a scale of 1:1,500. A tablet computer running ArcGIS and using a pen stylus was used to trace the banklines using stream mode digitizing. This methodology allowed us to capture a much more detailed bankline than using a mouse. Bankfull is defined as the stage above which flow starts to spread onto the floodplain. The extent of the lower limit of perennial, woody vegetation was used to define channel banks. This is based on the generally accepted concept that bankfull channels are inhospitable to woody vegetation establishment. Banklines were difficult to identify in some of the deeper canyon areas where shadows obscured the banklines. In general, these areas see limited channel movement due to channel migration, so accurate bankline mapping between imagery was not considered critical.

6.1.2. RATT Team Site Visits

In mid-March of 2022, the RATT team visited 31 sites to observe and document a range of flood impacts on the assessed streams. The sites were primarily identified by landowners who had submitted a questionnaire response to SVWC that described issues and requested a visit. In most cases, the landowner showed the team around, providing invaluable information regarding their individual impacts and concerns. The sites were concentrated on the Stillwater River, East Rosebud Creek, and Rosebud Creek; no requests were made for visits on West Rosebud Creek (Figure 36).

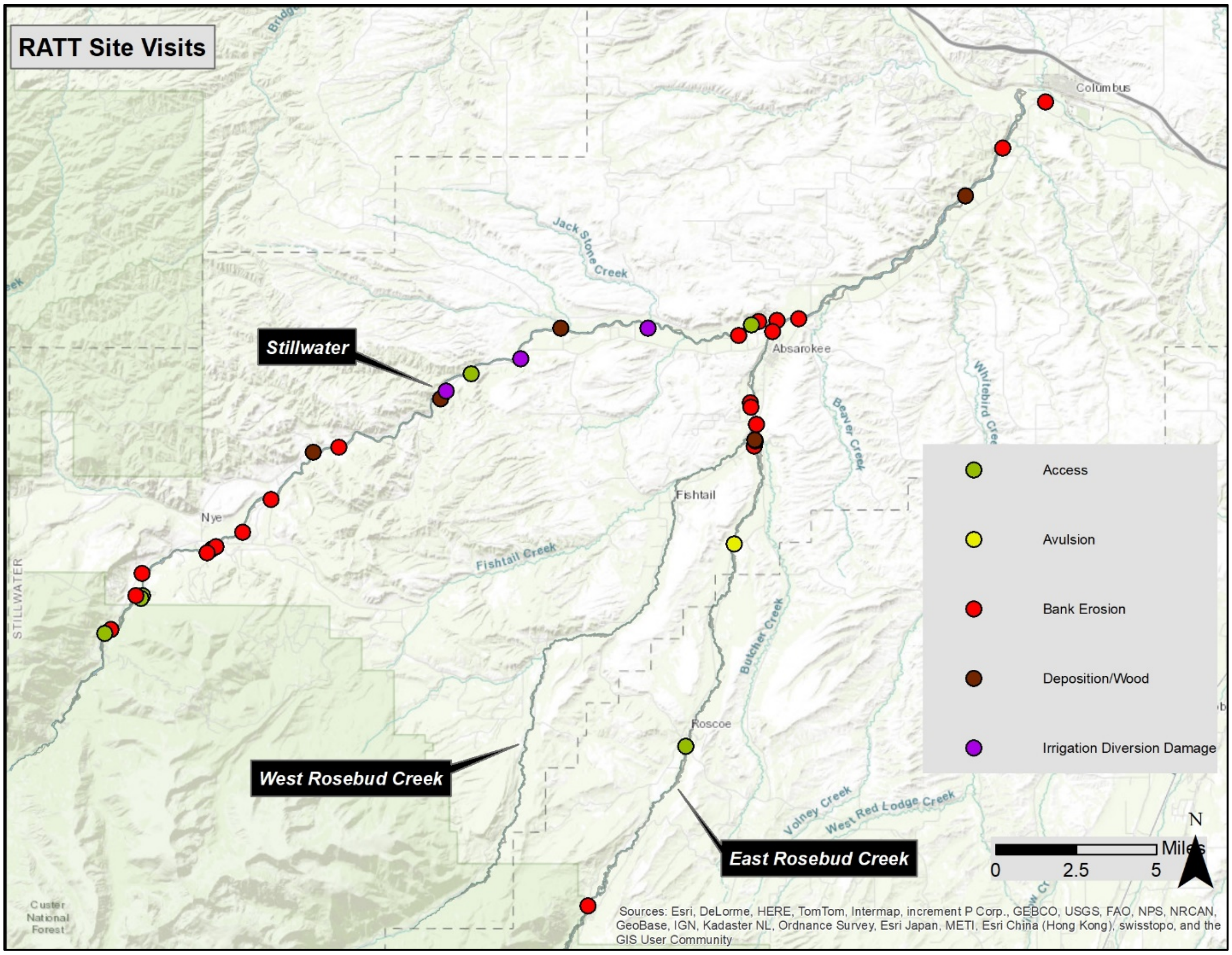


Figure 36. RATT site visit locations showing primary issue identified by landowner.

6.1.3. Project Reaches

> ***Note: The River Mile stationing used for this project was developed by Montana Fish Wildlife and Parks.***

The assessed streams were broken into a series of reaches (segments) to better summarize flooding impacts (Table 4). The reach boundaries reflect changes in geology, hydrology, or public/private land boundaries. The Stillwater was broken into four reaches beginning at RM 44.2 by the Sibanye-Stillwater Mine. Both East and Rosebud Creeks were broken into segments at the US Forest Service Boundary. Figure 37 and Figure 38 show the reach boundaries as well as the River Miles used in the flood impacts assessment.

Table 4. Reach segments used to summarize flood impacts.

Reach	River Mile Start	River Mile End	Length (miles)
Stillwater River			
Sibanye-Stillwater Mine to Nye	44.2	35.2	9
Stillwater Nye to Cliff Swallow FAS	35.2	23.3	11.9
Stillwater Cliff Swallow FAS to Absarokee	23.3	12.1	11.2
Stillwater Absarokee to Columbus	12.1	0	12.1
East Rosebud Creek			
East Rosebud above USFS Boundary	26.4	20.8	5.6
East Rosebud below USFS Boundary	20.8	0	20.8
West Rosebud Creek			
West Rosebud above USFS Boundary	22.9	21	1.9
West Rosebud below USFS Boundary	21	0	21
Rosebud Creek			
Rosebud Creek below Confluence	3.8	0	3.8

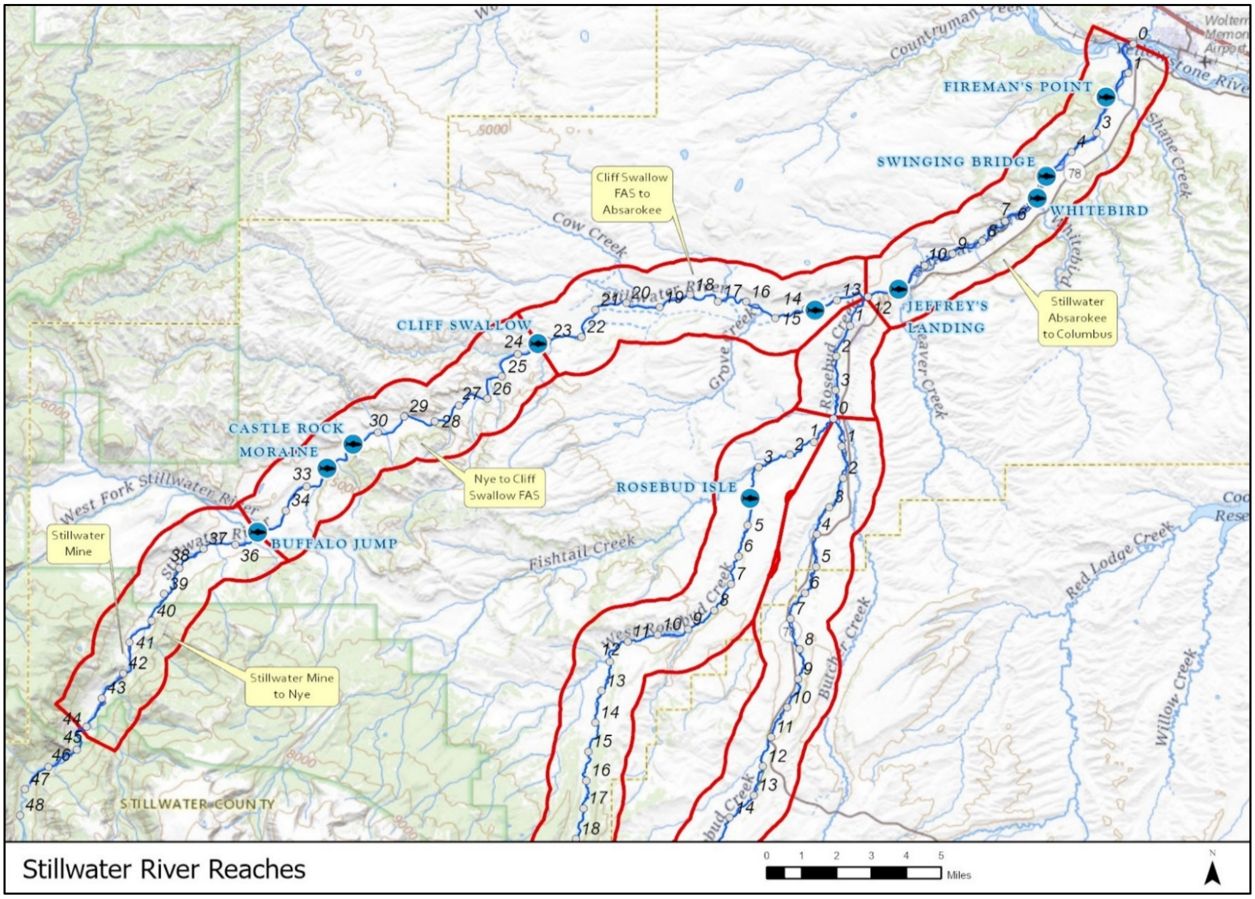


Figure 37. Reach delineations for Stillwater River.

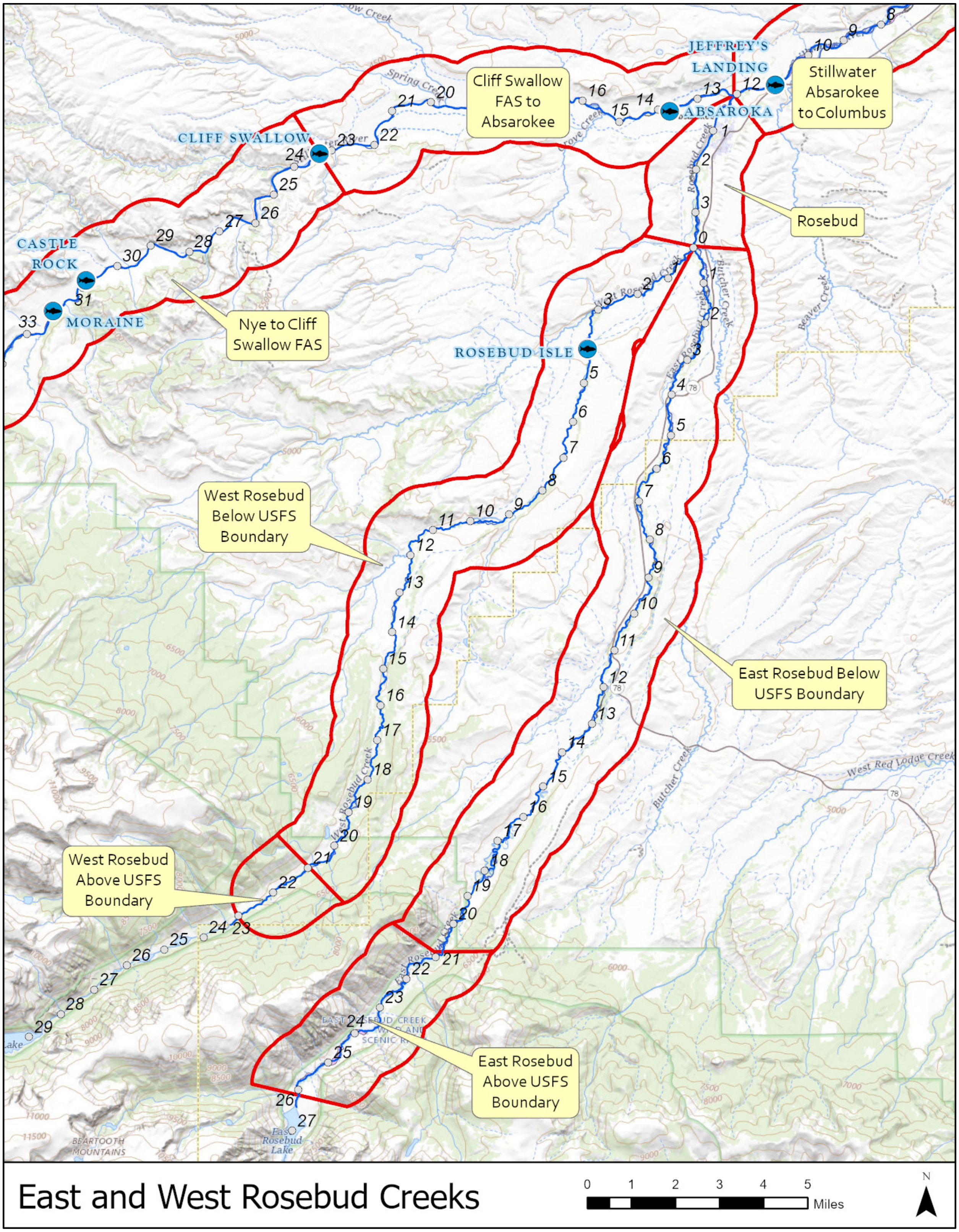


Figure 38. Reach delineations for East Rosebud Creek and West Rosebud creek.

