# Teton Countywide Floodplain Study:

## Hydraulic Analysis & Floodplain Mapping Report

### Teton River Mainstem & Tributaries

Teton County, Montana

**Submitted on February 17, 2023**

# Table of Contents

## List of Tables

# List of Figures

# Appendices

| | |
|---|---|
| Appendix A | Technical Reports |
| Appendix B | Modeling Inputs |
| Appendix C | Work Maps |
| Appendix D | Effective FIRM Maps |
| Appendix E | Flood Profiles |
| Appendix F | Floodway Data Tables |
| Appendix G | Study Area Photographs |
| Appendix H | Modeled Cross Sections |
| Appendix I | Model Review |
| Appendix J | Supplemental Structure Information |
| Appendix K | Unique Modeling Supplemental Data |
| Appendix L | Supplemental Decision Records |

# 1.0 Project Overview

## 1.1 Project Overview

Great West Engineering, under a contract with the Montana Department of Natural Resources and Conservation (DNRC), completed a hydraulic analysis of Teton River Mainstem & Tributaries as part of the Teton Countywide Modernization Floodplain Study Project. The studied streams will receive updated flood hazard information which will help inform risk assessments, emergency response, and future planning.

## 1.2 Community and Basin Description

Teton County is located in central Montana, with the Sawtooth Mountain Range to the West and plains and agricultural fields to the East. The City of Choteau is the County Seat and the largest community within Teton County. The upstream portion of the study is made up of mountainous, steep terrain within the Bob Marshall Wilderness area and transitions to flat plains and agricultural fields towards the eastern downstream portion of the study limits. Studied streams include the North Fork and South Fork of the Teton River, as well as their Tributaries, Spring Creek, Flat Coulee and its Tributaries, Tributaries to Teton River, and Teton River from the origin to the Teton County Boundary. All streams included in the study are shown in Figure 1.

The Teton River watershed has a mean basin elevation of 4,360 feet, with a maximum elevation of 9,372 feet in the watershed's mountain peaks. Sixteen percent of the basin is at an elevation above 5,000 feet and 10.2% of the basin is above 6,000 feet. Approximately 9.5% of the watershed is forested, 42% of the watershed is cultivated for crops and hay, and 5% is irrigated based on the Montana Final Land Unit classification. The basin receives a mean annual precipitation of 17 inches with an average annual temperature of 42 degrees.

At the most upstream end of the watershed, the upper reaches of the North Fork and South Fork of the Teton River, as well as their tributaries, flow through confined drainages high in the mountains. These steep streams are, for the most part, confined within their banks and produce relatively channelized floodplains with minimal overbank flow. The North Fork and South Fork of the Teton River join to form the Teton River, where the floodplain widens into the greater valley. The river then flows through a broad floodplain with numerous bends and turns, with sinuous mainstem flow and flows in the overbanks through historic channels and oxbows. After almost 24 miles of flowing due east, the Teton River begins to flow southeast as it heads toward the City of Choteau. This is also the point at which Teton River begins to flow parallel to Highway 89, with the river centerline being less than 150 feet away at certain points. Due to the proximity of Teton River to the highway, and the large flows analyzed, Teton River overtops the highway in several locations, beginning about 5 miles northwest of Choteau. The overflows from Teton begin with overland flows in the undeveloped fields east of the highway until they eventually become channelized and enter drainage of the nearby stream Spring Creek. Spring Creek is a shorter stream to the east that parallels Teton River separated by Highway 89 and the City of Choteau. During high flow events, the overflow from Teton River floods the majority of the area between the parallel streams, and eventually the City of Choteau with shallow flooding. Spring Creek and Teton River continue to interact and exchange flows until their confluence approximately three miles southeast of Choteau. From its confluence with Spring Creek, Teton River continues to flow through a wide, meandering floodplain for the entirety of the study, which ends at the eastern County boundary. There are numerous large oxbows and moderate overbank flow through the valley, especially at high flow events. Additional tributaries flow at short lengths through small coulees to meet the Teton River.

There are many irrigation systems originating from Teton River that deliver water across the watershed to other reservoirs, ranches, and farms but are relatively minor diversions when compared to the base flood volumes in Teton River. Eureka Reservoir is an off-stream storage reservoir constructed in 1936 that lies to the east of Highway 89 northwest of Choteau. It is not a flow-regulating structure and therefore was not considered in hydrology or hydraulics. There is another large reservoir, Bynum Reservoir which serves irrigation needs, near the town of Bynum, which is outside of the Teton River basin. The reservoir receives water from Teton River at a large in-channel diversion structure. The gates to the Bynum ditch were assumed to be closed during all flood events to conservatively model flows in Teton River and not account for flow losses that leave the watershed.

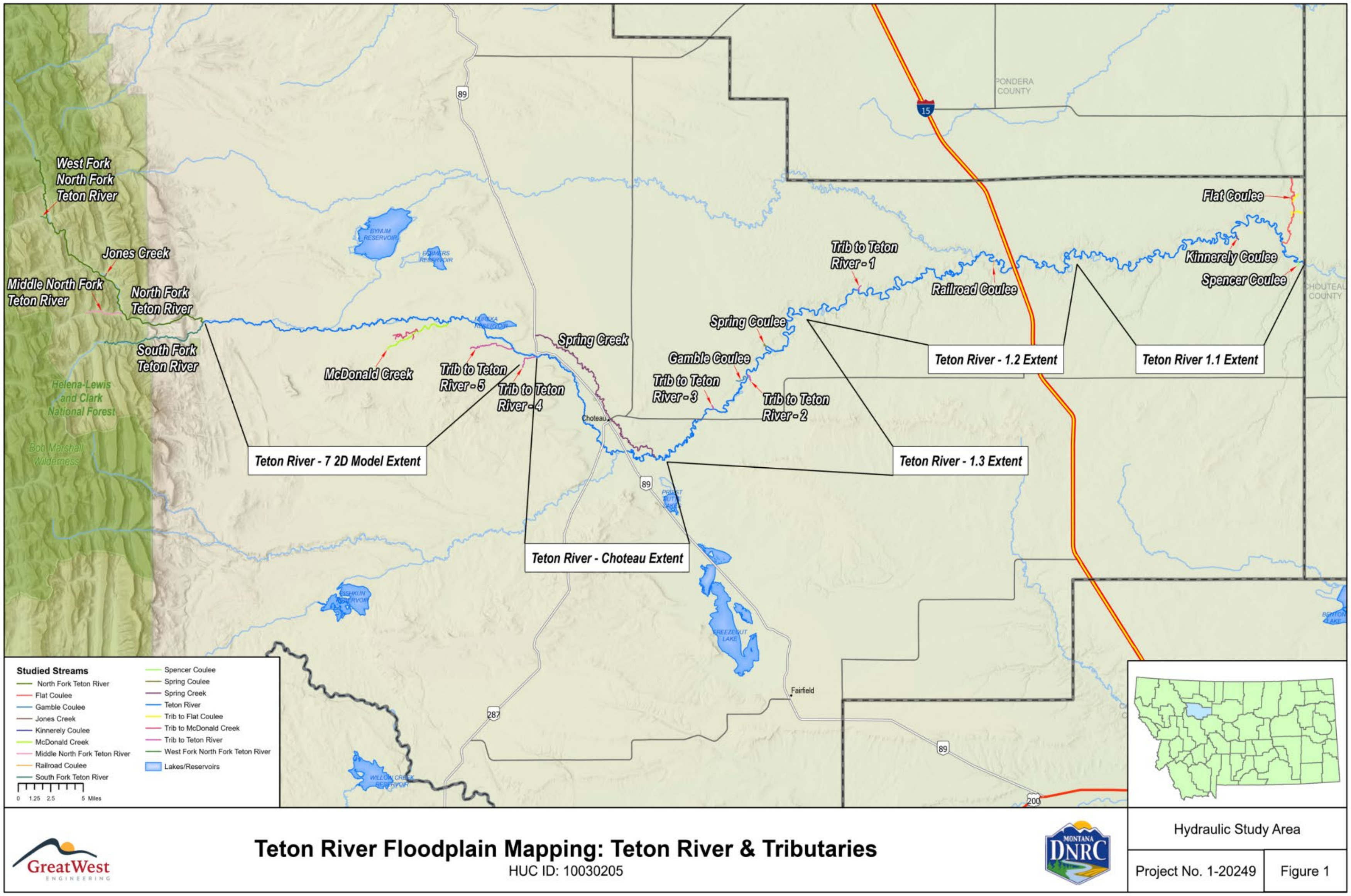


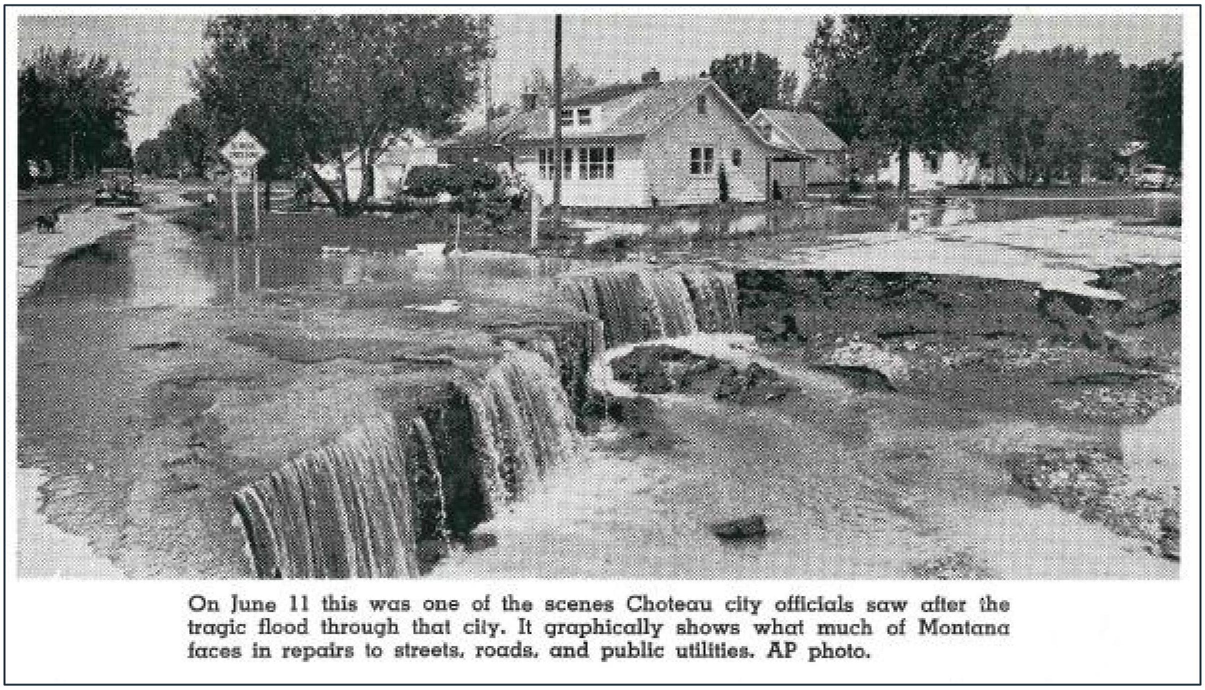
Figure 1 - Study Area and Studied Streams

## 1.3 Past Studies and Flood History

### 1.3.1 Flooding History

Teton County has been known to experience flooding events with records as early as the 1900s. Higher snowpack levels, subsequent snowmelt, and heavy rainfall occurring mostly in May and June are the most common causes of recorded flood events within the county. Five flood events of note are presented in historical records, occurring in 1948, 1953, 1964, 1975, and 2011. Delayed snowmelt and higher rainfall in late spring, coupled with heavy rain throughout Teton County in mid-June, resulted in widespread flooding through the City of Choteau and surrounding rural counties in 1948. Then, in 1953, the City of Choteau was more severely impacted, with localized peak rainfall reaching 0.86 inches in one hour.

The most severe flooding to occur to date throughout Montana and in Teton County occurred in 1964. Delayed June snowmelt coupled with heavy rainfall resulted in flooding with an annual exceedance probability of 0.5% (200-year event) as estimated by the USGS. The Teton River recorded a peak flow of 54,600 cubic feet per second (cfs). Near Choteau, the Teton River and flows in Spring Creek combined and inundated the entire area of Choteau, forcing evacuation of all residents with water as deep as 6 feet in some areas of the city. Property, bridges, roadways, and more were all severely damaged throughout the county during this event.



On June 11 this was one of the scenes Choteau city officials saw after the tragic flood through that city. It graphically shows what much of Montana faces in repairs to streets, roads, and public utilities. AP photo.

**Figure 2 - Excerpt from the Great Tribune's "1964 Flood"**

Similar spring conditions and late season rainfall produced heavy flooding along the Continental Divide in 1975 with costly impacts throughout the region. The Teton River overflowed into the Spring Creek drainage above Choteau on June 19, 1975, causing additional flooding damage through the city, though not as severe as that of 1964. The 1975 event was estimated as a 40-year flood event. Significant flooding occurred again in the late spring of 2011, which was a result of melting river ice and snowpack simultaneously with heavy May rainfall. Streams throughout the area remained at peak flow for a prolonged period of time resulting from these conditions and causing widespread flooding.

Additional flooding occurred throughout the county in early summer of 2018 and 2019. Flood events in 2018 caused by winter snowmelt and warm-weather rainfall caused roads throughout the county to be washed out, among other severe damage. Heavy rainfall in late May of 2019 again caused flooding on the Teton River, washing out roads and causing damage throughout the floodplain. In January of 2020, Spring Creek through the City of Choteau froze during a period of subzero temperatures, causing ice jams and pushing water outside of the creek banks. Basements, the sewer collection system, and manholes all experienced flooding and backups throughout the city.

Historic peak flow data at United States Geological Survey (USGS) gages throughout the study area is presented in Table 1 below.

**Table 1 – Historic Peak Flow Data at USGS Gages**

| USGS Station Number and Name | 02102500, Teton River Below South Fork, near Choteau | | 06103000, Teton River at Strabane | | 06108000, Teton River near Dutton | |
|---|---|---|---|---|---|---|
| **Period of Peak Flow Data** | 1948 – 2019 | | 1908 – 1925 | | 1955 - 2019 | |
| **Number of Peak Flow Records** | 30 | | 18 | | 65 | |
| **Largest Recorded Events** | **Date** | **Peak Flow (cfs)** | **Date** | **Peak Flow (cfs)** | **Date** | **Peak Flow (cfs)** |
| | 6/8/1964 | 54,600 | 6/21/1916 | 3,810 | 6/9/1964 | 71,300 |
| | 6/19/2018 | 11,100 | 5/26/1917 | 2,460 | 6/20/1975 | 16,000 |
| | 5/27/2019 | 3,560 | 6/10/1908 | 2,300 | 7/2/1966 | 8,580 |
| | 5/26/2008 | 3,200 | 6/2/1913 | 1,410 | 5/28/2019 | 7,380 |
| | 6/3/1948 | 2,780 | 7/27/1909 | 1,080 | 2/26/1986 | 7,290 |

### 1.3.2 Previous Hydraulic Studies

The current effective Flood Insurance Study (FIS) Report for Teton County is dated January 18, 1983. A supplemental FIS for the City of Choteau is dated October 3, 1983. Morrison-Maierle completed the hydrologic and hydraulic analyses for both studies in February 1982. The detailed study was completed for the Teton River near Choteau beginning at the US-89 crossing south of Choteau and extending about 5.5 miles upstream to northwest of Choteau. This detailed study also included the Spring Creek drainage basin for approximately 1 mile in length, from the city limits (in 1983) to just north of Choteau and study findings are presented in the City of Choteau FIS. According to the City FIS, during a 100-year flood, shallow flooding will occur along Spring Creek in Choteau at an average depth of 1 foot. Water is often trapped between the railroad tracks and along the eastern overbank. The FIS states that water eventually overtops 1st Street NE and flows downstream at a depth of less than 1 foot.

According to the County FIS, additional flood control measures have been considered since the 1964 flood, following which the U.S. Army Corps of Engineers performed some channel stabilization work on the Teton River. A dike was also proposed north and east of Choteau following the 1975 flood by the U.S. Soil Conservation Service through the Emergency Assistance Program, but no further action was ever completed. No supporting modeling was made available for any flood control measurements undertaken in areas within the study limits. Additional study documents have been produced by the USGS detailing flooding events in 1953, 1964, and 1975 in Teton County and are referenced in the current County FIS.

**Table 2 – New and Effective Studies for Teton River & Tributaries**

|  | Stream Name | Model ID | Length (mi) | Effective SFHA | Limits of Study |  | New Study Type |
|---|---|---|---|---|---|---|---|
|  |  |  |  |  | Upstream | Downstream |  |
| **Teton River Mainstem** | **Teton River** | TR_1.1 | 32.79 | Zone A | Teton River Station 173209 | Teton / Choteau County Boundary | Zone AE |
|  |  | TR_1.2 | 30.50 | Zone A | Teton River Station 334287 | Teton / Choteau County Boundary | Zone AE |
|  |  | TR_1.3 | 21.94 | Zone A | Teton River Station 449224 | Teton / Choteau County Boundary | Zone AE |
|  |  | TR_Choteau | 13.75 | Zone A, Zone AE with Floodway | Teton River Station 522262 | Teton / Choteau County Boundary | Zone AE, Zone AE with Floodway [1] |
|  |  | Teton River Overflow | 1.85 | - | Within City of Choteau, just downstream of 4th Ave SW and 7th St SW intersection | Confluence with Teton River | Zone AE with Floodway |
|  |  | TR_7 2D | 23.54 | Zone A | Origin of Teton River at confluence of North Fork Teton River and South Fork Teton River | Confluence with Teton River | Zone AE [3] |

| | Stream Name | Model ID | Length (mi) | Effective SFHA | Limits of Study | | New Study Type |
|---|---|---|---|---|---|---|---|
| | | | | | Upstream | Downstream | |
| Teton River Long Tribs *(reaches >1.5 miles)* | **Flat Coulee** | FLC_1 | 6.42 | Zone A | 6.42 miles upstream of confluence with Teton River, 2.56 miles upstream of convergence of Trib 3 to Flat Coulee | Confluence with Teton River | Zone AE |
| | **Middle North Fork Teton River** | MNFTR_1 | 2.30 | Zone A | 2.30 miles upstream of confluence with North Fork Teton River | Confluence with North Fork Teton River | Zone AE |
| | **South Fork Teton River** | SFTR_1 | 6.89 | Zone A | 4.5 miles upstream of South Fork Road crossing | Confluence with North Fork Teton River | Zone AE |
| | **North Fork Teton River** | NFTR_1 | 9.22 | Zone A | North Fork Teton River Station 48689 | Confluence with South Fork Teton River | Zone AE |
| | | NFTR_2 | 1.47 | Zone A | North Fork Teton River Station 56433 | Confluence with South Fork Teton River | Zone AE |
| | | NFTR_3 | 5.80 | Zone A | 16.49 miles upstream of confluence with South Fork Teton River | Confluence with South Fork Teton River | Zone AE |
| | **Trib to Teton River - 5** | TTR_5 | 1.58 | Zone A | 1.58 miles upstream of confluence with Teton River | Confluence with Teton River | Zone AE |
| Spring Creek Mainstem | **Spring Creek** | SPC_Choteau | 11.93 | Zone A,<br>Zone AE with Floodway | 11.93 miles upstream of confluence with Teton River | Confluence with Teton River | Zone AE,<br>Zone AE with Floodway [2] |
| | | Teton River Highway 89 Split | 1.3 | - | East of Hwy 89 north of Choteau, just upstream of Saylor Road | Confluence with Spring Creek | Zone AE |

|  | Stream Name | Model ID | Length (mi) | Effective SFHA | Limits of Study |  | New Study Type |
|---|---|---|---|---|---|---|---|
|  |  |  |  |  | Upstream | Downstream |  |
|  |  | SPC_Upper 2D | 2.20 | Zone A | 14.13 miles upstream of confluence with Teton River | Confluence with Teton River | Zone AE |
| **Teton River Short Tribs** ***(reaches <1.5 miles)*** | **Gamble Coulee** | GC_1 | 0.79 | Zone A | Outflow of reservoir, approximately 0.05 miles upstream of private access road crossing | Confluence with Teton River | Zone AE |
|  | **Jones Creek** | JC_1 | 0.32 | Zone A | 0.15 miles upstream of Teton Canyon Road crossing | Confluence with North Fork Teton River | Zone AE |
|  | **Kinnerely Coulee** | KC_1 | 0.35 | Zone A | 0.35 miles upstream of confluence with Teton River | Confluence with Teton River | Zone AE |
|  | **Railroad Coulee** | RRC_1 | 0.63 | Zone A | 0.63 miles upstream of confluence with Teton River | Confluence with Teton River | Zone AE |
|  | **Spring Coulee** | SC_1 | 0.39 | Zone A | 0.05 miles upstream of private road crossing | Confluence with Teton River | Zone AE |
|  | **Spencer Coulee** | SPCO_1 | 0.31 | Zone A | 0.31 miles upstream of confluence with Teton River | Confluence with Teton River | Zone AE |
|  | **Trib to Flat Coulee – 2** | TFC_2 | 0.65 | Zone A | 0.65 miles upstream of confluence with Flat Coulee | Confluence with Flat Coulee | Zone AE |
|  | **Trib to Flat Coulee – 3** | TFC_3 | 0.61 | Zone A | 0.61 miles upstream of confluence with Flat Coulee | Confluence with Flat Coulee | Zone AE |

|  | Stream Name | Model ID | Length (mi) | Effective SFHA | Limits of Study |  | New Study Type |
|---|---|---|---|---|---|---|---|
|  |  |  |  |  | Upstream | Downstream |  |
| **Teton River Short Tribs** *(reaches <1.5 miles)* | **Trib to Teton River - 1** | TTR_1 | 0.34 | Zone A | 0.34 miles upstream of confluence with Teton River | Confluence with Teton River | Zone AE |
|  | **Trib to Teton River – 2** | TTR_2 | 0.47 | Zone A | 0.32 miles upstream of New Rockport Colony entrance road crossing | Confluence with Teton River | Zone AE |
|  | **Trib to Teton River - 3** | TTR_3 | 0.26 | Zone A | 0.19 miles upstream of private road crossing | Confluence with Teton River | Zone AE |
|  | **Trib to Teton River - 4** | TTR_4 | 1.13 | Zone A | 1.13 miles upstream of confluence with Teton River | Confluence with Teton River | Zone AE |
|  | **West Fork North Fork Teton River** | WFNFTR_1 | 0.77 | Zone A | 0.64 miles upstream of Teton Canyon Road crossing | Confluence with North Fork Teton River | Zone AE |

Notes:

1. Teton River mainstem includes 5.7 miles of Zone AE with Floodway – see Figure 6
2. Spring Creek includes 1.5 miles of Zone AE with Floodway – see Figure 6
3. TR_7 2D and SPC_Upper 2D are 2D Regulatory Models

