SUN RIVER AND TRIBUTARIES
HYDRAULIC ANALYSIS AND FLOODPLAIN MAPPING REPORT

TETON COUNTY, MONTANA

FEMA

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TETON COUNTY, MONTANA

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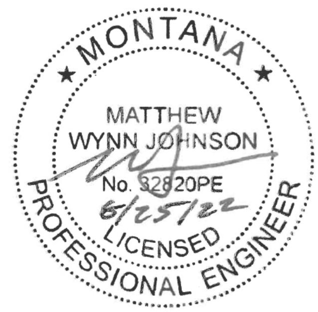

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1.0 PROJECT OVERVIEW

1.1. PROJECT OVERVIEW

As part of the Risk Mapping Activity Statement (MAS) contract, MAS No. 2020-01, for Teton County, Montana (Reference 7), RESPEC Company LLC, in cooperation with Montana Department of Natural Resources and Conservation (DNRC) and the Federal Emergency Management Agency (FEMA), has completed enhanced floodplain studies for the Sun River and 19 of its tributaries, as well as four flooding sources scoped for base level analyses. Table 1-1 summarizes the flooding sources in this study.

Table 1-1. Studied Flooding Sources.

Flooding Source	Study Type	Reach Length (mi)
Diversion Lake Reservoir	Base Level Analysis	0.9
Gibson Reservoir	Base Level Analysis	5.7
Isolated Flooding Areas (2 Total)	Base Level Analysis	1.4
Sun River Mainstem	Enhanced	55.8
Sun River Mainstem*	Enhanced w/Floodway	4.1
Sun River Tributaries (19 total) **	Enhanced	14.8
	Total	82.7

**Includes 1.9 miles of enhanced with floodway study completely within Cascade County.*
***Includes 0.4 miles of enhanced study of Big Coulee Creek completely within Cascade County.*

This report explains the methods used to determine flooding extents and risks according to standards set by FEMA. The report documents the hydraulic and floodplain mapping analyses and provides results for incorporation into the Teton County and Unincorporated Areas Flood Insurance Study (FIS), and other adjacent counties. A hydraulic analysis was developed for each flooding source that simulated the 10%, 4%, 2%, 1%, 1%+, and 0.2% annual chance (10-, 25-, 50-, 100-, 100-plus-, and 500-year) flood events.

Multiple contractors participated in the development of data used in this study. Morrison-Maierle, Inc. completed a field survey of hydraulic structures, river bathymetry, and United States Geological Survey (USGS) stream gages (Reference 16). LiDAR topographic data was provided by Quantum Spatial Inc. (Reference 17). Michael Baker International (MBI) provided the hydrologic analyses for the entire countywide study (Reference 14), in conjunction with the United States Geologic Survey (USGS) who updated peak-flow frequency analysis for select gages in or near Teton County, MT (Reference 22). FEMA reviewed and approved all topographic, field survey, and hydrologic data used to develop the Hydraulic Data Capture and Floodplain Mapping Data Capture tasks.

An overview of the Sun River and Tributaries floodplain study reaches is shown in Figure 1-1 and listed in Table 1-2, followed with a discussion of the community, watershed, and flood history.

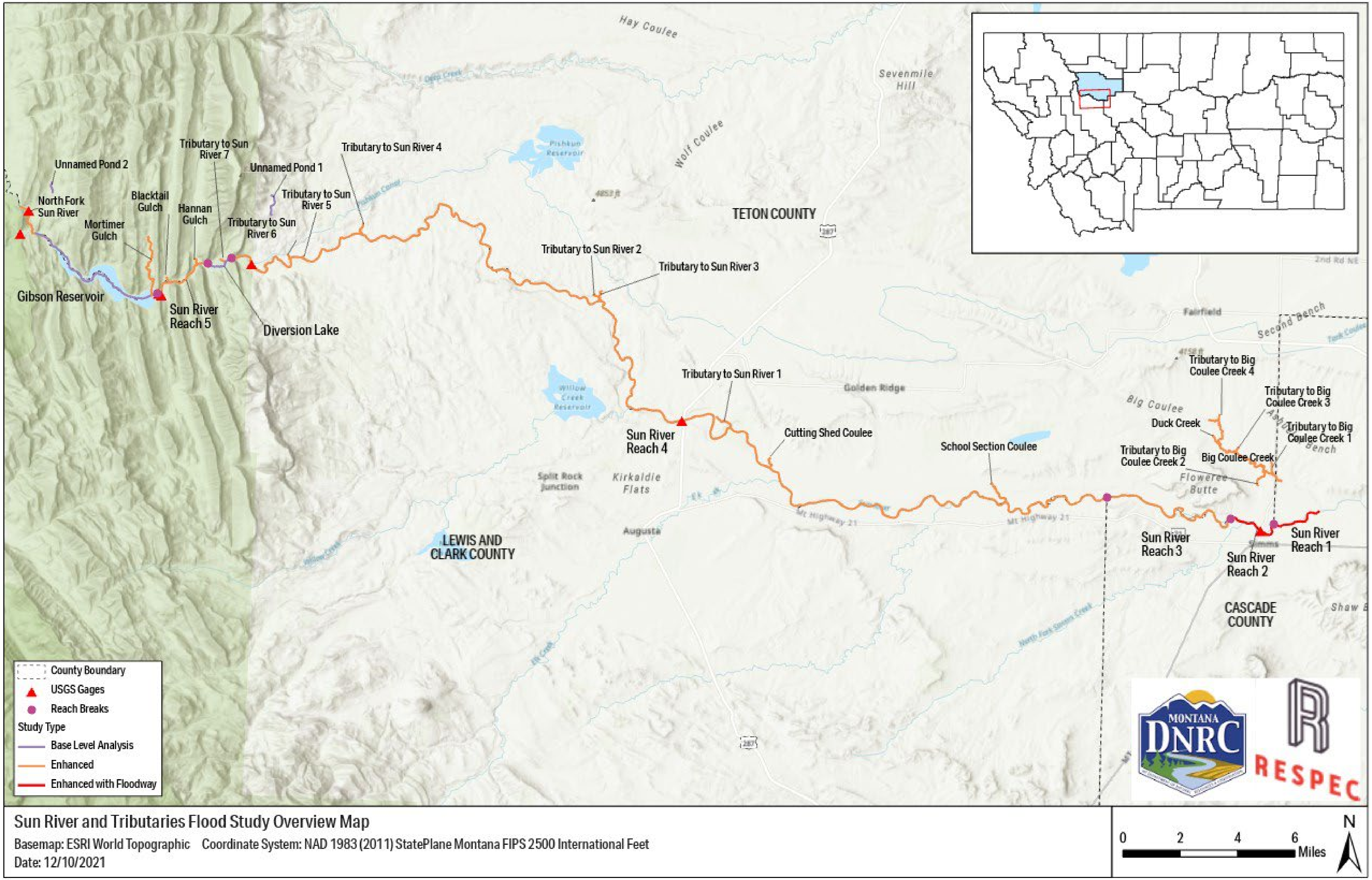

Figure 1-1. Sun River and Tributaries study overview.

Table 1-2. Sun River and Tributaries River Stationing.

Reach Name	Upstream Description	Downstream Description	Starting Station (ft)	Ending Station (ft)
Big Coulee Creek	Approximately 0.9 miles downstream of South Division Lane	Cascade County boundary	24,610	58,786
Blacktail Gulch	Sunriver Canyon Rd	Approximately 0.05 miles upstream of confluence with Sun River	269	1,033
Cutting Shed Coulee	Approximately 0.8 miles downstream of Floweree Road	Approximately 0.3 miles upstream of confluence with Sun River	1,485	2,727
Diversion Lake	Inlet to Diversion Lake	Outlet of Diversion Lake	292,246	296,750
Duck Creek	Approximately 0.5 miles upstream of confluence with Big Coulee Creek	Approximately 0.2 miles upstream of confluence with Big Coulee Creek	993	2,690
Gibson Reservoir	Inlet to Gibson Reservoir	Outlet of Gibson Reservoir	310,536	340,714
Hannan Gulch	Just upstream of East Hannan Road	Confluence with Sun River	162	1,357
Mortimer Gulch	Mortimer Road	Approximately 1.3 miles upstream of confluence with Sun River	7,018	14,896
North Fork Sun River	Approximately 0.4 miles upstream of confluence with Arsenic Creek	Inlet to Gibson Reservoir	0	6,835
School Section Coulee	Floweree Road	Approximately 0.6 miles upstream of confluence with Sun River	3,137	6,860
Sun River Reach 1	Cascade County boundary	Approximately 1.9 miles downstream of Cascade County boundary	234,182	243,998
Sun River Reach 2	Approximately 2.1 miles upstream of Cascade County boundary	Cascade County boundary	0	11,357
Sun River Reach 3	Lewis and Clark County boundary	Approximately 2.1 miles upstream of Cascade County boundary	11,357	43,028

Reach Name	Upstream Description	Downstream Description	Starting Station (ft)	Ending Station (ft)
Sun River Reach 4	Outlet of Diversion Lake	Lewis and Clark County boundary	43,028	292,246
Sun River Reach 5	Outlet of Gibson Reservoir	Inlet to Diversion Lake	296,750	310,536
Tributary to Big Coulee Creek 1	Just downstream of 5th Road Southeast	Approximately 0.2 miles upstream of confluence with Big Coulee Creek	450	3,209
Tributary to Big Coulee Creek 2	Approximately 0.7 miles upstream of confluence with Big Coulee Creek	Confluence with Big Coulee Creek	233	3,408
Tributary to Big Coulee Creek 3	Approximately 0.3 miles upstream of confluence with Big Coulee Creek	Approximately 0.05 miles upstream of confluence with Big Coulee Creek	154	1,583
Tributary to Big Coulee Creek 4	Approximately 0.3 miles upstream of confluence with Big Coulee Creek	Confluence with Big Coulee Creek	59	1,339
Tributary to Sun River 1	Approximately 700 feet downstream of Floweree Canal	Confluence with Sun River	685	4,411
Tributary to Sun River 2	Approximately 800 feet downstream of Young Road	Approximately 0.2 miles upstream of confluence with Sun River	904	2,413
Tributary to Sun River 3	Approximately 0.4 miles upstream of confluence with Tributary to Sun River 2	Approximately 0.3 miles upstream of confluence with Tributary to Sun River 2	1,420	1,868
Tributary to Sun River 4	Approximately 0.8 miles downstream of Pishkun Canal Road	Confluence with Sun River	313	3,088
Tributary to Sun River 5	Approximately 0.1 miles upstream of confluence with Sun River	Confluence with Sun River	68	537
Tributary to Sun River 6	Approximately 0.1 miles downstream of Pishkun Canal Road	Confluence with Sun River	55	1,112
Tributary to Sun River 7	Approximately 0.2 miles upstream of confluence with Diversion Lake	Confluence with Diversion Lake	377	1,158

Reach Name	Upstream Description	Downstream Description	Starting Station (ft)	Ending Station (ft)
Unnamed Pond 1	Approximately 1.2 miles upstream of North Fork Sun River Wilderness Study Area	Approximately 0.3 miles upstream of North Fork Sun River Wilderness Study Area	3	4,905
Unnamed Pond 2	Approximately 0.5 miles upstream of confluence with Arsenic Creek	Approximately 0.1 miles upstream of confluence with Arsenic Creek	4	2,336

1.2. COMMUNITY AND BASIN DESCRIPTION

Teton County is in north-central Montana along the Rocky Mountain Front, east of the Continental Divide. The county is bordered by Pondera County to the north, Chouteau and Cascade Counties on the east, Lewis and Clark County on the south and southwest, and Flathead County on the northwest. The Sun River serves as the county boundary for Teton County with Lewis and Clark County, as well as with Cascade County.