6.2. Bank Erosion

Bank erosion was one of the most extensive and visible flood impacts. In order to better understand the locations and extent of flood-induced erosion, the pre- and post-flood banklines were intersected to estimate the acreage of ground eroded during the flood event (Figure 39). These data can also be used by individual landowners who would like to measure the amount of erosion or channel widening on their property.

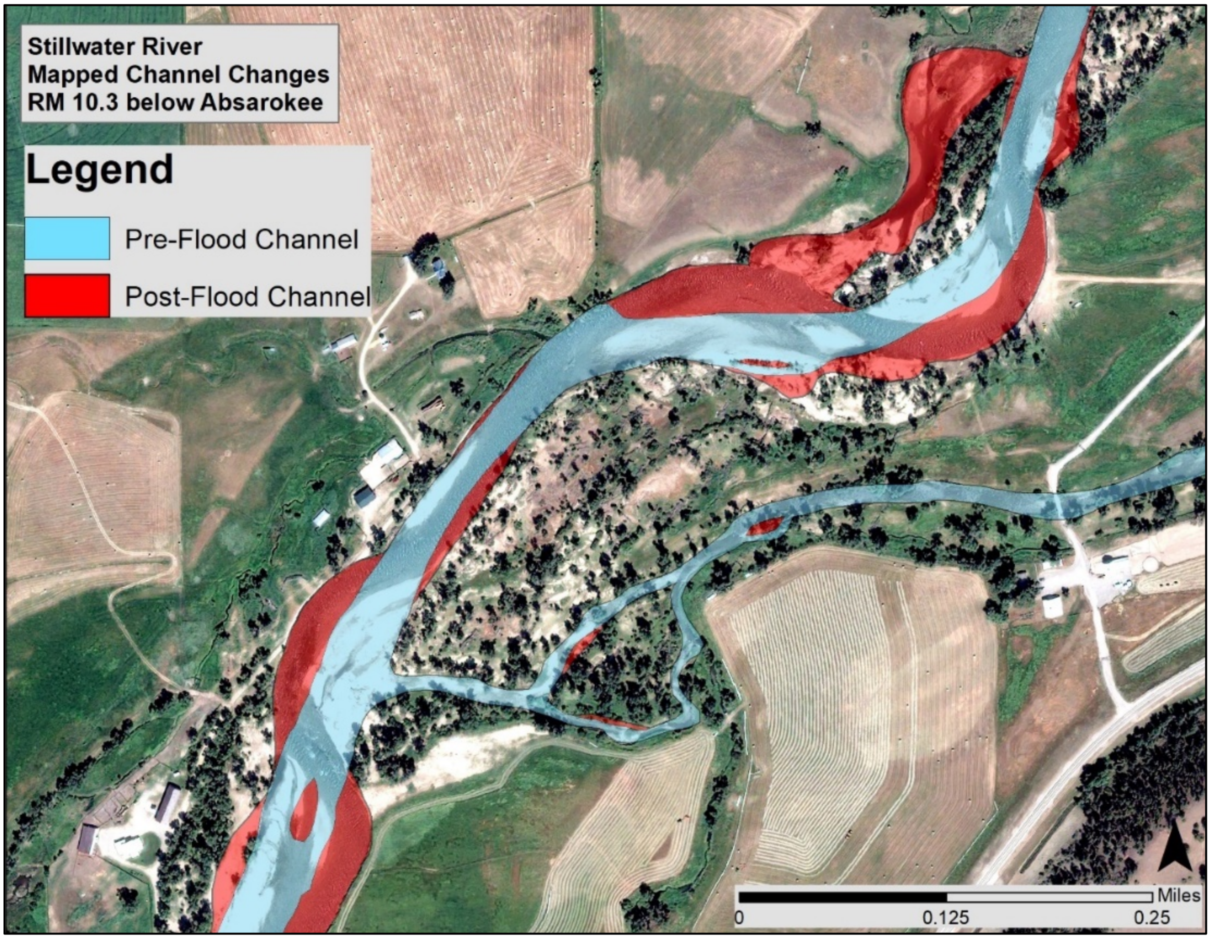


Figure 39. Example bankline mapping showing pre- and post-flood banklines capturing erosion location and extent, Stillwater River RM 10.3 below Absarokee.

For the reaches evaluated, just over 300 acres of total ground was mapped as eroded due to bankline shifts during the flood, with the vast majority on the Stillwater River and East Rosebud Creeks (Figure 40). Rosebud Creek at Absarokee is only 3.8 miles long, such that the total erosion was less than other streams but proportionately heavily eroded. West Rosebud Creek shows relatively minor erosion along its 23-mile length.

Figure 41 shows the amount of erosion by 1-mile increments for each stream, to help highlight the most impacted areas. On the Stillwater, erosion was clearly most intense on the upstream end near the Sibanye-Stillwater Mine as well as just above and below the Rosebud Creek confluence. Much of the erosion at River Mile 8 on the Stillwater was due to a major avulsion that reactivated an approximately 0.7-mile-long historic channel that had previously been blocked by roads and dikes (Figure 42).

Although East Rosebud Creek showed 143 acres of total erosion, the majority of that was in the upper watershed above the USFS boundary where erosion/gravel deposition was especially intense (Figure 43).

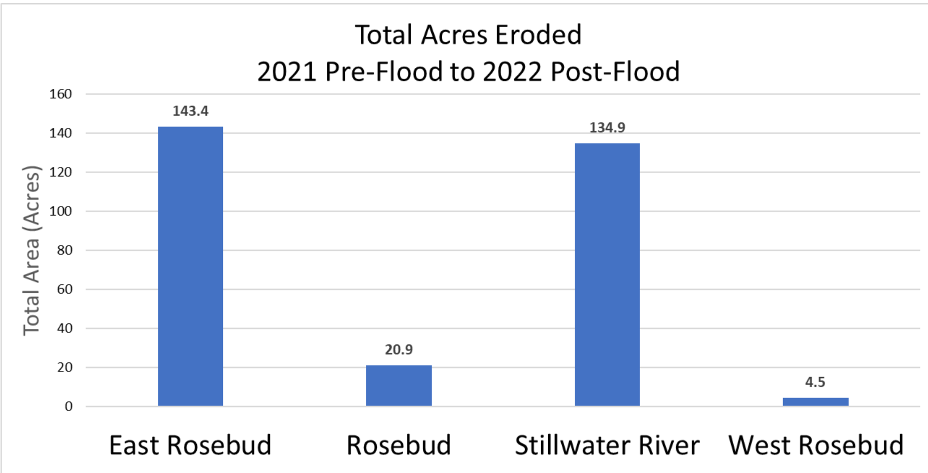
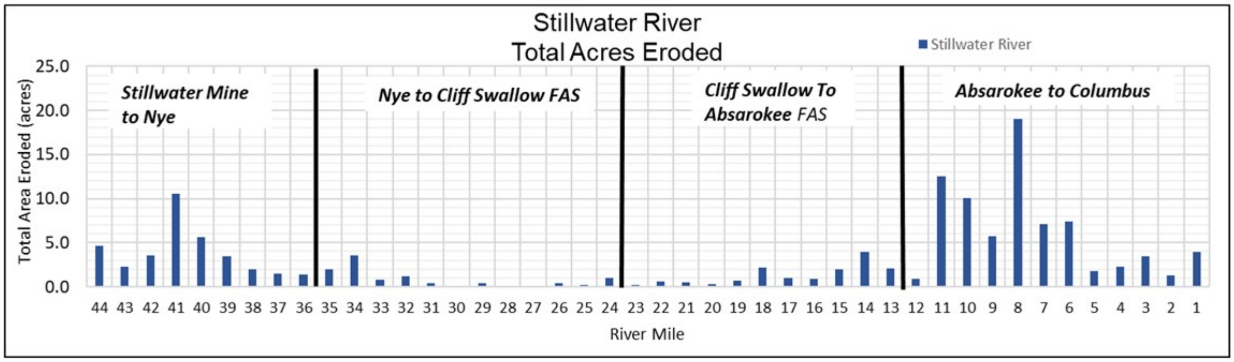
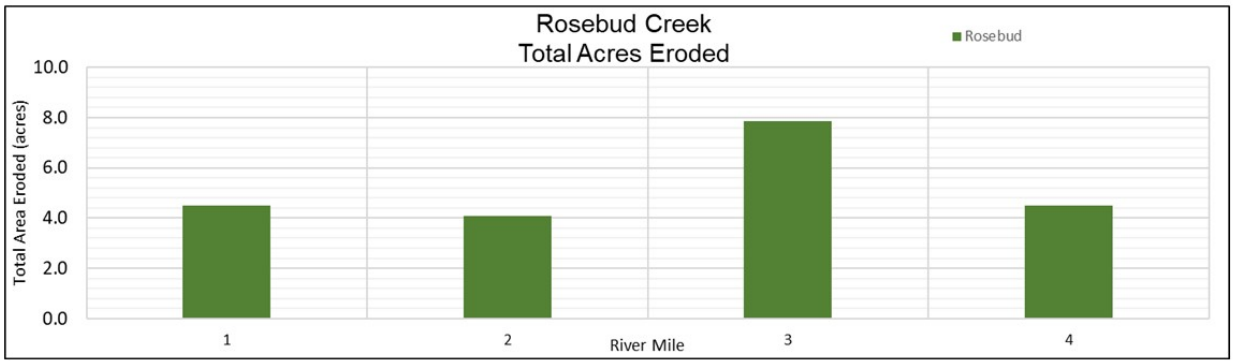
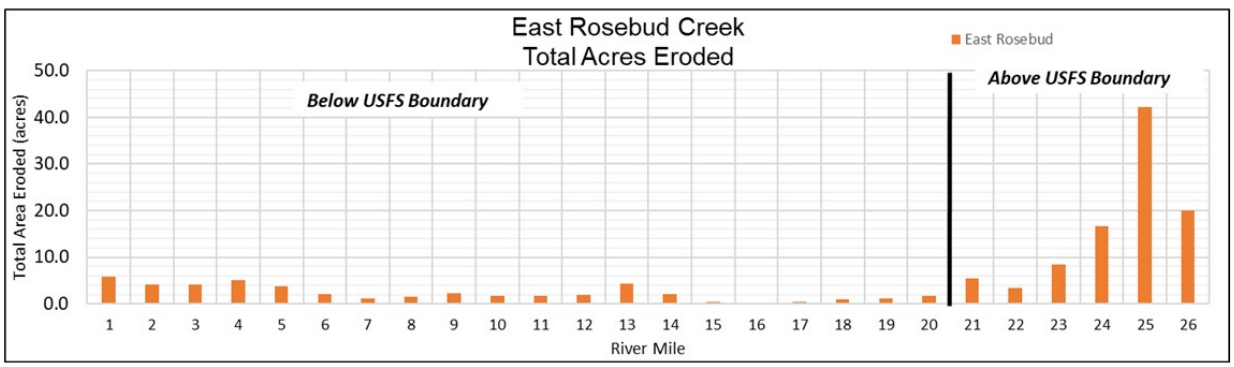


Figure 40. Total extent of erosion during the June 2022 flood window by river sub-basin.







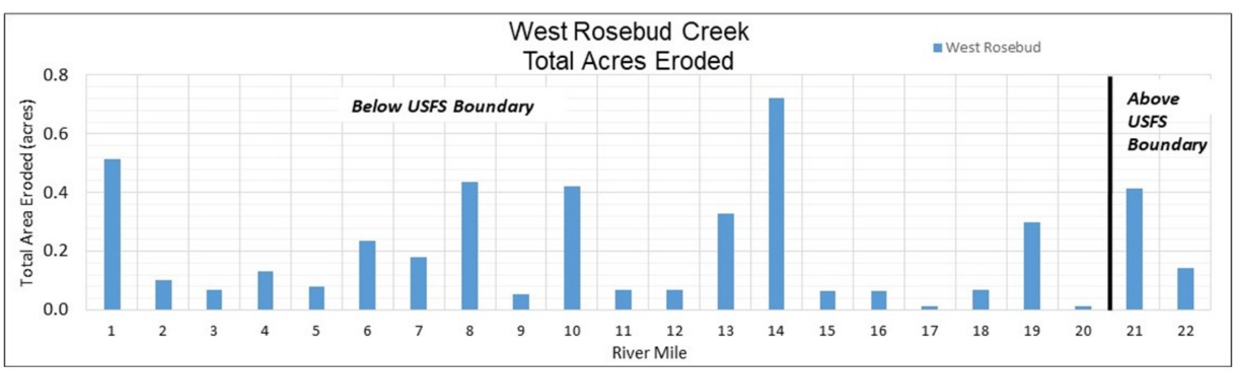


Figure 41. Total acreage eroded by river mile, (RM 1 value reflects eroded acres erosion from RM 0-RM 1; note that the scale of the vertical axes varies greatly between the plots.