**Figure 3 – Hydraulic Model ID's (1 of 3)**

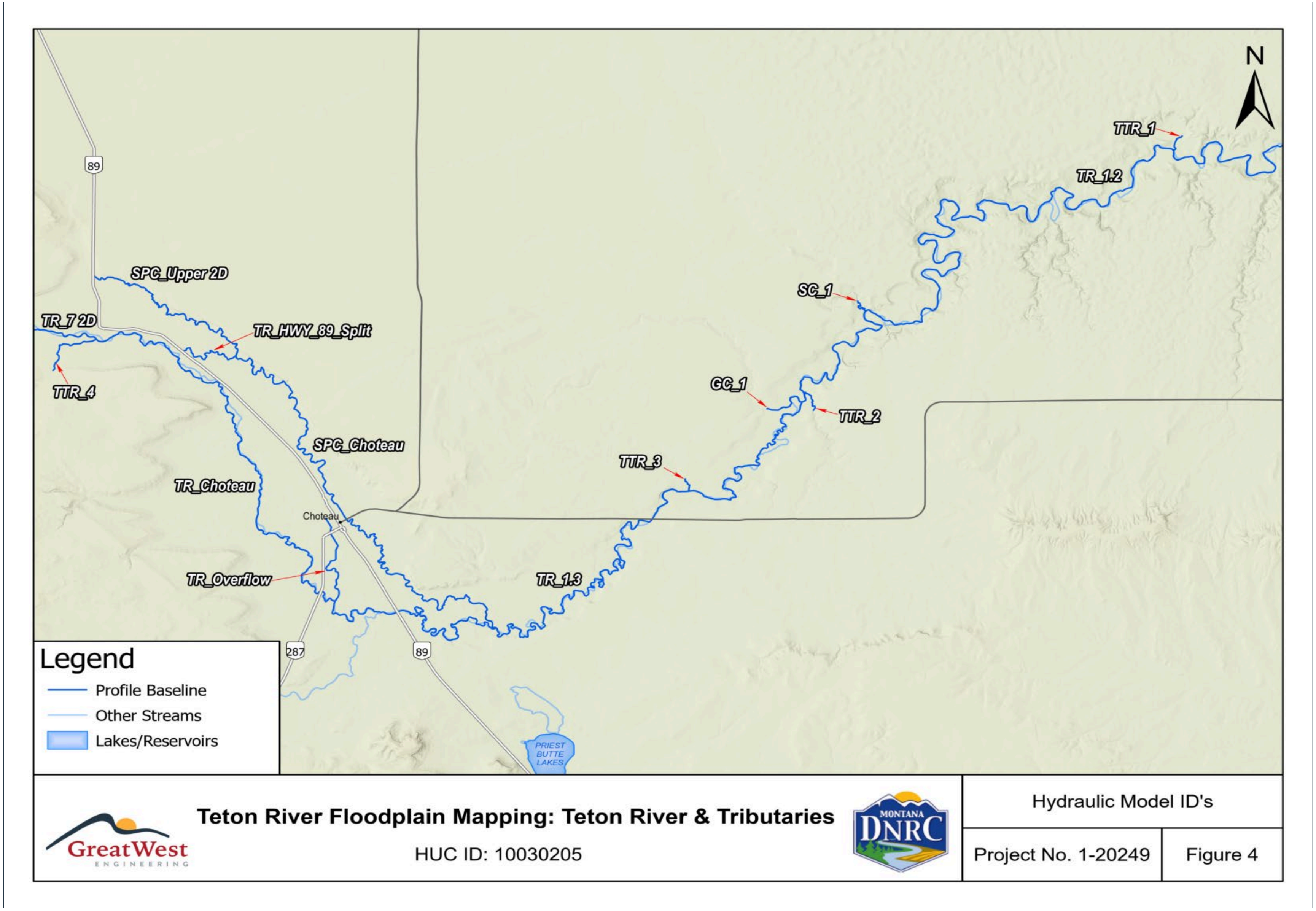


**Figure 4 – Hydraulic Model ID's (2 of 3)**

**Figure 5 – Hydraulic Model ID's (3 of 3)**

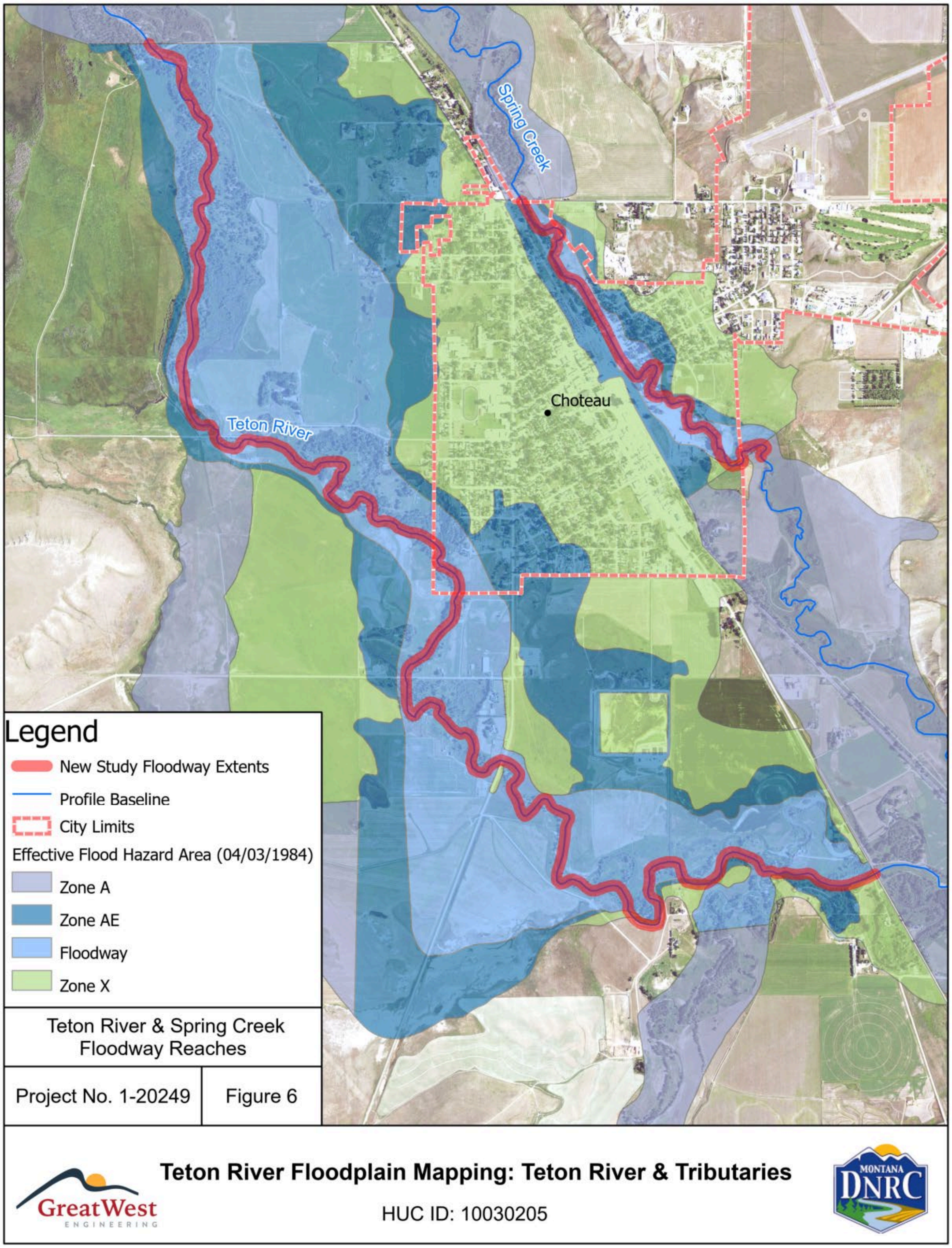


**Figure 6 – Teton River & Spring Creek Effective Floodway Reaches**

# 2.0 Hydrologic Analysis

Peak flows for Teton River and its tributaries were studied as part of the Teton County Physical Map Revision Hydrology Analysis and published in the report, dated August 2021 (Michael Baker International, 2021). The hydrologic analysis performed by Michael Baker utilized revised flood frequency results of select gages within Teton County to inform peak flows used in the hydraulic modeling efforts. Three primary USGS stream gages were used in hydrologic analysis relating to the Teton River study area: 1) Gage 06102500: Teton River bl South Fork nr Choteau, 2) Gage 06103000: Teton River at Strabane, and 3) Gage 06108000: Teton River near Dutton. Historic peak flow data for these gages is presented in Table 1 in Section 1.3.1 above, and gage locations relative to hydrologic flow nodes are included in the table below. Flow change locations were identified at intermediate locations throughout each stream that are associated with tributaries or significant changes in the contributing drainage areas. A more detailed explanation of the hydrologic analysis is outlined in Michael Baker's report. The following tables show the results of the analysis for each study reach and the approximate hydraulic model reference to which each flow node was applied.

**Table 3 – Summary of Peak Flows for Teton River Mainstem**

| Stream | Node ID | Model ID | Hydraulic Model Reference | Peak Flow (cfs) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 10% Annual Chance 10-year | 4% Annual Chance 25-year | 2% Annual Chance 50-year | 1% Annual Chance 100-year | 0.2% Annual Chance 500-year | 1% + Annual Chance 100-year+ |
| Teton River | TR-0.0 | TR_1.1 | XS 2146 | 4,750 | 10,200 | 17,300 | 28,100 | 51,800 | 79,100 |
| | TR-0.5 | | XS 14396 | 4,750 | 10,200 | 17,200 | 28,000 | 51,600 | 78,700 |
| | TR-2.8 | | XS 51941 | 4,740 | 10,100 | 17,100 | 27,700 | 50,800 | 77,600 |
| | TR-9.9 | | XS 96184 | 4,720 | 10,000 | 16,700 | 27,000 | 49,200 | 75,100 |
| | TR-18.3 | | XS 173209<br>*USGS Gage 06108000* | 4,710 | 9,960 | 16,600 | 26,800 | 48,800 | 74,500 |
| | TR-19.4 | TR_1.2 | XS 210095 | 4,710 | 9,960 | 16,600 | 26,800 | 48,800 | 74,500 |
| | TR-40.0 | | N/A [1] | 4,710 | 9,930 | 16,500 | 26,600 | 48,900 | 74,000 |
| | TR-42.1 | | XS 262305 | 4,690 | 9,740 | 16,100 | 25,900 | 49,200 | 71,600 |
| | TR-49.7 | | N/A [1] | 4,690 | 9,730 | 16,100 | 25,800 | 49,200 | 71,400 |
| | TR-56.5 | | XS 334287 | 4,690 | 9,720 | 16,000 | 25,700 | 49,200 | 71,300 |
| | TR-68.9 | TR_1.3 | N/A [1] | 4,680 | 9,670 | 15,900 | 25,500 | 49,300 | 70,600 |
| | TR-70.5 | | XS 380795 | 4,680 | 9,650 | 15,900 | 25,500 | 49,300 | 70,400 |
| | TR-72.1 | | N/A [1] | 4,680 | 9,640 | 15,900 | 25,400 | 49,300 | 70,300 |
| | TR-72.4 | | N/A [1] | 4,680 | 9,630 | 15,900 | 25,400 | 49,400 | 70,200 |
| | TR-76.6 | | XS 449224 | 4,680 | 9,620 | 15,800 | 25,300 | 49,400 | 70,000 |
| | TR-85.2 | TR_Choteau | XS 451575 | 4,670 | 9,600 | 15,800 | 25,200 | 49,400 | 69,700 |
| | TR-89.2 | | N/A [1] | 4,640 | 9,270 | 15,000 | 23,800 | 50,000 | 65,500 |
| | TR-90.1 | | XS 522262 | 4,640 | 9,250 | 15,000 | 23,700 | 50,100 | 65,200 |

| Stream | Node ID | Model ID | Hydraulic Model Reference | Peak Flow (cfs) 10% Annual Chance 10-year | 4% Annual Chance 25-year | 2% Annual Chance 50-year | 1% Annual Chance 100-year | 0.2% Annual Chance 500-year | 1% + Annual Chance 100-year+ |
|---|---|---|---|---|---|---|---|---|---|
|  | TR-99.7 | TR_7 2D | N/A [1] | 4,630 | 9,210 | 14,900 | 23,600 | 50,100 | 64,800 |
|  | TR-105.6 |  | N/A [1] | 4,630 | 9,120 | 14,700 | 23,200 | 50,300 | 63,600 |
|  | TR-121.4 |  | *USGS Gage 06102500* | 4,620 | 9,070 | 14,600 | 23,000 | 50,400 | 63,000 |

Notes:

1. Flow at node not applied. Flow changes in model were determined by hydraulic model.

**Table 4 – Summary of Peak Flows for Teton River Long Tributaries**

| Stream | Node ID | Model ID | Hydraulic Model Reference | Peak Flow (cfs) 10% Annual Chance 10-year | 4% Annual Chance 25-year | 2% Annual Chance 50-year | 1% Annual Chance 100-year | 0.2% Annual Chance 500-year | 1% + Annual Chance 100-year+ |
|---|---|---|---|---|---|---|---|---|---|
| **Flat Coulee** | FLC-1-0.0 | FLC_1 | XS 13630 | 379 | 751 | 1,170 | 1,720 | 2,850 | 3,890 |
|  | FLC-1-2.3 |  | XS 16023 | 363 | 717 | 1,120 | 1,630 | 2,700 | 3,670 |
|  | FLC-2.7 |  | XS 19962 | 281 | 548 | 845 | 1,220 | 2,020 | 2,680 |
|  | FLC-3.0 |  | N/A [1] | 279 | 545 | 840 | 1,210 | 2,010 | 2,660 |
|  | FLC-3.5 |  | XS 33662 | 226 | 439 | 670 | 960 | 1,590 | 2,060 |
|  | FLC-6.1 |  | N/A [1] | 212 | 410 | 625 | 892 | 1,480 | 1,900 |
| **Middle North Fork Teton River** | MNFTR-0.0 | MNFTR_1 | XS 7002 | 409 | 714 | 1,110 | 1,700 | 1,930 | 4,490 |
|  | MNFTR-1.3 |  | XS 12077 | 373 | 653 | 1,020 | 1,570 | 1,780 | 4,180 |
|  | MNFTR-2.3 |  | N/A [1] | 308 | 544 | 856 | 1,330 | 1,510 | 3,620 |
| **South Fork Teton River** | SFTR-0.0 | SFTR_ | XS 12522 | 1,020 | 1,710 | 2,540 | 3,730 | 4,240 | 9,000 |
|  | SFTR-2.4 |  | XS 18612 | 958 | 1,610 | 2,390 | 3,530 | 4,010 | 8,570 |
|  | SFTR-3.5 |  | XS 28077 | 872 | 1,470 | 2,200 | 3,260 | 3,700 | 7,980 |
|  | SFTR-5.4 |  | XS 36373 | 765 | 1,300 | 1,950 | 2,910 | 3,310 | 7,220 |
|  | SFTR-6.6 |  | N/A [1] | 652 | 1,110 | 1,690 | 2,540 | 2,890 | 6,400 |
| **North Fork Teton River** | NFTR-1-0.0 | NFTR_1 | XS 10903 | 2,430 | 3,900 | 5,560 | 7,860 | 8,930 | 17,400 |
|  | NFTR-1-2.1 |  | XS 26882 | 2,320 | 3,740 | 5,340 | 7,560 | 8,590 | 16,800 |
|  | NFTR-1-5.1 |  | XS 39451 | 2,000 | 3,240 | 4,650 | 6,640 | 7,540 | 15,000 |
|  | NFTR-1-7.6 |  | XS 47440 | 1,710 | 2,790 | 4,040 | 5,800 | 6,590 | 13,300 |
|  | NFTR-1-9.0 |  | XS 48689 | 1,420 | 2,340 | 3,420 | 4,950 | 5,620 | 11,600 |

| Stream | Node ID | Model ID | Hydraulic Model Reference | Peak Flow (cfs) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 10% Annual Chance 10-year | 4% Annual Chance 25-year | 2% Annual Chance 50-year | 1% Annual Chance 100-year | 0.2% Annual Chance 500-year | 1% + Annual Chance 100-year+ |
| | NFTR-3-11.9 | NFTR_3 | XS 67589 | 1,320 | 2,180 | 3,200 | 4,650 | 5,280 | 10,900 |
| | NFTR-3-12.9 | | XS 67953 | 1,240 | 2,050 | 3,020 | 4,400 | 5,000 | 10,400 |
| | NFTR-3-13.0 | | XS 76119 | 845 | 1,430 | 2,140 | 3,170 | 3,600 | 7,790 |
| | NFTR-3-14.4 | | XS 86945 | 702 | 1,200 | 1,810 | 2,700 | 3,070 | 6,770 |
| **Trib to Teton River 5** | TTR-5-0.0 | TTR_5 | XS 16106 | 399 | 736 | 1,090 | 1,510 | 2,500 | 3,050 |
| | TTR-5-1.6 | | N/A[1] | 392 | 721 | 1,060 | 1,470 | 2,440 | 2,960 |

Notes:

1. Flow at most upstream node not applied, as flows are applied upstream in hydraulic model.

**Table 5 – Summary of Peak Flows for Spring Creek Mainstem**

| Stream | Node ID | Model ID | Hydraulic Model Reference | Peak Flow (cfs) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 10% Annual Chance 10-year | 4% Annual Chance 25-year | 2% Annual Chance 50-year | 1% Annual Chance 100-year | 0.2% Annual Chance 500-year | 1% + Annual Chance 100-year+ |
| **Spring Creek** | SPC-1-0.1 | SPC_Choteau | N/A[1] | 270 | 511 | 767 | 1,080 | 1,790 | 2,250 |
| | SPC-1-1.4 | | N/A[1] | 253 | 477 | 715 | 1,000 | 1,660 | 2,070 |
| | SPC-2-4.4 | | N/A[1] | 234 | 440 | 656 | 918 | 1,520 | 1,880 |
| | SPC-3-5.3 | | N/A[1] | 213 | 398 | 591 | 822 | 1,360 | 1,670 |
| | SPC-5-5.4 | | N/A[1] | 210 | 392 | 581 | 808 | 1,340 | 1,630 |
| | SPC-5-7.2 | | N/A[1] | 183 | 340 | 501 | 693 | 1,150 | 1,380 |
| | SPC-5-10.2 | | XS 60135 | 173 | 321 | 471 | 649 | 1,080 | 1,280 |
| | SPC-5-10.9 | | XS 63057 | 168 | 311 | 455 | 627 | 1,040 | 1,230 |
| | SPC-5-11.7 | SPC_Upper 2D | N/A[1] | 137 | 252 | 366 | 499 | 827 | 963 |
| | SPC-5-12.3 | | N/A[1] | 129 | 236 | 342 | 465 | 771 | 891 |
| | SPC-5-12.9 | | Inflow BC | 108 | 196 | 282 | 381 | 632 | 716 |
| | SPC-5-13.6 | | N/A[1] | 94 | 169 | 242 | 325 | 539 | 602 |

Notes:

1. Flow at node not applied. Flows in model were determined by hydraulic model.

**Table 6 – Summary of Peak Flows for Teton River Short Tributaries**

| Stream | Node ID | Model ID | Hydraulic Model Reference | Peak Flow (cfs) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 10% Annual Chance | 4% Annual Chance | 2% Annual Chance | 1% Annual Chance | 0.2% Annual Chance | 1% + Annual Chance |
| | | | | 10-year | 25-year | 50-year | 100-year | 500-year | 100-year+ |
| **Gamble Coulee** | GC-0.0 | GC_1 | XS 4125 | 341 | 655 | 996 | 1,420 | 2,350 | 3,050 |
| | GC-0.8 | | N/A[1] | 341 | 654 | 994 | 1,420 | 2,350 | 3,040 |
| **Jones Creek** | JC-1-0.0 | JC_1 | XS 1664 | 372 | 651 | 1,010 | 1,560 | 1,770 | 4,170 |
| **Kinnerely Coulee** | KC-0.0 | KC_1 | XS 1836 | 543 | 1,070 | 1,680 | 2,460 | 4,080 | 5,620 |
| **Railroad Coulee** | RRC-0.1 | RRC_1 | XS 3238 | 339 | 655 | 1,000 | 1,430 | 2,370 | 3,110 |
| **Spring Coulee** | SC-1-0.0 | SC_1 | XS 1993 | 542 | 1,060 | 1,650 | 2,400 | 3,980 | 5,410 |
| **Spencer Coulee** | SPCO-0.0 | SPCO_1 | XS 1643 | 284 | 545 | 828 | 1,180 | 1,960 | 2,520 |
| **Trib to Flat Coulee 2** | TFC-2-0.0 | TFC_2 | XS 3458 | 169 | 325 | 490 | 694 | 1,150 | 1,450 |
| | TFC-2-0.6 | | N/A[1] | 168 | 322 | 486 | 687 | 1,140 | 1,430 |
| **Trib to Flat Coulee 3** | TFC-3-0.0 | TFC_3 | XS 3224 | 182 | 350 | 529 | 750 | 1,240 | 1,580 |
| | TFC-3-0.6 | | N/A[1] | 181 | 347 | 524 | 743 | 1,230 | 1,560 |
| **Trib to Teton River 1** | TTR-1-0.0 | TTR_1 | XS 1763 | 94 | 172 | 250 | 340 | 652 | 564 |
| **Trib to Teton River 2** | TTR-2-0.0 | TTR_2 | XS 2494 | 287 | 547 | 825 | 1,170 | 1,940 | 2,460 |
| | TTR-2-0.5 | | N/A[1] | 285 | 543 | 819 | 1,160 | 1,920 | 2,460 |
| **Trib to Teton River 3** | TTR-3-0.0 | TTR_3 | XS 1422 | 205 | 385 | 573 | 801 | 1,330 | 1,630 |
| **Trib to Teton River 4** | TTR4-0.0 | TTR_4 | XS 5978 | 287 | 532 | 787 | 1,090 | 1,810 | 2,210 |
| | TTR4-0.7 | | N/A[1] | 250 | 460 | 676 | 932 | 1,550 | 1,850 |

| Stream | Node ID | Model ID | Hydraulic Model Reference | Peak Flow (cfs)<br>10% Annual Chance<br>10-year | 4% Annual Chance<br>25-year | 2% Annual Chance<br>50-year | 1% Annual Chance<br>100-year | 0.2% Annual Chance<br>500-year | 1% + Annual Chance<br>100-year+ |
|---|---|---|---|---|---|---|---|---|---|
| **West Fork North Fork Teton River** | WFNFTR-0.0 | WFNFTR_1 | XS 4050 | 561 | 964 | 1,470 | 2,230 | 2,530 | 5,700 |

Notes:

1. Flow at node not applied, as flows are applied upstream in hydraulic model.

# 3.0 Hydraulic Analysis

Details of the hydraulic analysis and supporting data are presented in the following sections.