The Sun River originates in the mountains of the western boundary of Teton County. The Sun River flows east from the mountains, through the foothills area and eventually into the Missouri River in Cascade County. The Sun River Tributaries, in general, originate in the foothills and flow south into the Sun River, except for Big Coulee Creek. Big Coulee Creek originates in the foothills and flows east and southerly adjacent to Sun River, to enter Sun River in Cascade County.

The population of Teton County in 2019 is estimated to be 6,147, as compared to 6,491 estimated in the 1980 census as reported in the current effective Flood Insurance Study (FIS) (Reference 3). The community is primarily rural, with irrigated agriculture comprising the dominant land use in the county. There are several impoundments in the county to provide irrigation water. The largest impoundment is Gibson Reservoir, an approximately 99,000 acre-ft reservoir on the Sun River immediately below the confluence of the North and South Fork Sun River in Lewis and Clark National Forest. Approximately 2.5 miles downstream of Gibson Reservoir is another impoundment, Diversion Lake, which provides minimal storage.

The study area is located within the Sun River watershed (HUC 8 #10030104). The Sun River is a major tributary to the Missouri River, coming to a confluence near Great Falls, Montana. Climate in Teton County varies with its topography. Elevations range from mountain peaks exceeding 9,000 feet along the continental divide, to about 3,400 feet where the Teton River leaves the county. Teton County exhibits a continental climate type. Summer temperatures range from 80 degrees in the afternoon, to 50 degrees in the mornings. Winter temperatures vary, with extreme low temperatures reaching 50 degrees below zero Fahrenheit. Most precipitation falls during the growing season. The mean annual precipitation is just over 10 inches per year, while the mountain areas can receive up to 60 inches of precipitation per year.

1.3. PAST STUDIES AND FLOOD HISTORY

The effective FIS for Teton County, Montana was published on January 18, 1983. Much of the 1983 approximate mapping was based on Flood Hazard Boundary Maps (FHMBs) produced in 1977. Majority of the Sun River and its tributaries is designated Approximate A Zone on the effective Flood Insurance Rate Maps (FIRMs), with the exception of a short reach of detailed study with Floodway on the Sun River near the Cascade County boundary. That section of mapping was studied for development of the Cascade County FIS.

The effective Sun River detailed study was developed in the late 1970s and used water surface elevations computed from the USGS E-431 step-backwater program. Cross section information was collected by the United States Army Corps of Engineers through field surveys. The starting water surface elevations were determined by the profile convergence method. Roughness values were assigned based on site visits and ranged in the channel between 0.028 to 0.035, with overbank values that ranged from 0.028 to 0.100.

It is unknown whether technical information that supports the approximate mapping of the remainder of Sun River and its Tributaries exists. No other detailed flood studies are known to exist in the county for Sun River and Tributaries.

All effective FEMA Letters of Map Change were downloaded for Teton County and reviewed. No Letter of Map Revisions exist in the county and there is one Letter of Map Amendment (LOMA) that exists within the study limits of Mortimer Gulch. The case 20-08-0471A for Mortimer Gulch includes an elevation certificate for a residential structure and a base flood elevation determined "developed in house using stream stats data & USGS 40ft topo as best available data". Preliminary review suggests the structure lowest adjacent grade is in close proximity to the simulated water surface elevation for the 1% annual chance event determined in this study.

A detailed hydrologic analysis was developed by Michael Baker International (Reference 14) for the Teton countywide study that includes a detailed flood history narrative, including a summary of USGS gage historical records and anecdotal information for each historical flood event. The flood history for the Sun River and Tributaries is summarized below.

Most flooding along the Rocky Mountain Front results from cool spring temperatures and higher-than-normal spring snowfall, followed by rapid warming and abundant rainfall into late May and early June. Historical floods have occurred in 1948, 1953, 1964, 1975, and 2011. The 1964 flooding was catastrophic. There was loss of life and extensive infrastructure damage. More recent flooding has occurred in 2018, which also caused abundant damage to infrastructure and agricultural operations.

The largest documented flooding event occurred in June 1964, with a peak flood flow of 50,000 cfs recorded at the Sun River at Simms, MT USGS gage. The USGS estimated that the flood had an annual exceedance probability of 0.5%, which classified it as a 200-year event. A combination of snowmelt and prolonged heavy rains lead to the Gibson Reservoir overtopping its dam crest with a 3′ depth. Following that overtopping event, the dam was retrofitted to ensure safe passage of an inflow design flood. The overtopping event in 1964 was captured in a photograph and shown in Figure 1-2.

Figure 1-2. 1964 Flood Overtopping Gibson Dam (adapted from "Montana Flood 1964" published by Great Falls Tribune-Leader).

1.4. DESCRIPTION OF STUDIED REACHES

1.4.1. SUN RIVER

The Sun River study reach interfaces with multiple political jurisdictions and changing study level. The Sun River at its downstream most extent is completely within Cascade County (Sun River Reach 1). The Cascade County and Teton County boundary serves as the upstream limit of Sun River Reach 1 and the downstream limit of Sun River Reach 2. Both these reaches were scoped as enhanced with floodway study level. These two reaches will supersede the current effective detailed study with floodway shown on the FIRMs for Cascade County and Teton County, where the Sun River serves as the boundary between the two counties. The upstream extent of Sun River Reach 2 coincides with the limit of detailed study on the FIRM, which serves as the transition to Sun River Reach 3. The Sun River Reach 3 model was scoped as enhanced level, without floodway, and extends in the upstream direction to the Lewis and Clark County boundary. Like Reach 2, the Sun River serves as the boundary between Teton and Cascade counties. At the Lewis and Clark County boundary, Sun River Reach 4 begins and extends in the upstream direction to the outlet of Diversion Lake. The Diversion Lake reach was scoped as Base Level Analysis, so was partitioned from the enhanced study reaches of the Sun River. A relatively short reach of Sun River was scoped as enhanced level between Diversion Lake and Gibson Reservoir, which was defined as Sun River Reach 5. Like Diversion Lake, Gibson Reservoir was scoped as Base Level Analysis. The North Fork Sun River study reach was scoped as enhanced, and it extends Upstream of Gibson Reservoir to the upstream limit shown on the effective FIRM.

The Sun River's topography varies across the extent of the overall study. Areas surrounding Sun River are characterized by woody wetlands along the immediate banks and densely vegetated and forested overbanks. Beyond these areas are substantial swathes of cultivated farmland and agribusiness plots. The lower reaches of Sun River are defined by wide, meandering channels with historic and overflow channels that create a wide floodplain. The floodplain is regularly activated and is vegetated with ranging density of wetland plant species and larger trees. The floodplain limits are defined by steep terraces extending to upland areas.

Upstream from Freeman Road, the channel becomes more constricted due to rising terraces. Cultivated areas are still present along the banks with growing sparsity approximately 10.0 miles upstream of Freeman Road. From here on, the channel alternates from confined stretches bracketed by steep terraces to wide, open, and meandering segments and back again. Floodplain areas in the upper stretches of Sun River closely resemble those of the lower reaches studied. Several diversions have been constructed through the Sun River, particularly in the more enclosed stretches. Approximately 11.8 miles downstream of the Diversion Lake Dam, Sun River's confined characteristics are amplified with fewer active floodplain stretches. Terrace banks are much steeper as one approaches Diversion Lake and flow is well contained by the sheer banks.

Diversion Lake impounds approximately 1.0 mile of Sun River above the dam crest. Sun River between this point and the outlet of Gibson Reservoir flows through alternating segments of heavily constricted, steep-walled valley sections and broad floodplain reaches with several active channels that rejoin before entering the constricted sections again. Gibson Reservoir impounds approximately 5.7 miles of Sun River. Overbank areas vary from sharp rock cliffs to forested slopes to flat grassland areas. The last 0.8 miles of Sun River below the inlet to Gibson Reservoir exhibits characteristics of segments below the Gibson Reservoir Dam before flowing through a constriction and into the primary reservoir area.

1.4.2. SUN RIVER TRIBUTARIES

The Sun River tributaries are characterized by a range of steep, narrow channels. The tributaries within the mountainous part of the reach are often bounded by steep slopes, cross hillslopes where the channel becomes hard to define, and have overbanks dense with trees. The tributaries on the open floodplain of the Sun River have larger incised channels, are not confined by higher ground, and have overbanks consisting of grasslands, sage brush, and agricultural lands.

1.4.3. BIG COULEE CREEK AND TRIBUTARIES

Big Coulee Creek is a highly sinuous, low gradient channel. The channel has a significantly broader floodplain than the other Sun River tributaries, with some small topographic features controlling floodplain extents. Big Coulee Creek experiences constrictions on the lower half of the reach from roadway culverts on 5th Road SE and Simms Fairfield Road. The tributaries to the Big Coulee Creek feed from small topographic features adjacent the creek. They exhibit flatter channel slopes than the Sun River tributaries', have well defined channels, and have overbanks consisting of mainly grasses, sage brush, emergent herbaceous wetlands, and agricultural lands. Big Coulee Creek has similar overbanks to those of its tributaries.

2.0 HYDROLOGIC ANALYSIS

As mentioned, a detailed hydrologic analysis was performed by Michael Baker International for the entire Teton countywide study which was submit to and approved by FEMA in August 2021. For gaged locations, flood-frequency peak flow analyses for select stream gages was performed by USGS, using Bulletin 17C methods. Flood-frequency peak flow analyses for ungaged locations on ungaged streams were determined using regional regression equations developed by USGS, or for gaged streams, by applying a drainage-area ratio adjustment or logarithmic interpolation between a gaged and ungaged location The results of the hydrologic study for flow nodes pertinent to the Sun River and Tributaries study are summarized in Table 2-1.

Table 2-1. Sun River and Tributaries table of discharges summary from hydrologic analysis.

Reach	Node ID	River Station	Drainage Area	Percent Annual Chance Peak Discharge (cfs)					
			(Square Miles)	10%	4%	2%	1%	1%+	0.20%
Big Coulee Creek	BCC-5.6	56,786	39.5	549	1,050	1,600	2,280	3,780	4,930
	BCC-4.0	56,246	41.5	556	1,060	1,620	2,320	3,850	5,040
	BCC-2.9	48,128	53.8	602	1,160	1,790	2,580	4,280	5,690
	BCC-0.6	41,959	58.3	616	1,190	1,840	2,660	4,410	5,910
	BCC-0.1	29,561	59.5	619	1,200	1,850	2,680	4,440	5,960
	BCC-0.0	27,300	65.2	637	1,240	1,920	2,780	4,610	6,230
Blacktail Gulch	BLG-0.0	1,033	10.5	465	806	1,240	1,900	2,158	4,950
Cutting Shed Coulee	CSC-0.0	2,727	24.1	866	1,470	2,180	3,220	3,860	7,760
Diversion Lake	SR-56.2	297,834	609	11,900	17,400	22,400	28,200	39,000	45,300
	SR-55.4	292,278	610	11,900	17,400	22,400	28,200	39,000	45,300
Duck Creek	DC-0.0	2,690	11.3	273	522	789	1,120	1,860	2,370
Gibson Reservoir	SR-65.6	340,714	521	15,200	18,100	24,000	31,500	35,600	58,200
	SR-63.9	330,449	537	15,400	18,400	24,400	31,900	36,100	59,200
	SR-61.1	321,732	576	11,500	16,900	21,700	27,400	37,800	43,900
Hannan Gulch	HG-0.0	1,357	9.90	445	773	1,190	1,830	2,079	4,790
Mortimer Gulch	MG-0.0	14,896	2.65	153	280	455	730	829	2,130
North Fork Sun River	NFSR-1.0	6,835	259	4,950	8,390	13,200	21,200	35,600	69,400
	NFSR-0.2	5,086	266	5,050	8,550	13,400	21,600	36,200	70,500
School Section Coulee	SSC-2.4	6,860	40.9	621	1,170	1,760	2,490	4,115	5,300
Sun River Reach 1	SR-0.0	243,998	1,299	12,800	19,000	24,800	31,500	41,500	52,200