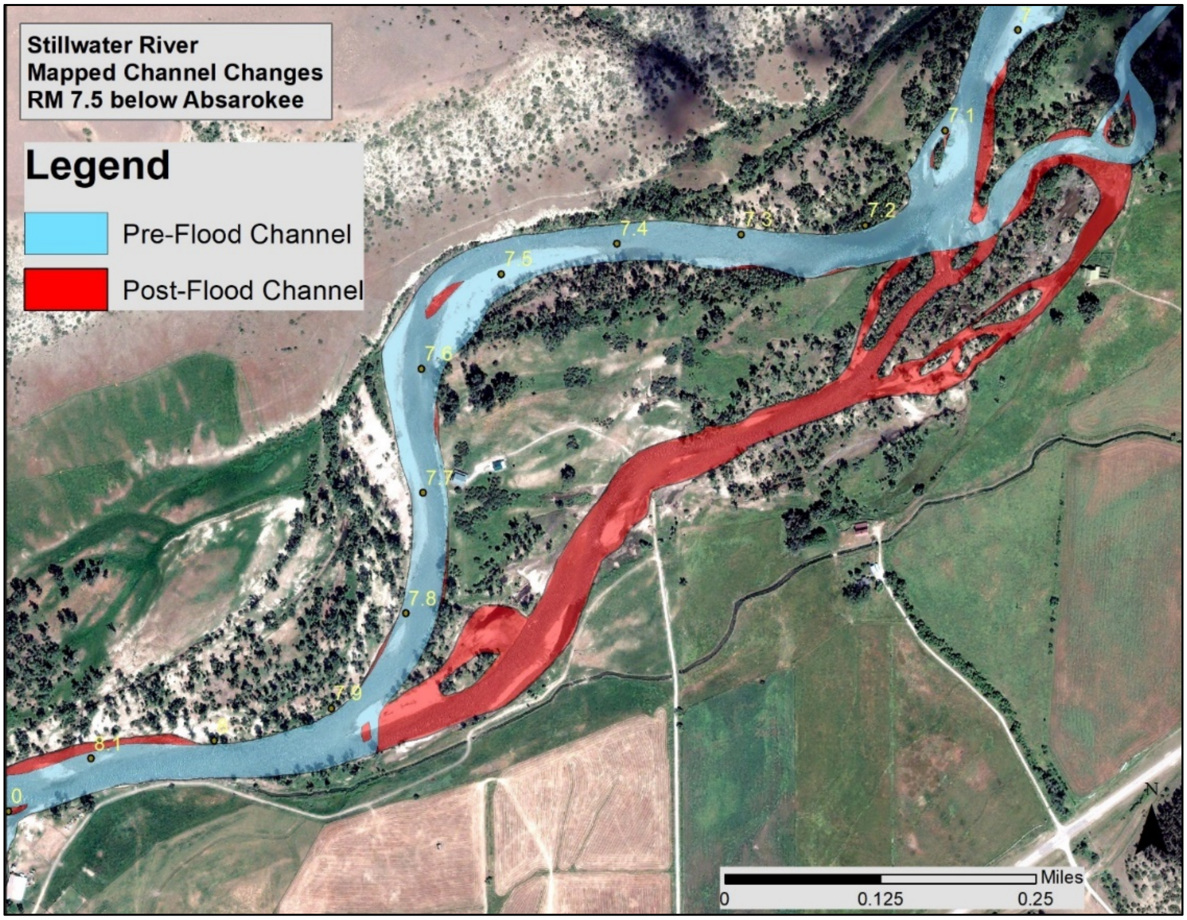


Figure 42. New channel formation at RM 7.5 below Absarokee showing extensive flood-induced erosion.

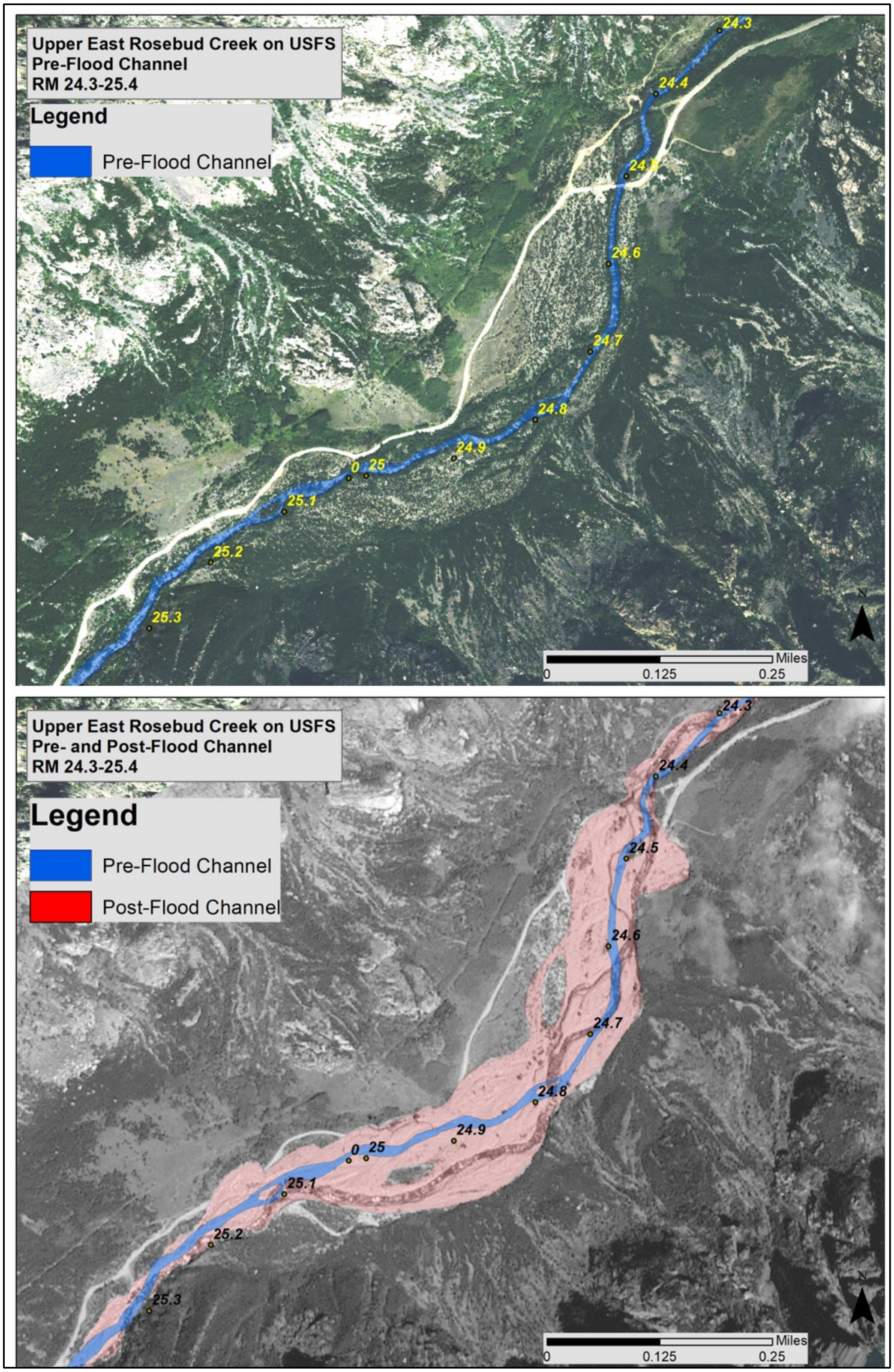


Figure 43. Pre-flood (top) and post-flood (bottom) imagery from East Fork Rosebud Creek above USFS boundary.

Whereas the erosion patterns described above capture channel migration, the percent change in total aerial footprint of the pre- and post- flood channels gives some indication of channel widening. Figure 44 shows the total change in channel footprint for all the streams evaluated. The Stillwater River expanded by 128.4 acres, which reflects a 16% expansion in total area. In contrast, West Rosebud Creek showed minimal change in area; the results indicate that West Rosebud Creek became slightly smaller after the flood due to local side channel abandonment.

The greatest overall expansion of the channel on the Stillwater River was on the upper end near the Sibanye-Stillwater Mine, and below Absarokee (Figure 45). The changes above Nye reflect only widening, whereas the changes below Absarokee reflect channel widening as well as new channel formation (avulsion). Figure 46 shows dramatic channel widening near the Sibanye-Stillwater Mine above Nye where several structures were lost during the flood.

It is important to note that this summary reflects only the 2-dimensional area of the channel footprint; since cross sectional was also strongly impacted by the flood, future channel capacity cannot be directly inferred from these data.

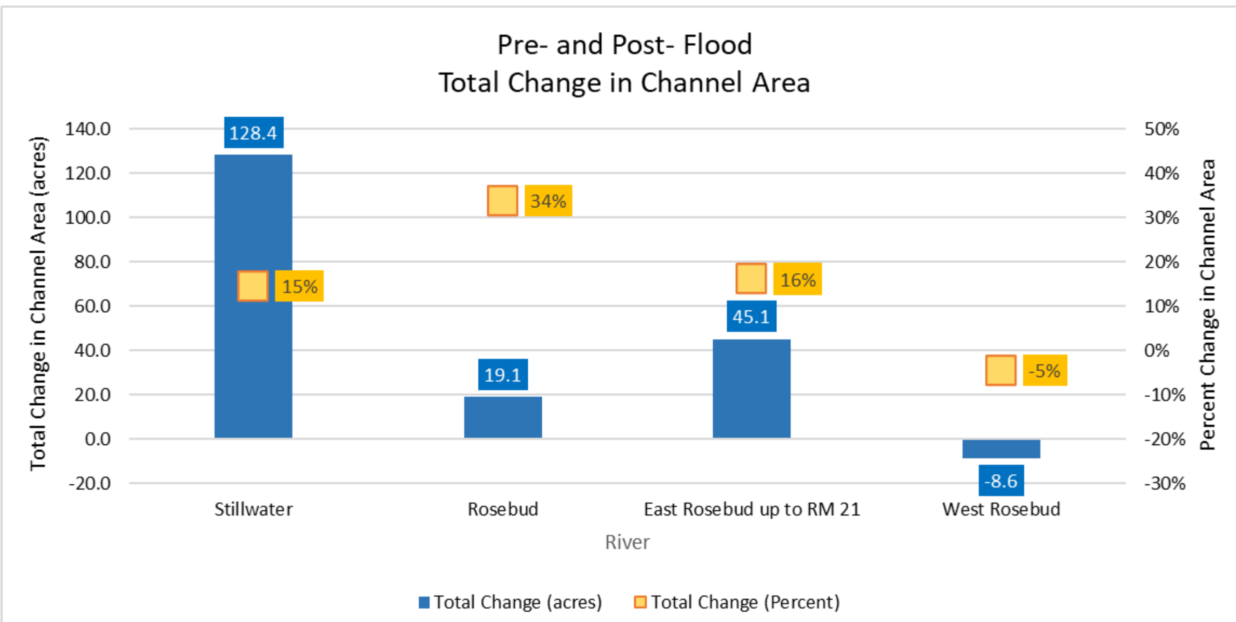


Figure 44. Total flood-driven change in channel area (aerial footprint) by river sub-basin.

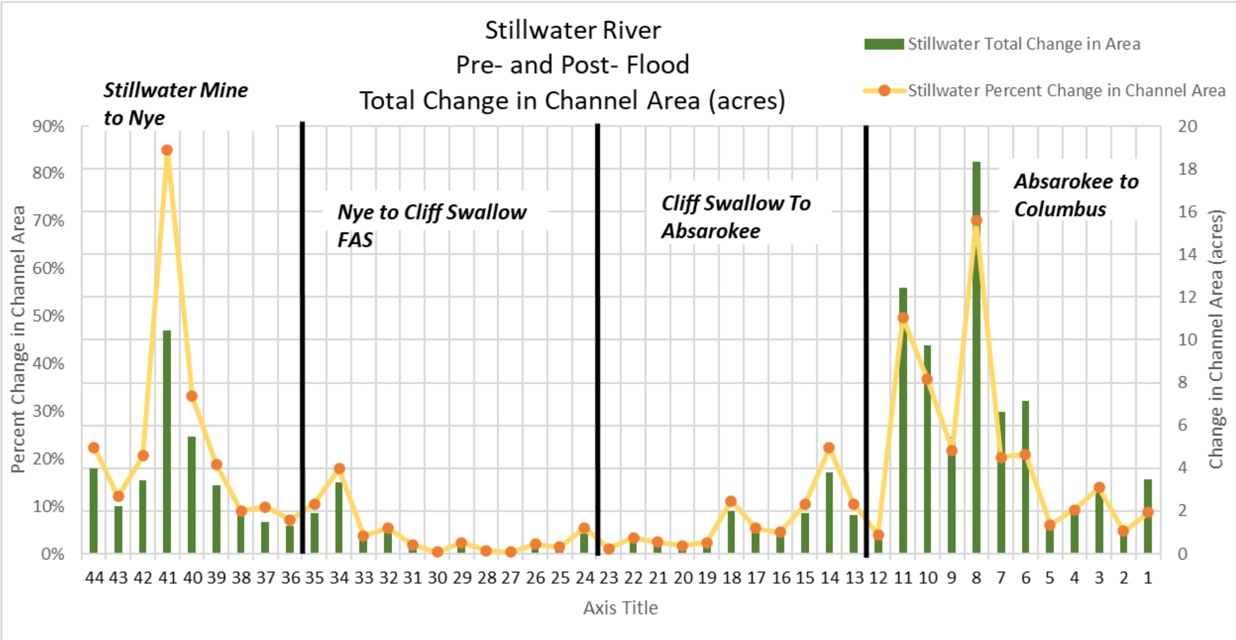


Figure 45. Total acreage of channel expansion (bars) and percent channel widening (lines) by river mile for the Stillwater River. Changes in the size of the channel footprint is shown on right-hand axis; percent change is on left-hand axis.