## 3.1 Hydraulic Analysis Procedures

The one-dimensional (1D), steady-state hydraulic modeling was performed using the United States Army Corps of Engineers (USACE) Hydrologic Engineering Center River Analysis System (HEC-RAS), using the latest Version 6.1.0. Hydraulic models were developed for the 10%, 4%, 2%, 1%, 0.2%, and 1% plus annual-chance (AC) flood events for Teton River mainstem and tributaries.

The mainstem of Teton River was originally divided into eight reaches to preserve boundaries of the existing effective flood hazard zones. The first reach of Teton River (85.23 miles in length) was then divided by Great West Engineering into three sub-reaches for ease of modeling. Reaches were modeled separately except for Teton River reaches two through six, which were combined into one large model based on the nature of the flooding conditions (combined 1D model hereafter referred to as TR_Choteau). Spring Creek reaches 1 through 4 were also combined into one reach (combined 1D model hereafter referred to as SPC_Choteau), due to its relationship to Teton River reaches two through six. The two-dimensional (2D) regulatory model (TR_7 2D) encompassed the upstream portion of Teton River (reaches TR_7 and TR_8), as well as McDonald Creek and its tributaries.

### 3.1.1 Model and Software Used

GeoHECRAS (Version 3.1) was used to build each model geometry and to input structure and channel survey data. Once models were fully developed, model calibration, floodways, and final model revisions were completed using HEC-RAS. All two-dimensional (2D) models were completed in HEC-RAS and outputs created using RAS Mapper results. All modeling outputs were processed in RAS Mapper and exported out as shapefiles. The floodway portion of the spatial flood hazard layer was smoothed in ArcGIS.

## 3.2 Topographic Data Acquisition

A terrain model was created during the Topographic Data Development task using Light Detection and Ranging (LiDAR) data. Quantum Spatial was contracted by the DNRC to acquire and process LiDAR data and produce a one-meter resolution, hydroflattened bare earth raster dataset, which was used to develop the terrain. The data were collected from 4/21/2020 to 7/05/2020. For further details, refer to Quantum Spatial's LiDAR Technical Data Report for Teton County, Montana, dated October 2, 2020.

Spatial specifications for the data are listed below:

- Projection: State Plane Montana FIPS 2500
- Horizontal Datum: NAD 1983 (2011)
- Vertical Datum: NAVD88 (GEOID 12B)
- Horizontal Units: Meters
- Vertical Units: Meters

## 3.3 Profile Baseline

Initial stream alignments were based on the S_Hydro_Reach shapefile provided with the approved hydrology package. Stream alignments were verified against terrain, collected survey data, and aerials. Any adjustments to the stream alignments by Great West Engineering for the profile baseline were considered on a case-by-case basis; additionally, some provided streamlines were extended upward to align with the existing floodplain boundary. The Teton River appears to be highly susceptible to minor, but frequent migration as high flows tend to produce lateral migration of the river channel. Aerial imagery supports this assumption, as differing imagery show differing stream paths depending on the source and date (NAIP, Google Imagery, ESRI, etc). Survey data were always the primary source for centerline verification where possible, followed by terrain, and lastly, imagery.

### 3.3.1 Streamlines Excluded from Modeling

After initial model development, select stream reaches were not modeled based on adjacent or joining inundation, and verified with modeled water surface elevations. A summary of scoped streamlines that were not modeled, as well as justification and any pertinent details, are summarized in Table 7 below. Inundation figures and supporting data are included in Appendix L.

**Table 7 – Streamlines Excluded from 1D Modeling**

| Stream Name | Model ID | Length (mi) | Reason not Modeled |
|---|---|---|---|
| **Cashman Coulee** | CAC_1 | 2.78 | Flooding is controlled by Teton River: Water surface elevations were higher on Teton versus preliminary Cashman Coulee modeling results. |
| **McDonald Creek** | MDC_1 | 4.27 | While 2D modeling TR_7, which runs parallel to McDonald Creek, it became evident that flows spill out of Teton River in several locations, and flow into the McDonald Creek drainage. These flows total roughly 4,000 cfs, which is four times that of McDonald's hydrology results. Therefore, McDonald Creek was not independently modeled and rather, is shown to be part of the Teton River system in the regulatory 2D model. |
| **Trib to McDonald Creek** | TMDC_1 | 2.04 | Tributary is included in the model domain for the TR_7 2D Regulatory model. |
| **Teton Ditch** | TD_1 | 0.34 | Streamline is inundated by Teton River floodplain. |
| **Trib to Flat Coulee 1** | TFC_1 | 0.33 | Streamline is inundated by Flat Coulee floodplain. |
| **Trib to McDonald Creek 2** | TMDC_2 | 0.50 | Tributary is included in the model domain for the TR_7 2D Regulatory model. |
| **Trib to McDonald Creek 3** | TMDC_3 | 0.26 | Tributary is included in the model domain for the TR_7 2D Regulatory model. |
| **Trail Coulee** | TRCO_1 | 0.48 | Streamline is inundated by Teton River floodplain. |

## 3.4 Boundary Conditions

For all 1D hydraulic models, reaches were modeled using a normal depth boundary condition. Because flow is assumed to be uniform, the energy grade slope was approximated using the channel bed slope for normal depth calculations. Along Teton River mainstem (Reaches 1.2 through TR_Choteau) and North Fork Teton River (Reaches 2 and 3), each reach was modeled using a common cross section with the downstream reach and the known water surface elevations for each profile. A summary of boundary conditions for all 1D hydraulic models can be found in Table 8 below; supplemental information is included in Appendix B.

**Table 8 – Summary of 1D Model Boundary Conditions**

| | Stream Name | Model ID | Downstream Boundary Condition |
|---|---|---|---|
| **Teton River Mainstem** | **Teton River – Reach 1.1** | TR_1.1 | Normal Depth, S = 0.0005 |
| | **Teton River – Reach 1.2** | TR_1.2 | Known WSE, TR_1.1 |
| | **Teton River – Reach 1.3** | TR_1.3 | Known WSE, TR_1.2 |
| | **Teton River – Choteau** | TR_Choteau | Known WSE, TR_1.3 |
| | **Teton River Overflow** | TR_Overflow | Junction |
| **Teton River Long Tribs** | **Flat Coulee** | FLC_1 | Normal Depth, S = 0.001 |
| | **Middle North Fork Teton River** | MNFTR_1 | Normal Depth, S = 0.03 |
| | **South Fork Teton River** | SFTR_1 | Normal Depth, S = 0.02 |
| | **North Fork Teton River – Reach 1** | NFTR_1 | Normal Depth, S = 0.01 |
| | **North Fork Teton River – Reach 2** | NFTR_2 | Known WSE, NFTR_1 |
| | **North Fork Teton River – Reach 3** | NFTR_3 | Known WSE, NFTR_2 |
| | **Trib to Teton River - 5** | TTR_5 | Normal Depth, S = 0.01 |
| **Spring Creek Mainstem** | **Spring Creek** | SPC_Choteau | Normal Depth, S = 0.002 |
| | **Teton River Highway 89 Split** | TR HWY_89_Split | Junction |
| **Teton River Short Tribs** | **Gamble Coulee** | GC_1 | Normal Depth, S = 0.002 |
| | **Jones Creek** | JC_1 | Normal Depth, S = 0.04 |
| | **Kinnerely Coulee** | KC_1 | Normal Depth, S = 0.002 |
| | **Railroad Coulee** | RRC_1 | Normal Depth, S = 0.003 |
| | **Spring Coulee** | SC_1 | Normal Depth, S = 0.01 |
| | **Spencer Coulee** | SPCO_1 | Normal Depth, S = 0.01 |
| | **Trib to Flat Coulee - 2** | TFC_2 | Normal Depth, S = 0.01 |
| | **Trib to Flat Coulee - 3** | TFC_3 | Normal Depth, S = 0.01 |
| | **Trib to Teton River - 1** | TTR_1 | Normal Depth, S = 0.004 |
| | **Trib to Teton River - 2** | TTR_2 | Normal Depth, S = 0.002 |

|  | Stream Name | Model ID | Downstream Boundary Condition |
|---|---|---|---|
|  | **Trib to Teton River - 3** | TTR_3 | Normal Depth, S = 0.02 |
|  | **Trib to Teton River - 4** | TTR_4 | Normal Depth, S = 0.01 |
|  | **West Fork North Fork Teton River** | WFNFTR_1 | Normal Depth, S = 0.02 |

Boundary conditions for 2D models are described in further detail in subsequent sections pertaining to each model. A summary of 2D boundary conditions is presented in the tables below.

**Table 9 – Summary of 2D Inflow Boundary Conditions**

| 2D Model | Boundary Condition | Control | Description |
|---|---|---|---|
| **Teton River - Choteau 2D Model** | TR-89.2 | Flow Hydrograph | Upstream Boundary Condition, E.G. Slope = 0.0048 |
|  | TR-85.2 | Flow Hydrograph | Flow Change Location, E.G. Slope = 0.0031 |
| **Trib to Teton River 4 - TTR_4 2D Model** | TTR_4-US | Flow Hydrograph | Upstream Boundary Condition, E.G. Slope = 0.0141 |
| **Teton River - TR_7 2D Model** | TR-8-US | Flow Hydrograph | Upstream Boundary Condition, E.G. Slope = 0.0087 |
|  | TR-121.4 | Flow Hydrograph | Flow Change Location, E.G. Slope = 0.0074 |
|  | TR-105.6 | Flow Hydrograph | Flow Change Location, E.G. Slope = 0.0050 |
|  | TR-99.7 | Flow Hydrograph | Flow Change Location, E.G. Slope = 0.0061 |
| **Spring Creek - SPC_Upper 2D Model** | US-SPC | Flow Hydrograph | Upstream Boundary Condition, E.G. Slope = 0.0041 |
|  | SPC-5-12.3 | Flow Hydrograph | Flow Change Location, E.G. Slope = 0.0078 |
|  | SPC-5-11.7 | Flow Hydrograph | Flow Change Location, E.G. Slope = 0.0018 |
|  | SPC-5-10.9 | Flow Hydrograph | Flow Change Location, E.G. Slope = 0.0083 |

**Table 10 – Summary of 2D Outflow Boundary Conditions**

| 2D Model | Boundary Condition | Control | Description |
|---|---|---|---|
| **Teton River - Choteau 2D Model** | Downstream | Normal Depth | Outflow Location, Friction Slope = 0.0022 |
| **Trib to Teton River 4 - TTR_4 2D Model** | Overflow Flooding | Normal Depth | Outflow Location, Friction Slope = 0.0020 |
| **Teton River - TR_7 2D Model** | North Outflow | Normal Depth | Outflow Location, Friction Slope = 0.0088 |
|  | Northeast Outflow | Normal Depth | Outflow Location, Friction Slope = 0.0047 |
|  | TR-7-DS | Stage Hydrograph | Outflow Location, 1% AC WSE = 3,991.44 ft |
| **Spring Creek - SPC_Upper 2D Model** | DS-SPC | Stage Hydrograph | Outflow Location, 1% AC WSE = 3,943.89 ft |

## 3.5 Cross Section Development

### 3.5.1 Cross Section Placement

In general, cross sections were placed roughly 500 feet apart and were drawn perpendicular to the direction of flow. Cross sections were also placed along existing bathymetric survey points where available. At structures, cross sections were placed at locations 4 through 1 as described in the HEC-RAS Hydraulic Reference Manual, which includes locations directly upstream and downstream of the structure as well as locations to capture the expansion and contraction areas, typically delineated by the collected bathymetric survey points.

For reaches that were informed by a 2D model, water surface contours were generated from the 1% annual chance (AC) event and cross sections were drawn to match or parallel these contours where reasonable. Where cross sections overlaid survey points, or at structures, the survey data took precedence over matching water surface contours.

### 3.5.2 Channel Modification

On streams with bathymetric survey data, channel modifications were made to non-surveyed cross sections to better represent the true channel bottom not captured by LiDAR data along the entirety of the stream. Cross sections that were drawn over bathymetry survey were brought into GeoHECRAS and the bathymetric survey points were conflated to replace the LiDAR terrain data in the channel only. A new channel terrain layer was created exclusively from surveyed cross sections, with interpolated terrain between the survey cross sections; this channel terrain was then merged with the existing terrain to create a “combined terrain” containing the original terrain in the overbanks with channel data burned in.

Cross sections could then be derived using this new terrain, which was more representative of the channel bottom and the area between the banks. Once cross sections were created using the interpolated channel data, the original terrain was plotted against the edited cross sections and each cross section was reviewed against the original LiDAR data to ensure the interpolated channel was reasonable. If survey data was not available within a reasonable distance to a cross section, conservative modification methods were used to avoid overestimation of channel capacity. Figure 7 below shows a surveyed cross section with the original LiDAR and surveyed elevations. Figure 8 is an example of an interpolated channel based on the nearest surveyed cross section.

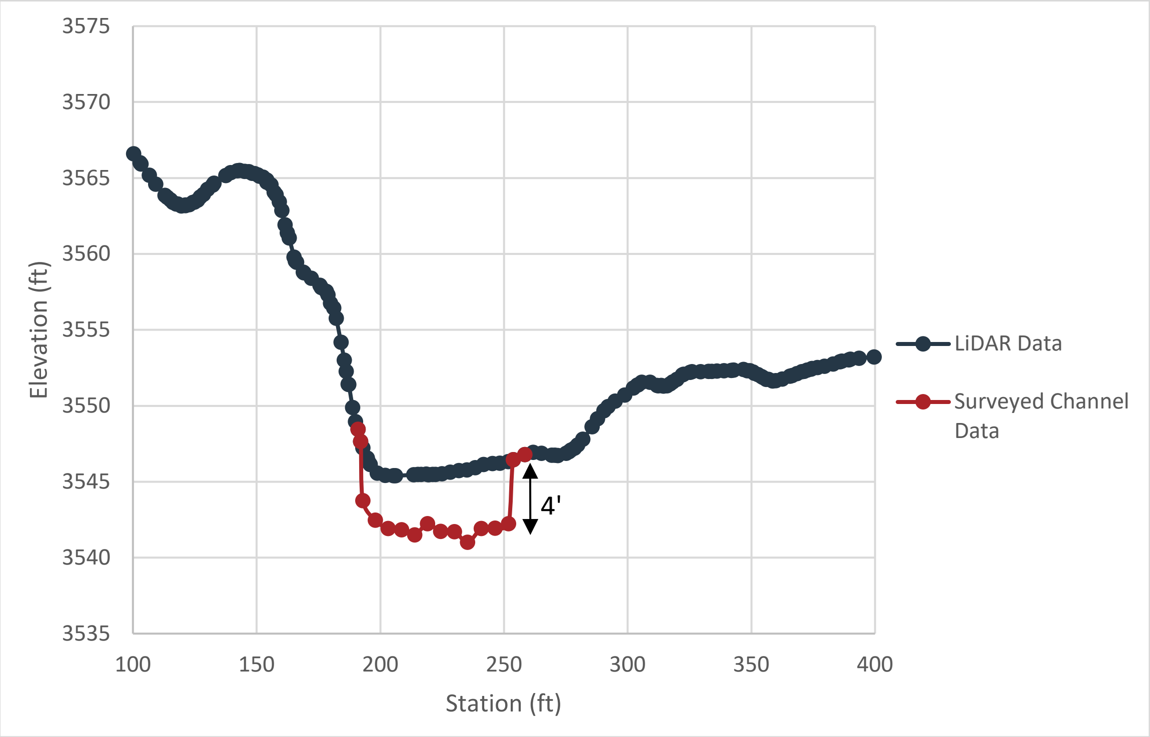


**Figure 7 - Surveyed points in channel versus LiDAR Data**

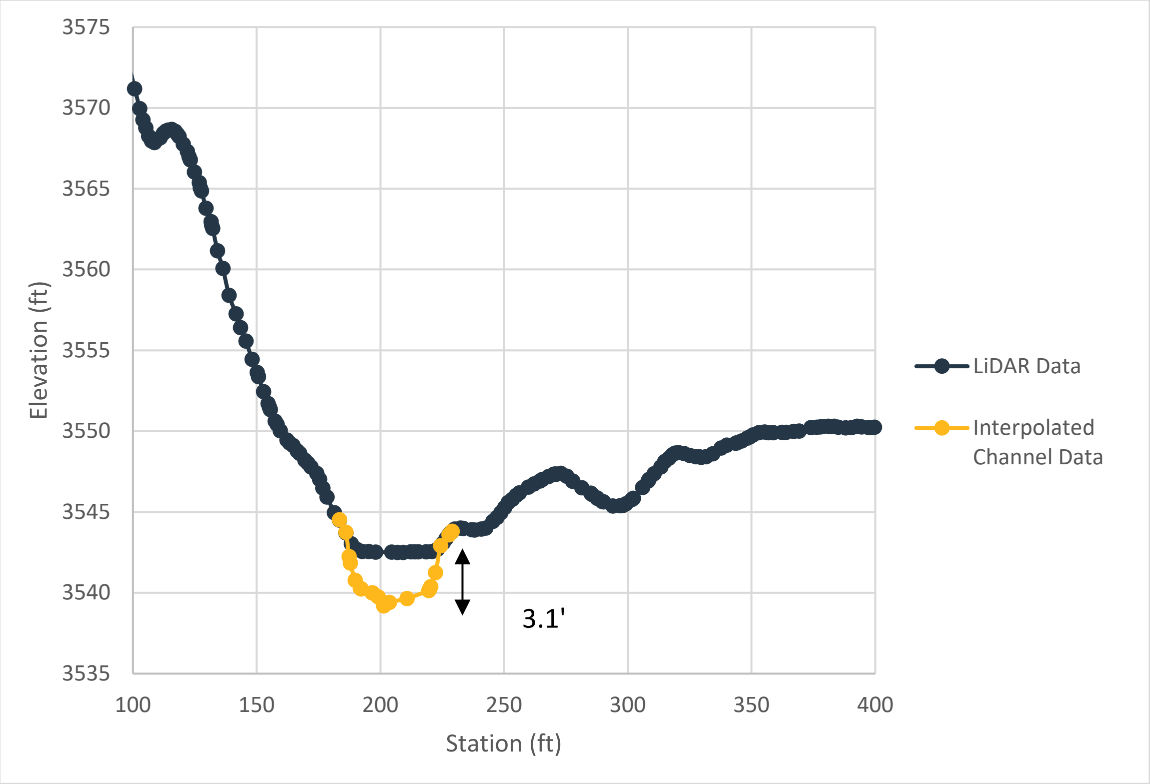


**Figure 8 - Interpolated channel points, based on upstream and downstream survey data**

On reaches with structures that were inventoried only (no GPS-level survey), a different technique was needed to lower the channel along the entire reach. At the cross sections bounding structures, where the terrain points had been manually modified to match data provided on survey sketch, the "drop" in channel was the difference between the survey data, and the original terrain. The "Channel Design/Modification" tool in HEC-RAS was then used to create a channel template representative of the channel with the identified drop applied at each cross section. For reaches with multiple surveyed structures with varying channel drops, modification depth was linearly interpolated between structures.

For reaches modified using this technique, multiple trapezoidal channel templates were created with varying bottom widths based on both the survey data provided and the existing cross section channel geometry. Trapezoidal geometries and the reaches associated with each are summarized in Table 11 below. Although each template had an initial depth set for the trapezoid, the "Fixed Elevation" column in the modification design editor was used to manually vary the channel bottom elevations at each cross section based on the identified drop. Additional adjustments were made on a case-by-case basis to adjust the template application location to line up with the center channel station and to make Manning's adjustments as needed.

**Table 11 – Channel Design & Modification for Long Tributaries**

| Stream Reach Applied To | Trapezoidal Bottom Width | Side Slope | Channel Depth |
|---|---|---|---|
| **North Fork Teton River - NFTR_1** | 5 | 2 | 5 |
| | 10 | 2 | 5 |
| | 15 | 2 | 5 |
| **North Fork Teton River - NFTR_2** | 5 | 2 | 5 |
| | 10 | 2 | 5 |
| | 15 | 2 | 5 |
| **North Fork Teton River - NFTR_3** | 3 | 2 | 5 |
| | 5 | 2 | 5 |
| | 10 | 2 | 5 |
| | 15 | 2 | 5 |
| **South Fork Teton River - SFTR_1** | 5 | 3 | 1 |
| | 10 | 3 | 1 |
| | 15 | 3 | 1 |
| **Middle North Fork Teton River - MNFTR_1** | 5 | 2 | 3 |
| | 10 | 2 | 3 |
| | 15 | 2 | 3 |
| **West Fork North Fork Teton River - WFNFTR_1** | 5 | 2 | 3 |
| | 10 | 2 | 3 |
| | 15 | 2 | 3 |

Notes:

1. During model refinement, any cross sections that were added were manually modified to match surrounding cross sections.

### 3.5.3 Channel Banks

Once initial model geometry was created, bank points were evaluated at each cross section. Most often banks were set based on topography, but also verified against aerials and nearby survey data. Bank placement also went through further adjustments once the models ran with all flows; banks were adjusted as necessary to be below the 1% WSE.

### 3.5.4 Expansion and Contraction Coefficients

Expansion and contraction coefficients were applied through each model to account for energy losses associated with changes in channel width. Default expansion and contraction coefficients are 0.1 and 0.3, respectively, for all cross sections. To account for the expansion and contraction at structures, the two upstream cross sections and bounding downstream cross section were adjusted to have coefficients of 0.3 and 0.5. Outside of structures, expansion and contraction coefficients were adjusted as needed, based on engineering judgement.

## 3.6 Hydraulic Structures

Structures that cross modeled streams were incorporated using the survey data collected and provided by Morrison-Maierle (Morrison-Maierle, 2021). Full details regarding the county-wide survey collection process can be found in the Survey Report referenced in Appendix A.

Collected data of hydraulic structures were classified by three types of survey: GPS level, Structure Inventory (SI), and Site Visit (SV), each with a varying level of detail associated with collection methods. Where GPS level data were available, the points with corresponding elevations were burned into each cross section at structures and at bathymetric cross section locations. For structures documented during Structure Inventory survey, the structure details were back-calculated using existing terrain with the specified dimensions detailed on the provided sketches. Each structure had a sketch and photographs to assist in the modeling process. A similar process supported by photographs was used for structures inventoried during site visit survey.

Many studied streams have several diversion dams, and control gates for irrigation ditches. Unless located on the main channel, all gates were assumed to be closed and no loss in flows were incorporated. Ineffective flow areas were assigned at each structure as appropriate to indicate areas along structure embankments which were not actively conveying flow.