Reach	Node ID	River Station	Drainage Area (Square Miles)	Percent Annual Chance Peak Discharge (cfs)					
				10%	4%	2%	1%	1%+	0.20%
Sun River Reach 2	SR-2.4	11,357	1,295	12,800	19,000	24,800	31,500	41,500	52,100
	SR-1.7	7,561	1,296	12,800	19,000	24,800	31,500	41,500	52,100
	SR-0.0	4,483	1,299	12,800	19,000	24,800	31,500	41,500	52,200
Sun River Reach 3	SR-2.4	43,028	1,295	12,800	19,000	24,800	31,500	41,500	52,100
Sun River Reach 4	SR-55.4	292,246	610	11,900	17,400	22,400	28,200	39,000	45,300
	SR-52.5	287,633	619	11,900	17,400	22,400	28,200	39,000	45,400
	SR-49.8	272,431	628	11,900	17,300	22,400	28,200	38,900	45,500
	SR-46.6	258,098	648	11,800	17,300	22,300	28,200	38,900	45,700
	SR-41.2	241,482	667	11,800	17,200	22,300	28,200	38,800	45,900
	SR-37.1	212,533	692	11,800	17,200	22,200	28,200	38,800	46,200
	SR-32.5	191,095	702	11,800	17,200	22,200	28,200	38,800	46,300
	SR-29.9	166,729	814	11,600	16,900	22,000	28,100	38,500	47,400
	SR-27.2	153,140	816	11,600	16,900	22,000	28,100	38,500	47,400
	SR-24.9	138,329	818	11,600	16,900	22,000	28,100	38,500	47,400
	SR-24.2	126,465	844	11,700	17,100	22,200	28,400	38,700	47,800
	SR-23.2	122,779	1,040	12,200	18,000	23,400	29,800	40,000	49,800
	SR-14.1	117,803	1,149	12,500	18,400	24,000	30,600	40,700	50,800
	SR-12.7	69,757	1,151	12,500	18,400	24,100	30,600	40,700	50,900
	SR-2.4	61,932	1,295	12,800	19,000	24,800	31,500	41,500	52,100
Sun River Reach 5	SR-61.1	310,536	576	11,500	16,900	21,700	27,400	37,800	43,900
	SR-59.7	307,161	590	11,700	17,100	22,000	27,700	38,300	44,500
	SR-56.2	299,523	609	11,900	17,400	22,400	28,200	39,000	45,300
Tributary to Big Coulee Creek 1	TBCC-1-0.0	3,209	4.30	174	328	489	684	1,130	1,390
Tributary to Big Coulee Creek 2	TBCC-2-0.6	3,408	0.300	53	96	137	183	303	335
	TBCC-2-0.3	3,039	0.550	69	126	182	246	408	461
	TBCC-2-0.2	1,615	0.660	75	138	199	270	448	510
	TBCC-2-0.0	957	0.870	85	155	226	308	511	590
Tributary to Big Coulee Creek 3	TBCC-3-0.0	1,583	2.91	147	275	407	565	937	1,130

Reach	Node ID	River Station	Drainage Area (Square Miles)	Percent Annual Chance Peak Discharge (cfs)					
				10%	4%	2%	1%	1%+	0.20%
Tributary to Big Coulee Creek 4	TBCC-4-0.0	1,339	1.37	106	196	286	392	650	760
Tributary to Sun River 1	TSR-1-0.0	4,411	0.0490	6	13	25	46	52	184
Tributary to Sun River 2	TSR-2-0.2	2,413	1.50	97	180	299	491	558	1,500
Tributary to Sun River 3	TSR-3-0.0	1,420	0.095	10	22	40	72	82	276
Tributary to Sun River 4	TSR-4-0.0	313	2.25	134	247	404	652	741	1,930
Tributary to Sun River 5	TSR-5-0.0	68	1.75	109	203	335	546	620	1,650
Tributary to Sun River 6	TSR-6-0.0	67	1.94	119	220	362	588	668	1,760
Tributary to Sun River 7	TSR-7-0.1	377	0.130	14	28	50	90	103	336
Unnamed Pond 1	UP-1-0.0	4,905	0.679	51	98	168	283	321	923
Unnamed Pond 2	UP-2-0.0	2,336	0.476	38	75	130	222	254	742

3.0 HYDRAULIC ANALYSIS

HEC-RAS version 6.1 (Reference 18) was used to model surface water hydraulics for all studied reaches. The methods used to complete the hydraulic analysis for the Sun River and Tributaries Floodplain Study are described in the following sections.

3.1. HYDRAULIC ANALYSIS PROCEDURES

All study reaches were simulated under a one-dimensional hydraulic approach. The FEMA Guidance document for Hydraulics: One-Dimensional Analysis (Reference 4) served as the primary reference for model development. Additionally, all cross sections and structures were defined in accordance with the HEC-RAS User Manual (Reference 20) and the HEC-RAS Hydraulic Reference Manual (Reference 19). The one-dimensional, steady flow models were developed based on their scoped level of study, as either enhanced with floodway, enhanced, or base level analysis. A summary of the individual hydraulic models developed in this study is provided in Table 3-1.

Table 3-1. Sun River and Tributaries hydraulic model summary.

Description	Plan(s)	HEC-RAS Version	Filename
Big Coulee Creek	Multiple Profile	6.1.0	BigCouleeCreek.prj
Blacktail Gulch	Multiple Profile	6.1.0	BlacktailGulch.prj
Cutting Shed Coulee	Multiple Profile	6.1.0	CuttingShedCoulee.prj
Diversion Lake	Multiple Profile	6.1.0	DiversionLake.prj
Duck Creek	Multiple Profile	6.1.0	DuckCreek.prj
Gibson Reservoir	Multiple Profile	6.1.0	GibsonReservoir.prj
Hannan Gulch	Multiple Profile	6.1.0	HannanGulch.prj
Mortimer Gulch	Multiple Profile	6.1.0	MortimerGulch.prj
North Fork Sun River	Multiple Profile	6.1.0	NorthForkSunRiver.prj
School Section Coulee	Multiple Profile	6.1.0	SchoolSectionCoulee.prj
Sun River Reach 1	Multiple Profile and Floodway	6.1.0	SunRiverReach1.prj
Sun River Reach 2	Multiple Profile, Floodway, and Calibration	6.1.0	SunRiverReach2.prj
Sun River Reach 3	Multiple Profile	6.1.0	SunRiverReach3.prj
Sun River Reach 4	Multiple Profile and Calibration	6.1.0	SunRiverReach4.prj
Sun River Reach 5	Multiple Profile	6.1.0	SunRiverReach5.prj
Tributary to Big Coulee Creek 1	Multiple Profile	6.1.0	TribtoBigCouleeCreek1.prj
Tributary to Big Coulee Creek 2	Multiple Profile	6.1.0	TribtoBigCouleeCreek2.prj
Tributary to Big Coulee Creek 3	Multiple Profile	6.1.0	TribtoBigCouleeCreek3.prj
Tributary to Big Coulee Creek 4	Multiple Profile	6.1.0	TribtoBigCouleeCreek4.prj
Tributary to Sun River 1	Multiple Profile	6.1.0	TribtoSunRiver1.prj
Tributary to Sun River 2	Multiple Profile	6.1.0	TribtoSunRiver2.prj
Tributary to Sun River 3	Multiple Profile	6.1.0	TribtoSunRiver3.prj
Tributary to Sun River 4	Multiple Profile	6.1.0	TribtoSunRiver4.prj
Tributary to Sun River 5	Multiple Profile	6.1.0	TribtoSunRiver5.prj

Description	Plan(s)	HEC-RAS Version	Filename
Tributary to Sun River 6	Multiple Profile	6.1.0	TribtoSunRiver6.prj
Tributary to Sun River 7	Multiple Profile	6.1.0	TribtoSunRiver7.prj
Unnamed Pond 1	Multiple Profile	6.1.0	UnnamedPond1.prj
Unnamed Pond 2	Multiple Profile	6.1.0	UnnamedPond2.prj

3.2. TOPOGRAPHIC DATA ACQUISITION

3.2.1. FIELD DATA COLLECTION AND SURVEY

Bathymetric cross-sectional survey data was collected to supplement the LiDAR surface within the main channel and provide detail beneath the hydroflattened channel surface. The surveyed cross-sections were spaced at approximately 2-mile intervals along the length of the main Sun River channel. Ground survey was also collected for major hydraulic structures crossing the Sun River. Majority of other hydraulic structures within the study area were subjected to a structure inventory and field measurement approach. The field survey was collected with the following specifications:

Projection:	Montana State Plane	Units
Datum:	Horizontal – NAD83 (2011)	International Feet
	Vertical – NAVD88, Geoid12B	US Survey Feet

3.2.2. LIDAR SURVEY

Quantum Spatial Inc. acquired topographic Light Detection and Ranging (LiDAR) data for the project area in 2020. LiDAR deliverables included digital elevation models (DEM), 1-foot contours, and a data summary report (Reference 17). The LiDAR data was collected with the following specifications:

Projection:	Montana State Plane	Units
Datum:	Horizontal – NAD 83 (2011)	Meters
	Vertical – NAVD88, Geoid12B	Meters

The LiDAR DEM (1-m resolution) served as the primary topographic source for the project and was utilized to develop the cross sections within HEC-RAS.

3.2.3. BATHYMETRIC SURFACES

The surveyed channel cross sections were interpolated at approximately 100-foot intervals of cross sections over each 2-mile spacing between surveyed cross sections in HEC-RAS. The interpolated cross sections were trimmed to banklines to ensure no terrain was affected outside the banklines and exported into a terrain file. The surface was trimmed in ArcGIS Pro to the hydroflattened water surface edges and adjusted so elevations above the hydroflattened water surface were reduced to the hydroflattened water surface elevation. This ensured no terrain features were added above the elevation of the hydroflattened surface, as well as to preserve terrain features such as islands in the channel. Figure 3-1 shows a comparison between the LiDAR hydroflattened surface and the superimposed bathymetric surface.

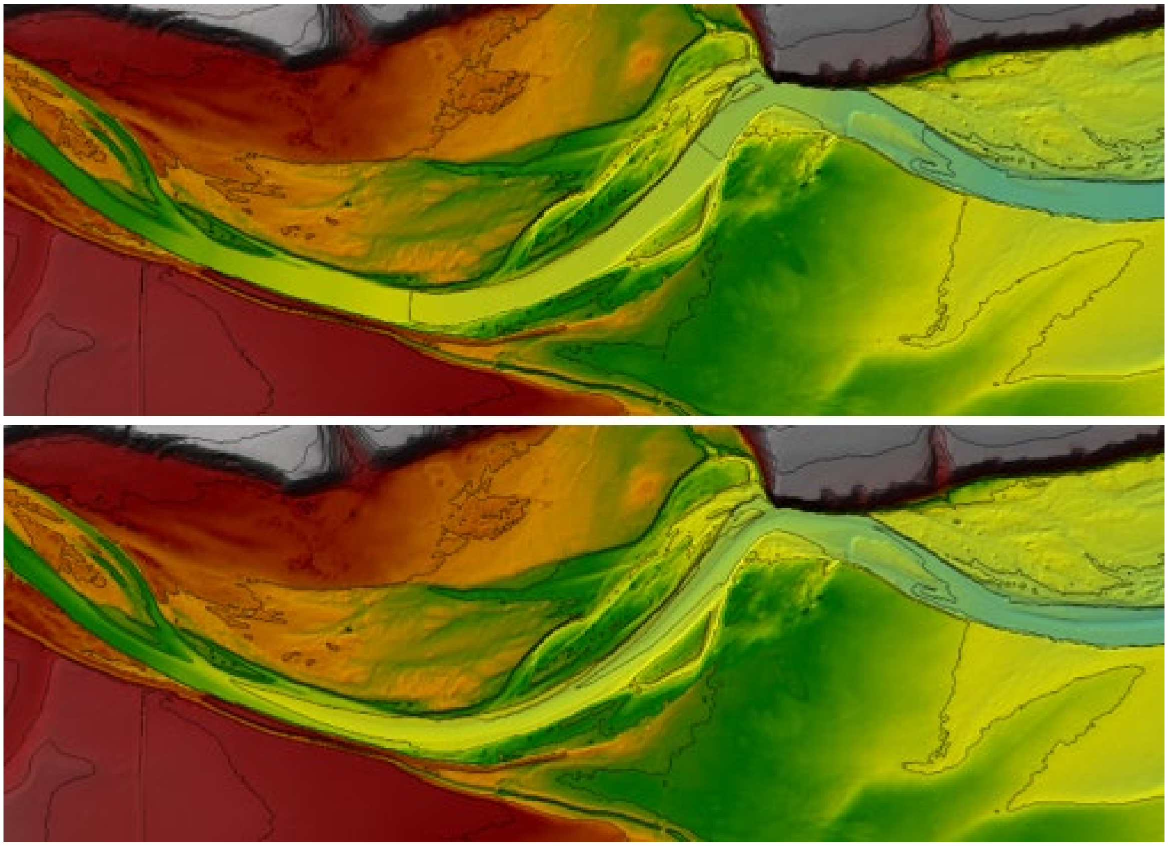

Figure 3-1. Comparison of the hydroflattened LiDAR channel (top) and the revised surface including channel bathymetry (bottom).