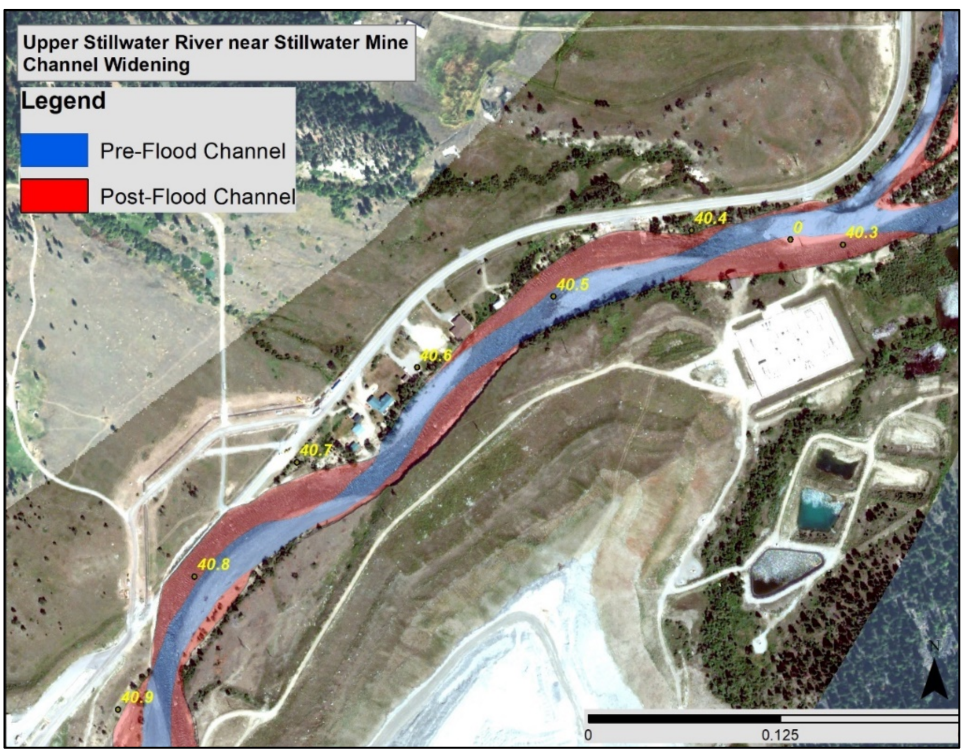


Figure 46. Channel widening due to flood erosion on upper Stillwater above Nye; the river doubled its width in several areas, destroying several structures. Channel widening also affected proximity of river to mine waste rock dump.

Figure 47 and Figure 48 show the locations of channel enlargement on East Rosebud Creek and Rosebud Creek, respectively.

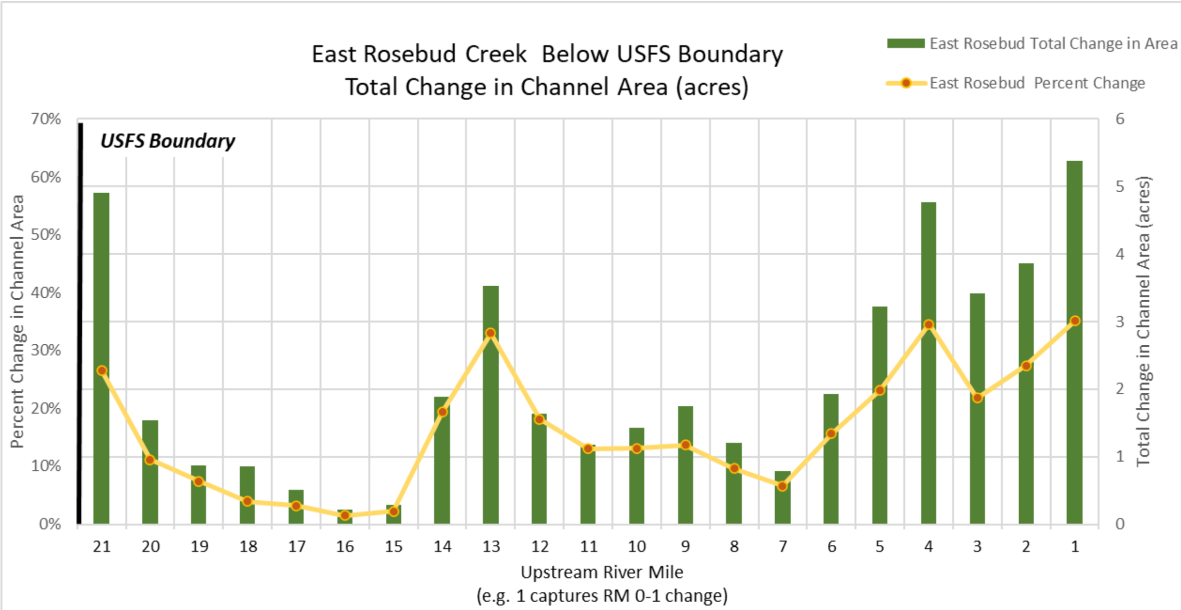


Figure 47. Total acreage of channel expansion (bars) and percent channel enlargement (lines) by river mile for East Rosebud Creek.

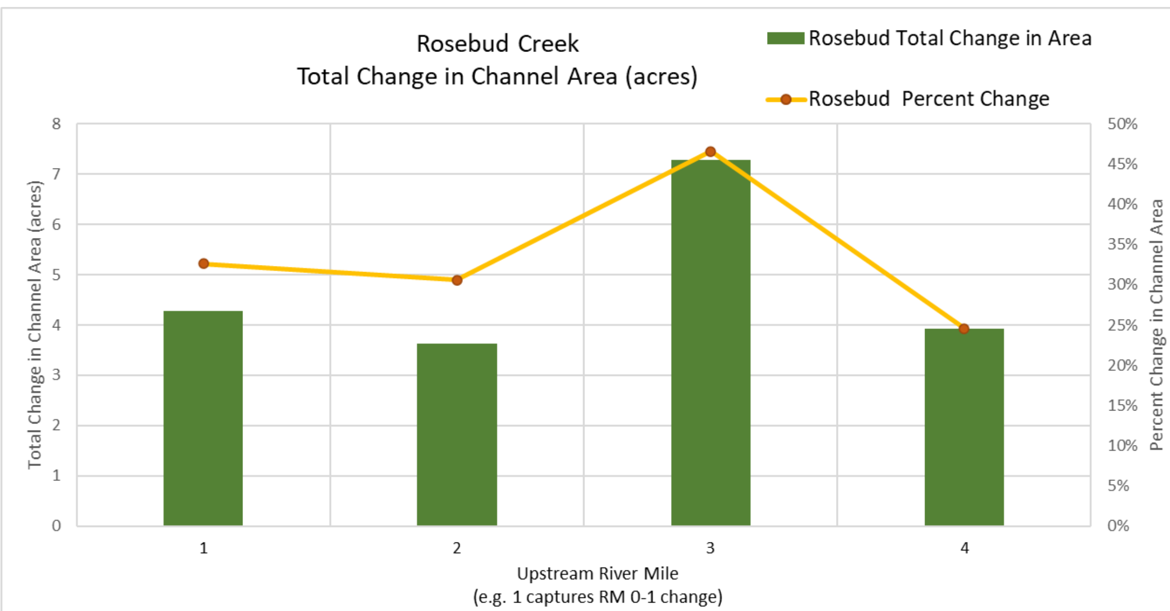


Figure 48. Total acreage of channel expansion (bars) and percent channel enlargement (lines) by river mile for Rosebud Creek (below East-West Rosebud confluence).

6.3. Bed Aggradation and Lost Channel Capacity

“At 2 am there was a tremendous thundering of rocks bouncing down the streambed”.

Channel infilling with coarse bedload sediment was a common flood impact. The flood had a rapid rate of recession such that bedload that was in transport during the peak was rapidly deposited as transport energy dropped. Field observations indicate that most of the bank material derived from severe erosional cuts was re-deposited in the next bar or two downstream, typically a distance of 500 to 1,000 feet. Lighter materials on the other hand traveled considerable distances. In one telling incident, a Stillwater River rancher lost dozens of large round bales to bank erosion near mile 13.7, and one of those bales was found embedded in a new cobble bar near river mile (RM) 11, about 2.7 miles downstream. There are currently no data available to quantify the extent of channel infilling, however it was possible to map side channels that appear to have become disconnected at low flow due to deposition (Figure 49). An estimated 10.8 miles of channels have become perched due to deposition, some of which have sediment concentrated at their entrances and others throughout their length (Figure 50 and Figure 51).

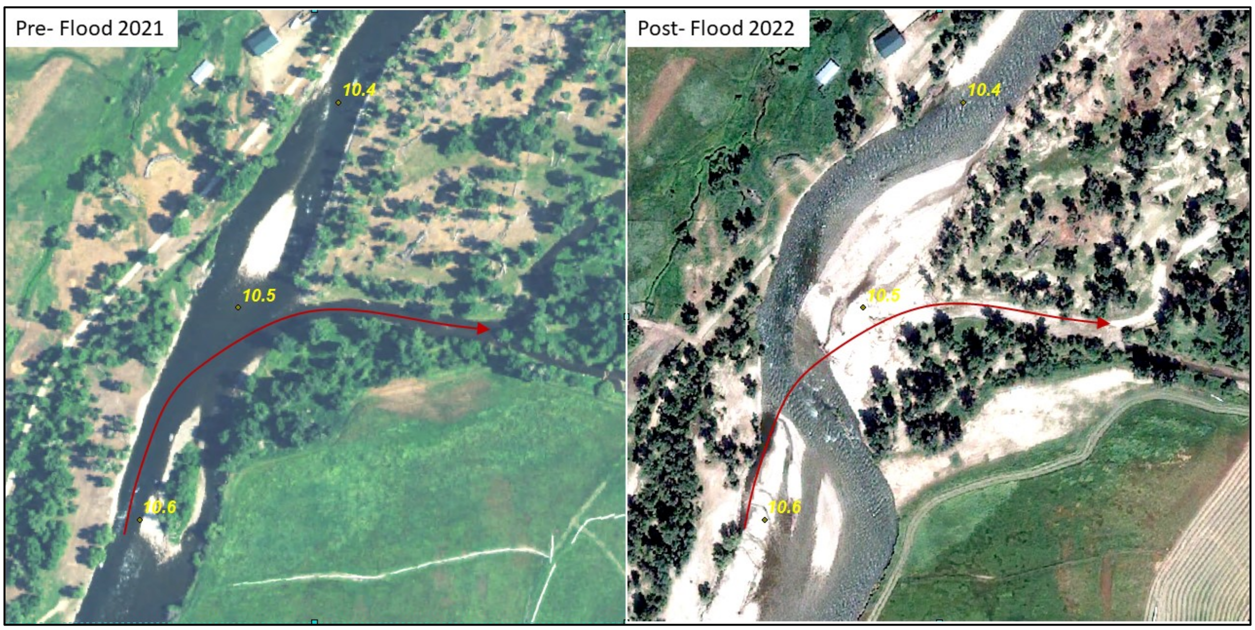


Figure 49. Large point bar deposition and loss of side channel connectivity on Stillwater River, RM 10.5.

Figure 50. View upstream of an aggraded side channel (main channel is on upper right edge of photo) Stillwater River near RM 13.5.

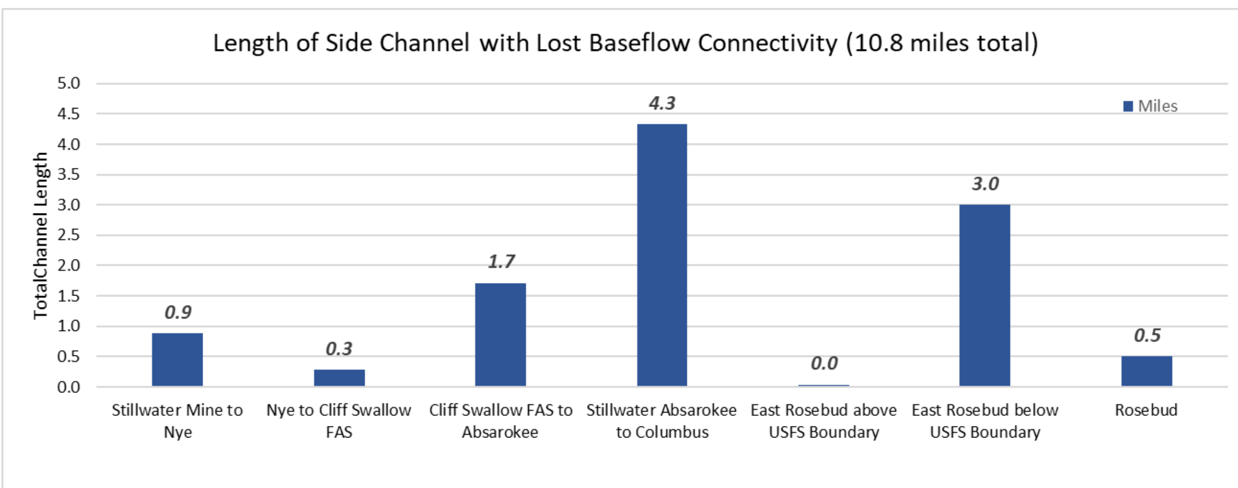


Figure 51. Mapped length of side channels that show lost baseflow connectivity due to sediment deposition.