Numerous structures captured during survey were not included in hydraulic models based on hydraulic significance, presence of existing structure (or lack thereof), and other hydraulic assumptions. Table 12 below presents justification for structures that were surveyed but not modeled. A complete list of surveyed structures, along with modeling details, is included in Appendix J.

**Table 12 – Structures not Modeled**

| Structure ID | Structure Type | Model Domain | Justification | In the Floodway? | On Profile Baseline? |
|---|---|---|---|---|---|
| **SPR_0120_GPS** | Culvert | SPC_Choteau | Culvert lacks hydraulic significance at the 1% AC event, as seen by 2D WSE contours. | Yes | No |
| **SPR_0130_GPS** | Culvert | SPC_Choteau | Culvert has no inlet, only an outlet. | Yes | No |

| Structure ID | Structure Type | Model Domain | Justification | In the Floodway? | On Profile Baseline? |
|---|---|---|---|---|---|
| **SPR_0200_SI** | Bridge | SPC_Choteau | Bridge deck is missing, only piers remain. Lacks hydraulic significance at the 1% AC event. | No | Yes |
| **SPR_0230_SV** | Culvert | SPC_Choteau | Culvert is not inundated at any flow events. | No | No |
| **SPR_0250_SV** | Culvert | SPC_Choteau | Culvert lacks hydraulic significance at the 1% AC event, as seen by 2D WSE contours. | No | No |
| **SPR_0280_SV** | Cattle Guard | SPC_Choteau | Lacks hydraulic significance. | No | No |
| **SPR_0340** | Culvert | SPC_Upper_2D | Culvert lies outside of 2D model domain. | No | N/A |
| **SPR_030_SI** | Culvert | SPC_Choteau | In an irrigation ditch with a headgate, assumes gate to be closed during flood events. | No | No |
| **SPR_060_GPS** | Culvert | SPC_Choteau | Culvert lacks hydraulic significance at the 1% AC event, as seen by 2D WSE contours. | No | No |
| **SPR_070_GPS** | Culvert | SPC_Choteau | Culvert lacks hydraulic significance at the 1% AC event, as seen by 2D WSE contours. | No | No |
| **SPR_080_GPS** | Culvert | SPC_Choteau | Culvert lacks hydraulic significance at the 1% AC event, as seen by 2D WSE contours. | No | No |
| **SPR_090_GPS** | Culvert | SPC_Choteau | Culvert lacks hydraulic significance at the 1% AC event, as seen by 2D WSE contours. | No | No |
| **SPR_0100_GPS** | Culvert | SPC_Choteau | Culvert lacks hydraulic significance at the 1% AC event, as seen by 2D WSE contours. | No | No |
| **TET_0345_SV** | Armored Drop | TR_7 2D | In an irrigation ditch with a headgate, assumes gate to be closed during flood events. | No | N/A |
| **TET_0430_SV** | Culvert | TR_7 2D | Not inundated at the 1% AC event. Excluded to reduce computational effort. | No | N/A |
| **TET_0440_SV** | Culvert | TR_7 2D | Not inundated at the 1% AC event. Excluded to reduce computational effort. | No | N/A |
| **CAS_010_SI** | Culvert | TR_Choteau | Culvert lacks hydraulic significance at the 1% AC event, as seen by 2D WSE contours. | Yes | No |
| **CAS_040_SI** | Culvert | TR_Choteau | Culvert lacks hydraulic significance at the 1% AC event, as seen by 2D WSE contours. | Yes | No |
| **CAS_050_SI** | Culvert | TR_Choteau | Culvert lacks hydraulic significance at the 1% AC event, as seen by 2D WSE contours. | Yes | No |
| **TET_0130_SV** | Drainage | TR_Choteau | Natural drainage with no structure. | No | No |
| **TET_0140_SI** | Bridge | TR_Choteau | Bridge lacks hydraulic significance at the 1% AC event, as seen by 2D WSE contours. | No | No |

| Structure ID | Structure Type | Model Domain | Justification | In the Floodway? | On Profile Baseline? |
|---|---|---|---|---|---|
| **TET_0150_SI** | Bridge | TR_Choteau | Bridge lacks hydraulic significance at the 1% AC event, as seen by 2D WSE contours. | No | No |
| **TET_0180_SV** | Culvert | TR_Choteau | Culvert lacks hydraulic significance at the 1% AC event, as seen by 2D WSE contours. | Yes | No |
| **TET_0190_SV** | Culvert | TR_Choteau | Culvert lacks hydraulic significance at the 1% AC event, as seen by 2D WSE contours. | Yes | No |
| **TET_0200_SV** | Culvert | TR_Choteau | Culvert lacks hydraulic significance at the 1% AC event, as seen by 2D WSE contours. | Yes | No |
| **TET_0201_SV** | Culvert | TR_Choteau | Culvert lacks hydraulic significance at the 1% AC event, as seen by 2D WSE contours. | Yes | No |
| **TET_0211_SV** | Culvert | TR_Choteau | Culvert lacks hydraulic significance at the 1% AC event, as seen by 2D WSE contours. | Yes | No |
| **TET_0230_SV** | Bridge | TR_Choteau | Old bridge was washed out, only piers remain. Lacks hydraulic significance at the 1% AC event. | Yes | Yes |
| **TET_0260_GPS** | Culvert | TR_Choteau | Culvert lacks hydraulic significance at the 1% AC event, as seen by 2D WSE contours. | Yes | No |
| **TET_0270_GPS** | Culvert | TR_Choteau | Culvert lacks hydraulic significance at the 1% AC event, as seen by 2D WSE contours. | Yes | No |
| **TET_0280_GPS** | Bridge | TR_Choteau | Cross sections are not orientated along bridge. WSE and inundation results more closely match 2D results when bridge is excluded. | Yes | Yes |
| **TET_0290_GPS** | Culvert | TR_Choteau | Culvert lacks hydraulic significance at the 1% AC event, as seen by 2D WSE contours. | Yes | No |
| **TET_0330_SI** | Culvert | TR_Choteau | Culvert with a headgate feeds into irrigation ditch, assumes gate to be closed during flood events. | No | No |
| **TET_0340_SI** | Culvert | TR_Choteau | In an irrigation ditch with a headgate, assumes gate to be closed during flood events. | No | No |
| **TET_0350_SV** | Culvert | TR_Choteau | In an irrigation ditch with a headgate, assumes gate to be closed during flood events. | No | No |
| **TET_0360_SI** | Culvert | TR_Choteau | Culvert d lacks hydraulic significance at the 1% AC event, as seen by 2D WSE contours. | No | No |
| **TET_0400_SV** | Culvert | TR_Choteau | In an irrigation ditch with a headgate, assumes gate to be closed during flood events. | No | No |
| **TET_0410_SI** | Bridge | TR_Choteau | Landowner reports that the bridge was destroyed several years ago. No abutments or piers remain. | No | No |

| Structure ID | Structure Type | Model Domain | Justification | In the Floodway? | On Profile Baseline? |
|---|---|---|---|---|---|
| **TET_0420_SV** | Culvert | TR_Choteau | In an irrigation ditch with a headgate, assumes gate to be closed during flood events. | No | No |
| **SFT_020_SI** | Bridge | SFTR_1 | No visible sign of structure. Bridge was washed out in 2018. | No | Yes |
| **SFT_030_SI** | Bridge | SFTR_1 | Remains of railroad tie abutments. Bridge was washed out in 2018. | No | Yes |
| **TET_1_010** | Culvert | TTR_2 | Backwater analysis from TR_1.3 indicates that regions downstream of XS 997 (including structure) are controlled by Teton water surface elevations; structure was not modeled. | No | Yes |
| **TRA_010** | Culvert | TRC_1 | Trail Coulee was not modeled. | No | N/A |
| **TET_020** | Control Structure | TR_1.1 | Private Diversion, assumes gate to be closed during flood events. | No | No |
| **TET_010** | Bridge | TR_1.1 | Private Diversion, could not locate. | No | No |
| **FLA_020** | Culvert | FLC_1 | Backwater analysis from TR_1.1 indicates that regions downstream of XS 6679 (including structure) are controlled by Teton water surface elevations; structure was not modeled. | No | No |
| **FLA_010** | Culvert | FLC_1 | Backwater analysis from TR_1.1 indicates that regions downstream of XS 6679 (including structure) are controlled by Teton water surface elevations; structure was not modeled. | No | No |
| **TET_0480** | Culvert | TR_7 2D | Survey sketch indicated no evidence of a structure. | No | No |
| **TET_0490** | Culvert | TR_7 2D | Flow does not reach the structure at the regulatory 100-year event. | No | No |
| **TET_0610** | Control Structure | TR_7 2D | Channel feature adequately captured using breaklines and LiDAR terrain. | No | Yes |

## 3.7 Roughness Coefficients

Manning’s ‘n’ values were initially designated along the study reaches using imagery and field survey information. A polygon was created in ArcMap to delineate various land uses and land cover in the overbanks of all streams. Importing the polygon into GeoRAS, Manning’s ‘n’ values were applied and varied by station at each cross section. In areas with dense development, a higher ‘n’ value was applied to represent the energy loss created by the structures. Increasing the roughness in these areas allowed for generalized sections where buildings had small footprints and were not continuous across the overbank between cross sections. Manning’s ‘n’ values were referenced from both USGS Guidance and Chow’s Open-Channel Hydraulics (Open-Channel Hydraulics, 1959). After initial model set up, all Manning’s values were subject to adjustments and further refinement during floodway analysis, eliminating critical depths, or uncrossing profiles. Roughness values were also adjusted during calibration, further described in Section 3.14. For all 2D models, Manning's 'n' values were reduced by 25% which is shown to better represent characteristics of 2D flow conditions. A general summary of 1D manning's values used is presented below in Table 13 and specific ranges of channel and overbank values on each studied stream are listed in Table 14.

**Table 13 – Land Use Descriptions for Manning's 'n' Values**

| | Land Use | Manning's 'n' |
|---|---|---|
| **Natural Setting** | Channel | 0.025 – 0.06 |
| | Open Water | 0.02 |
| | Grass | 0.04 |
| | Crops | 0.04 |
| | Pasture (No Brush) | 0.04 – 0.045 |
| | Light Brush | 0.045 – 0.05 |
| | Medium to Dense Brush | 0.06 – 0.065 |
| | Heavy Brush | 0.06 – 0.08 |
| | Post-Fire | 0.07 |
| | Trees | 0.075 – 0.08 |
| | Riparian | 0.06 – 0.1 |
| | Heavy Timber | 0.09 – 0.11 |
| **Urban Setting** | Low Density | 0.065 |
| | Medium Density | 0.07 – 0.08 |
| | High Density | 0.12 |
| | Roads | 0.011 |

**Table 14 – Range of Manning's 'n' Values per 1D Model**

| | Stream Name | Model ID | Manning's 'n' Value Range | |
|---|---|---|---|---|
| | | | Overbank | Channel |
| **Teton River Mainstem** | **Teton River – Reach 1.1** | TR_1.1 | 0.011 – 0.08 | 0.025 – 0.04 |
| | **Teton River – Reach 1.2** | TR_1.2 | 0.011 – 0.08 | 0.027 – 0.038 |
| | **Teton River – Reach 1.3** | TR_1.3 | 0.011 – 0.09 | 0.028 – 0.038 |
| | **Teton River – Choteau** | TR_Choteau | 0.011 – 0.12 | 0.025 – 0.048 |
| | **Teton River Overflow** | TR_Overflow | 0.02 – 0.12 | 0.05 |
| **Teton River Long Tribs** | **Flat Coulee** | FLC_1 | 0.011 – 0.052 | 0.035 – 0.045 |
| | **Middle North Fork Teton River** | MNFTR_1 | 0.011 – 0.075 | 0.052 – 0.065 |
| | **South Fork Teton River** | SFTR_1 | 0.011 – 0.08 | 0.062 – 0.065 |

|  | Stream Name | Model ID | Manning's 'n' Value Range |  |
|---|---|---|---|---|
|  |  |  | Overbank | Channel |
|  | **North Fork Teton River – Reach 1** | NFTR_1 | 0.011 – 0.08 | 0.05 – 0.062 |
|  | **North Fork Teton River – Reach 2** | NFTR_2 | 0.035 – 0.065 | 0.05 – 0.061 |
|  | **North Fork Teton River – Reach 3** | NFTR_3 | 0.011 – 0.08 | 0.05 – 0.064 |
|  | **Trib to Teton River - 5** | TTR_5 | 0.045 – 0.05 | 0.04 – 0.045 |
| **Spring Creek Mainstem** | **Spring Creek** | SPC_Choteau | 0.011 – 0.12 | 0.038 – 0.059 |
|  | **Teton River Highway 89 Split** | TR HWY_89_Split | 0.04 – 0.06 | 0.04 |
| **Teton River Short Tribs** | **Gamble Coulee** | GC_1 | 0.04 – 0.055 | 0.04 – 0.045 |
|  | **Jones Creek** | JC_1 | 0.011 – 0.09 | 0.055 – 0.062 |
|  | **Kinnerely Coulee** | KC_1 | 0.04 – 0.05 | 0.045 |
|  | **Railroad Coulee** | RRC_1 | 0.04 – 0.06 | 0.05 |
|  | **Spring Coulee** | SC_1 | 0.04 – 0.05 | 0.045 – 0.05 |
|  | **Spencer Coulee** | SPCO_1 | 0.04 – 0.06 | 0.05 |
|  | **Trib to Flat Coulee - 2** | TFC_2 | 0.04 – 0.05 | 0.035 – 0.045 |
|  | **Trib to Flat Coulee - 3** | TFC_3 | 0.04 – 0.055 | 0.035 – 0.043 |
|  | **Trib to Teton River - 1** | TTR_1 | 0.04 | 0.035 |
|  | **Trib to Teton River - 2** | TTR_2 | 0.045 | 0.035 |
|  | **Trib to Teton River - 3** | TTR_3 | 0.04 - 0.06 | 0.05 |
|  | **Trib to Teton River - 4** | TTR_4 | 0.05 | 0.04 – 0.047 |
|  | **West Fork North Fork Teton River** | WFNFTR_1 | 0.011 – 0.075 | 0.05 – 0.06 |

## 3.8 Non-Conveyance and Blocked Obstruction Areas

### 3.8.1 Ineffective Flow Areas

Ineffective flow areas were defined in HEC-RAS cross sections where water was not contributing to the active conveyance, often indicated through topography or based on initial floodplain maps. Ineffective areas were also placed upstream and downstream of structures to account for the decrease in conveyance created by the structure. During final model refinement and floodway analysis where applicable, ineffective areas were iteratively adjusted for model stability and to ensure that no profiles were crossing. Permanent ineffective areas were used to account for any ponding in the overbanks.

### 3.8.2 Blocked Obstructions

As described in Section 3.7, Manning's roughness coefficients were increased to account for the energy loss caused by buildings rather than using blocked obstructions, as the effect of a blocked obstruction is assumed across the entire area between cross sections. In certain scenarios, blocked obstructions rather than permanent ineffective areas were used to represent the flow that could not leave ponding areas in the overbanks.

## 3.9 Diverted / Split Flow Analysis

FEMA guidance states that “when two major flow directions are identified, split flow or diverted flow conditions exist. Split flow rejoins the main stream, while diverted flow is lost to the floodplain being modeled” (FEMA 2016). There are several areas of split flow identified and analyzed throughout the study area. Split flows were mostly identified through hydraulic modeling, where containment could not be achieved otherwise, or as part of the calibration analysis. As noted in Section 3.13.2, some flow paths were informed by 2D models. Specifics on each split is detailed by stream segment in Section 3.16.

In certain reaches, lateral weirs were needed in the model to quantify flows leaving the main channel. However, the most recent versions of HEC-RAS 6.0 and 6.1 do not allow the user to control the optimization of lateral structures in the software run. Additional details of this issue and Great West’s recommended approaches are summarized in a Technical Memo dated November 19th, 2021 (Appendix K). As recommended, 1D models that had a corresponding 2D model used flows extracted from the results via monitoring lines to manually code into the 1D model in place of a lateral structure analysis. If a 2D model was unavailable, the 1D model was created in HEC-RAS 5.0.7 and optimized to get appropriate flow-split results and then hard-coded into HEC-RAS 6.1 to run and produce results.

## 3.10 Ice Jam Analysis

An ice jam analysis was not completed for this project.

## 3.11 Levee Analysis

A levee analysis was not completed for this project. Details on non-levee embankments are presented below.

### 3.11.1 Non-Levee Embankments

Throughout the study area, there are several roads, berms, and areas of elevated high ground parallel to streamflow that have potential to block flow but are not engineered to be flood control structures. These features are considered Non-Levee Embankments. Because they are not flood control structures, nor certified as levees, the ability to block flows were evaluated closely on a case-by-case basis and modeled accordingly. More information on specific cases is detailed in the Stream Specific Modeling Details in Section 3.16. As a general modeling approach, ineffective areas were placed on high ground along these embankments, and water beyond the structures will be modeled as part of the floodplain to account for the uncertainty of the structure and embankment’s ability to hold back water.

## 3.12 Multiple / Worst Case Scenario

A multiple/worst case scenario analysis was not completed for this project.

## 3.13 2D Modeling Methodology

### 3.13.1 2D Regulatory Models

While no reaches were initially included in the scope of work as 2D regulatory models, it was determined after preliminary modeling results that select reaches would not be accurately characterized in a 1D space, and best represented with a 2D model. All 2D regulatory models were developed using HEC-RAS 2D (Version 6.1) and GeoHECRAS 2D (Version 3.1) and are described in further detail below.

### 3.13.1.1 Teton River - TR_7 2D Regulatory Model Development

A 2D regulatory hydraulic model was developed using HEC-RAS and GeoHECRAS software for the Teton River reach 7 (TR_7) upstream of Choteau, Montana near the Eureka Reservoir. For calibration purposes, Teton River reach 8 (TR_8) was also included in the 2D model, as USGS Gage 06102500 is located just upstream of TR_7 in the TR_8 reach.

LiDAR data provided by the DNRC was utilized in model development. The LiDAR data used in the hydraulic analysis was flown by Quantum Spatial in the summer of 2020. This LiDAR was processed into a digital elevation model (DEM) to create the terrain surface used in the model. Bathymetric survey data was utilized to create the channel surface. This channel surface was created by digitizing the surveyed channel cross sections and interpolating along the channel centerline to create a continuous surface. This channel terrain was then pasted onto the LiDAR terrain to create a combined surface for the 2D model. Other modifications were also made, namely manual edits to drop the LiDAR surface elevation below culvert invert elevations, as is required in HEC-RAS. A mesh containing the river basin with minimum width of 2,500 feet was generated with a base cell spacing of 75 feet. The mesh was further refined using breaklines to represent flow paths, high ground barriers, roadways, buildings, and various other features to represent changes in terrain with higher precision. Cell spacing for these breaklines varies from 5 feet to 50 feet. Structure survey data were used for structure incorporation, and bathymetric survey data were used for channel data which was burned into the original terrain to represent the true channel bottom elevations, which otherwise is not detected with LiDAR. For calibration purposes, a detailed surface around bridge TET_0780 was created to more accurately represent the topography in the vicinity of USGS Gage 06102500. See the TR_7 2D calibration write-up for more details.

Originally, the TR_7 2D model was developed to inform the creation of 1D models for TR_7 and included TR_8. However, preliminary model results showed a significant volume of flow leaving the Teton River mainstem in several locations and flowing into the McDonald Creek basin. This flow inundates McDonald Creek and its tributaries to a greater extent than the provided hydrology for these reaches. Modeling this scenario in a 1D model was not possible with the existing optimization function in version 6.1. However, even aside from the lack of function, lateral structures along the Teton River would need to be thousands of feet in length and likely cause model instability and produce less accurate results. For these reasons, it was decided that a large 2D model would be used to best represent flow conditions along reaches TR_7 and TR_8, with McDonald Creek and its tributaries.

To define flows entering the model reach, inflow hydrograph boundary condition lines were used. The upstream model boundary condition was defined as an inflow hydrograph starting at zero cfs, ramping up to the desired flow over eight hours, then holding the flow constant for an additional six hours to allow the model to reach steady state. Flow change locations along the model reach were added using internal boundary condition lines defined as flow hydrographs that ramp up similar to the upstream boundary condition. These hydrographs add the difference in flow rate between flow nodes, are placed at flow node locations, and are oriented perpendicular to the overall floodplain. Flows exit the system at two locations: the downstream end of the model leading into the TR_Choteau model and to the north of Eureka reservoir where flow overtops the road and exits the system through irrigation ditches. The downstream end of the mesh is aligned with the upstream 1D cross section from the TR_Choteau model, and the downstream boundary condition is defined as a stage hydrograph where the stage is set to the 1D WSEL at that cross section. See Table 9 in Section 3.4 for a summary of boundary conditions and Table 10 in Section 3.4 for the 1% AC water surface elevation used for the stage hydrograph at the downstream end of the model.

Table 15 – Discharges at Teton River - TR_7 2D Inflow Hydrographs

| Boundary Condition | 10% AC (cfs) | 4% AC (cfs) | 2% AC (cfs) | 1% AC (cfs) | 0.2% AC (cfs) | 1%+ AC (cfs) |
|---|---|---|---|---|---|---|
| **TR-8-US** | 4,620 | 9,070 | 14,600 | 23,000 | 50,400 | 63,000 |
| **TR-121.4** | 10 | 50 | 100 | 200 | 0 | 600 |
| **TR-105.6** | 0 | 90 | 200 | 400 | 0 | 1,200 |
| **TR-99.7** | 10 | 40 | 100 | 100 | 0 | 400 |

Notes:

[1] TR-121.4, TR-105.6, and TR-99.7 have 0 cfs at the 0.2% AC event due to a decrease in downstream flow in the hydrology report

[2] TR-105.6 has 0 cfs at the 10% AC event due to a lack of flow change from hydro-node TR-121.4 to TR-105.6

Table 16 – Computational Parameters for Teton River - TR_7 2D Regulatory Model

| Computational Parameters | Value |
|---|---|
| **Equation Set** | SWE-ELM [1] |
| **Simulation Time** | 14 hours |
| **Computational Interval** | 1 second |
| **Output Interval** | 5 minutes |
| **Theta** | 1 |
| **Theta Warmup** | 1[2] |
| **Water Surface Tolerance (ft)** | 0.01 |
| **Volume Tolerance (ft)** | 0.01 |
| **Maximum Iterations** | 50 |
| **Run Time (1% AC Event)** | 11 hours |

Notes:

[1] Shallow Water Equations, Eulerian-Lagrangian Method (SWE-ELM)

[2] A default value of 1 was used, lowering Theta caused undue model instability. Results with Theta = 1 were determined accurate and appropriate for the analysis.