A bathymetric reservoir terrain was constructed for both Gibson Reservoir and Diversion Lake in AutoCAD Civil3D. Profile lines were cut from the hydroflattened water surface elevation at the upstream end of the reservoirs and tied into the elevation just downstream of the dam faces. For Gibson Reservoir a 300-ft flat channel was carved along the profile, with bottleneck sections narrowed to a 100-foot channel. Diversion Lake was given a consistent 100-foot channel throughout the entire reach. Elevations were pulled from the channel bottom edges and graded up to the edge of hydroflattened water surface elevations to create storage basins representative of the reservoirs. A smaller side channel was split to the left side of the island in Diversion Lake, joining the main thread just downstream of the island and grading up to the island's hydroflattened water surface edge. The final bathymetric surfaces ensure no terrain features above or outside the extents of the hydroflattened surface were affected. Figure 3-2 provides a comparison between the LiDAR hydroflattened reservoir surface of Gibson Reservoir and the superimposed bathymetric surface.

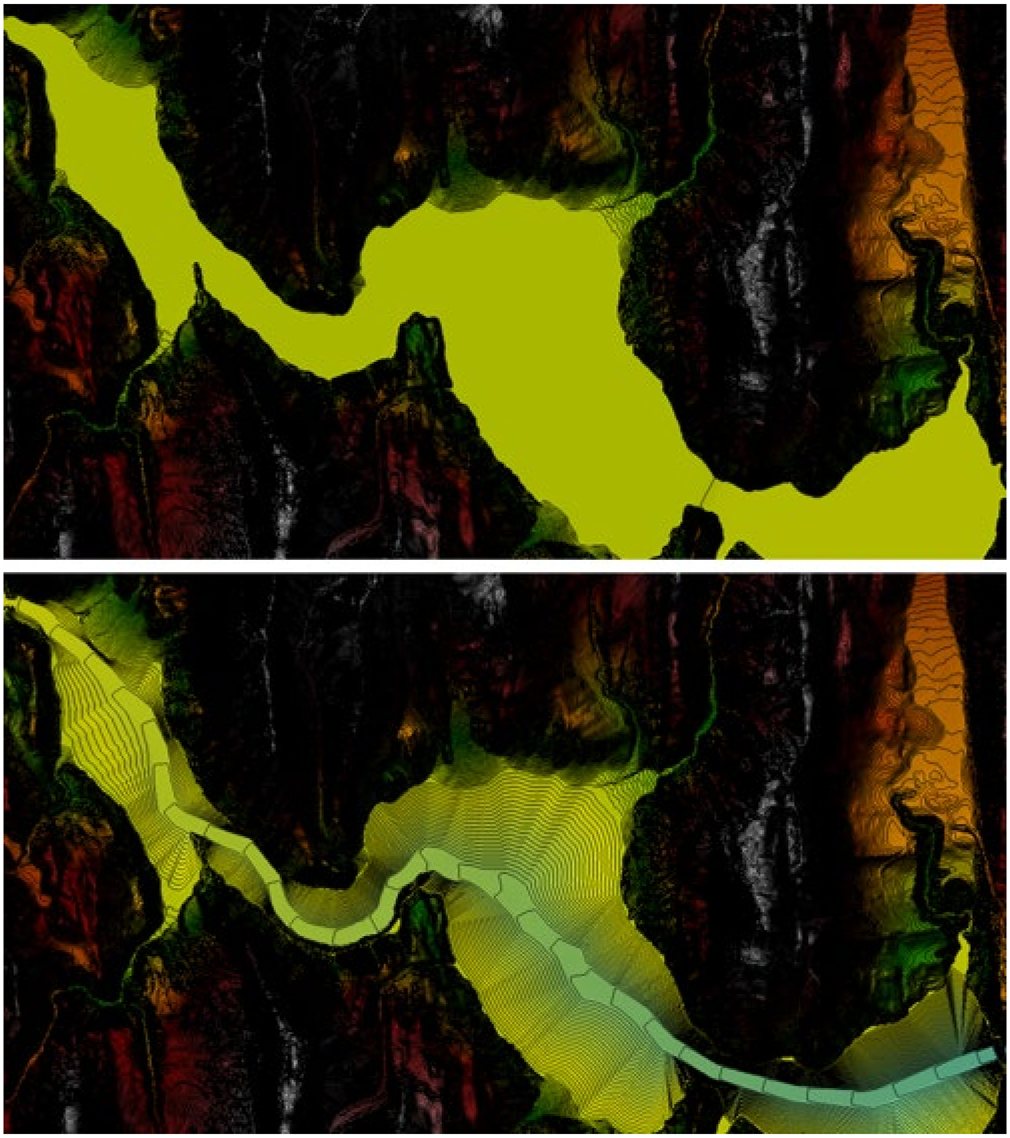

Figure 3-2. Comparison of the Gibson Reservoir hydroflattened LiDAR surface (top) and the revised surface including channel bathymetry (bottom).

3.2.4. COMPOSITED SURFACE

A terrain was constructed in ESRI's ArcGIS Pro utilizing the LiDAR Bare Earth DEM as a base surface model. Both the channel and reservoir bathymetric surfaces were superimposed over the base surface model in HEC-RAS to ensure the base surface was not modified.

3.3. REACHES

All studied streams were modeled independently and include an individual HEC-RAS model of the scoped study reach. Due to the long length of the Sun River study reach, the changing study level type, the two instream impoundments, and the Sun River's interface with multiple political jurisdictions, the stream was partitioned into several different HEC-RAS models.

3.4. BOUNDARY CONDITIONS

Hydraulic models require input of upstream and downstream boundary conditions to run a simulation. All study reaches were developed assuming subcritical flow, under steady-state flow conditions.

The upstream boundary condition is typically flow based, peak flood discharge, as defined in the hydrologic analysis. Peak flow values determined for each flow node in that analysis were applied to the HEC-RAS cross section at that location. That peak discharge was then applied to all sections upstream until the next flow node is encountered. This is applicable to the Sun River, where numerous flow change locations are required. Majority of the tributary reaches require only one flow definition at the top of the reach, using the peak flows computed at the mouth of the tributary.

Downstream boundary conditions are typically head based, with a starting water surface elevation corresponding to the 10%, 4%, 2%, 1%, 1%+, and 0.2% annual chance flood events. All study reaches relied on a normal depth downstream boundary condition. Table 3-2 summarizes the normal depth slopes calculated from the channel bed profile at the downstream limit of each study reach.

Table 3-2. Normal depth slope used for downstream boundary condition for each study reach.

Reach	Normal Depth Slope (ft/ft)	Reach	Normal Depth Slope (ft/ft)
Big Coulee Creek	0.002	Tributary to Big Coulee Creek 3	0.012
Blacktail Gulch	0.116	Tributary to Big Coulee Creek 4	0.018
Cutting Shed Coulee	0.019	Tributary to Sun River 1	0.036
Duck Creek	0.005	Tributary to Sun River 2	0.013
Hannan Gulch	0.018	Tributary to Sun River 3	0.028
Mortimer Gulch	0.099	Tributary to Sun River 4	0.021
North Fork Sun River	0.005	Tributary to Sun River 5	0.042
School Section Coulee	0.001	Tributary to Sun River 6	0.086
Sun River Reach 1	0.004	Tributary to Sun River 7	0.001
Tributary to Big Coulee Creek 1	0.004	Unnamed Pond 1	0.267
Tributary to Big Coulee Creek 2	0.010	Unnamed Pond 2	0.076

As mentioned in Section 1.4.1, the Sun River was partitioned into multiple models, where study level and political jurisdiction were the primary factors to define model breaks. Sun River Reach 1 used a normal depth boundary condition, and all models upstream used a "known water surface elevation" from simulated results at the coincident cross section from the model downstream. For example, the downstream most cross section of Sun River Reach 2 used a known water surface elevation for a downstream boundary condition that was the computed water surface elevation result for the identical upstream most cross section of Sun River Reach 1. This approach was used for Sun River Reach 2, Sun River Reach 3, Sun River Reach 4, Diversion Lake, Sun River Reach 5, and Gibson Reservoir. These starting water surface elevations are summarized in Table 3-3.

Table 3-3. Starting water surface elevation values used for linked Sun River models.

Reach	Starting Water Surface Elevations for Linked Models					
	10%	4%	2%	1%	1%+	0.20%
Diversion Lake	4,488.9	4,490.7	4,492.2	4,493.8	4,496.5	4498.0
Gibson Reservoir	4,736.7	4,737.4	4,738.3	4,739.1	4,739.8	4,744.6
Sun River Reach 2	3,575.9	3,576.8	3,577.4	3,578.0	3,578.8	3,579.5
Sun River Reach 3	3,655.8	3,657.2	3,658.0	3,658.8	3,659.7	3,660.6
Sun River Reach 4	4,400.5	4,405.0	4,408.6	4,412.5	4,419.1	4,422.6
Sun River Reach 5	4,569.3	4,571.0	4,572.4	4,574.1	4,576.4	4,577.6

The potential for coincident peak flooding was investigated prior to establishing the reach downstream limit and corresponding downstream boundary condition. A coincident peak flood may occur when peak flooding occurs at the confluence of two flooding sources. FEMA has provided guidance (Reference 4) to define when coincident peaks should be assumed. The following parameters must be met to assume coincident peak flooding will occur:

- The ratio of the drainage areas lies between 0.6 and 1.4;
- the arrival times of the flood peaks are similar for the two combining watersheds; and
- the likelihood of both watersheds being covered by the storm being modeled is high.

Drainage area ratios were evaluated for each mainstem and tributary confluence, and it was determined that all ratios are outside the range defined by FEMA.

3.5. CROSS SECTION DEVELOPMENT

As mentioned, the composited surface was used to create a terrain in HEC-RAS RASMAPPER. Cross sections were drawn in RASMAPPER, placed perpendicular to flow and along assumed equipotential lines. Cross sections were placed with less than 500′ spacing and extended to capture the boundaries of the 0.2-percent-annual-chance floodplain. Cross sections were placed at key locations along the reach, including breaks in channel slope, abrupt changes in floodplain width, changes in overbank roughness classifications, and at hydraulic structures.

Cross section downstream reach lengths are based on the profile baseline for the main channel length, and for overbank flowpath lines drawn in RASMAPPER for left and right overbank lengths.

Bank stations were assigned based on topographic breaks, changes in roughness, and the approximate 50% annual chance flow extents.