6.4. Debris

Debris accumulations were extensive on the river and included both man-made materials as well as large wood (Figure 52). Accumulations stacked on the floodplain, in the channel, and in side channels. In many cases the debris routed water onto different floodplain flow paths that created new obstacles and hazards for landowners. The accumulations are impressive; an estimated 20,000-30,000 cubic yards of debris was estimated to have been deposited over 1.5 miles of channel near the Sibanye-Stillwater Mine alone.

Figure 52. Example debris accumulation on upper Stillwater.

"When I woke up that morning and looked out the window… it was so high and dirty, I thought 'oh boy!'".

6.5. Bridge Failure

A total of 59 bridges were mapped in the assessment reaches, and 13 of those were completely destroyed by the flood. All the destroyed bridges were on either the Stillwater River or East Rosebud Creek. Several bridges provided primary access for residences such as the Rainbow Ranch Subdivision on the upper Stillwater (Figure 53). Other bridges visited in the field were substantially damaged but did not fail.

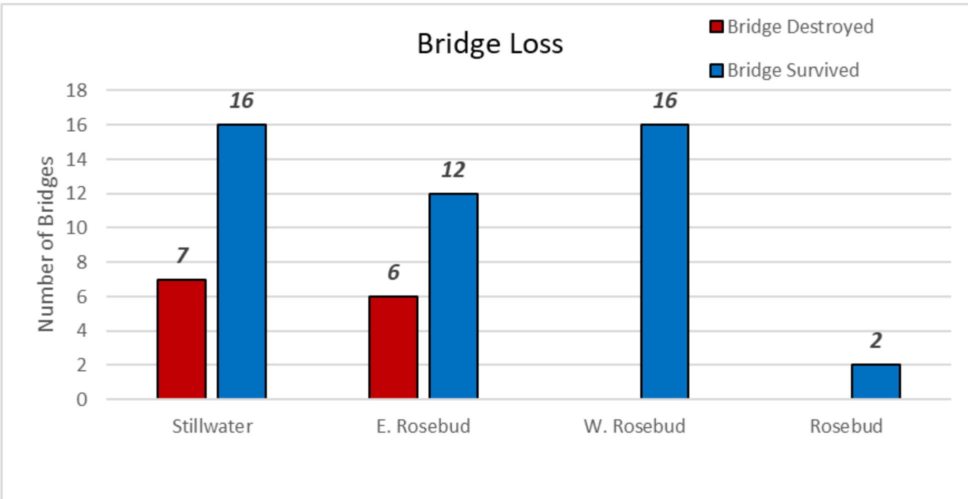


Figure 53. Total number of bridges mapped as having survived or been destroyed by the flood.

Figure 54. Upper Stillwater Bridge failure (RM 39.3); bridge provided the primary access route for the Rainbow Ranch Subdivision.

6.6. Damage to Irrigation Infrastructure

As irrigation structures tend to be somewhat unique in terms of placement and construction, the impacts to them were widespread but variable. In general, damages consisted of the following:

- Destroyed or damaged headgates
- Erosion around headgates causing structure destabilization and loss of functionality
- Sediment/wood accumulations at headgates or in diversion channels to headgates damming off river access or affecting performance
- Overwhelming of headgates by floodwaters causing downstream ditch flooding

6.7. Lost Structures

An estimated total of 17 structures were identified in the mapping as having been destroyed or undermined by the flood, including approximately 13 homes and 4 outbuildings (Figure 55). The majority of those were on the upper Stillwater, with 9 structures identified upstream of Nye. Most of the structures destroyed upstream of Nye were residential homes (Figure 56).

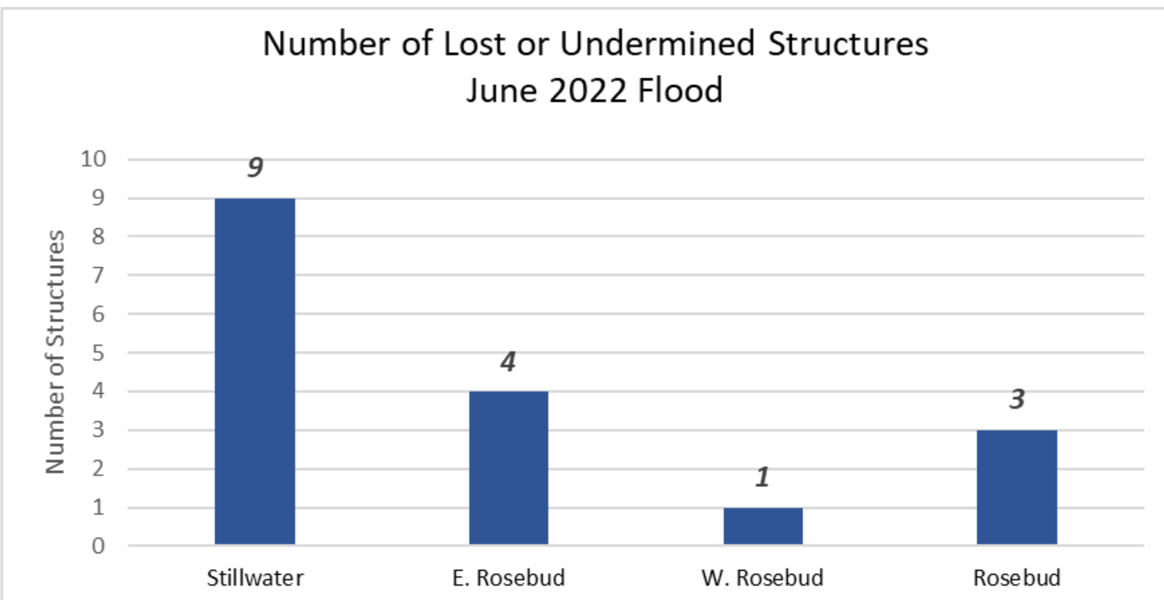


Figure 55. Number of mapped structures destroyed by 2022 Flood; most were residences.

Figure 56. Undermined structure on Stillwater River upstream of Nye as viewed in late August 2022.

6.8. Road Damage

A total of 4,520 feet of road was mapped in the post-flood imagery as having clear evidence of damage by bankline erosion. Of that, approximately 0.5 miles of road was directly impacted by erosion on the Stillwater and 0.3 miles on the East Rosebud. Whereas some of the road damage has been repaired, much of the damage on the North Stillwater Road near Absarokee remains unrepaired and the route was still closed as of March 2023. On the upper Stillwater above the mine, the road is still closed that provides public access to Woodbine Campground and public land beyond (Figure 57). Approximately 0.3 miles of the access road to East Rosebud Lake on USFS property was eroded over a 5-mile stretch, rendering that area inaccessible.

Figure 57. Road damage on upper Stillwater River near the Sibanye-Stillwater Mine (March 2023).

6.9. Avulsions

An ***avulsion*** is the rapid carving of a new channel through a floodplain surface that captures flow of the main channel thread. A total of 29 avulsions were mapped in the assessment area, with the majority occurring throughout the riparian bottomlands along East Rosebud Creek below the USFS boundary (Figure 58). About 5.2 miles of new channel formed, with almost half of that total length on East Rosebud Creek (Figure 59). Some of these channels will decay with time, especially if they did not erode deeply enough to carry typical flows. Some will persist as main channel threads. Although avulsions can create problems due to the dramatic channel change, they can also create beneficial habitat complexity and rejuvenation where infrastructure is not directly threatened (Figure 60).

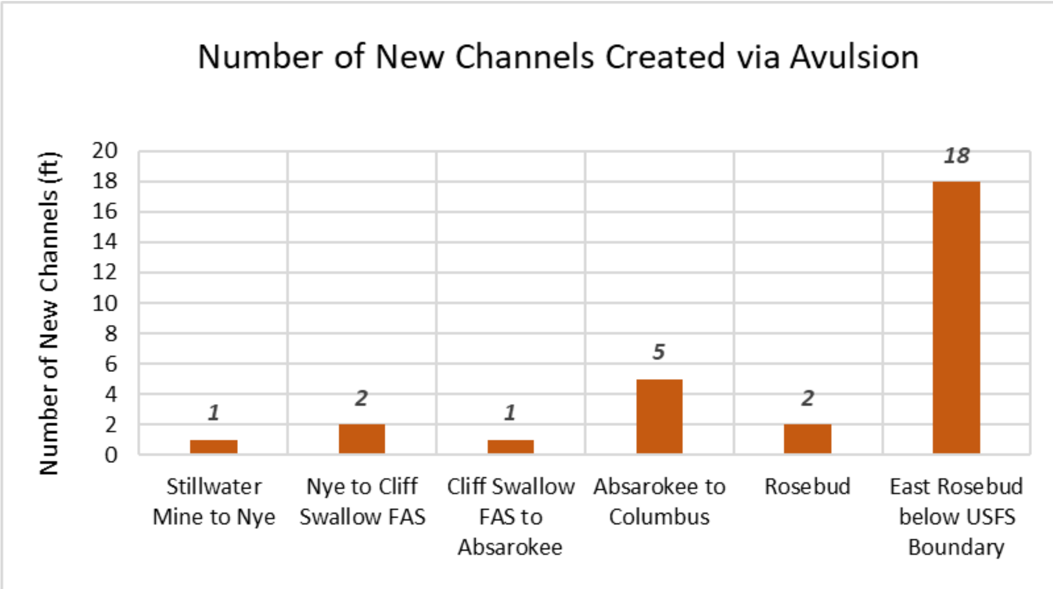


Figure 58. Distribution of mapped flood-induced avulsions.

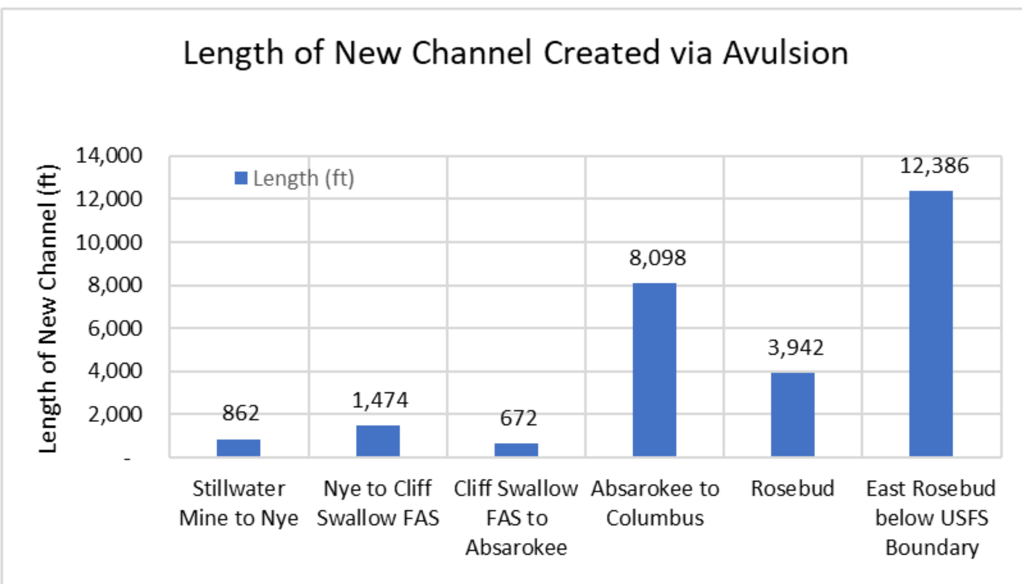


Figure 59. Length of mapped flood-induced avulsions.