Structures for Teton River and McDonald Creek including culverts, bridges and gates were incorporated into the model using survey data and sketches. Additional considerations for structures within the 2D model domain are described below:

- **TET_0460_SI, TET_0470_SI, TET_0500_SI, TET_0510_SI, TET_0530_SI, TET_0580_SI, TET_0650_SI, TET_0720_SI, TET_0740_SI, TET_0760_SI:** These structures pass under Teton Canyon Road. When flow passes through these structures, flows continue north, contained in ditches, and leaves the system. These openings were assumed to be closed by artificially blocking the openings in the model or removing culverts to keep all flows in Teton River for conservative measures. Under these conditions, the only way flows can exit the system to the north is by overtopping the road.
- **TET_0430_SV, TET_0440_SV:** These structures are within the 2D model domain but do not receive flow at the regulatory 100-year event. During larger flood events, the 36” diameter

culverts do not have a significant impact on flows. Therefore, the culverts have been excluded to reduce computational effort.

- **TET_0345_SV, TET_0346_SV:** These structures consist of armored drops in an irrigation ditch and do not have a significant impact on model results. They were excluded from the model to reduce computational effort.
- **TET_0750_GPS, TET_0750_2_GPS:** Structures were surveyed as one but were split into two structures for computational stability.
- **TET_0520_SI, TET_0600_SI, TET_0620_SI, TET_0660_SI, TET_0730_SI, TET_0750_GPS, TET_0750_2_GPS, TET_0770_SI:** These structures have gates that control flow into canals and ditches that subsequently direct flow out of the model domain. During a flood event, it is assumed that these gates would be closed by water users to keep flow in the river and prevent flooding downstream in the ditches.

After the mesh was created, all appropriate breaklines enforced and all structures incorporated, the results were analyzed to identify areas that required refinement. To resolve cell leakage in some areas, refinement regions were used with cell spacings varying from 25 to 60 feet. To better define the flow leaving the Teton River and entering McDonald Creek, large refinement regions with cell spacings of 25 feet were used rather than using breaklines as the overflow area spans thousands of feet and lacks well-defined channels.

At higher flow events Teton Canyon Road is overtopped in multiple areas; at these overtopped locations, the flow leaving Teton River never reenters the river. Initially, this flow accumulates against the 2D model domain, creating an artificial backwater affect. To prevent this, outflow boundary conditions were added to the northern end of the 2D domain to allow the split flows to exit the model domain. The flow quantity in these splits were considered inconsequential when compared to the total flow occurring during these events and no loss of flows were accounted for.

#### 3.13.1.2 Spring Creek - SPC_Upper 2D Regulatory Model Development

A 2D regulatory hydraulic model was developed, using HEC-RAS and GeoHECRAS software, at the upstream end of Spring Creek, north of Choteau, and approximately two miles in total length.

While a 1D was originally proposed, a 2D model was determined necessary due to the effects of a large embankment lying across the stream at its upstream end. The origin of the embankment is unknown but assumed to be an abandoned roadway or railway. At its apex, the embankment rises 17 feet above the ground and creates significant backwater due to its height and an undersized culvert. This backwater then forms a secondary flow path along the toe of the embankment perpendicular to the Spring Creek centerline. This secondary flow eventually passes through the embankment in two locations and rejoins Spring Creek. This complex flow situation was not well represented in a 1D model, and thus a 2D regulatory model was determined to be the best representation of the system. Figure 8 below displays the depth grid of the 1% event and shows the scenario described above.

The surface of the SPC_Upper 2D model was associated with LiDAR and the mesh was comprised of uniform cells with an average spacing of 75 feet. The mesh was further refined using breaklines and refinement regions to represent flow paths and distinct grade breaks (e.g., roadways, embankments, etc.). Cell spacing on breaklines varied from 5 to 10 feet and spacing within refinement regions varied from 5 feet to 15 feet.

No bathymetric features were surveyed along this reach; therefore, no channel modifications were made to the channel. Structures identified during survey data collection within the 2D domain were modeled to reflect the surveyed features.

Six flow files were created to represent each profile in the hydrology report and had respective inflow boundary conditions for each profile. Each hydrograph boundary condition held a constant discharge between the hours of 08:00 and 16:00, to represent steady-state conditions. From hours 00:00 to 08:00, the model increased flow from zero cfs to the target flow; this method was employed to ensure stability. The model has four inflow conditions, one external at the upstream end and three internal. The flow in each hydrograph was based on the flow nodes provided by Hydrology. Table 17 provides the specific discharge for each inflow hydrograph. There is one outflow boundary condition located approximately two miles downstream of the start of the model. The computational modeling parameters are outlined in Table 18.

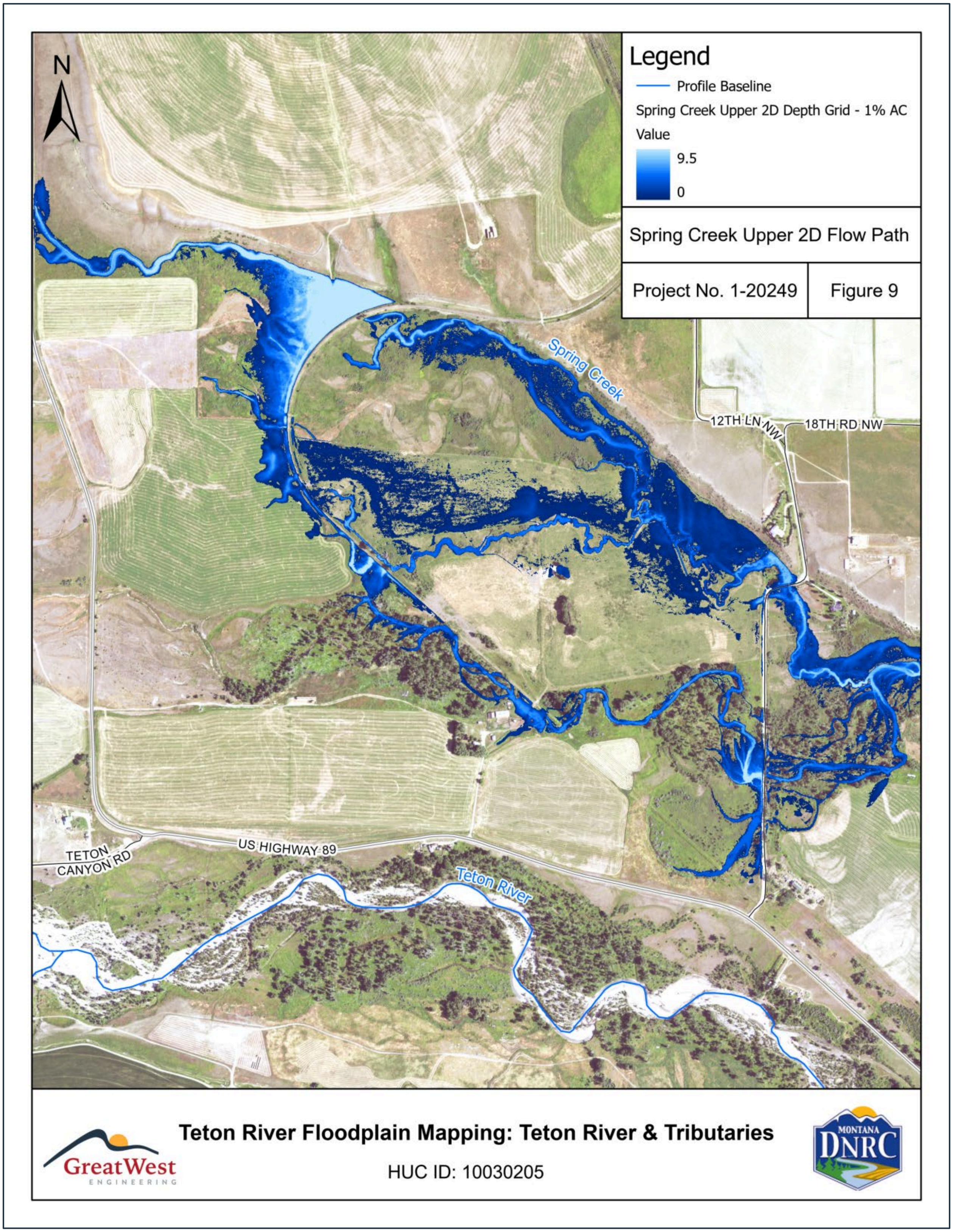


Figure 9 – Spring Creek - SPC Upper 2D Flow Path

**Table 17 – Discharges at Spring Creek - SPC_Upper 2D Inflow Hydrographs**

| Boundary Condition | 10% AC (cfs) | 4% AC (cfs) | 2% AC (cfs) | 1% AC (cfs) | 0.2% AC (cfs) | 1%+ AC (cfs) |
|---|---|---|---|---|---|---|
| **SPC-5-12.9** | 108 | 196 | 282 | 381 | 632 | 716 |
| **SPC-12.3** | 21 | 40 | 60 | 84 | 139 | 175 |
| **SPC-5-11.7** | 8 | 16 | 24 | 34 | 56 | 72 |
| **SPC-5-10.9** | 31 | 59 | 89 | 128 | 213 | 267 |

**Table 18 – Computational Parameters for Spring Creek - SPC_Upper 2D Regulatory Model**

| Computational Parameters | Value |
|---|---|
| **Equation Set** | SWE-ELM |
| **Simulation Time** | 16 hours |
| **Computational Interval** | 5 seconds |
| **Output Interval** | 15 minutes |
| **Theta** | 1[1] |
| **Theta Warmup** | 1 |
| **Water Surface Tolerance (ft)** | 0.01 |
| **Volume Tolerance (ft)** | 0.01 |
| **Maximum Iterations** | 20 |
| **Run Time (1% AC Event)** | 30 minutes |

Notes:

1. A default value of 1 was used, as this parameter was tested and determined yield the best results

## 3.13.2 2D Informed Models

Hydraulic modeling of selected Teton reaches, and tributaries, were performed using HEC-RAS (Version 6.1) and GeoHECRAS (Version 3.1). Eight segments were initially selected for 2D analysis (TR_2, TR_7, MDC_1, TMDC_1, SPC_1, SPC_5, TMDC_2, and TTR_4). However, as previously stated, SPC_Upper (the upstream region of SPC_5), TR_7, MDC_1, TMDC_1, and TMDC_2 have since become 2D regulatory models.

### 3.13.2.1 Teton River - Choteau 2D Model Development

A 2D model was developed encompassing Spring Creek and Teton River reaches 2 through 6 (TR_2 – TR_6). This 2D model was larger than initially identified in the scope of work due to the need to better understand the interaction between Teton River and Spring Creek, and the resulting flood depths. The purpose of this model was to inform 1D model development along the specified reaches.

The surface of the Choteau 2D model was associated with LiDAR and the mesh was comprised of uniform cells with an average spacing of 75 feet. Breaklines were used to force the placement of cell faces and increased cell density along distinct grade breaks (e.g., roadways, channels, embankments, buildings, etc.). Cell spacing along breaklines varied from 2 feet to 20 feet.

An interpolated channel based on bathymetric data was utilized along the Teton River to better represent the channel depth; no modifications were made to the Spring Creek channel. Surveyed structures within the 2D model domain were modeled to reflect the surveyed features. Structures with a headgate were modeled to reflect a closed gate, allowing no flow to pass though the structure. Bridges were not modeled due to their lack of hydraulic significance at the 1% AC event, as seen by water surface contours, and the instability they induced on the model.

The 2D model utilized the same Manning's roughness layer as the 1D model, which was determined using aerial imagery and field survey information. The roughness values were subsequently decreased by 25% to better reflect flow conditions in a 2D space. Contributing calibration efforts are detailed in Section 3.14.3.

Six unsteady flow files were created to represent each profile modeled in the 1D and had respective inflow boundary conditions. Each hydrograph boundary condition held a constant discharge between the hours of 08:00 and 16:00, to represent steady-state conditions. From hours 00:00 and 08:00, the model increased flow from zero cfs to the target flow; this method was employed to ensure stability. A coincident peak was not considered for Teton River and Spring Creek mainly because the two watersheds differ too greatly in size. Therefore, the model has two inflow conditions, one external and one internal, representing only the Teton River. The flow in each hydrograph was based on the flow nodes provided in the hydrology analysis. Table 19, below, provides the specific discharge for each inflow boundary condition. There is one outflow boundary condition located approximately 5.5 miles downstream of the Spring Creek and Teton River confluence.

**Table 19 – Discharges at Teton River - Choteau 2D Inflow Hydrographs**

| Flood Source | 10% AC (cfs) | 4% AC (cfs) | 2% AC (cfs) | 1% AC (cfs) | 0.2% AC (cfs) | 1%+ AC (cfs) |
|---|---|---|---|---|---|---|
| **TR-89.2** | 4,640 | 9,270 | 15,000 | 23,800 | 50,000 | 65,500 |
| **TR-85.2** | 30 | 330 | 800 | 1,400 | 0 | 4,200 |

Notes:

1. TR-85.2 has 0 cfs at the 0.2% AC event due to a decrease in downstream flow in the hydrology report

A comparison analysis was preformed to determine the ideal equation set for the Choteau 2D model. The Diffusion Wave plan utilized a simulation time of 24 hours to ensure relatively steady-state conditions. Results were evaluated from time step 24:00. Due to its run time, and steady-state conditions, the SWE-ELM plan utilized a simulation time of 16 hours. The table below outlines the computational modeling parameters for each plan.

**Table 20 –Computational Parameters for Teton River - Choteau 2D Model, Diffusion Wave vs. SWE-ELM**

| Computational Parameters | Diffusion Wave Plan | SWE-ELM Plan |
|---|---|---|
| **Simulation Time** | 24 hours | 16 hours |
| **Computational Interval** | 15 seconds | Time Step Adjusted Based on Courant |
| **Maximum Courant** | N/A | 2.0 |
| **Minimum Courant** | N/A | 0.5 |
| **Number of steps below minimum before doubling** | N/A | 4 |
| **Maximum number of doubling base time step** | N/A | 4 |

| Computational Parameters | Diffusion Wave Plan | SWE-ELM Plan |
|---|---|---|
| **Maximum number of halving base time step** | N/A | 4 |
| **Output Interval** | 15 minutes | 15 minutes |
| **Theta** | 1.0 | 1.0 |
| **Theta Warmup** | 1.0 | 1.0 |
| **Water Surface Tolerance (ft)** | 0.01 | 0.01 |
| **Volume Tolerance (ft)** | 0.01 | 0.01 |
| **Maximum Iterations** | 20 | 50 |
| **Run Time (1% AC Event)** | 3 hours | 33 hours |

A WSE comparison raster was created using results from both analyses in Arc-GIS. This created a visual comparison of the difference in computed water surface elevations; the maximum difference was 9.3 feet, but the average delta was in the 0-0.5 foot range. The areas of greatest difference are concentrated on the upstream end of hydraulic structures and may be the result of backwater effects and complex hydraulics occurring at structures. SWE-ELM captures such interactions and transmits these impacts to adjacent cells, whereas Diffusion Wave analyzes each flow transfer between cells in a more isolated fashion, where influences are not propagated.

Based on the comparison analysis, the SWE-ELM equation set was selected as preferred option for all plans in the Choteau 2D model; and all results are based on this equation set.

#### 3.13.2.2 Tributary to Teton River 4 - 2D Model Development

A 2D model was developed encompassing the Tributary to Teton River – 4 (TTR_4) to assist in the development of the 1D regulatory model.

The mesh was comprised of uniform cell with an average spacing of 50 feet. Breaklines were used to force the placement of cell faces and increased cell density along distinct grade breaks (e.g., roadways, embankments, buildings, channels, etc.). Cell spacing along breaklines varied from 10 to 20 feet. No modifications were made to the TTR_4 channel due to a lack of bathymetric survey data and no surveyed structures lie within the 2D domain.

All flow hydrograph boundary conditions represented the 1% AC flood and held a constant discharge between the hours of 08:00 and 16:00. Discharge was held constant over the 8-hour period to represent steady-state conditions. The inflow condition was a flow hydrograph with a discharge of 1,090 cfs. There is one downstream boundary condition with a normal depth of 0.002.

## 3.14 Model Calibration

Calibration was evaluated on a case-by-case basis and was dependent on available data. Sources included USGS gage data, historical imagery, and anecdotal narratives. Calibration methodology details specific for applicable model reaches are discussed below.

### 3.14.1 Teton River – TR_1.1 Calibration

Calibration on the TR_1.1 model, the furthest downstream reach, was performed using data from USGS Gage 06108000 Teton River near Dutton, MT. Surveyed reference mark elevations were obtained from the survey study and used to calculate gage datum elevations. Four surveyed reference marks were surveyed at this gage and an average gage datum elevation of 3240.60 (NAVD88) was used in the calibration analysis. Historical flow data for the gage was obtained from USGS to determine flow and corresponding gage heights during past flood events.

USGS Gage 06108000 is at Latitude 47°55’49.17”, Longitude 111°33’10.59” located in Teton County, Montana. It has a drainage area of 1,238 square miles and 66 years of record from 1954 to 2022.

The measuring station is located approximately 250 feet upstream of bridge TET_030 on 20th Lane NE (see figure below).

**Figure 10 - Bridge TET_030 (20th Lane NE) Looking Downstream from Streamflow Measuring Station**

Various data points were obtained from the USGS gage for use in the calibration and the selected data covered a wide range of flows to determine the applicability and accuracy of the calibration. These flows were used as the steady flow input for the model; additional calibration calculations are included in Appendix K. With a known gage datum elevation, stage and discharge, the water surface elevation was determined at the cross section directly adjacent to the streamflow measuring station at river station 97183.

Manning’s values were assigned to the model cross sections using aerial imagery and subsequently adjusted to achieve calibration. Initially, all Manning’s values were adjusted by equal percentages (i.e., all values were dropped by 15%). After several trials, the overbank values were restored to their initial values, the channel was assigned a value of n=0.025 and calibration was achieved. See Table 21 for a summary of calibration flows and water surface elevations.

**Table 21 – Summary of Calibration Flows and Water Surface Elevations for Teton River - TR_1.1**

| USGS Gage 06108000 Teton River near Dutton MT | | | | |
|---|---|---|---|---|
| Flood Event | Discharge (cfs) | Apparent Gage Water Surface Elevation (ft) | Modeled Elevation (ft), RS 97183 | Difference (ft) |
| June 9, 1964 | 71,300 | 3,261.08 | 3,261.82 | 0.74 |
| June 20, 1975 | 16,000 | 3,255.40 | 3,255.88 | 0.48 |
| May 28, 2019 | 7,380 | 3,252.75 | 3,252.26 | -0.49 |

The 1% AC flow determined by the hydrology analysis closest to the gage is 26,800 cfs and the closest flow of 16,000 cfs from 1975 was selected as the primary calibration data point. While all events were considered in calibration, the 1964 event was so large in scale, that calibrating to that event would not be representative of the existing study flow values. On the other hand, while the 2019 event was most recent and therefore closest to the existing channel conditions, the flows were less than one third of the modeled 1% event and therefore again not reflective of modeled conditions.  However, knowing that minor obstructions to flow, represented through Manning's value, have less effect on the WSE as flow and depth increase, it was expected that modeling the larger event (the modeled 26,800 cfs) would show a higher WSE with the current land use, and therefore the 2019 event being 0.49 feet below the gage elevation was deemed appropriate and realistic. Bounded by both the 1975 event and the 2019 event, by less than 0.5 feet re-iterated a model geometry reflective of existing conditions, and calibration efforts on this reach were concluded.

Calibration results compared against USGS Gage measurements and the historic flood events used for calibration are presented in the figure below. All historic observations for the gage were plotted and a rating curve was included to illustrate the calibrated events compared to gage measurements.

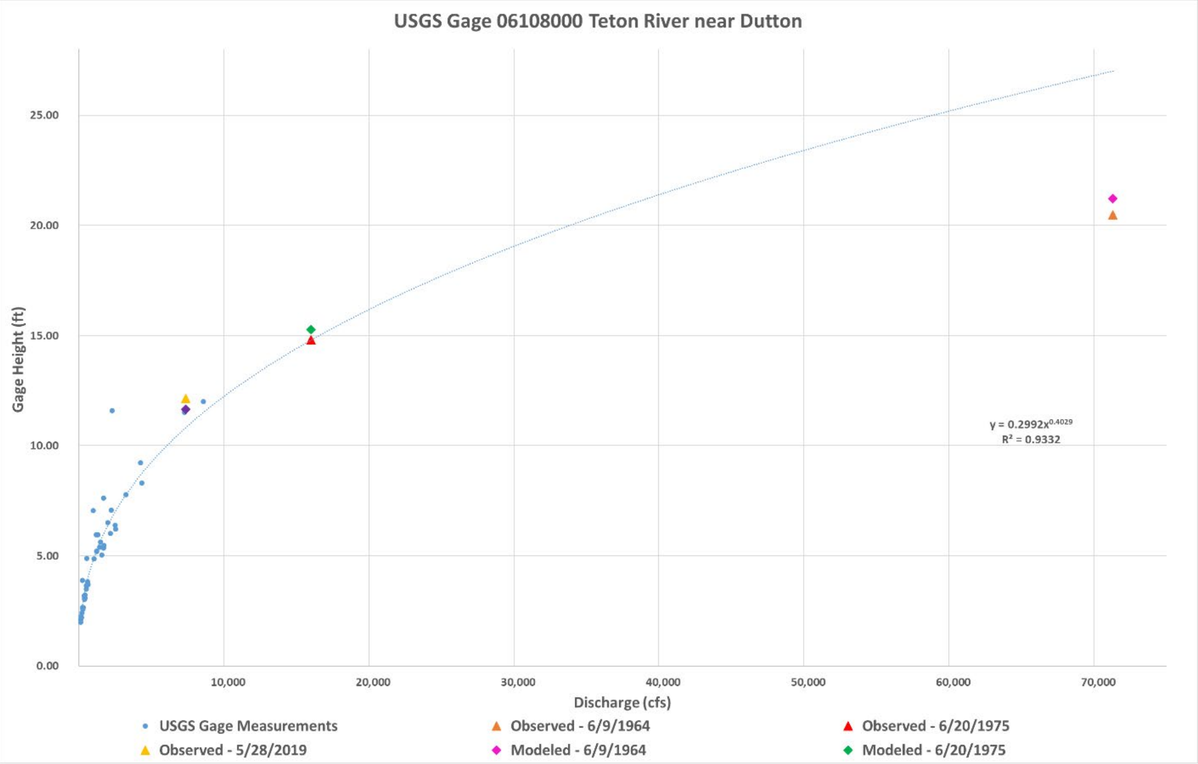


**Figure 11 – Recorded values, rating curve, and calibration results at USGS Gage 06108000, Teton River near Dutton**

### 3.14.2 Teton River – TR_1.2 Calibration

Calibration on the Teton River 1.2 model was performed using aerial imagery from 1975 provided by the Montana Department of Transportation (MDT). The main location of calibration is identified at the I-15 and Teton River intersection, at the downstream end of the TR_1.2 model. No gages are located within the TR_1.2 model, therefore a single gage transfer method was utilized to approximate flow in the area of interest; USGS Gage 06108000 Teton River near Dutton, MT was used for the gage transfer as it was the nearest gage to the location. Supplemental calibration calculations are included in Appendix K.