A pilot channel was determined necessary in Sun River Reach 5 and North Fork Sun River. Field bathymetric survey was not collected for these reaches. The dimensions of the pilot channel were based on expected width and depth from aerial imagery for times of high and low water levels. The pilot channel facilitated placement of bank stations and ineffective flow for portions of the reach with wide hydroflattening of the LiDAR surface.

3.6. HYDRAULIC STRUCTURES

Hydraulic structures were modeled in HEC-RAS using guidance provided in the HEC-RAS Hydraulic Reference manual and engineering judgement. Field survey data was collected for hydraulic structures within the study area. Crossings were defined using surveyed data, LiDAR data, and photographs. Table 3-4 summarizes the number and type of hydraulic structures included in each relevant study reach and Table 3-5 provides detail for each structure. Structures listed in Table 3-5 fall into two categories denoted by the suffix of the structure ID. Structures surveyed using GPS Topographic equipment have the 'GPS' suffix following the structure ID and those inventoried have the 'SI' suffix.

Table 3-4. Summary of hydraulic structures and types for pertinent study reaches.

Stream	Bridges	Culverts	Diversions	Total
Big Coulee Creek	0	3	0	3
Mortimer Gulch	0	1	0	1
North Fork Sun River	1	0	0	1
Sun River	7	2	3	12
Total:	8	6	3	17

For GPS surveyed structures, points collected in the field were projected to the bounding cross sections used in the hydraulic model to develop the deck/roadway profile and structure dimensions used in the model. GPS survey was supplemented with LiDAR data where extended deck/roadway profiles were needed. Detailed field sketches and notes were provided for the inventoried structures and included bridge span lengths and deck thicknesses, pier and abutment locations, height measurements taken from the bridge deck and/or guardrail to the channel and overbanks, guardrail heights and extents, and dimensions for culverts and diversions. Provided measurements were used to develop the structures within the model and recorded heights at bridge crossings were used to project channel topography onto the bounding sections when available. Projected information, whether from GPS survey or inventory notes, was centered with the channel and structure.

Two culverts on Sun River, SUN_030_SI and SUN_040_SI were not modeled due to the culverts no longer existing. Two diversions on the Sun River, MOR_1_010_SI and SUN_0120_SI, were not modeled due to the diversion either receiving no flow or no longer existing. One bridge, BLA_010_SI, and one culvert, SCH_010_SI, were not modeled because the reaches were not scoped for study.

Table 3-5. Detailed summary of bridge and culvert hydraulic structures modeled.

River	Structure ID	Structure Description	River Station	Structure Type	Bridge Data					Culvert Data				
					Span Length (ft)	Bridge Width (ft)	# of Spans	Pier/Drag Coefficient	Modeling Approach	Length (ft)	Type	Shape	Dimensions (L x H)	# of Barrels
Big Coulee Creek	BIG_010_SI	Simms Fairfield Road	26,785	Culvert	-	-	-	-	-	60	CMP	Circular	2-6' DIA, 1 - 4' DIA	3
Big Coulee Creek	BIG_020_SI	5th Road NE Overflow	41,145	Culvert	-	-	-	-	-	41	CMP	Circular	6' DIA	2
Big Coulee Creek	BIG_030_SI	5th Road NE	16,526	Culvert	-	-	-	-	-	41	CMP	Circular	6' DIA	1
Blacktail Gulch	BLA_010_SI	Mortimer Gulch Road	-	Bridge	Not Modeled – Model Extents Start Downstream of Bridge									
Mortimer Gulch	MG_010_SI	Sun River Road	7,440	Culvert	-	-	-	-	-	81	CMP	Circular	6' DIA	1
School Section Coulee	SCH_010_SI	Broken D Ranch Internal Road	-	Culvert	Not Modeled – Model Extents Start Downstream of Culvert									
North Fork Sun River	NFS_010_SI	K Bar L Private Access		Bridge	117	9	1		Energy	-	-	-	-	-
Sun River	SUN_010_GPS	Simms Fairfield Road	248,572	Bridge	378.7	33.8	4		Energy	-	-	-	-	-
Sun River	SUN_020_SI	Lowrey Road	277,067	Bridge	200	17	3		Energy	-	-	-	-	-
Sun River	SUN_030_SI	Broken O Canal 2	303,696	Culvert	Not Modeled – Destroyed or Missing									
Sun River	SUN_040_SI	Freeman Road	319,347	Culvert	Not Modeled – Destroyed or Missing									
Sun River	SUN_050_SI	Freeman Road	319,347	Bridge	91.5	31.7	1		Energy	-	-	-	-	-
Sun River	SUN_060_SI	Freeman Road	319,347	Culvert	-	-	-	-	-	44	CMP	Pipe Arch	4.83' x 3'	1
Sun River	SUN_090_GPS	US Highway 287	396,957	Bridge	332	21	3		Energy	-	-	-	-	-
Sun River	BRO_1_040_SI	Floweree Canal		Culvert	Not Modeled – Heavily Silted and Modeled WSE Lower than Culvert Inlet									
Sun River	MOR_1_010_SI	Morris Irrigation Canal 1	452,096	Culvert	Modeled as Diversion Structure Only									
Sun River	SUN_0120_SI	Sun River	471,526	Bridge	Not Modeled – Destroyed or Missing									
Sun River	SUN_0130_GPS	Pishkun Canal Road	531,673	Bridge	219	15.9	2		Energy	-	-	-	-	-
Sun River	SUN_0140_SI	Hannan Road		Bridge	257	14.4	3		Energy	-	-	-	-	-
Sun River	SUN_0150_SI	Mortimer Gulch Road		Bridge	215	29.2	3		Energy	-	-	-	-	-

As mentioned, six locations of irrigation infrastructure along the Sun River were identified with potential to affect flooding conditions. Two diversion structures were not modeled due to lack of inundation for the 1-percent-chance event or having been destroyed prior to the survey. The remaining four locations of irrigation infrastructure are generally an elevated rock weir spanning the width of the Sun River channel to create backwater during baseflow periods and divert irrigation water through concrete headwall and headgate structures. Rock weirs for the four diversions modeled on Sun River are heavily skewed to the channel. The irrigation infrastructure was modeled using two cross sections spaced 15 ft apart, aligned perpendicular to the channel at each diversion. The upstream section's bathymetry was modified to simulate the crest of each rock weir. Crest elevations were estimated from the provided field notes, sketches, and photos at each diversion. The downstream section was cut directly from the bathymetric and LiDAR surface to capture the elevation change from the weir. In general, the concrete headwall was simulated within the weir cross section by extracting its elevations from LiDAR. No headgates were simulated. The final weir and headwall geometry was compared to field survey measurements and found to agree reasonably well. Table 3-6 provides a summary of all irrigation structures collected in the survey within the study area.

Table 3-6. Detailed summary of irrigation diversion structures in the study area.

River	Survey Structure ID	Structure Description	River Station	Description	Crest Elevations (ft)
Sun River	FSI_010_SI	Diversion to Fort Shaw Canal	50,537	Rock weir	3,675.7
Sun River	BRO_1_010_SI	Diversion to Floweree Canal Headgate	166,729	Rock weir with large angular material	4,008.4
Sun River	MOR_1_010_SI	Diversion to Morris Irrigation Canal 1	208,088	Rock weir	4,124.3
Sun River	MOR_2_020_SI	Diversion to Irrigation Canal on Sun River	-	Not Modeled - Receives no flow at 100-Year	
Sun River	MOR_2_010_SI	Diversion to Morris Irrigation Canal 2	223,790	Rock weir	4,171.6
Sun River	SUN_0120_SI	-	227,528	Not Modeled - Destroyed or Missing	

3.7. ROUGHNESS AND CONTRACTION/EXPANSION COEFFICIENTS

3.7.1. MANNING'S ROUGHNESS

The Manning's roughness values assigned within the hydraulic model were determined based on the 2019 National Land Cover Database (NLCD) Land Cover raster, aerial photography, Table 3-1 from the HEC-RAS Hydraulic Reference Manual (Reference 19), and Chow's Open Channel Hydraulics (Reference 1). All reaches utilized single channel Manning's roughness values since, in general, changes in roughness characteristics were observed at a large scale. The ranges of values used in the modeling are shown in Table 3-7.

Table 3-7. Channel and overbank roughness values used in general study reaches.

Reach	Main Channel	Overbanks
Big Coulee Creek	0.040	0.045-0.055
Big Coulee Creek Tributaries	0.040-0.042	0.025-0.070
Sun River Main	0.035-0.045	0.036 - 0.160
Sun River Tributaries	0.040 - 0.075	0.040-0.120

For all tributaries excluding Big Coulee Creek and its tributaries, North Fork Sun River, School Section Coulee, and Tributary to Sun River 7, channel roughness values were adjusted to higher values due to the steep channel slopes existing within those reaches. The calculations were made using a determination of Manning's n in high gradient, small mountain streams equation outlined in the Determination of Roughness Coefficients for Streams in Colorado (Reference 13). The requirements for use of this equation are natural channels with slopes greater than 0.002 ft/ft and less than 0.05 ft/ft, that do not carry sediment concentrations so large to result in mudflows or debris flows. For each studied reach determined suitable, the parameters of channel area, wetted perimeter, and friction slope were pulled from HEC-RAS preliminary results and averaged over the length of the channel before using to calculate a larger roughness value. Channel roughness values used for the selected tributary models are summarized in Table 3-8.

Table 3-8. Adjusted channel roughness values used for steep reaches.

Reach	Main Channel	Average Channel Friction Slope (ft/ft)
Blacktail Gulch	0.066	0.034
Cutting Shed Coulee	0.056	0.017
Hannan Gulch	0.062	0.018
Mortimer Gulch	0.059	0.018
Tributary to Sun River 1	0.065	0.013
Tributary to Sun River 2	0.064	0.026
Tributary to Sun River 3	0.067	0.018
Tributary to Sun River 4	0.055	0.012
Tributary to Sun River 5	0.058	0.019
Tributary to Sun River 6	0.058	0.050
Unnamed Pond 1	0.074	0.025
Unnamed Pond 2	0.075	0.026

3.7.2. CONTRACTION AND EXPANSION COEFFICIENTS

Under normal contraction and expansion conditions, HEC-RAS Reference Manual suggests using contraction and expansion coefficients of 0.1 and 0.3, respectively. For culvert and bridge crossings, the coefficients are typically increased to 0.3 and 0.5, respectively, in conjunction with ineffective flow areas, for sections 2, 3, and 4, as defined in the HEC-RAS Reference Manual.

During initial model development, normal contraction and expansion coefficients were used throughout all study reaches. Review of the profile results revealed the presence of severe drawdowns at numerous locations. In addition to cross section reorientation, bank station revisions, Manning's roughness coefficient adjustments, and placement of ineffective flow to smooth transitions, it was determined that contraction and expansion coefficients should be increased on many sections.

There are several cases along the Sun River where wide floodplains immediately narrow to an incised reach where bedrock outcroppings define the section. These locations were captured with cross sections to ensure the changing hydraulics and backwater they impose were reflected in the flood profile. For many cases, to reconcile a severe drawdown, contraction and expansion coefficients were set to 0.3 and 0.5, and in some cases, increased to 0.6 and 0.8. These values are within the range presented in the HEC-RAS Reference Manual and deemed appropriate given the geologic setting.

3.8. NON-CONVEYANCE AND BLOCKED OBSTRUCTION AREAS

It is apparent that the analyzed reaches are comprised of multiple areas that are considered backwater or can be assumed to contain limited conveyance in the stream wise direction upon inspection of the inundation results. Cross sections bounding structures were assigned areas of non-conveyance to force the one-dimensional steady state model to accurately calculate the headloss due to flow contraction and expansion. The flow contraction and expansion areas were calculated using a 1:1 (stream wise: lateral) and a 2:1 ratio, respectively. The ratios of expansion and contraction were developed using the cross-sectional velocities, guidance within the HEC-RAS Hydraulic Reference Manual, and engineering judgment.