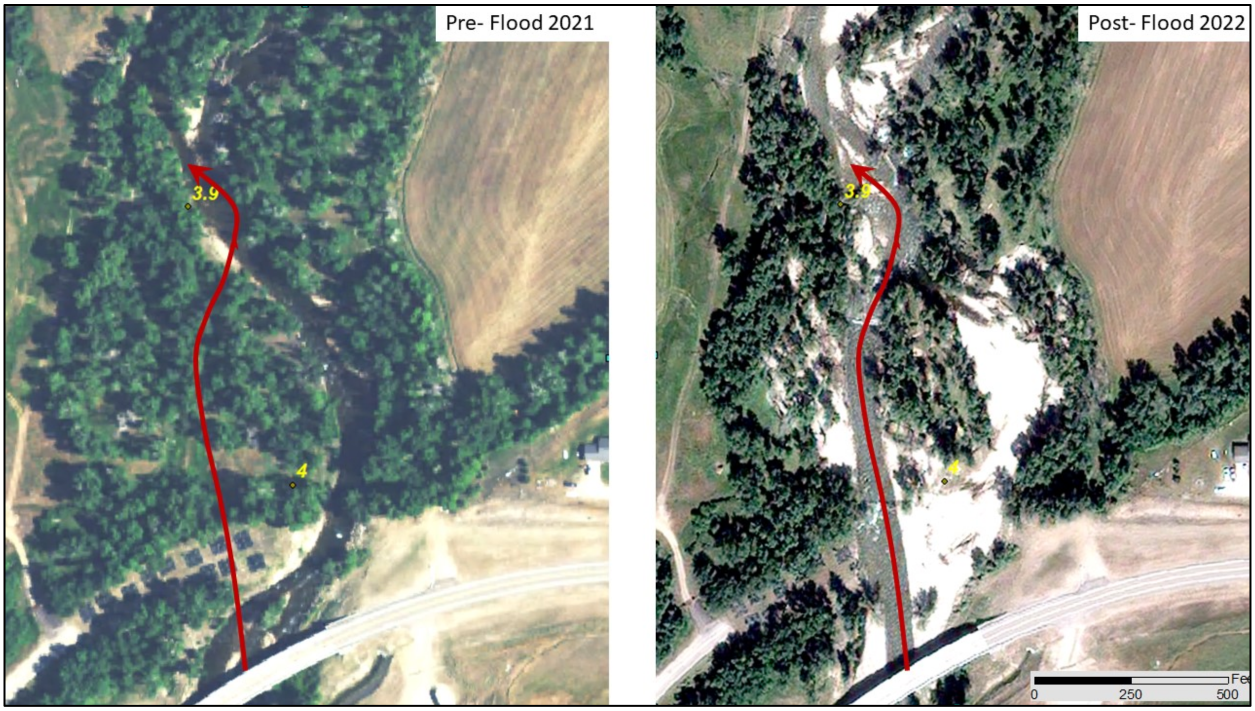


Figure 60. East Rosebud Creek below the new Highway 78 Bridge showing 2021 image (left) and post- flood 2022 image (right), with avulsion route mapped in red.

6.10.Fisheries Response

Both the Moraine and Absarokee electrofishing sections were sampled following the flood in June 2022. FWP saw no unexpected change in population density; the Moraine section showed a continued downward trend in population density, but this has been occurring for over 20 years (Figure 12). The Absarokee section remained relatively stable. The primary concern regarding the flood impacts relates to the loss of an age class by the flood due to scouring of eggs and loss of fry. FWP will not know the impact of the flood on the 2022 age class as the sampling methods are not able to effectively catch juvenile fish.

"One thing I like to stress right now is we don't want to mess too much with habitat so the fish have the opportunity to spawn this year'".

FWP also noted that the floods can perform as a "reset button" for the fishery, by adding new habitats (woody debris/side channels) for all life stages, and by adding new spawning gravels to the streams. The floods also scour pools along streambanks, below boulders, and around wood. During FWP's 2022 fall redd counts on West Rosebud Creek near Pine Grove Campground, two new side channels were surveyed that had redds in them, indicating that the fish can quickly find and use these new habitat features.

7. Examples of Impacts and Recommendations for Appropriate Response Actions

The following section describes recommended response actions for different types of flood impacts.

7.1. Considering the Appropriate Level of Response: Action, Adaptation, and No Action

As residents who were affected by the flood respond with project work, it is important to consider the appropriate level of response to a given impact. In some situations, immediate action is advisable, primarily where infrastructure is under immediate, demonstrable threat of substantial damage. In contrast, there is always substantial risk in reacting too early and too aggressively with some approaches such that the work is ineffective and/or ecologically detrimental.

"You've got to be your own advocate and figure it out".

The three general levels of response include Action, Adaptation, and No Action.

"***Action***" implies some degree of immediacy and could mean several responses- emergency measures to protect a bank, armoring and build-back at a high value structure, moving a structure, restoration of uplands, etc.

"***Adaptation***" implies a measured response and could also mean a number of responses less intrusive and less expensive than the above, including, soft bank protection measures, rehabilitation of or moving a point of diversion, re-routing a road instead of building back in original footprint, "wait, monitor and see", etc.

Rating keys such as that shown in Table 5 can be used as a systematic means of describing recommended levels of action.

Table 5. Example Rating Key for Response Action Levels

Rating Key	Risk to Life and Property	Action Level
S-Ac	Serious	Action Advisable
S-Ad	Serious	Adaptive Measures Advisable
M-NA	Moderate	Consider NO ACTION
M-Ac	Moderate	Some Action Advisable
M-Ad	Moderate	Adaptive Measures Advisable
L-Ad	Low	Adaptive Measures Advisable
L-NA	Low	Consider NO ACTION

7.2. Concepts to Consider in Strategy Development

Some general concepts to consider in developing response actions include the following:

1. ***Anticipated Future Adjustments:*** When unprecedented floods cause massive changes in stream geomorphology, and especially when the floods are of short duration, the impacted channels will undergo a long period of adjustment, generally reshaped into a new form by floods in subsequent years, along with recovery of vegetation. Continued adjustments on the assessed streams should be expected for decades as the river re-establishes equilibrium conditions of width, slope, and riparian integrity.

2. ***Floodplain Connectivity:*** The changes from the flooding have created new areas of floodplain access that will likely be undesirable for many landowners. However, floodplain connectivity is critical to stream health and flood energy dissipation, so allowing maximum floodplain connectivity where possible will provide positive long-term benefit.

> "There's no place for this water to go except houses and hayfields.".

3. ***Sediment Continuity:*** Sediment continuity refers to a balance of stream energy with incoming sediment load. The flood had highly magnified stream energy such that very coarse material was mobilized and redeposited elsewhere. Much of the redeposited material will continue to be reworked and transported by the rivers in coming runoff events. The largest material will likely remain in place for many years. Additional sediment sorting is inevitable, and projects should acknowledge these processes to avoid building costly treatments that presume a static condition and prove to be ineffective. It's important that flood response actions allow for downstream sediment transport.

4. ***Aquatic Habitat:*** As floods modify stream form and recruit woody debris into the channel, aquatic habitats can be both damaged and rejuvenated. Some response actions will result in clear negative impacts to aquatic habitat, where others will provide some benefit. Any project response should include a consideration of aquatic habitat impacts, whether it is preserving positive outcomes, improving negative outcomes, or integrating new habitat elements into any work. Streambank stabilization projects should consider incorporation of adequately anchored root wads and woody material to provide aquatic habitat.

5. ***Riparian Habitat:*** Major flooding can similarly have both positive and negative impacts on riparian habitats. Although a tremendous number of trees were eroded out during the flood, those trees contribute to aquatic habitat as well as floodplain complexity, driving deposition that creates new areas amenable for riparian colonization. During the field effort, young cottonwood seedlings were observed sprouting from recent flood deposits (Figure 61). Areas with new native riparian seedlings should be protected, weeds should be managed, and riparian plantings should be considered for integration into any project work.

6. ***Weeds:*** Weed dispersal is a common result of major flooding, and any expansion of weeds should be aggressively managed as a priority in any project area. Landowners and land management agencies should conduct post-flood weed and invasive species assessments and develop appropriate control plans.

Figure 61. Cottonwood seedlings sprouting from fresh flood deposits, Stillwater River near Absarokee.

7.3. Permitting Considerations

Any proposed project should be evaluated early in the conceptual design process for permitting requirements. The most commonly required basic permits are a 310 and 404, administered by Conservation Districts and the US Army Corps of Engineers, respectively. Additionally, a floodplain permit from the County is generally required for any action in the mapped regulatory floodway or connected special hazard areas. There are FEMA mapped floodplains in Stillwater and Carbon County which may require substantial analysis of project impacts. In the construction process, a Short-Term Water Quality Standard for Turbidity (318 Authorization) may be required from the Montana Department of Environmental Quality. Montana Fish Wildlife and Parks administers 124 permits, which are required if the applicant is any agency or subdivision of state, county, or city government.

For more information on permitting in Montana, go to:

https://dnrc.mt.gov/licenses-and-permits/stream-permitting/

7.4. Bank Erosion (Some with Structure Loss)

Appendix A contains a bank protection alternatives summary

"I've never seen a cobble river gain so much length".

Bank erosion was a predominant landowner concern, as it resulted in damage to roads, buildings, headgates, bridges, and fence lines. The flood was so powerful that both constructed riprap and natural boulder armor that had accumulated over centuries was mobilized, thereby eliminating historic flood resistance along miles of bankline. Much of the erosion was accompanied by major sediment deposition and channel widening. This includes areas dominated by very coarse bedload such as on the Stillwater River above Nye (Figure 63), where the channel width more than doubled and bar formation "flipped" the planform creating new cutbanks against structures. Downstream, the rapid deposition of point bars drove erosion of the opposite banks, creating a more sinuous planform (Figure 64). In some cases, residences were directly threatened, but in many others the concern is not related to infrastructure but the general loss of ground. On Rosebud Creek where point bars developed and drove massive erosion during the flood event, post flood adjustments included the natural re-routing of the channel away from the eroding bank, greatly reducing the threat to the homes (Figure 64 and Figure 65).

7.4.1. Summary of Recommendations for Bank Erosion

1. Prioritize need, take a wait-and-see approach (NO ACTION) if possible.
2. Reduce bank angle to 3:1 if possible.
3. Consider alternatives to full-bank quarried rock riprap. Use wood/alluvium as treatment where infrastructure is not under immediate threat.
4. Concentrate on toe treatments along the base of the re-sloped bank; do not carry rock above the normal high water mark. Use vegetative treatments on upper bank slopes (See Appendix A for examples).
5. Consider using local boulders for a simple toe treatment. Make sure the bank slope is low and that the toe has the densest boulder placement. Toe rock sizing can be determined by an engineer for a given stream setting and level of protection.
6. Include a bankfull bench typically designed to the elevation of the bankfull discharge, composed of a reinforced toe, with compacted wood and alluvium behind it if the treatment encroaches into the channel; cap bench with alluvium/wood and plant perennial woody vegetation.
7. Where the channel widened dramatically, rearrange coarse bedload to keep thalweg off of bank. The thalweg is usually the portion of the stream cross-section carrying the deepest and fastest moving water.
8. Use wood treatments to deflect flows on upstream and/or downstream ends of eroding bank.
9. Rebuild fences anticipating a gentle layback of steep slopes (~3:1).
10. Encourage residential construction to incorporate a setback defined by a minimum interpolated slope angle of 4:1 from the low water's edge to the top bank (Figure 62).

"People in Stillwater County are going riprap crazy."

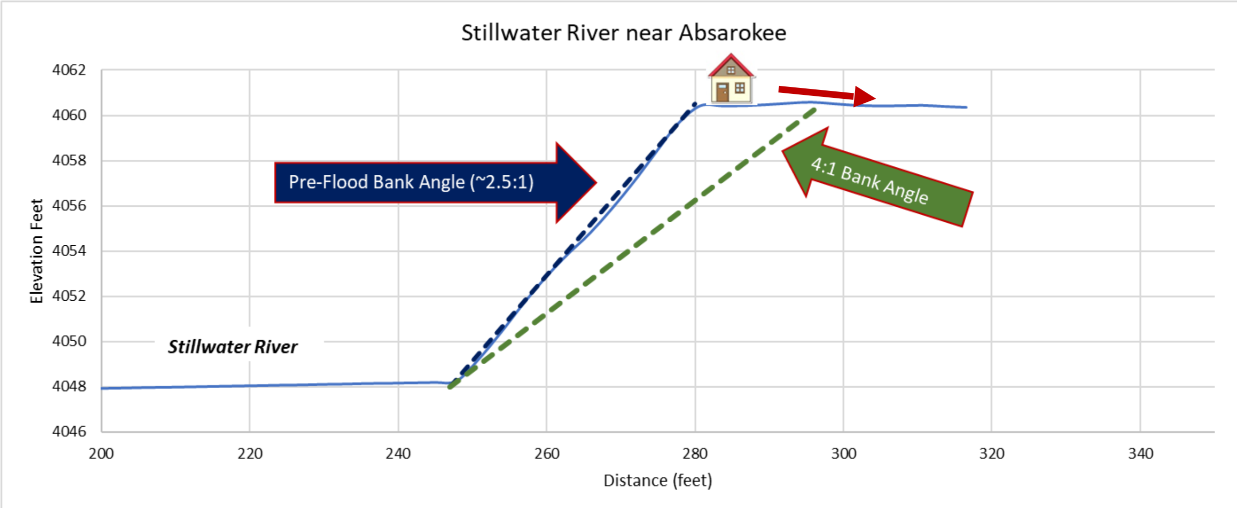
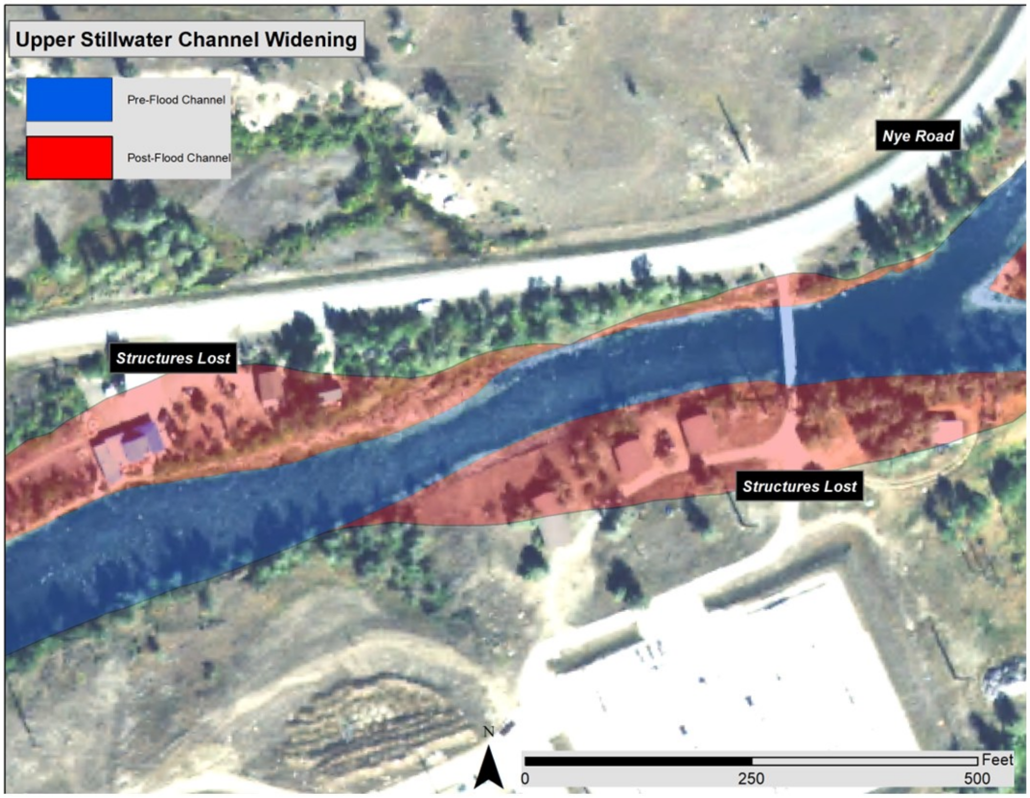


Figure 62. Example Stillwater River bankline where landowner had to place emergency riprap to protect home on steep bank near Absarokee.