For the calibration process, a shapefile was created based on the 1975 flood inundation boundary. The Manning's 'n' values were then adjusted to try and replicate the inundation boundary in the calibration model (Figure 12). The channel 'n' value was reduced from 0.04 to 0.03 to and overbank 'n' values remained the same throughout the process.

It should be noted that at the time of the 1975 flood, the current 1-15 alignment did not exist. Instead, what is now the Frontage Road was, at the time, the interstate. Due to this discrepancy in the terrain and manmade features, the inundation boundaries do not entirely match near the existing interstate.

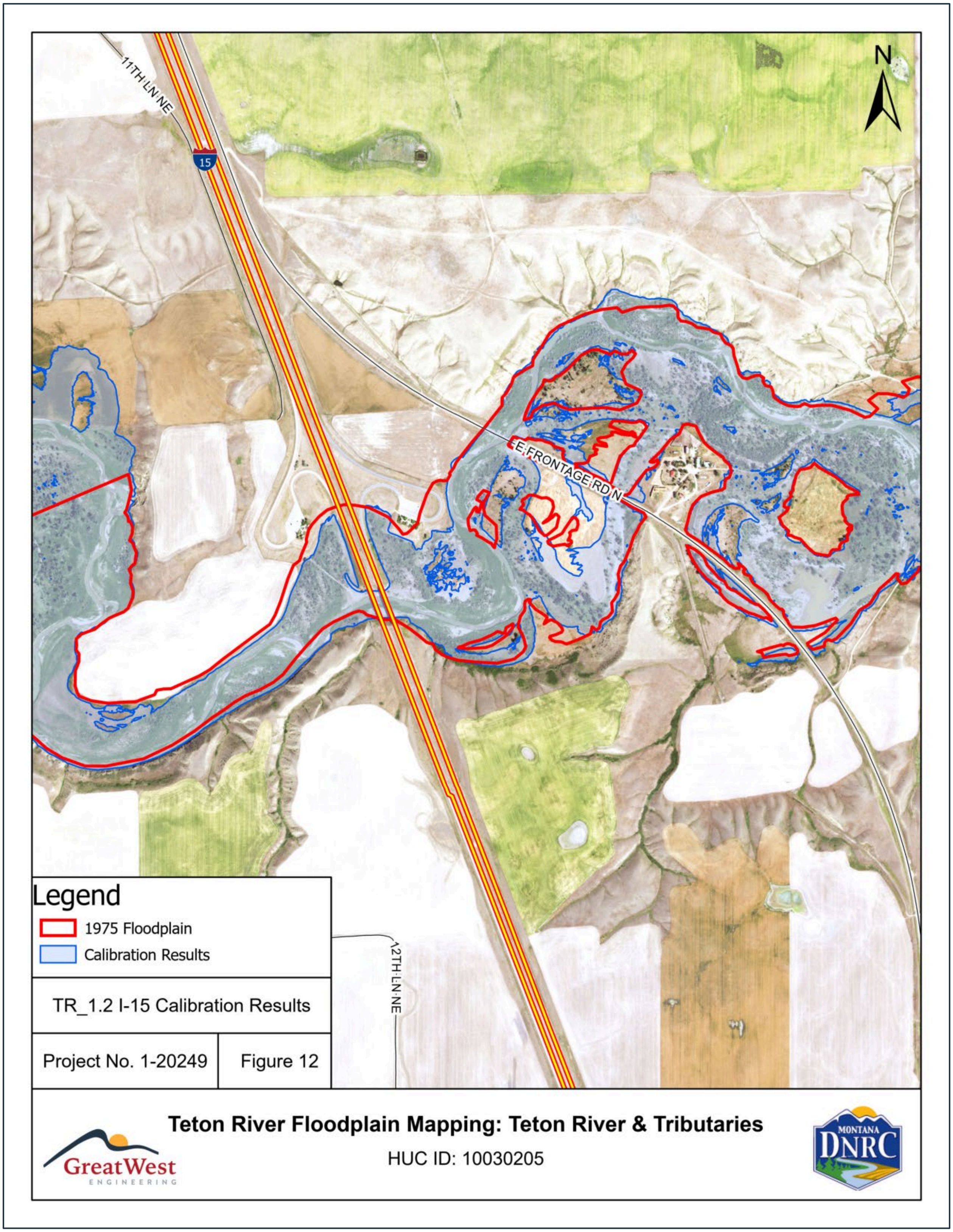


Figure 12 – Teton River – Reach 1.2 Calibration Results at I-15

### 3.14.3 Choteau 2D Calibration

The calibration along the 2D Choteau model, encompassing Teton River reaches 2 through 6 and all of Spring Creek, was evaluated with the best available data. Because of the history of flooding in the City of Choteau there were many photos available dating back to the 1964 flood through 2019. However, it should be noted Choteau is roughly 30 miles downstream of one gage, and 93 miles upstream of the only other gage in the study. Both gages are along Teton River, no gages exist on Spring Creek. Due to the distance, reliably accurate flow data in Choteau were not available to use for calibration. While exact flows are unknown, flooding can qualitatively be compared with historic flood photos shown below. Figures 13 and 14 show Choteau submerged by the 1964 event, which at the time was estimated by USGS to be a 200-year flood.

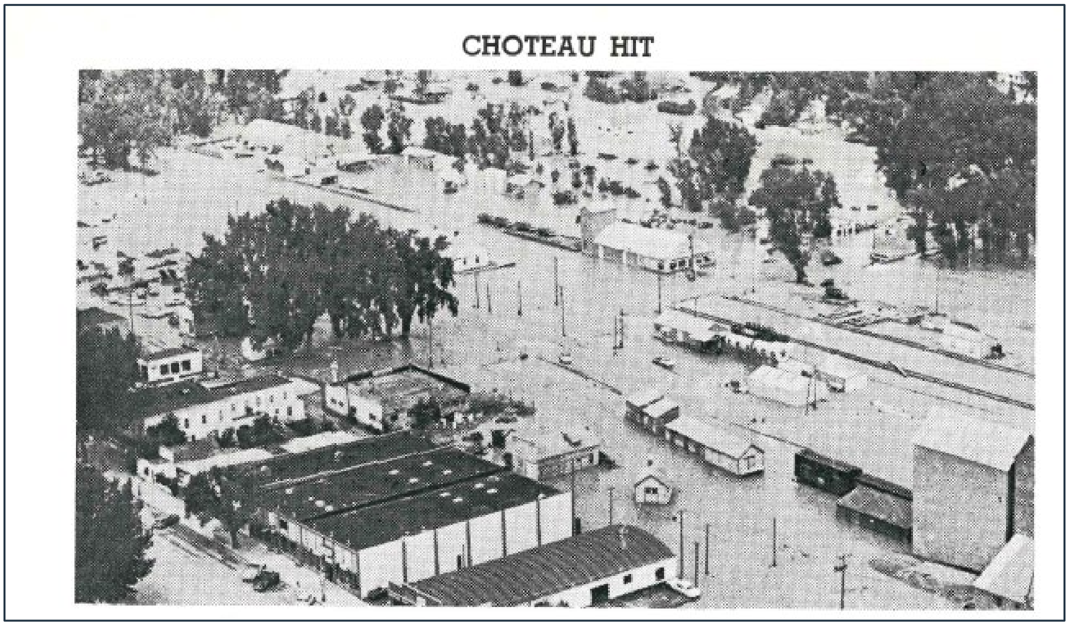


Figure 13 - Image from "1964 Flood" (Great Falls Tribune) showing flooding in downtown Choteau

Figure 14 – Flooding at 221 Main Ave N during the 1964 Flood

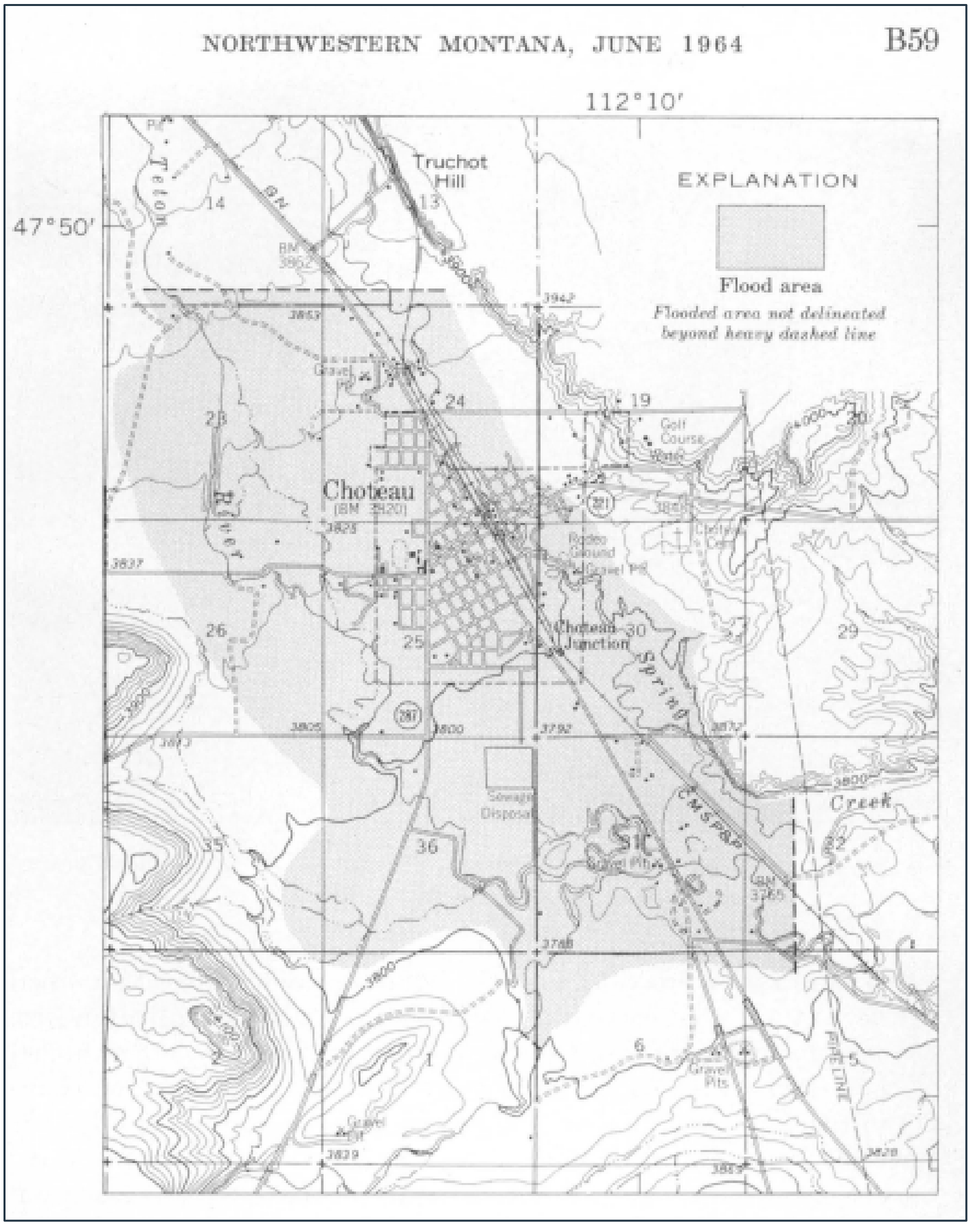


**Figure 15 - USGS estimated Flood Extents in Choteau (1964)**

Despite the distance to gages, calibration was still checked with the available data, using gage transfer, and comparing modeled flood extents to flood photos in the area. Specifically, the main location of calibration was done on the Teton River, approximately 3.5 miles north of Choteau along Highway 89. The 2011 flood is considered a low flow event for the Teton River, with the South Fork USGS Gage (06102500) recording an average daily flow of 1,270 cfs (located 30 miles upstream). Considering only flow from the Teton River, a single gage transfer method was used to approximate the flow at the area of interest. Supplemental calibration calculations are included in Appendix K. The 2D model results were validated by comparing the computed flood inundation extents to the 2011 flood photographs, showing in the figures below.

Figure 16 – 2D Calibration Results, Flooding on HWY 89, looking North

Figure 17 – Calibration results, flood comparison along HWY 89

### 3.14.4 Teton River – TR_7 2D Calibration

Calibration on the Teton River 7 (TR_7) and 8 (TR_8) reaches was performed using data from USGS Gage 06102500 Teton River below South Fork near Choteau, MT. Surveyed reference mark elevations were used to calculate gage datum elevations. Four reference marks were surveyed at this gage to obtain elevation, and field measurements were made to determine the height of the reference mark above the gage datum. These measurements were then subtracted from the surveyed elevations to calculate the gage datum. The average of the four calculated gage datum elevations using this method was 4,779.97 (NAVD88), and this value was used in the calibration analysis. Historical flow data at the gage site was obtained from USGS to determine flows and corresponding gage heights during past flood events.

USGS Gage 06102500 is located at Latitude 47°52’59.10”, Longitude 112°36’43.14” in Teton County, Montana. It has a drainage area of 110 square miles and years of record from 1947 to 2022. The streamflow gage is located on the upstream face of the Bellview Cutacross Road bridge, also often referred to as the South Fork Bridge (Structure ID: TET_0780). The gage is housed in a locked box adjacent to the bridge railing and the staff gage is anchored to the vertical concrete bridge abutment on river right.

Multiple data points were obtained from the USGS gage data for use as flow inputs for model calibration. The selected data covered a wide range of flows to assess the applicability and accuracy of the calibration. These data provided past flows and corresponding observed gage heights. In order to assess calibration in the 2D model, a profile line was drawn parallel to the bridge and in line with the gage location. This profile line was used to determine flows through Bridge TET_0780 at various time steps during the 2D model simulation. Time steps that correspond to the selected calibration flows were determined, and the profile line was used to determine the water surface elevations at these time steps.

Multiple iterations of Mannings ‘n’ adjustments were required to achieve adequate calibration for the model. After the initial Manning’s values were applied, the values were decreased by equal percentages in subsequent iterations until calibration was achieved. See Table 22 for a summary of calibration flows and water surface elevations. Additional calibration calculations are included in Appendix K.

**Figure 18 – Teton River at South Fork Bridge (Bellview Cutacross Road, TET_0780) in 2018 (source: Choteau Acantha)**

**Table 22 – Teton River – TR_ 7 2D Calibration Results**

| USGS Gage 06102500 Teton River below South Fork near Choteau, MT | | | | |
|---|---|---|---|---|
| Flood Event | Discharge (cfs) | Apparent Gage Water Surface Elevation (ft) | Modeled Elevation (ft), TET_0780 | Difference (ft) |
| May 27, 2019 | 3,560 | 4787.26 | 4786.67 | -0.59 |
| June 19, 2018 | 4,680 | 4787.66 | 4787.61 | -0.05 |

Calibration results compared against USGS Gage measurements and the historic flood events used for calibration are presented in the figure below. All historic observations for the gage were plotted and a rating curve was included to illustrate the calibrated events compared to gage measurements.

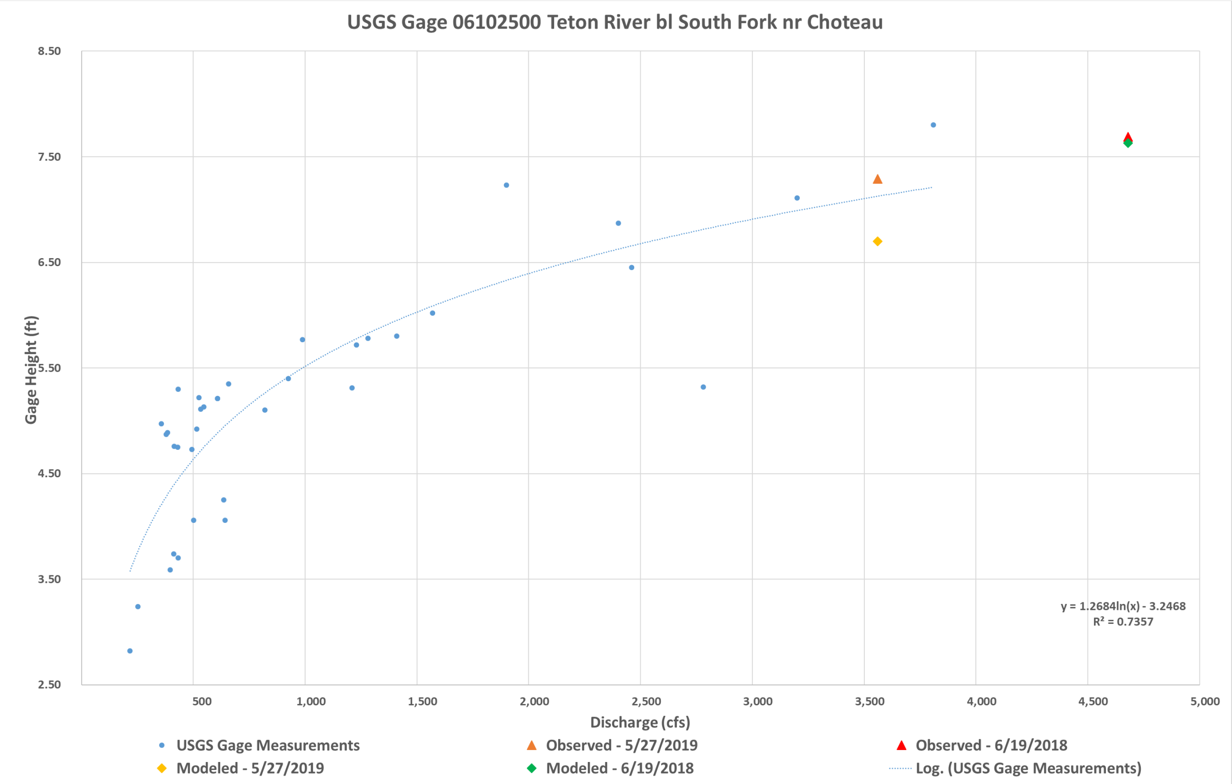


**Figure 19 – Recorded values, rating curve, and calibration results at USGS Gage 06102500, Teton River bl South Fork**

## 3.15 Floodway Modeling

Floodway analysis was performed for reaches with designated study type “Enhanced with Floodway” listed in Table 1 using the maximum allowable surcharge of 0.5 feet as required by the State of Montana. Encroachment Method 4 with equal conveyance was used to establish an initial floodway through each reach, followed by Method 1 to manually adjust encroachment stations and finalize the floodway extents. Each floodway extent was mapped in RASMapper and exported to ArcMap for final smoothing.

The only floodway extents analyzed in this study match existing extents and are along Teton River and Spring Creek near Choteau. While Spring Creek is its own flood source, Teton River flooding overtops Highway 89, and enters into Spring Creek exceeding any flooding generated in Spring Creek alone. This complex scenario is described in more detail in Sections 3.13.1.2 and 3.16.3, but in summary, Spring Creek behaves similarly to a split of Teton River beginning north of Choteau. With this in mind, a floodway would not be necessary on the ‘split’ or in this scenario, Spring Creek, if the full 1% event could be contained in the Teton River Floodway. However, Spring Creek has an effective floodway and therefore needs an updated floodway analysis as part of the study. After preliminary modeling, it was determined that the full 1% event could not be contained in the Teton River floodway alone, and therefore, the diverted Teton River flows would need to be factored into the Spring Creek floodway analysis. For further documentation of these decisions refer to the Technical Memo prepared by Great West Engineering, included in Appendix K.

## 3.16 Stream Specific Modeling Details

Models with unique modeling situations requiring further explanation are detailed below.

## 3.16.1 Teton River Mainstem

Teton River mainstem was initially split into eight reaches. Through the modeling process some reaches were divided into sub-reaches and others were combined into larger models. The sections below discuss the modeling methodologies employed along the Teton River mainstem.

### 3.16.1.1 Teton River - Reach 1 (TR_1)

As previously mentioned, this reach was divided into three sub-reaches for ease of modeling distribution. A preliminary 2D hydraulic model of TR_1 provided water surface contour lines that were used in the development of the 1D cross sections. Following the contour lines provided more accurate water surface elevation results in the 1D models. By following the contours, some cross sections are not oriented perpendicular to the floodplain but are oriented to be perpendicular to the flow direction to more accurately model the river hydraulics. Cross section adjustment and deviation from water surface contour lines were made using engineering judgement. Several cross sections have channel Manning's 'n' values that are higher or lower than the calibrated values in each sub-reach. This was necessary to resolve critical depths and crossing profiles within the model. After these edits, the models were verified to ensure they were still within calibration.

### 3.16.1.2 Teton River - Reaches 2 – 6 (TR_Choteau)

Starting just north of Choteau, Teton River reaches 2 through 6 spans (TR_Choteau) approximately 14 miles, paralleling Highway 89 to the west and ending at its confluence with Spring Creek, three miles downstream of Choteau.

Initially, only reach 2 was proposed as a 2D model, which provides a higher level of detail to inform the 1D study area. However, due to the proximity of Spring Creek and historic precedence, a larger 2D model was created encompassing TR reaches 2 through 6 and all of Spring Creek, see Section 3.13.2.1 for further details on the 2D model development.

Cross section orientation was determined using WSE contours for the 1% AC provided by the TR_Choteau 2D model. The contour lines provided more accurate water surface elevations in the 1D model and assisted in the identification of split flows as well as the comparison between the 1D and 2D models. Due to following contours, some cross sections are not oriented perpendicular to the floodplain but are perpendicular to the flow direction as indicated by the 2D model. Cross section adjustment and deviation from WSE contour lines were made using engineering judgement. Some structures were not modeled due to their lack of hydraulic impact at the 1% AC event and because the 1D results more closely matched the 2D results without the structures modeled, see Table 12 for a full list of structures not modeled.

From the 2D 1% AC WSE contours, it was determined that there is an overflow split from the Teton River, spilling into the City of Choteau. Initially, the flows spill into the flat, urban setting of Choteau exhibiting very different flow characteristics to the flows which remained in Teton. The flows across Choteau result in shallow flooding and is best represented with the 2D model results. Once downstream of the City, the split becomes channelized and is modeled using a 1D model that joins back to Teton River. Flows creating the split were determined using the results from the Choteau 2D model.

From the 2D analysis it was determined that there is a significant portion of floodwaters that exit the main channel and enter into Spring Creek. Teton River initially overtops HWY 89 north of Choteau, losing approximately one-third of its total flow, as waters continue to flow down Spring Creek, see Section 3.16.3 for further details on the Teton River HWY 89 Split. Due to the interaction between the two flood sources, flows were evaluated using 2D monitoring lines along the length of HWY 89 and other key areas. Using the monitoring line results, the flow data in the 1D model was adjusted and hardcoded for the flow loss, see Table 23 for TR_Choteau flow data. Significant flows leaving Teton River by overtopping are displayed in Figure 19, and all flows extracted by monitoring lines are included in Appendix K.