3.9. DIVERTED/SPLIT FLOW ANALYSIS

Flooding conditions along the Sun River and its tributaries were reviewed for split flow conditions during development of each model and subsequent geometric layout iteration. No areas were observed to require definition of split reaches and calculation of diversion of discharge to capture flood risk imposed by the various events simulated. All potential splits were verified to return to the mainstem in a short distance and were able to be contained within the cross sections of the main reach.

3.10. MULTIPLE/WORST-CASE SCENARIO ANALYSIS

Riverine environments that include substantial development of infrastructure typically include artificial embankments for transportation and irrigation. The Sun River and Tributaries contain very few artificial embankments within the riverine corridor, primarily attributed to the low population density in the study area. Transportation infrastructure is primarily located on the high terraces, above the riverine corridor and outside the floodplain. The tributary reaches studied are, in general, also remote with few roads that could impede or affect flood flow distribution. It was determined during model development that no multiple scenarios were needed to simulate various worst case scenario conditions throughout all the study reaches. The geometries developed were determined to portray the worst-case flooding scenario.

Irrigation infrastructure exists along Sun River with potential to affect flood flow distribution. As mentioned, four irrigation diversions were included in the Sun River model. Each location was investigated for need of a worst-case scenario analysis. The four diversion structures were comprised of a rock weir that ran either perpendicular to the channel or skewed upstream at varying angles. Each rock weir is meant to back up flow for diversion through a headgate structure.

Initial iterations of modeling approach for these diversions included simulation of the area without the weir incorporated into the geometry. It was observed that under this scenario, the headgate structure and irrigation canal downstream of it were completely inundated and connected to the main channel flooding during the base flood event. Once the weirs were added, conditions downstream were identical, being completely inundated, and conditions upstream portrayed backwater. It was determined that regardless of weirs being included in the geometry, the amount of discharge in the canal downstream of the headgate structure would be the same whether the headgate was open, closed, or non-existent. The canals themselves were not considered for split reach since they diverge from the Sun River corridor and remain a perched system with limited capacity. One the canal is full, any excess flow immediately spills back to the Sun River and no areas downstream of the canal were identified with potential for discharge to collect and create high flood risk.

3.11. MODEL CALIBRATION

The FEMA guidelines for one-dimensional hydraulic analysis requires that models be calibrated to recorded water surface elevations at available gage stations on the river of study if possible. Available USGS stream gages served as the primary data source for calibration.

3.11.1. USGS STREAM GAGE DATA

There are three, active USGS gages along the studied portion of Sun River and one on North Fork Sun River One gage on Sun River, just below Gibson Dam (06080000) is inactive. The gages have a period of record ranging from 19 to 38 recorded annual peak flow measurements, summarized in Table 3-9 below.

Table 3-9. USGS stream gages along Sun River and North Fork Sun River.

River	Gage ID	Description	Total Records
Sun River	06085800	Sun River at Simms MT	29
Sun River	06082200	Sun River below Willow Creek near Augusta MT	23
Sun River	06080900	Sun River below Diversion Dam near Augusta MT	19
Sun River	06080000	Sun River near Augusta MT	27
North Fork Sun River	06078500	North Fork Sun River near Augusta MT	38

USGS stream gage reference markers were field surveyed by Morrison-Maierle and an apparent gage zero elevation in NAVD88 datum was defined for each gage. No gage reference mark information was available for USGS 06080000 so utilization of the stage information for calibration purposes was not possible.

For the four gages converted to NAVD88 datum, the annual peak flow record was scrutinized for measurement accuracy, confidence, and for general trend. Key floods of record were reviewed at each gage, and were found to approximately align with the 10%- (June 2018), 1%- (June 1975), and 0.2%- (June 1964) annual chance events based on comparison to the current hydrologic analysis. The peak flows recorded at each gage during these events is shown in Table 3-10.

Table 3-10. USGS stream gage recorded peak floods and approximate flood-event-equivalent investigated for calibration.

River	Gage ID	Flood Year		
		June 2018	June 1975	June 1964
Sun River	06085800	18,100	37,900	50,000
Sun River	06082200	13,300	34,000	46,700
Sun River	06080900	10,500	32,000	59,700
North Fork Sun River	06078500	4,120	-	51,100

- Flood outside of period of record

The June 1975 flood was targeted as the primary calibration event since it most closely approximates the 1% annual chance flood event. Gages were scrutinized further to access suitability for calibration. Tabulations of all data provided insight into overall accuracy of each measurement and general trends from the gage history were identified through plotting the period of record. Sun River gage 06082200 has two measurements for the June 1975 flood and has the gage height is coded as an estimate. Additionally, initial calibration attempts showed large discrepancies in water surface elevation between model results and recorded elevations where the discrepancies at the other two bounding Sun River gages correlated more closely to each other.

The North Fork Sun River gage 06078500 has large discrepancies in gage height for similar low flows, which could be attributed to a changed datum reference, or measurement error. Additionally, there are two discharge values recorded for the 1964 flood with the same stage value. Lastly, this gage did not record the 1975 flood event that was targeted for calibration of models. For these reasons, gages 06082200 and 06078500 were not used in calibration of Sun River and North Fork Sun River models, respectively.

The apparent gage zero elevation for the two remaining gage stations was used in conjunction with gage height measurements for each flood event of interest to define the apparent gage water surface elevation under the range of flows analyzed.

As mentioned, water surface elevations for the June 1975 flood event were targeted in the Sun River hydraulic models through the refinement of cross sections, ineffective flow areas around the gages, and selected Manning's roughness coefficients applied in the channel and overbanks throughout the entirety of the Sun River model. The best calibration results for the Sun River were obtained using a channel roughness of 0.035, which was used for the channel across the entirety of the studied sections of Sun River and the North Fork Sun River. Modeled water surface elevations calculated for the listed floods are compared to the apparent gage water surface elevations in Table 3-11.

Table 3-11. Sun River calibration results.

USGS Gage 06085800 Sun River at Simms MT				
Flood Event	Discharge	Apparent Gage Water Surface Elevation	Modeled Elevation RS 4483	Difference
June-2018	18,100	3562.04	3561.73	-0.31
June-1975	37,900	3563.56	3563.54	-0.02
June-1964	50,000	3564.78	3564.49	-0.29
USGS Gage 06085800 Sun River below Diversion Dam near Augusta MT				
Flood Event	Discharge	Apparent Gage Water Surface Elevation	Modeled Elevation RS 287633	Difference
June-2018	10,500	4375.23	4374.53	-0.70
June-1975	32,000	4382.27	4382.29	0.02
June-1964	59,700	4388.02	4389.66	1.64

The 1975 event calibrated well at both gage locations. However, discrepancies in water surface elevation for the June 2018 and June 1964 floods exist. Inspection of the gage record for these events revealed that the 1964 flood is coded with blockage by heavy debris. Gage heights for both the 2018 and 1975 floods at both gages are also listed as estimates at time of recording.

To access the calibration over the suite of simulated flood events, all available historic observations for each gage were plotted, and a rating curve was fit to the higher flows. These plots also illustrate the variability and reliability for gages not used. Results for the simulated flood events, along with the various flows used to develop the new study are shown for each gage location in Figure 3-3 through Figure 3-6.

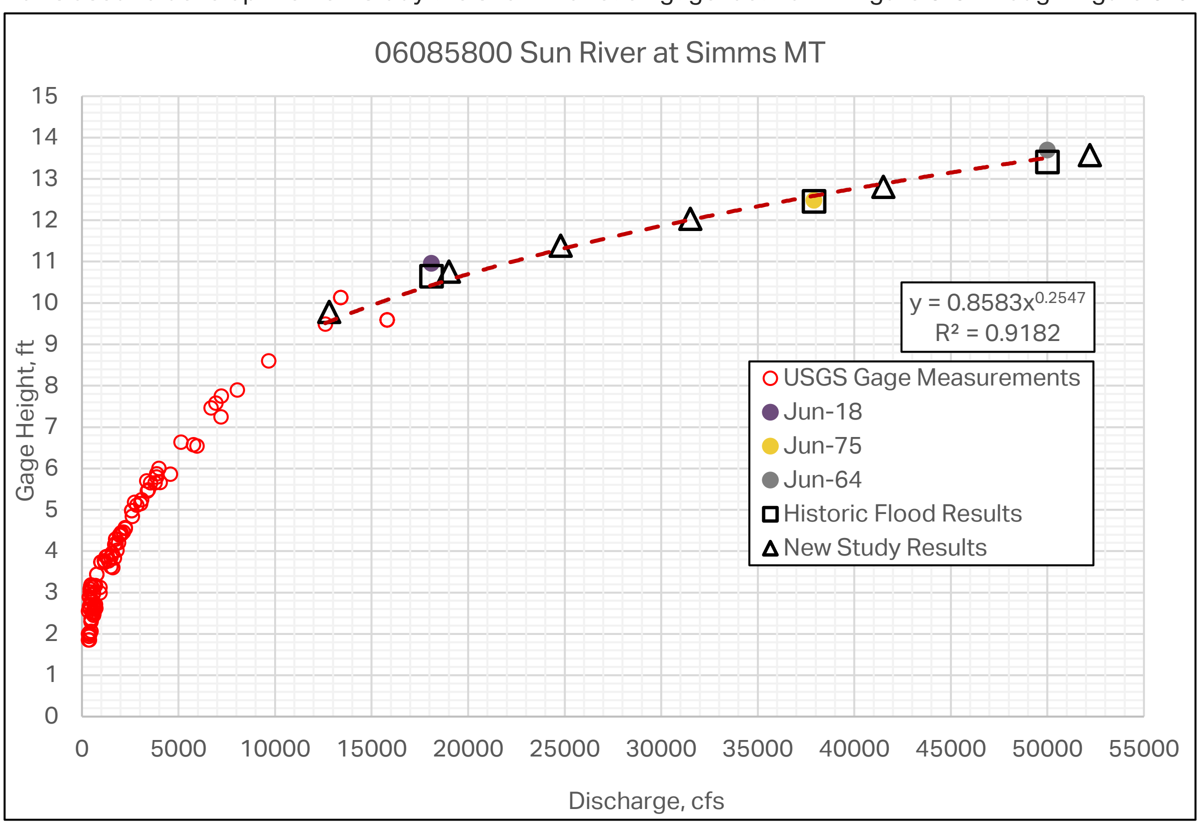

Figure 3-3. Recorded values, rating curve, and simulated results at RS 4483 for USGS gage 06085800.