Upper Stillwater Channel Widening
Pre-Flood Channel
Post-Flood Channel
Nye Road
Structures Lost
Structures Lost
N
0
250
500
Feet


Upper Stillwater Channel Widening
Pre-Flood Channel
Nye Road
Structures Lost
Structures Lost
N
0
250
500
Feet

Figure 63. Stillwater imagery from pre-flood (top, erosion shown in red) and post-flood (bottom, pre-flood channel shown in blue) showing channel widening from about 80 feet to 200 feet.

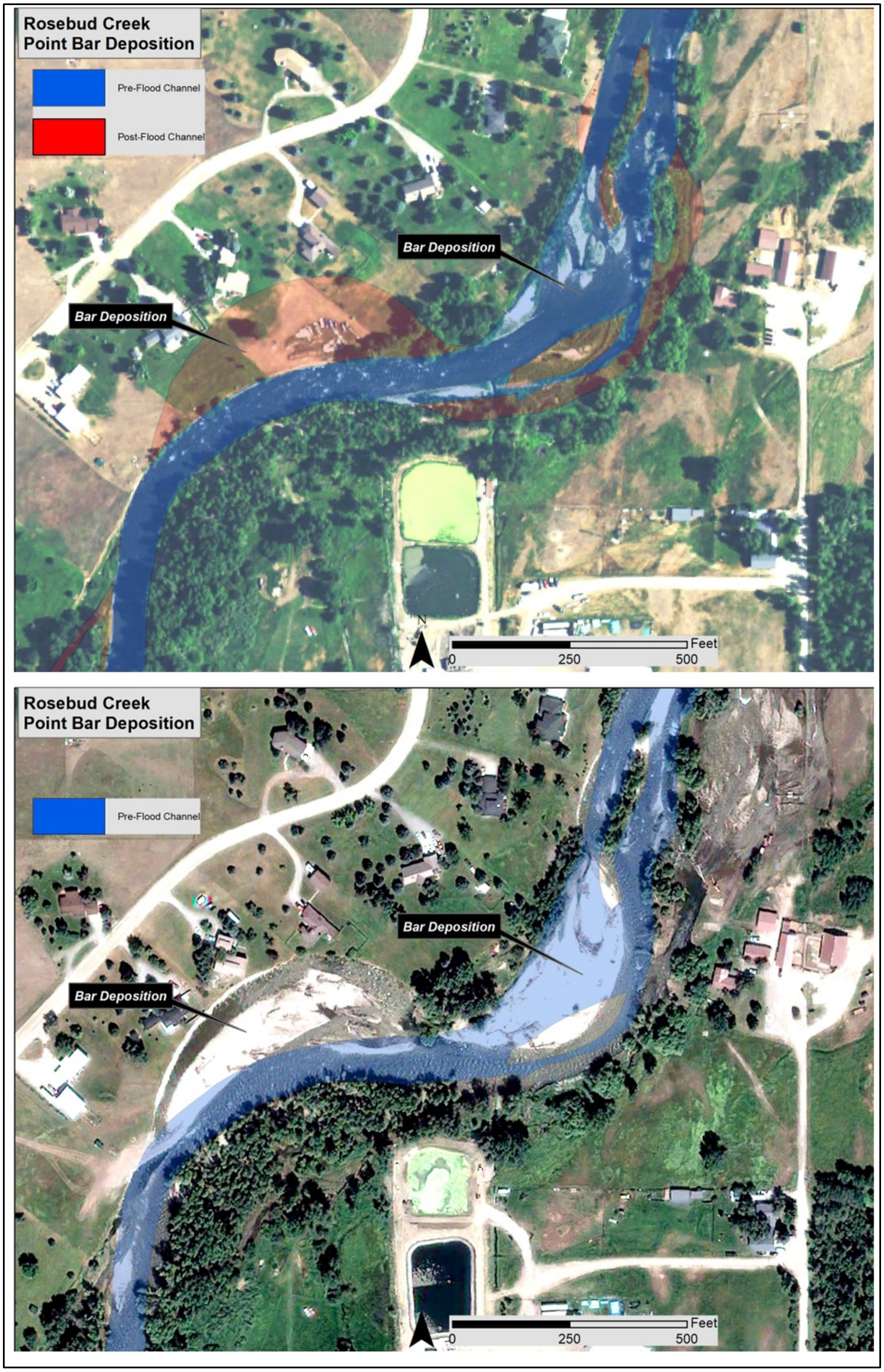


Figure 64. Rosebud Creek imagery from pre-flood (top, erosion shown in red) and post-flood (bottom, pre-flood channel shown in blue) showing large bar formation and associated bank erosion.

Figure 65. Erosion intensity visible at site shown in Figure 64 during the flood event; the channel flowing against the homes was diverted with a dike to the south, reducing the property threat (see Figure 64). The berm has since been removed.

7.4.2. Low Bank (Floodplain) Erosion

Bank erosion is an important process that supports stream health by creating and rejuvenating habitats and allowing physical cross section/planform adjustments to accommodate changing inputs of flow and sediment. Treating erosion sites with full bank rock riprap is the most expensive and ecologically impactful approach, so quarried rock armor should only be used where absolutely necessary to protect infrastructure (Figure 66).

"All that riprap creates a chute and causes trouble downstream".

The most erosive energy is on the bank toe, so the treatment should concentrate on the toe and shift to softer treatments in the upper bank to preserve some opportunity for riparian development. Any rock treatment should not extend above that natural topbank unless the project is permitted/specifically designed as such to also act as a berm (Figure 67). In other areas, erosion sites can be monitored or treated with wood structures to provide near-term flow deflections in areas of high energy as the river continues to evolve post-flood. As the river used to have natural boulder accumulations that provided some bank toe protection, those can be rebuilt using local materials (potentially using the larger material deposited on the opposite bank to redevelop the coarse toe (Figure 70).

Figure 66. Large riprap staged on bankline; note lack of infrastructure threat and relatively passive bank margin post-flood.

Figure 67. View downstream on lower Stillwater showing recently armored bankline extending above natural floodplain elevation.

Figure 68. View upstream of local erosion on end of riprap; local use of wood can effectively deflect flows from bankline of concern and provide habitat.

Figure 69. Localized erosion where homes are set back some distance from channel. This situation would warrant monitoring.

Figure 70. Natural analog for using locally derived rounded boulders to reinforce bank toes.

7.4.3. High Bank (Terrace) Erosion

Bank erosion into ancient high stream terraces (versus low floodplain) was very common during this flood. This is a common issue on rivers of Montana where glaciated headwaters historically generated very high sediment loads, creating vast deposits of glacial outwash sediment that formed broad plains of braided stream channels. Over the last several thousand years, rivers downcut through that material, leaving those surfaces perched well above the streams. Although these surfaces are commonly well above the mapped floodplain, their propensity for erosion makes residences built along their edges highly prone to undermining. Landowners are commonly unaware of this risk and presume that safety from flood inundation is equivalent to flood safety (Figure 71 and Figure 72). One of the major issues with structures on high terraces against the streambanks is that it is impossible to drop the bank slope back to construct treatments without intercepting the structure itself or other connected infrastructure such as on upper East Rosebud Creek (Figure 73).

High terrace erosion is difficult to treat due to the need to either lay the bank back or encroach into the channel to reestablish a stable bank slope. In the event there is no room and a toe treatment is necessary, wood/alluvial treatments can be used along the toe to deflect flow energy while minimizing habitat impacts.

In many cases where damage or any continuing threat was minimal, and a boulder toe remains against the terraces, simple monitoring over the next several runoff events is advisable (Figure 74).

In the event encroachment into the channel is necessary, integrating a bankfull bench against the river into bank treatments provides opportunities for riparian vegetation to develop which adds further protection (Figure 75).

And lastly, prospective riverside homebuilders should be made fully aware of these risks, such that they will hopefully incorporate a setback from any terrace edge that provide for much lower bank angle in the future, preferably at least 4:1 (Figure 76).

Figure 71. Example high terrace erosion threatening home on upper Yellowstone River, June 2022 (Kestrel Aerial Services).

Figure 72. High bank residence being actively undermined during flood, Stillwater River.

Figure 73. High terrace erosion in which achieving a 2:1 bank angle is problematic. Erosion control here will be best achieved with woody treatments and maintenance.

Figure 74. Coarse native boulder toe accumulations provide natural armor, no action recommended.

Figure 75. Natural analog showing bankfull bench supporting woody vegetation.

Figure 76. Steep bankline that was repaired under emergency status due to threat to property. This type of project can deteriorate and may not survive subsequent runoff events.

7.5. Channel Infilling/Loss of Capacity/Change in Planform

The depositional patterns described above have created massive new bar deposits that have reduced overall channel capacity in some areas (Figure 77). This material can be very coarse, perched high above typical stream stages, and thus largely immune to future reworking under normal flow conditions. These in-stream features have fundamentally altered planform and created erosion issues on opposite banks. Excavating material from the channel has been discussed above, and there are opportunities to increase channel capacity without creating major negative impacts to in-stream habitat. This includes the focused excavation of blocked side channels to re-activate those channels and provide additional capacity (Figure 78). In some areas, only the side channel entrance would require excavation. Where side channels are reactivated, placing a wood jam at the head of the island can help keep side channels open into the future.

Where general removal of infilled sediment is done, the bars should not be entirely removed (leaving a trapezoidal channel) but skimmed to make sure the channel retains a low-flow thread.

7.5.1. Recommendations for Lost Channel Capacity

1. Reactivate side channels by excavating sediment/building apex log jams at heads of islands.

2. Skim tops of bars versus removing entire feature to maintain a low flow channel.

3. Retain wood jams and woody debris that aren't creating problems to improve habitat diversity.

4. Restore side channels that have aggraded to improve conveyance/habitat.

Figure 77. Coarse bar deposit created during flood event on upper Stillwater.

Figure 78. View downstream showing new deposition in Stillwater River side channel (on right) near Absarokee.

7.6. Floodplain Wood Accumulations/Altered Flow Paths

The flood deposited massive wood accumulations both within and beyond the active channel that have altered both low- and high-water flow paths (Figure 79). It is first important to recognize that this wood can provide excellent habitat value for fish and wildlife, and that habitat restoration projects commonly include the addition of large wood to those environments. There is concern, however, that floodplain wood in particular has created floodwater flow paths that direct water towards infrastructure, mainly residences. State and county agencies also may have concerns that retained wood could be mobilized by future floods and cause hazards at downstream bridges.

"This flood filled the fields with wood piles as big as my house".

7.6.1. Recommendations for Managing Floodplain Wood

1. Rearrange floodplain wood and create openings along side channels and sloughs to better route overflows back to channel.

2. Concentrate wood at points of overflow to reduce overflow volumes.

3. Leave scattered wood in developing overflow channels to prevent their capture of the main thread.

4. Where possible, relocate wood to use as bank treatments; anchor with boulders to minimize risk of remobilization.

5. Creative incorporation of large woody debris such as root wads into restoration work can significantly improve fish habitat.

Figure 79. Floodplain wood accumulations that have altered typical floodplain flow paths, putting structures in jeopardy.

7.7. Road Damage/Loss Due to Bank Erosion

As described in Section 6.8, almost a mile of road length was mapped on the imagery as damaged or eroded out by flood erosion, which, in combination with bridge failures, created huge access problems throughout the watershed (Figure 80). Feedback from landowners included some desire to relocate road segments or fully abandon non-critical gravel roads. Those options should always be considered to best accommodate future channel changes. Where those approaches aren't viable, basic concepts in road margin protection should be applied.

7.7.1. Recommendations for Damaged Roads

1. If possible, relocate road back from stream to improve safety, reduce bank slope, and provide for bank habitat restoration.
2. Build strong rock toe; try to avoid extending rock into stream corridor.
3. Consider alternate treatments in upper bank (fabric lifts, woody/alluvial treatments)
4. Consider abandoning of or re-purposing roads for local use only where repair costs are prohibitive.