**Table 23 – Teton River - TR_Choteau Flow Data**

| Flow Change Location | | | Profile Names and Flow Rates | | | | | |
|---|---|---|---|---|---|---|---|---|
| **River** | **Reach** | **RS** | **10% Annual Chance** | **4% Annual Chance** | **2% Annual Chance** | **1% Annual Chance** | **0.2% Annual Chance** | **1%+ Annual Chance** |
| **Teton River** | **TR_Choteau _US** | **522262** | 4,640 | 9,250 | 15,000 | 23,700 | 50,100 | 65,200 |
| **Teton River** | **TR_Choteau _US** | **512658** | 4,640 | 9,132 | 14,444 | 21,666 | 38,333 | 45,755 |
| **Teton River** | **TR_Choteau _US** | **510514** | 4,640 | 9,132 | 14,446 | 21,631 | 37,433 | 44,268 |
| **Teton River** | **TR_Choteau _US** | **507912** | 4,640 | 9,068 | 13,087 | 17,792 | 28,375 | 32,954 |
| **Teton River** | **TR_Choteau _US** | **503836** | 4,640 | 8,697 | 12,115 | 15,760 | 23,163 | 26,199 |
| **Teton River** | **TR_Choteau _US** | **502933** | 4,640 | 8,517 | 11,739 | 15,127 | 22,194 | 25,190 |
| **Teton River** | **TR_Choteau _US** | **500505** | 4,640 | 8,511 | 12,009 | 15,871 | 24,808 | 29,261 |
| **Teton River** | **TR_Choteau _US** | **499900** | 4,640 | 8,511 | 11,906 | 15,295 | 22,584 | 26,490 |
| **Teton River** | **TR_Choteau _US** | **497981** | 4,640 | 8,514 | 12,004 | 15,652 | 24,268 | 29,696 |
| **Teton River** | **TR_Choteau _US** | **493452** | 4,640 | 8,514 | 12,004 | 15,664 | 27,217 | 35,611 |
| **Teton River** | **TR_Choteau _US** | **486211** | 4,335 | 7,702 | 10,605 | 13,740 | 23,171 | 30,242 |
| **Teton River** | **TR_Choteau _US** | **483960** | 4,274 | 7,488 | 10,220 | 13,220 | 22,023 | 28,555 |
| **Teton River** | **TR_Choteau _US** | **483137** | 4,274 | 7,488 | 10,220 | 13,220 | 20,926 | 26,176 |
| **Teton River** | **TR_Choteau _US** | **480134** | 4,274 | 7,488 | 10,206 | 13,030 | 20,361 | 25,399 |
| **Teton River** | **TR_Choteau _DS** | **477212** | 4,640 | 8,464 | 12,038 | 16,065 | 28,487 | 37,134 |
| **Teton River** | **TR_Choteau _DS** | **470259** | 4,670 | 8,814 | 12,838 | 17,565 | 27,244 | 34,843 |
| **Teton River** | **TR_Choteau _DS** | **465256** | 4,670 | 8,392 | 11,855 | 15,932 | 24,446 | 28,121 |
| **Teton River** | **TR_Choteau _DS** | **462458** | 3,845 | 5,828 | 7,853 | 10,199 | 13,139 | 15,114 |
| **Teton River** | **TR_Choteau _DS** | **460832** | 3,845 | 5,823 | 7,776 | 9,880 | 11,644 | 13,394 |
| **Teton River** | **TR_Choteau _DS** | **458499** | 3,843 | 5,795 | 7,721 | 9,781 | 11,464 | 13,187 |
| **Teton River** | **TR_Choteau _DS** | **457077** | 3,845 | 5,838 | 7,894 | 10,224 | 13,691 | 15,749 |
| **Teton River** | **TR_Choteau _DS** | **453844** | 3,845 | 5,838 | 7,892 | 10,207 | 14,145 | 16,272 |
| **Teton River** | **TR_Choteau _DS** | **452478** | 3,844 | 5,818 | 7,848 | 10,286 | 15,233 | 17,523 |
| **Teton River** | **TR_Choteau _DS** | **451575** | 4,670 | 9,600 | 15,800 | 25,200 | 49,400 | 69,700 |
| **Teton River** | **TR_Choteau _DS** | **449224** | 4,680 | 9,620 | 15,800 | 25,300 | 49,400 | 70,000 |
| **Teton River Overflow** | **Reach_1** | **5827** | 366 | 1,026 | 1,882 | 2,867 | 6,976 | 9,425 |
| **Teton River Overflow** | **Reach_1** | **4369** | 366 | 1,026 | 1,882 | 2,867 | 8,074 | 11,804 |
| **Teton River Overflow** | **Reach_1** | **1952** | 366 | 976 | 1,832 | 3,035 | 8,126 | 11,735 |

Notes:

[1] Flows were determined from the Choteau 2D model, see Section 3.13.2.1 for additional information about 2D model

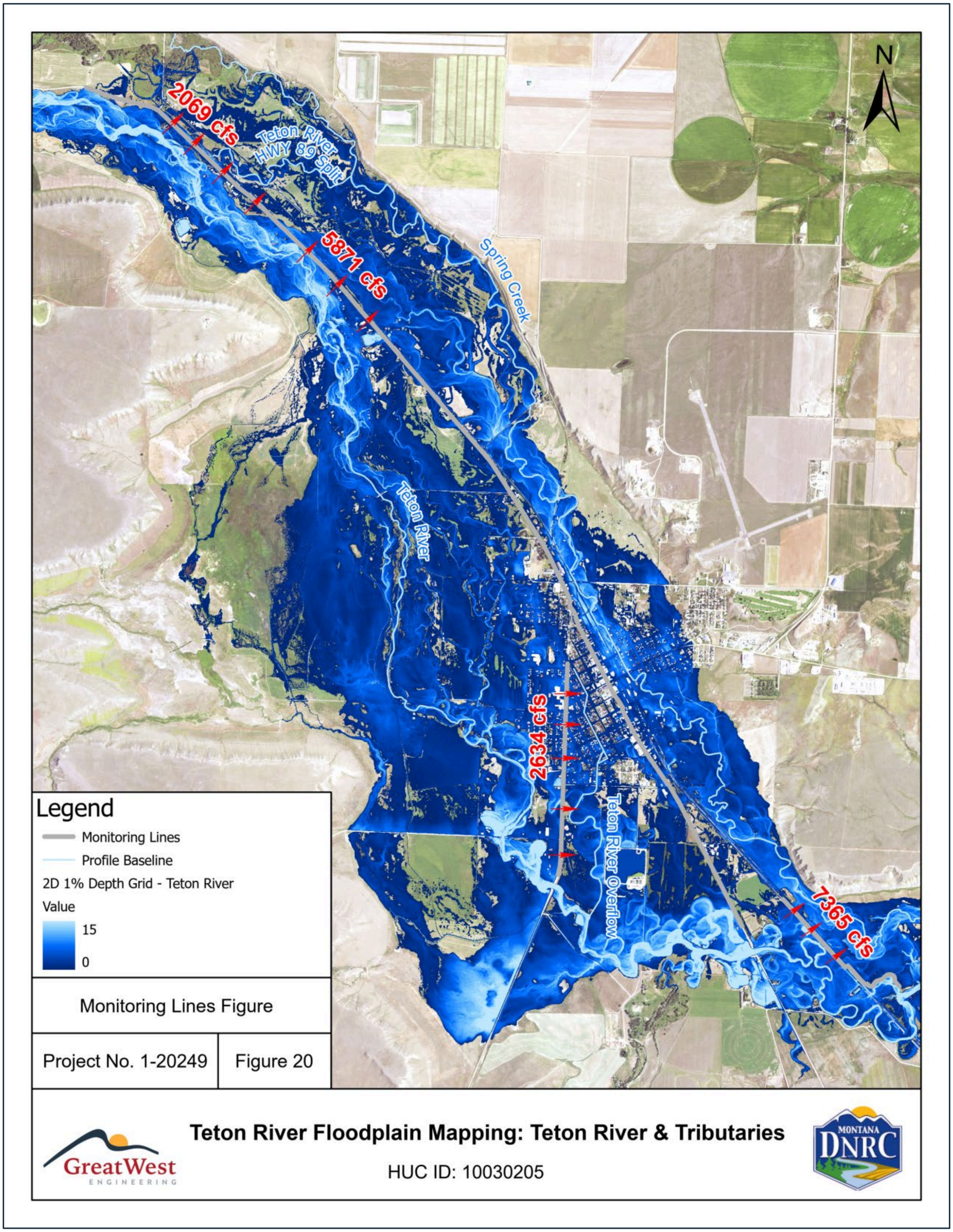


**Figure 20 – Teton River - Monitoring Line Placement and Flows**

## 3.16.2 Teton River Long Tributaries

Long tributaries to Teton River were designated as streamlines greater than 1.5 miles in length.

### 3.16.2.1 Flat Coulee (FLC_1)

Flat Coulee is approximately 6.5 miles long and joins Teton River close to the downstream study limit, just three miles upstream of the county boundary. Throughout the reach, flows are fairly channelized until close to the confluence, where the flows begin to spill out of Flat Coulee on the right bank, flowing across the floodplain, until eventually joining Teton River, upstream of the actual confluence. The flows leaving Flat Coulee were quantified using a lateral structure and modeled in HEC-RAS 5.0.7. Using the results, the flow data in the regulatory HEC-RAS 6.0.1 model were adjusted for the flow loss, and hardcoded. The 5.0.7 version of the model is included in the Supplemental Data folder as part of submittal.

### 3.16.2.2 Middle North Fork Teton River (MNFTR_1)

Middle North Fork Teton River is a tributary to North Fork Teton River and flows through a well-defined, densely wooded drainage. The floodplain is relatively channelized until the confluence and the reach is fairly steep. Due to the steep gradient and to account for changes in flow profiles, this model was run using mixed flow regime. This allows the model to more accurately calculate the flow scenario and account for changes and hydraulic jumps throughout the reach.

## 3.16.3 Spring Creek – Reaches 1 – 4 (SPC_Choteau)

Starting just north of Choteau, Spring Creek (SPC_Choteau) spans approximately 14 miles, paralleling HWY 89 to the east and ending at its confluence with Teton River, three miles downstream of Choteau.

Initially, only reaches 1 and 5 were scoped to have a 2D model, which provides a higher level of detail to inform the 1D study area. However, due to the proximity of Teton River and historic precedence of Teton River overflows, a large 2D model was developed encompassing all of Spring Creek and Teton River reaches two through six, see Section 3.13.2.1 and 3.13.2.2 for further details on the 2D model development.

As described in Section 3.16.1.2, flows from Teton River overtop Highway 89 and occupy the Spring Creek drainage. A comparison analysis was completed to determine if/when Teton River 1% AC water surface elevations surpassed those that originate in Spring Creek. The analysis was completed using the 2D modeling results from both the Teton River, and Spring Creek. It was determined that at Spring Creek station 54181 the Teton River flows supersede Spring Creek flows at the 1% AC event; for lower flood events, this point occurs further downstream. Therefore, downstream of RS 54181, all flows are based on the diverted Teton River flows, replacing the Spring Creek hydrology which governs upstream of this point. The initial overflow is modeled as a split, allowing the diverted Teton River flows to enter Spring Creek. This split, known as the Teton River Highway 89 Split, was determined using the Choteau 2D depth grid and the 1% AC WSE contours. The split totals 1.3 miles in length and ends at its confluence with Spring Creek at RS 54181. The split is also a physical representation of the overflows from Teton replacing the hydrology from Spring Creek. The cross sections downstream of 54181 span the entire area from Highway 89 to Spring Creek allowing all additional overflows overtopping the highway from Teton River to be accounted for. About 0.5 miles downstream of the Teton River Highway 89 Split, there is an additional area with significant overtopping of the highway shown in the depth grid in Figure 21, which continues downstream and joins Spring Creek at Truchot Rd. These additional flows are accounted for with a flow change but were not modeled as an individual split. Based on the 1% WSE contours from the 2D model, it was determined that the water surface elevations for the overbank flow, caused by HWY 89 overtopping and for Spring Creek, matched within a 0.5 foot tolerance. Therefore, it was determined that this area was best represented with long cross sections without adding a new split; the addition of a split would add unnecessary complexity to the model and was not warranted.

A table with the flow data and a visual representation of the flow exchange can be seen below. Additional figures detailing flow interactions between Teton River and Spring Creek can be found in Appendix K.

**Table 24 – Spring Creek – SPC Choteau Flow Data**

| Flow Change Location | | | Profile Names and Flow Rates | | | | | |
|---|---|---|---|---|---|---|---|---|
| **River** | **Reach** | **RS** | **10% Annual Chance** | **4% Annual Chance** | **2% Annual Chance** | **1% Annual Chance** | **0.2% Annual Chance** | **1%+ Annual Chance** |
| **Spring Creek** | **SC_US** | **63057** | 168 | 311 | 455 | 627 | 1,040 | 1,230 |
| **Spring Creek** | **SC_US** | **60135** | 173 | 321 | 471 | 649 | 1,080 | 1,280 |
| **Teton River HWY 89 Split** | **Reach_1** | **6813** | 1[1] | 118 | 556 | 2,034 | 11,767 | 19,445 |
| **Teton River HWY 89 Split** | **Reach_1** | **4057** | 1[1] | 118 | 554 | 2,069 | 12,667 | 20,932 |
| **Teton River HWY 89 Split** | **Reach_1** | **141** | 1[1] | 182 | 1913 | 5,908 | 21,725 | 32,246 |
| **Spring Creek** | **SC_DS** | **54181** | 173 | 553 | 1,913 | 5,908 | 21,725 | 32,246 |
| **Spring Creek** | **SC_DS** | **47236** | 173 | 553 | 2,885 | 7,940 | 26,937 | 39,001 |
| **Spring Creek** | **SC_DS** | **45053** | 173 | 733 | 3,261 | 8,573 | 27,906 | 40,010 |
| **Spring Creek** | **SC_DS** | **41468** | 173 | 739 | 2,991 | 7,829 | 25,292 | 35,939 |
| **Spring Creek** | **SC_DS** | **40572** | 173 | 739 | 3,094 | 8,405 | 27,516 | 38,710 |
| **Spring Creek** | **SC_DS** | **35900** | 173 | 736 | 2,996 | 8,048 | 25,832 | 35,505 |
| **Spring Creek** | **SC_DS** | **31022** | 173 | 736 | 2,996 | 8,036 | 22,883 | 29,589 |
| **Spring Creek** | **SC_DS** | **27982** | 173 | 736 | 2,996 | 7,941 | 22,061 | 28,499 |
| **Spring Creek** | **SC_DS** | **26277** | 173 | 736 | 2,996 | 7,898 | 21,703 | 27,999 |
| **Spring Creek** | **SC_DS** | **22951** | 173 | 736 | 2,898 | 7,613 | 21,100 | 27,220 |
| **Spring Creek** | **SC_DS** | **19841** | 173 | 786 | 2,962 | 7,635 | 21,613 | 28,066 |
| **Spring Creek** | **SC_DS** | **12890** | 173 | 786 | 2,962 | 7,635 | 22,156 | 34,857 |
| **Spring Creek** | **SC_DS** | **11372** | 173 | 1,208 | 3,945 | 9,268 | 24,954 | 41,579 |
| **Spring Creek** | **SC_DS** | **10040** | 825 | 3,772 | 7,947 | 15,001 | 36,261 | 58,334 |
| **Spring Creek** | **SC_DS** | **9453** | 825 | 3,777 | 8,024 | 15,320 | 37,756 | 61,134 |
| **Spring Creek** | **SC_DS** | **8042** | 827 | 3,805 | 8,079 | 15,419 | 37,936 | 60,788 |
| **Spring Creek** | **SC_DS** | **7016** | 825 | 3,762 | 7,906 | 14,976 | 35,709 | 57,829 |
| **Spring Creek** | **SC_DS** | **4509** | 825 | 3,762 | 7,908 | 14,993 | 35,255 | 56,757 |
| **Spring Creek** | **SC_DS** | **3546** | 826 | 3782 | 7952 | 14,914 | 34,167 | 55,080 |

Notes:

[1] No overtopping occurs from the Teton River at the 10% AC event. For model stability, 1 cfs was added to the split flow.

[2] Flows were determined from the Choteau 2D model, see Section 3.13.2.1 for additional information about 2D model.

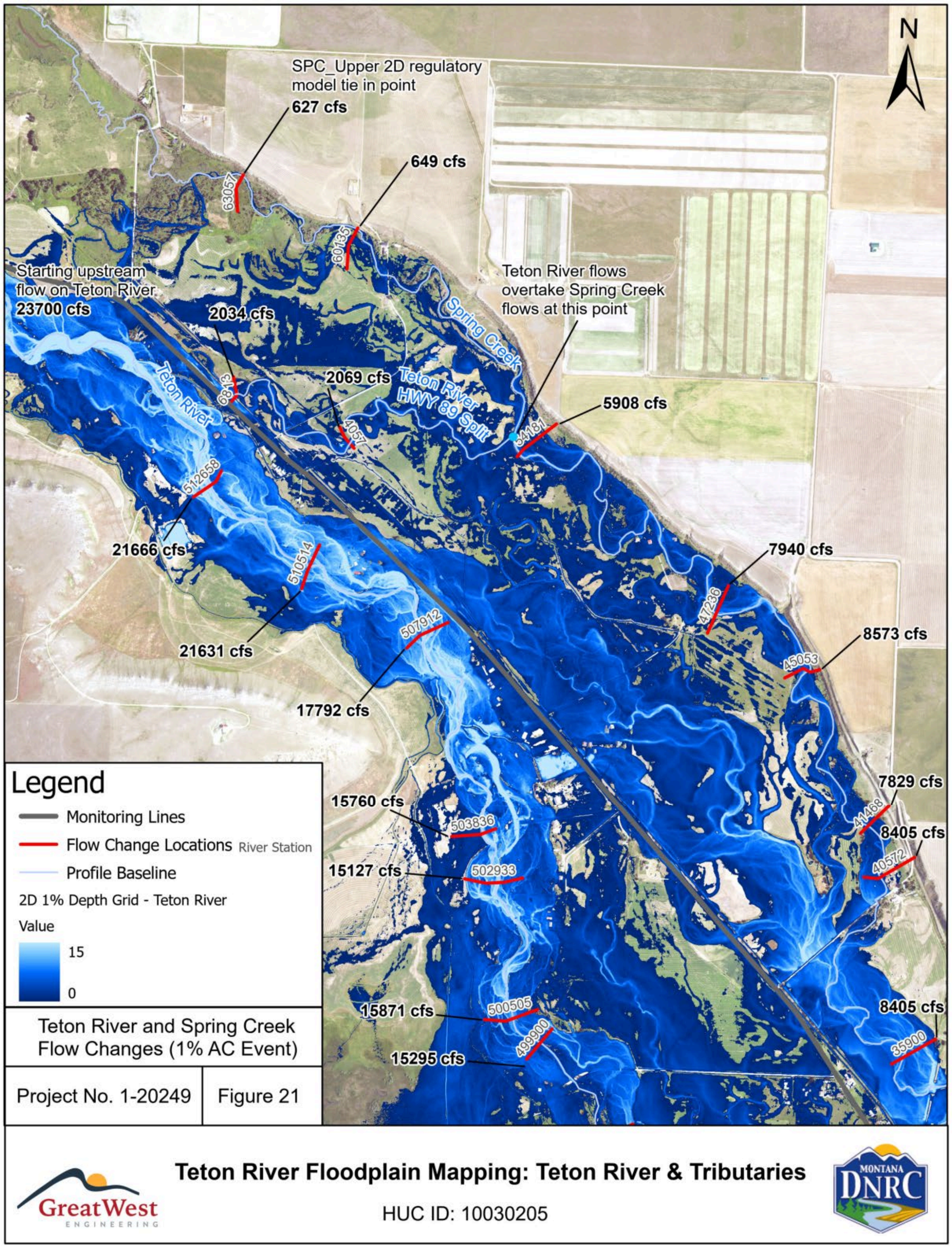


**Figure 21 - Teton River and Spring Creek Flow Changes**

Cross section orientation was determined using WSE contours provided by the Spring Creek 2D model and the Choteau 2D model. Upstream of the Teton River HWY 89 Split, cross sections are based on the Spring Creek 2D model, and downstream of the split cross sections reference the Choteau 2D model. The contour lines provided more accurate water surface elevations in the 1D model and assisted in the identification of split flows. Due to following contours, some cross sections are not oriented perpendicular to the floodplain but are perpendicular to the flow direction as indicated by the 2D model. Cross section adjustment and deviation from WSE contour lines were made using engineering judgement.

### 3.16.4 Teton River Short Tributaries

Short tributaries to Teton River were designated as streamlines under 1.5 miles in length.

#### 3.16.4.1 Tributary to Teton River – 4

The 2D model developed for TTR_4 drove streamline revisions including adjusting the tie-in location with Teton River. Cross sections were also drawn based on 2D water surface elevation contours to model flow patterns accurately. After preliminary model development, water surface elevations were compared to water surfaces from the TR_7 reach to evaluate backwater impacts on the tributary and to identify where water surfaces on the tributary are overtaken and influenced by the mainstem of Teton River. Resulting water surface elevations from the 1D model were then compared to the 2D water surface elevations. In general, elevations from the 1D model were within 0.5-feet of the 2D model.

# 4.0 Flood Insurance Study Products

Flood Insurance Study products provided with this analysis are the floodway data tables and flood profiles. These products were developed using RASPLOT Version 3.0, which extracts the hydraulic results from the HEC-RAS analysis and creates database for each stream modeled. All hydraulic values listed in the created Microsoft Access database were verified against the HEC-RAS data and were manually edited to correct if necessary. Floodway data tables were automatically created from the database and exported using RASPLOT. Similarly, flood profiles were automatically created from data at each flood event and, once user inputs to plot extents and labels were entered, RASPLOT exported the profile information to DXF files. The DXF files were reviewed and placement of labels were adjusted (if necessary) before exporting to PDF.

For the Mapping submittal, flood profiles were revised where necessary to account for backwater effects from other flood sources. Backwater elevations and influenced extents were reflected on the profile and labeled where applicable. Preliminary flood profiles for the 2D models were also developed in a similar manner, plotting water surface elevations along the profile baseline provided during preliminary hydraulic scoping. This profile baseline also followed the main flow path of the 2D model, and water surface elevations were extracted from the 2D grids at noted locations (average spacing of 5-feet along baseline) to identify data used for input into the RASPLOT interface. Structure data and crossing locations were also displayed along these 2D profiles.