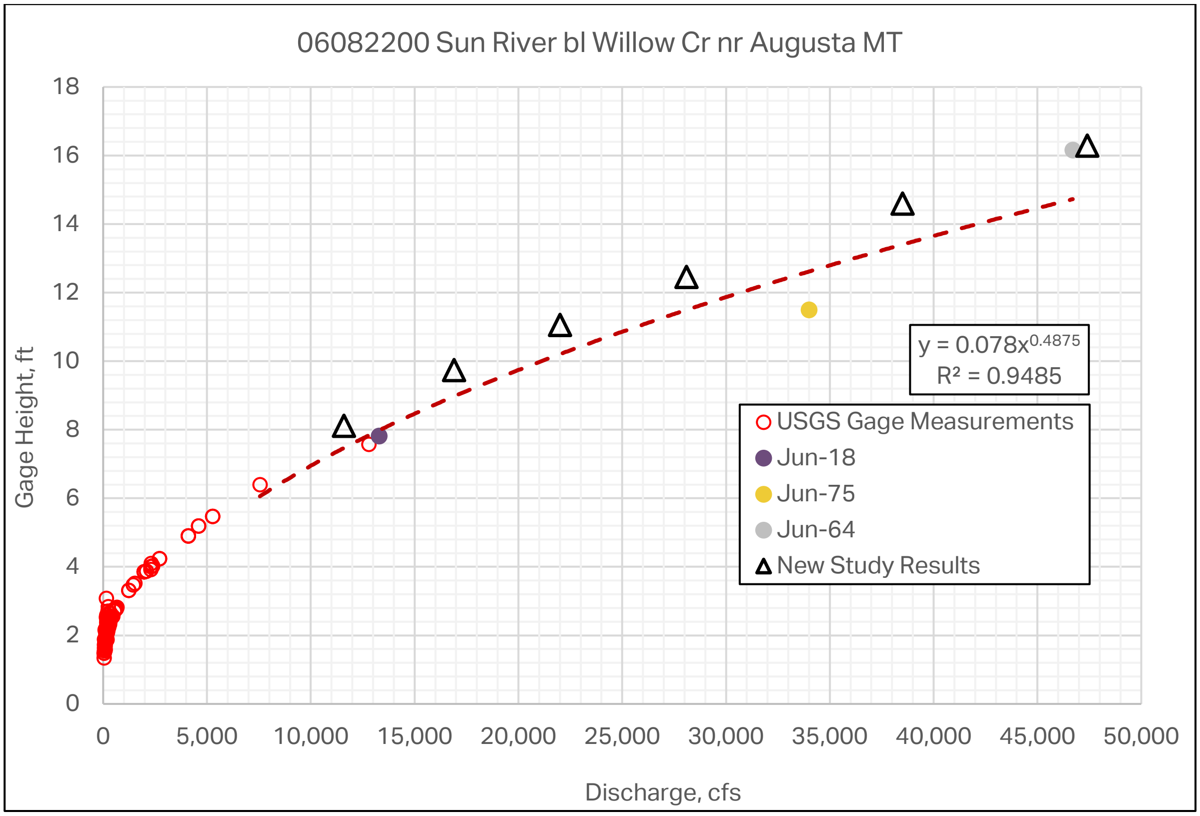

Figure 3-4. Recorded values, rating curve, and simulated results from RS 153366 and 153140 for USGS gage 06082200.

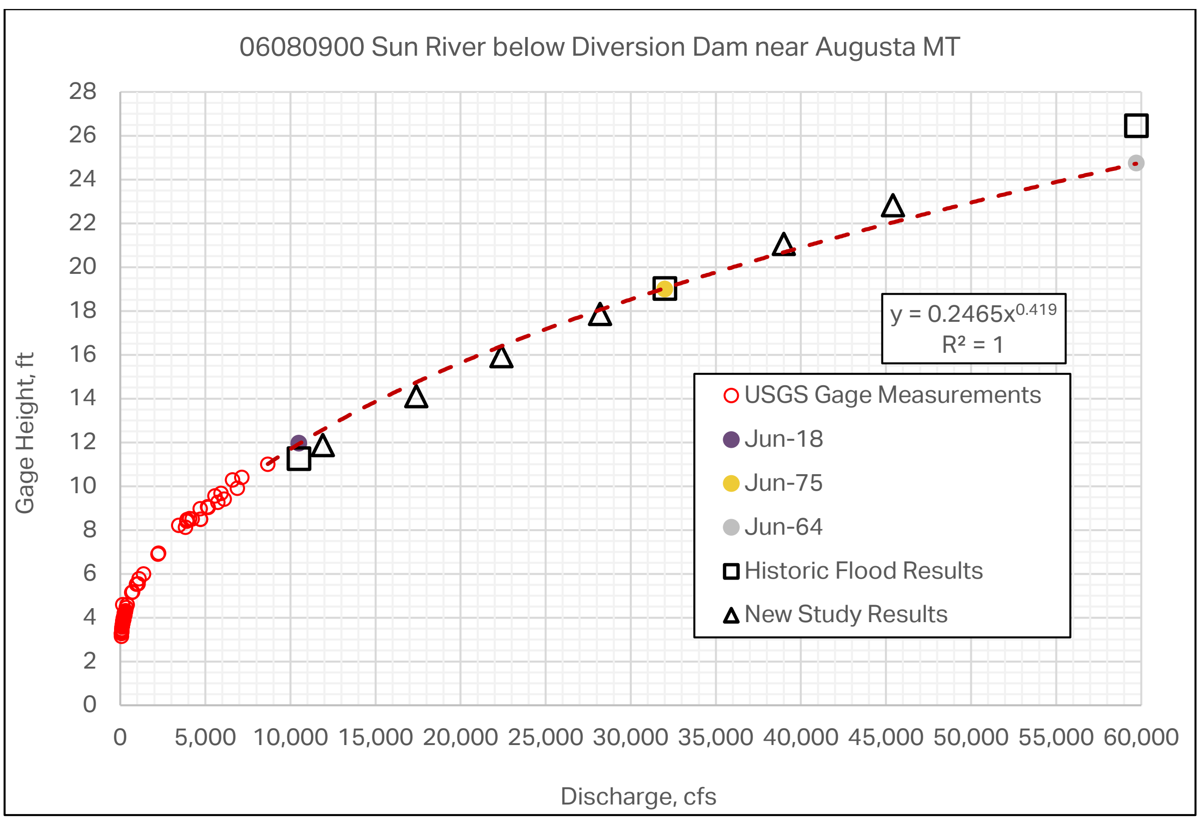

Figure 3-5. Recorded values, rating curve, and simulated results at RS 287633 for USGS gage 06080900.

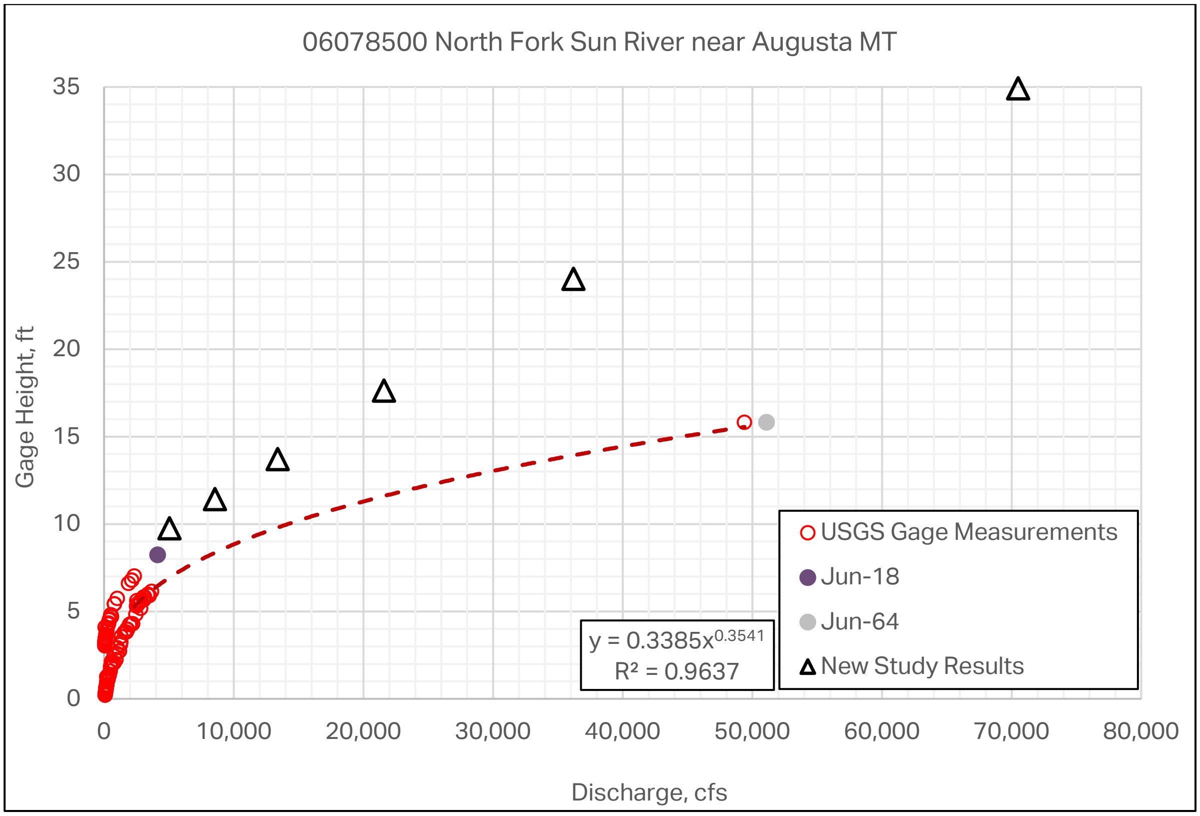

Figure 3-6. Recorded values, rating curve, and simulated results at RS 5086 for USGS gage 06078500.

In general, the two gage sites used for calibration of the 1975 show measured stage event agree reasonably well between the measured events and the simulated flows. The other two gage sites that were omitted from calibration show less agreeance.

The Sun River below Willow Creek near Augusta MT gage that was omitted follows the trendline shape but simulated results show a consistently higher departure than the gages with higher reliability. The North Fork Sun River near Augusta MT gage that was also omitted, does not appear to follow the trendline well. There is low confidence in the trendline fit due to the missing 1975 event and the large magnitude 1964 event being an estimated value, with the same stage reported for two different flows. Due to the factors described above, the reliability of these two gage sites for calibration and validation is low so were not considered.

3.12. FLOODWAY ANALYSIS

The locations for floodway analyses were determined through coordination by Montana DNRC with community stakeholders at the start of the project. Any new floodway mapping was done where the community has a regulatory need due to anticipated development in the area. After technical review by Montana DNRC and FEMA, the floodplain mapping and floodway delineation are made available to the community as part of the Flood Risk Review phase of the project.

A regulatory floodway is defined as the channel of a river or other watercourse and the adjacent land area that is reserved from encroachment in order to discharge the base flood without cumulatively increasing the water-surface elevation by more than a designated height. The National Flood Insurance Program minimum regulations designate a maximum height of 1.0 foot, although Montana state law restricts the maximum height to 0.5 foot.

A floodway analysis was performed for Sun River Reach 1 and Sun River Reach 2. The floodway was computed based on equal conveyance reduction from each side of the floodplain. As described in "Guidance for Flood Risk Analysis and Mapping, Floodway Analysis and Mapping" (Reference 5), the encroachment analysis used the normal depth boundary condition with the same energy slope as defined for the 1-percent-annual-chance regulatory analysis. Additionally, the maximum allowable surcharge was targeted for the starting cross section, with consideration for surcharge results in upstream sections in development of a smooth floodway boundary. The Sun River Reach 2 floodway analysis used a known water surface elevation boundary condition from results of Sun River Reach 1 floodway analysis.

The floodway encroachment analysis was initially performed with equal conveyance reduction using Method 4 and a target water surface surcharge of 0.5 feet, the Montana maximum allowable surcharge. Once Method 4 was completed, the encroachments stations were manually refined (Method 1) to ensure that there were no negative surcharges and that the contraction and expansion of the floodway boundary followed a 1:1 (stream wise: lateral) and a 2:1 ratio, respectively. Encroachment stationing began at the downstream section with the intent of maximizing the surcharge while avoiding large variations in encroachment top widths for adjacent cross sections. The results of the floodway computations are tabulated at the lettered cross-sections in the Floodway Data Table (FWDT) found in Appendix F.

3.13. BASE LEVEL ANALYSIS

3.13.1. GIBSON RESERVOIR AND DIVERSION LAKE

Gibson Reservoir and Diversion Lake are two instream impoundments on the Sun River. In accordance with FEMA guidance and summarized in the Michael Baker International guidance document for reservoirs and closed basins (Reference 15), it was determined during the hydrologic analysis developed by Michael Baker International there is sufficient gage record to reflect the impoundment's effects on flows within the system.

Since both impoundments were scoped for base level analyses, guidance documents suggest cross sections should be placed along the dam crest, as well as upstream and downstream of the impoundment. One-dimensional HEC-RAS models were developed for both impoundments. The modeled reaches are seamless with the other Sun River reaches. Sun River Reach 4 ties into the outlet of Diversion Lake and Sun River Reach 5 is the riverine segment between the two impoundments. Upstream of Gibson Reservoir, the North Fork Sun River study reach continues.