Figure 80. Flood damaged gravel access road margin on upper Stillwater River; this rock is on an over-steepened bank which will need to be regraded to remain stable.

Figure 81. Downstream view of North Stillwater Road undergoing repair near Absaroka Fishing Access.

7.8. Lost Access due to Bridge Damage/Failure

At least 13 bridges were fully destroyed by the flood, severely impacting access to homes and properties. Some bridges completely overtopped during the event (Figure 82). Bridges were damaged by erosion, debris, and hydraulic pressure. The most vulnerable bridge components appeared to be either the abutments, or piers that rested on the channel bed (Figure 83 and Figure 84). Road fill material forming the approaches to bridges was particularly vulnerable to erosion due to overtopping, turbulence and hydraulic pressure. As of the field review in March 2023, failed bridge debris was still on-site in several locations (Figure 85 and Figure 86).

"It gives me goosebumps to talk about it—there were huge waterfalls".

7.8.1. Recommendations for Bridges

1. Remove old or destroyed bridge piers, spans and remnants when replacing structure/restoring site.
2. Make sure bridge piers are designed to withstand bed scour.
3. Replace bridges with spans of sufficient length to avoid constricting the river which leads to excessive scour and greater flood stages.
4. Eliminate and do not create hazards for other river users floating the river or utilizing the zone below the ordinary high water marks.

Figure 82. Private bridge along the Stillwater Road overtopping during flood (courtesy of Staci Grimm).

Figure 83. Active bridge abutment riprap reinforcement, Stillwater River.

Figure 84. Bridge pier above Cliff Swallow FAS replacing one that was undermined during flood event, causing bridge to deck to buckle but not fail.

Figure 85. View upstream of failed bridge debris lodged on channel margin, Rainbow Subdivision bridge, upper Stillwater River.

Figure 86. Small access bridge debris within active channel, middle Stillwater River.

7.9. Irrigation Infrastructure Damage

Irrigation infrastructure damage consisted of headgates and rock diversions getting overwhelmed by high water. The consequences included sediment/debris accumulations at headgates, complete headgate destruction, headworks erosion, and ditch flooding (Figure 87 and Figure 89). As each structure is different, so are recommended treatments. In some cases, irrigation diversions include rock weirs that extend diagonally upstream across the main channel (Figure 90). These structures inherently require more annual maintenance, as they tend to obstruct the downstream transport of sediment, carry excessive sediment into the ditch, block low flow channel threads, and pose an unavoidable hazard to floaters. Any designs developed to repair diversions should keep concepts of sediment transport and low flow conditions in mind, such that sediment is not excessively taken into the ditch, and the river retains a central thread of flow at low water.

Although most of the larger structures appear to be either repaired or slated for repair, some irrigations using smaller systems have chosen not to do repairs based on the cost of the repair versus the value of the irrigated crop.

"If the juice was worth the squeeze I'd do it, but this field ain't worth $50k to irrigate."

7.9.1. Recommendations for Irrigation Infrastructure

1. Clean out debris in approach channel.
2. Ensure that there is a high flow release structure down ditch if headgate overtopped.
3. Repair flanked headgates as necessary with rock.
4. When making repairs, mitigate fish entrainment at the diversion (consult FWP).
5. Where rock diversions extend into river, maintain a low flow thread in river to support the fishery, pass sediment, and reduce risks to floaters.
6. To avoid rock weirs that cross the main channel, extend rock diversions further upstream but with a narrower opening that does not protrude excessively into the river mainstream.

“Those trees falling in just might have saved this structure”

Figure 87. View downstream showing Mendenhall Ditch Co. diversion that experienced major debris/sediment accumulations at headgate; material has been removed and structure is slated for additional repairs.

Figure 88. View upstream of Yanzik Diversion that experienced major abutment erosion during flood.

Figure 89. Diversion intake that experienced erosion damage; the bank was rebuilt with a cobble berm.

Figure 90. View upstream of rock diversion on the Stillwater River above Cliff Swallow spanning the entire channel. This diversion channel could be narrowed and extended upstream closer to the bedrock bank which would maintain flow and bedload transport capacity in the main channel.

7.10. Avulsions

A total of 29 avulsions (new channel formations) were mapped on the imagery, and most of those were relatively minor as they formed short, small channels. In these areas, avulsions tend to create additional habitat area and complexity, and no action should be considered as the first response (Figure 91). In other areas, however, they do pose continued risk. One notable site is at the mouth of the Stillwater River near Columbus, where erosion and debris buildup destroyed headgates and sent additional water down an older distributary channel (Figure 92). The main concern at the site is the instability of the channel and risks it poses to recreational and watercraft safety as well the potential complete capture of the Stillwater River. During the field review, debris and ice had built up at the avulsion node (breakout point), which will increase risk if the current channel becomes blocked. In the long term this will be a persistent problem, as the avulsion path as mapped along an older distributary channel (Figure 93) is 0.6 miles shorter than the current channel route, meaning it is substantially steeper and more efficient. In the short term, added roughness (e.g. woody debris) in the floodplain channels can dissuade their enlargement, however careful monitoring and potential engineering work is recommended if the potential hazards of this avulsion prove unacceptable.

7.10.1. Recommendations for Avulsions

1. If possible, maintain multithread channel connectivity for future flood relief, habitat, but with the main flow retained in the pre-flood channel.

2. Add large wood at the entrance to developing floodplain channels to dissuade their enlargement.

3. Monitor and, if a large avulsion is imminent and unacceptable, develop more aggressive alternatives to prevent wholesale channel relocation.

Figure 91. View downstream showing new channel formed via avulsion below the Highway 78 Bridge; note increased habitat and in-stream complexity provided by the two channels.

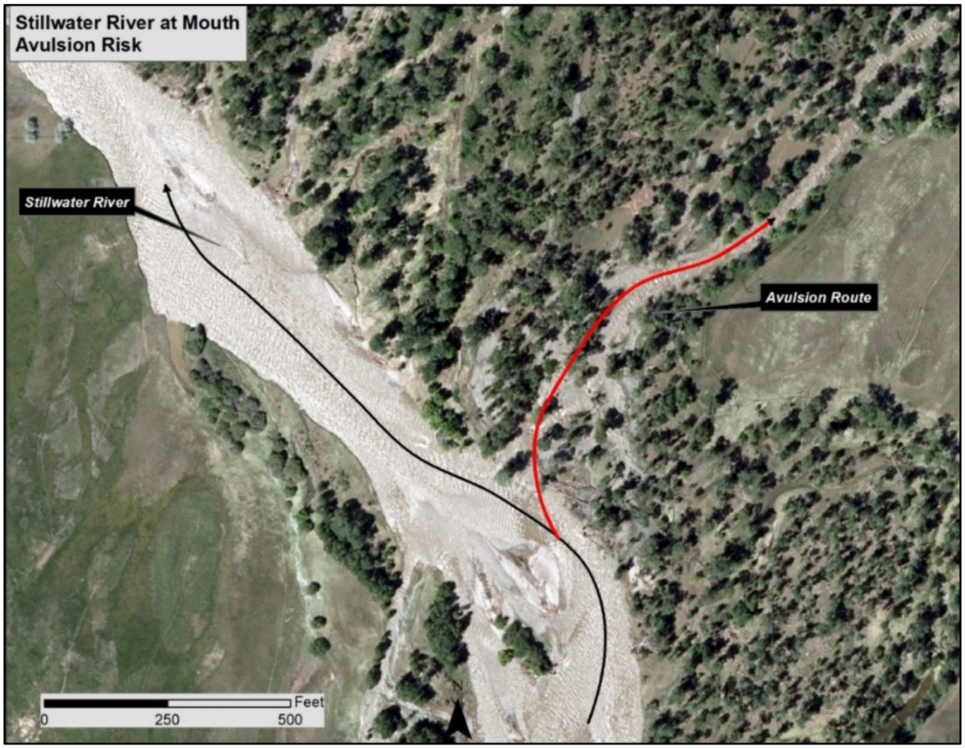


Figure 92. High flow image of avulsion node (breakout point) on outside bend, Stillwater River near mouth.

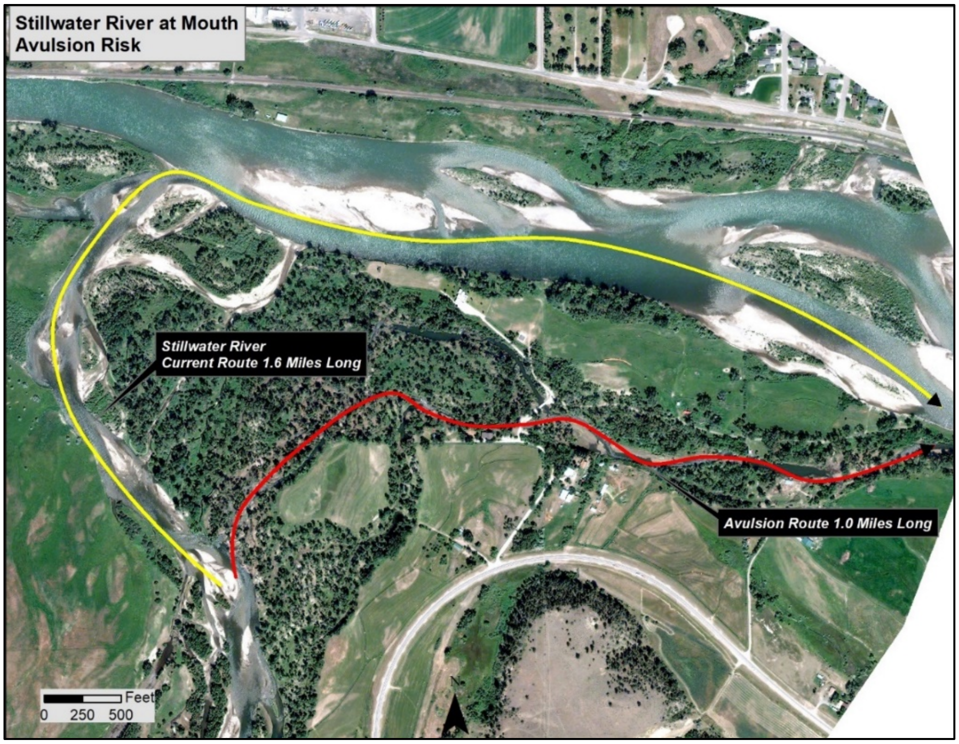


Figure 93. The risk of avulsion at this site (red line) will persist due to the more efficient (shorter and steeper) route of the avulsion path relative to the current path. It should be closely monitored during the 2023 runoff season.

8. Summary and Discussion

Managing the re-establishment of equilibrium (a dynamic yet largely stable channel form) over dozens of miles of river corridor in the Stillwater River watershed will be best achieved by applying thoughtful site-by-site approaches to flood and erosion mitigation, as the recovery process requires the accommodation and/or encouragement of continued change. Bank armor will be necessary in certain areas, yet it can impede long-term recovery where it interferes with the natural trajectory towards equilibrium. Excessive riprap armoring will create challenges for landowners as the locations of erosion issues shift with time and the practice generally degrades aquatic and riparian habitat. We are also concerned that upstream and downstream neighbors will begin to have problems as those who aggressively armor may perpetuate erosion in off-site areas.

Where channel capacity has been substantially lost due to sediment deposition, landowners should anticipate overbank flooding at lower flows than before the flood. This phenomenon will likely affect Stillwater Valley residents in coming years as the river reestablishes a more typical form. Reactivating side channels or strategically using in-stream materials to construct bank treatments can help restore channel capacity, however this work should be carefully designed to minimize impacts to aquatic habitat.

Our primary recommendation for the Stillwater Watershed community is to digest this report, ask questions, and work collaboratively to improve the long-term resiliency of our streams and communities to future flooding, especially since the probability of flooding is going to be affected by changes in our climate. This requires accommodating or encouraging the river to regain an equilibrium configuration, which is the slope, size, and shape that creates a balance between sediment transport and stream energy (sediment in = sediment out). This configuration can also support high quality aquatic and riparian habitats. For decades these rivers changed gradually and appeared to have maintained their overall equilibrium. But the massive flood has disrupted and reset the flow-sediment-channel condition that we must work within during the years to come.

The re-establishment of resiliency and equilibrium on the river should include the following considerations:

- Adopting the decision framework of Action, Adaptation and No Action thoughtfully site by site.
- Allow bank erosion and main channel thread adjustment in areas of low economic productivity (riparian bottoms, undeveloped terraces, etc.).
- Reconnect side channels to dissipate flood energy (access by high flows).
- Encourage riparian recovery within the meander corridor, including meander cores, potential avulsion paths, and field buffers.
- Use bank protection techniques that support woody riparian recovery.

Additionally, management of the river corridor should include aggressive noxious weed/invasive species control and the encouragement of long-term native woody species sustainability on the floodplain. It is important to note that all of these management strategies are compatible with the strategic management of fisheries and riparian areas to also recover an ecologically robust system.

We as the RAT Team concur that staying flexible and allowing the river to adjust to the “new normal” will serve as an economic and ecological advantage for river corridor producers, residents, and stakeholders, as well as for future generations that will ultimately take on the management role.

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Appendix A: Bank Protection Alternatives (Separate Attachment)

Appendix B: Potential Funding Sources (Separate Attachment)