# 5.0 Floodplain Mapping

Based on the results from each hydraulic model, the floodway (as applicable), 1% AC and 0.2% AC flood boundaries were delineated using RASMapper. For the hydraulic submittal, each of the outputs were included in the spatial data and on the draft WorkMaps. As part of the Floodplain Mapping task, these floodplain boundaries were further refined using smoothing technology within ArcPro, along with manual changes as necessary to best reflect realistic conditions.

The following programs were used in the development of the floodplain mapping deliverables:

- Environmental Systems Research Institute (ESRI) ArcMap Version 10.8
- ESRI ArcPro
- Hydrologic Engineering Center – River Analysis System (HEC-RAS) Version 6.1 (Floodplain/Floodway Models)
- RASPLOT Version 3.0

## 5.1 Floodplain Mapping Methodology

The 1% AC and 0.2% AC floodplain elevations were computed by the HEC-RAS models at each cross section. Initial floodplains were generated with the RASMapper program within HECRAS. Then each floodplain was exported as a shapefile and further refined using editing tools in ArcPro. The following steps were used to smooth, clean, and combine the floodplain polygons:

- The 'eliminate polygon part' tool was used to remove all polygons within each boundary with less than a total area of 15,625 square feet.
- The smoothing tool in advanced editing was used with a 25-foot tolerance to smooth the polygons.
- Islands were removed based on best practices and engineering judgement.
- Backwater areas were evaluated based on the modeled water surface elevation at each cross section and adjusted to match realistic conditions.

The 1 percent annual-chance flood risk areas were attributed as Zone AE. The 0.2 percent annual-chance floodplains or any areas designated as shallow flooding were attributed as Zone X. At this time, no areas were designated as Zone AO.

Like the floodplains, the floodway polygons were initially generated in RASMapper and then smoothed in ArcPRO. The polygons were then reviewed to ensure that the polygon correctly delineated the floodway based on the placement of the encroachment stations at each cross section. In between cross sections, the floodway is based on the model output, topography, or engineering judgment.

## 5.2 Floodplain Refinement

Within each hydraulic model, there are inherent limitations to the results produced by RASmapper. For example, the floodplain is cutoff at the boundary created by the limits of each cross section. Although usually avoided within modeling, if the floodplain in actuality extends past the cross sections, those boundaries can only be created manually based on topography and channel characteristics. Similarly, where monitoring lines were used for split flows, the mapping is cut off at each cross section and may require the area to be manually adjusted based on the modeling.

### 5.2.1 Mapping Supplemented by 2D Results

There can be limitations to mapping with 1D models as the only results exist within the boundary of the cross sections. Therefore, in the case of the Choteau modeling area, any deficiencies in the 1D mapping results were supplemented with the 2D model. In general, the only mapped areas supplemented by the 2D model are Zone X. The results were referenced as needed to connect the floodplain between the 1D models TR_Choteau and SPC_Choteau as well as to connect the 2D regulatory model: SPC_Upper. The final floodplain was delineated manually using the Choteau 2D results including inundation boundaries, and depth grids for the 1% and 0.2% AC results. Flood depths less than 0.5 feet were filtered out of the grid, and only those depths above 0.5 feet were considered for the manual delineation.

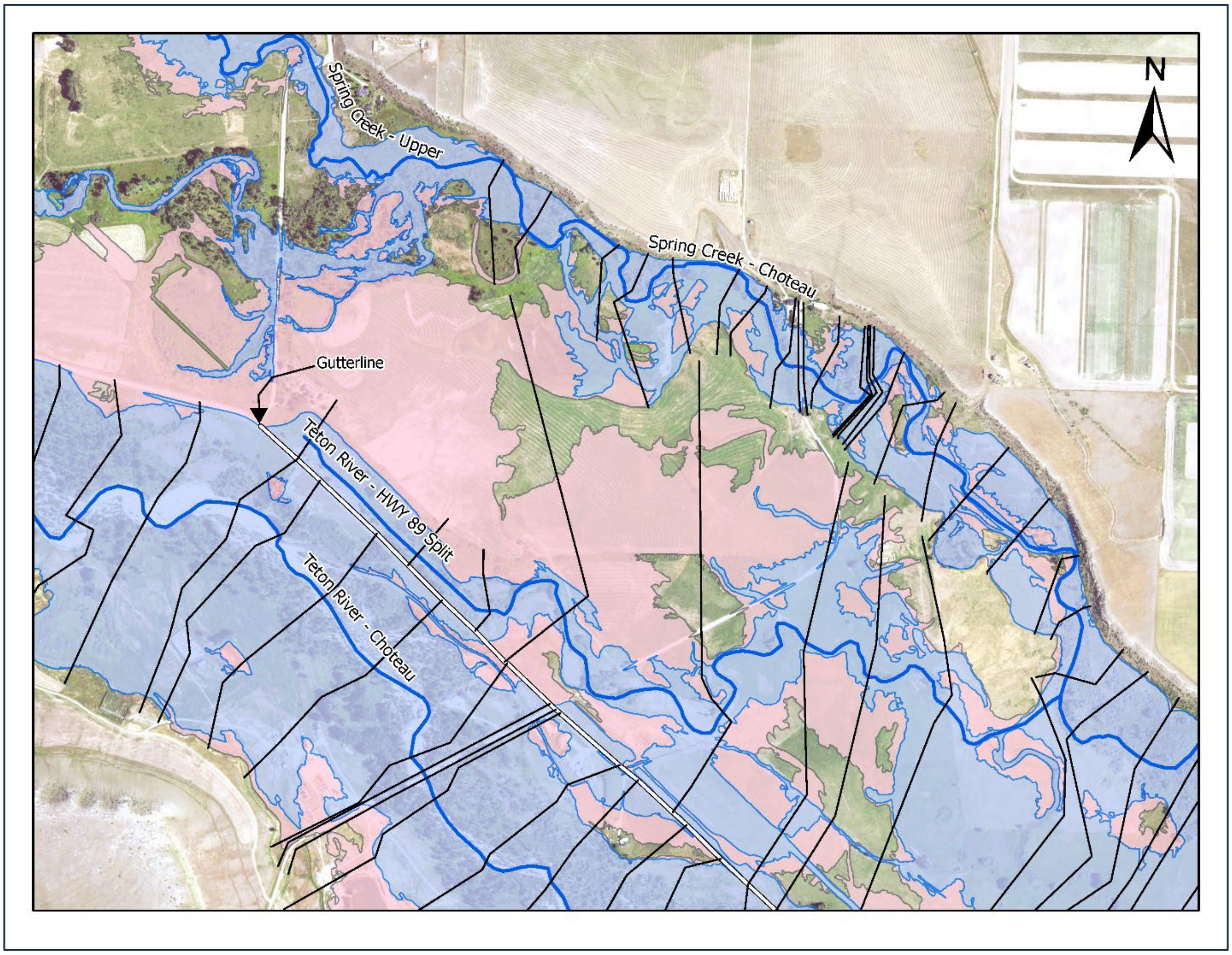


Figure 22 – Tie-In Location Between TR_Choteau, SPC_Choteau, and SPC_Upper_2D

The supplemental 2D model was also used at the tie in between TR_Choteau and the Teton River Overflow. Due to cross section orientation, some areas of the floodplain between the two reaches were cut off and missing. The deficiencies from the 1D mapping were filled in using the 2D inundation boundary and engineering judgement.

## 5.2.2 Stream Specific Mapping Details

Models with unique mapping situations requiring further explanation are detailed below.

### 5.2.2.1 Teton River & Spring Creek Through Choteau

TR_Choteau and SPC_Choteau are two individual 1D models which are informed by data from the 2D model including flow exchanges, flood depths, etc. For further details on modeling methodologies refer to Section 3.16.1.2. Due to the cross sections of both models terminating at the highway, the raw mapping results did not present a complete picture of the relationship between the Teton River and Spring Creek. Multiple datasets were utilized to determine the locations of overtopping and the extent in which it impacts the floodplain, such as, 1D modeling results, 2D modeling results, and terrain data.

As previously discussed in Section 3.16.1.2, the upstream portion of the Teton River Overflow, a split of Teton River found in the Choteau model, is best represented using the 2D modeled results as the flood waters occupy the flat, urban setting in downtown Choteau. The 1% AC flooding within this area has an average depth of less than one foot and no discernible flow path or stream centerline; therefore, the flooding within this area is best characterized as Shallow flooding, and represented with a Zone X. Depth grid from the 2D model is shown in Figure 23 below, as well as the border of the shallow flooding, which is bounded by 1D modeling data.

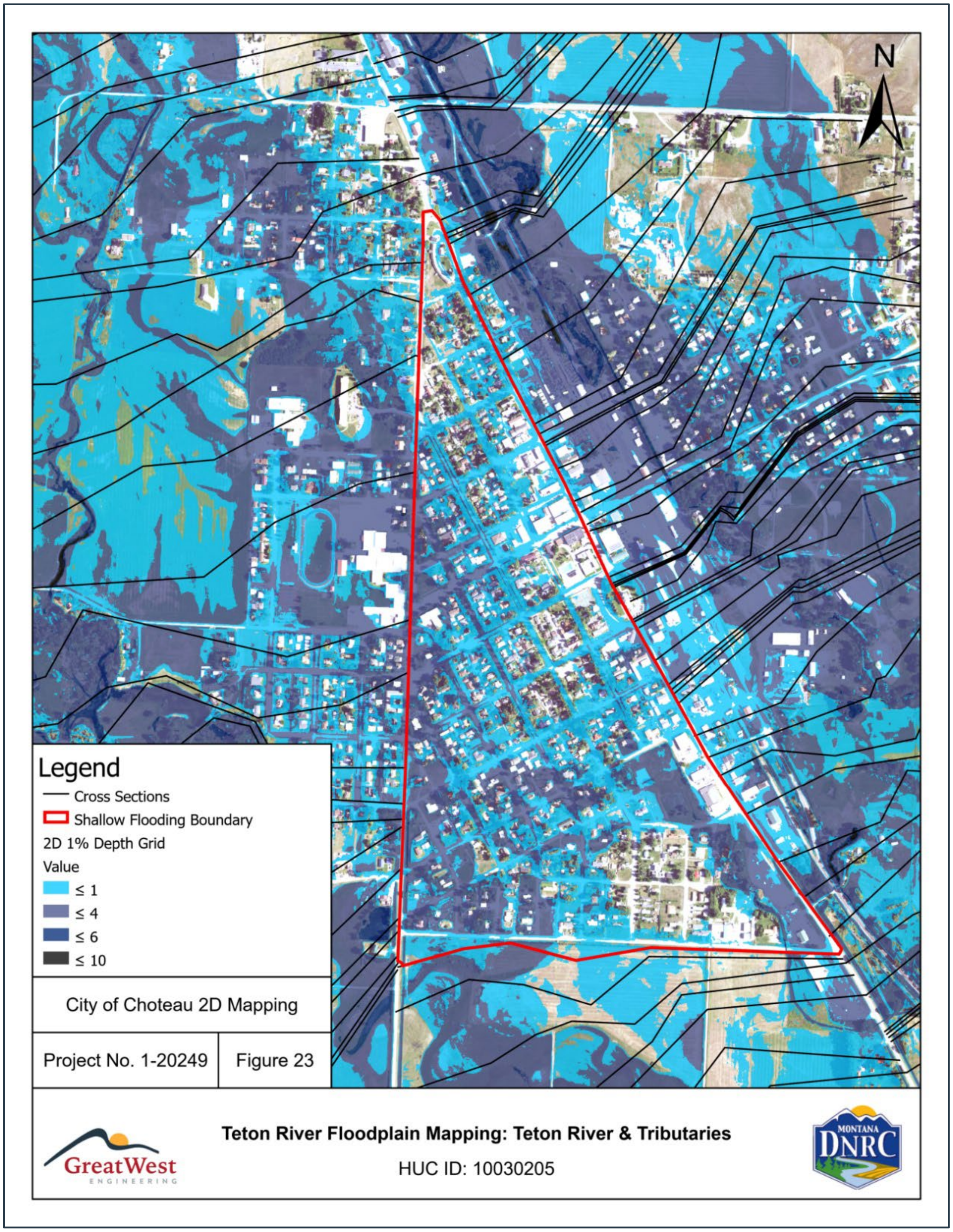


**Figure 23 – Shallow Flooding within Choteau**

### 5.2.3 Non-Levee Features

Non-levee features are defined as physical manmade structures not designed or constructed as levees, and therefore cannot reliably provide flood protection. Therefore, it is considered standard practice to extend cross sections beyond non-levee features during the hydraulic modeling phase in order to account for flooding on both sides of the feature. A memo provided by the MT DNRC and dated May 2021 discusses the multiple approaches for modeling and mapping non-levee features (Appendix A). The first approach, found on page 3 of the memo, was used for this study:

> *"First Approach – Simply extend the BFEs from the stream side to the landward side. This approach is appropriate where the flow areas on the landside of the levee would not be significant and would not significantly reduce the BFE. Examples of this approach include when the area behind the embankment is very small and/or primarily ineffective flow area, or a populated area where the ground is not significantly lower than the with levee BFE and you have a lot of obstructions to the flow. Engineering judgment should be used to determine when this approach is appropriate."*

It should be noted that there are numerous non-levee features including Highway 87 as well as railroad embankments present through the Choteau area; however, flooding on both sides of the highway is well accounted for in the modeling.

### 5.2.4 Gutterlines

Gutterlines are polylines used in the mapping phase that are manually delineated and included in the S_FLD_HAZ_LN layer to provide clarity when two adjoining studies or flood sources overlap. The line helps delineate the boundary of each study or adjoining tributary, to better understand which stream's data governs the area of overlap.

## 5.3 Tie Ins

There are two tie-ins with other study data along the Teton River. One is the confluence of Deep Creek occurring just downstream of the City of Choteau and the other of Muddy Creek further downstream. Coordination with the other study contractors allowed for a final and seamless tie-in at both locations which is being presented as part of this submittal for initial review. At the Muddy Creek tie-in there is a gutter line proposed to separate the mapped studies on the left bank of the Teton River and upstream of the confluence. The downstream boundary of this study terminates at the Teton County boundary, downstream of which has no effective data as Choteau County is currently an unmapped county.

## 5.4 Floodplain Boundary Standards

A Floodplain Boundary Standard audit was performed manually on the 1% floodplain. There was a total of 30,523 points checked along the 1% floodplain boundary, which based on both vertical and horizontal tolerances, demonstrated a 99% passing rate. More information about the pass/fail specifics are included in the FBS Report documentation located in the Supplemental Folder of this submittal.

# 6.0 Discussion of Results

The results of the hydraulic modeling and floodplain mapping outlined in the sections above were used to create visual products, including work maps and spatial data to best view the results. All water surface elevations from the 10%, 4%, 2%, 1%, 0.2%, and 1%+ annual chance flood events can be found in the L_XS_Elev table, included in the spatial database. All 1% elevations are included in the S_XS file and labeled on each cross section, shown on the work maps. For 2D models which have no hydraulic cross sections, BFE lines are used to show flood elevations within the 1% mapped floodplain, at a one-foot interval. BFE lines were further reduced along Teton River to show elevations at a 5-foot interval to improve map readability. Supplemental BFEs were also added along select reaches where there was a water surface elevation drop greater than 5 feet between cross sections.

## 6.1 Comparison to Effective

Most of the effective study is a Zone A, and therefore does not have elevation data in which can be compared to this new study. The effective Zone A floodplain presumably used the 100-year discharge of 16,000 cfs as listed in the 1983 FIS report. In this analysis, using the updated hydrology, the 100-year discharge is 23,700 cfs. Though the TR_Choteau flows do fluctuate in the model due to the flow losses over the highway, the total amount of flow is still represented in the floodplain with some of the flow being added into the SPC_Choteau model. This increase in flow causes the new floodplains to be wider than the previous approximated floodplain across the study limits.

Near Choteau, there are extents on both Teton River and Spring Creek with effective base flood elevation data, (Zone AE) as well as a floodway which were used for comparison. Hydrology for both the 1983 FIS and peak flow data used in this study, as well as water surface and BFE comparisons, are summarized in the tables below. There is a significant difference in new regulatory water surface elevations compared to the effective regulatory elevations and base flood elevations, likely due to the significantly higher flows modeled (in Teton river the 1% flows are almost 50% higher than effective); this can also be seen in the comparison of the floodway widths. New regulatory elevations developed during this study through Teton River and Spring Creek account for the flows being exchanged between the two flooding sources using current hydrology.

**Table 25 –Hydrology Comparison**

| | Summary of Discharges, 1983 FIS | | | | New Discharges | | | |
|---|---|---|---|---|---|---|---|---|
| Flooding Source and Location | 10% AC (cfs) | 2% AC (cfs) | 1% AC (cfs) | 0.2% AC (cfs) | 10% AC (cfs) | 2% AC (cfs) | 1% AC (cfs)/ Floodway (cfs) | 0.2% AC (cfs) |
| **Teton River – Above Choteau** | 3,400 | 10,000 | 16,000 | 45,800 | 4,640 | 15,000 | 23,700 | 50,100 |
| **Spring Creek – at Choteau[1]** | 375 | 1,100 | 1,700 | 8,075 | 173 | 2,996 | 7,941 | 22,061 |

Notes:

1. Spring Creek at Choteau account for flows gained from the Teton diverted flows

**Table 26 – Water Surface and Base Flood Elevation Comparison**

| River Reach | Cross Section | New Regulatory WSEL (ft) | Effective Regulatory WSEL (ft) | Effective BFE (ft) | Difference (ft) |
|---|---|---|---|---|---|
| **Teton River** | 496058 | 3,848.2 | 3,845.5 | | 2.7 |
| | 483137 | 3,806.1 | 3,802.7 | | 3.4 |
| | 479898 | 3,798.4 | | 3,794 | 4.4 |
| | 479799 | 3,794.2 | | 3,793 | 1.2 |
| | 475421 | 3,789.6 | 3,785.8 | | 3.8 |
| **Spring Creek** | 29640 | 3,833.1 | 3,827.6 | | 5.5 |
| | 28662 | 3,828.9 | | 3,823 | 5.9 |
| | 27982 | 3,825.8 | 3,821.6 | | 4.2 |
| | 27138 | 3,820.6 | 3,814.6 | | 6.0 |

Note: Comparisons were only made where new cross sections aligned with effective data

**Table 27 – New and Effective Floodway Widths**

| River Reach | Cross Section Station | Letter ID | New Floodway width (ft) | Effective Floodway width (ft) | Delta (new - effective) (ft) |
|---|---|---|---|---|---|
| **Teton River** | 497981 | IN | 3,451 | 1,855 | 1,596 |
| | 496058 | IM | 4,125 | 2,474 | 1,651 |
| | 493843 | IL | 4,764 | 3,365 | 1,399 |
| | 491928 | IK | 4,206 | 3,669 | 537 |
| | 489702 | IJ | 3,970 | 2,149 | 1,821 |
| | 488243 | II | 2,259 | 1,226 | 1,033 |
| | 486211 | IH | 2,378 | 1,436 | 942 |
| | 483960 | IG | 2,715 | 2,020 | 695 |
| | 482095 | IF | 1,268 | 2,161 | -893 |
| | 479898 | IE | 3,609 | 3,685 | -76 |
| | 477980 | ID | 2,919 | 3,066 | -147 |
| | 476201 | IC | 2,625 | 2,388 | 237 |
| | 474333 | IB | 2,270 | 2,265 | 5 |
| | 472393 | IA | 1,240 | 1,134 | 106 |
| | 470259 | HZ | 1,173 | 890 | 283 |
| **Spring Creek** | 29788 | W | 535 | 422 | 113 |
| | 28662 | V | 601 | 271 | 330 |
| | 27442 | U | 1290 | 452 | 838 |
| | 26436 | T | 1235 | 560 | 675 |
| | 25151 | S | 1250 | 512 | 738 |
| | 23958 | R | 1440 | 750 | 690 |
| | 22951 | Q | 1620 | 476 | 1,144 |

Note: Comparisons were only made on streams with effective floodway data

# 7.0 References Cited

Chow, Ven Te, 1959. *Open-Channel Hydraulics*; New York, McGraw-Hill Book Company.

CivilGEO Engineering Software, 2019. “GeoHECRAS.”

Environmental Systems Research Institute (ESRI), 2016. “ArcGIS Desktop: Version 10.5.1.”

Federal Emergency Management Agency (FEMA), April 2015. “RASPLOT Version 3.0 User Guide.”

Federal Emergency Management Agency (FEMA), December 2020. “Guidance for Flood Risk Analysis and Mapping: Flood Profiles.”

Federal Emergency Management Agency (FEMA), October 1983. “Flood Insurance Study, City of Choteau, Montana.”

Federal Emergency Management Agency (FEMA), January 1983. “Flood Insurance Study, Teton County, Montana Unincorporated Areas.”

Federal Emergency Management Agency (FEMA), November 2021. “Guidance for Flood Risk Analysis and Mapping: Floodway Analysis and Mapping.”

Federal Emergency Management Agency (FEMA), November 2016. “Guidance for Flood Risk Analysis and Mapping: Hydraulics: One-Dimensional Analysis.”

Federal Emergency Management Agency (FEMA), December 2020. “Guidance for Flood Risk Analysis and Mapping: Hydraulics: Two-Dimensional Analysis.”

Federal Emergency Management Agency (FEMA), December 2020. “Guidance for Flood Risk Analysis and Mapping: Profile Baseline Guidance.”

Great Falls Tribune-Leader, 1964. “Montana Flood 1964.” Tribune Printing.

Michael Baker International, May 2021. “Non-Levee Feature Modeling and Mapping.”

Michael Baker International, August 2021. “Teton County Watersheds Hydrologic Analysis: Deep Creek, Muddy Creek, Teton River, and Sun River, Teton County, MT.”

Morrison-Maierle, July 2021. “Survey Report, 2020 Teton Countywide Modernization.”

Quantum Spatial, October 2020. “Teton County Montana LiDAR Technical Data Report.”

Thornton, Nancy. “Teton County Rivers, Streams Flooding Low-Lying Areas.” Choteau Acantha, 8 June 2011, http://www.choteauacantha.com/news/article_2d030a90-7e96-51c1-b3e8-4a9b532ea48f.html.

United States Army Corps of Engineers (USACE), September 2021. “HEC-RAS 6.1.0.”

United States Army Corps of Engineers (USACE), May 2021. “HEC-RAS Version 6.0 User’s Manual.”

United States Army Corps of Engineers (USACE), May 2021. “HEC-RAS Version 6.0 2D Modeling User’s Manual.”

United States Army Corps of Engineers (USACE), December 2020. “HEC-RAS Mapper User’s Manual.”

United States Army Corps of Engineers (SACE), May 2021. “HEC-RAS Version 6.0 Hydraulic Reference Manual.”

United States Department of Agriculture (USDA), 2017. “National Aerial Imagery Program (NAIP).”