The model configuration and cross section placement assumes the entire simulated discharge overtops the dam crest and that backwater effects from the dam are projected upstream.

3.13.2. ISOLATED PONDS

Two isolated ponds are shown on the effective FIRMs. The two areas are separated from the main Sun River valley, at higher elevation than other flooding sources shown on the FIRM. Both isolated ponds show characteristics of ponding, primarily in the form of wetlands, but the reaches also show characteristics of a riverine environment with a sloping ground profile. Consequently, one-dimensional HEC-RAS models were created for these reaches to best capture flood hazard in these remote areas.

3.14. INTERNAL QAQC

Each model was subjected to internal Quality Assurance and Quality Control (QAQC) process prior to submittal. The process included an independent initial review with comments generated followed by a revision and response period. All reviews were documented and included in Appendix I.

4.0 FLOOD INSURANCE STUDY PRODUCTS

A Draft Flood Insurance Study (FIS) Section 5.2 was prepared, along with Floodway Data Tables, Flood Hazard Data Tables, and Water Surface Elevation Profiles for all reaches scope with enhanced study level.

4.1. FIS TEXT

A Draft FIS was prepared with data from this study and has been provided in the submittal.

4.2. FLOODWAY DATA TABLES AND FLOOD HAZARD DATA TABLES

Cross-section lettering was performed for all Sun River and Tributaries study reaches that were scoped as an enhanced level study. Floodway Data Tables (FDTs) were created for Sun River Reach 1 and Sun River Reach 2 where a floodway was developed.

Flood Hazard Data Tables (FHDTs) were created for all study reaches scoped as enhanced, but no floodway analysis was performed. The FDTs and FHDTs are provided in Appendix F.

4.3. WATER SURFACE ELEVATION PROFILES

Digital Flood Profiles of the 10%, 4%, 2%, 1%, 1%+, and 0.2%, annual chance flood WSELs were developed for enhanced level studies within the Sun River and Tributaries study reaches. The RASPLOT Version 3 software (Reference 8) was used to develop the profiles, which are included in Appendix E. At confluence areas of tributary and main stem studies, the mainstem backwater was projected onto the Flood Profile for the tributary study, where applicable.

5.0 FLOODPLAIN MAPPING

5.1. FLOOD HAZARD BOUNDARY REFINEMENT

The Floodplain Mapping Data Capture task was performed for the Sun River and Tributaries Floodplain Study. Under this task, refined floodplain boundaries were developed from inundation areas exported from HEC-RAS into ArcGIS where they were modified for suitability to the end users. Mapping refinements are necessary for:

- Replacement of a sloped water surface with a constant water surface for backwater areas
- Elimination of low-lying islands or those not visible at map scale
- Reflect different flooding sources, such as tributaries
- Eliminate rapid expansion and contraction of the floodplain to create a realistic floodplain
- Add roadway/structure overtopping where applicable
- Remove hydraulically disconnected areas shown as flooding, such as irrigation ditches

These refinements lead to differences between modeled and mapped top widths, which were evaluated and verified for each cross section.

5.2. TIE-IN TO EFFECTIVE MAPPING

Similar to floodplain boundary refinement under the Floodplain Mapping Data Capture Task, tie-ins to effective mapping have been completed. This study supersedes all effective flooding along Sun River and Big Coulee Creek shown on the FIRMs in Teton County, so no tie-ins are required. However, at the downstream extent of Sun River Reach 1, the Enhanced Zone AE study has been graphically tied into an Approximate Zone A defined for Sun River in Cascade County.

5.3. TIE-IN OF TRIBUTARY STUDIES

Tributary studies for the Sun River and Big Coulee Creek were tied-in at the confluence areas. For all studied tributaries, the downstream study limit was extended with additional cross sections to a point where calculated water surface elevations were below those of the mainstem study. This approach was necessary since downstream boundary conditions of tributary studies were not based on modeled results of the mainstem study since the presumption of coincident peak flooding is not correct. This approach ensures no interpolation between studied reaches was necessary and that all regulatory elevations shown on the eventual FIRMs are supported with a hydraulic model.

During Floodplain Mapping Data Capture Task, a source break (gutter line) was delineated between each tributary study and the parent stream. The source break is included in the S_FLD_HAZ_LN feature and attributed in LN_TYP as “Other Boundaries”.

5.4. MAPPING OF BASE LEVEL ANALYSIS REACHES

Gibson Reservoir and Diversion Lake were simulated in HEC-RAS similar to all study reaches. Detailed hydrologic reservoir outflow routing was not performed, but rather a conservative approach of placing a cross section along the dam crest was used. Additional cross sections were placed in the upstream direction to a point where the profile results indicated a sloping water surface elevation profile resumed. The models were terminated at that section to ensure the model and Approximate Zone A mapping limits coincide. The resulting floodplain boundaries for Diversion Lake and Gibson Reservoir are based on the calculated water surface elevation for each cross section and interpolated between. For Diversion Lake, the backwater profile imposed by the dam crest is flat and one water surface elevation is applicable. For Gibson Reservoir, the backwater profile is not completely flat. It was observed that a prominent bedrock outcropping narrows the cross section considerably and produces a slight increase in backwater elevation upstream.

Mapping for Unnamed Pond 1 and Unnamed Pond 2 is based on the HEC-RAS model developed for those reaches. Cross sections were placed along the entire study length as done for all other reaches in the study. Floodplain delineations along the reach are based on the calculated water surface elevation for each cross section and interpolated between.

5.5. FLOODPLAIN BOUNDARY AUDIT

In compliance with the FEMA guidance document, Floodplain Boundary Standards (FBS), November 2019, a Floodplain Boundary Audit was conducted to quantify the reliability of the floodplain boundary by assessing the vertical difference between the flood elevation and the terrain elevation at an audit point taken every 100' along the flood hazard boundary.

The Sun River, Big Coulee Creek, and their tributaries are defined as Risk Class "C", where 85% of audit points should be within a one-foot difference. The results of this audit are summarized in the audit report, which reveal the delineations in the study pass FBS. The audit summary report is included in this submittal, along with the FBS points used to develop the audit.

5.6. HYDRAULIC WORKMAPS

The Hydraulic Workmaps show the final refined floodplain boundaries. Along with the flood boundaries, the work map also displays the profile baseline, the configuration of cross sections, base flood elevations (BFEs) for each cross section, modeled hydraulic structures, and the resultant floodway, if simulated. The basemap of the hydraulic work map is the 2017 National Agriculture Imagery Program (NAIP) Aerial Photographs and LiDAR contours. Hydraulic Workmaps are provided in Appendix C.

6.0 DISCUSSION OF RESULTS

Computed water surface elevations and discharge results for each study reach are summarized in the Hydraulic Results Tables, included in Appendix B. In general, results are as expected for the mainstem Sun River, its tributary studies, and Big Coulee Creek and its tributaries. Complicating factors for modeling the Sun River are primarily the abrupt transitions from wide floodplains to narrow bedrock outcroppings. The energy loss associated with these transitions was estimated using increased contraction and expansion coefficients, as well as ineffective flow areas used to smooth the transitions from contracted to fully expanded flow.

The primary complication in the tributary studies were related to steep channel slopes. Many sections default to critical depth solution, even with increased channel roughness coefficients used. In some tributary studies, containment at the confluence area with the mainstem stream required cross sections extending into the mainstem with U-shaped alignments.

6.1. COMPARISON TO HISTORIC STUDIES

As mentioned, the Sun River (Near Simms) study from the Cascade County FIS coincides with Sun River Reach 1 and Sun River Reach 2 from this study. Calculated water surface elevation results between the two studies range in their difference throughout the common reach. For a simple comparison approach, cross sections from the new study were associated to cross sections from the historic study (via Cascade County DFIRM database) and relative stationing was developed, since most sections are not coincident. Figure 6-1 shows how calculated water surface elevations vary between the two studies.

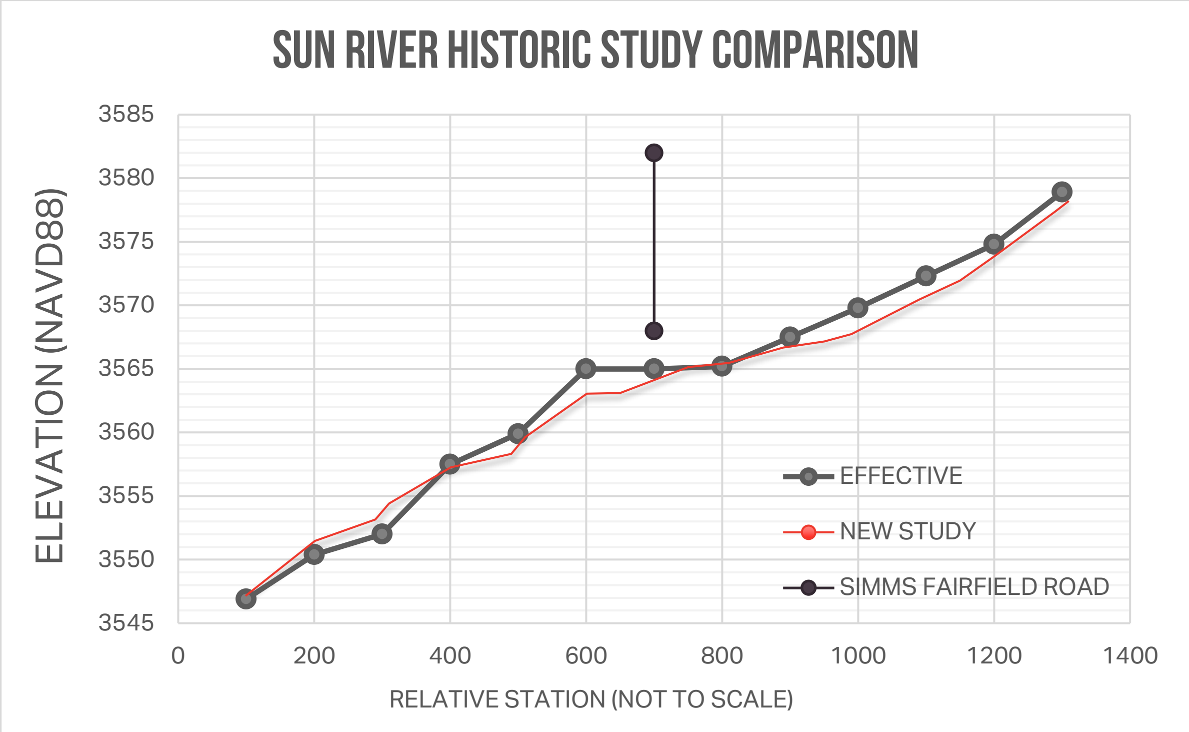

Figure 6-1. Relative water surface elevation comparison between effective and new Sun River study near Simms.

In general, the two studies compare reasonably well at the downstream limit of effective study as well as just upstream of Simms Fairfield Road bridge. Further upstream of the bridge, there is consistent difference of the new study being approximately 1′ lower in calculated water surface elevation than the effective study.

There are numerous potential explanations for the disparity such as: changed river morphology, different modeling software, and/or differing level of detail in topographic definition and structure information incorporated into the model, as well as modeling approach. The clearest explanation may be in the difference in base flood discharge.

Base flood discharges were compared in the Teton County Hydrologic Analysis developed by MBI. It was shown that base flood discharges reduced from the effective flow of 38,000 cfs to 31.500 cfs. This 17% reduction in discharge could explain the discrepancy.

That explanation does not support the downstream reach, where in general, the new study is showing higher calculated water surface elevations, with a lesser discharge. The exception is at the downstream limit of effective study, where the difference is only 0.25′. Again, there may be several factors contributing to the discrepancy is this reach, but it is possible the use of ineffective flow to remove portions of the right overbank from conveyance is a primary factor.

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MODELED XS GEOMETRIES

APPENDIX I

INTERNAL QAQC DOCUMENTATION